Matching Data Storage to Consumer Applications

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Outline

• Data Storage Market and Technology
• Important Data Storage Characteristics for Consumer Applications
  – Price
  – Storage Capacity
  – Performance and New Application Features
  – Ruggedness, Acoustics, and Vibration
  – Power Consumption
  – Size
• Conclusions
Data Storage Market and Technology
Drivers for Storage Growth

- Growth in digital information from faster processors and the digitization of human content (from literature, audio, and video to our genes)
- Ever lower cost of digital data storage
- Increasing availability of high data rate access
- New applications inspired by low cost that generate even more digital information
Cumulative Storage Capacity of Disk Memory
(PetaBytes)

In 2001 only 10% of worldwide storage was shared!
Household Broadband Access Growth

- **Cable Modem**
- **DSL**
- **Fixed Wireless**
- **Satellite**


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Emerging storage consuming products

Your product here
Data Storage Technologies

Holography
Disk Drive Growth Trends
(Millions of Drives)
Regardless of exact forecast numbers, cumulative GC sales will provide for large volume of HDDs.

Opportunity grows only larger if Xbox competitors adopt internal HDD strategy in next products.
Market Size – Mobile Devices

- Worldwide Unit Forecast
  - Major segments where high density data storage is required
  - Smart Handhelds include new category of “Convergence Cell Phone”

Source: IDC/WebFeet/SanDisk 2001
Shipments of Mobile Storage Devices
(note log scale)

Important Data Storage Characteristics for Consumer Applications

- Price
- Storage Capacity
- Performance
- New Application Features
- Ruggedness
- Acoustics and Vibration
- Power Consumption
- Size
Prices
X-Box Estimated Cost vs. Price

**Estimated Cost**

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
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<tbody>
<tr>
<td>Integrated circuits</td>
<td>$92</td>
</tr>
<tr>
<td>Discretes</td>
<td>38</td>
</tr>
<tr>
<td>Modules</td>
<td>5</td>
</tr>
<tr>
<td>Connectors</td>
<td>10</td>
</tr>
<tr>
<td>Pcb-board cards</td>
<td>29</td>
</tr>
<tr>
<td>SMT assembly</td>
<td>18</td>
</tr>
<tr>
<td>Test</td>
<td>5</td>
</tr>
<tr>
<td>Dvd+ hard disk</td>
<td>90</td>
</tr>
<tr>
<td>Enclosures/mechanical</td>
<td>31</td>
</tr>
<tr>
<td>Final assembly</td>
<td>1</td>
</tr>
<tr>
<td>Accessories</td>
<td>4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$323</strong></td>
</tr>
</tbody>
</table>

**List Price $299**

EE Times, Feb. 18, 2002
Inside a High-End Handset

Some of the key components that make up a cellphone and their typical cost:

- Color screen: $15
- Printed circuit board: $8
- Radio chip and related electronics: $35
- Baseband chip: $30
- Flash memory: $20
- Battery: $25
- License for reference design for phone: $5*
- License for user interface software: $3*
- License for operating system software: $5*

*Could be developed in-house

NOTE: Licensing for reference design and other software could be developed in-house, but typically costs up to $13 from outside suppliers.

Source: Gartner; WSJ reporting

Illustration by Dan Ion/The Wall Street Journal

Complete Handset  $200
Add-on Product Market Penetration vs. Add-on Price/Device Price Ratio (assuming added value, no negatives with price)
Flash Volume vs. Price

Highest Volume Products, <$50
Average Mobile Electronic Product Price Projections

Projections based on Intelect Market Tracking for Digital Cameras and PDAs, 2000
Microdrive Price and Capacity Projections

Price

Capacity

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Average Desktop Drive Prices vs. Time
(Sources: Disktrend 1999 and PRC 2002)
The $30 Cost Consumer Products Disk Drive

- Single Head, high volume, simplified manufacturing.
- Acceptable acoustics, shock resistance
- *Sells for less than $45* for games, PVRs.
- Reduced Parts Count, high electronic integration
  - electronics ~$10.50
  - head and media ~$9.50
  - mechanics ~$10.00
  - total cost ~$30.00
AREAL DENSITY PROGRESSION

(Source: PRC, 2002)
Storage Capacity
Content Based Storage Requirements

**Commercial Video**
- ~1 TB is required for a digital theater complex
- ~800 TB may be required for single movie production
- Including TV, movie, commercial production, and video distribution the annual video production storage market may be 740 PB by 2006

**Personal Video**
- 50 years of MPEG-2 quality digitized television content is estimated to require 912 PB by 2006
- With 10% utilization this would result in about 91 PB downloaded/year
- With mirroring this online content might require 3.6 EB by 2006
High Resolution Images - A BIG Driver

- High End Customers are initial drivers
  - medical file transfer
  - movie distribution
  - interactive collaborations
  - physical and biological simulation

Bandwidth Requirements (MB/sec)

Storage Requirements (GB/hr)

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Home Entertainment Data Storage Requirements

- Digital Audio Jukebox
  - Today – 40GB – 100GB

- PVR/Set-Tops
  - Today – 40GB – 180GB
  - Future – 100GB – 250GB (Network gateway will probably be in place.

- Media Gateway
  - Today – 100GB – 500GB
Top Mobile Product Requirements - 2004

- Smart Handheld Devices – **116M Units**
  - **128MBytes – 512MBytes** primary demand
  - Primarily consists of PDA’s and Convergence Phones
  - Store everything from PIM data to emails to Audio to Video (future)
  - Requires very small memory device – cell phones, PDA’s, VAD’s.
  - Memory Card slot in Devices allows capacity and price to scale with application need

- Digital Cameras – **99M Units**
  - **64MBytes – 512MBytes** primary demand
  - Primarily consists of Digital Still and Video Still cameras
  - Store 1.3M to 4.2Mpixel Images
  - Requires very small memory device – palm-size DSC’s and DVC’s
  - Memory Card slot in Devices allows capacity and price to scale with application need

- Consumer Devices – **54M Units**
  - **64MBytes – 256MBytes** primary demand
  - Primarily consists of Portable Compressed Audio Players and Handheld GPS
  - Store Music and Maps
  - Requires very small memory device – belt-clip and wristwatch players
  - Memory Card slot in Devices allows capacity and price to scale with application need

Source: IDC/WebFeet/SanDisk 2001
SanDisk, Storage Visions 2002
Smartphones and Web Tablets

- Features, Present & Future
  - All the features in high-end phones, plus…
  - Integration of phone and PDA, more than the sum of the parts
  - Wireless communications and PDA functions each have a dedicated processor
  - Bulk storage integrated with PDA function
  - Larger wireless PDAs and Web Tablets have an expansion slot for a micro-drive
- Bulk storage applications in a smartphone
  - Interactive maps, music or video, still images
  - Games
  - Barcode scanning data

Qualcomm, Storage Visions 2002
Storage Sharing in Wireless PAN

- Wireless Personal Area Network (PAN) allows sharing of bulk storage between devices.
  - Phone has access to your address book and MP3 files stored in PDA.
  - PDA actively synchronizes database with wireless enabled laptop.
- Potential networks are Bluetooth or 802.15.3 TG3.
Performance and New Application Features
Access, Rotational and Seek Time Trends (Source: IBM)

<table>
<thead>
<tr>
<th></th>
<th>1987</th>
<th>1999</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPU</td>
<td>1 MIPS</td>
<td>700 MIPS</td>
<td>700X</td>
</tr>
<tr>
<td>Memory</td>
<td>100 microsec</td>
<td>100 nanosec</td>
<td>1,000X</td>
</tr>
<tr>
<td>Drives</td>
<td>60 msec</td>
<td>6 msec</td>
<td>10X</td>
</tr>
</tbody>
</table>
Trends in Data Access

• While areal densities have been increasing by about 2X per year the access time to data has only been increasing about 2.5X every 10 years.

• Thus for a given disk form factor and RPM the time to get to a particular data item is increasing by about 80% annually.

• This may cause a change in form factor (3.5 inch to 2.5 inch), disk RPM, or a change in disk architecture to improve data access performance.
Dual Actuator Disk Drive

• Allows recovering data independently from multiple surfaces.
• This allows faster time to data.
• Extra actuator has a significant increase in drive cost.
• One could also see using the surfaces for interesting internal drive architectures, such within drive mirroring.
Home Gateways and PVRs

• Personal Video Recorders record television signals on a hard disk drive for time-shifted viewing.

• Home Gateways provide a home entertainment and computer network that can distribute video, music, and data.

• A home network may also include a small disk drive array or NAS system.

• Home based data storage tends to use IDE interface disk drives.
PVRs - Evolution from the Broadcaster to the Viewer

**TV Station**
- 1956 Time Shifting (Ampex VTR/$250k)
- 1963 “Instant Replay” (CBS/Army-Navy Football/$250k VTR)
- 1967 Slow Motion/Instant Access/Trick Play (Ampex/$250k HDR)
- 1969 Live Time Delay (NBC/2-Ampex VTRs)
- 1995 Video Server (Tektronix Profile/$100k)
- 1995 Downloadable Content (TV Spot Recorder/$50k)

**Home**
- 1998 Personal Video Recorder (TiVo & ReplayTV/<$500)
  - Record and playback concurrently
  - Pause playback while continuing to record
  - Automatically record selected and/or suggested programs for later viewing

Maxtor, Storage Visions 2002
Embedding Additional Functions into Disk Drives for Fun and Profit

• Modern disk drives have a sophisticated microprocessor used for motor control and data transfer. The capability of these processors is not fully utilized.
• Furthermore electronics integration leaves lots of potential board space unused on a disk drive.
• Could disk drive microprocessors be used for additional functions?
• One example is to incorporate other devices into the disk drive, such as a PVR built on the drive.
• An added benefit is utilizing the low cost manufacturing expertise of disk drive manufacturers to make consumer electronics products.
Different Strokes for Different Folks

• There may develop different types of storage services in the future
  – High performance drives with multiple actuators, higher RPM, short stroking, higher data rates, faster servo systems, etc. for use in fast cache applications (>$$$).
  – Slower, higher capacity drives for use in “data tub” applications. Such products are now being introduced by NetApp and Quantum to replace or augment tape backup (<$$$’s).
• Price to performance trade-offs determine choices (e.g. vs. solid-state drives).
Ruggedness, Acoustics, and Vibration
## Specifications of Microdrive vs Compact Flash Memory (2001)

<table>
<thead>
<tr>
<th></th>
<th>Non-Op Shock (G)</th>
<th>Op Shock (G)</th>
<th>Max. Power (W)</th>
<th>Write Access Time (ms)</th>
<th>Read Access Time (ms)</th>
<th>Data Rate (MB/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compact Flash</strong></td>
<td>2000</td>
<td>2000</td>
<td>0.450</td>
<td>2.5</td>
<td>2.0</td>
<td>4.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.198</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(5V)</td>
<td></td>
<td>(3.3V)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Microdrive</strong></td>
<td>1500-2000</td>
<td>175-250</td>
<td>1.3</td>
<td>15</td>
<td>15</td>
<td>4.2</td>
</tr>
<tr>
<td></td>
<td>2000</td>
<td></td>
<td>0.775 (5V)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(3.3V)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4H-5

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System-Level Shock Events

• A new environment for hard drives
• Non-operating shock

Non-Op Shock Tolerance inGs

Annual Return Rate (ARR)


Medalist  4242  Medalist  13640  Medalist  17242  Medalist  8641  Medalist  8641

Medalist  4242  Medalist  8641  Medalist  13640  Medalist  17242  Medalist  17242

U4  U8/U10  U Series 5  U Series 6
High Shock Resistant Drive Packaging

• Non-operating shock specifications as high as 10,000 G’s are available by surrounding a disk drive with a shock adsorbing foam.

• Shock resistance is very important for many consumer electronics and mobile storage applications.
Improving System Acoustics

Trend: Seagate Desktop Products
Idle Acoustics (typical sound power)–dB

Seagate, Storage Visions 2002

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Power Consumption
Wireless Personal Multimedia Device

- Download media at video store or other shopping location.
- Digital media is much more flexible for improvements in compression and resolution (just download a new codec, upgrade to HDTV later)

<table>
<thead>
<tr>
<th>Mbps</th>
<th>download time (seconds)</th>
<th>download time (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1000</td>
<td>16</td>
<td>0.3</td>
</tr>
<tr>
<td>500</td>
<td>32</td>
<td>0.5</td>
</tr>
<tr>
<td>200</td>
<td>80</td>
<td>1.3</td>
</tr>
<tr>
<td>100</td>
<td>160</td>
<td>2.7</td>
</tr>
<tr>
<td>50</td>
<td>320</td>
<td>5.3</td>
</tr>
<tr>
<td>20</td>
<td>800</td>
<td>13.3</td>
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<tr>
<td>10</td>
<td>1600</td>
<td>26.7</td>
</tr>
<tr>
<td>5</td>
<td>3200</td>
<td>53.3</td>
</tr>
</tbody>
</table>

Desired read and write speeds differ by a factor of 200 to 500

Qualcomm, Storage Visions 2002
Dealing with Microdrive vs. Compact Flash Power Consumption Differences

- For streaming applications where the required data rate is less than the microdrive data rate such as in an audio MP3 player or a video MPEG-2 player, proper memory buffering with the microdrive can reduce the power requirements to be similar to compact flash.

<table>
<thead>
<tr>
<th>Device Type</th>
<th>Currents and Voltage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microdrive</td>
<td>300 mA @ 3.3V, 5% duty cycle, 15 mA average</td>
</tr>
<tr>
<td>RAM Buffer</td>
<td>15 mA @ 3.3V</td>
</tr>
<tr>
<td>MP3 Player</td>
<td>70 mA @ 3.3V</td>
</tr>
<tr>
<td>Flash Memory Card</td>
<td>35 mA @ 3.3V</td>
</tr>
<tr>
<td>MP3 Player</td>
<td>70 mA @ 3.3V</td>
</tr>
</tbody>
</table>

330 mW

347 mW
Average Power Budget

- Monitor \( x \)
- Storage \( y \)
- Transceiver & electronics \( z \)
- Total \( x + y + z = t \)
- Battery Rating (Ah, ampere-hours), Voltage V
- Battery Life = \((\text{Ah})V/t\)
Size
# Mobile Memory Form Factors

<table>
<thead>
<tr>
<th>Storage Device</th>
<th>Size</th>
<th>Typical Capacity¹</th>
<th>Optional Adapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microdrive</td>
<td>42.8 x 36.4 x 5.0 mm</td>
<td>170 MB and 340 MB</td>
<td>PC Card adapter</td>
</tr>
<tr>
<td><strong>PC Card (PCMCIA)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Type I</td>
<td>85.6 x 54.0 x 3.3 mm</td>
<td>Type II Memory= 4 MB-128 MB</td>
<td>External Reader/Writer Notebook slot</td>
</tr>
<tr>
<td>- Type II</td>
<td>85.6 x 54.0 x 5.0 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Type III</td>
<td>85.6 x 54.0 x 10.5 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>CompactFlash cards</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Type I</td>
<td>42.8 x 36.4 x 3.3 mm</td>
<td>4 MB-128 MB</td>
<td>External Reader/Writer PC Card adapter</td>
</tr>
<tr>
<td>- Type II</td>
<td>42.8 x 36.4 x 5.0 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SmartMedia Card</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>45 x 37 x 0.76 mm</td>
<td>4 MB-32 MB</td>
<td>PC Card adapter Floppy adapter</td>
</tr>
<tr>
<td><strong>MultiMedia Card</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>32 x 24 x 1.4 mm</td>
<td>2 MB-16 MB</td>
<td>Available</td>
</tr>
<tr>
<td><strong>Memory Stick</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>21 x 50 x 2.8 mm</td>
<td>4 MB-32 MB</td>
<td>Available</td>
</tr>
<tr>
<td><strong>Miniature Card</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>38 x 33 x 3.5 mm</td>
<td>4 MB-32 MB</td>
<td>Available</td>
</tr>
</tbody>
</table>
Transition to 2.5 inch Form Factor

• 2.5 inch most popular mobile computer form factor.
• 65-mm disks used in 15k RPM enterprise disk drives (although not yet in 2.5 inch form factor box)
• For new consumer products size and volume will become important.
• Dense server and storage environments favor many more smaller drives. This also gives better performance since the time to data is faster for smaller form factors
• New consumer electronics initiatives using smaller form factor disk drives such as the Japanese iVDR consortium.
• 2.5 inch drives should be as inexpensive or less expensive per box compared to 3.5 inch disk drives.
Disk Drive Form Factor Changes

Percentage (%)

2000 2001 2002 2003 2004

<1.8 inch 2.5 inch 3.5 inch 5.25 inch

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Conclusions

• Data generation continues to grow, driving the need for more data storage.
• Disk drive areal density growth and lower unit costs have made them attractive for many applications from network storage through various consumer and even mobile applications.
• The choice of data storage for a particular application depends on the interplay of a number of important requirements.
• In the future expect even lower drive prices, smaller form factors, higher RPM.
• Could other products be embedded in a disk drive?