Personal Removable Data Storage

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Since the dawn of the electronic computer age in the 1950s, storage and control of data has been a recurring demand for multiple reasons, some individual, some enforced by an employer, others required by the environment (e.g. security). Until the 21st century, data removability – the ability to take one's personal data and programs with you – was a relatively niche market, but one with a rich history which is described in this paper.

Tape

Introduced in 1801, the "Jacquard loom is often considered a predecessor to modern computing because its interchangeable punch cards inspired the design of early computers". [1] The chain of loom cards was big and clumsy, but a user-friendly paper tape alternative[2] came into wide use for telegraphic communications in the 1840's.[3] In the rapid development of computers after World War II, a Teletype terminal with paper tape reader and punch was a common input/output device.

When minicomputers appeared in the early to mid-1960s, they often relied on paper tape as an I/O medium. Teletypes remained a widely-used I/o device. In 1961, the LINCtape[4] was introduced as the primary storage peripheral for the MIT/NIH LINC computer (Massachusetts Institute of Technology / National Institutes of Health Laboratory Instrument Computer). The LINCtape reel was 3.5" in diameter, the media had a fixed block format, and a block could be accessed in either direction. The random-access capability made it an excellent (though slow) device. Since the latter was a federally funded project, the plans were public domain, and a number of companies built their own. DECtape was the most successful, in part due to DEC's dominance of the minicomputer market.

		
Chain of Jacquard cards	Teletype with paper tape	DECtape reel and cartridge

Source: https://upload.wikimedia.org/wikipedia/commons/0/09/Jacquard.loom.cards.jpg

Source: https://en.wikipedia.org/wiki/File:Teletype_33_ASR.jpg

Source: https://en.wikipedia.org/wiki/File:DECtape.jpg

Hewlett Packard's programmable desktop calculators used magnetic cards to load programs and store results. The cards came in different sizes, depending on the machine, with the smallest being those used by the handheld HP-65 calculator. [5] When the 1972 HP 9830 calculator replaced the cards with cassettes, it was the first use of the Philips compact audio cassette for data storage.

When 3M introduced the DC300 cartridge in 1972, it founded a dynasty. The trade association QIC (Quarter Inch Cartridge) issued a plethora of standards which endorsed member company variations. To stay relevant, the cartridges changed size to accommodate 8mm media, extended tape length to boost capacity, and in 1989 made a failed attempt to compete with the DC100 by shrinking in size.[6]

When higher capacity was needed for its calculators, HP and 3M co-developed a 1/3 sized variation of the DC300. Like its big brother, the 1975 DC100[7] spawned a family of devices in part because it fit the standard 3.5" PC front panel slot. It became a popular backup choice on personal computers using the standard IBM floppy disk drive interface.[8]

The first microcomputers were sold in kits, and honors for the first assembled microcomputer go to the French company R2E, which sold the Micral N for process control applications in 1973. The Altair 8800 computer kit featured on the front cover of *Popular Electronics* in January 1975 ignited home computer growth. The compact audio cassette became a mainstay storage medium for this new class of computer after *Popular Electronics* published an article in September on how to use tones to represent digital 0s and 1s. *Byte* magazine took things a step further in 1976 when it published the "Kansas City" cassette standard in its first issue.[9] The FloppyROM vinyl record bound into magazines distributed software (the turntable's audio output could be plugged into the cassette interface). Computer software broadcast on radio could be recorded, and played back.[10]

The 1977 Commodore Pet integrated a cassette into the case, and sold the Datasette as an accessory. [11] Digital recording gave a huge uptick in data reliability and third-party cards quickly appeared to provide the same benefits to competitor's models. Europe embraced the digital cassette, but the clock had run out in the United States as the floppy disk became the preferred peripheral.

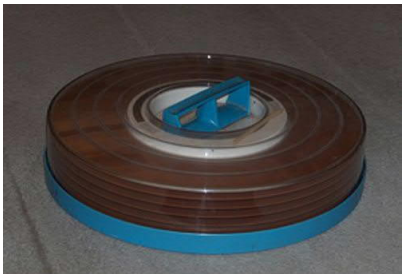
'Big Iron' Cartridges

IBM in the 1950s had two types of customer: commercial (decimal architecture) and scientific (binary/floating point architecture). The two most popular models were the IBM1401 (~12,000 units) and IBM 1620 Data Processing Systems (~2,000 units). Unlike IBM's other scientific computers, the

1620 used the variable length decimal logic of the 1401 and was equipped with similar peripheral complements. The 2311 disk drive, with its 1316 disk pack, was primarily used as a program loader to replace paper tape and punched cards.

Scientific users were more individual than commercial, and IBM marketing identified the lack of 'personal control' over data as a marketing deficiency on the 1620. The successor IBM 1130 Computing System addressed this by introducing the 2310[12] disk drive and the companion 2315 cartridge to complement the 2311/1316 pair. The 6-platter 1316 disk pack weighed almost 10 pounds and the single platter 2315 weighed less than 2. More importantly, the 2315 was not a machine room purchase, it was a consumable – it could be paid for out of a department budget. Individual contributors were able to control access to their research by removing their 'own' 2315 and storing it on a shelf in their office.

The 2315 was an ‘insert’ cartridge, the 5440 designed for the System/3 chose to use the disk pack top loading method. The cartridge could be better sealed, which reduced the level of contamination caused by the way users stored cartridges. The 5444 drive supported low- and high-density cartridges.

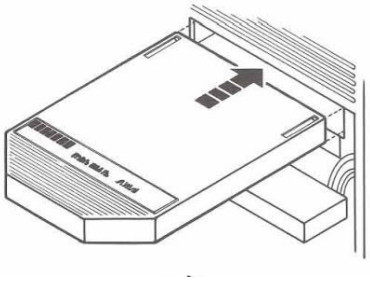
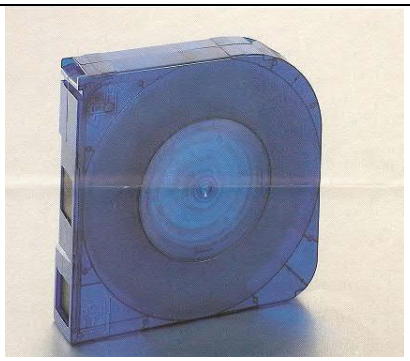
		
IBM 1316 Disk Pack	IBM 2315 Disk Cartridge	IBM 5440 Cartridge in use

Source: https://archive.computerhistory.org/resources/physical-object/ibm/L2006-1-3.lg.jpg

Source: http://images.computerhistory.org/revonline/images/x761.86p-03-01.jpg

Source: http://www.ibmsystem3.nl/images/IBM5410g.jpg

The best was yet to come as the cartridge became ubiquitous on minicomputers. Digital Equipment (DEC) sourced the 1971 RK02/RK03 from Diablo Systems until the DEC-built RK04/RK05 replacements were ready for shipment. The unique 5440-like RL01 in 1975 may have been the first use of an embedded servo and the RK06/RK07 added a platter, which used a dedicated servo surface. CDC used density advances to boost capacity on the CDC 9448, last of the 14" cartridges.

		
DEC RK07 Disk Cartridge	DEC RC25 Disk Cartridge	CDC 1209 RSD

Source: http://q7.neurotica.com/Oldtech/Media/RK07K-DC-4L.jpg

Source: http://www.vaxhaven.com/images/b/b2/EK-0RC25-UG-002.pdf

Source: http://q7.neurotica.com/Oldtech/Media/CDCL1209RSD.jpg

DEC's use of 8" diameter disks resulted in the compact RC25 drive which was not embraced by the user base.[13] [14] CDC's 8" Lark family[15] met with better acceptance but it too was the end of the line. The 9" CDC 9710[16] and 3-platter CDC 1209 was a one-shot wonder which blurred the distinction between disk cartridges and disk packs.

Floppies

IBM developed the floppy for its own use as a microcode program loader, and the drives were read-only.[17] IBM was slow to realize that a read/write drive was a user-friendly storage product, and Memorex shipped the first such drive in 1972. Shugart Associates was founded in 1973 and became the dominant producer.[18]

Word processing computers had become a big business, and Wang Labs argued for a smaller form factor that cost less. Shugart Associates introduced the 5.25" floppy disk in 1976. The next transition occurred in 1982 when Sony was chosen as a supplier of Microfloppy Industry Committee-compatible 3.5"[19] drives by Apple. The soft cover of the previous floppies was replaced by a hard plastic cover with a shutter to reduce exposure to dust and dirt.

	
IBM 23FD (Read Only) Floppy	Shrinking size and 3.5" use of shutter to reduce contamination

Source: https://commons.wikimedia.org/wiki/File:Floppy_disk_2009_G1.jpg

Source: https://pbs.twimg.com/media/D7dMR1KXkAAeTCy?format=jpg&name=360x360

At the height of its influence, Shugart Associates had to cede 'ownership' of the floppy world to the multitude of other floppy manufacturers - Xerox had bought the company, and by prior agreement any manufacturing offshore had to be approved by Fuji Xerox, which never came. As floppy prices plummeted, Shugart Associates could not compete. [20]

Capacity was not controlled by the drive, it was a function of the controller, and few formats were alike. The floppy became a primary storage device when Apple II incorporated two 5.25" drives in its 1977 Apple II computer, and other manufacturers followed suit. There was little or no interchangeability between machines until IBM introduced the PC in 1981. The PC format became a de facto standard through generations of single-sided, double-sided, and areal density increases. The floppy as primary storage for personal computers ended when Seagate pioneered the 5.25" hard disk drive.

A wide variety of small floppies were used for proprietary purposes in cameras, word processors, and some microprocessors. None of them saw wide adoption.

Bernoulli

IBM retained an interest in removable media but changed direction from rigid disk to a project pursuing high density recording on flexible media. When the project being pursued in IBM Boulder's tape lab was killed in 1969, a number of disappointed engineers left IBM to found IOMEC. A prototype failed to attract sufficient funding to bring a product to market. IBM Hursley (UK) initiated a similar technology effort in 1975. The project was transferred to IBM Boulder in early 1978 and met its demise in late 1979 after the tape division was re-located to Tucson.

The technology which appealed strongly enough to justify two projects in two labs separated by an ocean is based on the Bernoulli effect which maintains a cushion of air between a spinning flexible disk and a read/write head. See Appendix A.

History repeated itself. Disappointed IBMers went off on their own, and Iomega was founded on April 1 of the following year. The Bernoulli Box was introduced two years later with a 5 MB removable cartridge. The cartridge was a rectangle, amost the size of a ream of paper, and met success in the Apple world of graphics and publishing applications. Reliability was as much or more of a promotional point than removability. Iomega boasted in its advertisements that heads could not crash.

The drives were external and often stacked in pairs, there was even a portable ‘suitcase’ so it could be used between different computers. Doubling capacity to 10 MB, and again to 20 MB did little to lower the price premium over hard disk drives. The vaunted reliability endeared it to markets where cost was less of an issue than data protection.

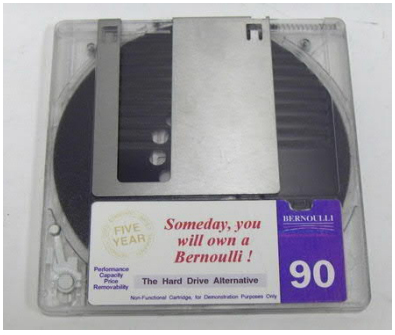
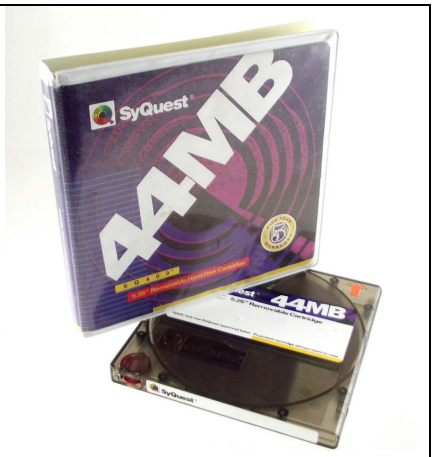
		
Pair of Bernoulli Box Drives	Pair of Bernoulli II Drives	Syquest SQ5110 Drive

Source: http://www.brutman.com/Bernoulli_Box/Bernoulli_A220_cutout.jpg

Source: https://i.etsystatic.com/20693881/r/il/8214fa/4875511998/il_1588xN.4875511998_c8mm.jpg

Source: https://i.ebayimg.com/images/g/5nIAAOSwm1Nfz9vT/s-l1600.jpg

The 1987 Bernoulli II drive fitted a 5.25" PC slot and the cartridge resembled an oversized 3.5" floppy. It was not unusual to see tower cabinets with several drives. The initial introduction was 20 MB, and density improvements were made on an irregular schedule until it reached 230 MB in 1994.

		
Bernoulli Box Cartridge	Bernoulli II cartridge	SyQuest SQ400 Cartridge

Source: http://legacycomputersnparts.com/catalog/images/PICT0006.JPG

Source: https://www.computerhistory.org/collections/catalog/102691690

Source: https://obsoletemedia.org/wp-content/uploads/2014/10/SyQuest-5.25-inch-disk-cover-200x230.jpg

High-Capacity Rigid Cartridge

A new entrant in the removable market was SyQuest, founded by ex-Seagate personnel. They knew the rigid disk world well and were determined to bring a high-capacity removable product the size of the next smaller floppy. A successor had not emerged yet, and SyQuest bet on the IBM 3.9" format, which lost to the Sony 3.5".

The path to production of the 1984 SQ306RD with its 3.9" 5 MB SQ100 cartridge was littered with failures because the rigid platter required superior media and a clean environment. SyQuest was forced to develop and manufacture its own media, until the facility was sold to Domain Technology. Capacity improvements to 10 MB and 15 MB followed rapidly but were no threat to Iomega's Bernoulli Box, except in federal agencies.

Cleanliness is a virtue difficult to achieve in a removable media. See Appendix B.

SyQuest's 1986 SQ555 was a home run, its SQ400 cartridge offered 44 MB capacity and took Iomega's market by storm. Within a year the SQ400 became the preferred medium of interchange. The re-packaged Bernoulli II did little to stem the tide, and with its stranglehold on the specialty Apple application markets SyQuest appeared invincible. SyQuest was well aware of the risk that contamination represented to reliability, and recommended that cartridges be stored in the case they were sold in.

Prior to going public in 1991 SyQuest was said to control 90% of the removable storage market, primarily for the Apple and federal agencies markets.[21] The appeal, however, was universal, and it was so well-liked that it became the primary disk storage for some manufacturers.[22] [23]

SyQuest practiced the razor blade strategy of selling an attractive product at a loss, while reaping profits from the consumables it requires (in this case, blank cartridges). The increased capacity SQ cartridges of 88 and 200 MB generated profits and revenue to the point where projections were for a billion-dollar company.[24] The high margins were doomed when French startup Nomai began producing compatible cartridges.[25] Iomega jumped on the opportunity to weaken SyQuest by signing up as the worldwide distributor.[26]

High-Capacity Flexible Cartridge

The combination of SyQuest, plunging sales, bloated inventories, and a 30% drop in revenue saw Iomega teetering on the edge of bankruptcy in 1987. [27] With the workforce cut in half and energies focused on a comeback, Iomega left the premium world for the mass market of the personal computer. The cultural shift was brutal, but it was not the technical pursuit of a low-cost product that was the master stroke, it was the consumer campaign that differentiated the new Iomega.

Iomega's ZIP drive's introduction in 1994 was helmed by new hires familiar with distribution, advertising, and retail sales channels. Selected retailers participated in the design of the packaging and influenced the promotional campaign. Even Iomega-branded fashion accessories (T-shirts, caps, etc.) were created.

ZIP growth was phenomenal - when deliveries began in 1995, the retail inventory sold out the first day. The stock soared from $2 to $20 as Iomega struggled to meet demand from a new factory in Malaysia, partnered with Seiko Epson in Japan, and established distribution in Europe, Asia and the Pacific. Sales topped 2M units in 15 months, and it was Iomega which became the billion-dollar company when revenues soared to $1.2B in 1996.

		
Iomega Progression	Iomega ZIP 100	Iomega Clik!/Pocket ZIP

Source: https://obsoletemedia.org/wp-content/uploads/2019/03/Iomega-disk-comparison-966x1024.jpg

Source: https://www.howtogeek.com/wp-content/uploads/2020/02/zip_01.jpg

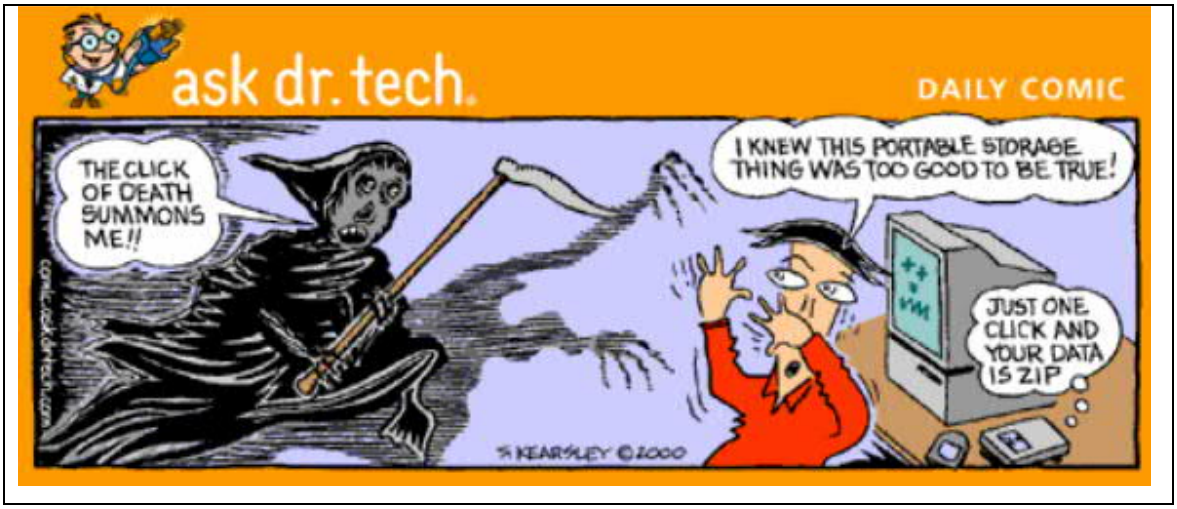
Source: https://www.howtogeek.com/wp-content/uploads/2020/02/zip_04.jpg

The impact on SyQuest was immediate - revenue shrank by 80% - Iomega had retaliated to SyQuest's critical blow with a mortal blow. The devastation of SyQuest was a consequence of the overwhelming success of the $200 ZIP drive and $20 100 MB cartridge capacity. ZIP became the interchange medium for 'everything' and although not large enough to back up a then-in-use gigabyte hard drive, it was more than enough for incremental backups and for storing moderately large files.

SyQuest introduced a flurry of rigid-media products in different sizes and capacities [28], none of which met strong acceptance. The company filed for bankruptcy in 1998, and the crowning insult was the purchase of its patents by Iomega.

The ZIP drive was built to sell for a price, and the catchword was 'good enough'. It certainly was, the ramping production required constant re-designs to add component suppliers. Unfortunately for Iomega, the behavior of a drive unable to orient itself to the servo was that the actuator hit the crash stop. The drive re-tried 10 times and reported an error, then the operating system software re-tried the error 10 times. The sound of 100 crash stops was nicknamed the Click of Death.[29]

Iomega's Achilles Heel was Iomega: a series of blunders blunted growth. To complement the ZIP, Iomega introduced the rigid media GB Jaz drive, and although it made some progress in Mac-dominant applications it tended to overheat and also suffered the ZIP's Click of Death malady.



Source: https://www.grc.com/tip/codfaq1.htm

Iomega was less than open about the Click of Death, complaints (at $14.99 per support call) were met with denial and a class action suit was initiated against the company. The failures were eventually acknowledged, and Iomega eventually committed to replace every failed drive regardless of warranty. The class action lawsuit was settled with coupons off future purchases. Too little, too late, the crown was tarnished.

To make matters worse, former ally Nomai popped up with ZIP-compatible cartridges.[30] Iomega launched into an aggressive legal battle of multiple lawsuits to prevent wide distribution. The court rulings were not always to Iomega's liking, and the company chose to settle all of them in favor of Iomega in one fell swoop - by buying Nomai.

Marketing blundered badly when a smaller cartridge was introduced in 1999 as the Clik! It resurrected the image of the Click of Death, and renaming it as the Pocket ZIP did not help. It was ineffectual against the PCMCIA (Personal Computer Memory Card International Association) flash memory and 1.8" disk drive cards.

In an effort to stay relevant, Iomega introduced 250 and 750 MB cartridges, but the bloom was off the rose. The role of ZIP as the preferred interchange media shrank as the long-promised 'Year of the LAN' became real and online transfers reduced the role of 'Sneakernet'. [Sneakernet refers to a person, wearing sneakers, hand carrying data from one location or computer to another.] Compact Discs (CDs) replaced the floppy as the second slot in a computer, and its 650 MB media was a cheap backup solution.

High-Capacity Floppy

A number of companies developed backwards compatible floppies with larger (4-16 MB) capacities, but none reached the market until Brier trialed the Flextra BR3020 in 1987. Insite Peripherals introduced the Floptical in 1991 and investor Iomega built its own version named the Insider.[31] These products were designed and priced for the premium markets and had little success against SyQuest.

SyQuest had the opportunity to build a 100 MB removable when Fuji made an approach in late 1993. Engineering was enthusiastic and marketing was sure it would be a dud. Even if SyQuest had built a product, it is unlikely it would have had any effect on ZIP's success. It took Iomega over five years to change its engineering and marketing cultures; a SyQuest 100 MB floppy would have had a higher build cost and the company had no distribution or retail savvy.

After Iomega dropped the Floptical/Insider, co-investor 3M partnered with Matsushita to develop the 120 MB LS-120 SuperDisk. The pursuit of reliability delayed the backwards compatible LS-120 introduction until 1997, and it was installed as a floppy alternative by Compaq, Dell, and laptop vendors. Despite this, Superdisk failed to knock ZIP from its perch in the United States, but it was successful internationally where a double-density LS-240 was released. One has to wonder, had ZIP and LS-120 been introduced around the same time, would history have been any different?

Sony won the floppy wars of 1981 and attempted a repeat with the 200 MB HiFD (High Density Floppy Disk) in 1997. The promise of high rpm/fast transfer rate died when deliveries were delayed until 1999, and those that shipped suffered loss of data from head crashes. It was an ignominious end, shared by startup Caleb with its UHD144 diskette.

Trays

When the development of RAID (Redundant Array of Independent Disks) products swept across the storage industry like a wave in the late 1980s, disk drives were packed into as small a space as possible. This led to 'hot plug' connectors and wrapper designs that made it easy for users to remove a failed drive and replace it while the system was running. The wrappers were ruggedized to avoid inadvertent damage by poor handling.

The ability to provide personal removability in a PC Tower or an external case came without rugged protection but at a low price ($15-30) from many vendors. Trays (aka sleds, docks, racks) have a variety of uses - a pair of trays made upgrading to a larger disk drive easy. A tray could ease transition shifts e.g. SATA (Serial AT Attachment) drives for an IDE-based PC or vice versa. Cooling fans kept drive temperatures as low or lower than that of drives direct mounted in a tower.

		
ViPower tray for IDE to SATA	Individual cooling for trays	Syba Tray holds a 3.5" and a 2.5" SATA drive

Source: http://en.vipower.com/files/VP-1001LSF-S.gif

Source: https://m.media-amazon.com/images/I/81Grj3zEKPL._AC_SL1500_.jpg

Source: https://m.media-amazon.com/images/I/51ixtA1Lh-L._AC_SL1200_.jpg

Removable Stalwarts

Staffed by SyQuest refugees, Castlewood introduced a single platter cartridge for the Orb drive using magnetoresistive heads. Although it sold for less than Iomega's 2-platter Jaz drive it did not succeed, and a follow on 5.7 GB could not save the company.[24]

Iomega attempted to carve a future in the tape backup marketplace with the Ditto tape cassette drive. It was slow, it had a proprietary format, and it was unsuccessful against the QIC and DC100 cartridges.

If you cannot beat them, join them, was the next thrust by Iomega: the optical Zip CD650 and Zip CDRW drives were a disastrous incursion into optical technology: and resulted in another class action lawsuit being brought against the company. A revival of the SyQuest/Orb mission in 2004 with the 35/70/200 GB Rev drives suffered reliability issues, high failure rates, and the same fate as SyQuest/Orb. The world of LAN was the next resort, and Iomega introduced NAS (Network Attached Storage) systems which became popular. Despite the hiccup of shipping with password security disabled (a number of major companies were hacked), the NAS effort was successful.

Iomega was acquired by EMC in 2008, and re-emerged as part of the Small Office division. The name itself disappeared five years later when EMC sold a majority stake to Lenovo.

Removable HDDs

The first company to design a 'whole' disk drive for removable environments was Hewlett Packard in 1992 with the 1.3" Kittyhawk drive of 20 and 40 MB capacities. The emerging markets that were expected to utilize the product failed to materialize.

Integral Peripherals' introduction of the 40 MB 1.8" drive the same year was more successful - it was integrated into PCMCIA cards which inserted into the slots of every laptop. Other disk drive manufacturers followed, and cards reached a capacity of 40 GB before being obsoleted by USB thumb drives.

IBM introduced the 170 MB Compact Flash-sized 1" Microdrive in 1998. The advantage was higher capacity and lower cost than semiconductor memory. Again, other manufacturers followed, and capacity eventually reached 10 GB before end of life. Most were integrated into consumer products, and others were sold as thumb drive alternatives (which found little favor in the market). Kudos to Toshiba for the smallest disk drive at 0.85" which was announced in 2004, and found a short-lived home in cameras, audio players, phones, and other consumer products.

Samsung resurrected the Microdrive form factor in 2008 with a 1.3" 40GB drive. [32] The why is questionable, flash meda was already at 32GB and 128GB arrived in 2009. [33]

High-capacity storage alternatives continue in the niche world of ruggedized packaging for severe environments e.g. space or customer applications such as security. Prostor packages RDX magnetic, solid state, and optical drives for those users who require removability.

Longevity

The turn of the century saw a shift in removable storage from a high-priced niche product with questionable reliability to a low cost commonly available product with more than acceptable reliability. Personal removable storage is mainstream for computers, phones, cameras, audio, and other consumer products.

The traditional role of magnetic removable storage on computers is provided by the thumb drive, which was introduced by Trek2000 of Singapore. Others may lay claim to having invented it, but the first product was demonstrated at Hannover's CeBIT Fair of 2000. [34]

The consumer world has a plethora of removable storage products which evolved for proprietary and/or industry reasons. Some had short lives, and others have expanded in variations under the

auspices of industry associations e.g. the SD in 2000 has proliferated to Mini and Micro sizes, and to Extended and Ultra capacities.

The Sneakernet of interoperable media survives in a heterogeneous form e.g. a camera card being read or written on a computer.

There is not even any need for physical media to achieve removability, a connection to the cloud is sufficient.

Something visceral has been lost along the way, like the feeling of ownership when holding a cartridge in hand, and the comfort of security felt after locking a cartridge in a safe.

APPENDIX A: Physics behind the Bernoulli Box

Iomega's Bernoulli technology relies on the Bernoulli effect, illustrated in Figure 1 where a flexible disk (11) spins in close proximity to a stationary plate (12). As the thin layer of air between the spinning disk and the plate is ejected towards the outer diameter by centrifugal action, the pressure drops, pulling the disk towards the plate, and rigidifying it. This stabilizing effect allows for greater rotational speed, with the Bernoulli 8" disks spinning at 1500 RPM, vs 300 RPM for the conventional floppy drive. This technology had been investigated earlier by IBM [A1], but was abandoned. Iomega perfected the technology, including the integration of head technology (18) that provided stable spacing, using simple positive pressure air-bearing [A2].

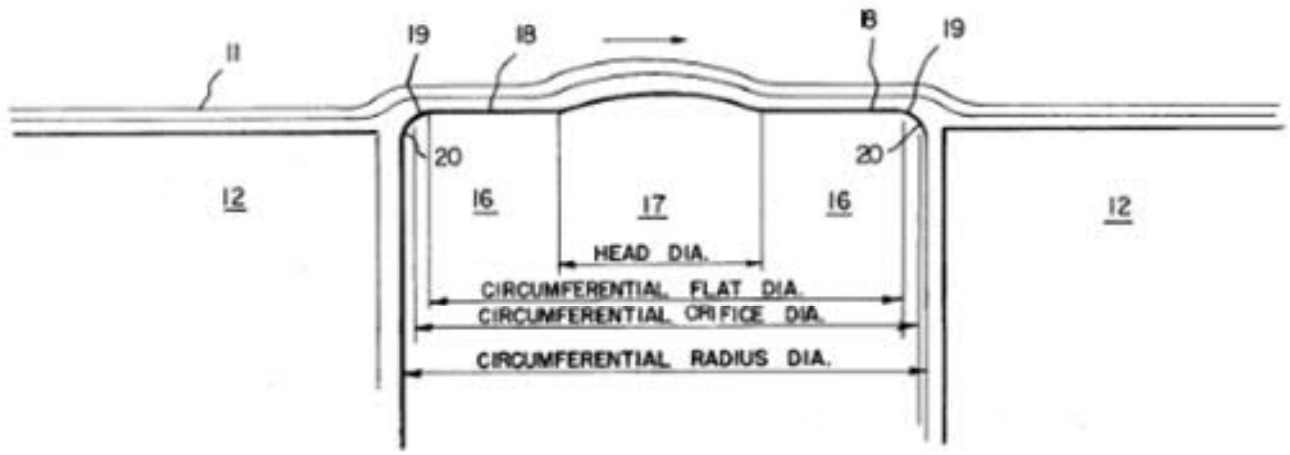


Figure 1: Schematics of the head-disk interface of the Iomega Bernoulli box (from ref [A2])

[A1] Flexible record disk signal storage apparatus, Assignee: IBM, US Patent #4,167,269A, Priority: 1977

[A2] Support for stabilizing the movement of a magnetic medium over a magnetic head, Assignee: Iomega, US Patent #4,414,592A, Priority: 1981

Recommended Reading: http://www.bitsavers.org/pdf/iomega/00701300-000_IOMEGA_Alpha_10H_Technical_Description_Manual_Nov84.pdf

APPENDIX B: Impact of cartridge contamination on reliability

In magnetic data storage, a key enabler to high storage density is small physical separation between the Read-Write head and the top of the recording layer of the disk [B1]. High-capacity removable storage products of the 1980's and 1990's therefore relied, in part, on maintaining a well-controlled head flying height in the 10-50 nm range [B2]. To put this in perspective, this is about 1/1000th the size of a typical dust particle!

Hard Disk Drives (HDD) have the luxury to seal the head-disk enclosure from outside contamination [B3], but removable disk cartridges are much more challenging. Schemes have been used to filter the air inside the cartridge while operating [B4-B5], but it is near-impossible to prevent small amounts of contaminants from entering the cartridge during loading/unloading. Even during storage, small gaps in the shutter or disk clamp let contaminants inside the cartridge.

Once on the disk, particulates or liquid droplets that interfere with proper head-disk integrity led to failure [B3]. As a result, the reliability of high-capacity removable storage products was often poor.

[B1] B. Marchon and T. Olson, Magnetic Spacing Trends: From LMR to PMR and Beyond, IEEE Trans. Magn., 45(10), 3608 (2009)
[B2] J. Briggs, Enabling technologies for a 100MB 3.5" floppy Zip disk drive, Photonics East 1995, 220/SPIE vol. 2604
[B3] Chemical Integration and Contamination Control in Hard Disk Drive Manufacturing, L. Nebenzahl et al, Journal of the IEST (1998) 41 (5): 31–35.
[B4] Particulate removing means for cartridges, Assignee: Iomega, US Patent #4,969,061A, Priority: 1989
[B5] Removable cartridge disk drive with an integral head loading ramp, air filter and removable cartridge door safety stop, Assignee: SyQuest, US Patent #5,204,793A, Priority: 1991

APPENDIX C: Table of Products

The table below lists products within the three categories by date of introduction, and subsequent introductions by the same company. This muddles the chronology but illustrates the role of the company in removable storage. In cases when a product had a large number of manufacturers, only the first is listed. If known, capacity is usable, not nominal.

Tape Drives with Removable Media

Company	Drive	Media		Width (")	Start	Min	Max
Wheatstone	Paper Tape	Roll and Fanfold			1837		
LINC	LINCtape	Reel	3.5"	0.75	1961		192K
DEC	DECtape	Reel	4"	0.75	1963		216K
	DECtape II	Cartridge		0.15	1978		256K
Philips	Compact Cassette	Cassette		0.15	1964	60K	60.0M
Hewlett Packard	HP9100A	Card			1968		
	DC100...DC2000	Cartridge		0.15	1977	560K	80.0M
3M	DC300…QIC	Cartridge		0.25	1972	250K	250.0M
Commodore	Datasette	Cassette		0.15	1977		100K

Disk Drives with Removable Media

Company	Drive	Cartridge	Type	Dia (")	Start	Min	Max
IBM	2310	2315	Rigid	14	1965		1.0M
	5444	5440	Rigid	14	1970	1.25M	2.5M
Diablo	Series 30	2315-like	Rigid	14	1970	1.2M	2.4M
	Series 40	5440-like	Rigid	14	1975	2.5M	5.0M
DEC	RK01	2315-like	Rigid	14	1971		1.2M
	RK02/RK03	2315-like	Rigid	14	1971	1.2M	2.4M

	RK04/RK05	2315-like	Rigid	14	1972	1.2M	2.4M
	RL01/RL02	RL01K/RL02K	Rigid	14	1975	5.2M	10.4M
	RK06/RK07	RK06K/RK07K	Rigid	14	1977	13.8M	27.6M
	RC25	RC25K	Rigid	8	1983		26.0M
Hewlett Packard	7900A/7901A/9880B	2315-like	Rigid	14	1971		2.4M
	7905A	5440-like	Rigid	14	1975		5.0M
Mitsubishi	M801/M802	5440-like	Rigid	14	1972	3.2M	6.4M
CDC	9425/9427 aka Hawk	5440-like	Rigid	14	1973	2.5M	5.0M
	9448 aka Phoenix	91204	Rigid	14	1981		16.0M
	9455/9457 aka Lark	91208/91210	Rigid	8	1982	8.35M	25.0M
	9710	1209	Rigid	9	1982		76.0M
Memorex	650		Flexible	8	1972	175K	1.2M
Shugart	SA-400		Flexible	5.25	1975	110K	1.2M
Sony	OM-D3310		Flexible	3.5	1981	280K	2.88M
	HiFD		Flexible	3.5	1997	150.0M	200.0M
Iomega	Bernoulli	B5/B10/B20	Flexible	8	1982	5.0M	20.0M
	Bernoulli II	B20/B35/B44/.../B230	Flexible	5.25	1987	20.0M	230.0M
	Insider		Flexible	3.5	1991		20.8M
	Zip	Zip100/Zip250/Zip750	Flexible	3.5	1994	100.0M	750.0M
	Jaz	Jaz1/Jaz2	Rigid	3.5	1995	1.0G	2.0G
	PocketZip	PocketZip40	Flexible	3.5	1999		40.0M
	Rev	Rev35/Rev70/Rev120	Rigid	3.5	2004	35.0G	120.0G
SyQuest	SQ306RD/312/319	SQ100/SQ200/SQ300	Rigid	3.9	1984	5.0M	15.0M
	SQ555/5110/5200C	SQ400/SQ800/SQ2000	Rigid	5.25	1986	44.0M	200.0M
	SQ3105/SQ3270	SQ310/SQ327	Rigid	5.25	1993	105.0M	270.0M
	EZDrive/EZFlyer	EZ135/EZ230	Rigid	3.5	1995	135.0M	230.0M
	SQ2542	SQ2542	Rigid	2.5	1996		42.8M
	SQ1080	SQ60/SQ80	Rigid	1.8	1996	60.0M	80.0M
	SyJet	SQ1500	Rigid	3.5	1996		1.5G
	SparQ	SparQ 1.0	Rigid	3.5	1997		1.0G

	Quest	Quest 4.7	Rigid	3.5	1998		4.7G
Brier	Flextra	BR3020/BR3225	Flexible	3.5	1987		21.4M
Insite Peripherals	Floptical		Flexible	3.5	1991		20.8M
3M Imation	SuperDrive	LS-120/LS-240	Flexible	3.5	1997	120.0M	240.0M
Caleb	UHD144		Flexible	3.5	1998		144.0M
Castlewood	ORB2SE00/?	2P01/?	Rigid	3.5	1999	2.2G	5.7G

Removable Disk Drives

Company	Drive		Type	Dia (")	Start	Min	Max
Hewlett Packard	Kittyhawk	Only provider	HDD	1.3	1992	20.0M	40.0M
PCMCIA	Integral Peripherals	First to introduce	HDD	1.8	1992	40.0M	40.0G
IBM	Microdrive	First to introduce	HDD	1	2000	170.0M	10.0G
USB Thumb Drive	Trek 2000	First to demonstrate	Flash		2000	4.0M	n
Samsung	Spinpoint A1	Microdrive Form Factor	HDD	1.3	2008	30.0G	40.0G

Contributors

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Storage Special Interest Group
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FOOTNOTES

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