Motivation
- Next generation fixes problems of last gen.
- 1960s: batch processing + slow turnaround ⇒ Timesharing
  - 15-20 years of performance improvement, cost reduction (minicomputers, semiconductor memory)
- 1980s: Time sharing + inconsistent response times ⇒ Workstations/Personal Computers
  - 15-20 years of performance improvement, cost reduction (microprocessors, DRAM memory, disk)
- 2000s: PCs + difficulty of use/high cost of ownership ⇒ ???

Perspective on Post-PC Era
- PostPC Era Divides built on two technologies:
  1) Mobile Consumer Electronic Devices
     - e.g., successor to PDA, Cell phone
     - Prior talks in this session
     - See Posters on Ninja, Iceberg, IRAM (12-1:30) and
       Post PC session 1:30-3:30 in 306 Soda
  2) Infrastructure to Support such Devices
     - e.g., successor to Big Fat Web Servers, Databases
     - This talk and Posters on ISTORE (12-1:30)
Background for ISTORE: RAID-I

- RAID-I (1989)
  - consisted of a Sun 4/280 workstation with 128 MB of DRAM, four dual-string SCSI controllers, 28 5.25-inch SCSI disks and specialized disk striping software

Background for ISTORE: RAID-II

- RAID-II (1993)
  - A network attached storage device. 2 outer racks contained 144 disks (3.5” IBM 320 MB SCSI) & power supplies. Center rack in 3 parts: top chassis holds VME disk controller boards, center chassis contains custom crossbar switch and HIPPI network (1Gb/s) interface boards; bottom chassis contains the Sun 4/280 workstation.

Background: Tertiary Disk

- Tertiary Disk (1997)
  - cluster of 20 PCs hosting 364 3.5” IBM disks (8.4 GB) in 7’x19” racks, or 3 TB. The 200MHz, 96 MB P6 PCs run FreeBSD and a switched 100Mb/s Ethernet connects the hosts. Also 4 UPS units.
  - Hosts world’s largest art database: 72,000 images in cooperation with San Francisco Fine Arts Museum: Try www.thinker.org

Tertiary Disk HW Failure Experience

Reliability of hardware components (20 months)

- 7 IBM SCSI disk failures (out of 364, or 2%)
- 6 IDE (internal) disk failures (out of 20, or 30%)
- 1 SCSI controller failure (out of 44, or 2%)
- 1 SCSI Cable (out of 39, or 3%)
- 1 Ethernet card failure (out of 20, or 5%)
- 1 Ethernet switch (out of 2, or 50%)
- 3 enclosure power supplies (out of 92, or 3%)
- 1 short power outage (covered by UPS)

Did not match expectations:
SCSI disks more reliable than cables!
Saw 2 Error Messages per Day

- **SCSI Error Messages:**
  - Time Outs: Response: a BUS RESET command
  - Parity: Cause of an aborted request

- **Data Disk Error Messages:**
  - Hardware Error: The command unsuccessfully terminated due to a non-recoverable HW failure.
  - Medium Error: The operation was unsuccessful due to a flaw in the medium (try reassigning sectors)
  - Recovered Error: The last command completed with the help of some error recovery at the target
  - Not Ready: The drive cannot be accessed

---

**Zoom In: Disk Recovered Errors**

### SCSI Bus 0

- Disk Recovered Errors
- SCSI Time Outs

---

**Can we predict a disk failure?**

- Yes, we can look for Recovered Error messages on 10-16-98:
  - There were 433 Recovered Error Messages
  - These messages lasted for slightly over an hour between: 12:43 and 14:10

- On 11-24-98: Disk 5 on m0 was “fired”, i.e. it appeared to operator it was about to fail, so it was swapped
**SCSI Time Outs + Hardware Failures (m11)**

**SCSI Bus 0**

- Disk Hardware Failures
- SCSI Time Outs

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>8/15/98</td>
<td>0:00</td>
</tr>
<tr>
<td>8/17/98</td>
<td>0:00</td>
</tr>
<tr>
<td>8/19/98</td>
<td>0:00</td>
</tr>
<tr>
<td>8/21/98</td>
<td>0:00</td>
</tr>
<tr>
<td>8/23/98</td>
<td>0:00</td>
</tr>
<tr>
<td>8/25/98</td>
<td>0:00</td>
</tr>
<tr>
<td>8/27/98</td>
<td>0:00</td>
</tr>
<tr>
<td>8/29/98</td>
<td>0:00</td>
</tr>
<tr>
<td>8/31/98</td>
<td>0:00</td>
</tr>
</tbody>
</table>

**Can we predict a disk failure?**

- Yes, look for Hardware Error messages
  - These messages lasted for 8 days between: 8-17-98 and 8-25-98
  - On disk 9 there were:
    - 1763 Hardware Error Messages, and
    - 297 SCSI Timed Out Messages
- On 8-28-98: Disk 9 on SCSI Bus 0 of m11 was “fired”, i.e. appeared it was about to fail, so it was swapped

**SCSI Bus 2 Parity Errors (m2)**

**SCSI Bus 2**

- SCSI Parity Errors

<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>9/2/98</td>
<td>0:00</td>
</tr>
<tr>
<td>9/12/98</td>
<td>0:00</td>
</tr>
<tr>
<td>9/22/98</td>
<td>0:00</td>
</tr>
<tr>
<td>10/2/98</td>
<td>0:00</td>
</tr>
<tr>
<td>10/12/98</td>
<td>0:00</td>
</tr>
<tr>
<td>10/22/98</td>
<td>0:00</td>
</tr>
</tbody>
</table>

**Can We Predict Other Kinds of Failures?**

- Yes, the flurry of parity errors on m2 occurred between:
  - 1-1-98 and 2-3-98, as well as
  - 9-3-98 and 10-12-98
- On 11-24-98
  - m2 had a bad enclosure
    ⇒ cables or connections defective
  - The enclosure was then replaced
Lessons from Tertiary Disk Project

- Maintenance is hard on current systems
  - Hard to know what is going on, who is to blame
- Everything can break
  - It's not what you expect in advance
  - Follow rule of no single point of failure
- Nothing fails fast
  - Eventually behaves bad enough that operator fires poor performer, but it doesn't quit
- Many failures may be predicted

Outline

- Motivation and Background: Berkeley's Past
- ISTORE Goals
- Hardware Architecture
- Software Architecture
- Discussion and Feedback

Storage Priorities: Research v. Users

Current Research Priorities
1) Performance
2) Cost
3) Scalability
4) Availability
5) Maintainability

Current Server Customer Priorities
1) Availability
2) Maintainability
3) Scalability
4) Performance
5) Cost

(From Sun marketing presentation, 2/99)

Intelligent Storage Project Goals

- ISTORE: a hardware/software architecture for building scaleable, self-maintaining storage
  - An introspective system: it monitors itself and acts on its observations
- Self-maintenance: does not rely on administrators to configure, monitor, or tune system
**Self-maintenance**
- Failure management
  - devices must fail fast without interrupting service
  - predict failures and initiate replacement
  - failures \(\not\) immediate human intervention
- System upgrades and scaling
  - new hardware automatically incorporated without interruption
  - new devices immediately improve performance or repair failures
- Performance management
  - system must adapt to changes in workload or access patterns

**ISTORE-I Hardware**
- ISTORE uses “intelligent” hardware
  - **Intelligent Chassis:** scaleable, redundant, fast
    - network + UPS
  - **Device**
    - CPU, memory, NI
  - **Intelligent Disk “Brick”:** a disk, plus a fast embedded CPU, memory, and redundant network interfaces

**ISTORE-I: Summer 99?**
- **Intelligent disk**
  - Portable PC Hardware: Pentium II, DRAM
  - Low Profile SCSI Disk (9 to 18 GB)
  - 4 100-Mbit/s Ethernet links per Idisk
  - Placed inside Half-height canister
  - Monitor Processor/path to power off components?
- **Intelligent Chassis**
  - 64 IDisks: 8 enclosures, 8 IDisks/enclosure
    - 64 x 4 or 256 Ethernet ports
  - 2 levels of Ethernet switches: 14 small, 2 large
    - Small: 20 100-Mbit/s + 2 1-Gbit; Large: 25 1-Gbit
  - Enclosure sensing, UPS, redundant PS, fans

**ISTORE Hardware Vision**
- System-on-a-chip enables computer, memory, redundant network interfaces without increasing size of disk canister
- Disk enclosure includes (redundant) 1st-level switches as well as redundant power supplies, fans
- Rack includes 2nd-level switches, UPS
ISTORE-I Software Plan
- Modify Database (e.g., Predator) to send log to mirrored Idisk
  - Since 1 processor per disk, continuously replay the log on mirrored system
- Insert faults in original Idisk to get fail over
- Add monitoring, maintenance, fault insertion
- Run **ix OS
  - By running Linix binaries, can get multiple OS with same API: Linix, Free BSD Unix, ...
  - Increase genetic base of OS software to reduce chances of simulatenous software bugs
  - Periodic reboot to “refresh” system

Benefits of ISTORE
- Decentralized processing (shared-nothing)
  - system can withstand partial failure
- Monitor their own “health,” test themselves, manage failures, collect application-specified performance data, and execute applications
  - fault insertion to test availability
  - provides the foundation for self-maintenance and self-tuning
- Plug & play, hot-swappable bricks ease configuration, scaling
  - hardware maybe specialized by selecting an collection of devices: DRAMs, WAN/LAN interfaces

Other (Potential) Benefits of ISTORE
- Scalability: add processing power, memory, network bandwidth as add disks
- Smaller footprint vs. traditional server/disk
- Less power
  - embedded processors vs. servers
  - spin down idle disks?
- For decision-support or web-service applications, potentially better performance than traditional servers

Related Work
- ISTORE adds several recent research efforts
  - Active Disks, NASD (UCSB, CMU)
  - Network service appliances (NetApp, Snap!, Qube, ...)
  - High availability systems (Compaq/Tandem, ...)
  - Adaptive systems (HP AutoRAID, M/S AutoAdmin, M/S Millennium)
  - Plug-and-play system construction (Jini, PC Plug&Play, ...)
Interested in Participating?

- Project just getting formed
- Contact us if you're interested: http://iram.cs.berkeley.edu/istore
  email: patterson@cs.berkeley.edu
- Thanks for support: DARPA
- Thanks for advice/inspiration: Dave Anderson (Seagate), Greg Papadopolous (Sun), Mike Ziegler (HP)

ISTORE Cluster?
- 8 - 12 disks / enclosure
- 12 enclosures / rack = 96 - 144 disks/rack

Cluster of PCs?
- 2 disks / PC
- 10 PCs / rack = 20 disks/rack
- Reliability?
- Ease of Repair?
- System Admin.?
- Cost only plus?

ISTORE and IRAM
- ISTORE relies on intelligent devices
- IRAM is an easy way to add intelligence to a device
  - embedded, low-power CPU meets size and power constraints
  - integrated DRAM reduces chip count
  - fast network interface (serial lines) meets connectivity needs
- Initial ISTORE prototype won't use IRAM
  - will use collection of commodity components that approximate IRAM functionality, not size/power