Characteristics of memory

✦ Location
  ✷ on CPU, main memory, external

✦ Capacity
  ✷ how many bits

✦ Cost
  ✷ cost per unit, space

✦ Unit of transfer
  ✷ words, addressable units

✦ Access method
  ✷ sequential, direct, random, associative

✦ Performance
  ✷ access time
  ✷ memory cycle time
  ✷ transfer rate

✦ Physical type
  ✷ semiconductor, magnetic, optical

✦ Physical characteristics
  ✷ volatile, erasable, power consumption

✦ Organization
  ✷ internal structure
DRAM Modules

addr (row = i, col = j)

64 MB memory module consisting of eight 8Mx8 DRAMs

64-bit doubleword at main memory address A

64-bit doubleword
Hard drives

- Platter
- Motor
- Read/write head
- Actuator
- Interface
- Jumpers
- Power supply
- Tracks
- Surface
- Cylinder k
- Track k
- Gaps
- Sectors
- Surface 0
- Surface 1
- Surface 2
- Surface 3
- Surface 4
- Surface 5
- Platter 0
- Platter 1
- Platter 2
- Spindle
Disk service time

After BLUE read

Seek for RED

Rotational latency

After RED read

Data transfer

Seek

Rotational latency

Data transfer
<table>
<thead>
<tr>
<th>technology</th>
<th>access time</th>
<th>$/GB</th>
<th>in my Laptop</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRAM</td>
<td>0.5-2.5ns</td>
<td>$1500-$5000</td>
<td>4.5 MB</td>
</tr>
<tr>
<td>DRAM</td>
<td>50-70ns</td>
<td>$6 - $20</td>
<td>8 GB</td>
</tr>
<tr>
<td>magnetic disk</td>
<td>5,000,000 -20,000,000 ns</td>
<td>$0.07 - $0.20</td>
<td>1TB</td>
</tr>
<tr>
<td>flash</td>
<td>85,000 ns</td>
<td>$1.5-$2 (SSD)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$0.50 - $1.25 (thumb)</td>
<td></td>
</tr>
</tbody>
</table>