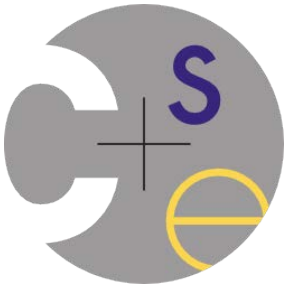
UNIVERSITY of WASHINGTON

Computer Science, Global Challenges, and National Policy

Ed Lazowska

Bill & Melinda Gates Chair in Computer Science & Engineering

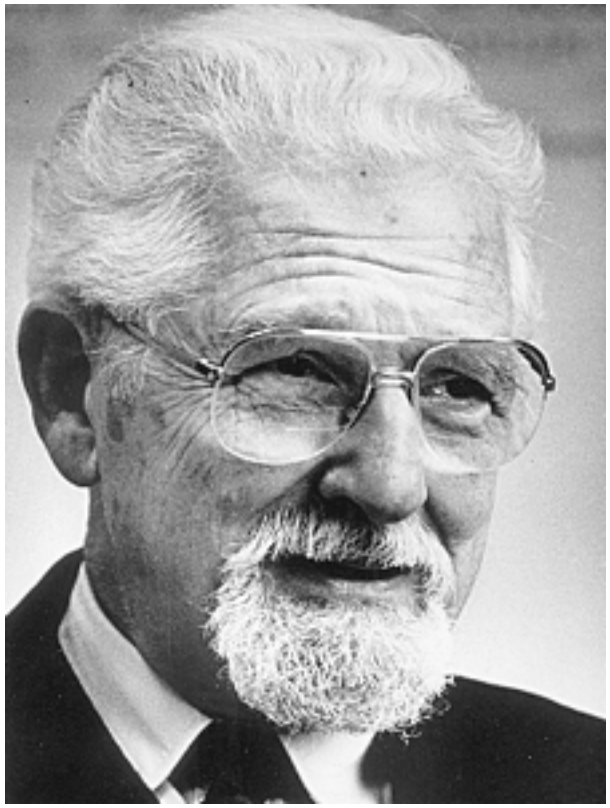
University of Washington



The Carolyn and Edward Wenk, Jr., Lecture in Technology and Public Policy

Johns Hopkins University

April 2014



Ed Wenk, 1920-2012

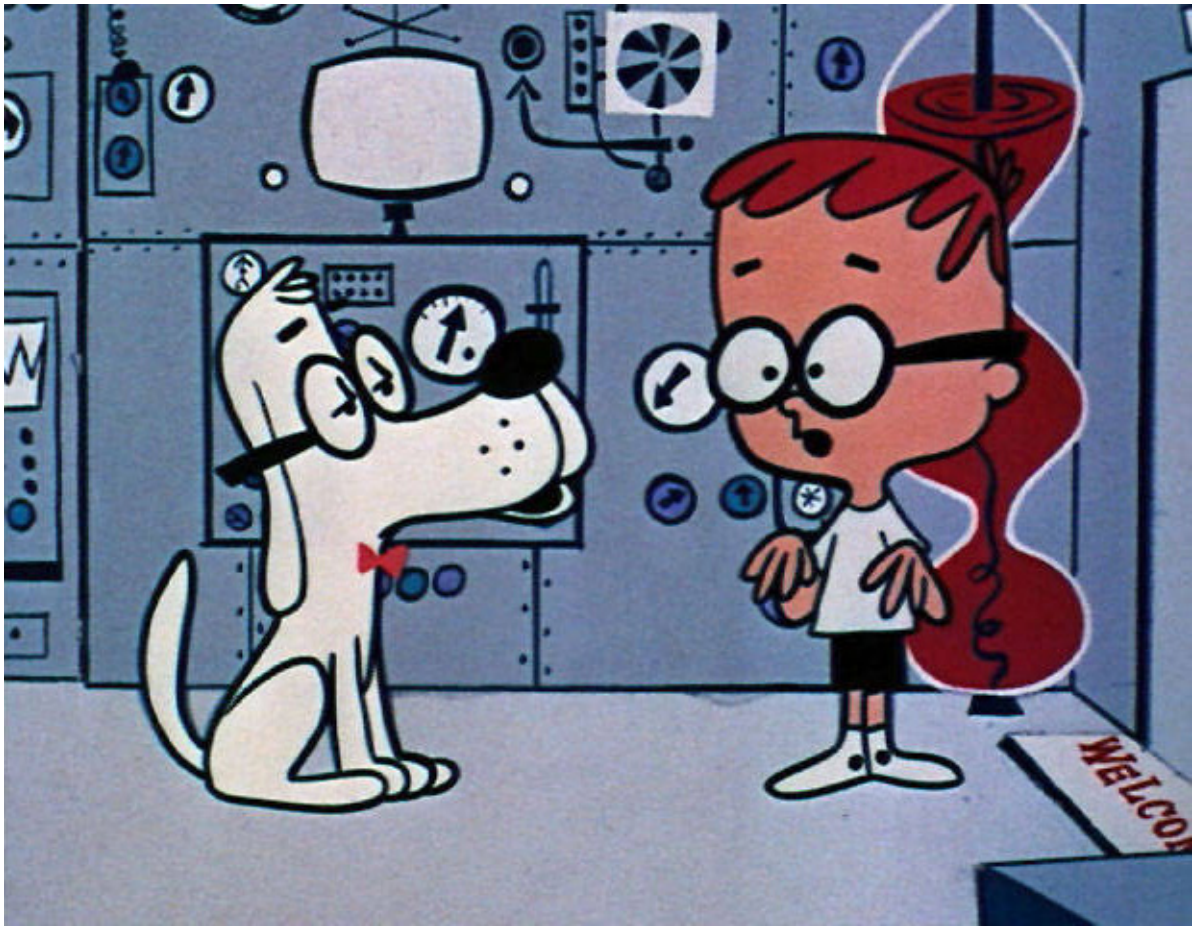
Johns Hopkins University B.E. 1940, D. Eng. 1950

University of Washington Professor of Engineering, Public Affairs, and Social Management of Technology, 1970-1990

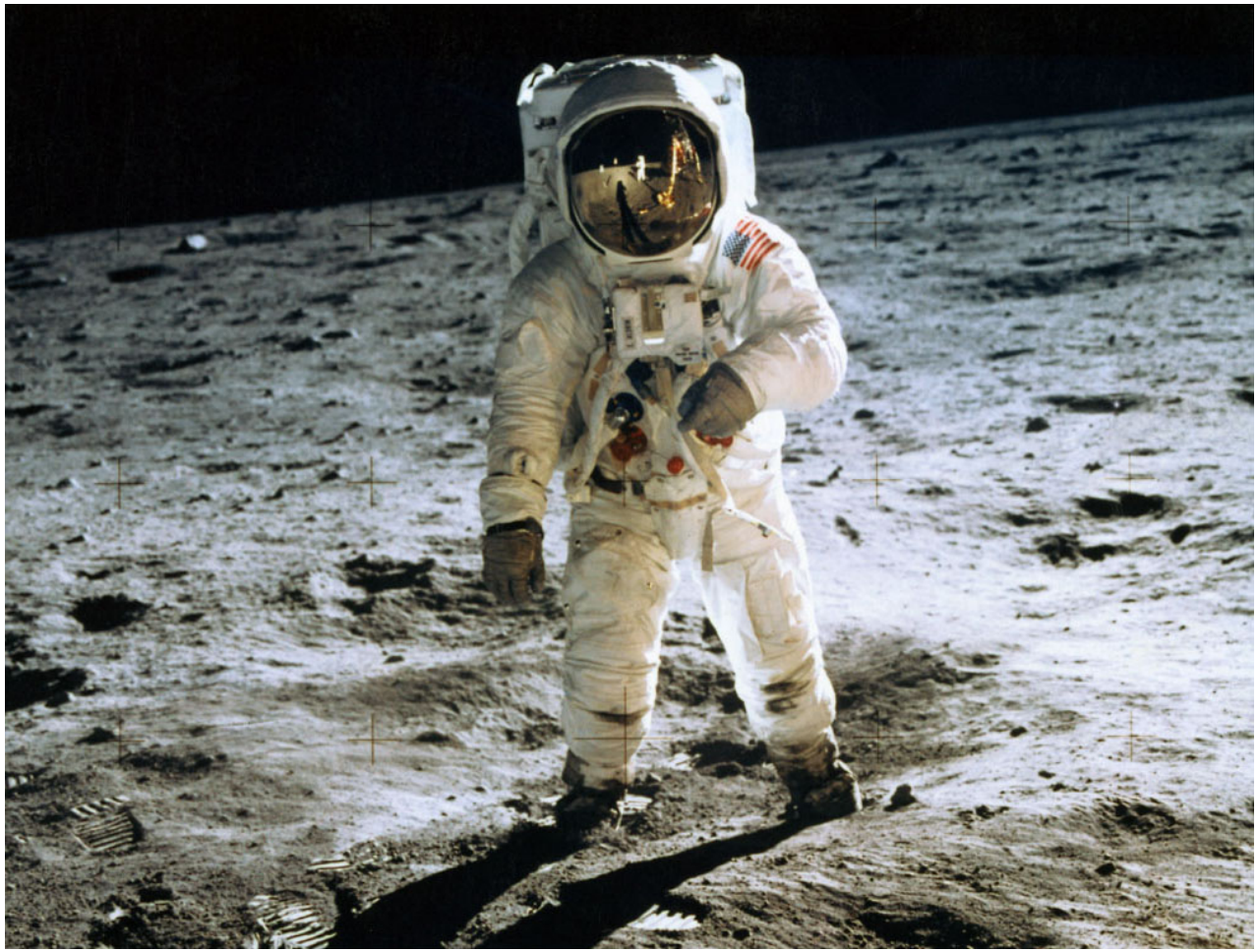
Today

- A reminder of the extraordinary progress that computer science has achieved
- How did America become the world leader in this field?
- Why is it imperative that we remain the leader?
- How should our competitiveness be defined, going forward?
- The coming decade: Dramatic improvements in technology and algorithms enable “smart everything”
- A modern view of the field
- Some research and education policy implications

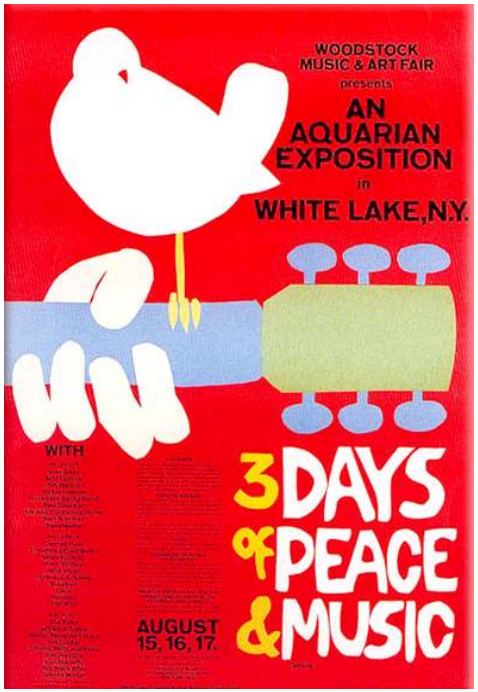
Forty five years ago …



Credit: Peter Lee, Microsoft Research




1969

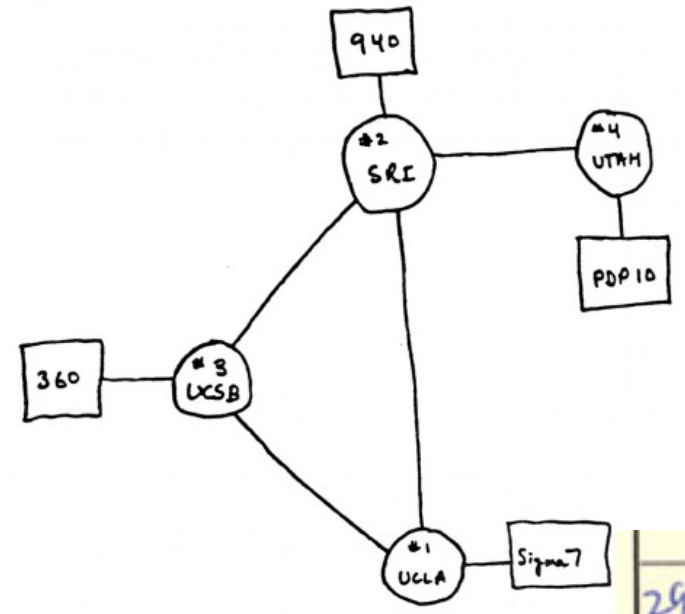

WOODSTOCK
MUSIC & ART FAIR
presents
AN
AQUARIAN
EXPOSITION
in
WHITE LAKE, N.Y.
WITH
3 DAYS
of PEACE
& MUSIC
AUGUST
15, 16, 17.


1969


1969 WORLD SERIES
NEW YORK METS


WORLD
CHAMPIONS
NEW YORK METS
1969


1969



THE ARPA NETWORK
DEC 1969
4 NODES

29OCT69	2100	LOADED OP. PROGRAM FOR BEN BARKER BBN	CSK
	22:30	Talked to SRI Host to Host	csk
		Left op. imp. program running after sending a host dead message to imp.	csk

With 4+ decades of hindsight, which had the greatest impact?

- Unless you're big into Tang and Velcro (or sex and drugs), the answer is clear …

- And so is the reason …

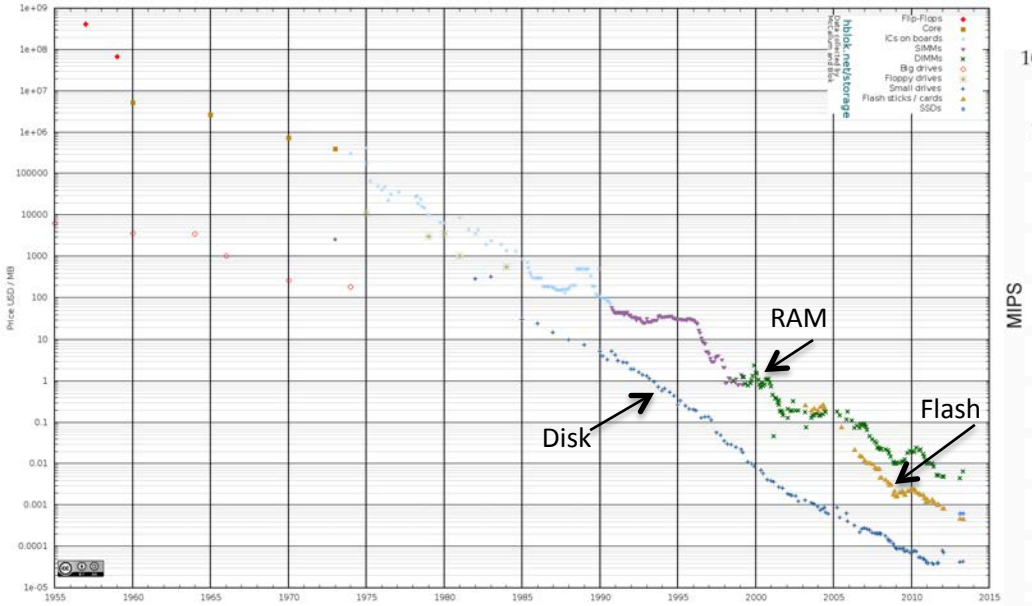
EXPONENTIALS  US

Every aspect of computing has experienced exponential improvement

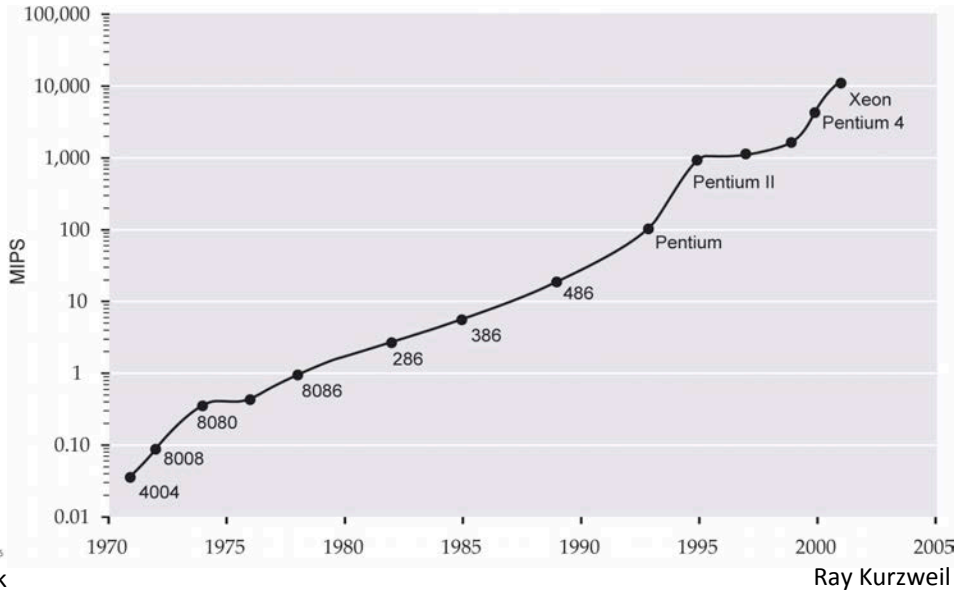
- Processing capacity
- Storage capacity
- Network bandwidth
- Sensors
- Astonishingly, even algorithms in some cases!

You can exploit these improvements in two ways

- Constant capability at exponentially decreasing cost
- Exponentially increasing capability at constant cost



Storage Price / MB, USD



Microprocessor Performance, MIPS


UNIVAC

Then and now …

- 20 years ago, microprocessors had 4 million transistors
  - Today they have 4 billion
- 20 years ago, the Internet had 1 million users
  - Today, it has 1 billion
- 20 years ago, only 15% of households had a computer
  - Today, nearly everyone owns a mobile phone
  - In the past year, more than half of all mobile phones purchased worldwide were smartphones – putting the Internet in the owner's pocket

Waking up

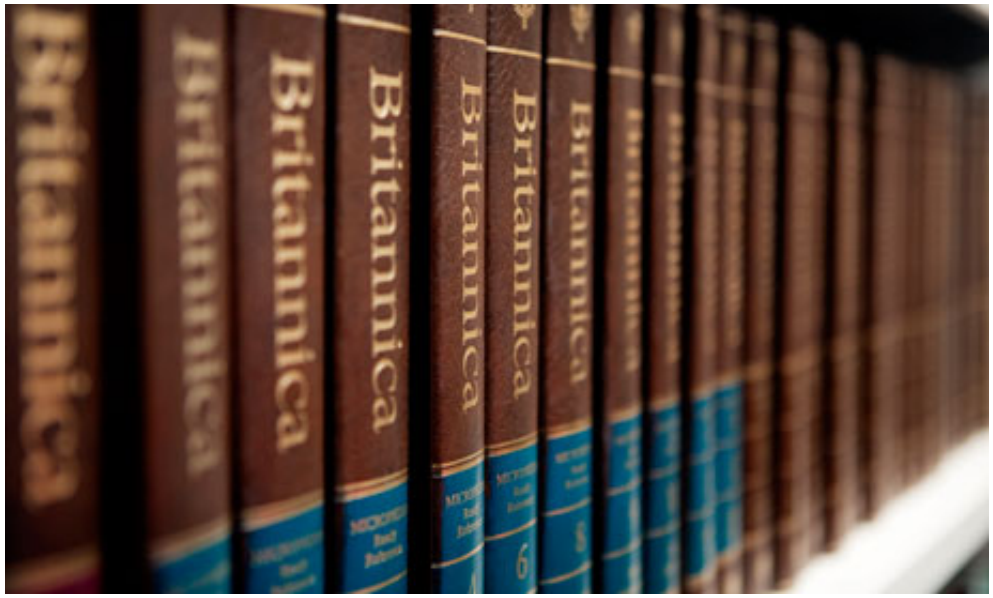
Credit: Jeannette Wing, Microsoft Research

Falling asleep

Turning on the lights

Turning up the heat

Searching for information



Google

WIKIPEDIA

Searching for directions

Searching for love

Reading books

Listening to music

Watching movies

Cleaning the house

Shopping

amazon.com

ebay

drugstore.com
the uncommon drugstore

zulily

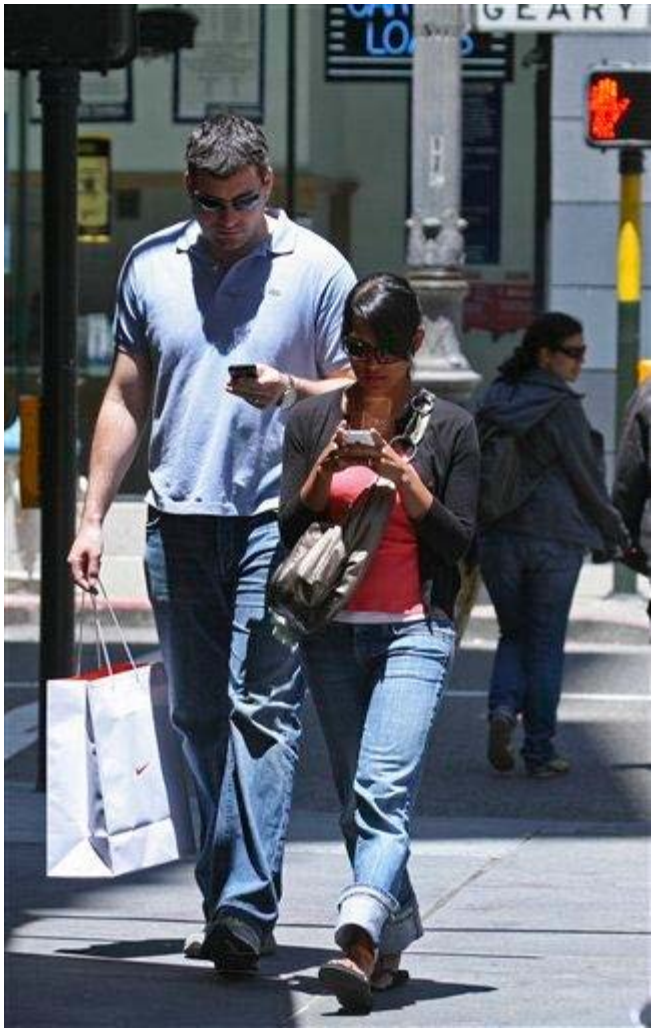
Expedia

Zillow

corbis

blue nile

Taking a stroll



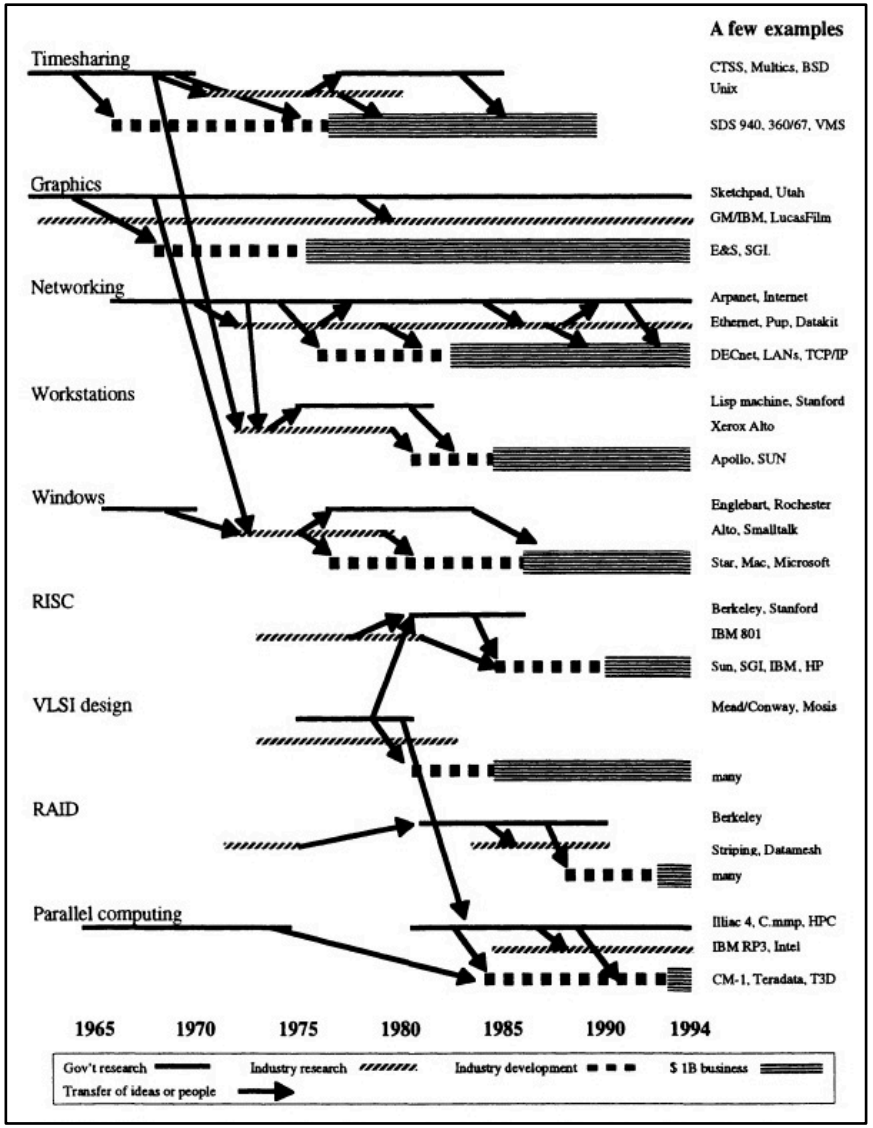
Visiting grandma and grandpa

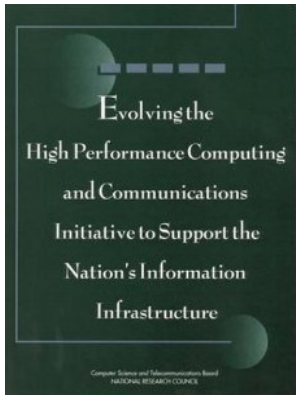
During the decade of the 2000's …

xconomy
Business + Technology in the Exponential Economy

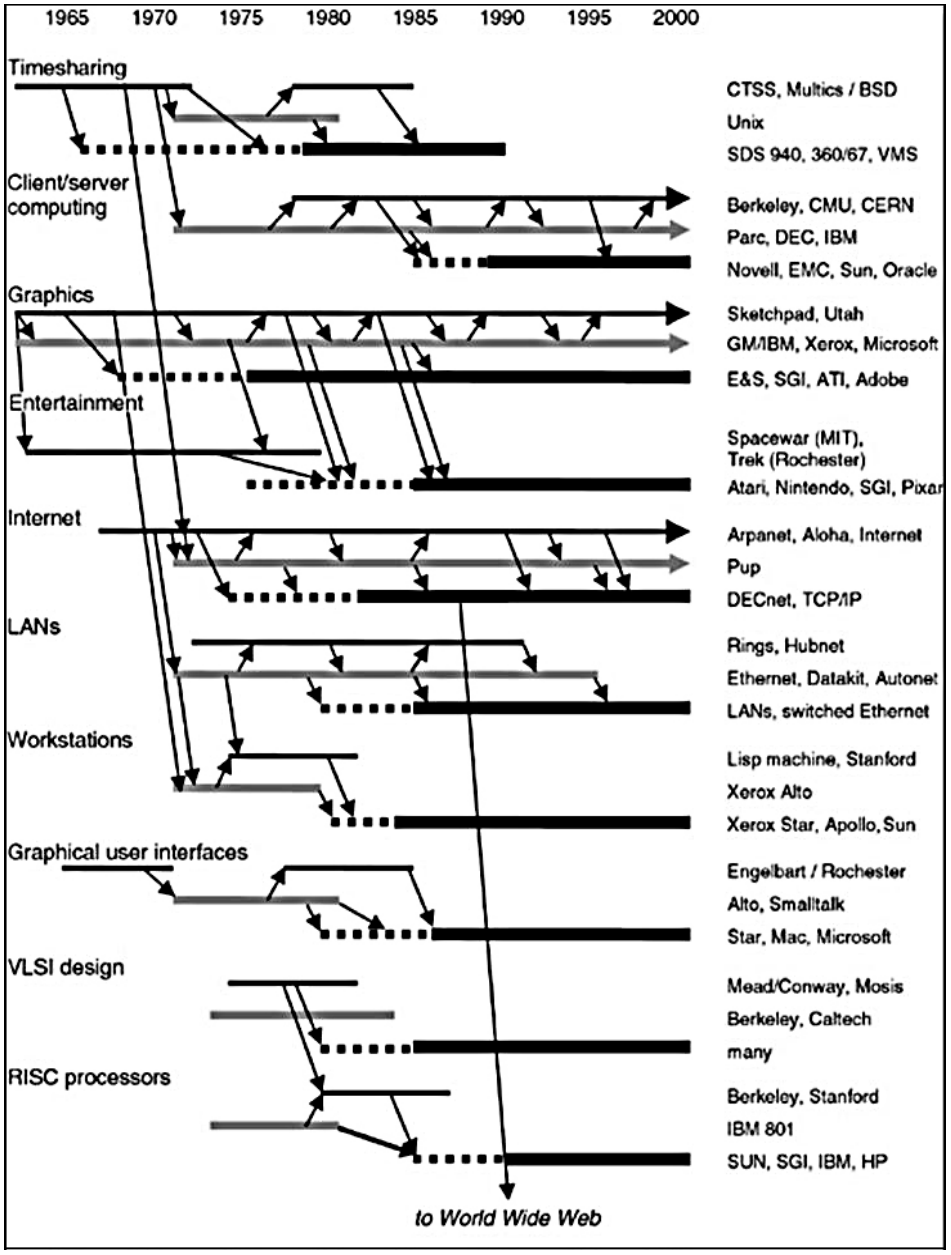
- Search
- Scalability
- Digital media
- Mobility
- eCommerce
- The Cloud
- Social networking and crowd-sourcing

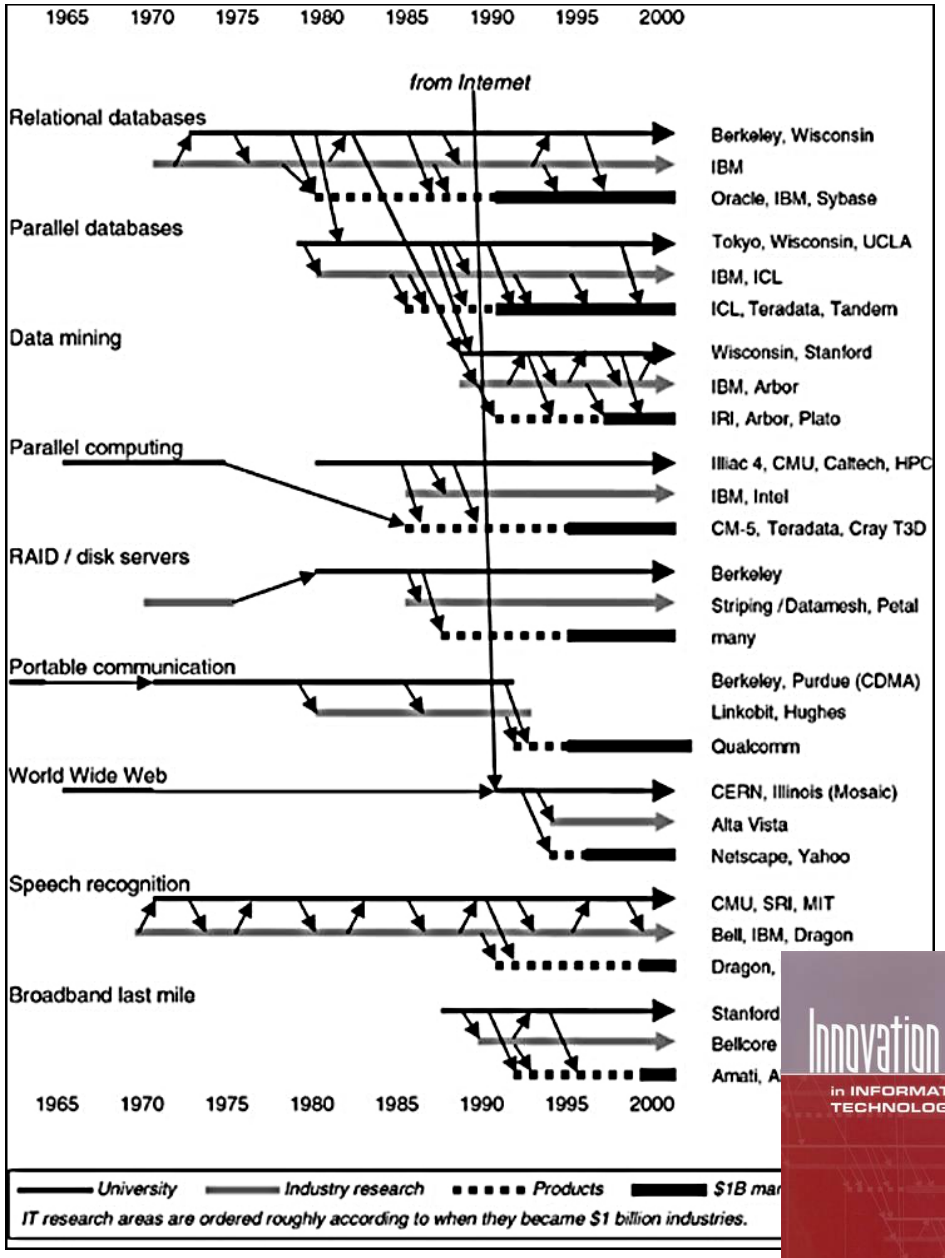
How did America become the world leader in this field?

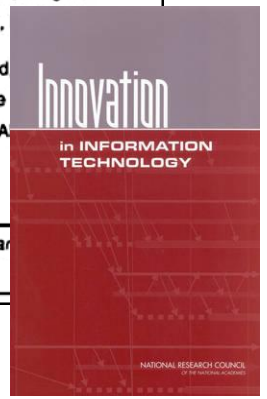




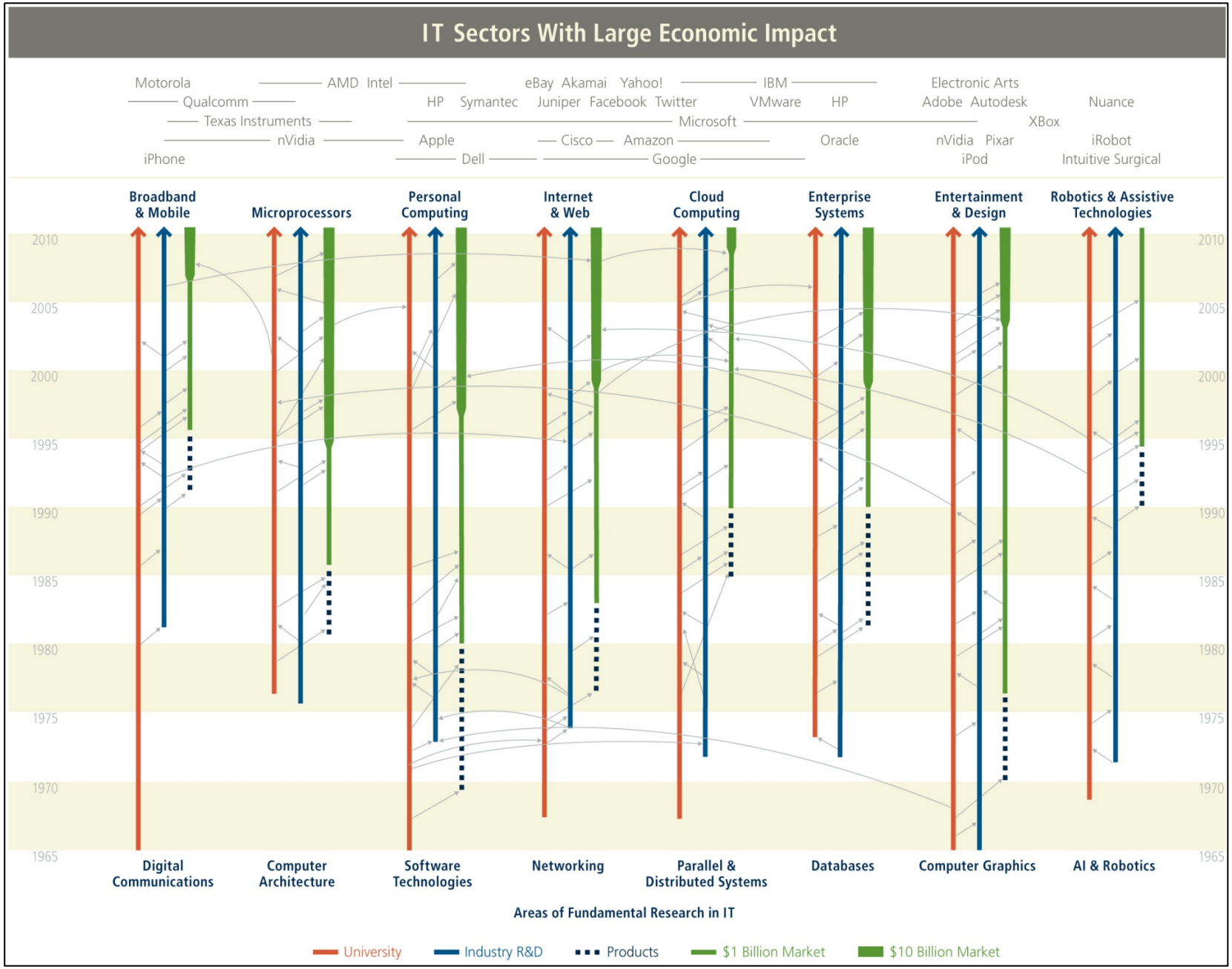
1995


1965 1970 1975 1980 1985 1990 1995 2000
Timesharing
CTSS, Multics / BSD
Unix
SDS 940, 360/67, VMS
Client/server computing
Berkeley, CMU, CERN
Parc, DEC, IBM
Novell, EMC, Sun, Oracle
Graphics
Sketchpad, Utah
GM/IBM, Xerox, Microsoft
E&S, SGI, ATI, Adobe
Entertainment
Spacewar (MIT),
Trek (Rochester)
Atari, Nintendo, SGI, Pixar
Internet
Arpanet, Aloha, Internet
Pup
DECnet, TCP/IP
LANs
Rings, Hubnet
Ethernet, Datakit, Autonet
LANs, switched Ethernet
Workstations
Lisp machine, Stanford
Xerox Alto
Xerox Star, Apollo, Sun
Graphical user interfaces
Engelbart / Rochester
Alto, Smalltalk
Star, Mac, Microsoft
VLSI design
Mead/Conway, Mosis
Berkeley, Caltech
many
RISC processors
Berkeley, Stanford
IBM 801
SUN, SGI, IBM, HP
to World Wide Web


1965 1970 1975 1980 1985 1990 1995 2000
from Internet
Relational databases
Berkeley, Wisconsin
IBM
Oracle, IBM, Sybase
Parallel databases
Tokyo, Wisconsin, UCLA
IBM, ICL
ICL, Teradata, Tandem
Data mining
Wisconsin, Stanford
IBM, Arbor
IRI, Arbor, Plato
Parallel computing
Illiac 4, CMU, Caltech, HPC
IBM, Intel
CM-5, Teradata, Cray T3D
RAID / disk servers
Berkeley
Striping / Datamesh, Petal
many
Portable communication
Berkeley, Purdue (CDMA)
Linkobit, Hughes
Qualcomm
World Wide Web
CERN, Illinois (Mosaic)
Alta Vista
Netscape, Yahoo
Speech recognition
CMU, SRI, MIT
Bell, IBM, Dragon
Dragon,
Broadband last mile
Stanford
Bellcore
Amati, A
1965 1970 1975 1980 1985 1990 1995 2000
University
Industry research
Products
$1B ma
IT research areas are ordered roughly according to when they became $1 billion industries.


Innovation
in INFORMATION
TECHNOLOGY
NATIONAL RESEARCH COUNCIL

2003

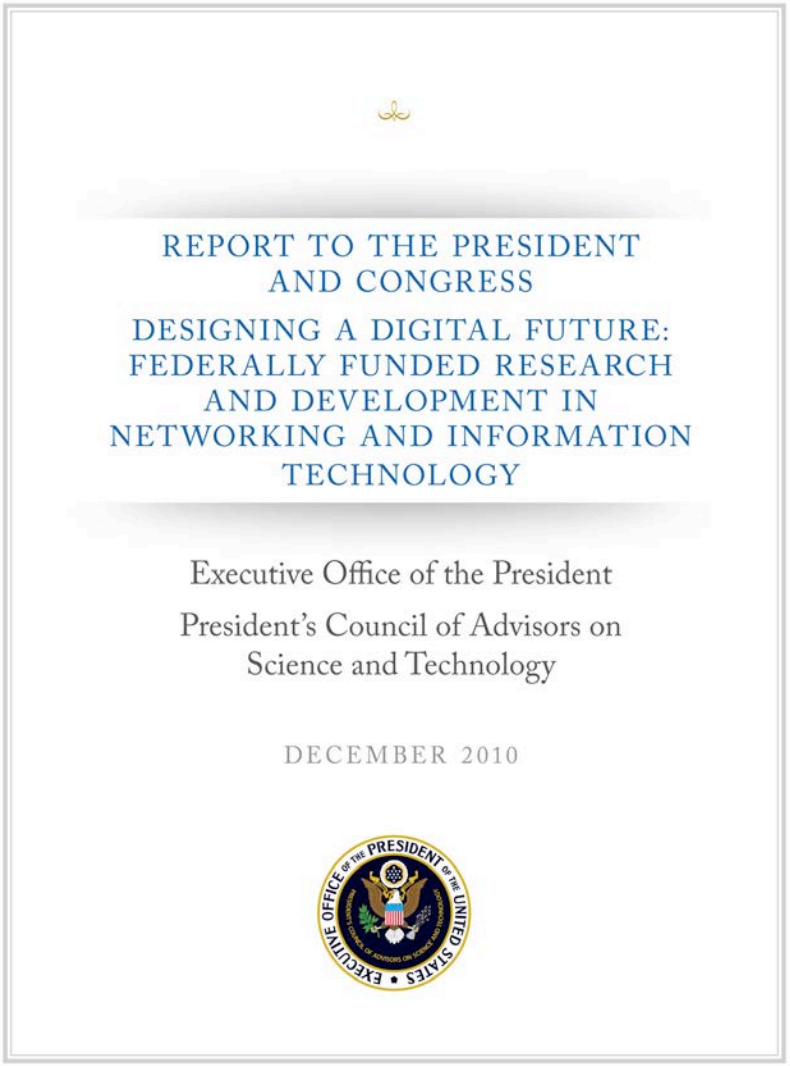

IT Sectors With Large Economic Impact
Motorola
Qualcomm
Texas Instruments
nVidia
iPhone
AMD
Intel
HP
Symantec
Apple
Dell
eBay
Akamai
Yahoo!
Juniper
Facebook
Twitter
Microsoft
Cisco
Amazon
Google
IBM
VMware
HP
Oracle
Electronic Arts
Adobe
Autodesk
XBox
nVidia
Pixar
iPod
Nuance
iRobot
Intuitive Surgical
Broadband & Mobile
Microprocessors
Personal Computing
Internet & Web
Cloud Computing
Enterprise Systems
Entertainment & Design
Robotics & Assistive Technologies
2010
2005
2000
1995
1990
1985
1980
1975
1970
1965
Digital Communications
Computer Architecture
Software Technologies
Networking
Parallel & Distributed Systems
Databases
Computer Graphics
AI & Robotics
Areas of Fundamental Research in IT
University
Industry R&D
Products
$1 Billion Market
$10 Billion Market


Continuing
Innovation
IN INFORMATION TECHNOLOGY

2012

- Key takeaways:
  - America is the world leader in information technology due to a rich interplay of government, academia, and industry
  - Every major market segment bears the clear stamp of Federal research investments
  - There's nothing linear about the path from research to major market segment: ideas and people flow every which way
  - Unanticipated results are often as important as anticipated results
  - The interaction of research ideas multiplies their impact
  - Entirely appropriately, corporate R&D is very heavily tilted towards D: engineering the next release of a product, vs. a 5- 10- or 15-year horizon

Why is imperative that we remain the world leader?



REPORT TO THE PRESIDENT AND CONGRESS

DESIGNING A DIGITAL FUTURE: FEDERALLY FUNDED RESEARCH AND DEVELOPMENT IN NETWORKING AND INFORMATION TECHNOLOGY

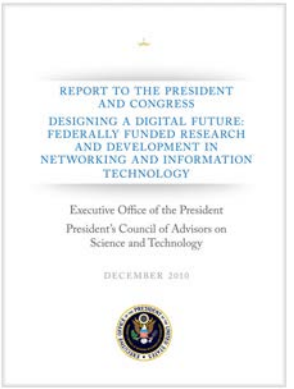
Executive Office of the President

President's Council of Advisors on Science and Technology

DECEMBER 2010

Why is imperative that we remain the world leader?

- "A key driver of economic competitiveness"
- "Crucial to achieving our major national and global priorities in areas such as energy and transportation, education and life-long learning, healthcare, and national and homeland security"
- "Accelerates the pace of discovery in nearly all other fields"
- "The dominant factor in America's science and technology employment"
- An intellectual agenda "as rich as that of any other field of science or engineering"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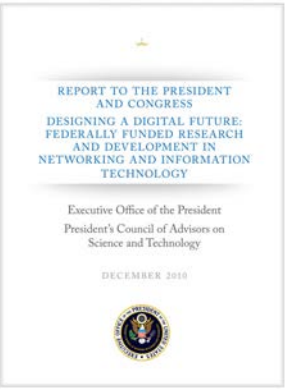
DECEMBER 2010

How should our competitiveness be defined?

- "At the time of the High-Performance Computing Act of 1991, the importance of high performance computing and communication (HPCC) to scientific discovery and national security was a major factor underlying the special attention given by Congress to NIT. Although HPCC continues to contribute in important ways to scientific discovery and national security, many other aspects of NIT have now risen to comparable levels of importance."

N.B. This does not say that the importance of HPCC is decreasing! It simply notes that other aspects of the field have risen to comparable levels of importance, and must be weighed in assessing our competitiveness.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Executive Office of the President

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DECEMBER 2010

During the current decade …

xconomy
Business + Technology in the Exponential Economy

- Smart homes
- Smart cars
- Smart health
- Smart robots
- Smart crowds and human-computer systems
- Smart interaction (virtual and augmented reality)
- Smart discovery (exploiting the data deluge)

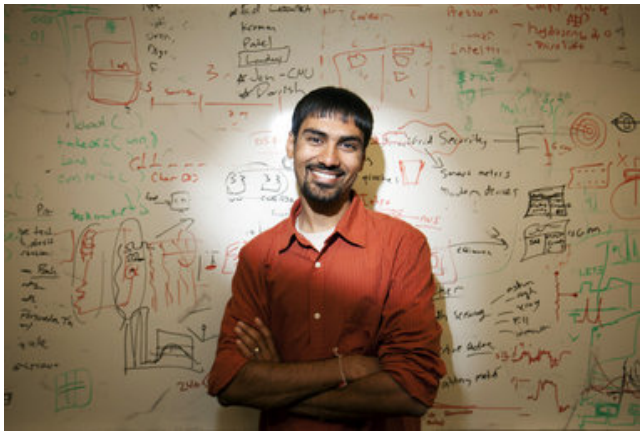
Dramatic improvements in technology and algorithms enable "smart everything"

- A proliferation of sensors
  - Think about the sensors on your phone
- More generally, the creation of almost all information in digital form
  - It doesn't need to be transcribed in order to be processed
- Dramatic cost reductions in storage
  - You can afford to keep all the data
- Dramatic increases in network bandwidth
  - You can move the data to where it's needed

- Dramatic cost reductions and scalability improvements in computation
  - With Amazon Web Services, or Google App Engine, or Microsoft Azure, 1000 computers for 1 day costs the same as 1 computer for 1000 days
- Dramatic algorithmic breakthroughs
  - Machine learning, data mining – fundamental advances in computer science and statistics

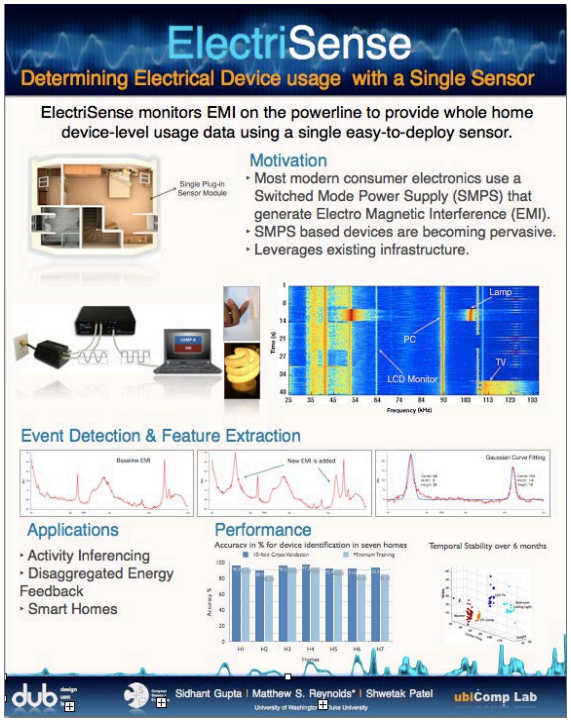
The "big data" revolution is what actually puts the "smarts" in "smart everything"

Smart homes (the leaf nodes of the smart grid)



Shwetak Patel,
University of Washington
2011 MacArthur Fellow

MACARTHUR
The John D. and Catherine T. MacArthur Foundation



belkin echo

Smart cars

DARPA Grand Challenge

DARPA Urban Challenge

Google Self-Driving Car

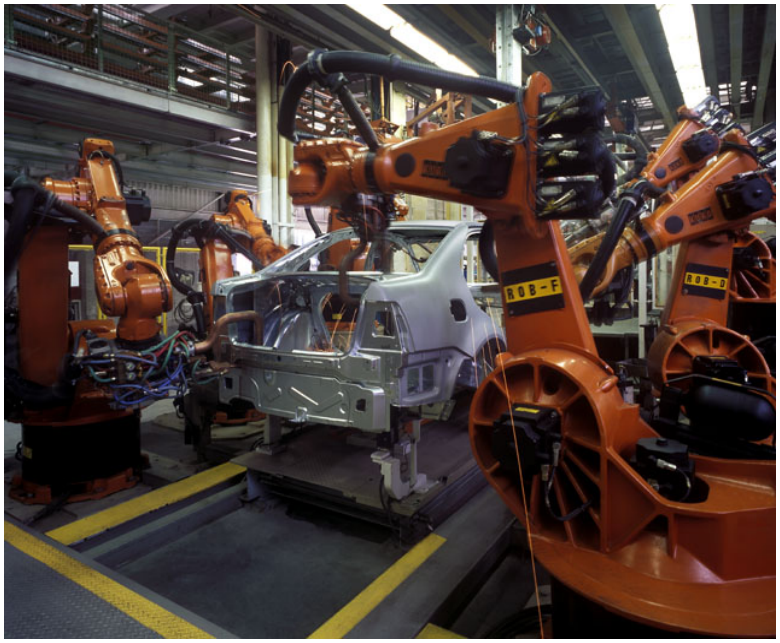
Smart health

Larry Smarr – "quantified self"

Evidence-based medicine

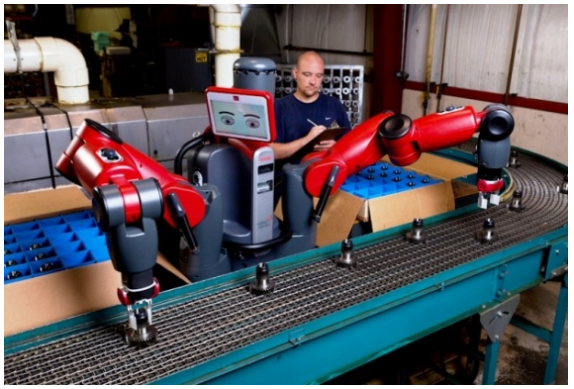
P4 medicine

Smart robots



iRobot

rethink robotics

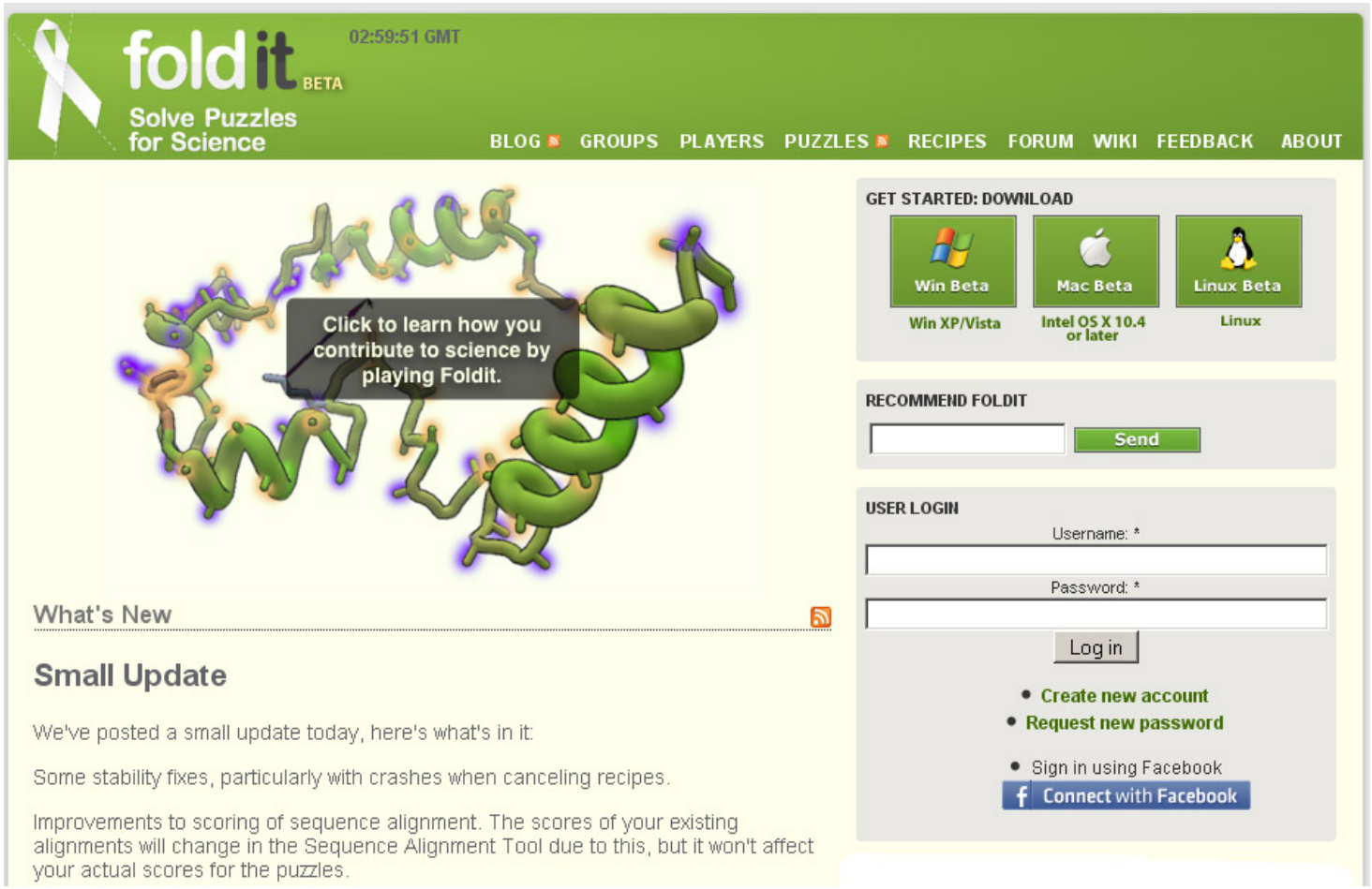


Smart crowds and human-computer systems

(+ smart education)

Zoran Popovic,
UW Computer Science & Engineering

David Baker,
UW Biochemistry



Smart crowds and human-computer systems
(+ smart education)

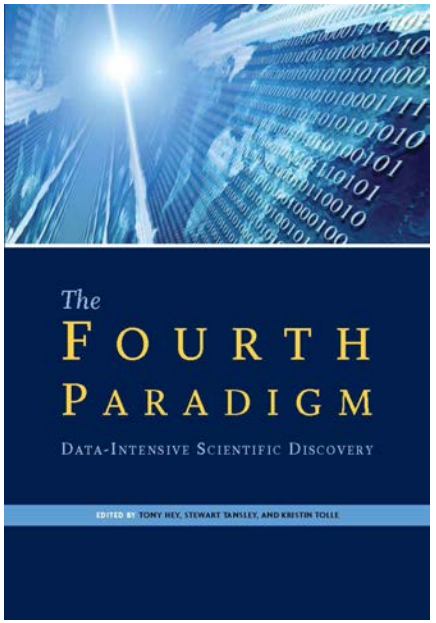
Zoran Popovic,
UW Computer Science & Engineering

Center for Game Science

Smart interaction

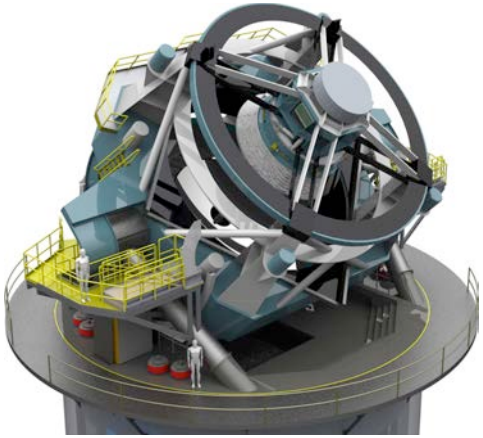
KINECT™
for XBOX 360

Smart discovery (data-intensive discovery, or *eScience*)



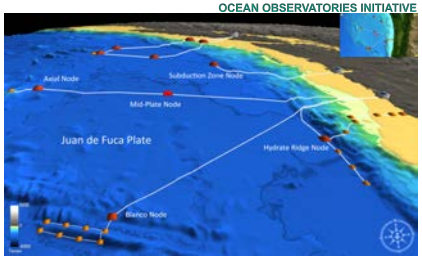
Transforming science (again!)

Nearly every field of discovery is transitioning from "data poor" to "data rich"

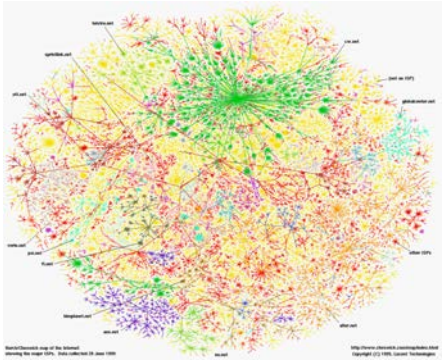


Astronomy: LSST

Physics: LHC



Oceanography: OOI



Sociology: The Web

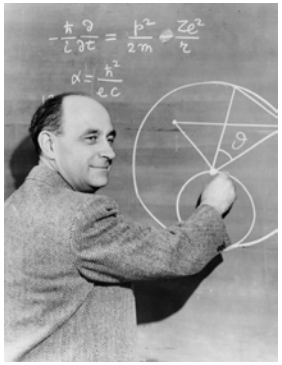
Biology: Sequencing

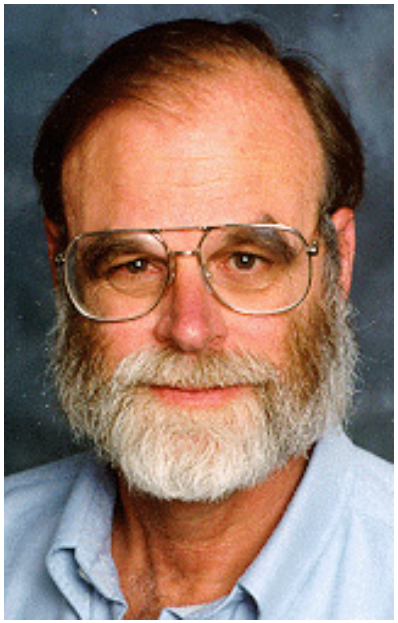
Economics: POS terminals

Neuroscience: EEG, fMRI

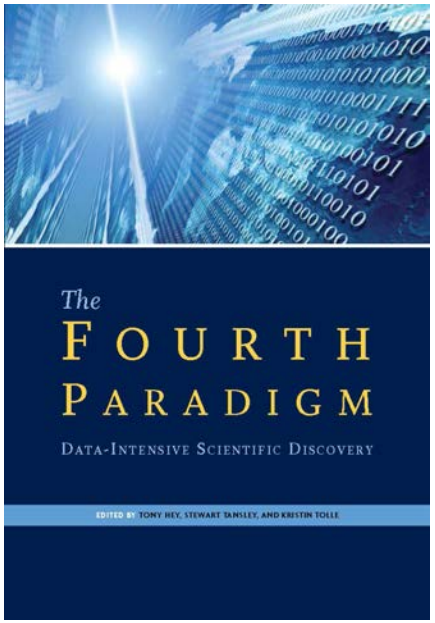
The Fourth Paradigm

1. Empirical + experimental
2. Theoretical
3. Computational
4. Data-Intensive

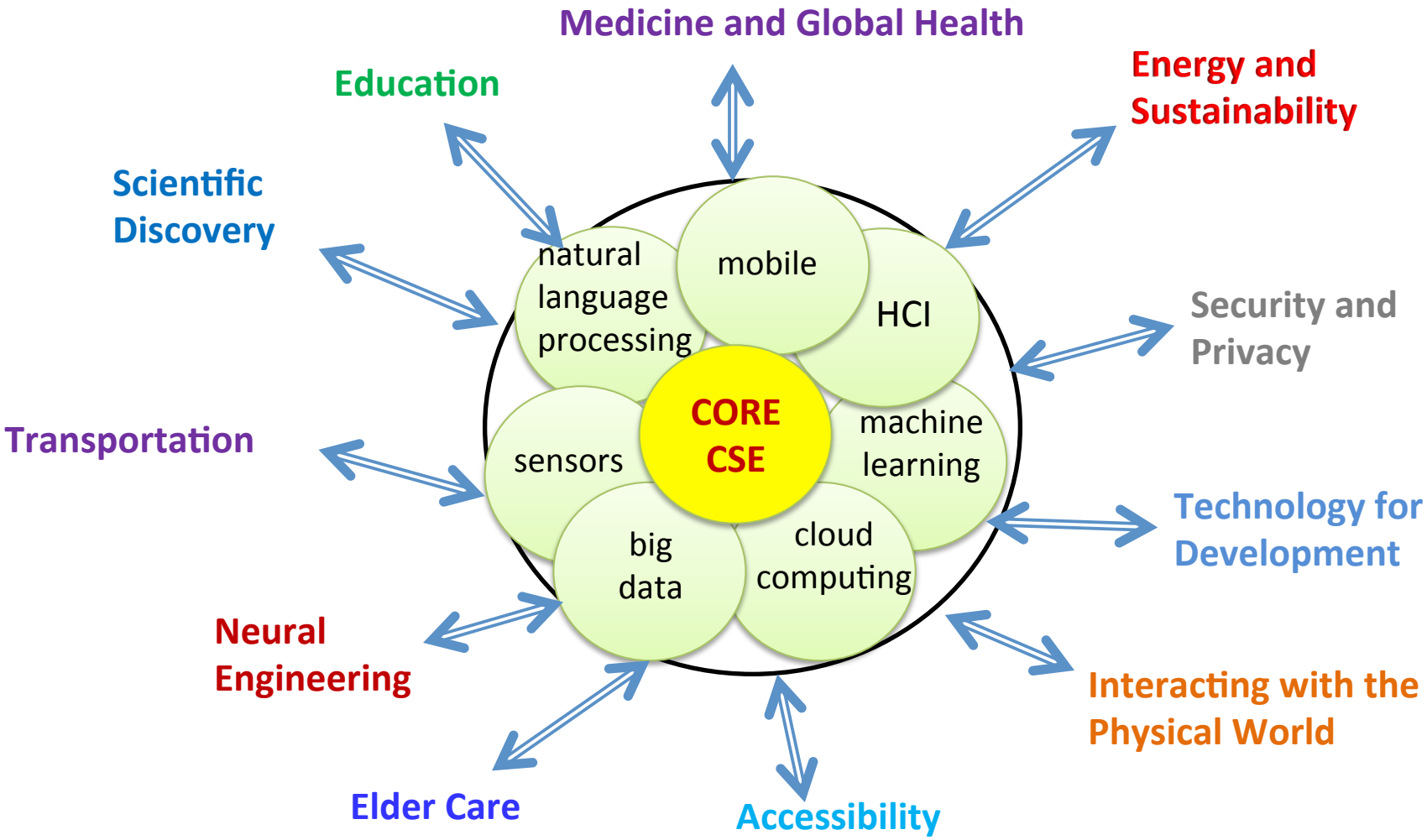




Jim Gray,
Microsoft Research



A modern view of the field



A modern view of the field

Medicine and Global Health

Education

Energy and Sustainability

Scientific Discovery

Security and Privacy

Transportation

Technology for Development

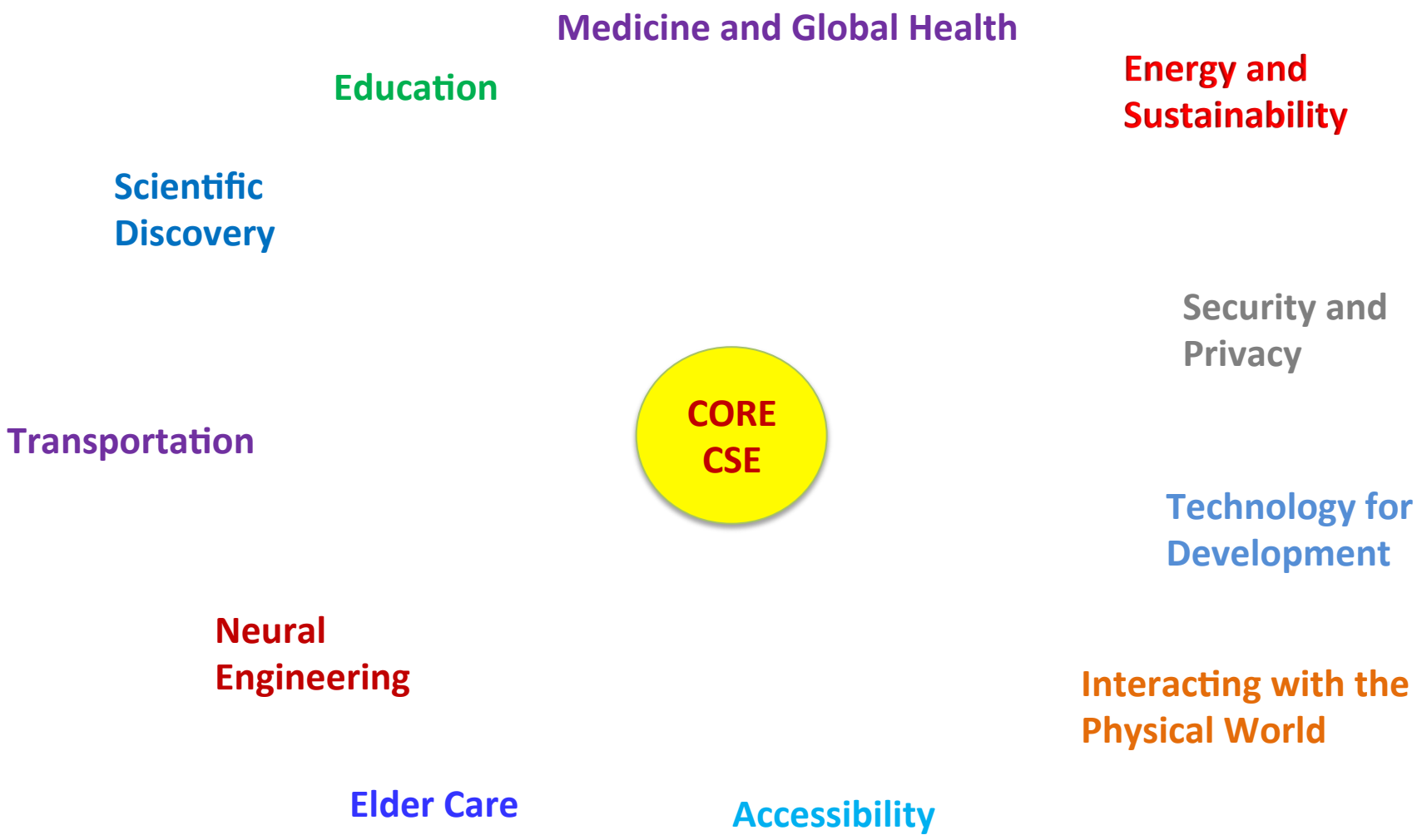
Neural Engineering

Interacting with the Physical World

Elder Care

Accessibility

A modern view of the field



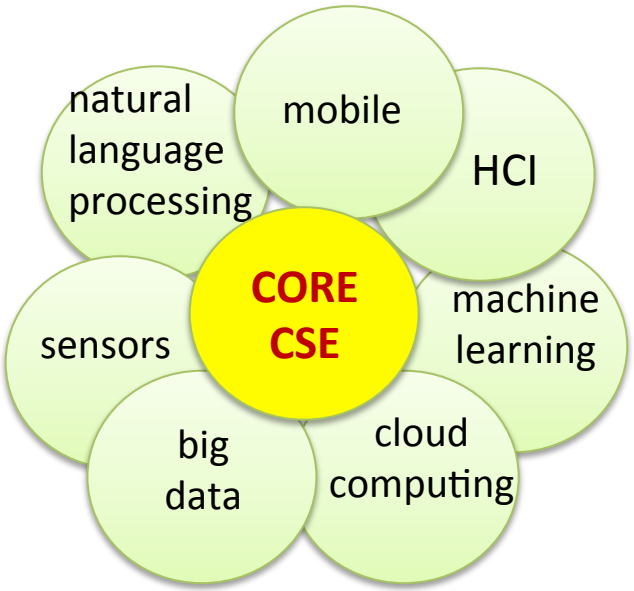
A modern view of the field

Medicine and Global Health

Education

Energy and Sustainability

Scientific Discovery



Security and Privacy

Transportation

Technology for Development

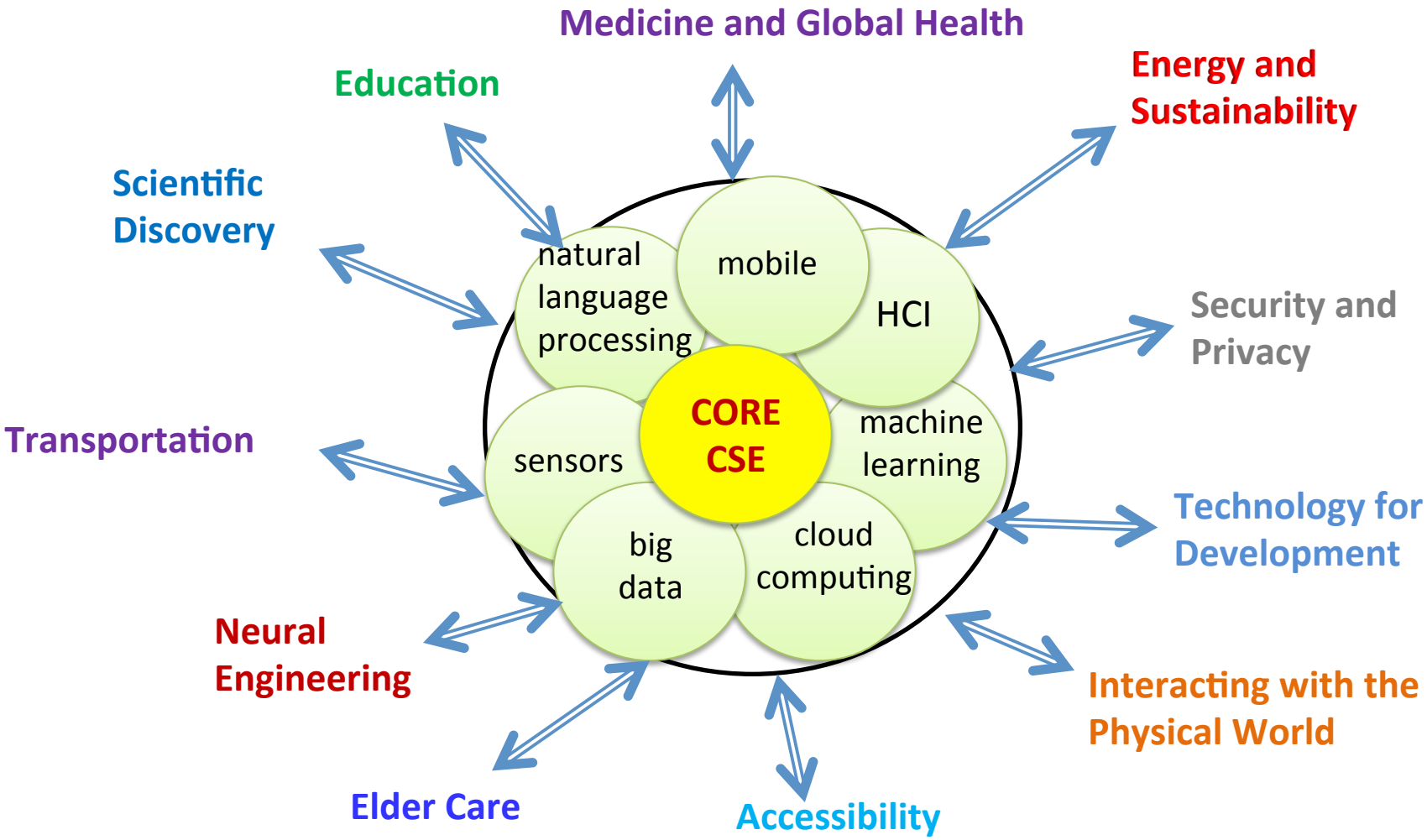
Neural Engineering

Interacting with the Physical World

Elder Care

Accessibility

A modern view of the field



The Computing Community Consortium

The **mission** of Computing Research Association's Computing Community Consortium (CCC) is to **catalyze** the computing research community and **enable** the pursuit of innovative, high-impact research.

CCC conducts activities that **strengthen** the research community, **articulate** compelling **research visions**, and **align** those visions with pressing **national and global challenges**.

CCC **communicates** the importance of those visions to **policymakers**, government and industry **stakeholders**, the **public**, and the **research community** itself.

The CCC Council

- Executive Committee
  - Susan Graham, UC Berkeley (Chair)
  - Greg Hager, Johns Hopkins Univ. (Vice Chair)
  - Ed Lazowska, Univ. Washington (Past Chair)
  - Elizabeth Mynatt, Georgia Tech
  - Fred Schneider, Cornell Univ.
  - Sue Davidson, Univ. Pennsylvania
  - Ann Drobnis, Director
  - Andy Bernat, CRA Executive Director

Implications for national leadership

- If you care about national security, the financial system, access to justice, precision agriculture, the balance of trade, health care, urban ecology, transportation efficiency, energy independence, education, scientific discovery, … *then you need to care about advances in computer science!*
- Issues such as online privacy and security, Internet governance, software patents / intellectual property, electronic voting, etc., are now front-and-center on the policy agenda and require a combination of technical, legal, and sociological approaches.


Ed Felten


Steve Bellovin


Latanya Sweeney

Chief Technologists of the
Federal Trade Commission

Implications for university leadership

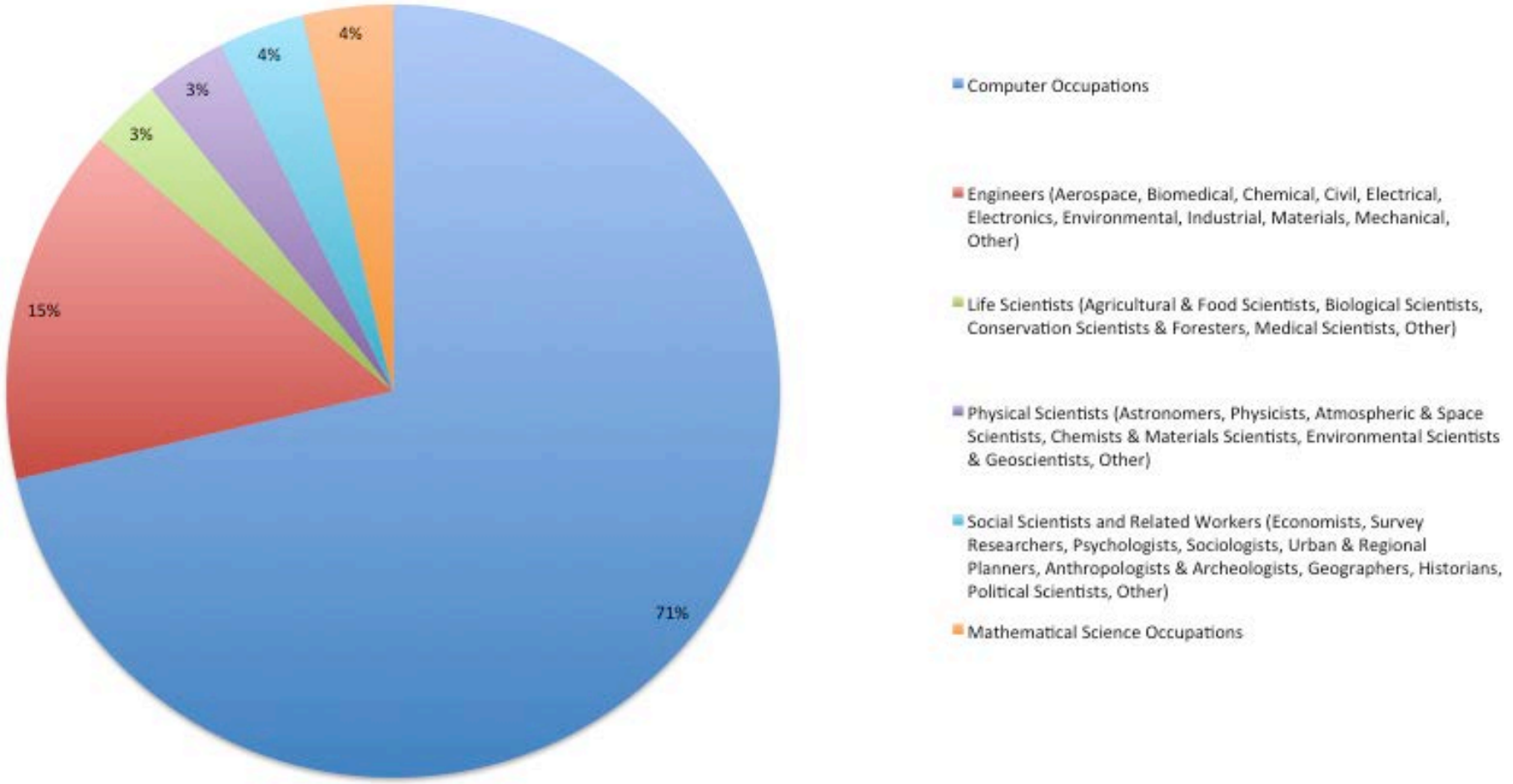
- *Every 21st century citizen needs to have facility with "computational thinking"* – abstraction, modeling, algorithmic thinking, algorithmic expression, problem decomposition, stepwise fault isolation (we call it "debugging").
  - Computational thinking is not "this particular operating system" or "that particular programming language."
  - Computational thinking is not even programming. It's a mode of thought – a way of approaching the world.
  - Programming is the hands-on, inquiry-based way that we teach computational thinking and the principles of computer science.

- Fields from anthropology to zoology are becoming information fields. Those who can bend the power of the computer to their will – computational thinking but also computer science in greater depth – will be positioned for greater success than those who can't. *If, as an institution, you aspire to excel in anything, you need to excel in computer science.*

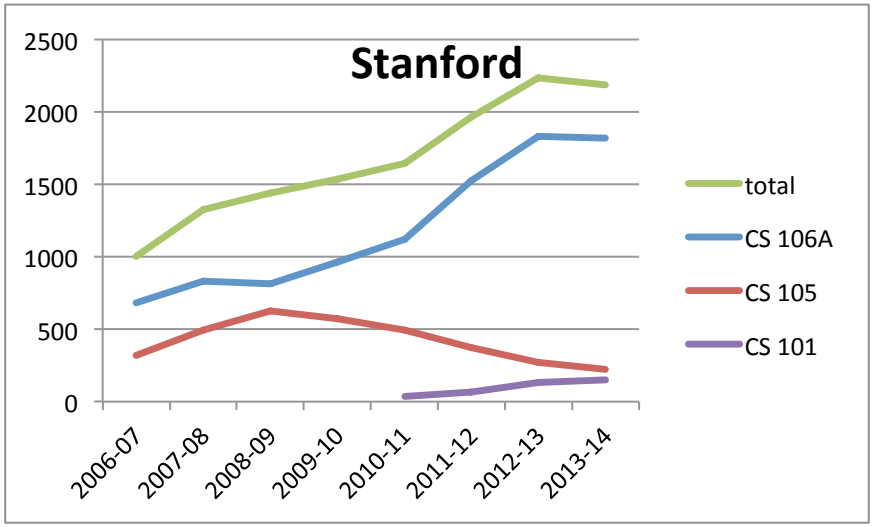
- While fluency with computational thinking and with computer science are important to all fields, *the job prospects in the field of computer science itself are extraordinary*, and these jobs are creative, interactive, change-the-world jobs.
  - The U.S. Bureau of Labor Statistics recently released its job projections for the decade 2012-2022. Computer occupations will be responsible for 71% of *all* the job growth in *all* fields of STEM (Science, Technology, Engineering, and Mathematics) – the many dozens of fields that comprise the life sciences, the physical sciences, the social sciences, engineering, and the mathematical sciences – and for 57% of all available jobs, whether newly-created or available due to replacement.
  - "STEM worker shortage?" Fuggedaboutit! *"It's all computer science, all the time."*

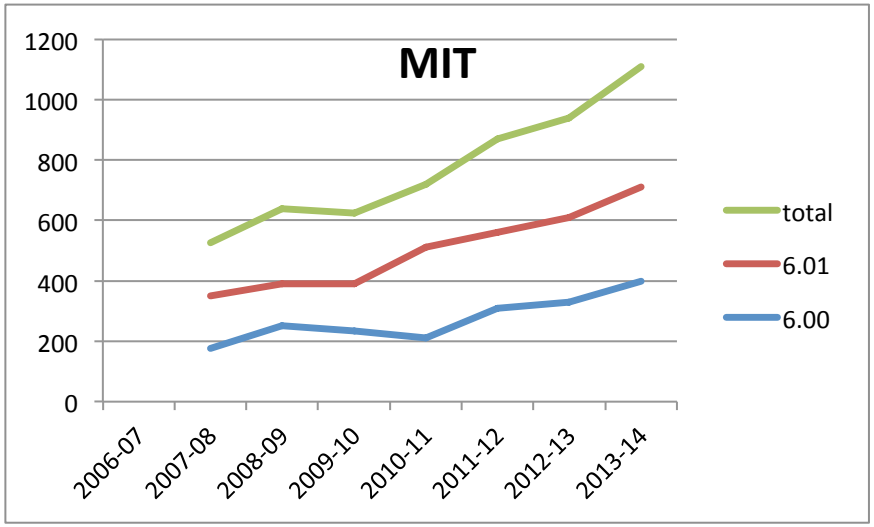
Job Growth, 2012-22 – U.S. Bureau of Labor Statistics

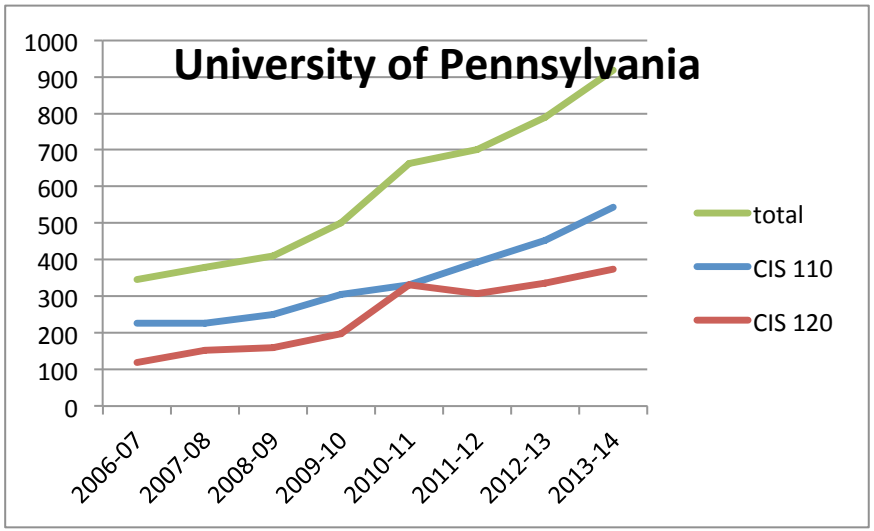
Computer Occupations = 71% of all STEM

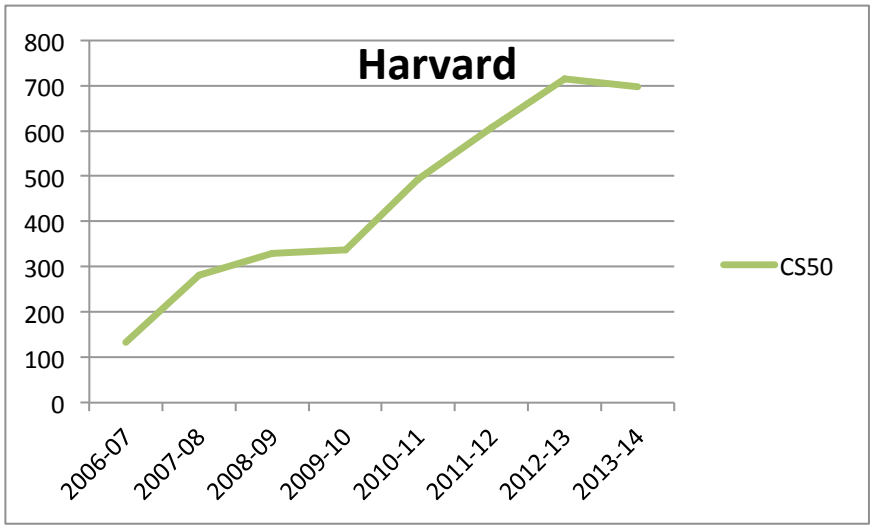


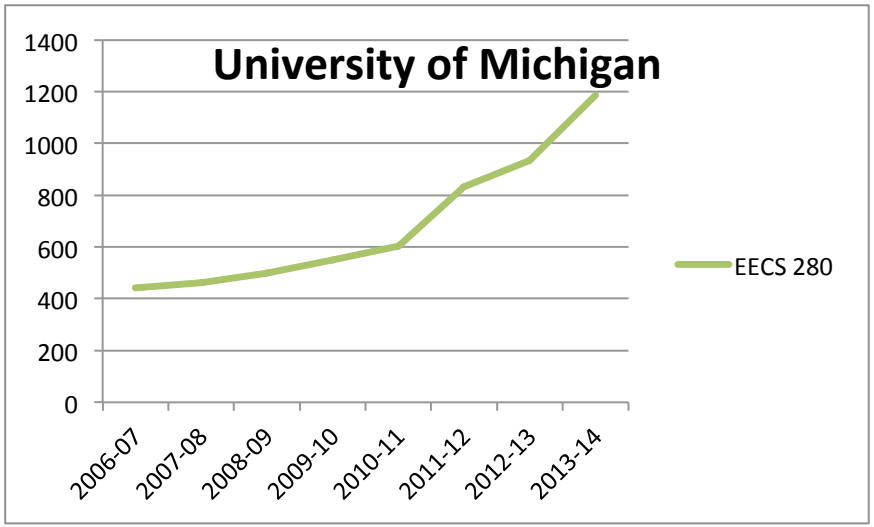
Students are figuring this out: Introductory course enrollments are exploding







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1200
1000
800
600
400
200
0
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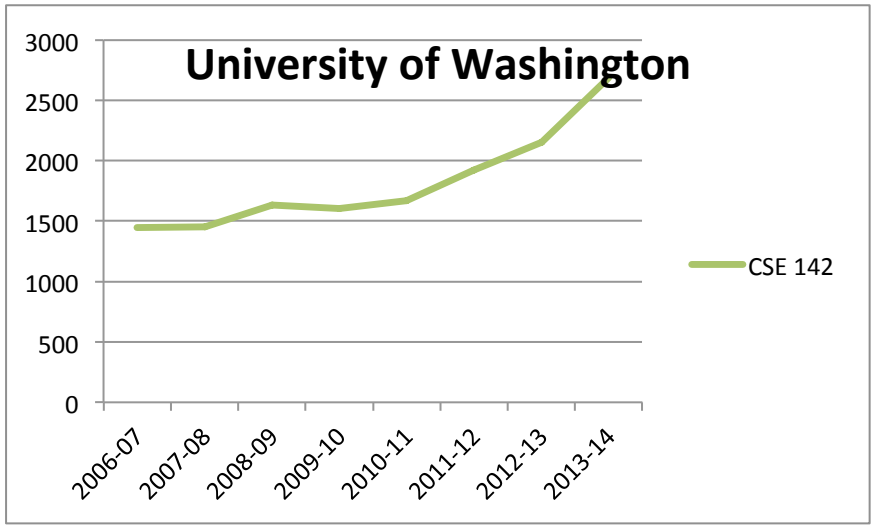
2007-08
2008-09
2009-10
2010-11
2011-12
2012-13
2013-14
EECS 280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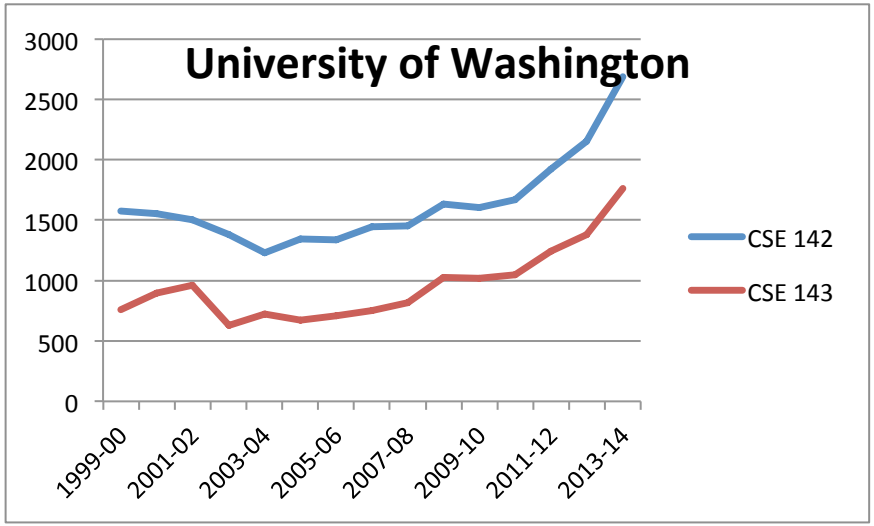
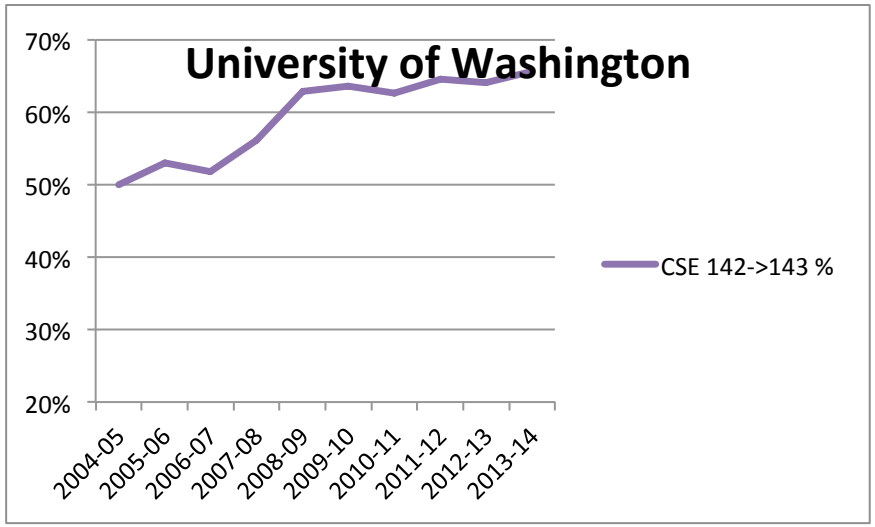
2012-13
2013-14
CSE 142

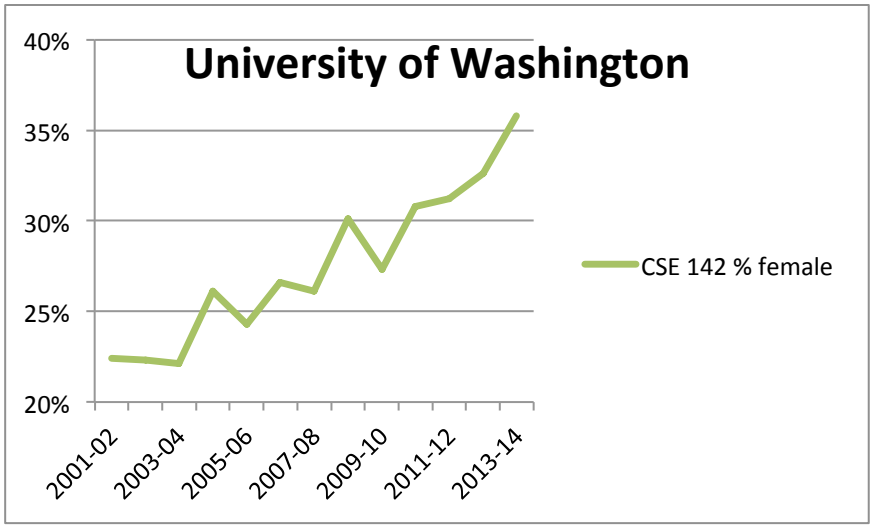
Blowing past previous highs



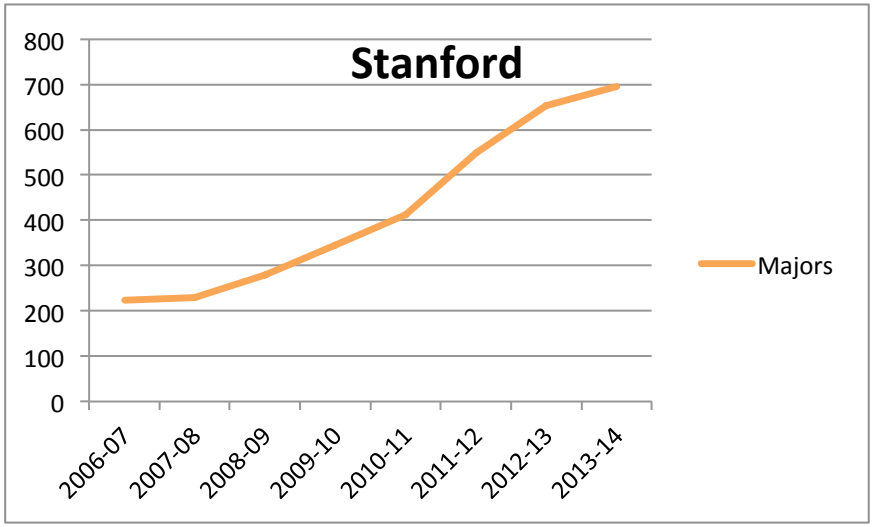
With increasing proportions electing follow-on courses

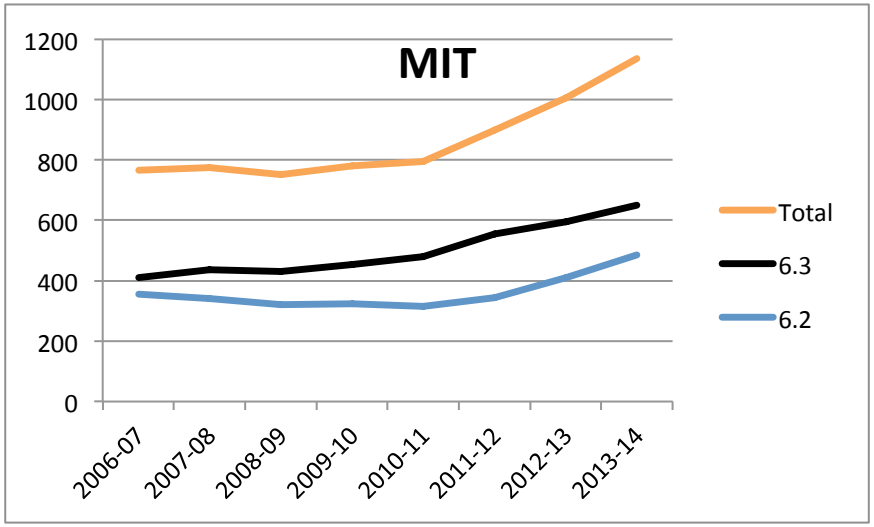


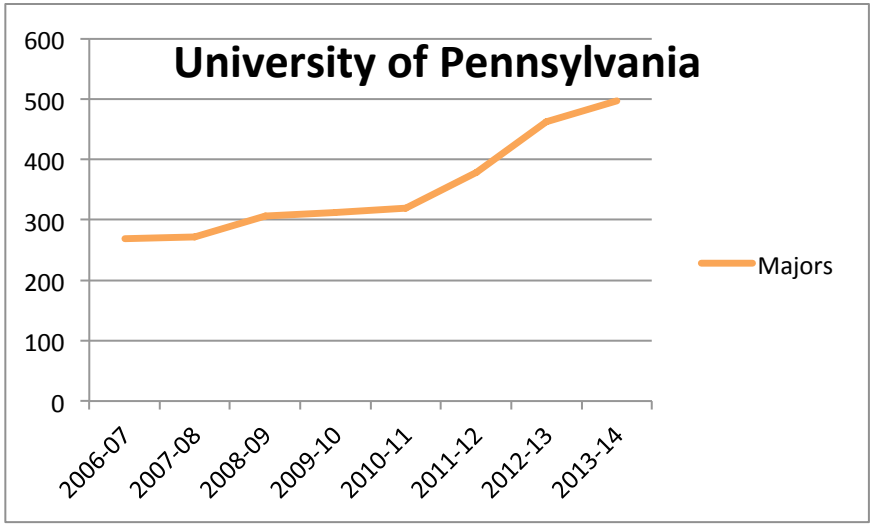
And increasing proportions of women

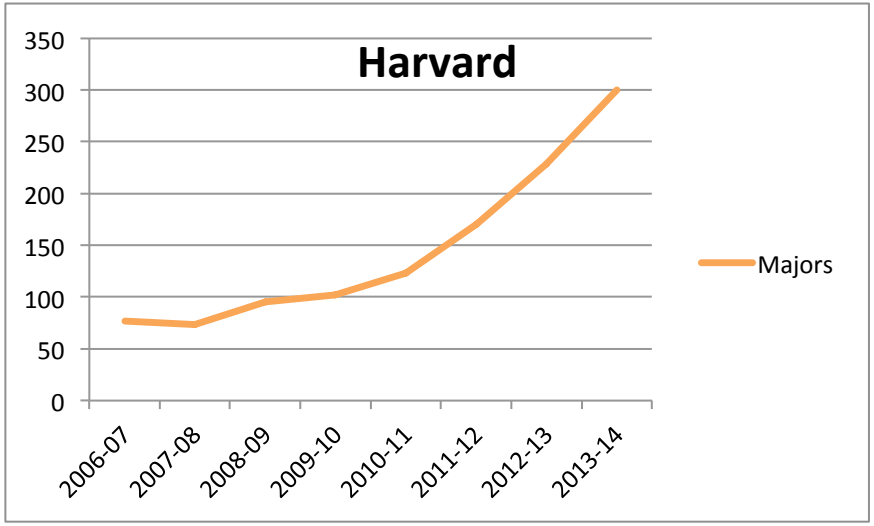


Demand for the major is exploding

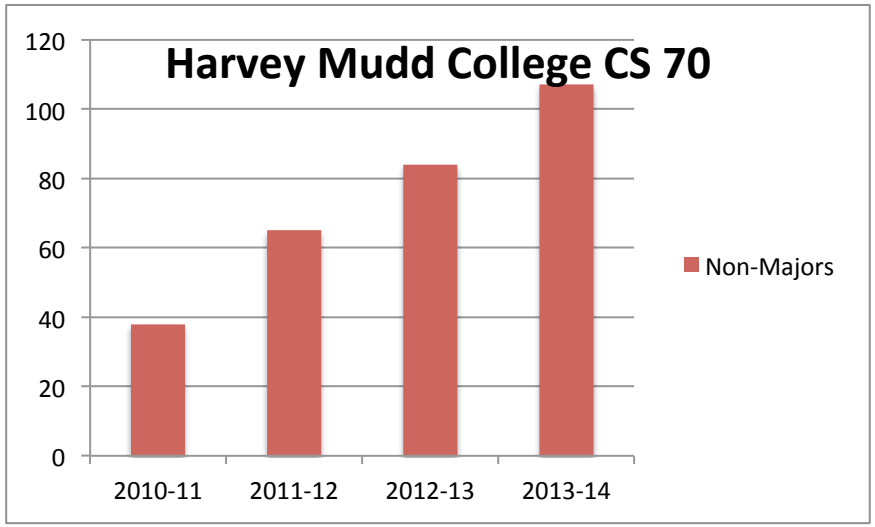


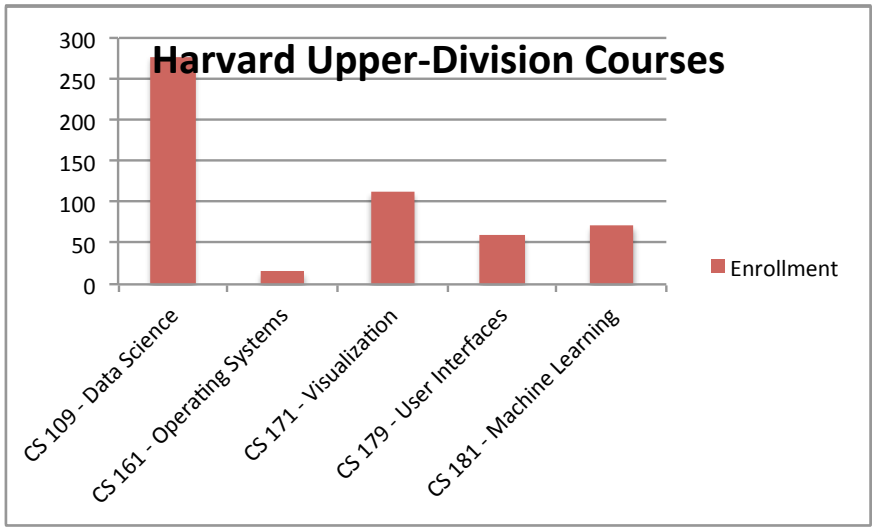


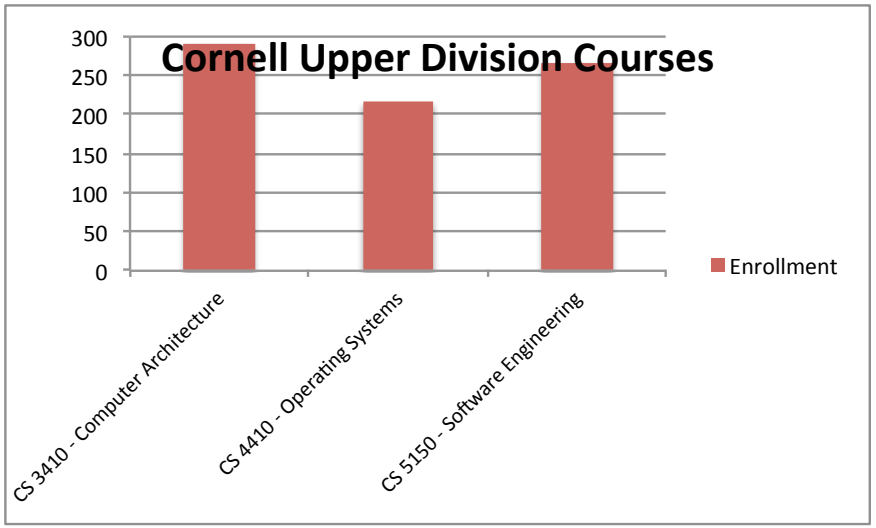




As well as non-major demand for upper-division courses







Implications for K-12 education
Computer Science in K-12, 1983

A Nation At Risk

Our Nation is at risk. Our once unchallenged preeminence in commerce, industry, science, and technological innovation is being overtaken by competitors throughout the world. This report is concerned with only one of the many causes and dimensions of the problem, but it is the one that undergirds American prosperity, security, and civility.

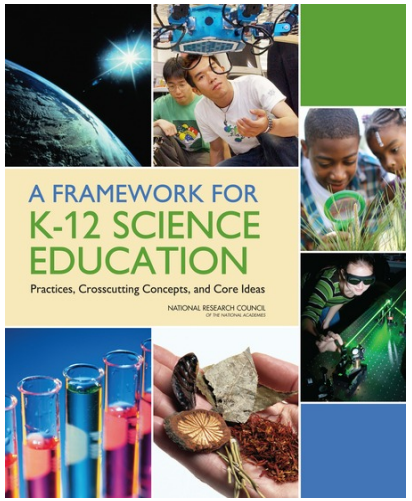
If an unfriendly foreign power had attempted to impose on America the mediocre educational performance that exists today, we might well have viewed it as an act of war. As it stands, we have allowed this to happen to ourselves.

Recommendation A: Content

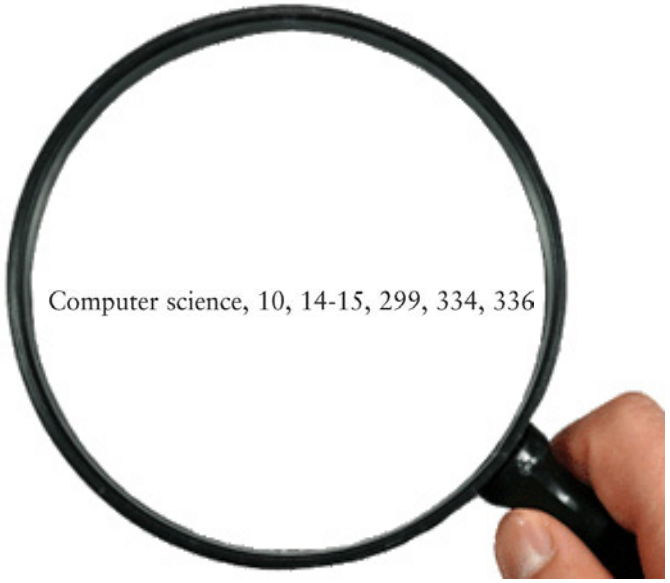
We recommend *that State and local high school graduation requirements be strengthened and that,* at a minimum, all *students seeking a diploma be required to lay the foundations in the Five New Basics by taking the following curriculum during their 4 years of high school: (a) 4 years of English; (b) 3 years of mathematics; (c) 3 years of science; (d) 3 years of social studies; and (e) one-half year of computer science.*

IBM PC XT
4.77 MHz 8088
128 KB RAM
PC DOS 2.0

Computer Science in K-12, 2013



401 page report
15 page index



Elementary (K–5)

Storylines: K–2 3–5 PDFs: K 1 2 3 4 5

K. Forces and Interactions: Pushes and Pulls
K. Interdependent Relationships in Ecosystems: Animals, Plants, and Their Environment
K. Weather and Climate
1. Waves: Light and Sound
1. Structure, Function and Information Processing
1. Space Systems: Patterns and Cycles
2. Structure and Properties of Matter
2. Interdependent Relationships in Ecosystems
2. Earth's Systems: Processes that Shape the Earth
K-2. Engineering Design
3. Forces and Interactions
3. Interdependent Relationships in Ecosystems
3. Inheritance and Variation of Traits
3. Weather and Climate
4. Energy
4. Waves
4. Structure, Function, and Information Processing
4. Earth's Systems: Processes that Shape the Earth
5. Structure and Properties of Matter
5. Matter and Energy in Organisms and Ecosystems
5. Earth's Systems
5. Space Systems: Stars and the Solar System
3-5. Engineering Design

PS: Physical Sciences

Middle School (6–8) Storyline PDF	High School (9–12) Storyline PDF
MS. Structure and Properties of Matter	**HS.** Structure and Properties of Matter
MS. Chemical Reactions	**HS.** Chemical Reactions
MS. Forces and Interactions	**HS.** Forces and Interactions
MS. Energy	**HS.** Energy
MS. Waves and Electromagnetic Radiation	**HS.** Waves and Electromagnetic Radiation

LS: Life Sciences

Middle School (6–8) Storyline PDF	High School (9–12) Storyline PDF
MS. Structure, Function, and Information Processing	**HS.** Structure and Function
MS. Matter and Energy in Organisms and Ecosystems	**HS.** Matter and Energy in Organisms and Ecosystems
MS. Interdependent Relationships in Ecosystems	**HS.** Interdependent Relationships in Ecosystems
MS. Growth, Development, and Reproduction of Organisms	**HS.** Inheritance and Variation of Traits
MS. Natural Selection and Adaptations	**HS.** Natural Selection and Evolution

ESS: Earth and Space Sciences

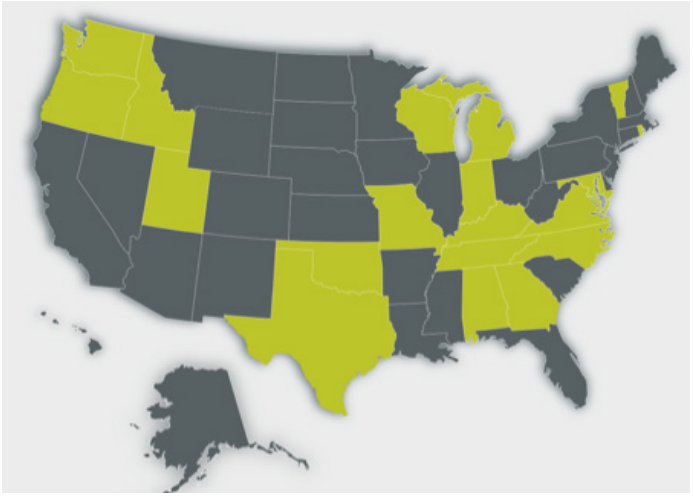
Middle School (6–8) Storyline PDF	High School (9–12) Storyline PDF
MS. Space Systems	**HS.** Space Systems
MS. History of Earth	**HS.** History of Earth
MS. Earth's Systems	**HS.** Earth's Systems
MS. Weather and Climate	**HS.** Weather and Climate
MS. Human Impacts	**HS.** Human Sustainability

ETS: Engineering, Technology, and Applications of Science

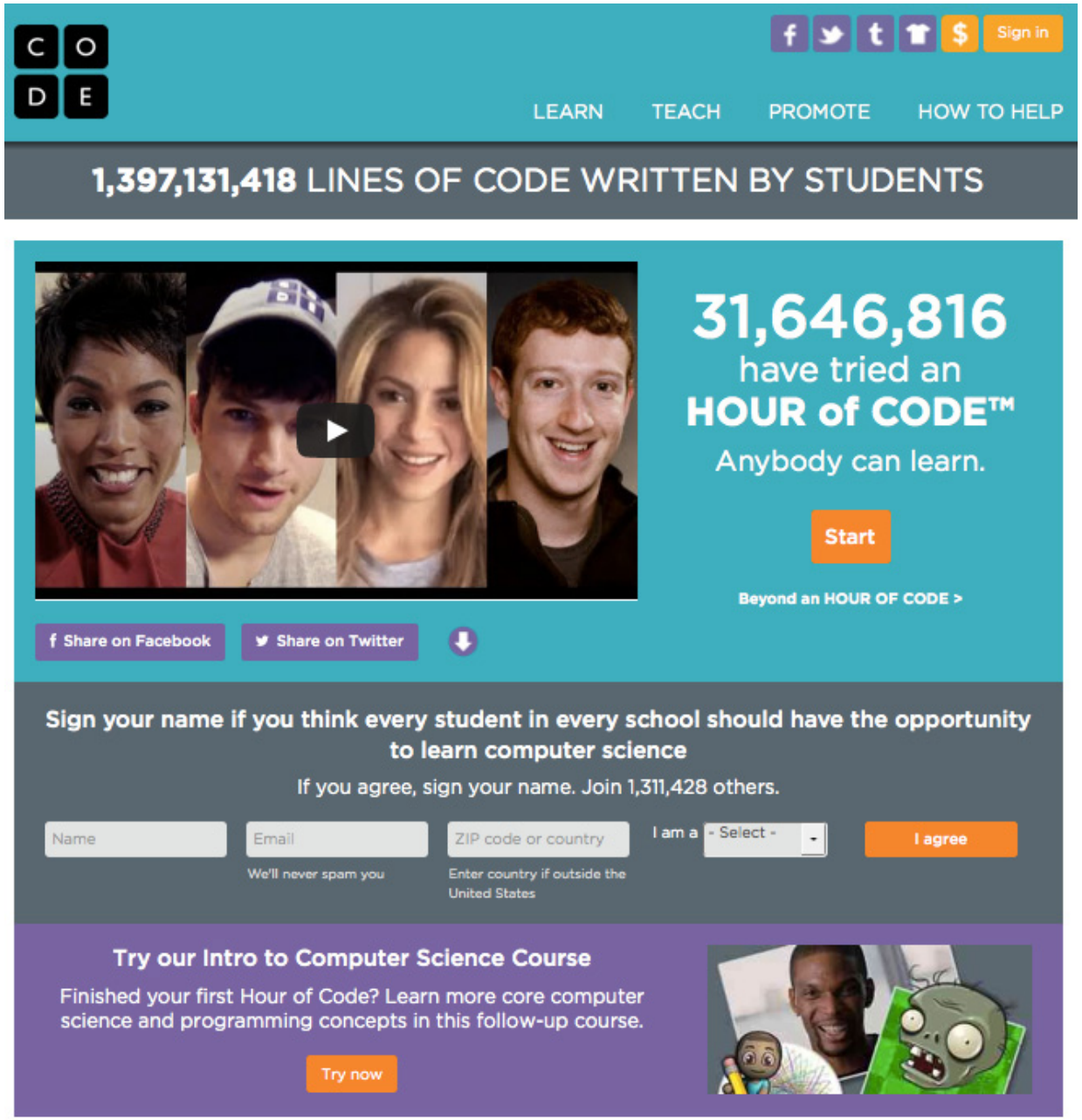
Middle School (6–8) Storyline PDF	High School (9–12) Storyline PDF
MS. Engineering Design	**HS.** Engineering Design

- In 9 out of 10 high schools nationwide, computer science is not offered

- In 31 of the 50 states, computer science does not count towards the math or science graduation requirement



Yet computer science – "computational thinking" – is a key capability for just about every 21st century endeavor



Hadi Partovi
Code.org

Is this a great time or what?

http://lazowska.cs.washington.edu/Wenk.pdf