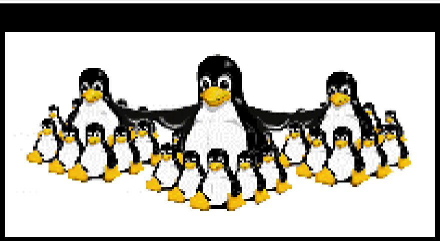
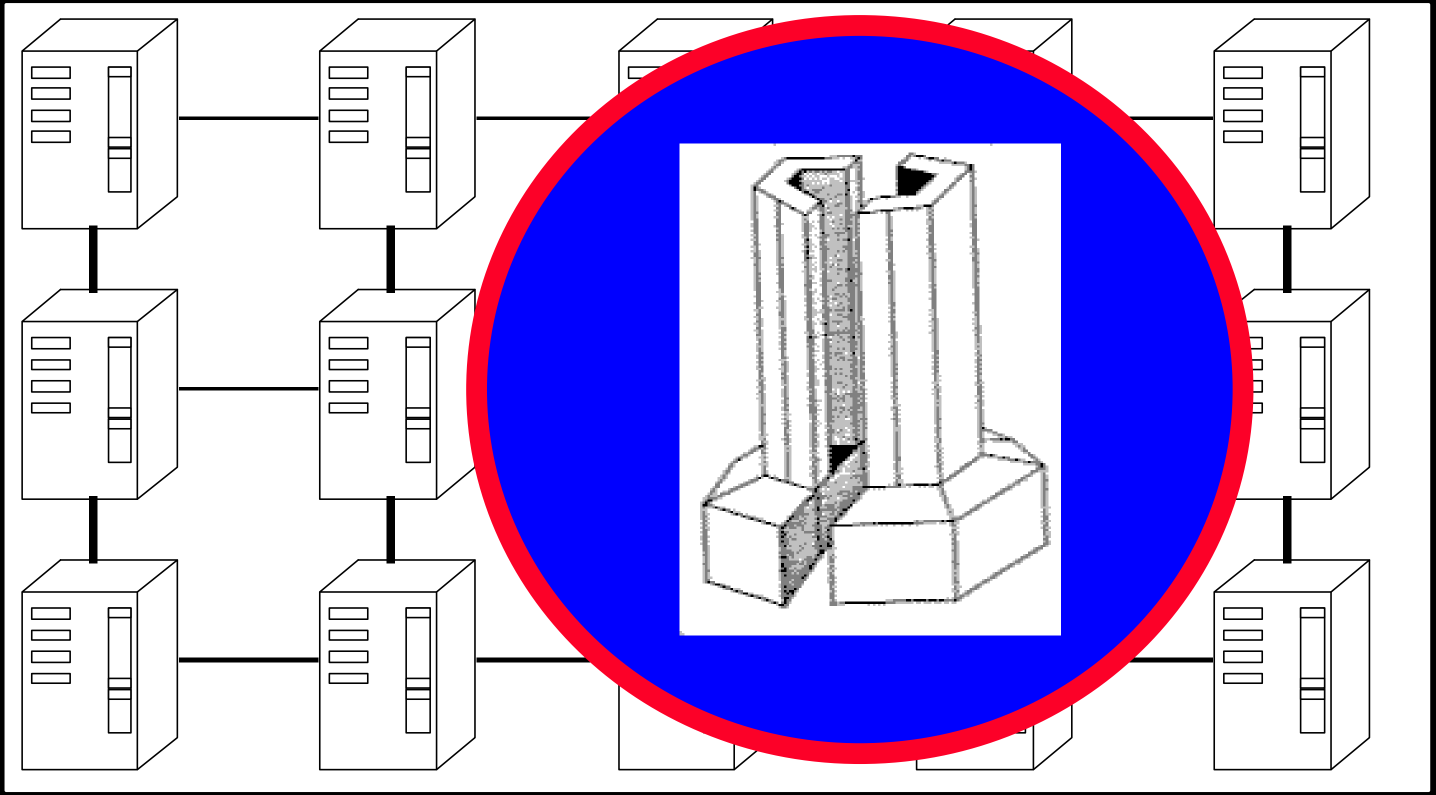
(c) Raj



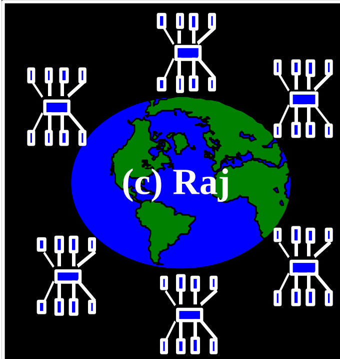
No ~~Low~~ Cost Supercomputing

Parallel Processing on Linux Clusters



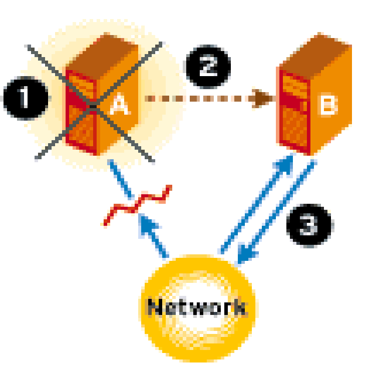
Rajkumar Buyya, Monash University, Melbourne, Australia.

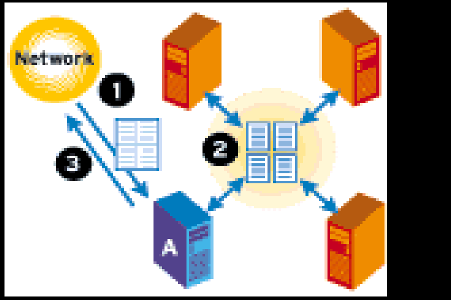
rajkumar@ieee.org http://www.dgs.monash.edu.au/~rajkumar



Agenda

- Cluster ? Enabling Tech. & Motivations
- Cluster Architecture
- Cluster Components and Linux
- Parallel Processing Tools on Linux
- Cluster Facts
- Resources and Conclusions





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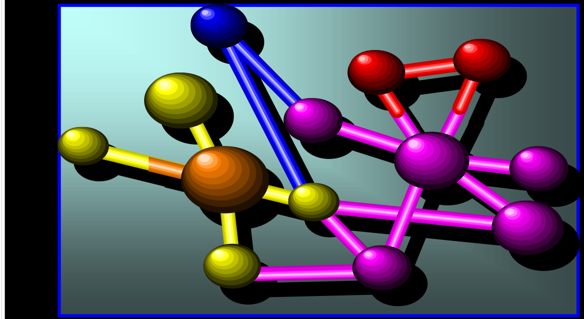
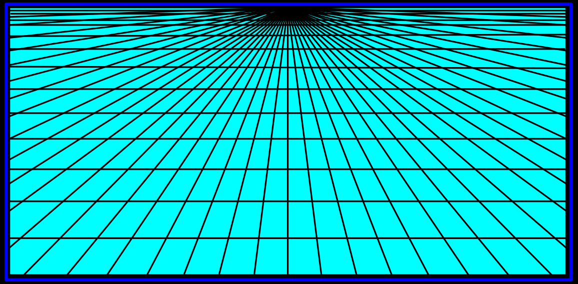
Need of more Computing Power: Grand Challenge Applications

Solving technology problems using computer *modeling*, *simulation* and *analysis*

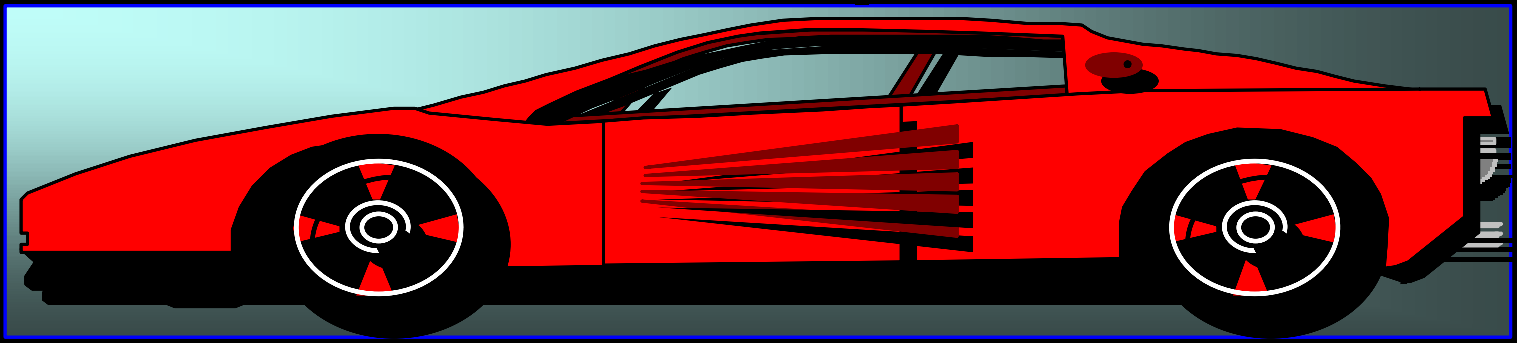


Life Sciences

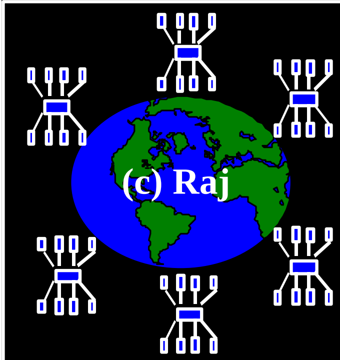


Aerospace

Geographic Information Systems



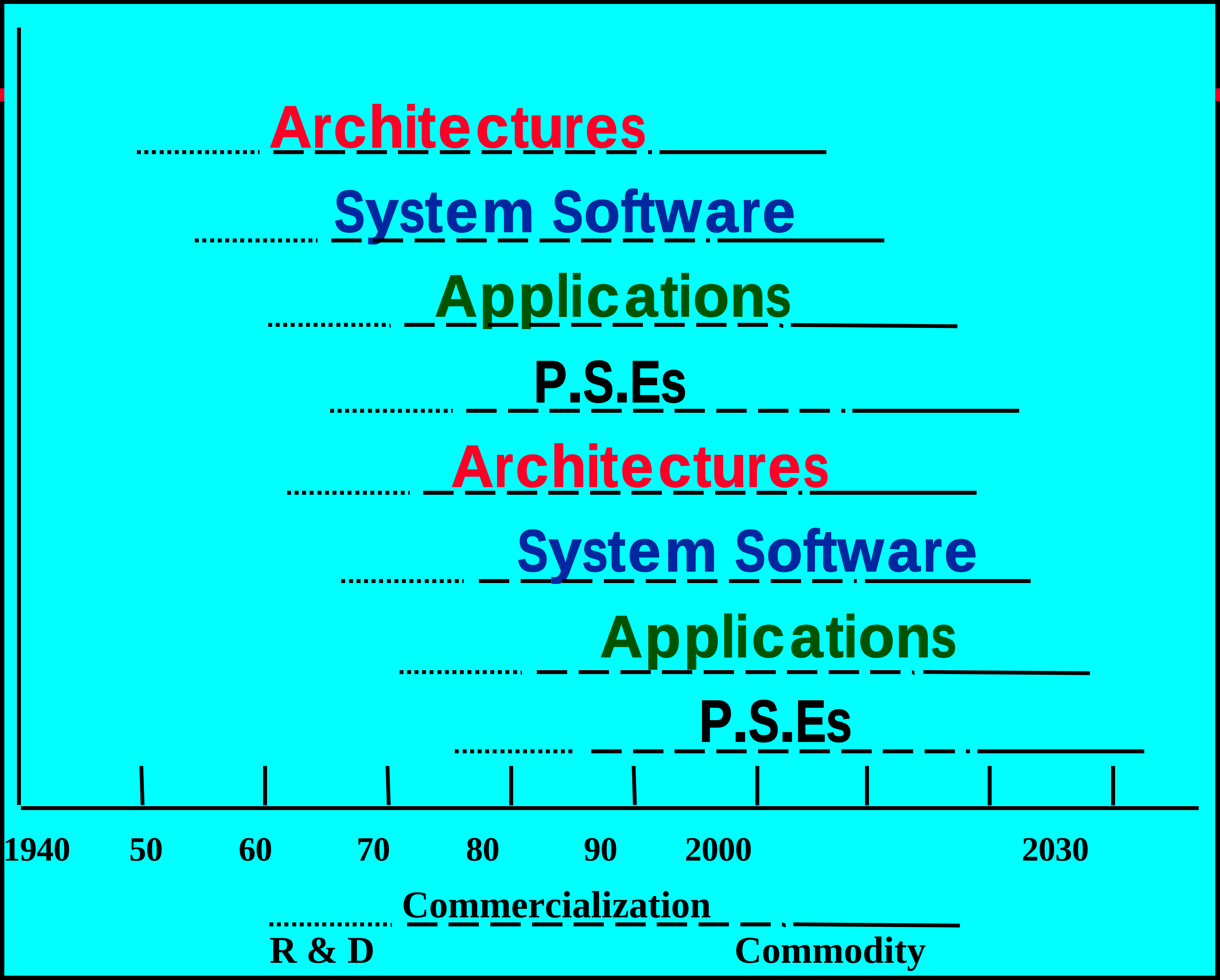
Mechanical Design & Analysis (CAD/CAM)



Two Eras of Computing

Sequential Era

Parallel Era



Architectures

System Software

Applications

P.S.Es

Architectures

System Software

Applications

P.S.Es

1940 50 60 70 80 90 2000 2030

Commercialization

R & D

Commodity

Competing Computer Architectures

- **Vector Computers (VC) ---proprietary system**

  provided the breakthrough needed for the emergence of computational science, buy they were only a partial answer.

- **Massively Parallel Processors (MPP)-proprietary system**

  high cost and a low performance/price ratio.

- **Symmetric Multiprocessors (SMP)**

  suffers from scalability

- **Distributed Systems**

  difficult to use and hard to extract parallel performance.

- **Clusters -- gaining popularity**

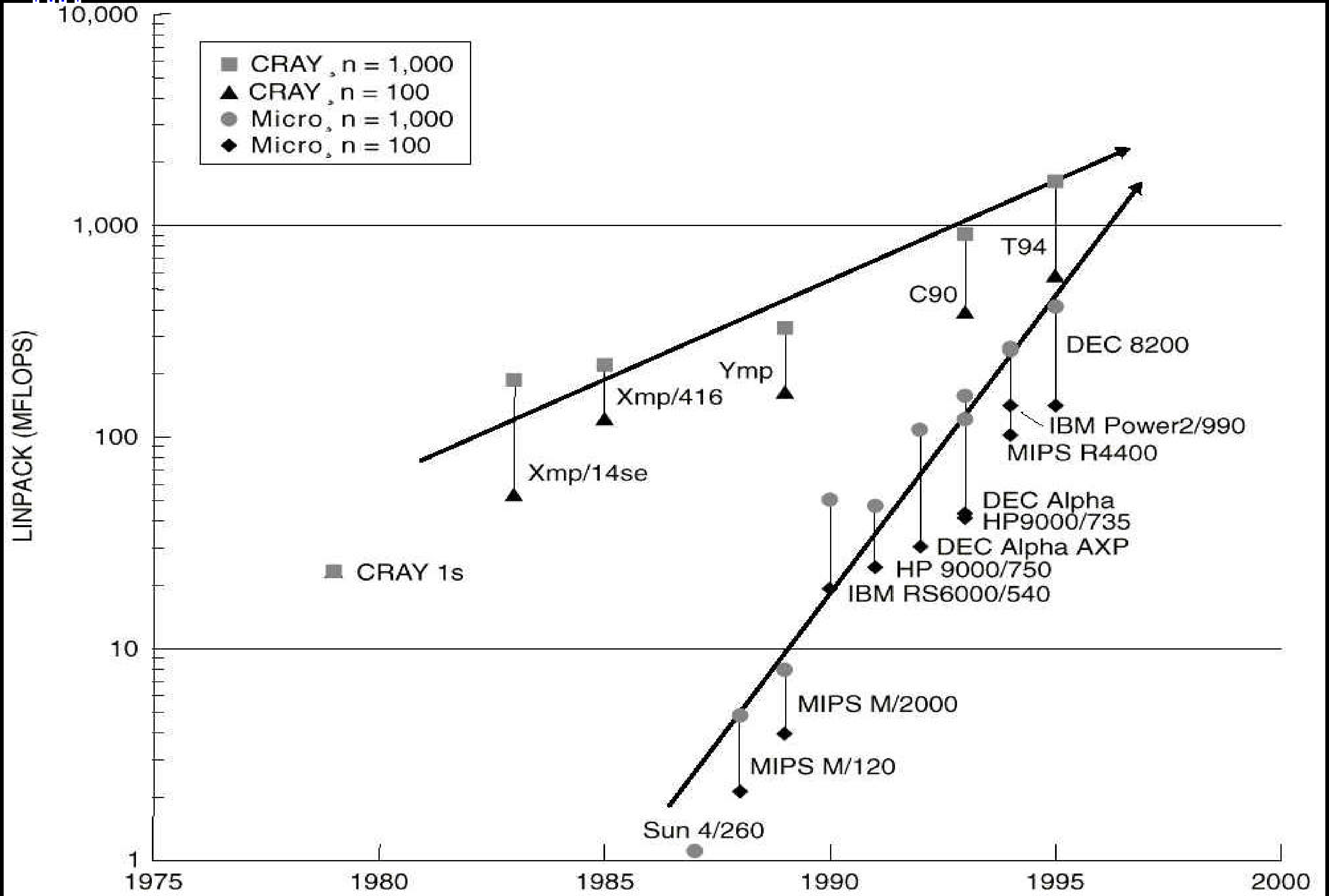
  High Performance Computing---Commodity Supercomputing

  High Availability Computing ---Mission Critical Applications

Technology Trend...

- **Performance of PC/Workstations components has almost reached performance of those used in supercomputers…**
  - Microprocessors (50% to 100% per year)
  - Networks (Gigabit ..)
  - Operating Systems
  - Programming environment
  - Applications
- **Rate of performance improvements of commodity components is too high.**

Technology Trend



The Need for Alternative Supercomputing Resources

- **Cannot afford to buy “Big Iron” machines**

  due to their high cost and short life span.

  cut-down of funding

  don t fit better into today’s funding model.

  •

- **Paradox: time required to develop a parallel application for solving GCA is equal to:**

  half Life of Parallel Supercomputers.

Clusters are best-alternative!

- Supercomputing-class commodity components are available
- They “fit” very well with today’s/future funding model.
- Can leverage upon future technological advances
  - VLSI, CPUs, Networks, Disk, Memory, Cache, OS, programming tools, applications,...

Best of both Worlds!

- **High Performance Computing (talk focused on this)**
  - parallel computers/supercomputer-class workstation cluster
  - dependable parallel computers
- **High Availability Computing**
  - mission-critical systems
  - fault-tolerant computing

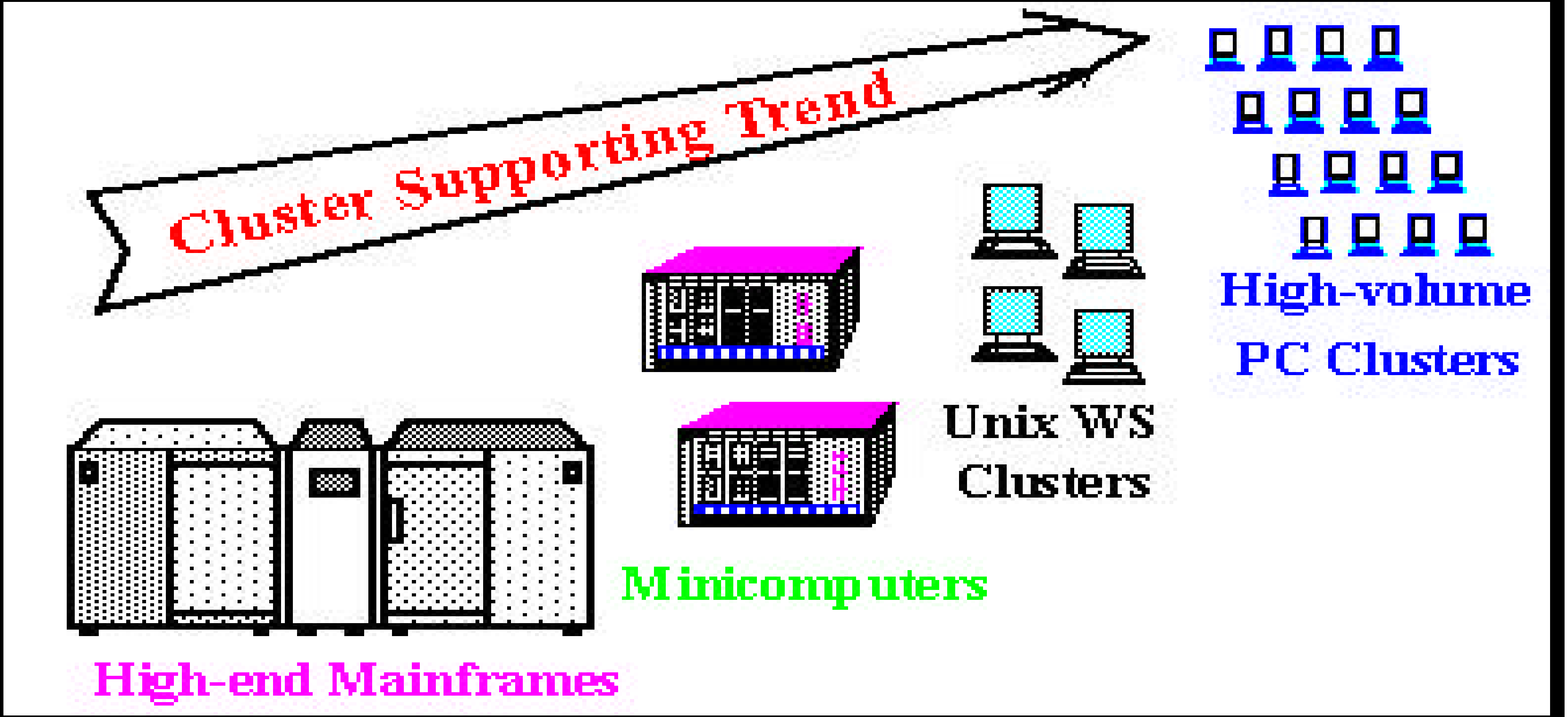
What is a cluster?

- A cluster is a type of parallel or distributed processing system, which consists of a collection of interconnected stand-alone computers cooperatively working together as a single, integrated computing resource.
- A typical cluster:
  - Network: Faster, closer connection than a typical network (LAN)
  - Low latency communication protocols
  - Looser connection than SMP

So What’s So Different about Clusters?

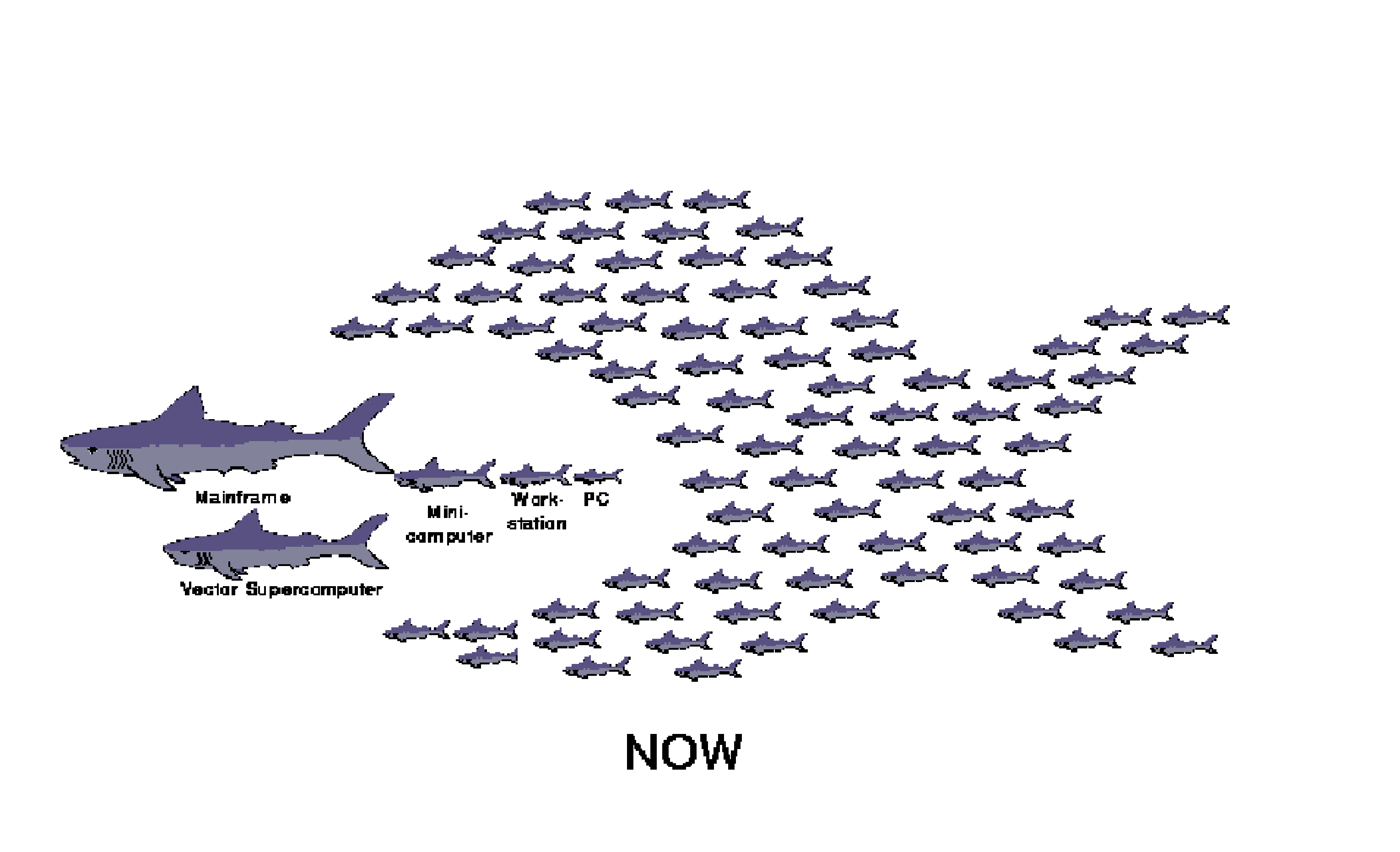
- Commodity Parts?
- Communications Packaging?
- Incremental Scalability?
- Independent Failure?
- Intelligent Network Interfaces?
- Complete System on every node
  - virtual memory
  - scheduler
  - files
- Nodes can be used individually or combined...

Clustering of Computers for Collective Computating



1960 1990 1995+

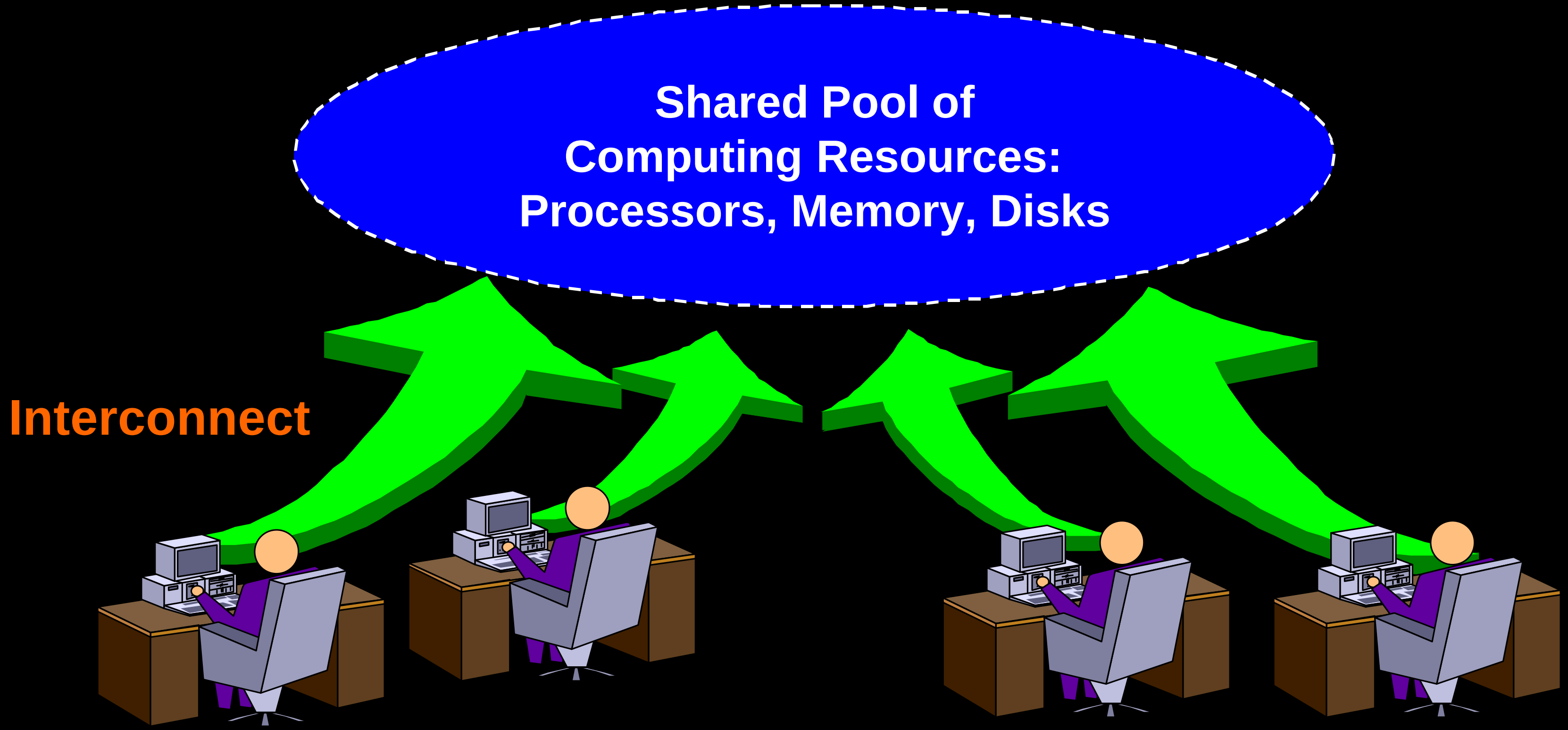
Computer Food Chain (Now and Future)



Demise of Mainframes, Supercomputers, & MPPs

Cluster Configuration..1
Dedicated Cluster

Cluster Configuration..2
Enterprise Clusters (use JMS like Codine)



Shared Pool of
Computing Resources:
Processors, Memory, Disks

Interconnect

Guarantee at least one workstation to many individuals (when active)

Deliver large % of collective resources to few individuals at any one time

Windows of Opportunities

- **MPP/DSM:**

  Compute across multiple systems: parallel.

- **Network RAM:**

  Idle memory in other nodes. Page across other nodes idle memory

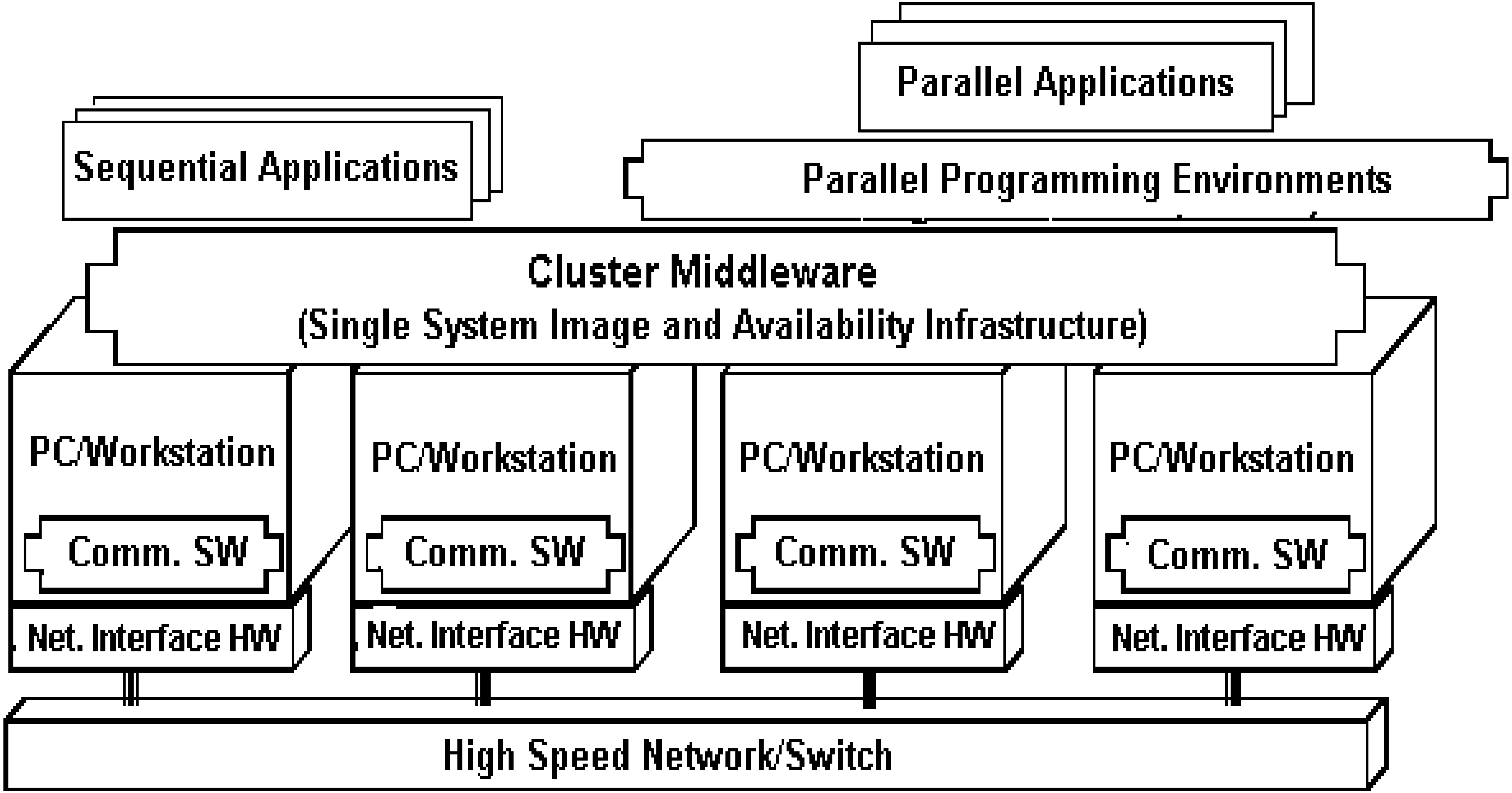
- **Software RAID:**

  file system supporting parallel I/O and reliability, mass-storage.

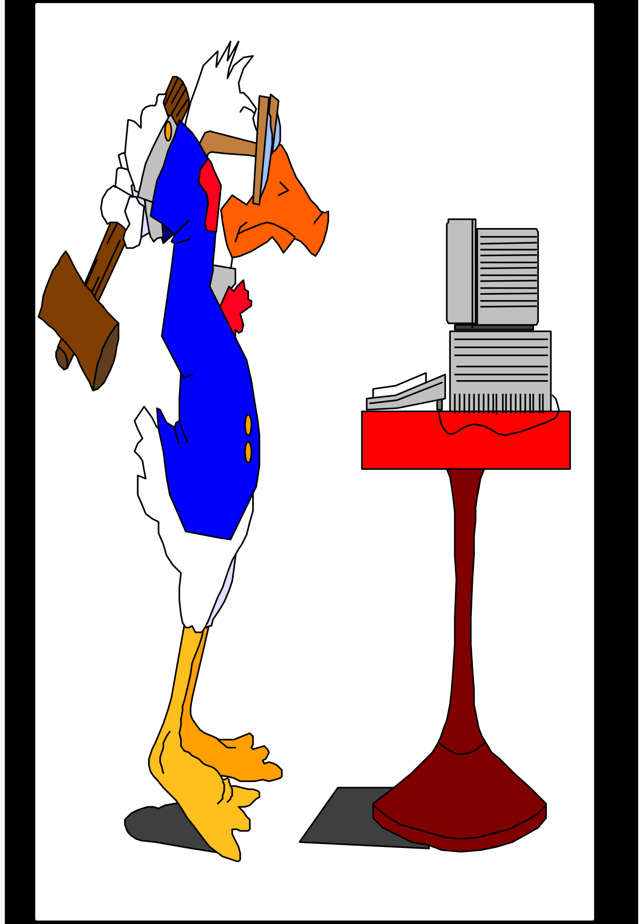
- **Multi-path Communication:**

  Communicate across multiple networks: Ethernet, ATM, Myrinet

Cluster Computer Architecture

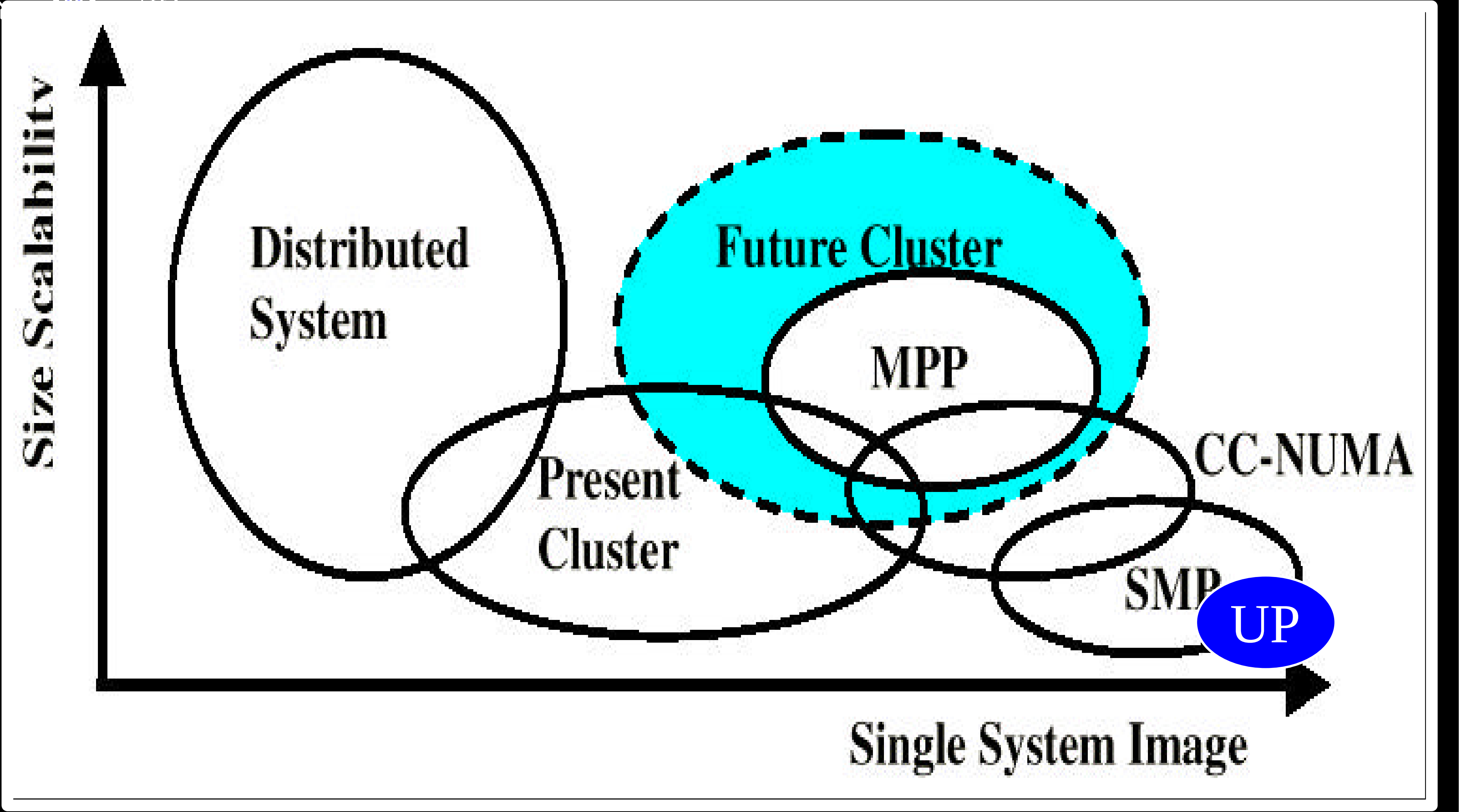


Major issues in cluster design



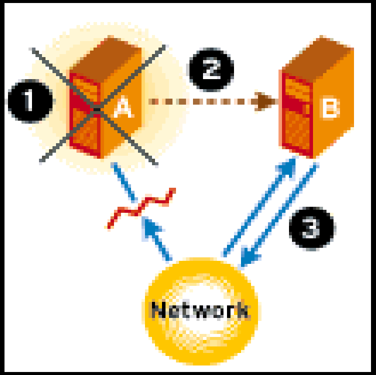
- Size Scalability (physical & application)
- Enhanced Availability (failure management)
- Single System Image (look-and-feel of one system)
- Fast Communication (networks & protocols)
- Load Balancing (CPU, Net, Memory, Disk)
- Security and Encryption (clusters of clusters)
- Distributed Environment (Social issues)
- Manageability (admin. And control)
- Programmability (simple API if required)
- Applicability (cluster-aware and non-aware app.)

Scalability Vs. Single System Image

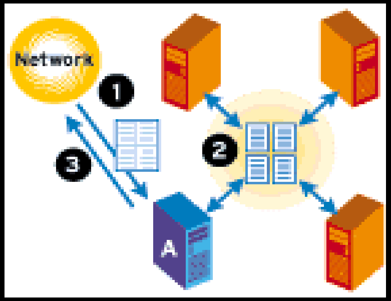


Linux-based Tools for

High Availability Computing



High Performance Computing



Hardware

- **Linux OS is running/driving...**
  - PCs (Intel x86 processors)
  - Workstations (Digital Alphas)
  - SMPs (CLUMPS)
  - Clusters of Clusters
- **Linux supports networking with**
  - Ethernet (10Mbps)/Fast Ethernet (100Mbps),
  - Gigabit Ethernet (1Gbps)
  - SCI (Dolphin - MPI- 12micro-sec latency)
  - ATM
  - Myrinet (1.2Gbps)
  - Digital Memory Channel
  - FDDI

Communication Software

- **Traditional OS supported facilities (heavy weight due to protocol processing)..**
  - Sockets (TCP/IP), Pipes, etc.
- **Light weight protocols (User Level)**
  - Active Messages (AM) (Berkeley)
  - Fast Messages (Illinois)
  - U-net (Cornell)
  - XTP (Virginia)
  - Virtual Interface Architecture (industry standard)

Cluster Middleware

- Resides Between OS and Applications and offers in infrastructure for supporting:
  - Single System Image (SSI)
  - System Availability (SA)
- SSI makes collection appear as single machine (globalised view of system resources). telnet cluster.myinstitute.edu
- SA - Check pointing and process migration..

Cluster Middleware

- OS / Gluing Layers
  - Solaris MC, Unixware, **MOSIX**
  - **Beowulf Distributed PID**
- Runtime Systems
  - Runtime systems (software DSM, PFS, etc.)
  - Resource management and scheduling (RMS):
    - CODINE, CONDOR, LSF, PBS, NQS, etc.

Programming environments

- Threads (PCs, SMPs, NOW..)
  - POSIX Threads
  - Java Threads
- MPI
  - http://www-unix.mcs.anl.gov/mpi/mpich/
- PVM
  - http://www.epm.ornl.gov/pvm/
- Software DSMs (Shmem)

Development Tools

GNU -- www.gnu.org

- **Compilers**

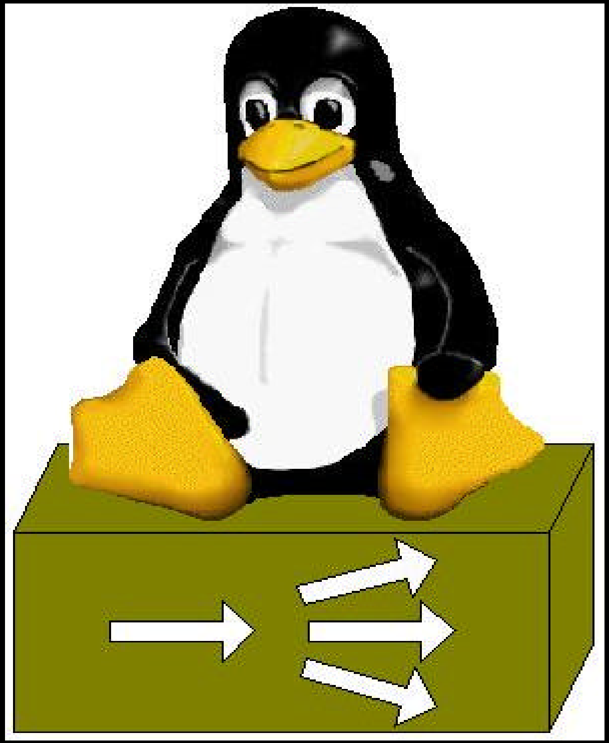
  C/C++/Java/

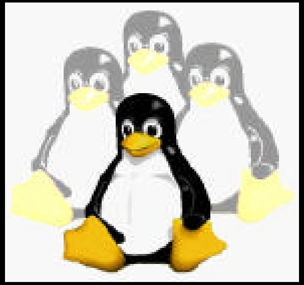
- **Debuggers**
- **Performance Analysis Tools**
- **Visualization Tools**

Applications

- Sequential (benefit from the cluster)
- Parallel / Distributed (Cluster-aware app.)
  - Grand Challenging applications
    - Weather Forecasting
    - Quantum Chemistry
    - Molecular Biology Modeling
    - Engineering Analysis (CAD/CAM)
    - Ocean Modeling
  - PDBs, web servers,data-mining

Linux Webserver
(Network Load Balancing)



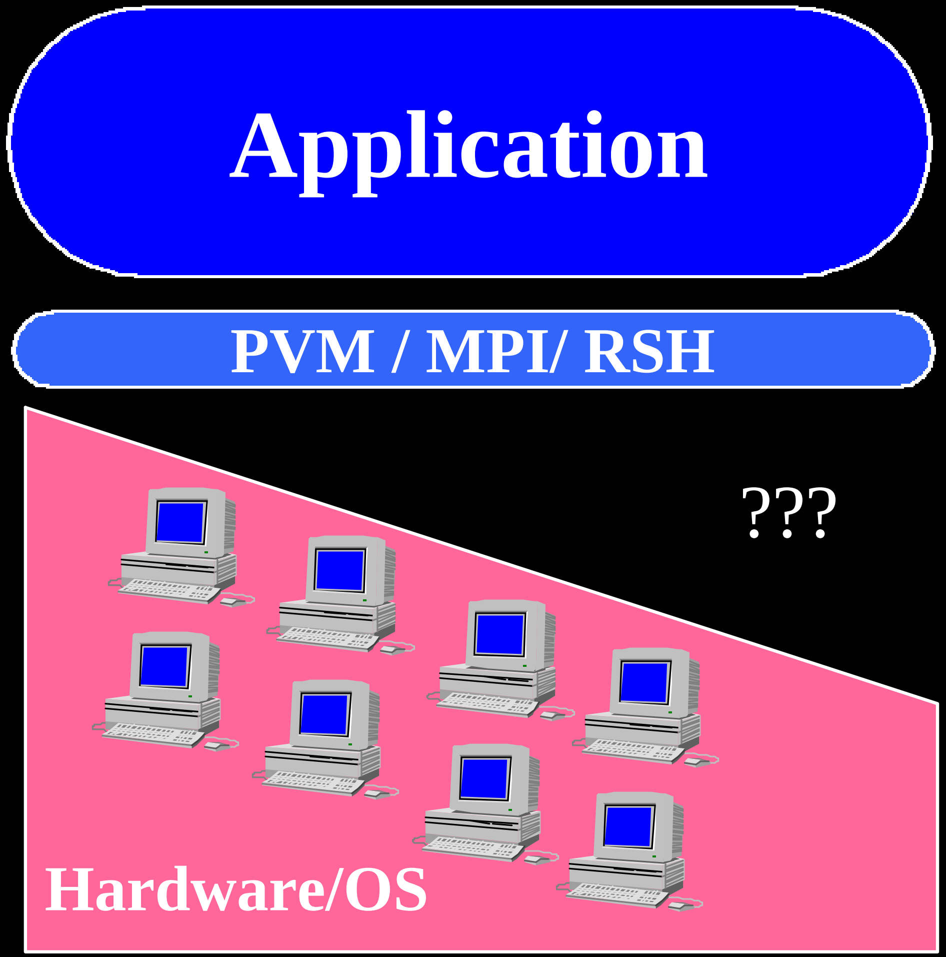


http://proxy.iinchina.net/~wensong/ippfvs/

- High Performance (by serving through light loaded machine)
- High Availability   (detecting failed nodes and isolating them from the cluster)
- Transparent/Single System view

(c) Raj

A typical Cluster Computing Environment



Application

PVM / MPI/ RSH

???

Hardware/OS

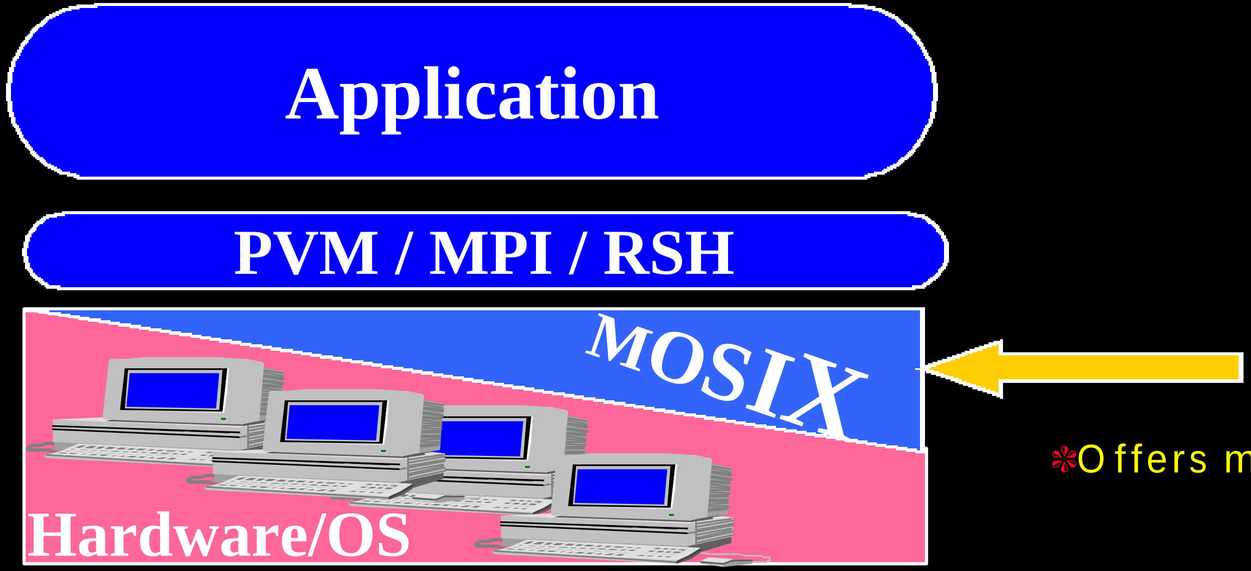
CC should support

- Multi-user, time-sharing **environments**
- Nodes with different CPU **speeds and** memory sizes (heterogeneous configuration)
- Many processes**, with** unpredictable **requirements**
- Unlike SMP**: insufficient “**bonds**” between nodes**
  - Each computer operates independently
  - Inefficient utilization of resources

Multicomputer OS for UNIX (MOSIX)

http://www.mosix.cs.huji.ac.il/

- An OS module (layer) that provides the applications with the illusion of working on a single system
- Remote operations are performed like local operations
- Transparent to the application - user interface unchanged



- Offers missing link

MOSIX is Main tool

Preemptive process migration that can migrate--->any process, anywhere, anytime

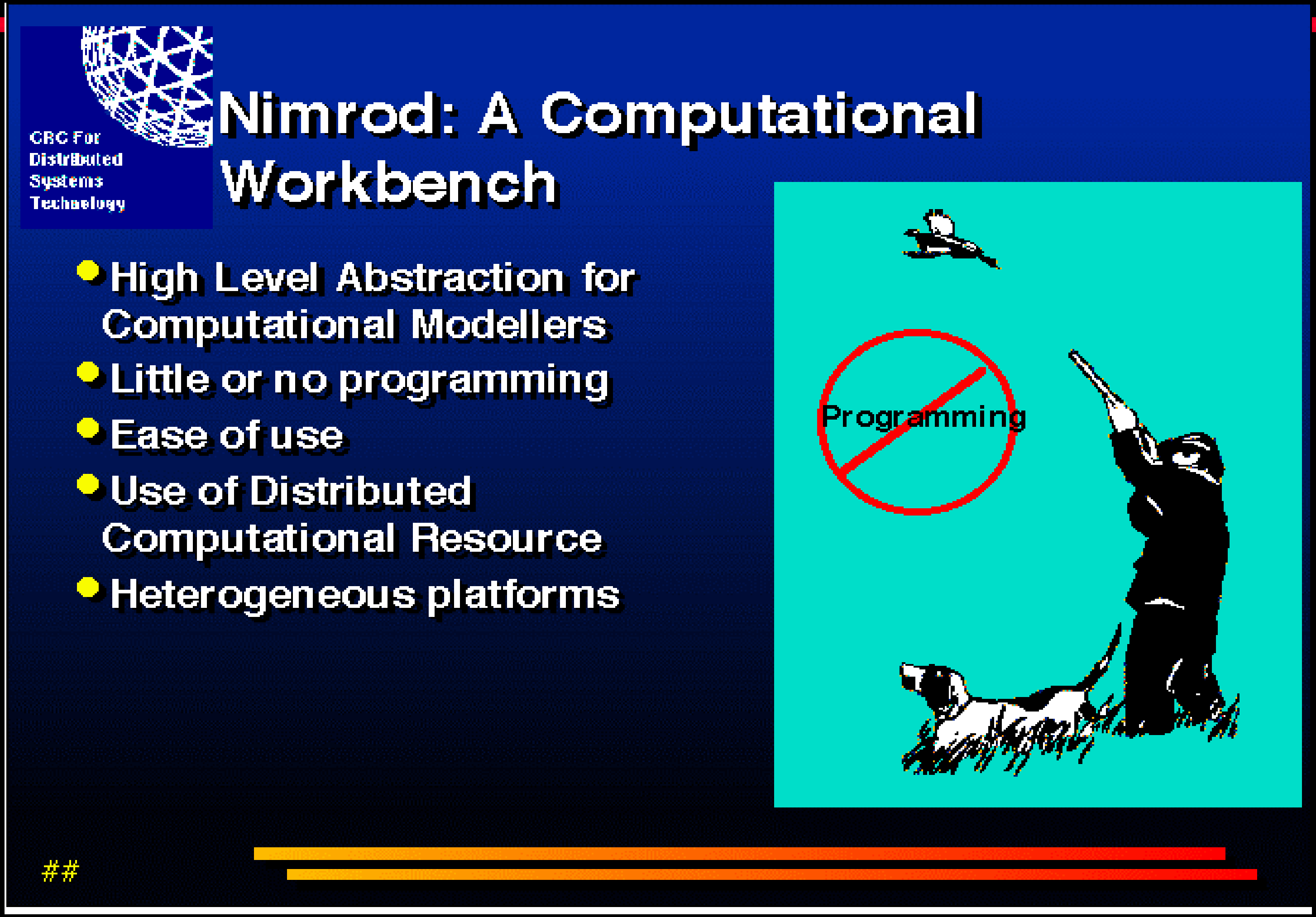
- Supervised by distributed algorithms **that respond on-line to global resource availability -** transparently
- Load-balancing **- migrate process from over-loaded to under-loaded nodes**
- Memory ushering **- migrate processes from a node that has exhausted its memory, to prevent paging/swapping**

MOSIX for Linux at HUJI

- A scalable cluster configuration:
  - 50 Pentium-II 300 MHz
  - 38 Pentium-Pro 200 MHz (some are SMPs)
  - 16 Pentium-II 400 MHz (some are SMPs)
- Over 12 GB cluster-wide RAM
- Connected by the Myrinet 2.56 G.b/s LAN

  Runs Red-Hat 6.0, based on Kernel 2.2.7
- Upgrade: HW with Intel, SW with Linux
- Download MOSIX:
  - http://www.mosix.cs.huji.ac.il/

Nimrod - A tool for parametric modeling on clusters



CRC For Distributed Systems Technology

Nimrod: A Computational Workbench

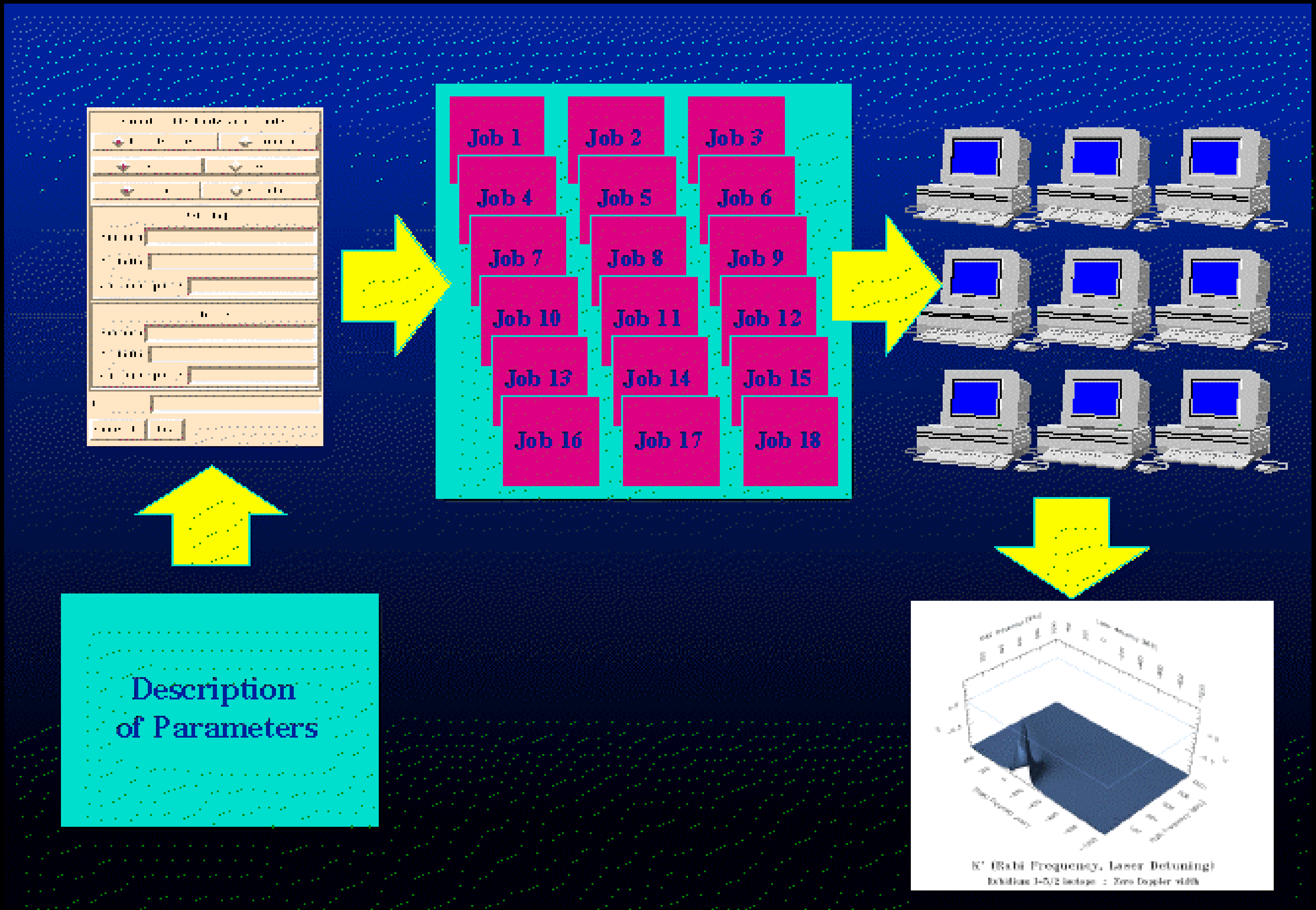
- High Level Abstraction for Computational Modellers
- Little or no programming
- Ease of use
- Use of Distributed Computational Resource
- Heterogeneous platforms

Programming

##

- http://www.dgs.monash.edu.au/~davida/nimrod.html

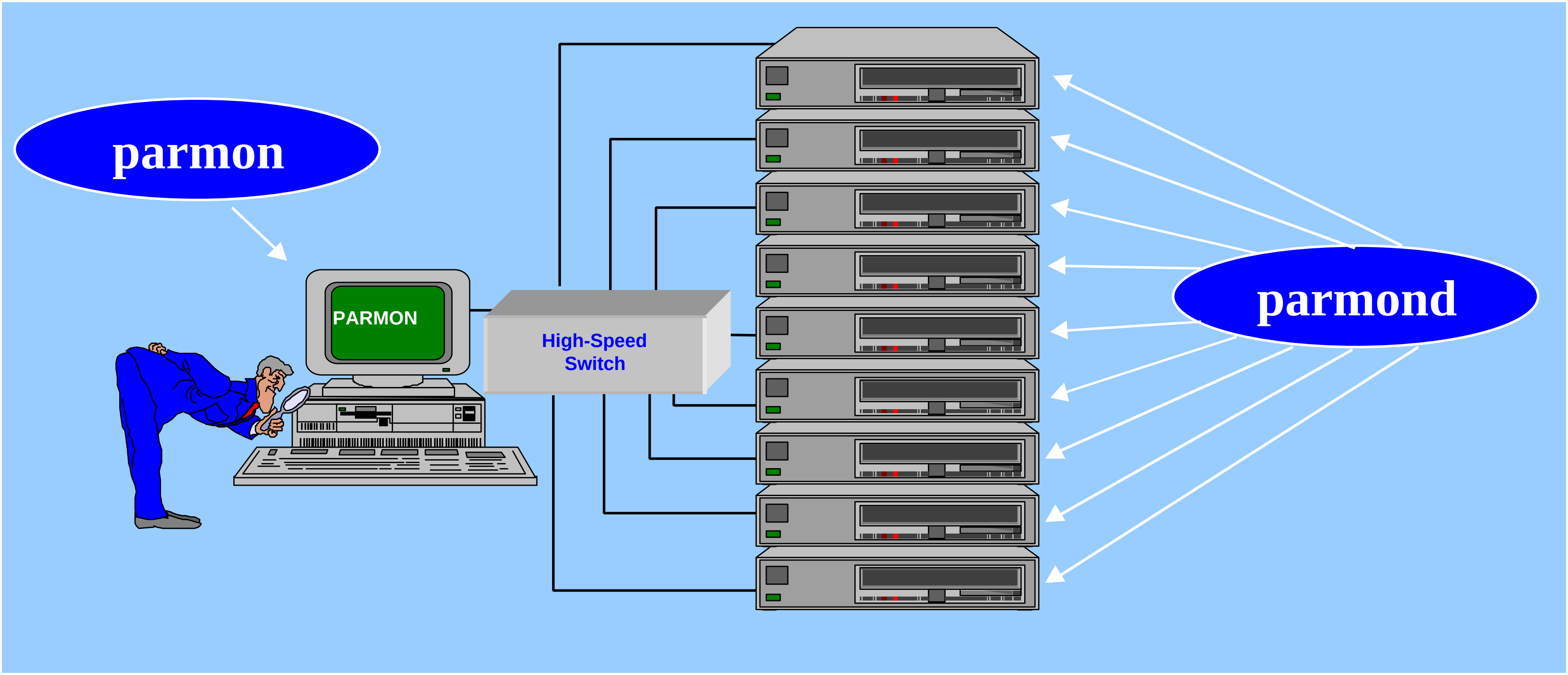
Job processing with Nimrod


Description of Parameters
Job 1
Job 2
Job 3
Job 4
Job 5
Job 6
Job 7
Job 8
Job 9
Job 10
Job 11
Job 12
Job 13
Job 14
Job 15
Job 16
Job 17
Job 18
K' (Rabi Frequency, Laser Detuning)
Rubidium 3-5/2 Isotope : Zero Doppler width

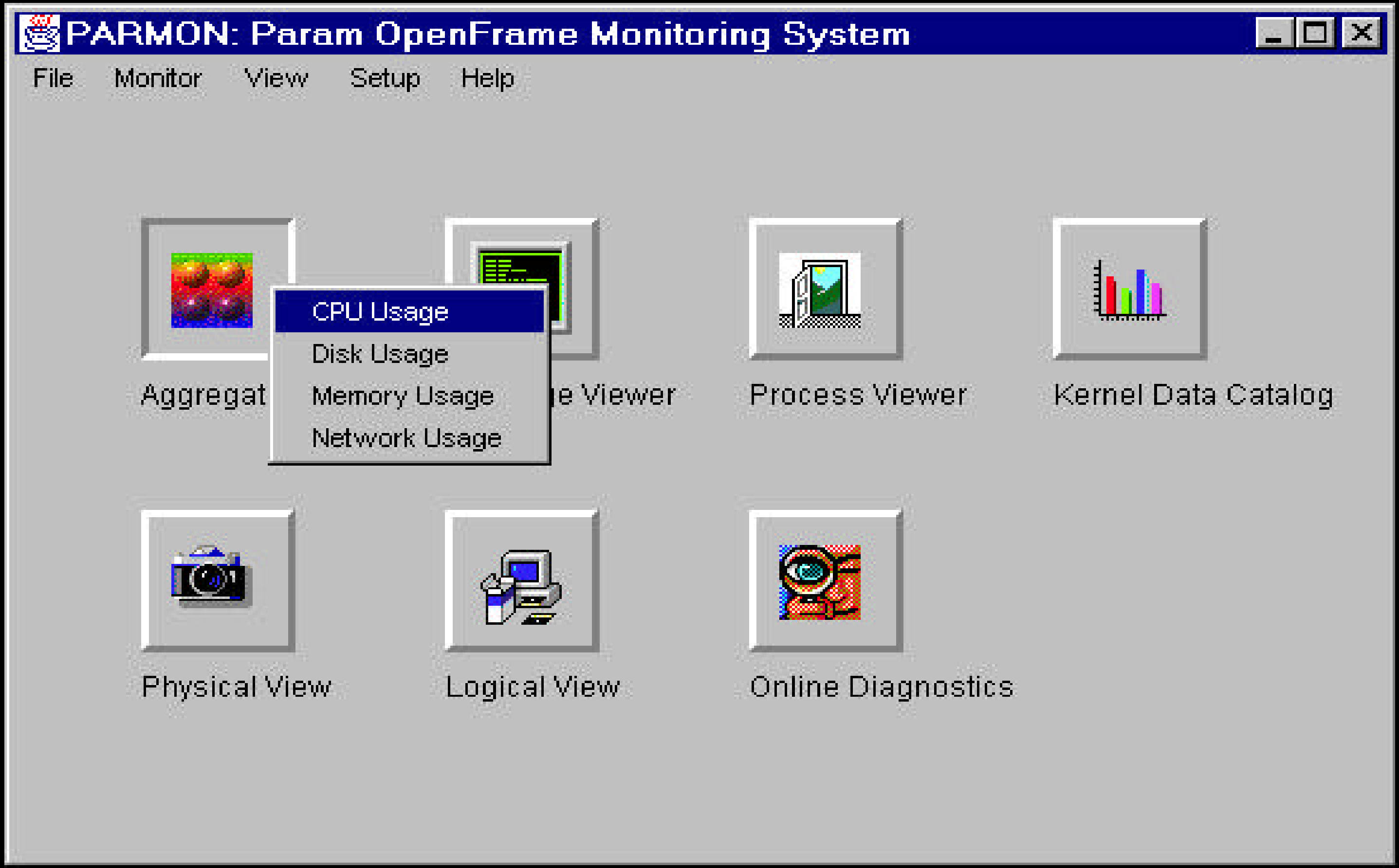
PARMON: A Cluster Monitoring Tool

PARMON Client on JVM

PARMON Server on each node



Resource Utilization at a Glance

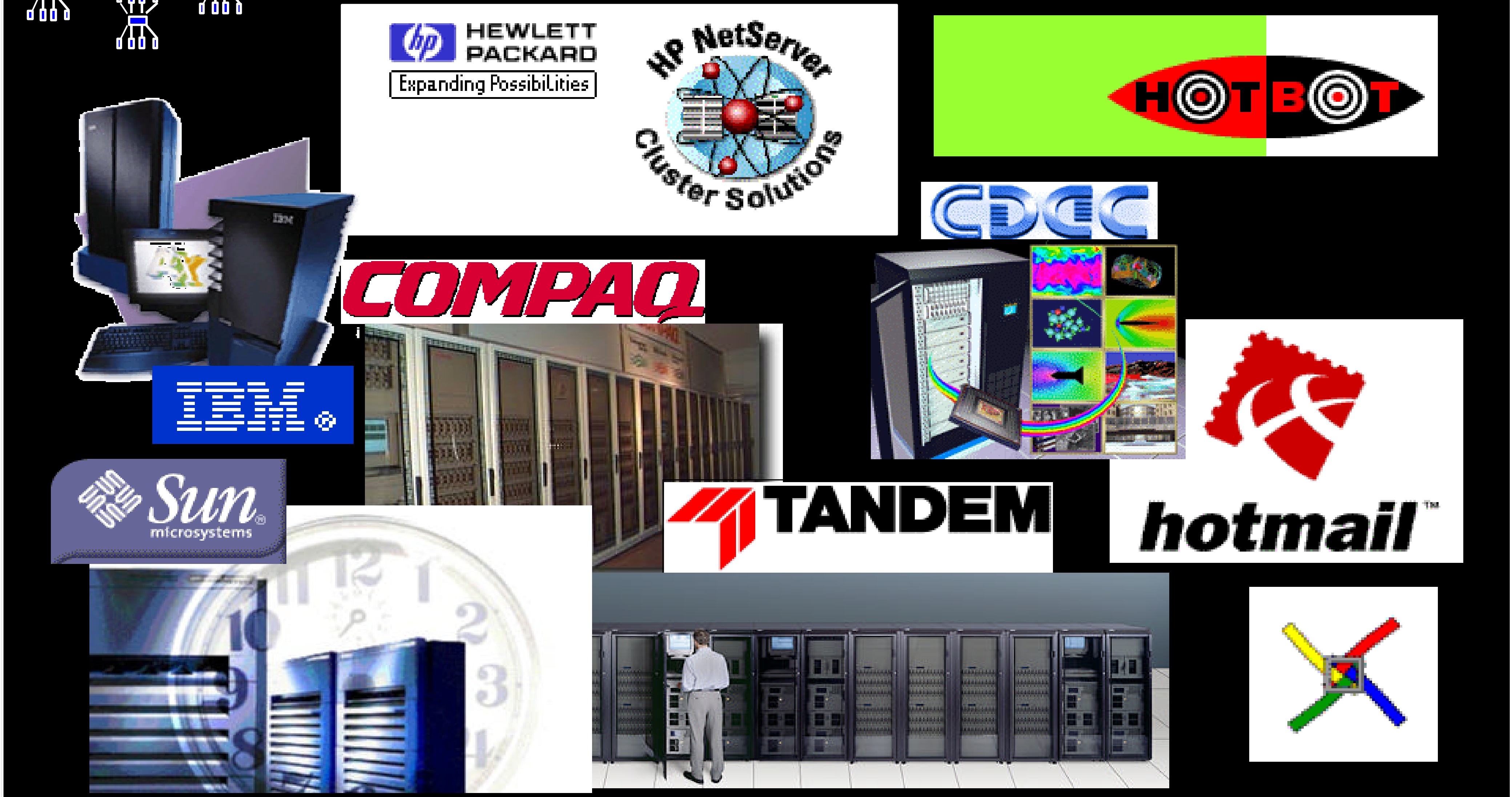


Linux cluster in Top500

Top500 Supercomputing (www.top500.org) Sites declared Avalon(http://cnls.lanl.gov/avalon/), Beowulf cluster, the 113th most powerful computer in the world.

- 70 processor DEC Alpha cluster
- Cost: $152K
- Completely commodity and Free Software
- price/performance is $15/Mflop,
- performance similar to 1993   s 1024-node CM-5

Adoption of the Approach



Conclusions Remarks

☞ **Clusters are promising..**

- ☞Solve parallel processing paradox
- ☞Offer incremental growth and matches with funding pattern
- ☞New trends in hardware and software technologies are likely to make clusters more promising and fill SSI gap..so that
- ☞Clusters based supercomputers (Linux based clusters) can be seen everywhere!