Superhuman Cyberinfrastructure—Crossing the Rubicon

Invited Talk
Singularity University
NASA Ames
Mountain View, CA
July 27, 2009

Dr. Larry Smarr
Director, California Institute for Telecommunications and Information Technology
Harry E. Gruber Professor,
Dept. of Computer Science and Engineering
Jacobs School of Engineering, UCSD

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An estimate of the input rate of the human eye-brain system is ~10^9 bits/sec (1 gigabit/sec) and the human brain's compute speed is ~10^{15} to 10^{17} operations per second. With the use of dedicated fiber optics, scientific research labs globally are now routinely connecting with data-intensive streams at 10 gigabit/sec. This enables streaming of uncompressed high definition video (1.5 gigabit/sec) or digital cinema video with four times that resolution (7.6 gigabit/sec) on a planetary scale at near photorealism. In our laboratories, transmissions are being demonstrated with bandwidths exceeding terabit/sec, roughly one thousand times what a human eye-brain system can process. Persistent petaFLOPs (10^{15} floating point operations per sec) supercomputers are running complex scientific simulations and the planning is under way for Exascale computers, which will run at 1000 petaFLOPS, likely exceeding the capacity of a human brain. Visualization has expanded from the million pixels on most PCs to a fraction of a billion pixels, exceeding the resolution of a human eye. This allows for interactive viewing of hierarchical complex systems at high resolution, including brain structure. I will illustrate each of these post-human capabilities and explain how they are currently being interconnected on a planetary-scale, a critical step on the path to the Singularity.

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Three Accelerators for an Exponentially Data Rich World

- **Supercomputers Surpassing Human Brain Speed**
- **Scalable Visualization Surpassing Human Eye**
- **Personal Lightpaths Surpassing Eye-Brain I/O**

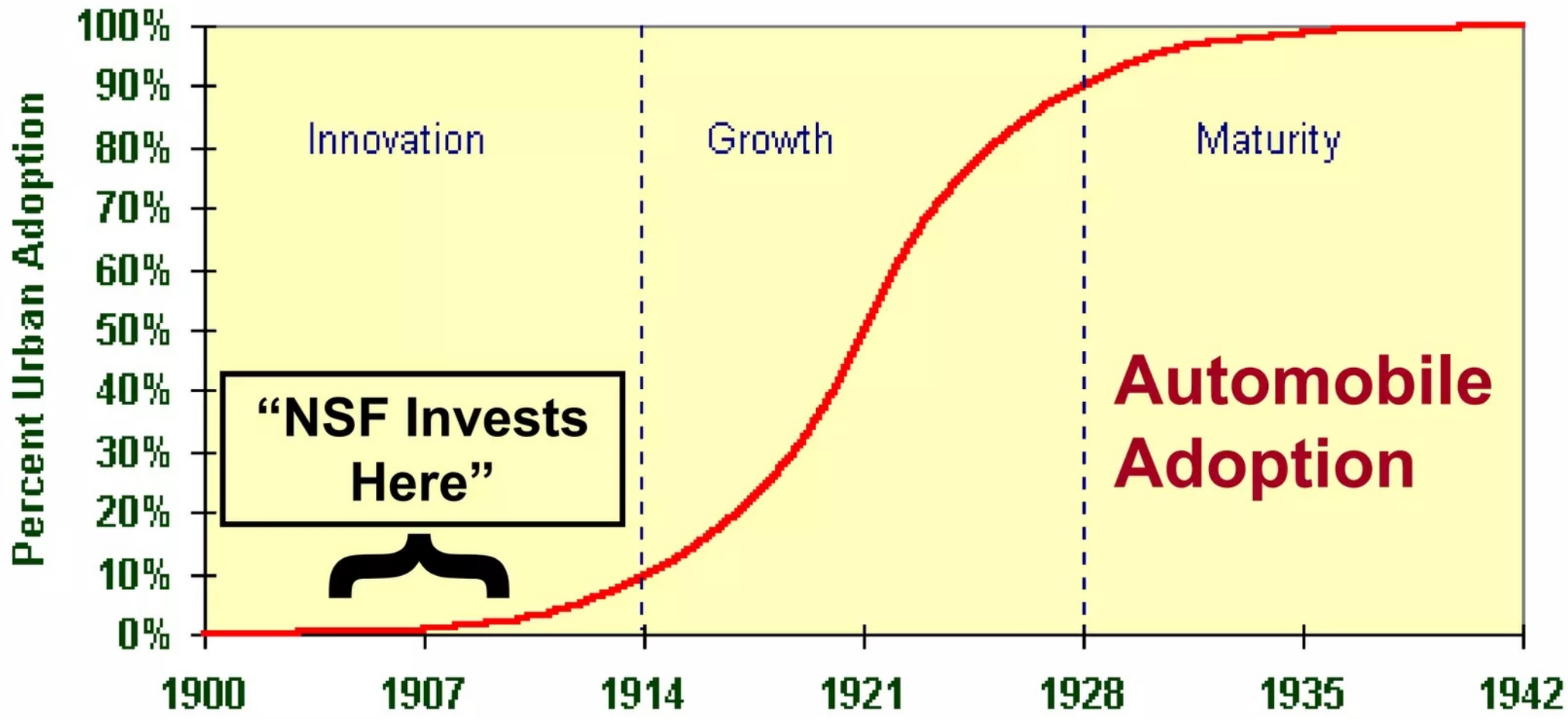
All Are Transformational for Singularity University

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From Elite Science to the Mass Market

- **Four Examples I Helped "Mid-Wife":**
  - **Supercomputers to GigaHertz PCs**
  - **Scientific Visualization to Movie/Game Special Effects**
  - **CERN Preprints to WWW**
  - **NSFnet to the Commercial Internet**
- **Technologies Diffuse Into Society Following an S-Curve**



Source: Harry Dent, The Great Boom Ahead

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Fifteen Years from Bleeding Edge Research to Mass Consumer Market

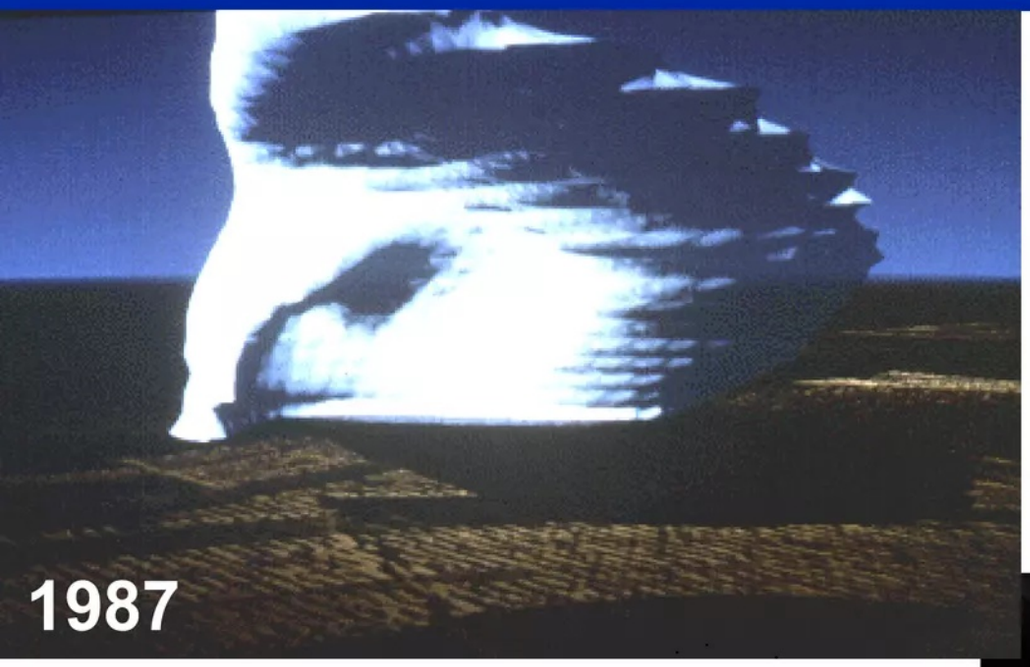
- 1990 Leading Edge University Research Center-NCSA
  - Supercomputer GigaFLOPS Cray Y-MP ($15M)
  - Megabit/s NSFnet Backbone
- 2005 Mass Consumer Market
  - PCs are Multi-Gigahertz ($1.5k)
  - Megabit/s Home DSL or Cable Modem



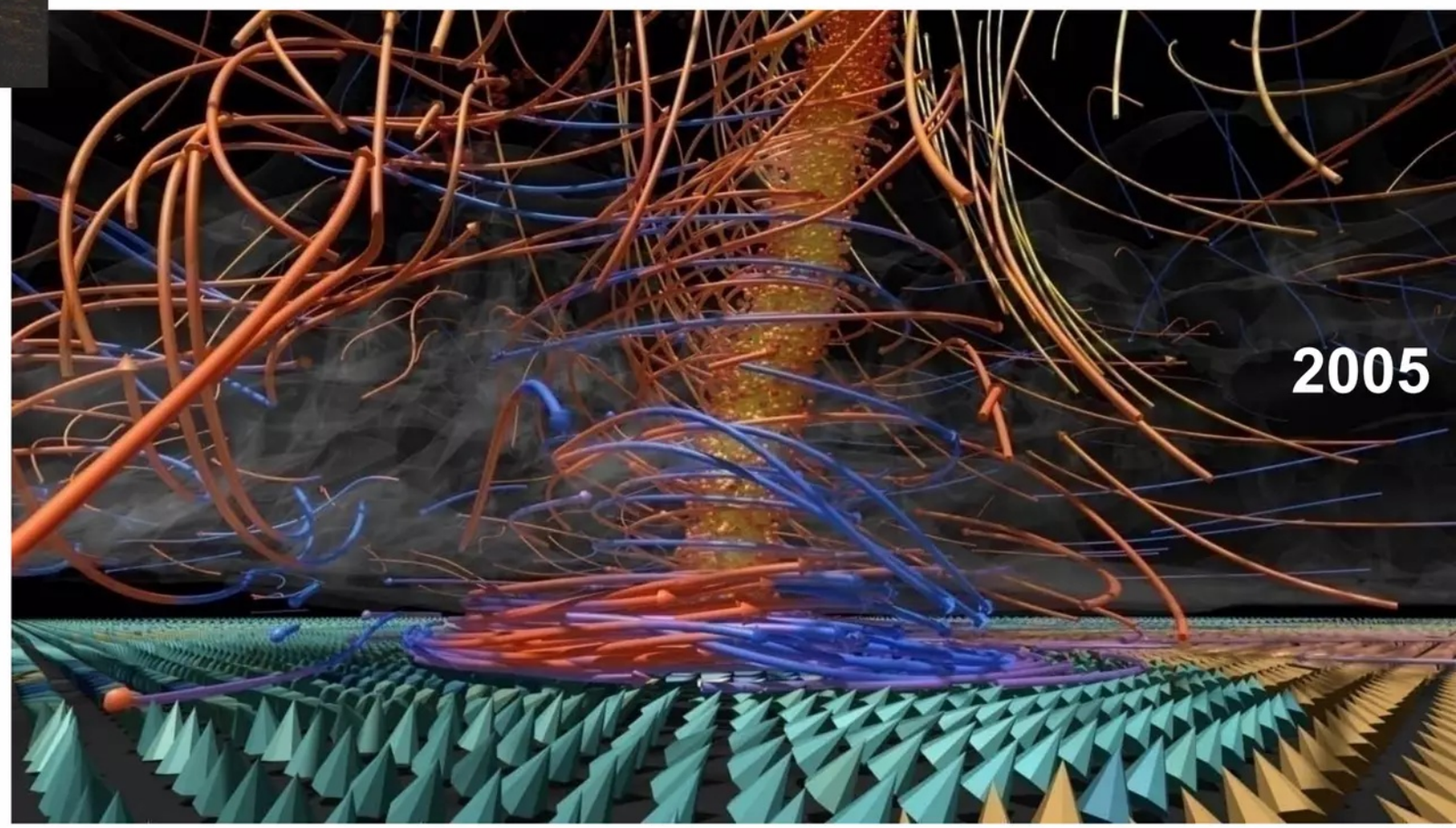
NSF Blue Waters Petascale Supercomputer (2011)
Will be Over 1 Million Times Faster than Cray Y-MP!
Enormous Growth in Parallelism
Processors: Y-MP 4, Blue Waters 200,000

www.ncsa.uiuc.edu/BlueWaters/system.html

Exponential Increases in Supercomputer Speed and Visualization Technology Drive Understanding and Applications



Showed Thunderstorms Arise from Solving Physics Equations

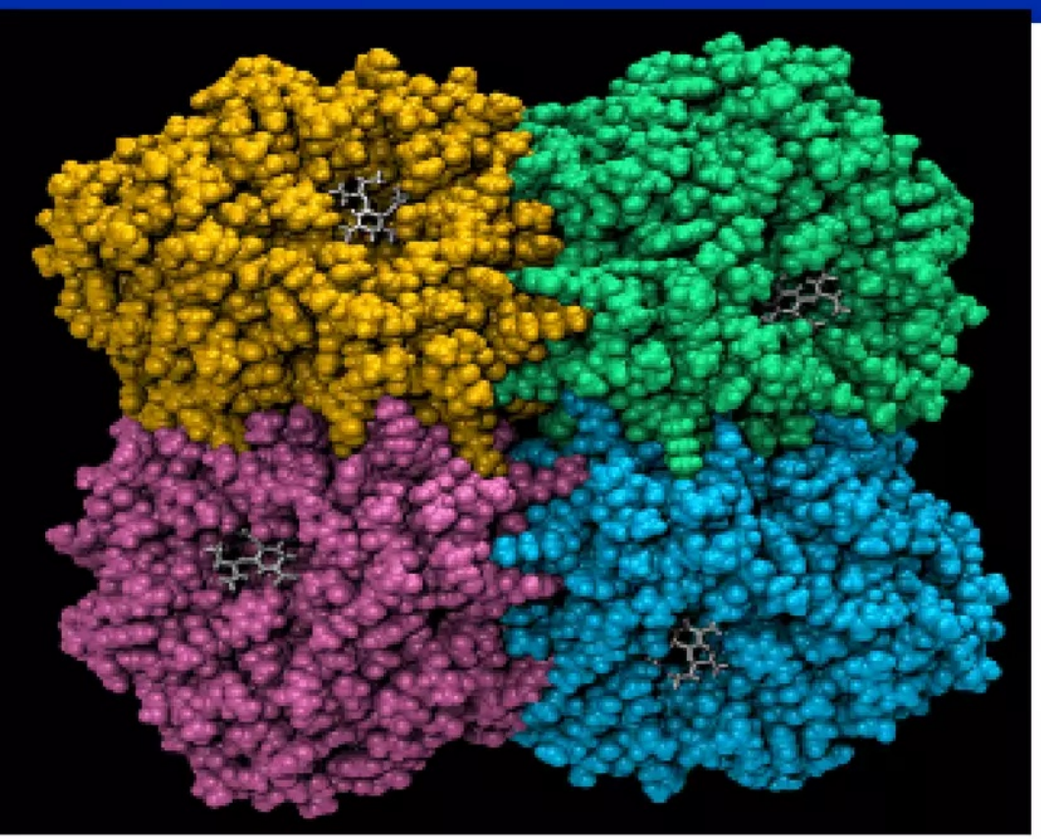


Vastly Higher Resolution Uncovers Birth of Tornadoes

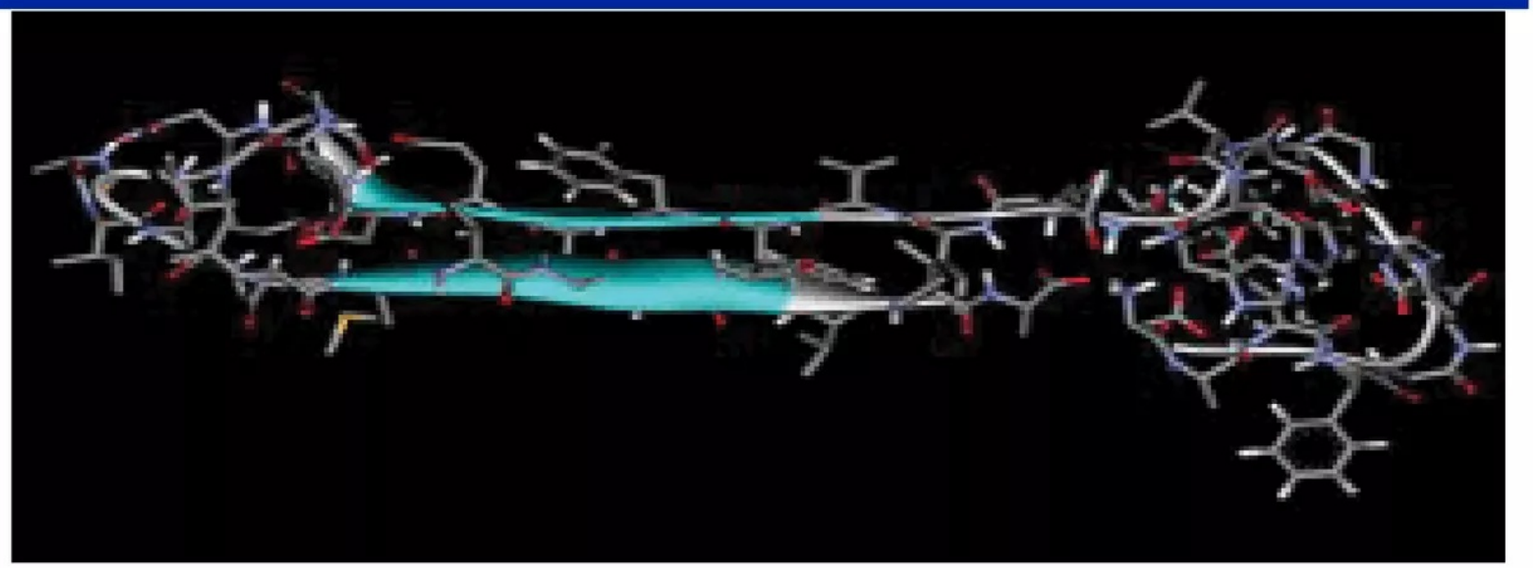
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Source: Donna Cox, Robert Patterson, Bob Wilhelmson, NCSA

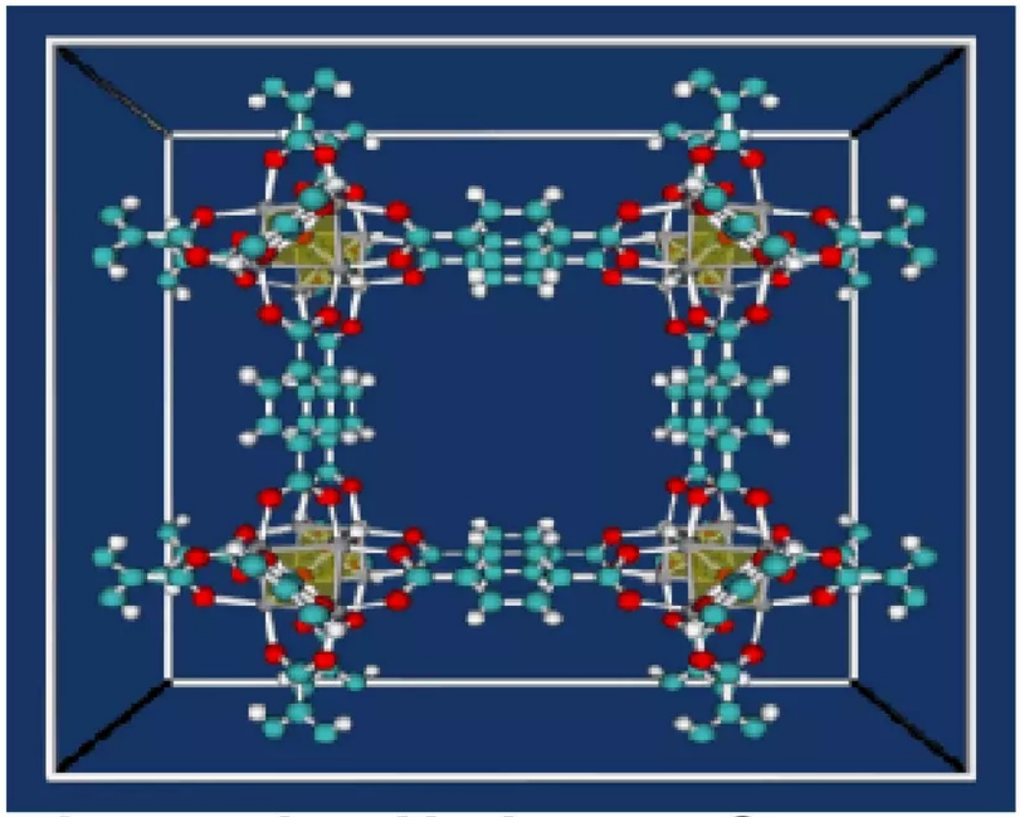
Frontier Applications of High Performance Computing Enabled by NSF's TeraGrid



Designing Bird Flu Drugs



Investigating Alzheimer's Plaque Proteins



Improving Hydrogen Storage in Fuel Cells

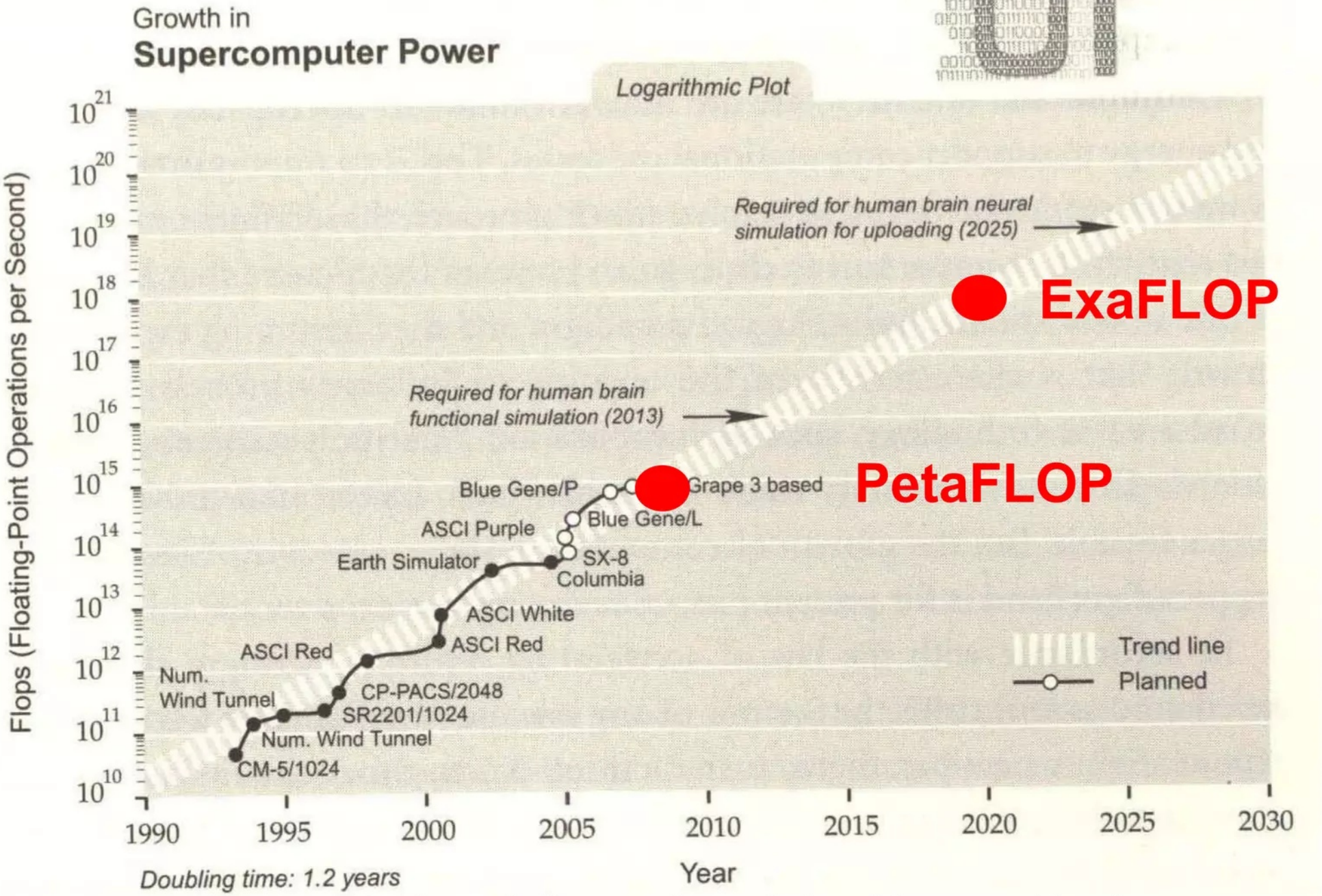


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During the Next Decade We Will Witness the Transition of Silicon Supercomputers Pass Human Brain Speed

Source: Ray Kurzweil, *The Singularity is Near*



Computational Capacity of the Human Brain—
"I will Use a More Conservative Figure of 10^{16}cps for Our Subsequent Discussions."--Kurzweil

Los Alamos Roadrunner-
World's First PetaFLOP Supercomputer



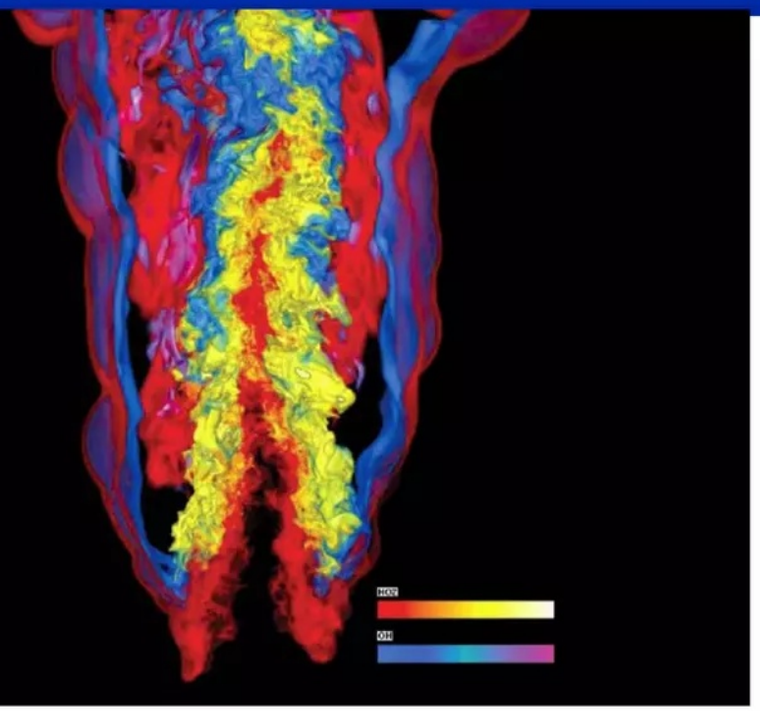
PetaVision models the human visual system—mimicking more than 1 billion visual neurons and trillions of synapses.

Los Alamos researchers believe they can study in real time the entire human visual cortex

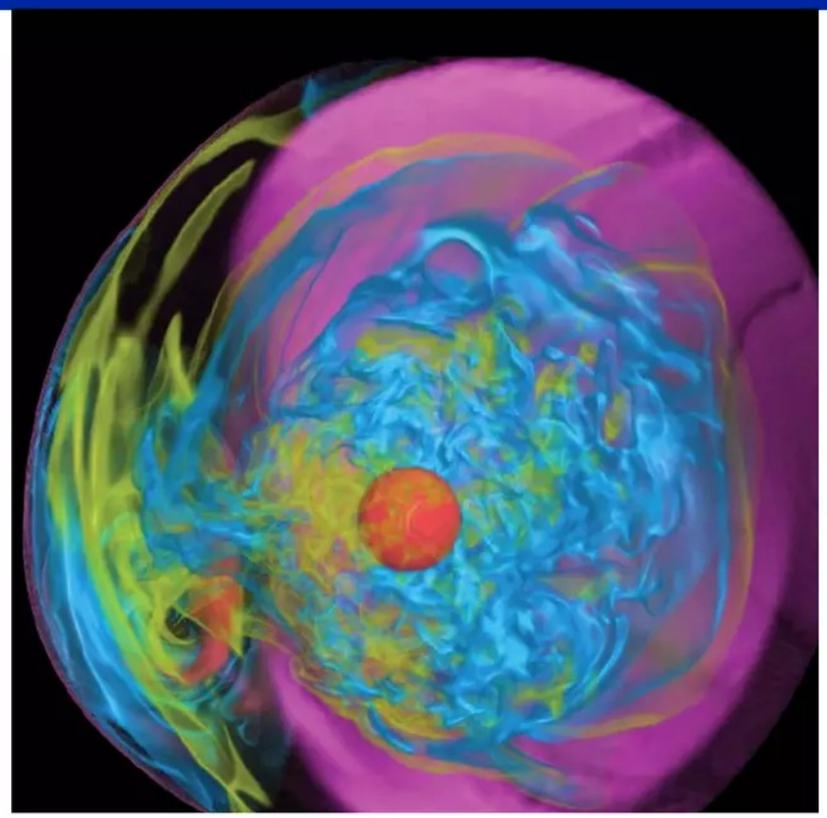
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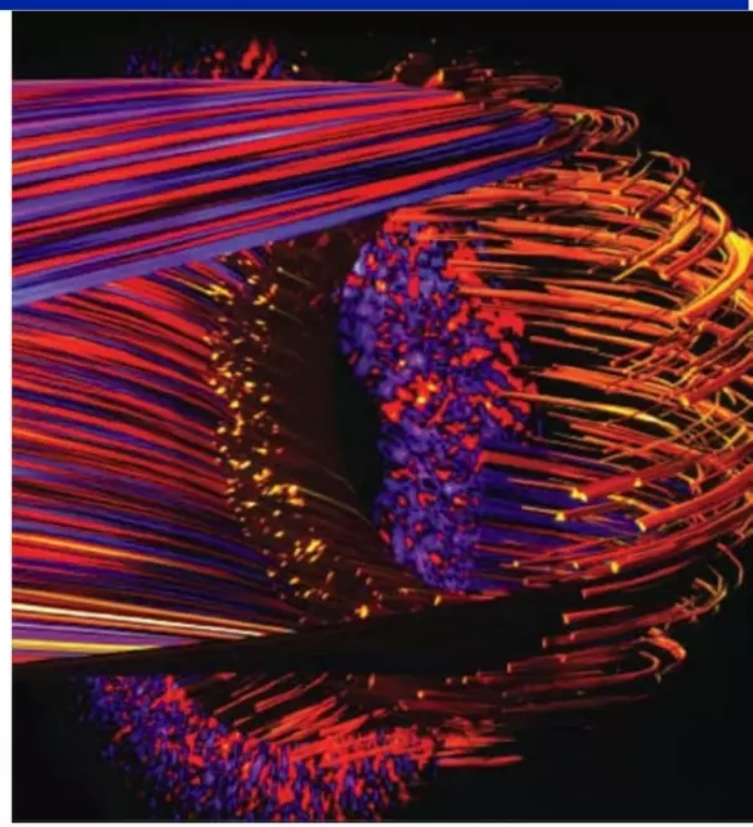
Department of Energy Office of Science
Leading Edge Applications of Petascale Computers



Flames

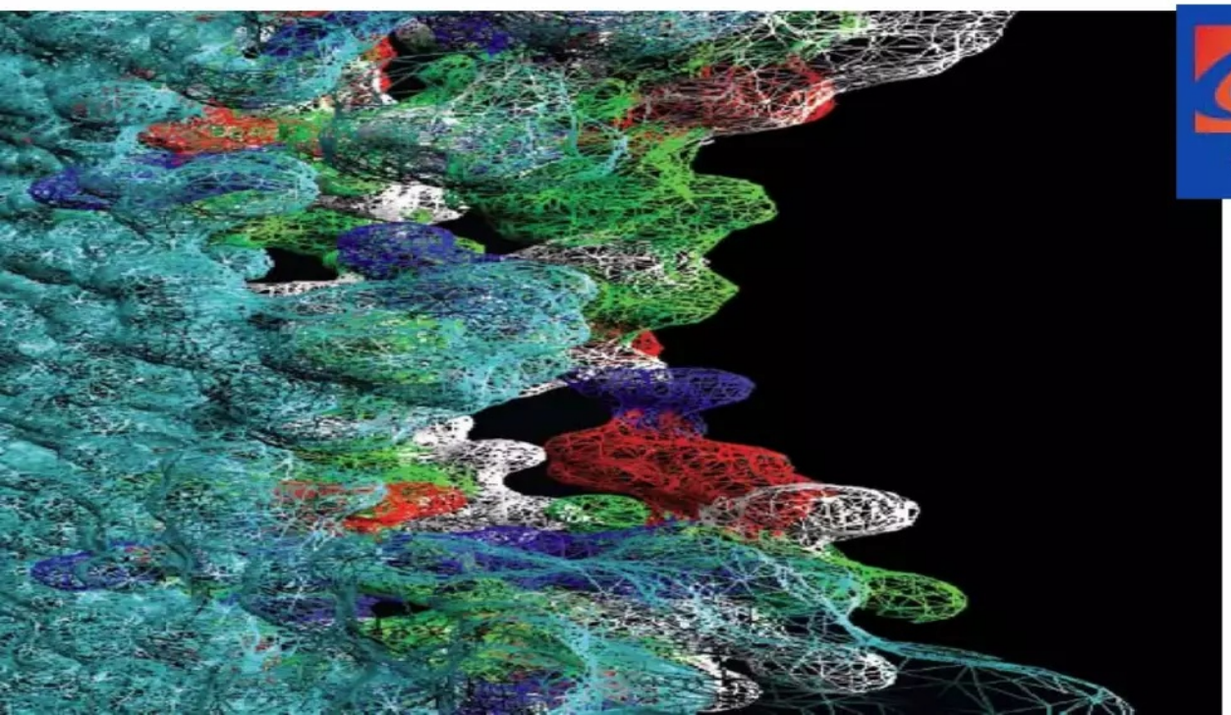


Supernova



Fusion

Parkinson's



Office of Science
U.S. DEPARTMENT OF ENERGY



The Road to the ExaFLOP

JUNE 09, 2009

Oak Ridge Jaguar Supercomputer Going to About 2.7 Petaflops by Yearend

NEC claims 10-Petaflop supercomputing breakthrough

Fujitsu Building 10 Petaflop Supercomputer

Armonk, NY - 03 Feb 2009: **IBM plans 20 petaflop supercomputer**

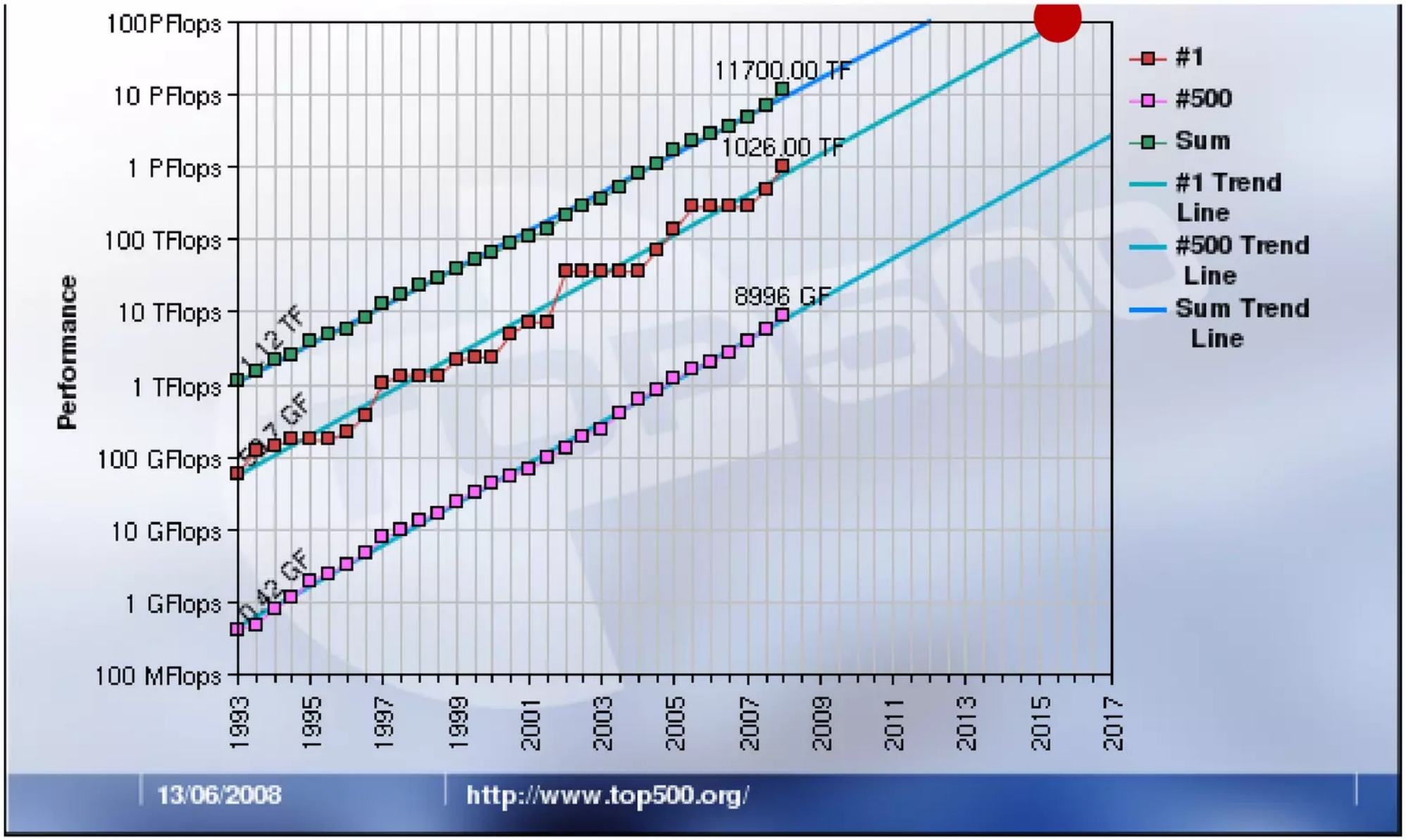
"Both the Department of Energy's Office of Science and the National Nuclear Security Administration have identified exascale computing as a critical need in roughly the 2018 timeframe,"

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Fastest Computer on Earth will Reach ~ Human Brain Speed 100 PetaFLOPS by 2016

- Requires Megacomputers~One Million Cores
- Runs ~ One Million Times Hotter than Brain



www.top500.org/lists/2008/06/performance_development

Exploring the Limits of Scalability
The Metacomputer as a Megacomputer

- **Napster Meets Entropia**
  - Distributed Computing and Storage Combined
  - Assume Ten Million PCs in Five Years
    - Average Speed Ten GigaFLOPs
    - Average Free Storage 100 GB
  - Planetary Computer Capacity
    - 100 PetaFLOPs Speed
    - 1,000 PetaByte Storage
- **~1-100 PetaFLOPs is Roughly a Human Brain-Second**
  - Morovec-Intelligent Robots and Mind Transferral
  - Kurzweil-The Age of Spiritual Machines
  - Joy-Humans an Endangered Species?
  - Vinge-Singularity

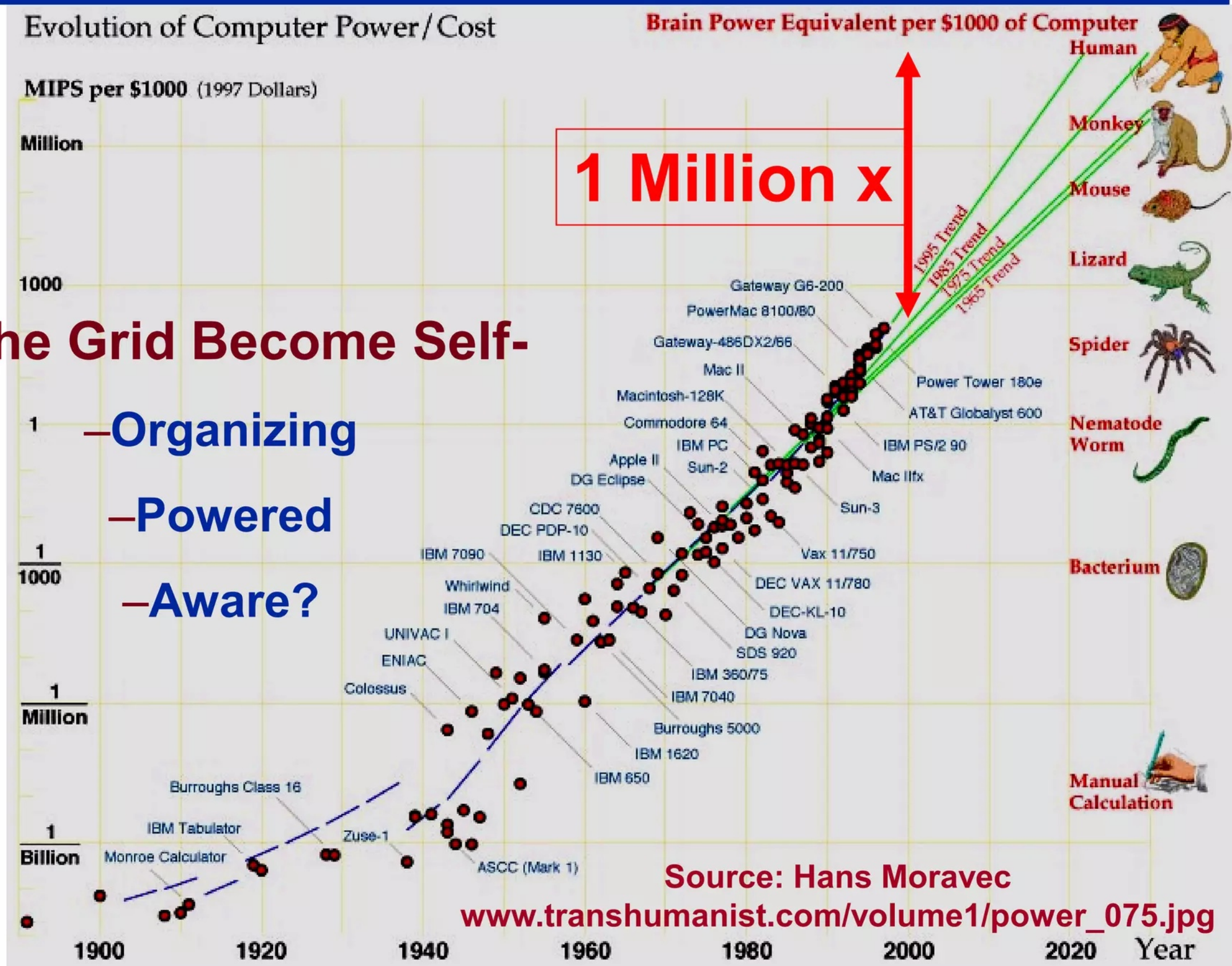
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Source: Larry Smarr Megacomputer Panel
SC2000 Conference

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The Planetary Computing Power is Passing Through an Important Threshold

- **Will the Grid Become Self-**
  - **Organizing**
  - **Powered**
  - **Aware?**



Source: Hans Moravec
www.transhumanist.com/volume1/power_075.jpg

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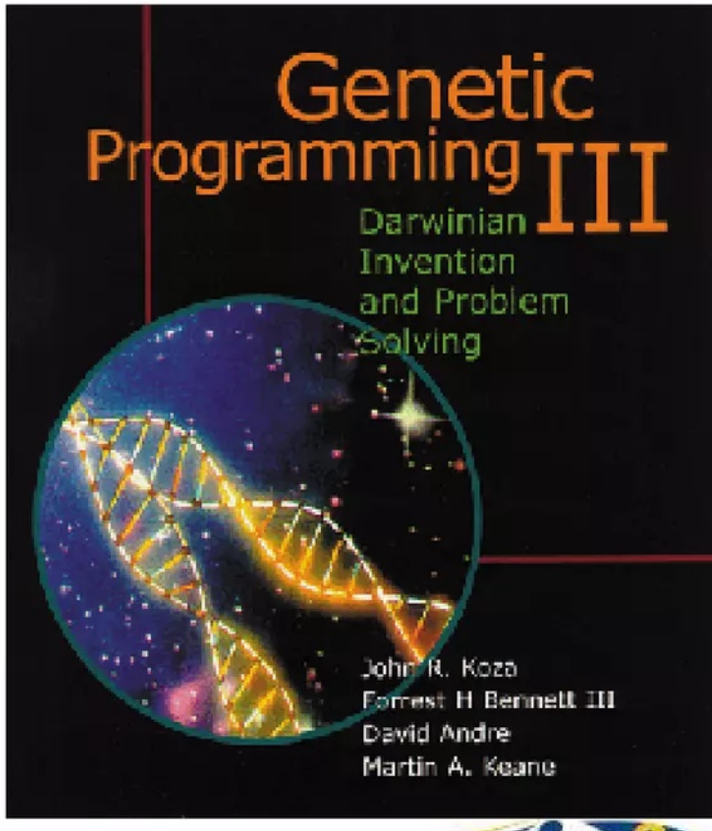
From Software as Engineering to Software as Biology

- Stanford Professor John Koza
- Uses Genetic Programming to Create a Working Computer Program From a High-Level Problem Statement of a Problem
- Starting With a Primordial Ooze of Thousands of Randomly Created Computer Programs, a Population of Programs Is Progressively Evolved Over a Series of Generations
- Has Produced 21 Human-Competitive Results





1,000-Pentium Beowulf-Style Cluster Computer for Genetic Programming



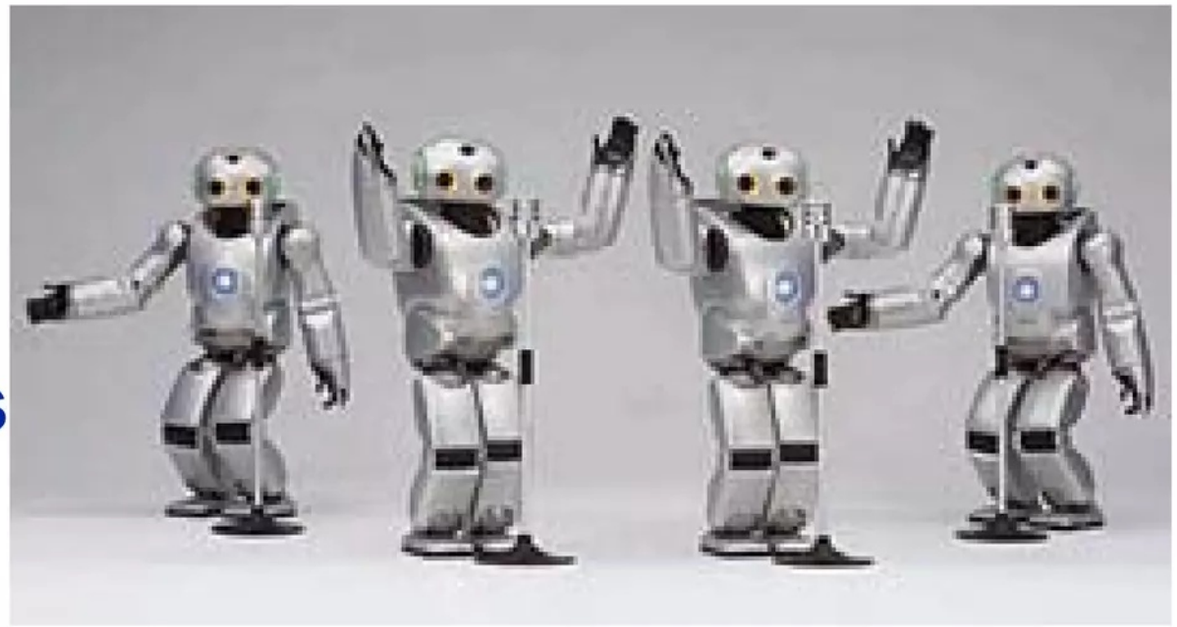
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www.genetic-programming.com/

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Accelerator: Robots Tap the Power of the Planetary Computer

- **Sensors**
  - Temperature
  - Distance
  - Speed
  - Accelerations
  - Pressure
  - IR
  - Vibration
  - Imaging



Sony's AIBO and SDR-4X



- **Linked to Internet by Wi-Fi Wireless Broadband**
  - Completely Changes Robotics Architecture
  - Access to Nearly Infinite Computing, Storage, Software
  - Marriage of Net Software Agents to Physical Probes
  - Ad Hoc Teams of Interacting Intelligent Robots

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"Broadband" Depends on Your Application: Data-Intensive Science Needs Supernetworks



- **Mobile Broadband**
  - **0.1-0.5 Mbps**

100,000 Fold Range
All Here Today!



- **Home Broadband**
  - **1-5 Mbps**

"The future is already here,
it's just not evenly distributed"
William Gibson, Author of Neuromancer



- **University Dorm Room Broadband**
  - **10-100 Mbps**



- **Dedicated Supernetwork Broadband**
  - **1,000-10,000 Mbps**

What is the Rate at Which the Eye-Brain System Can Ingest Information?

Frame Resolution Color Depth Frame Rate

10 Mpixels x 24 bits/pixel x 30 frames/sec

= 7,200 Mbps or ~10 Gbps

The Limits of Human Vision, *Michael F. Deering, Sun Microsystems*

A model of the perception limits of the human visual system is presented, resulting in an estimate of ~15 million variable resolution pixels per eye. Assuming a 60 Hz stereo display with a depth complexity of 6, we make the prediction that a rendering rate of approximately ten billion triangles per second is sufficient to saturate the human visual system.

www.swift.ac.uk/vision.pdf

"How Much the Eye Tells the Brain"

The human retina transmits data to the brain at the rate of 10 Mbps

Koch et al., Current Biology 16, 1428–1434, July 25, 2006

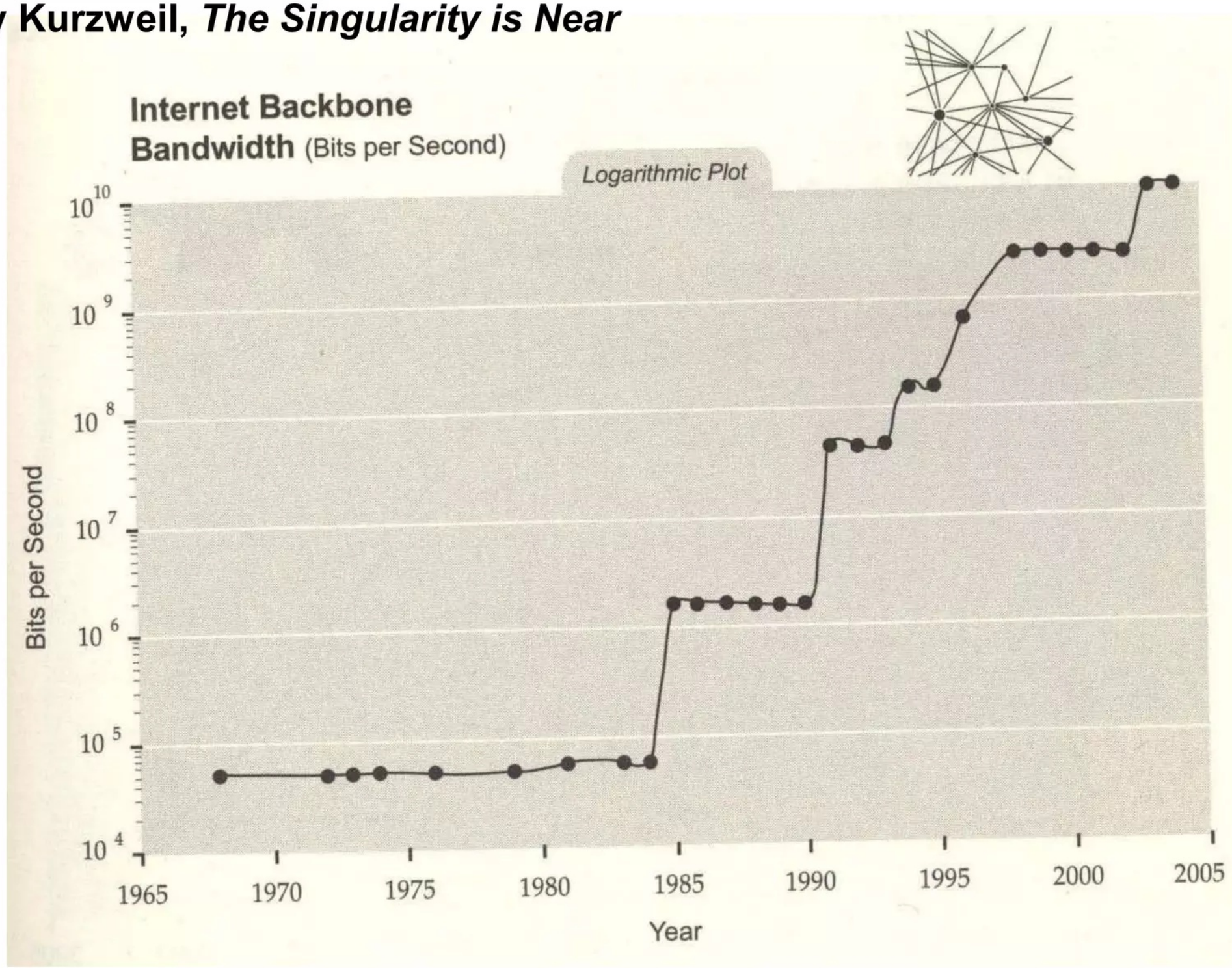
http://citeseer.ist.psu.edu/cache/papers/cs2/127/http:zSzzSzretina.anatomy.upenn.eduzSzpdfileszSz6728.pdf/current-biology-july-elsevier.pdf

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The Shared Internet Has a 10,000 Mbps Backbone

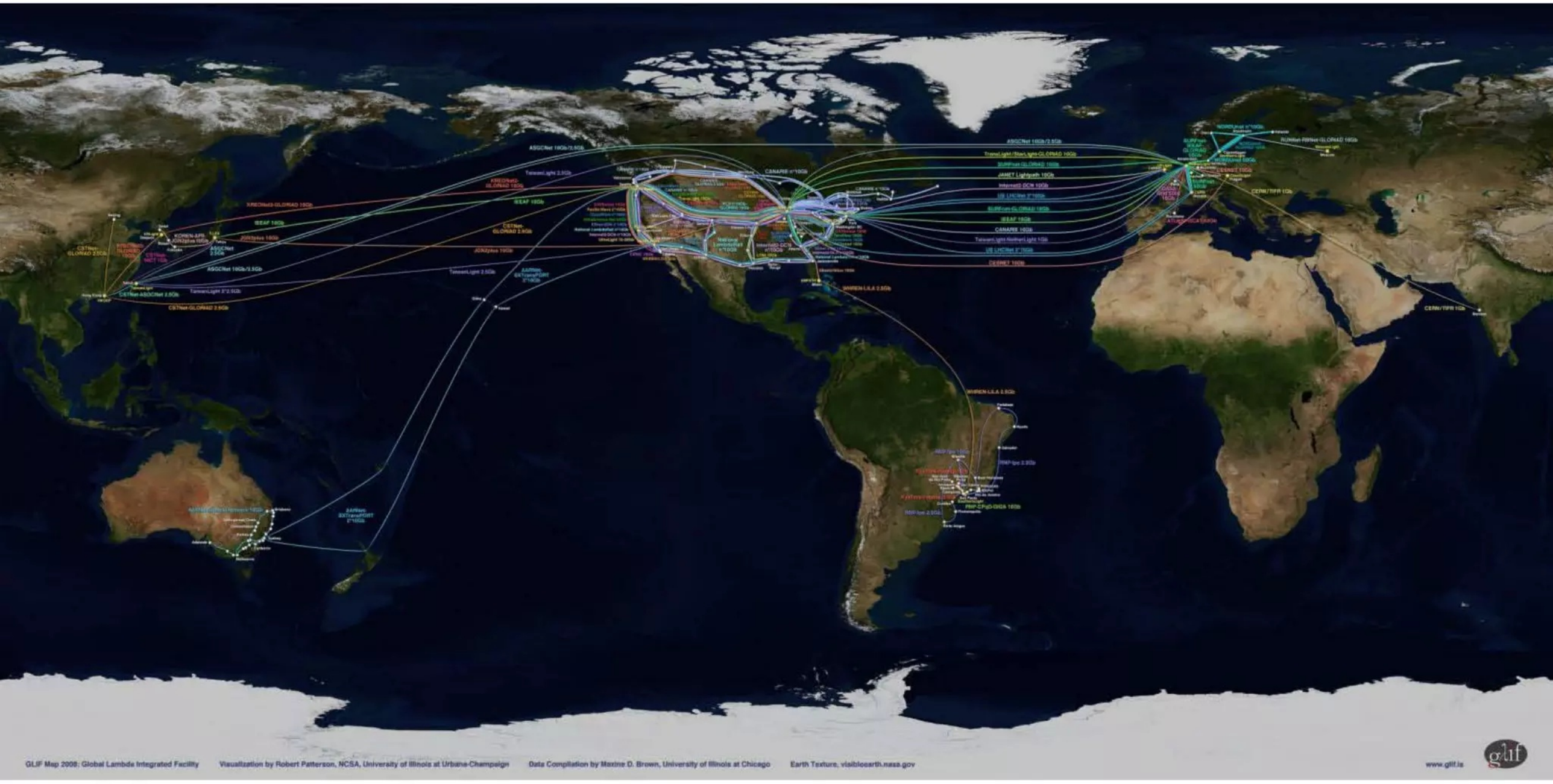
Source: Ray Kurzweil, *The Singularity is Near*



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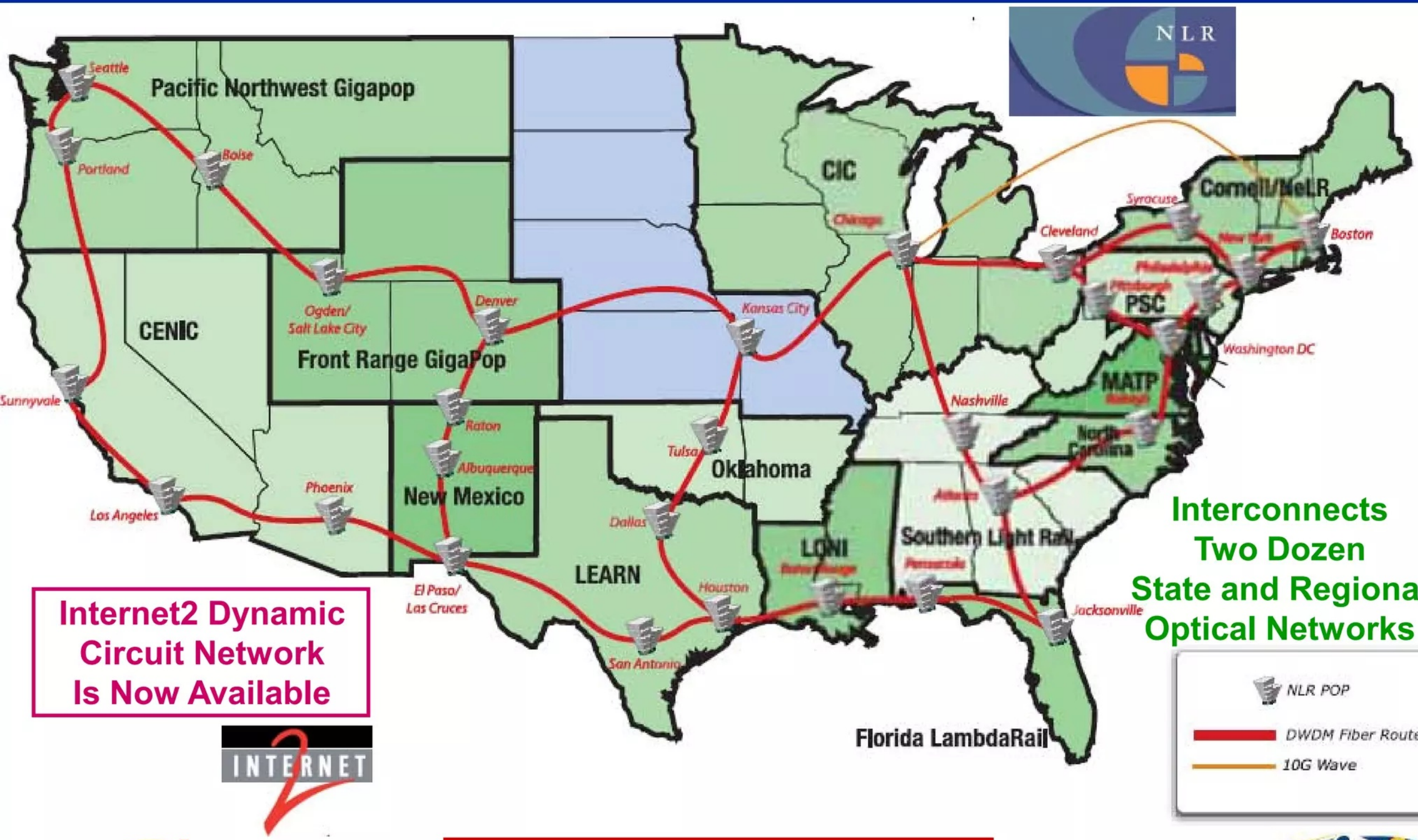
Global Innovation Centers are Being Connected with 10,000 Megabits/sec Clear Channel Lightpaths



100 Gbps Commercially Available
Research on 1 Tbps; 50 Tbps By 2020

Source: Maxine Brown, UIC and Robert Patterson, NCSA

Dedicated 10,000Mbps Supernetworks Tie Together State and Regional Fiber Infrastructure



Interconnects Two Dozen State and Regional Optical Networks

Internet2 Dynamic Circuit Network Is Now Available

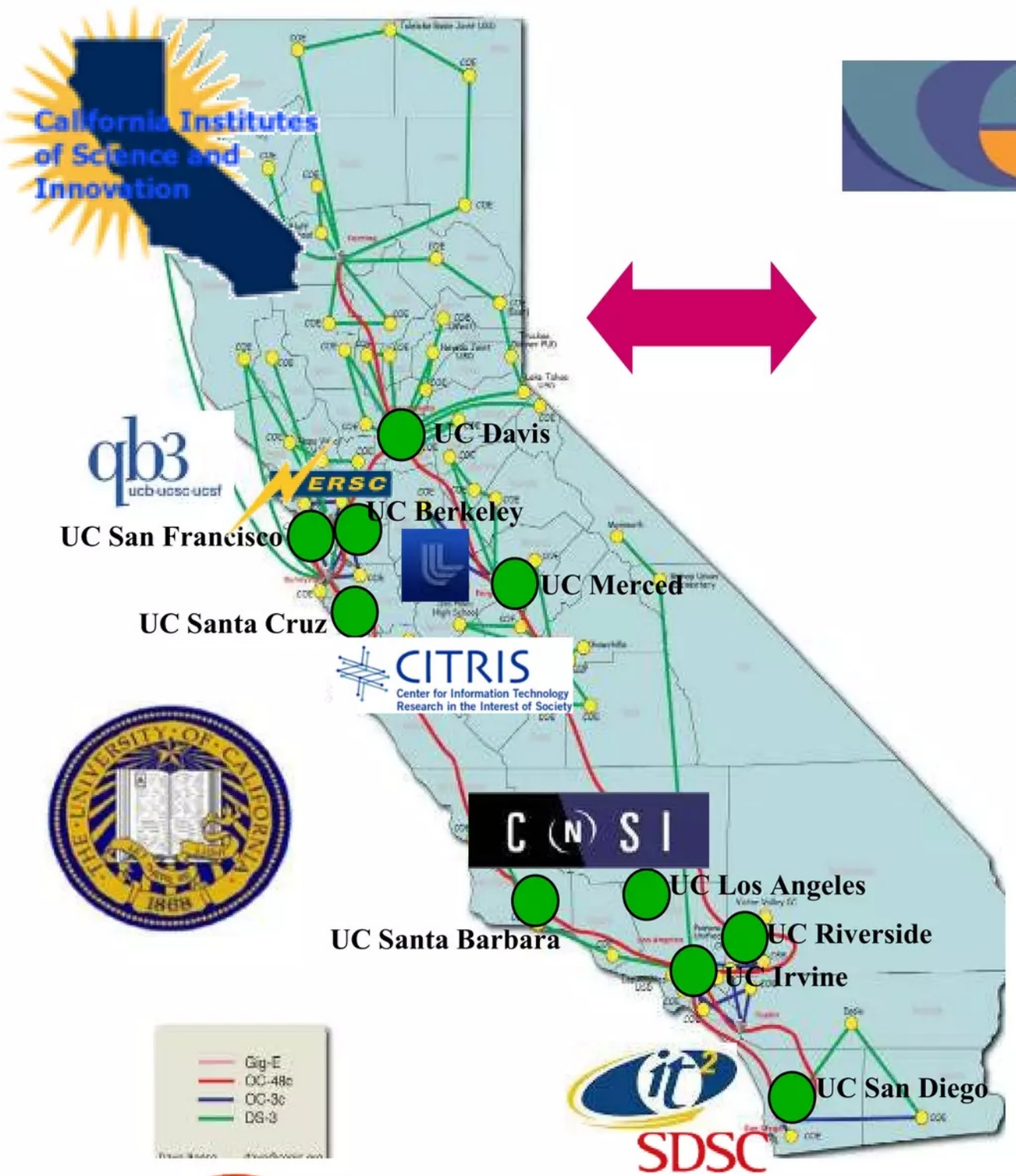
INTERNET 2

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NLR 40 x 10Gb Wavelengths Expanding with Darkstrand to 80

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Creating a California Cyberinfrastructure of OptIPuter "On-Ramps" to NLR, I2DC, & TeraGrid



NLR NATIONAL LAMBDARAIL

TeraGrid™

Internet2 Network
Dynamic Circuit Network

Creating a Critical Mass of OptIPuter End Users on a Secure LambdaGrid

CENIC Workshop at Calit2
Sept 15-16, 2008

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Accelerator: Global Connections Between University Research Centers at 10Gbps

Maxine Brown, Tom DeFanti, Co-Chairs

iGrid 2005

THE GLOBAL LAMBDA INTEGRATED FACILITY

www.igrid2005.org



the UC Discovery Grant

September 26-30, 2005

Calit2 @ University of California, San Diego

California Institute for Telecommunications and Information Technology



21 Countries Driving 50 Demonstrations
1 or 10Gbps to Calit2@UCSD Building
Sept 2005

First Trans-Pacific Super High Definition Telepresence Meeting in New Calit2 Digital Cinema Auditorium

Like High-Def? Here Comes the Next Level

By JOHN MARKOFF
Published: September 26, 2005

The New York Times ON THE WEB

Keio University President Anzai

UCSD Chancellor Fox

Lays Technical Basis for Global Digital Cinema

Sony
NTT
SGI

iGrid 2005

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NSF Instruments Generate Data at Enormous Rates-- Requiring Photonic Interconnects



"The VLA facility is now able to generate 700 Gigabits/s of astronomical data and the Extended VLA will reach 3.2 Terabits/sec by 2009."

--Dr. Steven Durand, National Radio Astronomy Observatory, e-VLBI Workshop, MIT Haystack Observatory., Sep 2006.



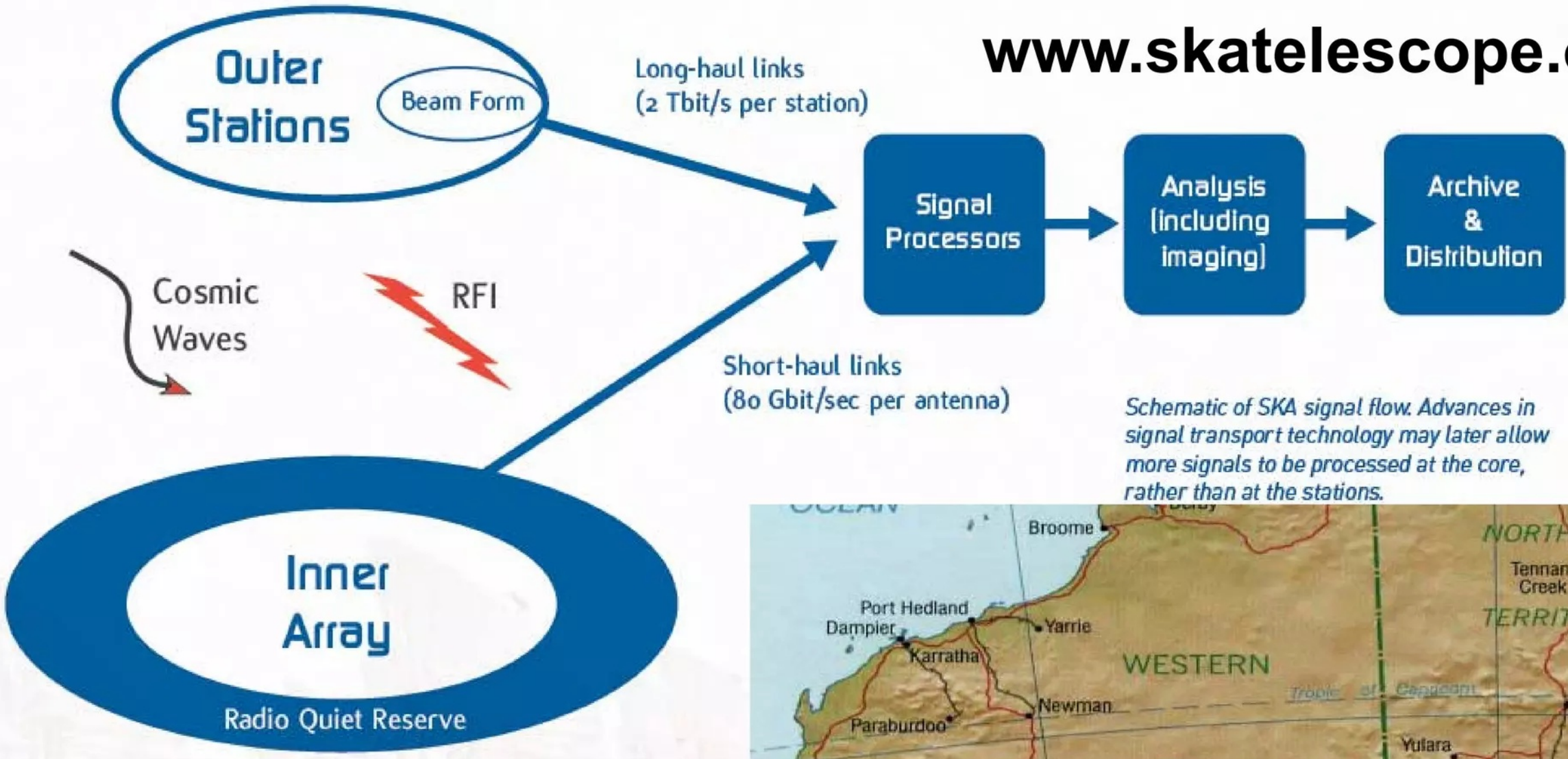
ALMA Has a Requirement for a 120 Gbps Data Rate per Telescope

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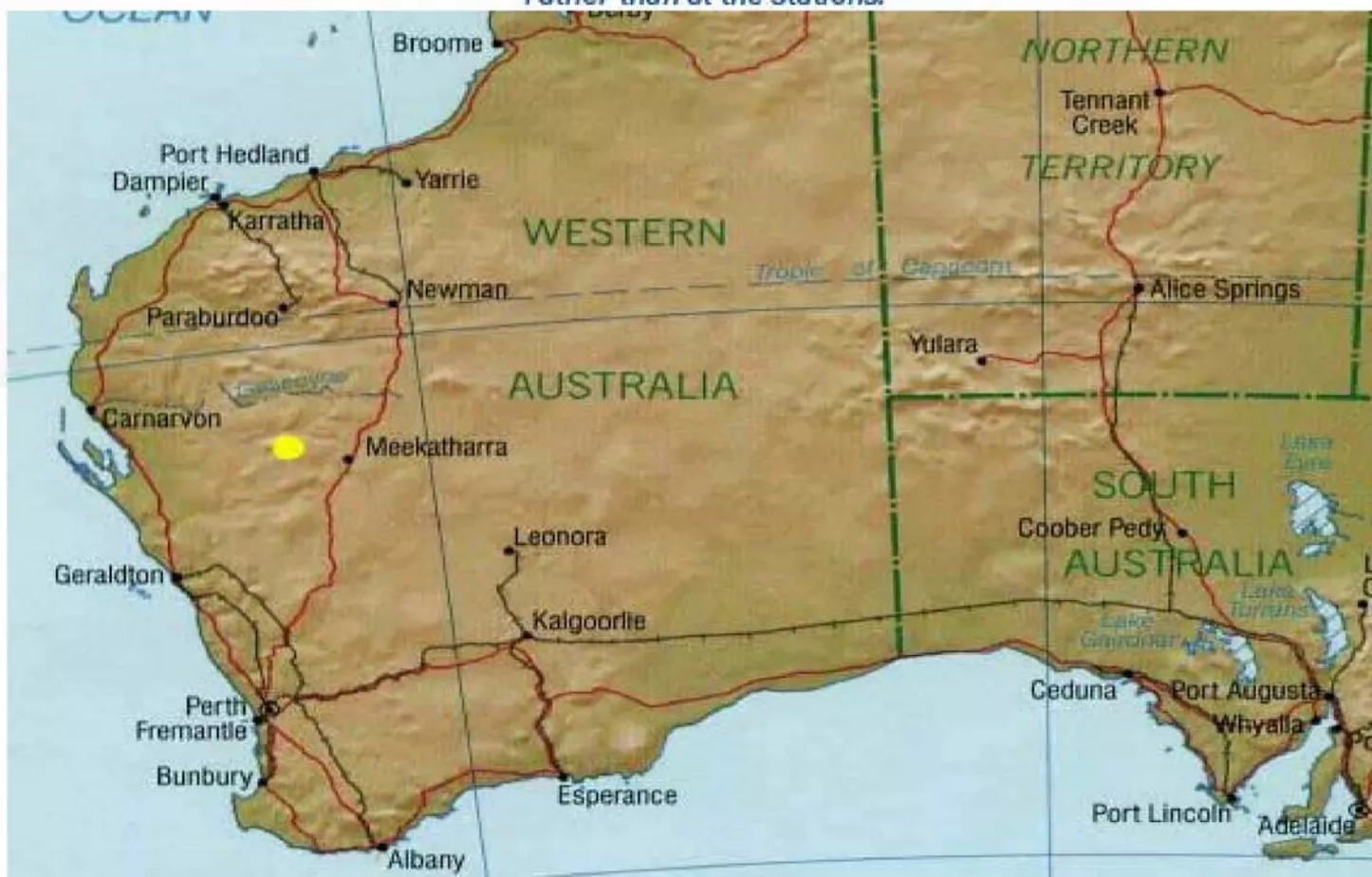
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Next Great Planetary Instrument:
The Square Kilometer Array Requires Dedicated Fiber

www.skatelescope.org



Schematic of SKA signal flow. Advances in signal transport technology may later allow more signals to be processed at the core, rather than at the stations.



Transfers Of 1 TByte Images World-wide Will Be Needed Every Minute!

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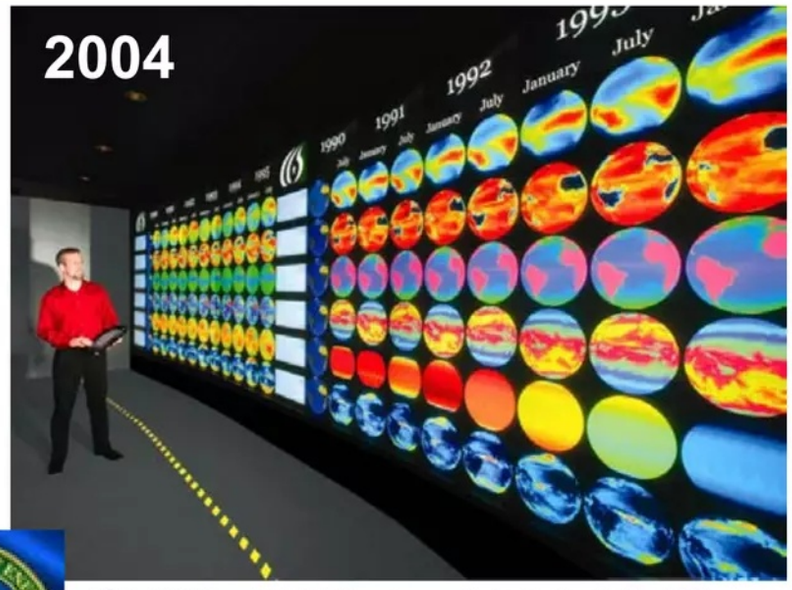
Challenge—How to Bring Scalable Visualization Capability to the Data-Intensive End User?



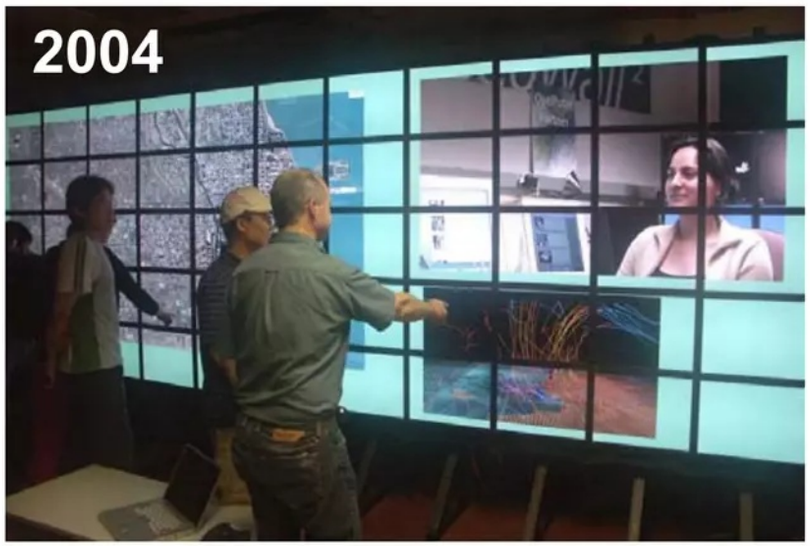
NCSA 4 MPixel
NSF Alliance PowerWall



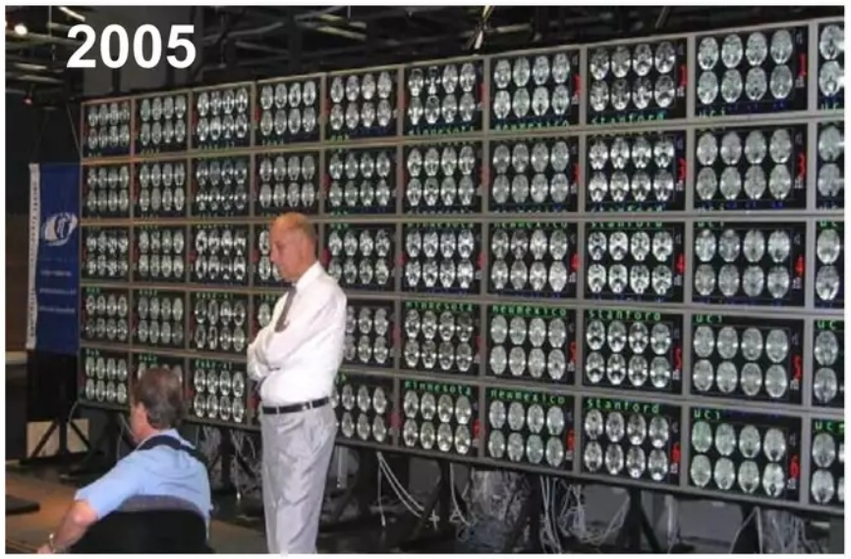
LLNL 20 Mpixel Wall



ORNL 35Mpixel EVEREST



EVL 100 Mpixel LambdaVision
NSF MRI



Calit2@UCI 200 Mpixel HiPerWall
NSF MRI



TACC 307 Mpixel Stallion
NSF TeraGrid

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NSF

**A Decade of NSF and DoE Investment--
Two Orders of Magnitude Growth!**

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NSF's OptIPuter Project: Using Supernetworks to Meet the Needs of Data-Intensive Researchers



OptIPortal–Termination Device for the OptIPuter Global Backplane

evl electronic visualization laboratory

SDSC SAN DIEGO SUPERCOMPUTER CENTER

NCMIR NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH at San Diego, an NIH supported resource center

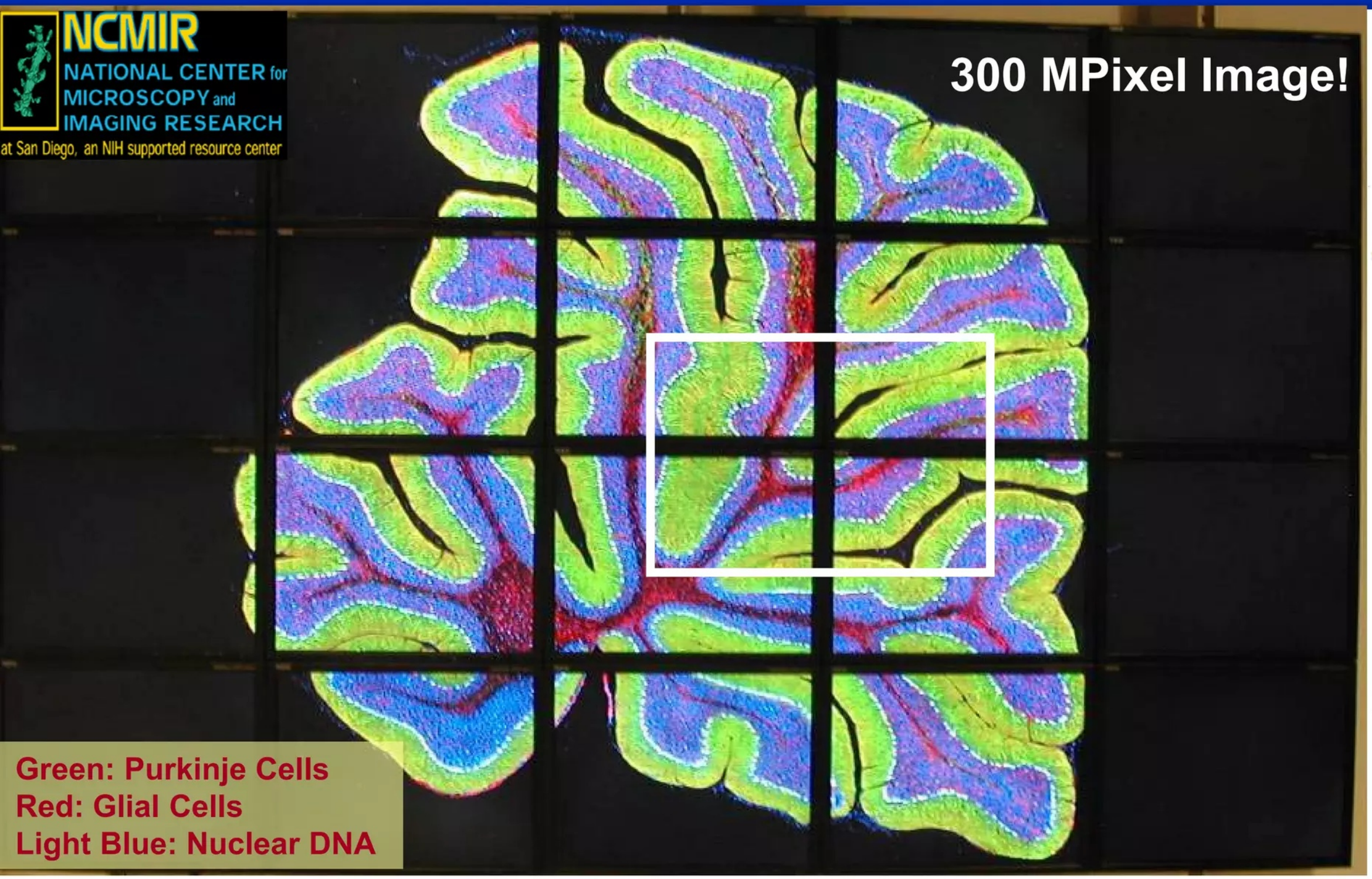
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Calit2 (UCSD, UCI), SDSC, and UIC Leads—Larry Smarr PI
Univ. Partners: NCSA, USC, SDSU, NW, TA&M, UvA, SARA, KISTI, AIST
Industry: IBM, Sun, Telcordia, Chiaro, Calient, Glimmerglass, Lucent

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Accelerator: Visualize Vast Data Sets Using Scalable Commodity Systems

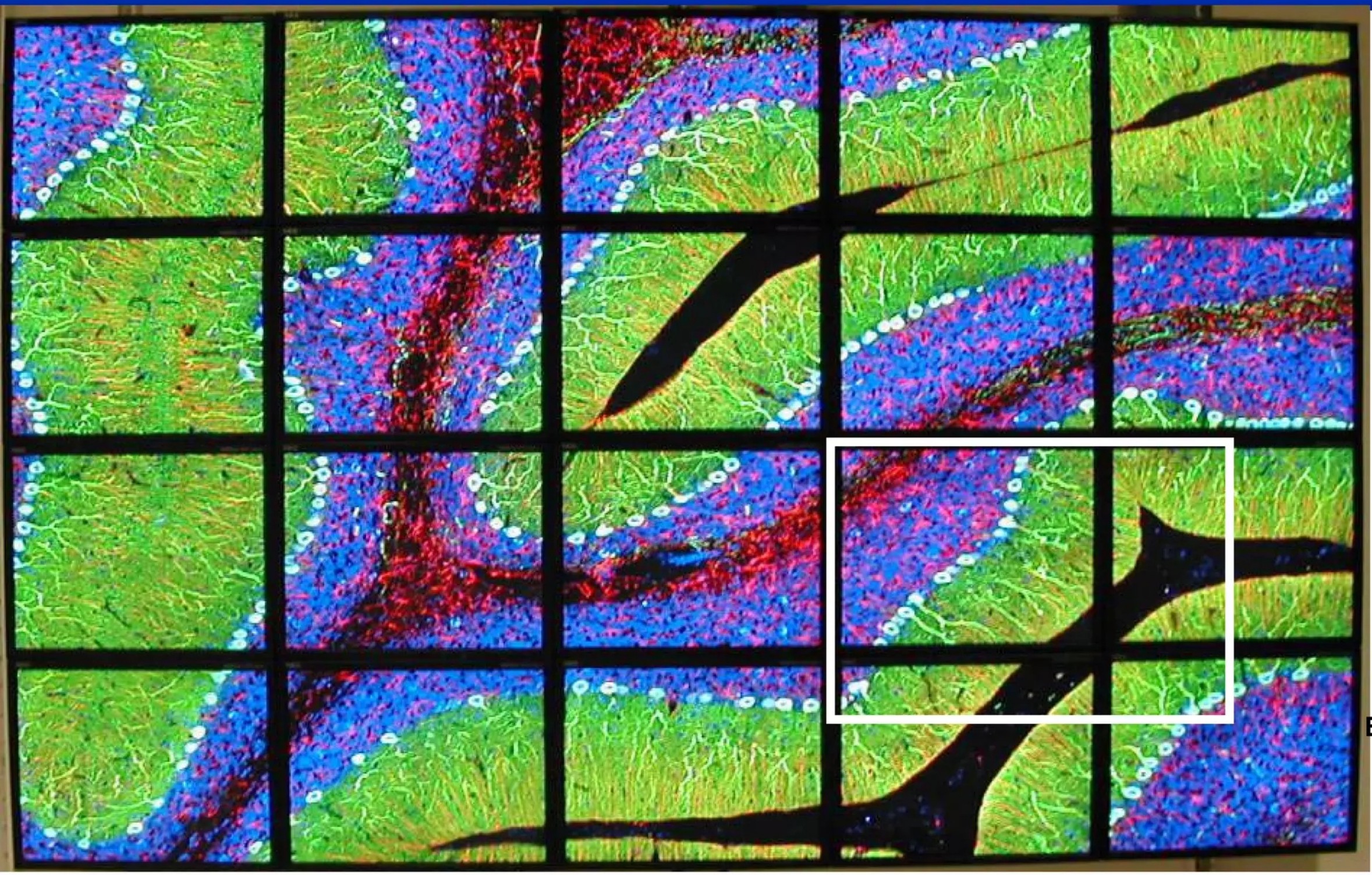
NCMIR
NATIONAL CENTER for MICROSCOPY and IMAGING RESEARCH
at San Diego, an NIH supported resource center



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Source: Mark Ellisman, David Lee, Jason Leigh

Scalable Displays Allow Both Global Content and Fine Detail



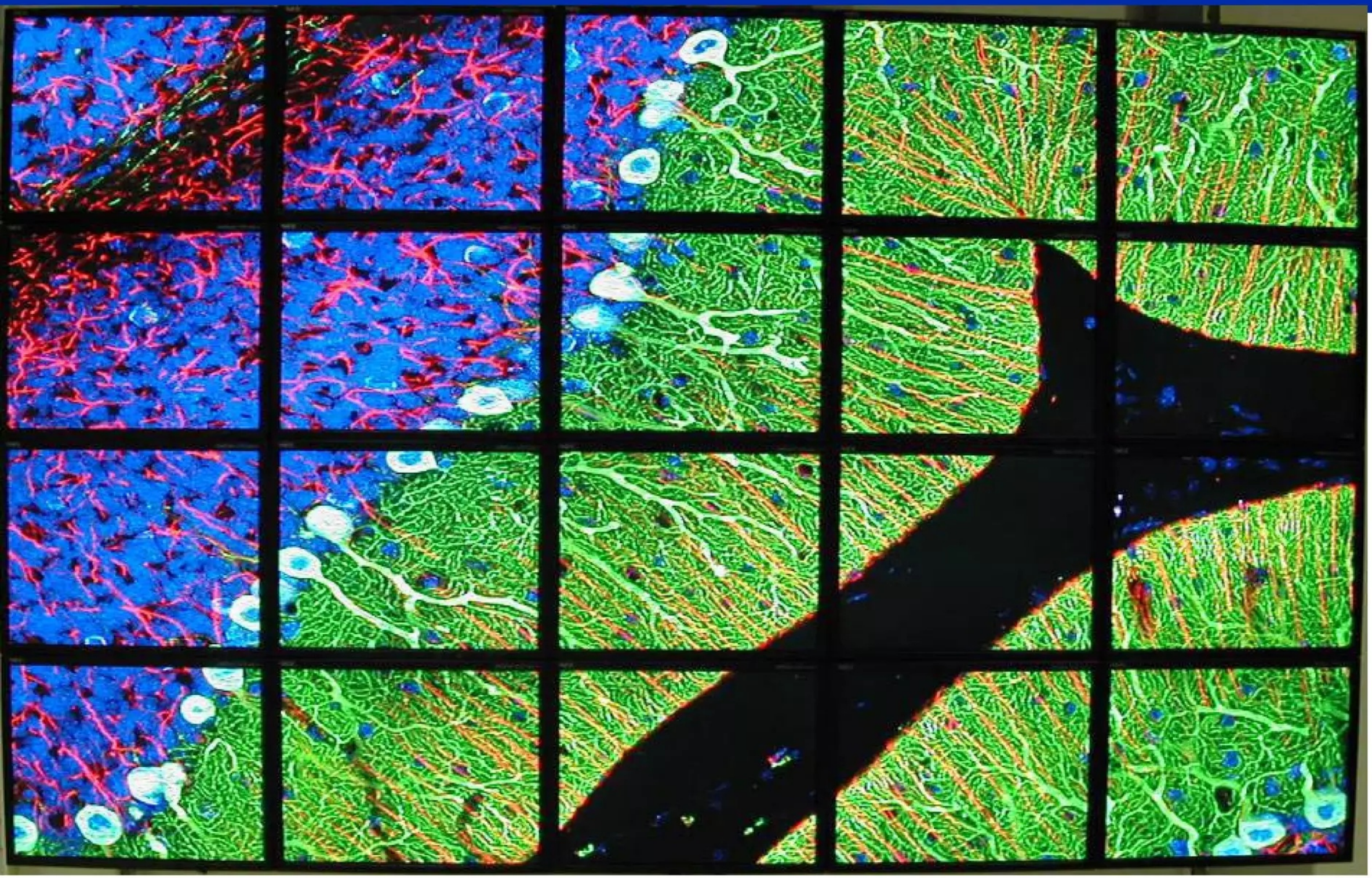
Source: Mark Ellisman, David Lee, Jason Leigh

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30 MPixel SunScreen Display Driven by a 20-node Sun Opteron Visualization Cluster

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Allows for Interactive Zooming from Cerebellum to Individual Neurons



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Source: Mark Ellisman, David Lee, Jason Leigh

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UM Professor Graeme Jackson Planning Brain Surgery for Severe Epilepsy

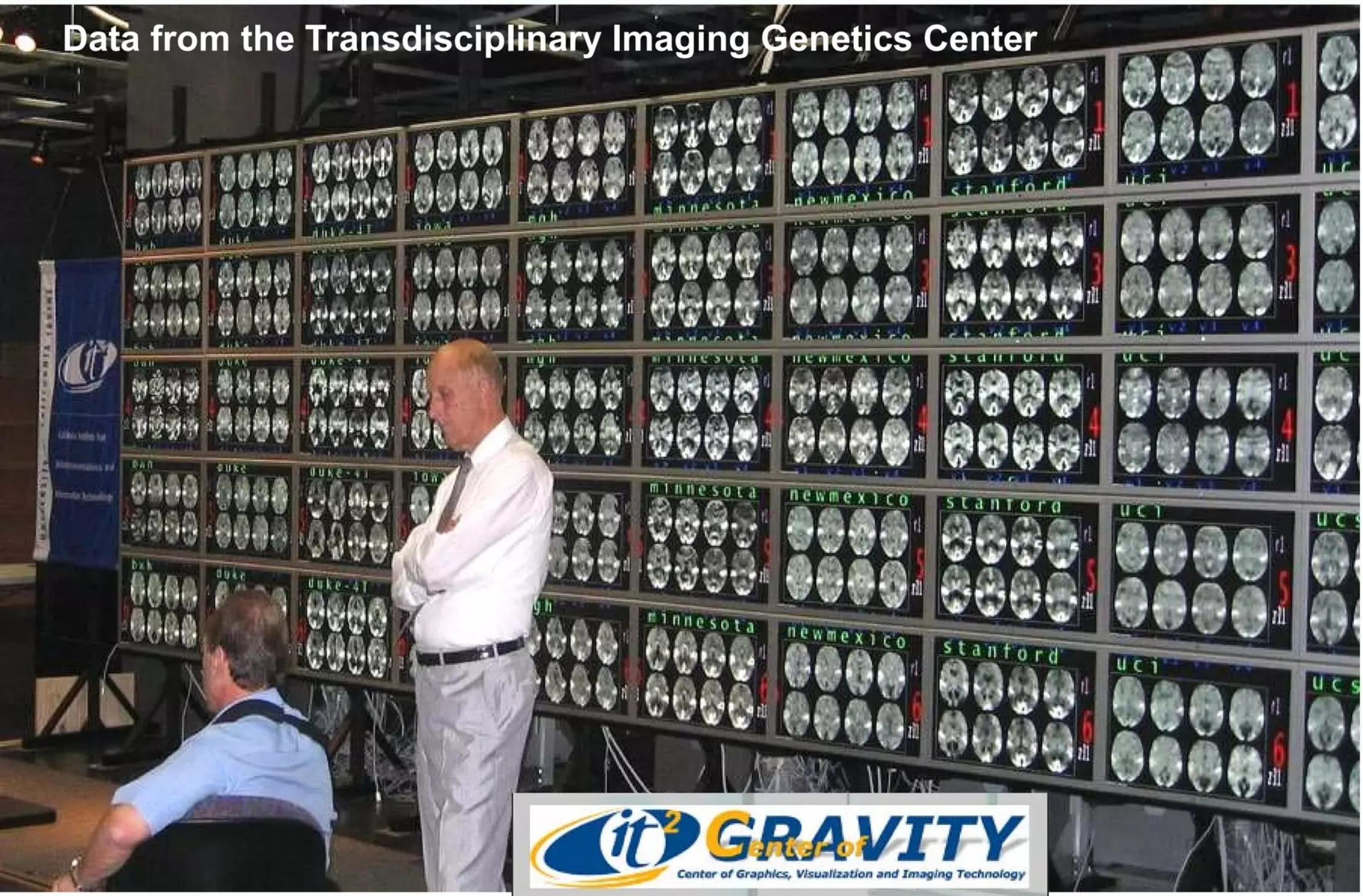


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www.calit2.net/newsroom/release.php?id=1219

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Prototyping the PC of 2015: Two Hundred Million Pixels Connected at 10Gbps



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50 Apple 30” Cinema Displays Driven by 25 Dual-Processor G5s

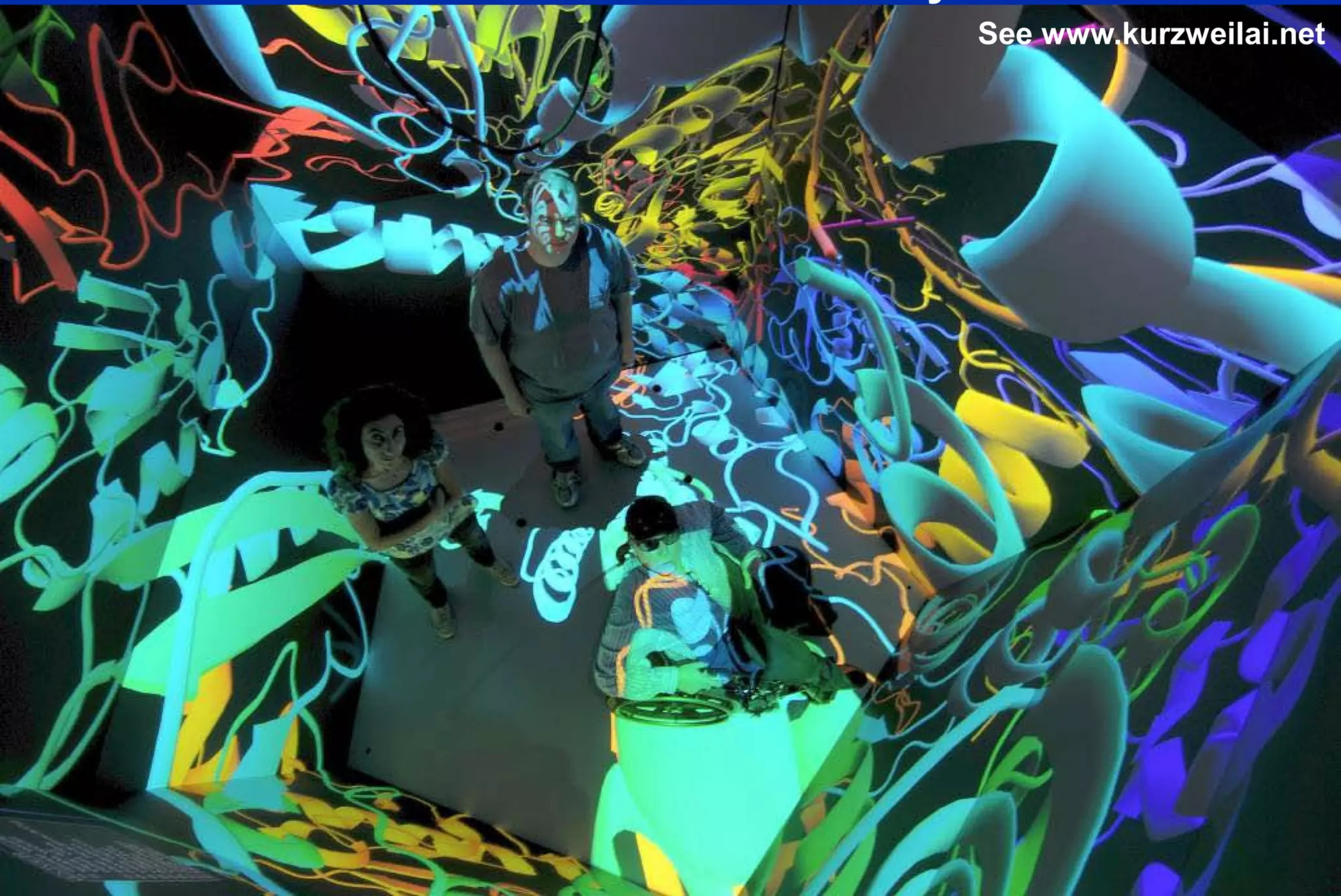
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Source: Falko Kuester, Calit2@UCI
NSF Infrastructure Grant

Visualizing Human Brain Pathways Along White Matter Bundles that Connect Distant Neurons



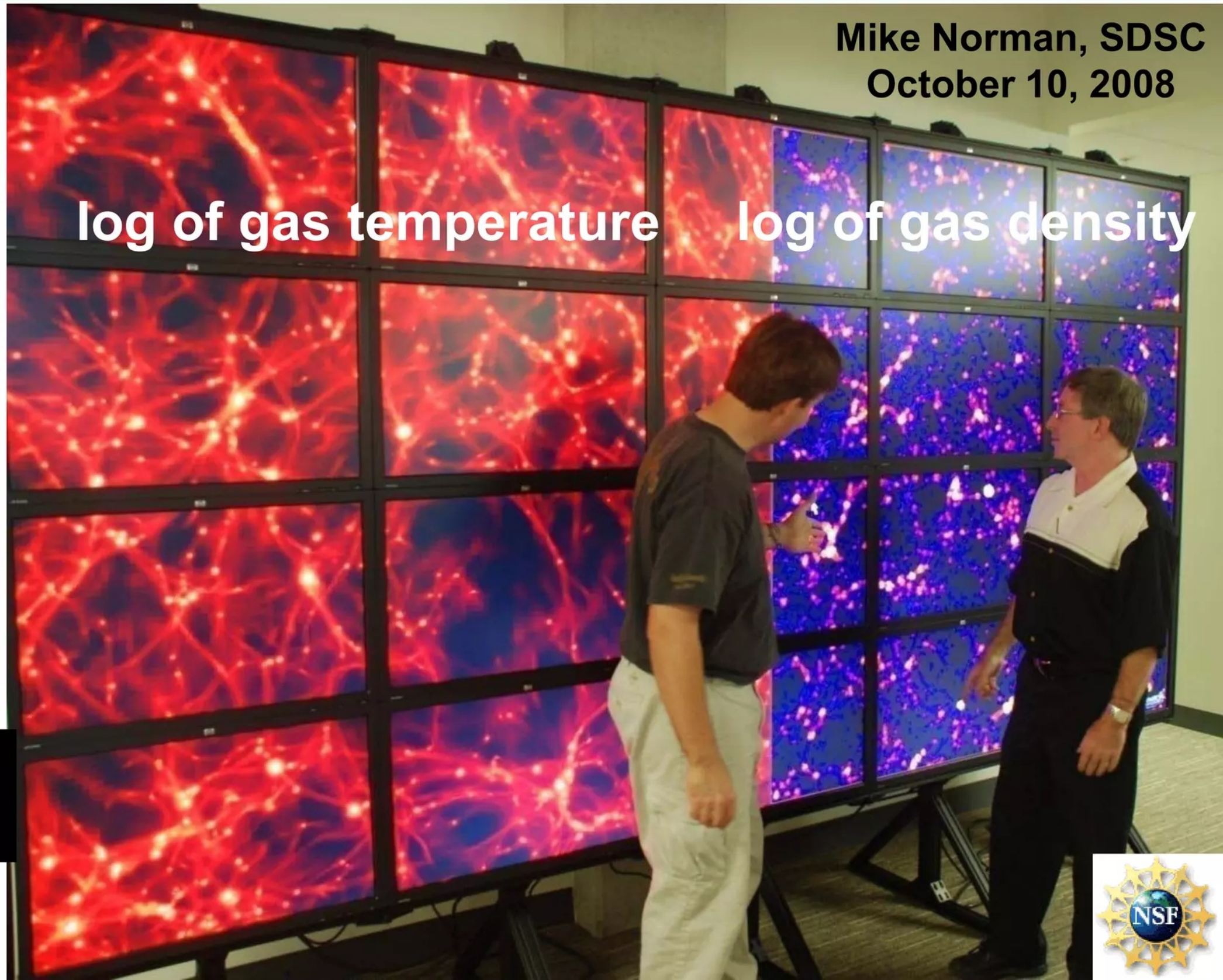
Ultra Resolution Virtual Reality:
3D Global Collaboratory



OptIPortals: Scaling up the Personal Computer For Supernetwork Connected Data-Intensive Users

SDSC
SAN DIEGO SUPERCOMPUTER CENTER

Two 64K Images From a Cosmological Simulation of Galaxy Cluster Formation



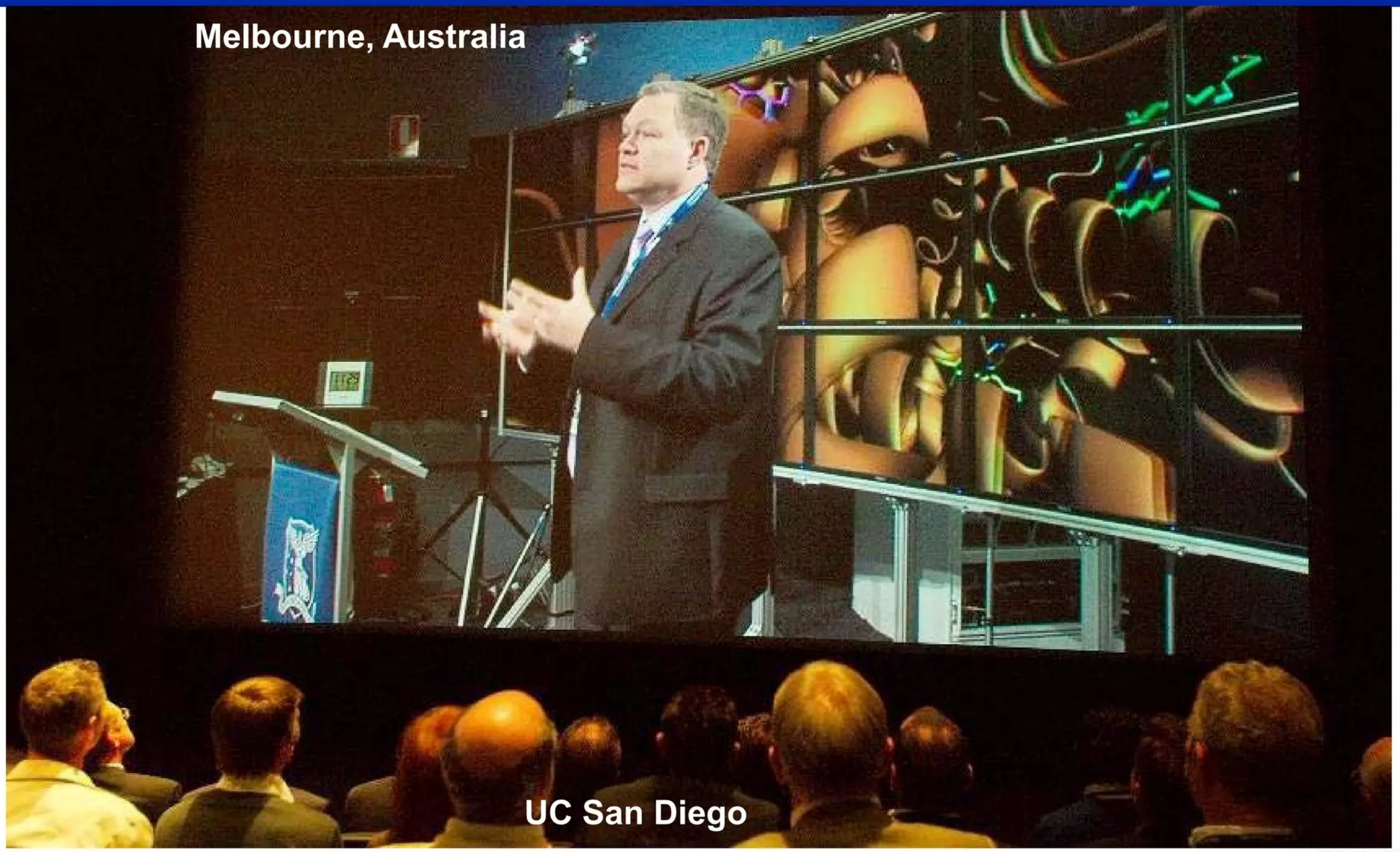
ROCKS
www.rocksclusters.org

CGLX
CROSS-PLATFORM CLUSTER GRAPHICS LIBRARY

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Optical Fiber Telepresence Will Accelerate Rate of Global Discovery



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Victoria Premier and Australian Deputy Prime Minister Asking Questions



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www.calit2.net/newsroom/release.php?id=1219

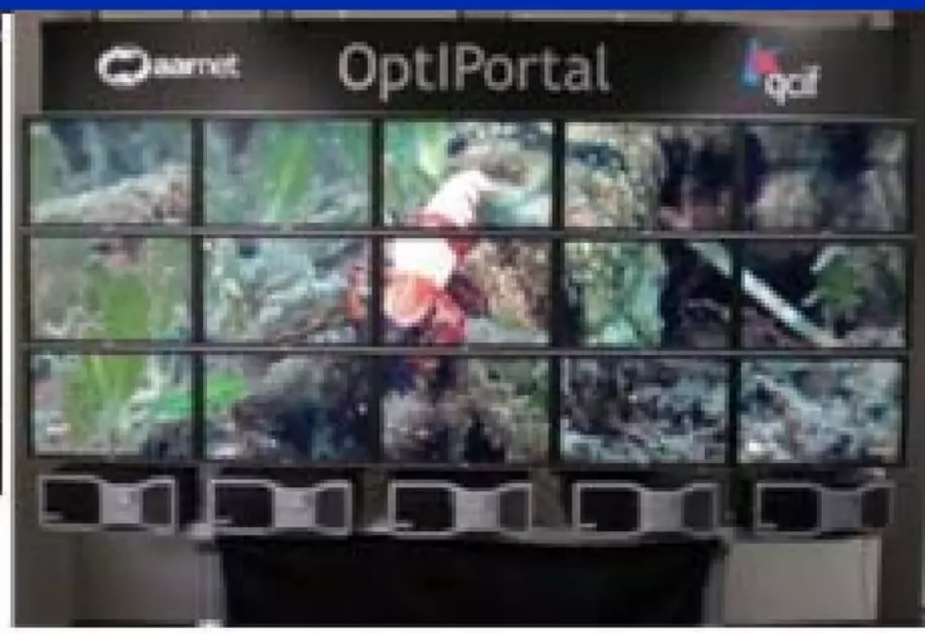
University of Melbourne Vice Chancellor Glyn Davis in Calit2 Replies to Question from Australia



ANU



U Queensland



AARNet



Monash U-Caufield



CSIRO



Monash U-Clayton



U Wellington, NZ

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OptIPlanet Collaboratory Persistent Infrastructure Between Calit2 and U Washington

Photo Credit: Alan Decker

Feb. 29, 2008



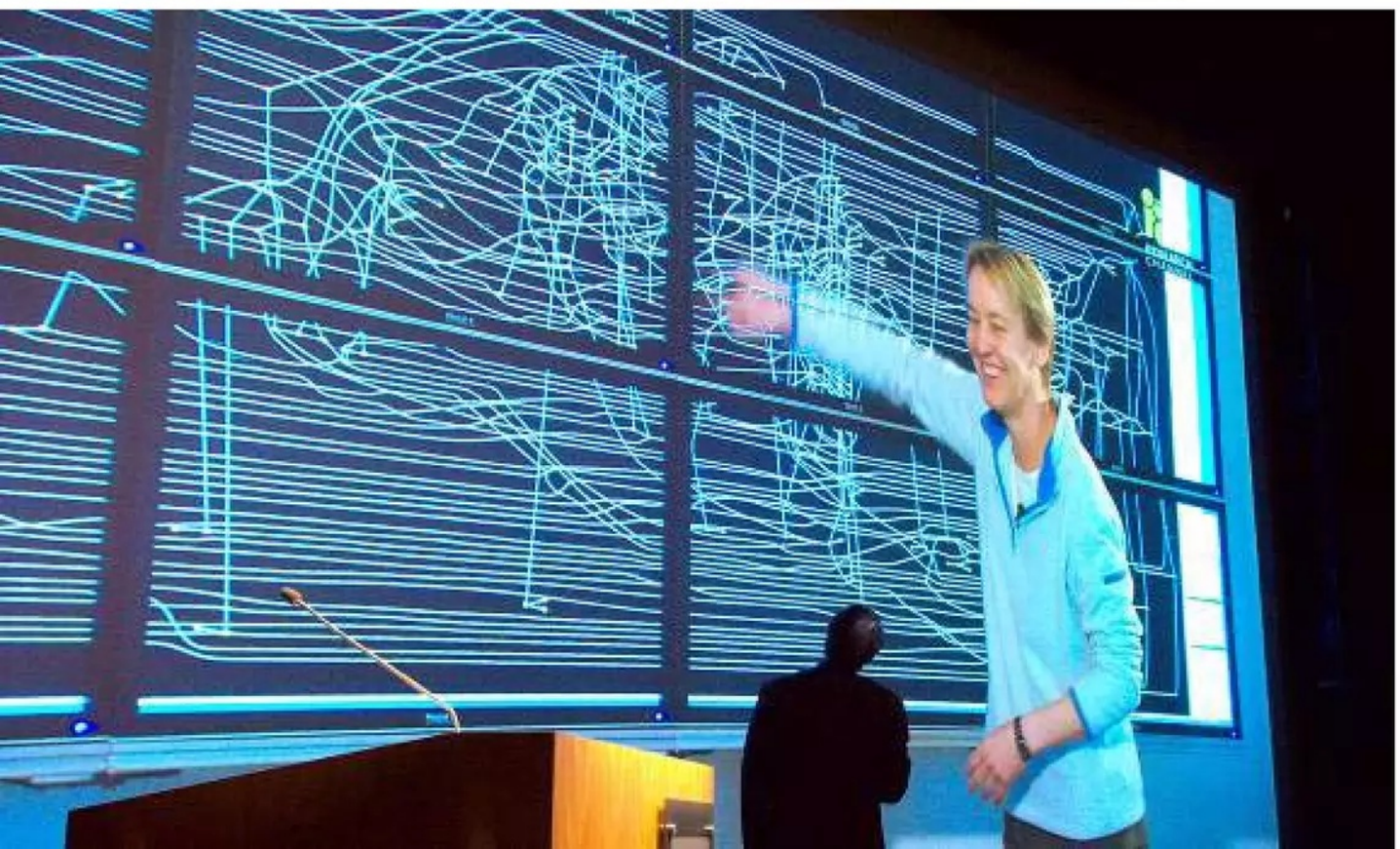
iHDTV: 1500 Mbits/sec Calit2 to UW Research Channel Over NLR

OptIPuter

Ginger Armbrust's Diatoms: Micrographs, Chromosomes, Genetic Assembly

ROCKS







UW's Research Channel Michael Wellings

it²

Remote Control of Scientific Instruments: Live Session with JPL and Mars Rover from Calit2



OptIPuter

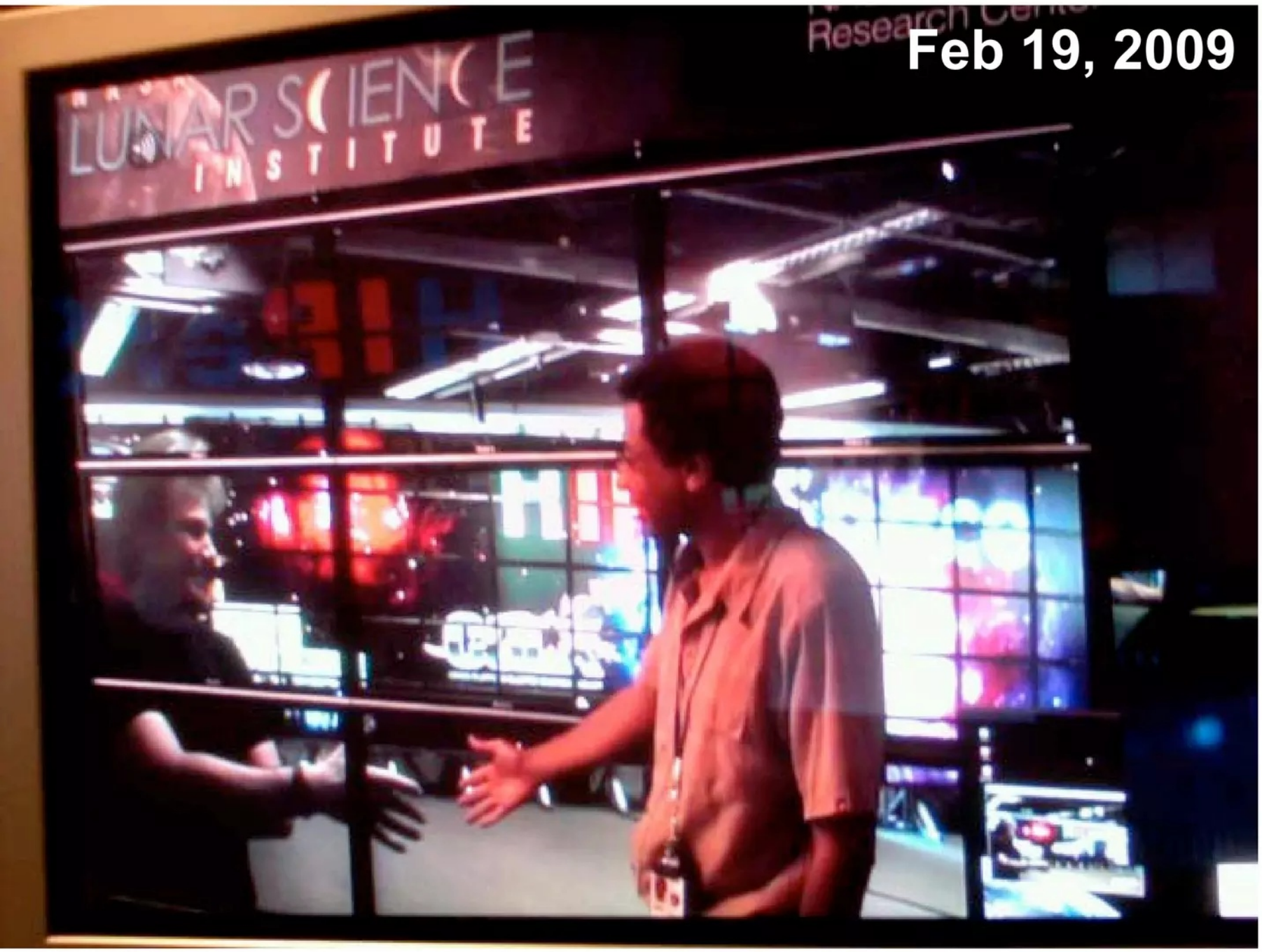
CGLX

Powered by Rocks ROCKS

it2

Source: Falko Kuester, Calit2; Michael Sims, NASA

Just in Time OptIPlanet Collaboratory: Live Session Between NASA Ames and Calit2@UCSD



From Start to This Image in Less Than 2 Weeks!

View from NASA Ames Lunar Science Institute Mountain View, CA

Virtual Handshake

HD compressed 6:1

NASA Interest in Supporting Virtual Institutes

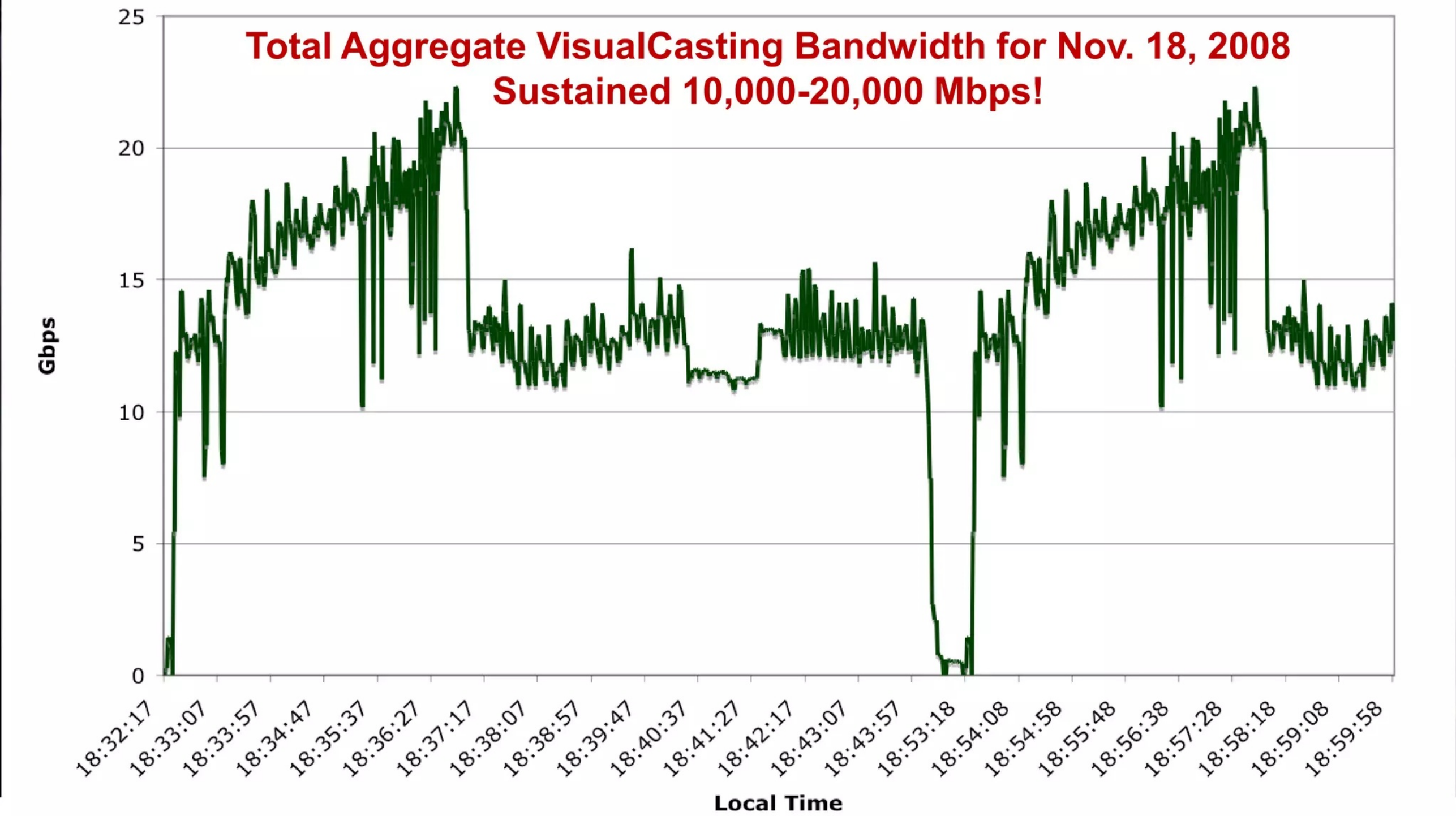
OptIPuter

CGLX

it²

Source: Falko Kuester, Calit2; Michael Sims, NASA

EVL's SAGE OptIPortal VisualCasting Multi-Site OptIPuter Collaboratory



OptIPuter

Source: Jason Leigh, Luc Renambot, EVL, UI Chicago

it²

Academic Research "OptIPlatform" Cyberinfrastructure: A 10Gbps Lightpath Cloud



End User OptIPortal



Instruments



HD/4k Telepresence

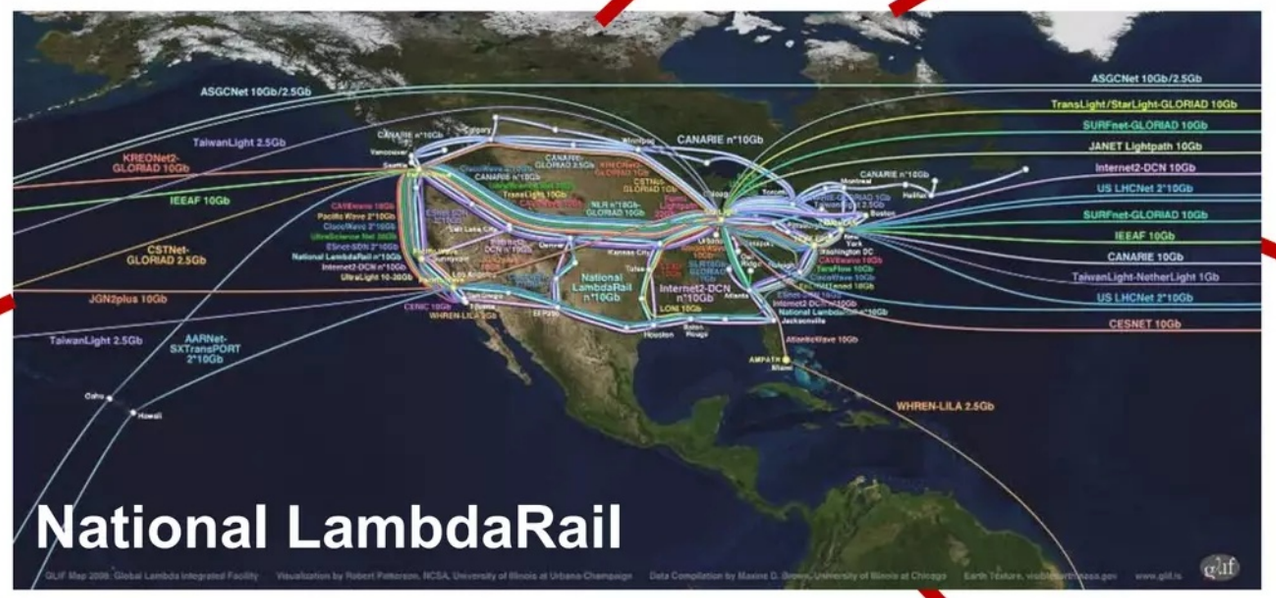


HD/4k Video Cams

HPC



10G Lightpaths



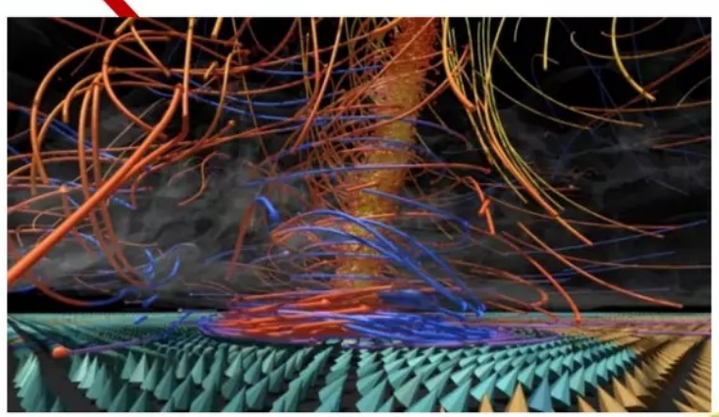
National LambdaRail

TeraGrid

Campus Optical Switch



Data Repositories & Clusters



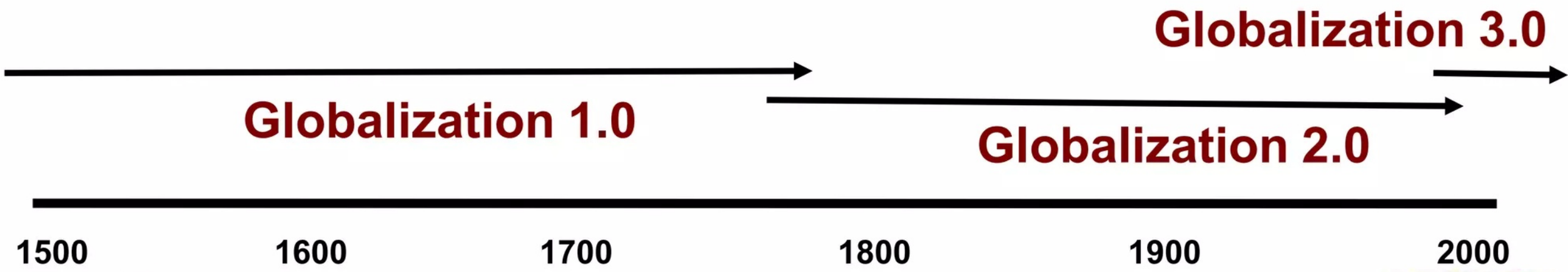
HD/4k Video Images

OptIPuter

it²

We Stand at the Beginning of the Globalization 3.0 Era

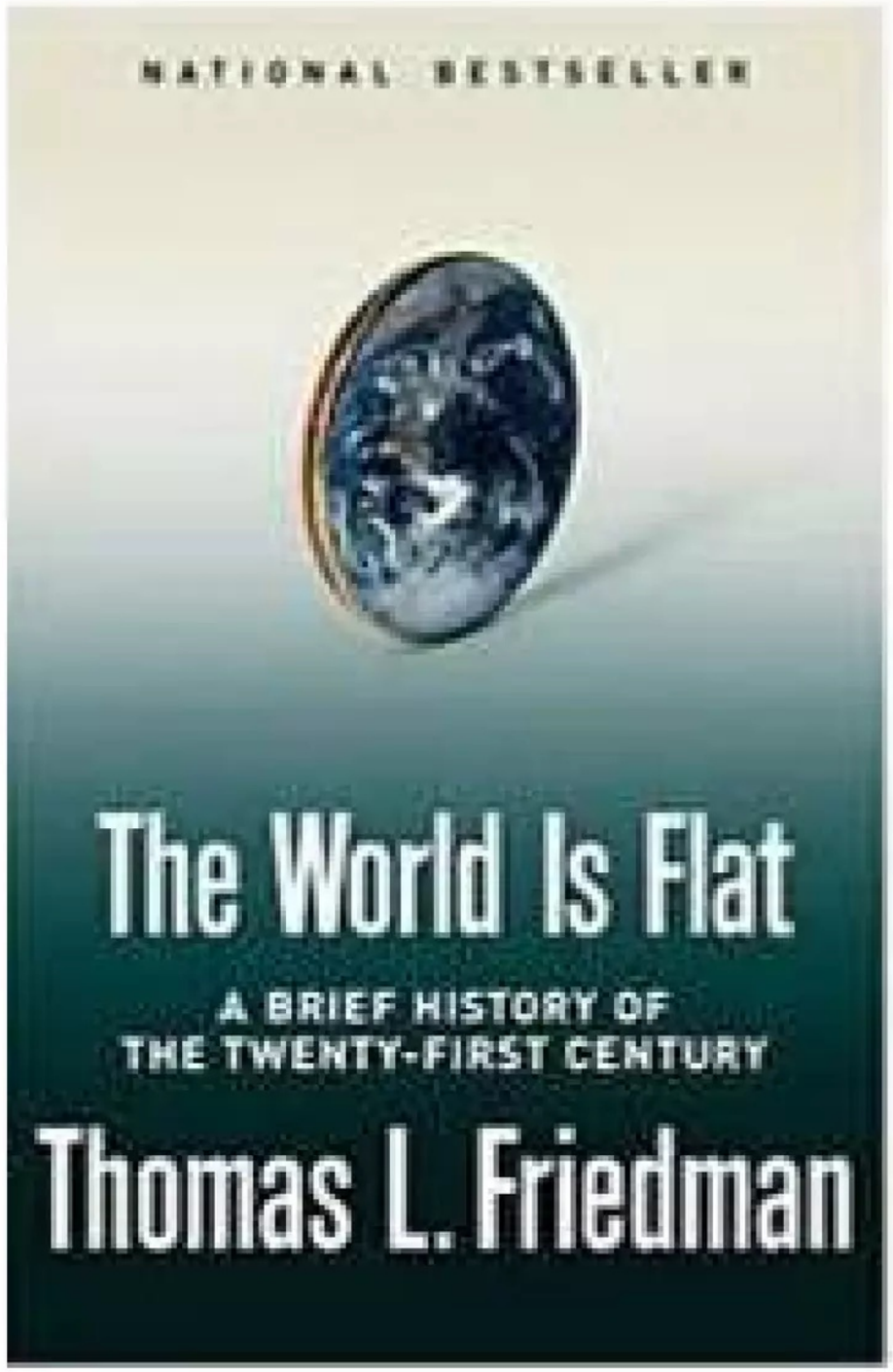
Globalization 1.0 was about countries and muscles. In Globalization 2.0 the dynamic force driving global integration was multinational companies. The dynamic force in Globalization 3.0 is the newfound power for individuals to collaborate & compete globally. And the lever that is enabling individuals and groups to go global is software in conjunction with the creation of a global fiber-optic network that has made us all next-door neighbors."



OptIPuter

it²

The Technology Innovations of Ten Years Ago-the Shared Internet & the Web-Have Been Adopted Globally



- **But Today's Innovations**
  - **Dedicated Fiber Paths**
  - **Streaming HD TV**
  - **Ubiquitous Wireless Internet**
  - **Location Aware Software**
  - **SensorNets**
- **Will Reduce the World to a "Single Point" in Ten Years**

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