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Education

Fundamentals and Futures of Long Term Storage Media

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Abstract

- Fundamentals and Futures of Removable Long Term Storage Media
  - This session will appeal to those curious about the "nuts and bolts" of solutions to meet the digital storage requirements of today. Do requirements drive solutions or reverse? How have tapes matured and what is their potential? Why is it important and who is buying them? What happened to large or small-format optical disks? What happened to Emerging Technologies of the past? Are storage limits economic or physical? What about forward/backward compatibility? How big does the catcher's mitt have to be?

Personal Background

- '83 – introduced to optical disk technology
- '84 – met industry leaders/saw LOC installation
- '85 – first consulted for USAF & NASA
- '86 – first technology survey published
- '87 – introduced to analog tape systems (THIC)
- '90 – made first presentation of storage media
- '93 – published Media Mania! The Fundamentals and Futures of Removable Mass Storage Media
- '94 – MM: 1st electronically-published book in Brazil
- '97 – 5th edition released/Bill Gates/Explorers Club

Resetting the Research Clock-1

- Printed Pre-Internet Sources
  - Laser Focus World
  - Electronic Engineering Times
  - Government and Military Video
  - The BMDO Update
  - Optical Memory News
  - Washington Technology
  - Heads Up News Service
  - Datapro Information Services
  - Computer Technology Review
  - Journal of Electronic Defense
  - IEEE: The Institute
  - BYTE Magazine
  - Electronic Design
  - Photonics Spectra
  - Imaging Magazine
  - Popular Science
  - Datamation
  - Business Wire
  - Scientific American
  - NML Bits

Resetting the Research Clock-2

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- Pre-Internet Conferences and Meetings
  - THIC (Tape Head Interface Committee) founded to ensure inoperability of scientific tape drive/media systems
  - Goddard Conferences on Mass Storage Systems and Technology
  - AIIM (Association for Information and Image Management) National Conferences
  - Proceedings from the Fifth Biennial Non-Volatile Memory Technology Review
  - Optical Storage Association
  - Proceedings of the International Telemetering Conference, ITC/USA/'89
  - IEEE Symposiums on Mass Storage Systems ('97-'11)

Paper vs. Pits

Baseline Definitions

- Paper scanned at 200x200 with 10:1compression, 1 GB represents 20,000 digital images, enough to fill 4-four drawer file cabinets. (64 GB i-Pad holds 1.28M images)
- 1,000 GB = 1 Terabyte
- 1,000 TB = 1 Petabyte
- 1,000 PB = 1 Exabyte (a trillion million bytes)
- 1,000 EB = 1 Zettabyte (a trillion billion bytes)
- 1,000 ZB = 1 Yottabyte (a trillion trillion bytes)
- 1,000 YB = 1 Brontobyte (coined by US Navy Commander Rick Kercz to identify something REALLY big!)

Historic Paper Math Magic

- Resource usage:
  - 500B pages of ASCII requires 42,000 trees to print
- Weight at Sea
  - In '93, the avg weight of the paper (37 tons) on a Naval vessel was just short of the weight of the planes on board!
- Weight in Space
  - In '90 paper cost $30,000/lb to launch into space
- What is an LOC anyway?
  - In '90 the GAO stated the text of the 15M books in Library of Congress would fit into 10.5 TB

12-Inch Optical Platters

- Early Progression of WORM
  - Spring '84: Thompson CSF Digital 1 GB Optical Disk used by IA in 100-platter jukebox at LOC. (Xerox first in '82)
  - Fall '84 – Fall '95: 2 GB to 15 GB
- First Users:
  - Banks, Hospitals, Gov agencies, military, security, etc.
- WORM Conclusion
  - Spring '97: 16 GB, 26.4 Mbps projecting 30 GB in '99
  - Goal '97: 60 GB in future
  - Reality '00: Final generation of 30 GB reached

14-Inch Optical Platters - 1

- Initial Erasable/Rewritable Magneto/Optic Systems
  - May '86: RCA working to develop m/o disk system: 125 GB on 12 14-inch platters in stand-alone unit
    - RCA bought by GE then Martin Marietta
  - July '92: Martin Marietta and NASA Langley completed system based on 11.4 GB m/o disks (SODR)
  - July '93: Martin Marietta and USAF Rome Labs developing Mil-Std 1 GB m/o disk (S/TODS)
  - Spring '96: Kodak and USAF Rome Labs developing 15 GB m/o disk
- *"Probably killed by 5.25 media for economies of scale and investment."*

14-Inch Optical Platters - 2

- WORM SYSTEMS
  - Spring '86: Kodak announced 6.8 GB - released at 10.2 GB
  - Spring '94: Kodak announced 14.8 GB
    - Loral: $1B for IRS 770 TB DPS using Kodak – cancelled 10/96
  - Spring '96: Kodak announced goals:
    - 25 GB by mid-98 *System development stopped here.*
    - 50 GB by mid-99
    - 200 GB by '01 with layered phase change technology
  - Spring '95, Kodak, SDL and Carnegie-Mellon received 4-year $6.3M grant from Dept of Commerce to store 1 TB using blue-lasers, multi-layered platters, and advanced r/w heads

From Entertainment to Data Storage

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- '81 Introduction of CD-Audio
  - Dr Toshi Doi
  - From Consultant to Chairman: Norio Ohga (1930-2011)
  - Why 650 MB to hold 74 minutes and 44 seconds?
  - Commercially available since '82
- '85 Introduction of CD-ROM
  - 650-900 MB on single side
- '95 Introduction of DVD Came to US: 3/97
  - Single-sided 4.7 GB – enough to hold a single movie!

Invasion of Handy 5.25-Inch Formats

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- WORM Progression
  - '93: 940 MB uncompressed (Phase Change)
  - '95: 2.5 GB compressed
- Rewritable Magneto/Optic (M/O) Systems
  - Note: disk was the same size as center hole of RCA 14"
  - '85: 3M predicted 300-500 MB m/o disk
  - '93: Sony and 3M introduced 1.3 GB
  - '96: 2.6 GB systems shipped
  - '97: 4.6 GB dual-sided systems shipped
- '11: 30 GB WORM and M/O Shipping

Analog turns digital

- Beta vs. VHS
- State of Requirements vs. State of the Art
  - Outer space and inner offices!
- Early adopters
  - Drive changes
  - '90 AIIM Convention mayhem
- 19mm formats: Broadcast to Brontobytes
  - '93: Digital Data -1 (DD-1) 16-micron Ferric-oxide tape
    - DD-1S (Small): 16 GB; DD-1M (Medium) 40 GB; DD-1L(Large) 96 GB
  - '93: Digital Data-2 (DD-2) 13-micron metal-particle
    - DD-2S: 25 GB; DD-2M: 75 GB; DD-2L: 165 GB
  - '96: DD-2 capacities doubled: S: 50 GB, M: 150 GB L: 330 GB

Historic-Amazing Tapes!

- Single hub-Format on 0.5 inch tape
  - '84: Capacity – 200 MB
  - '96: Capacity – 20 GB (100x improvement)
  - '11: Capacity – 800 GB (DLT)
  - '11: Capacity – 5 TB (250x improvement) (3480-type)
  - Projected: 35 TB
  - Goal: 100 TB
- Cassette (2 reel) –Formats/Current Capacity
  - 0.15 inch (4 mm)/36 GB
  - 0.25 inch (6.35 mm)/70 GB
  - 0.31 inch (8 mm)/ 400 GB WORM

The Marriage of Optical and Tape

- Open Reel Optical Tape - Circa: '87-'95
  - 14-inch 10-pound Terabyte WORM
  - Space Data Users: Canada, South Africa, Australia, Saudi Arabia and France
  - Naval Users: Canada
  - Proposed US Placement: Internal Revenue Service
  - 35 drives in place by '95
- 3480-style Optical Tape – Circa '89 – '97
  - Capacity: 1 TB
  - From ATP to auction

1991-1996 Emerging Technologies-1

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- Progression of laser colors from 7/93-2/96:
  - Blue Laser on 5.25" magneto/optic disk
    - Please thank IBM Research, Boston, Brown & Purdue Universities
    - Capacity: 6.5 GB using VHS-size Blue laser device
    - '96 developers included Philips, Sony, Toshiba
  - Blue-Green Laser
    - Sony worked to increase CD/DVD capacity
    - Rome Labs managed $12B for 3M, IBM, Philips NV and Philips USA to store 20 GB on 5.25-inch dual-sided m/o disk
  - Green Laser
    - Sony Research developed early of the green laser diode.

1991-1996 Emerging Technologies-2

- HD-ROM ('95)
  - Los Alamos National Labs: Used ion beam to etch data on 2" pins of long-lasting material.
    - Data read with Atomic Force Microscope
  - Corporate adoption of HD-ROM ('97)
    - Projected to store 650 GB on 12cm (4.72") optical disk
    - Particle beam used to etch in metal is 50 billionths of a meter wide
  - Recent applications '08-'11
    - The ion beam is used to etch personal information on diamonds and gems stones for identification
    - The Rosetta format is similar to high density microfilm except on 500-micron thick nickel discs. Thinner nickel discs - like 100 micron or less could be used. A recent project was completed that had 18,000 images placed in a two inch diameter circle

1991-1996 Emerging Technologies-3

- Crystal Cubes ('96)
  - 3D Technology Labs demonstrated a stamp-sized prototype cube of fluoride-glass layers doped with rare-earth metals to emit blue of green light when excited by 2 intersecting laser beams to display a 3D image.
- Multi-layered Holographic Disks ('94)
  - '94: Tamarack Storage Devices designed the Multi-Store WORM disk composed of 30 recording layers each storing 1 GB on DuPont photopolymer material.
  - '95: Stanford's Center for Nonlinear Optical Materials demonstrated the first fully automated digital holographic data storage systems by storing a picture of the Mona Lisa.

1991-1996 Emerging Technologies-4

- Multi-Layered Improvements ('94-'96)
  - Goal: 10-100 thin layers promising 1-5 TB
  - '11: 2-layer DVD: 8.54 GB, Blue-Ray: 25/50 GB
  - '19: multi-color, multi-layer: 10 TB projected!
- Bytes on Bacteria: Halobacterium Storage
  - Predicted 480 GB in "matchbox" optical device.
  - Status: undetermined
- Ion-Etching Technologies!
  - Potentially improving lasers in HDD/CD/DVD recording heads

1991-1996 Emerging Technologies- 5

- "Electronic" Microscopy
  - Inventers of these technologies won '86 Nobel Prize
  - Atomic Force Microscope ('94)
    - Goal: Store content of CD on 1cm disc
    - Reduce power consumption a million fold
  - Scanning Tunneling Microscope ('94)
    - Goal: store 10,000 hard drives on a thumb-nail device
    - Bit size 10-70 billionths of a meter (nanometers)
  - '09 Goal: Putting a supercomputer on a sugar cube

1991-1996 Emerging Technologies- 6

- Memory Cards ('94-'96)
  - Terminology: semiconductor memory, postage size PCMCIA storage, 1 GB DRAM 1x1.5-inch, "small" cards to replace 45 floppy disks, and SSFDC or Standard Small Format Data Cards
  - Goal Applications: digital cameras, portable information equipment, pocket-size music players or personal computers

1991-1996 Emerging Technologies- 7

- Memory Cards ('11)
  - 8-128 MB Smart Memory Cards (SSFDC)
  - PCMCIA replaced by Express Card/computer i/f in '03
  - DRAM currently competing with Flash memory
  - Semiconductor memory widely used in smart phones, Mobile PCs and tablet computers
  - New phones sell with 32 GB microSD cards small enough to lose easily – *when was your last backup???*

1991-1996 Emerging Technologies- 8

- Hard Drives ('96)
  - Ohio State intro 1-molecule lubrication
  - Zurich Research Labs: nanoscale abacus of Buckyballs
  - Demonstration of 5 Gb/in^2
- Hard Drives ('11)
  - Released 9/11: 4 TB in 6x5-inch format. Dual enclosure can provide 8 GB
- The "Electron" in Electronic Storage ('93-'96)
  - Goals: storing 1 bit per electron & writing on an atom
  - Goals: Developing quantum dots for 15,000x storage
    - Initially more suited to Qubit computing than storage ('11)

1995 – The 6 ATP Award Winners

- Department of Commerce funded the following:
  - NOTE: The government funded these kind of programs for two reasons: to stimulate growth and create leading-edge jobs AND to be sure we were prepared for the data tsunami they could see from the crow's nest position!
  - High Performance Variable Data Rate, Multi-Media Magnetic Tape Recorder ($10.4M)
  - Enhanced Rigid Disk Drive Technology: High Resonance Suspension ($1.9M)
  - Digital Data Storage Technology via Ultrahigh-Performance Optical Tape Drive Using Short-Wavelength Laser ($1.9M)

1995 ATP Ward Winners (cont'd)

- Technology Development for Optical-Tape-based Rapid Access Affordable Mass Storage (TRAAMS) ($11.5M)
- Ultrahigh-Capacity Optical Disk: Multi-layer Short Wavelength Write-Once and Erasable Optical Disk Recording System ($10.3M)
- Revolutionary High-Density, High-Speed Low-Cost Optical Information Storage Technology ($1.9M)

- TOTAL: $37.9M in funds for advanced storage technology. Important then – Important now.

Mid-2011 Emerging Technologies

- "Stone-like" Optical Disc aka the M-Disc
  - 1,000 year lifetime Capacity: 4.75 GB
  - Media tested at Naval Warfare Center
  - I/O speed: 5.28 MB/sec (1/2 DVD Rate)
  - Readable on any "upgraded" DVD player
  - Predicted late '11
- Micro-holographic 4.72" Optical Disc
  - Capacity: 500 GB
  - Goal: 1 TB
  - I/O speed: 10.56 MB/sec (DVD Rate)
  - Predicted: '12

May 2011 IEEE Storage Drivers

- Large Hadron Collider (CERN)
  - '10: 93 PB(T)/99 PB(HDD) – '12:166 PB(T)/165 PB(HDD)
- Yahoo
  - 100B events/day = 200 PB with additional 50 TB/day
- Hollywood
  - 2 TB/movie x 25/year x 25 versions each = 1.25 PB +
- NASA National Center for Climate Simulation
  - Anticipation of 300 TFLOPS filling 8 PB data archives
- High Performance Storage Systems (HPSS)
  - 35 PB stored; growth: 250 PB by '15

Q&A / Feedback

- Please send any questions or comments on this presentation to SNIA: tracktutorials@snia.org

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