Education in Computational Science and Engineering

What must be done!

Lennart Johnsson
Department of Computer Science and
Texas Learning and Computation Center
University of Houston
Department of Numerical Analysis and Computer Science and
ParallelDatorCentrum
Royal Institute of Technology and Stockholm University
Department of Computer Science and HiPerSoft
Rice University
The Mission
Educate for lifelong learning

- Offer scientific and engineering insight
- Teach skills
- Enhance interest in discovery and invention
- Teach methodologies
- Develop communication skills
- Group learning
Capabilities - Technology
The power of exponentials

- Computing
- Storage
- Communication
- Human interfaces
### The SIA CMOS Roadmap

#### Table 1b  Product Generations and Chip Size Model—Long Term Years

<table>
<thead>
<tr>
<th>Year Technology Node</th>
<th>2008 70 nm</th>
<th>2011 50 nm</th>
<th>2014 35 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Memory</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generation at introduction §</td>
<td>—</td>
<td>64G</td>
<td>—</td>
</tr>
<tr>
<td>Gbits/cm² at production §</td>
<td>3.05</td>
<td>7.51</td>
<td>18.5</td>
</tr>
<tr>
<td>**Logic (High-volume Microprocessor) Cost-performance *</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functions per chip (million transistors (Mtransistors))</td>
<td>539</td>
<td>1,523</td>
<td>4,308</td>
</tr>
<tr>
<td>Transistor density SRAM at introduction (Mtransistors/cm²)</td>
<td>577</td>
<td>1,423</td>
<td>3,510</td>
</tr>
<tr>
<td>Transistor density logic at introduction (Mtransistors/cm²)</td>
<td>109</td>
<td>269</td>
<td>664</td>
</tr>
<tr>
<td>Chip size at introduction (mm²) ***</td>
<td>468</td>
<td>536</td>
<td>615</td>
</tr>
</tbody>
</table>
### The SIA CMOS Roadmap

**Table 1b  Product Generations and Chip Size Model—Long Term Years (continued)**

<table>
<thead>
<tr>
<th>YEAR TECHNOLOGY NODE</th>
<th>2008 70 nm</th>
<th>2011 50 nm</th>
<th>2014 35 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Logic (High-volume Microprocessor) Cost-performance</strong> * (continued)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost-performance MPU M transistors/cm² at introduction (including on-chip SRAM) ***</td>
<td>115</td>
<td>284</td>
<td>701</td>
</tr>
<tr>
<td>Chip size at ramp (mm²) ***</td>
<td>269</td>
<td>308</td>
<td>354</td>
</tr>
<tr>
<td>Cost performance MPU M transistors/cm² at ramp (including on-chip SRAM) ***</td>
<td>100</td>
<td>247</td>
<td>609</td>
</tr>
<tr>
<td><strong>Logic (Low-volume Microprocessor) High-performance</strong> **</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Functions per chip (million transistors)</td>
<td>2,494</td>
<td>7,053</td>
<td>19,949</td>
</tr>
<tr>
<td>Chip size at ramp (mm²) ***</td>
<td>713</td>
<td>817</td>
<td>937</td>
</tr>
<tr>
<td>High-performance MPU M transistors/cm² at ramp (including on-chip SRAM) ***</td>
<td>350</td>
<td>863</td>
<td>2,130</td>
</tr>
</tbody>
</table>
The SIA CMOS Roadmap

<table>
<thead>
<tr>
<th>Chip Frequency (MHz)</th>
<th>2008</th>
<th>2011</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-chip local clock, (high-performance)</td>
<td>6,000</td>
<td>10,000</td>
<td>13,500</td>
</tr>
<tr>
<td>On-chip, across-chip clock (high-performance)</td>
<td>2,500</td>
<td>3,000</td>
<td>3,600</td>
</tr>
<tr>
<td>On-chip, across-chip clock (high-performance ASIC)</td>
<td>1,200</td>
<td>1,500</td>
<td>1,800</td>
</tr>
<tr>
<td>On-chip, across-chip clock (cost-performance)</td>
<td>1,400</td>
<td>1,800</td>
<td>2,200</td>
</tr>
<tr>
<td>Chip-to-board (off-chip) speed</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(high-performance, reduced-width, multiplexed bus)</td>
<td>2,500</td>
<td>3,000</td>
<td>3,600</td>
</tr>
<tr>
<td>Chip-to-board (off-chip) speed (high-performance, for peripheral buses)</td>
<td>1,285</td>
<td>1,540</td>
<td>1,800</td>
</tr>
</tbody>
</table>
The SIA CMOS Roadmap

### Table 7b  Cost—Long Term Years

<table>
<thead>
<tr>
<th>YEAR TECHNOLOGY NODE</th>
<th>2008 70 nm</th>
<th>2011 50 nm</th>
<th>2014 35 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Affordable Cost per Function ++</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DRAM cost/bit (packaged microcents) at samples/introduction</td>
<td>—</td>
<td>0.66</td>
<td>—</td>
</tr>
<tr>
<td>DRAM cost/bit (packaged microcents) at production §</td>
<td>—</td>
<td>0.24</td>
<td>—</td>
</tr>
<tr>
<td><strong>Cost-performance MPU (microcents/transistor)</strong> (including on-chip SRAM) at introduction ***</td>
<td>—</td>
<td>27</td>
<td>—</td>
</tr>
<tr>
<td><strong>Cost-performance MPU (microcents/transistor)</strong> (including on-chip SRAM) at ramp ***</td>
<td>—</td>
<td>16</td>
<td>—</td>
</tr>
<tr>
<td><strong>High-performance MPU (microcents/transistor)</strong> (including on-chip SRAM) at ramp ***</td>
<td>—</td>
<td>3.8</td>
<td>—</td>
</tr>
</tbody>
</table>
The SIA CMOS Roadmap

Thomas Sterling, JPL/Caltech

Year of Technology Availability

MB per DRAM Chip
Logic Transistors per Chip (M)
uP Clock (MHz)
SIA CONCLUSION

- Approximately a tripling of I/O Pin transfer rates over the next 9 years.
- Overall
  - we see 10x the gate count
  - we see 3x the number of pins
  - we see 3x the I/O pin speeds (source sink, greater with clock recovery mechanisms)
ARCH. - LONG TERM - 2009

• THE SIA STUDY TEACHES US:
  – 64 gbits of dram - (8 gbytes)
  – 8 gbits of sram
  – 520 million MPU transistors
  – 70 nm lithography, 2.54 cm on-a-side
  – 6 ghz clock within vliw/risc core
  – 2.5 ghz across die
  – 2500 external signal pins
The SIA CMOS Roadmap

Year of Technology Availability

# Chips/Petabyte
# uP/Petaflop

Chip Count

100,000,000
10,000,000
1,000,000
10,000
100,000
100,000
10,000

1997
1999
2001
2003
2006
2009
2012

Thomas Sterling, JPL/Caltech

S. Lennart Johnsson, Arcade 2000, November 27 - 28, Bergen, Norway
Capabilities - Technology
The power of exponentials

Today

Sony Playstation 2

5 Gflop, 64-bit precision, $299 (retail); $60/Gflop

In 2010: $600/TFlop
Capabilities - Technology
The power of exponentials
Storage

• Secondary
• Tertiary
Capabilities - Technology
The power of exponentials
Storage

Example 1: In 2015, 500 million books of 350 pages of text can be stored on disk for $2,000.

In 1995, 415 million books were housed collectively by the members of the U.S. Association of Research Libraries (108 academic and 11 other libraries).
Capabilities - Technology
The power of exponentials
Storage

Example 2: In 2010, disk storage for 1,000 10 Mpixel images in 24-bit color is expected to cost about $1.
Capabilities - Technology
The power of exponentials

Communication -- Networks
AMPLIFIER TECHNOLOGY

WAVELENGTH DIVISION MULTIPLEXING (WDM)

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

\[ c = \lambda \times f \]

![Graph showing fiber loss vs. wavelength, with range of high gain EDFAs highlighted.](image_url)
AON - THE BOTTLENECK

Assume:
- 50 fibers,
- 100 wavelengths,
- 40 Gb/s per wavelength

\[(50/2) \times 100 \times 40 = 100\] Tb's in each direction

This node would require 200 Tb/s input + 200 Tb/s output capacity.

The dominant traffic in the network is IPLAN, WAN, SAN(?) - Convergence

Network Junction of large fiber bundles
Key Enablers: Bandwidth Acceleration

- 10 Mbps
- 100 Mbps
- 1 Gbps
- 10 Gbps

Time

Performance

Network Performance (Intranet)

Network Performance (Internet)

CPU Performance

Shahin Kahn

S. Lennart Johnsson, Arcade 2000, November 27 - 28, Bergen, Norway
Capabilities - Technology
The power of exponentials

Example: At 40 Gbps the transfer of a 10 Mpixel image in 24-bit color takes about 7 ms.

Within 10 years, fiber to the desktop will be economically feasible (Lucent).

Today, fiber-to-the-home (FTTH) is commercially viable at <$50/mo (PITAC).
Teledesic provides access to existing networks.

- Telepresence extends the network of existing networks.
- Unlimited gateway rights allow service providers to interconnect their networks with the Teledesic network.
- Low-Earth-orbit satellites provide fiber-like quality.
- User equipment is low-cost and user-installable.
Network technologies

- All optical networks
- Broadband wireless
- Everywhere
- Quality of service
Capabilities - Technology
Human Interface

- Visualization
- Voice
- Audio
- Tactile
Computation and Information Infrastructure

- Everything networked
- Billions of devices
- Ubiquitous access
- Multimedia databases
- Special/rare instruments
- Telescience
The New World of HPC: Web-Centric Supercomputing

Supercomputing

Internet

.comHPC

Performance on demand

High performance at all costs

Universal access

Shahin Kahn
HPC Tomorrow: Web-centric

Universal connectivity. Universal accessibility.

Integrated Web-based N-tier servers

- Parallel Compute Servers
- Data Servers
- Remote DataBase
- Remote Very Large Scale Comp Resource

Intranet / Internet

Gbps / GBps

Hierarchical MetaComputing

- Smart card
- Cell phone
- Palm
- PC
- WS

Client / GUI written in Java
Browser functionality via Inter-applet communication

Shahin Kahn
The Service Driven Network

Shahin Kahn
Internet and Web Growth

Data Source: http://info.iscc.org/guest/zakon/Internet/History/HIT.html

Bob Knighten

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Peer-Peer Computing: Wave as strong as the introduction of Mosaic

Pre-Mosaic
- Web:
  - NNTP
  - WAIS
  - Gopher
  - WWW

Infrastructure
- Ease of Use
- Common Protocols
- Standards
- Scalability

Mosaic

Created the ‘e’ Revolution

Pre Peer – Peer Web
- Shared Drives
- FTP
- Windows for WG

Infrastructure
- Ease of Use
- Common Protocols
- Standards
- Scalability
- Security

Napster
Gnutella

The Next Computing Revolution

Infrastructure is the Key success factor. Intel enables infrastructure.

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Bob Knighten

Intel Labs

TLC²

PDC
Enabling Science
Information Technology

Leverage always on, always connected client side storage to deliver significantly lower cost storage solution

Peer-to-Peer Storage
- Inexpensive Equipment
- Inexpensive Desk Space
- Low Maintenance
- Inexpensive Redundancy

Server Storage
- Expensive Equipment
- Expensive Floor Space
- Expensive Administration
- Expensive Redundancy

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Bob Knighten
Enterprise Usage Models:
Peer-to-Peer Virus Protection

"In March, a coalition of Sandia [Peer-to-Peer] cyberagents successfully protected five network-linked computers over two full working days of concentrated attack by a four-person hacker force called the Red Team, an expert hacker group, also at Sandia, whose purpose is to test the defenses of governmental and corporate computer systems."

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What is Needed? Performance

- What are the performance implications of a billion connected computers?
- 100 million virtual private webs?
- What are the inherent scalability limits?
- What are the performance limits of protocols?
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
SETI@home was the Breakthrough to PC Internet Computing

- Running on 500,000 PCs, ~1000 CPU Years per Day
  - 428,438 CPU Years so far
- Sophisticated Data & Signal Processing Analysis
- Distributes Datasets from Arecibo Radio Telescope

Next Step - Allen Telescope Array
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

Larry Smarr
Computer Science & Engineering
Exponential Growth in Scale of PC Parallel Computers

1,000,000x in Only Ten Years

Larry Smarr
Computer Science & Engineering

NASA Beowulf (1 GF)
Sandia ASCI Red (1 TF)
SETI@home (10 TF)
Megacomputers (PFs)

Computation and Information Infrastructure

• New paradigms
• Global Virtual Communities
• Telescience
• Real-time data assimilation
• Virtual laboratories
• Anytime anywhere access
The Needs

- Traditional Sciences and Engineering
- Material Science
- Optimization
- Life Sciences
- Biomedical Engineering
- Medicine
- Environmental Sciences and Engineering
- Computational finance
Center for Integrated Turbulence Simulation
Fire Scales & Simulation

assisted by adaptive mesh refinement
(parallel scalable AMR)

teraflop computing:
$10^8 - 10^9$ mesh cells
$10^3 - 10^5$ timesteps

fire simulation:
.........200m X 200m X 1000m.........
..............................3 hours..............................

resolve scales in the vicinity of object of interest (~3m)
Coupling Processes at all Time Scales

"quantum engineering"

rate | time
--- | ---
$10^{15}$ | $10^{-15} = $ fs electron transfer
$10^{12}$ | $10^{-12} = $ ps stretching vibration rotation
$10^{9}$ | $10^{-9} = $ ns translation
$10^{6}$ | $10^{-6} = $ μs rotation & translation
$10^{3}$ | $10^{-3} = $ ms fast chem rxn large molecules soot growth soot oxidation
$10^{0}$ | $10^{0} = $ s
$10^{-3}$ | $10^{3} = $ Ks
$10^{-6}$ | $10^{6} = $ Ms
$10^{-9}$ | $10^{9} = $ Gs human lifetime
$10^{-12}$ | $10^{12} = $ Ts age of earth
$10^{-15}$ | $10^{15} = $ Ps age of universe
Reaction Time Scales

fire/soot chemistry

- oxidation
- agglomeration
- growth
- inception/nucleation

particle zone

C_6H_2 + C_6H_6 = C_{12}H_8 + H + H
C_{10}H_4 + C_2H = C_{12}H_8
C_6H_2 + C_6H_6 = C_{10}H_6 + H
C_3H_3 + C_3H_3 + THIRD = C_4H_8 + THIRD

molecular zone

CH_3^• = C_2H_5^• = C_2H_3^•

OH + C_2H_5 = C_2H_3 + H_2O
C_2H_5 = C_2H_4 + H
CH_4 + O_2 = CH_3 + HO_2
CH_4 + THIRD = CH_3^•
Electromagnetics

Erik Engquist, Per Oster, Lennart Johnsson, KTH
Scheduling

Continental Airlines
Electron Tomography -- Biology

Measurements of Mitochondrial Membrane Structures

Cristae Junction
28 + 6 nm

Cristae Diameter
31 + 7 nm

Contact Diameter
14 + 7 nm

Outer-Inner Membrane
22 - 4 nm

Contact Width
14 - 2 nm

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

S. Lennart Johnsson, Arcade 2000, November 27 - 28, Bergen, Norway
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Electron Tomography -- Biology

0.5 μ Section of chick cerebellum containing one mitochondrion
Biological Imaging

400 kV electron image of herpesvirus capsids

500 Å
Medical Imaging

MRI

Nuclear Medicine

X-ray Computed Tomography

Optical Tomography
Biological Imaging

Adaptive Resolution Image Acquisition

Acquisition of structural Data in live Brain Tissue

Neuron filled with Fluorescent Probe, Imaged with Confocal Microscope

Morphological Reconstruction

Reconstruction of Dendrites with NeuronTracer to study Structure-Function Relationship

Typical file size: > 100 Mb

Image Restoration

Deconvolution of Confocal Optical Sections with Huygens2 Image Restoration Software

Typical file size: 50-100 Mb

Peter Saggau
Baylor College of Medicine
Houston, TX
### Biological Imaging

<table>
<thead>
<tr>
<th>Resolution</th>
<th>8.5 Å</th>
<th>4.5 Å</th>
</tr>
</thead>
<tbody>
<tr>
<td>B = 100 Å²</td>
<td>6,000</td>
<td>5,000,000</td>
</tr>
<tr>
<td>B = 50 Å²</td>
<td>3,000</td>
<td>150,000</td>
</tr>
</tbody>
</table>
Biological Imaging

Data Acquisition
- Electron Microscopy
- Confocal Microscopy
- Functional MRI
- EEG, EMG

Image Restoration
- Deconvolution
- Filtering

Image Reconstruction
- 3D Reconstruction

Image Analysis
- Extraction
- Segmentation
- Structure recognition
- Functional identification

Visualization

Interaction with the Experiment

Postprocessing, Simulation, Bioinformatics

Image/data processing

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Virtual Lung from PNNL's Virtual Biology Center

**NWGrid & NWPhys**

designed to simulate coupled fluid dynamics and continuum mechanics in complex geometries using 3-D, hybrid, adaptive, unstructured grids.

- NWGrid - grid generation & setup toolbox
- NWPhys - collection of computational physics solvers
Particle Distribution in the Flow Airways

(Particle occurs in right branch of bifurcation)

Airway passage

membrane wall

particle

Harold Trease, PNNL

U.S. Department of Energy
Pacific Northwest National Laboratory

S. Lennart Johnsson, Arcade 2000, November 27 - 28, Bergen, Norway
Pressure Contours of the Flow Field throughout the Lung Airways

Particles occur in every right branch of a bifurcation

Harold Trease, PNNL

U.S. Department of Energy
Pacific Northwest National Laboratory
Environmental Studies

Los Angeles, CA
Environmental Studies

Houston, air quality measurement stations

S. Lennart Johnsson, Arcade 2000, November 27 - 28, Bergen, Norway
Real-time data access
National Center for Atmospheric Research

Surface data
Radar data
Balloon data
Satellite data
Los Alamos Forest Fires
NOAA-15 AVHRR HRPT
Multi-channel False Color Image
May 11, 2000 @ 0122 UTC

Fires
SMOKE PLUME
NEW MEXICO
TEXAS

NOAA
Wildland Fires
NOAA-12 HRPT
Color Enhanced
August 9, 2000 @ 00:17 UTC

Heat signatures (red) and smoke (light blue) blanket much of southwestern Montana and parts of Idaho.
Hurricane Carlotta
GOES-10
2km Visible
June 21, 2000 @ 1500 UTC

PACIFIC OCEAN

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The CERN Data Grid

The LHC Detectors

ATLAS

CMS

Raw recording rate 0.1 – 1 GB/sec
3.5 PetaBytes/year
~10^8 events/year
Computational Science and Engineering

• Computationally demanding
• Very large data sets
• Multidisciplinary
• Integrated environments
• Collaborative
• Interactive
Deep Computing Institute

Computational Biology
Bioinformatics
Computational Materials Science
Computational Chemistry
Data Mining
Optimization
Visualization
High Performance Computing
Theory of Computing
Computational Science and Engineering

Challenges

• Depth versus Breadth; Skills versus Insight
• Information, service and software economy
• Increased role of methodologies
• Proficiency with a diversity of tools
• Global virtual communities
• Global competition (at all levels)
• Reduced “half-life” of course content
• Life long learning (for students and faculty)
Computational Sciences and Engineering

Actions

• Form virtual communities for teachers
• Revisit the role of the teacher
• Develop and provide proper tools
• Recognize that education is more than courses
• Encourage and reward teacher creativity
• Encourage and reward research (higher ed.)
• Engage students in (research) projects
• Encourage and support student leadership
Computational Science and Engineering

Actions

• Form virtual communities for teachers
  
  - Collaborative curriculum development
  - Collaborative course development
  - Establish telelaboratories
  - Establish virtual laboratories
  - Teacher stimulation through collaboration and increased exposure
Computational Science and Engineering

Actions

• Revisit the role of the teacher

  Traditional role: Lecture
  Reading assignments
  Formal lecture - blackboard
  Homework

  New role: Mentor
  Stimulate discussion/dialogue
  Explore “what-if” scenarios
  Guide problem formulation and solution
Computational Science and Engineering

Actions

• Develop and provide proper tools
  - Create problem solving environments
    Biology Workbench
    Cactus
    SimDB
  
  - Develop management/admin. tools
The Biology Workbench

http://workbench.sdsc.edu
Problem Solving Environments

Cactus

Plug-In “Thorns” (modules)
- extensible APIs
- ANSI C
- parameters
- scheduling
- Core “Flesh”
- error handling
- make system
- grid variables
- wave evolvers
- multigrid
- coordinates
- black holes
- equations of state
- boundary conditions
- remote steering
- Fortran/C/C++
- Java/Perl/Python
- driver
- input/output
- interpolation
- SOR solver
- grid variables
- parameters
- scheduler
- extensible APIs
- remote steering
- Fortran/C/C++
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- grid variables
- parameters
- scheduler
- extensible APIs
- remote steering
- Fortran/C/C++
- Java/Perl/Python

http://www.cactuscode.org
The CERN Data Grid

The Grid from a Services View

Applications
- Chemistry
- Cosmology
- Environment
- Biology
- High Energy Physics

Application Toolkits
- Distributed Computing Toolkit
- Data-Intensive Applications Toolkit
- Collaborative Applications Toolkit
- Remote Visualization Applications Toolkit
- Problem Solving Applications Toolkit
- Remote Instrumentation Applications Toolkit

Grid Services (Middleware)
- Resource-independent and application-independent services
  - authentication, authorization, resource location, resource allocation, events, accounting, remote data access, information, policy, fault detection

Grid Fabric (Resources)
- Resource-specific implementations of basic services
  - E.g., Transport protocols, name servers, differentiated services, CPU schedulers, public key infrastructure, site accounting, directory service, OS bypass

ECFA June 2000

F. Giardi - CERN/IT 5
SimDB

Matin Abdullah, Michael Feig, Lennart Johnsson, Monte Pettitt, UH
GEMSviz at INET2000

Erik Engquist, Per Oster, Lennart Johnsson, KTH
Distributed Applications

App Server
Nexus CAVERNsoft

Grid

Globus
DUROC Nexus

Viz Client
VTK Nexus CAVERNsoft

Comp Client
MPI Nexus

Erik Engquist, Per Oster, Lennart Johnsson, KTH
Actions

- Recognize that education is more than courses

  Quality education is a “total” experience
  teachers
  classmates
  social and other events
  confidence building
Computational Science and Engineering

Actions

• Encourage and reward teacher creativity

In organizing and delivering courses
In financing facilities
In motivating students
Computational Science and Engineering

Actions

• Encourage and reward research

Research is necessary for quality education
Things Are About to Get Very Interesting…
Arcade2000
CSE Education Panel

- Recruiting and retention
- Faculty Currency (keeping up)
- Infrastructure
- Role of Higher Education in the total educational enterprise
- Role of academic HPC Centers
ARCADE 2000
Architecture Panel

Computational and Information Grids
Seamless integration of resources (instruments, computational platforms, networking, (multimedia) databases)

Data Paths (I/O, memory buses, Infiniband, Myrinet, Giganet, 10 GigE, …)

Visualization (Immersive Viz, high resolution graphics, …)

Software (code restructuring tools, libraries, ….)

Algorithm development