

# Computer Science: Past, Present, and Future

Ed Lazowska

Bill & Melinda Gates Chair in  
Computer Science & Engineering  
University of Washington

Chair, Computing Community Consortium

CIS 40<sup>th</sup> Anniversary  
University of Oregon

April 2010

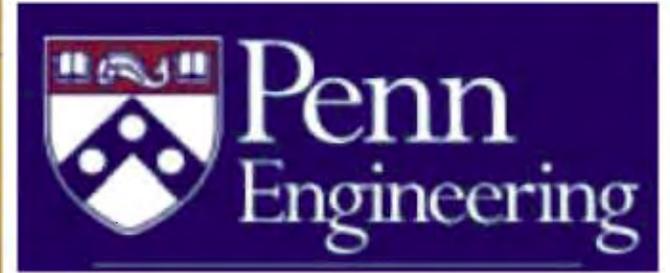
<http://lazowska.cs.washington.edu/oregon.pdf>



## This evening ...

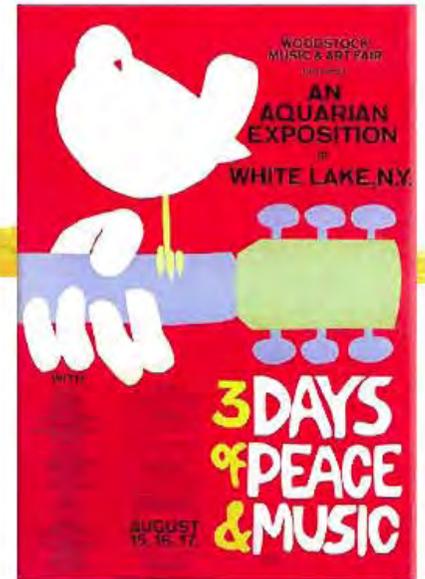


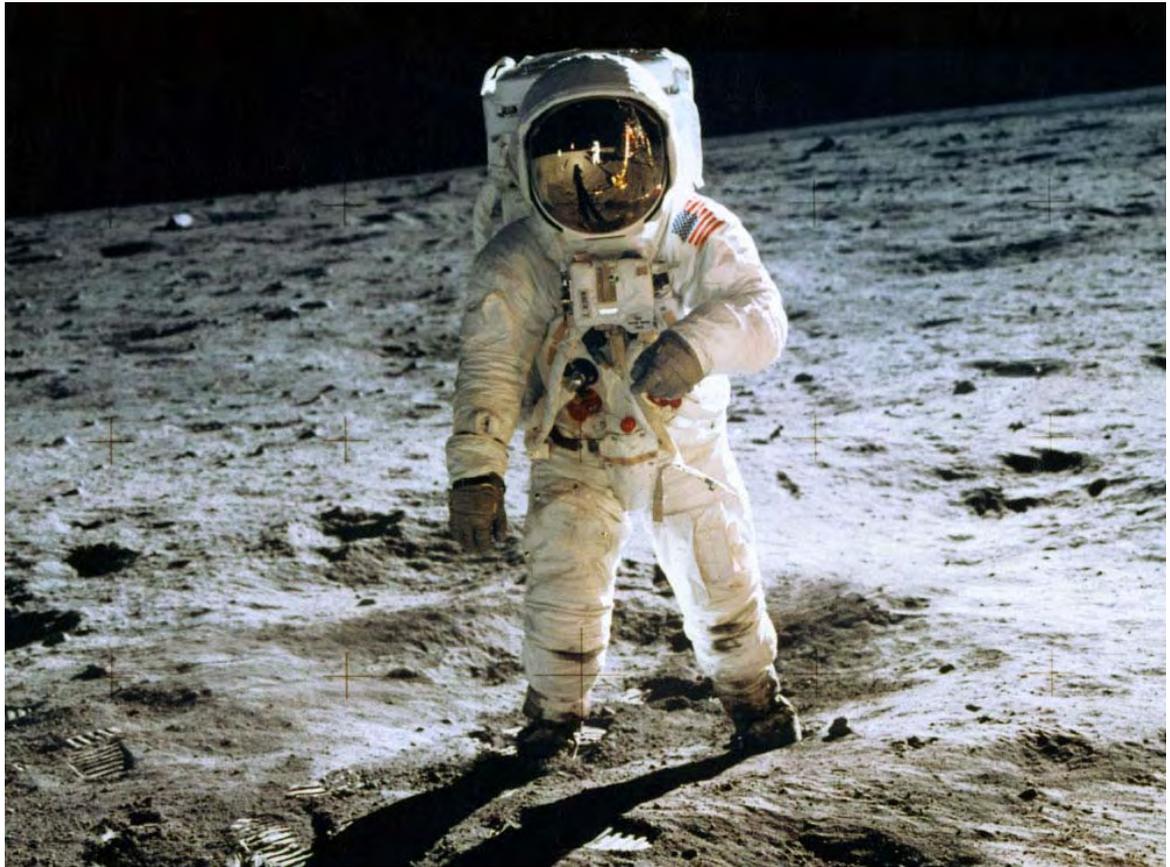
- A quick reminder of what we've accomplished as a field
- The Computing Community Consortium: origins, goals, recent activities
- Some research challenges for our field
- Be a Myth Buster!



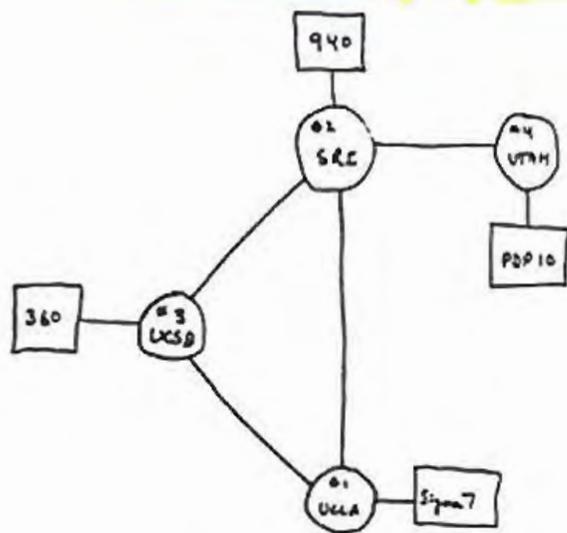
Forty years ago ...







[Peter Lee, DARPA, and Pat Lincoln, SRI]



THE ARPA NETWORK  
DEC 1969  
4 NODES

|           |       |  |    |
|-----------|-------|--|----|
| 29 OCT 69 | 2100  | LOADED OP. PROGRAM   | SK |
|           |       | EDIC BEN BARKER  |    |
|           |       | BBV  |    |
|           | 22:30 | Talked to SRC<br>Host to Host  | SK |
|           |       | Left op program<br>running after sending<br>a host dead message<br>to imp. | SK |



# With forty years 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 ...

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THE COUNT

Internet, Mobile Phones Named Most Important Inventions

By PHYLLIS KORRICK Published: March 7, 2009

In response to the shouted-out question, "What are some of the greatest inventions of all time?," nearby office workers in a recent informal survey gave the following answers: the wheel, the engine, the ballpoint pen, diapers and the cheese Danish.

Life Changers

The top innovations of the last 30 years, according to judges at the Wharton School of the University of Pennsylvania.

1. Internet, broadband
2. PC and laptop computers
3. Mobile phones
4. E-mail
5. DNA testing and sequencing
6. Magnetic resonance imaging
7. Microprocessors
8. Fiber optics
9. Office software
10. Laser/robotic surgery
11. Open-source software
12. Light-emitting diodes
13. Liquid crystal display
14. GPS devices
15. E-commerce and auctions
16. Media file compression
17. Microfinance
18. Photovoltaic solar energy
19. Large-scale wind turbines
20. Internet social networking

THE NEW YORK TIMES

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Good, important choices all, but for classic, long-lasting appeal, they still can't beat the wheel. PHYLLIS KORRICK

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## Named Most Important Inventions

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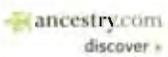
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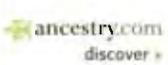
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# Landmark contributions by students



- Use of Boolean logic to model digital circuits
  - Claude Shannon, MIT, 1937
- Huffman coding
  - David Huffman, MIT, 1951
- Mathematical foundation of packet communication
  - Len Kleinrock, MIT, 1962
- Interactive computer graphics
  - Ivan Sutherland, MIT, 1963
- Computer vision
  - Larry Roberts, MIT, 1963
- Symbolic mathematics
  - William A. Martin & Joel Moses, MIT, 1967

- 
- The FLEX language and machine
    - Alan Kay, Utah, 1969
  - The Boyer-Moore theorem prover
    - Robert S. Boyer and J Strother Moore, Edinburgh, 1971
  - Efficient graph planarity testing using depth-first search
    - Bob Tarjan, Stanford, 1972
  - Ethernet
    - Bob Metcalfe, Harvard, 1973
  - BSD Unix
    - Bill Joy, Berkeley, 1977
  - VisiCalc
    - Bob Frankston & Dan Bricklin, MIT, 1979

- 
- Public key cryptography
    - Ralph Merkle, Berkeley & Stanford, 1979
  - The SUN workstation
    - Andy Bechtolsheim, Stanford, 1982
  - The Connection Machine
    - Danny Hillis, MIT, 1983
  - Sphinx (speech recognition)
    - Kai-Fu Lee, Carnegie Mellon, 1988
  - Linux
    - Linus Torvalds, Helsinki, 1991
  - BDD-based symbolic model checking
    - Ken McMillan, Carnegie Mellon, 1992



- Mosaic

- Marc Andreessen, Illinois, 1994

- The PCP theorem

- Sanjeev Arora, Berkeley, 1994

- Google

- Larry Page & Sergey Brin, Stanford, 1998

- Akamai

- Danny Lewin, MIT, 1999

- Peer-to-peer file sharing

- Shawn Fanning, Northeastern, 1999

# The most recent ten years ...

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



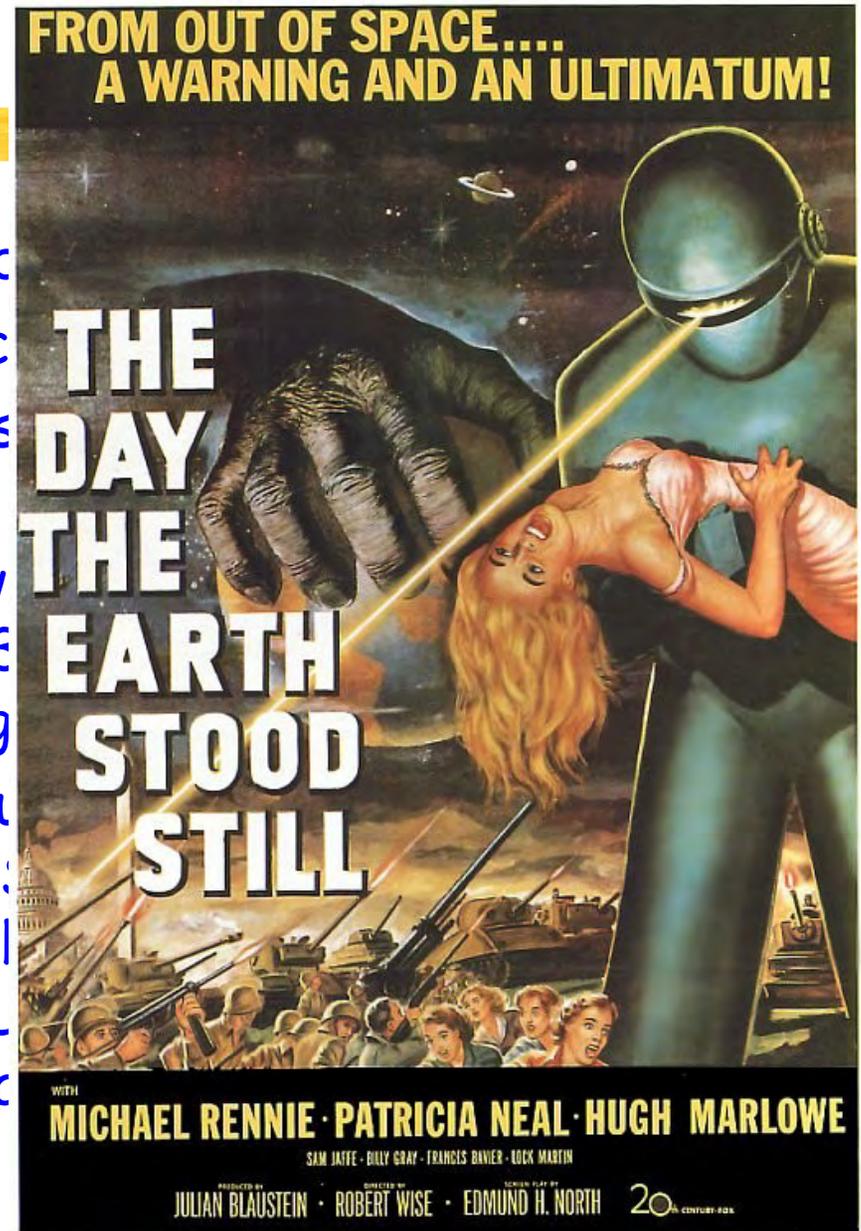
# Imagine spending a day without information technology



- A day without the Internet and all that it enables
- A day without diagnostic medical imaging
- A day during which automobiles lacked electronic ignition, antilock brakes, and electronic stability control
- A day without digital media - without wireless telephones, high-definition televisions, MP3 audio, DVD video, computer animation, and videogames
- A day during which aircraft couldn't fly, travelers had to navigate without benefit of GPS, weather forecasters had no models, banks and merchants couldn't transfer funds electronically, factory automation ceased to function, and the US military lacked technological supremacy

# Imagine spending a day without information technology

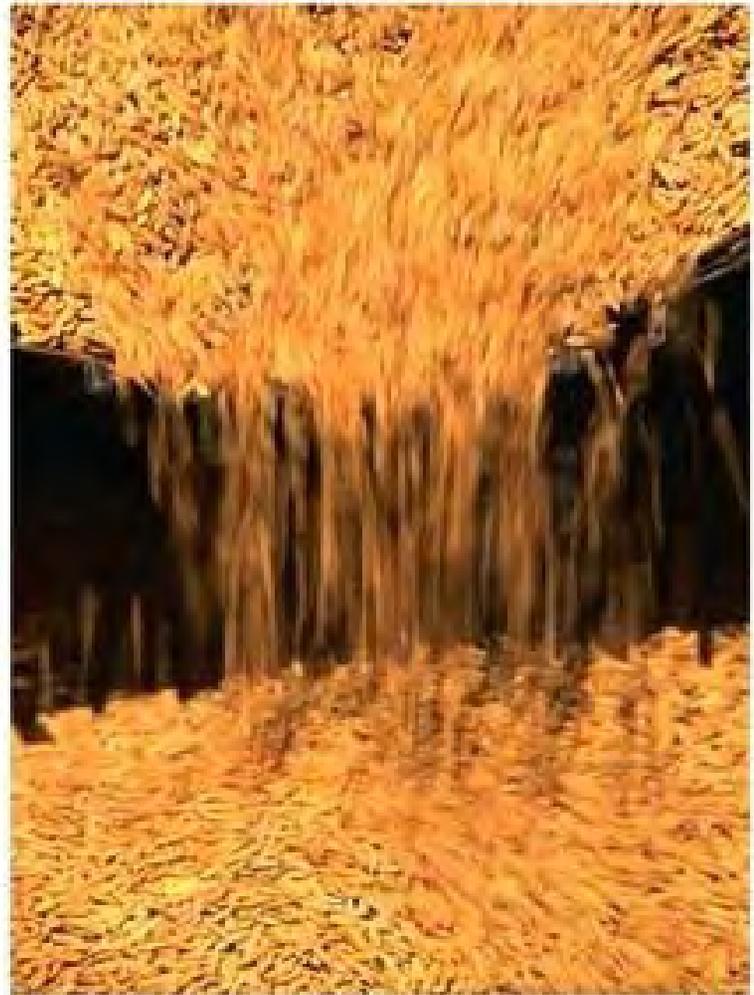
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2004: 10,000,000,000,000,000,000  
grains of rice

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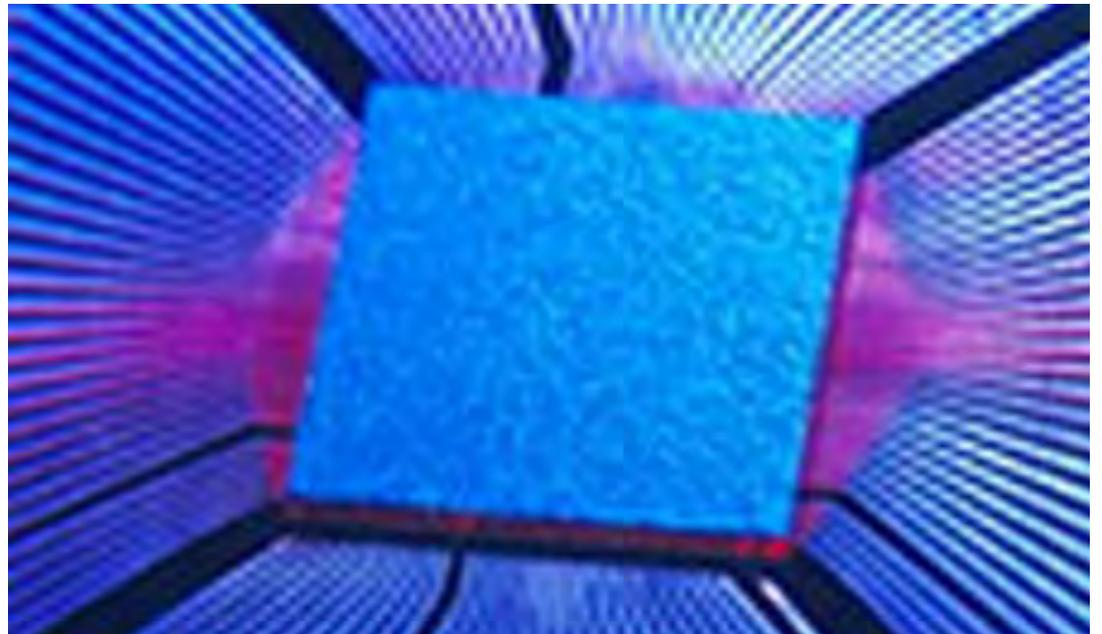
- Ten quintillion:  $10 \cdot 10^{18}$ 
  - The number of grains of rice harvested in 2004



2004: 10,000,000,000,000,000,000  
transistors

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- Ten quintillion:  $10^{18}$ 
  - The number of grains of rice harvested in 2004
  - The number of transistors fabricated in 2004



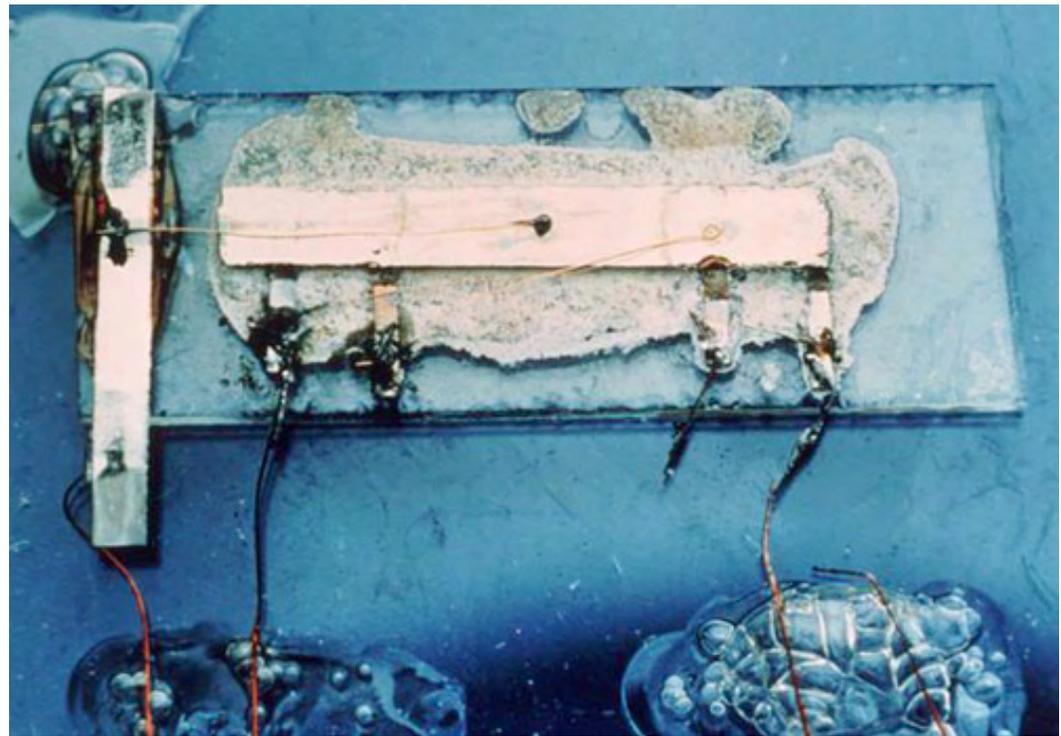
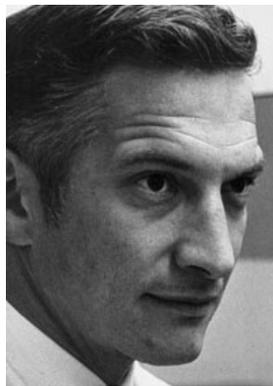
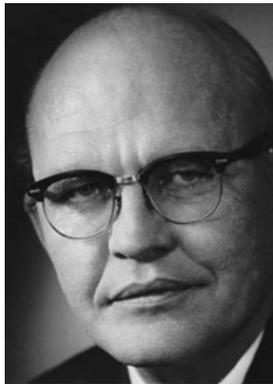
# The transistor

- William Shockley, Walter Brattain and John Bardeen, Bell Labs, 1947



# The integrated circuit

- Jack Kilby, Texas Instruments, and Bob Noyce, Fairchild Semiconductor Corporation, 1958

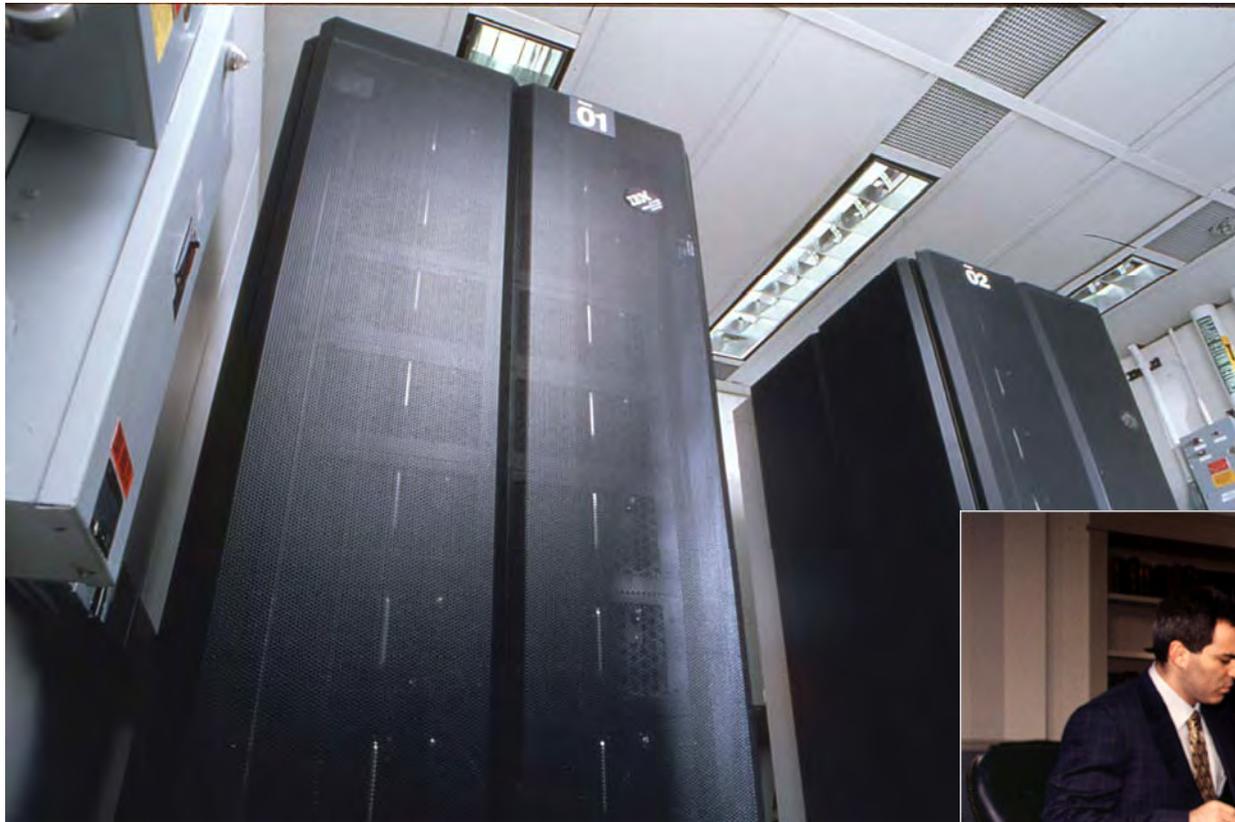






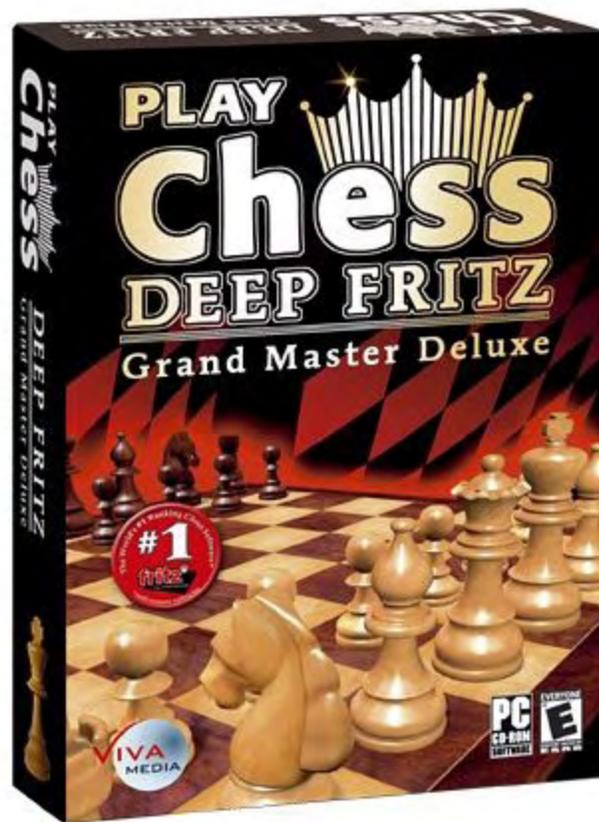


# Software makes equal progress



Deep Blue, 1997





Price: **\$19.99** & eligible for free shipping  
with **Amazon Prime**

Deep Fritz, 2002



## AlphaServer 1200 product brief

### Leadership

"To support our rapid growth, we had to find a highly upgradable and scaleable Internet server. The AlphaServer platform provides the upgrade path we need."

Jeff Bezos  
CEO and Founder  
Amazon.com



amazon.com<sup>®</sup>



Web commerce back-end, 1997

## ■ Contrast ...

- The cheapest imaginable components
  - | Failures occur all the time
  - | You couldn't afford to prevent this in hardware
- Software makes it
  - | Fault-Tolerant
  - | Highly Available
  - | Recoverable
  - | Consistent
  - | Scalable
  - | Predictable
  - | Secure



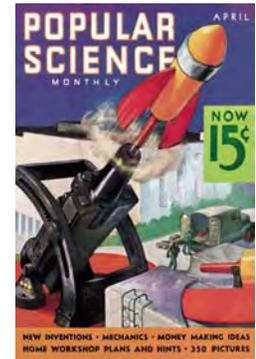
Web commerce back-end, 2007

# This sort of progress makes it dicey to predict the future



"I think there is a world market for maybe five computers" - Thomas J. Watson, founder and Chairman of IBM, 1943

"Computers in the future may weigh no more than 1.5 tons" - *Popular Science*, 1949



"There is no reason anyone would want a computer in their home" - Ken Olsen, founder and President of Digital Equipment Corporation, 1977

Today: More than 1 billion PCs in use ...

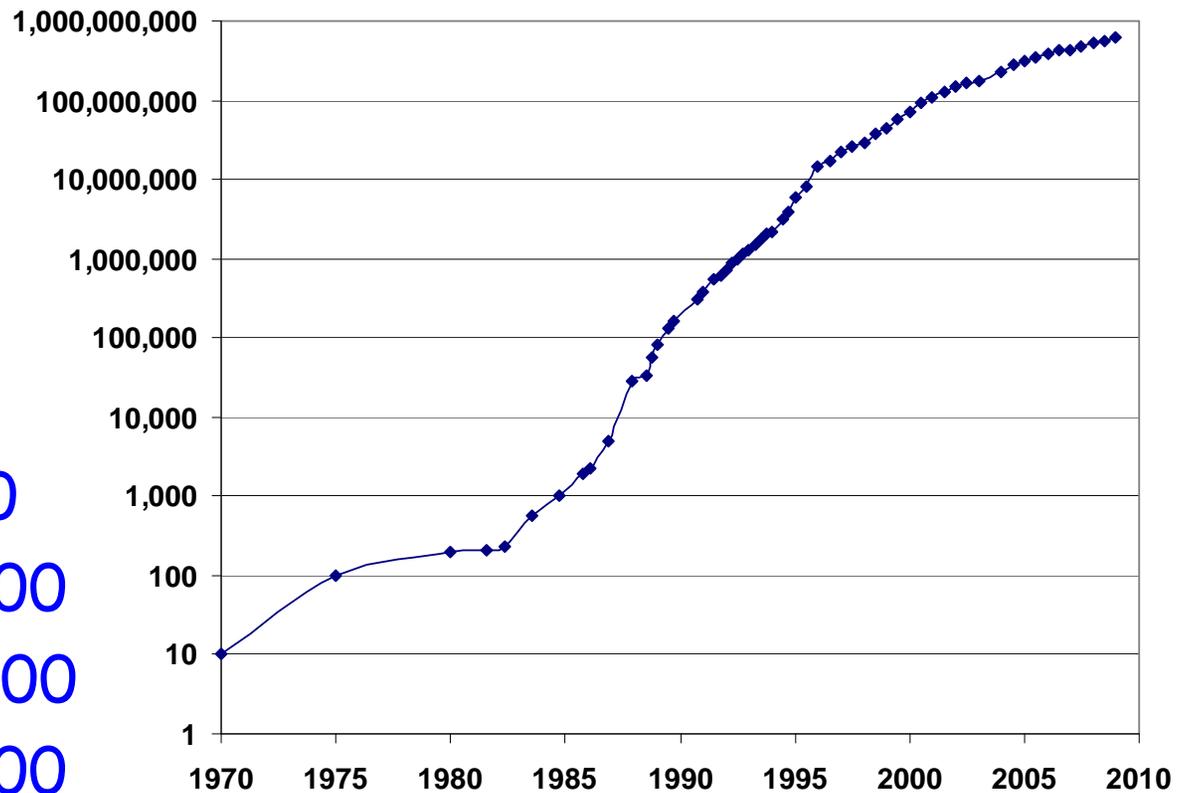


# Representing less than 2% of all processors!

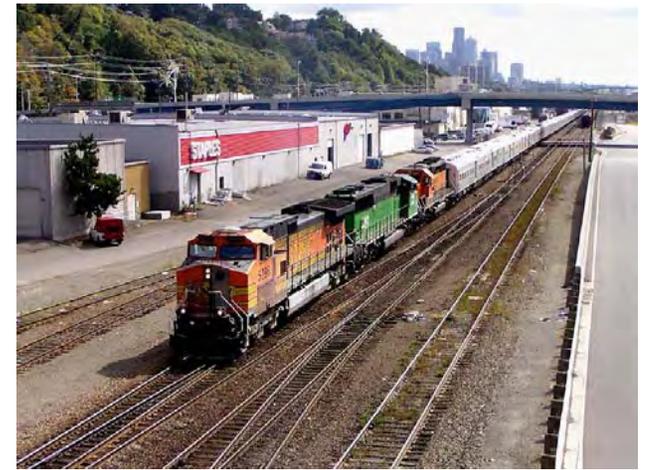


# Number of Internet hosts

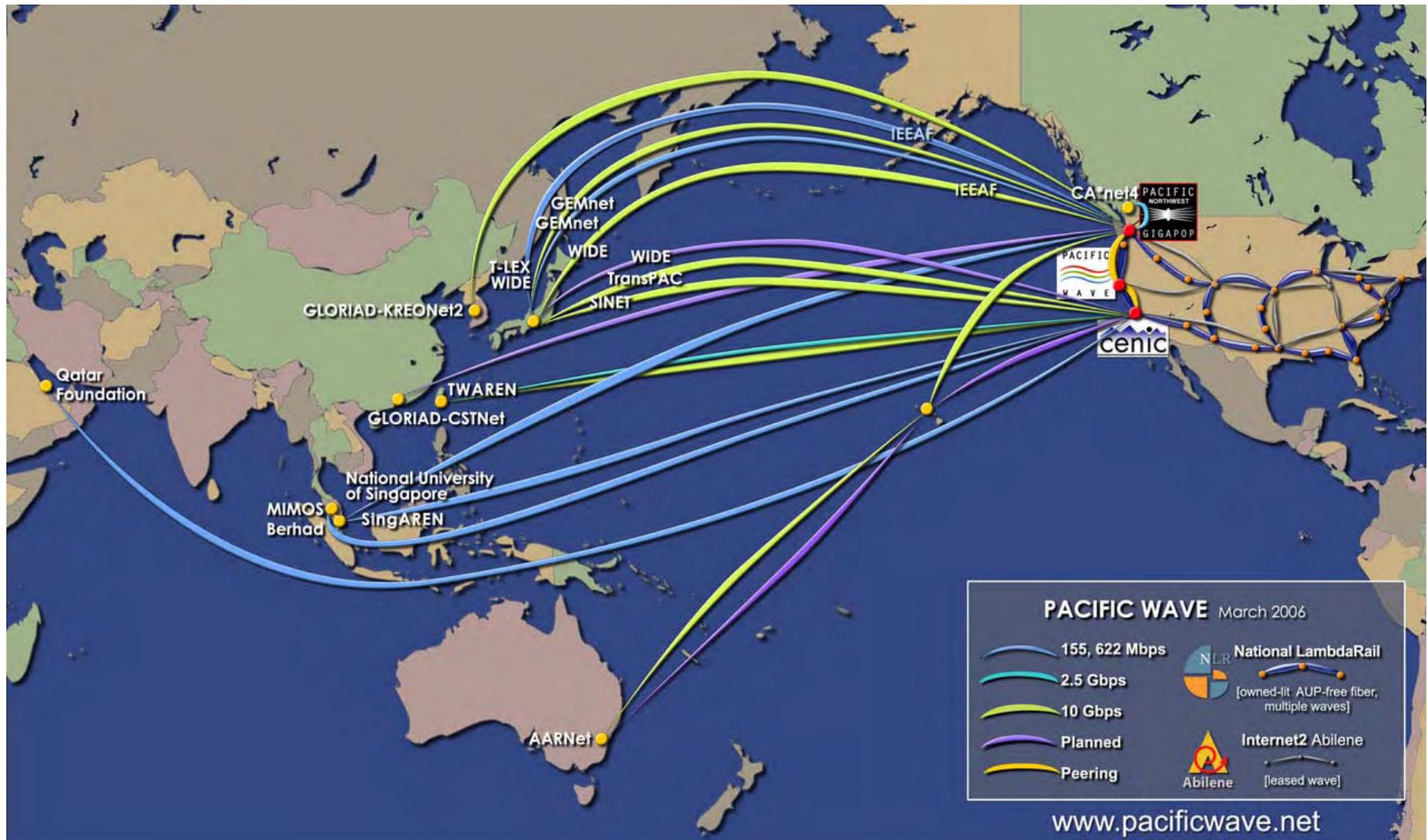
- 1970: 10
- 1975: 100
- 1980: 200
- 1985: 2,000
- 1990: 350,000
- 1995: 10,000,000
- 2000: 100,000,000
- 2005: 375,000,000
- 2010: 700,000,000



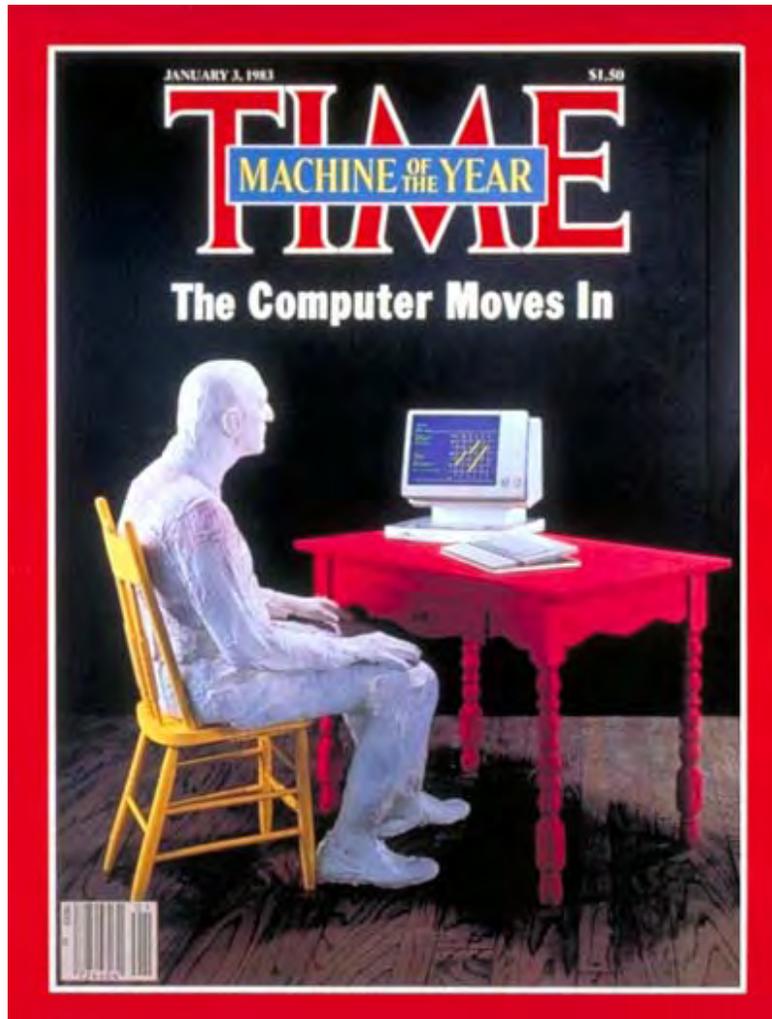
# A connected region - then



# A connected region - now



# The Computer: *Time Magazine's* 1982 "Machine of the Year"



- "In medicine, the computer, which started by keeping records and sending bills, now suggests diagnoses. The process may sound dehumanized, but in one hospital ... a survey of patients showed that they found the machine 'more friendly, polite, relaxing and comprehensible' than the average physician."



- 
- "When the citizen of tomorrow wants a new suit, one futurist scenario suggests, his personal computer will take his measurements and pass them on to a robot that will cut his choice of cloth with a laser beam and provide him with a perfectly tailored garment."

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- 
- "In the home, computer enthusiasts delight in imagining machines performing domestic chores."

- “In the home, computer enthusiasts delight in imagining machines performing domestic chores.”

vacuum your carpet



**iRobot®**

- “In the home, computer enthusiasts delight in imagining machines performing domestic chores.”

wash your floor



**iRobot**<sup>®</sup>

- “In the home, computer enthusiasts delight in *imagining* machines performing domestic chores.”

scrub your pool



**iRobot®**

- "In the home, computer enthusiasts delight in imagining machines performing domestic chores."

clean your gutters



**iRobot®**

- "In the home, computer enthusiasts delight in imagining machines performing domestic chores."

amuse your pet



**iRobot®**

- “In the home, computer enthusiasts delight in imagining machines performing domestic chores.”

detonate your IED's



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# The Computing Community Consortium



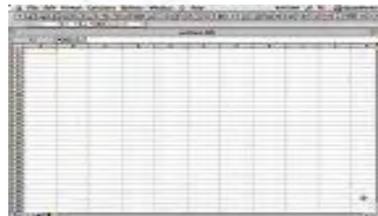
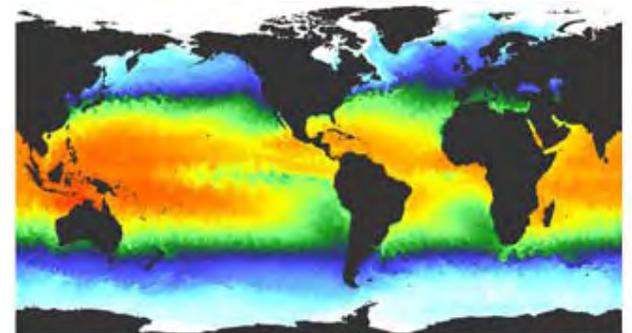
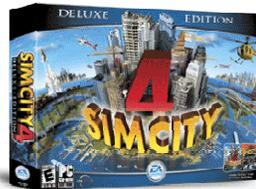
Computing Community Consortium

*We support the computing research community in creating compelling research visions and the mechanisms to realize these visions.*

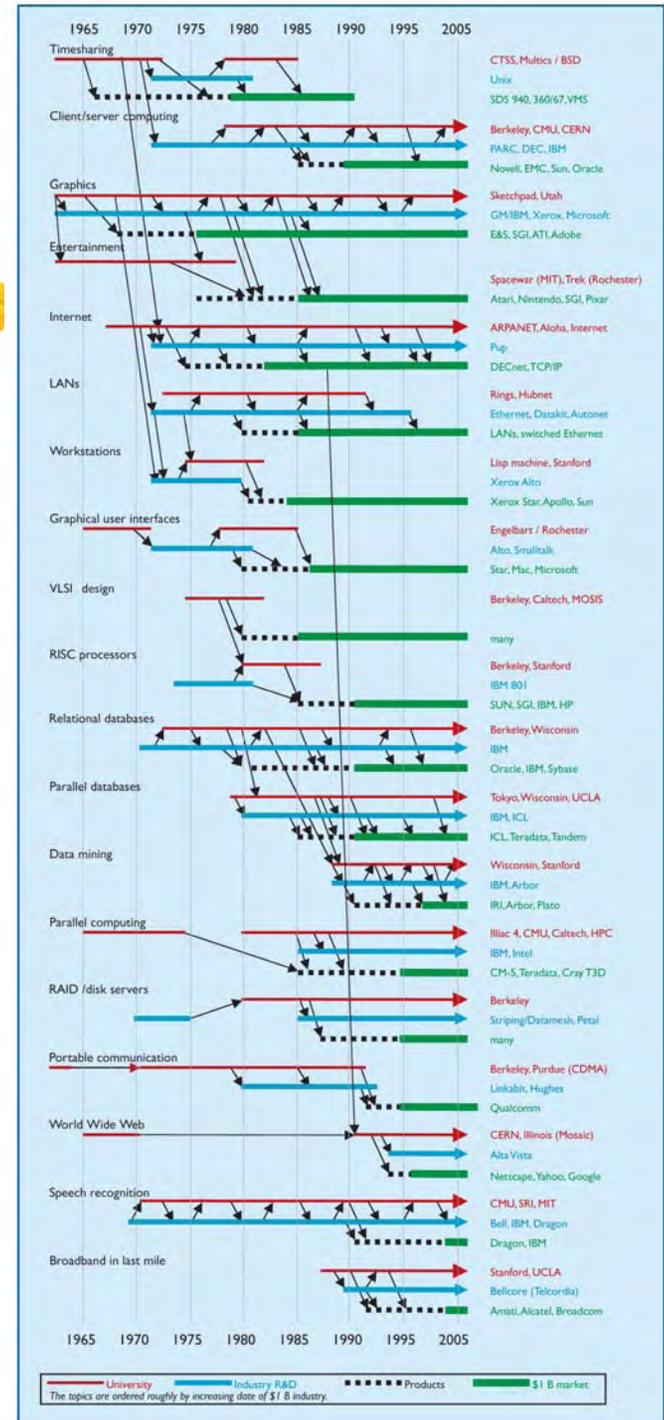
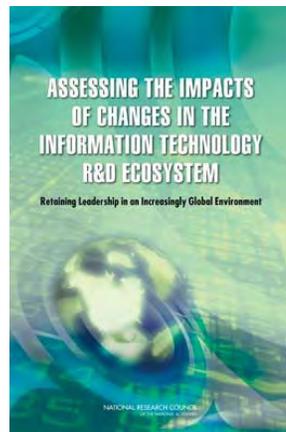
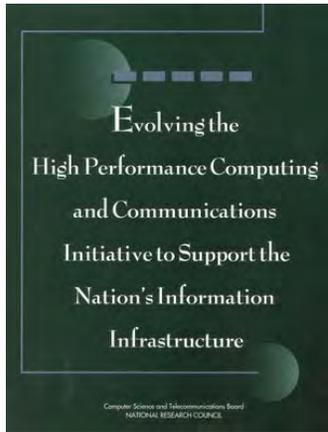


# Computing has changed the world

- Advances in computing change the way we live, work, learn, and communicate
- Advances in computing drive advances in nearly all other fields
- Advances in computing power our economy
  - Not just through the growth of the IT industry - through productivity growth across the entire economy

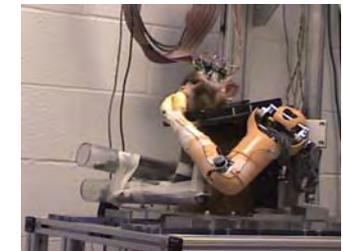
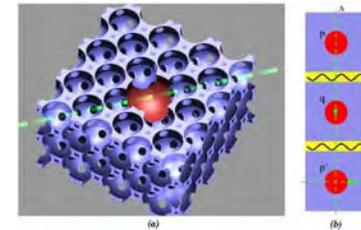
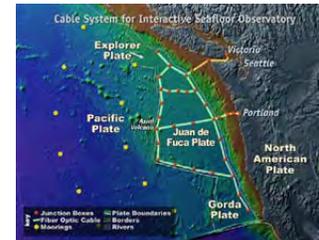
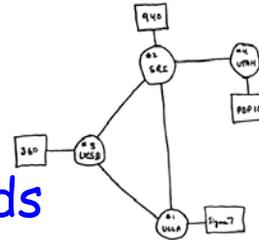


# Research has built the foundation



# The future is full of opportunity

- Creating the future of networking
- Driving advances in all fields of science and engineering
- Revolutionizing transportation
- Personalized education
- The smart grid
- Predictive, preventive, personalized medicine
- Quantum computing
- Empowerment for the developing world
- Personalized health monitoring => quality of life
- Harnessing parallelism
- Neurobotics
- Synthetic biology



# We must work together to establish, articulate, and pursue visions for the field

- The challenges that will shape the intellectual future of the field
- The challenges that will catalyze research investment and public support
- The challenges that will attract the best and brightest minds of a new generation



# To this end, NSF asked CRA to create the Computing Community Consortium

- To catalyze the computing research community to consider such questions
  - To envision long-range, more audacious research challenges
  - To build momentum around such visions
  - To state them in compelling ways
  - To move them towards funded initiatives
  - To ensure "science oversight" of large-scale initiatives
- A "cooperative agreement" with NSF
  - Close coordination



# The CCC Council - broad representation

## ■ Chair

- Ed Lazowska

## ■ Terms ending 2013

- Randy Bryant
- Lance Fortnow
- Hank Korth
- Eric Horvitz
- Beth Mynatt
- Fred Schneider
- Margo Seltzer

## ■ Terms ending 2012

- Stephanie Forrest
- Chris Johnson
- Anita Jones
- Frans Kaashoek
- Ran Libeskind-Hadas
- Robin Murphy

## ■ Terms ending 2011

- Bill Feiereisen
- Susan Graham (v ch)
- Dave Kaeli
- John King
- Bob Sproull

## ■ Ex Officio

- Andy Bernat
- Erwin Gianchandani

## ■ Rotated off

- Dick Karp, 2010
- Andrew McCallum, 2010
- Dave Waltz, 2010
- Greg Andrews, 2009
- Peter Lee, 2009
- Karen Sutherland, 2009

# Major continuing activities

## ■ Countless talks

### The Computing Community Consortium: Stimulating Bigger Thinking

Ed Lazowska

Bill & Melinda Gates Chair in  
Computer Science & Engineering  
University of Washington

Chair, Computing Community Consortium

Tapia Conference Career Workshop  
April 2009

<http://www.cra.org/ccc/>



# Major continuing activities

- Countless talks
- Countless articles

**V** viewpoints

DOI:10.1145/1378704.1378714 Ed Lazowska

## Viewpoint

### Envisioning the Future of Computing Research

*Advances in computing have changed our lives—the Computing Community Consortium aims to help the research community continue that lineage.*

**H**OW CAN WE work together to establish, articulate, and pursue compelling visions for our field—visions that will shape the intellectual future of the field, that will catalyze research investment and public support, and that will attract the best and brightest minds of a new generation?

The National Science Foundation

many Internet hosts.

It was only 10 years ago that Deep Blue—a supercomputer by any definition—defeated world chess champion Garry Kasparov. Today, thanks more to progress in software than to progress in hardware, you can download for your PC a chess engine with a rating 10% higher than any human player. Most of the “futurist scenar-

try: timesharing, computer graphics, networking (LANs and the Internet), personal workstation computing, windows and the graphical user interface, RISC architectures, modern integrated circuit design, RAID storage, and parallel computing. In each case, the role of federally sponsored research was clear.

The panel conducting this study (I

# Major continuing activities

- Countless talks
- Countless articles
- CCC blog

The screenshot shows the CCC Blog website. The header includes the CCC logo and the title 'CCC BLOG THE COMPUTING COMMUNITY CONSORTIUM'. Navigation links for 'HOME', 'ABOUT THE CCC', and 'ABOUT THIS BLOG' are present. A sidebar on the left offers a 'Subscribe in a reader' link, a 'Subscribe to this Blog' form with an email input field and 'Subscribe'/'Unsubscribe' buttons, and a 'Recent Posts' section listing several articles.

The main content area features a post titled 'Where the jobs are ...' dated 'JAN 4', filed under 'Uncategorized, pipeline, resources'. It contains two bar charts and text. The first chart, 'Employment growth within the 10 BLS major occupational groups, 2008-18', shows growth rates for various categories. The second chart, 'Employment growth within the 8 BLS "Professional and related" occupations, 2008-2018', shows growth rates for a subset of these categories.

| Occupational Group                         | Growth Rate (%) |
|--|-----------------|
| Total all occupations                      | 10.1%           |
| Management, business, and financial        | 10.8%           |
| Professional and related                   | 18.8%           |
| Service                                    | 11.8%           |
| Sales and related                          | 6.2%            |
| Office and administrative support          | 7.8%            |
| Food, drinking water, and lodging          | 0.1%            |
| Construction and extraction                | 13.0%           |
| Transportation, equipment, and maintenance | 7.4%            |
| Healthcare                                 | 0.9%            |
| Production and transportation              | 4.0%            |

| Occupational Group        | Growth Rate (%) |
|---------------------------|-----------------|
| Computer and mathematical | 18.8%           |
| Engineering               | 22.2%           |
| Architecture              | 10.2%           |
| Life science              | 19.0%           |
| Healthcare                | 14.0%           |
| Legal                     | 10.1%           |
| Education and training    | 14.4%           |
| Arts, design, and media   | 12.1%           |
| Information               | 21.4%           |

Every second year, the US Bureau of Labor Statistics provides a ten-year forecast of job growth in all fields of employment. The most recent forecast, released in November 2009 and covering the period 2008-2018, may be found [here \(pdf\)](#). Among the highlights:

- Among the 10 major BLS occupational groups, the "Professional and related" category (which includes computer science occupations) is projected to grow by the largest percentage between now and 2018.

# Major continuing activities

- Countless talks
- Countless articles
- CCC blog
- Computing research highlight of the week



The screenshot displays the homepage of the Computing Community Consortium (CCC). The header features the CCC logo and the text "Computing Community Consortium" with the tagline "We support the computing research community in creating compelling research visions and the mechanisms to realize these visions." Below the header is a navigation menu with links for HOME, YOUR VISION, PLANS, ACTIVITIES (highlighted in green), RESOURCES, ABOUT, CRA, and a GO button. The main content area is titled "COMPUTING RESEARCH HIGHLIGHT OF THE WEEK [January 14 - 21, 2010]" and features an article titled "'One Keypad per Child' Lets School Children Share Screen to Learn Math". The article text describes a system developed by University of Washington computer science undergraduates that allows up to four students to share a single computer for interactive math problems. It includes a quote from Joyojeet Pal, a lecturer in UW Computer Science & Engineering, and mentions that the system, called MultiLearn, will be tested with 180 students in rural India. The article is accompanied by two images: one showing two young girls looking at a computer screen, and another showing a man with a play button overlay on his face, likely a video thumbnail. On the right side of the page, there are sections for "Relevant Links" (Press Release, Project Web Page, Research Papers, Media Contact), "Keywords" (educational technology, information technology for development, University of Washington), and "Buzz" (RSS SUBSCRIBE, EMAIL NOTIFY, EMBED CODE, SHARE).

# Major continuing activities

- Countless talks
- Countless articles
- CCC blog
- Computing research highlight of the week
- Community visioning exercises

The screenshot shows the homepage of the Computing Community Consortium (CCC). The header features the CCC logo and the text "Computing Community Consortium" with the tagline "We support the computing research community in creating compelling research visions and the mechanisms to realize these visions." Below the header is a navigation menu with links for HOME, YOUR VISION, PLANS, ACTIVITIES, RESOURCES, ABOUT, CRA, and a GO button. The main content area has a large heading "What questions shape our intellectual future?" followed by a paragraph of text and a link to "Click on the tabs below to see some of these activities." Below this is a row of tabs for various research areas: NetSE, Cyber Physical Systems, Robotics, Big Data Computing, Theoretical CS, FOSS, Online Education, XLayer, Global Development, ACAR, and HealthIT. The page also features two highlighted sections: "Computing Research that Changed the World" and "Highlight of the Week" with a sub-heading "New Search Technique for Images and Videos".

**Computing Community Consortium**  
We support the computing research community in creating compelling research visions and the mechanisms to realize these visions.

HOME YOUR VISION PLANS ACTIVITIES RESOURCES ABOUT CRA GO

## What questions shape our intellectual future?

What attracts the best and brightest minds of a new generation? What are the next big computing ideas, the ones that will define the future of computing, galvanize the very best students, and catalyze research investment and public support? The Computing Community Consortium (CCC) seeks to mobilize the computing research community to answer these questions by identifying major research opportunities for the field.

Click on the tabs below to see some of these activities.

»» NetSE Cyber Physical Systems Robotics Big Data Computing Theoretical CS  
FOSS Online Education XLayer Global Development ACAR HealthIT

### Computing Research that Changed the World

This invitation only symposium, "Computing Research that Changed the World: Reflections and Perspectives," was organized by the Computing Community Consortium in collaboration with Congressman Bart Gordon (D-TN), Congressman Ralph Hall (R-TX), Congressman Daniel Lipinski (D-IL), Congressman Vern Ehlers (R-MI), Congressman Rush Holt (D-NJ) and Sen. Jay Rockefeller (D-WV). It was held in the Library of Congress on March 25, 2009.

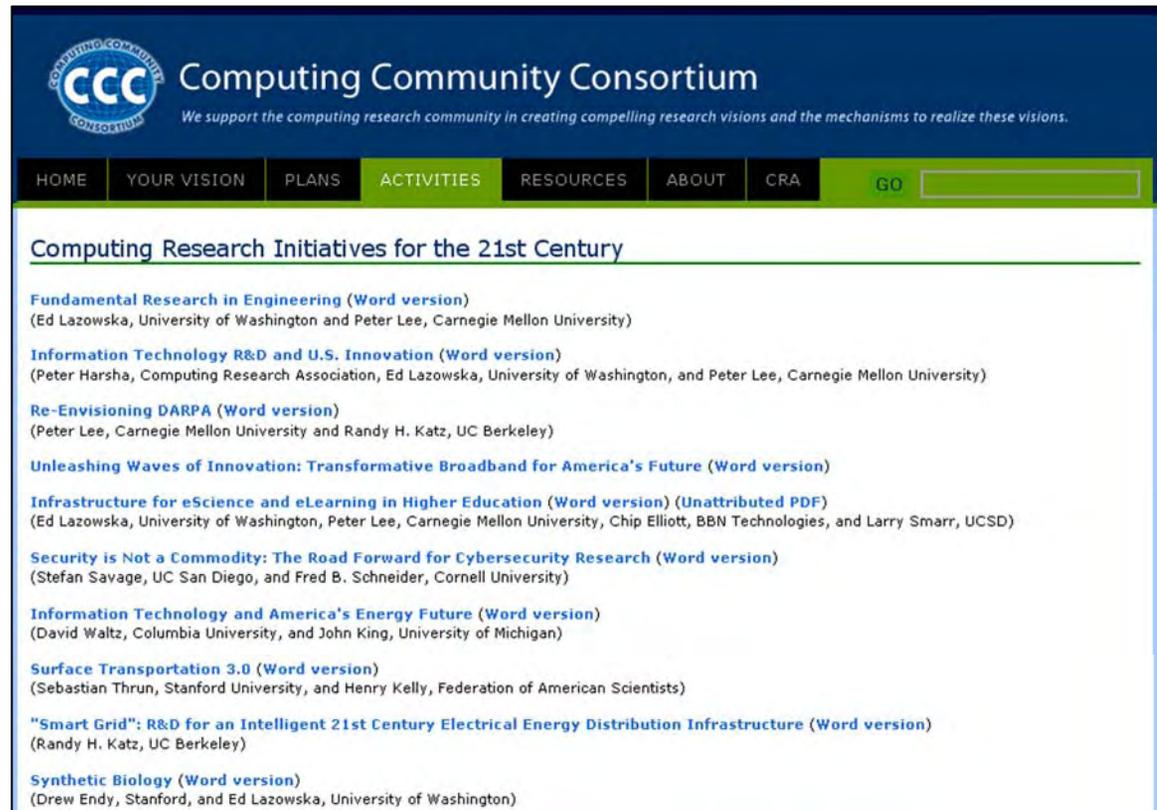
### Highlight of the Week

#### New Search Technique for Images and Videos

University of Washington computer science undergraduates have developed a system that lets up to four students share a single computer to do interactive math problems. Early tests show that students using

# Major special initiatives

## ■ Transition Team white papers



The screenshot shows the homepage of the Computing Community Consortium (CCC). The header features the CCC logo and the text "Computing Community Consortium" with the tagline "We support the computing research community in creating compelling research visions and the mechanisms to realize these visions." Below the header is a navigation menu with links for HOME, YOUR VISION, PLANS, ACTIVITIES, RESOURCES, ABOUT, and CRA. A search bar with a "GO" button is also present. The main content area is titled "Computing Research Initiatives for the 21st Century" and lists several white papers with their authors and affiliations.

**Computing Community Consortium**  
We support the computing research community in creating compelling research visions and the mechanisms to realize these visions.

HOME YOUR VISION PLANS **ACTIVITIES** RESOURCES ABOUT CRA GO

### Computing Research Initiatives for the 21st Century

- [Fundamental Research in Engineering \(Word version\)](#)  
(Ed Lazowska, University of Washington and Peter Lee, Carnegie Mellon University)
- [Information Technology R&D and U.S. Innovation \(Word version\)](#)  
(Peter Harsha, Computing Research Association, Ed Lazowska, University of Washington, and Peter Lee, Carnegie Mellon University)
- [Re-Envisioning DARPA \(Word version\)](#)  
(Peter Lee, Carnegie Mellon University and Randy H. Katz, UC Berkeley)
- [Unleashing Waves of Innovation: Transformative Broadband for America's Future \(Word version\)](#)
- [Infrastructure for eScience and eLearning in Higher Education \(Word version\) \(Unattributed PDF\)](#)  
(Ed Lazowska, University of Washington, Peter Lee, Carnegie Mellon University, Chip Elliott, BBN Technologies, and Larry Smarr, UCSD)
- [Security is Not a Commodity: The Road Forward for Cybersecurity Research \(Word version\)](#)  
(Stefan Savage, UC San Diego, and Fred B. Schneider, Cornell University)
- [Information Technology and America's Energy Future \(Word version\)](#)  
(David Waltz, Columbia University, and John King, University of Michigan)
- [Surface Transportation 3.0 \(Word version\)](#)  
(Sebastian Thrun, Stanford University, and Henry Kelly, Federation of American Scientists)
- ["Smart Grid": R&D for an Intelligent 21st Century Electrical Energy Distribution Infrastructure \(Word version\)](#)  
(Randy H. Katz, UC Berkeley)
- [Synthetic Biology \(Word version\)](#)  
(Drew Endy, Stanford, and Ed Lazowska, University of Washington)

# Major special initiatives

- Transition Team white papers
- Library of Congress Symposium



# Major special initiatives

- Transition Team white papers
- Library of Congress Symposium
- Computing Innovation Fellows project  
1209 mentors  
526 applicants

COMPUTING RESEARCH ASSOCIATION (CRA) NSF NATIONAL SCIENCE FOUNDATION (NSF) COMPUTING COMMUNITY CONSORTIUM (CCC)

## Computing Innovation Fellows Project

Home CRA CCC CISE

*The 2009 Computing Innovation Fellows have been selected!*

[View the press release with the names of the 2009 Fellows and their Mentors.](#)

Congratulations to everyone who was selected for a CIFellow award!  
*Thank you for your interest in CIFellows. The response has been tremendous!*  
[For up-to-the-minute news on the progress of the selection process, check out the forum.](#)

In the light of the response that the CIFellows has received, we have set up a courtesy website where employers can post available positions suitable for new computing PhD's. This site is available at <http://cifellows.org/opportunities>.

An additional courtesy site has been set up for computing PhD's to post their profiles and availability. This website is available at <http://cifellows.org/profiles>. We encourage employers and candidates to make use of these complimentary services.

The Computing Community Consortium (CCC) and the Computing Research Association (CRA), with funding from the National Science Foundation, announce a program for new PhD graduates to obtain one-to-two year postdoctoral positions

# Major special initiatives

- Transition Team white papers
- Library of Congress Symposium
- Computing Innovation Fellows project
- Landmark Contributions by Students

## Landmark Contributions by Students in Computer Science

Version 11: September 15, 2009

There are many reasons for research funding agencies (DARPA, NSF, etc.) to invest in the education of students. Producing the next generation of innovators is the most obvious one. In addition, though, there are an impressive number of instances in our field in which undergraduate and graduate students have made truly game-changing contributions in the course of their studies.

The inspiring list below was compiled by the following individuals and their colleagues: Bill Bonvillian (MIT), Susan Graham (Berkeley), Anita Jones (University of Virginia), Ed Lazowska (University of Washington), Pat Lincoln (SRI), Fred Schneider (Cornell), and Victor Zue (MIT).

We solicit your suggestions for additional student contributions of comparable impact – post them on the Computing Community Consortium blog, <http://www.cccb.org/2009/08/28/landmark-contributions-by-students-in-computer-science/>, or send them to Ed Lazowska, [lazowska@cs.washington.edu](mailto:lazowska@cs.washington.edu).

# Major special initiatives

- Transition Team white papers
- Library of Congress Symposium
- Computing Innovation Fellows project
- Landmark Contributions by Students
- NetSE Research Agenda

## NetSE Research Agenda: Executive Summary and Recommendations

Over the past forty years, computer networks, and especially the Internet, have gone from research curiosity to fundamental infrastructure. In terms of societal impact, the Internet has changed the way we live, work and play, and altered our notions of democracy, education, healthcare, entertainment and commerce. In terms of its design, the Internet has shown a remarkable ability to adapt to, even inspire, changes in technologies and applications. In short, the Internet has been a powerful engine for technological innovation and societal evolution.

However, this is no time to rest on the successes of the past. To meet society's future requirements and expectations, networks in general, and the Internet in particular, will need to be better: more secure, more accessible, more predictable, and more reliable.

In 2008, the Computing Community Consortium (CCC) charged the Network Science and Engineering (NetSE) Council with developing a comprehensive research agenda that would support the development of better networks. The NetSE Council was to consider previous reports such as those produced by the Global Environment for Network Innovation (GENI) Science Council, as well as encourage new interdisciplinary participation. Over the summer and fall of 2008, the NetSE Council held a number of disciplinary and interdisciplinary workshops that, together with several GENI and pre-GENI workshops and documents, resulted in the network science and engineering research agenda detailed in this report. The NetSE-sponsored interdisciplinary workshops were structured to bring participants from closely related fields together with networking researchers to explore problems and opportunities in the intersection. The diversity of backgrounds of the workshop participants highlights the breadth of the intellectual space.

# Major special initiatives

- Transition Team white papers
- Library of Congress Symposium
- Computing Innovation Fellows project
- Landmark Contributions by Students
- NetSE Research Agenda
- Health IT

The screenshot shows the website for the Computing Community Consortium (CCC). The header includes the CCC logo and the text "Computing Community Consortium" with the tagline "We support the computing research community in creating compelling research visions and the mechanisms to realize these visions." Below the header is a navigation menu with links for HOME, YOUR VISION, PLANS, ACTIVITIES, RESOURCES, ABOUT, and CRA, followed by a search bar with a "GO" button. The main content area is titled "Discovery and Innovation in Health IT" and contains the following text:

This invitation only workshop, "Discovery and Innovation in Health IT," is sponsored by the National Science Foundation, the Office of the National Coordinator for Health Information Technology, the National Institute of Standards and Technology, the National Library of Medicine, the Agency for Healthcare Research and Quality, the Computing Community Consortium, and the American Medical Informatics Association. It will be held at the Parc 55 Hotel in San Francisco on October 29 and 30, 2009.

**The talks and plenary discussions will be videotaped and a web presence will be developed to make the workshop material broadly available.**

The goals of the workshop are to:

- Explore and define fundamental research challenges and opportunities in healthcare IT in both the near- and long-term;
- Provide opportunities for relevant academic and industrial researchers, healthcare practitioners and IT healthcare suppliers to identify mutual interests in healthcare IT, as they relate to both near- and long-term challenges and solutions;
- Identify a range of "model" proof-of-concept, integrative systems that might serve as motivating and unifying forces to drive fundamental research in healthcare IT and accelerate the transition of research outcomes into products and services;

The workshop will have four half-day sessions. Each of the first three sessions will have two plenary talks followed by small-group breakout discussions to define particular research challenges, multiple lines of attack, and possible test-beds or demonstration systems. Each of these sessions, which are further described subsequently, will end with short reports from the

On the right side of the page, there is a yellow box with the text: "Content is still being added to this site. Please Check back periodically. The last change was made on: December 16, 2009." Below this is a section titled "Session Videos" featuring a video player for "HIT - Thursday Morning Op...". The video player shows a man speaking and has a play button overlay. Below the video player is a section titled "Reply/Registration" with a link to "Link to Reply/Registration Form" and a section titled "Logistics" with the date "Date: October 29-30, 2009".

# Current initiatives



- Computing research and health care
- Computing research and sustainability / energy / transportation
- From Data to Knowledge to Action:
  - Enabling Evidence-Based Healthcare
  - Enabling the New Biology
  - Enabling 21<sup>st</sup> Century Discovery in Science and Engineering
  - Enabling Advanced Intelligence and Decision Making for America's Security
  - Enabling a Revolution in Transportation
  - Enabling a Transformation of American Education
  - Enabling the Smart Grid

The next ten years ...



# Greatest Engineering Achievements OF THE 20<sup>TH</sup> CENTURY

◆ [About](#) ◆ [Timeline](#) ◆ [The Book](#)

## Welcome!

How many of the 20th century's greatest engineering achievements will you use today? A car? Computer? Telephone? Explore our list of the top 20 achievements and learn how engineering shaped a century and changed the world.

1. Electrification
2. Automobile
3. Airplane
4. Water Supply and Distribution
5. Electronics
6. Radio and Television
7. Agricultural Mechanization
8. Computers
9. Telephone
10. Air Conditioning and Refrigeration
11. Highways
12. Spacecraft
13. Internet
14. Imaging
15. Household Appliances
16. Health Technologies
17. Petroleum and Petrochemical Technologies
18. Laser and Fiber Optics
19. Nuclear Technologies
20. High-performance Materials







# GRAND CHALLENGES FOR ENGINEERING



Make solar energy economical



Provide energy from fusion



Develop carbon sequestration methods



Manage the nitrogen cycle



Provide access to clean water



Restore and improve urban infrastructure



Advance health informatics



Engineer better medicines



Reverse-engineer the brain



Prevent nuclear terror



Secure cyberspace



Enhance virtual reality



Advance personalized learning



Engineer the tools of scientific discovery

|            |       |            |           |
|------------|-------|------------|-----------|
| CHALLENGES | IDEAS | NEXT STEPS | COMMITTEE |
|------------|-------|------------|-----------|



Make solar energy economical



Provide energy from fusion



Develop carbon sequestration methods



Manage the nitrogen cycle



Provide access to clean water



Restore and improve urban infrastructure



Advance health informatics



Engineer better medicines



Reverse-engineer the brain



Prevent nuclear terror



Secure cyberspace



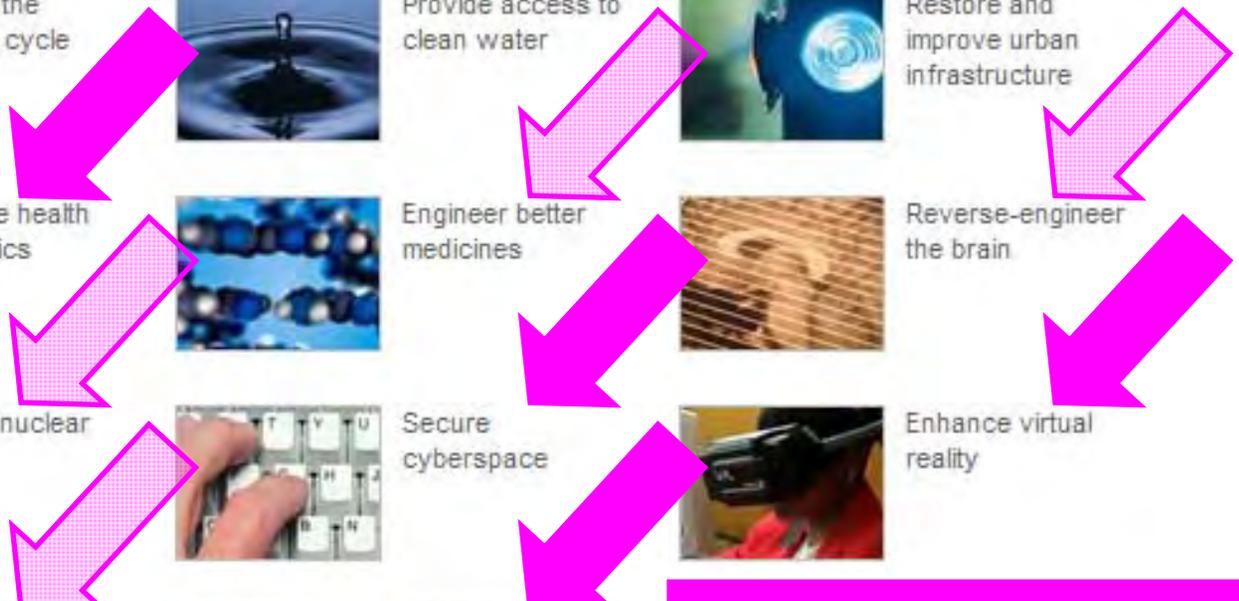
Enhance virtual reality



Advance personalized learning



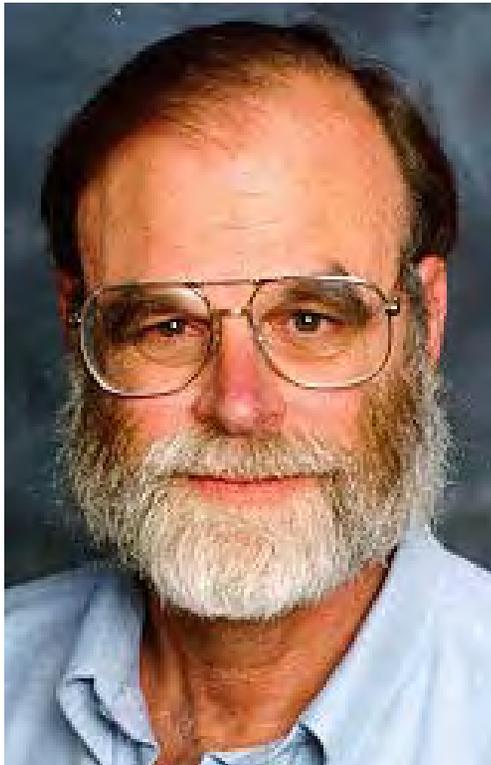
Engineer the tools of scientific discovery



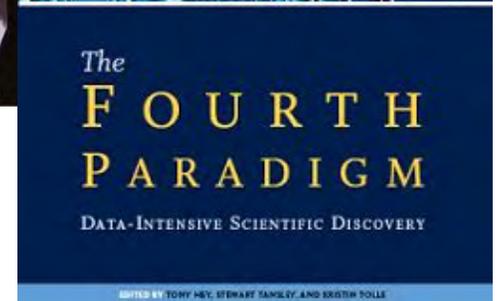
Predominant CS component

Significant CS component

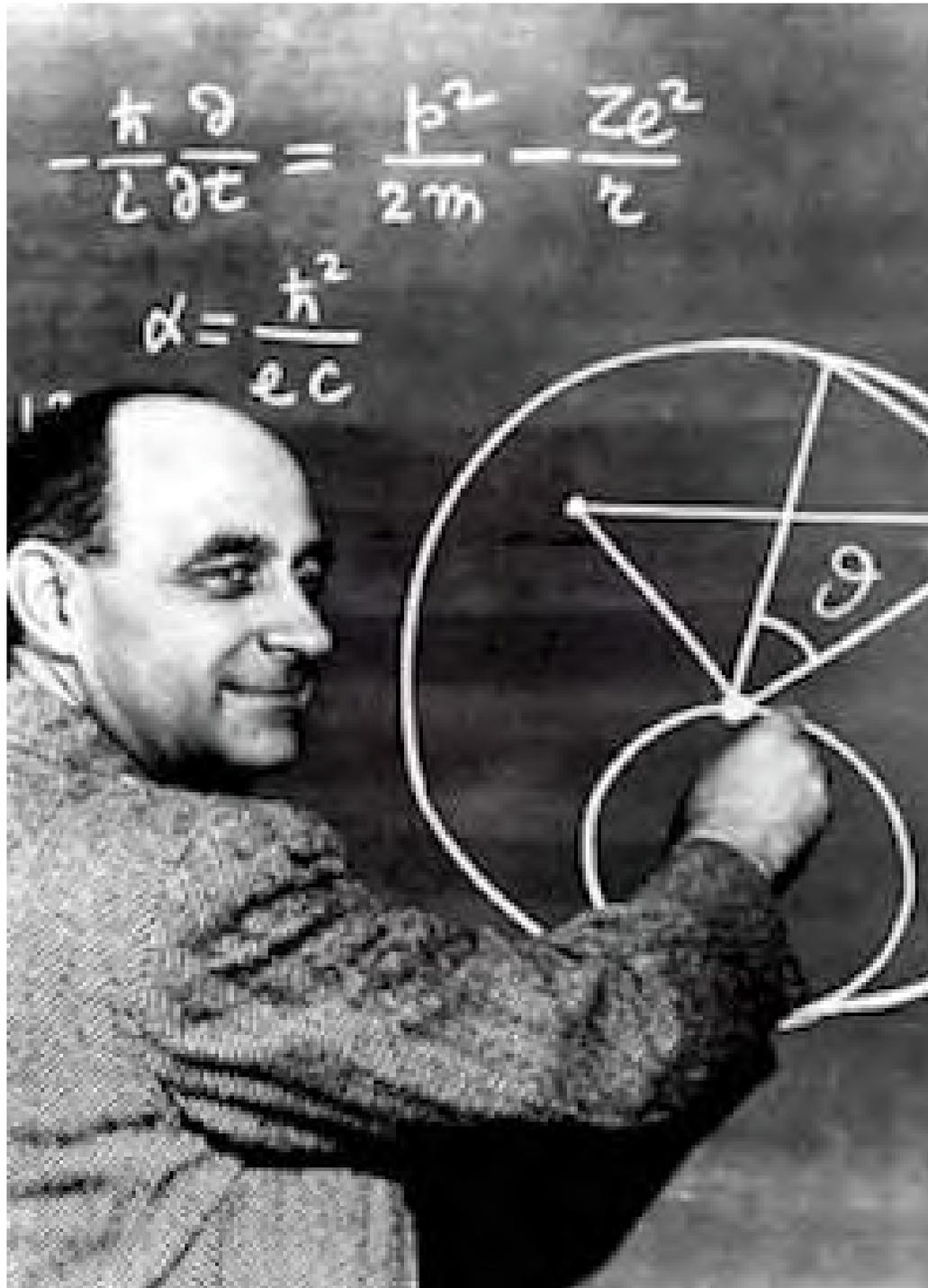
# eScience: Sensor-driven (data-driven) science and engineering



Jim Gray



Transforming science (again!)



Theory  
Experiment  
Observation



Theory  
Experiment  
Observation

Theory  
Experiment  
Observation



[John Delaney, University of Washington]



Theory  
Experiment  
Observation  
**Computational  
Science**



Theory  
Experiment  
Observation  
Computational  
Science  
**eScience**



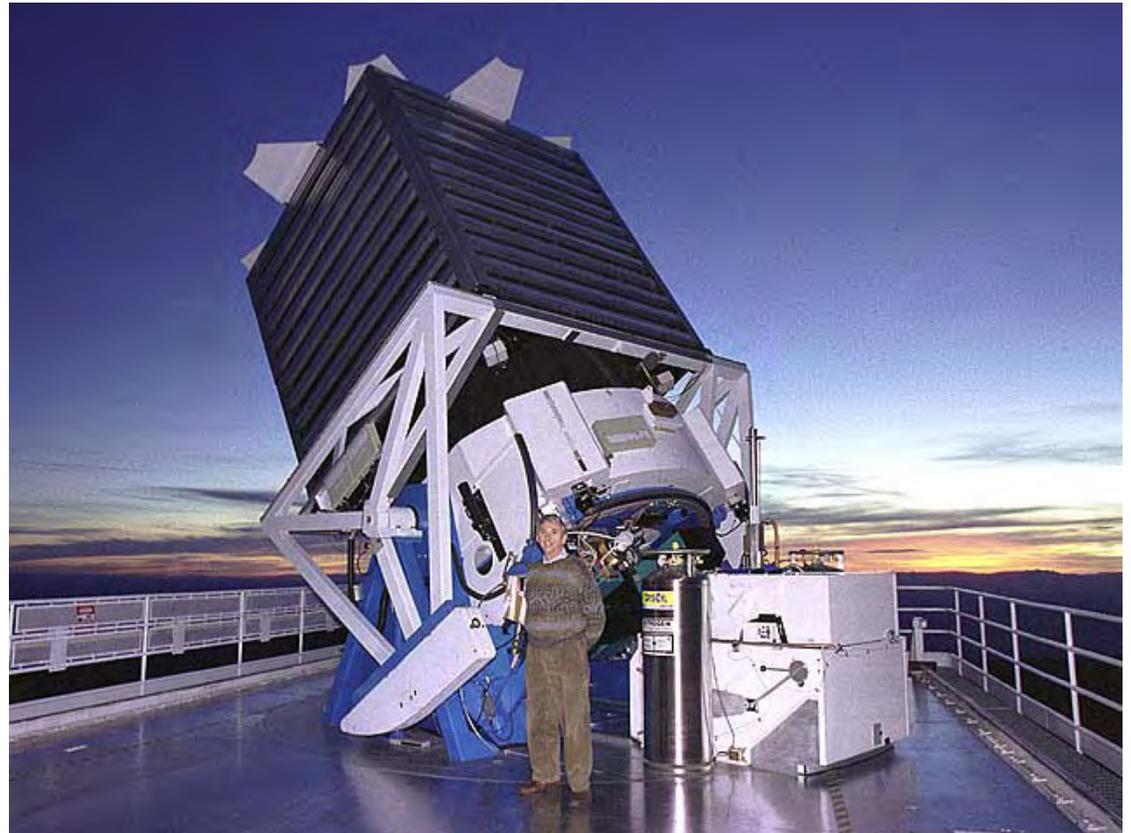
SLOAN DIGITAL SKY SURVEY

# eScience is driven by *data* more than by cycles

- Massive volumes of data from sensors and networks of sensors

**Apache Point telescope,  
SDSS**

**80TB of raw image data  
(80,000,000,000,000 bytes)  
over a 7 year period**

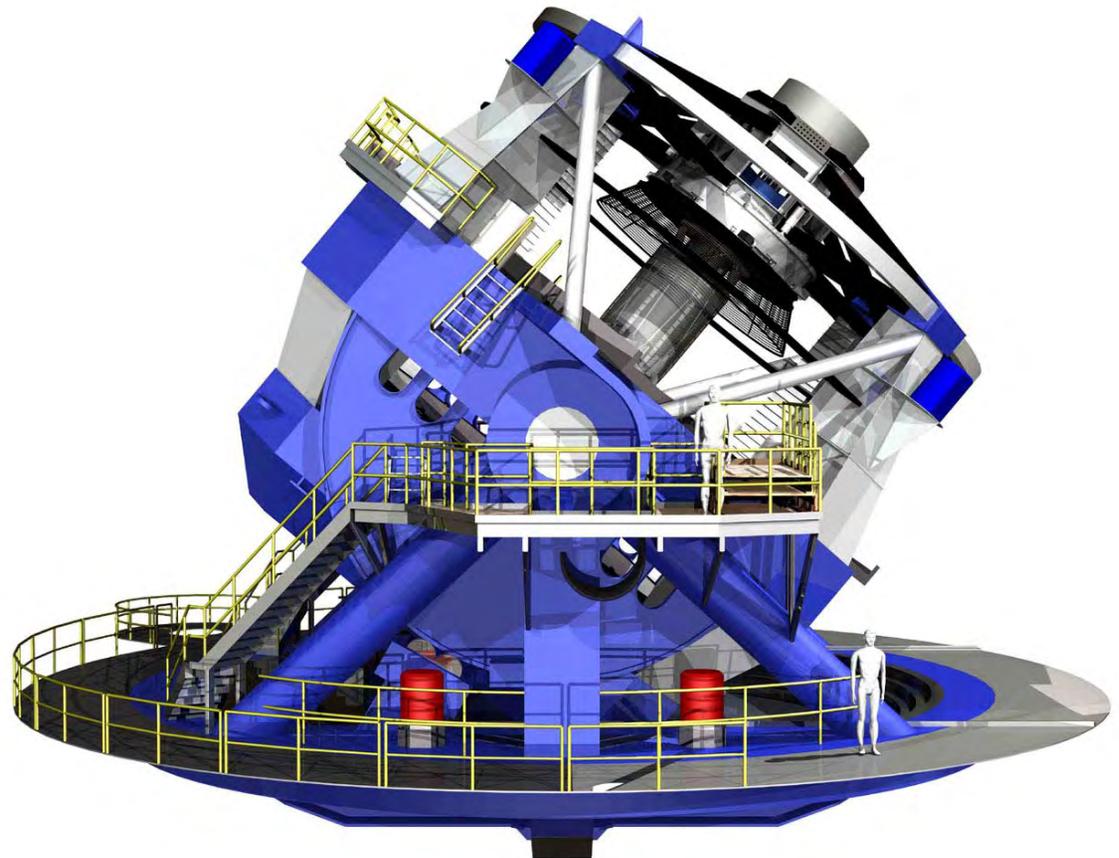




**Large Synoptic Survey  
Telescope (LSST)**

**40TB/day  
(an SDSS every two days),  
100+PB in its 10-year  
lifetime**

**400mbps sustained data  
rate between  
Chile and NCSA**





**Large Hadron Collider**

**700MB of data  
per second,  
60TB/day, 20PB/year**



**Illumina  
HiSeq 2000  
Sequencer  
~1TB/day**

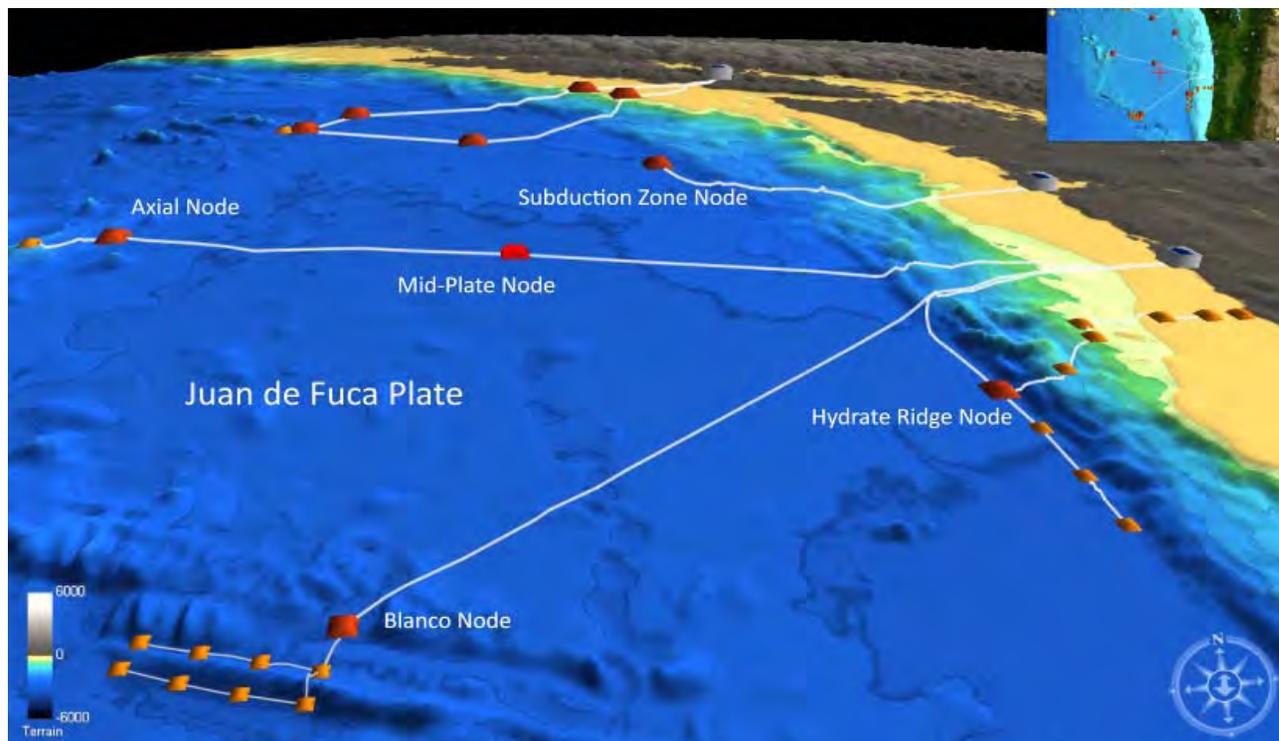


**Major labs  
have 25-100  
of these  
machines**



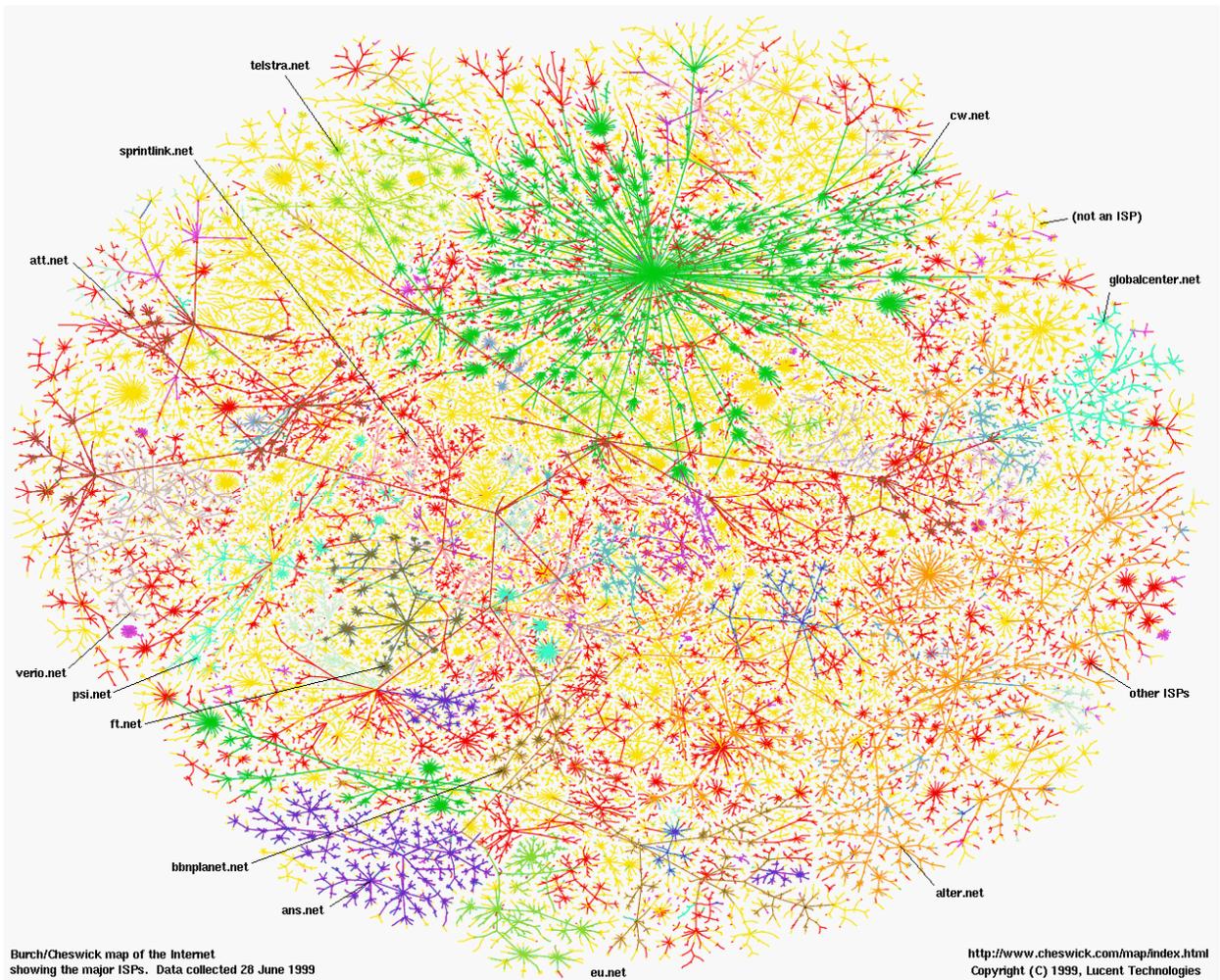
**Regional Scale  
Nodes of the NSF  
Ocean Observatories  
Initiative**

**1000 km of fiber  
optic cable on the  
seafloor, connecting  
thousands of  
chemical, physical,  
and biological  
sensors**





**The Web**  
**20+ billion web pages**  
**x 20KB = 400+TB**  
**One computer can**  
**read 30-35 MB/sec**  
**from disk => 4 months**  
**just to read the web**





**Point-of-sale terminals**

# eScience is about the *analysis* of data



- The automated or semi-automated extraction of knowledge from massive volumes of data
  - There's simply too much of it to look at
- It's not just a matter of volume
  - Volume
  - Rate
  - Complexity / dimensionality

# eScience utilizes a spectrum of computer science techniques and technologies

- Sensors and sensor networks
- Backbone networks
- Databases
- Data mining
- Machine learning
- Data visualization
- Cluster computing at enormous scale

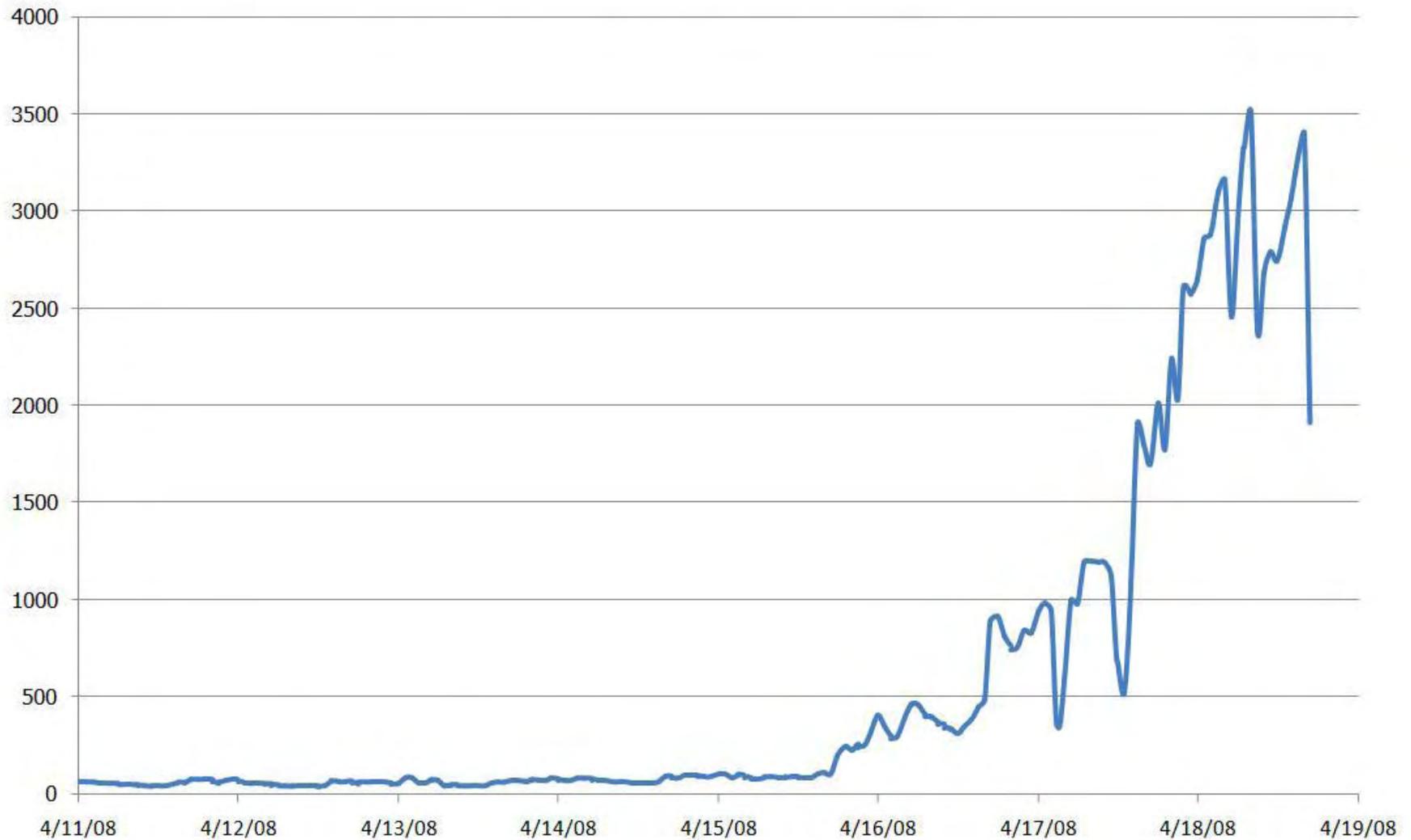


# eScience is married to the cloud: Scalable computing and storage for everyone

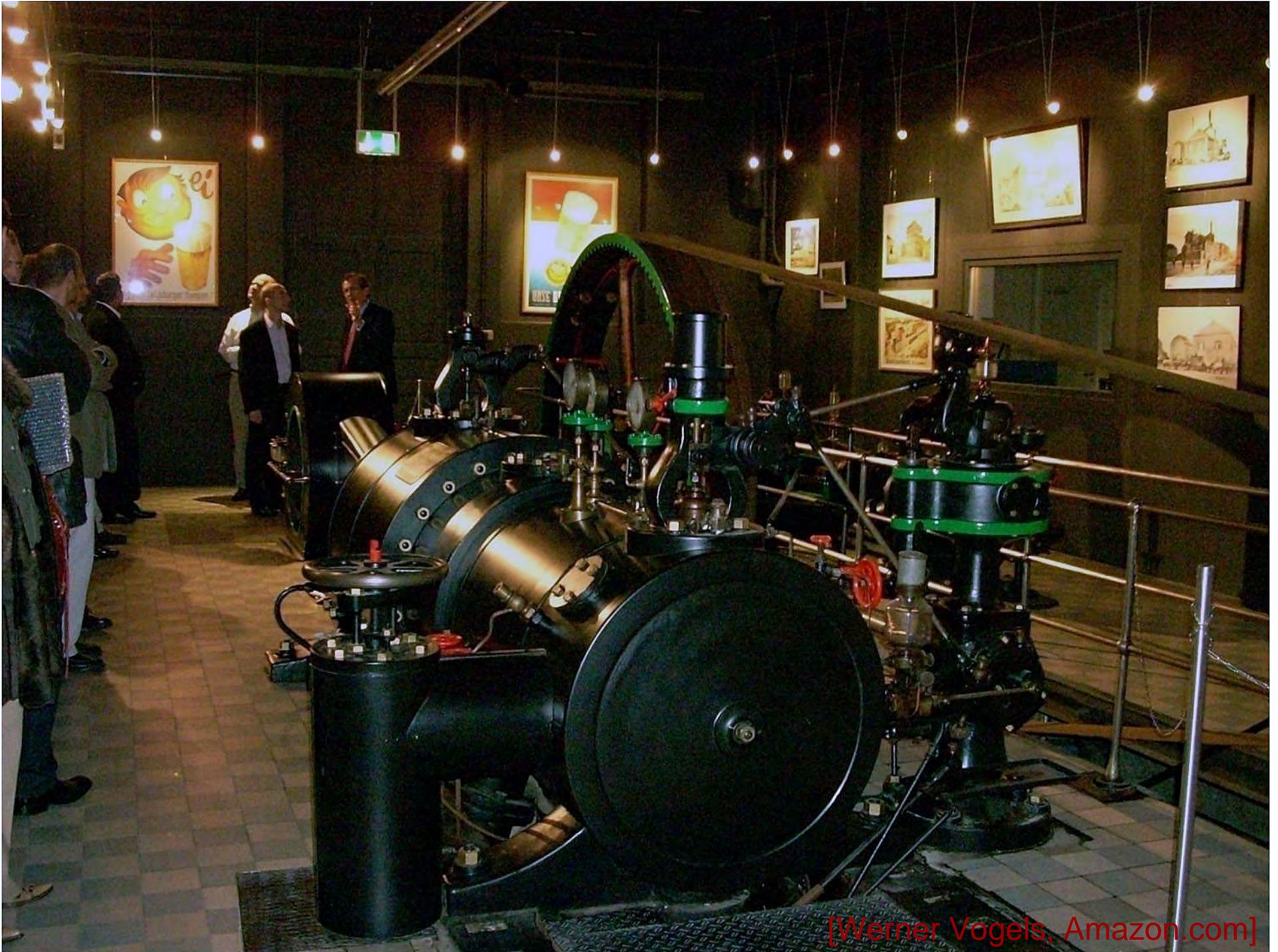
The collage features three overlapping elements:

- BusinessWeek Magazine:** The top-left corner shows the magazine cover with the title "BusinessWeek" in large white letters on a red background. Below it, the text "NEXT Imagine what you" is visible. Further down, there are two article teasers: "MEXICO: THE UGLY SIDE OF MICRO-LOANS 038" and "CENTRAL BANKERS TO THE RESCUE 025". At the bottom left, there is a barcode and the price "\$4.99US \$6.99CAN".
- Google App Engine:** The middle-left portion shows the Google App Engine website. It features the Google logo with the word "Code" underneath. A search bar contains the text "e.g. 'templates' or 'datastore'". Below the search bar, there are navigation links: "Home", "Docs", "FAQ", "Articles", "Blog", "Community", "Terms", and "Download". The main heading is "Google App Engine" with a rocket icon. Below this, there is a section titled "An Early Look at J" with a sub-heading "App Engine is unveiling its se" and a paragraph of text. A small video player shows a man speaking.
- Amazon Web Services:** The right and bottom-right portions show the AWS website. The top navigation bar includes "Home", "About", "Solutions", "Services", "Resources", "Community", and "Sign In". The main heading is "amazon web services". Below this, there is a section titled "Hadoop + The AWS Cloud" with a sub-heading "Introducing Amazon Elastic MapReduce— the Hadoop-based infrastructure service that lets you build and deploy large-scale data processing applications in the cloud." Below this, there is a "Get Started" section with a "Sign Up Now" button. The bottom section is titled "Explore Products" and lists various services: Amazon Elastic Compute Cloud (Amazon EC2), Amazon SimpleDB, Amazon Simple Storage Service (Amazon S3), Amazon CloudFront, Amazon Simple Queue Service (Amazon SQS), Amazon Elastic MapReduce, and AWS Premium Support. There is also a "News & Events" section with a table of recent news items.

# Animoto: EC2 Instance Usage



[Werner Vogels, Amazon.com]



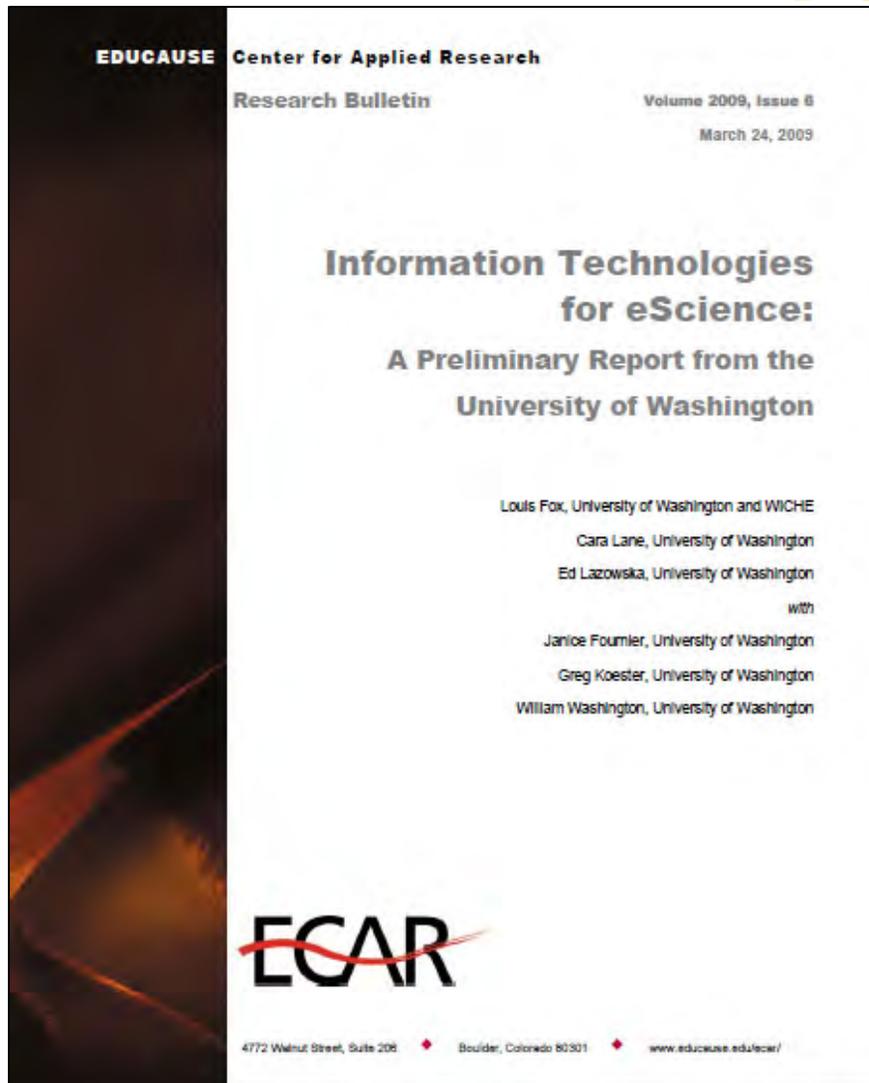
[Werner Vogels, Amazon.com]

# eScience will be pervasive

- Simulation-oriented computational science has been transformational, but it has been a niche
  - As an institution (e.g., a university), you didn't need to excel in order to be competitive
- eScience capabilities must be broadly available in any institution
  - If not, the institution will simply cease to be competitive



# Top scientists across all fields grasp the implications of the looming data tsunami



- Survey of 125 top investigators
  - "Data, data, data"
- Flat files and Excel are the most common data management tools
  - Great for Microsoft ... lousy for science!
- Typical science workflow:
  - 2 years ago: 1/2 day/week
  - Now: 1 FTE
  - In 2 years: 10 FTE
- Need tools, tools, tools!

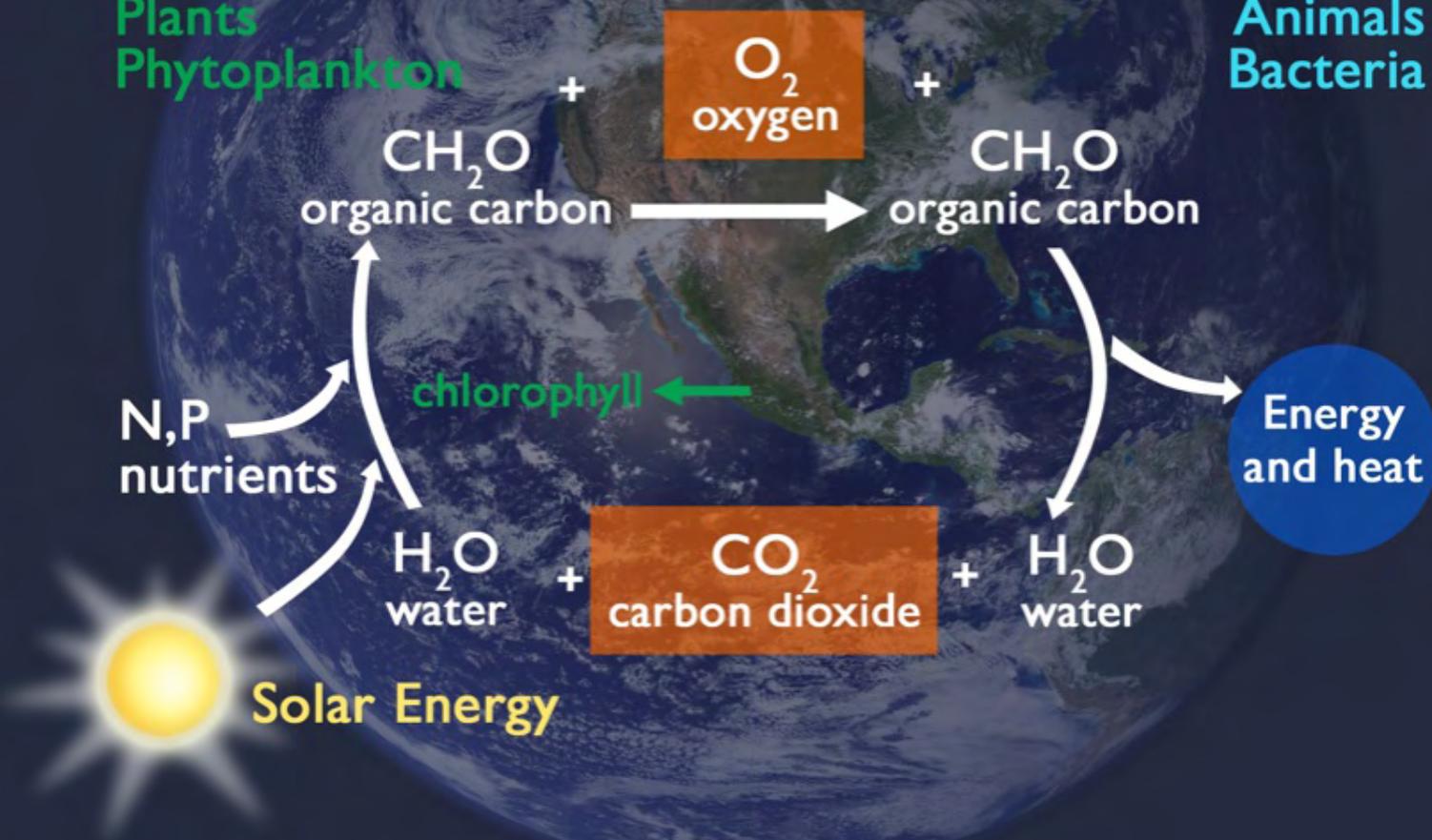
# Life on Planet Earth

## Photosynthesis

Plants  
Phytoplankton

## Respiration

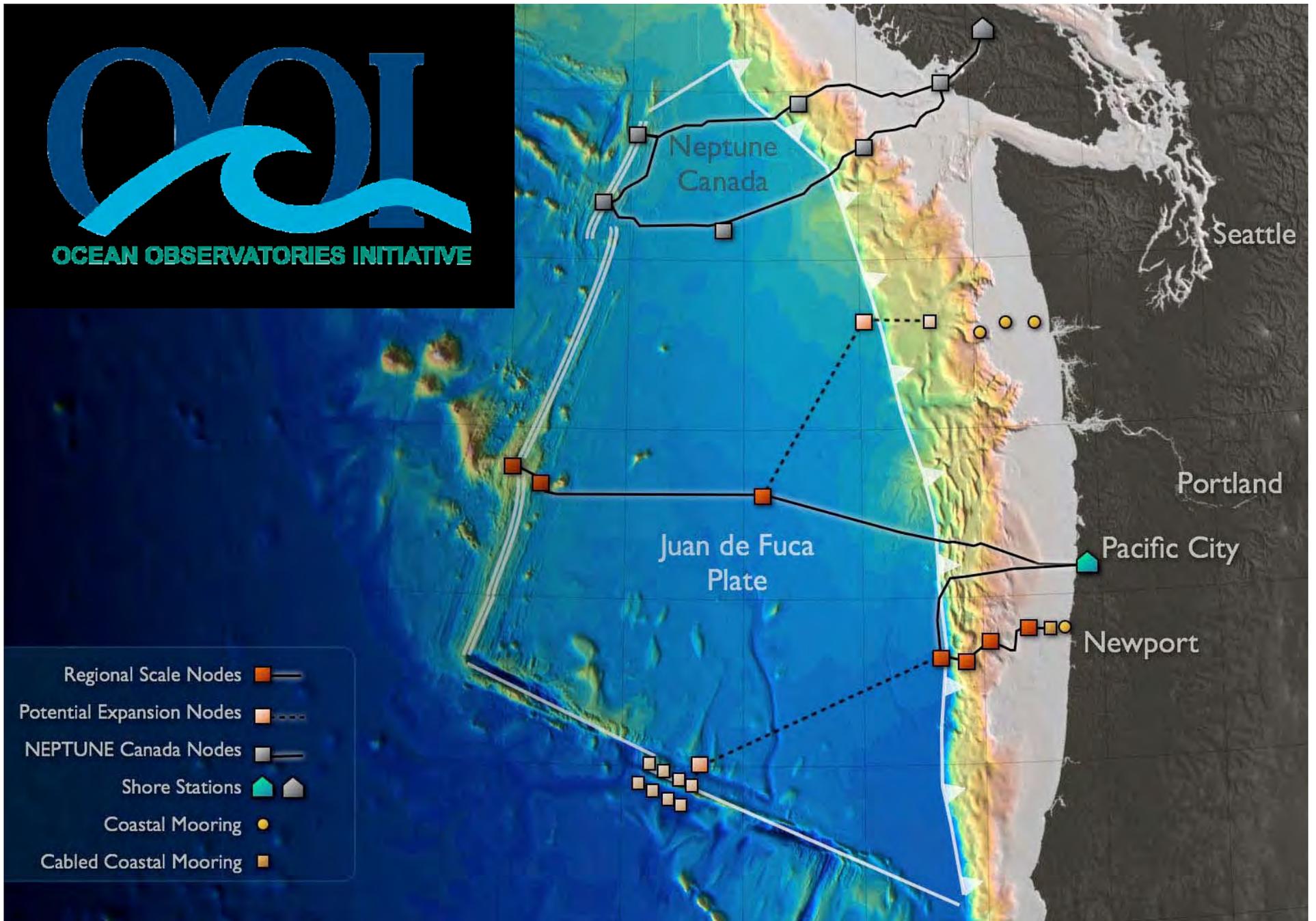
Animals  
Bacteria



[John Delaney, University of Washington]



[John Delaney, University of Washington]



[John Delaney, University of Washington]

# Human computation, and the wisdom of crowds



Luis von Ahn

Hours per year, world-wide, spent playing computer solitaire: 9 billion

Hours spent building the Panama Canal: 20 million (less than a day of solitaire)

The screenshot shows the Google Image Labeler interface. At the top, a timer indicates "Time left: 16". Below this, a box contains the word "Google" written in a stylized, handwritten font. A red-bordered box highlights the words "overlooks" and "inquiry" written in a similar font. Below the box, a yellow bar says "Type the two words:" followed by a red "S" button and a white "G" button. The main interface has a blue header with the "Google Image Labeler" logo and the text "Google Image Labeler". On the left, a "time left" section shows "01:52", a "score" section shows "0", and a "passes" section shows "0". In the center, there is a text input field, a "label" button, and a "pass" button. Below the input field, it says "Your partner has suggested 3 labels." To the right, a list of "off-limits" labels includes "building", "hotel", "car", "cars", and "sky". At the bottom right, there is a "my labels" section. A small image of a building is shown in the center, with a "zoom out" button below it.



David Baker





# Rosetta@home

Protein Folding, Design, and Docking



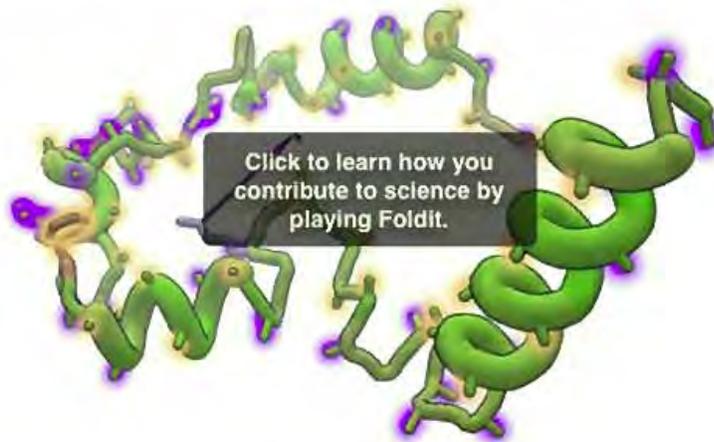
BOINC Application version 480 [workunit: ]

|  |  |  |  |
|--|--|--|--|
|  |  |  |  |
|  |  |  |  |

Accepted Energy

1.5% Complete  
CPU time: 0 hr 18 min 54 sec  
Jack Schonbrun - Total credit: 1000 - RAC: 500  
Baker Lab  
Rosetta@home v4.8 <http://boinc.bakerlab.org/rosetta/>

Stage: Ab initio  
Step: 9621  
Accepted RMSD: 11.12  
Accepted Energy: -29.31936



### What's New

### Small Update

We've posted a small update today, here's what's in it:

Some stability fixes, particularly with crashes when canceling recipes.

Improvements to scoring of sequence alignment. The scores of your existing alignments will change in the Sequence Alignment Tool due to this, but it won't affect your actual scores for the puzzles.

#### GET STARTED: DOWNLOAD



Win XP/Vista



Intel OS X 10.4 or later



Linux

#### RECOMMEND FOLDIT

Send

#### USER LOGIN

Username: \*

Password: \*

Log in

- [Create new account](#)
- [Request new password](#)

• [Sign in using Facebook](#)

[Connect with Facebook](#)



**fold it** BETA

Solve Puzzles  
for Science

20:48:49 GMT

[BLOG](#) [GROUPS](#) [PLAYERS](#) [PUZZLES](#)



## BootsMcGraw

Global Soloist Rank: #6

Global Soloist Score: 3784

[Cases](#)

### Profile

**Name:** BootsMcGraw

**Location:** Dallas, Texas USA

**Started Folding:** 12/06/08

**About me:** An educated redneck here, from Dallas, Texas.

When I was in grad school in 1985 at the State University of New York at Buffalo, my master's thesis was to construct and present a computer program that predicted the secondary structures (helix, sheet, loop) of proteins based on their amino acid sequences. Tertiary structure (i.e. folding) prediction was a pie-in-the-sky fantasy.

Imagine my delight, a quarter century later, to find out that not only are people determining tertiary structures of proteins, but they've made a "game" of it.

**Hobbies:** Licensed Massage Therapist; also a photographer, videographer, and webmaster. I have studied health and nutrition for over twenty years. Ask me my opinions about the subject.

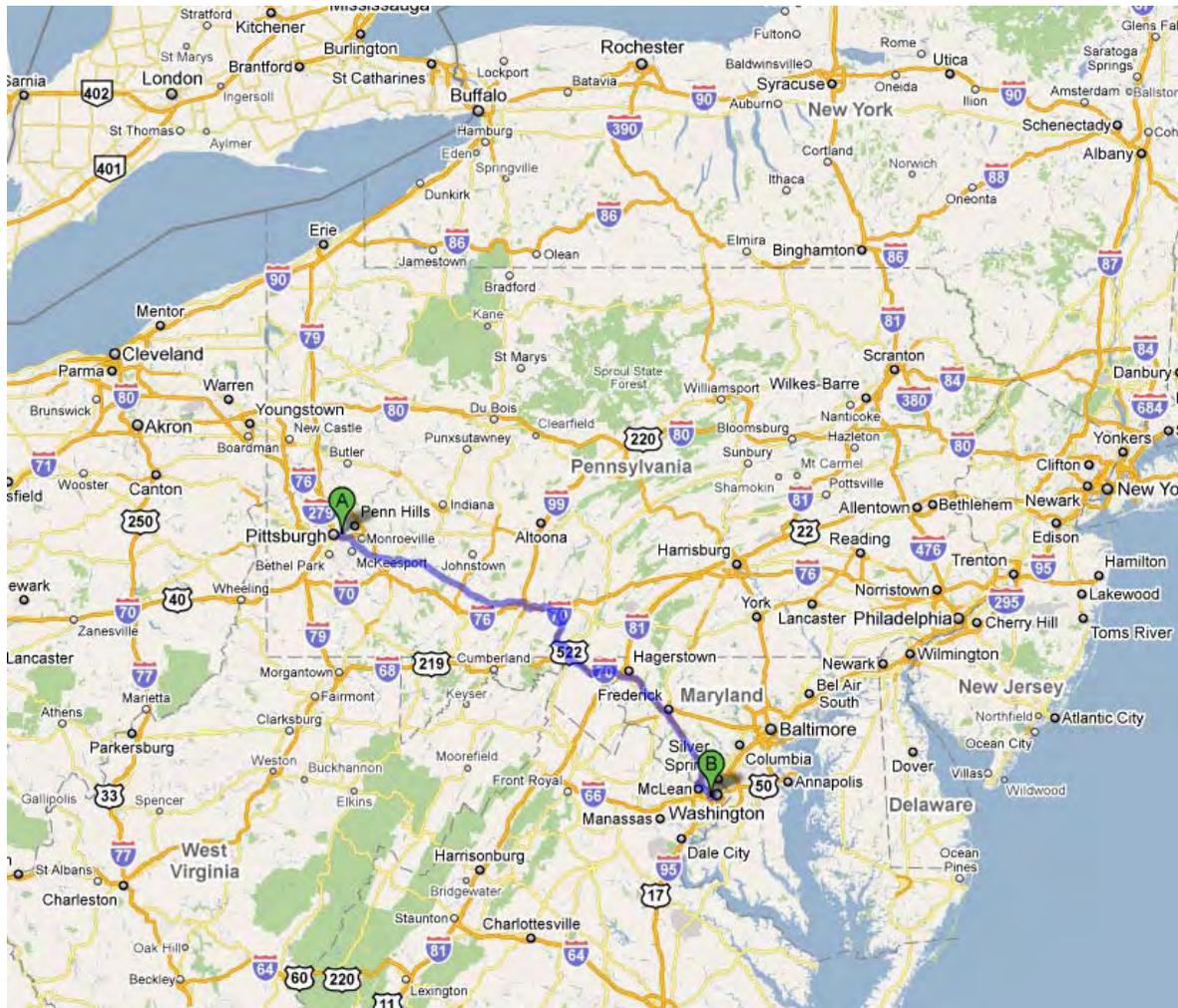
**Group:** [Contenders](#)



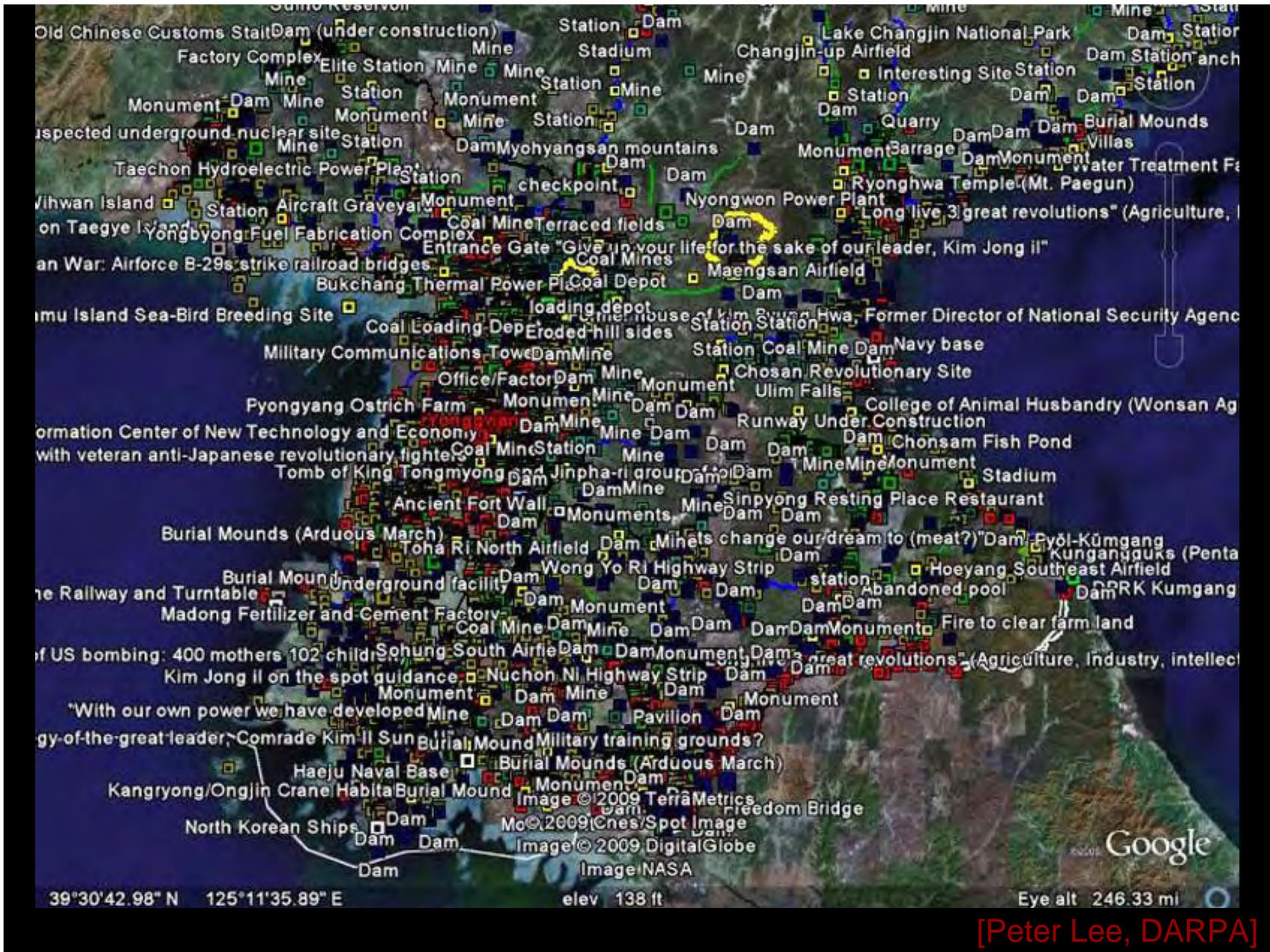
Regina Dugan



Peter Lee



[Peter Lee, DARPA]



[Peter Lee, DARPA]

# DARPA NETWORK CHALLENGE



40<sup>th</sup> Anniversary of the Internet

29 Oct – Announced  
5 Dec – Balloons Up

**\$40k Prize**



4367 registrants  
39 countries  
922 submissions  
370 correct locations

[Peter Lee, DARPA]

# Revolutionizing transportation





← Lane departure warning

**Stay on track.**

**Lane Departure Warning on the BMW 5 Series Sedan.**

The optional Lane Departure Warning gently vibrates the steering wheel just before you veer away from your lane - and only then. A camera mounted between the rear-view mirror and the windscreen "sees" the markings on the road ahead. Lane Departure Warning is deactivated when the indicator is used, so that you are not distracted by false signals.



← Adaptive cruise control



← Self-parking

## ■ In 2004, in just the United States:

- 6,181,000 police-reported traffic accidents
  - | 42,636 people killed
  - | 2,788,000 people injured
  - | 4,281,000 had property damage only
- ~ \$250 billion (that's *one quarter of a trillion dollars ...*) in annual economic cost
  - | 100 times greater than even an extravagant estimate of the nation's annual investment in computing research



### ENDNOTES

- 1 Availability of E 350 BlueTEC and 4MATIC models is delayed. See dealer for details.
- 2 DISTRONIC PLUS adaptive cruise control is no substitute for active driving involvement. It does not react to stationary objects, nor recognize or predict the curvature and lane layout of the road or the movement of vehicles ahead. It is the driver's responsibility at all times to be attentive to traffic and road conditions, and to provide the steering, braking and other driving inputs necessary to retain control of the vehicle. Drivers are cautioned not to wait for the DISTRONIC Proximity Warning System before braking, as that may not afford sufficient time and distance to brake safely. After braking the car for stopped traffic ahead, system resumes automatically only if traffic pauses for less than 3 seconds.
- 3 Driving while drowsy or distracted is dangerous and should be avoided. ATTENTION ASSIST may be insufficient to alert a fatigued or distracted driver of lane drift and cannot be relied on to avoid an accident or serious injury.
- 4 PRE-SAFE® closes the side windows and sunroof when the system's sensors detect side movement that suggests a possible accident.

# But there's more at stake than safety ...



## ■ Energy and the environment

- Highway transportation uses 22% of all US energy

## ■ Efficiency and productivity

- Traffic congestion in the US is responsible for 3.6 billion vehicle hours of delay annually

## ■ Equity

- The elderly, and low-income individuals forced to the exurbs, are disadvantaged

## ■ The economic and environmental costs of manufacturing automobiles

# And computing research is central to the solutions

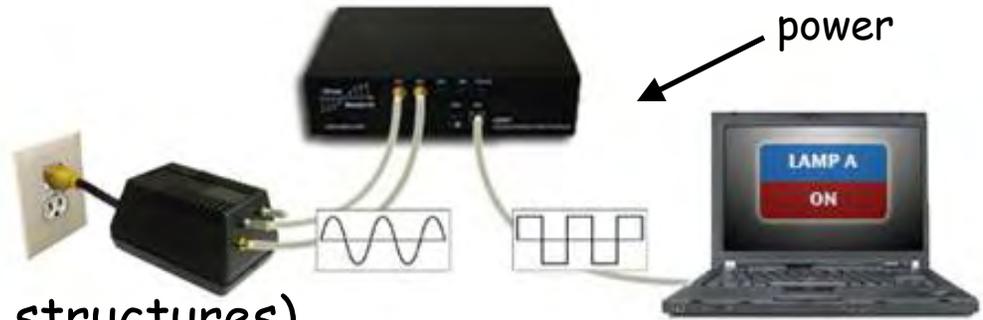
---

- Real-time sensor information for transit location
- Personalized, real-time information for choosing travel options
- Zipcar on steroids 
- Routing around congestion, for transit and personal vehicles
- Greater vehicle density through semi-automated control

# Transportation is one dimension of energy

## ■ The smart grid

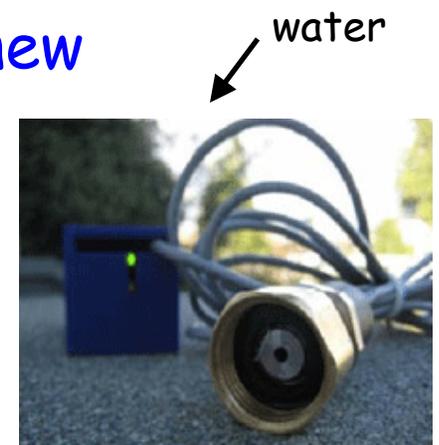
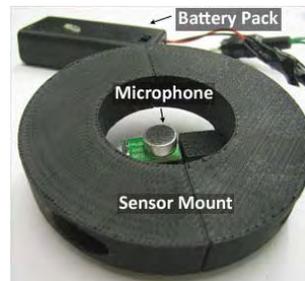
- Engineering
- Control
- Conservation (intelligent structures)



## ■ IT as a substitute for energy-intensive goods and services

## ■ IT as a tool for discovering and designing new energy sources

## ■ Improved energy efficiency in computation



[Shwetak Patel, UW]

# Health: Personalized health monitoring



Omron pedometer



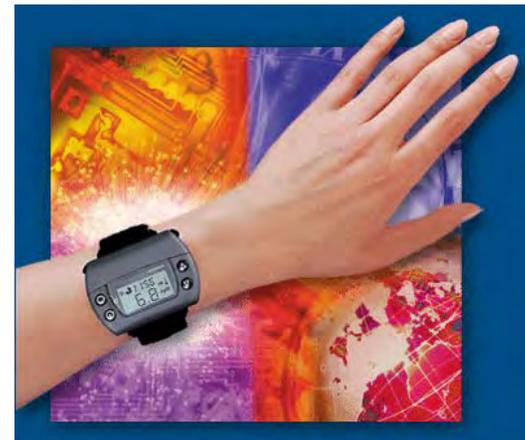
Nike + iPod



Bodymedia multi-function



Biozoom: body fat, hydration, blood oxygen, etc.



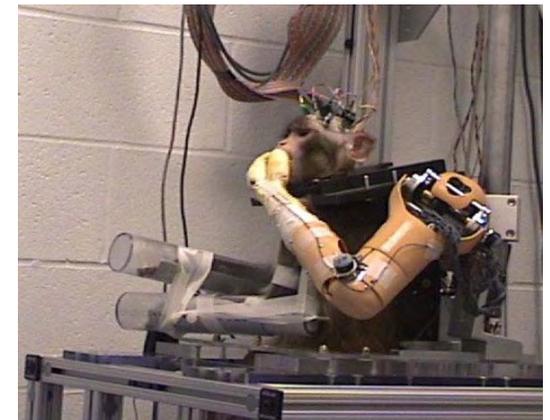
Glucowatch: measuring body chemistry

# Health: Evidence-based medicine

- Machine learning for clinical care
- Predictive models
- Cognitive assistance for physicians



# Health: Neurobotics



[Yoky Matsuoka and Raj Rao, UW]

# Health: P4 medicine



# ICTD: Empowering the developing world



***3 billion people in the rural developing world  
need the same information we do***

- ✓ Business: new opportunities
- ✓ Finance: capital to invest
- ✓ Government: services & programs
- ✓ Health: informed, consistent care
- ✓ Education: personal advancement



[Tapan Parikh, UW and UC Berkeley]

*3 billion people in the rural **developing world**  
have different limitations and capabilities*

- ✗ Money: to buy technology
- ✗ Education: to use technology
- ✗ Infrastructure: power, connectivity
- ✓ Time: lots of available labor
- ✓ Community: lots of relations



[Tapan Parikh, UW and UC Berkeley]

# CAM: Managing Information from the Grassroots

## ***Information systems are key to scaling microfinance***

- *Transaction processing*
- *Monitor members and groups*
- *Analyse performance and impact*
- *Offer more services*
- *Link to formal institutions*

## ***Can we design a UI to document member-level SHG transactions?***

- *Accurate and efficient*
- *Accessible to a variety of users*



[Tapan Parikh, UW and UC Berkeley]



[Tapan Parikh, UW and UC Berkeley]



# open-data-kit

Open Data Kit is a suite of tools to help organizations collect, aggregate and visualize their data.

[Project Home](#) [Downloads](#) [Wiki](#) [Issues](#) [Source](#)

[Summary](#) | [Updates](#) | [People](#)

## Welcome to ODK

Open Data Kit (ODK) is a suite of tools to help organizations collect, aggregate and visualize their data. Our goals are to make open-source and standards-based tools which are easy to try, easy to use, easy to modify and easy to scale. To this end, we are proud members of the [OpenMobile Consortium](#), the [OpenRosa Consortium](#), and active participants in the [JavaRosa](#) project.

Google maps  Search Maps [Show search options](#)

Find businesses, addresses and places of interest.

[Get Directions](#) [My Maps](#) [Save to My Maps](#) [RSS](#) [Print](#) [Send](#) [Link](#)

More... [Map](#) [Satellite](#) [Terrain](#)

### ODK Deployments

322 views - Public  
Created on Aug 21, 2009 - Updated Oct 20, 2009  
By ODK  
[Rate this map](#) - [Write a comment](#)

- [USAID-AMPATH \(Kenya\)](#)  
AMPATH is the largest HIV treatment program in
- [Grameen Foundation Application Laboratory \(Uganda\)](#)  
ODK Collect has been used by AppLab since November
- [DataDyne \(Kenya\)](#)  
DataDyne is active in over 20 countries in sub-Saharan
- [Human Rights Center at UC Berkeley \(Central African\)](#)  
The Human Rights Center investigates war crimes and
- [Wharton School of Business at University of](#)  
A team from UPenn's Wharton School of Business is
- [Information School and Haas School at UC Berkeley](#)  
Teams from University of California, Berkeley Information
- [Information School and Haas School at UC Berkeley](#)  
Teams from University of California, Berkeley Information
- [Information School and Haas School at UC Berkeley](#)  
Teams from University of California, Berkeley Information
- [Information School and Haas School at UC Berkeley](#)  
Teams from University of California, Berkeley Information
- [Vetaid \(Zanzibar\)](#)  
Vetaid supports animal health projects in Africa by
- [D-Tree \(Tanzania\)](#)  
D-Tree is putting the Integrated Management of
- [Frogtex \(Colombia\)](#)  
Frogtex is a social venture dedicated to creating
- [Brazilian Forest Service \(Brazil\)](#)  
The Brazilian Forest Service is piloting Open Data Kit for
- [Change at University of Washington \(Seattle\)](#)  
ODK's core developers are from the UW's Computer
- [Johns Hopkins Center for Clinical Global Health](#)  
eMOCHA is a free open-source application, developed
- [VillageReach \(Mozambique\)](#)  
VillageReach develops logistics and management

Antarctica

[Gaetano Borriello, UW]

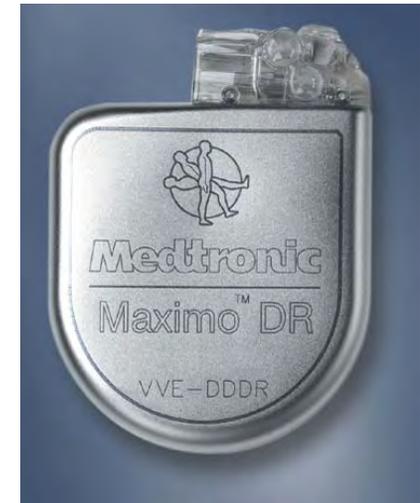
# Personalized education



Transforming American Education:  
**Learning**  
Powered by Technology

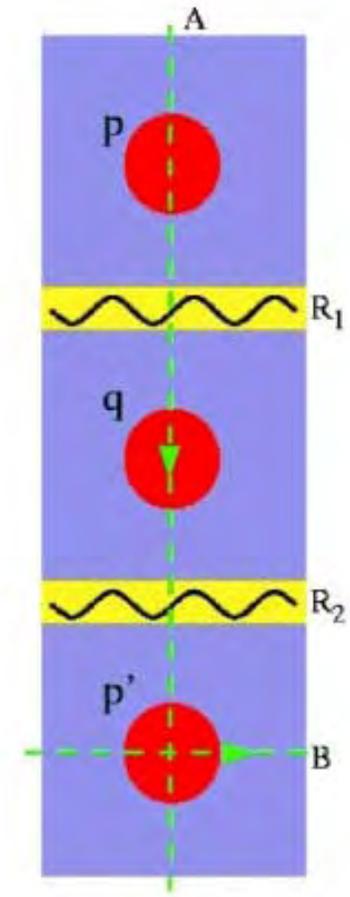
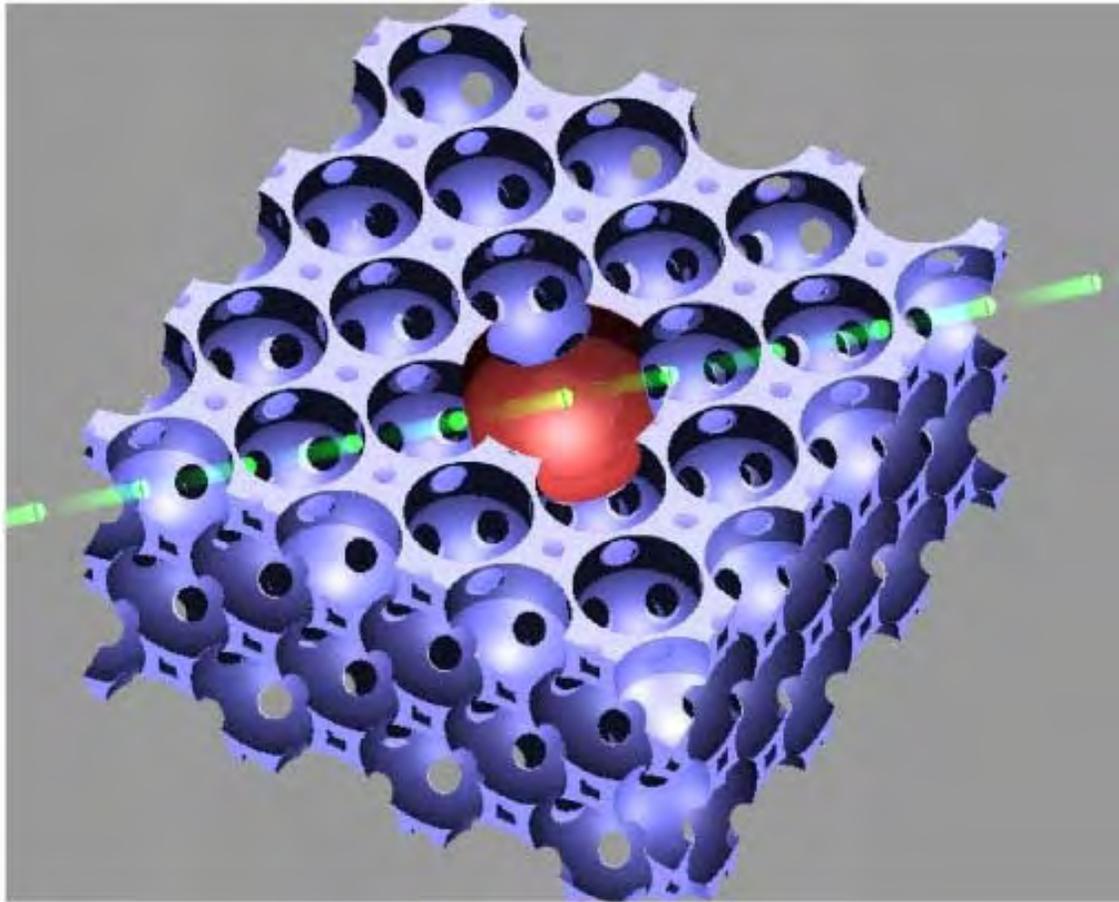
DRAFT  
National Educational Technology Plan 2010  
March 5, 2010  
Office of Educational Technology  
U.S. Department of Education

# Security and privacy

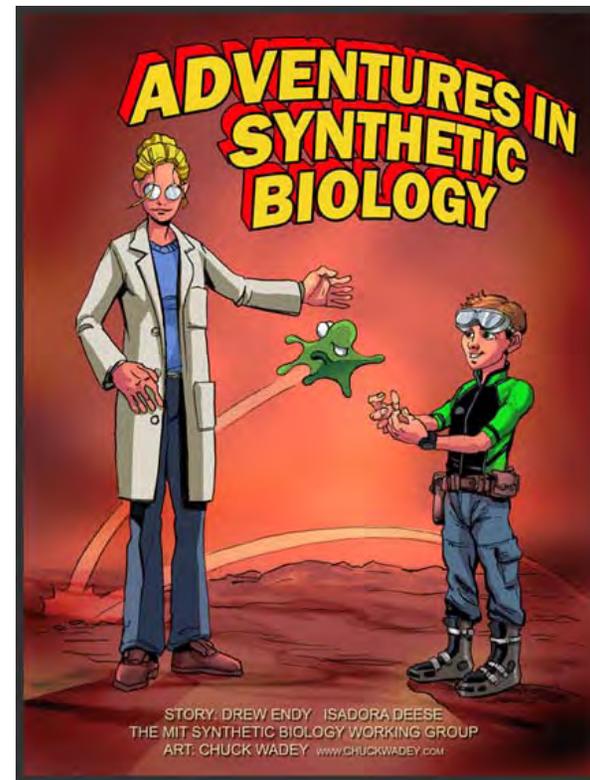
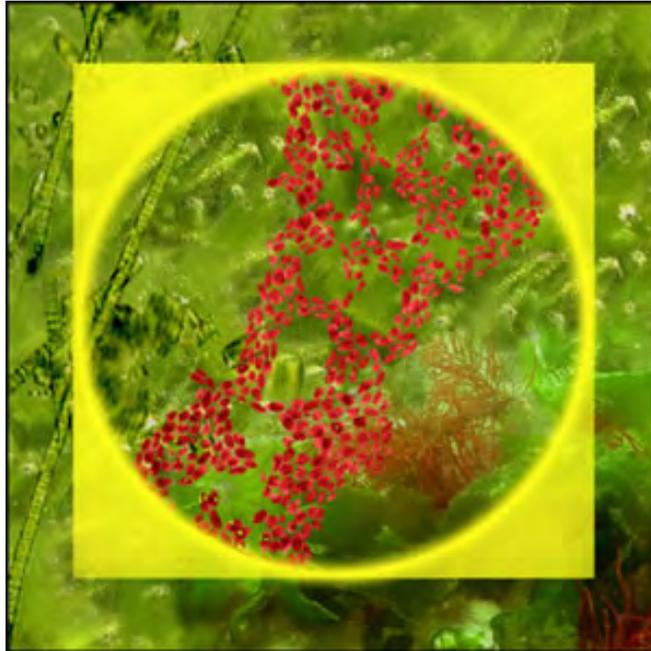


[Yoshi Kohno, UW]

# Quantum computing



# Synthetic biology / molecular engineering





### VIEWER Q&A >>

Get the truth on how the team really feels about the show.



### MUSIC MYTHS >>

Can that high note really shatter glass? Bust it now.

### JOIN THE MESSAGE BOARD

"Baby snakes do not have control of how much venom they use and will shoot it all into you while a full grown snake conserves their venom. Is this true?" -- jeredweaver56

### SUBMIT A MYTH >>

### BE A MYTHBUSTER >>

Debunk a few classic myths. Give this interactive a whirl.



**MYTHBUSTERS**  
WEDNESDAYS AT 9PM

An electric eel skin wallet can demagnetize credit cards.

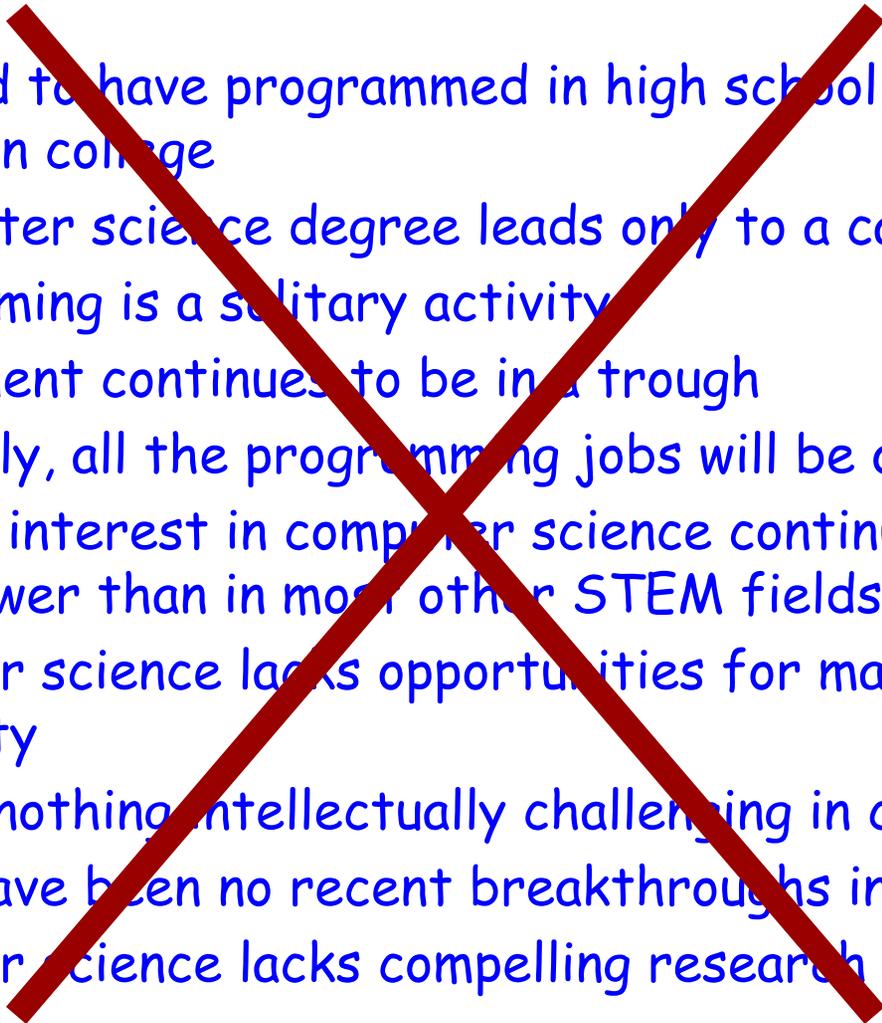
**BUSTED**

**VIDEO HIGHLIGHT >>**  
Big Rig Myths  
And See the Full Video Collection Now.

How's Your Brain Function? Watch Video and Take a Memory Exam.

# Dispel these myths!



- 
- You need to have programmed in high school to pursue computer science in college
  - A computer science degree leads only to a career as a programmer
  - Programming is a solitary activity
  - Employment continues to be in a trough
  - Eventually, all the programming jobs will be overseas
  - Student interest in computer science continues to be in a trough, and is lower than in most other STEM fields
  - Computer science lacks opportunities for making a positive impact on society
  - There's nothing intellectually challenging in computer science
  - There have been no recent breakthroughs in computer science
  - Computer science lacks compelling research visions

# We put the "smarts" in ...

- Smart homes
- Smart cars
- Smart bodies
- Smart robots
- Smart science (confronting the data tsunami)
- Smart crowds and human-computer systems
- Smart interaction (virtual and augmented reality)



# Is this a great time, or what?!?!



<http://lazowska.cs.washington.edu/oregon.pdf>

<http://www.cra.org/ccc/>

<http://www.cs.washington.edu/WhyCSE/>

