Computer Science:
Past, Present, and Future

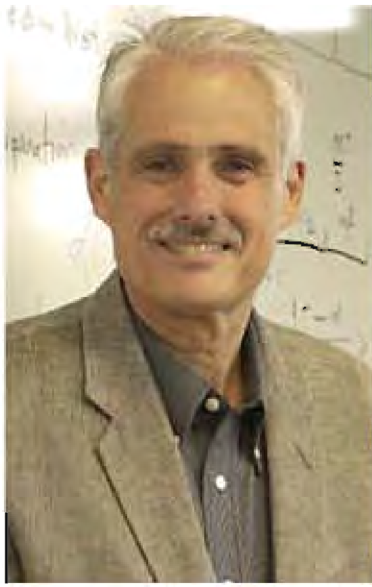
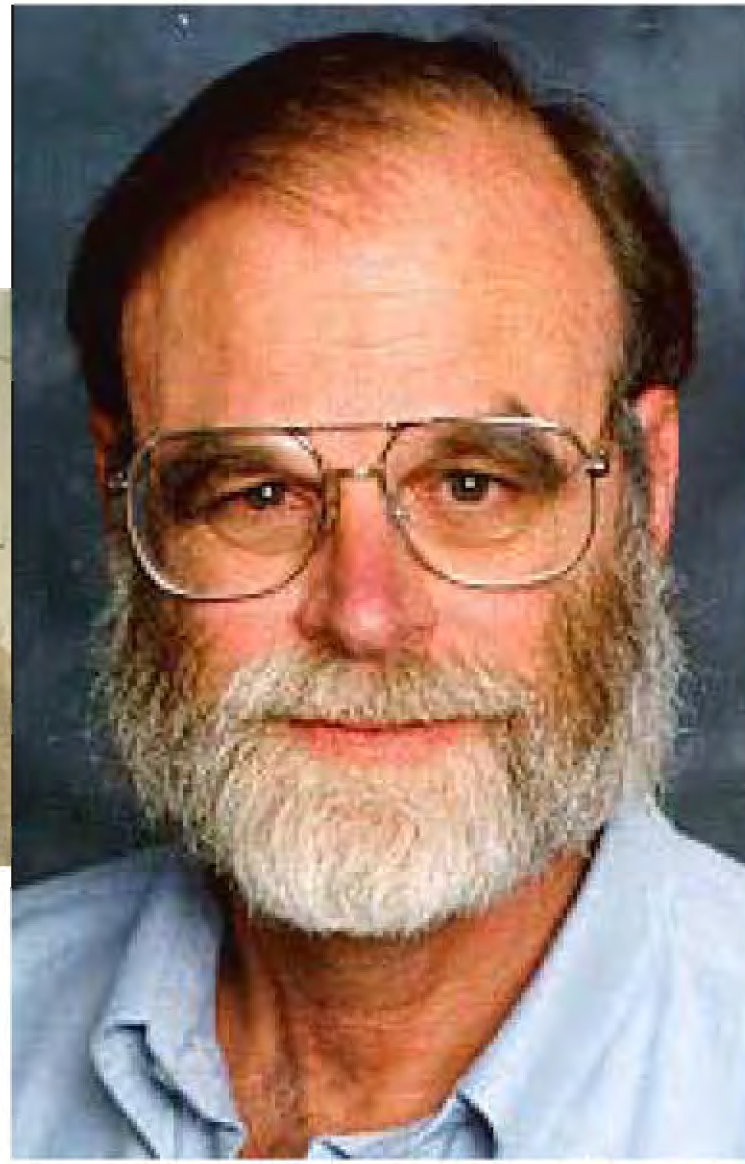
Ed Lazowska

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

Federated Computing Research Conference

June 2007

http://www.cra.org/ccc/fcrc/


Greatest Engineering Achievements OF THE 20TH CENTURY

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

Greatest Achievements

Greatest Engineering Achievements OF THE 20TH CENTURY

◆ About ◆ Timeline ◆ The Book

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Greatest Achievements

 Printer-Friendly Version. Text-Only Version. Contact Us.

10,000,000,000,000,000,000 grains of rice

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

10,000,000,000,000,000,000 transistors

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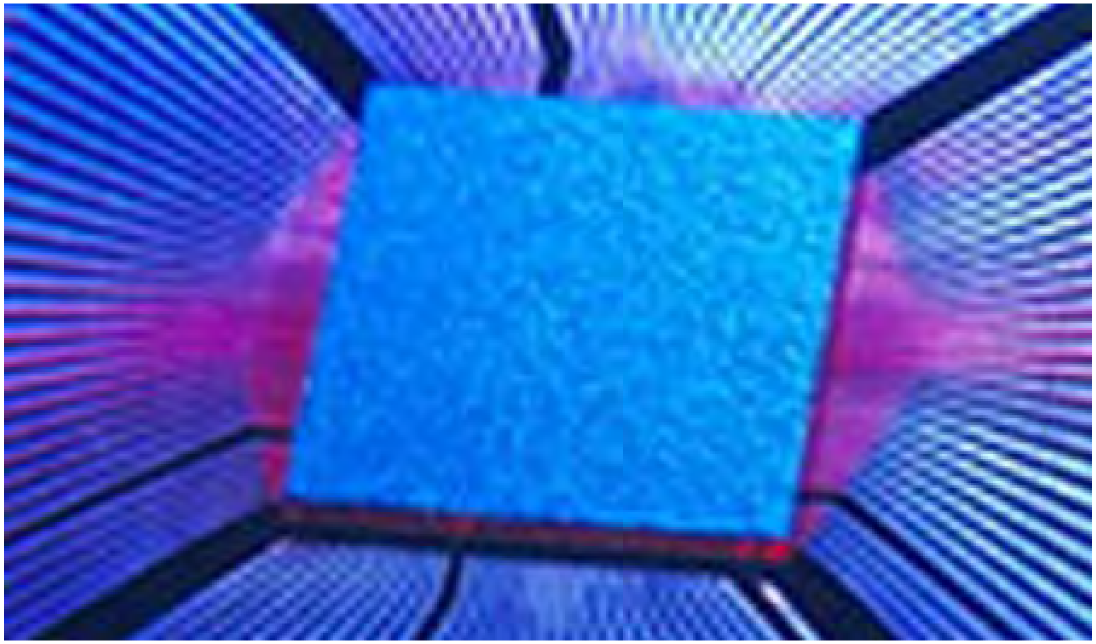
  - The number of transistors fabricated in 2004



The transistor

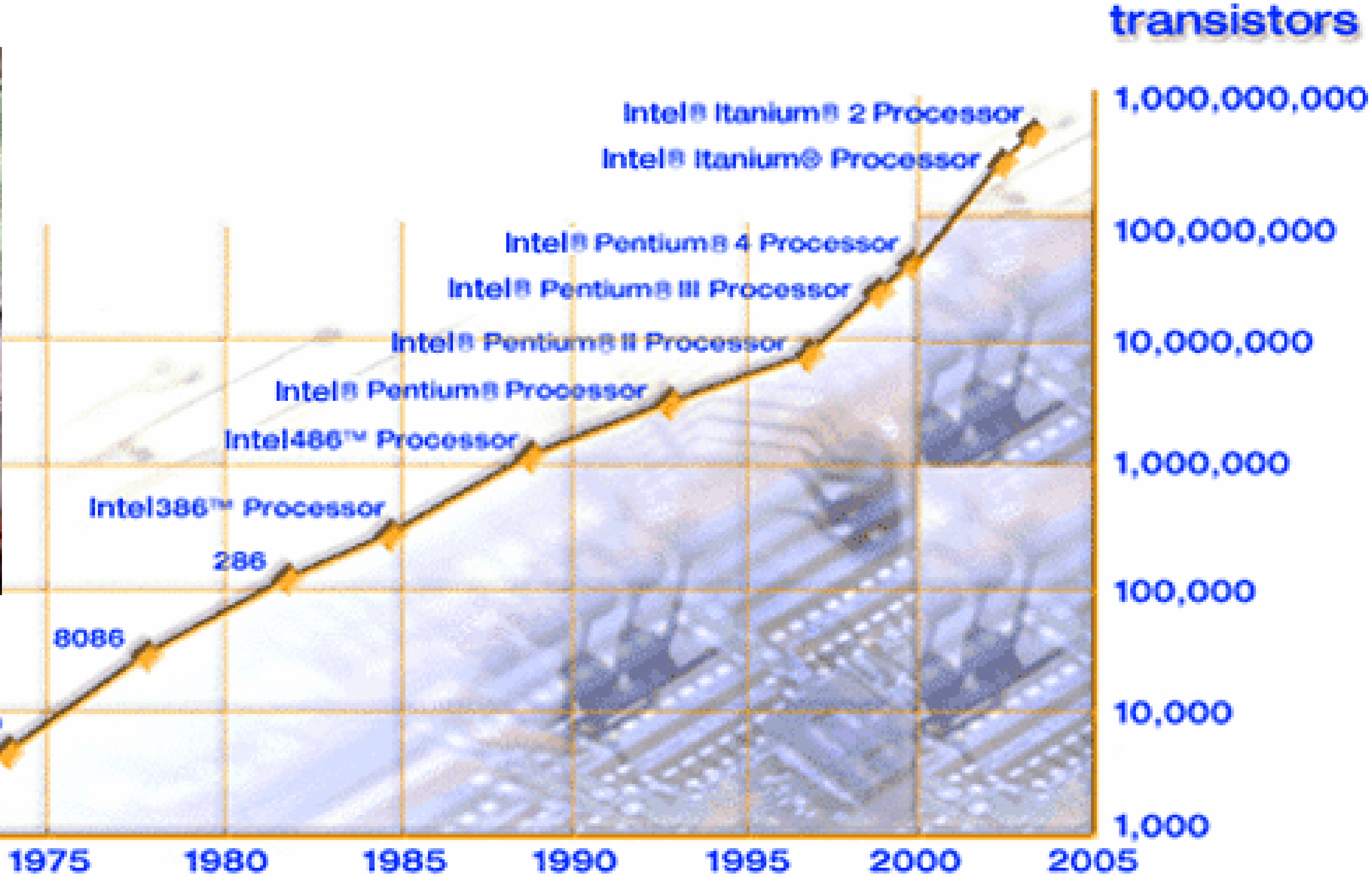
- William Shockley, Walter Brattain and John Bardeen, Bell Labs, 1947

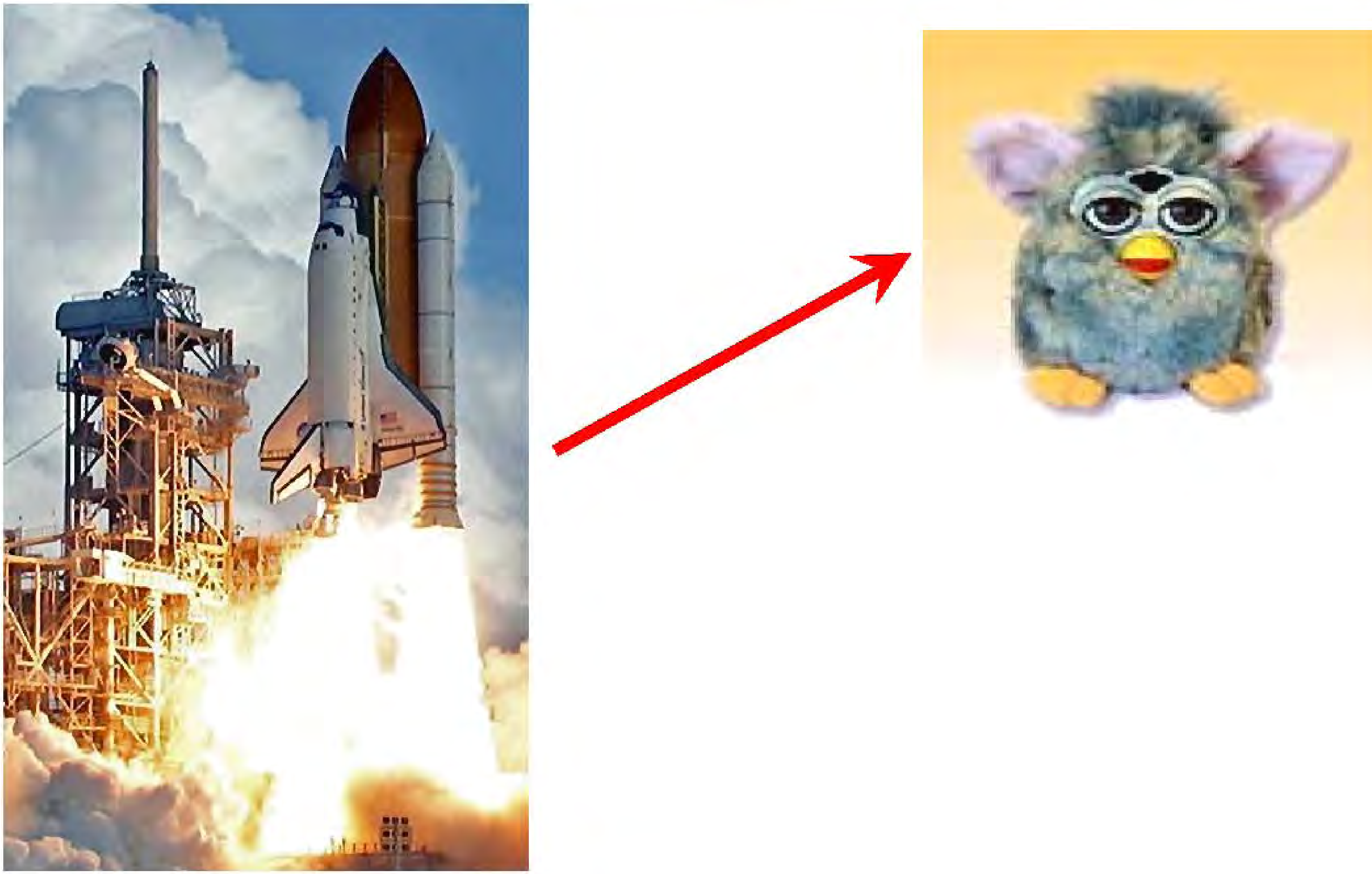
The integrated circuit

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

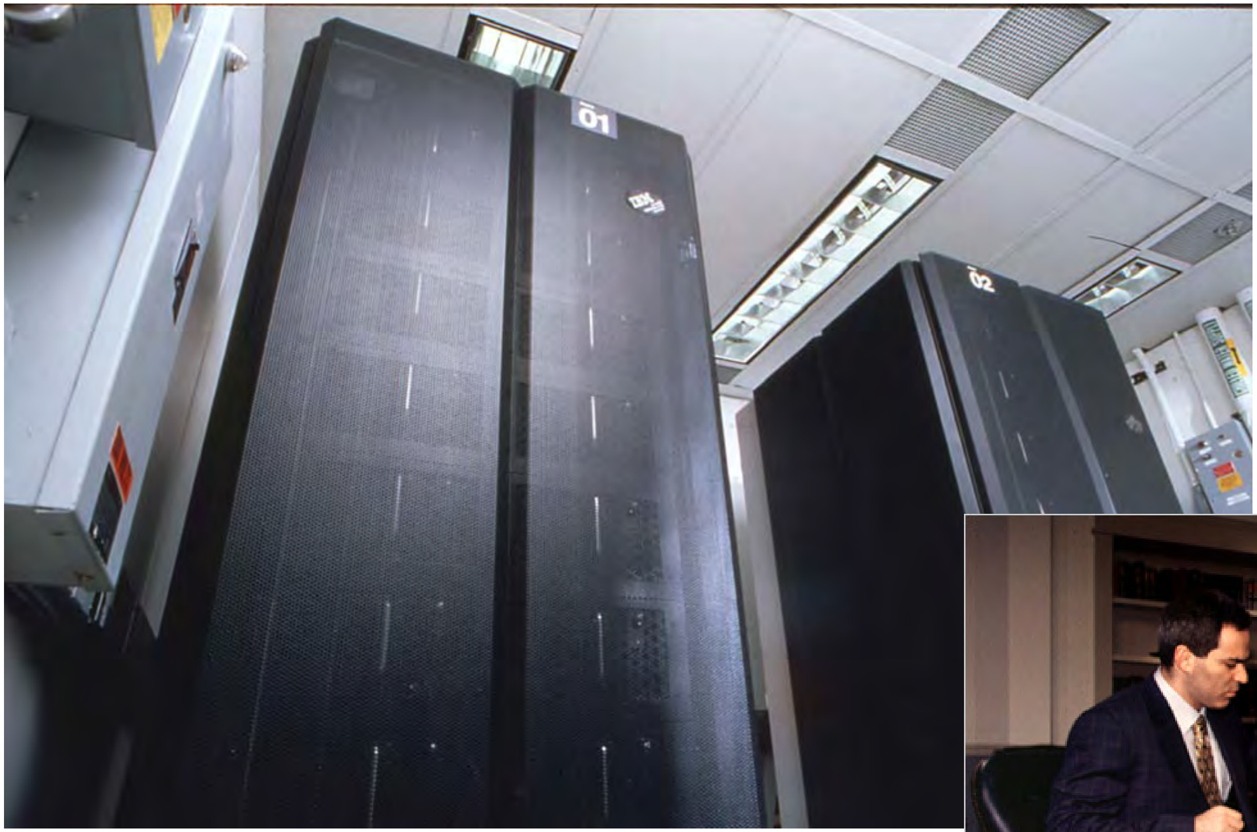
Exponential progress

- Gordon Moore, 1965

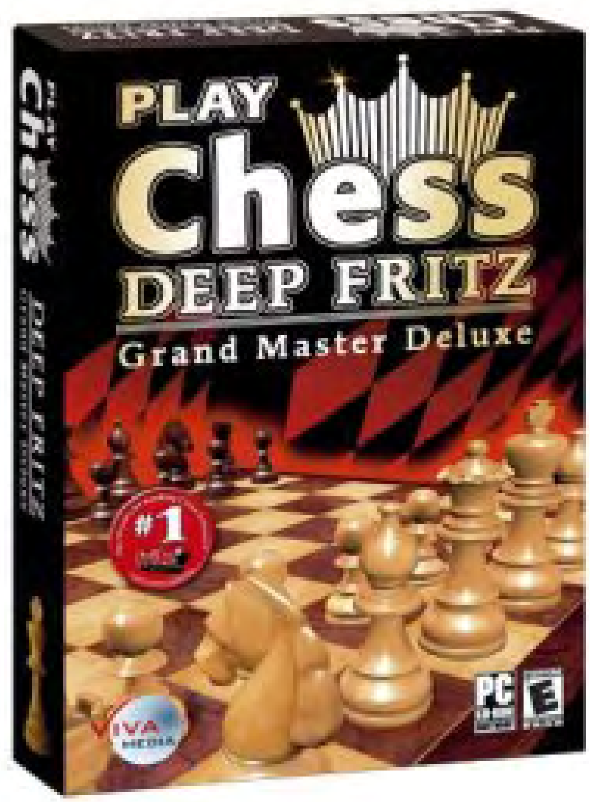




Software makes remarkable progress too!



Deep Blue, 1997



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Deep Fritz, 2002

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

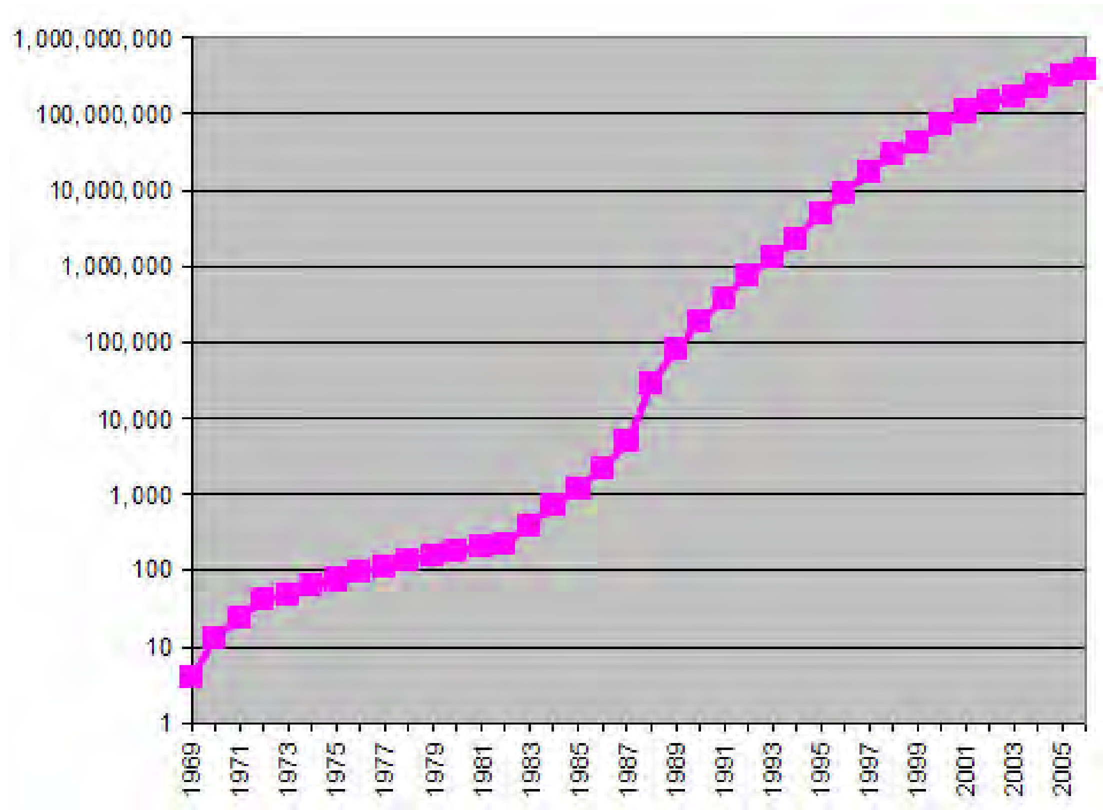
"There is no reason anyone would want a computer in their home" – Ken Olsen, founder and President of Digital Equipment Corporation, 1977

Today: Roughly 1 billion PCs …

Representing less than 2% of all processors!

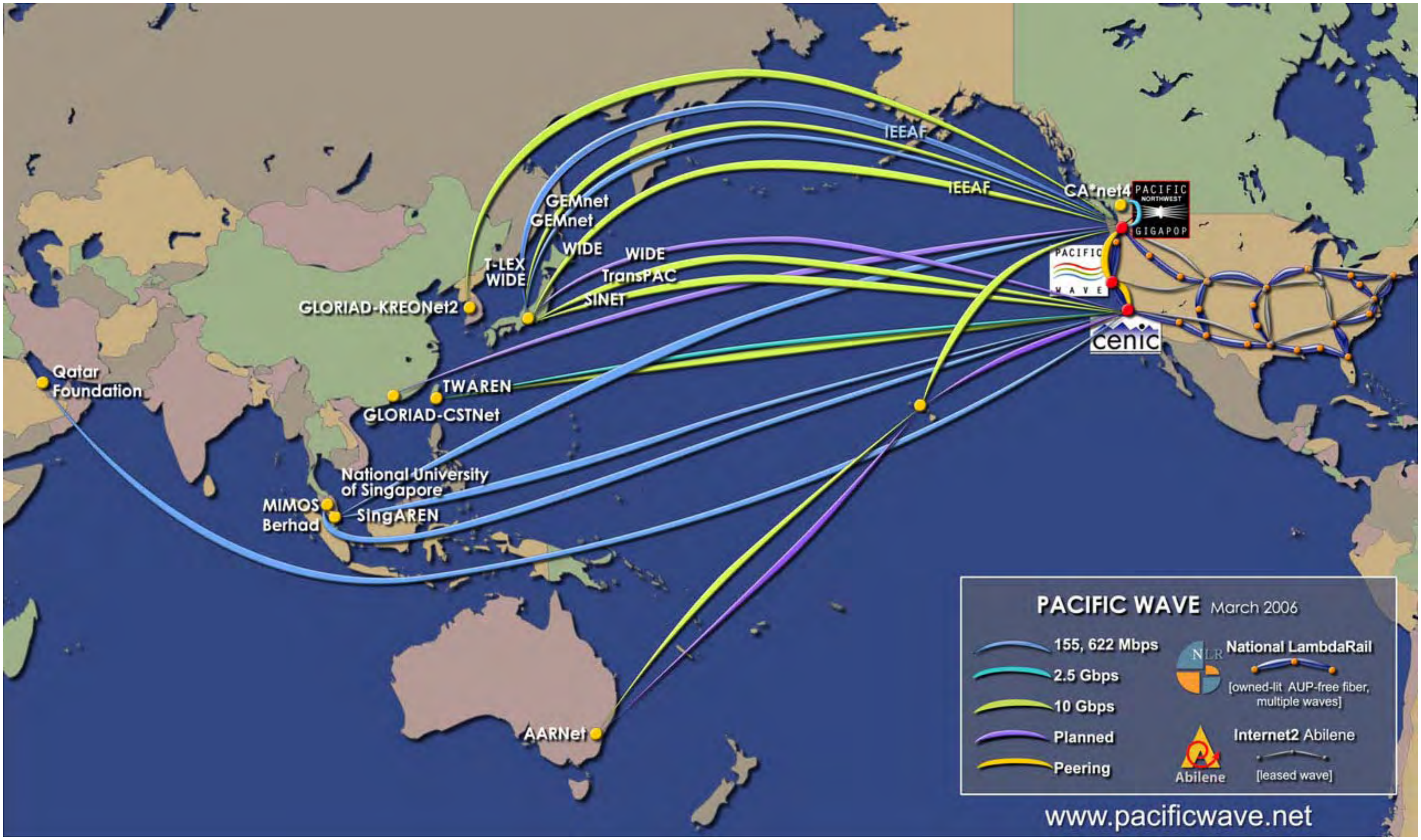
Number of Internet hosts

- 1970: 10
- 1975: 100
- 1980: 200
- 1985: 2,000
- 1990: 350,000
- 1995: 10,000,000
- 2000: 100,000,000
- 2005: 400,000,000

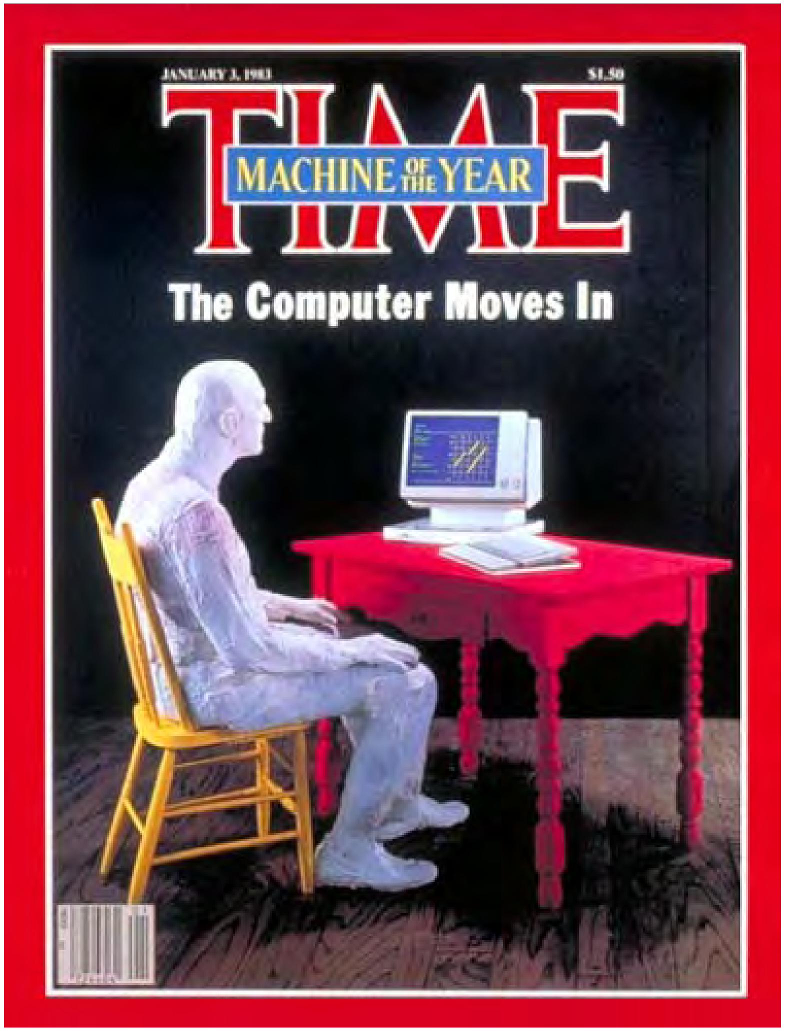


A connected region – then

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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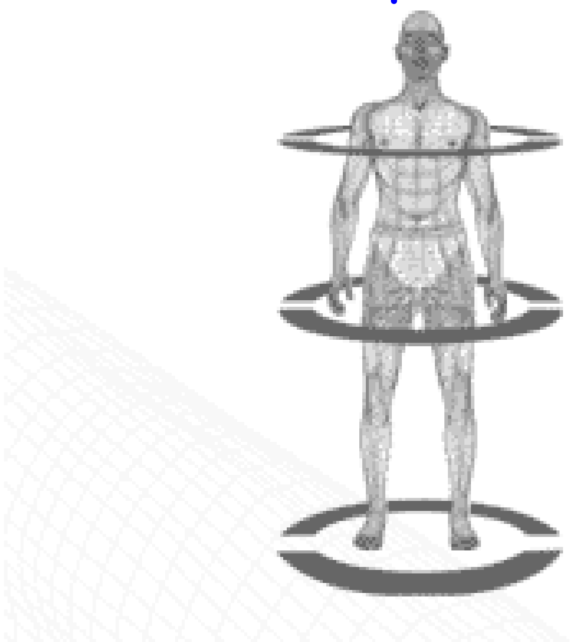

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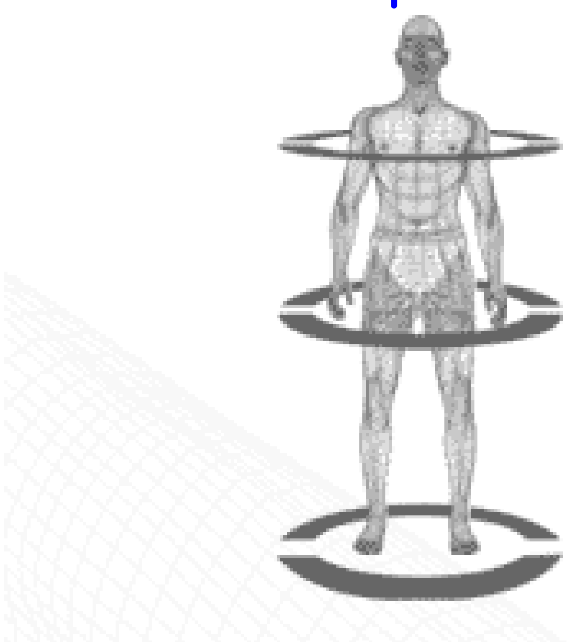

- “In the home, computer enthusiasts delight in imagining machines performing domestic chores.”

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- "Seymour Papert … author of *Mindstorms: Children, Computers and Powerful Ideas* …"

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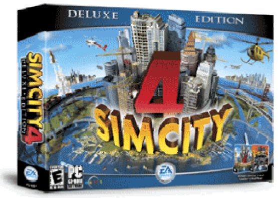
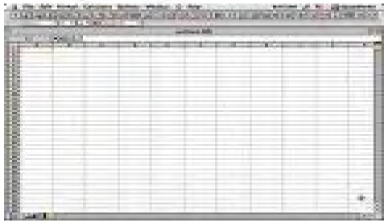
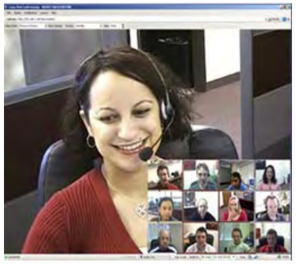
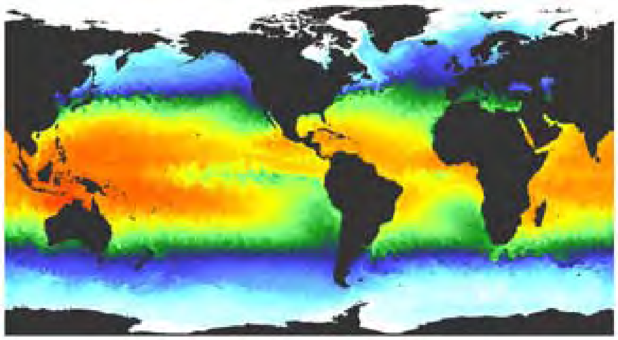
The Computing Community Consortium

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

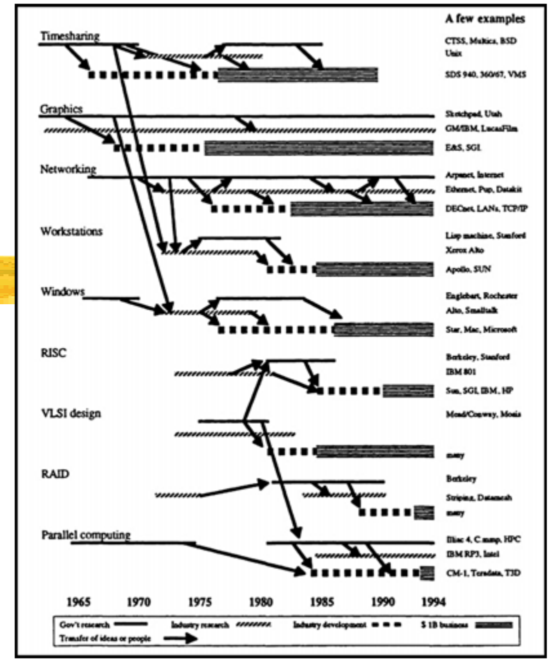


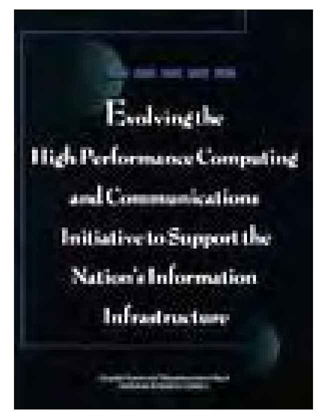


Research has built the foundation

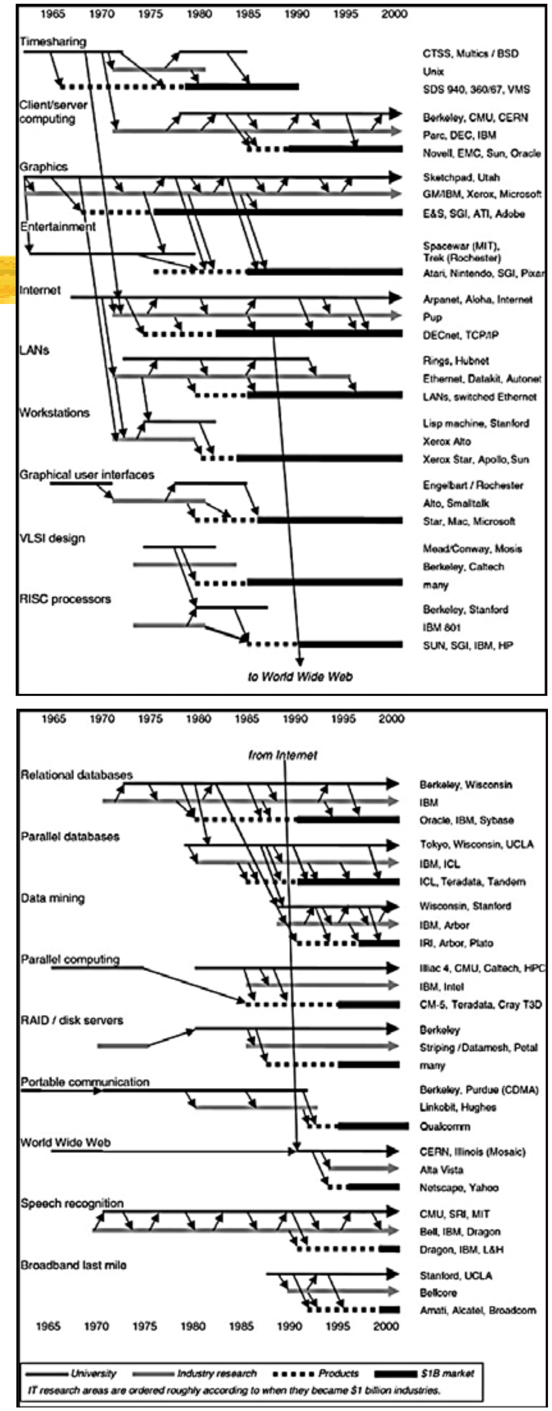
- Timesharing
- Computer graphics
- Networking (LANs and the Internet)
- Personal workstation computing
- Windows and the graphical user interface
- RISC architectures
- Modern integrated circuit design
- RAID storage
- Parallel computing





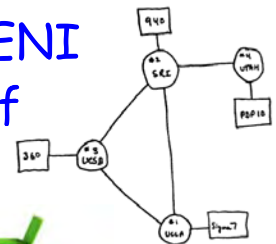
Much of the impact is recent

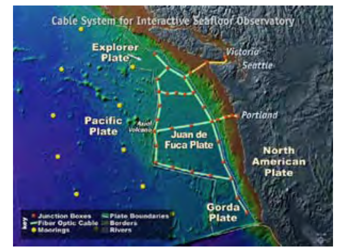
- Entertainment technology
- Data mining
- Portable communication
- The World Wide Web
- Speech recognition
- Broadband last mile

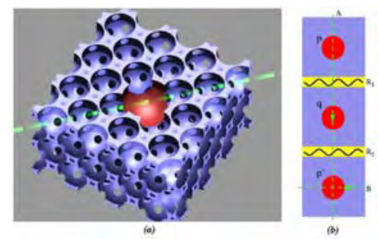


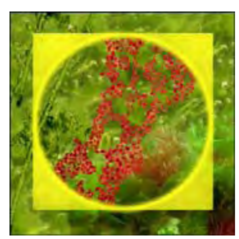
The future is full of opportunity

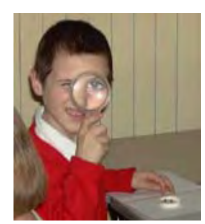
- Designing a next Internet – GENI
- Driving advances in all fields of science and engineering
- Wreckless driving
- Personalized education
- Predictive, preventive, personalized medicine
- Quantum computing
- Transforming the developing world
- Personalized health monitoring => quality of life
- Data-intensive supercomputing
- Neurobotics
- Synthetic biology
- The algorithmic lens => Cyber-enabled Discovery and Innovation











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 debate 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 "at scale" initiatives

The structure

- CCC is all of us!
  - This process *must* succeed, and it *can't* succeed without broad community engagement
- There is a CCC Council to guide the effort
  - The Council *stimulates* and *facilitates* – it doesn't "own"
  - The Council is in the final stages of creation, through an open process headed by Randy Bryant
    - Seeking diversity of all forms – not just "the usual suspects"
- The Council is led by a Chair
  - Ed Lazowska, University of Washington
  - 50% effort – not titular
- The CCC is staffed by CRA
  - Andy Bernat serves as Executive Director

- Those involved in shaping CRA's response to NSF's original challenge
  - Andy Bernat
  - Randy Bryant
  - Susan Graham
  - Anita Jones
  - Dick Karp
  - Ken Kennedy
  - Ed Lazowska
  - Peter Lee
  - Dan Reed
  - Wim Sweldens
  - Jeff Vitter
- Initial CCC Council
  - Greg Andrews
  - Bill Feiereisen
  - Susan Graham
  - Anita Jones
  - David Kaeli
  - Dick Karp
  - John King
  - Ed Lazowska
  - Peter Lee
  - Andrew McCallum
  - Beth Mynatt
  - Fred Schneider
  - Bob Sproull
  - Karen Sutherland
  - David Tennenhouse
  - Dave Waltz

CCC @ FCRC

Monday June 11, 6-7 p.m., Grand Exhibit Hall

Christos Papadimitriou, UC Berkeley

The Algorithmic Lens: How the Sciences are Being Transformed by the Computational Perspective

Abstract

Tuesday June 12, 6-7 p.m., Grand Exhibit Hall

Bob Colwell, Independent Consultant

Future of Computer Architecture '07

Abstract

Wednesday June 13, 6-7 p.m., Grand Exhibit Hall

Randal Bryant, Carnegie Mellon University

Data-Intensive Super Computing: Taking Google-Style Computing Beyond Web Search

Abstract

Thursday June 14, 6-7 p.m., Grand Exhibit Hall

Scott Shenker, UC Berkeley

We Dream of GENI: Exploring Radical Network Designs

Abstract

The desired outcome

- Broad community engagement in establishing more audacious and inspiring research visions for our field
  - Some will require significant research infrastructure (e.g., GENI); some will be new programs (e.g., CDI)
- Better public appreciation of the potential of the field
- Attraction of a new generation of students
- Greater impact!

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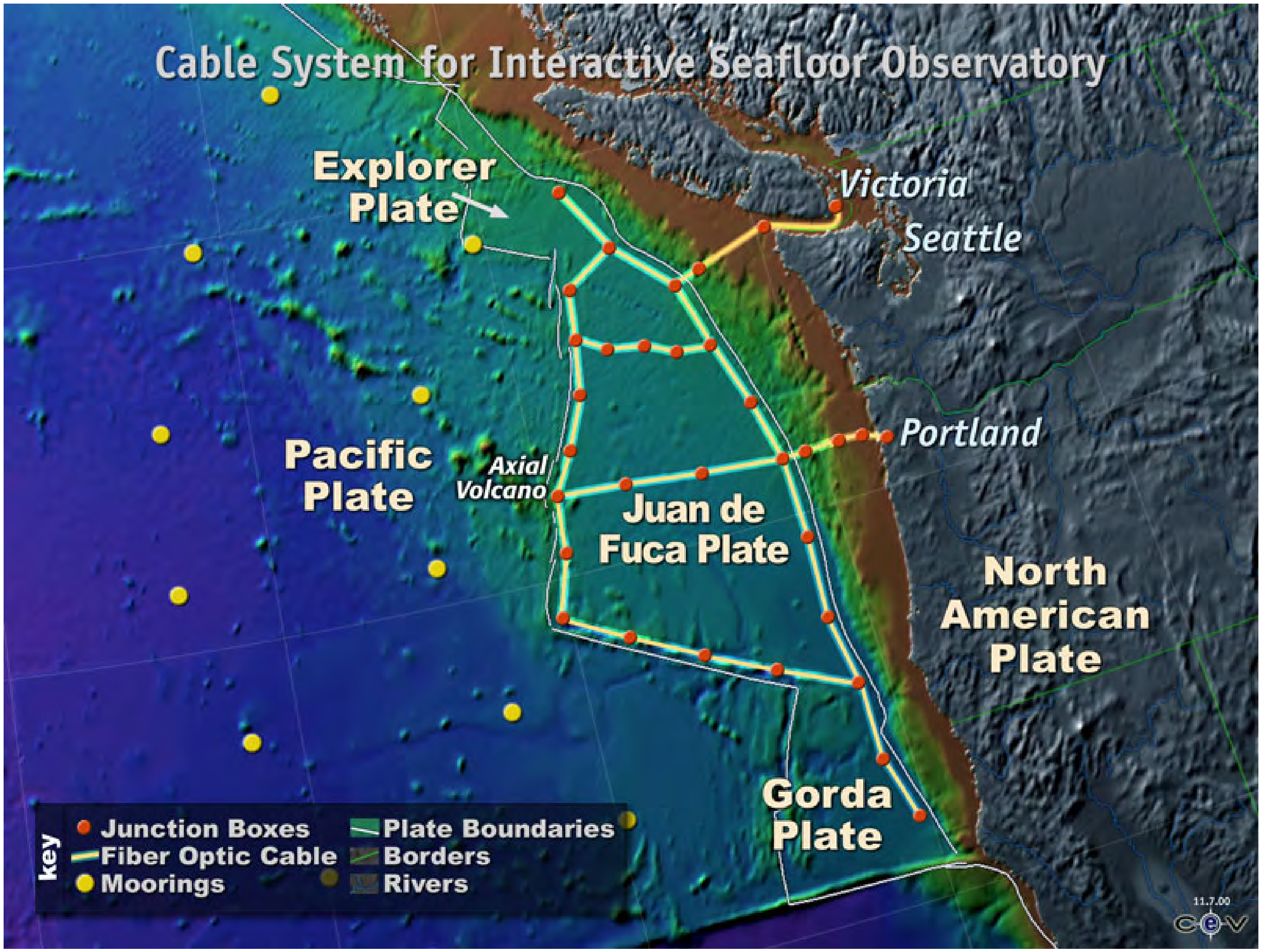
About the Book

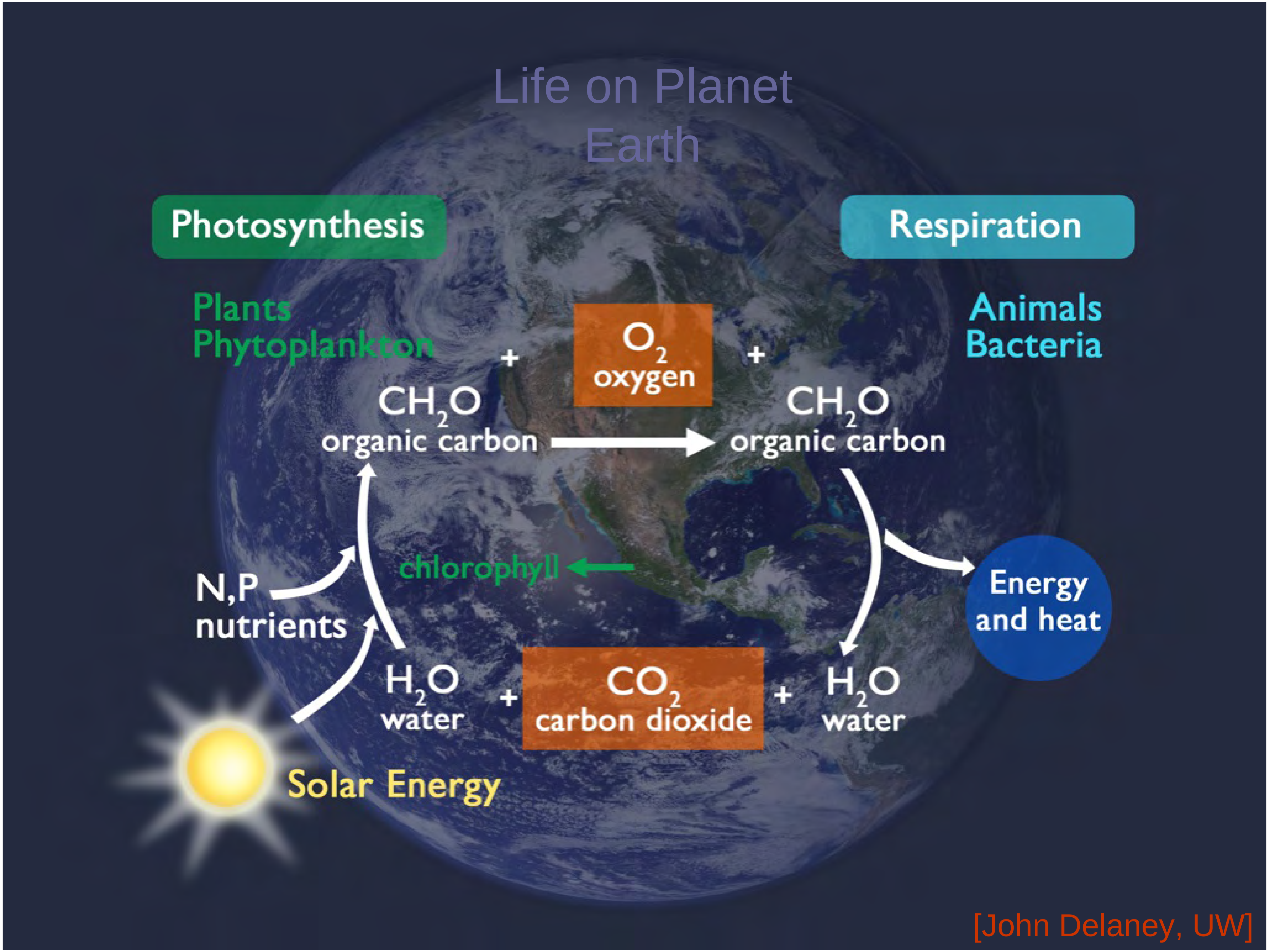
This monograph constitutes a thoroughly revise d extended version of the author's PhD thesis, which was selected as the winning thesis of the 2005 ACM Doctoral Dissertation Competition. Ben Liblit did his PhD work at the University of California, Berkeley, with Alexander Aiken as thesis adviser.

The next ten years …

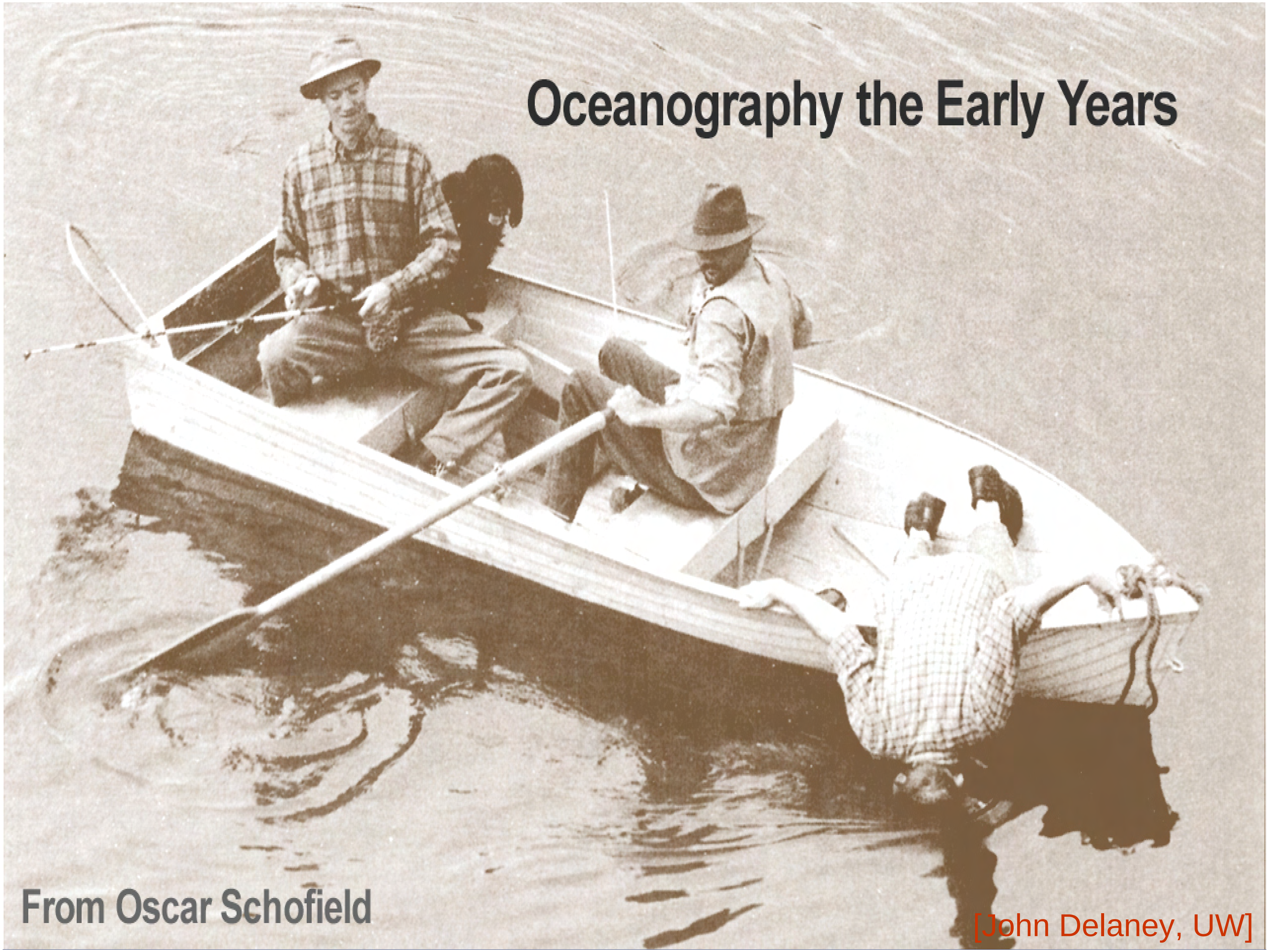
1. Sensor-driven (data-driven) science and engineering



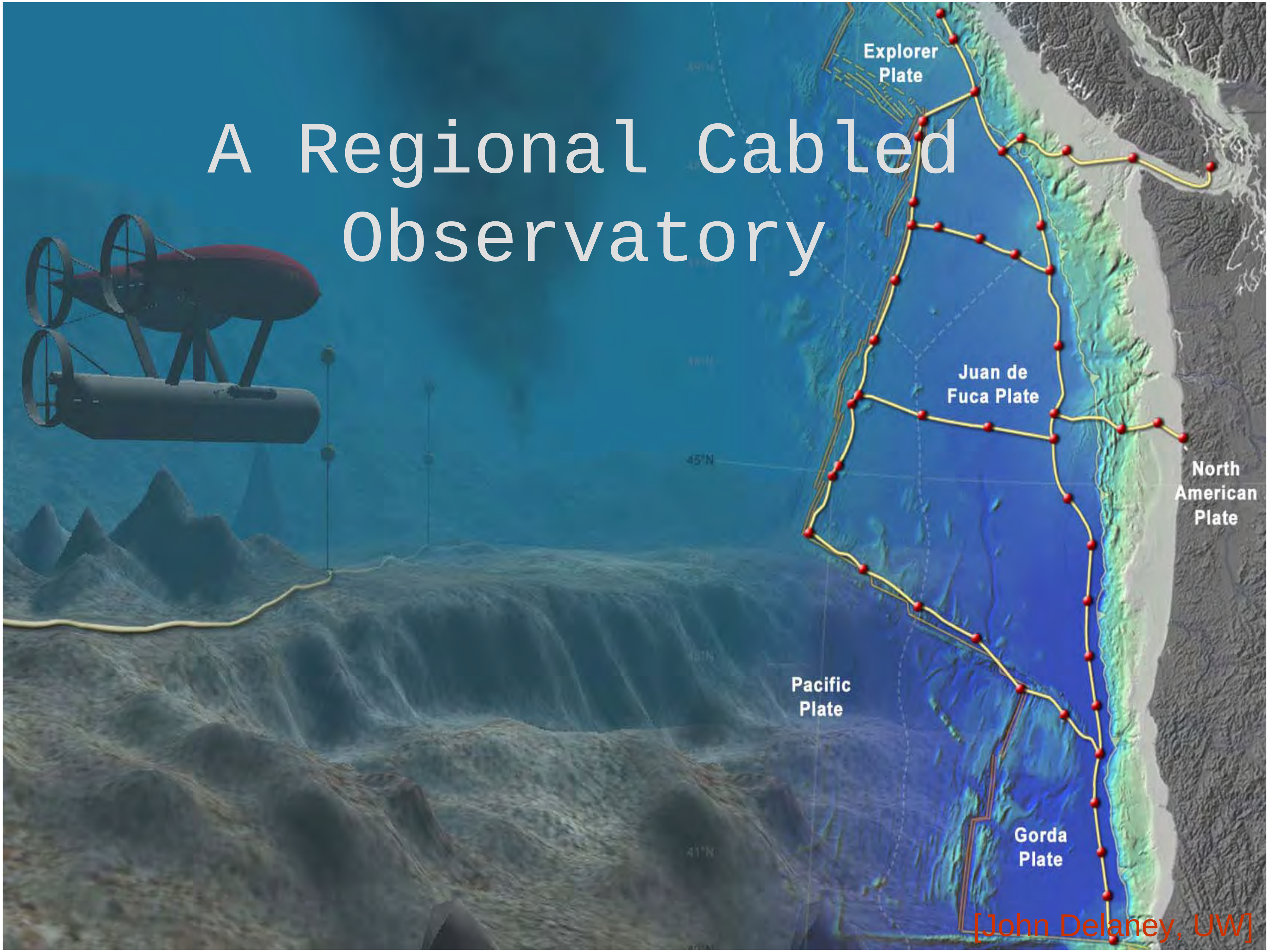
Life on Planet Earth



[John Delaney, UW]


Oceanography the Early Years
From Oscar Schofield
[John Delaney, UW]

A Regional Cabled Observatory



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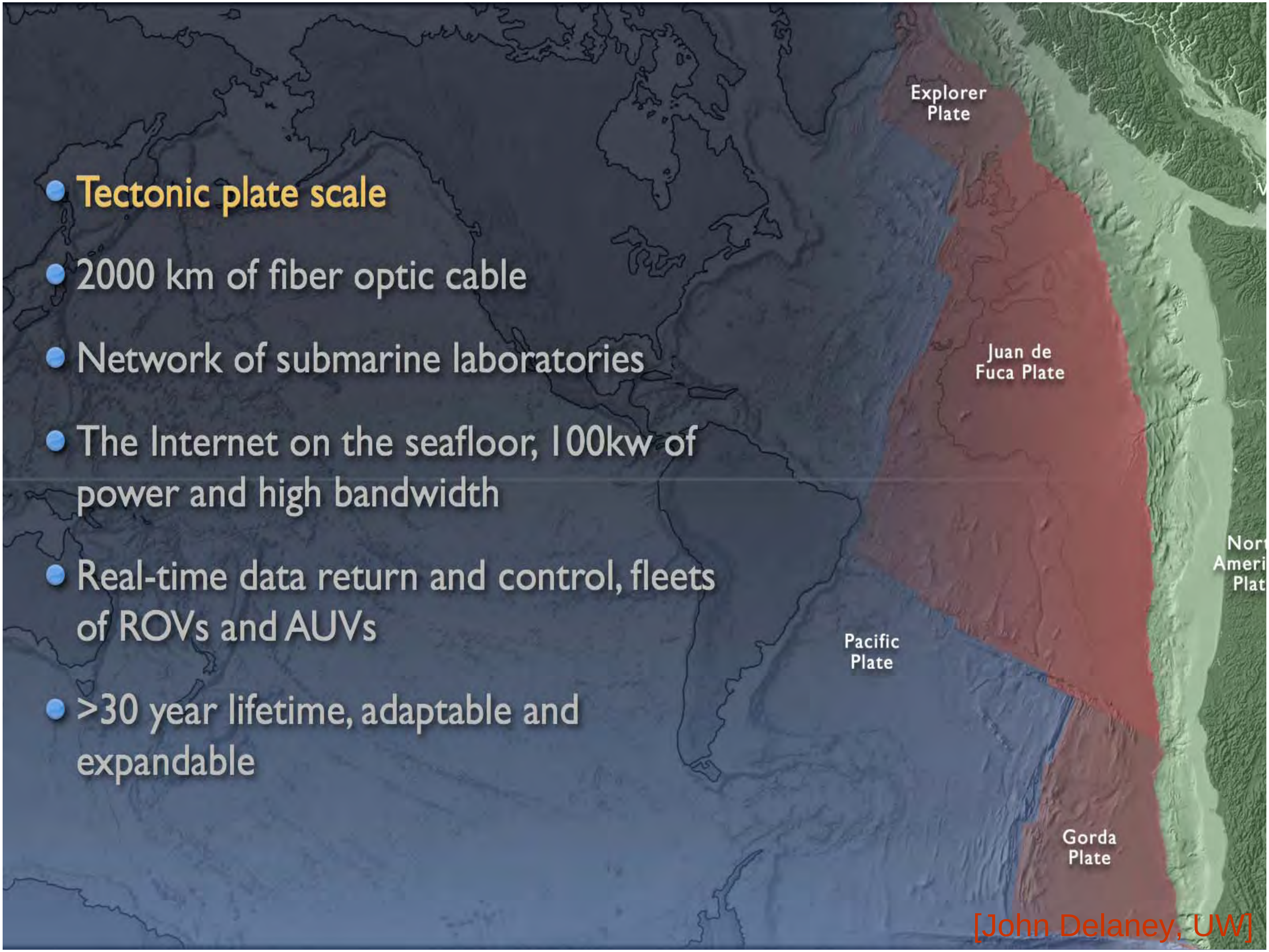
• Tectonic plate scale
• 2000 km of fiber optic cable
• Network of submarine laboratories
• The Internet on the seafloor, 100kw of power and high bandwidth
• Real-time data return and control, fleets of ROVs and AUVs
• >30 year lifetime, adaptable and expandable
Explorer Plate
Juan de Fuca Plate
Pacific Plate
Gorda Plate
[John Delaney, UW]

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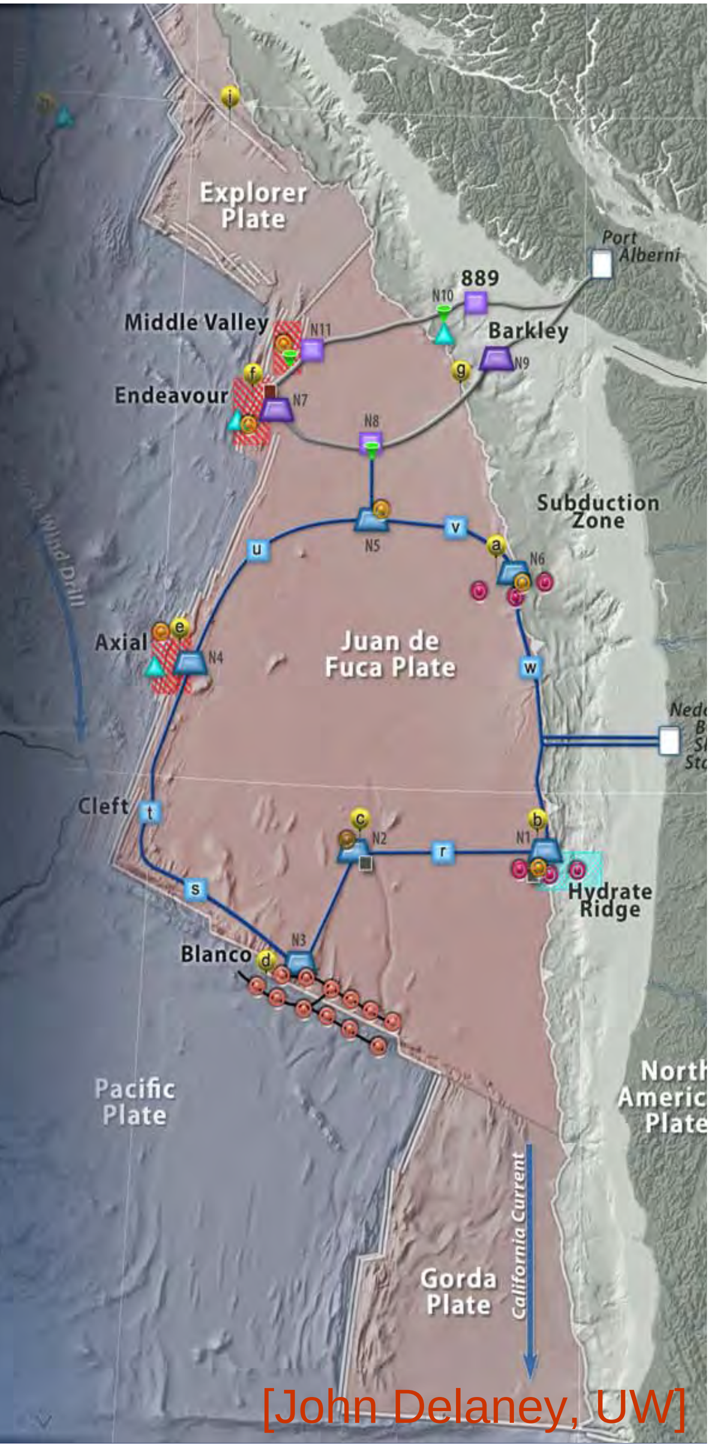

[John Delaney, UW]

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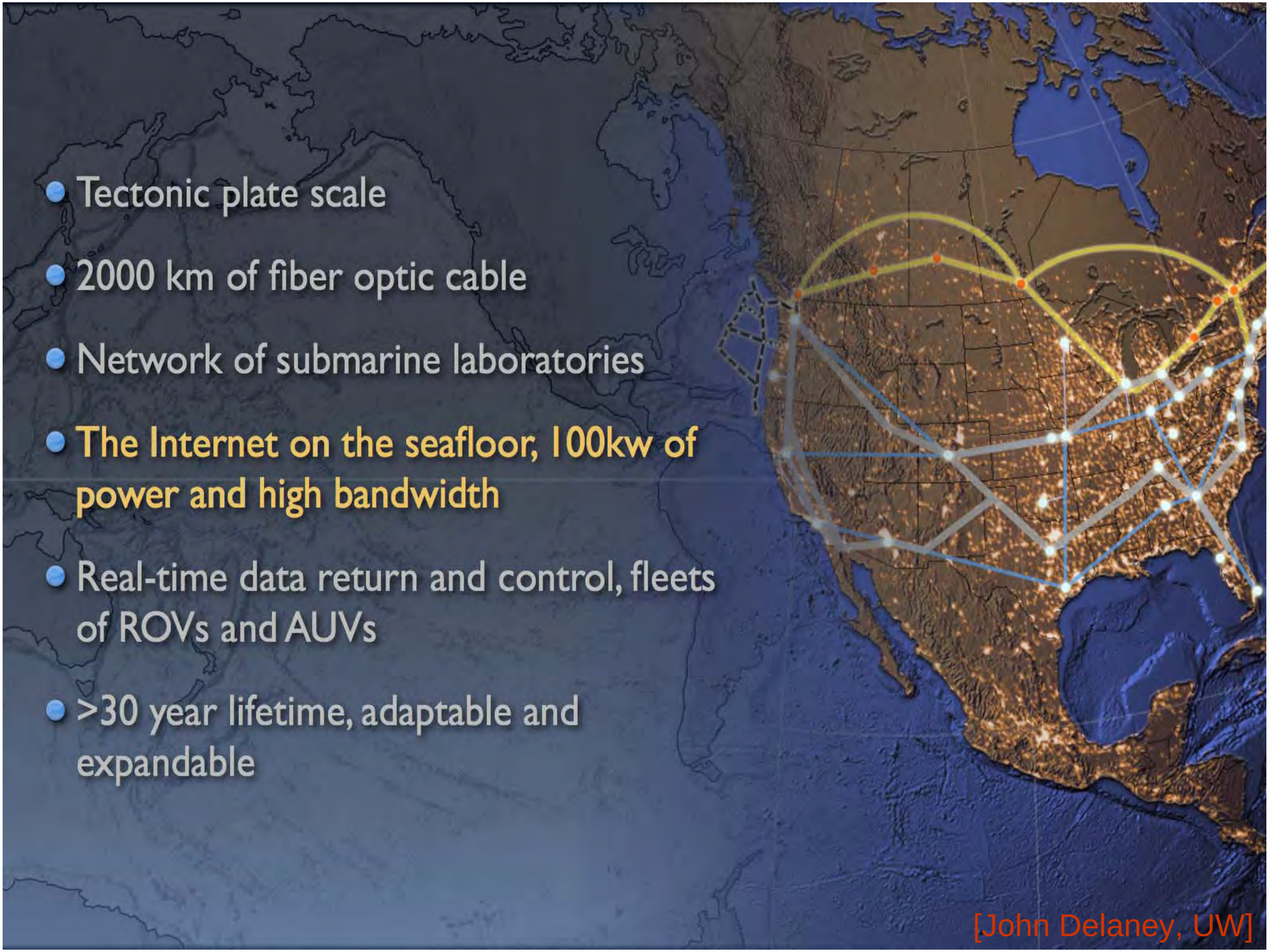

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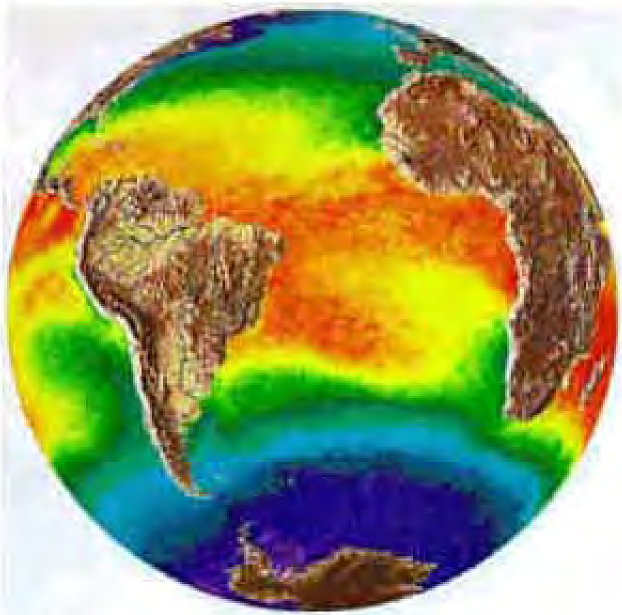
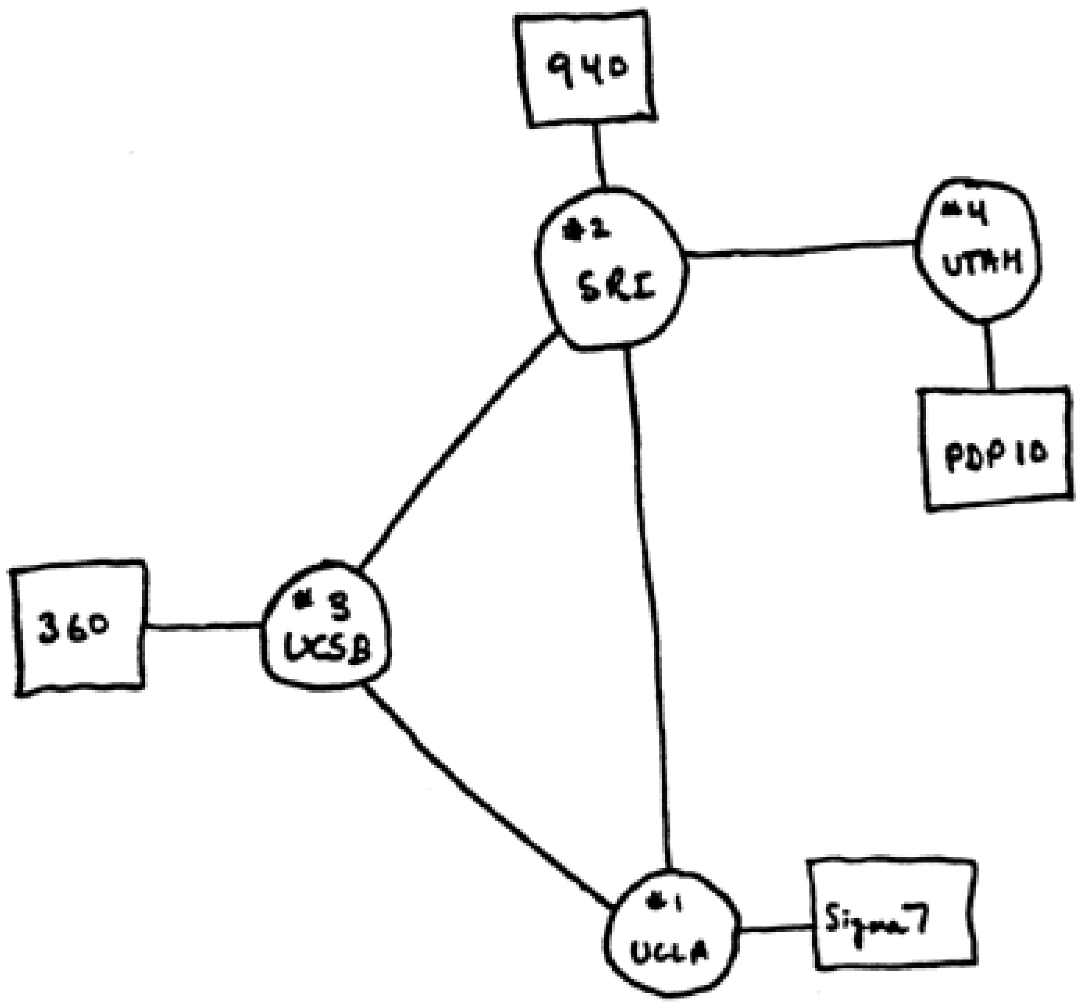
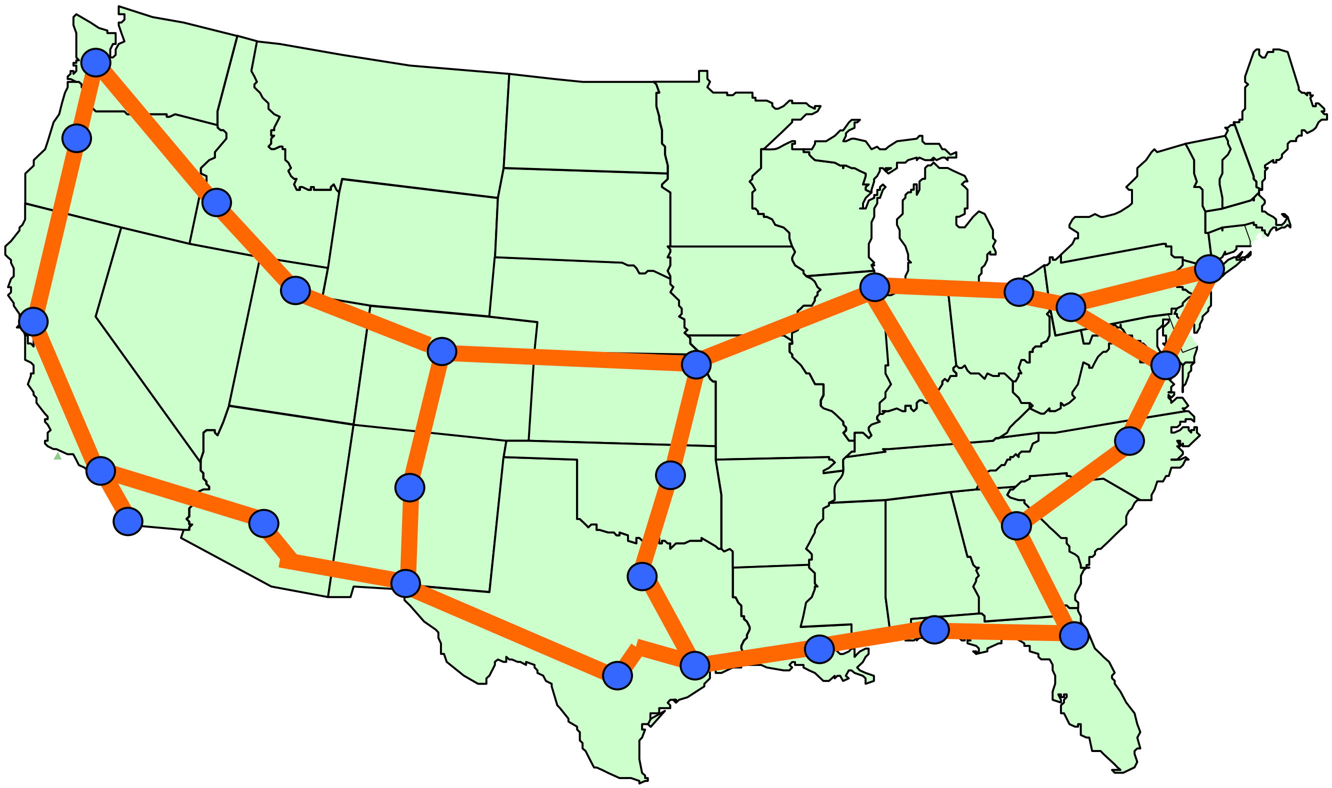


2. Re-architecting the Internet



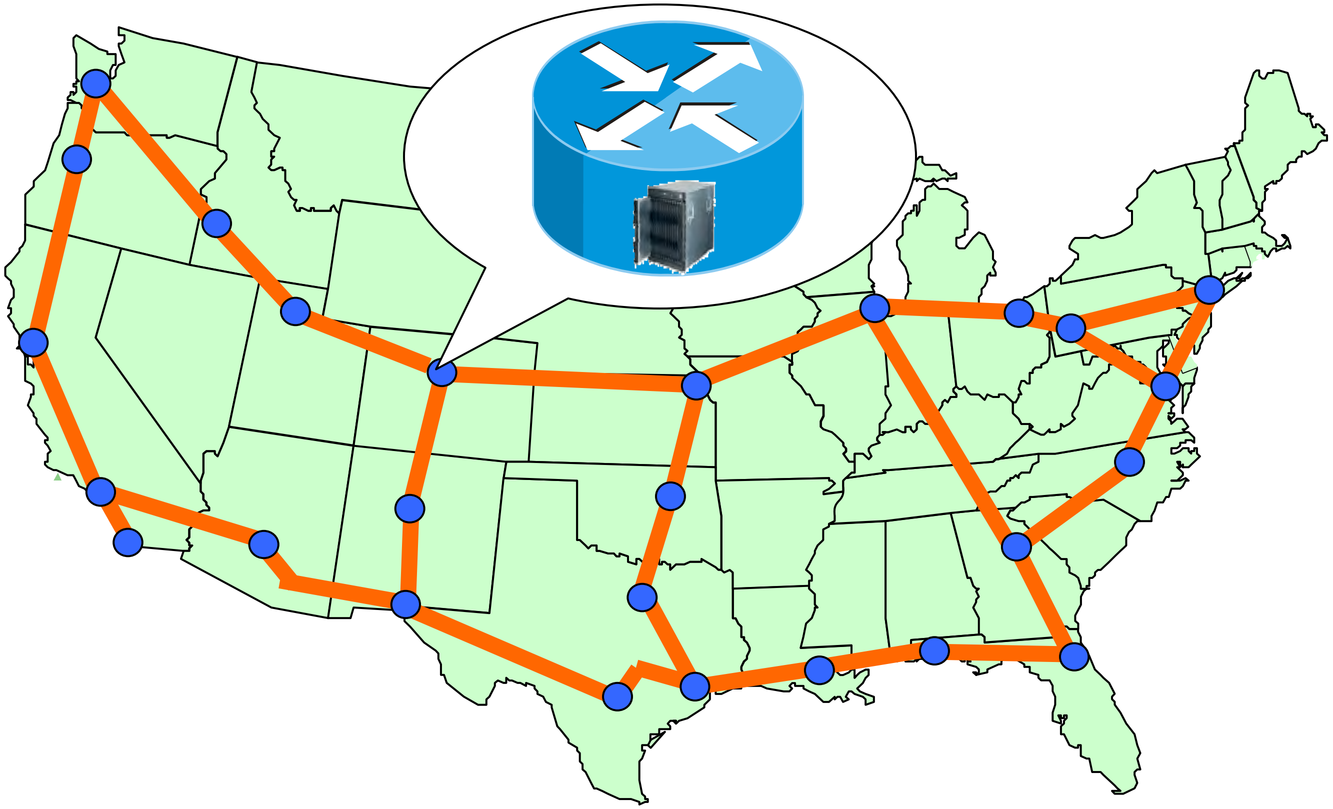
- Global Environment for Networking Innovations (GENI)
  - The Internet is a victim of its success!
    - This success has created dramatic new uses and requirements
    - These new requirements pose deep intellectual challenges
    - They require new designs, not more patches
  - Envision a new Internet that is more
    - Secure
    - Reliable
    - Scalable
    - Manageable
  - GENI is a National Science Foundation initiative
    - A proposed research instrument for exploring radical network designs

National Fiber Facility



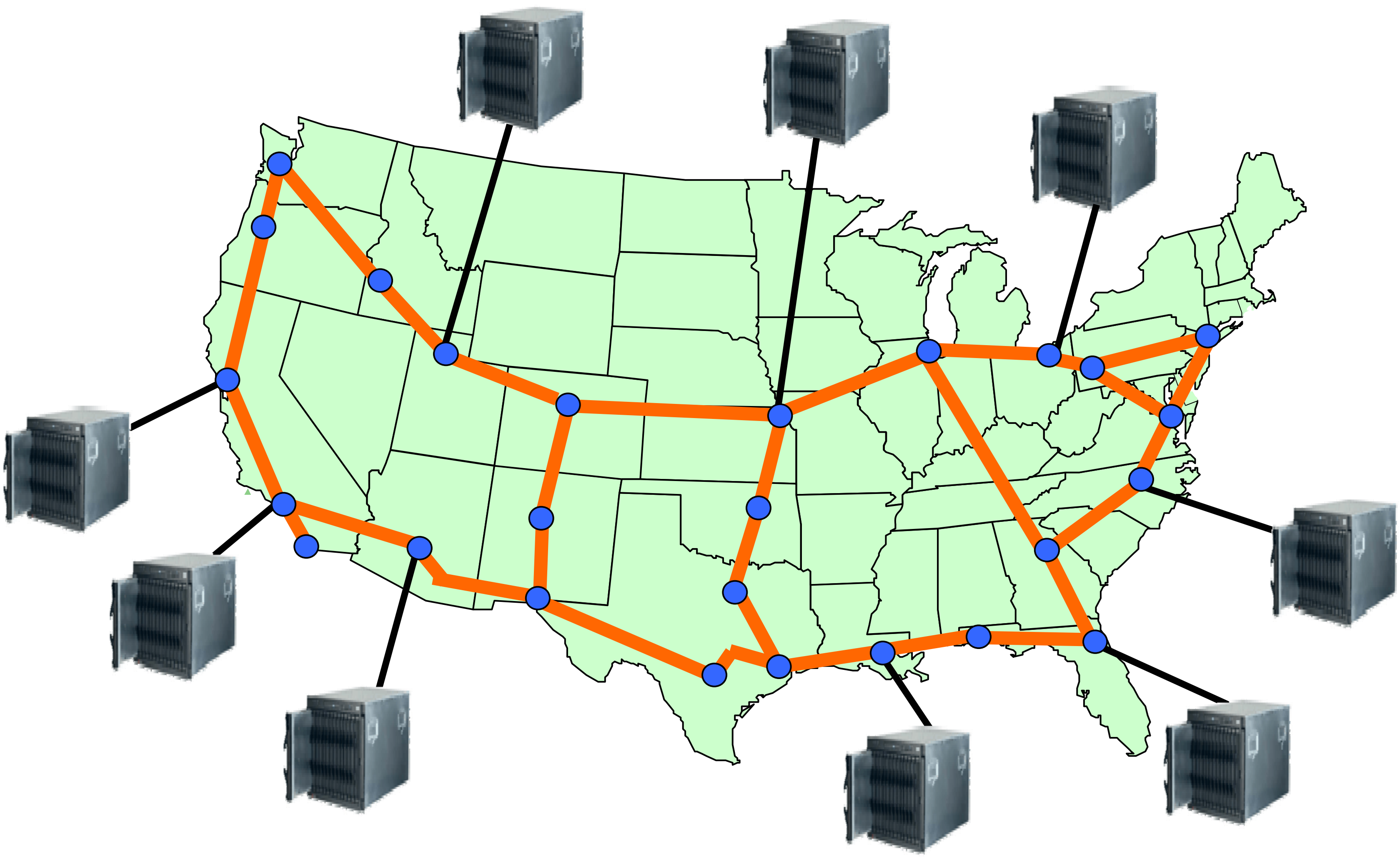
[Scott Shenker, UC Berkeley and ICSI]

+ Programmable Routers



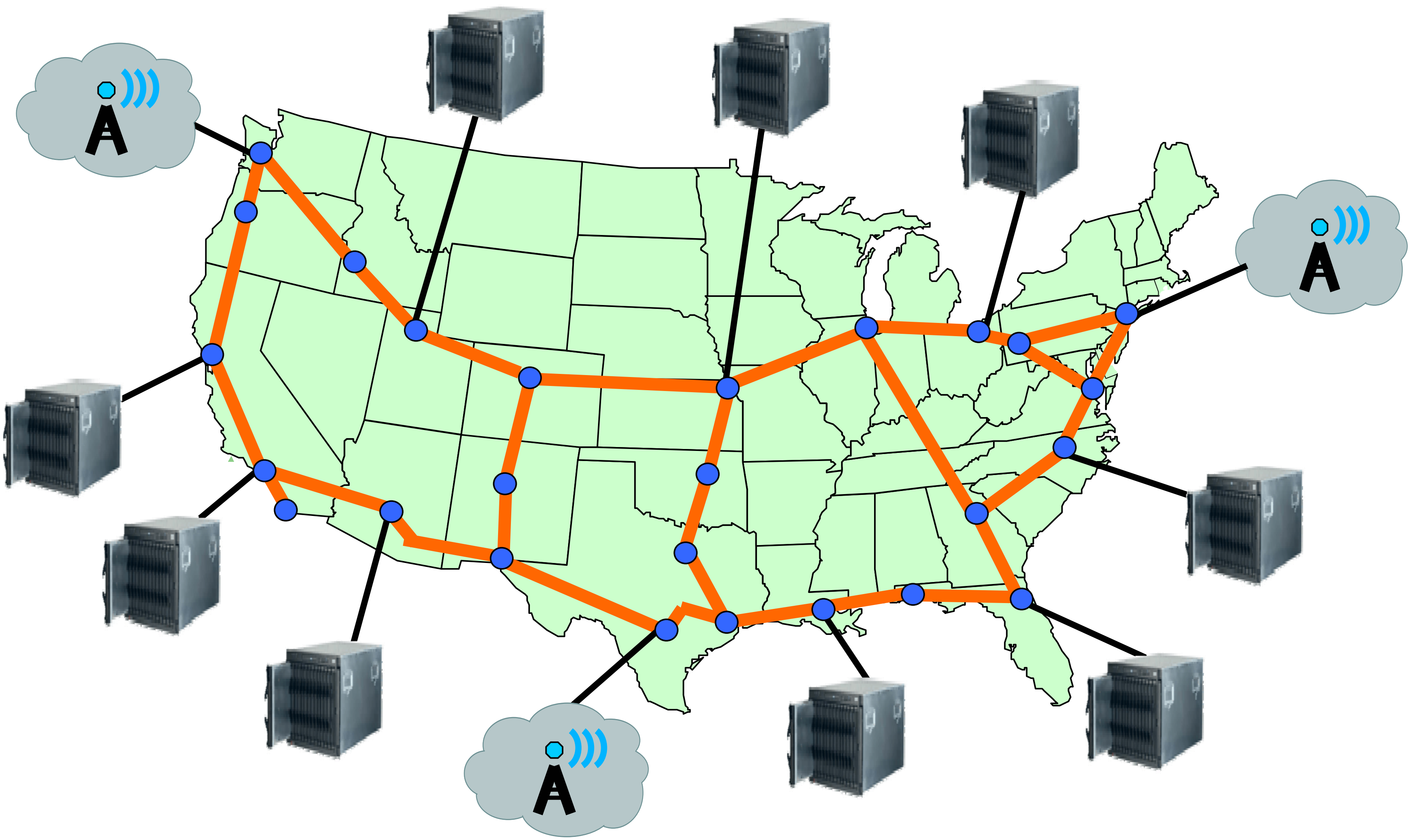
[Scott Shenker, UC Berkeley and ICSI]

+ Clusters at Edge Sites



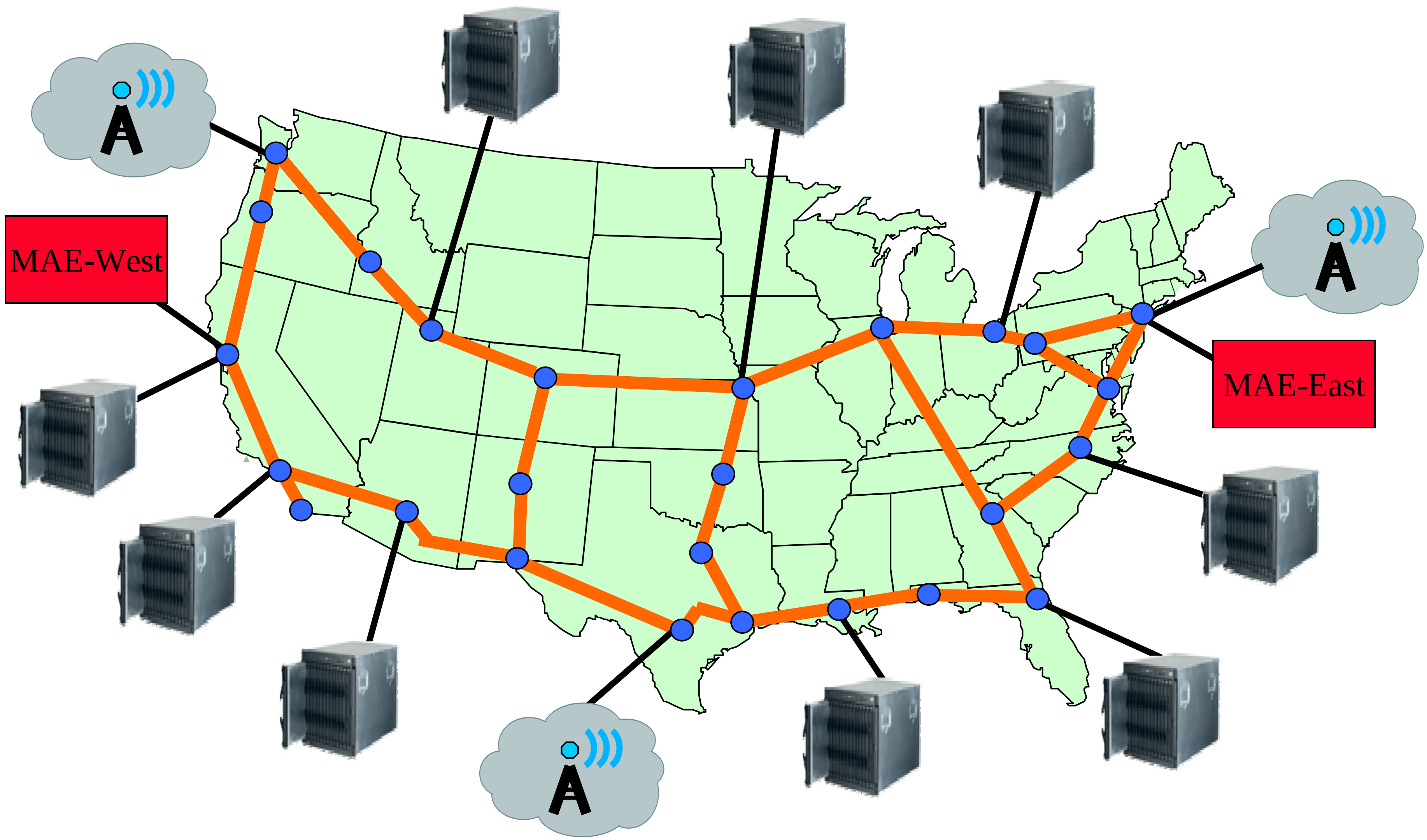
[Scott Shenker, UC Berkeley and ICSI]

+ Wireless Subnets



[Scott Shenker, UC Berkeley and ICSI]

+ ISP Peers



[Scott Shenker, UC Berkeley and ICSI]

GENI Will Enable Us To…

- Experiment at scale
- 1000s of simultaneous experiments
- Long-running services (operational experience)
- Integrate our designs across layers

[Scott Shenker, UC Berkeley and ICSI]

3. Flattening the world (transforming the developing world)

4 billion people in the ***rural developing world***
need the same <u>information</u> we do

- ✔ <u>Business</u>: new opportunities
- ✔ <u>Finance</u>: capital to invest
- ✔ <u>Government</u>: services & programs
- ✔ <u>Health</u>: informed, consistent care
- ✔ <u>Education</u>: personal advancement




*4 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]

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]


[Tapan Parikh, UW]

CAM: Agricultural Monitoring

Working with farmers in Guatemala and India

Extension staff collect geocoded video, images and data

Experts provide feedback and advice via parcel-wise blog

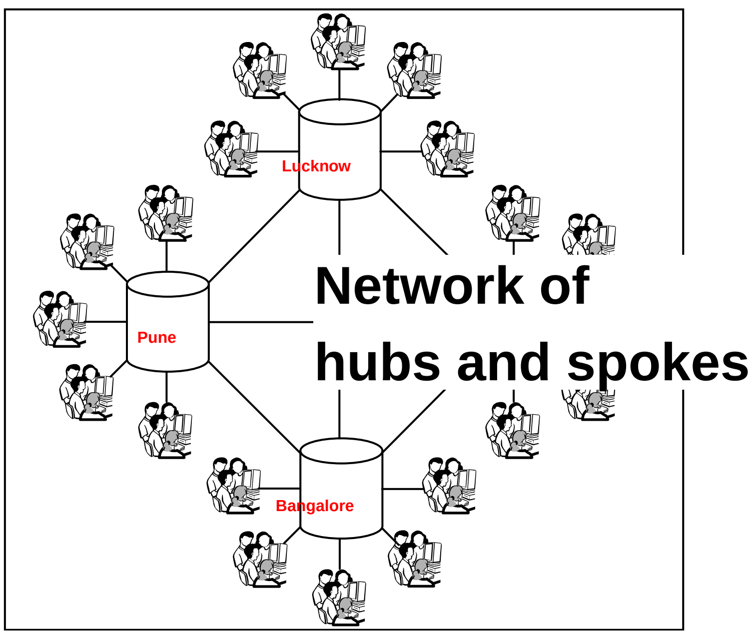
Enable remote certification – organic, bird-friendly, etc.

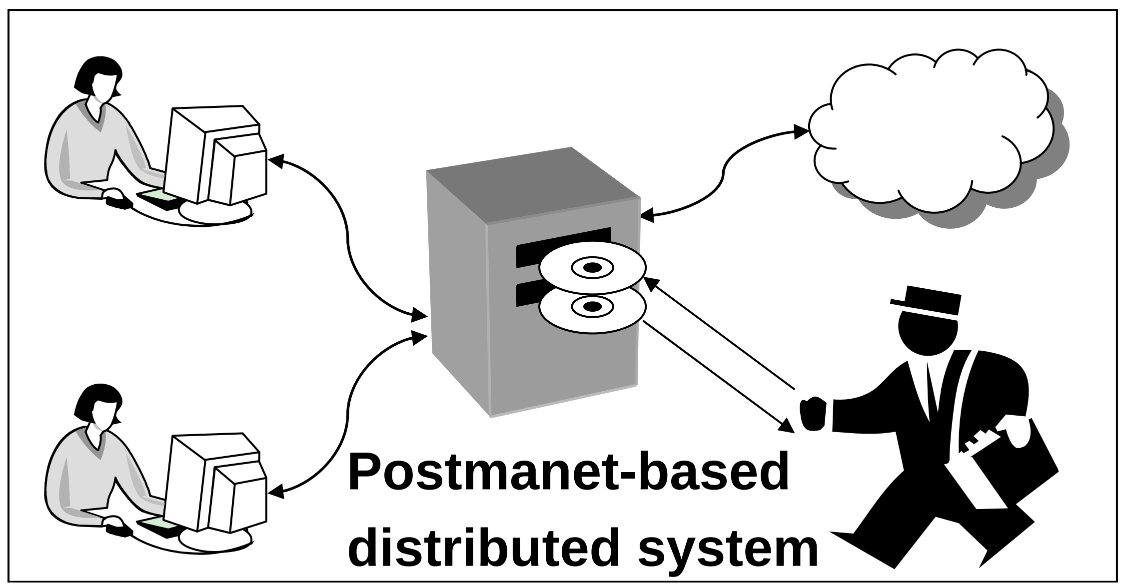
- Traceability
- Product Differentiation
- Land Use

[Tapan Parikh, UW]

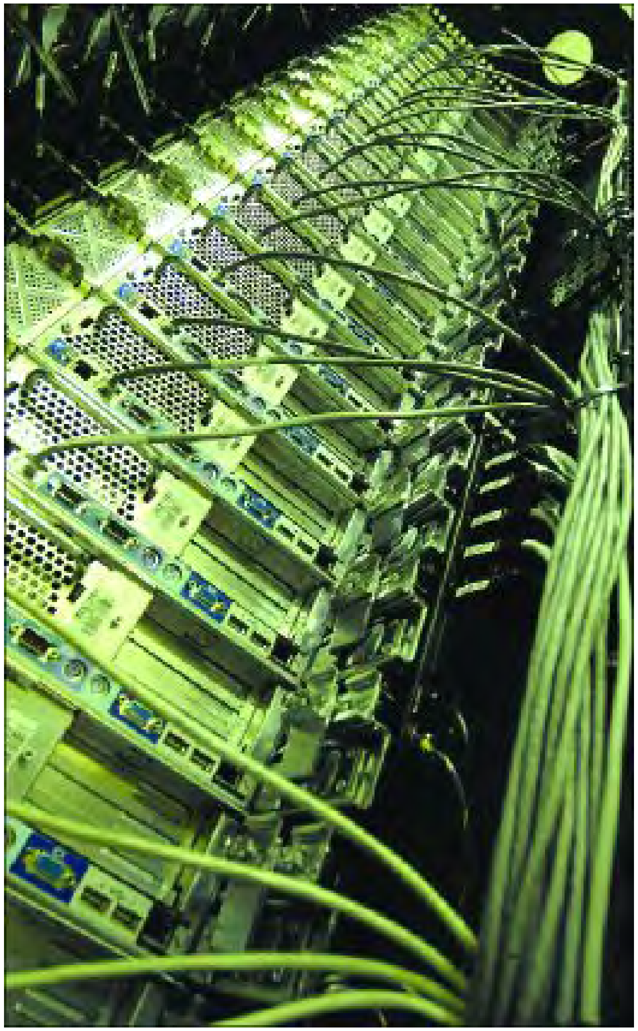
Digital Study Hall

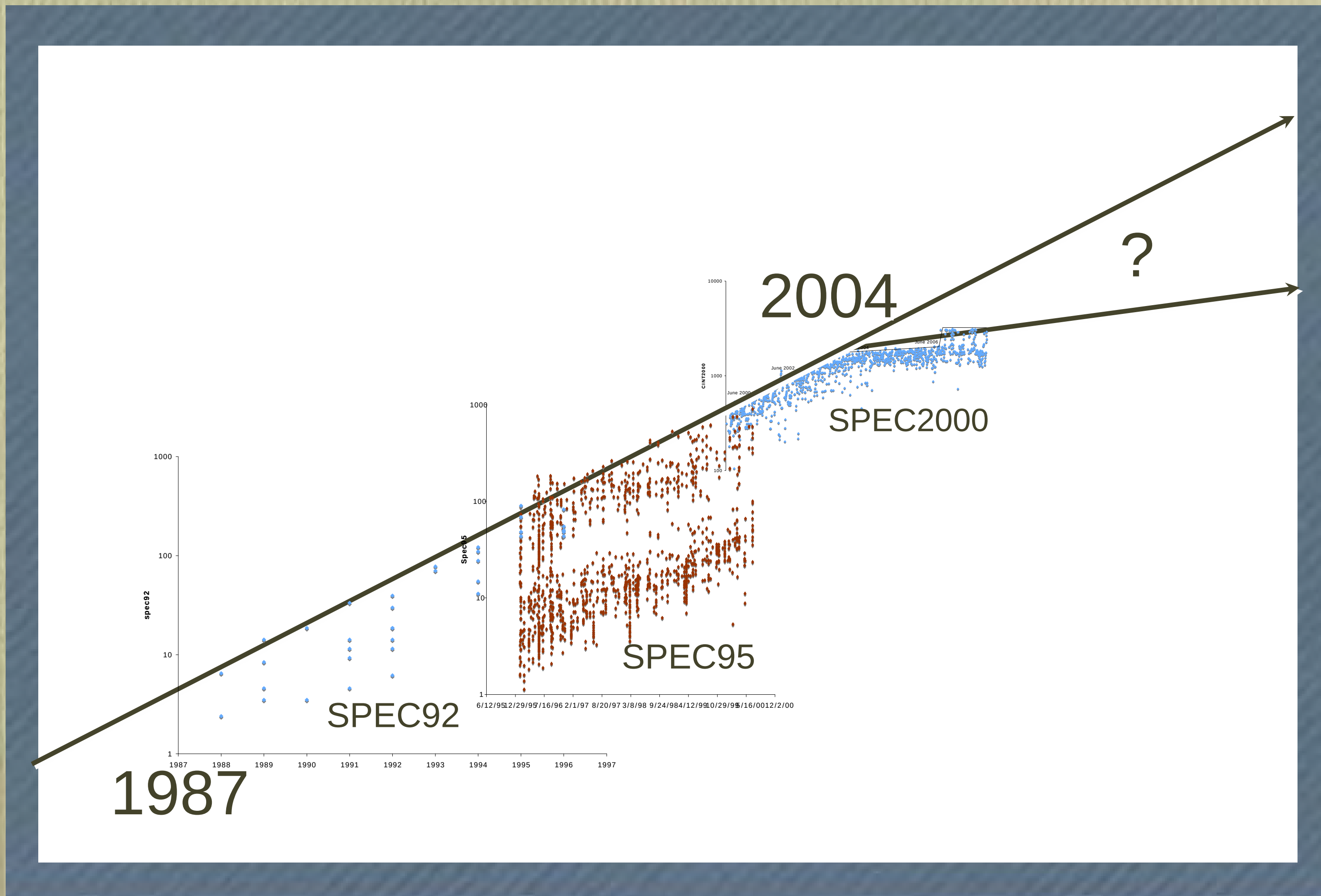
Randy Wang, Tom Anderson, Paul Javid



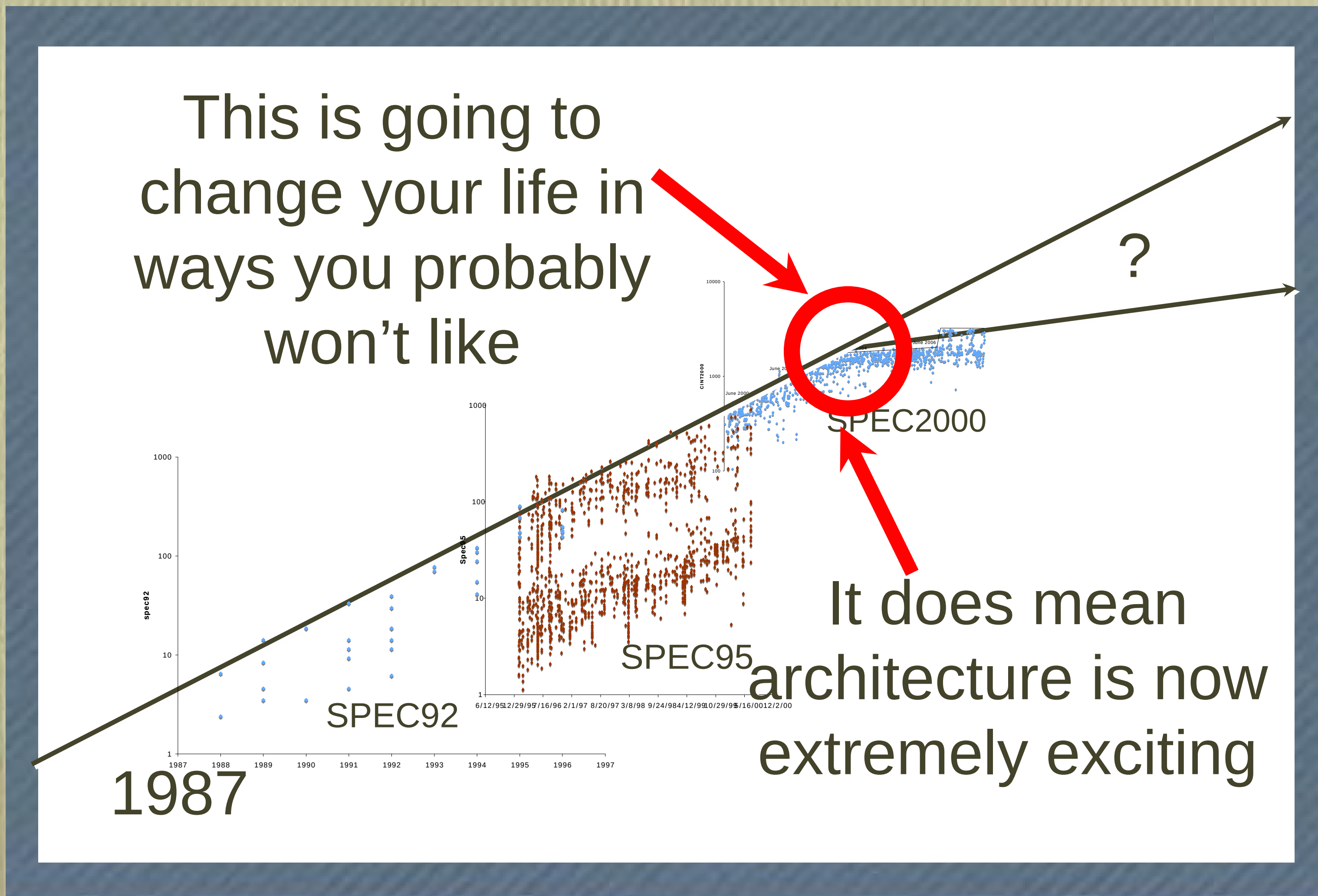


4. Harnessing parallelism





[Mark Oskin, UW]



[Mark Oskin, UW]

More Work Needed

In order of decreasing urgency

Research Needed

1. CMOS end-game electricals problems
2. Multicore SW
3. Power/thermals management
4. Thread and manycore sync: SW needs help
5. Expand synergies between embedded & GP
6. Design-in-the-Large
7. Grand Challenges
8. New technologies like reconfig fabrics, streaming machines, quantum, bio, nano

[Bob Colwell]

Google's Computing Infrastructure

System

- **~ 3 million processors in clusters of ~2000 processors each**
- **Commodity parts**
  - x86 processors, IDE disks, Ethernet communications
  - Gain reliability through redundancy & software management
- **Partitioned workload**
  - Data: Web pages, indices distributed across processors
  - Function: crawling, index generation, index search, document retrieval, Ad placement

Barroso, Dean, Hölzle, "Web Search for a Planet: The Google Cluster Architecture" IEEE Micro 2003

A Data-Intensive Super Computer (DISC)

- **Large-scale computer centered around data**
  - Collecting, maintaining, indexing, computing
- **Similar systems at Microsoft & Yahoo**

[Randal Bryant, CMU]

CS Research Issues

Applications

- Language translation, image processing, …

Application Support

- Machine learning over very large data sets
- Web crawling

Programming

- Abstract programming models to support large-scale computation
- Distributed databases

System Design

- Error detection & recovery mechanisms
- Resource scheduling and load balancing
- Distribution and sharing of data across system

[Randal Bryant, CMU]

5. The algorithmic lens – a computational perspective transforms the sciences

- Envisioned by the theory community
- Brought to life as the NSF Cyber-Enabled Discovery Initiative (CDI): $52M in FY08 => $250M in FY12

The lens of computation

- Processes in the ***physical and life sciences*** can often be productively thought of as computational; this results in novel insights which end up transforming these fields
- On the other hand, the dual computational/ social nature of the Internet and the www has inspired research in the interface between CS and the ***social sciences***

[Christos Papadimitriou, UC Berkeley]

The lens of computation (cont.)

- Finally, deep mathematical problems of computational origin have transformed the research agenda of ***Mathematics***
- These interfaces are typically initiated by research interactions between CS theorists and researchers of the particular scientific field

[Christos Papadimitriou, UC Berkeley]

Biology

- “Shotgun sequencing” of the human genome (the most innovative and impressive of the two successful approaches) was based on a simple algorithmic idea and its complexity analysis
- Understanding the cell is likely to advance by models of computational nature

[Christos Papadimitriou, UC Berkeley]

Quantum computation

- Conceived by turning a computational question on its head (Feynman)
- Insights from the Theory of Computation were key for its development and application
- Quantum Mechanics (the most elegant and powerful physical theory) is being pushed to its limits (and tested…) by computation

[Christos Papadimitriou, UC Berkeley]

Statistical Physics

- Deep connection between phase transitions and algorithmic speed (of convergence to the steady state)
- Insights from magnetic materials help understand threshold phenomena in the www and combinatorial problems
- Successful physics-inspired algorithms for hard problems

[Christos Papadimitriou, UC Berkeley]

Mathematics

- $P \neq NP$, the deepest problem in CS, is also considered as one of the most important open questions in Mathematics
- Crucial mathematical advances in Analysis and Geometry have come from algorithmic considerations

[Christos Papadimitriou, UC Berkeley]

Economics and Game Theory

- Algorithmic and economic insights are combined in the design of markets, auctions, incentives, and payment schemes
- Loss of efficiency because of participant selfishness (“the price of anarchy”): a key insight and performance measure for Internet-scale system design

[Christos Papadimitriou, UC Berkeley]

Sociology

- The web and the Internet have proven an invaluable lab for experimental sociology
- But also an arena for the development of important algorithmic ideas (e.g., for www search)
- The computational nature of key sociological insights such as "six degrees of separation" has been exposed

[Christos Papadimitriou, UC Berkeley]

In conclusion…

- Algorithmic thinking is penetrating and transforming the sciences, while CS is also being enriched
- Note that this important intellectual exchange between CS and the sciences is complementary to the more traditional interface re: computational problems arising in the fields in question

[Christos Papadimitriou, UC Berkeley]

6. Wreckless driving

VIEW BY

+ ALL FEATURES

+ MODEL --

Acoustic Control Induction System (ACIS)
Active Control Engine Mount
Adaptive Cruise Control (ACC)
Adaptive Variable Suspension (AVS)
Advanced Electronic Climate Control
Aerodynamic Drag Coefficient
AI Shift Artificial Intelligence Shift
Air Suspension
Bluetooth® technology
Brake Assist
Cruise Control
Direct Injection vs
Double Wishbone Suspension
DVD Navigation System
Electro Chromatic Device (ECD)
Electro Chromatic Mirrors
Electro Multi Vision Display (EMV)
Electronic Brakeforce Distribution (EBD)
Electronic Throttle Control System with intelligence (ETCS-i)
Electronically controlled Continuously Variable Transmission (ECVT)
E-shift - Sequential Shift Mode
Flush underbody panels

Adaptive Cruise Control (ACC)

AVAILABLE IN

IS 250
GS 300 & GS 430
GS 450h
LS 430

If traditional cruise control had a higher IQ, this would be the result. Adaptive Cruise Control (ACC) works just like a more conventional cruise control system - until it detects a car in front of it. Sensors detect that you are approaching a car ahead.
The system then automatically eases off the throttle or even gently applies the brakes to maintain a constant safe distance (which you can adjust) behind that vehicle. As soon as the vehicle pulls into another lane, ACC accelerates, smoothly and progressively, to your original chosen speed.

eGMCarTech
the CarTech Mag

Lexus Prices LS 460's Automated Parking Option Below $1,000

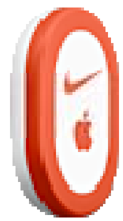
September 22nd, 2006 - Posted under Lexus

While Lexus still hasn't released more images or pricing info on the Lexus LS 460, the company is saying that it will price its Advanced Parking Guidance System below $1,000. The Automated Parking Option in the Lexus LS 460 backs the car into a parking space once the driver has lined up the car properly using rearview camera option on its in-dash screen. The driver will then use the brakes to adjust speed of the vehicle while the car adjusts the steering. Umm, we wouldn't spend even $500 for that options, but we're sure some people will try it off just to say they have it.

- 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
  - ~ $500 billion (that's *half a trillion dollars* …) in *annual* economic cost
    - 200 times greater than even an extravagant estimate of the nation's annual investment in computing research

7. Personalized health monitoring => quality of life

Omron pedometer



Nike + iPod

Bodymedia multi-function

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

Glucowatch: measuring body chemistry

Quality of Life Technology Engineering Research Center

Takeo Kanade
Director
U. A. and Helen Whitaker University Professor
Robotics Institute
Carnegie Mellon University

Rory Cooper
Co-Director
FISA/PVA Chair and Distinguished Professor
Dept of Rehabilitation Science and Technology
University of Pittsburgh

Intelligent systems that augment body and mind

... Technology to Enable Self-determination for Older Adults and People with Disabilities

QoLT Vision: Outcome

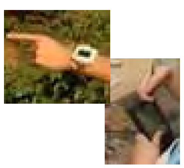
Intelligent systems that augment body and mind

Increase **employability** and **productivity** across the life span

Expand the range of environments in which people will be independently and safely mobile, increasing **community participation**

Expand the number of people and number of years that they can **live independently** at home

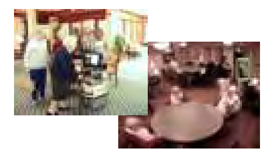
Enhance **QoL** and **capacity** of caregivers



Relate *human physiological, physical, and cognitive function* ***to the design*** *of intelligent systems*

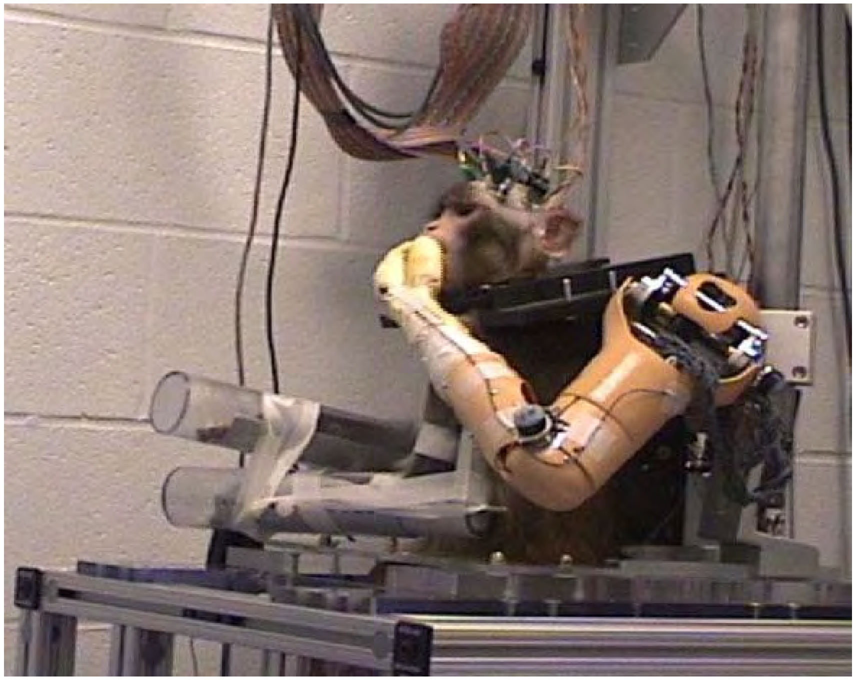
Create *technologies & systems that make* ***measurable positive impact*** *on quality of life*

Work closely *with user groups* ***throughout*** *design, development, test, and deployment phases for adoption, evaluation, and privacy concerns*



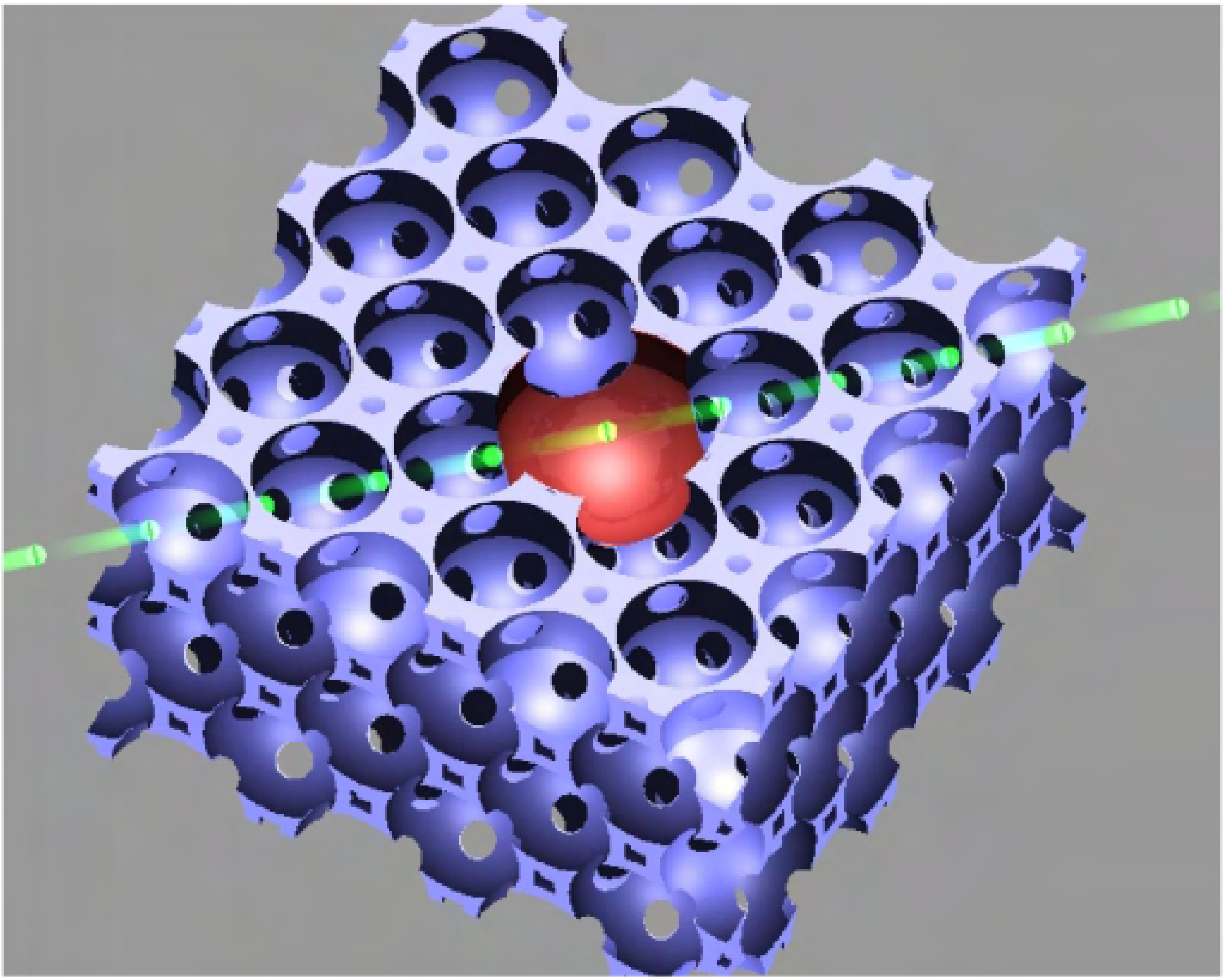
Develop *the QoLT curriculum,* ***motivate*** *students and* ***inspire*** *under-represented groups to pursue* ***QoLT careers***

8. Neurobotics

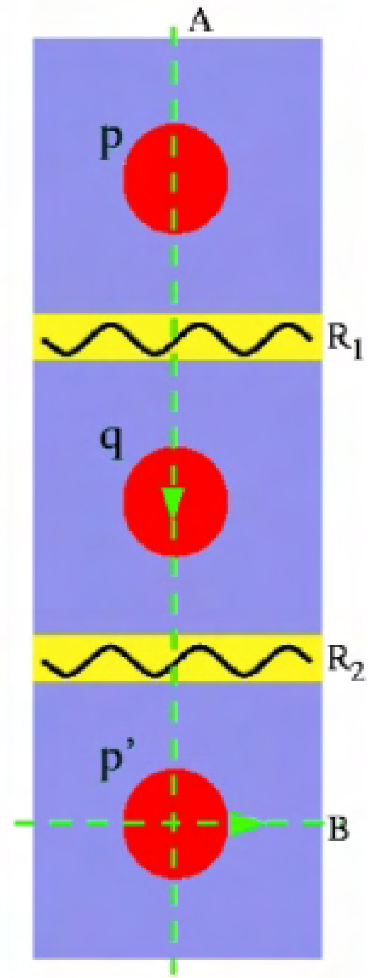


9. Personalized education

10. Quantum computing

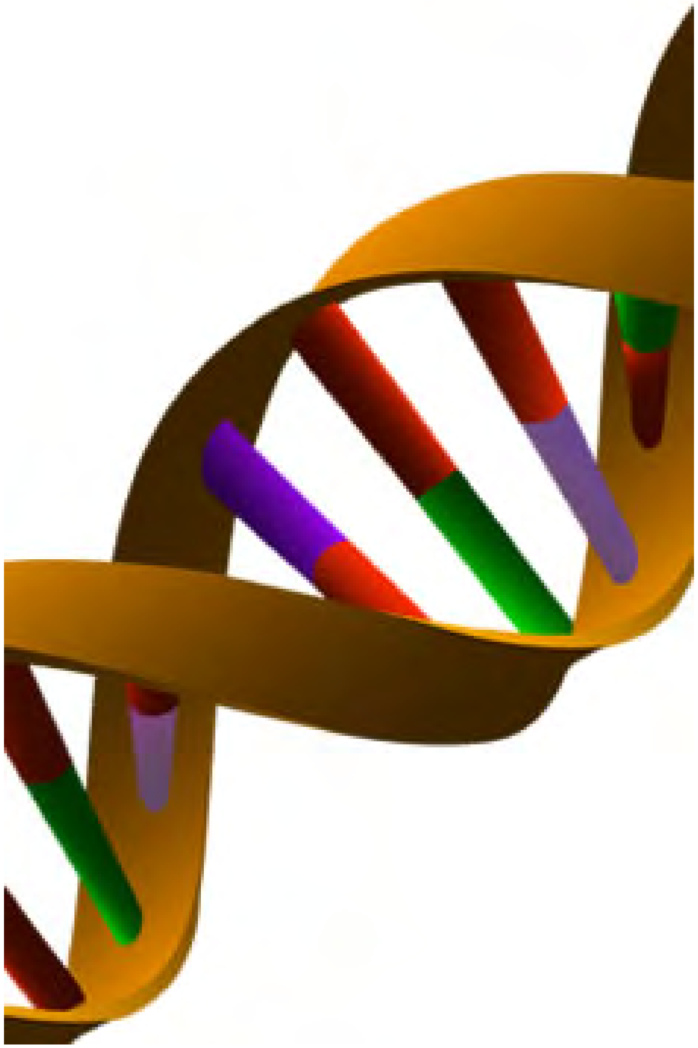


(a)

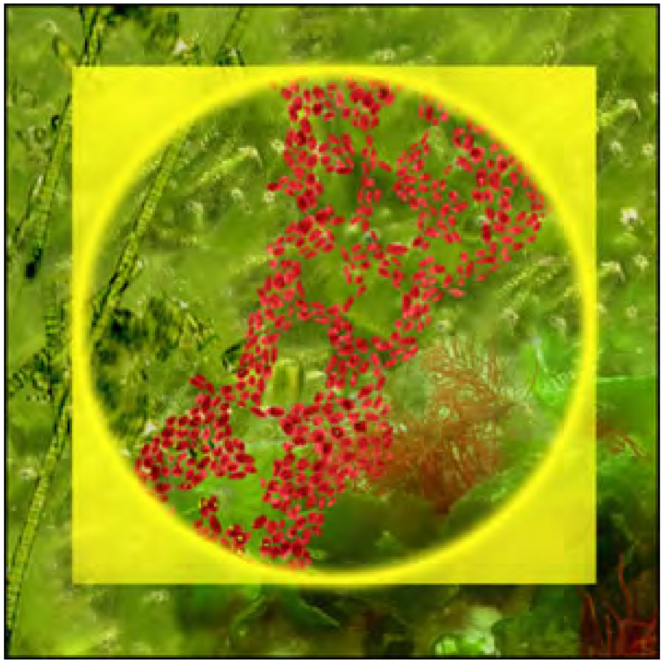


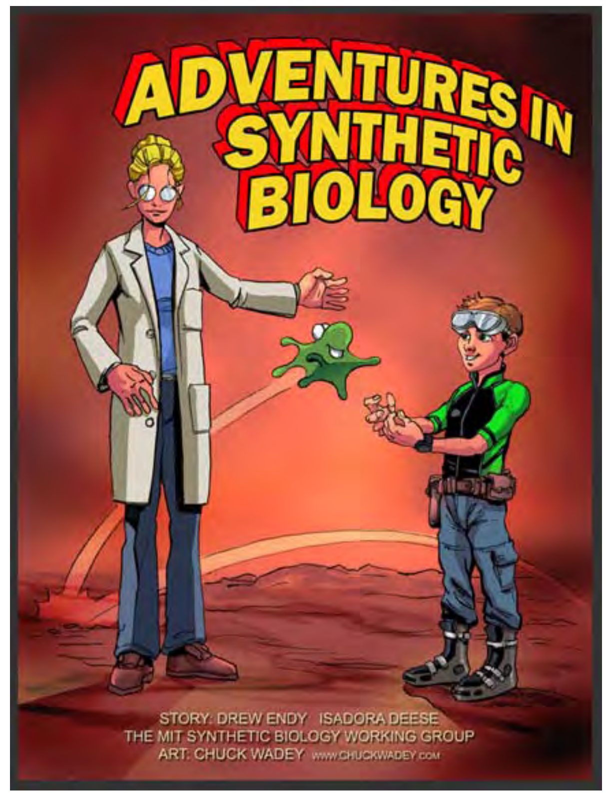
(b)

11. Predictive, preventive, personalized medicine



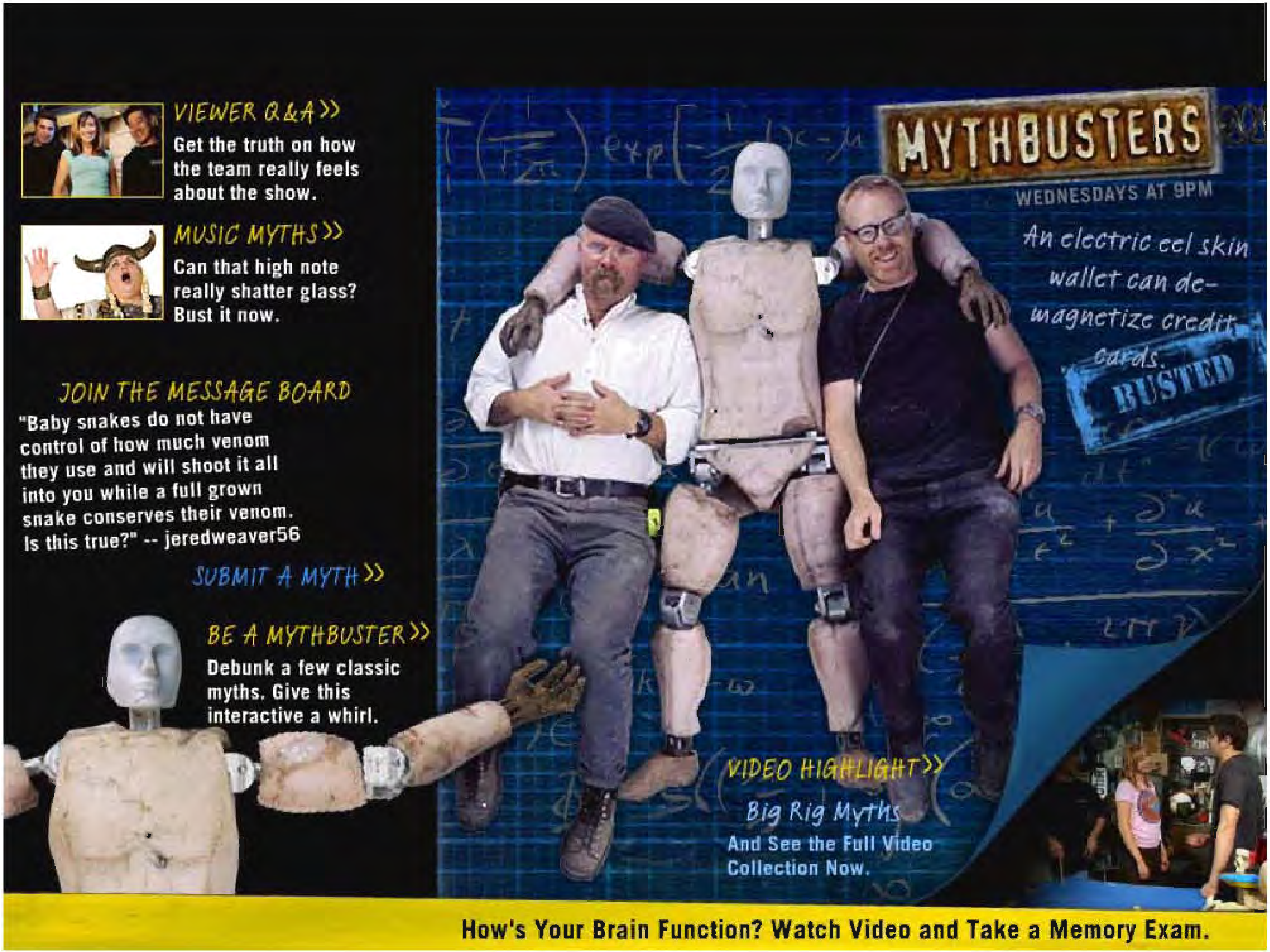
12. Synthetic biology





13. Entertainment technology; more broadly, content creation tools

14. Ubiquitous machine learning and data mining



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 de-magnetize 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 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

[Your part goes here]

- What are *your* compelling visions for the field?
- How can the CCC facilitate your pursuit of them?