Computing, Communications and You: The Next 10 Years and Beyond

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Argonne National Laboratory
and
The University of Chicago

“Here, my friends, in the prairies of Illinois and of the Middle West, we can see a long way in all directions. We look to east, to west, to north, and south. Our commerce, our ideas, come and go in all directions. Here there are no barriers, no defenses, to ideas and to aspirations. We want none; we want no shackles on the mind, or to the spirit, no rigid patterns of thought, and no iron conformity. We want only the faith and conviction that triumph in fair and free contest.”

Adlai Stevenson

Chicago IL , July 21, 1952

Outline

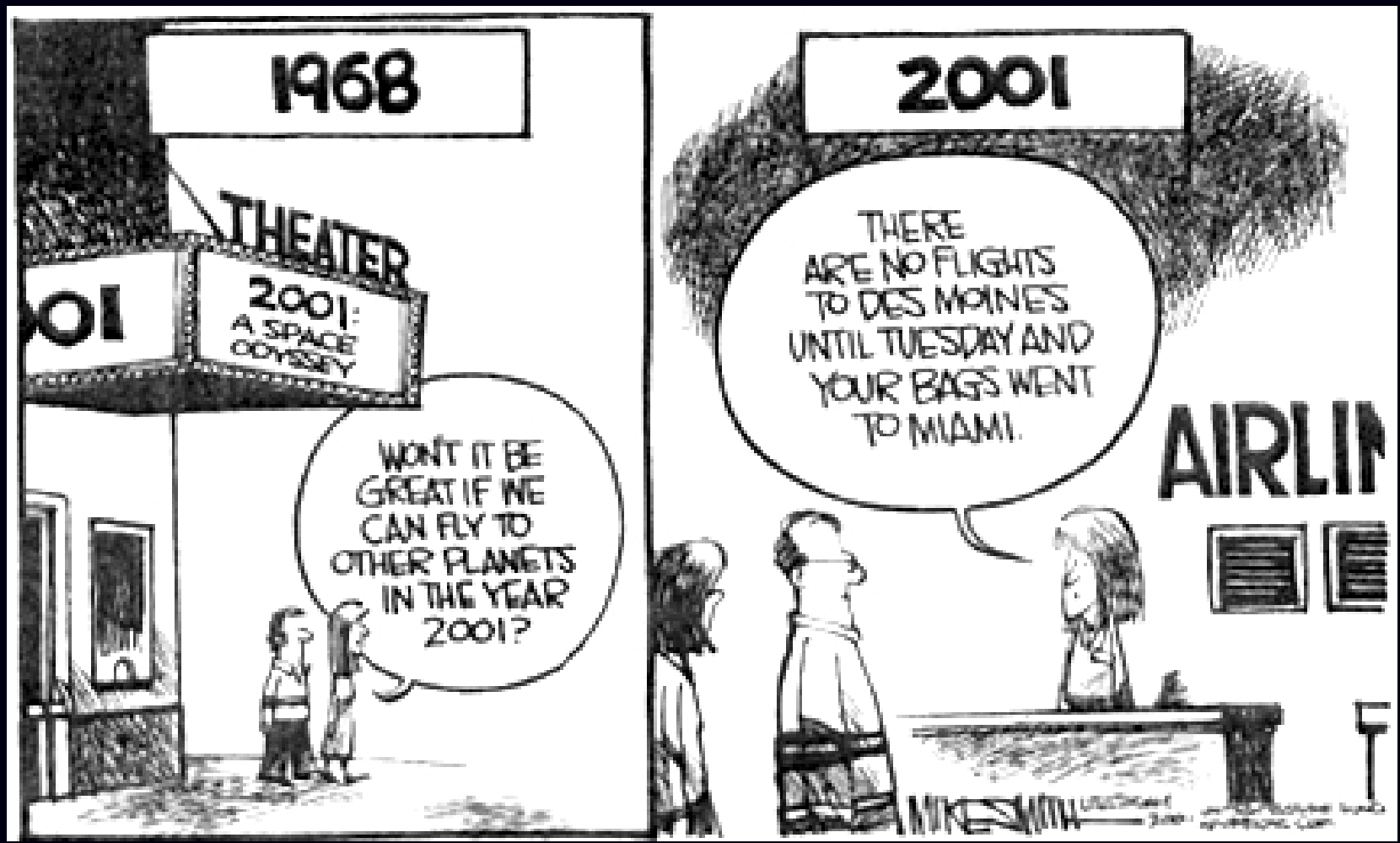
- Major Trends In Computing
- The Emergence of the Grid
- Collaboration and Visualization Technologies
- Future Directions for High-Speed Networking
- Supercomputing as a Time Machine
- The Next 500 Years of Biology
- Questions and Discussion

Observations on Futurism

- The Rules of Thumb about Technology Prediction
  - In the near term we over estimate changes
  - In the long term we under estimate changes
- Experts are better at predictions outside of their fields of expertise
  - Anti-Delphi effect
- The impacts from unforeseen science and technology developments are more important than extrapolating from today's technology base
  - But they are very difficult to predict ☺
- References:

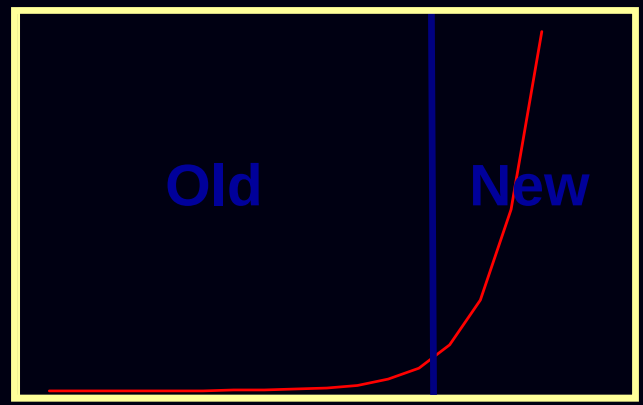
"Autonomous Technology" by Langdon Winner, MIT Press (1977)
"The Social Shaping of Technology" by MacKenzie and Wajcman, Open University (1985)

Predictions Are Hard, Especially Predictions About the Future!!



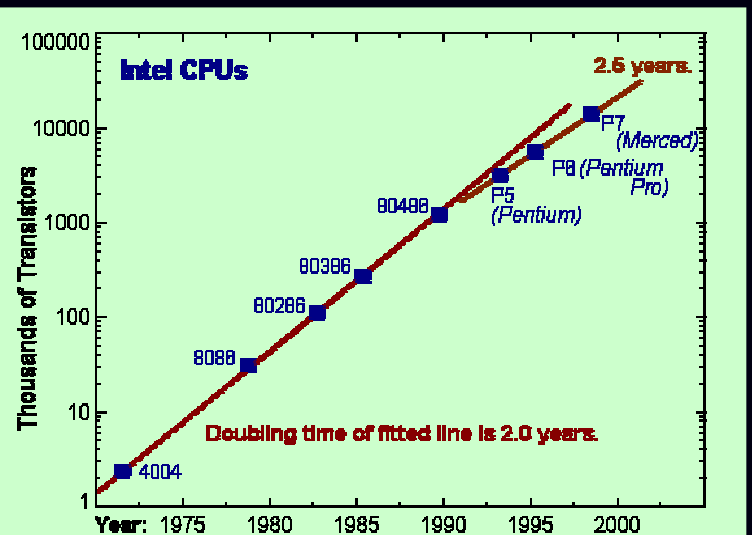
The Power of Exponentials

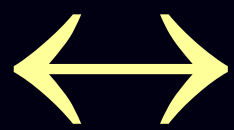
- Non-intuitive Exponentials
  - They Look Linear for a Long Time
  - Then a Phase Transition Occurs
- Understanding Change
  - Ride the Exponential
  - Recognize the Inflection Points
- Quantitative Begets Qualitative
  - Exponential Change
  - A Breakthrough Opportunity

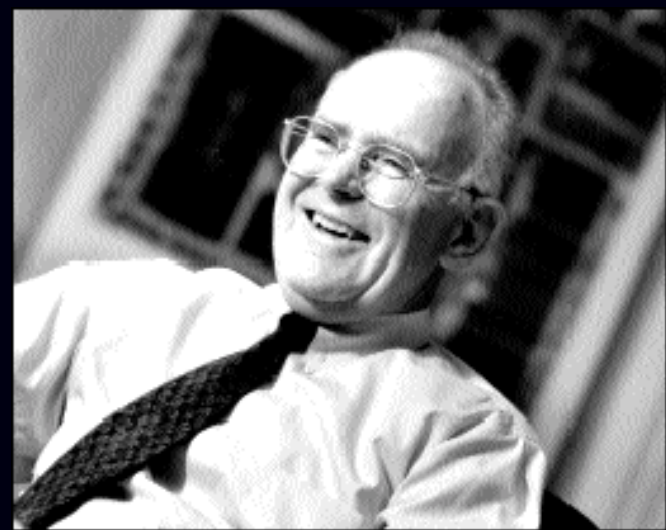


You Can’t Brake the Law, Moores’s Law That Is!

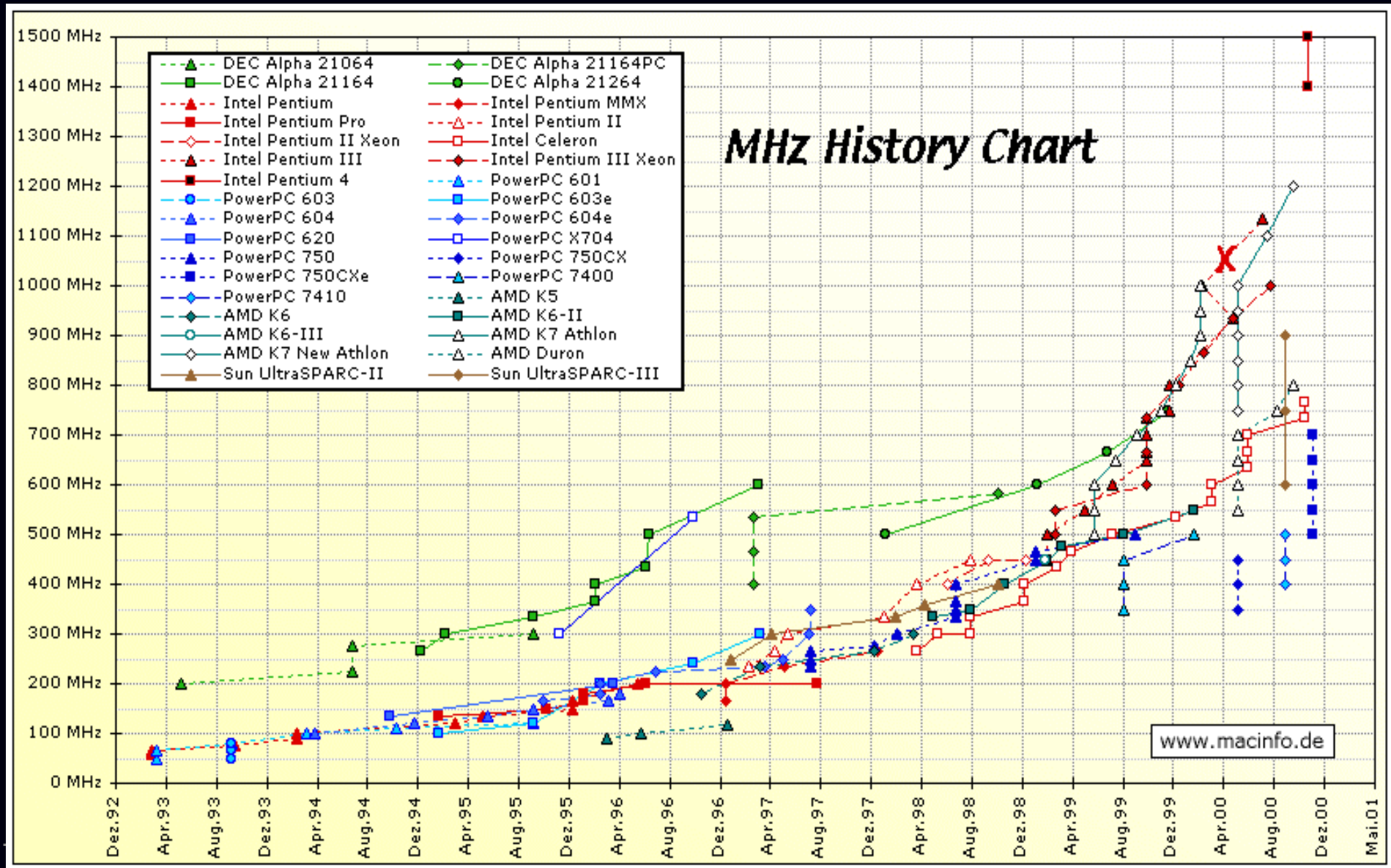
The observation made in 1965 by Gordon Moore, co-founder of Intel, that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented. Moore predicted that this trend would continue for the foreseeable future. In subsequent years, the pace slowed down a bit, but data density has doubled approximately every 18 months, and this is the current definition of Moore's Law, which Moore himself has blessed. Most experts, including Moore himself, expect Moore's Law to hold for at least another two decades.



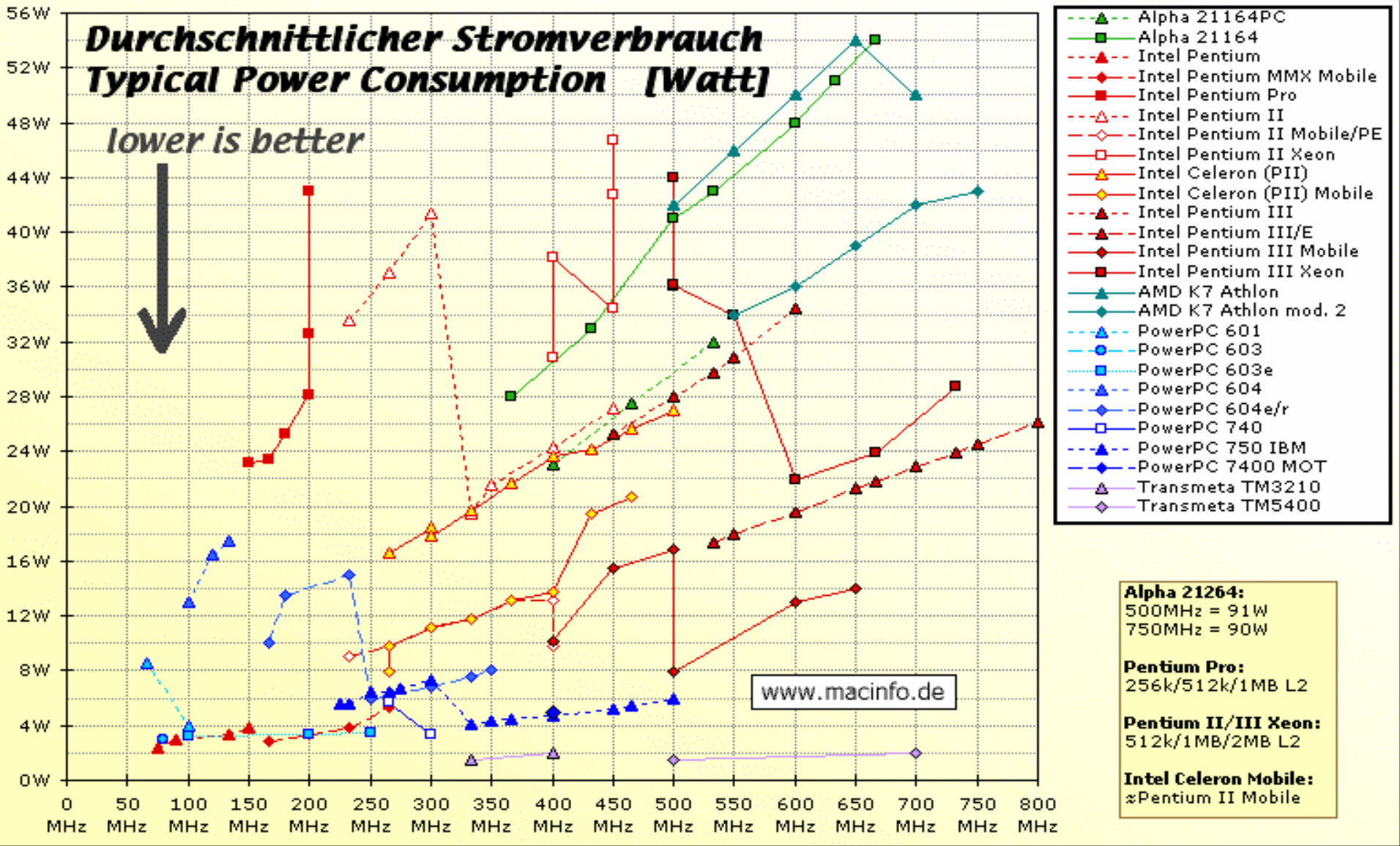




Chip Density and Clock Rate are Increasing



Unfortunately So is Power Consumption

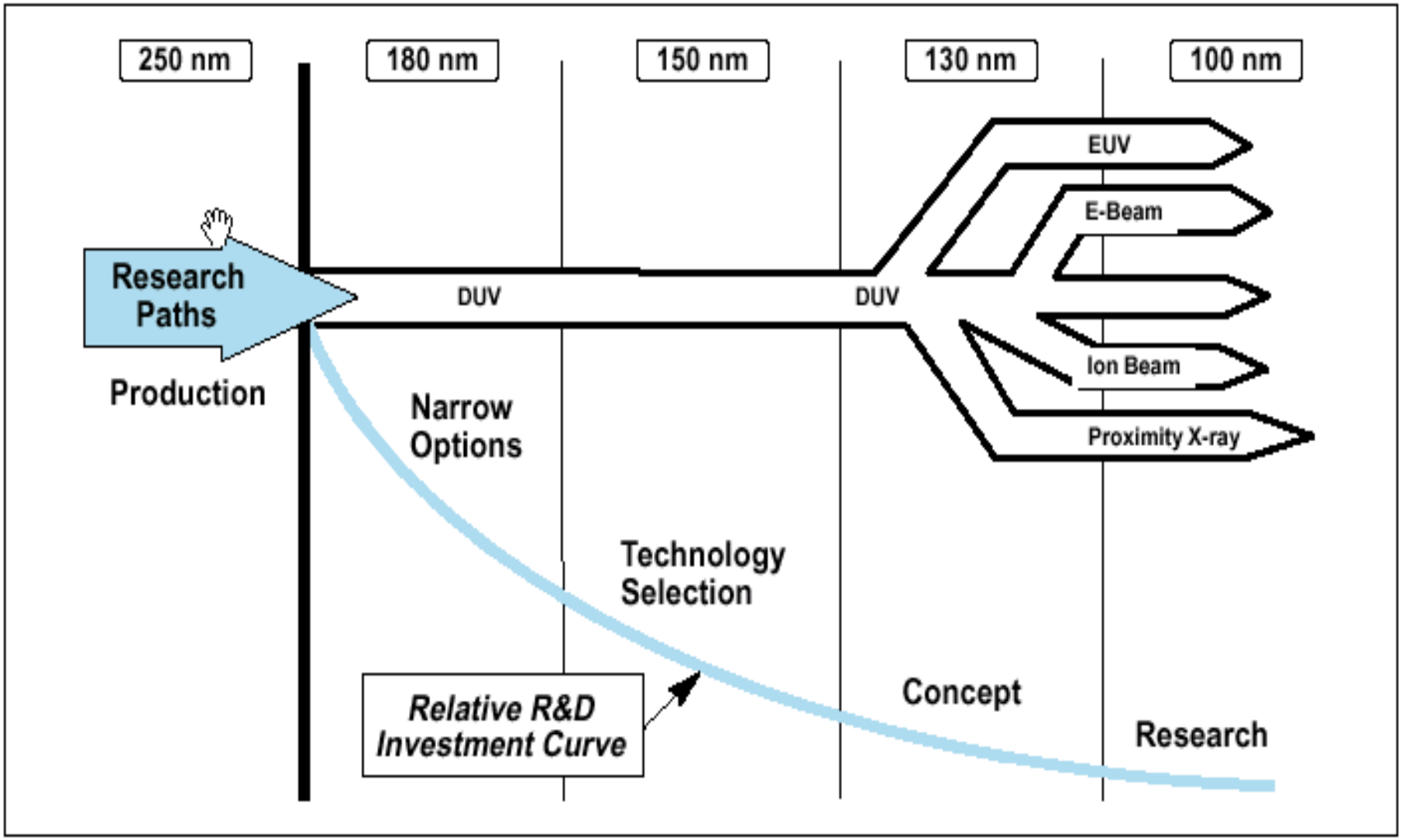


Semiconductor Industry Association Roadmap

Table 1 Technology Generations

Year of First Product Shipment	*1997*	*1999*	*2001*	*2003*	*2006*	*2009*	*2012*
Technology Generations Dense Lines (DRAM Half-Pitch) (nm)	*250*	*180*	*150*	*130*	*100*	*70*	*50*
Isolated Lines (MPU Gates) (nm)	*200*	*140*	*120*	*100*	*70*	*50*	*35*
Memory							
Generation @ samples/introduction	256M	1G	*	4G	16G	64G	256G
Generation @ production ramp	64M	256M	1G	1G	4G	16G	64G
Bits/cm^2 @ sample/introduction	96M	270M	380M*	770M	2.2B	6.1B	17B
Logic (high-volume, cost-performance: MPU)†							
Logic transistors/cm^2 (packed, including on-chip SRAM)	3.7M	6.2M	10M	18M	39M	84M	180M
*Logic (low-volume: ASIC)***‡							
Usable transistors/cm^2 (auto layout)	8M	14M	16M	24M	40M	64M	100M

* *Generation is for trend purposes only*
** *ASIC—application-specific integrated circuit*
† *Year 1 data will be less dense than subsequent shrinks*
‡ *Refers to high-performance, leading-edge, embedded-array ASICs*



DUV—deep ultraviolet
EUV—extreme ultraviolet
E-beam—electron beam

Figure 1 Conceptual Illustration of Today's Research and Development Investments for Future Production Technologies

PC Computing Technology in 2010

- Memory Capacity Continue quadrupling every 3 years
  - 256 MB today → 20 GB in 2010
  - GByte RAM chips ($1MB today.. ~$1GB in 2010)
- Disks 10 TB disks 1-2” form factor
  - 70 GB today → 1.5 TB in 2010
  - personal Petabyte DBs become possible (100 disks)
- Microprocessor performance increase at 60% per year .
  - 4GF today → 160 GF in 2010
  - 1.4 GHz in 2000 → 30 GHz in 2010
- Networking (Ethernet)
  - 10 Gigabit Ethernet in 2000 → Terabit Ethernet in 2010

Corollaries to Moore’s Law

"Gordon Moore just plain got it right . . . I should also mention that Moore's Law has also given rise to Machrone's Law, which was true for many years, which is that the machine you want always costs $5,000." *-Bill Machrone*

"A very small addendum to Moore's Law is Rock's Law which says that the cost of capital equipment to build semiconductors will double every four years."

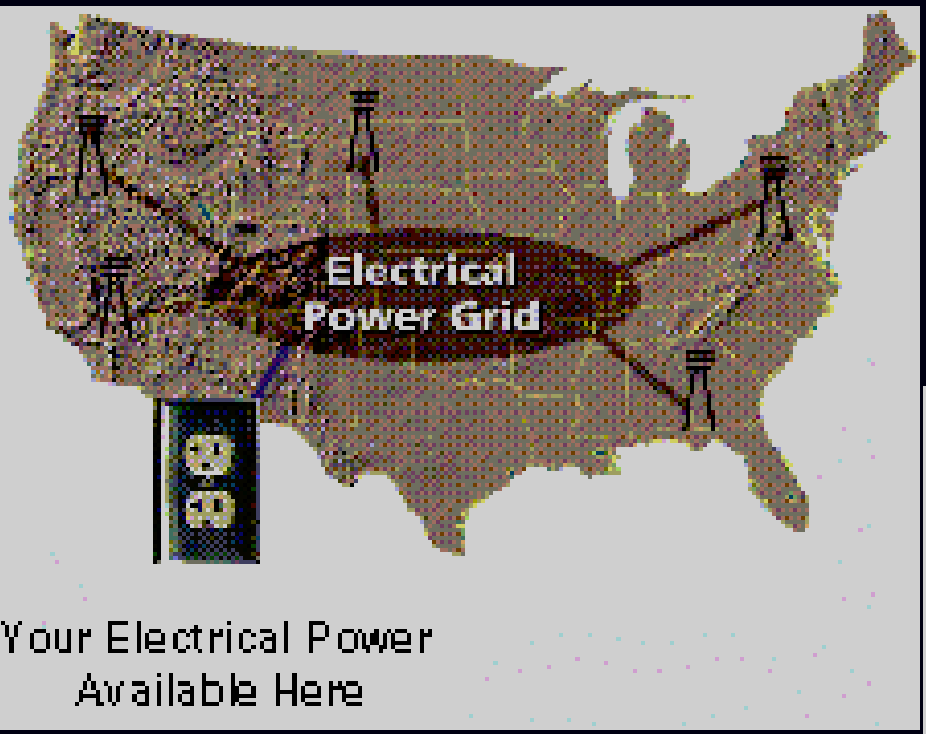
-Arthur Rock

The Emergence of the Grid

A Big Telecommunications Trend

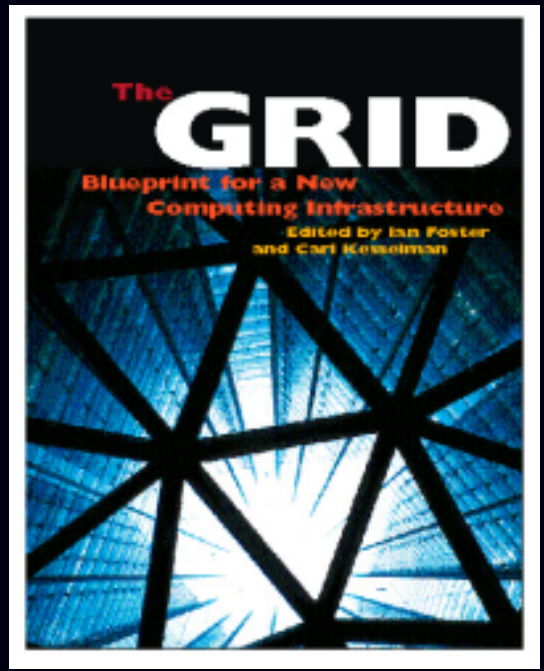
- Data traffic will exceed voice traffic in 3-5 years
- Voice traffic will become an small fraction of total traffic within 10 years
  - Unlimited POTS voice service will be tossed in as a perk
- Bandwidth prices will eventually begin to follow Moore's law or even accelerate
  - 2X capability every 18 months
- Eventually we will think of bandwidth as "free like the air"

The Emerging Concept of a National Scale Information Power Grid

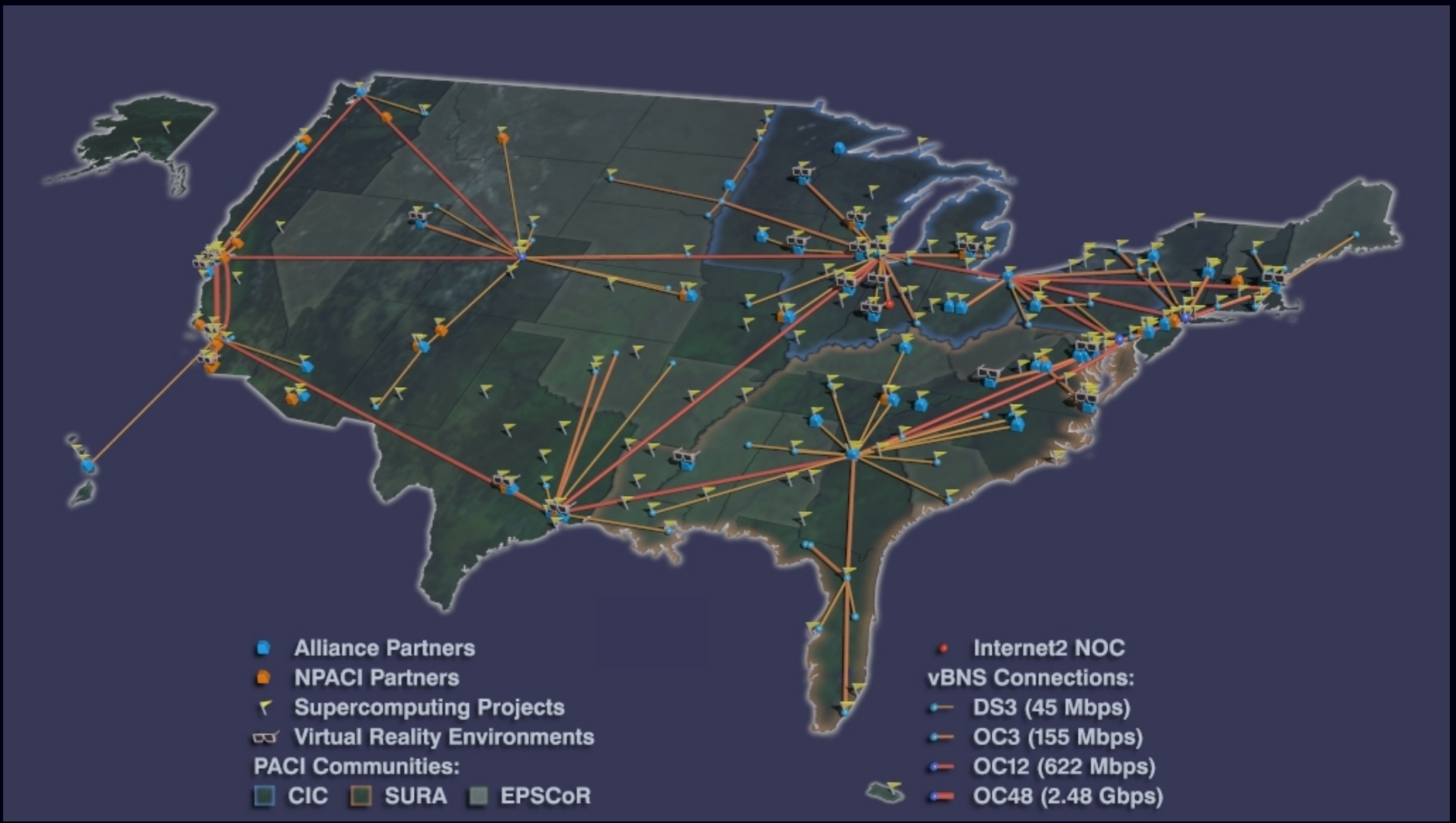


The Vision for the Grid

- Persistent, Universal and Ubiquitous Access to Networked Resources
- Common Tools and Infrastructure for Building 21st Century Applications
- Integrating HPC, Data Intensive Computing, Remote Visualization and Advanced Collaborations Technologies



Prototyping America's 21st Century Information Infrastructure

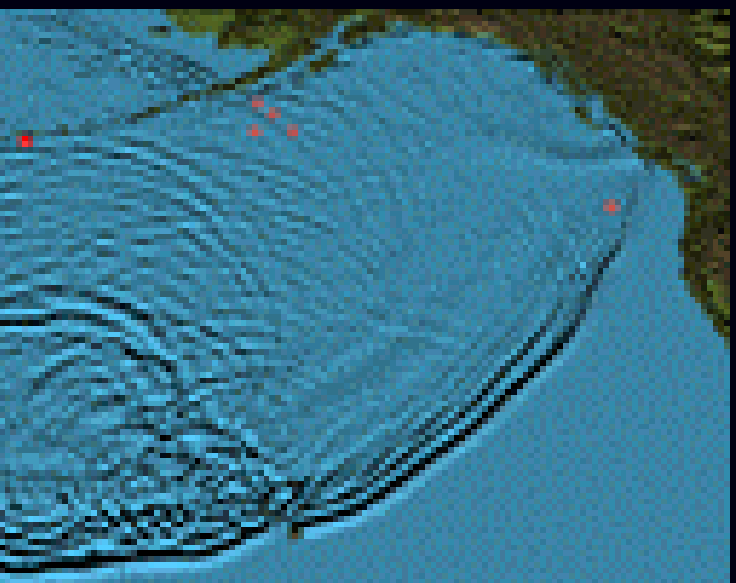


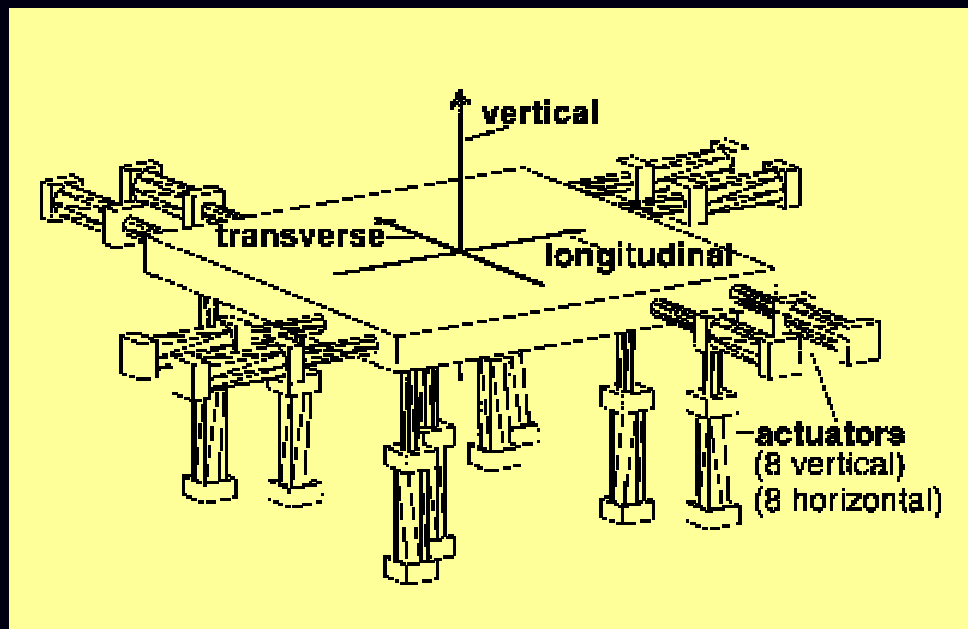
The National Technology Grid

Example Grid Communities : National Earthquake Engineering Simulation

- NEESgrid: national infrastructure to couple earthquake engineers with experimental facilities, databases, computers, & each other

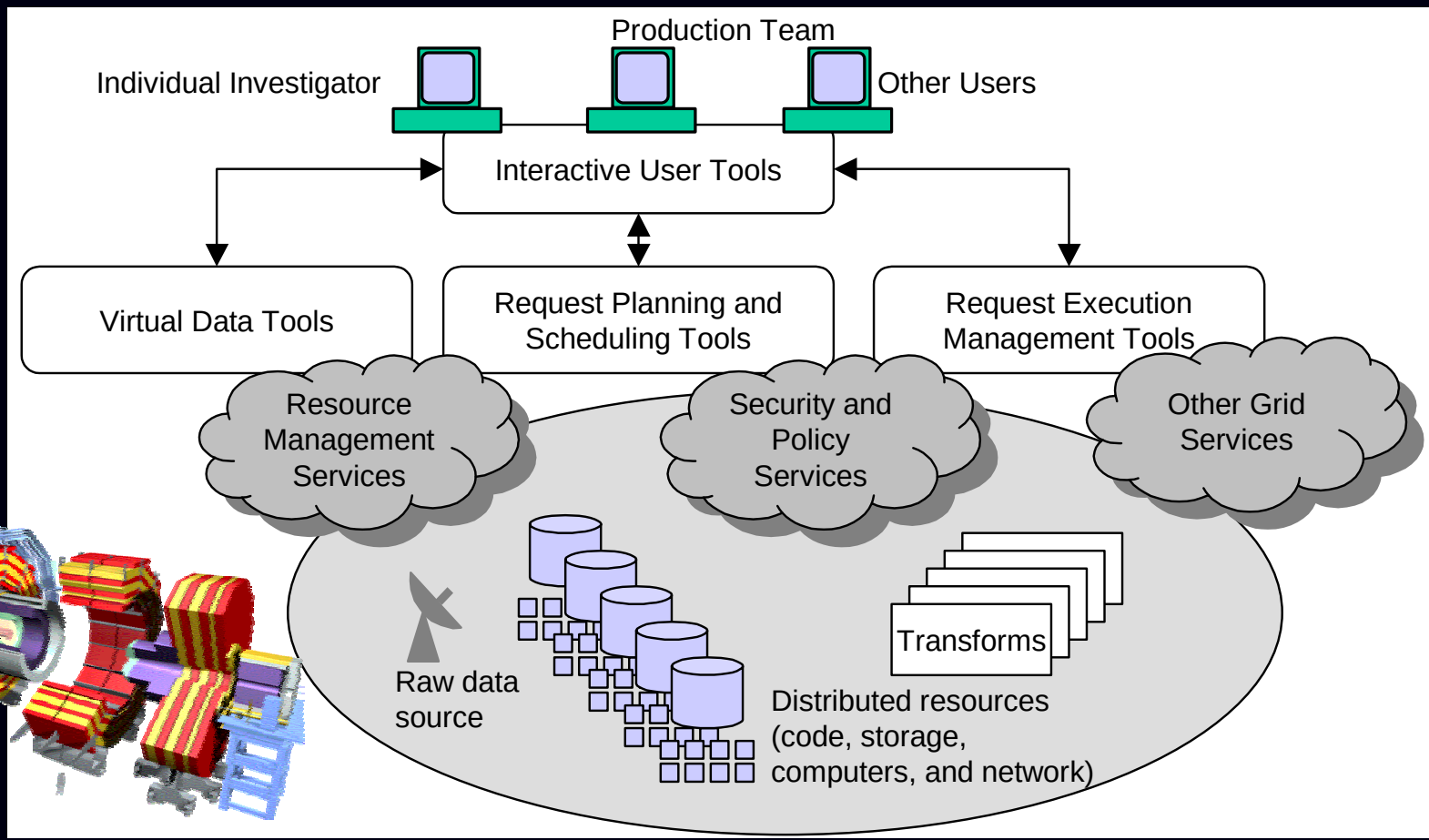
- On-demand access to data streams, computing, archives, collaboration spaces—subject to policy





Example Grid Communities: Grid Physics Network (GriPhyN)

- Enable (thousands of) physicists to pool data & computing resources for data-intensive analyses



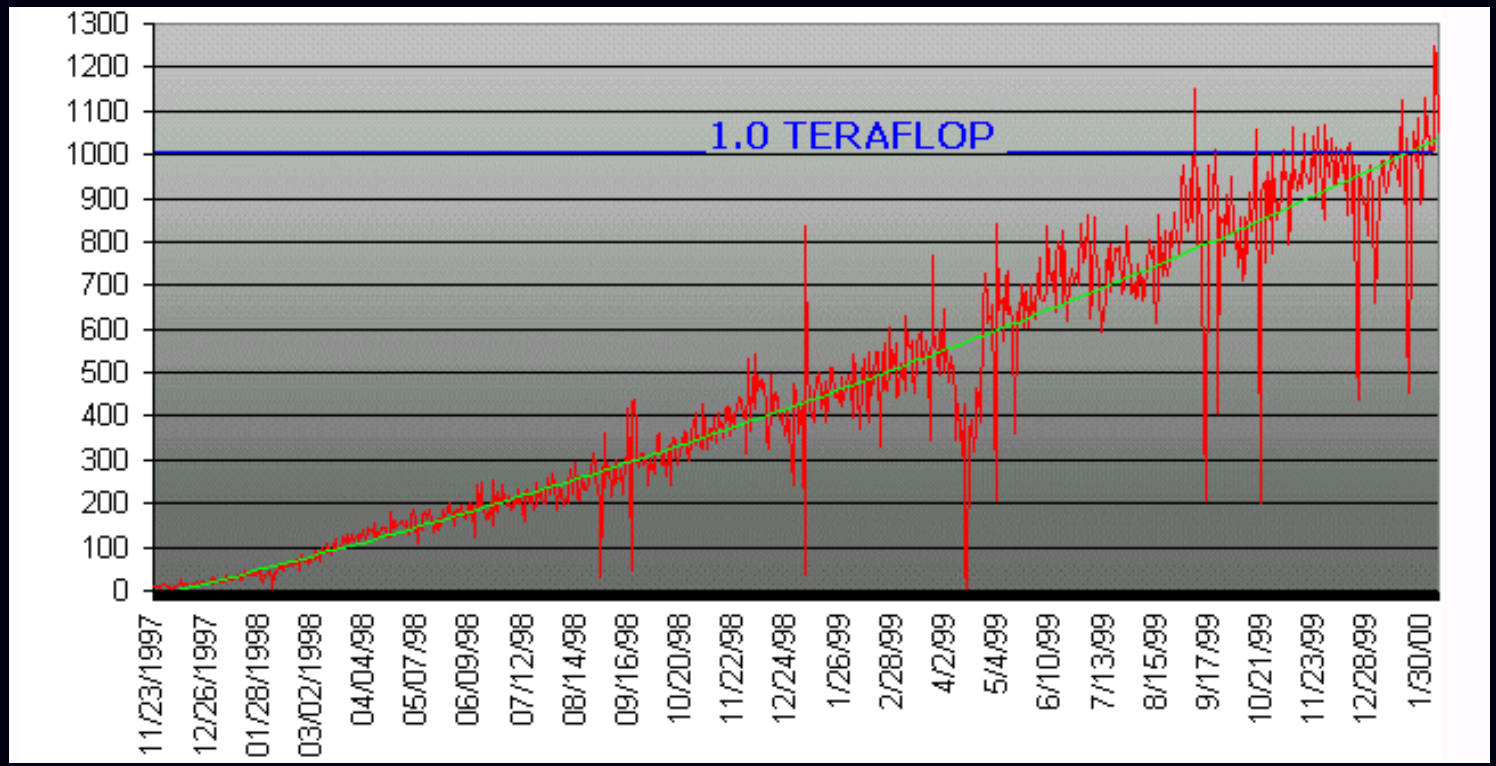
The Network is Becoming the Computer

- Internet Provides Connectivity
- Web Provides Hyperlinked File System
- Distributed Storage Moving from SAN to NAS
- Peer-to-Peer Computing Provides Vast CPU Power
- Result--The Distributed Global Computer
  - Storage everywhere
  - Scalable computing
  - Wireless Interfaces Greatly Outnumber PC Interfaces

“When the Network is as fast as the computer’s internal links, the machine disintegrates across the Net into a set of special purpose appliances”
-Gilder Technology Report June 2000

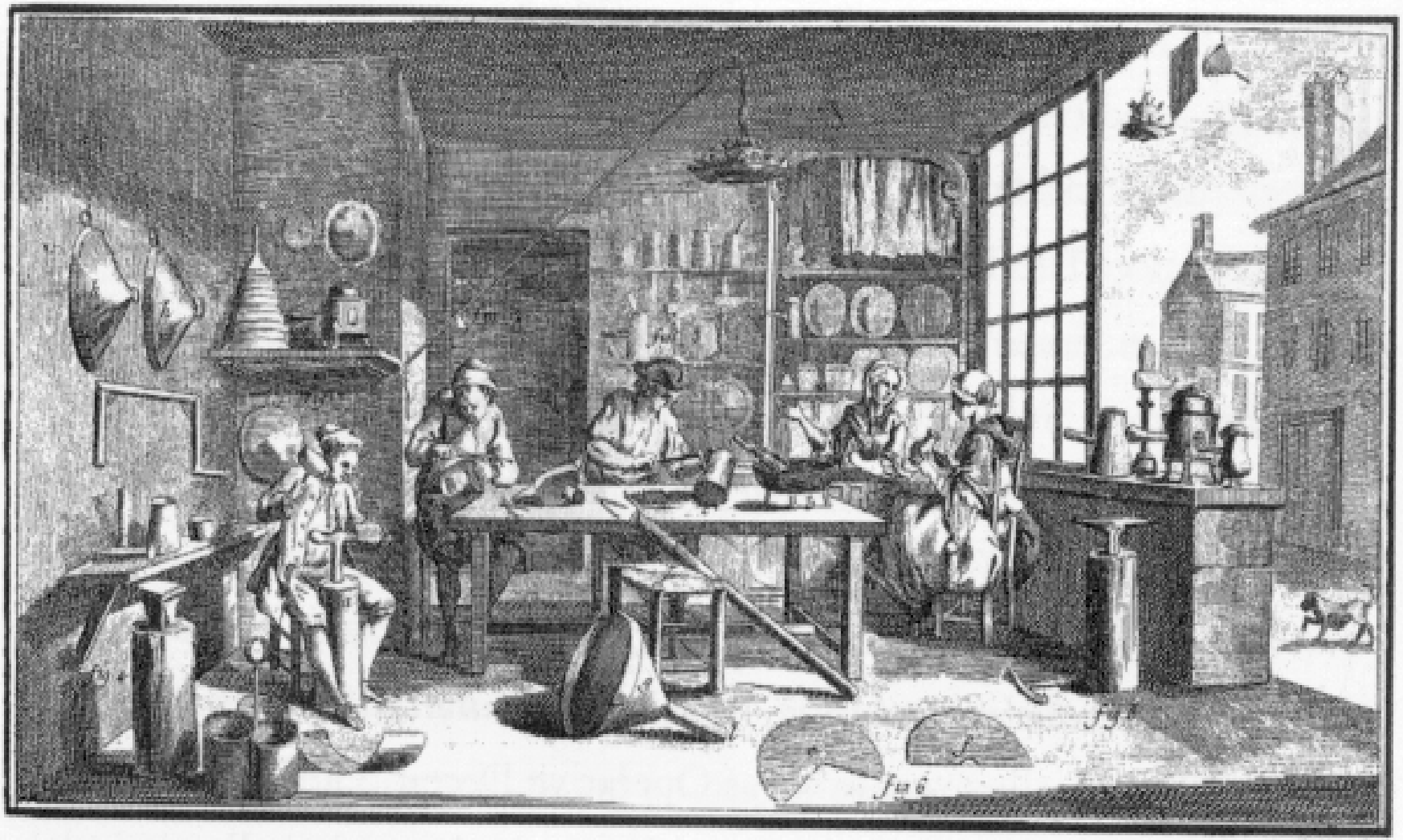
Entropia.com's PrimeNet Grew to a Teraflop in Only Two Years

The Great Mersenne Prime (2^P-1) Search (GIMPS)
Found the First Million Digit Prime
www.entropia.com



Sustained Throughput Today of 1.3 TF (30,000 PCs)
= 47 Cray T916s

Active Spaces $\Rightarrow$ Exploring Future Workspace Environments



Vol. IV, Perblantier, Pl. I.

1.3 Some of the hundreds of traditional craftsmen depicted in Diderot's *Encyclopédie*

Organizational and Social Trends

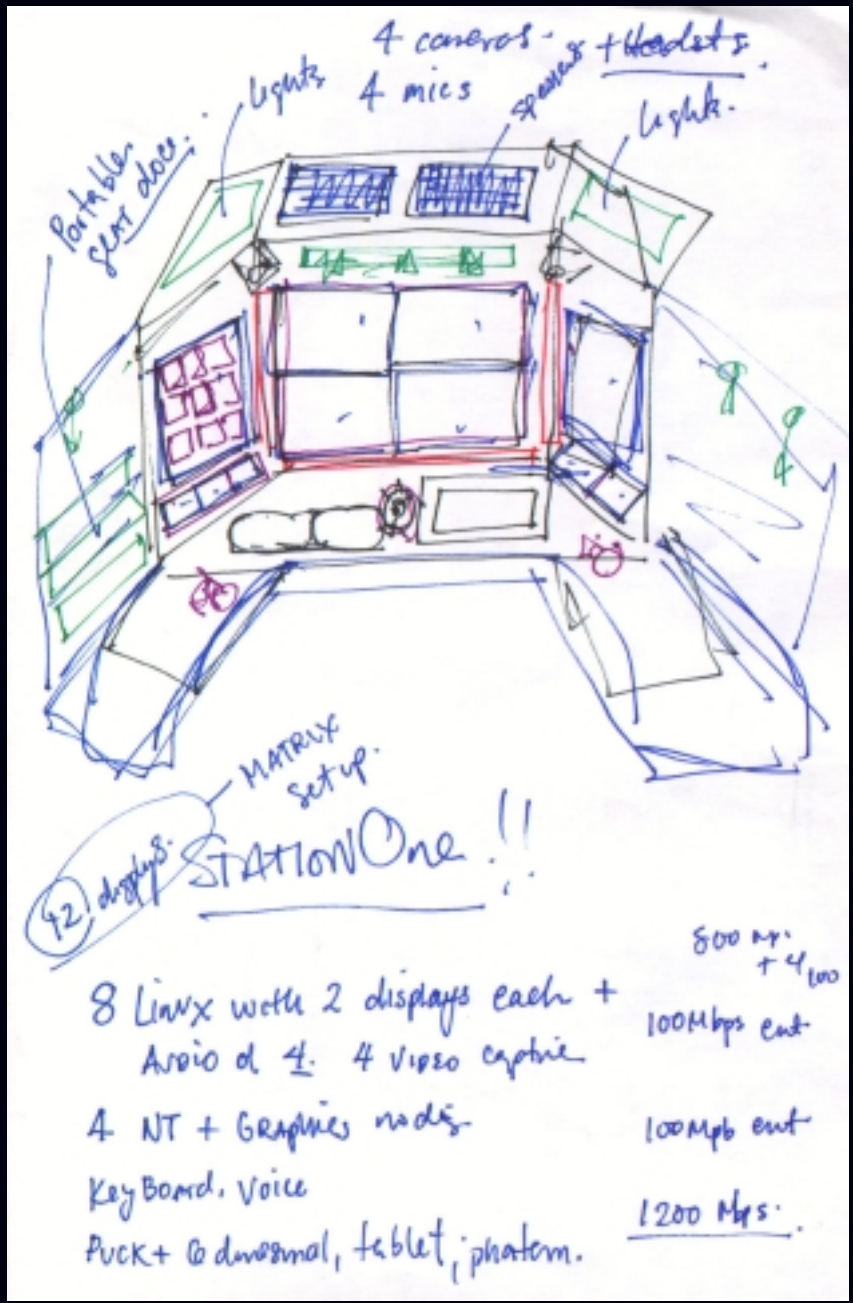
- Distribution and Virtualization of Organizations
- Merging of Work/play/home/learning
- Work As Conversation/communication/collaboration
- Emerging Dominance of Multidisciplinary Problems
- Emerging Dominance of Consumer Products/tech Drivers

What are possible infrastructures and environments to support future work, learning, living and play?

Active Spaces $\Rightarrow$ Workspace Environments

- Ensembles of Display and Computer Systems and Software Environments Cooperatively Working to Support the User
- New Application Environment Metaphor
  - Above, Beyond, Behind and Below the Desktop
- Includes the Desktop and Personal Devices, but Also Includes Large-format, Immersive and Room Scale Systems

- Challenges:
  - integrate these different modalities in positive ways to enable more rapid problem solving
  - provide bridges to existing tools and environments
  - combine with high-end visualization and collaboration systems



StationOne

Early Concept sketch for a single user visual SuperStation.

Designed to be both a high-resolution visualization environment and a high-end node in a collaboratory for advanced simulation.

Argonne Futures Lab Group (Stevens et al.)

Active Spaces ⇒ As Spaces

- Blending Workspace Architecture and Information and Technology Rich Environments
  - How groups of people organize for doing complex tasks
  - How space affects work/thinking
  - How distance and time affects working
- They are designed to be deployed within existing complex work environments (such as laboratories, design studios, research offices and class rooms) and so have to be compatible with existing furniture, lighting, and physical and digital infrastructure.
- They augment the space rather than replace it.

The Internet is Poised to Move Throughout the Physical World

Radio (1940s)

Internet (1990s)

Active Spaces ⇒ As Grid Nodes

- They support several key notions:
  - Blending of virtual and physical interfaces
- Uses variety of display types from immersion to small 2D displays
- Uses variety of scales of interfaces
  - Couple data resources to physical interfaces provides tangible handles or references to virtual resources
- Support scaling of streams and bandwidths to dozens of persistent real-time streams

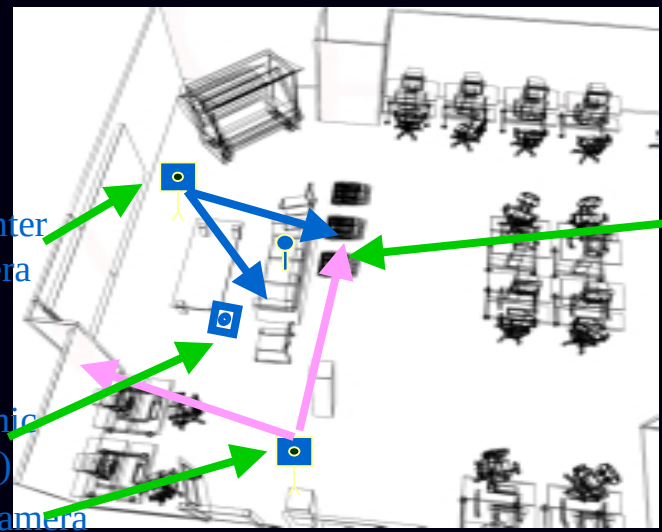
Stages of Collaborative Work

- Awareness
- Interaction
- Cooperation
- Collaboration
- Virtual Organization

Increasing need for persistent collaborative infrastructure

Can the concept of Persistent Shared Spaces enable the cost-effective support of virtual organizations?

Access Grid Basics

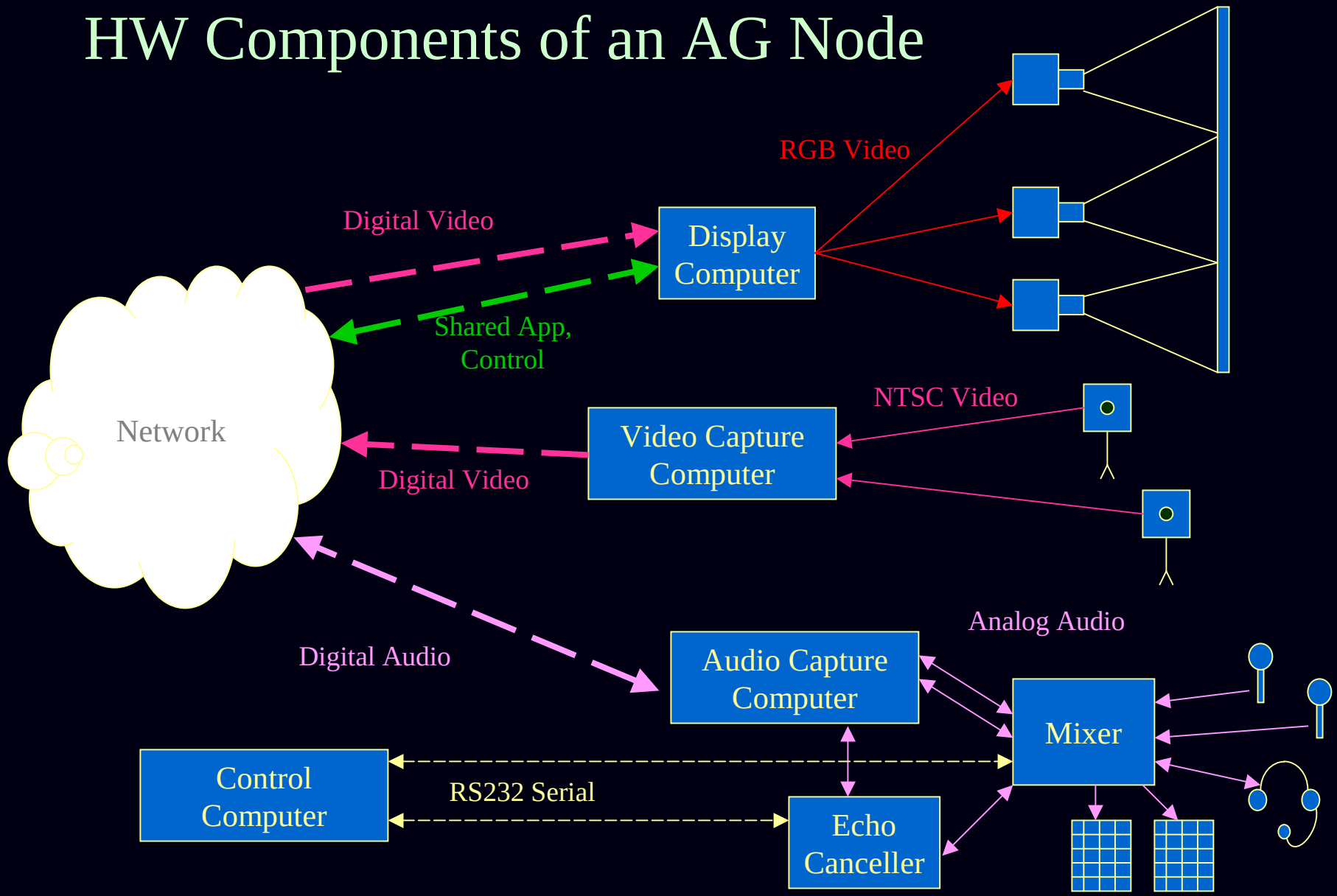


- Designed spaces for group interactions
- Hands free audio
- Multiple Video and Audio streams
- Wide field of view

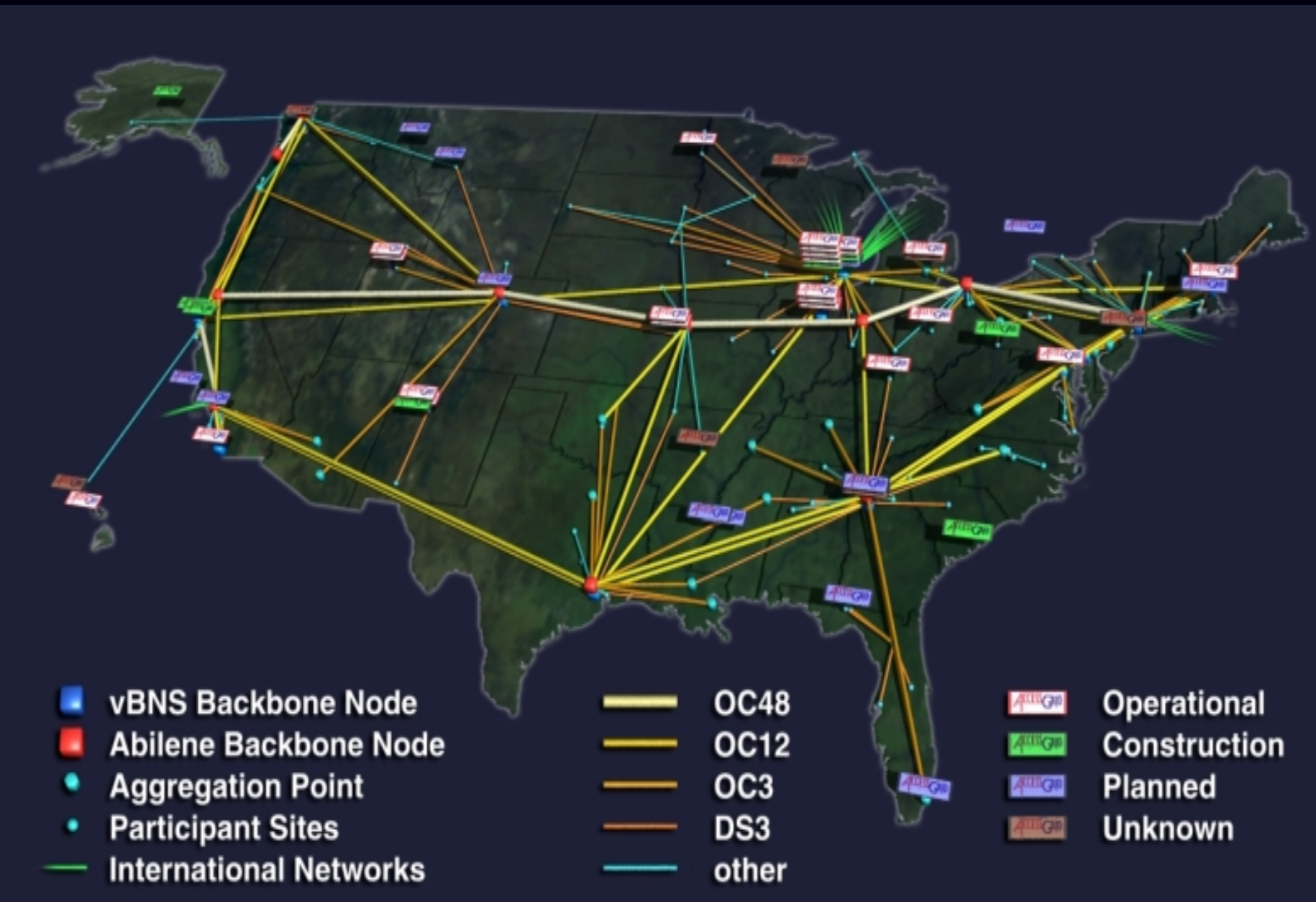
AG Project Goals

- Enable Group-to-Group Interaction and Collaboration
  - Connecting People and Teams via the Grid
- Improve the User Experience: Go Beyond Teleconferencing
  - Provide a Sense of Presence
  - Support Natural Interaction Modalities
- Use Quality but Affordable Digital IP Based Audio/video
  - Leverage IP Open Source Tools
- Enable Complex Multisite Visual and Collaborative Experiences
  - Integrate With High-end Visualization Environments
  - ActiveMural, Powerwall, CAVE Family, Workbenches
- Build on Integrated Grid Services Architecture
  - Develop New Tools Specifically Support Group Collaboration

HW Components of an AG Node



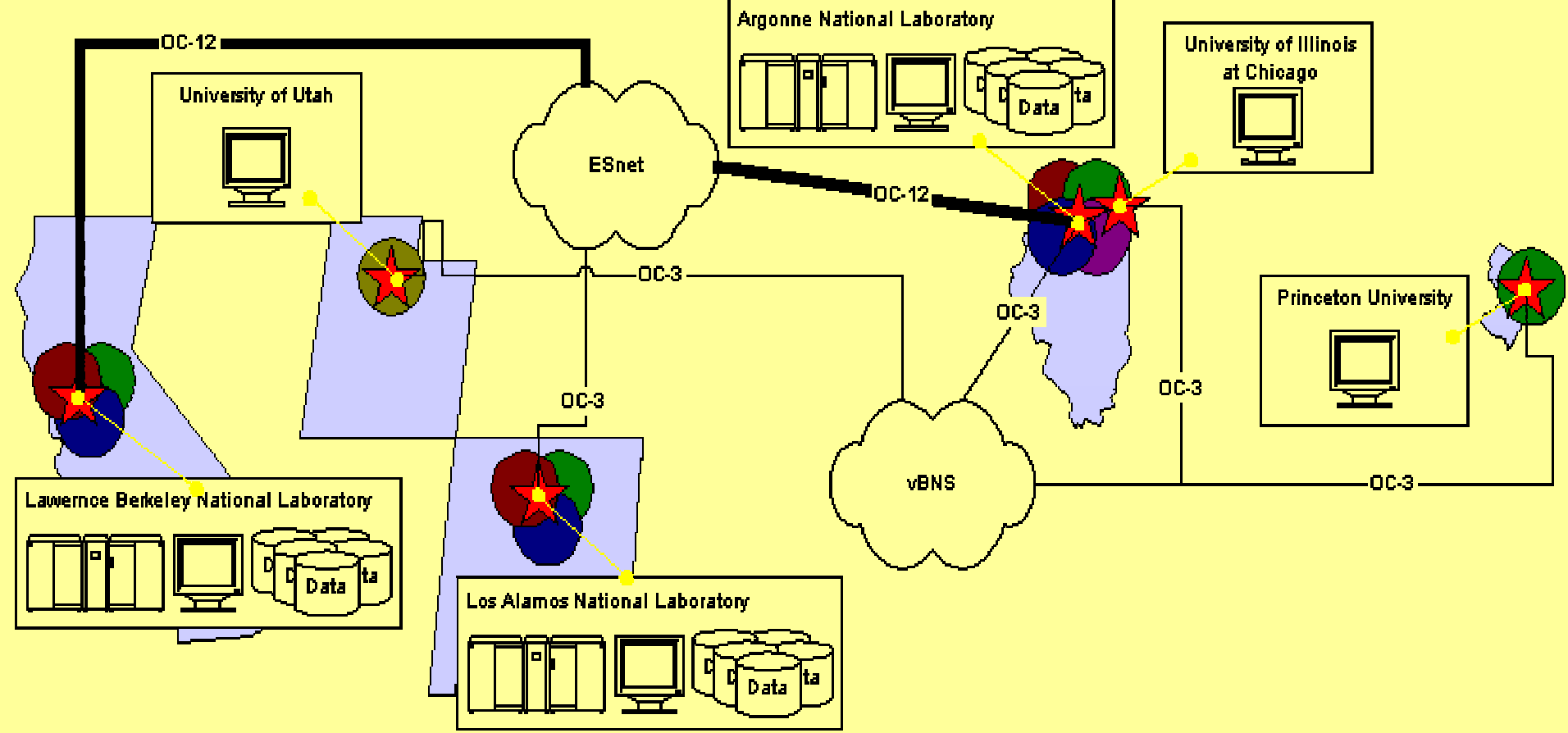
The AccessGrid Circa January 2001




北京航空航天大学
北京航空航天大学
清华大学
224.8.8.1/8000
NSFCnet
root@210.2
25 f/s 19 kb
静止
北京航空航
friend@210.
25 f/s 53 kb
静止
北京航空航
friend@210
25 f/s 19 kb
静止
北京航空航天
friend@210.25
25 f/s 128 kb/
静止
清华大学
Harry@210.
25 f/s .2 kb
静止
Peking Unive
chenben@21
23 f/s 7 Mb
静止
V1C v2.8nisde-2.1.0
菜单
帮助
退出
NSFCnet
解码器...
大小...
模式...
关闭
NSFCnet
解码器...
大小...
模式...
关闭
开始
13:56

Midwest Networked CAVE and ImmersaDesk Sites

- Argonne
- UIC-Chicago
- UIUC-Urbana
- U Wisconsin
- U Michigan
- Indiana U
- U Iowa
- Iowa State
- U Minnesota
- U of Chicago



Application Areas

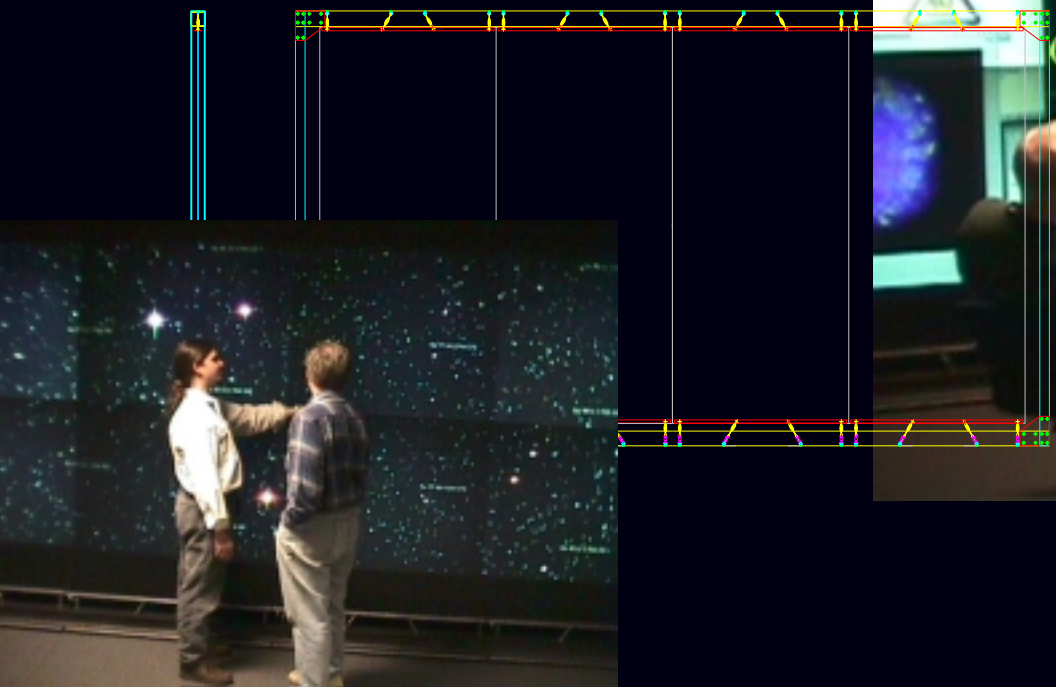
- Climate
- Combustion
- Fusion
- Center on Astrophysical Thermonuclear Flashes
- Center for the Simulation of Accidental Fires

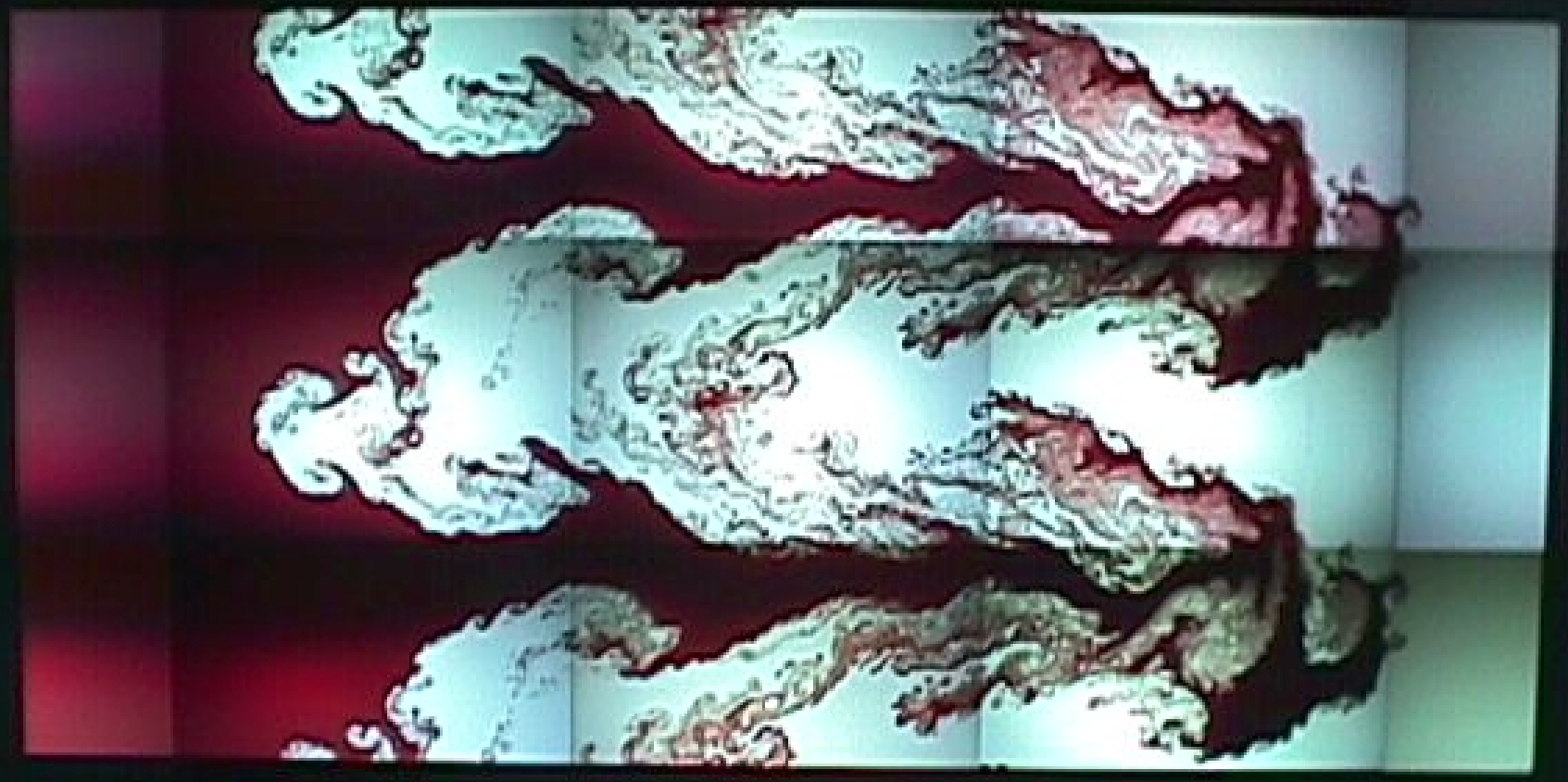
Resources

- Large Scale Visualization Environments
- Large Data Storage Facilities
- Supercomputing Facilities

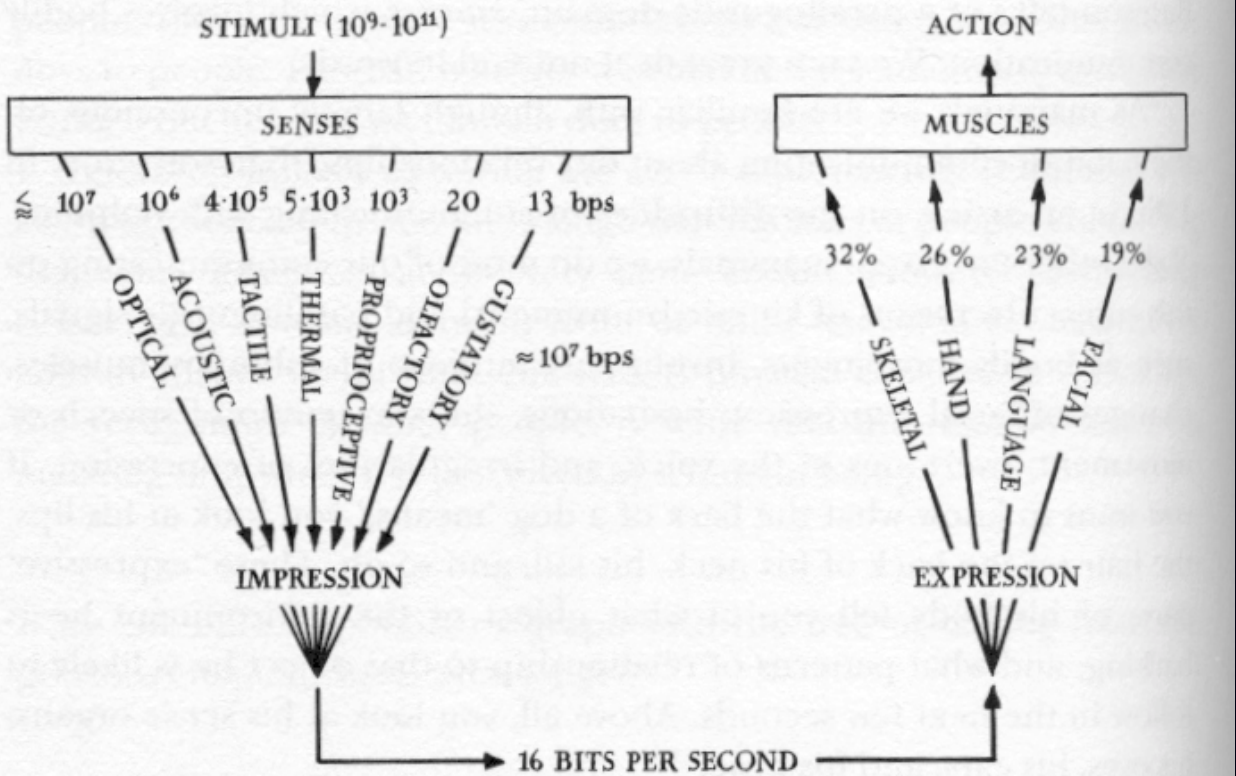
*Active*Mural, a Tiled Display Wall

- Argonne, Princeton and UIUC Collaboration
- 8’ x 16’ display wall
  - Jenmar Visual Systems BlackScreen™ technology, > 10000 lumens
  - 8 LCD → 15 DLP → 24 DLP
  - 8-20 MegaPixels
  - SGI and Linux drivers
  - VR and ActiveSpace UI



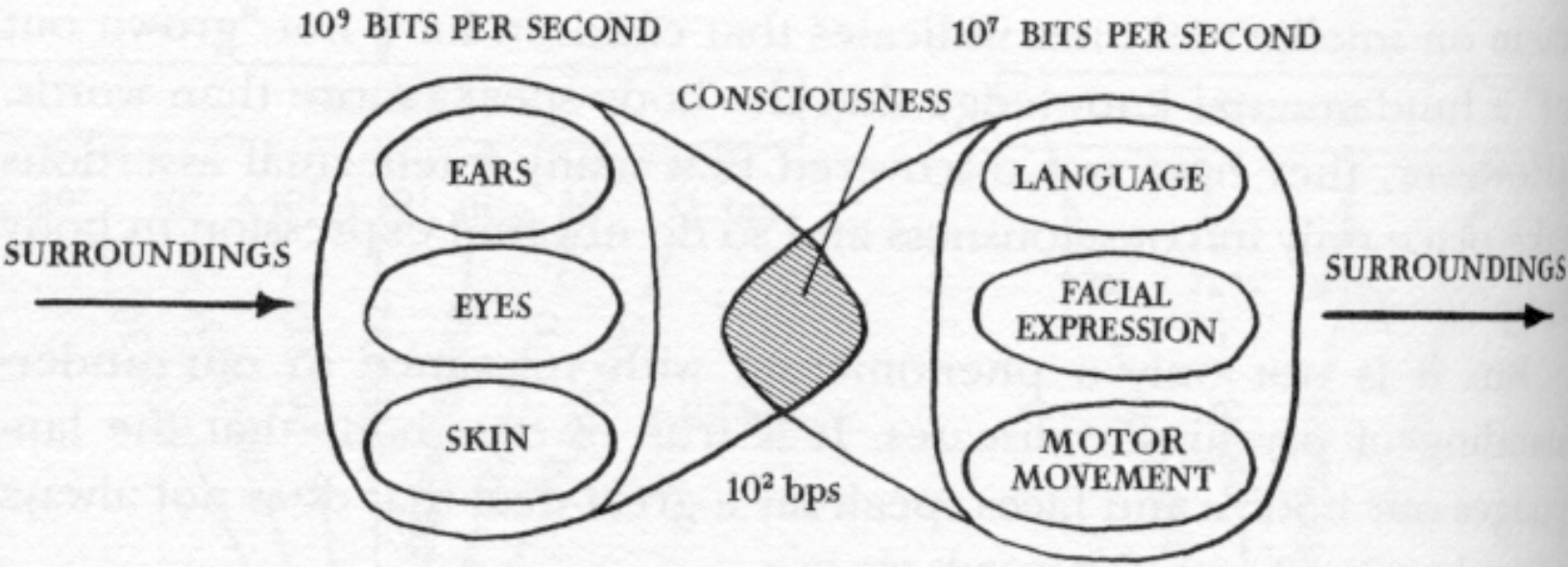


Information Flow Through a Human Being



An overview of the information flow through a human being, drawn up by the Erlangen School (Frank, Lehrl, et al.). A so-called organogram. Just as Küpfmüller's diagram it shows that more information goes in and out of humans than consciousness perceives.

Impression ⇒ Consciousness ⇒ Expression



Consciousness between impression and expression, sketched by W. D. Keidel of the Erlangen School.

Exformation vs Information Interfaces

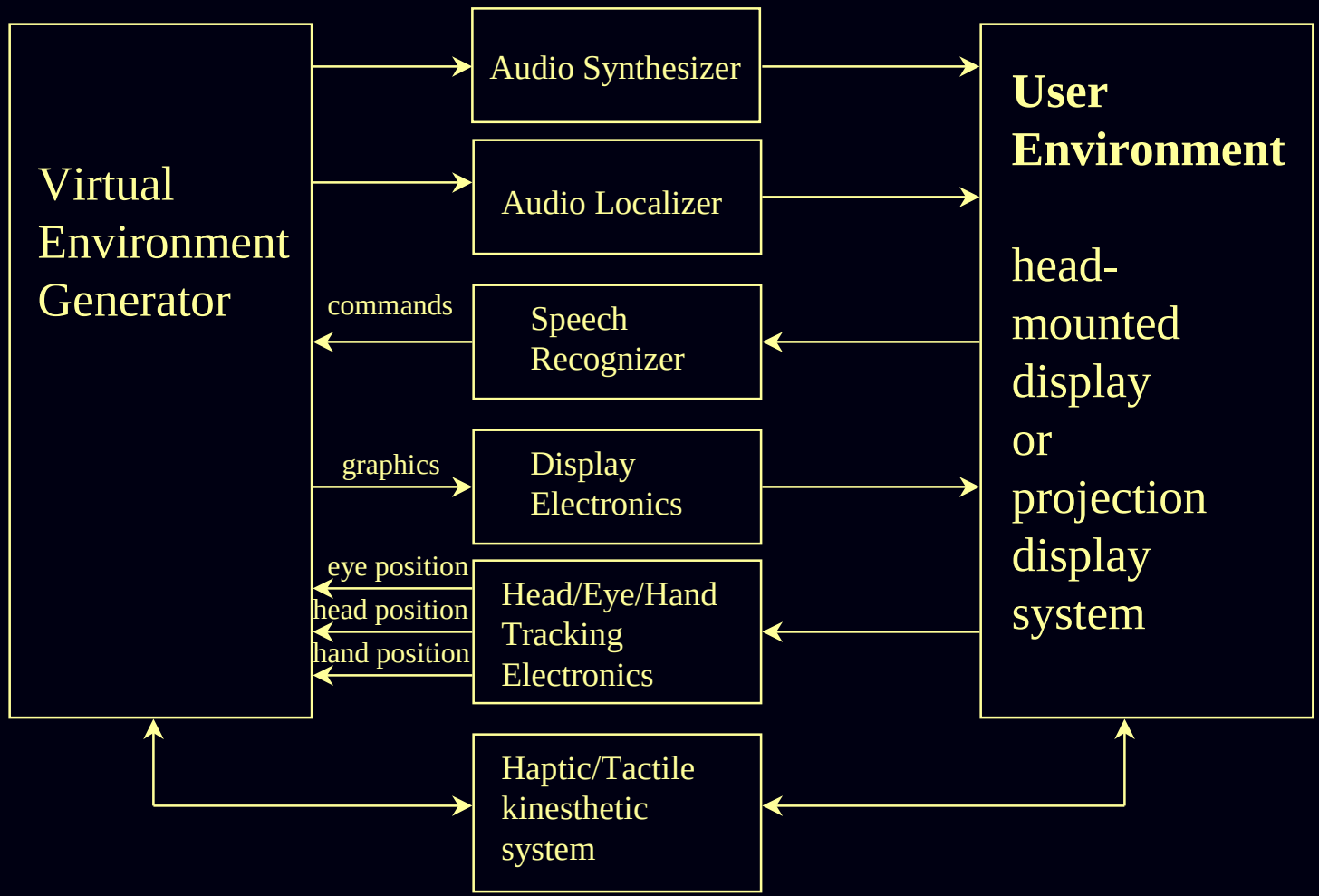
- *Exformation* is the totality of sensory inputs for human a given human experience outside ones conscious attention
- *Information* is what sensory data is perceived and attended too
- Current state-of-the-art human-computer interfaces largely focus on “information interfaces”
  - Screens, keyboards, speech, etc.
- Future virtual reality and augmented reality technologies may enable us to change this focus towards “exformation interfaces”

Exformation and Craft

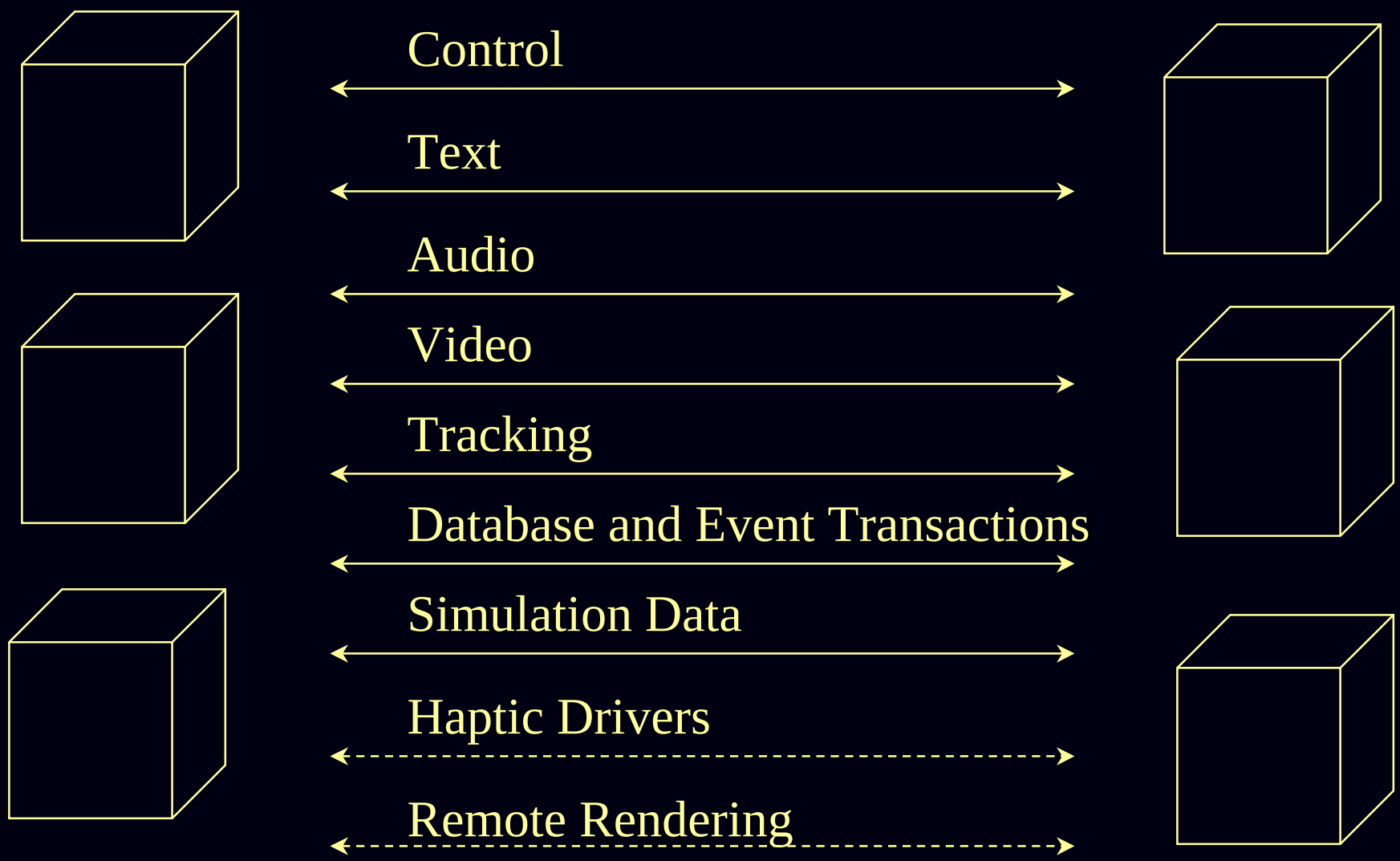
- Medium
  - Environment
  - Motion
  - Interface
- Whole body involvement
  - Learning
  - Experience
  - Practice

7.1 A medium defines a practice

A Local Immersive Virtual Reality Environment



Distributed Immersive Virtual Reality

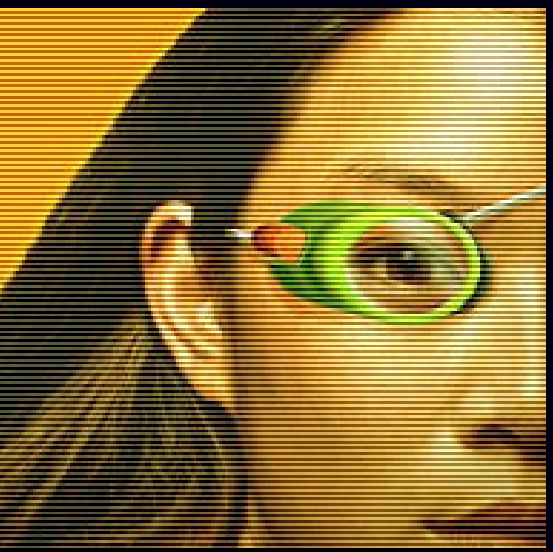


Digital Archeology

- Digitally preserving the cultural heritage of mankind
- Exabytes of images
- Petabyte of 3D models
- VR multi-user walkthroughs
- Automated analysis and translation
- Automated reconstruction

- This is the ASCI Problem for the Humanities!!

How Will You Know if The Kids Are on the Internet?



It connects to the audio piece and works like a tiny monitor that projects an image through the really cool bug-eye monocle into my eye. It has lots of 'serious' applications, but my favorite is to watch 'Buffy'.

My mom has already realized that when the video is on, the lenses become less transparent. That way she knows if I'm really paying attention to her or reading my email. She's caught on quickly.

http://wearables.www.media.mit.edu/projects/wearables/mit-ideo/

Some Future Networking Directions

Networking [circa 2001]

- Production networking
  - Gbs/sec [oc-48 to oc-192] — interfaces to computers are a problem
  - Dumb network model — smarts in edge devices
  - Switch competition based on price/performance for standard features
  - Little advanced networking services [QoS, multicast, etc.]
  - Low bandwidth wireless aimed at portable devices [128Kbps/s-2 Mbps]
- On the Horizon
  - DWDM with 1'000s of channels per fiber
  - Terabits/sec bandwidth possibilities point-to-point
  - All optical infrastructure → lambda markets and virtual networks
  - Network simulation recognized as important but not generally done!
  - Broadband wireless [terrestrial and orbital] insight $$ prospects unclear

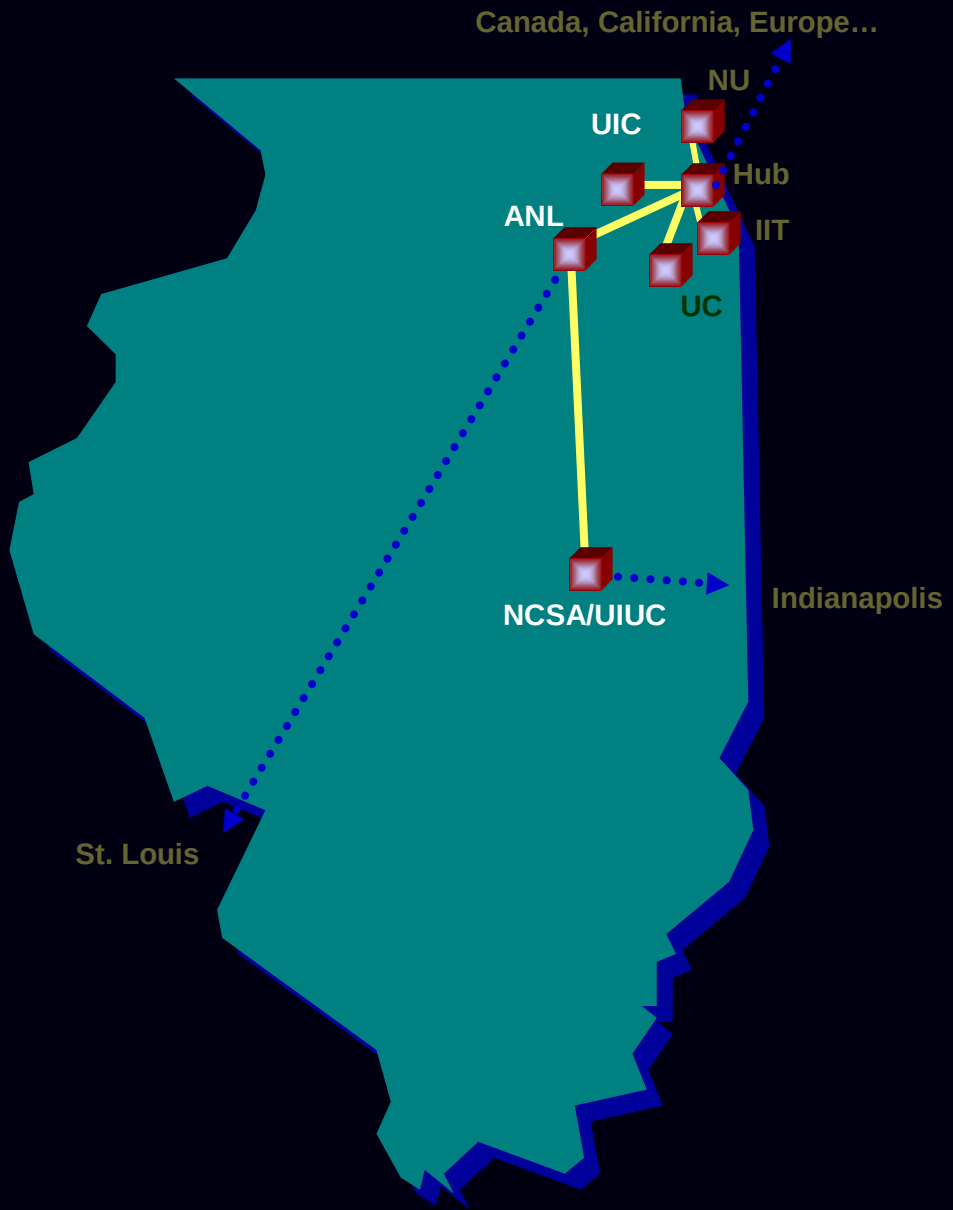
Optical Networking: 2x Moore's Law

- Moore's Law: 2x computer speed every 18 months at 50% cost
- John Roth, president and CEO, says that Nortel Networks is moving at twice the speed of Moore's Law, doubling the capacity of its fiber-optic systems and halving the cost every nine months.
  - 3 years: 16x capacity at 6% cost vs. 4x speed computers at 25% cost
  - 6 years: 256x capacity at 0.5% cost vs. 16x speed computers at 6% cost
- Lucent: single laser 1000-channel DWDM working in the lab
- 1999: Over 70M km dark fiber deployed worldwide
- Prediction: GbE will displace xDSL and cable modems by '03

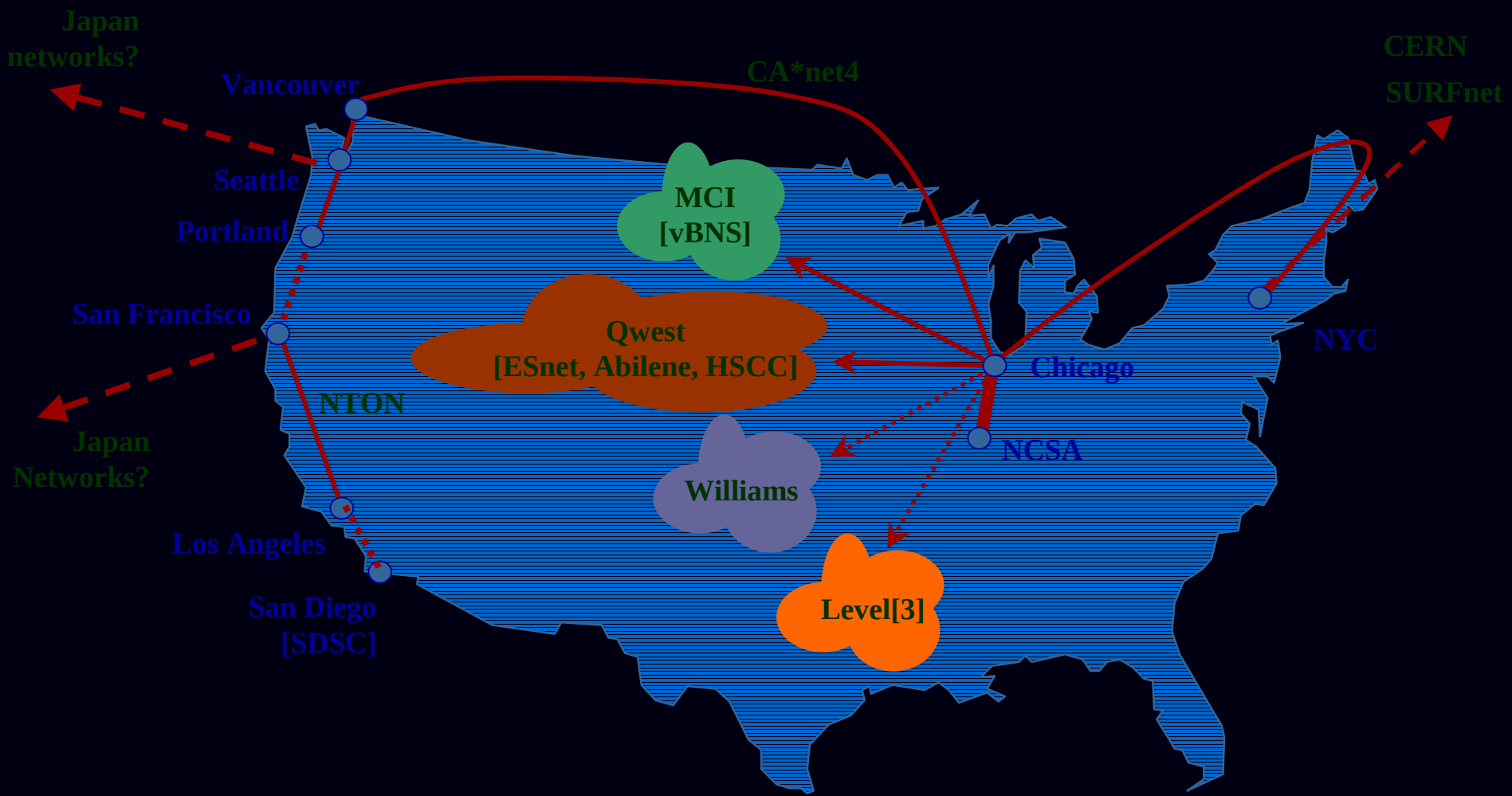
Perspective Shift: Networks [including WAN] much cheaper and much faster than end nodes. Bandwidth essentially free and ubiquitous

I-WIRE

- Leverages Longstanding Research Partnerships
  - ANL/UC, NCSA/UIUC, UIC, Northwestern, IIT
- Addresses Need for Network Research Program
  - Essential to DOE science, mathematics, computer science research
  - Recognition of rapid ongoing evolution in network technologies and exponential growth in demand.



I-WIRE in Context



STAR TAP: Enabling the International Grid

Canada

Australia

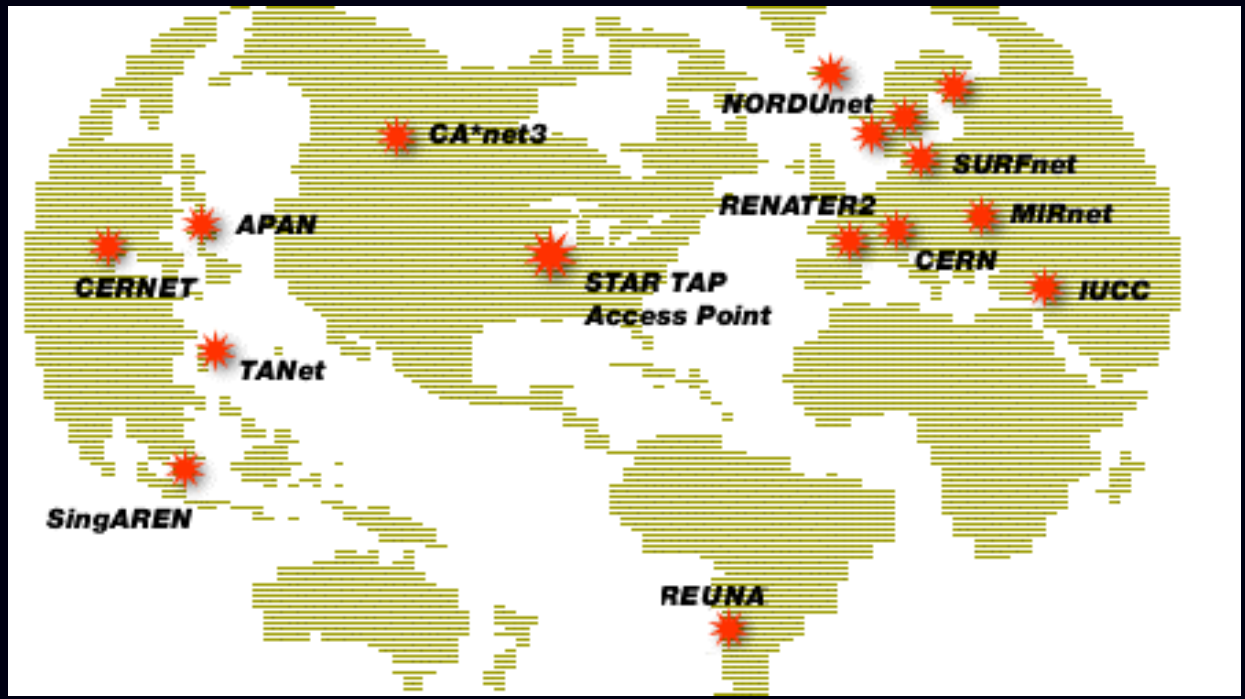
China

Japan

Korea

Singapore

Taiwan



CERN

Denmark

Finland

France

Iceland

Israel

Netherlands

Norway

Sweden

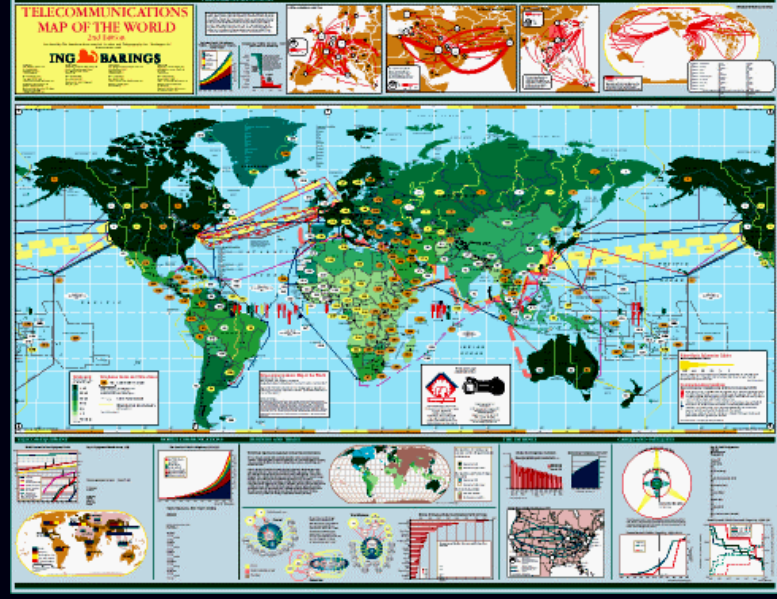
Chile

Russia

US Networks: vBNS, Abilene, ESnet, DREN, NREN/NISN

www.startap.net

Whole Internet Simulation



- ~10^6 – 10^8 routers
- ~10^9 – 10^{11} devices

- Modeling of routing and dynamic resource management
- Determining the response of the internet (and other networks) to accidental and intentional disruptions
- Creating an automated market for bandwidth, network CPU cycles, lambdas and network storage, etc

Networking in 2031

- Bandwidth
  - 2x per year x 30 $\Rightarrow$ 10^9 x Today $\Rightarrow$ 10^{20} bits/s link
- Installed Fiber Base
  - 10Km/hr x 30 years $\Rightarrow$ 2.6 x 10^5 x Today $\Rightarrow$ 1.8 x 10^{13} km
- Per captia bandwidth [bandwidth to the home]
  - ~T1 [1 Mbps] $\Rightarrow$ 10^6x – 10^9x $\Rightarrow$ 1 Tbps – 1 Pbps per person!!
- Quantum Networks
  - Use quantum superposition to improve bandwidth?
  - Transmitting qubits at speed of light $\Rightarrow$ exponential Q speedups!!

Supercomputing as a Time Machine

THE EXPONENTIAL GROWTH OF COMPUTING, 1900–2100

Ultimate Limit of Computing Power
~10^{50} ops/sec/kg

$1,000 OF COMPUTING BUYS

CALCULATIONS PER SECOND

10^{40}
10^{35}
10^{30}
10^{25}
10^{20}
10^{15}
10^{10}
10^{5}
10
10^{-5}
10^{-10}

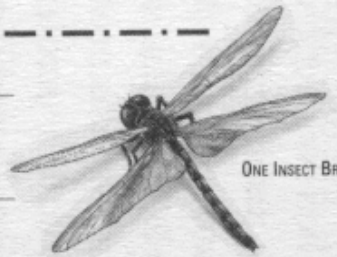
1900 1920 1940 1960 1980 2000 2020 2040 2060 2080 2100

YEAR

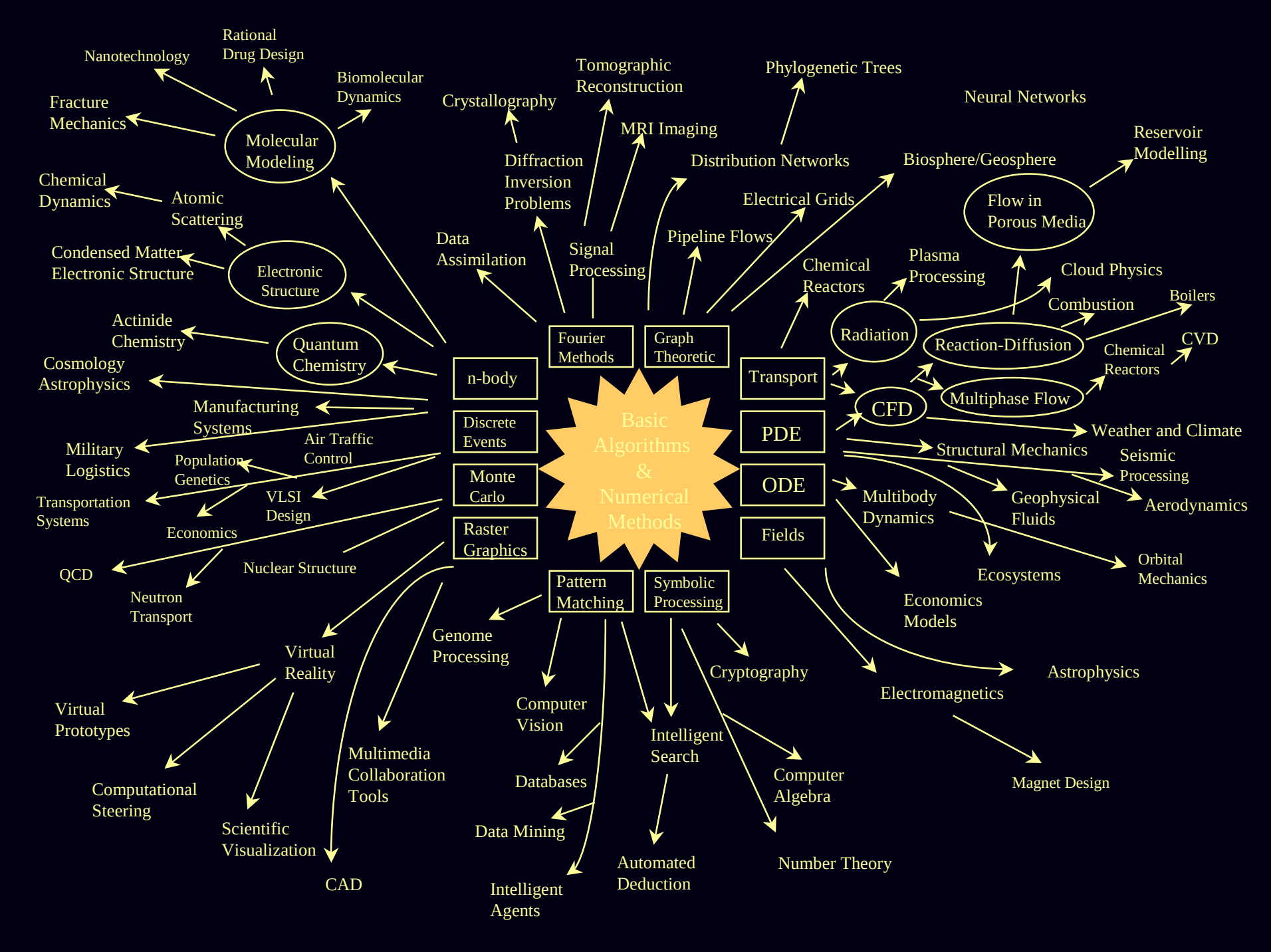
ALL HUMAN BRAINS

ONE HUMAN BRAIN

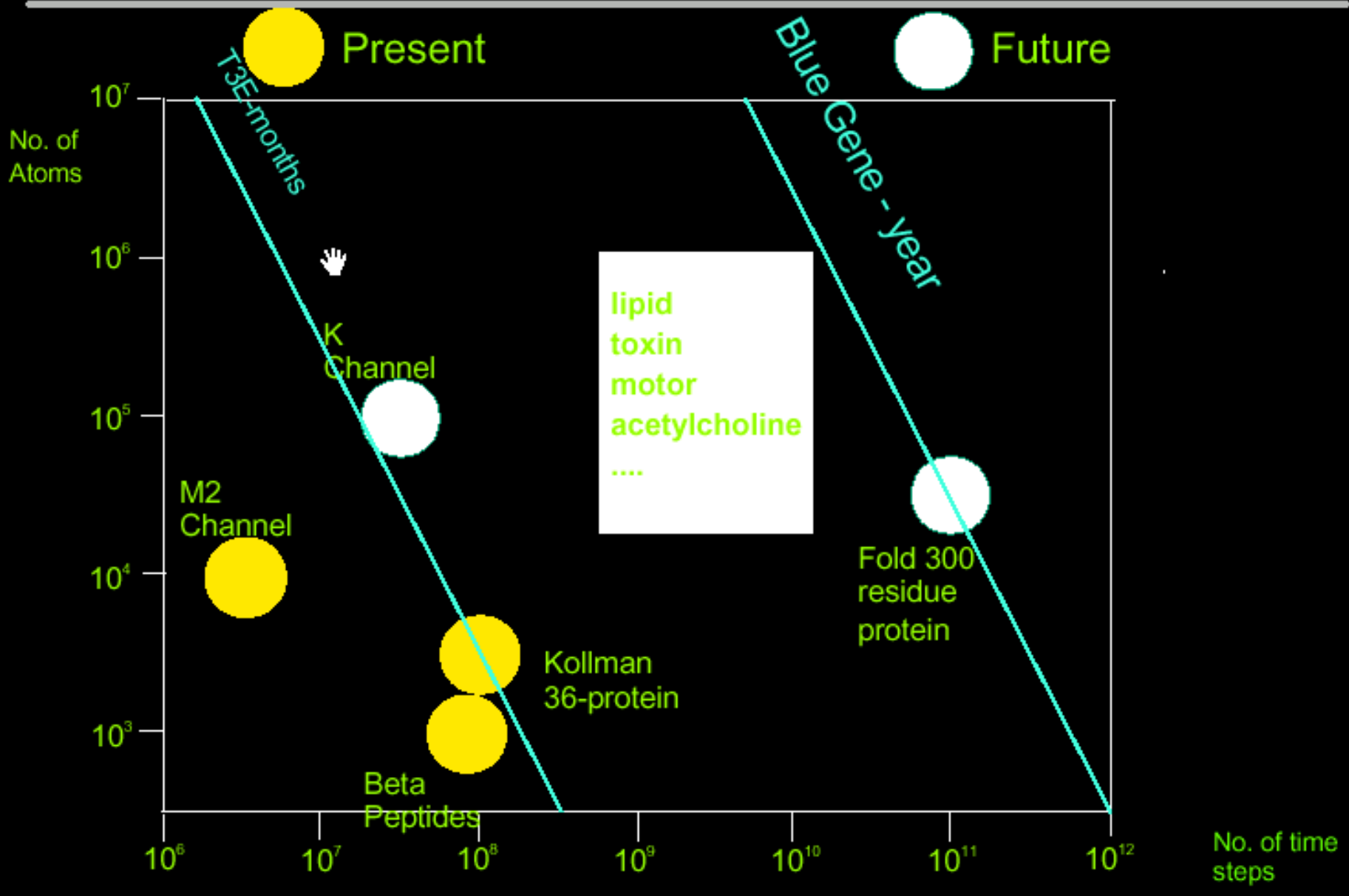
ONE MOUSE BRAIN



ONE INSECT BRAIN


Basic Algorithms & Numerical Methods
n-body
Discrete Events
Monte Carlo
Raster Graphics
Fourier Methods
Graph Theoretic
Transport
PDE
ODE
Fields
Pattern Matching
Symbolic Processing
Molecular Modeling
Nanotechnology
Rational Drug Design
Biomolecular Dynamics
Fracture Mechanics
Electronic Structure
Chemical Dynamics
Atomic Scattering
Condensed Matter Electronic Structure
Quantum Chemistry
Actinide Chemistry
Cosmology Astrophysics
Manufacturing Systems
Military Logistics
Population Genetics
Air Traffic Control
Transportation Systems
VLSI Design
Economics
QCD
Neutron Transport
Nuclear Structure
Data Assimilation
Crystallography
Diffraction Inversion Problems
Tomographic Reconstruction
Signal Processing
MRI Imaging
Pipeline Flows
Distribution Networks
Electrical Grids
Phylogenetic Trees
Neural Networks
Biosphere/Geosphere
Reservoir Modelling
Flow in Porous Media
Chemical Reactors
Plasma Processing
Radiation
Cloud Physics
Combustion
Boilers
Reaction-Diffusion
CVD
Chemical Reactors
CFD
Multiphase Flow
Weather and Climate
Structural Mechanics
Seismic Processing
Geophysical Fluids
Aerodynamics
Multibody Dynamics
Ecosystems
Orbital Mechanics
Economics Models
Astrophysics
Electromagnetics
Magnet Design
Cryptography
Number Theory
Computer Algebra
Intelligent Search
Automated Deduction
Computer Vision
Databases
Data Mining
Intelligent Agents
Genome Processing
Multimedia Collaboration Tools
CAD
Virtual Reality
Virtual Prototypes
Computational Steering
Scientific Visualization

Time Window into Biophysics



Flash Point – Do it Yourself Supercomputers

- Synthesis of just-ready hardware/software elements
- Narrow window of opportunity
- PCs just capable of a few Mflops
- Ethernet LAN [10 base-T] just cheap enough
- A cost constrained requirement with funding
- An open source Unix, albeit immature
- Experience with clustering
- A stable message passing library
- Talent availability to fill the gaps
- Willingness to win or fail
- Modest and well define goals, vision, and path

Some Large Clusters

Possible Extreme Linux Systems in 2010 [conservative]

- 4.8 GHz Clocks
- 16 way SMP node
- 300 Gflops node
- > 4 GB RAM
- >160 GB disk
- 8 x 400+ MB/s interfaces/node
- < 1 kW power/ node
- $2000/node + $2000 other
- 8000 nodes
- 2.5 PetaFLOPS peak
- Total system Price ~$16M
- Annual power bill ~$8M

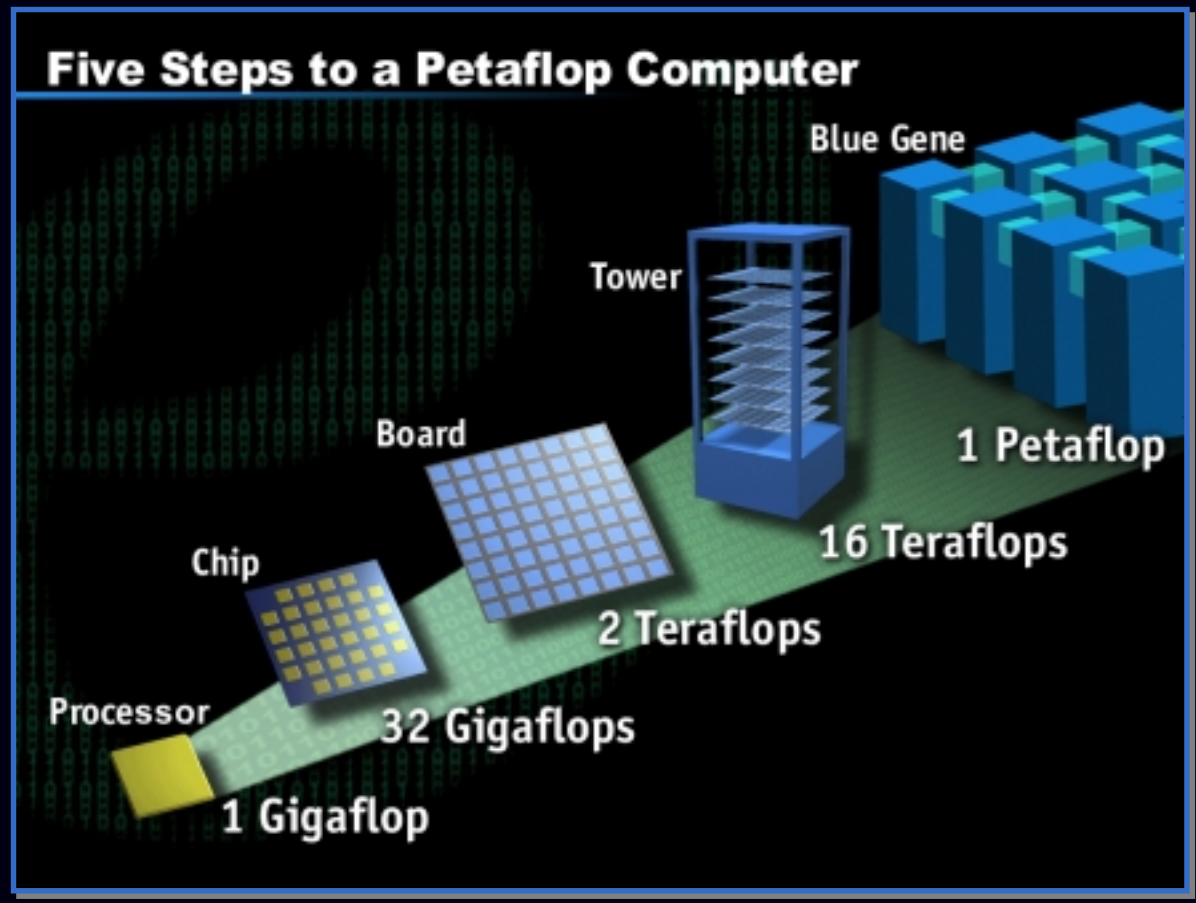
	1998	2001	2004	2007	2010
Clock	300	600	1200	2400	4800
FLOPS/clock	1	2	2	4	4
CPU/Board	2	4	6	8	16
FLOPS/Node	600	4800	14400	76800	307200
L0 Cache KB	16	32	64	128	256
L1 Cache KB	512	1024	2048	4096	8192
L2 Cache MB	2	4	8	16	32
L3 Cache MB	0	8	16	32	64
RAM MB	256	512	1024	2048	4096
DISK GB	10	20	40	80	160
Net Interfaces/board	3	4	4	8	8
MB/s per Interface	10	100	200	400	400
Power CPU W	20	16	12.8	10.24	8.192
Power System Board	150	150	150	150	150
Total Power W	190	250	500	750	1000
Price Node	2000	2000	2000	2000	2000
Price Network/Node					
Nodes/System	500	1000	2000	4000	8000
Peak GFLOPS/System	300.0E+0	4.8E+3	28.8E+3	307.2E+3	2.5E+6
Total SYSTEM RAM (GB)	128.0E+0	512.0E+0	2.0E+3	8.2E+3	32.8E+3
Total System DISK (TB)	5.0E+0	20.0E+0	80.0E+0	320.0E+0	1.3E+3
Bi-section BW (MB/s)	670.8E+0	12.6E+3	35.8E+3	202.4E+3	286.2E+3
Total Power	95.0E+3	250.0E+3	1.0E+6	3.0E+6	8.0E+6
Total Price	1.0E+6	2.0E+6	4.0E+6	8.0E+6	16.0E+6
Price of Power/year	99.9E+3	262.8E+3	1.1E+6	3.2E+6	8.4E+6

Let's Connect a Million PCs in One Machine Room

- 1B$
- 100 Megawatt (the power consumption of a small city)
- 20,000 cabinets, 5 acres
- One million MS Windows licences (Oh no!)
- 1,000 technicians scurrying around to fix broken PCs
- A PC failure every few seconds

☞ Need x100 fewer chips and much simpler software at each chip

IBM Blue Gene Project



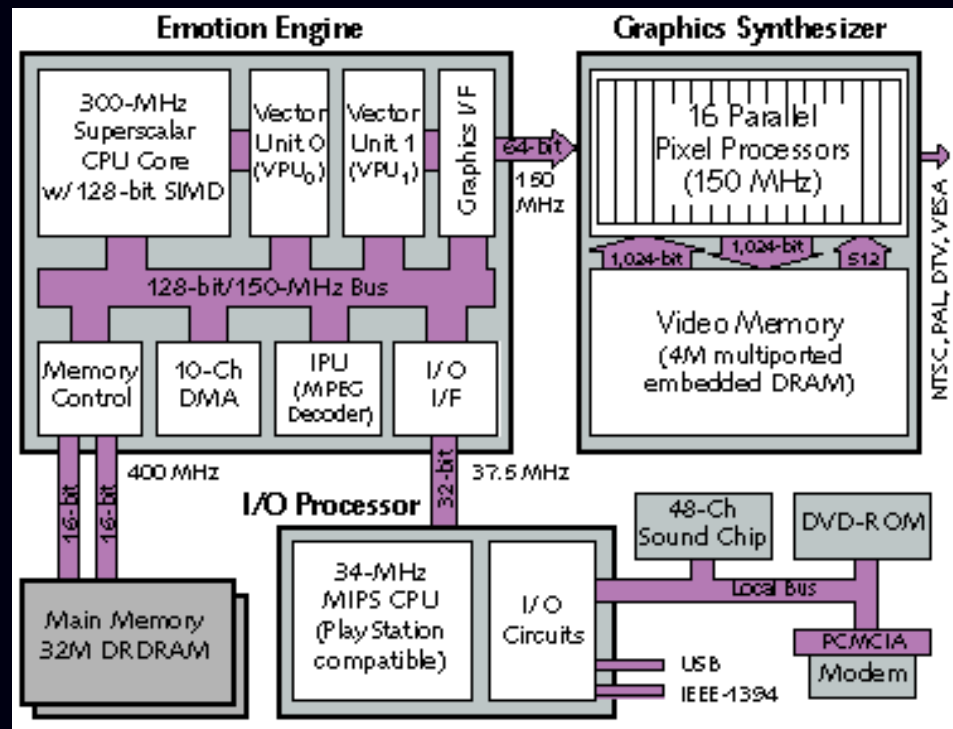
- $100M project
- Protein folding studies

Some Trends/opportunities

- Increased use of commodity technologies for high-end scientific applications
  - Supercomputers from PCs & Cell phone parts
    - These will be best price/performance
  - Internet based Computing
    - Networks for entertainment – TV settop boxes
    - Parabon, Entropia, United Devices, Popular Power
  - Evolution of infrastructure for post-PC world
    - Piggyback global sensor networks
    - Leverage of MEMS technologies

Are We Destined to Compute on Toys?

- 128-bit RISC chip running at 300 MHz
- RAM: 32MB DRAM
- Graphics Processor: 150 MHz, 4MB integrated VRAM
- Sound: SPU2, 2MB RAM [AC3, Dolby Digital, DTS support]
- Drive: 4X DVD, 24X CD read speeds [PlayStation, DVD, audio CD support]
- Weight: 2.1 kg [4 lbs. 10 oz.]



IBM, Sony and Toshiba “Cell” Project

- $400M investment towards Teraflop processor
- Targeted at PS3, broadband applications
  - Each company will produce products based on the core technology
- 100 nm feature size
- Design Center in Austin TX opening later this year
- Sony’s description of PS3 is 1000x performance of PS2
  - Will become the driver for all of Sony’s product lines
  - Video, Audio, Computer Games, PCs Etc.

Million Person Virtual Theme Parks

New Directions in Computer Based Entertainment

- Assume: 10^6 High-end Game Consoles
  - 10^8– 10^9 polygon/sec graphics each
  - 1 Gigabit/s broadband to the home

- Need: PetaFLOPS/ExaBYTE shared world physics computer
  - VR models, avatar interactions
  - Synthetic worlds server, Audio synthesis
  - Complex and Dynamic games
  - Real-time multi-user narrative generator

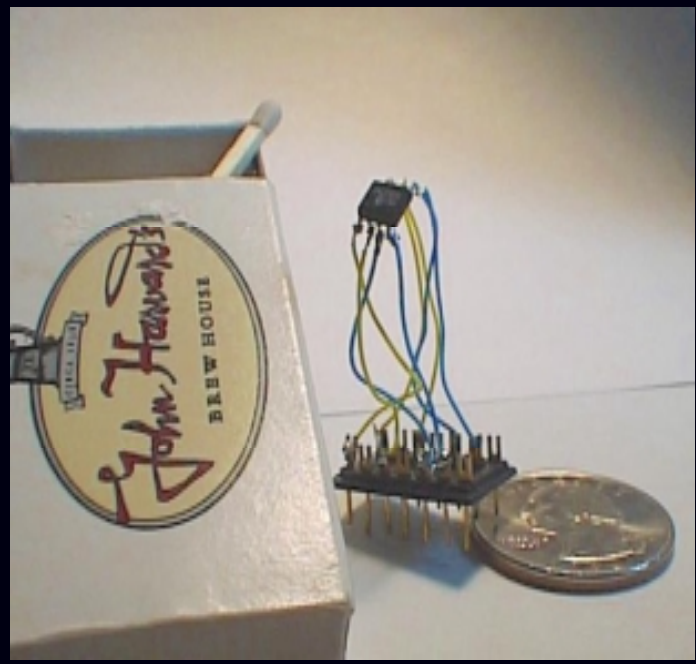
Compaq Itsy Pocket Computer

- Hardware
  - 200 MHz StrongARM SA-1100 Processor
  - 16MB DRAM, 4MB Flash Memory
  - Audio CODEC, microphone, speaker
  - LCD Display and Touch screen
  - Serial, IrDA and USB IO, pushbuttons
- Software
  - Runs Linux
  - MIDI
  - MPEG Video Playback
  - Text to Speech, Speech to Text
  - Wireless Web Server

http://www.research.digital.com/wrl/projects/Itsy/index.html

IPic – Match Head Size Web Server

- PIC 12C509A running @ 4MHz
- IPic Tiny TCP/IP stack
- HTTP 1.0 compliant web server
- Simple telnet server
- 24LC256 i2c EEPROM



http://www-ccs.cs.umass.edu/~shri/iPic.html

As Our Bodies Move On-Line
Bioengineering and Bioinformatics Merge

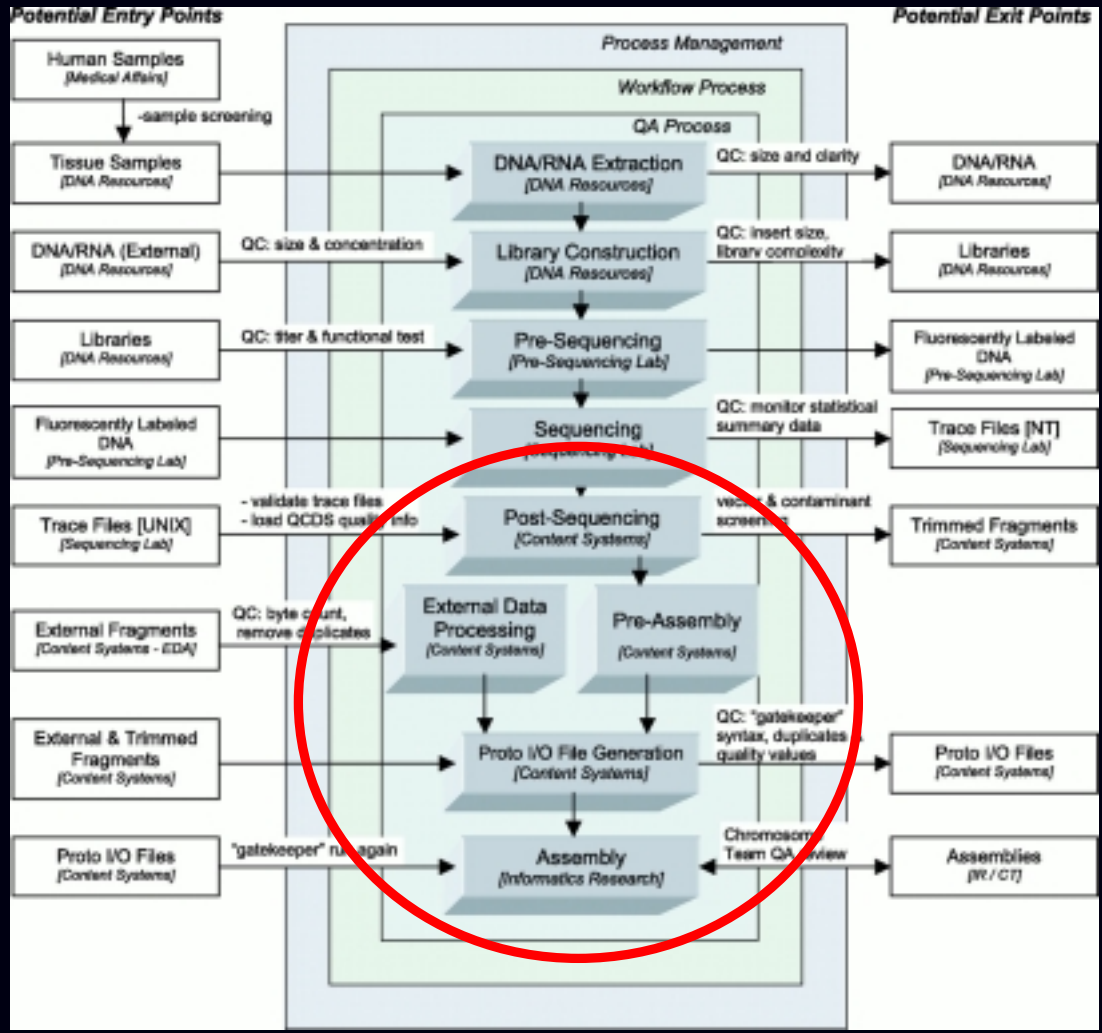
- New Sensors—Israeli Video Pill
  - Battery, Light, & Video Camera
  - Images Stored on Hip Device
- Next Step—Putting You On-Line!
  - Key Metabolic and Physical Variables
  - Wireless Internet Transmission
  - Model -- Dozens of 25 Processors and 60 Sensors / Actuators Inside of our Cars
- Post-Genomic Individualized Medicine
  - Combine Your Genetic Code & Imaging, with Your Body's Data Flow
  - Use Powerful AI Data Mining Techniques

Computing Platforms in 2031

- Personal Computer O[$1000]
  - 10^9 Flops/sec in 2001 $\Rightarrow$ 10^{15} – 10^{17} Flops/sec
- Supercomputer O[$100,000,000]
  - 10^{13} Flops/sec in 2001 $\Rightarrow$ 10^{18} – 10^{20} Flops/sec
- Number of Computers [global population ~10^{10}]
  - SCs $\Rightarrow$ 10^{-8} –10^{-6} per person $\Rightarrow$ 10^2 – 10^4 systems
  - PCs $\Rightarrow$ .1x – 10x per person $\Rightarrow$ 10^9 – 10^{11} systems
  - Embedded $\Rightarrow$ 10x – 10^5x per person $\Rightarrow$ 10^{11} – 10^{15} systems
  - Nanocomputers $\Rightarrow$ 0x – 10^{10} per person $\Rightarrow$ 0 – 10^{20} systems
- Available Flops Planetwide
  - 10^{24} – 10^{30} Flops/sec [assuming classical models of computation]

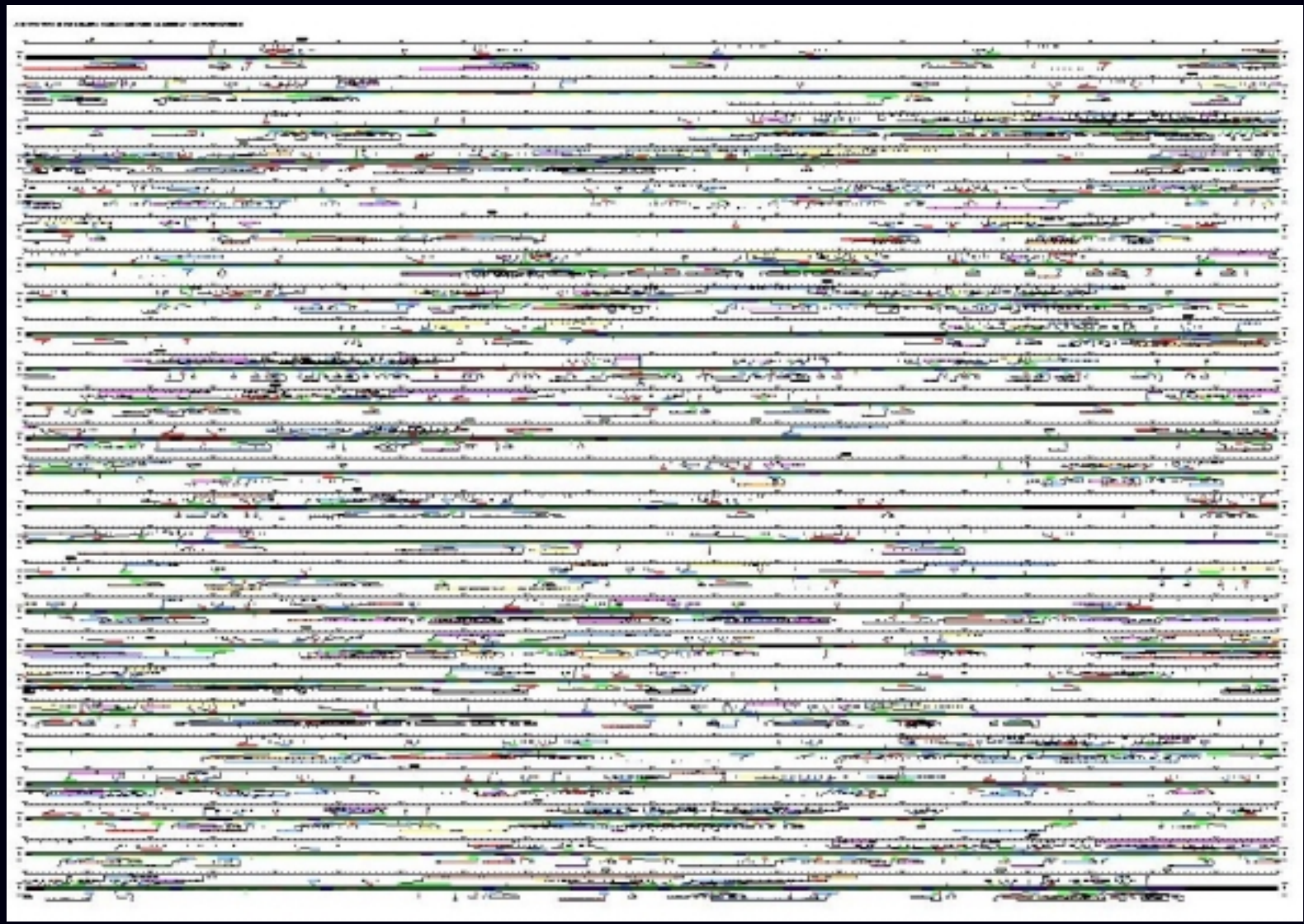
The Next 500 Years of Biology

Celera Sequencing Process



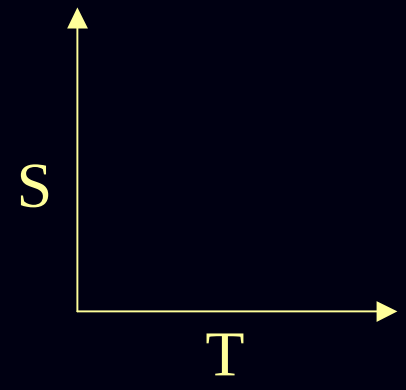
Source: *Science*

Chromosome Two



Biological Hierarchies

- Genes
- Proteins
- Complexes
- Molecular Machines
- Pathways, Signaling and Regulation Networks
- Cells
- Multicellular communities and organisms
- Ecologies



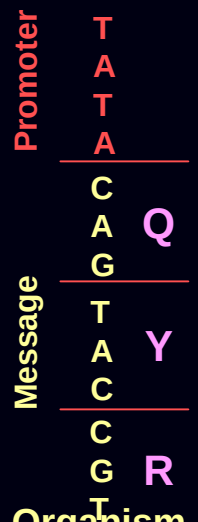
- Structure
- Dynamics
- Behavior
- Evolution

Computational analysis and simulation have important roles in the study of each step in the hierarchy of biological function

DNA sequence

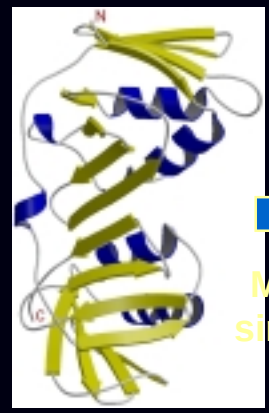
Sequence Annotation

Protein sequence and regulation



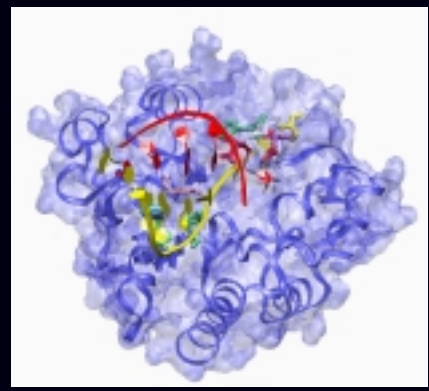
Homology based protein structure prediction

Protein structure



Molecular simulations

Protein/enzyme function

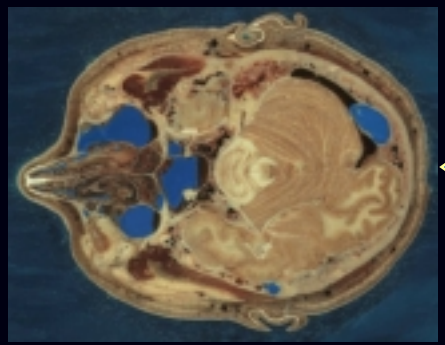


Data integration

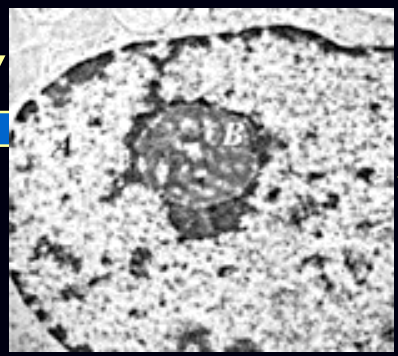
Network analysis

Pathway simulations

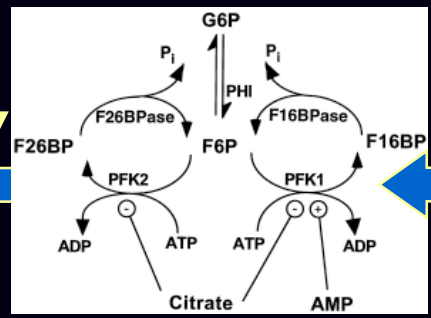
Organism simulations



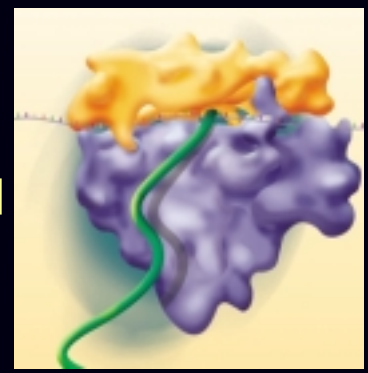
Bacterial communities & multicellular organisms



Bacteria and cells



Metabolic pathways & regulatory networks



Multi-protein machines

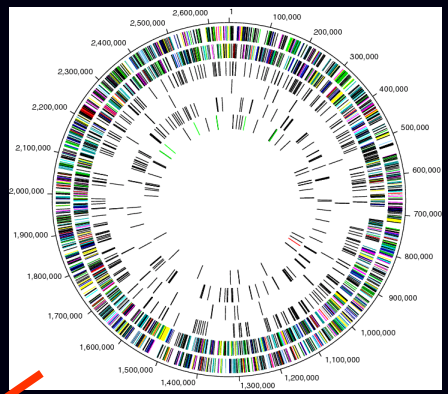
Source: M. Colvin

All models of microbial behavior will depend on information about the macromolecular machines that mediate function

Computation has roles at each step in deriving this data

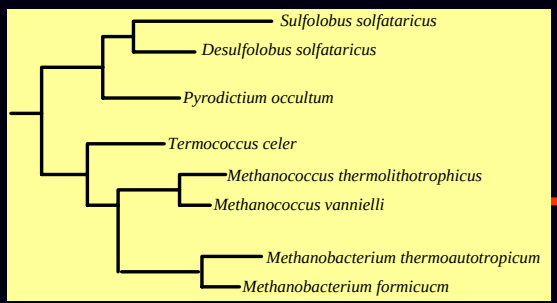
Raw DNA sequencing reads

Assembled genome

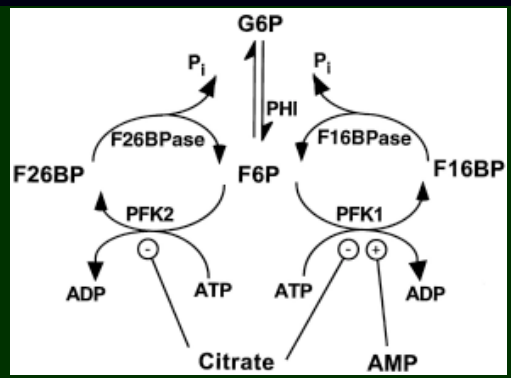


Sequence homologues

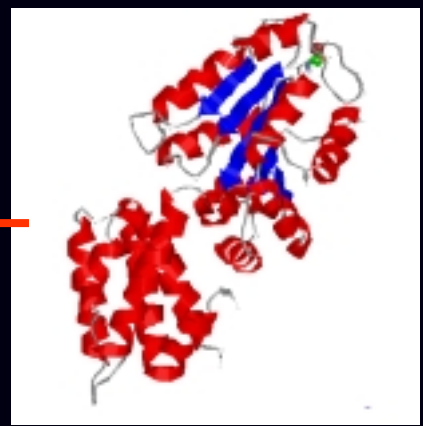
```
cagggccgcgtgcatcccgccactgtgg
||||||||  |||   |||||||  ||
cagggccgattgcgcgccgccaccctga

gcccaggcctggggcgagcggctgcgcg
||  | |||||||||| ||  ||||||||
gcggaagcctggggccagaagctgcgcg
```



Phylogenetic relationships



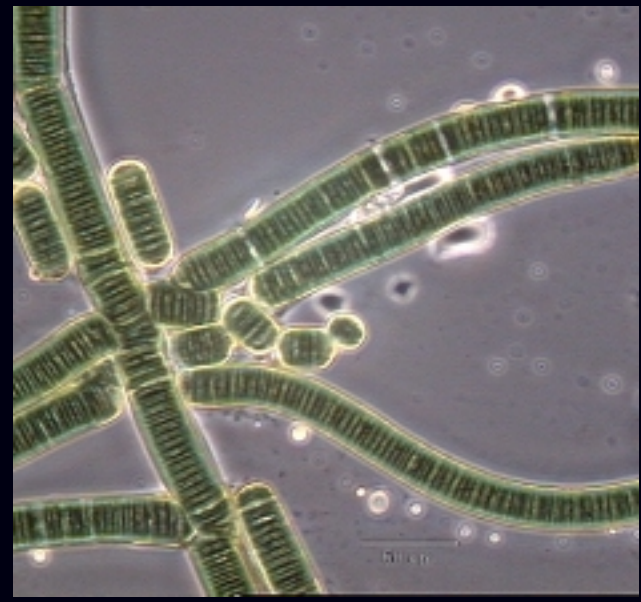
Protein function



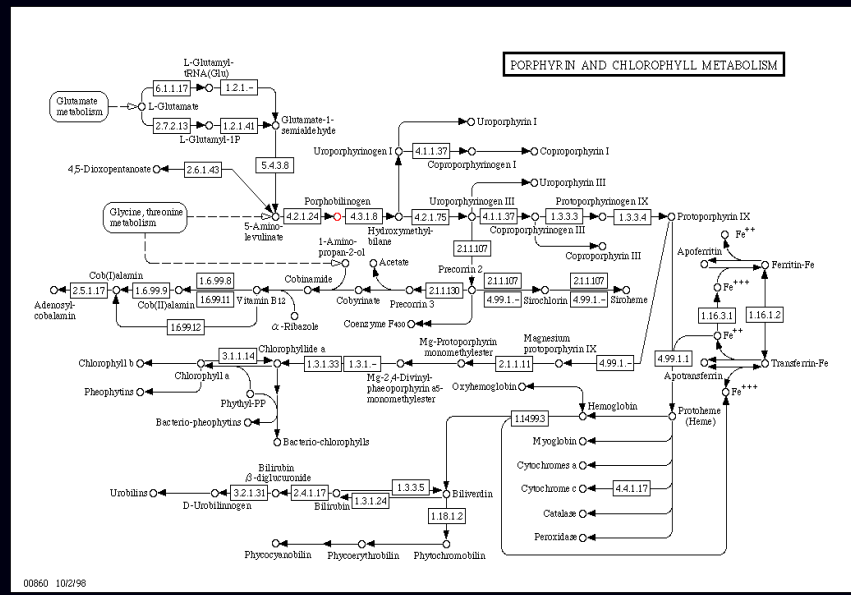
Protein structure

Source: M. Colvin

Biological CAD:
Tools for Design in Life Science



- Understand biological systems from an information systems standpoint [e.g., organization, communication, transformation]
- Modeling biological systems: genes, molecules, pathways, organelles, cells, tissues, organs and organisms, communities
- Designing new biological structures and systems
  - New biochemical pathways
  - Genomic CAD
  - Designed microorganisms



Building a Virtual Biosphere 2

Understanding Closed Ecosystems ⇒ Space Travel and Managing the Earth

- Building systems O(10)
- Flow fields & Microclimates O(10^2)
- Physical processes O(10^3)
- Biological processes O(10^3-10^4)
- Ecosystem Interactions O(10^5-10^7)

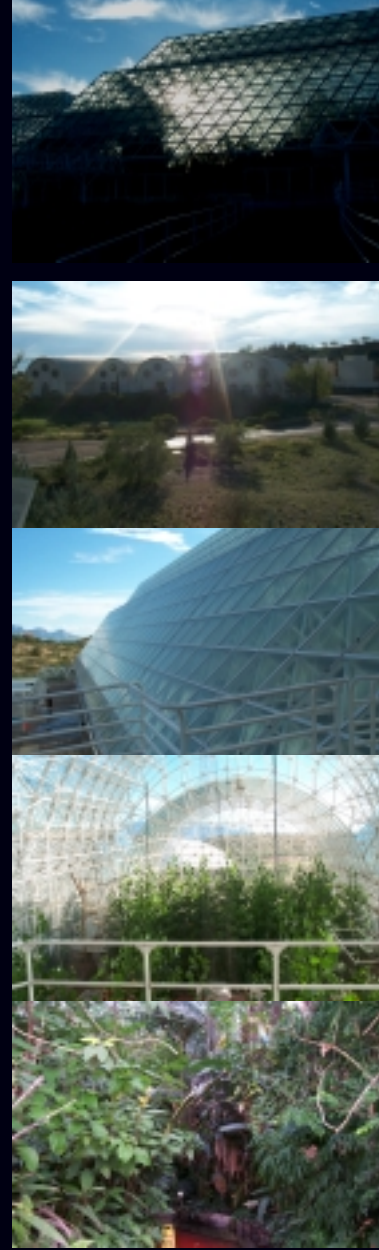
- B2 ~200,000 m^3
- m^3 ⇒ ~1s/ts @ 1GF
- cm^3 ⇒ ~1s/ts @ 1 PF

Populations

mm^3 ~10^{13}

cm^3 ~ 10^{10}

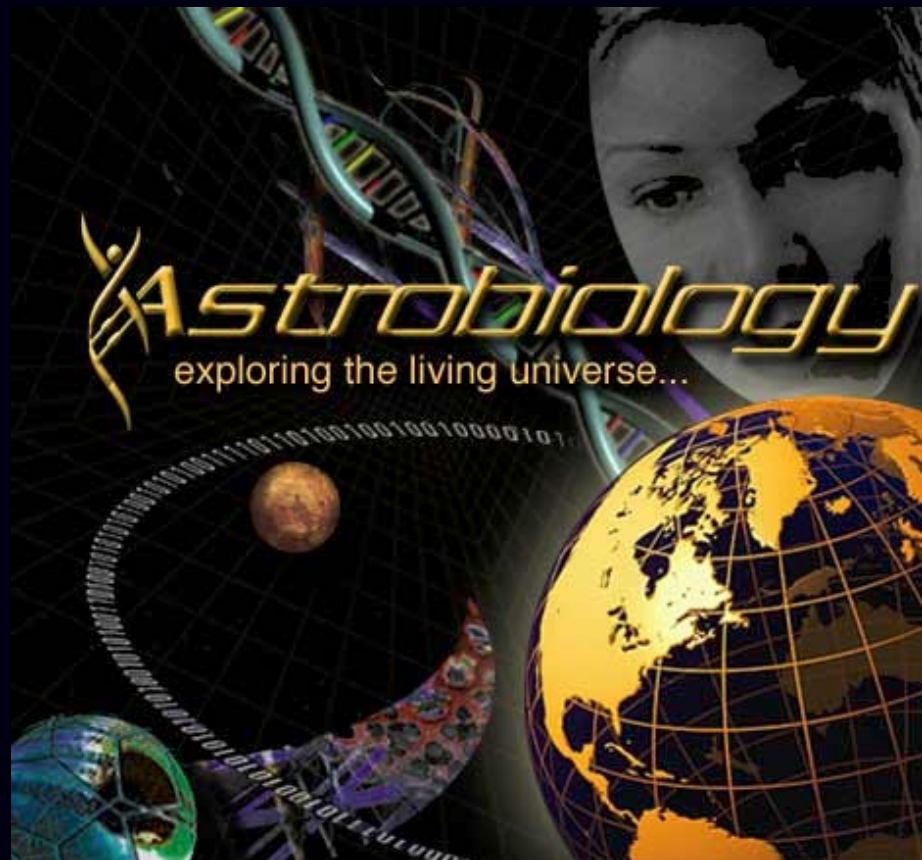
dm^3 ~ 10^7



Computational Astrobiology

Using Computation to Investigate the Origin of Life in the Universe

- Interstellar Media Evolution and Transport
- Planetary Formation and Evolution
- Microclimate Modeling
- Self-organizing Systems
- Molecular Evolution



Digital Databases of Human Knowledge

- Several Projects are underway attempting to catalogue and archive all openly available knowledge bases and databases

- Could use these to study the evolution of intelligence
  - Rates of knowledge increase and adoption
  - Organization of knowledge bases
  - Automated translation and understanding

- Could use these databases as a start of a reply message effort
  - How to construct the “Earth Download” message
  - Actually do it

Future Computing and the Human Experience

- By building on:
  - Virtual reality and augmented reality interface technologies
  - Increasing compute, networking and storage capabilities
  - And understanding of the role of information and experience
- One may imagine a more rich existence than today
  - Full sensory interfaces to imagined worlds
- Or a more poor existence…
  - Aesthetically polluted info/techno space of complete human manufacture


For as long as space endures
And for as long as living beings remain,
Until then may I too abide
To dispel the misery of the world.