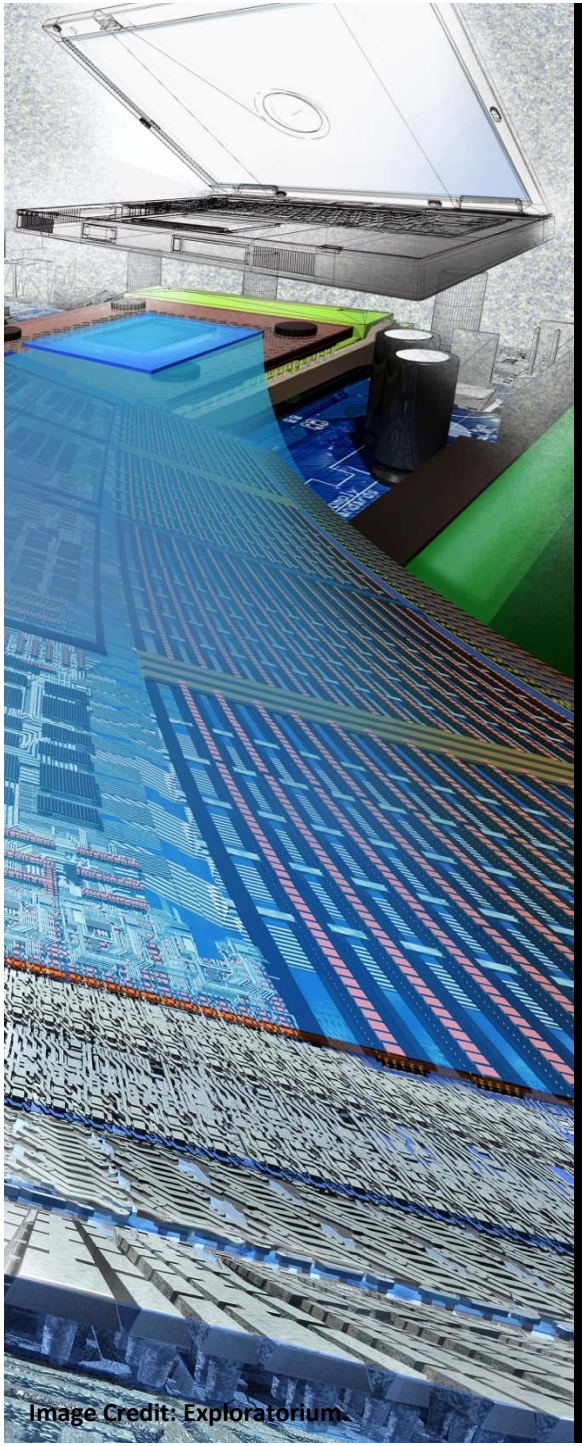


Big Data R&D Initiative

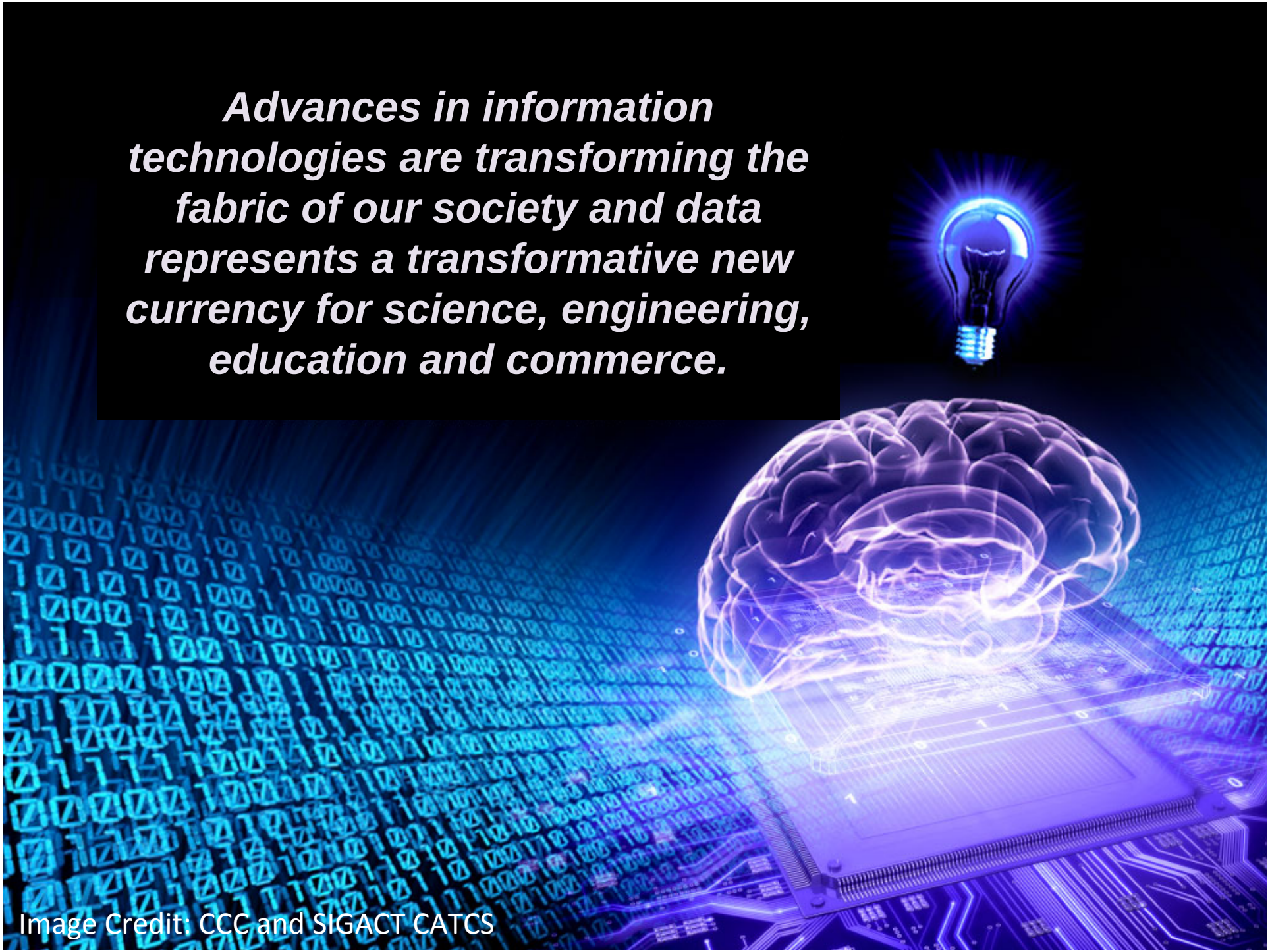
Mhyron Gutmann

Directorate for the Social, Behavioral and Economic Sciences

National Science Foundation

Digital Preservation 2012

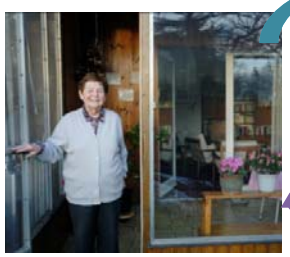
July 25, 2012


Advances in information technologies are transforming the fabric of our society and data represents a transformative new currency for science, engineering, education and commerce.
Image Credit: CCC and SIGACT CATCS

Smart Sensing, Reasoning and Decision

Environment Sensing



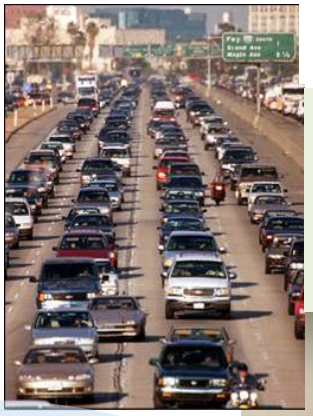

Percepts (sensors)

Agent (Reasoning)

Actions (controllers)

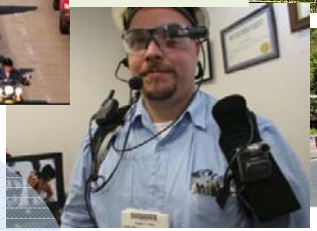
Pervasive Computing

Emergency Response



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


Credit: Photo by US Geological Survey




Social Informatics

People-Centric Sensing

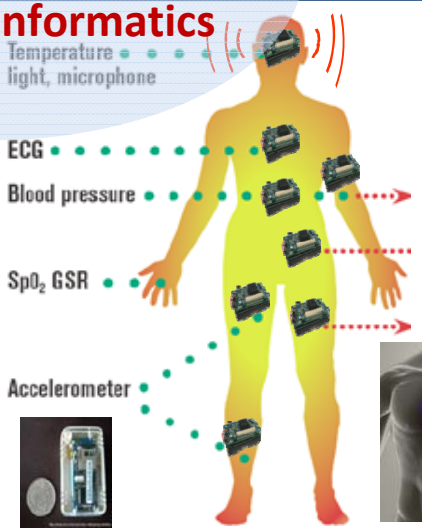



Public Sensing

Personal Sensing

Social Sensing

Smart Health Care



Source: Sajal Das, Keith Marzullo

New Paradigms for Communications

Today

1988

Remarkable
Pace of Innovation

MOBILE **SOCIAL NETWORKS** **BLOGS**

EMAIL **VOIP** **VIDEO**

Communications Volume & Traffic Diversity

VoIP → 663M registered Skype users in 2011. Represents 20% of long distance minutes world-wide. If Skype were a carrier, it would be the 3rd largest in the world (behind China Mobile and Vodaphone). Largest provider of cross-border communication.

Video → Recent estimates as high as 60% of internet traffic is video and music sharing; 35 hours of new videos are uploaded every minute in 2011; 2 billion views per day.

Twitter → Currently 175 million registered users.

Broadband → 20% of global internet users have residential broadband; 68% in US subscribe to broadband.

Mobile → 5.3 billion mobile phone subscribers; 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.

Data Deluge

- Science gathers data at an ever-increasing **rate** across all **scales** and **complexities** of natural phenomena
- Sloan Digital Sky Survey in 2000, collected more data in its 1st few weeks than had been amassed in the entire history of astronomy
  - Within a decade, over 140 terabytes of information collected
  - The proposed Large Synoptic Survey Telescope (3.3 gigapixel digital camera) will generate 40 terabytes of data nightly
- By 2015, the world will generate the equivalent of approximately 93 million Libraries of Congress
- Estimated 40 exabytes of unique new information generated worldwide in 2010
- Only 5% of the information created is “structured” in a standard format of words or numbers; the rest are from cameras, smart phones, etc.

How Big is *Big*?

- "Big Data": "Datasets whose size is beyond the ability of typical database software tools to captre, store, manage, and analyze"

  -McKinsey Global Institute, Big data: the next frontier for innovation, competition, and productivity, May 2011.

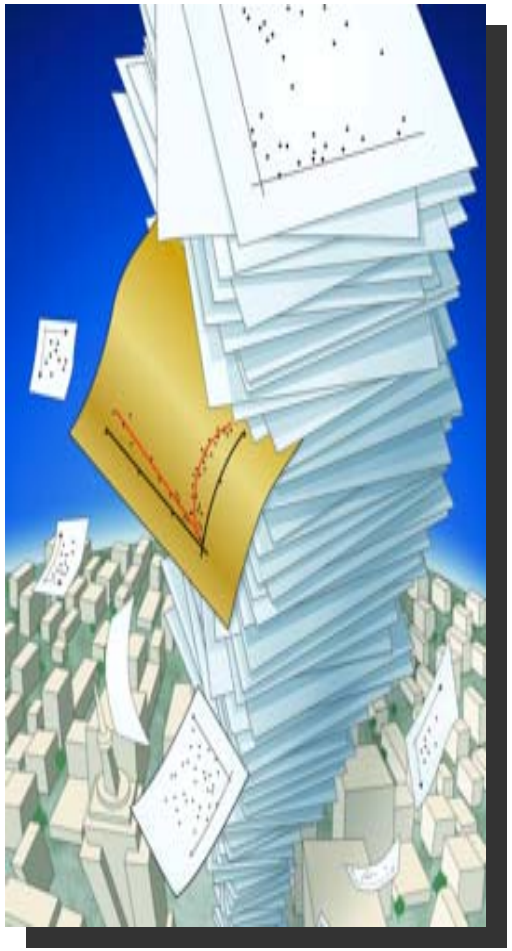


Image Credit: *Sigrid Knemeyer*

…Not Just Volumes of Data

- The science of big data is not just about volumes and velocity of data, but also
  - Heterogeneity and diversity
    - Levels of granularity
    - Media formats
    - Scientific disciplines
  - Complexity
    - Uncertainty
    - Incompleteness
    - Representation types

Why is Big Data Important?

- Transformative implications for commerce and economy
- Potential for addressing some of the society's most pressing challenges
- Critical to accelerating the pace of discovery in almost every science and engineering discipline

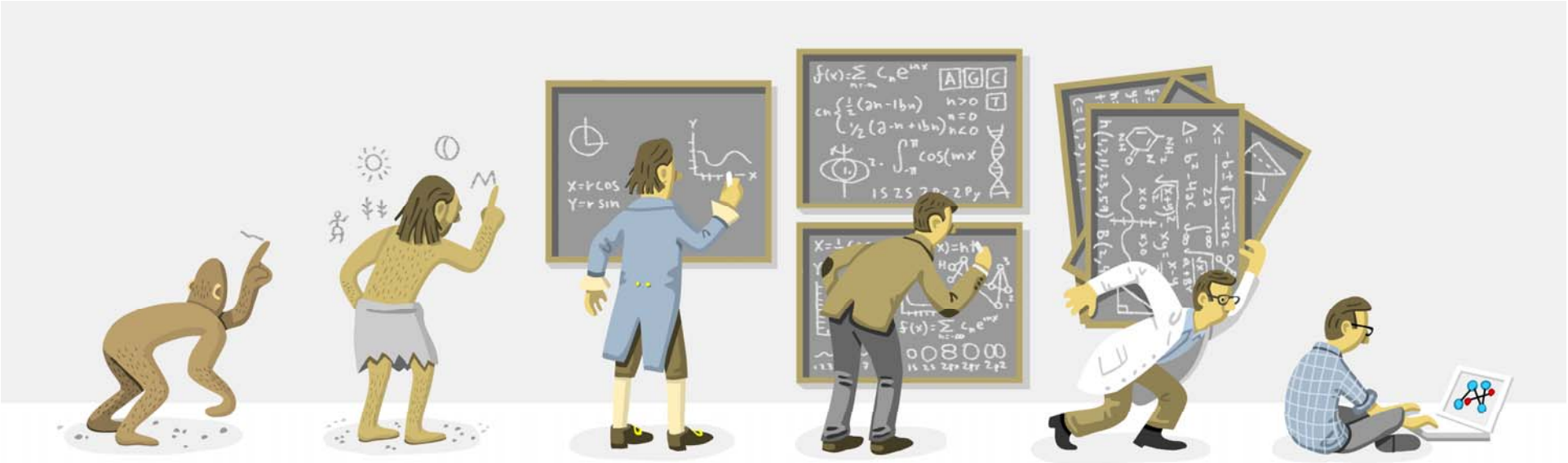
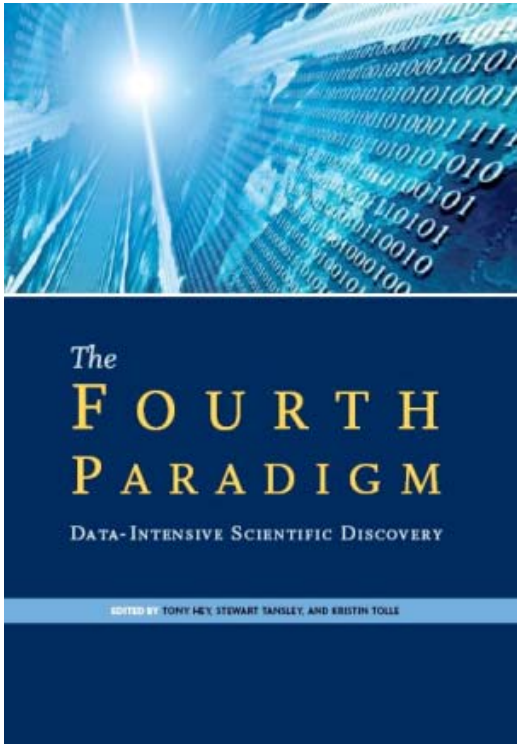


Image Credit: *Chi Birmingham*

Paradigm Shift: from Hypothesis-driven to Data-driven Discovery



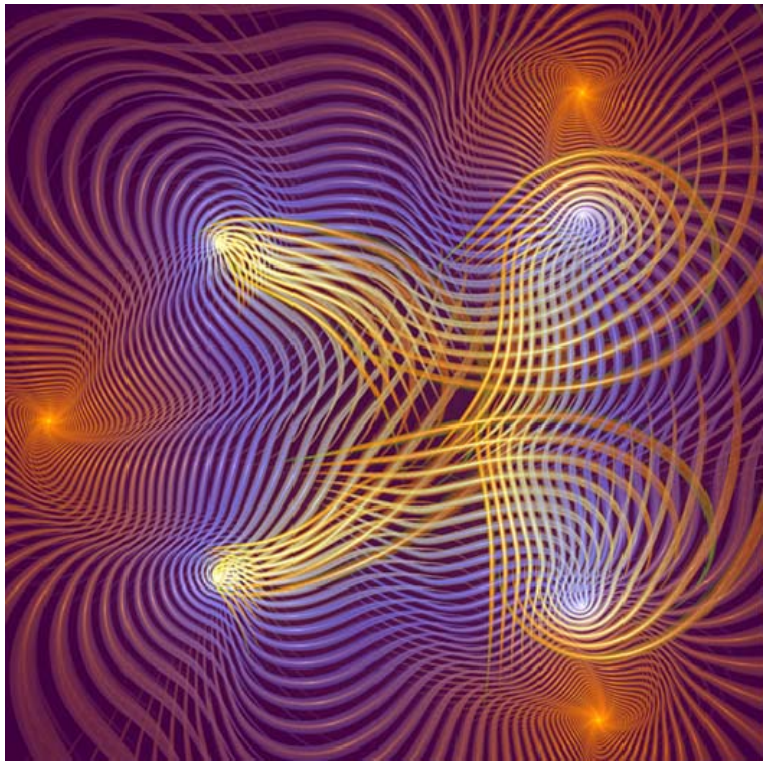
http://www.sciencemag.org/site/special/data/

http://www.economist.com/node/15579717

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

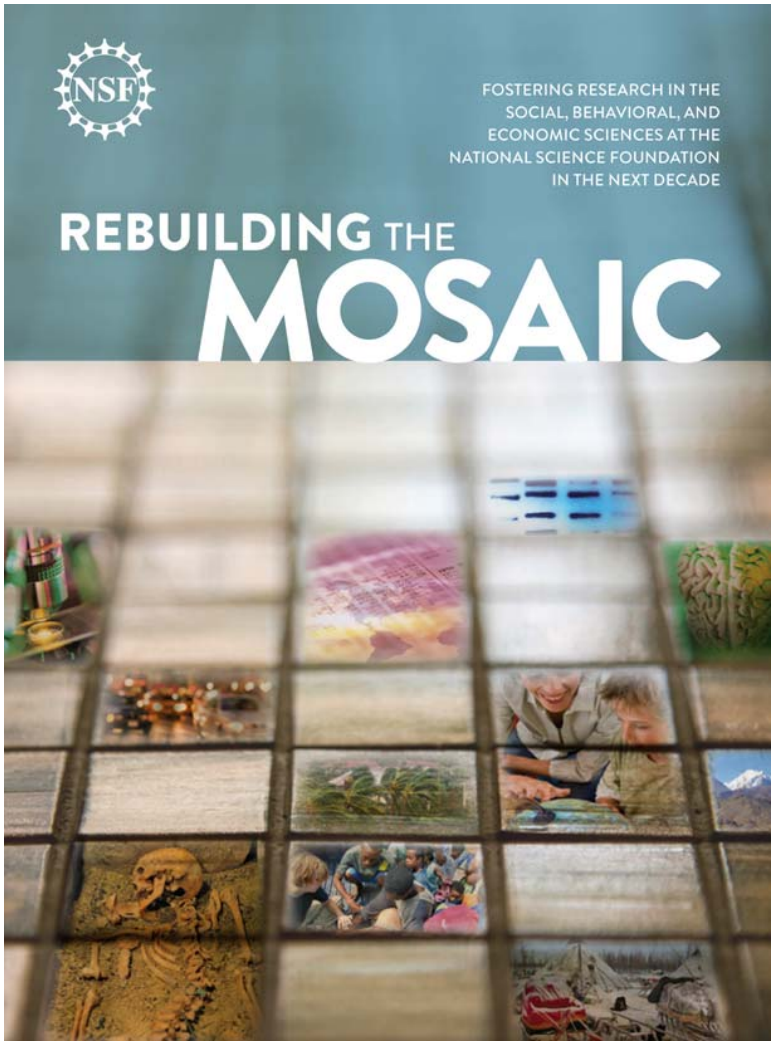
The Age of Data: From Data to Knowledge to Action

- **Data-driven discovery is** revolutionizing scientific exploration and engineering innovations
- **Automatic extraction of new knowledge** about the physical, biological and cyber world continues to accelerate
- Multi-cores, concurrent and parallel algorithms, virtualization and advanced server architectures will enable **data mining and machine learning**, and **discovery and visualization of Big Data**



Future SBE research: Technology and data drivers

- Scale: More data from more sources (environmental, sensor, administrative, survey, commercial, usage, and so on)
- Density (merge, overlap, georectify)
- Tools (statistics, GIS, network analysis, modeling, scenarios)
- Granularity (fMRI, administrative, commercial and behavioral level)
- Greater access to and demand for high performance computational resources

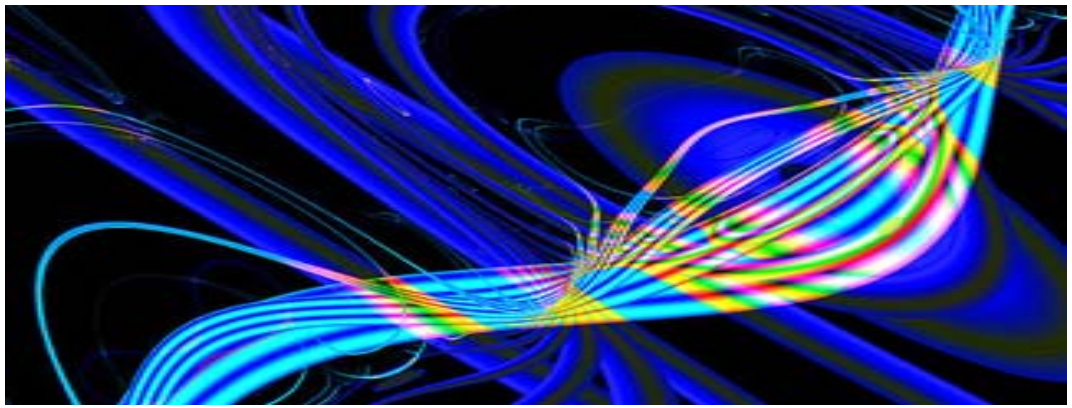


Examples of Research Challenges

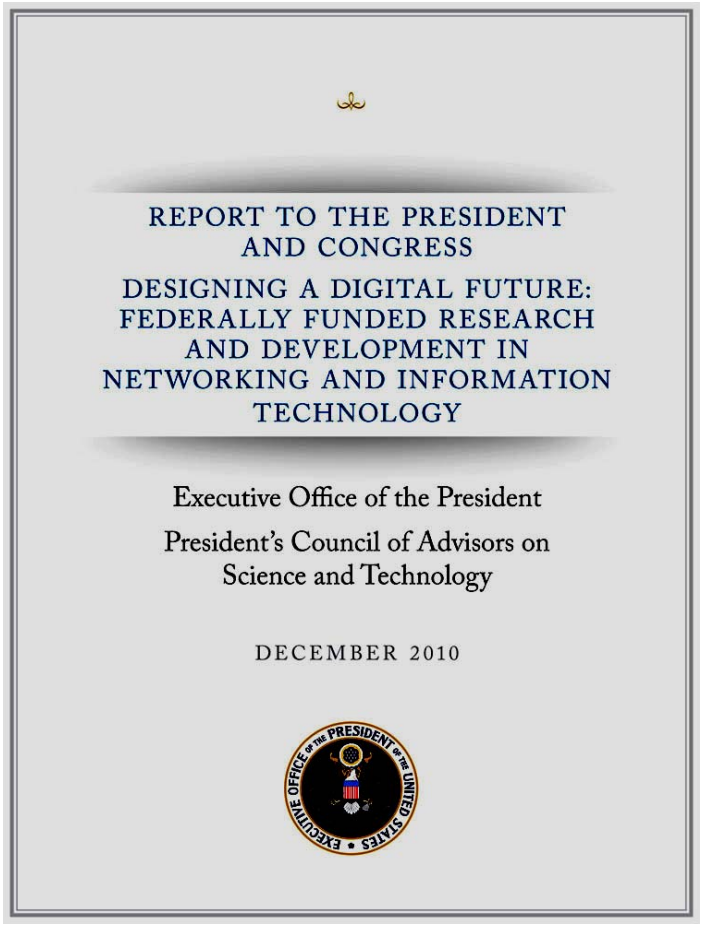
- More data is being collected than we can store
  - Analyze the data as it becomes available
  - Decide what to archive and what to discard
- Many data sets are too large to download
  - Analyze the data wherever it resides
- Many data sets are too poorly organized to be usable
  - Better organize and retrieve data
- Many data sets are heterogeneous in type, structure, semantics, organization, granularity, accessibility …
  - Integrate and customize access to federate data
- Utility of data limited by our ability to interpret and use it
  - Extract and visualize actionable knowledge
  - Evaluate results
- Large and linked datasets may be exploited to identify individuals
  - Design management and analysis with built-in privacy preserving characteristics

A Complex Policy Setting

- Researchers want data.
- Public policy requires access to data.
- Public policy also requires protection of privacy and intellectual property and other sensitive information.
- Much more to be done: Policy on data management and data access



A National Imperative



PCAST calls on the Federal government to increase R&D investments for collecting, storing, preserving, managing, analyzing, and sharing the increasing quantities of data.

Source: PCAST (December 2010), "Report to the President and Congress: Designing a Digital Future…"– a periodic congressionally-mandated review of the Federal Networking and Information Technology Research and Development (NITRD) Program.

Administration's Big Data Research and Development Initiative

- Big Data Senior Steering Group – chartered in spring 2011 under the Networking and Information Technology R&D (NITRD) Program
  - Members from DARPA, DOD OSD, DHS, DOE-Science, NASA, NIST, NOAA, NSA, and USGS
  - Co-chaired by NIH and NSF

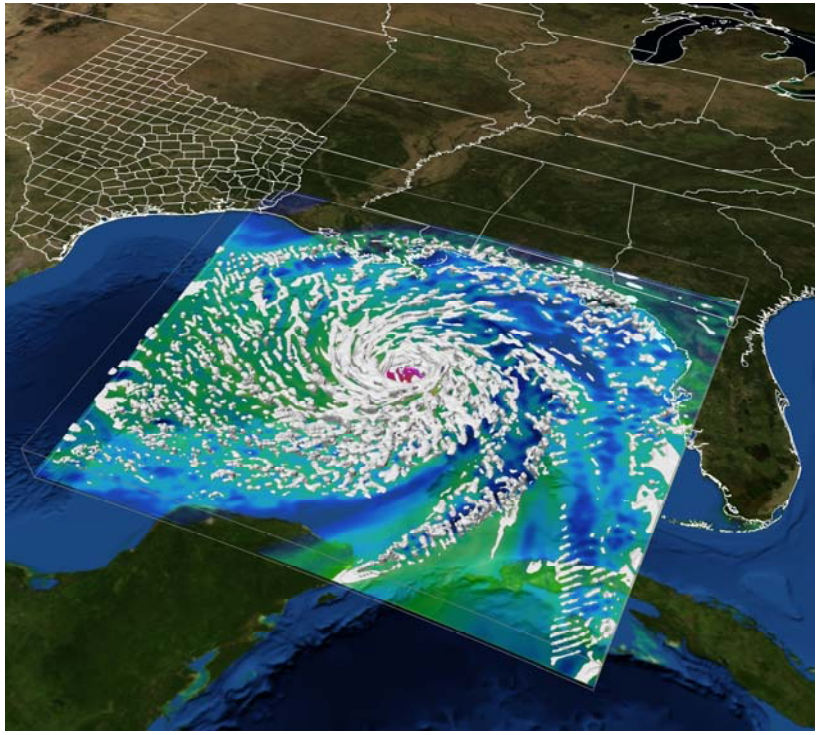


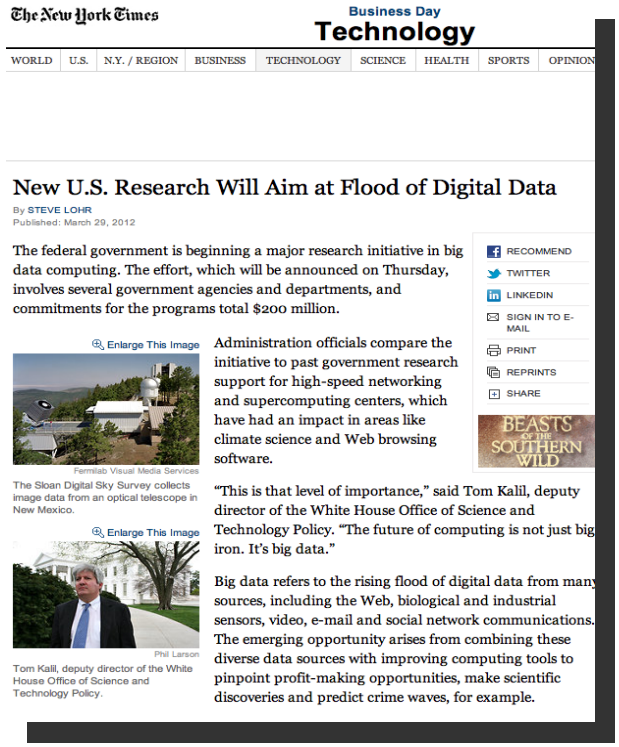
Image Credit: *Fuqing Zhang and Yonghui Weng, Pennsylvania State University; Frank Marks, NOAA; Gregory P. Johnson, Romy Schneider, John Cazes, Karl Schulz, Bill Barth, The University of Texas at Austin*

Big Data Launch

- Federal Big Data R&D Initiative launched by White House OSTP on March 29, 2012 at AAAS

Image Credit: *National Science Foundation*

- Federal Announcements:
  - NSF – Subra Suresh
  - NIH – Francis Collins
  - USGS – Marcia McNutt
  - DoD – Zach Lemnios
  - DARPA Ken Gabriel
  - DOE – William Brinkman


The New York Times — Business Day — Technology

WORLD | U.S. | N.Y. / REGION | BUSINESS | TECHNOLOGY | SCIENCE | HEALTH | SPORTS | OPINION

New U.S. Research Will Aim at Flood of Digital Data

By STEVE LOHR
Published: March 29, 2012

The federal government is beginning a major research initiative in big data computing. The effort, which will be announced on Thursday, involves several government agencies and departments, and commitments for the programs total $200 million.

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Enlarge This Image

Fermilab Visual Media Services

The Sloan Digital Sky Survey collects image data from an optical telescope in New Mexico.

Administration officials compare the initiative to past government research support for high-speed networking and supercomputing centers, which have had an impact in areas like climate science and Web browsing software.

"This is that level of importance," said Tom Kalil, deputy director of the White House Office of Science and Technology Policy. "The future of computing is not just big iron. It's big data."

Enlarge This Image

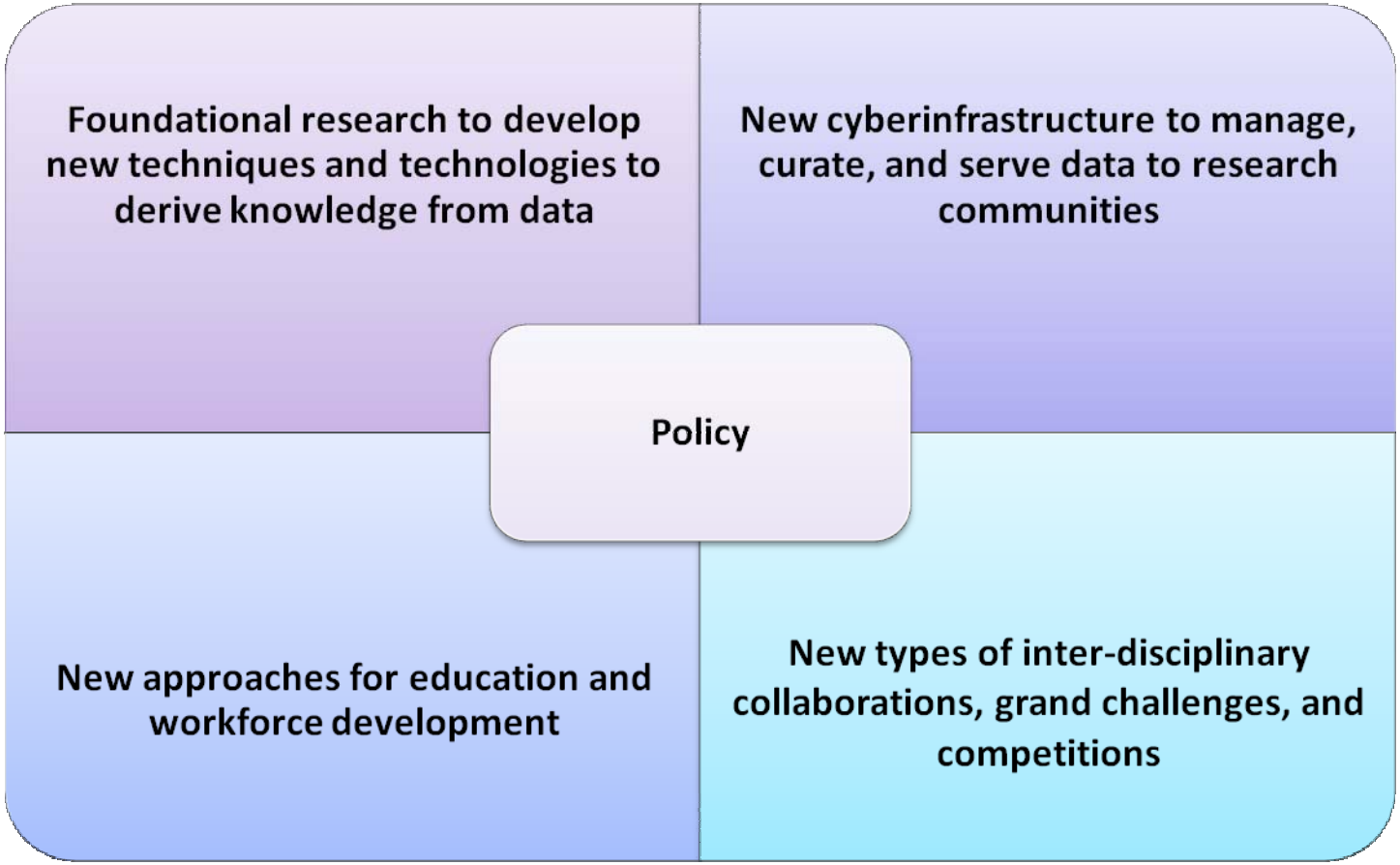
Phil Larson

Tom Kalil, deputy director of the White House Office of Science and Technology Policy.

Big data refers to the rising flood of digital data from many sources, including the Web, biological and industrial sensors, video, e-mail and social network communications. The emerging opportunity arises from combining these diverse data sources with improving computing tools to pinpoint profit-making opportunities, make scientific discoveries and predict crime waves, for example.

More information available at:
http://nsf.gov/news/news_summ.jsp?org=CISE&cntn_id=123607&preview=false

NSF Strategy to Address Big Data



Core Techniques and Technologies for Advancing Big Data Science & Engineering (BIG DATA)

Foundational research to extract knowledge from data

Foundational research to advance the core techniques and technologies for managing, analyzing, visualizing, and extracting useful information from large, diverse, distributed and heterogeneous data sets.

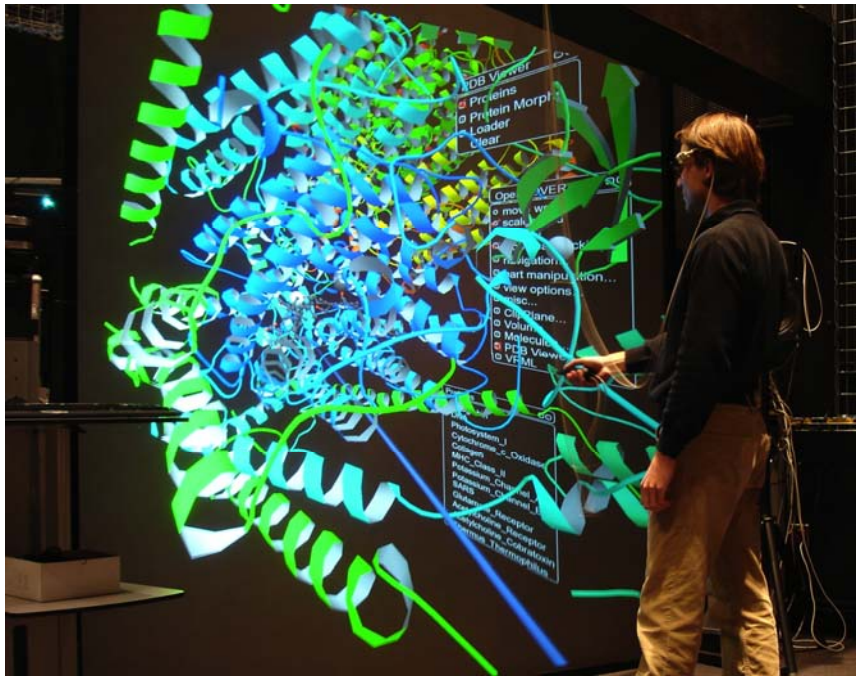


Image Credit: *Jurgen Schulze, Calit2, UC-San Diego*

Cross-Directorate Program: NSF Wide

Multi-agency Commitment: NSF and NIH

BIG DATA Research Thrusts

Collection, Storage, and Management of "Big Data"

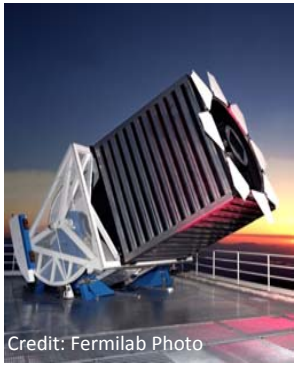
- Data representation, storage, and retrieval
- New parallel data architectures, including clouds
- Data management policies, including privacy and access
- Communication and storage devices with extreme capacities
- Sustainable economic models for access and preservation

Data Analytics

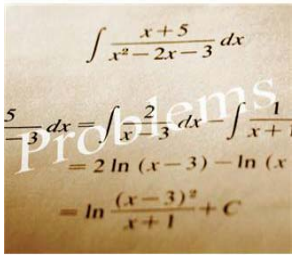
- Computational, mathematical, statistical, and algorithmic techniques for modeling high dimensional data
- Learning, inference, prediction, and knowledge discovery for large volumes of dynamic data sets
- Data mining to enable automated hypothesis generation, event correlation, and anomaly detection
- Information infusion of multiple data sources

Research in Data Sharing and Collaboration

- Tools for distant data sharing, real time visualization, and software reuse of complex data sets
- Cross disciplinary model, information and knowledge sharing
- Remote operation and real time access to distant data sources and instruments



Credit: Fermilab Photo



Earthcube

- EAGER awards announced as part of White House Big Data
- Integrates geosciences data and high-performance computing technologies in an open, adaptable and sustainable framework to enable transformative research and education in Earth System Science
- Innovative Model: *Community designed, community owned, community governed*
- Interdisciplinary research:
  - Building and sustaining “new” communities
  - Workshops to bring together (GEO, SBE, CISE) communities
  - EAGER awards to seed new research

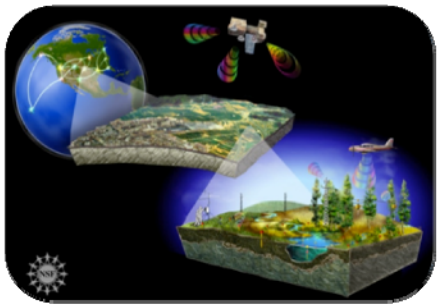
NSF Announcements

- ***Dear Colleague Letters:***
  - **Encourage CIF21 IGERTs** to educate and support a new generation of researchers able to address fundamental Big Data challenges: http://www.nsf.gov/pubs/2012/nsf12555/nsf12555.htm
  - **Data Citation to the Geosciences Community** to encourage transparency and increased opportunities for the use and analysis of data sets: http://www.nsf.gov/pubs/2012/nsf12058/nsf12058.jsp
  - **Data-Intensive Education-Related Research Funding Opportunities** announcing an Ideas Lab, for which cross disciplinary participation will be solicited, to generate transformative ideas for using large datasets to enhance the effectiveness of teaching and learning environments: http://www.nsf.gov/pubs/2012/nsf12060/nsf12060.jsp

- ***Expeditions-in-Computing award:***
  - UC Berkeley, "Making Sense at Scale with Algorithms, Machines, and People" http://www.nsf.gov/awardsearch/showAward.do?AwardNumber=1139158

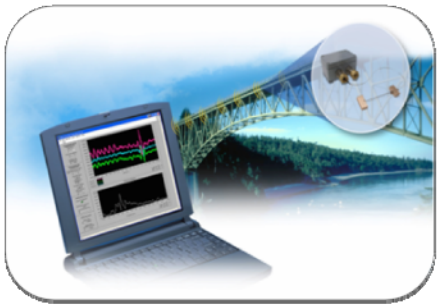
Big Data to Address National Priorities

Health & Wellbeing



Environment & Sustainability

Emergency Response & Disaster Resiliency



Manufacturing, Robotics, & Smart Systems

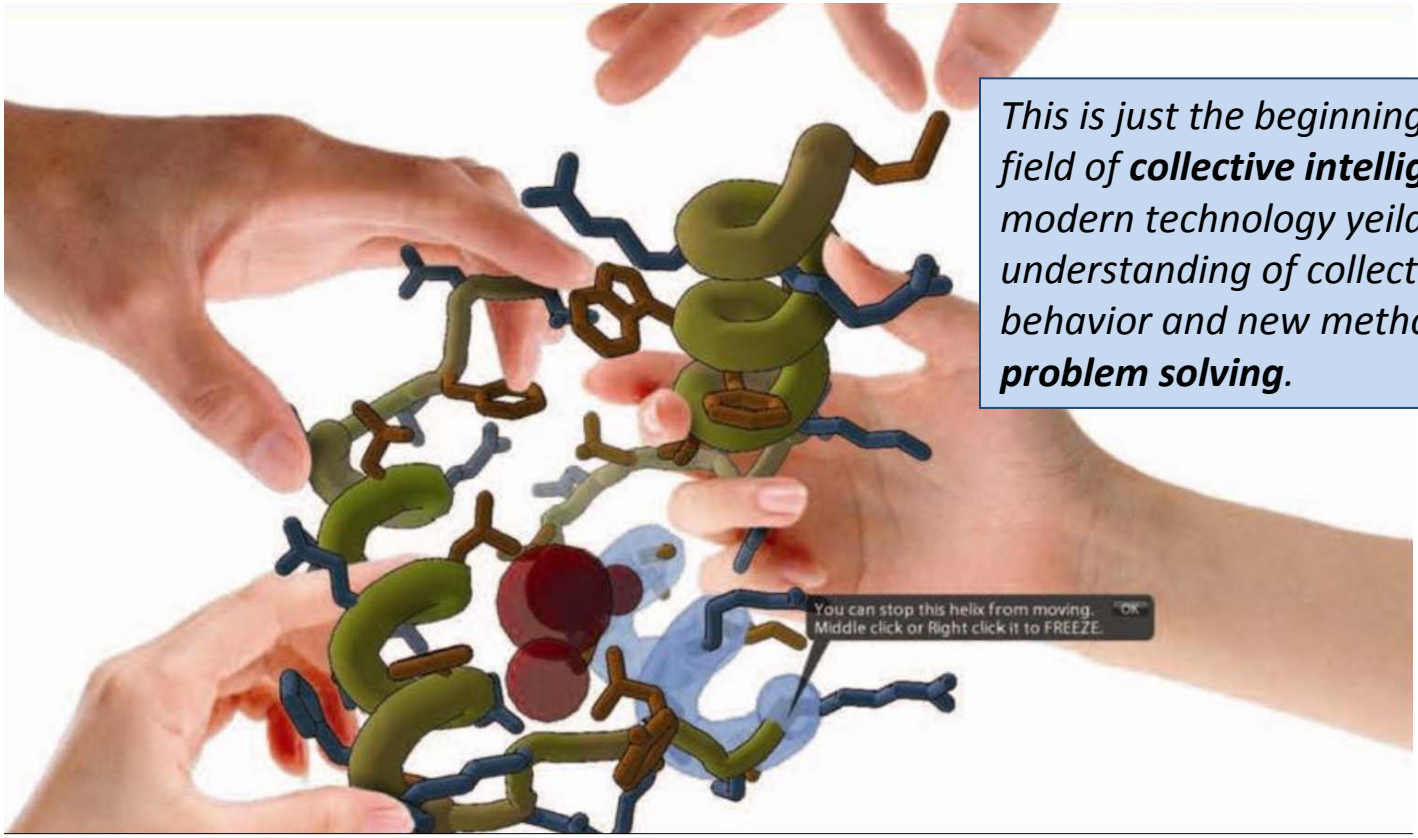
Secure Cyberspace

Transportation & Energy

Education and Workforce Development

Social Networks Solving Complex Problems

Networks of human minds are taking citizen science to a new level



*This is just the beginning of a new field of **collective intelligence** in which modern technology yeilds new understanding of collective human behavior and new methods for **problem solving**.*

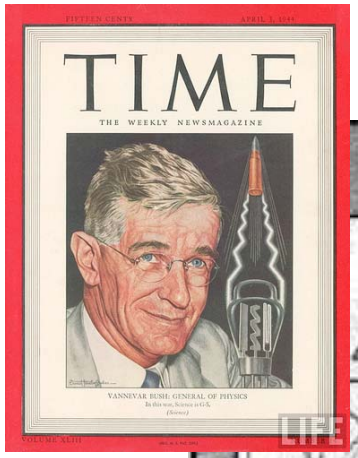
Foldit image: Univ. Washington Center For Game Science; artwork by W. Fernandes, Nature, Aug 2010

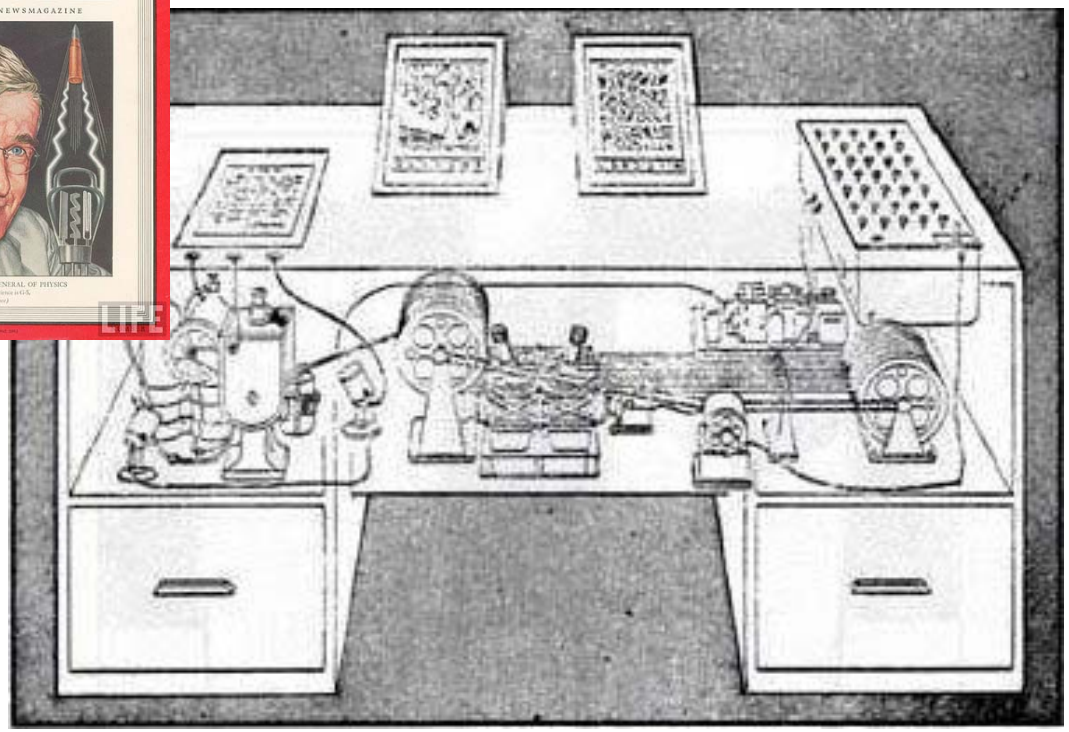
In 2011, players of Foldit helped to decipher the crystal structure of the Mason-Pfizer monkey virus (M-PMV) retroviral protease, an AIDS-causing monkey virus. Players produced an **accurate 3D model** of the enzyme **in just ten days**. The problem of how to configure the structure of the enzyme had **stumped scientists for 15 years**.

Vannevar Bush's Vision of the Memex

Innovations for access to and interacting with information

1945 → Today





Big Opportunities for the Future

- Our investments in **research and education** have returned exceptional dividends to our nation.

- Scientific discovery and technological innovation are at the core of our response to **national and societal challenges** – from environment, energy, transportation, sustainability and healthcare, to cyber security and national defense.

- Many of tomorrow's breakthroughs will occur at the **intersections of diverse disciplines**.

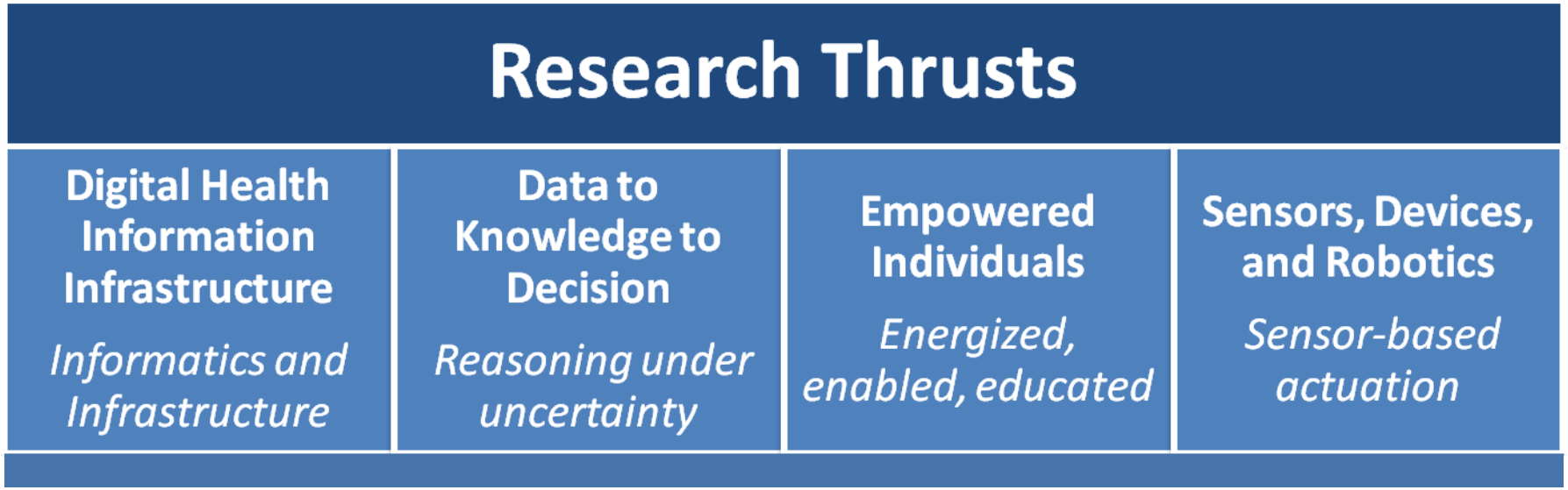
Thanks!

mgutmann@nsf.gov

Smart Health & Wellbeing

Transforming healthcare knowledge, delivery, and quality of life through IT

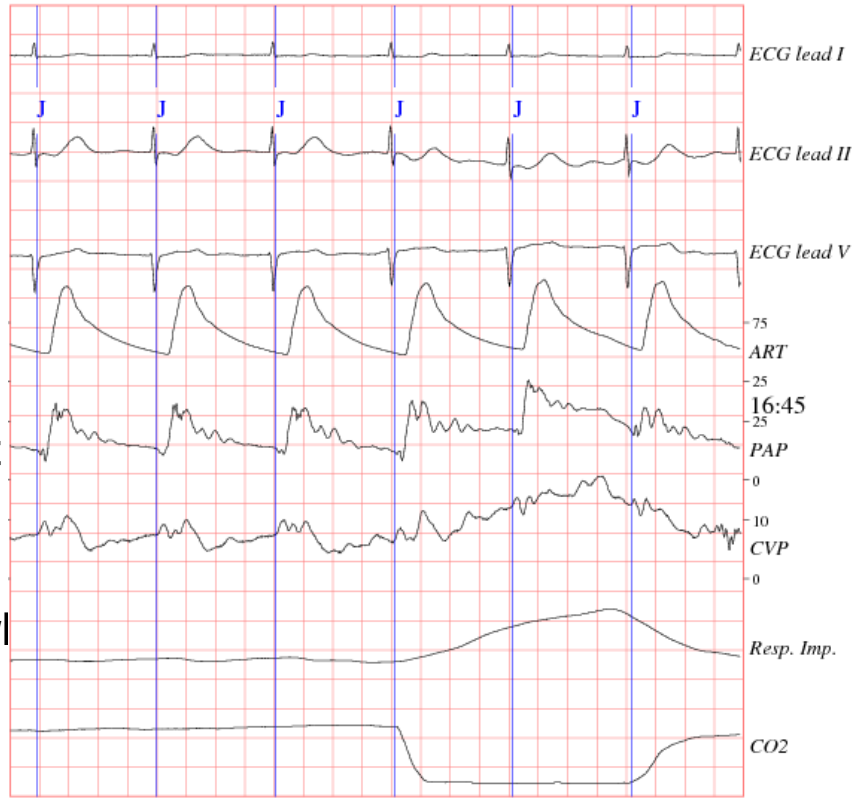
Paradigm Shift: transforming healthcare from reactive and hospital-centered to preventive, proactive, evidence-based, person-centered and focused on wellbeing rather than disease.



Cross-Directorate Program: CISE, ENG, and SBE

Era of “Big Data” in Healthcare

- **Large volumes of data currently collected**
  - **EHRs and PHRs**
    - **Multi-scale and multi-source**
  - **During hospitalizations**
    - **For safety and diagnosis**
  - **On an out-patient basis**
    - **Typically event monitors**
  - **Via ubiquitous mobile sensors**
    - **Behavior, physiology, environment**
  - **As part of clinical studies**
    - **To evaluate safety and efficacy**
  - **From growing body of scientific knowl**
    - **In biomedical research literature**



- **Gigabits/patient/day**
  - **High sampling rates**
  - **Multiple signals**
- **Accumulating data is getting easier, but using data is hard**

Data to Knowledge to Decision

Reasoning under uncertainty

The ability to acquire, aggregate and mine clinical, scientific, behavioral data will create an unprecedented amount of high quality data from individuals and population

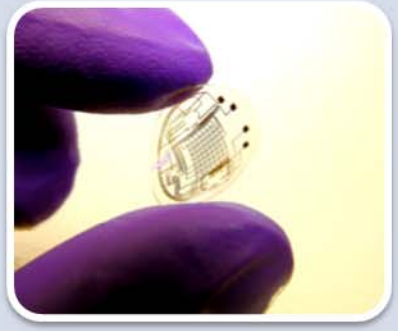
Enabling evidence-based medicine, early diagnoses, personalized assessments and care

Data to Knowledge to Decision

Reasoning under uncertainty

New patient-centric decision support tools for diagnosis and treatment through integration of biomedical knowledge and clinical data with health records

Discovery of causal relationships and predictive indicators for individual and population health – better understanding of behavioral, genetic and environmental causes



Potential impact on discovery and clinical trial for new drugs and medical devices – faster, less expensive with more predictable outcomes

Rapid coordinated response to infectious disease outbreaks and natural/man-made disasters

Secure and Trustworthy Cyberspace (SaTC)

Securing our Nation's cyberspace

- **New interdisciplinary program** that aims to support fundamental scientific advances and technologies to protect cyber-systems from malicious behavior, while preserving privacy and promoting usability.

- **Scholarship for Service (SFS)** will increase the number of qualified students entering the fields of information assurance and cybersecurity
  Of over 1500 funded through the program, over 1100 have been placed in Federal agencies

Image Credit: *ThinkStock*

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

SaTC Perspectives
Research Opportunities

Trustworthy Computing Systems

- Perspective aims to provide scientific basis for designing, building and operating cyber-infrastructure with improved resilience and resistance
- Support for both theoretical and experimental approaches
- Investigation of tradeoff among trustworthy properties

Social, Behavioral & Economic

- Perspective includes research at individual, group, organizational, market and societal levels, identifying risks and exploring solution feasibility
- Understanding attack or defense behaviors to develop more effective strategies and solutions
- Cyber economic incentives including metrics and models

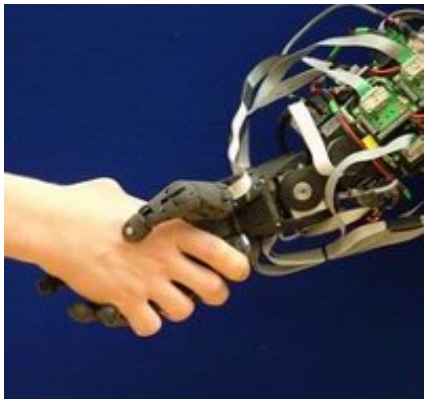
Transition to Practice

- Perspective addresses the challenge of moving from research to practice
- Focus on later stages of R&D activities including evaluation and experimental deployment
- Software required to be released under open software license

National Robotics Initiative (NRI)

Developing the next generation of collaborative robots to enhance personal safety, health, and productivity

A nationally concerted cross-agency program to provide U.S. leadership in science and engineering research and education aimed at the development and use of cooperative robots that work alongside people across many sectors.



Credit: *Bristol Robotics Lab*

Research Thrusts

- **Fundamental research in robotics science & engineering**
- **Understanding the long term social, behavioral, and economic implications across all areas of human activity**
- **Use of robotics to facilitate and motivate STEM learning across the K-16 continuum**

Cross-Directorate Program: CISE, EHR, ENG, and SBE

Multi-agency Commitment: NSF, NASA, NIH, USDA

Cyberlearning: Transforming Education

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

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

DO-IT Center, University of Washington, Seattle

Cross-Directorate Program: CISE, EHR, OCI, SBE

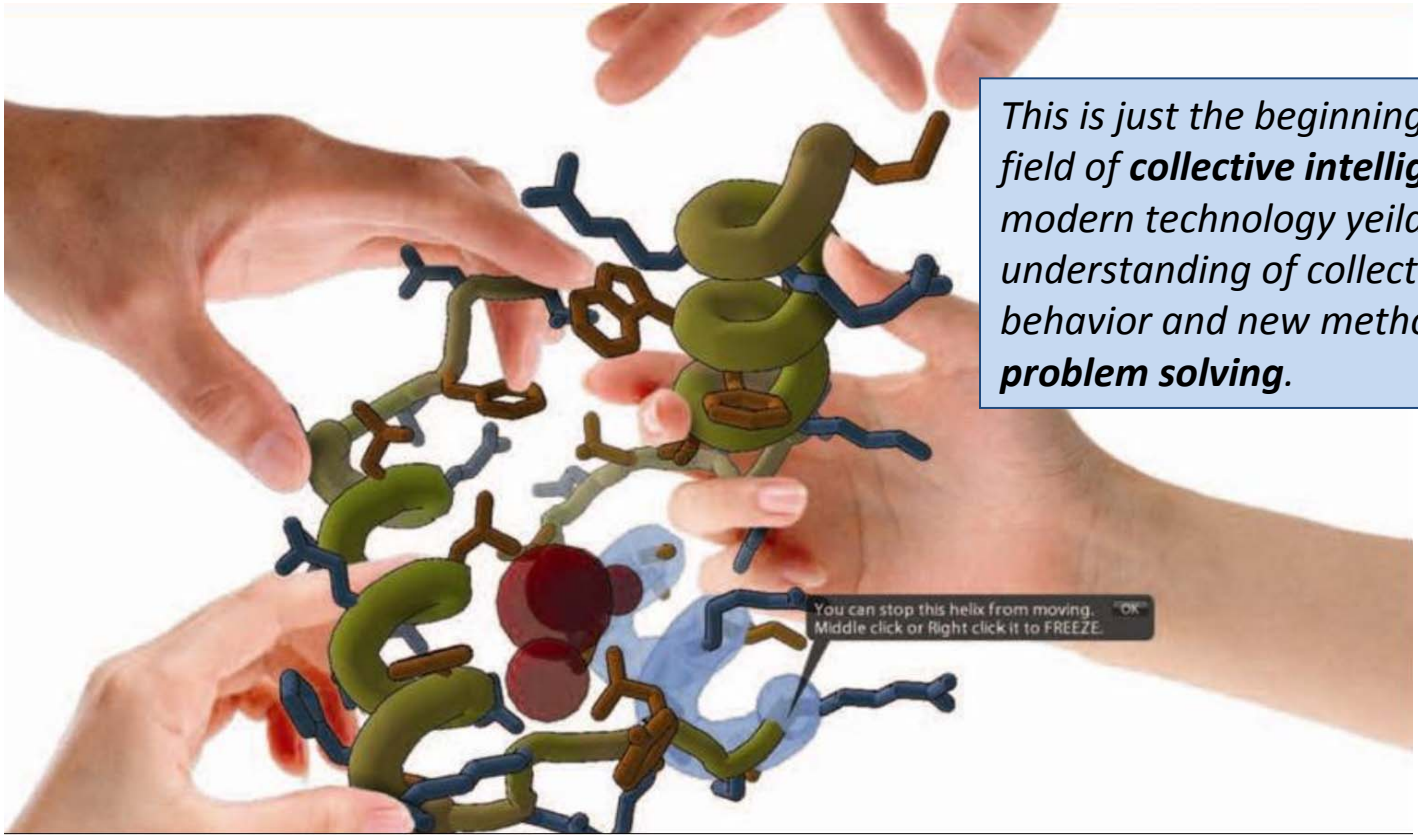
Networked Society

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

- We are increasingly becoming a networked society
- Networks of human minds are taking citizen science to a new level - new methods for problem solving.
- 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

Social Networks Solving Complex Problems

Networks of human minds are taking citizen science to a new level



*This is just the beginning of a new field of **collective intelligence** in which modern technology yeilds new understanding of collective human behavior and new methods for **problem solving**.*

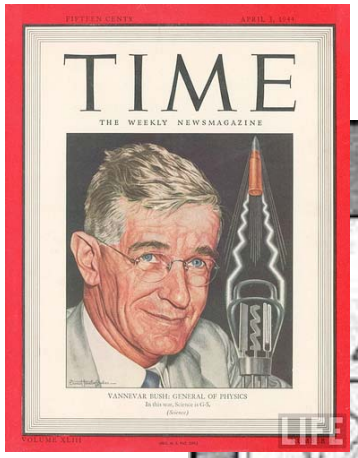
Foldit image: Univ. Washington Center For Game Science; artwork by W. Fernandes, Nature, Aug 2010

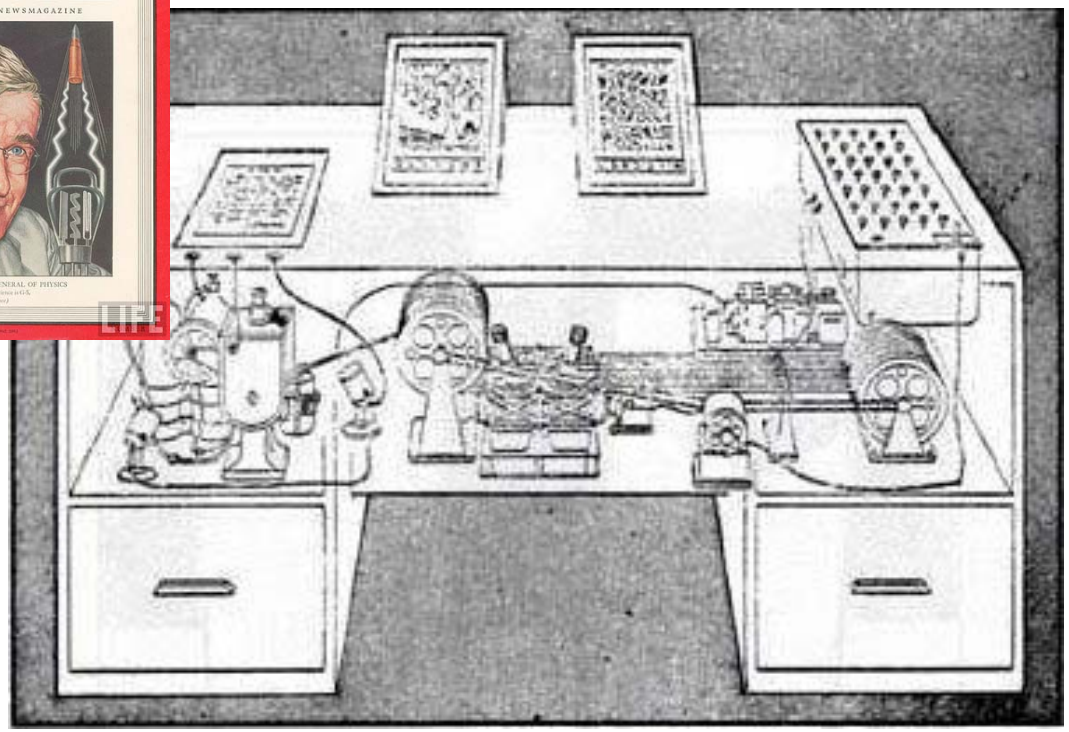
In 2011, players of Foldit helped to decipher the crystal structure of the Mason-Pfizer monkey virus (M-PMV) retroviral protease, an AIDS-causing monkey virus. Players produced an **accurate 3D model** of the enzyme **in just ten days**. The problem of how to configure the structure of the enzyme had **stumped scientists for 15 years**.

Vannevar Bush's Vision of the Memex

Innovations for access to and interacting with information

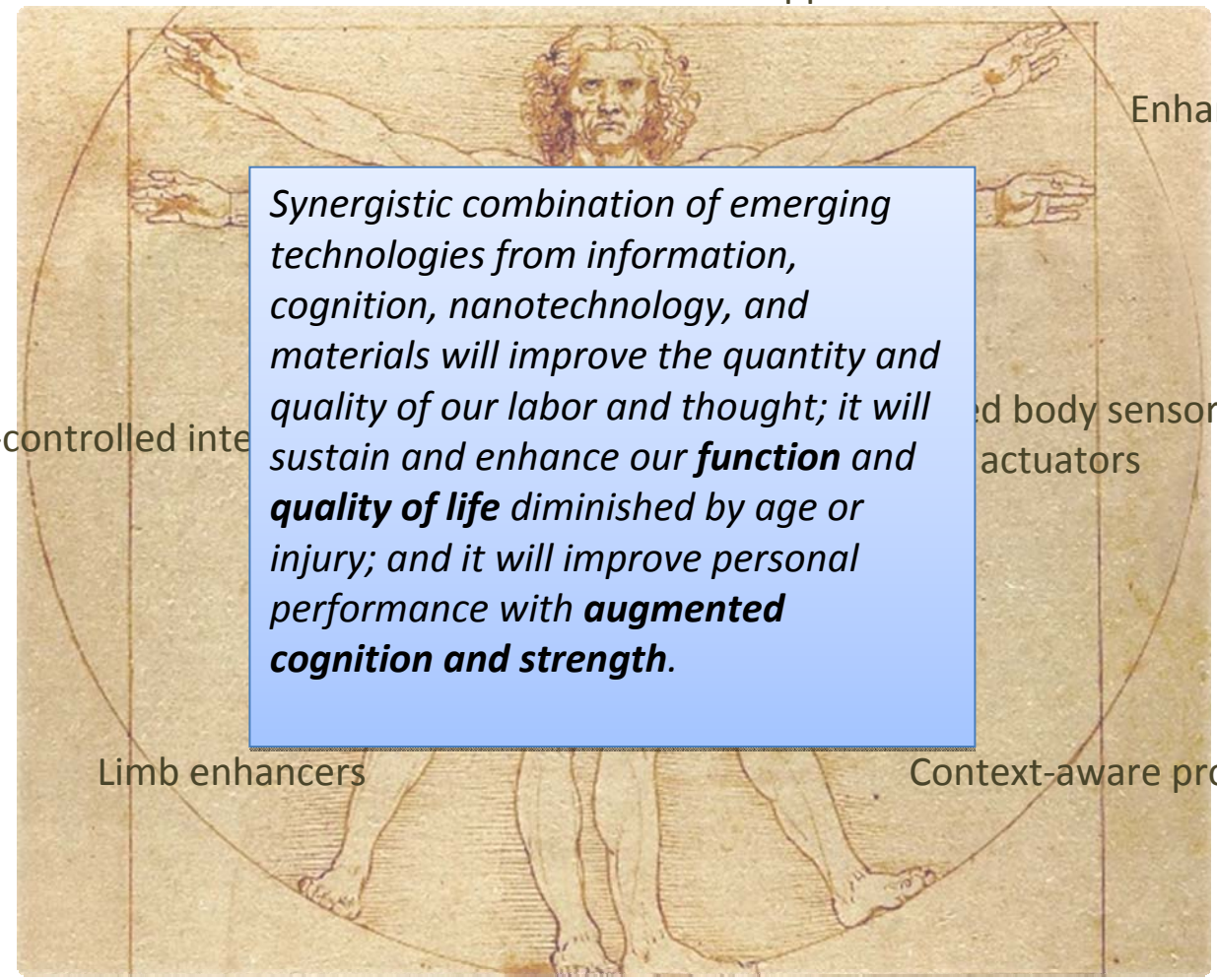
1945 → Today





Augmented Human Capabilities

Converging technologies for enhancing performance and quality of life



Big Opportunities for the Future

- Our investments in **research and education** have returned exceptional dividends to our nation.

- Scientific discovery and technological innovation are at the core of our response to **national and societal challenges** – from environment, energy, transportation, sustainability and healthcare, to cyber security and national defense.

- Many of tomorrow's breakthroughs will occur at the **intersections of diverse disciplines**.