The Goal of This Week

- Magnetic Disks
- RAID
- Advanced Dependability/Reliability/Availability
- I/O Benchmarks, Performance and Dependability
- Research Meetings
Case for Storage

- Shift in focus from computation to communication and storage of information
  - E.g., Cray Research/Thinking Machines vs. Google/Yahoo
  - “The Computing Revolution” (1960s to 1980s)
    ⇒ “The Information Age” (1990 to today)
- Storage emphasizes reliability and scalability as well as cost-performance
- What is “Software king” that determines which HW actually features used?
  - For processor: Compiler
  - For storage: Operating System
- Also has own performance theory—queuing theory—balances throughput vs. response time

Motivation

- CPU Performance: 50% to 100% per year
- I/O system performance limited by mechanical delays
  < 5% per year (IO per sec or MB per sec)
- Amdahl’s Law: system speed-up limited by the slowest part!
  - 10% IO & 10x CPU ⇒ 5x Performance (lose 50%)
  - 10% IO & 100x CPU ⇒ 10x Performance (lose 90%)
- I/O bottleneck:
  Diminishing fraction of time in CPU
  Diminishing value of faster CPUs
Historical Perspective

- 1956 IBM Ramac — early 1970s Winchester
  - Developed for mainframe computers, proprietary interfaces
  - Steady shrink in form factor: 27 in. to 14 in.
- Form factor and capacity drives market more than performance
- 1970s developments
  - 5.25 inch floppy disk (microcode into mainframe)
  - Emergence of industry standard disk interfaces
- Early 1980s: PCs and first generation workstations
- Mid 1980s: Client/server computing
  - Centralized storage on file server
    - accelerates disk downsizing: 8 inch to 5.25
  - Mass market disk drives become a reality
    - industry standards: SCSI, IPI, IDE
    - 5.25 inch to 3.5 inch drives for PCs, End of proprietary interfaces
- 1990s: Laptops => 2.5 inch drives
- 2000s: What new devices leading to new drives?

Disk History

<table>
<thead>
<tr>
<th>Year</th>
<th>Data Density (Mbit/sq.in)</th>
<th>Capacity (MBytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1973</td>
<td>1.7</td>
<td>140</td>
</tr>
<tr>
<td>1979</td>
<td>7.7</td>
<td>2300</td>
</tr>
</tbody>
</table>

Disk History

1989:  
63 Mbit/sq. in  
60,000 MBytes

1997:  
1450 Mbit/sq. in  
2300 MBytes

1997:  
3090 Mbit/sq. in  
8100 MBytes

“Makers of disk drives crowd even more data into even smaller spaces”

1 inch Disk Drive

• 2000 IBM MicroDrive:
  – 1.7” x 1.4” x 0.2”
  – 1 GB, 3600 RPM, 5 MB/s, 15 ms seek
  – Digital camera, PalmPC?
• 2006 MicroDrive
• 9 GB, 50 MB/s!
Disk Trends: Density

- Today: Processing power doubles every 18 months
- Today: Memory size doubles every 18 months (4X/3 yrs)
- Today: Disk capacity doubles every 18 months
- Disk positioning rate (seek + rotate) doubles every ten years!

Disk Trends: Price

- Today: Processing power doubles every 18 months
- Today: Memory size doubles every 18 months (4X/3 yrs)
- Today: Disk capacity doubles every 18 months
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Disk Trends: Performance

- Continued advance in capacity (60%/yr) and bandwidth (40%/yr)
- Slow improvement in seek, rotation (8%/yr)
- Time to read whole disk

<table>
<thead>
<tr>
<th>Year</th>
<th>Sequentially</th>
<th>Randomly</th>
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<tbody>
<tr>
<td></td>
<td>(1 sector/seek)</td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>4 minutes</td>
<td>6 hours</td>
</tr>
<tr>
<td>2000</td>
<td>12 minutes</td>
<td>1 week(!)</td>
</tr>
<tr>
<td>2006</td>
<td>56 minutes</td>
<td>3 weeks (SCSI)</td>
</tr>
<tr>
<td>2006</td>
<td>171 minutes</td>
<td>7 weeks (SATA)</td>
</tr>
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</table>

Use Arrays of Small Disks

Katz and Patterson asked in 1987:
Can smaller disks be used to close gap in performance between disks and CPUs?

Conventional: 4 disk designs

<table>
<thead>
<tr>
<th>Size</th>
<th>Low End</th>
<th>High End</th>
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</thead>
<tbody>
<tr>
<td>3.5”</td>
<td>10”</td>
<td>14”</td>
</tr>
<tr>
<td>5.25”</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Disk Array: 1 disk design

<table>
<thead>
<tr>
<th>Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5”</td>
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