An Expanding and Expansive View of Computer and Information Science and Engineering

Advanced Cyberinfrastructure | Computing & Communication Foundations | Computer & Network Systems | Information & Intelligent Systems
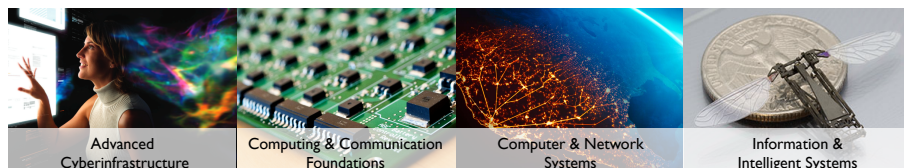
Jim Kurose
Assistant Director, NSF
Computer & Information Science & Engineering

Johns Hopkins University
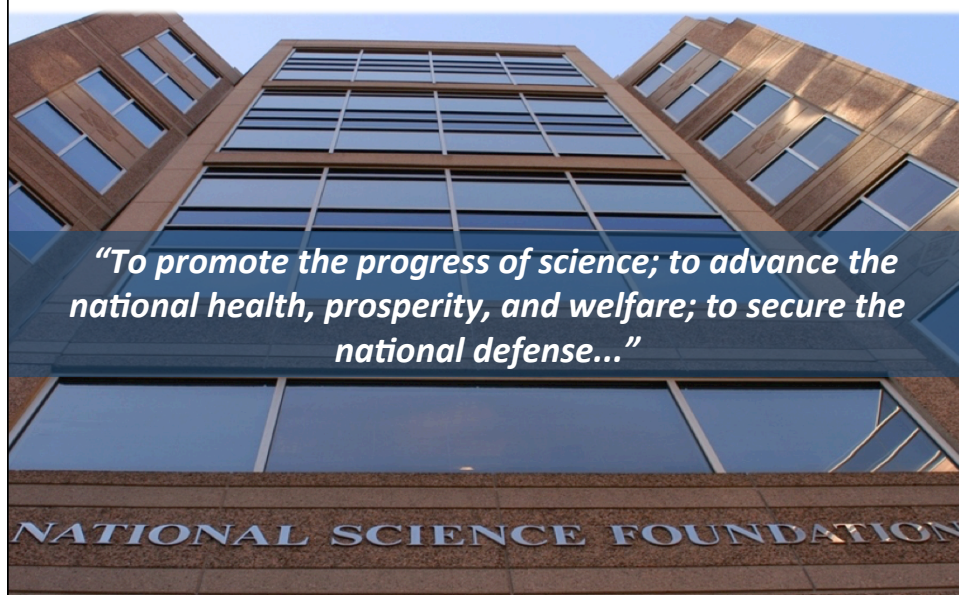November 2016

Overview

- CISE: the national imperative
- NSF CISE: programmatics
- Future challenges and opportunities (CISE)

National Science Foundation's Mission

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

CISE programs to address national priorities

Big Data

Cybersecurity

National Robotics Initiative
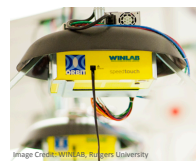
Understanding the Brain

National Strategic Computing Initiative

Smart Cities
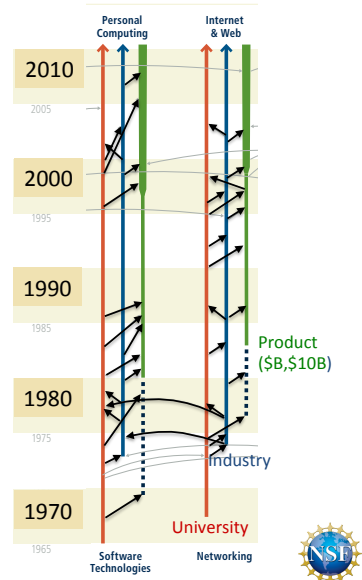
Computer Science for All

Advanced Wireless Research

From federally-funded research to $B industries

Advances in computing, communications, information technologies, cyberinfrastructure:

- drive U.S. competiveness, sustainable economic growth (IT: 25% of economic growth since 1995)
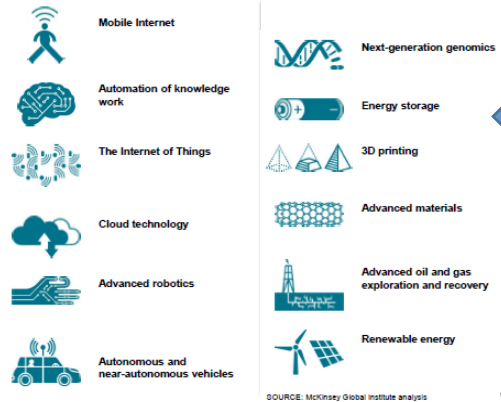- underpin national security
- have profound impacts on our daily lives

From *Continuing Innovation in Information Technology*, NRC, 2012.

…. across many industries
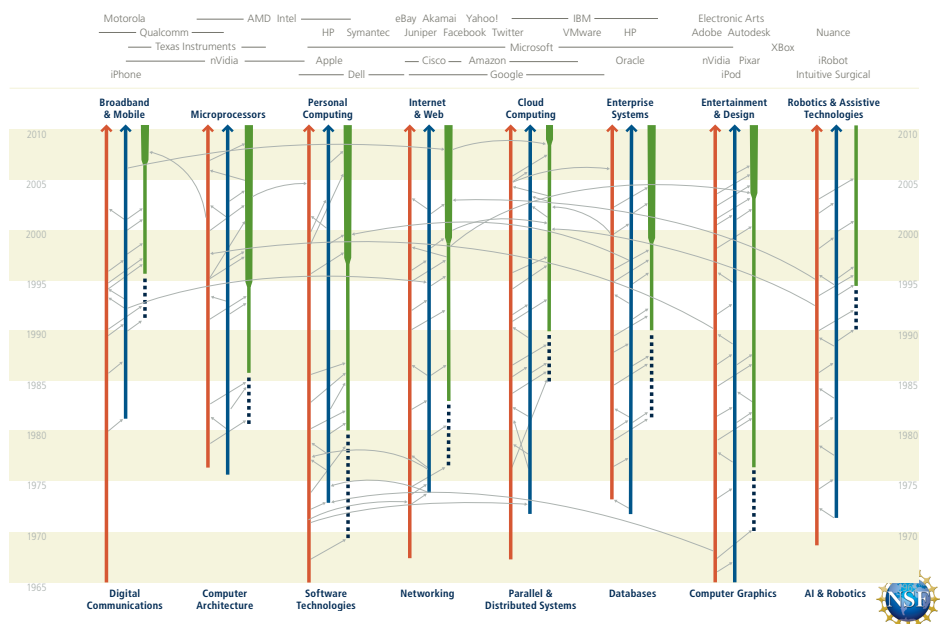
… and this impact will continue

Top twelve economically disruptive technologies (by 2025)

Disruptive technologies: Advances that will transform life, business, and the global economy

Many STEM jobs are in computing
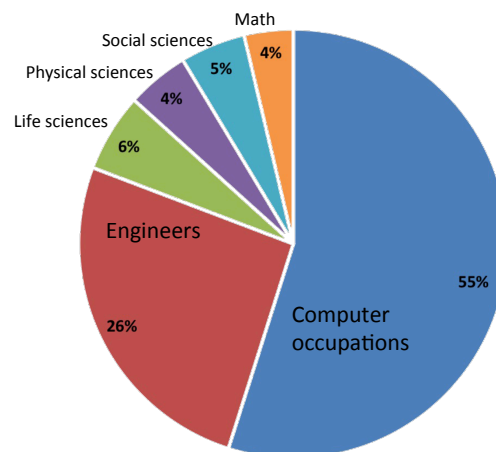
Job Openings 2014 – 2024 (growth and replacement)
US Bureau of Labor Statistics

Data from the spreadsheet linked at http://www.bls.gov/emp/ind-occ-matrix/occupation.xlsx

Growth in CS Undergrad Majors

Newly declared undergrad CS/CE majors
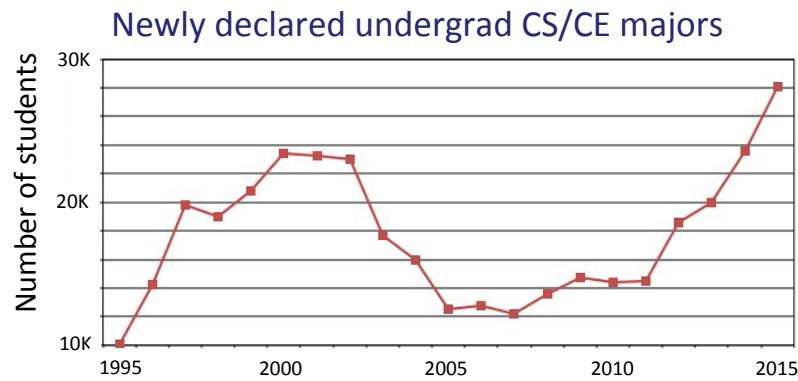
Source: 2015 CRA Taulbee Survey

NSF/CISE: **research** leadership in government

- *2016 Federal R&D Strategic Plans:*
  - Privacy
  - CyberSecurity
  - Artificial Intelligence
- Networking and Information Technology R&D (NITRD)
  - Coordination among 18 18 federal agencies
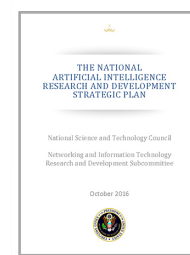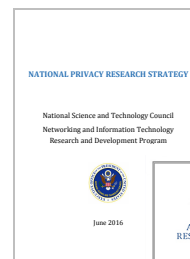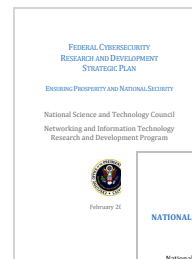
It is an
exciting, impactful and important time
to be in
computer and information science and
engineering!!

Overview

- CISE: the national imperative
- **NSF CISE: programmatics**
- Future challenges and opportunities (CISE)

CISE Organization

CISE Directorate
Jim Kurose, AD
Erwin Gianchandani, DAD

Senior Advisor for
ch Cyberinfrastructure
Peter Arzberger

enior Advisor for
Data Science
Chaitan Baru

Advanced Cyberinfrastructure (ACI)
Irene Qualters, DD

- Data
- High Performance Computing
- Networking/ Cybersecurity
- Software

Computing and Communication Foundations (CCF)
Rao Kosaraju, DD

- Algorithmic Foundations
- Communication and Information Foundations
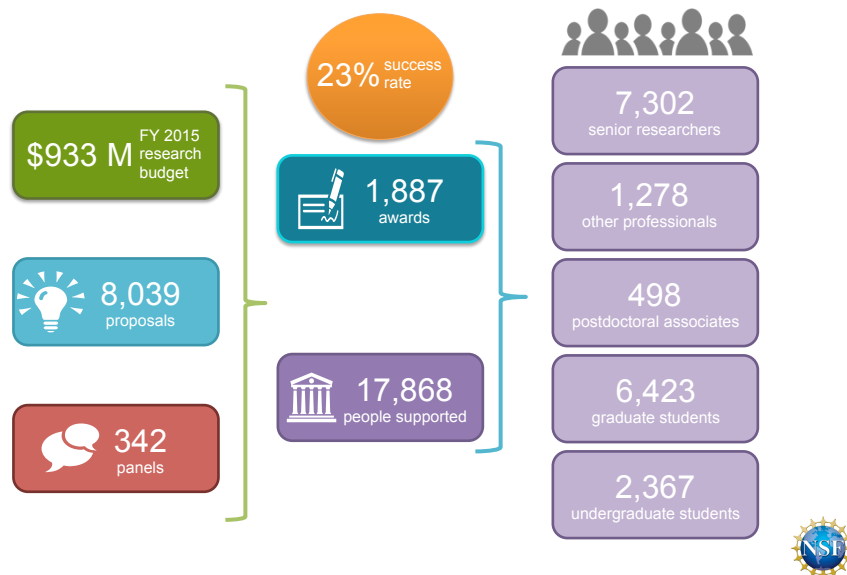- Software and Hardware Foundations

Computer and Network Systems (CNS)
Ken, Calvert, DD

- Computer Systems Research
- Networking Technology and Systems
- Education and Workforce Development

Information and Intelligent Systems (IIS)
Lynne Parker, DD

- Cyber Human Systems
- Information Integration and Informatics
- Robust Intelligence

CISE by the Numbers: FY 2015

23% success rate

$933 M FY 2015 research budget

8,039 proposals

342 panels

1,887 awards

17,868 people supported

7,302 senior researchers

1,278 other professionals

498 postdoctoral associates

6,423 graduate students

2,367 undergraduate students
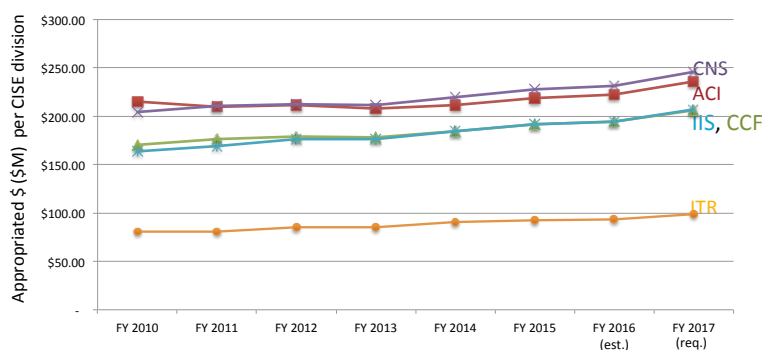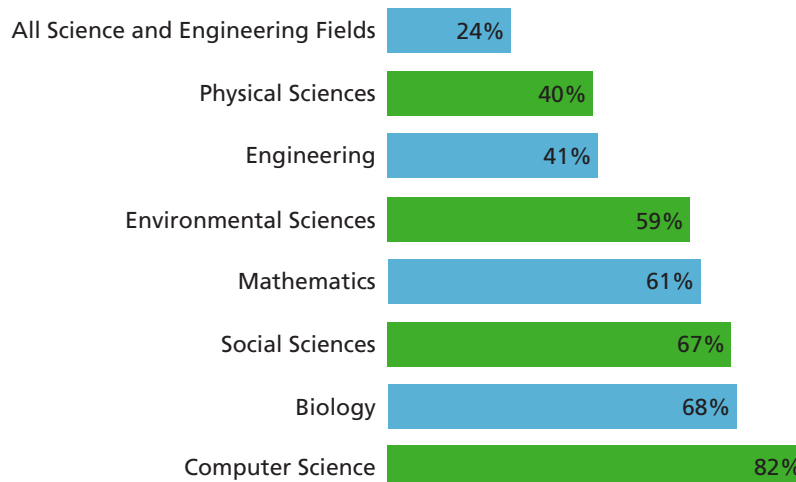
CISE Division Budgets

Modest growth across all CISE divisions

NSF Support of Academic Basic Research

(as a percentage of total federal support)

- All Science and Engineering Fields: 24%
- Physical Sciences: 40%
- Engineering: 41%
- Environmental Sciences: 59%
- Mathematics: 61%
- Social Sciences: 67%
- Biology: 68%
- Computer Science: 82%

Source: NSF/NCSES, Survey of Federal Funds for Research & Development, FY 2014

An expanding, expansive view of computing

CISE foundations

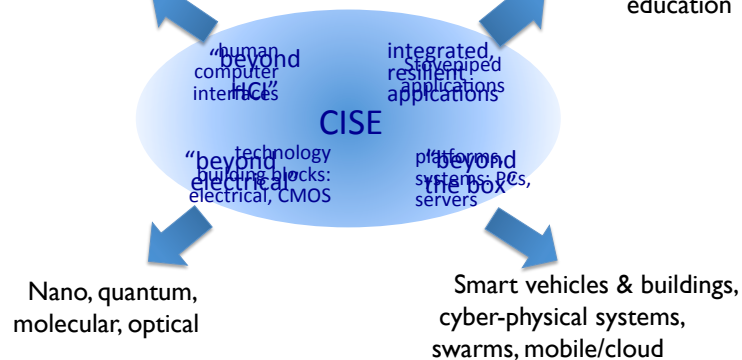|	
Theoretical foundations	Computational science
Algorithms	Software
Programming languages	Security
Learning	Intelligence
Systems: networks, OS, DB	Computational neuroscience
data to knowledge to action	Information sys
Societal impacts	Communication, control

An expanding, expansive view of computing

Human-centered computing
Assistive technologies, affective computing, social informatics, mind/machine interface, brain

Science, societal applications
Science, engineering, humanities health, security, environment. energy, transport, commerce, education

"beyond human computer interfaces"

integrated, resilient, dependable applications

CISE

technology building blocks: electrical, CMOS

"beyond electrical"

platforms beyond systems: PCs, servers

"beyond the box"

Nano, quantum, molecular, optical

Smart vehicles & buildings, cyber-physical systems, swarms, mobile/cloud
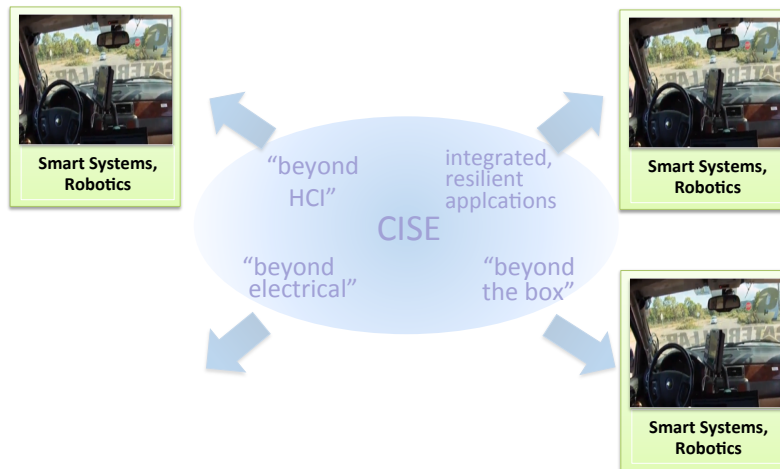
Changing "physicalness" of computing

computing embedded around us

An expanding, expansive view of computing

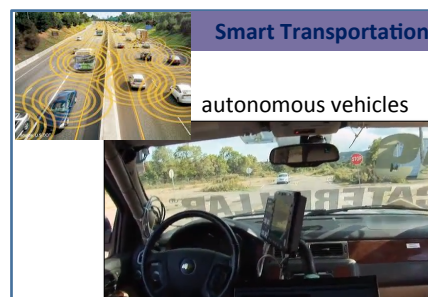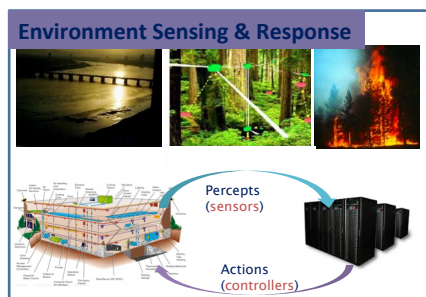*Human-centered computing*

Science, societal applications

Smart Systems, Robotics

Smart Systems, Robotics

"beyond HCI"

integrated, resilient applcations

CISE

"beyond electrical"

"beyond the box"

Smart Systems, Robotics

Changing "physicalness" of computing

computing embedded around us

Smart Systems: Sensing, Reasoning, and Decision

Environment Sensing & Response

Percepts (sensors)

Actions (controllers)

Smart Transportation

autonomous vehicles

Smart and Connected Health

Inference

Datamining

Personal Sensing

Smart cities: transportation, energy, safety, security, resources, environment, planning

Smart Cities

Source: Sajal Das, Keith Marzullo

Images: *Courtesy of us-ignite.org*

Research to Enable Smart Systems

Image Credit: *MicroStrain, Inc.*

Smart and Connection Communities
- *Deeply integrate computation, communication, and control into physical systems*
- 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, usability, privacy

Image Credit: *Bristol Robotics Lab*
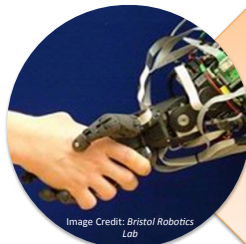
National Robotics Initiative (NRI)
- *Develop next generation of collaborative robots, or co-robots, that work beside and cooperatively with people*
- nationally concerted cross-agency effort among NSF, NASA, USDA, and NIH
- long-term social, behavioral, and economic implications; enhance personal safety, health, and productivity

Application sectors

Transportation

Energy and Industrial Automation

Health and Medical Care

Critical Infrastructure

National-scale experimental infrastructure

GLOBAL ENVIRONMENT FOR NETWORKING INNOVATIONS (GENI)
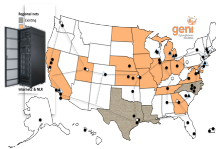At-scale virtual laboratory experimentation via deeply programmable "sliced" network

US IGNITE
Gigabit applications with high-impact public benefit

NSF FUTURECLOUD
End-end cloud virtualization

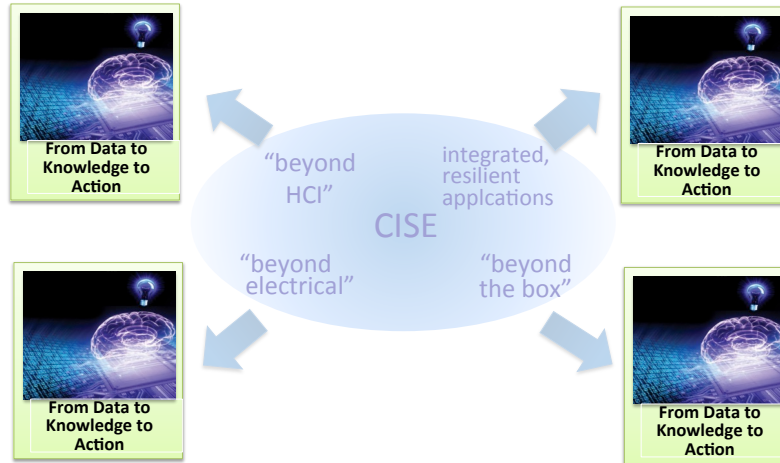**PLATFORMS FOR ADVANCED WIRELESS RESEARCH (PAWR)**
at-scale wireless testbeds (industry collaboration)

An expanding, expansive view of computing

Human-centered computing
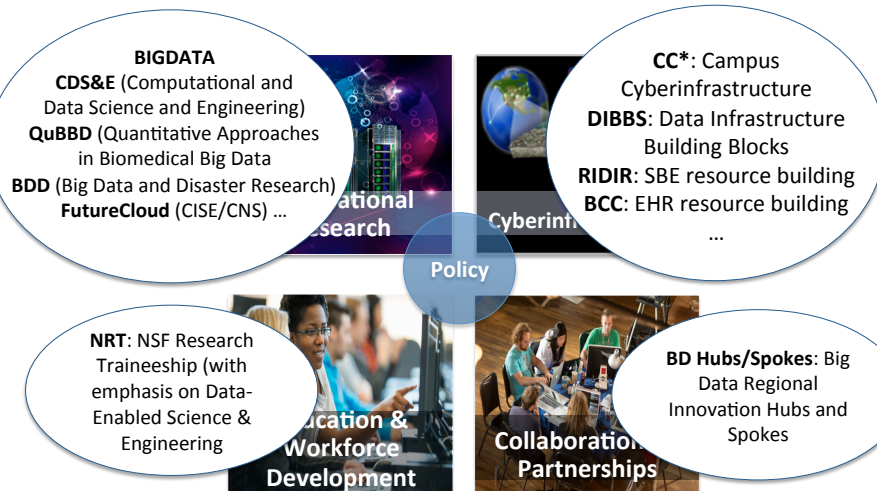
Science, societal applications

"beyond HCI"

integrated, resilient applcations

CISE

"beyond electrical"

"beyond the box"

From Data to Knowledge to Action

From Data to Knowledge to Action

From Data to Knowledge to Action

From Data to Knowledge to Action

Changing "physicalness" of computing

computing embedded around us

NSF's Big Data / Data Science Programs

BIGDATA
CDS&E (Computational and Data Science and Engineering)
QuBBD (Quantitative Approaches in Biomedical Big Data
BDD (Big Data and Disaster Research)
FutureCloud (CISE/CNS) …

CC*: Campus Cyberinfrastructure
DIBBS: Data Infrastructure Building Blocks
RIDIR: SBE resource building
BCC: EHR resource building
…

Policy

NRT: NSF Research Traineeship (with emphasis on Data-Enabled Science & Engineering

BD Hubs/Spokes: Big Data Regional Innovation Hubs and Spokes

Education & Workforce Development

Collaboration, Partnerships

Big Data Regional Innovation Hubs

Northeast: Columbia University
West: UCSD, UC Berkeley, UW
South: NC Capel Hill, Georgia Tech
**MidWest**: UIUC

- Goal: ignite new **Big Data public-private partnerships** across the Nation
- Hub:
  - Consortium from academia, industry, gov't
  - focus on Big Data challenges, opportunities for region
- Support breadth of local stakeholders, *achieve common Big Data goals not be possible alone*

Big Data Spokes of the BDHubs

Each Hub supports subcommitees on **topical areas of interest** ("Spokes")

BDSpokes solicitation aims to support **collaborative projects** surfaced or developed by the Hubs and Spokes
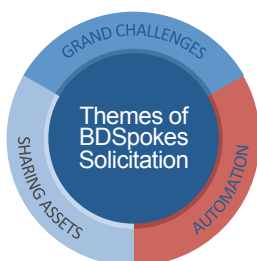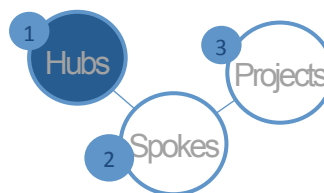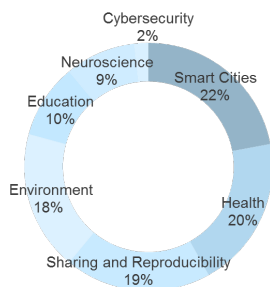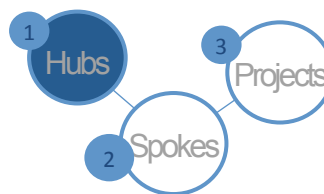

- Two award categories: **Planning Grants** (100K for 1 year) and **Spokes** ($1M total over 3 years)
- Total funding: $12M
- 10 Spokes, 10 Planning Grants

Big Data Spokes of the BDHubs

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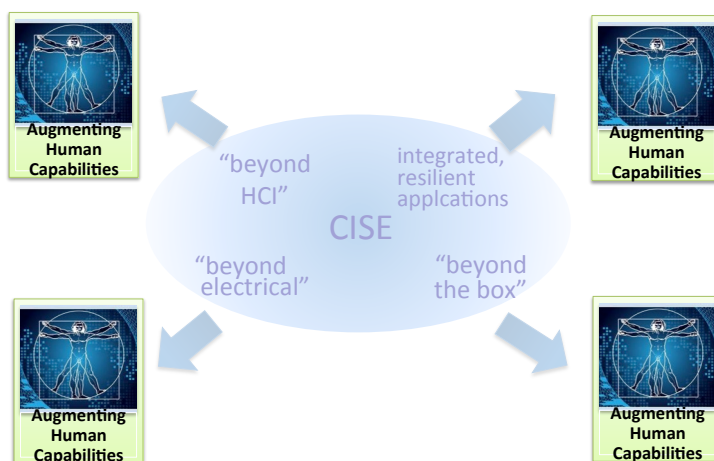

- 1 Hubs
- 3 Projects
- 2 Spokes

Cybersecurity 2%
Neuroscience 9%
Smart Cities 22%
Education 10%
Environment 18%
Health 20%
Sharing and Reproducibility 19%

- Two award categories: **Planning Grants** (100K for 1 year) and **Spokes** ($1M total over 3 years)
- Total funding: $12M
- 10 Spokes, 10 Planning Grants

An expanding, expansive view of computing

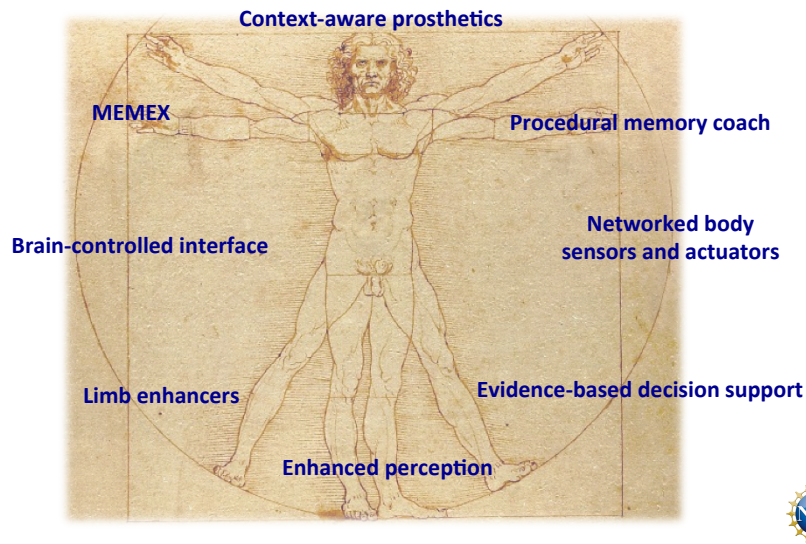*Human-centered computing*

Science, societal applications

Augmenting Human Capabilities

Augmenting Human Capabilities

"beyond HCI"

integrated, resilient applcations

CISE

"beyond electrical"

"beyond the box"

Augmenting Human Capabilities

Augmenting Human Capabilities

Changing "physicalness" of computing

computing embedded around us

Augmenting Human Capabilities

Converging technologies for enhancing performance and quality of life

Context-aware prosthetics

MEMEX

Procedural memory coach

Brain-controlled interface

Networked body sensors and actuators

Limb enhancers

Evidence-based decision support

Enhanced perception

Cognitive Science and Neuroscience

BRAIN INITIATIVE
BRAIN RESEARCH THROUGH ADVANCING INNOVATIVE NEUROTECHNOLOGIES

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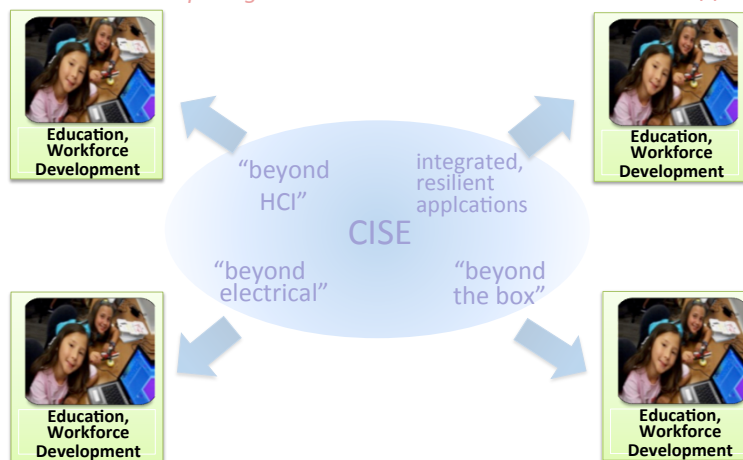- Builds on NSF's unique ability to catalyze multi-disciplinary research and ongoing NSF investments.

- **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

An expanding, expansive view of computing

Human-centered computing

Science, societal applications

Education, Workforce Development

Education, Workforce Development

"beyond HCI"

integrated, resilient applcations

CISE

"beyond electrical"

"beyond the box"

Education, Workforce Development

Education, Workforce Development

Changing "physicalness" of computing

computing embedded around us

Education: Computer Science for All

2007 — 2010 — 2016

BPC Alliances   CS10K   Computer Science For All
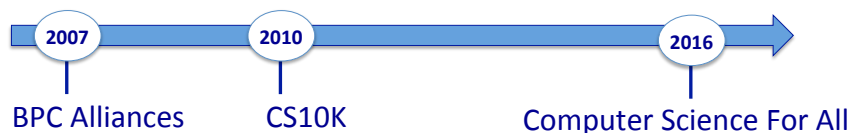
- Enable *all* students to have access to high-quality CS education in K-12:
  - Knowledge base, capacity for rigorous, engaging CS education
  - Teacher PD
- Inter-agency WG under CoSTEM kicking off today!
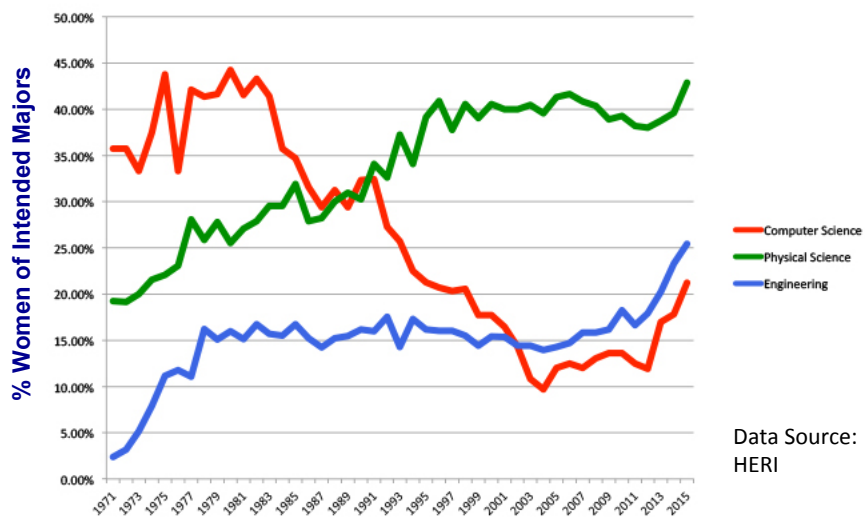- Collaboration: industry, non-profits
- NSF: $120 million over five years

"In the new economy, computer science isn't an optional skill – It's a basic skill…"
President's Weekly Address 1/30/2016

Hopeful!

Data Source: HERI

NSF "Big Ideas"

NSF "Big Ideas"

RESEARCH IDEAS
- Harnessing Data for 21st Century Science and Engineering
- Shaping the new Human – Technology Frontier
- Understanding the Rules of Life: Predicting Phenotype
- The Quantum Leap: Leading the Next Quantum Revolution
- Navigating the New Arctic
- Windows on the Universe: The Era of Multi-messenger Astrophysics

PROCESS IDEAS
- Growing Convergent Research at NSF
- Mid-scale Research Infrastructure
- NSF 2050
- INCLUDES

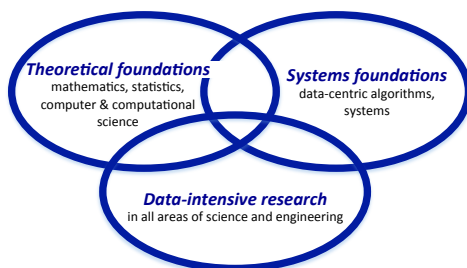*Video of NSB presentation and discussion is at:
http://www.tvworldwide.com/events/nsf/160505/globe_show/default_go_archive.cfm?gsid=2957&type=flv&test=0&live=0
(the presentation/discussion starts about 20 minutes into this video)

Harnessing the Data Revolution

Research across all NSF Directorates

Theoretical foundations
mathematics, statistics, computer & computational science

Systems foundations
data-centric algorithms, systems

Data-intensive research
in all areas of science and engineering

Educational pathways

Innovations grounded in an education-research-based framework

Advanced cyberinfrastructure ecosystem
Accelerating data-intensive research

Work at The Human-Technology Frontier: Shaping the Future

Emerging technologies and human-technology interactions are transforming the world of work and the lives of workers

Understanding how constantly evolving technologies are actively shaping our lives and how we in turn can shape those technologies, especially in the world of work
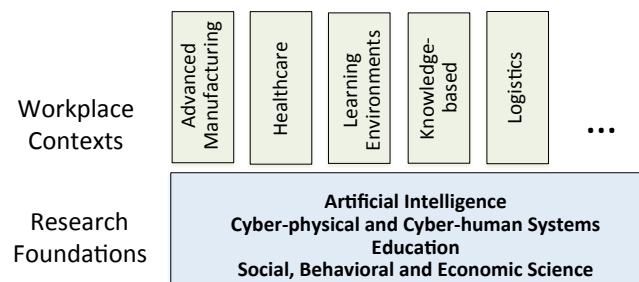
- understand benefits, risks of new technologies: efficiency, quality, productivity, human dynamics
- science and engineering: creating technologies that promise to enhance work lives
- *Education:* changing work*place* demands changing work*force*

Work at The Human-Technology Frontier: Shaping the Future

Seamless collaboration between human, cyber-enabled systems:
- understanding of reciprocal human-technology interactions;
- Systems: tailored, optimized, continuously adapted for humans; and
- education and lifelong learning to create requisite workforce

Workplace Contexts

| Advanced Manufacturing | Healthcare | Learning Environments | Knowledge-based | Logistics | ... |

Research Foundations

**Artificial Intelligence
Cyber-physical and Cyber-human Systems
Education
Social, Behavioral and Economic Science**

Overview

- CISE: the national imperative
- NSF CISE: programmatics
- **Future challenges and opportunities (CISE)**

Partnerships: Many dimensions

Partnerships **build capacity**, **leverage resources**, **increase the speed of translation** from discovery to innovation

New 2016 activities

industry

universities

international

local gov't

Federal agencies

societal org's

- PAWR: Platforms for Advanced Wireless Research
- NSF/SRC: E2CDA
- NSF/Intel: Information-Centric Networking
- NSF/VMware: Software Defined Infrastructure for Clean-Slate Computing Security
- Innovation Transition DCL
- Infrastructure collaborations

Prescription 3: Establishing a More Robust National Government-University-Industry Research Partnership

Partnerships: Many dimensions

Partnerships **build capacity**, **leverage resources**, **increase the speed of translation** from discovery to innovation

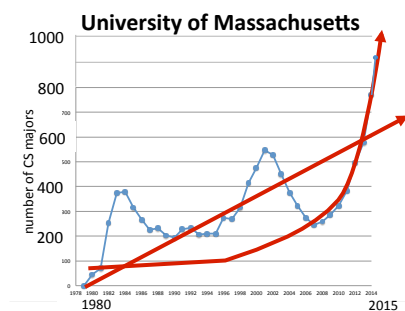- Cyber Physical Systems (CPS): DHS, DOT, NASA, NIH
- National Robotics Initiative (NRI): DARPA, NASA, NIH, USDA
- Smart and Connected Health (SCH): NIH
- Collaborative Research in Computational Neuroscience (CRCNS): NIH

all joint with other NSF directorates

Partnerships: Many dimensions

Partnerships **build capacity**, **leverage resources**, **increase the speed of translation** from discovery to innovation

New 2016 activities

- NSF-BSF (Israel): CCF and CNS core, SATC
- US-Japan: interest in BIGDATA, ML
- NSF-Finland: WIFUS
- NSF-India: S&CC
- NSF-Netherlands: privacy
- NSF-Brazil: cybersecurity

Education

CS UG programs

Booming CS enrollments

University of Massachusetts

number of CS majors

1000
800
600
400
200

1980   2015

Explosion of interest seems different this time around
- broader interests
- minors, other disciplines

Education

CS UG programs

*Booming CS enrollments*

Education

CS UG programs

Booming CS enrollments

- Increasing CISE footprint, program sizes imply increasing TT faculty sizes?
  - additional grant pressures
  - funding expectations based on history 10+ years ago
  - career pathways for PhD students?
- Interesting reading:
  - "Rescuing US Bio-medical Research from its systemic flaws," Alberts, Kirschner, Tilgham, Varmus, *PNAS*

Education

CS UG programs

Booming CS enrollments

Breadth of computing interests, K-12 pipeline
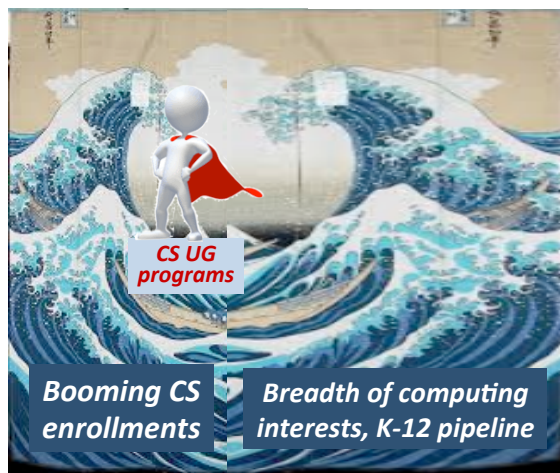
- *second sea change (tsunami):* broadening interest in computing among incoming students
- success of K-12 activities
- CS+X

An *amazing* time to be in CISE!

Ubiquity
Computing is *everywhere* – across all of science and engineering, and all of society

Engagement
Computing intertwines with many *communities*

Urgency
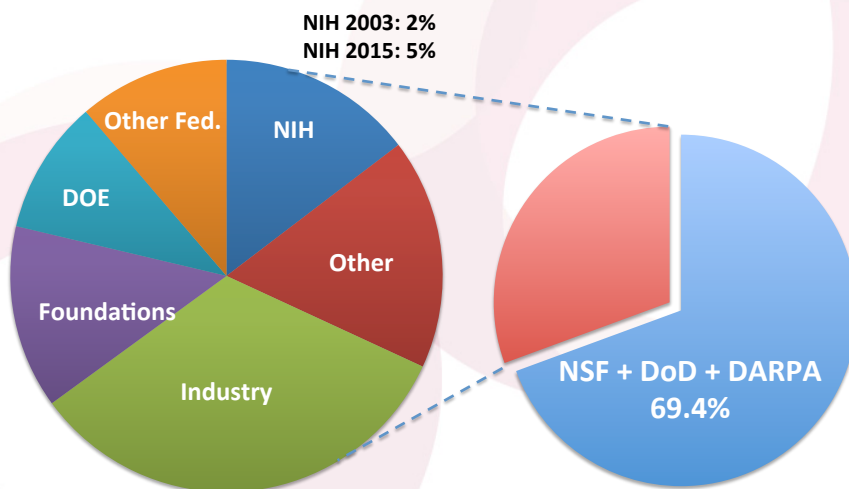**Computing is *rapidly expanding and evolving*. There is tremendous opportunity … *now!***

Get Involved!

- *Participate* in NSF, CRA/CCC workshops, visioning activities
- *Volunteer* to reviews proposals, serve on panels
- *Visit* NSF, get to know your program(s) and program director(s)
- *Join* NSF: serve as program officers, division directors, Assistant director
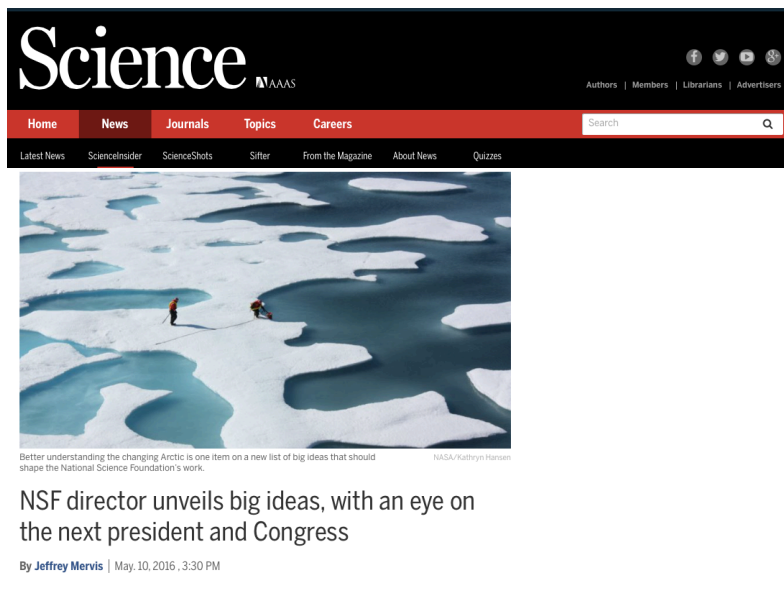
CS RESEARCH FUNDING PORTFOLIO

NIH 2003: 2%
NIH 2015: 5%

NSF + DoD + DARPA 69.4%

Source: 2015 Taulbee Survey, Table R2; slide courtesy of G. Hager.

NSF "Big Ideas"

Science AAAS

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Latest News   ScienceInsider   ScienceShots   Sifter   From the Magazine   About News   Quizzes

Better understanding the changing Arctic is one item on a new list of big ideas that should shape the National Science Foundation's work.

NASA/Kathryn Hansen

NSF director unveils big ideas, with an eye on the next president and Congress

By Jeffrey Mervis | May. 10, 2016 , 3:30 PM

NSF "Big Ideas"

RESEARCH IDEAS

- Harnessing Data for 21st Century Science and Engineering
- Shaping the new Human – Technology Frontier
- Understanding the Rules of Life: Predicting Phenotype
- The Quantum Leap: Leading the Next Quantum Revolution
- Navigating the New Arctic
- Windows on the Universe: The Era of Multi-messenger Astrophysics

PROCESS IDEAS

- Growing Convergent Research at NSF
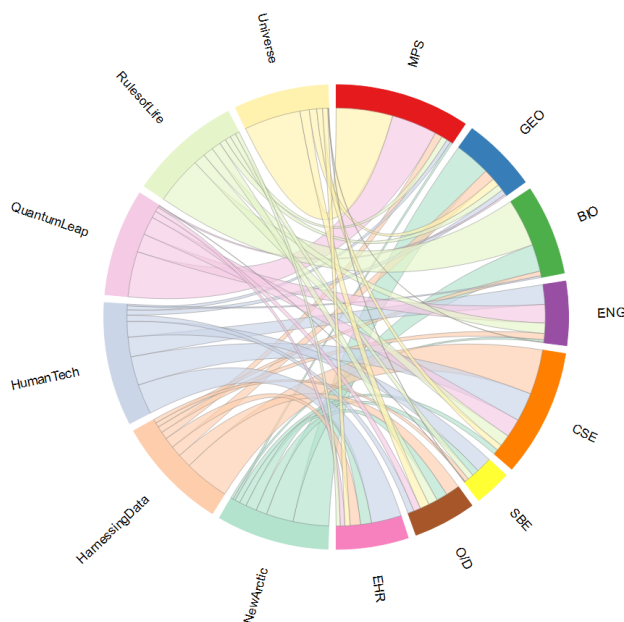- Mid-scale Research Infrastructure
- NSF 2050
- INCLUDES

*Video of NSB presentation and discussion is at:
http://www.tvworldwide.com/events/nsf/160505/globe_show/default_go_archive.cfm?gsid=2957&type=flv&test=0&live=0
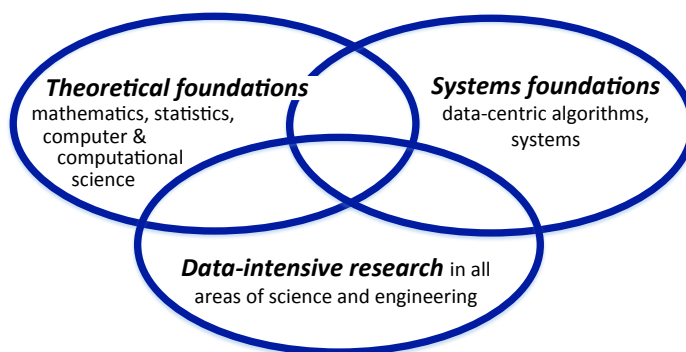 (the presentation/discussion starts about 20 minutes into this video)

An Interconnected NSF – Solving the Big Idea Challenges Together

Harnessing the Data Revolution

Theoretical foundations
mathematics, statistics,
computer &
computational
science

Systems foundations
data-centric algorithms,
systems

Data-intensive research in all
areas of science and engineering

+ Advanced cyberinfrastructure ecosystem for
accelerating data-intensive research, including large-scale facilities

+ Innovative educational pathways, grounded in an
education-research-based framework

The Human-Technology Frontier

Computing will be embedded around, on, and in us. These engineered systems will be more pervasive, more personal, more intimate.

Understanding how constantly evolving technologies are actively shaping our lives and how we in turn can shape those technologies, especially in the world of work

- understand benefits, risks of new technologies: efficiency, quality, productivity, human dynamics
- science and engineering: creating technologies that promise to enhance work lives
- *Education:* changing work*place* demands changing work*force*
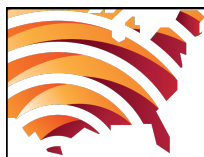
Platforms for Advanced Wireless Research (PAWR)

Over **20 companies** have partnered to establish a new **Industry Consortium**

# PAWR: *Platforms for Advanced Wireless Research*

- at-scale experimental exploration of robust new wireless devices, communication techniques, networks, systems
  - dynamic spectrum, mmWave, network architecture, wide-area wireless backhaul, metrology
- public-private partnership: $50M NSF/CISE investment, > $40M in industry consortium investment (7 years)
- Up to 4 wireless research testbeds
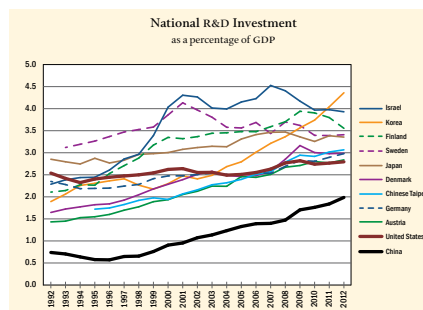- Program solicitation NSF 16-585: project office

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An Interconnected NSF – Solving the Big Idea Challenges Together
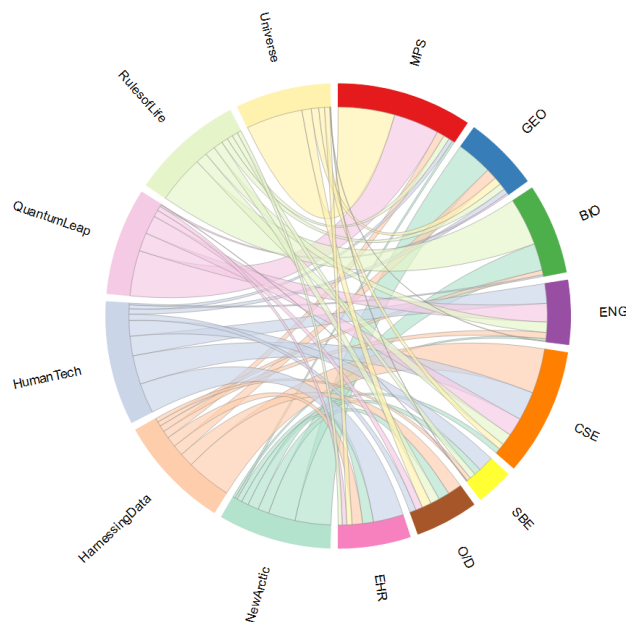
Challenge: research investment
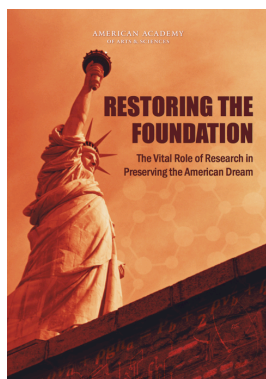
American Academy of Arts & Sciences, 2014, available at https://www.aau.edu/WorkArea/ DownloadAsset.aspx?id=15491.

- US: now 10th in national R&D (% GDP)
- investment federal support for basic research down 13% from 10 years ago (% of GDP)
- CISE: *growing* field

CISE leads an expansive view of research infrastructure driven by research priorities and the scientific process
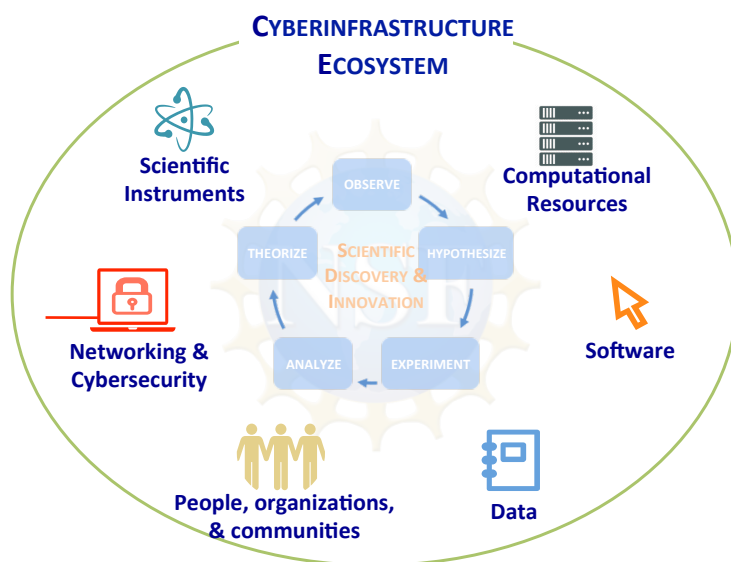
A diversity of computational resources support the nation's data- and computational-intensive science