Moore's law is no law of nature

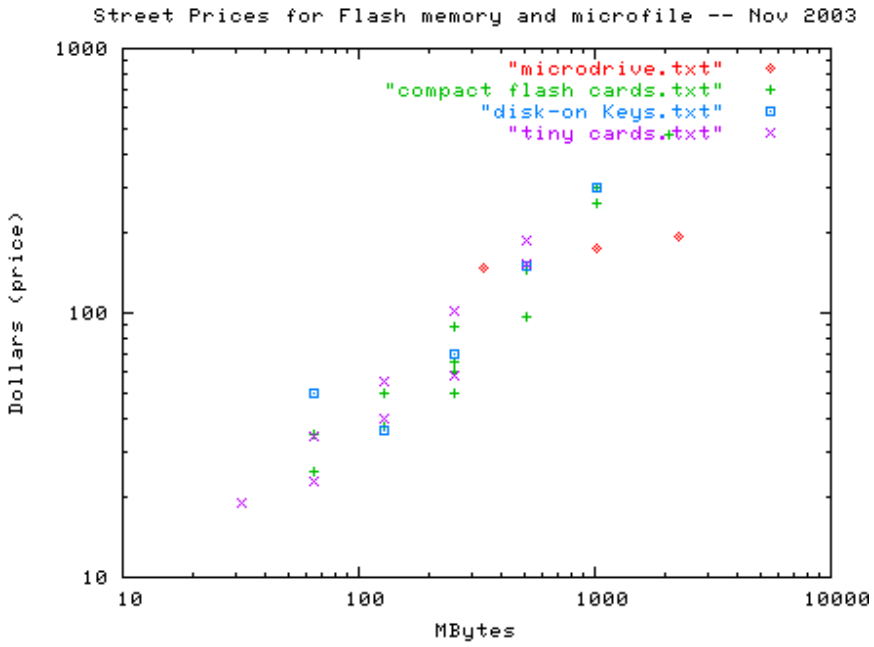
A social imperative, so
It requires organization and planning

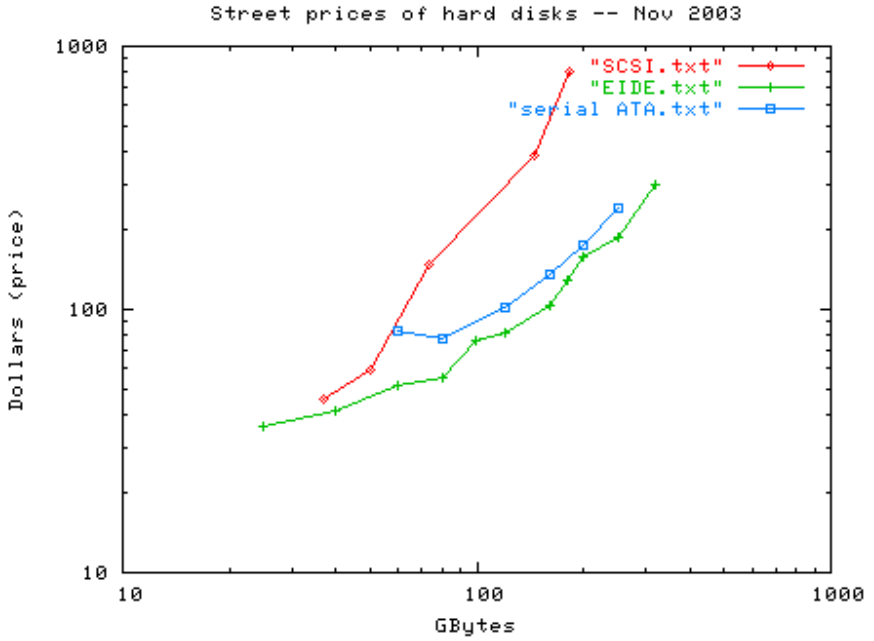
Individual companies have regular processes
- Technology outlook
- Strategy
  - Core competencies
  - Make or buy
- Business plan for technology development

Industry wide activities
- Semiconductor industry
  - http://public.itrs.net
  - SIA, KSIA, TSIA, EECA, JEITA
    - and Sematech
  - 2003 edition of Roadmap due Dec 2, 2003
- Magnetic recording industry
  - www.nsic.org → www.insic.org
- Batteries
  - Intel has taken some responsibility for this !!
  - Roughly 10 year doubling time
    - Limited by time to introduce each new system
- Communications links
  - Standards organizations are dominant fora

Technologies are predictable, infrastructure is not

Street Prices and sweet spots -- 2003





Sources: www.amazon.com, www.pricewatch.com . These things change at least weekly.

Storage Technology Trends

Three or four technologies:
- Hard disk, magnetic tape, optical disk, (holographic?)
- Consumer markets attract the major investments
  - CD-audio disk, VCR tape brought major advances
    - DVD media currently the cheapest per GB
    - miniDV tape newest development
  - Next consumer outlet – hard disk for settop box

Information sources from the storage industry:
- Thompson and Best article on magnetic recording (IBM JR&D)
  - Note figs. 1, 2, 12
- NSIC studies
  - Optical Disk Roadmap, 2/2000
  - Holographic Storage, 3/1999
    - May displace tape someday, not before 2010
  - Tape Roadmap, 6/1998
    - (As reviewed by “spy tape” users in 2001)

How they work:
- Magnetic storage
  - Writing by inductive (thin film) heads, continuous media
  - Reading is inductive for tape, magnetoresistive for HD
    - Inductive signal proportional to medium speed
    - MR signal is “medium noise limited”
  - Limits are thermal demagnetization
    - Proposed solution – nanopatterned bits
- Optical
  - Has least expensive “printing” technologies
  - Laser to read or write benefits from shorter wavelengths
  - Less delicate than tape or hard disk

Storage Technology, ctd.

Cost comparisons:

Go to http://www.pricewatch.com

Drives range from dirt cheap to limiting in their expense:

Floppy drive	$3
DVD reader	$30
CD-RW/DVD	$70
DVD-RAM	$300
DLT tape	$500
Ultrium tape	$3000

Media prices

DVD-R media	$1-2 for 4.7/9.4 GB ($0.1-0.2/GB)
Mini-DV tape	$5 for 12.5 GB ($0.4/GB)
DLT, Ultrium	about $0.75/GB

Laptop and desktop files: (figures from Haystack, Pricewatch)

Magnetic Tape

- Has offered best medium information density (3D)
  - 0.5 TB/cm^3 by 2010
  - Currently laptop hard files are passing tape:
    - miniDV tape cassette 38 cc, 12.5 GB => 330MB/cc
    - laptop 40GB hardfile 60 cc, 40 GB => 750MB/cc
- Analysis:
  - Heads
    - Borrow technology from hard files
  - Media
    - 1000 bpi → 20,000
    - tpi only 50-500, with 100 typical
  - Channel, transport, etc…
- Worst for access time
- Media costs need to be 1% of disk for viability
  - This was true 10 yr ago, but ratio dropping to 10-20%
- Conclusion – tape will be increasingly restricted to high end
  - Backup systems (increasingly automated)
  - Personal archive (fits in a car trunk, top of closet…)
  - Reliability the major issue:
    - Heads wear, so that reading old tapes is uncertain

Storage Technologies, ctd.

- Optical disk ("inferior in every way to magnetic recording" – DAT)
  - Fundamentally a low end technology for information distribution
    - Too big for PDA's or camcorders
    - unless 2.5" format succeeds
  - 15 yr prevalence of audio CD, now CD-ROM (120 mm)
    - Red Book, Yellow Book standards make CDDB possible
  - CD-ROM, -R, -RW 680 MB
  - DVD family 4.7 – 17 GB (originally stamped)
    - 17 GB requires 2 sides, 2 layers
  - DVD-R, -RW (1000 writes) and –RAM (100,000 writes)
    - Still incompatible
  - TV/Movies drive desired storage size
    - 4 hrs of SDTV = 10-20 GB
    - 4 hrs of HDTV = 40-90 GB
  - Blue lasers, magneto-optical hybrids make 30 GB possible
    - (by 2010 ?)
    - and 2 GB/cm^2
  - Control of copyright slows infrastructure devlopment

Progress in Magnetic Disks

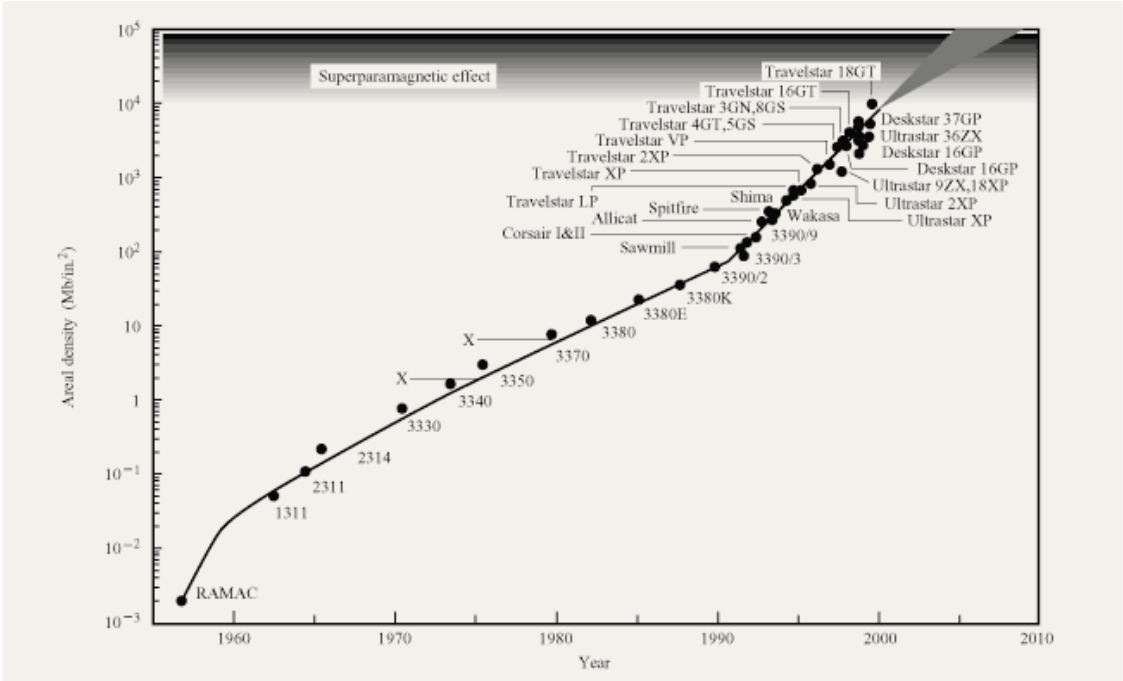


Figure 1

Magnetic disk storage areal density vs. year of IBM product introduction. The Xs mark the ultimate density predictions of References [4] and [5].

Magnetic Storage, ctd.

Magnetic hard disk
- Has scaled dimensions 1000x since introduction in 1956
- At least 3-10x more is possible without radical change
- Currently density/$ improves 2x per year (an anomaly)
  - 4/2002 Pricewatch → $1/GB !
  - historic rate of improvement -- 2X in 2 yrs
  - expect 30-100X further improvement in decade
    - $0.10 - $0.03/GB (= 1 TB for $30-100)
- MR heads (insensitive to head velocity)
  - noise a media issue alone
  - greatly increased sensitivity (GMR…)
- Trend to smaller diameter files is driven by vibration, datarate
- 2x reduction in S/N requirements possible with longer ECC
  - advantage for video and media (Tivo, music players)
  - disadvantage for small records
- Nano-patterned "grains" could give another 10x in density
  - after 2010

What to expect in this decade:
- Tape → 1-2 GB/cm^2
- Optical → 2 GB/cm^2
- Hard disk → 3+ GB/cm^2

Capacities depend on useable areas of rotating media
- 5.25", 3.5", 2.5", 1.25" → 111, 52, 25, 8 cm^2

Optical disks
- Expect DVD to dominate after 2003
- Mainstream products 20-30GB

Hard disks
- 3.5" disk, 4 surfaces → >640 GB in 2005, 2-5 TB in 2010
- 2.5" disk, 2 surfaces → 100-200GB in 2005, 0.6-1TB in 2010
- Microfile (ultrathin) → 15-30GB in 2005
  - (6-12 hrs of MPEG2 video!)
  - (but…is the market there to pull this along?)