"Metacomputer Architecture of the Global LambdaGrid"

Invited Talk
Department of Computer Science
Donald Bren School of Information and Computer Sciences
University of California, Irvine
January 13, 2006

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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Abstract

I will describe my research in metacomputer architecture, a term I coined in 1988, in which one builds virtual ensembles of computers, storage, networks, and visualization devices into an integrated system. Working with a set of colleagues, I have driven development in this field through national and international workshops and conferences, including SIGGRAPH, Supercomputing, and iGrid. Although the vision has remained constant over nearly two decades, it is only the recent availability of dedicated optical paths, or lambdas, that has enabled the vision to be realized. These lambdas enable the Grid program to be completed, in that they add the network elements to the compute and storage elements which can be discovered, reserved, and integrated by the Grid middleware to form global LambdaGrids. I will describe my current research in the four grants in which I am PI or co-PI, OptIPuter, Quartzite, LOOKING, and CAMERA, which both develop the computer science of LambdaGrids, but also couple intimately to the application drivers in biomedical imaging, ocean observatories, and marine microbial metagenomics.

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Metacomputer: Four Eras

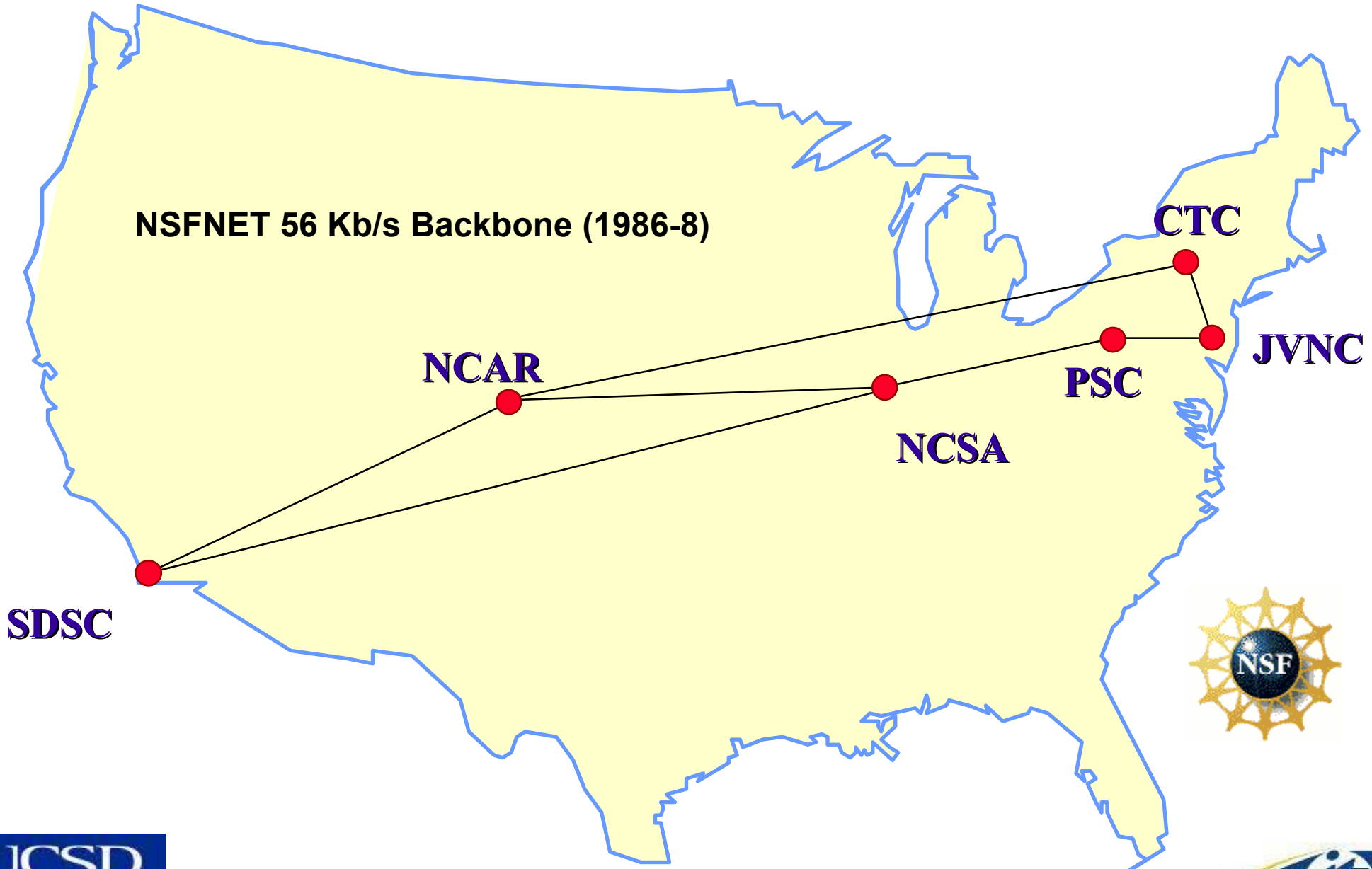
- The Early Days (1985-1995)
- The Emergence of the Grid (1995-2000)
- From Grid to LambdaGrid (2000-2005)
- Community Adoption of LambdaGrid (2005-2006)

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Metacomputer:
The Early Days (1985-1995)

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The First Metacomputer: NSFnet and the Six NSF Supercomputers



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NCSA Telnet--"Hide the Cray"
One of the Inspirations for the Metacomputer



- NCSA Telnet Provides Interactive Access
  - From Macintosh or PC Computer
  - To Telnet Hosts on TCP/IP Networks
- Allows for Simultaneous Connections
  - To Numerous Computers on The Net
  - Standard File Transfer Server (FTP)
  - Lets You Transfer Files to and from Remote Machines and Other Users

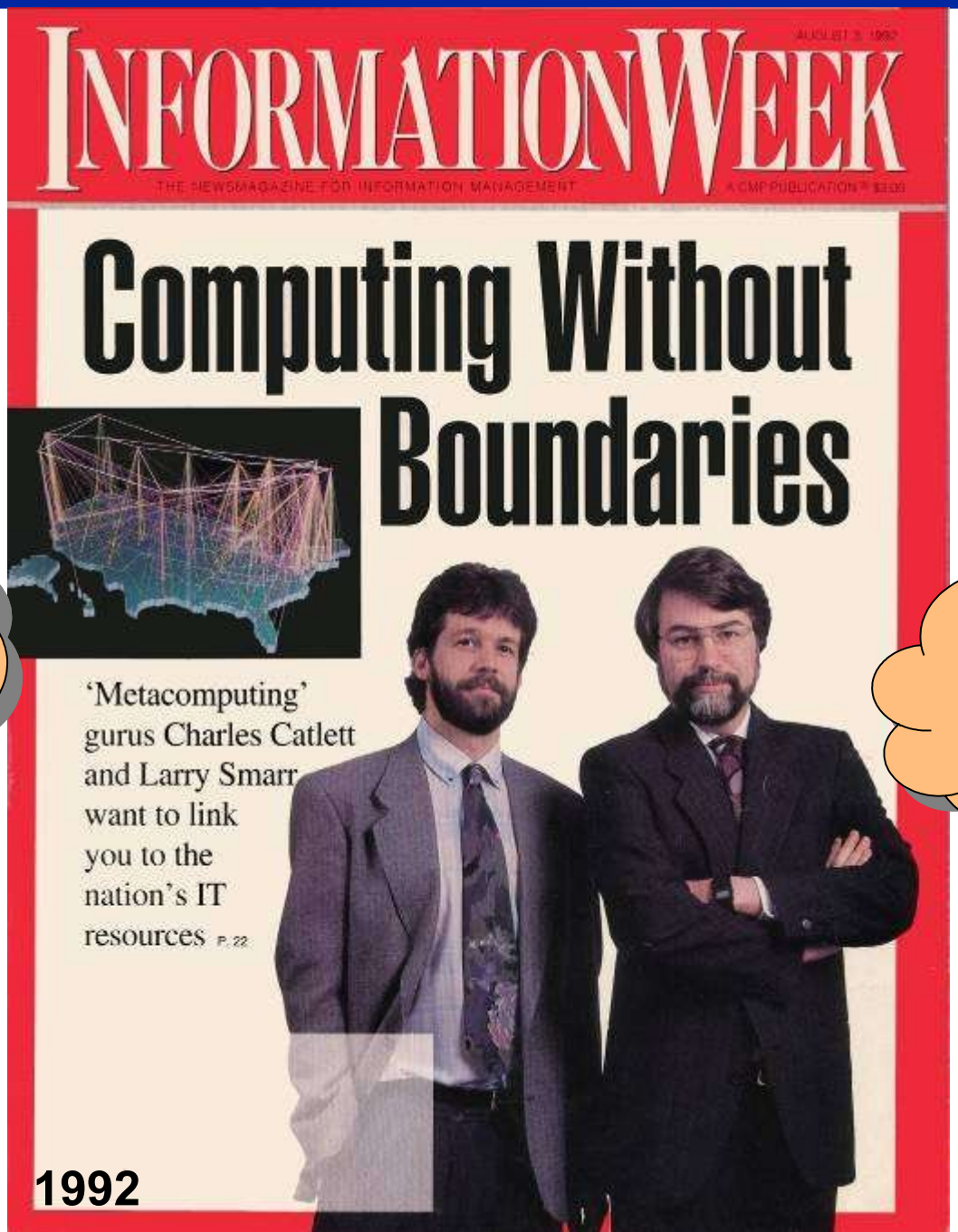
John Kogut Simulating
Quantum Chromodynamics
He Uses a Mac—The Mac Uses the Cray

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Source: Larry Smarr 1985

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From Metacomputer to TeraGrid and OptIPuter: 15 Years of Development



"Metacomputer" Coined by Smarr in 1988

TeraGrid PI

OptIPuter PI

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Long-Term Goal: Dedicated Fiber Optic Infrastructure
Using Analog Communications to Prototype the Digital Future

"What we really have to do is eliminate distance between individuals who want to interact with other people and with other computers."
— Larry Smarr, Director, NCSA

SIGGRAPH 1989







"We're using satellite technology…to demo what It might be like to have high-speed fiber-optic links between advanced computers in two different geographic locations."

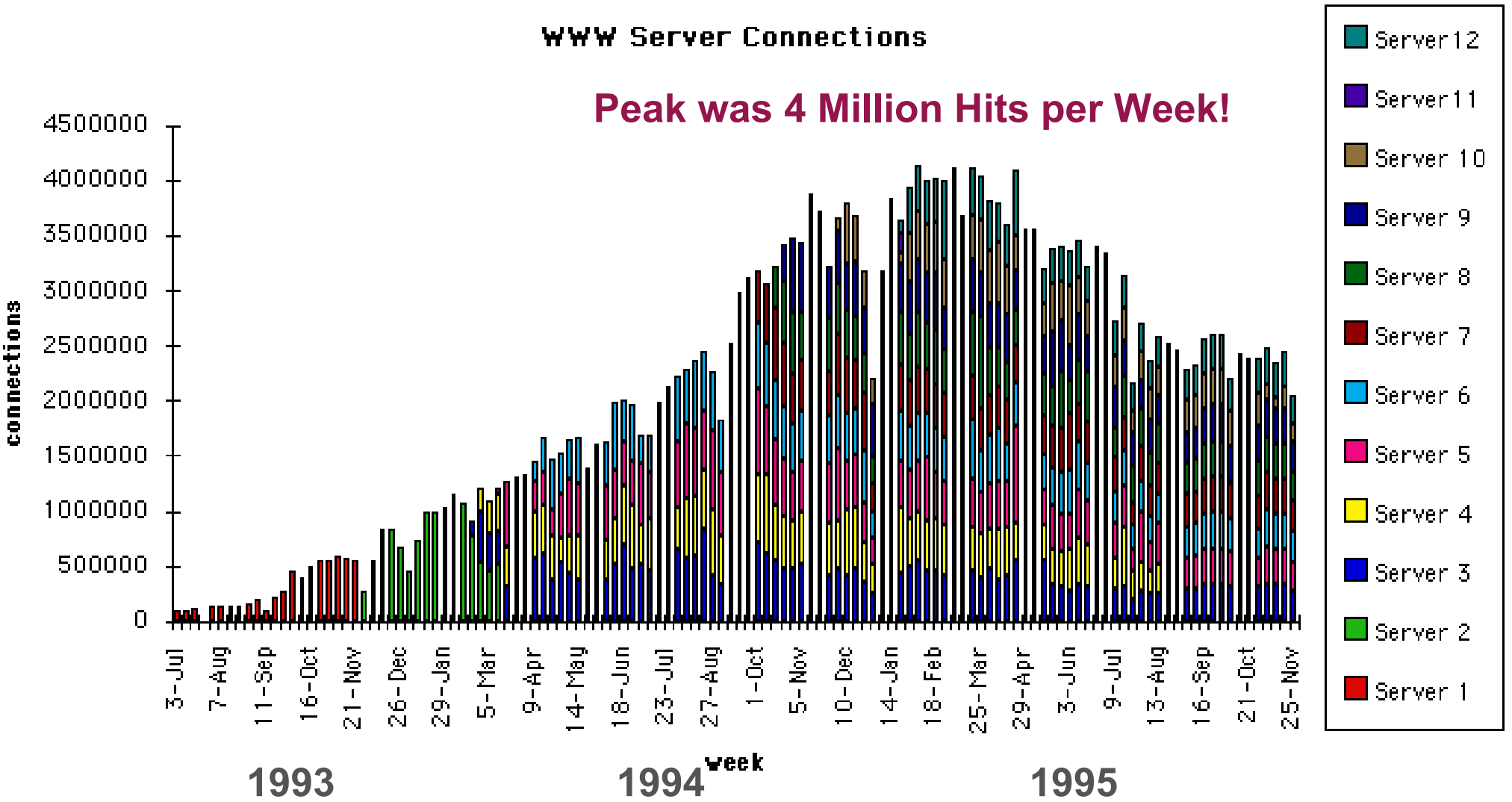
— Al Gore, Senator
Chair, US Senate Subcommittee on Science, Technology and Space

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NCSA Web Server Traffic Increase Led to NCSA Creating the First Parallel Web Server



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Data Source: Software Development Group, NCSA,
Graph: Larry Smarr

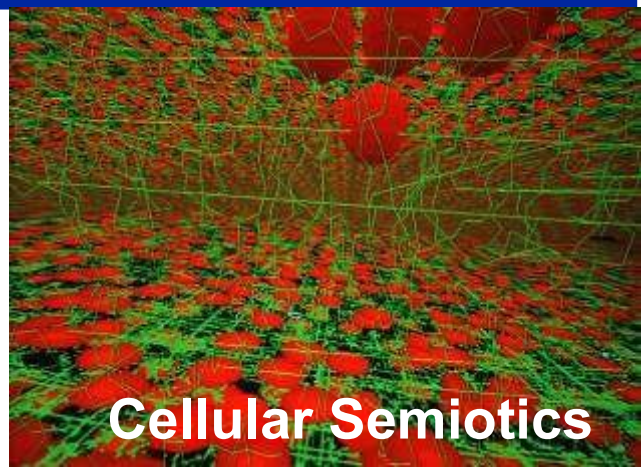
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Metacomputer: The Emergence of the Grid (1995-2000)

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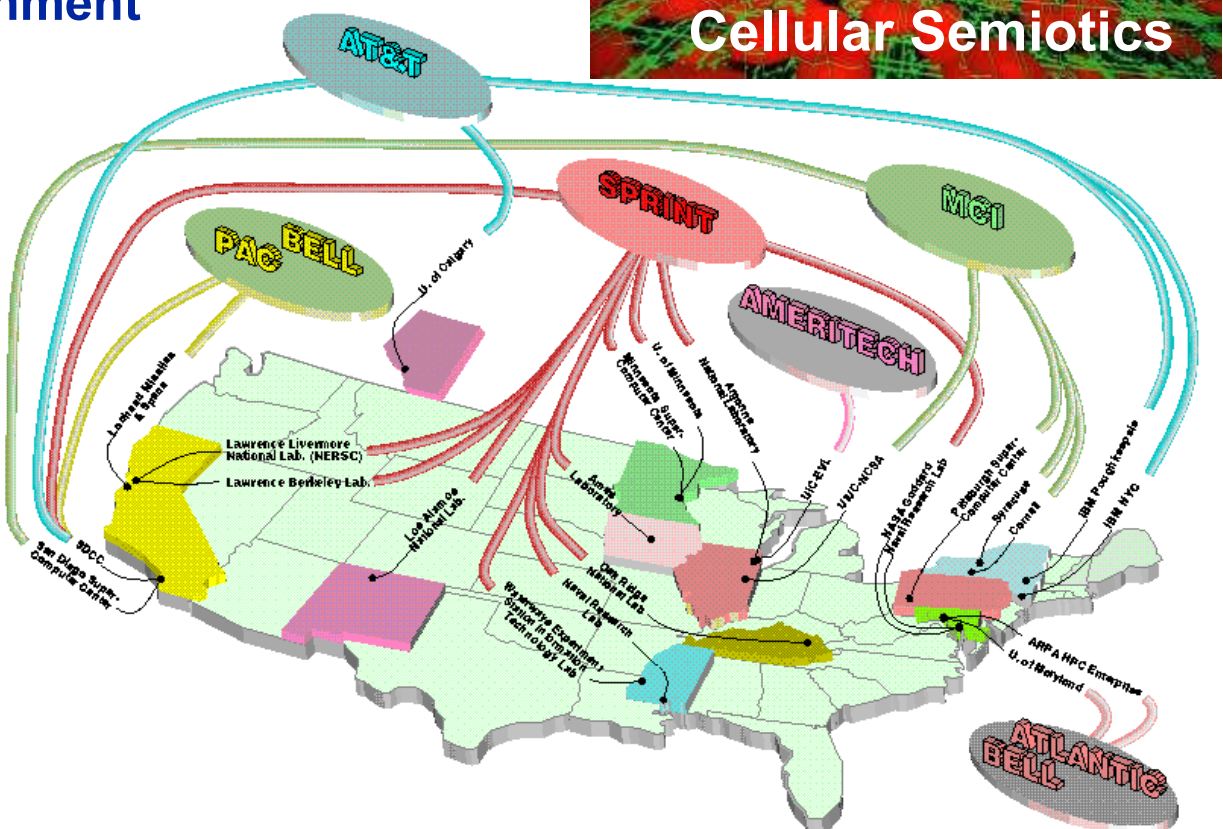
I-WAY Prototyped the National Metacomputer -- Supercomputing '95 I-WAY Project

- 60 National & Grand Challenge Computing Applications
- I-Way Featured:
  - IP over ATM with an OC-3 (155Mbps) Backbone
  - Large-Scale Immersive Displays
  - I-Soft Programming Environment
    - Led Directly to Globus



UI mcs NCSA





http://archive.ncsa.uiuc.edu/General/Training/SC95/GII.HPCC.html

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Source: Larry Smarr, Rick Stevens, Tom DeFanti

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The NCSA Alliance Research Agenda- Create a National Scale Metacomputer

A Nationwide Parallel Computing Environment

How to get there? Through a scalable software environment coupling the small parallelism (a few processors) of the desktop to the large-scale parallelism (thousands of processors) in Alliance machines.

Ken Kennedy, Charles F. Bender, John W.D. Connolly, John L. Hennessy, Mary K. Vernon, and Larry Smarr

The Alliance will strive to make computing routinely parallel, distributed, collaborative, and immersive.
--Larry Smarr, CACM Guest Editor

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Source: Special Issue of Comm. ACM 1997

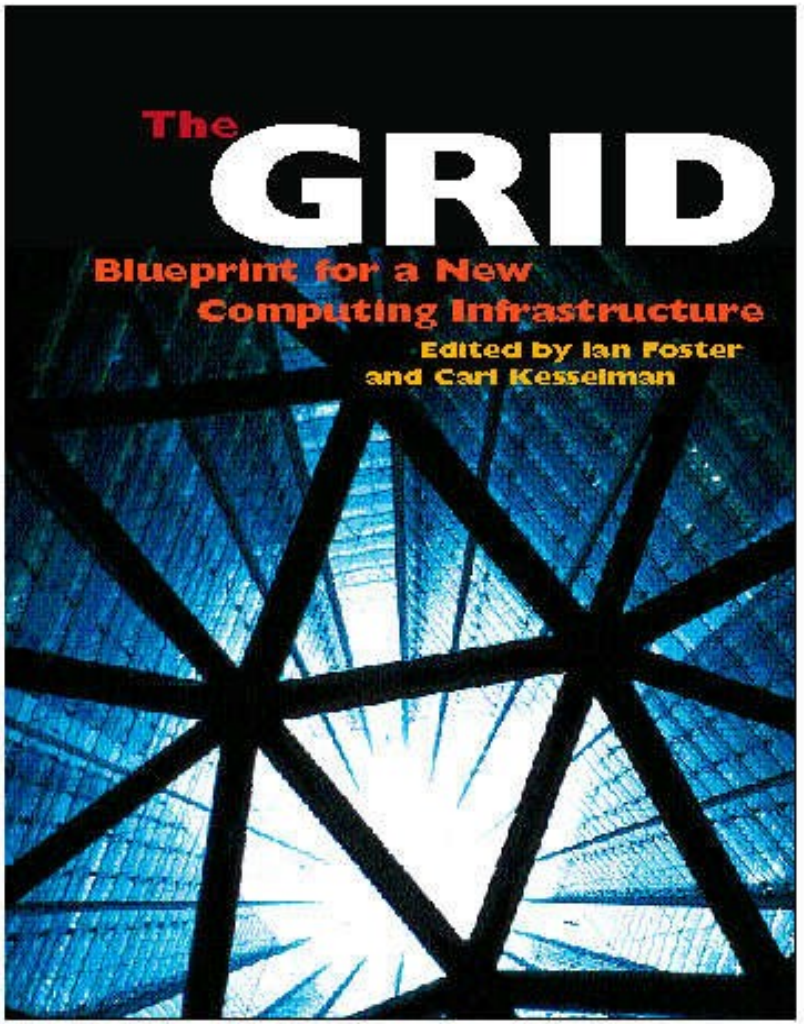
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From Metacomputing to the Grid

- **Ian Foster, Carl Kesselman (Eds), Morgan Kaufmann, 1999**
- **22 chapters by expert authors including:**
  - **Andrew Chien,**
  - **Jack Dongarra,**
  - **Tom DeFanti,**
  - **Andrew Grimshaw,**
  - **Roch Guerin,**
  - **Ken Kennedy,**
  - **Paul Messina,**
  - **Cliff Neuman,**
  - **Jon Postel,**
  - **Larry Smarr,**
  - **Rick Stevens,**
  - **and many others**

Meeting Held at Argonne Sept 1997

"A source book for the history of the future" -- Vint Cerf



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http://www.mkp.com/grids

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 Gigaflop
    - Average Free Storage 100 GB
  - Planetary Computer Capacity
    - 100,000 TeraFLOP Speed
    - 1 Million TeraByte Storage
- **1000 TeraFLOPs 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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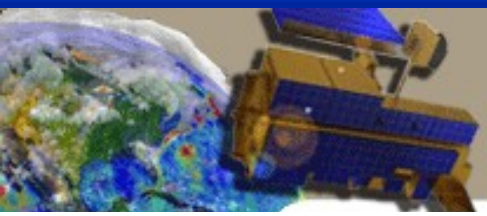
Source: Larry Smarr Megacomputer Panel
SC2000 Conference

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Metacomputer:
From Grid to LambdaGrid (2000-2005)

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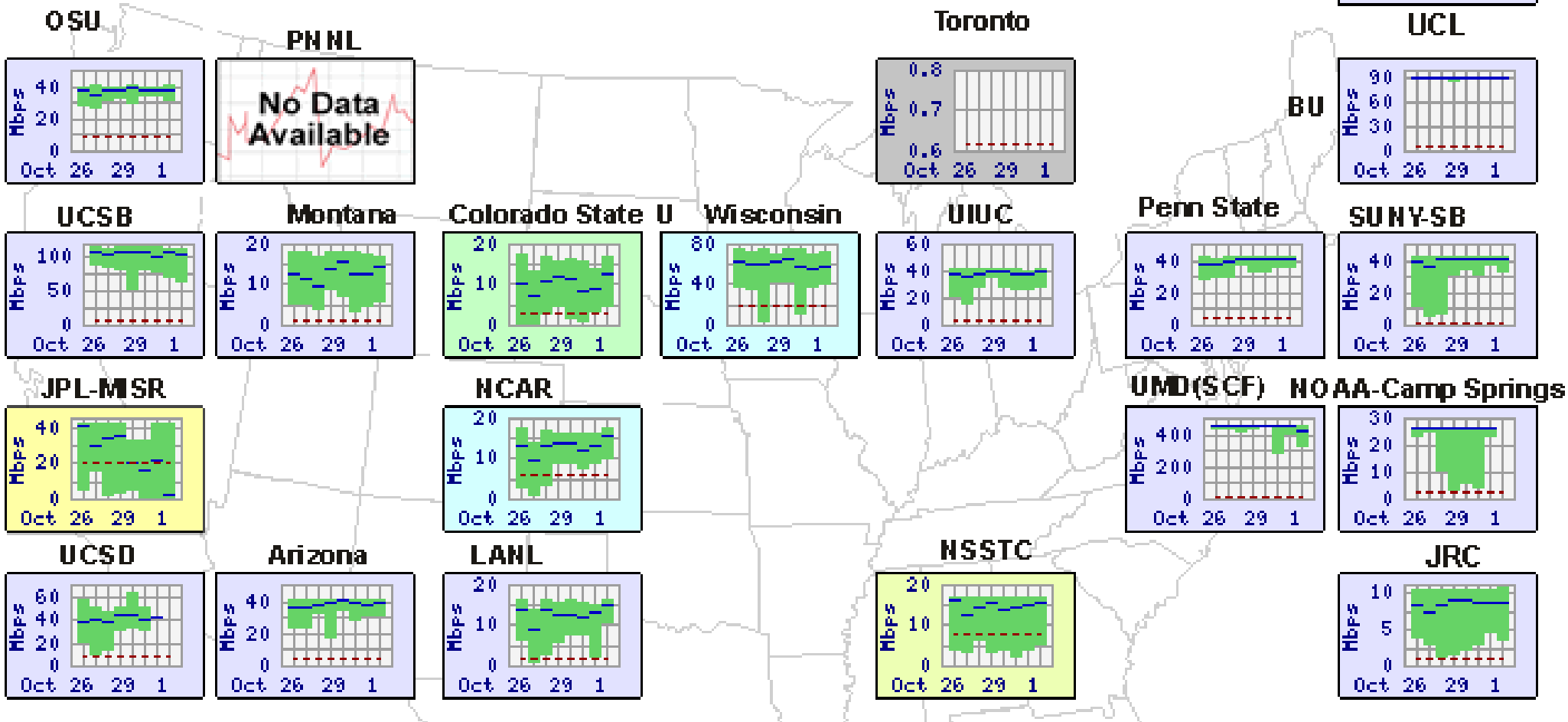
Challenge: Average Throughput of NASA Data Products to End User is < 50 Mbps



ENSIGHT Active Testing TERRA Destinations

Tested October 2005

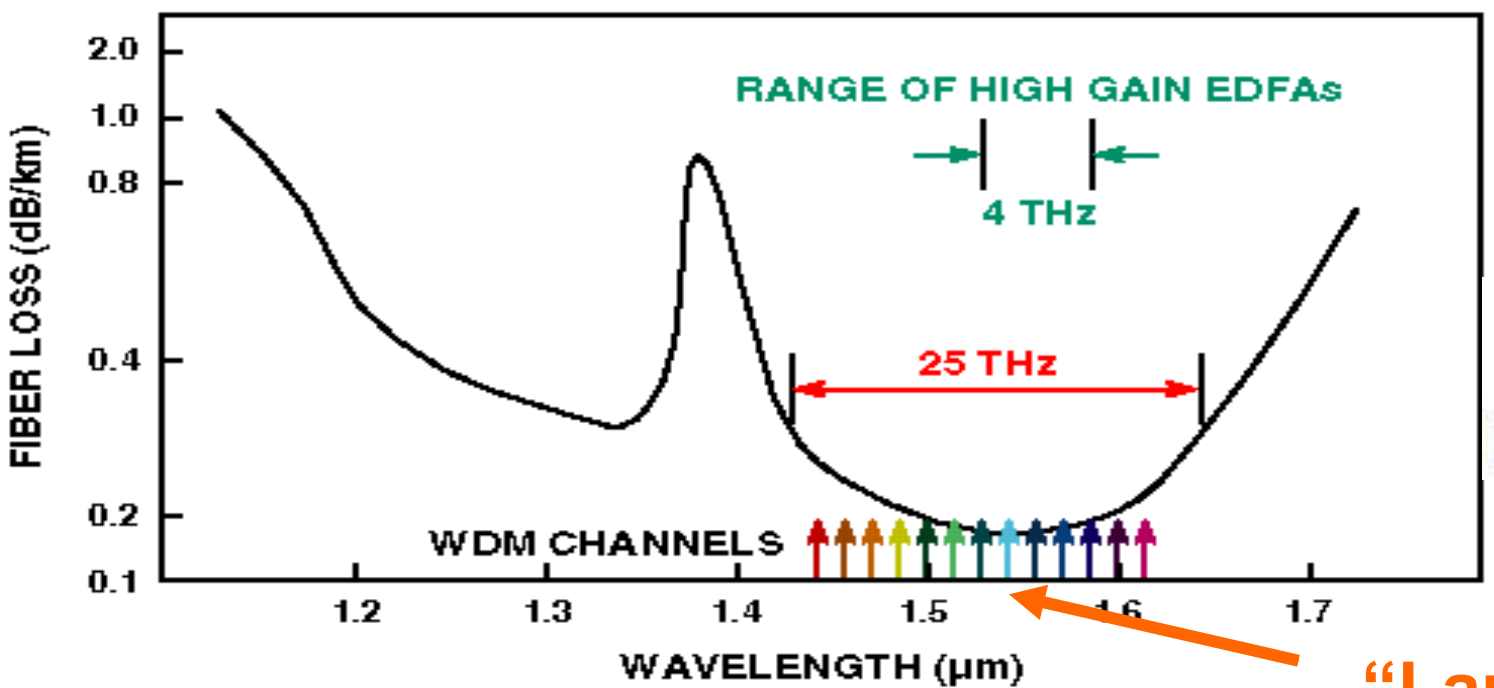
Internet2 Backbone is 10,000 Mbps!
Throughput is < 0.5% to End User



Each Optical Fiber Can Now Carry Many Parallel Line Paths or "Lambdas"

WAVELENGTH DIVISION MULTIPLEXING (WDM)

- EXPLOITS
  - ENORMOUS BANDWIDTH OF SILICA FIBER
  - HIGH-GAIN WIDEBAND OPTICAL AMPLIFIERS



"Lambdas"

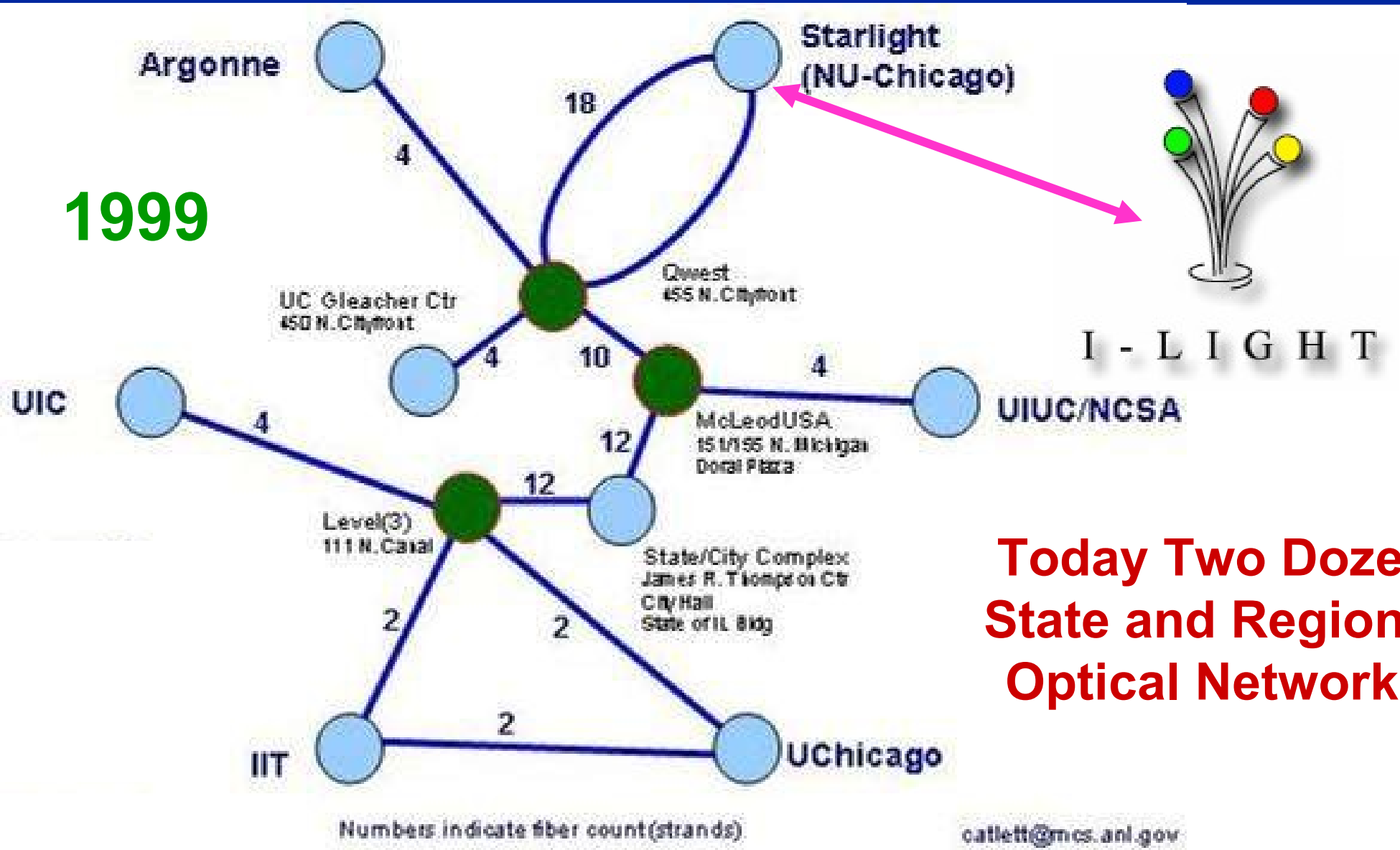
CHIARO

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Source: Steve Wallach, Chiaro Networks

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States are Acquiring Their Own Dark Fiber Networks -- Illinois's I-WIRE and Indiana's I-LIGHT

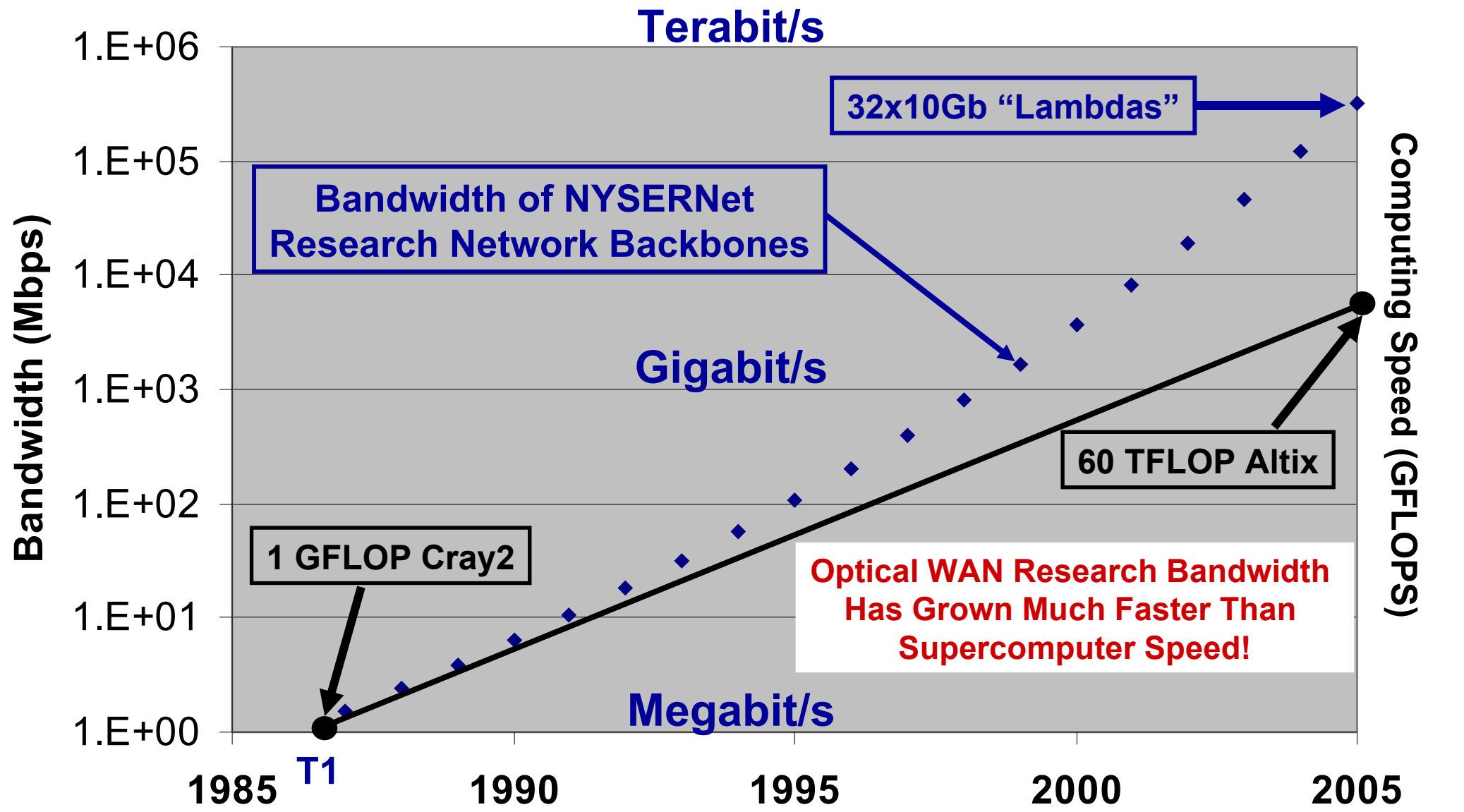


Today Two Dozen State and Regional Optical Networks

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Source: Larry Smarr, Rick Stevens, Tom DeFanti, Charlie Catlett

From "Supercomputer–Centric" to "Supernetwork-Centric" Cyberinfrastructure



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Network Data Source: Timothy Lance, President, NYSERNet

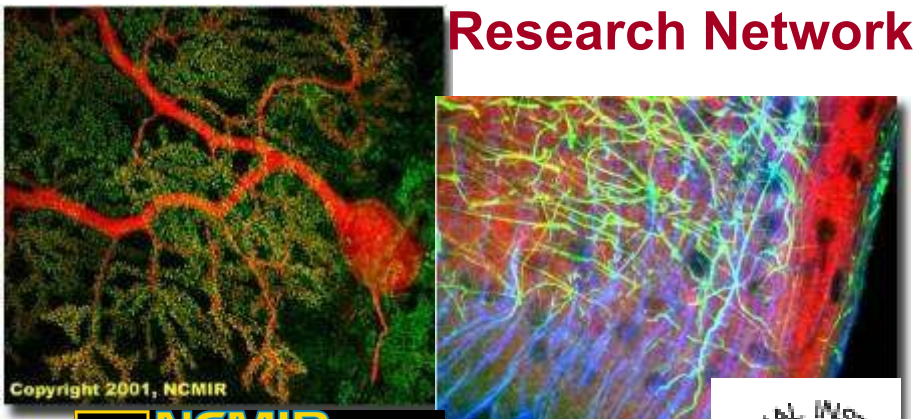
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The OptIPuter Project –

Creating a LambdaGrid "Web" for Gigabyte Data Objects

- **NSF Large Information Technology Research Proposal**
  - Calit2 (UCSD, UCI) and UIC Lead Campuses—Larry Smarr PI
  - Partnering Campuses: USC, SDSU, NW, TA&M, UvA, SARA, NASA
- **Industrial Partners**
  - IBM, Sun, Telcordia, Chiaro, Calient, Glimmerglass, Lucent
- **$13.5 Million Over Five Years**
- **Linking Global Scale Science Projects to User's Linux Clusters**

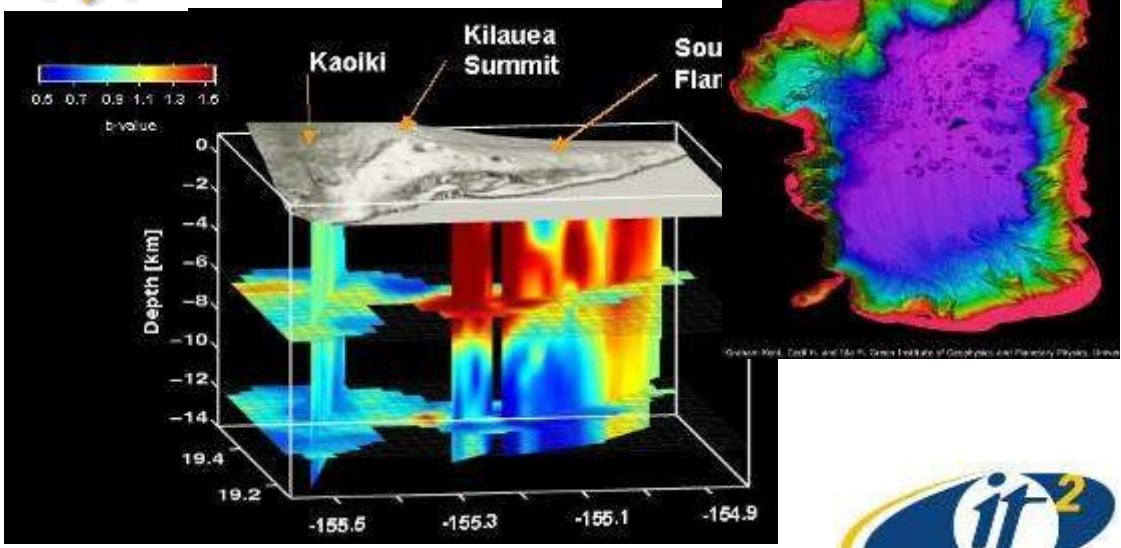
NIH Biomedical Informatics Research Network



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

NATIONAL INSTITUTES OF HEALTH

NSF EarthScope and ORION



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SDSC
SAN DIEGO SUPERCOMPUTER CENTER

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What is the OptIPuter?

- Applications Drivers → Interactive Analysis of Large Data Sets
- OptIPuter Nodes → Scalable PC Clusters with Graphics Cards
- IP over Lambda Connectivity →Predictable Backplane
- Open Source LambdaGrid Middleware→ Network is Reservable
- Data Retrieval and Mining → Lambda Attached Data Servers
- High Defn. Vis., Collab. SW → High Performance Collaboratory

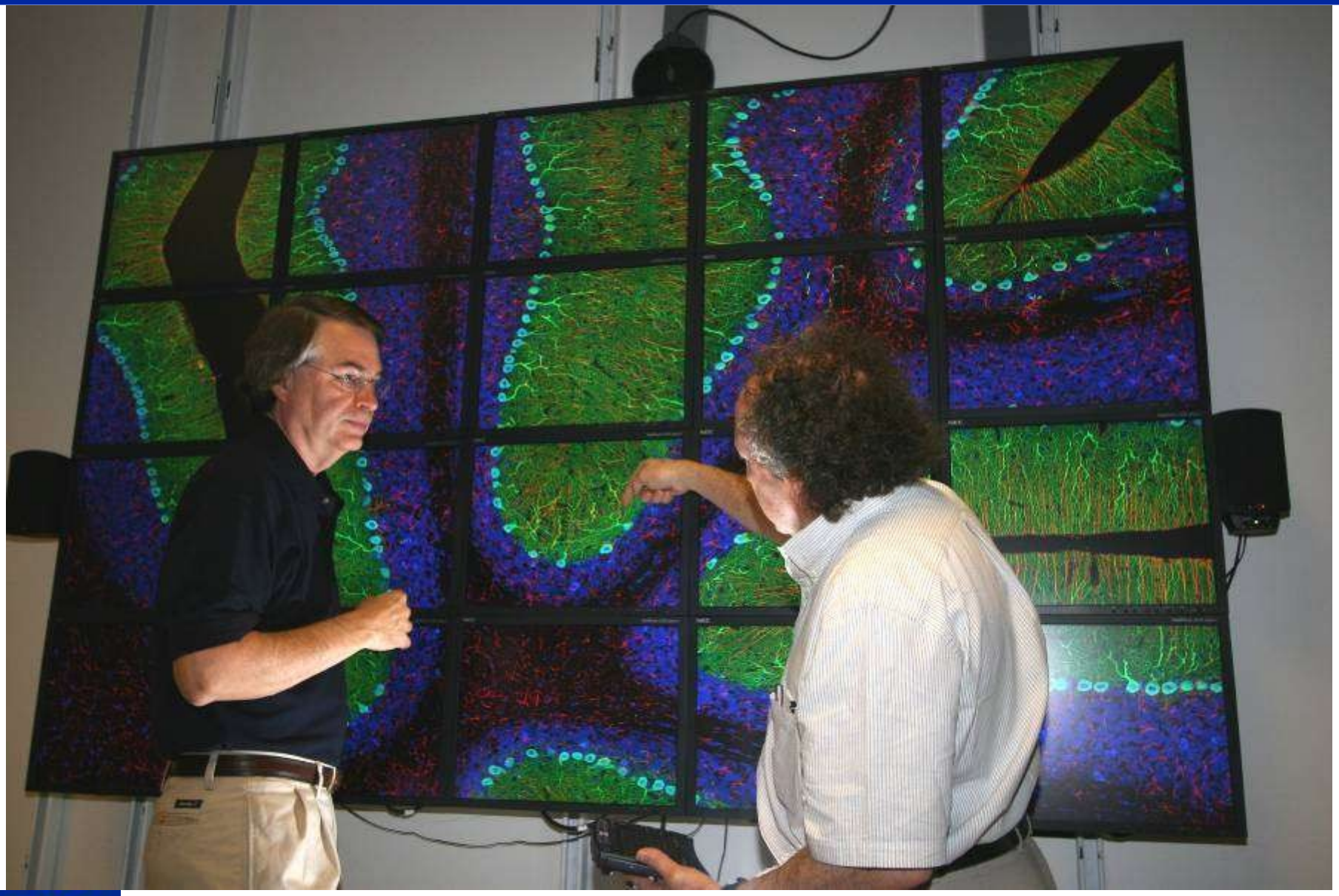
www.optiputer.net

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See Nov 2003 Communications of the ACM
for Articles on OptIPuter Technologies

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End User Device
Tiled Wall Driven by OptIPuter Graphics Cluster



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Source: Mark Ellisman, OptIPuter co-PI

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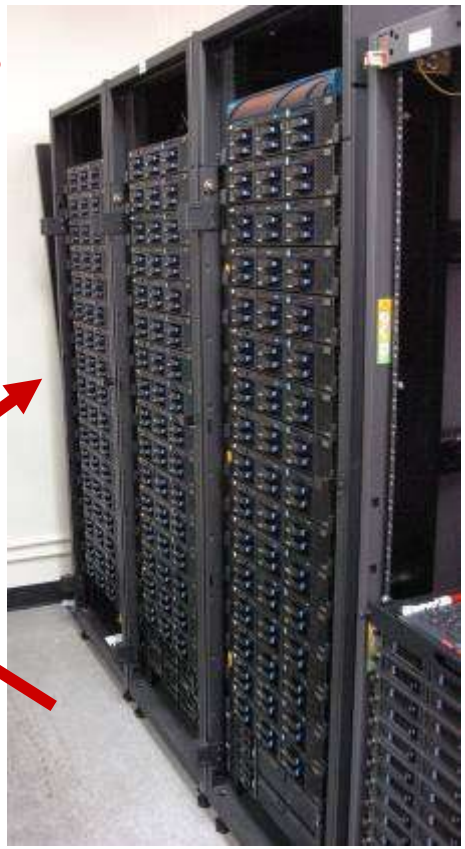
Campuses Must Provide Fiber Infrastructure to End-User Laboratories & Large Rotating Data Stores

SIO Ocean Supercomputer



UCSD Campus LambdaStore Architecture

IBM Storage Cluster



Streaming Microscope

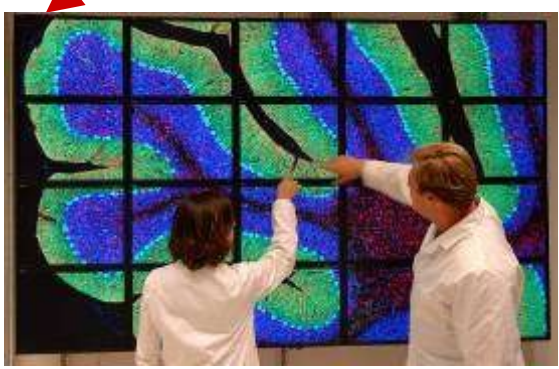






2 Ten Gbps Campus Lambda Raceway







Global LambdaGrid

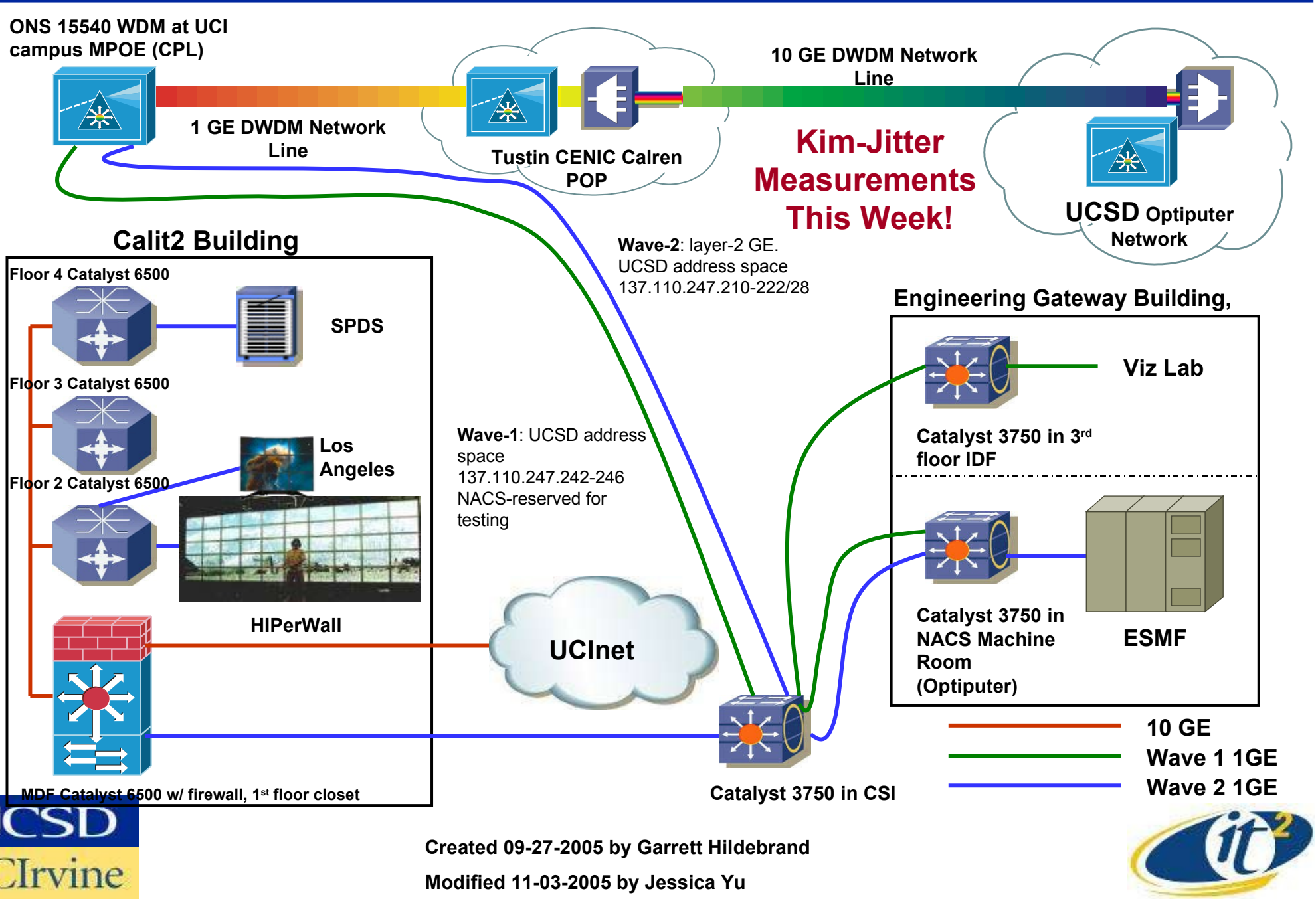
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Source: Phil Papadopoulos, SDSC, Calit2

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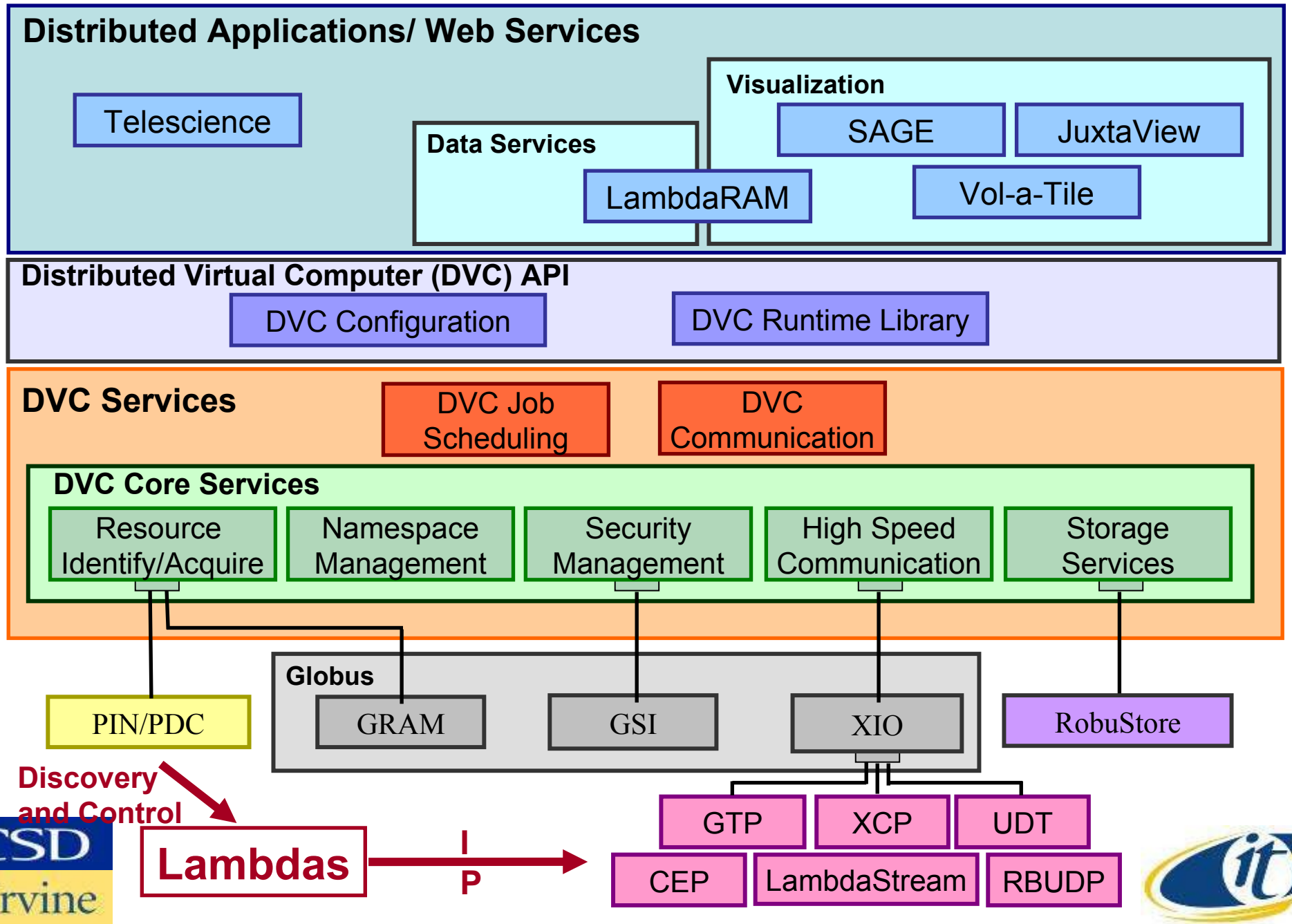
OptIPuter@UCI is Up and Working



Created 09-27-2005 by Garrett Hildebrand

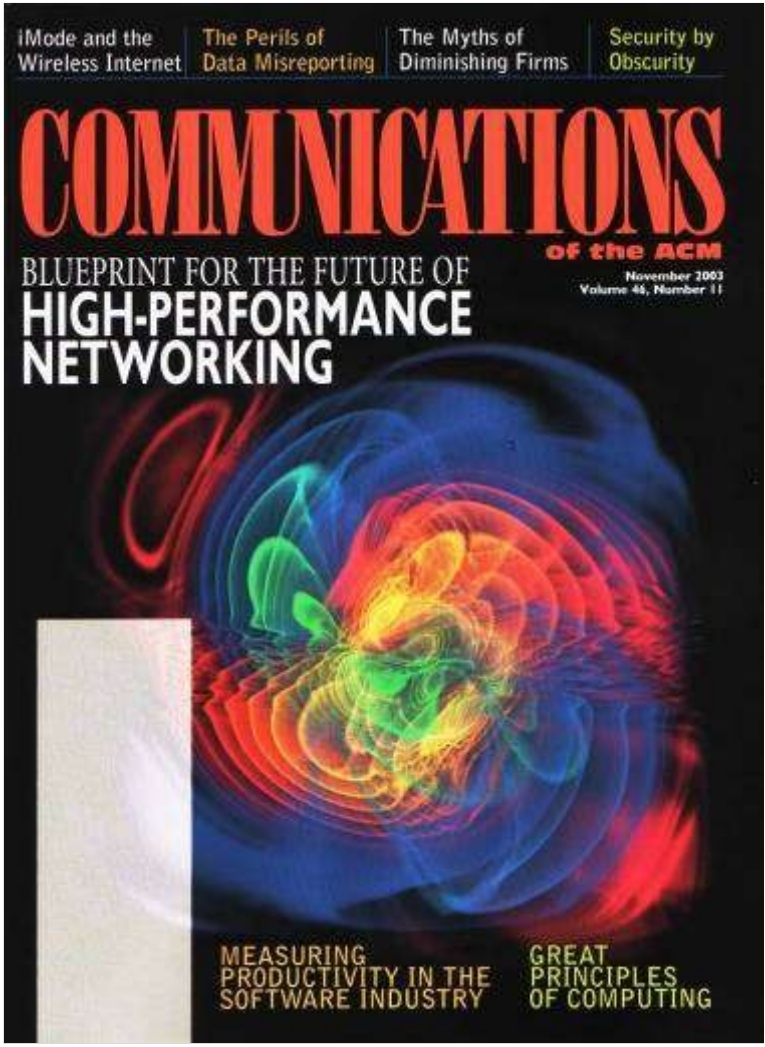
Modified 11-03-2005 by Jessica Yu

OptIPuter Software Architecture--a Service-Oriented Architecture Integrating Lambdas Into the Grid



Special issue of Communications of the ACM (CACM): Blueprint for the Future of High-Performance Networking

- Introduction
  - Maxine Brown (guest editor)
- TransLight: A Global-scale LambdaGrid for e-Science
  - Tom DeFanti, Cees de Laat, Joe Mambretti, Kees Neggers, Bill St. Arnaud
- Transport Protocols for High Performance
  - Aaron Falk, Ted Faber, Joseph Bannister, Andrew Chien, Bob Grossman, Jason Leigh
- Data Integration in a Bandwidth-Rich World
  - Ian Foster, Robert Grossman
- The OptIPuter
  - Larry Smarr, Andrew Chien, Tom DeFanti, Jason Leigh, Philip Papadopoulos
- Data-Intensive e-Science Frontier Research
  - Harvey Newman, Mark Ellisman, John Orcutt



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Source: Special Issue of Comm. ACM 2003

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NSF is Launching a New Cyberinfrastructure Initiative

"Research is being stalled by 'information overload,' Mr. Bement said, because data from digital instruments are piling up far faster than researchers can study. In particular, he said, campus networks need to be improved. High-speed data lines crossing the nation are the equivalent of six-lane superhighways, he said. But networks at colleges and universities are not so capable. "Those massive conduits are reduced to two-lane roads at most college and university campuses," he said. Improving cyberinfrastructure, he said, "will transform the capabilities of campus-based scientists."

-- Arden Bement, the director of the National Science Foundation



www.ctwatch.org

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The Optical Core of the UCSD Campus-Scale Testbed -- Evaluating Packet Routing versus Lambda Switching

Goals by 2007:

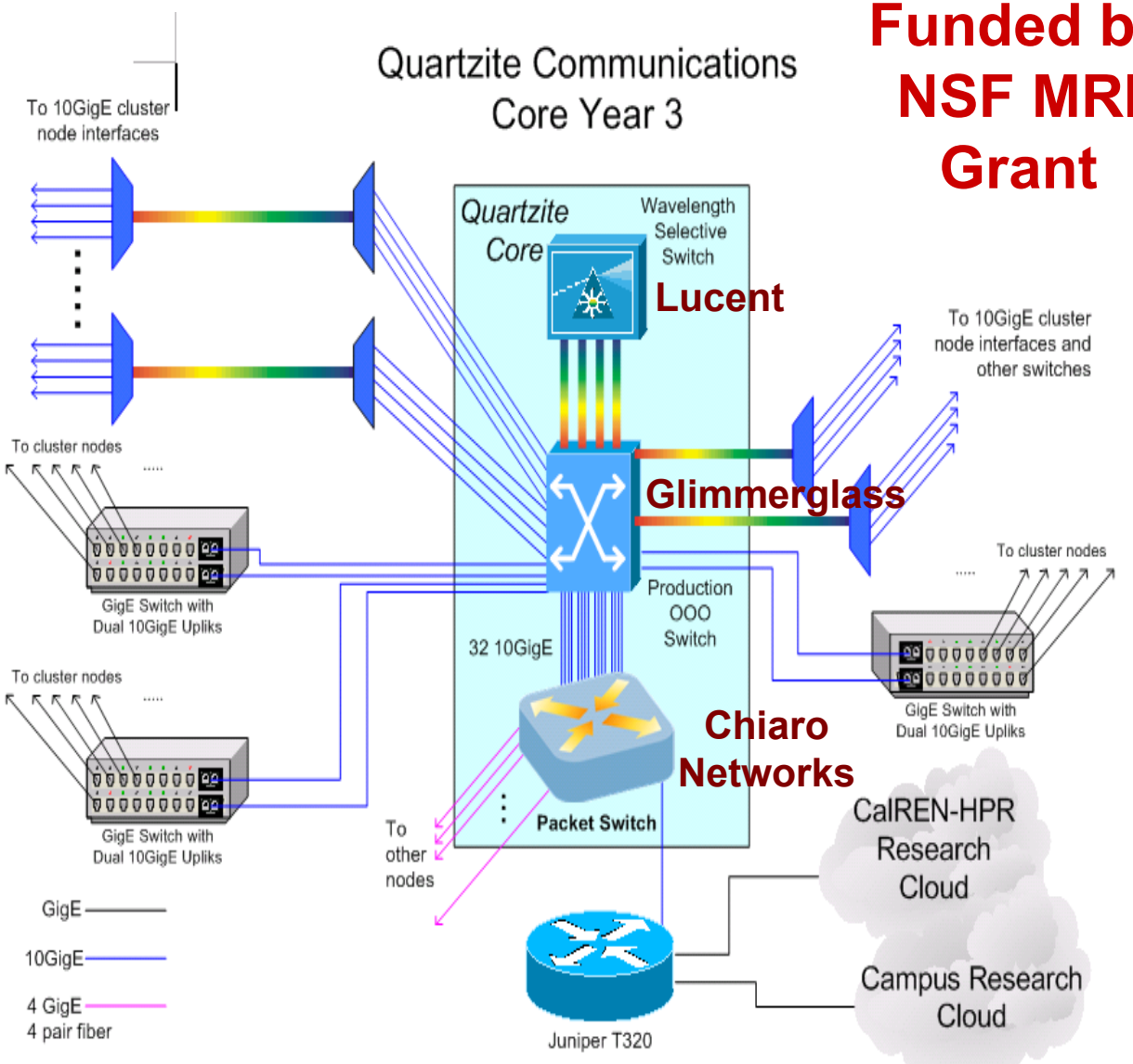
>= 50 endpoints at 10 GigE

>= 32 Packet switched

>= 32 Switched wavelengths

>= 300 Connected endpoints

Approximately 0.5 TBit/s Arrive at the "Optical" Center of Campus
Switching will be a Hybrid Combination of:
Packet, Lambda, Circuit -- OOO and Packet Switches Already in Place



Funded by NSF MRI Grant

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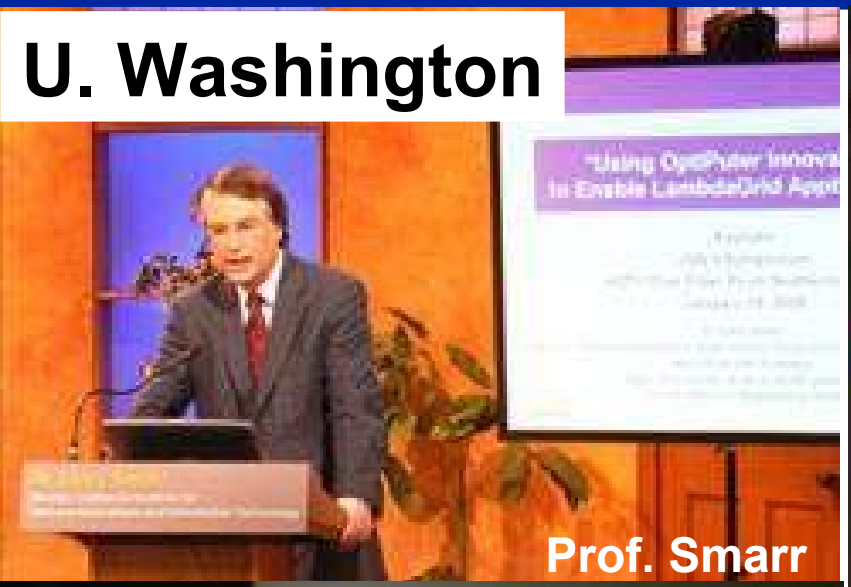
“Access Grid” Was Developed by the Alliance for Multi-site Collaboration



Access Grid Talk with 35 Locations on 5 Continents— SC Global Keynote Supercomputing ‘04

Problems Are Video Quality of Service and IP Multicasting

Multiple HD Streams Over Lambdas Will Radically Transform Global Collaboration





Telepresence Using Uncompressed 1.5 Gbps HDTV Streaming Over IP on Fiber Optics--
75x Home Cable "HDTV" Bandwidth!



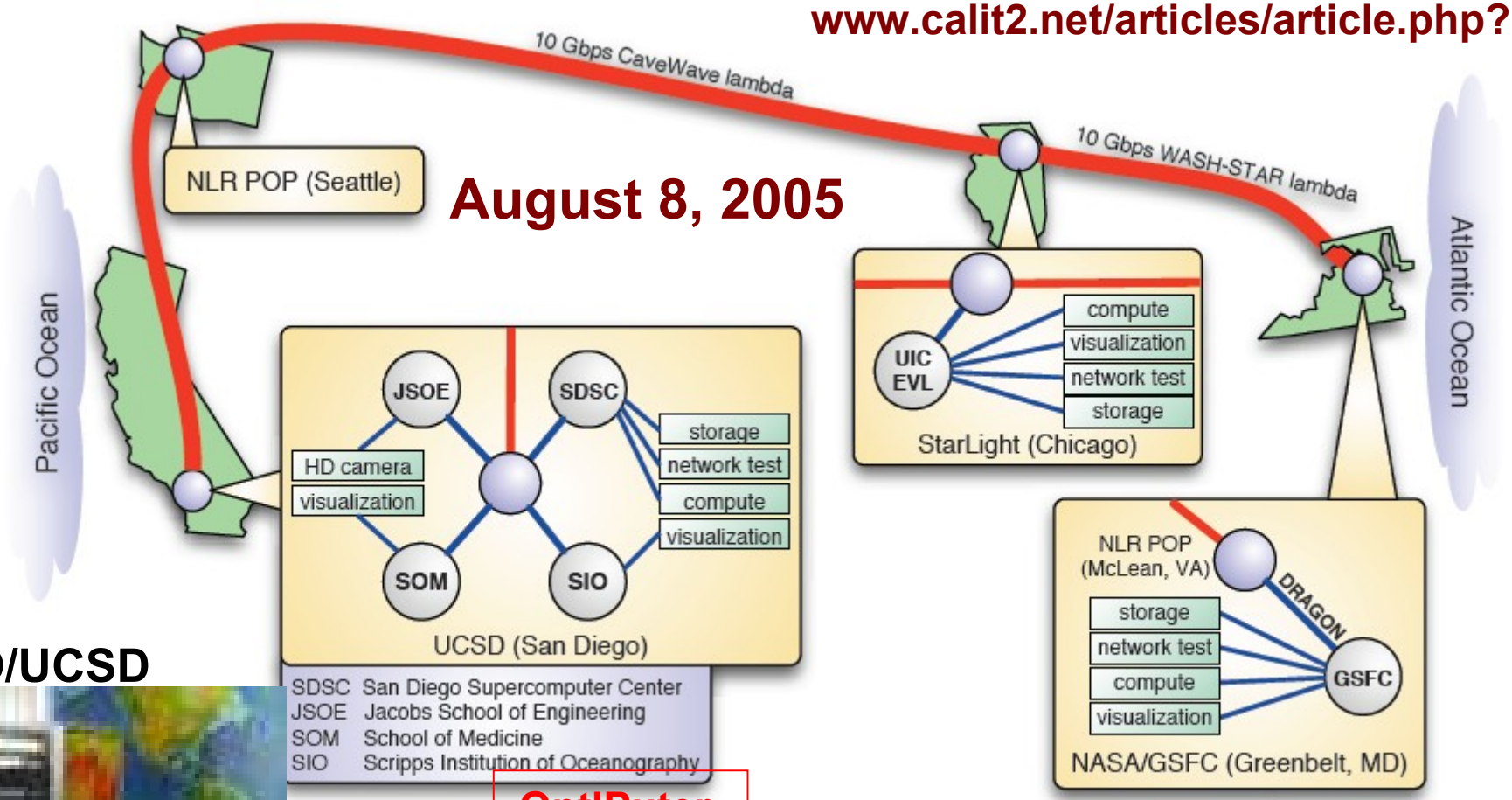
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Source: U Washington Research Channel

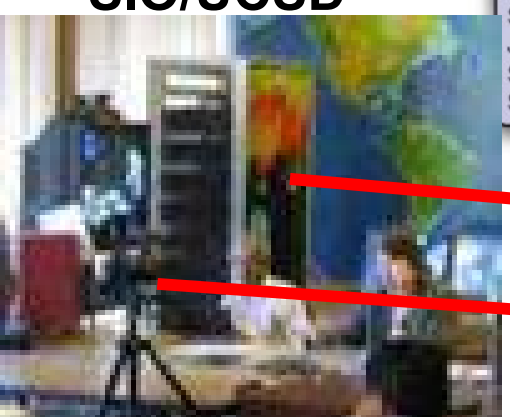
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Partnering with NASA to Combine Telepresence with Remote Interactive Analysis of Data Over National LambdaRail

www.calit2.net/articles/article.php?id=660



SIO/UCSD



OptIPuter Visualized Data

HDTV Over Lambda



NASA Goddard

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The Global Lambda Integrated Facility (GLIF) Creates MetaComputers on the Scale of Planet Earth

Maxine Brown, Tom DeFanti, Co-Chairs

iGrid 2005

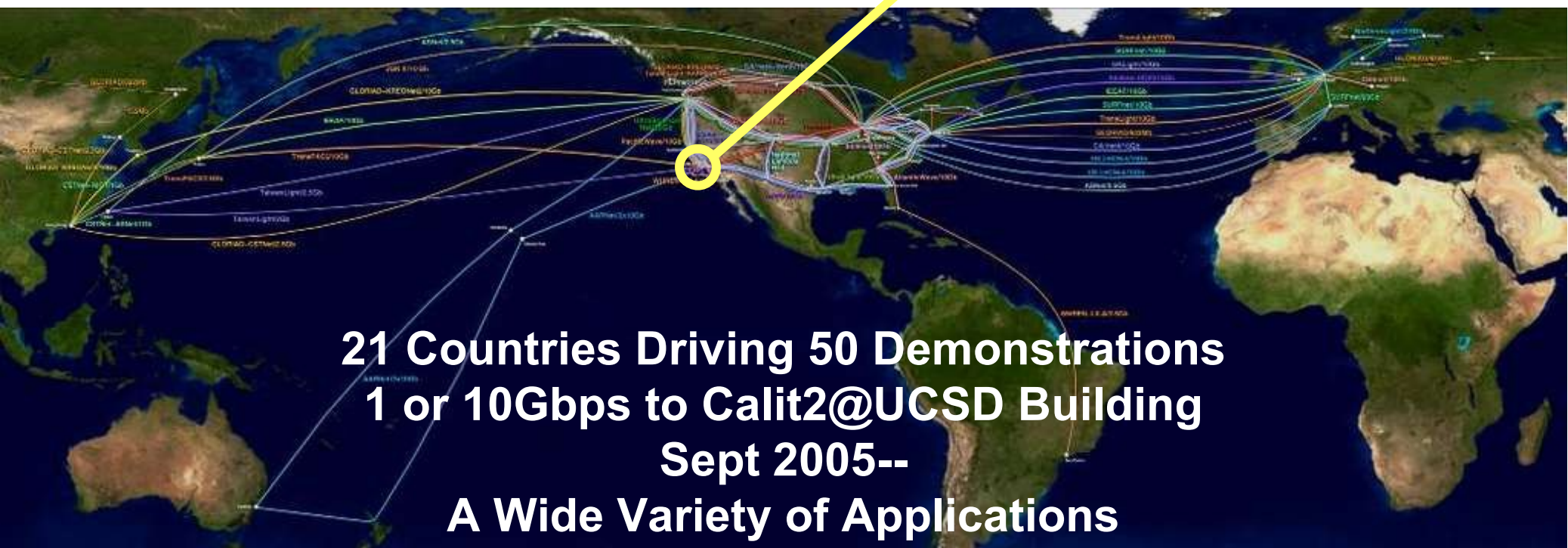
THE GLOBAL LAMBDA INTEGRATED FACILITY

www.igrid2005.org



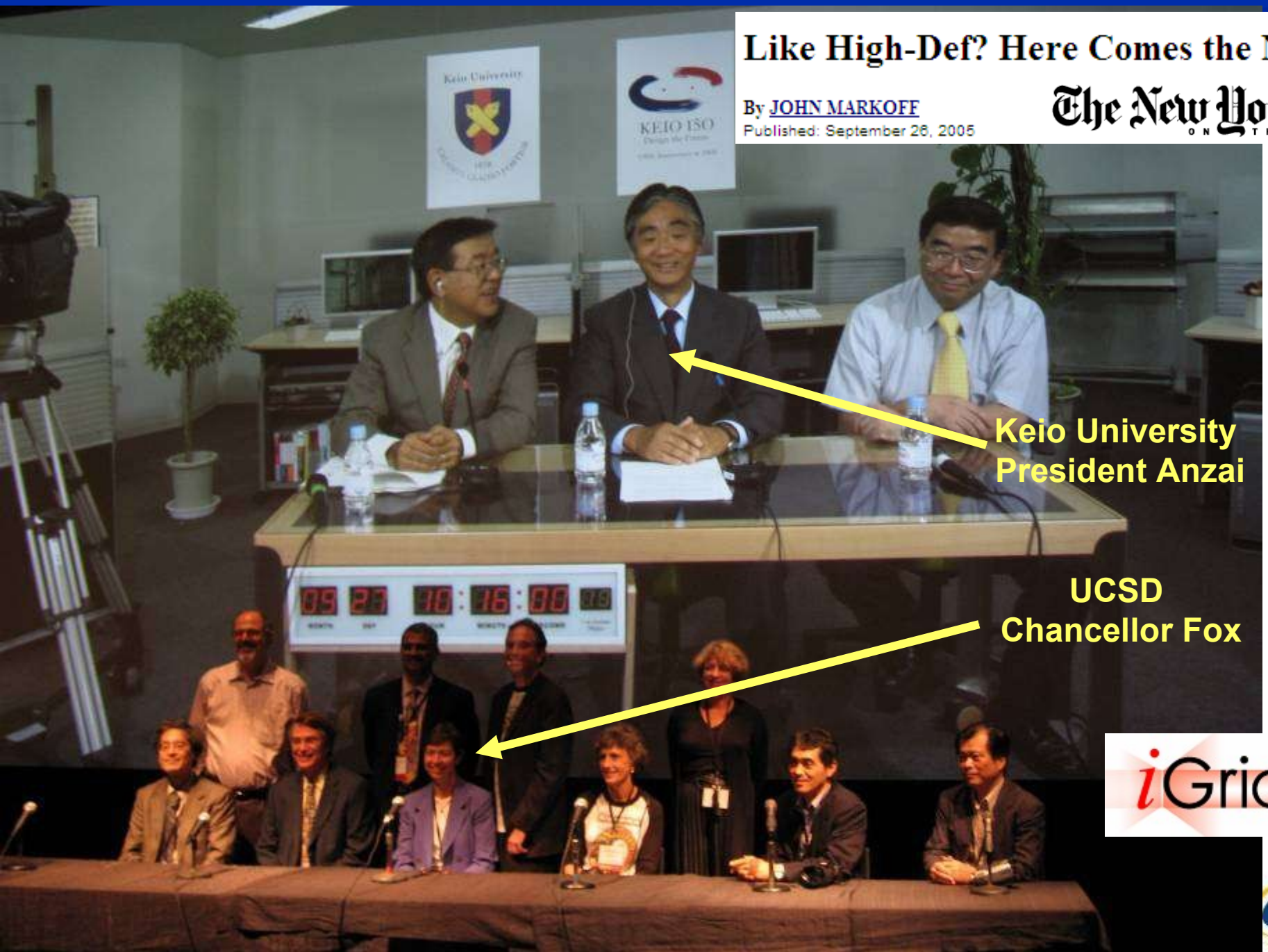
the UC Discovery Grant

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--
A Wide Variety of Applications

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

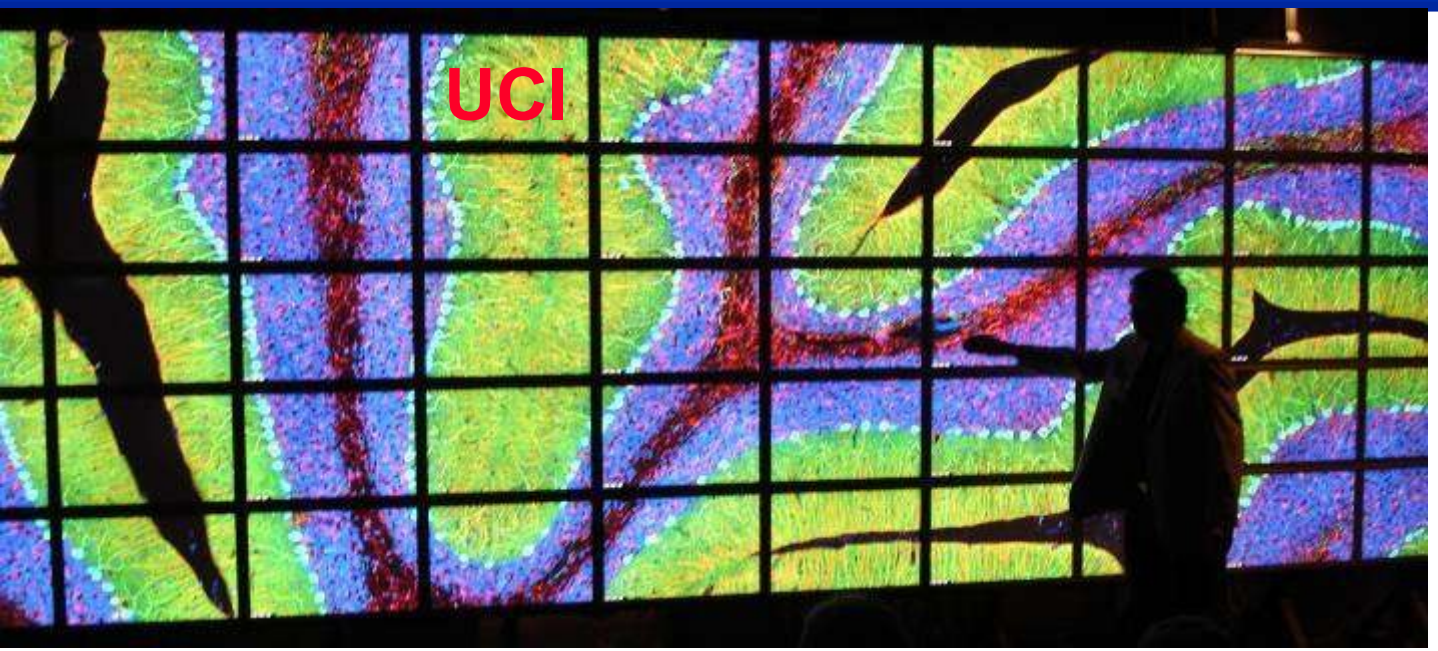
Lays Technical Basis for Global Digital Cinema

Sony
NTT
SGI

iGrid 2005

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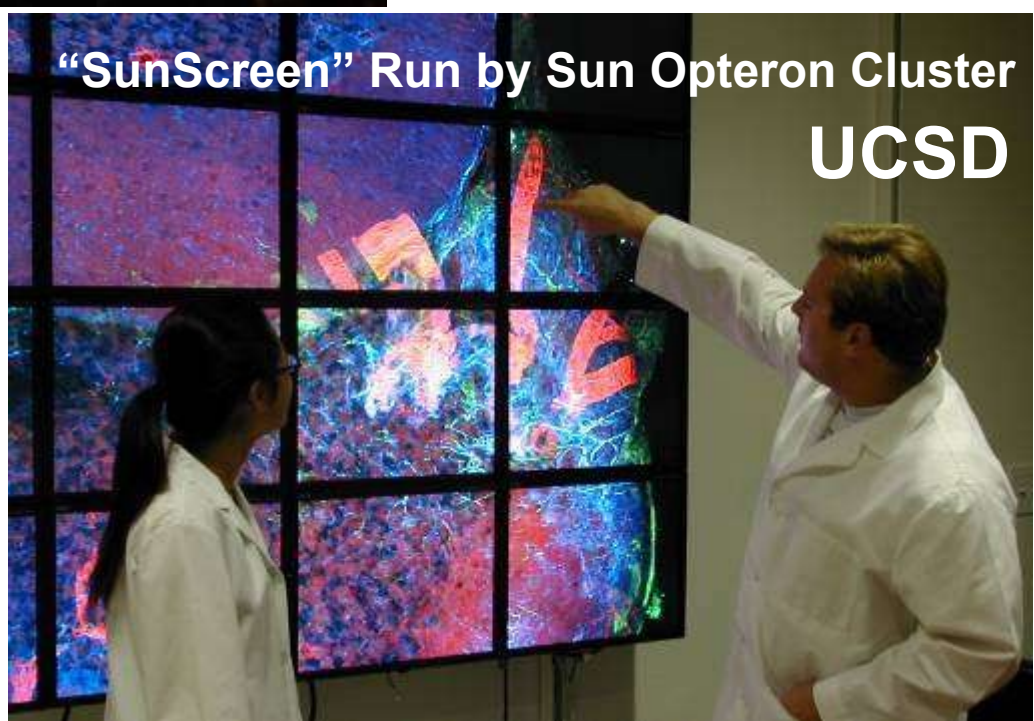
The OptIPuter Enabled Collaboratory: Remote Researchers Jointly Exploring Complex Data



OptIPuter

OptIPuter will Connect
The Calit2@UCI
200M-Pixel Wall
to
The Calit2@UCSD
100M-Pixel Display
With Shared Fast Deep Storage

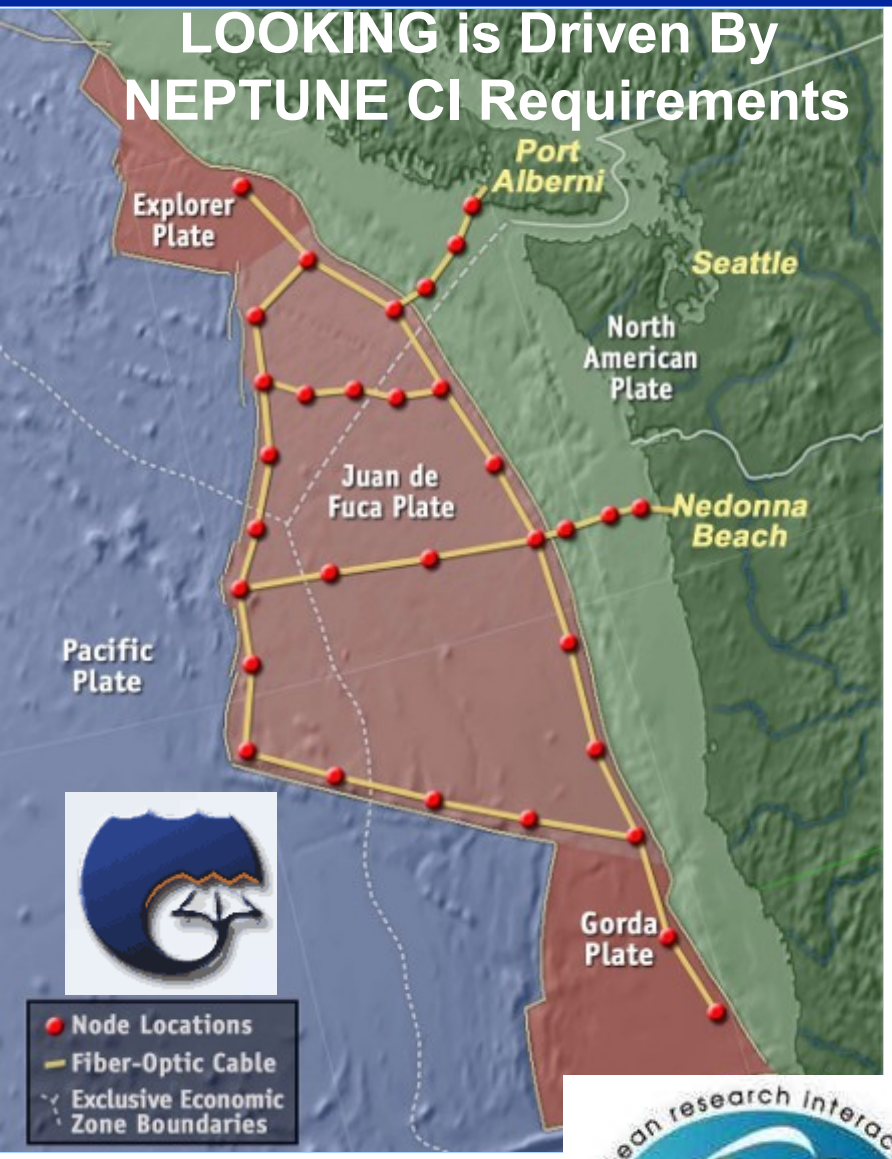
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Metacomputer: Community Adoption of LambdaGrid (2005-2006)

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Adding Web & Grid Services to Optical Channels to Provide Real Time Control of Ocean Observatories



LOOKING:
(Laboratory for the Ocean Observatory Knowledge Integration Grid)

http://lookingtosea.ucsd.edu/

- **Goal:**
  - Prototype Cyberinfrastructure for NSF's Ocean Research Interactive Observatory Networks (ORION)
- **LOOKING NSF ITR with PIs:**
  - John Orcutt & Larry Smarr - UCSD
  - John Delaney & Ed Lazowska –UW
  - Mark Abbott – OSU
- **Collaborators at:**
  - MBARI, WHOI, NCSA, UIC, CalPoly, UVic, CANARIE, Microsoft, NEPTUNE-Canarie

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NSF

ocean research interactive ORION observatory networks

Making Management of Gigabit Flows Routine

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First Remote Interactive High Definition Video Exploration of Deep Sea Vents



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Source John Delaney & Deborah Kelley, UWash

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CAMERA: Community Cyberinfrastructure for Advanced Marine Microbial Ecology Research and Analysis

National LambdaRail
Direct Connect
Computation and Storage Complex

Funded by: Gordon and Betty Moore Foundation

Joint Partnership of:

UCSD
UCIrvine

PI Larry Smarr

Building On Centers of Excellence and Achievement









Powered by Rocks









The Scripps Genome Center

Supported by:









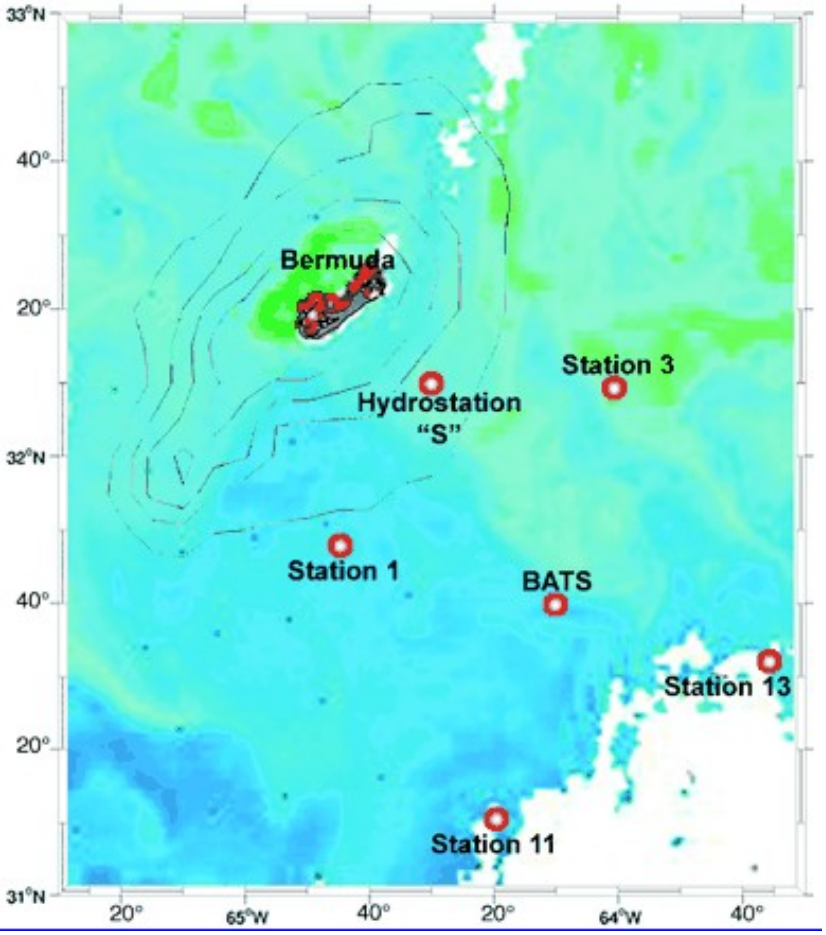


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Announcing Tuesday January 17, 2006

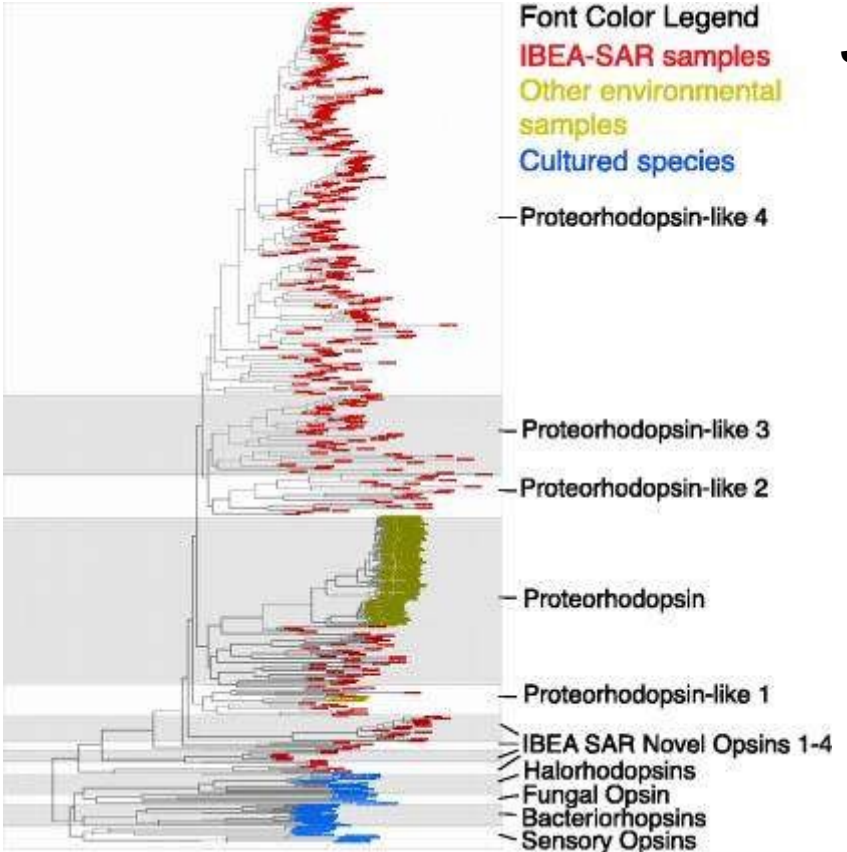
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The Sargasso Sea Experiment
The Power of Environmental Metagenomics



MODIS-Aqua satellite image of ocean chlorophyll in the Sargasso Sea grid about the BATS site from 22 February 2003

- Yielded a Total of Over 1 billion Base Pairs of Non-Redundant Sequence
- Displayed the Gene Content, Diversity, & Relative Abundance of the Organisms
- Sequences from at Least 1800 Genomic Species, including 148 Previously Unknown
- Identified over 1.2 Million Unknown Genes



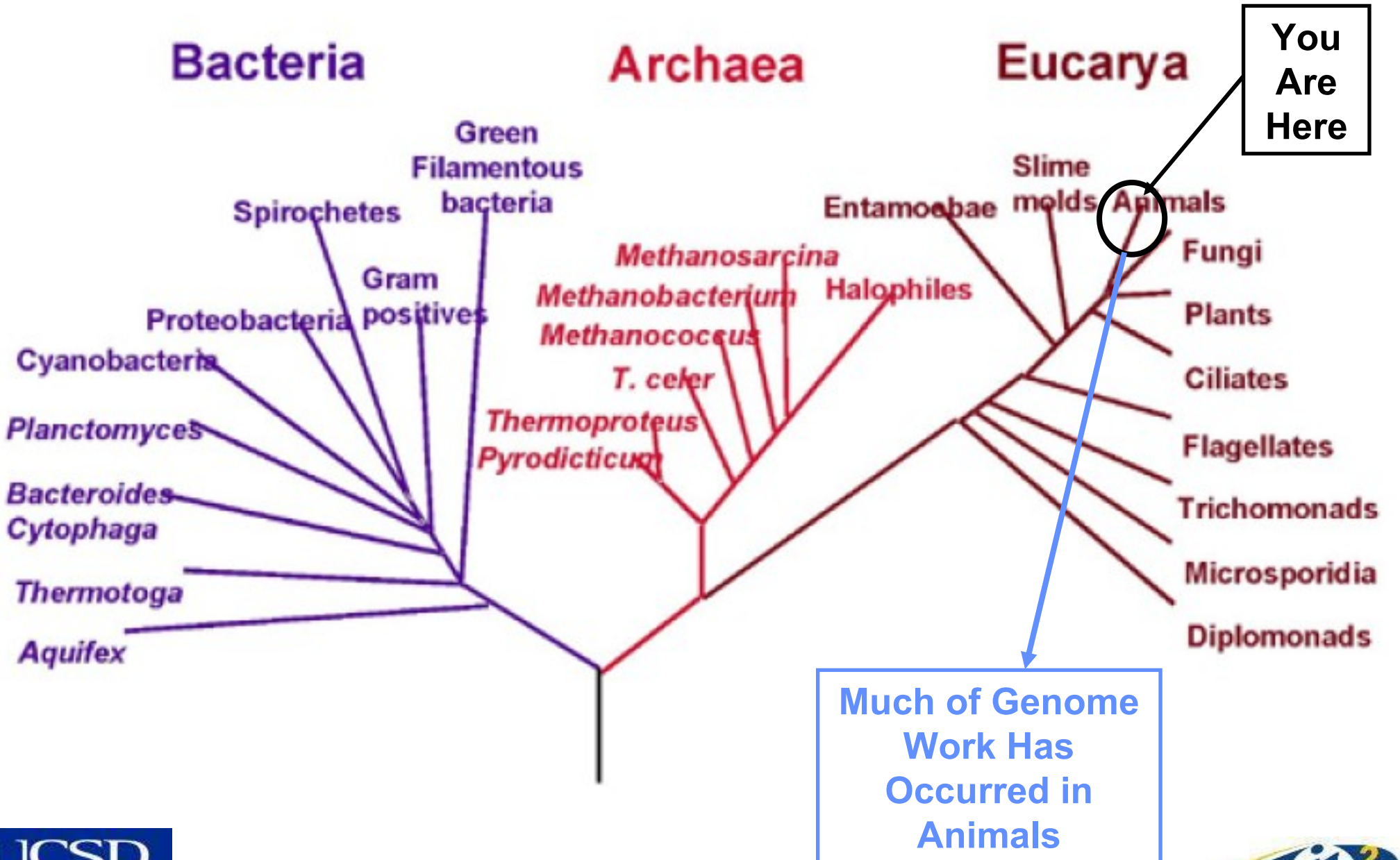
J. Craig Venter, et al.
Science
2 April 2004:
Vol. 304.
pp. 66 - 74



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Evolution is the Principle of Biological Systems: Most of Evolutionary Time Was in the Microbial World

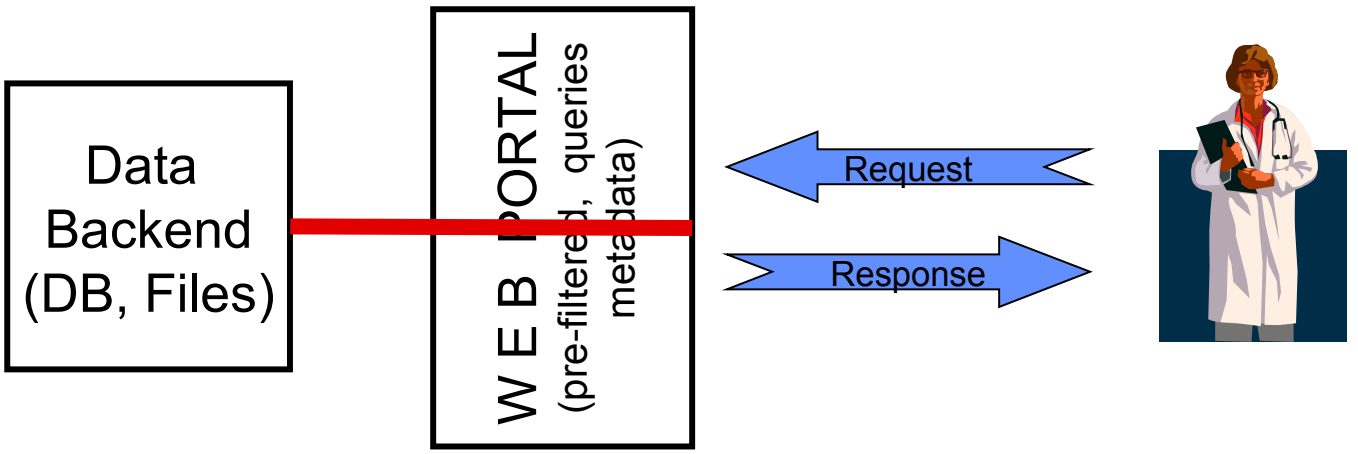


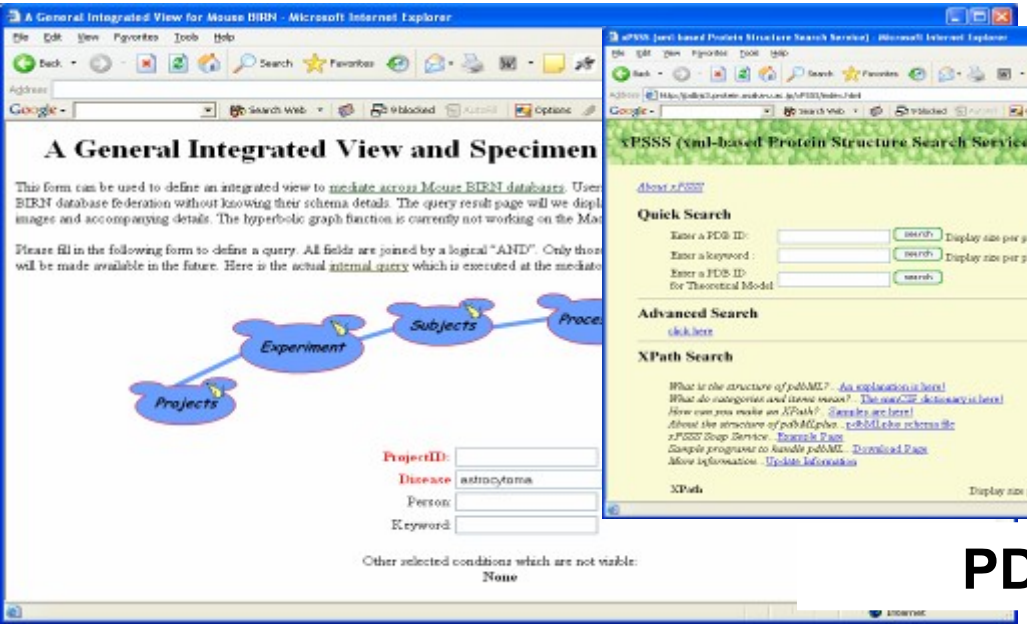
Source: Carl Woese, et al

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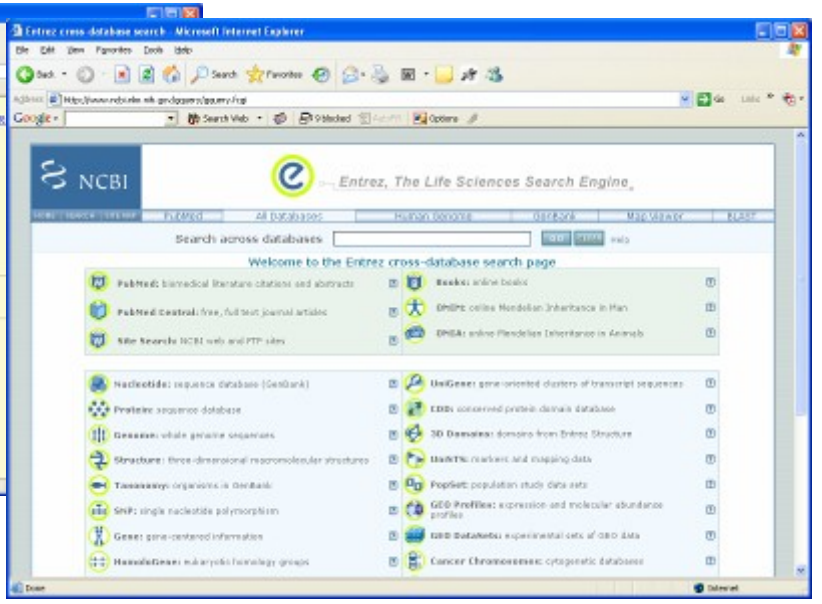
Calit2 Intends to Jump Beyond Traditional Web-Accessible Databases





BIRN

PDB



NCBI Genbank

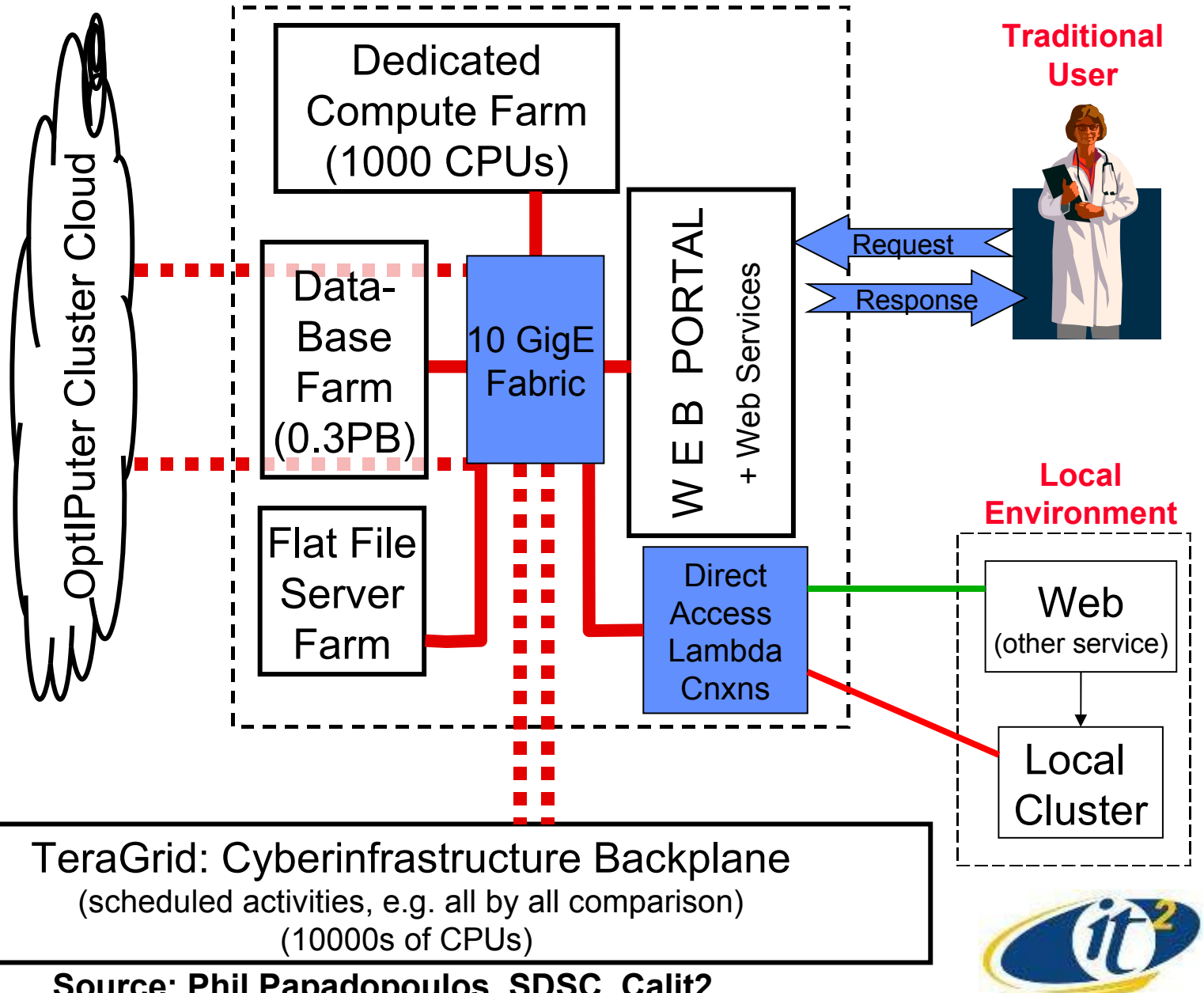
+ many others

Source: Phil Papadopoulos, SDSC, Calit2

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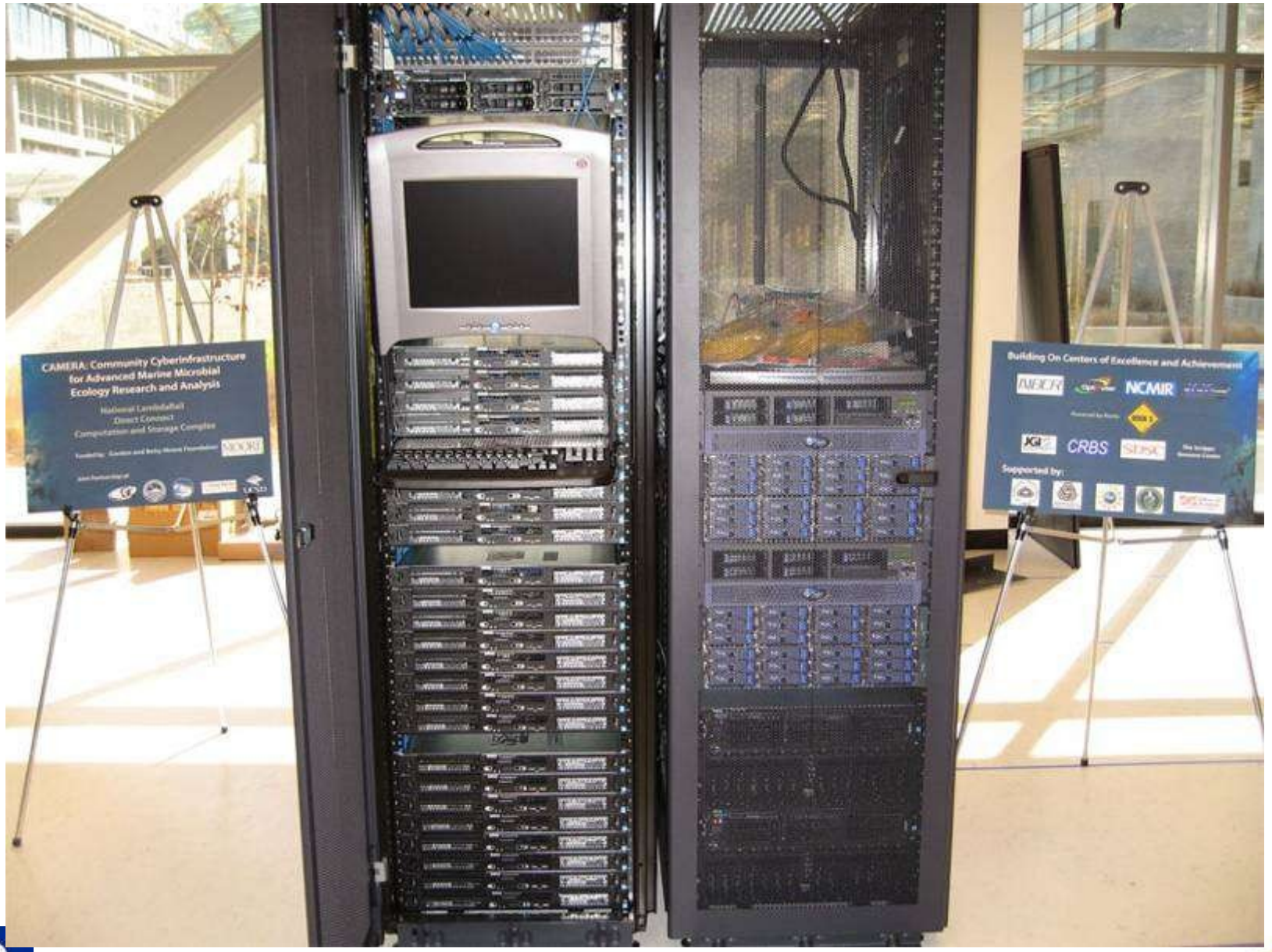
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Data Servers Must Become Lambda Connected to Allow for Directly Optical Connection to End User Clusters



Source: Phil Papadopoulos, SDSC, Calit2

First Implementation of the CAMERA Complex in Calit2@UCSD Server Room



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January 12, 2006

Calit2/SDSC Proposal to Create a UC Cyberinfrastructure of OptIPuter "On-Ramps" to TeraGrid Resources



OptIPuter + CalREN-XD + TeraGrid = "OptiGrid"



Creating a Critical Mass of End Users on a Secure LambdaGrid

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Source: Fran Berman, SDSC , Larry Smarr, Calit2