RAID Systems

CS 537 - Introduction to Operating Systems

Mass Storage

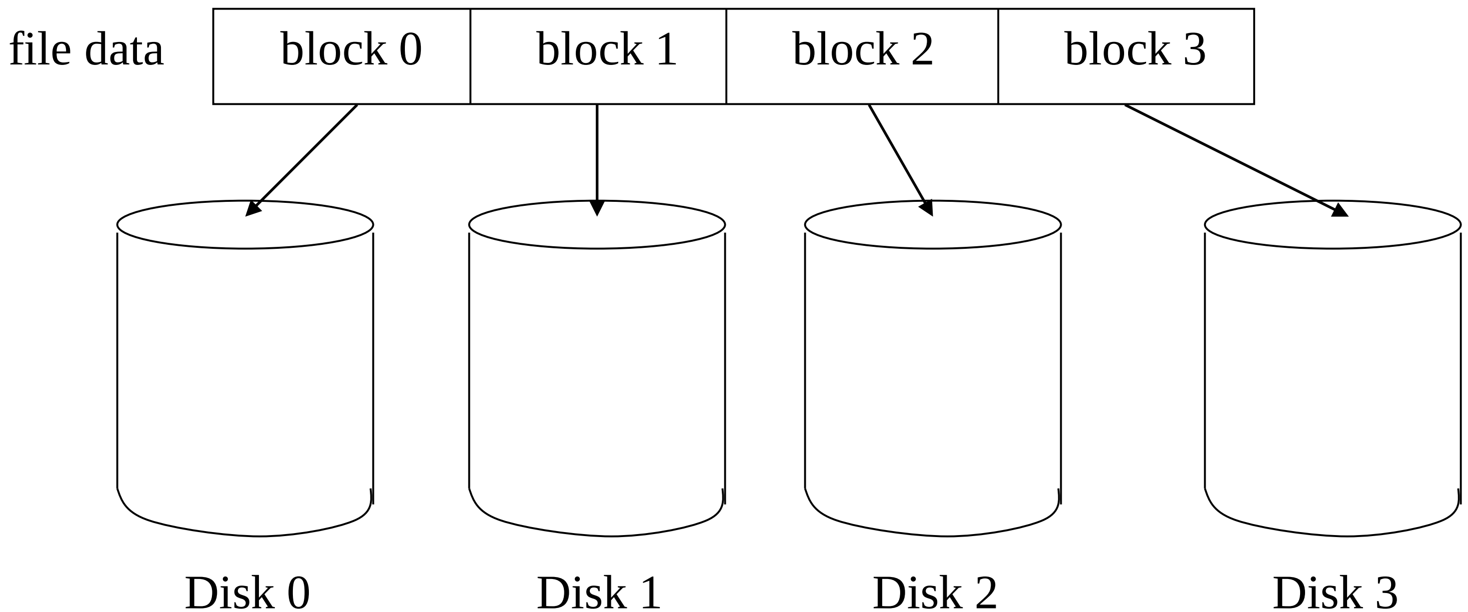
- Many systems today need to store many terabytes of data
- Don’t want to use single, large disk
  - too expensive
  - failures could be catastrophic
- Would prefer to use many smaller disks

RAID

- Redundant Array of Inexpensive Disks
- Basic idea is to connect multiple disks together to provide
  - large storage capacity
  - faster access to reading data
  - redundant data
- Many different levels of RAID systems
  - differing levels of redundancy, error checking, capacity, and cost

Striping

- Take file data and map it to different disks
- Allows for reading data in parallel



Parity

- Way to do error checking and correction
- Add up all the bits that are 1
  - if even number, set parity bit to 0
  - if odd number, set parity bit to 1
- To actually implement this, do an exclusive OR of all the bits being considered
- Consider the following 2 bytes

byte	parity
10110011	1
01101010	0

- If a single bit is bad, it is possible to correct it

Mirroring

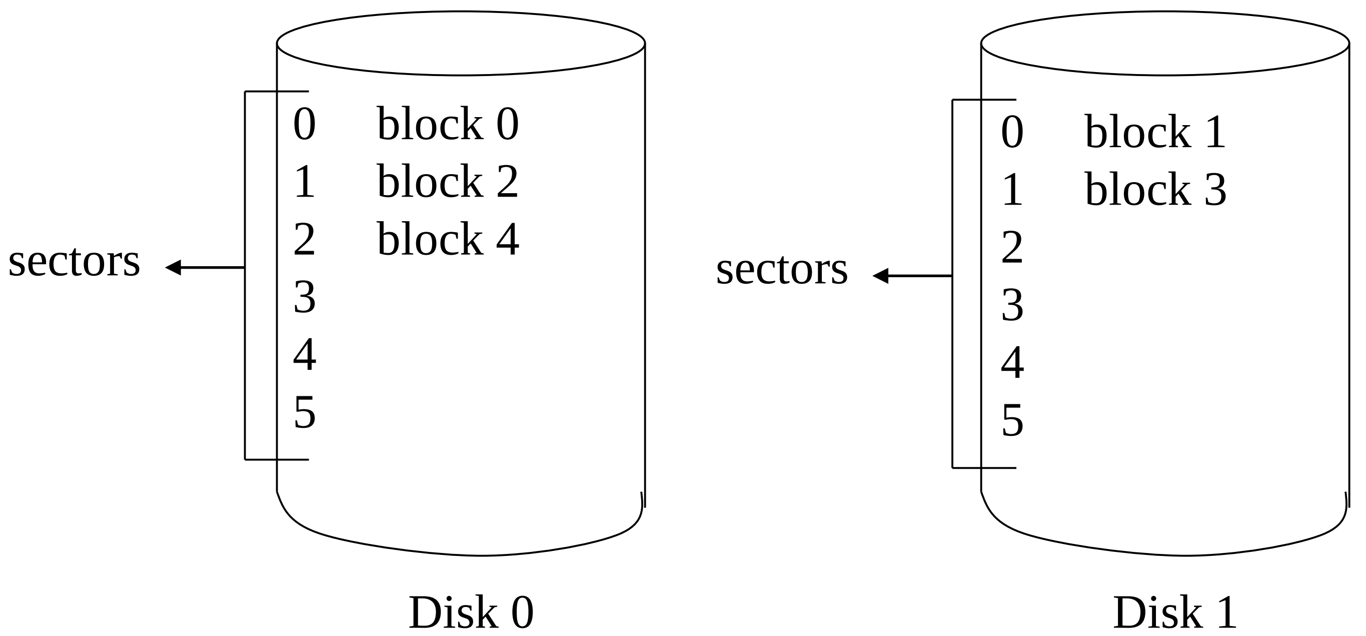
- Keep to copies of data on two separate disks
- Gives good error recovery
  – if some data is lost, get it from the other source
- Expensive
  – requires twice as many disks
- Write performance can be slow
  – have to write data to two different spots
- Read performance is enhanced
  – can read data from file in parallel

RAID Level-0

- Often called striping
- Break a file into blocks of data
- Stripe the blocks across disks in the system
- Simple to implement
  - disk = file block % number of disks
  - sector = file block / number of disks
- provides no redundancy or error detection
  - important to consider because lots of disks means low Mean Time To Failure (MTTF)

RAID Level-0

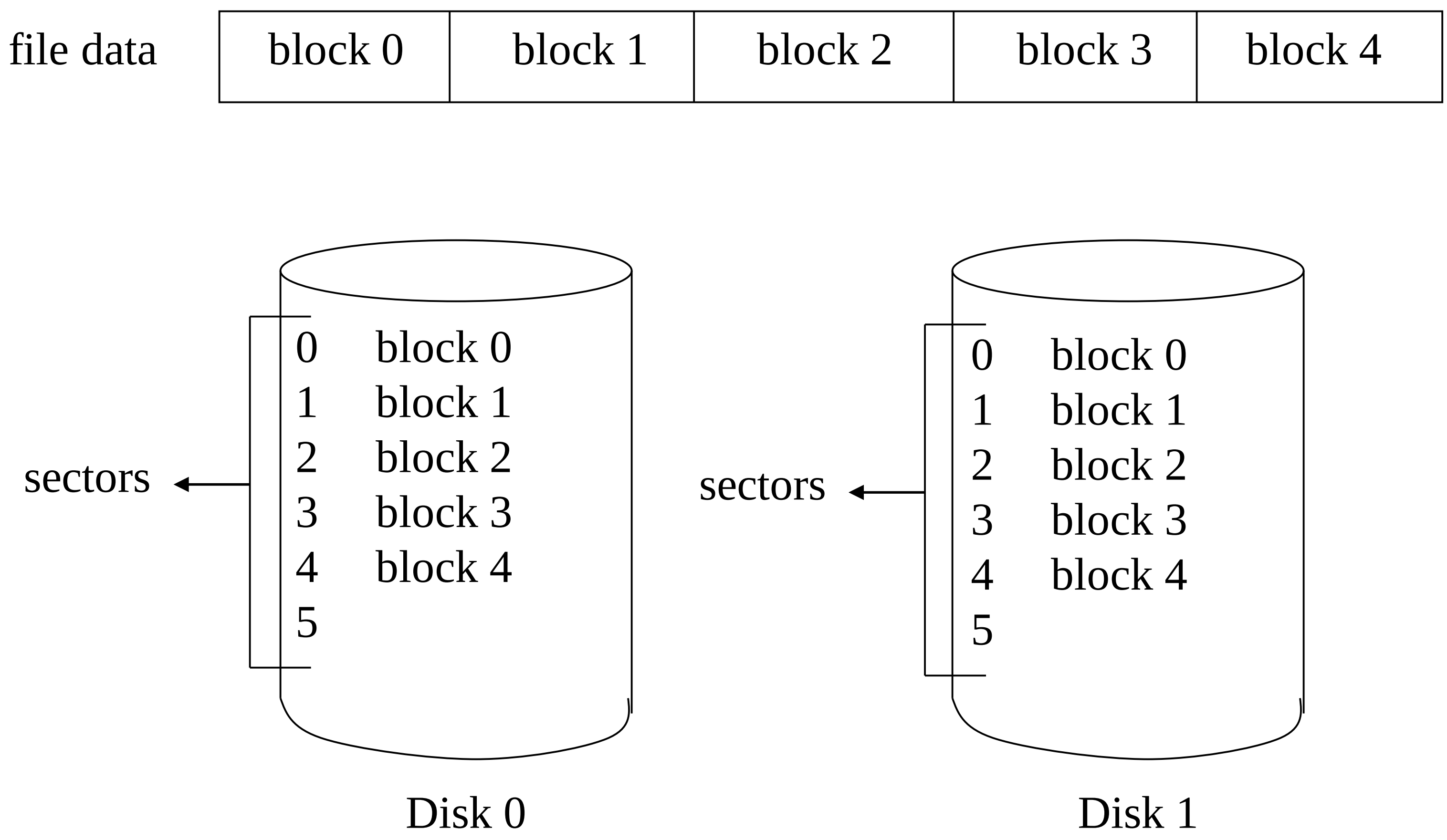
file data	block 0	block 1	block 2	block 3	block 4



RAID Level-1

- A complete file is stored on a single disk
- A second disk contains an exact copy of the file
- Provides complete redundancy of data
- Read performance can be improved
  - file data can be read in parallel
- Write performance suffers
  - must write the data out twice
- Most expensive RAID implementation
  - requires twice as much storage space

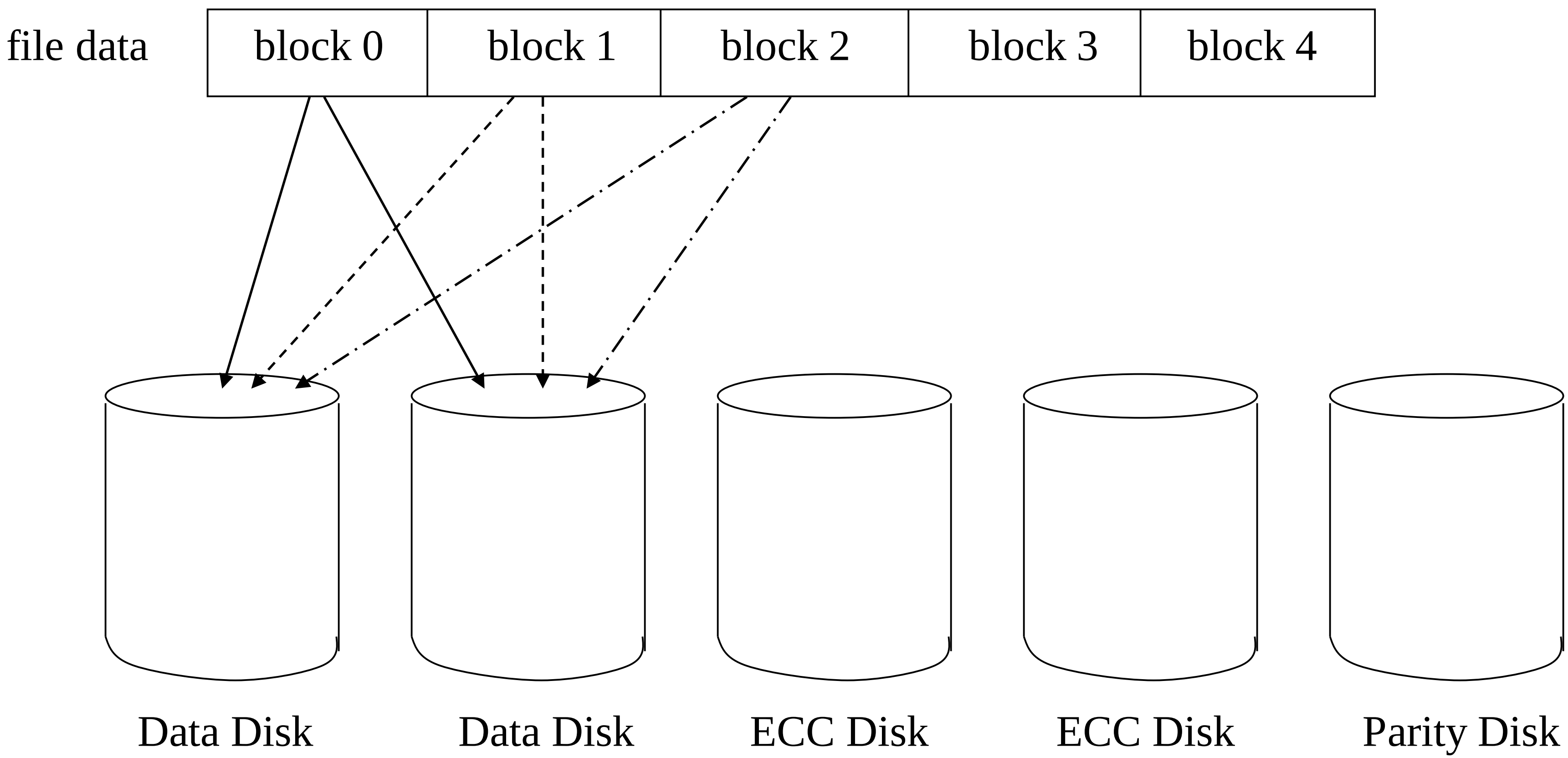
RAID Level-1


file data
block 0
block 1
block 2
block 3
block 4
sectors
0 block 0
1 block 1
2 block 2
3 block 3
4 block 4
5
Disk 0
sectors
0 block 0
1 block 1
2 block 2
3 block 3
4 block 4
5
Disk 1

RAID Level-2

- Stripes data across disks similar to Level-0
  - difference is data is bit interleaved instead of block interleaved
- Uses ECC to monitor correctness of information on disk
- Multiple disks record the ECC information to determine which disk is in fault
- A parity disk is then used to reconstruct corrupted or lost data

RAID Level-2


file data
block 0
block 1
block 2
block 3
block 4
Data Disk
Data Disk
ECC Disk
ECC Disk
Parity Disk

RAID Level-2

- Reconstructing data
  - assume data striped across eight disks
  - correct data: 10011010
  - parity: 0
  - data read: 10011110
  - if we can determine that disk 2 is in error
  - just use read data and parity to know which bit to flip

RAID Level-2

- Requires fewer disks than Level-1 to provide redundancy
- Still needs quite a few more disks
  - for 10 data disks need 4 check disks plus parity disk
- Big problem is performance
  - must read data plus ECC code from other disks
  - for a write, have to modify data, ECC, and parity disks
- Another big problem is only one read at a time
  - while a read of a single block can be done in parallel
  - multiple blocks from multiple files can’t be read because of the bit-interleaved placement of data

RAID Level-3

- One big problem with Level-2 are the disks needed to detect which disk had an error
- Modern disks can already determine if there is an error
  - using ECC codes with each sector
- So just need to include a parity disk
  - if a sector is bad, the disk itself tells us, and use the parity disk to correct it

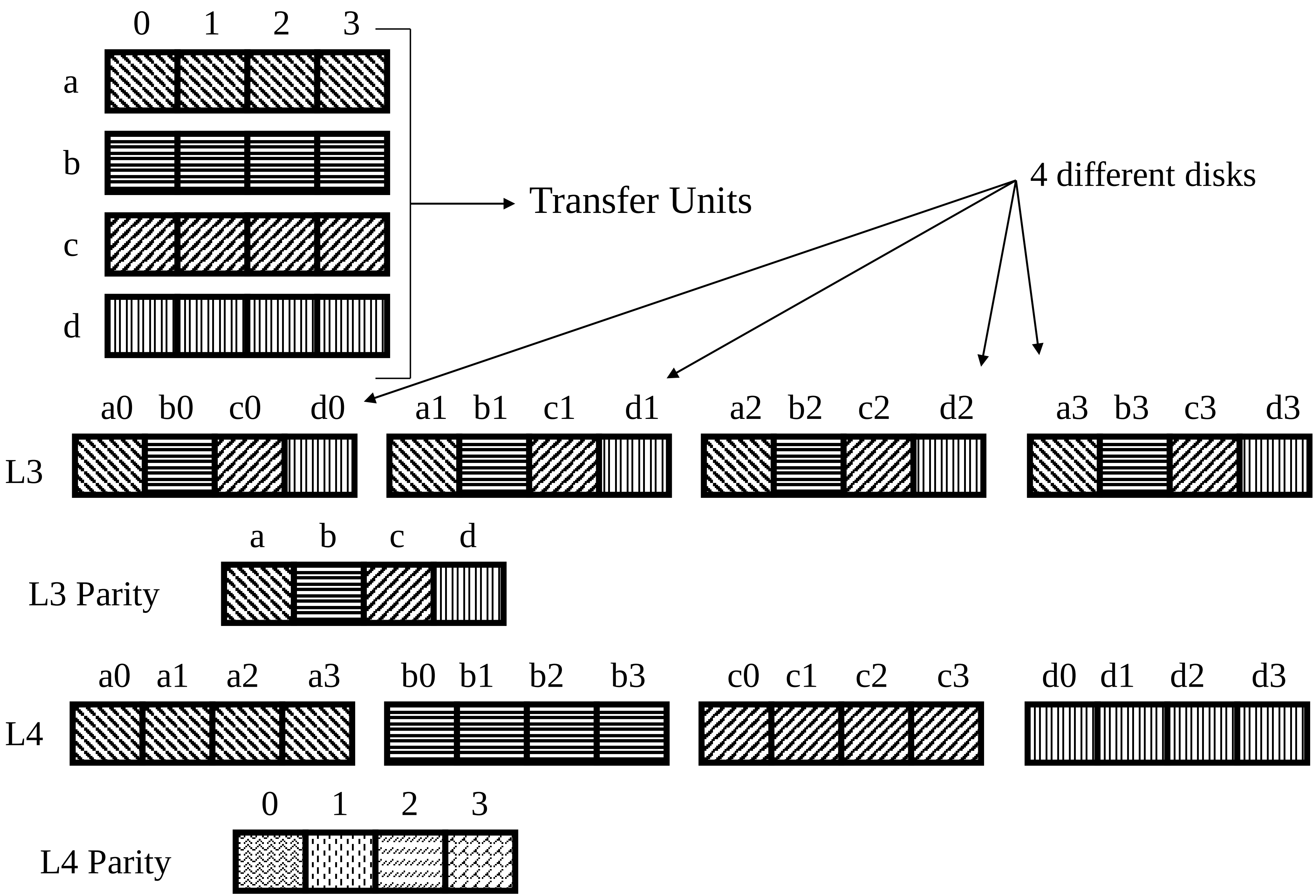
RAID Level-4

- Big problem with Level-2 and Level-3 is the bit interleavening
  - to access a single file block of data, must access all the disks
  - allows good parallelism for a single access but doesn’t allow multiple I/O’s
- Level-4 interleaves file blocks
  - allows multiple small I/O’s to be done at once

RAID Level-4

- Still use a single disk for parity
- Now the parity is calculated over data from multiple blocks
  - Level-2,3 calculate it over a single block
- If an error detected, need to read other blocks on other disks to reconstruct data

Level-4 vs. Level-2,3



RAID Level-4

- Reads are simple to understand
  - want to read block A, read it from disk 0
  - if there is an error, read in blocks B,C, D, and parity block and calculate correct data
- What about writes?
  - it looks like a write still requires access to 4 data disks to recalculate the parity data
  - not true, can use the following formula
    - new parity = (old data xor new data) xor old parity
  - a write requires 2 reads and 2 writes

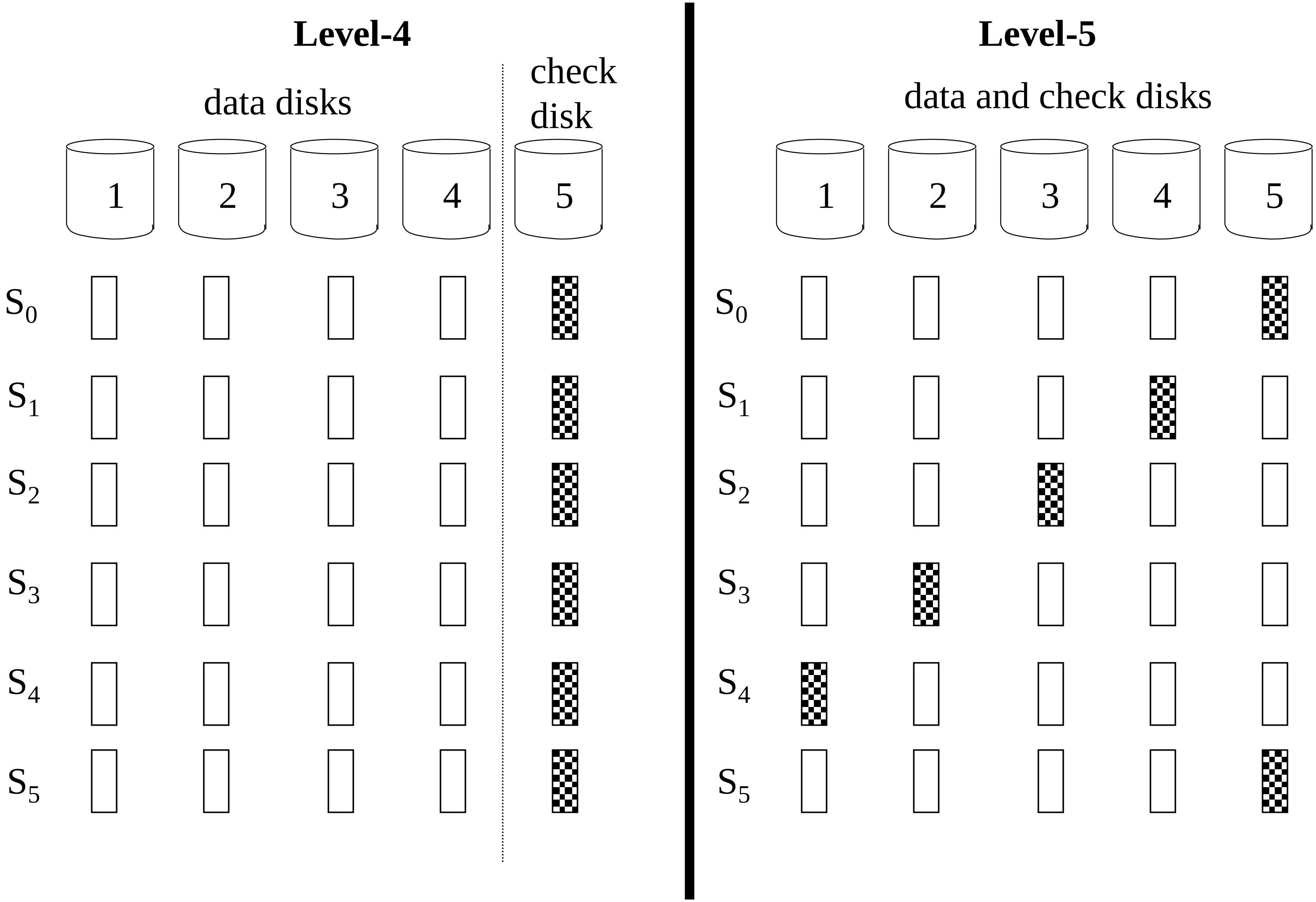
RAID Level-4

- Doing multiple small reads is now faster than before
- However, writes are still very slow
  - this is because of calculating and writing the parity blocks
- Also, only one write is allowed at a time
  - all writes must access the check disk so other writes have to wait

RAID Level-5

- Level-5 stripes file data and check data over all the disks
  - no longer a single check disk
  - no more write bottleneck
- Drastically improves the performance of multiple writes
  - they can now be done in parallel
- Slightly improves reads
  - one more disk to use for reading

RAID Level-5


Level-4
data disks
check disk
1
2
3
4
5
S_0
S_1
S_2
S_3
S_4
S_5
Level-5
data and check disks
1
2
3
4
5
S_0
S_1
S_2
S_3
S_4
S_5

RAID Level-5

- Notice that for Level-4 a write to sector 0 on disk 2 and sector 1 on disk 3 both require a write to disk five for check information
- In Level-5, a write to sector 0 on disk 2 and sector 1 on disk 3 require writes to different disks for check information (disks 5 and 4, respectively)
- Best of all worlds
  - read and write performance close to that of RAID Level-1
  - requires as much disk space as Levels-3,4

RAID Level-10

- Combine Level-0 and Level-1
- Stripe a files data across multiple disks
  - gives great read/write performance
- Mirror each strip onto a second disk
  - gives the best redundancy
- The most high performance system
- The most expensive system