Chapter #6
External Memory

External Memory Overview

- Types:
  - Magnetic Disk
    - Floppy disk
    - Hard disk
    - RAID
  - Optical Disk
    - CD-ROM
    - DVD-ROM
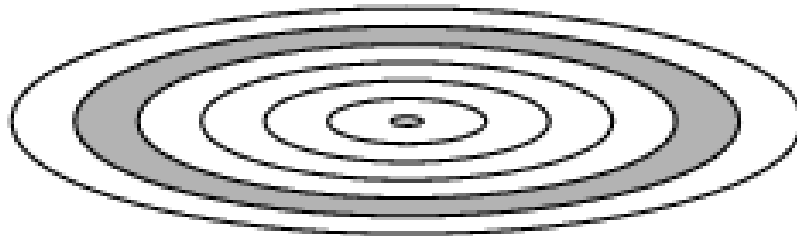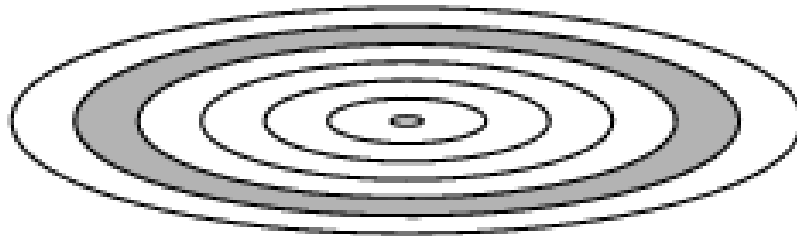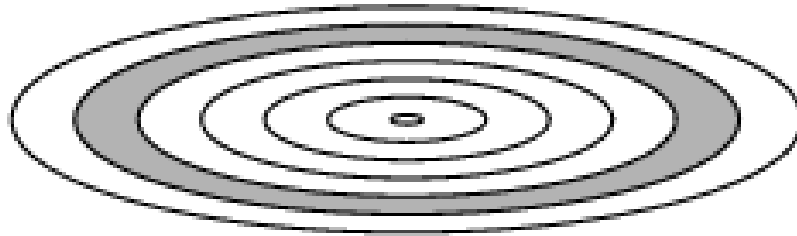   - BD-ROM
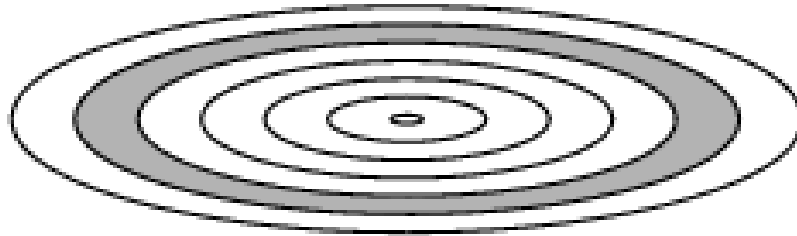- Issues:
  - Capacity
  - Speed
  - Access time

Magnetic Disk Data Organization

- Sector:

  — minimum storage unit in bytes

- Tracks:

  —Concentric rings on disk platter

- Cylinder:

  —Set of tracks in same relative position on platter

- Total capacity:

  —# bytes/sector $\times$ sectors/track $\times$ # tracks/cylinder $\times$ # cylinders

Magnetic Disk Data Layout
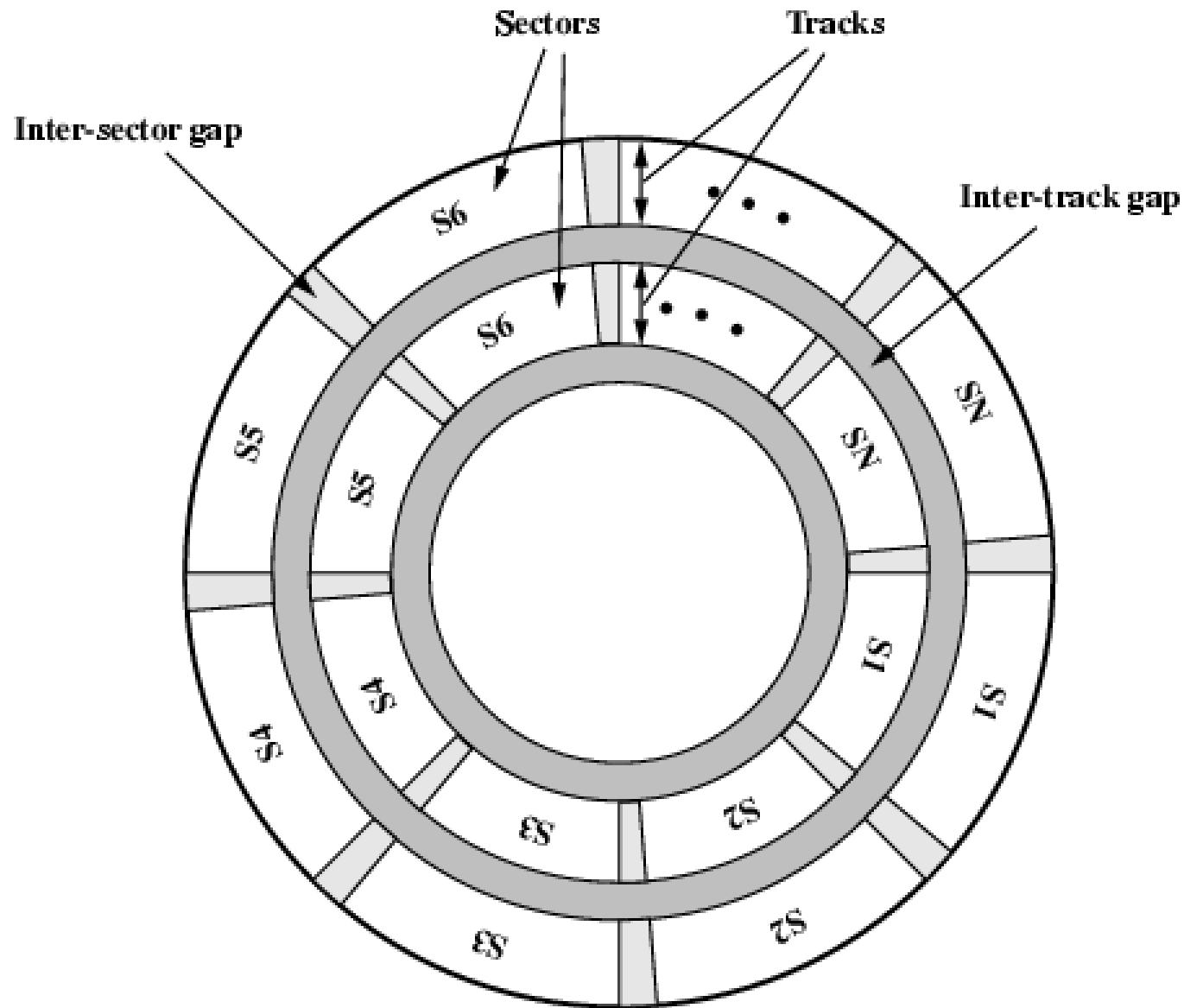
Cylinders

Magnetic Disk Performance

- Average seek time in ms (T_s)
- Transfer size in bytes (b)
- Rotation speed in revolutions/minute (r)
- Number of bytes on track (N)
- Transfer time:
  $$T = b/rN$$
- Average access time:
  $$T_a = T_s + (1/2r) + T$$

RAID Overview

- Definition:
  - —Redundant Array of Independent Disks
  - —Term coined at Berkeley in 1988 (orig. I="Inexpensive")
  - —Categorized into non-hierarchical 7 levels (0 to 6)
- Characteristics of 7 levels of design architecture:
  - —Set of physical disks viewed by O/S as single logical disk
  - —Data distributed across physical disks of array
  - —Redundant disk capacity used to store parity information to recover data in case of disk failure
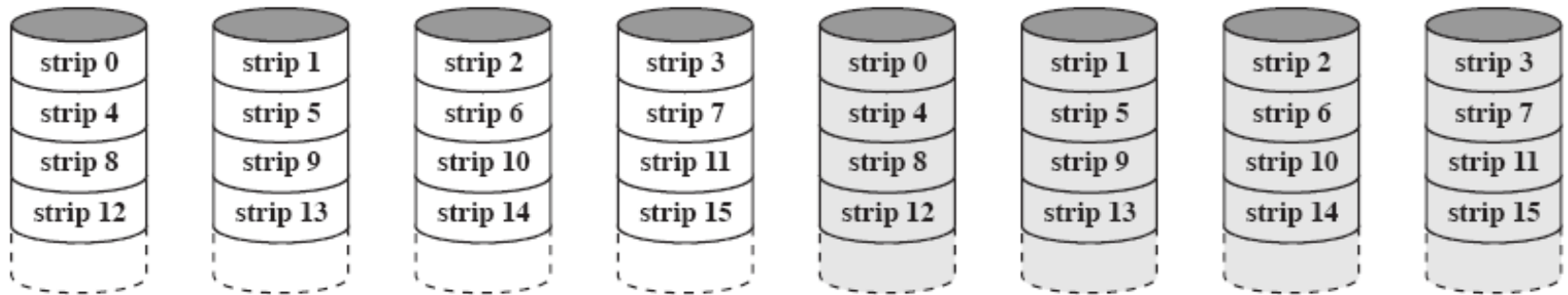
RAID 0 Diagram
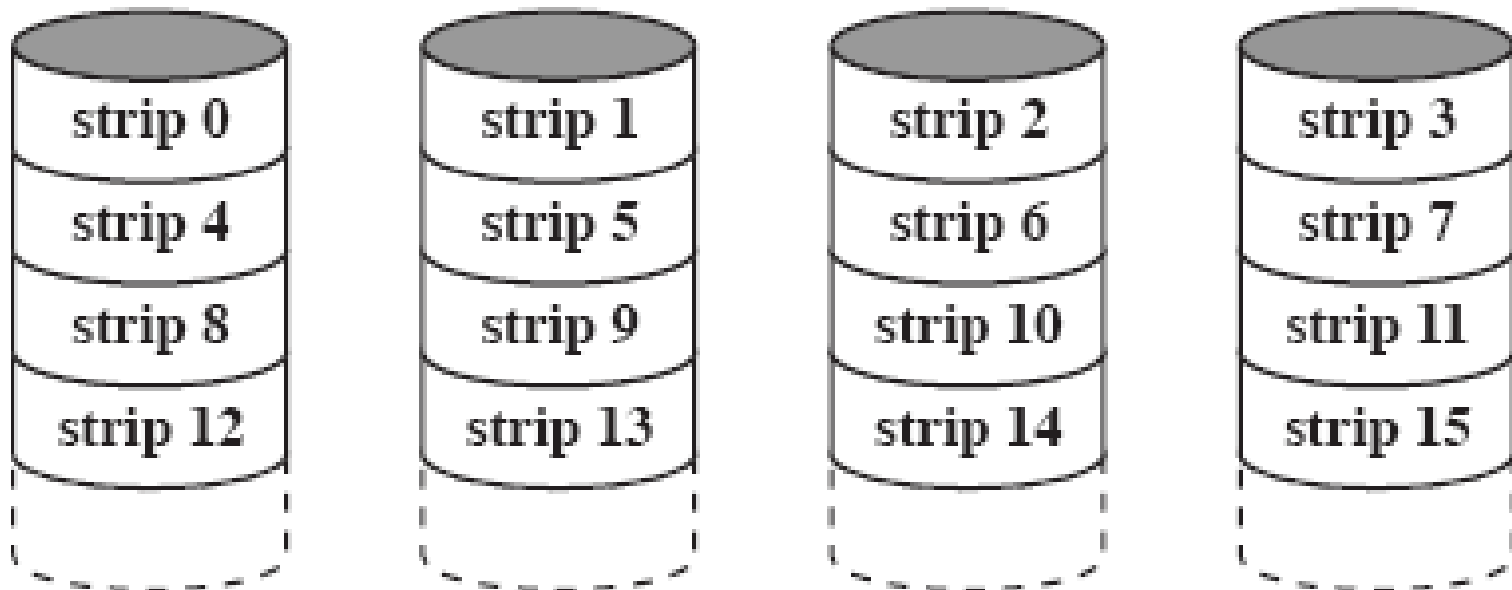
RAID 0 Details

- Redundancy:
  —No redundancy
- Distribution of data:
  —Round-robin striping of data across disks
- Adv:
  —Simple, easy, no overhead calculations, improves speed
- Disadv:
  —No recovery scheme in case of failed disk
- Applications:
  —Video & image editing
 —Any appl. requiring high bandwidth

RAID 1 Diagram

RAID 1 Details

- Redundancy:
  - Mirrored disks

- Distribution of data:
  - Round-robin striping of data (2 copies on separate disks)
  - Read from either copy, write to both copies

- Adv:
  - Simple design, recovery is simple for even mutiple failures

- Disadv:
  - Highest disk overhead→expensive & inefficient

- Applications:
  - Accounting, payroll, financial
 - Any appl. requiring very high availability

RAID 2 Diagram
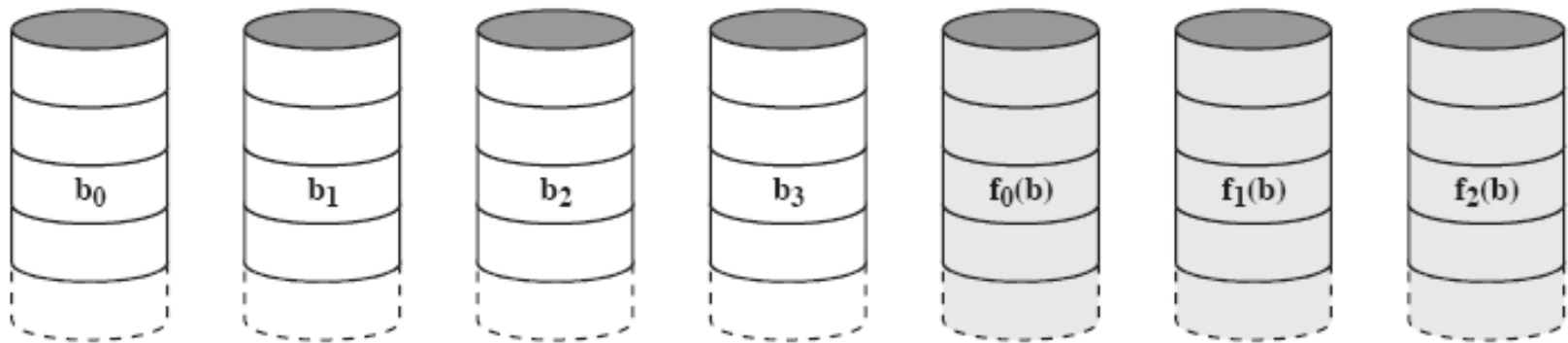
RAID 2 Details

- Redundancy:
  - —Hamming code utilizing $\log_2 n$ disks to store parity of corresponding bits across n disks
- Data distribution:
  - —Very small stripes, often single byte/word
- Adv:
  - —High data transfer rate, simple design
- Disadv:
  - —Inefficient & costly (high ratio of parity to data disks)
- Applications:
 - —None→not commercial implementations exist

RAID 3 Diagram
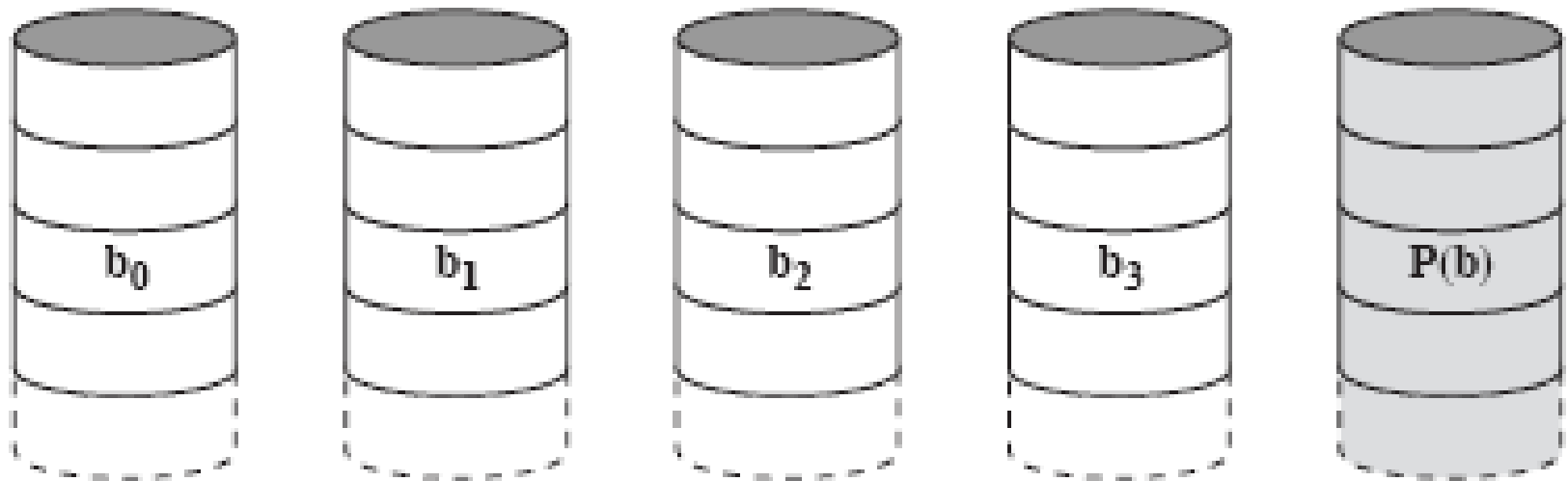
RAID 3 Details

- Redundancy:
  - One disk storing parity information for each set of corresponding bits
  - Data on failed disk can be recovered from other disks and parity info
- Data distribution:
  - Bit-interleaved
- Adv:
  - Very high read/write transfer rates
  - High efficiency (1 parity disk for any # of data disks)
- Disadv:
  - Transfer rate equal to single disk at best
- Applications:
  - Video/image editing
 - Any application requiring high throughput

RAID 4 Diagram
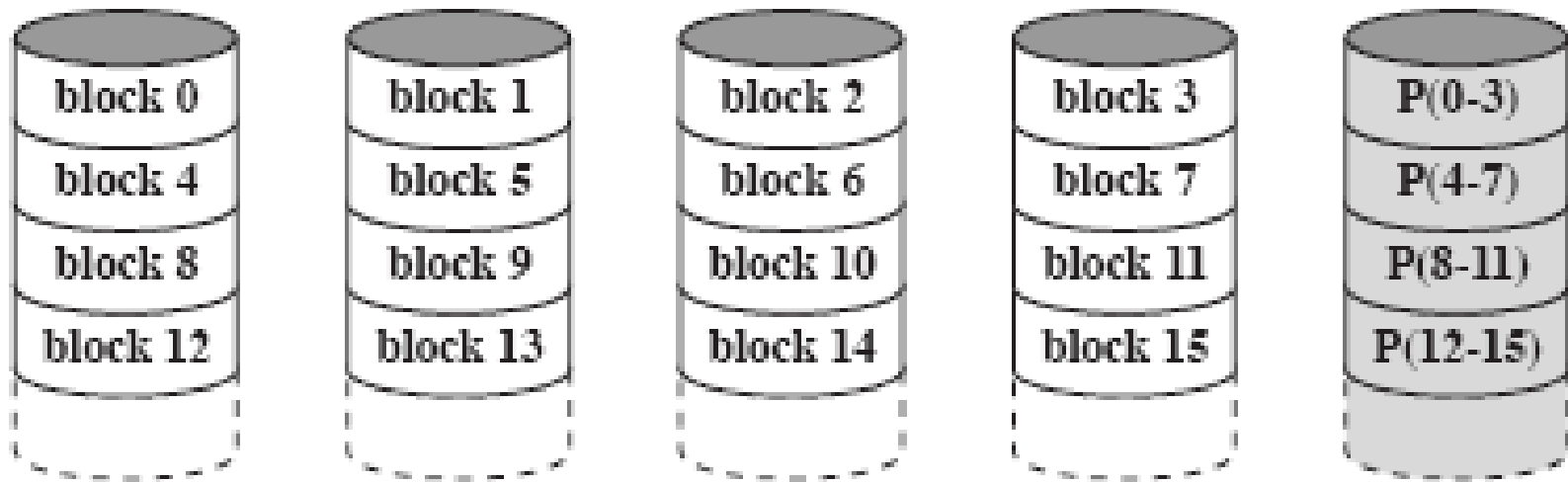
RAID 4 Details

- Redundancy:
  - Block-level parity
- Data distribution:
  - Striping of large blocks
  - Each disk operates independently
- Adv:
  - High read transaction rate
  - High efficiency (low ratio of parity to data disks)
- Disadv:
  - Inefficient to recover failed disk, low write transaction rate
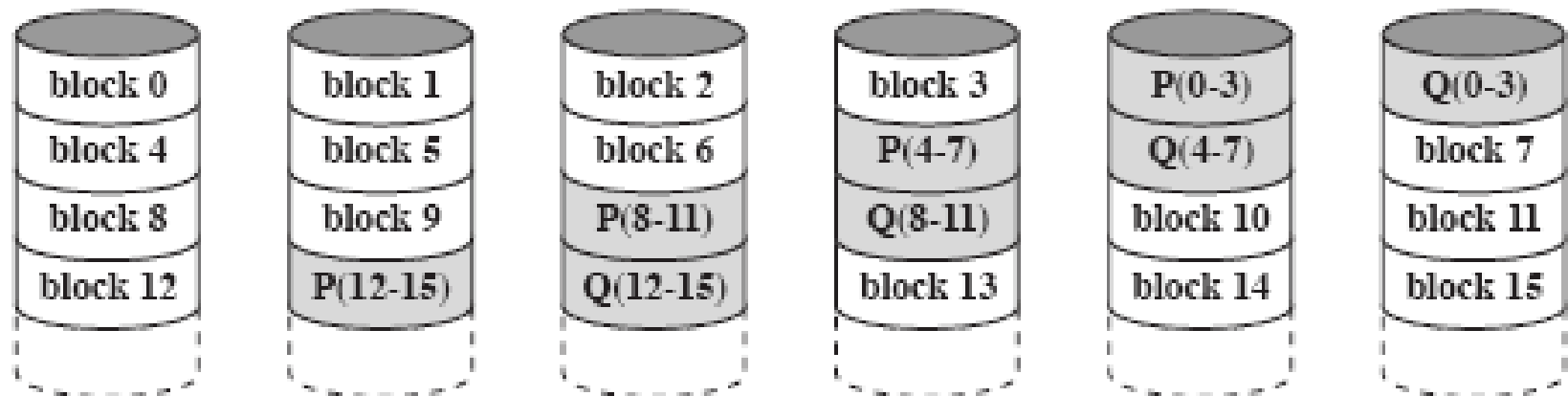- Application:
  - None→no commercial implementation exists

RAID 5 Diagram
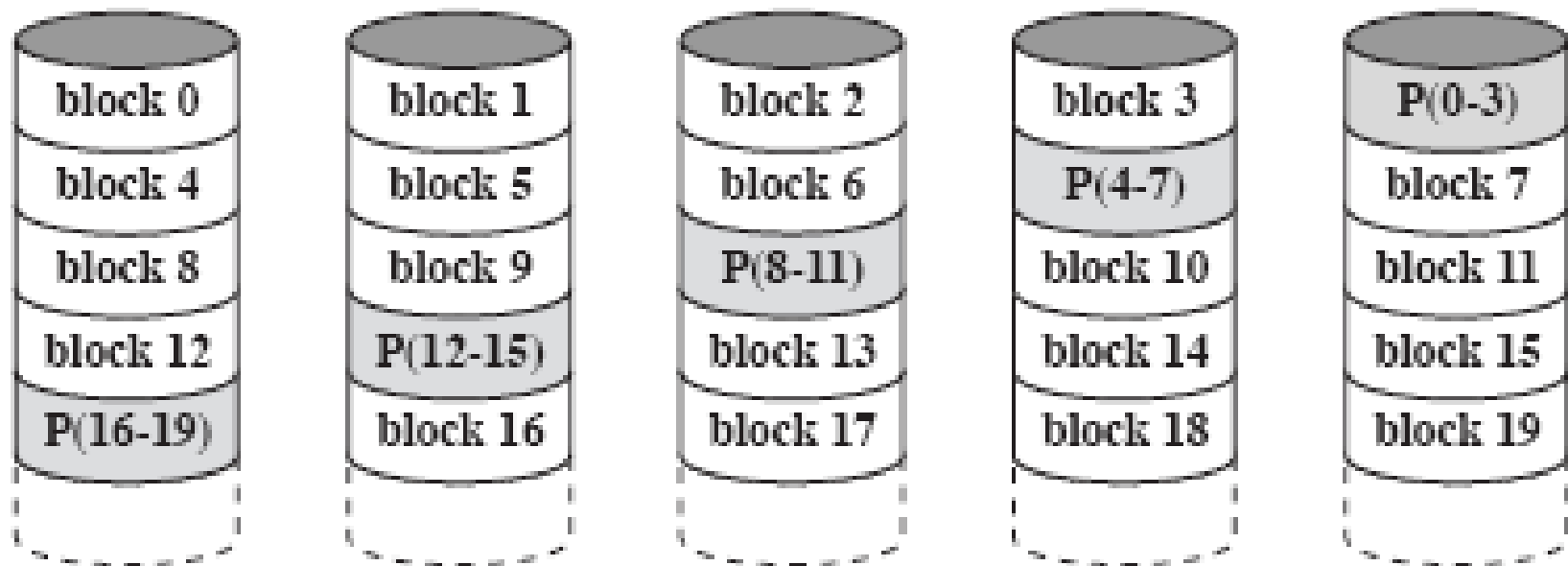
RAID 5 Details

- Redundancy:
  - —Block-level distributed parity
- Data distribution:
  - —Round robin parity striped across all disks
- Adv:
  - —Highest read transaction rate
  - —High efficiency (low ratio of parity to data disks)
  - —Avoids RAID 4 bottleneck at parity disk
- Disadv:
  - —More difficult to rebuild data when disk fails
- Applications:
  - —Network servers

RAID 6 Diagram

RAID 6 Details

- Redundancy:
  —Dual block-level distributed parity

- Data distribution:
  —Round robin parity striped across all disks

- Adv:
  —High fault tolerance to sustain multiple disk failures

- Disadv:
  —Parity computation overhead is high

- Applications:
  —Mission-critical applications