NASD: A Cost-Effective, High-Bandwidth Storage Architecture

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Responding to data rate improvements

- disk data rate averaging 40% faster each year
- fastest drive in 1998: 27.5 MB/s internally
- peripheral interconnect at 100 MB/s and rising

Sponsored by DARPA/ITO Quorum/Scalable Systems
and HP, Quantum, Seagate, STK, Symbios, Clariion, Compaq, Wind River, Intel, 3Com

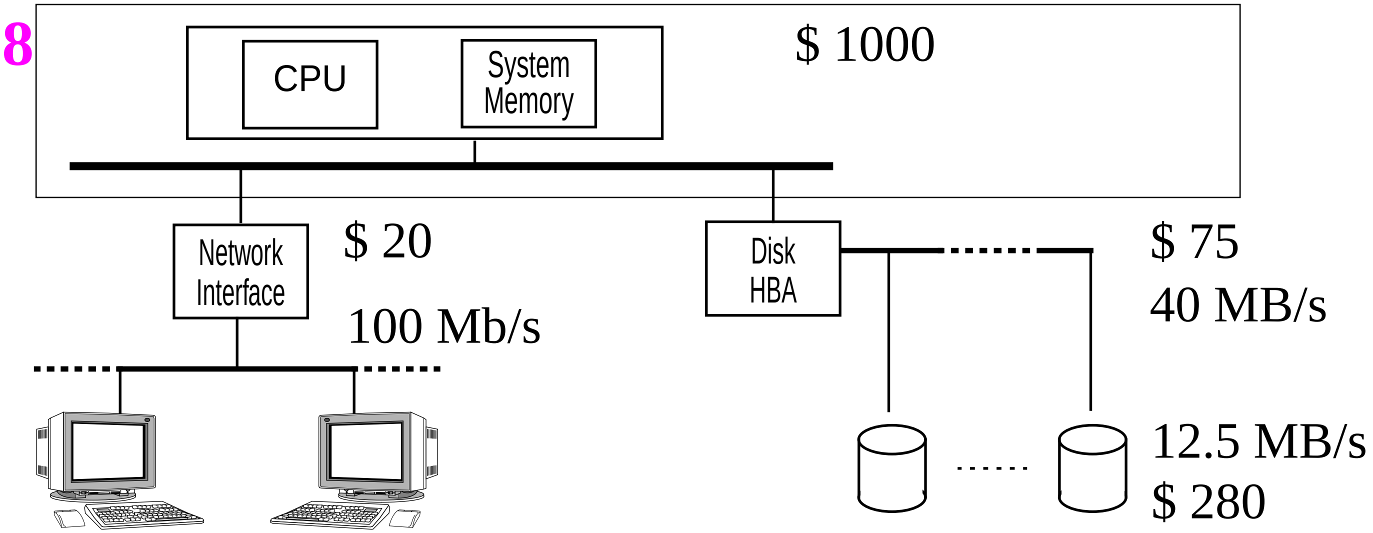
Server-Attached Disks (SAD) don’t deliver bandwidth

Cheap server machine, fast ether, UltraWide SCSI

- one net, one drive with **server overhead cost of > 390**
- AMORTIZE low-cost server with more drives
  5 drive, 5 NICs, 2 HBAs (7 PCI slots?)   **> 89%**

Store-and-forward copying **doubles** storage cost

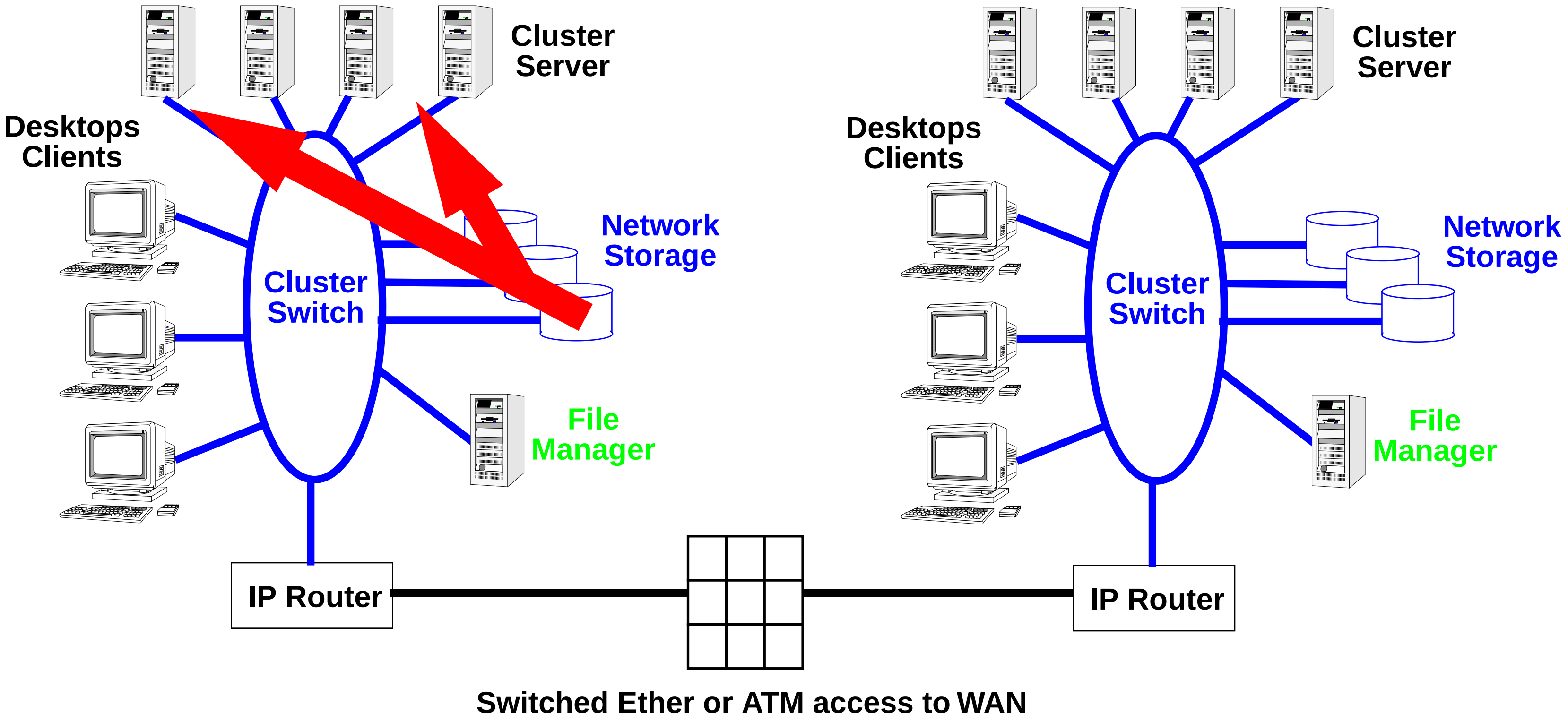
10/98



Take file server off datapath: 3rd party transfer

Direct transfer between client and storage

- exploit scalable switched cluster area networking
- split file service: into primitives (in drive), policy (in manager)



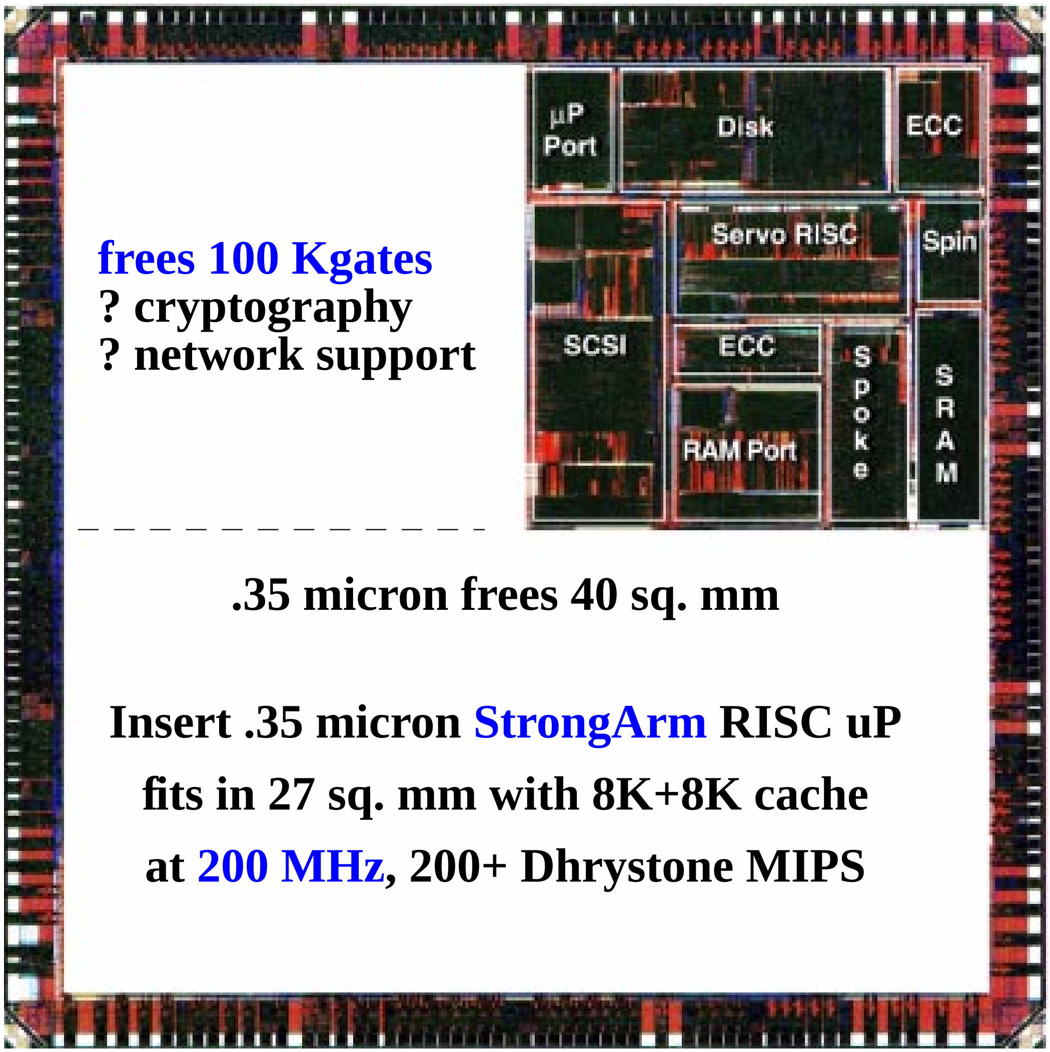
Device cycles are available now

Quantum Trident drive

- **Control: M68020**
- **Datapath ASIC** →
- **.68 micron in 1997**
- **4 indep clock domains, each 40 MHz**
  SCSI processor
  disk R/W channel
  uP control port
  DRAM port
- **~ 110 Kgates + 22Kb**
- **.35 micron next gen. enables integration of control uP onto ASIC**

Also Siemens TriCore

Current .68 micron chip is 74 sq. mm



frees 100 Kgates
? cryptography
? network support

.35 micron frees 40 sq. mm

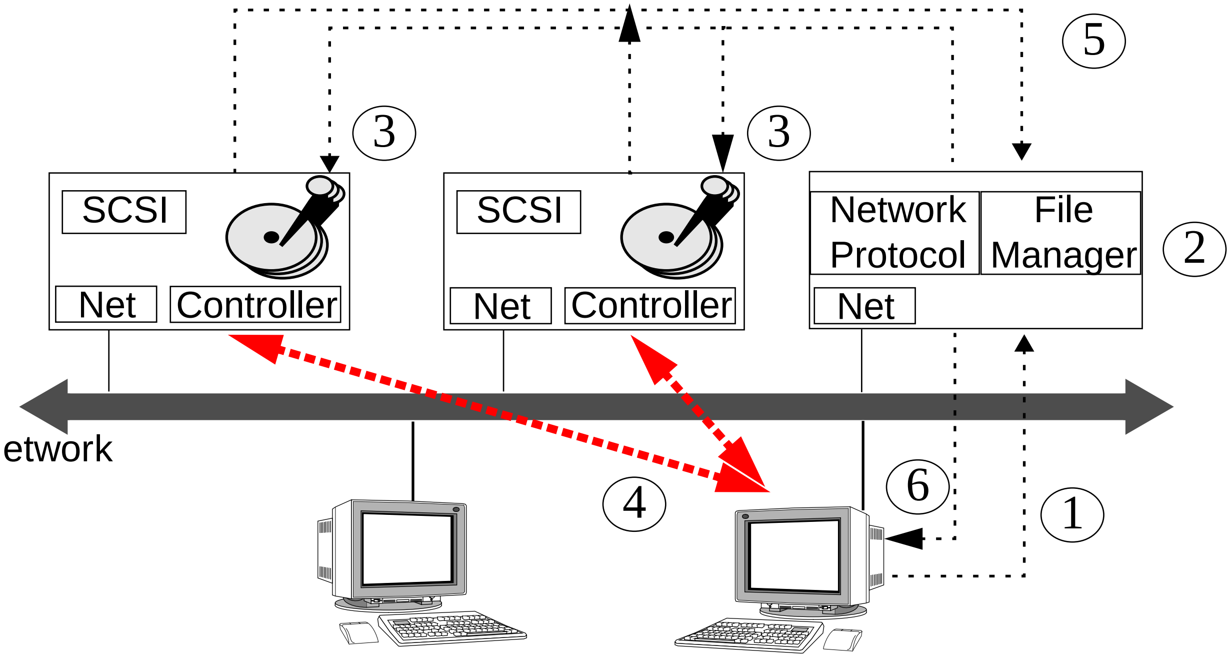
Insert .35 micron StrongArm RISC uP fits in 27 sq. mm with 8K+8K cache at 200 MHz, 200+ Dhrystone MIPS

First approach: Networked SCSI (NetSCSI)

Minimize change in HW, SW, IF: RAID-II, HPSS

- server translates (2) and forwards (3) request (1)
- drive delivers data directly to client (4)
- drive status to server (5), server status to client (6)

Scalable bandwidth through network striping



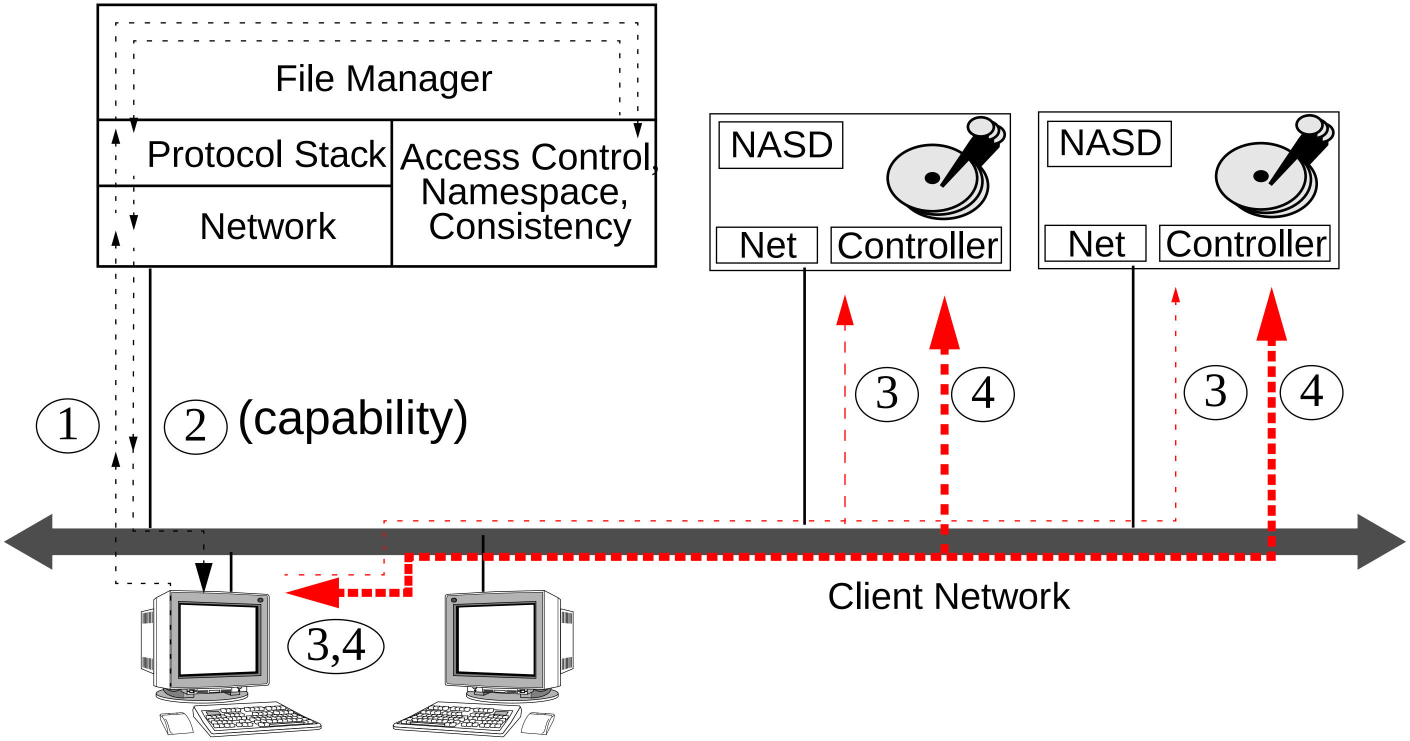
Sigmetrics97

More scalable: NASD enforces cached policy decisions

Avoid file manager unless new policy decision needed

- spread access computation over all drives under manager
- access control once (1,2) for all accesses (3,4) to drive object

Scalable BW thru striping, off-load manager



NASD Interface Design: Storage Objects

Per-file metadata in drive to avoid manager

- Not at client: don’t rest integrity on trusted client
- Not in capability: too large, hard to optimize in drive

Layout is best (actually) done below SCSI

- real-time support possible; accurate geometry
- transparent performance optimization (ie. AutoRAID)

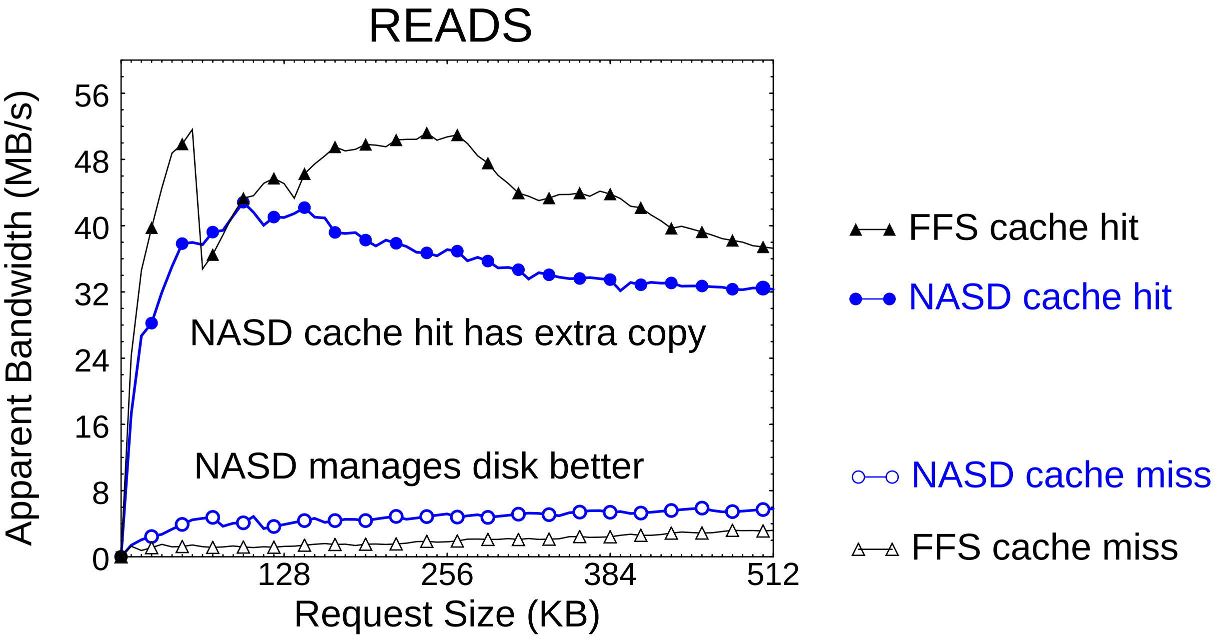
A NASD is an Object-Based Disk

NASD object store prototype

Prototype as psuedo-device in DU3.2, 16K loc, DCE

Performance comparable to FFS for file access

- 133 MHz Alpha, striped dual ST52160s
- replace NASD RPC interface with local system call



NASD cache hit has extra copy

NASD manages disk better

NASD computation is affordable

Prototype measured: 40 Kinstr/request + 3 instr/byte

- scale to 200 MHz: plenty fast enough for cache misses
- too slow during cache hits (need 0.3ms 1B; 2.2ms 64KB)
- but instrumentation shows most code in RPC/protocol stack

Commodity drives not built like workstations

- ASIC state machines for data: communications; copying
- of course, Alpha (21064) is not a microcontroller

Operation	Total Instructions (K) / % Communications						Operation time (msec) (200 MHz, CPI = 2.2)		
Request Size (B)	1		8 K		64 K		1	8 K	64 K
read - cold cache	46	70	67	79	247	90	0.51	0.74	2.7
read - warm cache	38	92	57	94	224	97	0.42	0.63	2.5

Adapting filesystems to NASD drives

Reorganize decomposition of function (aka port)

Primitives become drive responsibility

- data transfer, synchronous/automatic metadata updates

Policy remains manager responsibility

- namespace definition/navigation
- access control policy
- client cache management
- multi-access atomicity

Managers retain control through capabilities

- exploiting attributes for naming and revocation

Mapping filesystem to NASD objects

Simple model

- each file and directory bound to separate NASD object
- file attributes inherit object attributes (times, logical size)

Multiple objects per file?

- internal structure: database pages, mpeg group-of-pictures
- NASD striping, redundancy

Multiple files/directories per object?

- probable contiguity, prefetching; shared metadata overhead
- capabilities can be restricted to object region

NFS, AFS simple model; Cheops PFS multiple per file

Cheops: striping storage middleware for bandwidth

Asynchronous storage management oversight

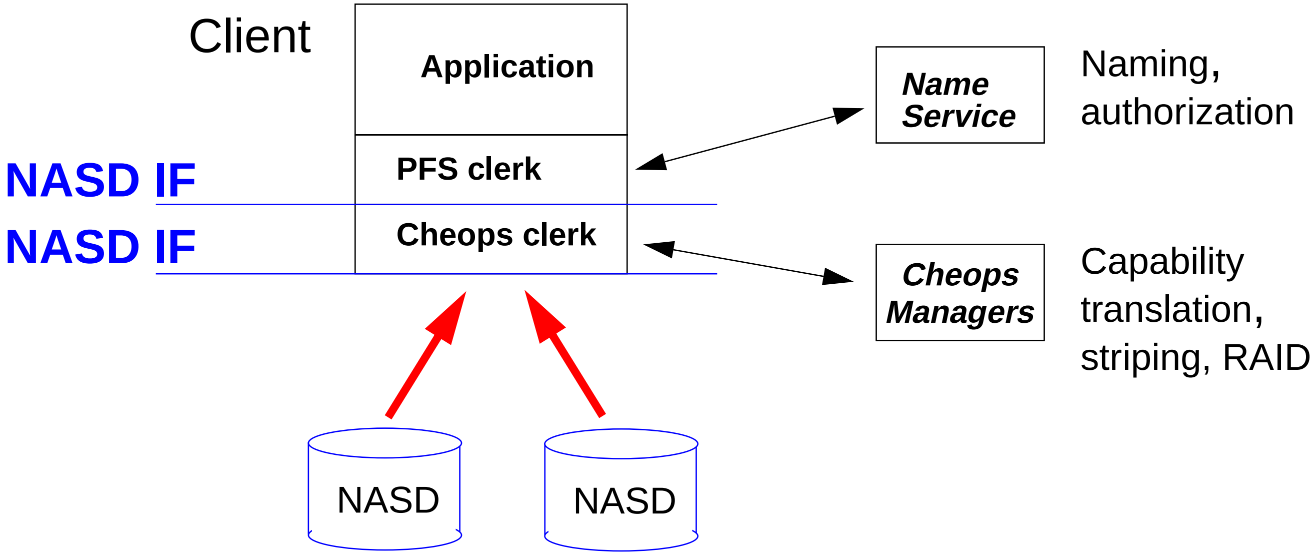
- first access installs capabilities/maps for aggregate object

Client asking for service pays for it (synchronizer)

- striping, RAID, incremental growth, consistent caches

Compatible with user-level network access

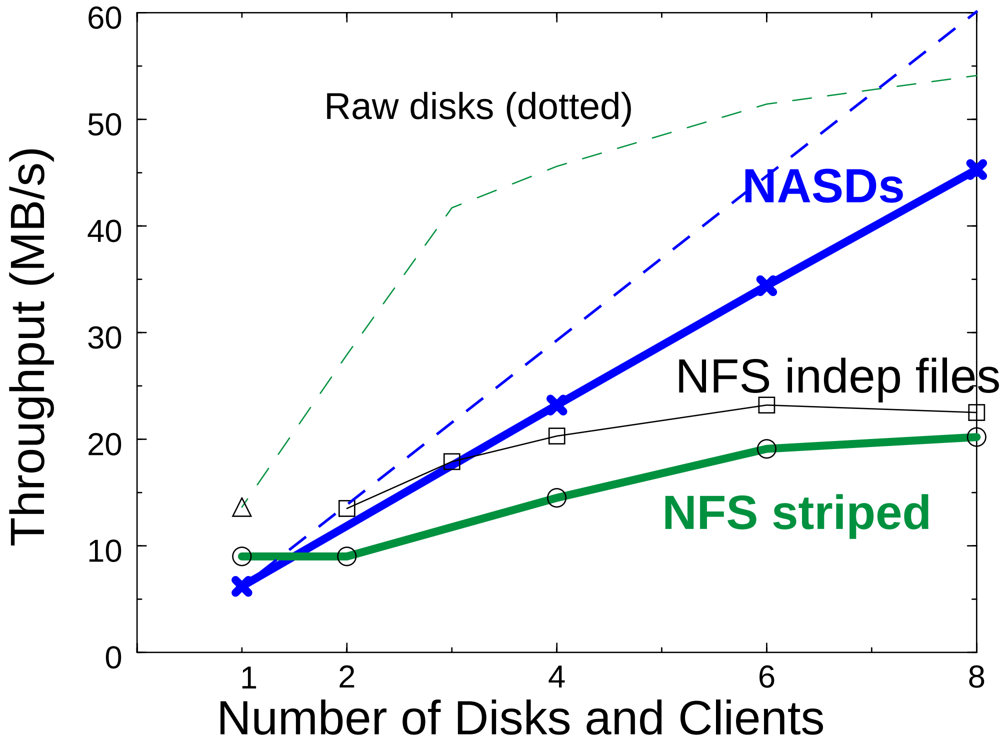
- NIC protocol processing leaves client to run application



Demonstration: scalable bandwidth for applications

NASD PFS delivers aggregate of raw disks’ bandwidth

- **Parallel association rule discovery on 300 MB of sales records**
- **NASD middleware fetches 4 x 512KB blocks in parallel**
- **NFS server delivers 20% disk BW (60% net BW) @ 8 pairs**



- **133Mhz NASDs**
  6 MB/s drive’s max
- **233Mhz clients**
- **MPI + SIO LLAPI**
- **switched OC3 ATM**
- **500 Mhz NFS server**
  14 MB/s drive’s max
  dual OC3 links

What to do with device cycles left over?

Large database systems - lots of disks, lots of power

System	Processing (MHz)		Data Rate (MB/s)	
	CPU	Disks	I/O Bus	Disks
Compaq TPC-C	4 x 200=**800**	*113* x 75=**8,475**	**133**	**1,130**
Microsoft Terraserver	4 x 400=**1,600**	*320* x 75=**24,000**	**532**	**3,200**
Digital 500 TPC-C	1 x 500=**500**	*61* x 75=**4,575**	**266**	**610**
Digital 4100 TPC-D	4 x 466=**1,864**	*82* x 75=**6,150**	**532**	**820**

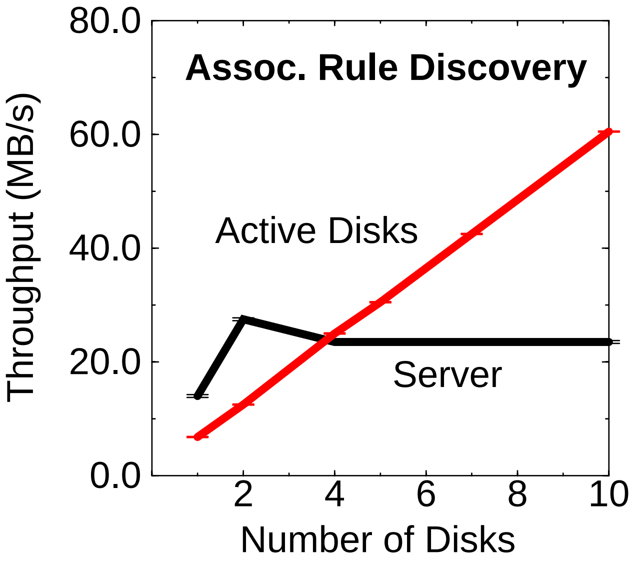
- **assume disk offers equivalent of 75 host MHz**
- **assume disk sustained data rate of 10 MB/s**

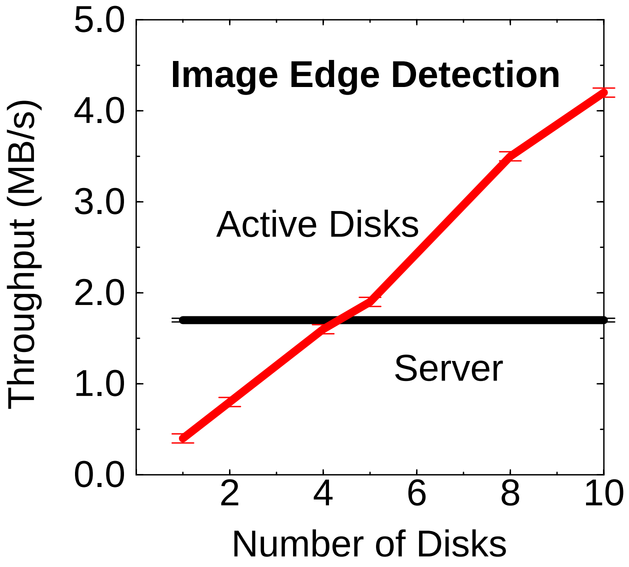
More cycles and MB/s in disks than in host

Simple throughput model for scan apps

Offload parallelized filter/scan operators

- speedups of 2-3X on 10 disks for 4 mining/image apps
- object model makes programming in drive simple

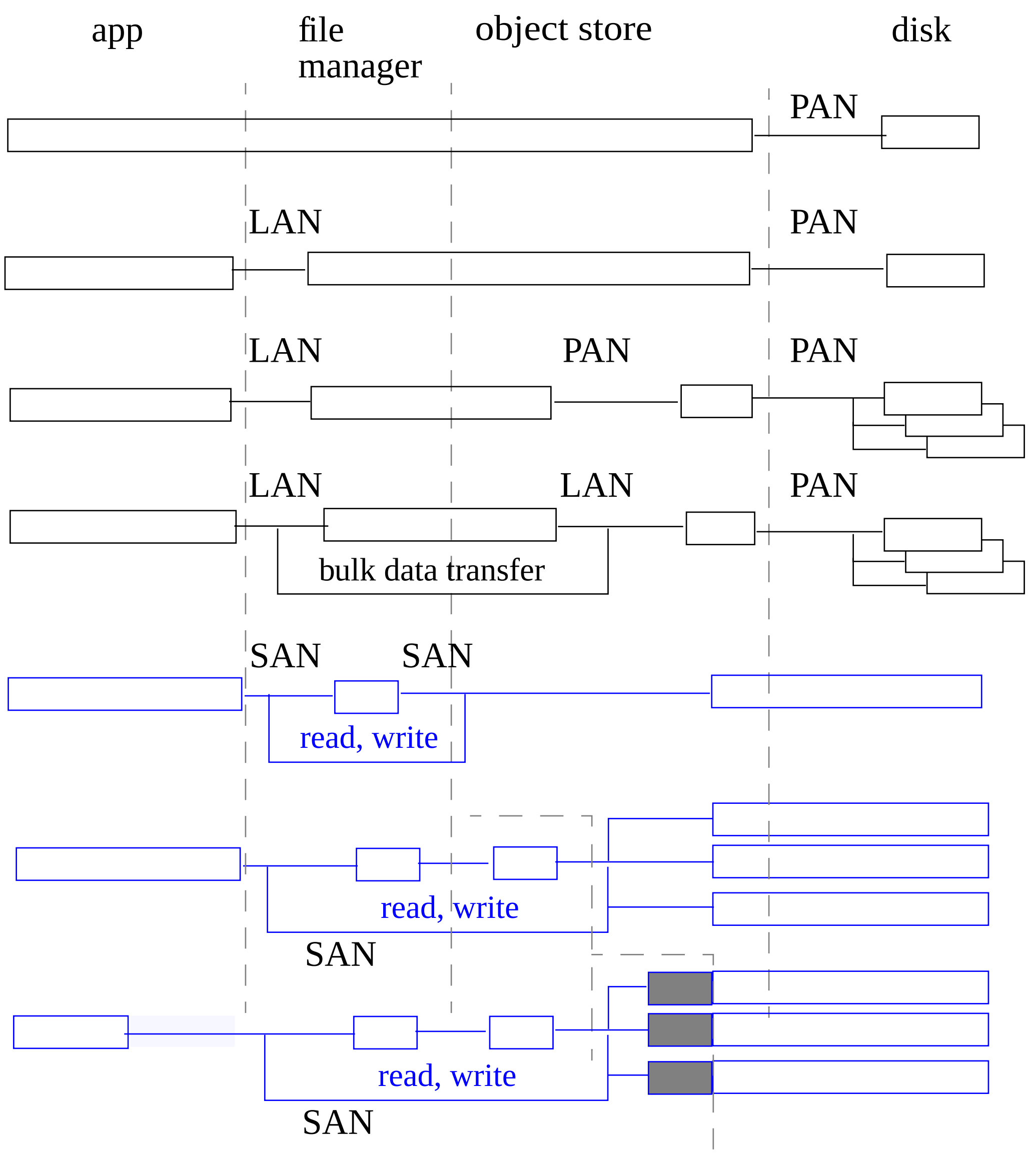




VLDB98

- crossover: host/disk-cpu-speed ratio ~ 4 (2 generations)

Storage interface evolution taxonomy



computers in data/control path	
2	Local Filesystem
3	Distributed FS (DFS)
4	DFS + RAID
3/4	DFS + HPSS bypass
2/2+	DFS w/ NASD
2/2++	DFS w/ NASD, Cheops
2/2++	DFS w/ NASD, Cheops and Active Disks

NASD: A cost-effective, high-bandwidth storage architecture

Cost-effective storage bandwidth starts in the drive

NASD is

- Direct transfer between client & storage device
- Asynchronous policy managememt
- (Cryptographic) capabilities
- Object-based management in drive, across drives

Cost-effective, efficient networking is critical

Storage architecture changes need standards

- www.nsic.org/nasd and www.snia.org