Storing Your Life
Consumer Digital Storage—
Personal, Shared, Hierarchical
and Virtual

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Outline

• Drivers for Digital Storage in the Home
• The Consumer Electronics Storage Hierarchy
• New and Emerging Digital Storage Applications
• Intelligence in CE Storage Devices
• Connecting Everything in the Home and Home Virtualization
• Conclusions

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Drivers for Storage in the Home
The Cosmic Wheel of Storage Karma

Content Creation
Content Editing
Content Archiving
Content Distribution
Content Reception
Consumer Storage Mark-up Through the Retail Distribution Chain

HDD Value $50.00

CE Device

HDD Value $65.00

30% Markup

Distributor

HDD Value $84.50

Retailer

HDD Value $109.85

30% Markup

Consumer

(1.30 \times 1.30 \times 1.30) = 220\%

\$199.99/220\% = \$90.90\ BOM\ Cost

\$50.00/\$90.90 = HDD\ is\ 55\%\ of\ BOM
Storage and streaming bandwidth for music and video formats

<table>
<thead>
<tr>
<th>Format</th>
<th>Bandwidth (Mbps)</th>
<th>Storage Capacity/Hour (GB)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MUSIC FORMATS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MP3</td>
<td>~0.128</td>
<td>~0.057</td>
</tr>
<tr>
<td>Loss-less Compressed CD</td>
<td>~0.700 min.</td>
<td>~0.315</td>
</tr>
<tr>
<td>CD Quality</td>
<td>1.400</td>
<td>0.630</td>
</tr>
<tr>
<td>DVD Audio</td>
<td>9.600 max.</td>
<td>4.320</td>
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<tr>
<td><strong>VIDEO FORMATS</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Format for iPOD (MPEG-4)</td>
<td>~0.750</td>
<td>~0.337</td>
</tr>
<tr>
<td>DVD MPEG 2</td>
<td>11.080</td>
<td>2.700</td>
</tr>
<tr>
<td>MPEG 4</td>
<td>~1.400</td>
<td>~0.630</td>
</tr>
<tr>
<td>SDTV</td>
<td>~8.000</td>
<td>~2.000</td>
</tr>
<tr>
<td>Blu Ray/HD DVD</td>
<td>36.550</td>
<td>3.750</td>
</tr>
<tr>
<td>HDTV</td>
<td>~19.300</td>
<td>~8.890</td>
</tr>
<tr>
<td>Ultra-HDTV</td>
<td>~295.000</td>
<td>~133.000</td>
</tr>
</tbody>
</table>
Media Units vs. Storage Capacity for Various Resolution Photos, Music, and Video Files

Here is storage required for various applications at various resolutions:

- A 4-megapixel photo viewer with 20,000 images needs 20 GB, 8-megapixel needs 40 GB
- A 10,000 song MP3 player needs 40 GB, HiD (e.g. compressed DVD audio) needs 1.5 TB
- A 100 movie player at VGA resolution needs 70 GB, at DVD resolution needs >400 GB

- A combination 20k 4-Mpixel photo, 10k MP3 song, 100 VGA movie player needs 130 GB
- A combination 20k 8-Mpixel photo, 10k HiD song, 100 DVD movie player needs 1.75 TB
Accumulated Digital Content Per Average Household

- Even an average household will have Terabytes of commercial data in the next decade
- As content resolution increases the required storage capacity must increase as well

**Consumer Survey on Digital Storage in Consumer Electronics** (Coughlin Associates, January 2008)
Drivers of Consumer Digital Storage

- Ease of content creation: Being built into many modern consumer devices e.g. cameras, digital recorders—Growth of User Generated Content (UGC)
- Content Sharing: Easy to multiple digital content 1,000 or more through on-line sharing.
- New methods of creating metadata automatically so content can be used easier.
- New ways to share and coordinate data around the home.
Storage capacity for content sharing between interacting nodes (3 GB file, units in GB)

- **Metcalf's law:**
  - “The value of a telecommunications network is proportional to the square of the number of users of the system (n^2).”

- **Reed's law:**
  - “Not only is a member connected to the entire network, but also to many significant subsets of the network. These subsets add value independent of either the individual or the network.

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>Participation Factor</th>
<th>Metcalf</th>
<th>Reed</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>100</td>
<td>0.05</td>
<td>30</td>
<td>78</td>
</tr>
<tr>
<td>1,000</td>
<td>0.007</td>
<td>63</td>
<td>360</td>
</tr>
<tr>
<td>10,000</td>
<td>0.0008</td>
<td>84</td>
<td>741</td>
</tr>
<tr>
<td>100,000</td>
<td>0.000085</td>
<td>96</td>
<td>1,058</td>
</tr>
<tr>
<td>1,000,000</td>
<td>0.000009</td>
<td>108</td>
<td>1,506</td>
</tr>
<tr>
<td>10,000,000</td>
<td>0.00000095</td>
<td>121</td>
<td>2,141</td>
</tr>
<tr>
<td>100,000,000</td>
<td>0.00000001</td>
<td>135</td>
<td>3,039</td>
</tr>
</tbody>
</table>

With sharing a 3 GB file can get multiplied by 1,000 X over the network.
Estimated growth of personal and commercial content in CE devices

(storage units in exabytes)

<table>
<thead>
<tr>
<th>Year</th>
<th>Commercial Content</th>
<th>Self Generated Personal Content</th>
<th>Shared Personal Content</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>4</td>
<td>5</td>
<td>0</td>
<td>9</td>
</tr>
<tr>
<td>2007</td>
<td>8</td>
<td>9</td>
<td>0</td>
<td>17</td>
</tr>
<tr>
<td>2008</td>
<td>16</td>
<td>13</td>
<td>0</td>
<td>29</td>
</tr>
<tr>
<td>2009</td>
<td>30</td>
<td>24</td>
<td>1</td>
<td>55</td>
</tr>
<tr>
<td>2010</td>
<td>48</td>
<td>35</td>
<td>3</td>
<td>86</td>
</tr>
<tr>
<td>2011</td>
<td>69</td>
<td>113</td>
<td>7</td>
<td>189</td>
</tr>
<tr>
<td>2012</td>
<td>93</td>
<td>274</td>
<td>17</td>
<td>384</td>
</tr>
<tr>
<td>2013</td>
<td>120</td>
<td>603</td>
<td>39</td>
<td>762</td>
</tr>
<tr>
<td>2014</td>
<td>150</td>
<td>1,279</td>
<td>88</td>
<td>1,517</td>
</tr>
<tr>
<td>2015</td>
<td>184</td>
<td>2,664</td>
<td>194</td>
<td>3,041</td>
</tr>
</tbody>
</table>

*Digital Storage in Consumer Electronics*, Thomas Coughlin, Newnes, March 2008
Exabytes Shipped for Consumer (OPTICAL DISK, HDD AND FLASH MEMORY)

- By 2013 over 600 Exabytes of storage shipped annually for CE applications

The CE Storage Hierarchy
Traditional computer storage hierarchy

- Computer scientists often refer to the characteristics of various memory devices as constituting a *storage hierarchy*. The concept of a storage hierarchy allows sorting various memory products based on important attributes or characteristics for the applications for which they are to be used.
- This figure gives a typical example of a computer storage hierarchy based upon data access speed.
Mobile consumer electronics storage hierarchy

- In this figure we construct a mobile consumer electronic storage hierarchy
- We look at Flash, HDDs and optical storage as a function of importance performance and cost considerations
Major components of a hard disk drive
(Image Courtesy of Hutchinson Technology)
HDD Advances

- Hitachi introduced a 500 GB 2.5-inch drive, 320 GB in notebook form factor by several manufacturers
- Toshiba introduced a 160 GB 1.8-inch drive (Samsung announced)
- Hitachi, Seagate, Western Digital and Samsung producing 1 TB 3.5-inch drives
- In Mobile 2.5-inch HDDs in 2007
  - FDE drives with in-drive encryption (Trusted Computing Group)
  - Hybrid drives with non-volatile flash used for HDD write cache (Hybrid Drive Association)
HDDs in Consumer Applications

- Digital Storage in Consumer Electronics
  (Coughlin Associates, January 2008)

- Decline in 2007 vs. 2006—particularly in mobile CE market—short term or long term trend?
- In 2007 majority HDDs in static storage with some mobile applications
Flash Memory

Sandisk Ducati

Corsair

Inexpensive PCs

SanDisk

Intel Z-P140

Samsung

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Increasing Flash Storage Density

• Line width reductions with semiconductor process development
• Multi-level cells increase storage capacity
  – However wear out faster with MLCs by a factor of 10X per doubling of per cell capacity
  – Smart flash controllers with wear leveling can hide most of this wear from the user (gradual degradation rather than catastrophic failure)
• Flash can also be stacked allowing denser volumetric storage
Flash Memory in Consumer Applications

Digital Storage in Consumer Electronics
(Coughlin Associates, January 2008)
More synergy than competition between flash and HDDs

• Most of flash memory used in CE applications where content is first downloaded to HDDs and then “temporary” copy loaded on flash memory for playout

• Many flash memory applications such as digital cameras usually reuse the flash memory, downloading the captured content to HDDs

• Both commercial and personal content (such as photographs) are often backed up requiring even more HDD content
Optical Disks
Optical Formats

CD
\(\lambda = 780\) nm
NA=0.50
650 MB

DVD
\(\lambda = 658\) nm
NA=0.65
4.7 GB

HD DVD
\(\lambda = 405\) nm
NA=0.65
15 GB

Blu ray
\(\lambda = 405\) nm
NA=0.85
23 GB

The Winner!
Holographic Storage
Professional Devices & Media

Archive for -
Professional Video & Data Archive

**DRIVE**  $18,000 List Price

- 300 GB Capacity
- 20 MB/S; 160 Mbs Transfer Rate
- 250 ms worst case seek time
- Form factor W: 5.750” H: 4.875” L: 26”

**MEDIA**  $180 List Price

- Write once
- 130 mm disc
- 3 year shelf life (prior to recording)
- >50 year archive life
- No special handling required
- 5.25” X 6” X .25”

Proposed Roadmap:

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Transfer Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>300GB</td>
<td>20MB/s</td>
</tr>
<tr>
<td>800GB</td>
<td>80MB/s</td>
</tr>
<tr>
<td>1.6TB</td>
<td>120 MB/s</td>
</tr>
</tbody>
</table>

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Optical Disk Drives in Consumer Applications

Digital Storage in Consumer Electronics
(Coughlin Associates, January 2008)

- Auto Navigation
- Auto Entertainment
- Camcorder
- DVD

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New and Emerging Digital Storage Applications
Roadmap to future automobile storage demand

- More integration of other functions into the electronics for navigation, entertainment, etc.
- Once autonomous driving systems go into consumer transportation, riders will have time to do more than just watch the road while they drive.
- Real-time traffic and road updates using a wireless network or radio system and a re-writable storage device such as a hard disk drive.
- Information on locations, commercial information on the area and other information automatically recorded in an automobile as it approached a destination.
Power in CE devices

• In mobile devices power is a serious design parameter.
• New power options:
  – Fuel cells
  – Wireless charging
  – Power saving and caching
• Power brings a mobile device “POWER”
  – Personal projectors
  – Wireless communication
  – More time for capturing higher resolution content
  – Drives storage

More power = more storage!

Potentially power hungry personal projector (Novellus)
Media Content Size Trends

![Graph showing multimedia object size vs. data rate.](image)

- **Virtual Reality, 3D Movie**
- **Ultra HD Movie**
- **HD Movie**
- **DVD Movie (MPEG-2)**
- **CD Quality Stereo Audio**
- **One page ASCII text**

**Multimedia Object Size**

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Digital Video Recorder

Inside a Tivo DVR

Circuit Board of a Tivo DVR
eSATA storage expansion box attached to an digital video recorder enabled set-top box.
DVR storage requirements over time  
(combination of internal and external storage)

<table>
<thead>
<tr>
<th>Year</th>
<th>Internal Storage</th>
<th>External Storage</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>40 GB</td>
<td>0</td>
<td>No valid ext. storage options</td>
</tr>
<tr>
<td>2010</td>
<td>80 GB</td>
<td>1 TB</td>
<td>Ext. storage options available</td>
</tr>
<tr>
<td>2014</td>
<td>160 GB</td>
<td>10 TB</td>
<td>Assumes able to retain considerable recorded programming</td>
</tr>
<tr>
<td>2018</td>
<td>320 GB</td>
<td>100 TB</td>
<td>Lots of stuff—some non-commercial</td>
</tr>
<tr>
<td>2024</td>
<td>640 GB</td>
<td>1 PB</td>
<td>Huge capacity anticipated</td>
</tr>
</tbody>
</table>

*Digital Storage in Consumer Electronics*, Thomas Coughlin, Newnes, March 2008
Metadata

• Metadata--information about a file or data object that allows easier search and use of the content
• Currently most metadata is entered manually
• Automated generation of metadata using content robots and sensors
• With inexpensive storage, metadata could become unlimited,
Block diagram of personal memory assistant showing major component functions

Digital Storage (>10 TB)

Experience Capture HW and SW (capture metadata includes location and time)

Life Log Device

Personal Map of Experiences, Places and Times

Life Search Function

User Interface and privacy protection

Off-line processing in home storage utility

Wireless background search and compilation

Such a device could require 10 TB of storage capacity on-board!
• This device only has 4 GB of flash memory at present
• This device “wants” a high capacity hard drive so it can capture higher resolution content
• Plenty of room for evolution of these types of products
Affect of Personal Recording on Home Storage Demand

Accumulated Personal Digital Content in 2015
Per Top 10% Household with 1 life-log

- **Life Log**: 92%
- Photos: 2%
- SD Home Video: 1%
- Email: 1%
- HD Home Video: 4%
- Commercial Content Capacity
- Personal Content Capacity

Digital Storage in Consumer Electronics 2008
(Coughlin Associates, release January 2008)
Personal Area Network Storage (PANS)

- A hard disk drive-based external storage device with wireless connectivity allows storage expansion, streaming and content aggregation.
Intelligence in CE Storage Devices
Digital Storage is a Significant Fraction of Total Product Cost

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DVR</td>
<td>250</td>
<td>$450</td>
<td>$200</td>
<td>$80</td>
<td>40%</td>
<td>HDD</td>
</tr>
<tr>
<td>Game System Ext. Storage</td>
<td>20</td>
<td>$90</td>
<td>$80</td>
<td>$65</td>
<td>89%</td>
<td>HDD</td>
</tr>
<tr>
<td>Personal Video Player</td>
<td>60</td>
<td>$390</td>
<td>$195</td>
<td>$130</td>
<td>67%</td>
<td>HDD</td>
</tr>
<tr>
<td>MP3 Player</td>
<td>4</td>
<td>$240</td>
<td>$190</td>
<td>$140</td>
<td>74%</td>
<td>Flash</td>
</tr>
</tbody>
</table>
USB-run software applications

- Flash memory devices are being created with greater intelligence and functional capability
- In essence a USB device is like a small portable computer
- Because a USB drive has its own CPU and a file system it is capable of performing applications
- USB application initiatives:
  - USB Flash Drive Alliance (UFDA)
  - U3
Flash Cache for HDDs

- Two approaches being promoted
  - Hybrid Drive or ReadyDrive with flash write cache in drive PCB
  - Robson or Turbo Cache with flash cache in motherboard
  - Maybe best combination of advantages of HDDs and flash memory
Trusted Drives

- (Partitioned) Hidden Memory
- Security firmware/hardware
- Trusted Send/Receive Commands
- Assign Hidden Memory to Applications

From Seagate, DPS 2007
Putting Applications on Storage Devices

- For many applications the digital storage device is highest cost items in the BOM
- Many CE applications are reaching a level of maturity that they could be implemented as a sequence of standard command calls in the hard drive electronics
- Reduced cost of CE products by eliminating second circuit board and integrating product test into drive test

- Modern hard disk drive printed circuit assemblies (PCAs) are much smaller, typically occupying only a fraction of one side of a 3.5-inch hard disk drive.
Example of Applications on a Hard Disk Drive

Disk Drive SoC
(CPU, Elec. Channel, ECC, Servo and Interface Control)

Other Electronics And Drive Connections

Motor and VCM Control Electronics

Analog Application Electronics
(Antenna Interface, Display Driver and Human Interface)

Flash Memory and Proprietary PMP Program
(Possible 2nd CPU, CE Interface)

ATA Interface

CE Interfaces

Power

Give designers new ways to improve performance and save money!
Connecting Everything in the Home and Home Virtualization
Typical Home in 2017 (Home Storage Utility)

- Things won’t look like they do now
- Everything will be connected
- Content and storage will be shared and there will be many copies—storage is cheap and capacities are large
- Content is managed, indexed and automatically backed up
The home storage utility should provide the following basic functions:

- content backup and deduplication in the home
- content backup outside the home (to provide home disaster recovery)
- content sharing in and around the home with optimal use of network resources
- indexing and organizing home content
- synchronization of content as needed
- Automatic management and control of storage and network resources
Conclusions

- The demand for storage for CE applications is very elastic—if they have more storage they will use it!
- The modern storage hierarchy is more complex than in the past and includes more storage options depending upon performance and storage economics.
- Digital storage enables new applications for mobile and home devices that should make managing, organizing, preserving and using content easier.
- With the growth in personal content and content sharing through social networking the growth of digital storage for consumer applications is virtually unlimited.
- Managing, organizing and protecting home content will lead to new concepts applied to virtualize and aggregate digital storage in the home.
Sources

- **Digital Storage in Consumer Electronics Report 2008**, Coughlin Associates
- **Consumer Survey on Digital Storage in Consumer Electronics 2008**, Coughlin Associates
- Presentations at **2006, 2007 and 2008 Storage Visions Conferences** ([www.storagevisions.com](http://www.storagevisions.com)) and CES

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