# Distributed Systems

Clusters

Paul Krzyzanowski
pxk@cs.rutgers.edu



## Designing highly available systems

Incorporate elements of fault-tolerant design
- Replication, TMR

Fully fault tolerant system will offer non-stop availability
- You can't achieve this!

Problem: expensive!

## Designing highly scalable systems

SMP architecture

Problem:
performance gain as *f*(# processors) is sublinear
- Contention for resources (bus, memory, devices)
- Also … the solution is expensive!

## Clustering

Achieve reliability and scalability by interconnecting multiple independent systems

**Cluster:** group of standard, autonomous servers configured so they appear on the network as a **single machine**

*approach single system image*

## Ideally…

- Bunch of off-the shelf machines
- Interconnected on a high speed LAN
- Appear as one system to external users
- Processors are load-balanced
  - May migrate
  - May run on different systems
  - All IPC mechanisms and file access available
- Fault tolerant
  - Components may fail
  - Machines may be taken down

## we don't get all that (yet)

(at least not in one package)

## Clustering types

- Supercomputing (HPC)
- Batch processing
- High availability (HA)
- Load balancing

## High Performance Computing (HPC)

## The evolution of supercomputers

- Target complex applications:
  - Large amounts of data
  - Lots of computation
  - Parallelizable application
- Many custom efforts
  - Typically Linux + message passing software + remote exec + remote monitoring

## Clustering for performance

Example: One popular effort

- **Beowulf**
  - Initially built to address problems associated with large data sets in Earth and Space Science applications
  - From Center of Excellence in Space Data & Information Sciences (CESDIS), division of University Space Research Association at the Goddard Space Flight Center

## What makes it possible

- Commodity off-the-shelf computers are cost effective
- Publicly available software:
  - Linux, GNU compilers & tools
  - MPI (message passing interface)
  - PVM (parallel virtual machine)
- Low cost, high speed networking
- Experience with parallel software
  - Difficult: solutions tend to be custom

## What can you run?

- Programs that do not require fine-grain communication
- Nodes are dedicated to the cluster
  - Performance of nodes not subject to external factors
- Interconnect network isolated from external network
  - Network load is determined only by application
- Global process ID provided
  - Global signaling mechanism

## Beowulf configuration

Includes:
- BPROC: Beowulf distributed process space
  - Start processes on other machines
  - Global process ID, global signaling
- Network device drivers
  - Channel bonding, scalable I/O
- File system (file sharing is generally not critical)
  - NFS root
  - unsynchronized
  - synchronized periodically via *rsync*

## Programming tools: MPI

- Message Passing Interface
- API for sending/receiving messages
  - Optimizations for shared memory & NUMA
  - Group communication support
- Other features:
  - Scalable file I/O
  - Dynamic process management
  - Synchronization (barriers)
  - Combining results

## Programming tools: PVM

- Software that emulates a general-purpose heterogeneous computing framework on interconnected computers
- Present a view of virtual processing elements
  - Create tasks
  - Use global task IDs
  - Manage *groups* of tasks
  - Basic message passing

## Beowulf programming tools

- PVM and MPI libraries
- Distributed shared memory
  - Page based: software-enforced ownership and consistency policy
- Cluster monitor
- Global *ps, top, uptime* tools
- Process management
  - Batch system
  - Write software to control synchronization and load balancing with MPI and/or PVM
  - Preemptive distributed scheduling: not part of Beowulf (two packages: *Condor* and *Mosix*)

## Another example

- **Rocks Cluster Distribution**
  - Based on CentOS Linux
  - Mass installation is a core part of the system
    - Mass re-installation for application-specific configurations
  - Front-end central server + compute & storage nodes
  - Rolls: collection of packages
    - Base roll includes: PBS (portable batch system), PVM (parallel virtual machine), MPI (message passing interface), job launchers, …

## Another example

- **Microsoft HPC Server 2008**
  - Windows Server 2008 + clustering package
  - Systems Management
    - Management Console: plug-in to System Center UI with support for Windows PowerShell
    - RIS (Remote Installation Service)
  - Networking
    - MS-MPI (Message Passing Interface)
    - ICS (Internet Connection Sharing) : NAT for cluster nodes
    - Network Direct RDMA (Remote DMA)
  - Job scheduler
  - Storage: iSCSI SAN and SMB support
  - Failover support

# Batch Processing

## Batch processing

- Common application: graphics rendering
  - Maintain a queue of frames to be rendered
  - Have a dispatcher to remotely exec process
- Virtually no IPC needed
- Coordinator dispatches jobs

## Single-queue work distribution

Render Farms:

Pixar:

- 1,024 2.8 GHz Xeon processors running Linux and Renderman
- 2 TB RAM, 60 TB disk space
- Custom Linux software for articulating, animating/lighting (Marionette), scheduling (Ringmaster), and rendering (RenderMan)
- Cars: each frame took 8 hours to Render. Consumes ~32 GB storage on a SAN

DreamWorks:

- >3,000 servers and >1,000 Linux desktops
  HP xw9300 workstations and HP DL145 G2 servers with 8 GB/server
- Shrek 3: 20 million CPU render hours. Platform LSF used for scheduling + Maya for modeling + Avid for editing+ Python for pipelining – movie uses 24 TB storage

## Single-queue work distribution

Render Farms:

- ILM:
  - 3,000 processor (AMD) renderfarm; expands to 5,000 by harnessing desktop machines
  - 20 Linux-based SpinServer NAS storage systems and 3,000 disks from Network Appliance
  - 10 Gbps ethernet
- Sony Pictures' Imageworks:
  - Over 1,200 processors
  - Dell and IBM workstations
  - almost 70 TB data for Polar Express

## Batch Processing

OpenPBS.org:

- Portable Batch System
- Developed by Veridian MRJ for NASA

- Commands
  - Submit job scripts
    - Submit interactive jobs
    - Force a job to run
  - List jobs
  - Delete jobs
  - Hold jobs

# Load Balancing for the web

## Functions of a load balancer

Load balancing

Failover

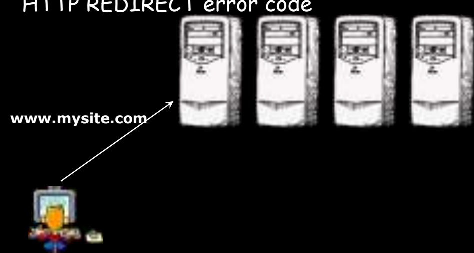
Planned outage management

## Redirection

Simplest technique
  HTTP REDIRECT error code

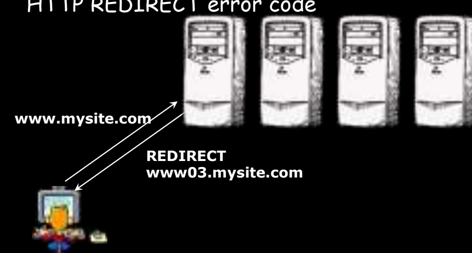
## Redirection

Simplest technique
  HTTP REDIRECT error code



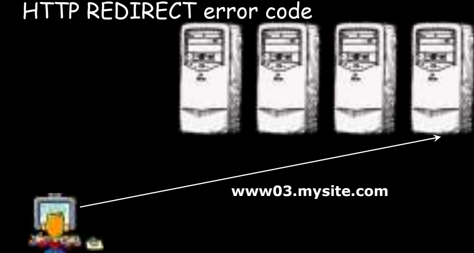

## Redirection

Simplest technique
  HTTP REDIRECT error code




## Redirection

Simplest technique
  HTTP REDIRECT error code




## Redirection

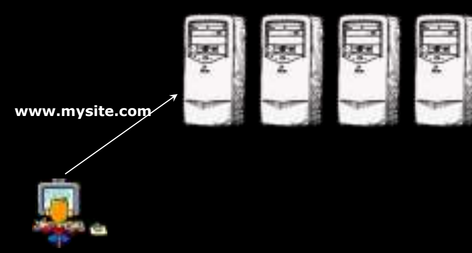
- Trivial to implement
- Successive requests automatically go to the same web server
  - Important for sessions
- Visible to customer
  - Some don't like it
- Bookmarks will usually tag a specific site

## Software load balancer

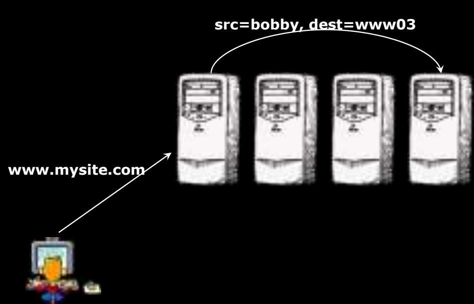
e.g.: IBM Interactive Network Dispatcher Software

Forwards request via load balancing
- Leaves original source address
- Load balancer not in path of outgoing traffic (high bandwidth)
- Kernel extensions for routing TCP and UDP requests
  - Each client accepts connections on its own address and dispatcher's address
  - Dispatcher changes MAC address of packets.

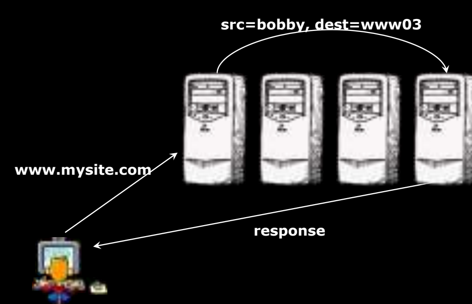
## Software load balancer




## Software load balancer




## Software load balancer




## Load balancing router

Routers have been getting smarter
- Most support packet filtering
- Add load balancing

Cisco LocalDirector, Altheon, F5 Big-IP

## Load balancing router

- Assign one or more virtual addresses to physical address
  - Incoming request gets mapped to physical address
- Special assignments can be made per port
  - e.g. all FTP traffic goes to one machine

**Balancing decisions:**
- Pick machine with least # TCP connections
- Factor in weights when selecting machines
- Pick machines round-robin
- Pick fastest connecting machine (SYN/ACK time)

# High Availability (HA)

## High availability (HA)

| Class | Level | Annual Downtime |
|---|---|---|
| Continuous | 100% | 0 |
| Six nines (carrier class switches) | 99.9999% | 30 seconds |
| Fault Tolerant (carrier-class servers) | 99.999% | 5 minutes |
| Fault Resilient | 99.99% | 53 minutes |
| High Availability | 99.9% | 8.3 hours |
| Normal availability | 99-99.5% | 44-87 hours |

## Clustering: high availability

Fault tolerant design

Stratus, NEC, Marathon technologies

- Applications run uninterrupted on a redundant subsystem
  - NEC and Stratus has applications running in lockstep synchronization
- Two identical connected systems
- If one server fails, other takes over instantly

Costly and inefficient

- But does what it was designed to do

## Clustering: high availability

- Availability addressed by many:
  - Sun, IBM, HP, Microsoft, SteelEye Lifekeeper, …
- If one server fails
  - Fault is isolated to that node
  - Workload spread over surviving nodes
  - Allows scheduled maintenance without disruption
  - Nodes may need to take over IP addresses

## Example: Windows Server 2003 clustering

- Network load balancing
  - Address web-server bottlenecks
- Component load balancing
  - Scale middle-tier software (COM objects)
- Failover support for applications
  - 8-node failover clusters
  - Applications restarted on surviving node
  - Shared disk configuration using SCSI or fibre channel
  - Resource group: {disk drive, IP address, network name, service} can be moved during failover

## Example: Windows Server 2003 clustering

Top tier: cluster abstractions

- Failover manager, resource monitor, cluster registry

Middle tier: distributed operations

- Global status update, quorum (keeps track of who's in charge), membership

Bottom tier: OS and drivers

- Cluster disk driver, cluster network drivers
- IP address takeover

## Clusters

Architectural models

## HA issues

How do you detect failover?

How long does it take to detect?

How does a dead application move/restart?

Where does it move to?

## Heartbeat network

- Machines need to detect faulty systems
  - "ping" mechanism
- Need to distinguish system faults from network faults
  - Useful to maintain **redundant networks**
  - Send a **periodic heartbeat** to test a machine's liveness
  - Watch out for **split-brain**!
- Ideally, use a network with a bounded response time
  - Lucent RCC used a serial line interconnect
  - Microsoft Cluster Server supports a dedicated "private network"
    - Two network cards connected with a pass-through cable or hub

## Failover Configuration Models

Active/Passive (N+M nodes)

- M dedicated failover node(s) for N active nodes

Active/Active

- Failed workload goes to remaining nodes

## Design options for failover

**Cold failover**

- Application restart

**Warm failover**

- Application checkpoints itself periodically
- Restart last checkpointed image
- May use writeahead log (tricky)

**Hot failover**

- Application state is lockstep synchronized
- Very difficult, expensive (resources), prone to software faults

## Design options for failover

**With either type of failover …**

**Multi-directional failover**

- Failed applications migrate to / restart on available systems

**Cascading failover**

- If the backup system fails, application can be restarted on another surviving system

## System support for HA

- Hot-pluggable devices
  - Minimize downtime for component swapping
- Redundant devices
  - Redundant power supplies
  - Parity on memory
  - Mirroring on disks (or RAID for HA)
  - Switchover of failed components
- Diagnostics
  - On-line serviceability

## Shared resources (disk)

**Shared disk**

- Allows multiple systems to share access to disk drives
- Works well if applications do not generate much disk I/O
- Disk access *must* be synchronized
  - Synchronization via a **distributed lock manager (DLM)**

## Shared resources (disk)

**Shared nothing**

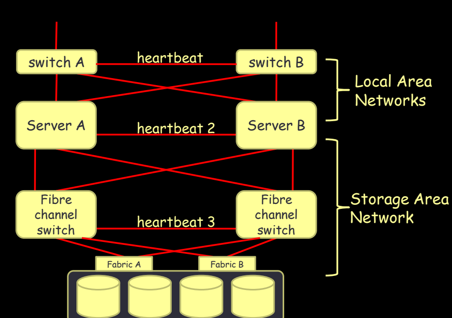
- No shared devices
- Each system has its own storage resources
- No need to deal with DLMs
- If a machine *A* needs resources on *B*, *A* sends a message to *B*
  - If *B* fails, storage requests have to be switched over to a live node

## Cluster interconnects

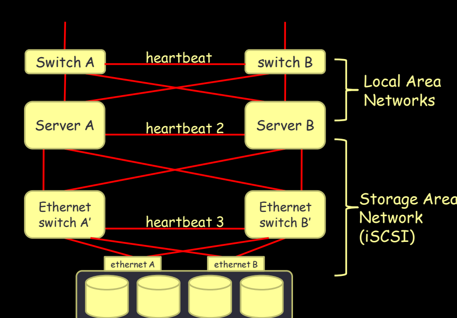
Traditional WANs and LANs may be slow as cluster interconnect

- Connecting server nodes, storage nodes, I/O channels, even memory pages
- **Storage Area Network** (SAN)
  - Fibre channel connectivity to external storage devices
  - Any node can be configured to access any storage through a fibre channel switch
- **System Area Network** (SAN)
  - Switched interconnect to switch cluster resources
  - Low-latency I/O without processor intervention
  - Scalable switching fabric
  - (Compaq, Tandem's ServerNet)
  - Microsoft Windows 2000 supports Winsock Direct for SAN communication

## Achieving High Availability




## Achieving High Availability



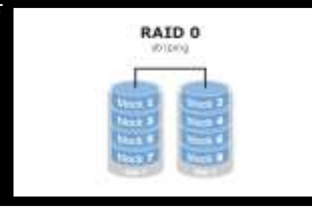
## HA Storage: RAID

Redundant Array of Independent (Inexpensive) Disks

## RAID 0: Performance

**Striping**

- Advantages:
  - Performance
  - All storage capacity can be used
- Disadvantage:
  - Not fault tolerant




## RAID 1: HA

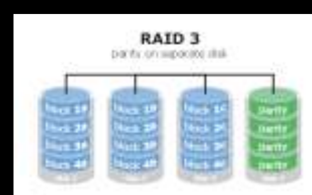
**Mirroring**

- Advantages:
  - Double read speed
  - No rebuild necessary if a disk fails: just copy
- Disadvantage:
  - Only half the space


## RAID 3: HA

**Separate parity disk**

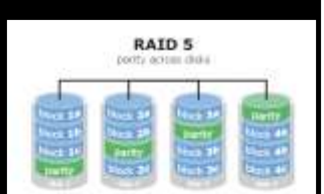
- Advantages:
  - Very fast reads
  - High efficiency: low ratio of parity/data
- Disadvantages:
  - Slow random I/O performance
  - Only one I/O at a time




## RAID 5

**Interleaved parity**

- Advantages:
  - Very fast reads
  - High efficiency: low ratio of parity/data
- Disadvantage:
  - Slower writes
  - Complex controller




## RAID 1+0

Combine mirroring and striping

- Striping across a set of disks
- Mirroring of the entire set onto another set

The end