SCSI overview

- **SCSI *domain* consists of devices and an SDS**
  - Devices: host adapters & SCSI controllers
  - *Service Delivery Subsystem* connects devices–e.g., SCSI bus
- **SCSI-2 bus (SDS) connects up to 8 devices**
  - Controllers can have > 1 "logical units" (LUNs)
  - Typically, controller built into disk and 1 LUN/target, but "bridge controllers" can manage multiple physical devices
- **Each device can assume role of *initiator* or *target***
  - Traditionally, host adapter was initiator, controller target
  - Now controllers act as initiators (e.g., COPY command)
  - Typical domain has 1 initiator, ≥ 1 targets

SCSI requests

- **A *request* is a command from initiator to target**
  - Once transmitted, target has control of bus
  - Target may disconnect from bus and later reconnect (very important for multiple targets or even multitasking)
- **Commands contain the following:**
  - *Task identifier*—initiator ID, target ID, LUN, tag
  - *Command descriptor block*—e.g., read 10 blocks at pos. N
  - Optional *task attribute*—SIMPLE, ORDERD, HEAD OF QUEUE
  - Optional: output/input buffer, sense data
  - *Status byte*—GOOD, CHECK CONDITION, INTERMEDIATE, . . .

Executing SCSI commdns

- **Each LUN maintains a queue of *tasks***
  - Each task is DORMANT, BLOCKED, ENABLED, or ENDED
  - SIMPLE tasks are dormant until no ordered/head of queue
  - ORDERED tasks dormant until no HoQ/more recent ordered
  - HOQ tasks begin in enabled state
- **Task management commands available to initiator**
  - Abort/terminate task, Reset target, etc.
- **Linked commands**
  - Initiator can link commands, so no intervening tasks
  - E.g., could use to implement atomic read-modify-write
  - Intermediate commands return status byte INTERMEDIATE

SCSI exceptions and errors

- **After error stop executing most SCSI commands**
  - Target returns with CHECK CONDITION status
  - Initiator will eventually notice error
  - Must read specifics w. REQUEST SENSE
- **Prevents unwanted commands from executing**
  - E.g., initiator may not want to execute 2nd write if 1st fails
- **Simplifies device implementation**
  - Don't need to remember more than one error condition
- **Same mechanism used to notify of media changes**
  - I.e., ejected tape, changed CD-ROM

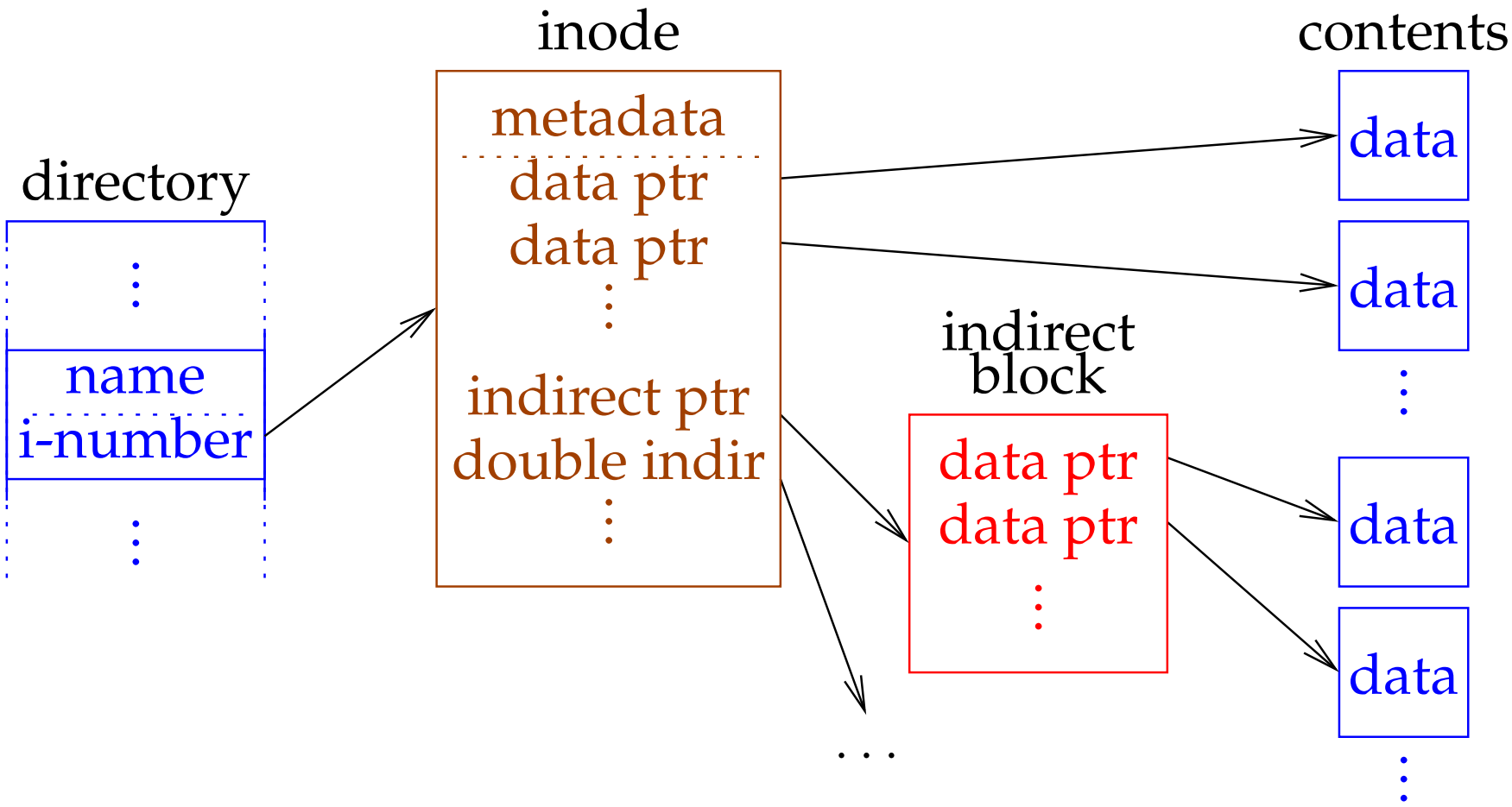
But back in the 80s…

- **Disks spin at 3,600 RPM**
  - 17 ms/Rotation (vs. 4 ms on fastest disks today)
- **Fixed # sectors/track (no zoning)**
- **Head switching free (?)**
- **Requests issued one at a time**
  - No caching in disks
  - Head must pass over sector after getting a read
  - By the time OS issues next request, too late for next sector
- **Slower CPUs, memory**
  - Noticeable cost for block allocation algorithms

Original Unix file system

- **Each FS breaks partition into three regions:**
  - Superblock (parameters of file system, free ptr)
  - Inodes – type/mode/size + ptr to data blocks
  - File and directory data blocks
- **All data blocks 512 bytes**
- **Free blocks kept in a linked list**

Inodes


inode
contents
directory
metadata
data ptr
data ptr
indirect ptr
double indir
name
i-number
indirect
block
data ptr
data ptr
data
data
data
data
. . .

Problems with original FS

- **FS never transfers more than 512 bytes/disk access**
- **After a while, allocation essentially random**
  - Requires a random seek every 512 bytes of file data
- **Inodes far from both directory data and file data**
- **Within a directory, inodes not near each other**
- **Usability problems:**
  - File names limited to 14 characters
  - No way to update file atomically & guarantee existence after crash

Fast file system

- **New block size must be at least 4K**
  - To avoid wasting space, use “fragments” for ends of files
- **Cylinder groups avoid spread inodes around disk**
- **Bitmaps replace free list**
- **FS reserves space to improve allocation**
  - Tunable parameter, default 10%
  - Only superuser can use space when over 90% full

FFS superblock

- **Contains file system parameters**
  - Disk characteristics, block size, CG info
  - Information necessary to get inode given i-number
- **Replicated once per cylinder group**
  - At shifting offsets, so as to span multiple platters
  - Contains magic to find replicas if 1st superblock dies
- **Contains non-replicated "summary info"**
  - # blocks, fragments, inodes, directories in FS
  - Flag stating if FS was cleanly unmounted

Cylinder groups

- **Groups related inodes and their data**
- **Contains a number of inodes (set when FS created)**
  - Default one inode per 2K data
- **Contains file and directory blocks**
- **Contains bookkeeping information**
  - Block map – bit map of available fragments
  - Summary info within CG – # free inodes, blocks/frags, files, directories
  - # free blocks by rotational position (8 positions)

Inode allocation

- **Allocate inodes in same CG as directory if possible**
- **New directories put in new cylinder groups**
  - Consider CGs with greater than average # free inodes
  - Chose CG with smallest # directories
- **Within CG, inodes allocated randomly (next free)**
  - Would like related inodes as close as possible
  - OK, because one CG doesn't have that many inodes

Fragment allocation

- **Allocate space when user writes beyond end of file**
- **Want last block to be a fragment if not full-size**
  - If already a fragment, may contain space for write – done
  - Else, must deallocate any existing fragment, allocate new
- **If no appropriate free fragments, break full block**
- **Problem: Slow for many small writes**
  - (Partial) soution: new `stat` struct field `st_blksize`
  - Tells applications file system block size
  - stdio library can buffer this much data

Block allocation

- **Try to optimize for sequential access**
  - If available, use rotationally close block in same cylinder
  - Otherwise, use block in same CG
  - If CG totally full, find other CG with quadratic hashing
  - Otherwise, search all CGs for some free space
- **Problem: Don't want one file filling up whole CG**
  - Otherwise other inodes will have data far away
- **Solution: Break big files over many CGs**
  - But large extents in each CGs, so sequential access doesn't require many seeks

Directories

- **Inodes like files, but with different type bits**
- **Contents considered as 512-byte *chunks***
- **Each chunk has `direct` structure(s) with:**
  - 32-bit inumber
  - 16-bit size of directory entry
  - 8-bit file type (NEW)
  - 8-bit length of file name
- **Coalesce when deleting**
  - If first `direct` in chunk deleted, set inumber = 0
- **Periodically compact directory chunks**

Updating FFS for the 90s

- **No longer want to assume rotational delay**
  - With disk caches, want data contiguously allocated
- **Solution: Cluster writes**
  - FS delays writing a block back to get more blocks
  - Accumulates blocks into 64K clusters, written at once
- **Allocation of clusters similar to fragments/blocks**
  - Summary info
  - Cluster map has one bit for each 64K if all free
- **Also read in 64K chunks when doing read ahead**

Dealing with crashes

- **Suppose all data written asynchronously**
- **Delete/truncate a file, append to other file, crash**
  - New file may reuse block from old
  - Old inode may not be updated
  - Cross-allocation!
  - Often inode with older mtime wrong, but can't be sure
- **Append to file, allocate indirect block, crash**
  - Inode points to indirect block
  - But indirect block may contain garbage

Ordering of updates

- **Must be careful about order of updates**
  - Write new inode to disk before directory entry
  - Remove directory name before deallocating inode
  - Write cleared inode to disk before updating CG free map
- **Solution: Many metadata updates syncrhonous**
  - Of course, this hurts performance
  - E.g., untar much slower than disk b/w
- **Note: Cannot update buffers on the disk queue**

Fixing corruption – fsck

- **Summary info usually bad after crash**
  - Scan to check free block map, block/inode counts
- **System may have corrupt inodes (not simple crash)**
  - Bad block numbers, cross-allocation, etc.
  - Do sanity check, clear inodes with garbage
- **Fields in inodes may be wrong**
  - Count number of directory entries to verify link count, if no entries but count $\neq 0$, move to `lost+found`
  - Make sure size and used data counts match blocks
- **Directories may be bad**
  - Holes illegal, `.` and `..` must be valid, ...
  - All directories must be reachable