Macintosh Clusters:
“Plug-and-Play” Parallel Computing

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Parallel Computing becoming more common

- Necessary for 3D calculations
- Programming becoming standardized (MPI)
- Building your own cheap “supercomputer” possible

Why Macs?

Easy to use

Special expertise in OS is not required

Hardware and software are well integrated

– even a 6th grader has built a Mac cluster!

Good performance with PowerPC

– G4 even has a vector processor

Advanced features built-in

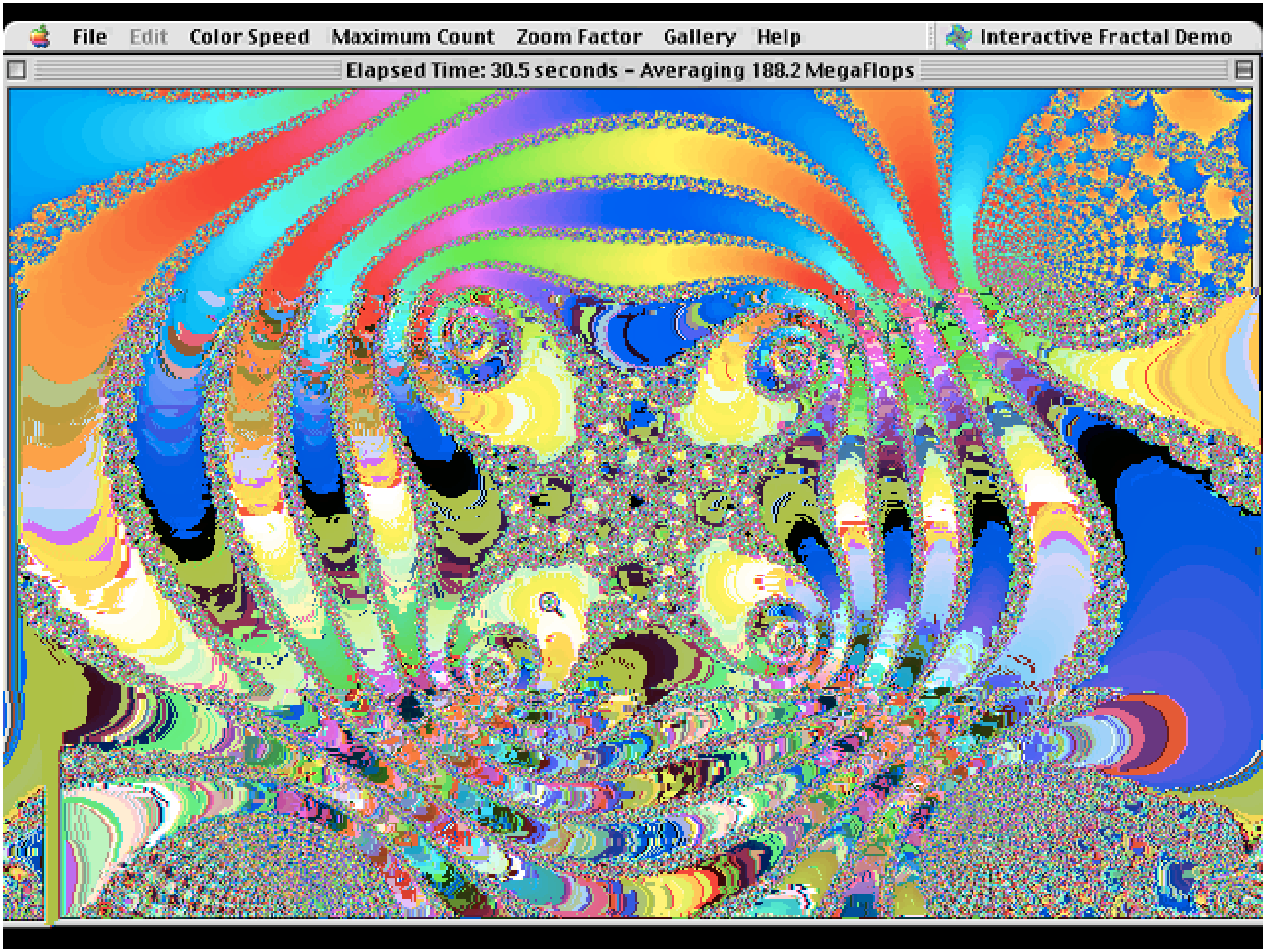
– gigabit and wireless networking
– CD/DVD-burning
– FireWire and multimedia support

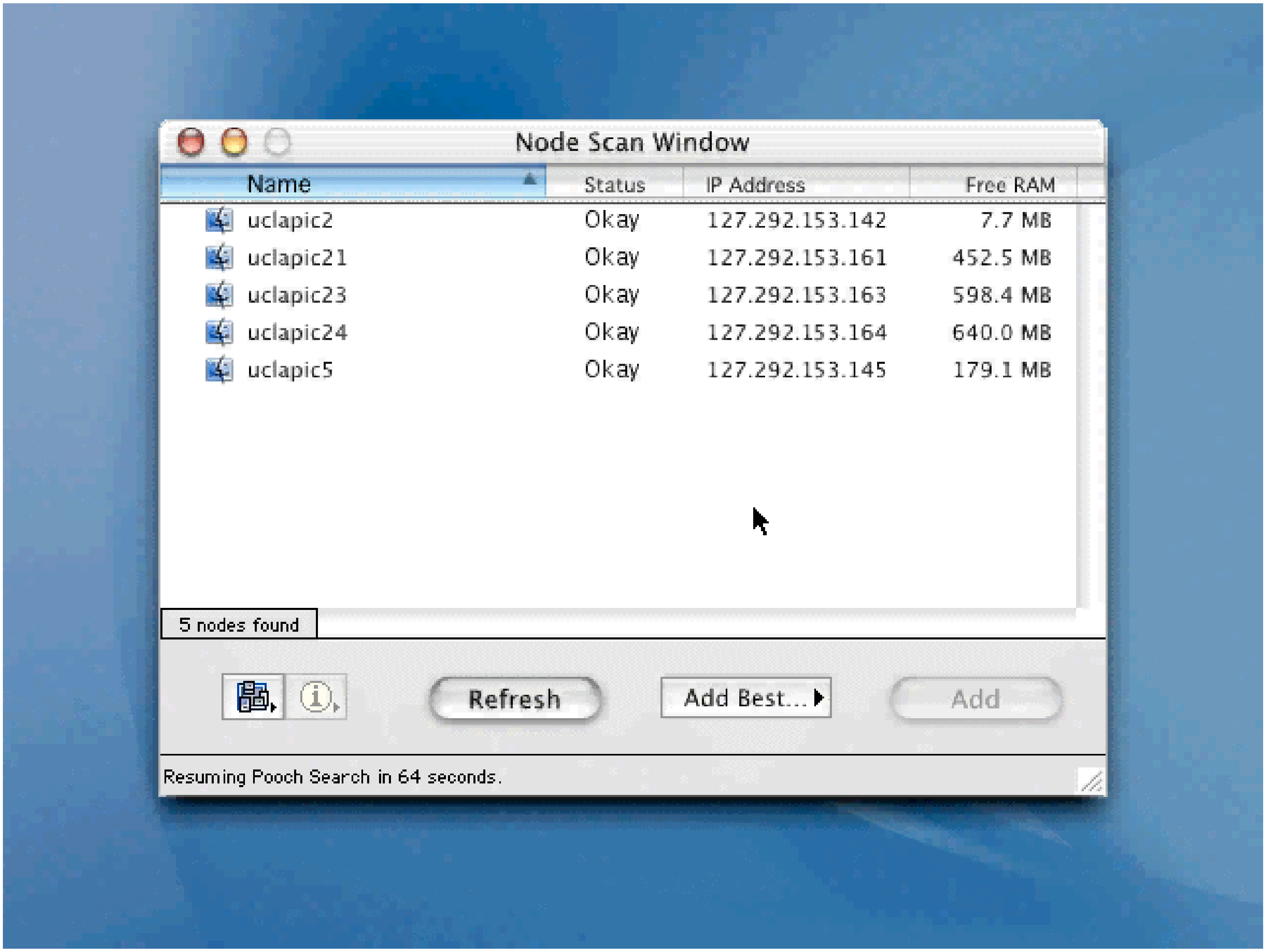
Recipe for building your own Mac Cluster

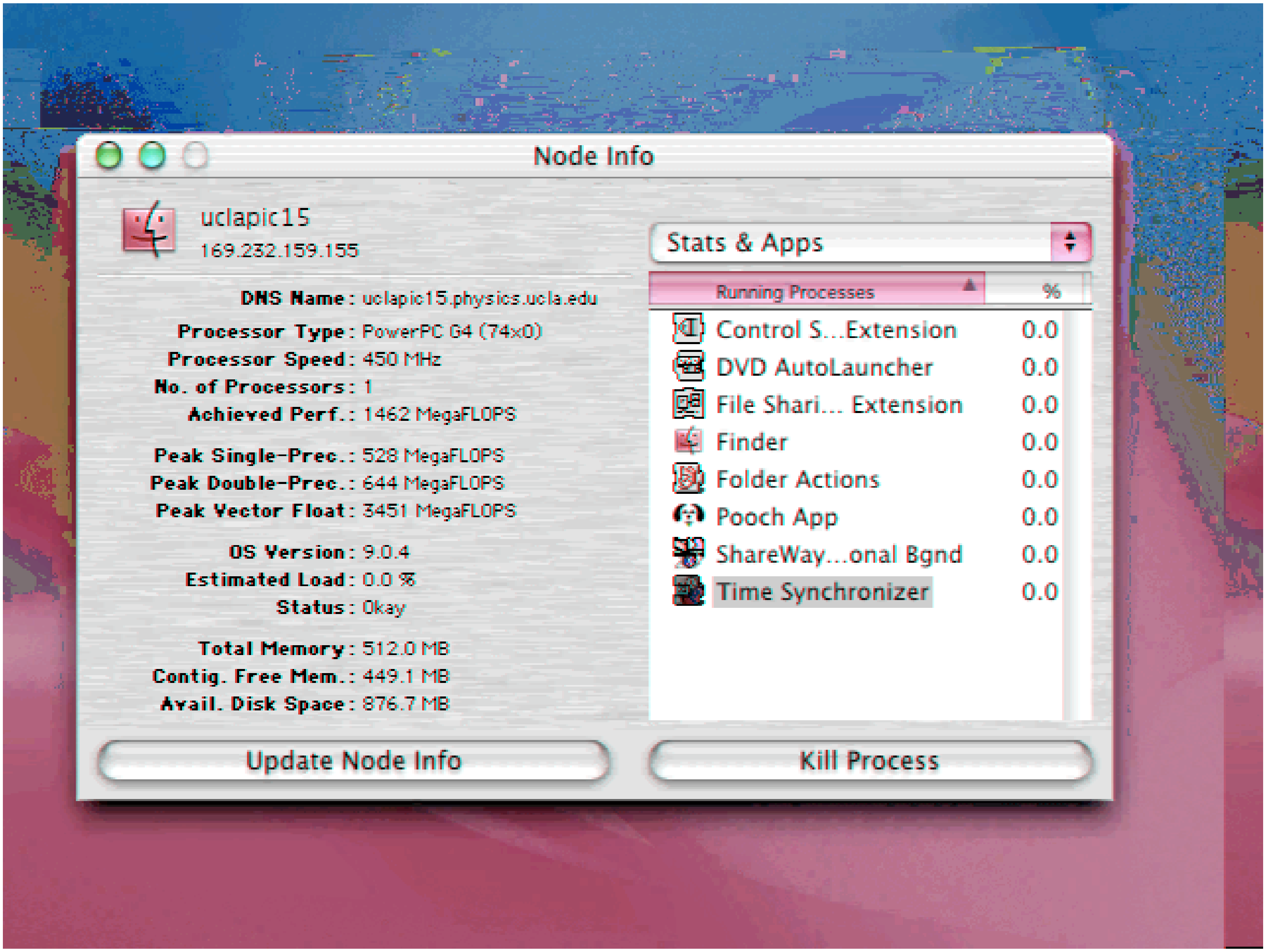
- Obtain several Macintosh G4s
- Upgrade memory as desired
- [illegible]
- Obtain Category 5 Ethernet Cables (one each)
- Connect cables from Macs to switch
- Download Pooch from http://daugerresearch.com/pooch
- Install Pooch on each Mac

Altivec Fractal Carbon program can be downloaded to test cluster

To write your own programs get MacMPI from
http://exodus.physics.ucla.edu/appleseed/


File
Edit
Color Speed
Maximum Count
Zoom Factor
Gallery
Help
Interactive Fractal Demo
Elapsed Time: 30.5 seconds - Averaging 188.2 MegaFlops


Node Scan Window
Name
Status
IP Address
Free RAM
uclapic2
Okay
127.292.153.142
7.7 MB
uclapic21
Okay
127.292.153.161
452.5 MB
uclapic23
Okay
127.292.153.163
598.4 MB
uclapic24
Okay
127.292.153.164
640.0 MB
uclapic5
Okay
127.292.153.145
179.1 MB
5 nodes found
Refresh
Add Best...
Add
Resuming Pooch Search in 64 seconds.



Node Info
uclapic15
169.232.159.155
DNS Name : uclapic15.physics.ucla.edu
Processor Type : PowerPC G4 (74x0)
Processor Speed : 450 MHz
No. of Processors : 1
Achieved Perf. : 1462 MegaFLOPS
Peak Single-Prec. : 528 MegaFLOPS
Peak Double-Prec. : 644 MegaFLOPS
Peak Vector Float : 3451 MegaFLOPS
OS Version : 9.0.4
Estimated Load : 0.0 %
Status : Okay
Total Memory : 512.0 MB
Contig. Free Mem. : 449.1 MB
Avail. Disk Space : 876.7 MB
Stats & Apps
Running Processes
%
Control S...Extension 0.0
DVD AutoLauncher 0.0
File Shari... Extension 0.0
Finder 0.0
Folder Actions 0.0
Pooch App 0.0
ShareWay...onal Bgnd 0.0
Time Synchronizer 0.0
Update Node Info
Kill Process

UCLA Physics Appleseed configuration:

Dedicated: 12 Mac G4/450 + 2 G3/350's + 1 G3/300 + 1 G3/266

average per machine: 512 MB RAM, 20 GB disk

24 port Fast Ethernet Cisco Switch

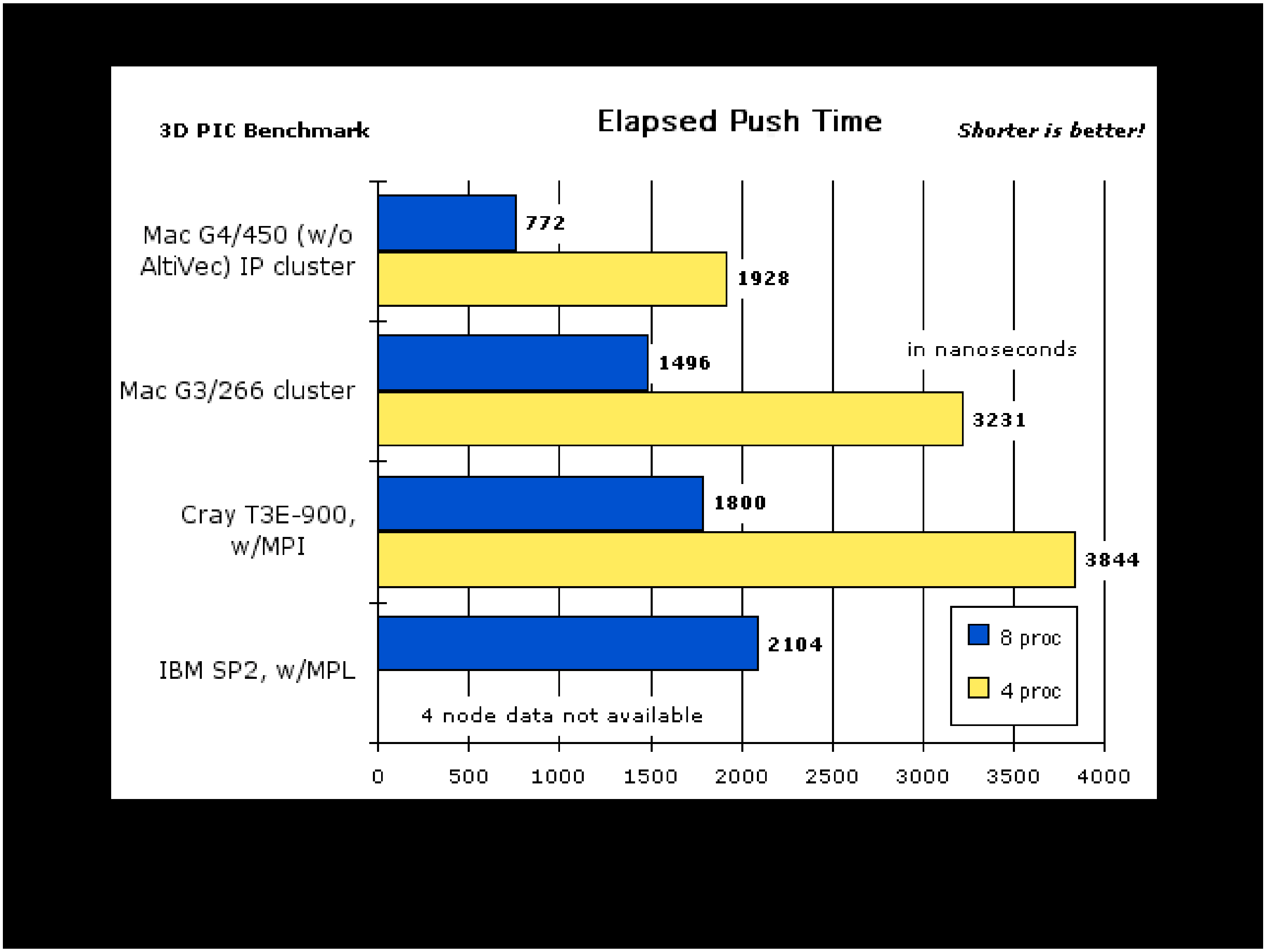
Cost today (August 2001):

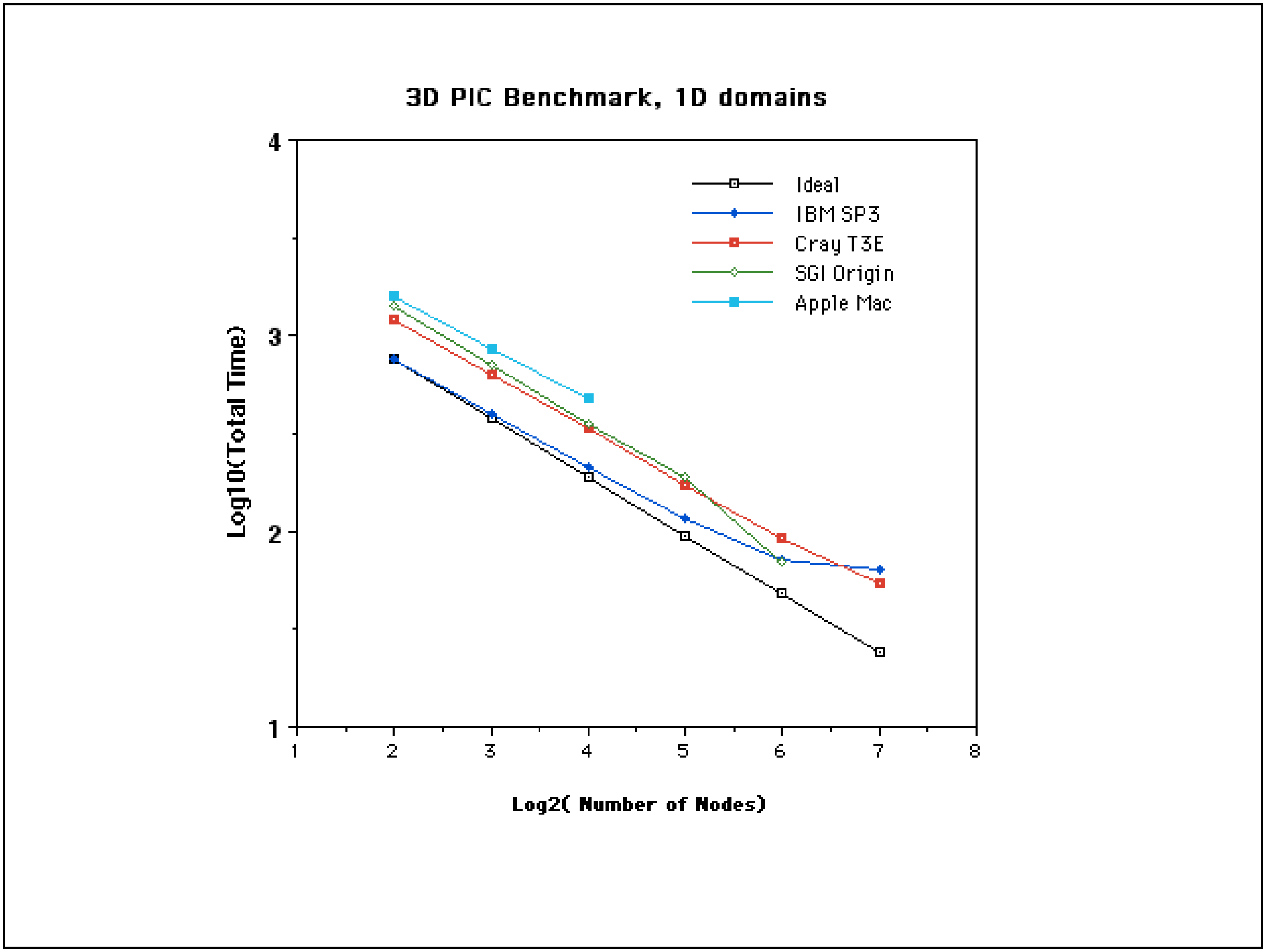
- 8 node dual processor G4/800, w/switch: $25,000
- 8 node G4/733, w/switch: $12,000

16 Macs dedicated for numerical computing

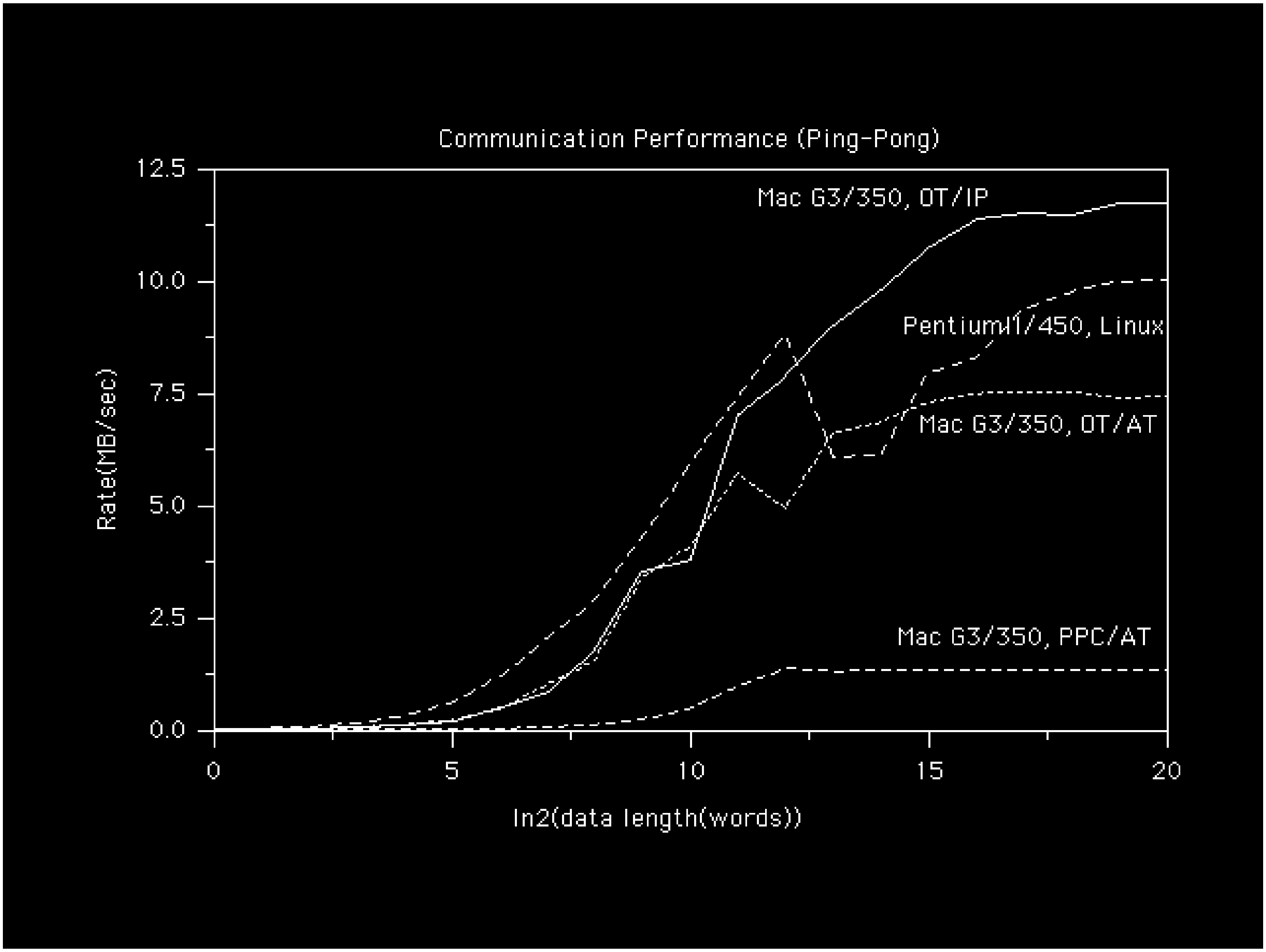
Plus: 12 are user-owned Macs, available nights, weekends, vacations


APPLESEED

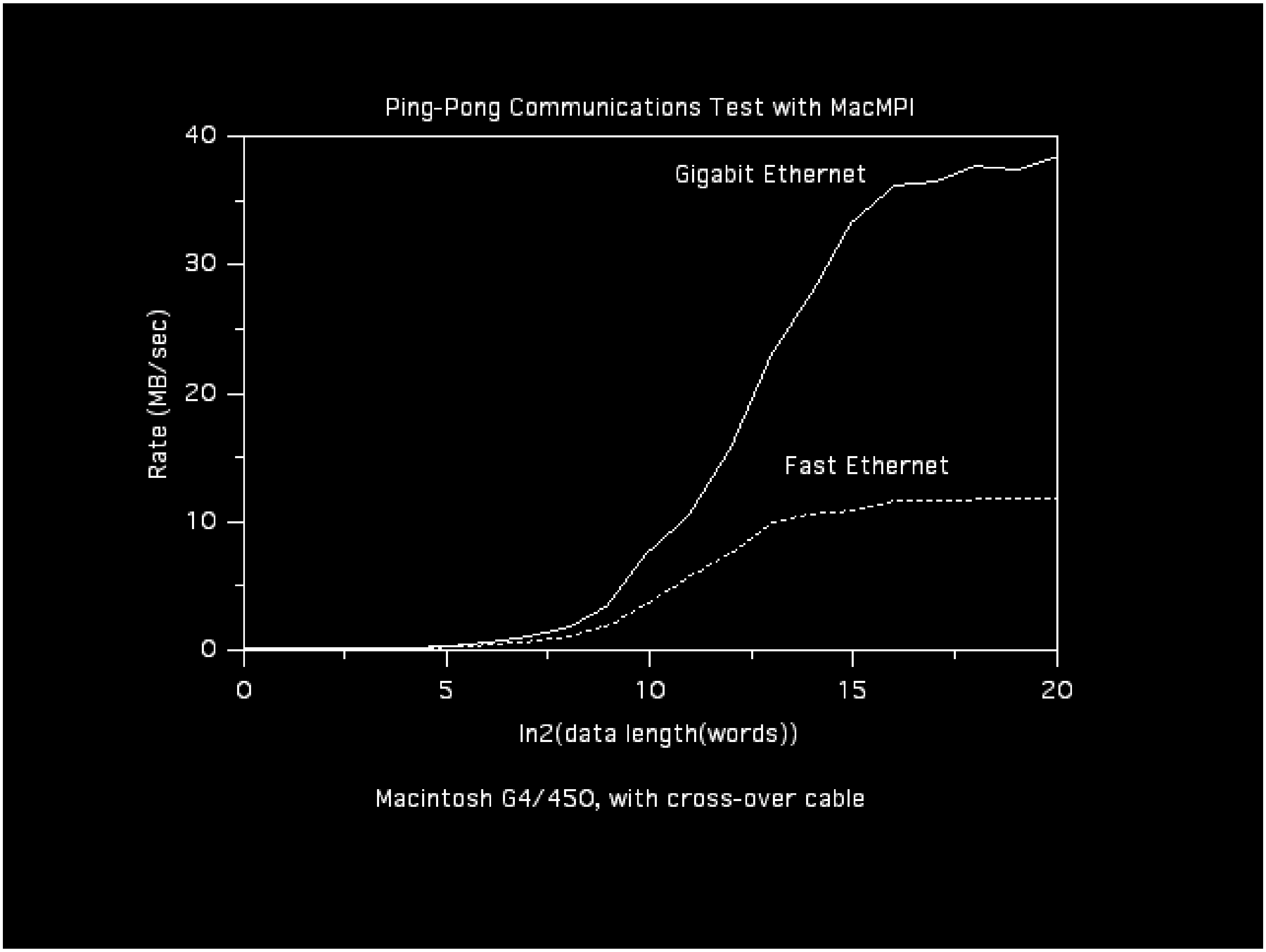

3D PIC Benchmark
Elapsed Push Time
Shorter is better!
Mac G4/450 (w/o AltiVec) IP cluster
772
1928
Mac G3/266 cluster
1496
3231
in nanoseconds
Cray T3E-900, w/MPI
1800
3844
IBM SP2, w/MPL
2104
4 node data not available
8 proc
4 proc
0
500
1000
1500
2000
2500
3000
3500
4000



3D PIC Benchmark, 1D domains
Ideal
IBM SP3
Cray T3E
SGI Origin
Apple Mac
Log10(Total Time)
Log2(Number of Nodes)
1
2
3
4
5
6
7
8



Communication Performance (Ping-Pong)
Mac G3/350, OT/IP
Pentium II/450, Linux
Mac G3/350, OT/AT
Mac G3/350, PPC/AT
Rate(MB/sec)
12.5
10.0
7.5
5.0
2.5
0.0
0
5
10
15
20
ln2(data length(words))


Ping-Pong Communications Test with MacMPI
Gigabit Ethernet
Fast Ethernet
Rate (MB/sec)
0
10
20
30
40
0
5
10
15
20
ln2(data length(words))
Macintosh G4/450, with cross-over cable

PIC codes integrate the trajectories of millions of particle interacting self-consistently via electromagnetic fields

A grid is used as a scaffolding to calculate forces
=> the grid reduces calculation to order N

Main loop:

1. Calculate charge (and current) densities from particles:

$$\rho(r) = \Sigma\, q_i\, S(r-r_i)$$

2. Solve Maxwell's equation, Spectral or Finite-Difference

3. Advance particle's coordinates:

$$m_i(dv_i/dt) = q_i[E(r_i) + v_i \times B(r_i)/c]$$
$$dx_i/dt = v_i$$

Generally used when fluid models fail, or to test new models

Numerical Tokamak Turbulence Project

a collaborative High Performance Computing project

Goal: predict plasma and heat transport in different magnetic configurations

UCLA workers: J.-N. Leboeuf, M. W. Kissick, V. K. Decyk, & J. M. Dawson + R. D. Sydora, U. Alberta

Extensive use of 3D gyrokinetic PIC calculations to study drift waves driven unstable by temperature gradients

Extensive use of 3D gyrokinetic PIC calculations to study drift waves driven unstable by temperature gradients

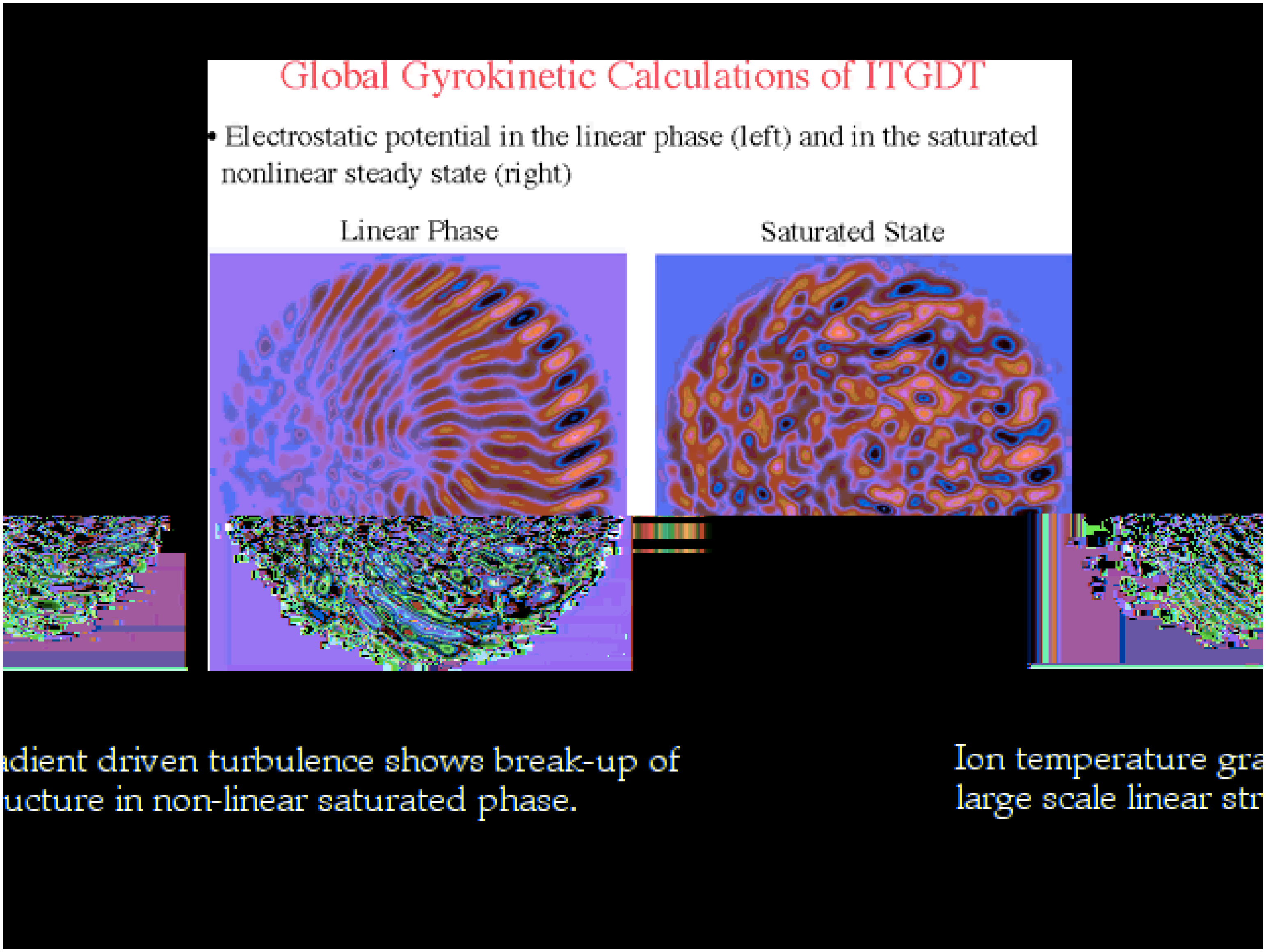
Especially interested in mechanisms for turbulence suppression:

- by external electric fields, UCLA Electric Tokamak
- by impurity injection, DIII-D

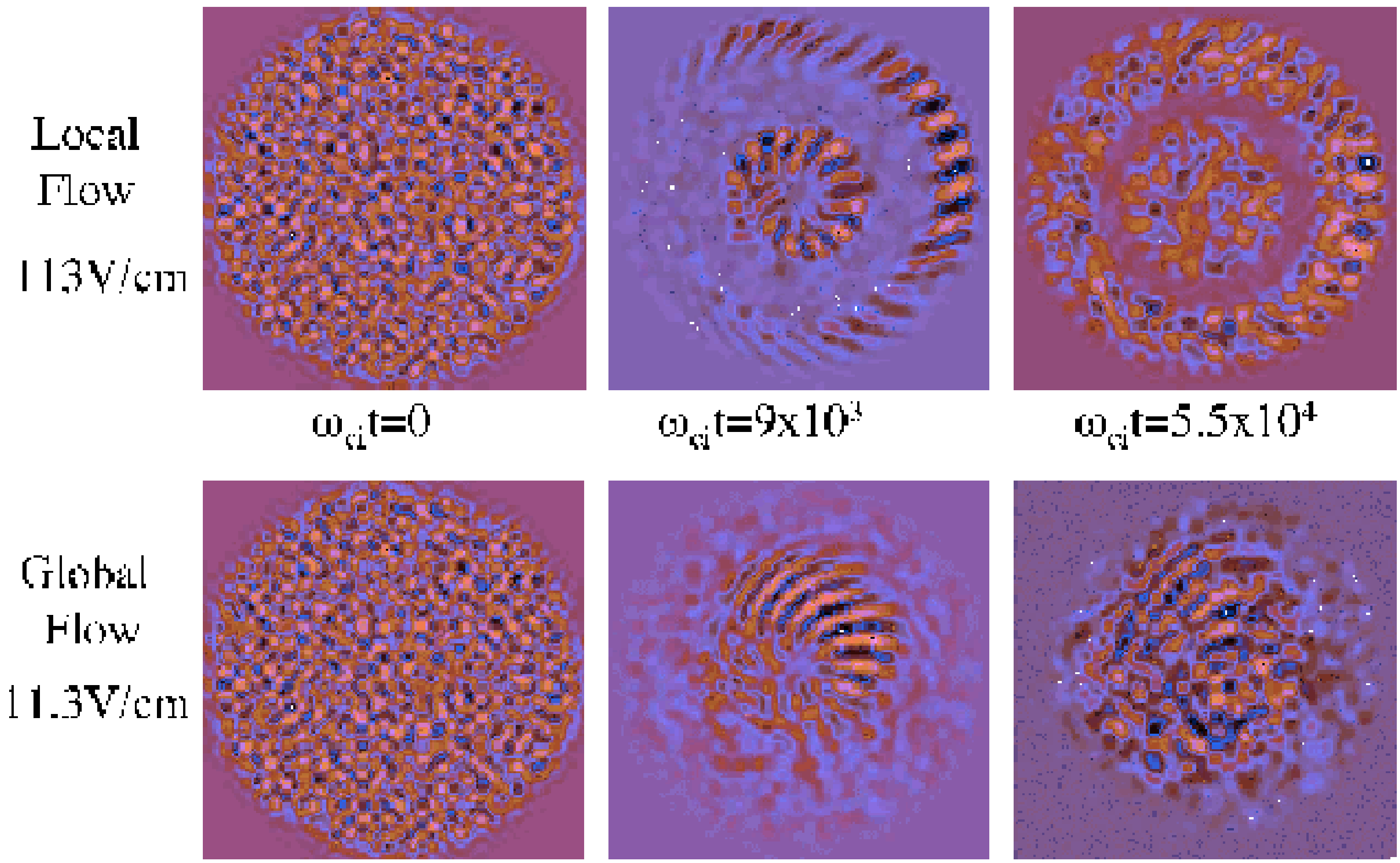
Small problems run on AppleSeed because of fast turnaround

Large problems run on supercomputer centers

See: http://exodus.physics.ucla.edu/numerical%20tokamak


Global Gyrokinetic Calculations of ITGDT
• Electrostatic potential in the linear phase (left) and in the saturated nonlinear steady state (right)
Linear Phase
Saturated State
Ion temperature gra
large scale linear str
adient driven turbulence shows break-up of
ucture in non-linear saturated phase.

Suppression of Fluctuations by Flows



- Localized flow suppresses fluctuations where flow shear is largest

Quantum Particle-in-Cell code

- Semi-classical approximation of Feynman path integrals
- each quantum particle represented by tens of thousands of classical particles which sample phase space
- takes advantage of highly efficient plasma PIC code

Student project with small funding

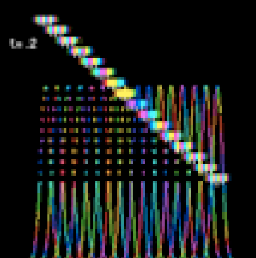
Makes use of sophisticated interactive diagnostics on Mac

QuickTime movies, sonification

See http://dauger.com/DaugerDissertation.pdf

16 Quantum Particles in a 1-D Infinite Well

Computed using a Quantum Particle-In-Cell code on a Power Mac G3 cluster



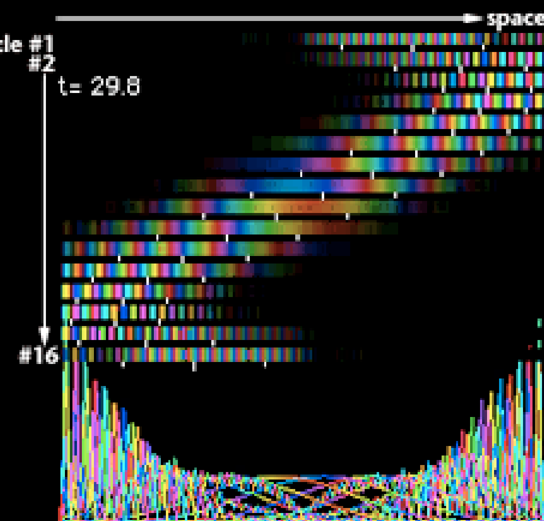
Initial Conditions: The probability distribution of each wavefunction was a Gaussian centered at a distribution of position and momentum.

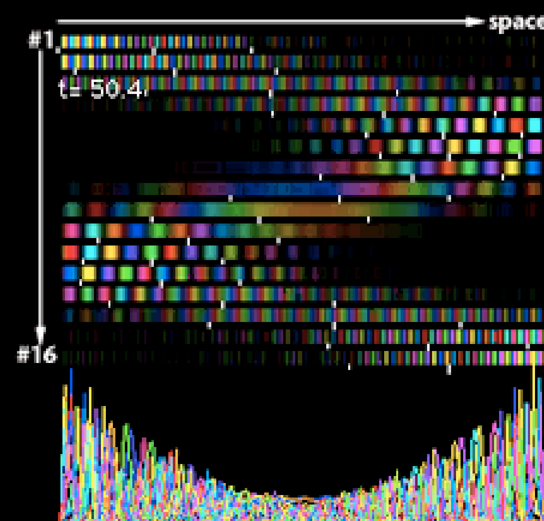
Number of virtual classical particles per quantum particle: 81920

Quantum time step size: 0.2

Number of classical pushes per quantum time step: 32

Real time per time step (each time step includes 16 field-solves, 1,310,720 wavefunction deposits, and 41,943,040 classical pushes) on two Power Mac G3's: ≈5 minutes





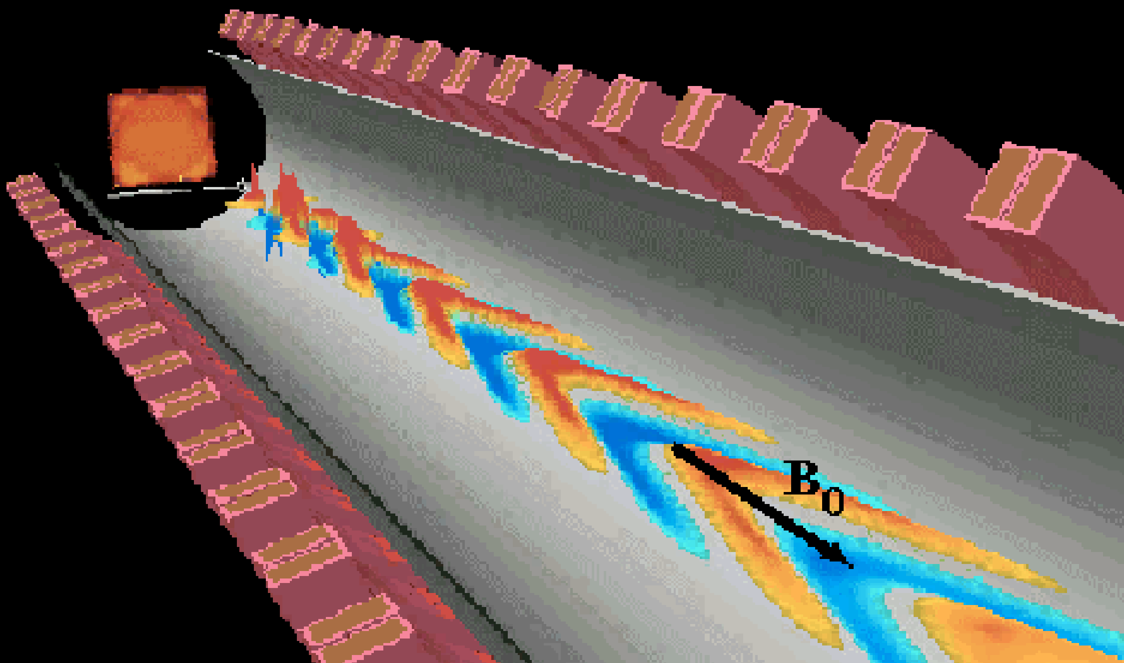
PIC Simulation of Shear Alfven Waves

Frank S. Tsung and K. J. Reitzel

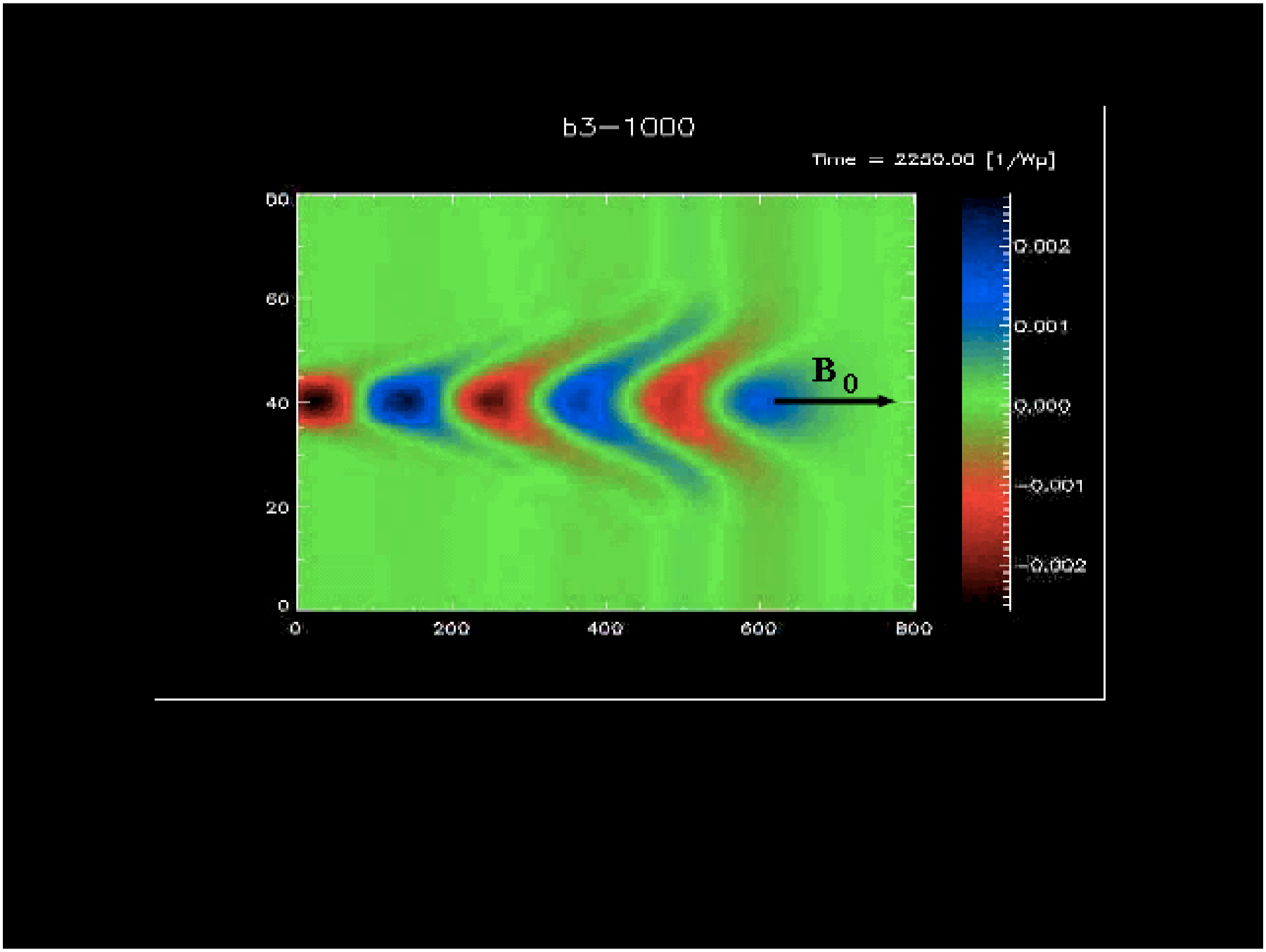
Purpose is to understand mass transport due to Shear Alfven waves, similar to that observed in the LAPD experiment at UCLA

As a first step, they launched the waves by an external antenna and verified that the resulting plasma response was correct.

They then increased the problem size and are now studying transport.



LAPD Image courtesy of W. Gekelman


b3−1000
Time = 2250.00 [1/Wp]
B_0
0.002
0.001
0.000
−0.001
−0.002
0
20
40
60
80
0
200
400
600
800

Classroom use of AppleSeed

Physics 260, "Exploring plasma physics using computer models"

Dedicated AppleSeed cluster enabled our first use of complex 3D modeling of plasmas in the classroom

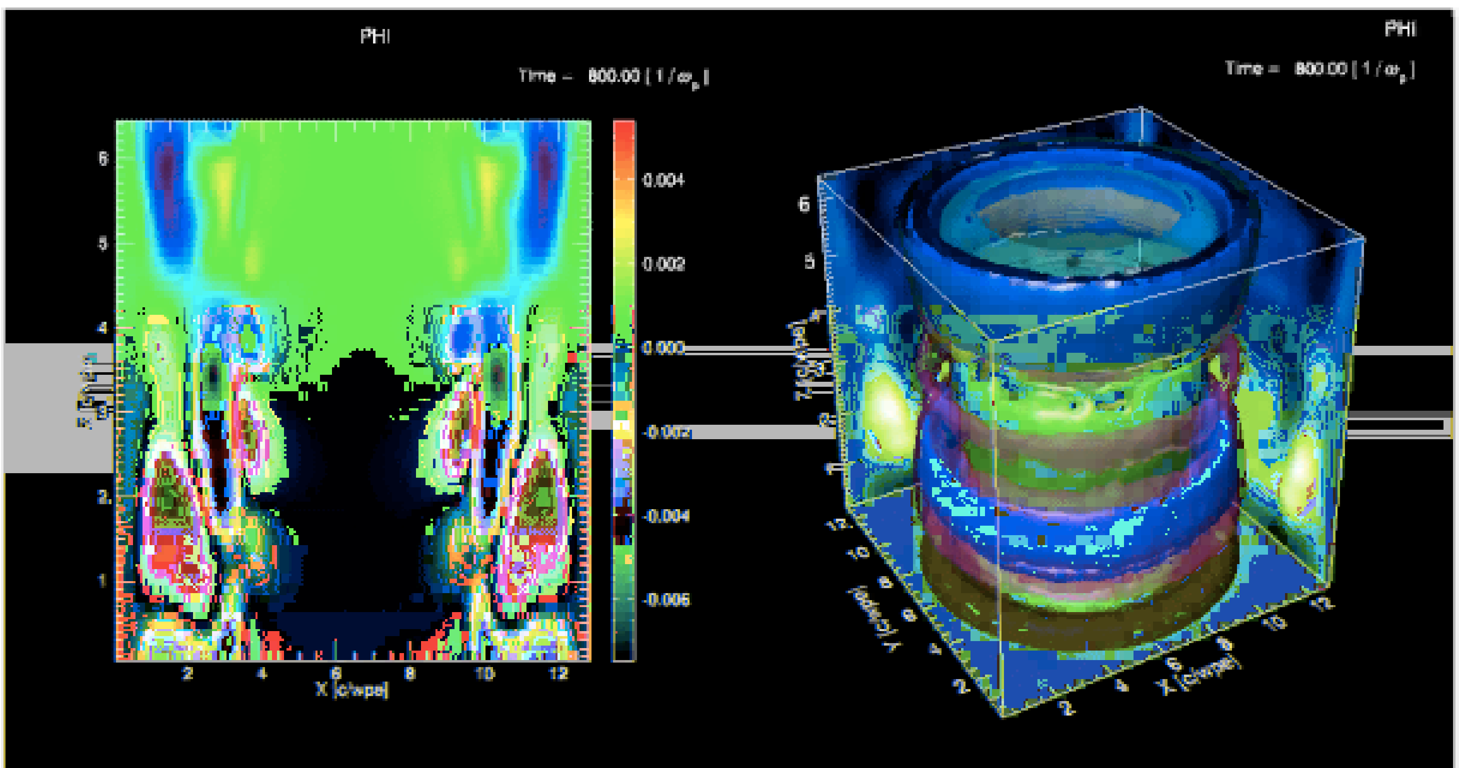
- Simulation started at the end of one class was ready by beginning of the next (typically 4 Macs used per simulation)
- Negligible time spent teaching the "mechanics" of computing

Earlier attempt to use Supercomputer Center unsuccessful

- Took too long to teach students the intricacies of Unix
- Queues long, job completion unpredictable

Potential Plots

$$n \propto r^{-4} \quad T \ \ const$$



Recent milestone with AppleSeed:

3D PIC Simulation of 100 million interacting particles
on an 8 node Macintosh G4 dual processor cluster

17.8 seconds/time-step, with a grid of 128x128x256

1 GB memory/node, cost today about $2,000/node

It was only 5 or 6 years ago that such a calculation required the world's largest supercomputer.

Thanks to Bedros Afeyan, Polymath Research, Inc.
http://polymath-usa.com/

Some other AppleSeed sites:

- EP2 cluster in IST, Portugal (16 dual G4s)
  http://cfp.ist.utl.pt/golp/epp/
  Extreme plasma physics

- ICOMP cluster, NASA Glenn, Ohio (13 dual G4s)
  http://polymath-usa.com/
  Computational Propulsion

- Polymatch Research, Inc., California (8 dual G4s)
  http://polymath-usa.com/
  Laser Plasma Physics

- D'Artagnan cluster, Toronto, Canada (7 G4 & G3s)
  High Energy Physics

- Cochlear Implant RC, Ames, Iowa (5 G4s)
  Computational hearing

Three versions of MacMPI available:

MacMPI

- Basic version, simple to implement, based on AppleTalk

MacMPI_IP

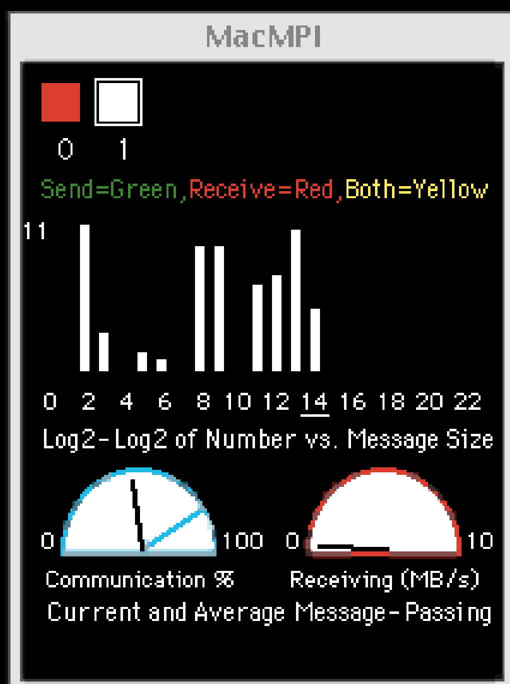
- High-performance version, based on TCP/IP

MacMPI_X

- Carbon version, based on TCP/IP, for Mac OS 9 and X

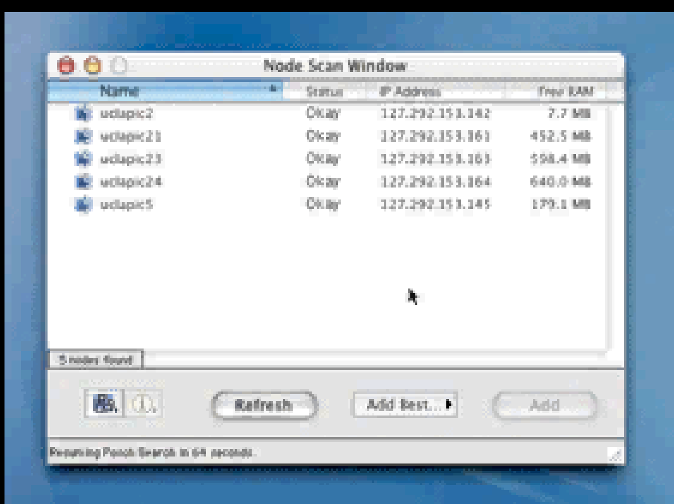
Added features to MacMPI to help students write parallel code

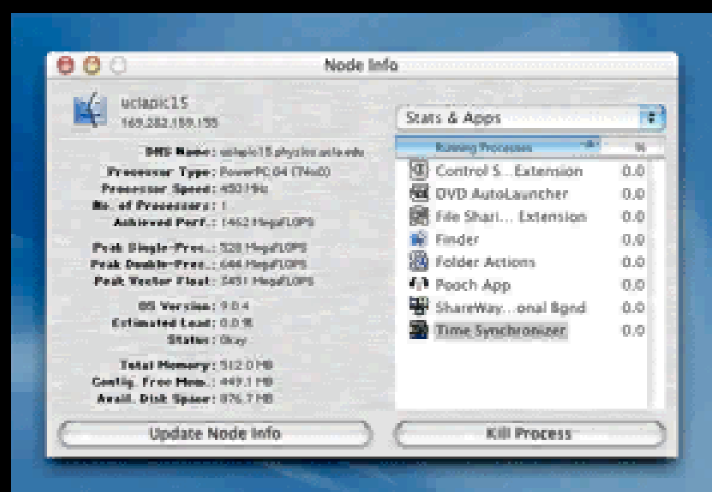
- Visualization Monitor, shows communication pattern, packet size, and performance



Pooch has additional features:

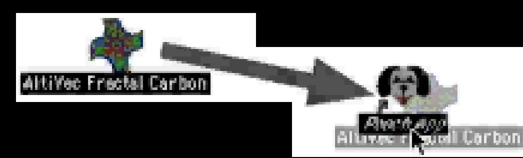
- Grid-like features - dynamic resource discovery
  - searches for nodes - anywhere on the Internet
  - determines capabilities and capacities of compute nodes
  - queries for current status, job queues, etc.





Pooch has additional features:

- Brings Mac GUI to parallel computing:
  - supports drag–and–drop!

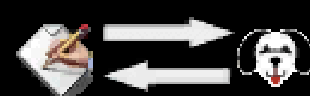


- Scriptability   **tell application** "Pooch App" to launch job

- Can be controlled from a UNIX CLI:

```
% plaunch pingpong.out -n 4 -d pingfolder
```

- Can be controlled by other applications



Brings parallel computing to the masses!

Evaluation - Mac cluster useful for:

- Student training in parallel programming
- Unfunded research
- Long runs with short deadlines
- Fast Ethernet is slow compared to supercomputers: students learn to write better algorithms
- Encourages more interactive style of computing
- Simple to maintain, even for high school students
- Useful for coursework with time constraints:
  - Negligible training time for students
  - Large jobs can finish by the next class period

Most common problem area:

- Networking, a common problem in all clusters, e.g., Unix

Future:

Mac OS X is Unix-based, bringing a wealth of Unix software to the Mac

- E.g, public domain MPI implementations

- Can Apple make Unix friendly?

Apple is usually quick to provide easy to use, advanced technology, when it is affordable

- Gigabit networking
- Firewire for digital multimedia
- Vector processors

What surprises await?

For further details on Project AppleSeed:

http://exodus.physics.ucla.edu/appleseed/