Datorsystem VT 2022

F7

Input/Output
&
Storage Systems

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Outline

- An overview of the:
  - Input / Output, I/O Architectures & Control of I/O.
- Interrupts controller , Interrupts vector & Interrupt Service Routine (ISR)
- I/O BUSES
- Connecting Buses to I/O devices
- Data Transmission Modes
- **R**edundant **A**rray of **I**ndependent **D**isks (RAID)

Data storage I/O

- Data storage and retrieval is one of the primary functions of computer systems.
  - One could easily make the argument that computers are more useful to us as data storage and retrieval devices than they are as computational machines.
- All computers have I/O devices connected
  - To achieve **good performance** I/O should be kept to a **minimum!**

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I/O and Performance

- I/O throughput have effect, dragging down overall system performance.
  - This is especially true when virtual memory is involved.
- The fastest processor in the world is of little use if it spends most of **its time waiting for data**.

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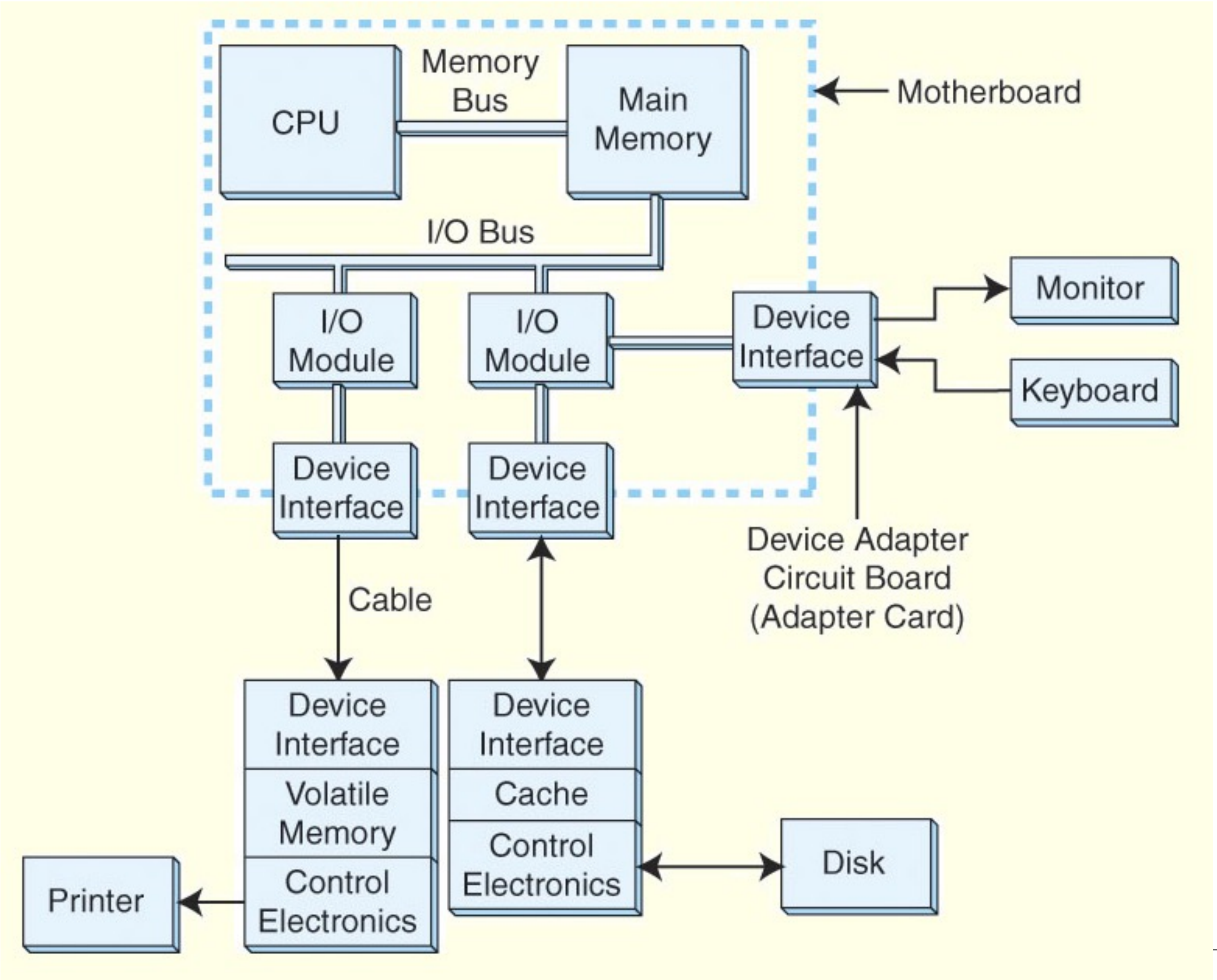
I/O Architectures



A model I/O configuration

I/O Architectures

- Input/output as a subsystem of components
  - Moves coded data between **external devices** and a **host system**.
- I/O **subsystems include**:
  - Blocks of main memory that are devoted to I/O functions.
  - Buses that move data into and out of the system.
  - Control modules in the **host** and in **peripheral devices**
  - Interfaces to external components such as keyboards and disks.
  - Cabling or communications links between the host system and its peripherals.

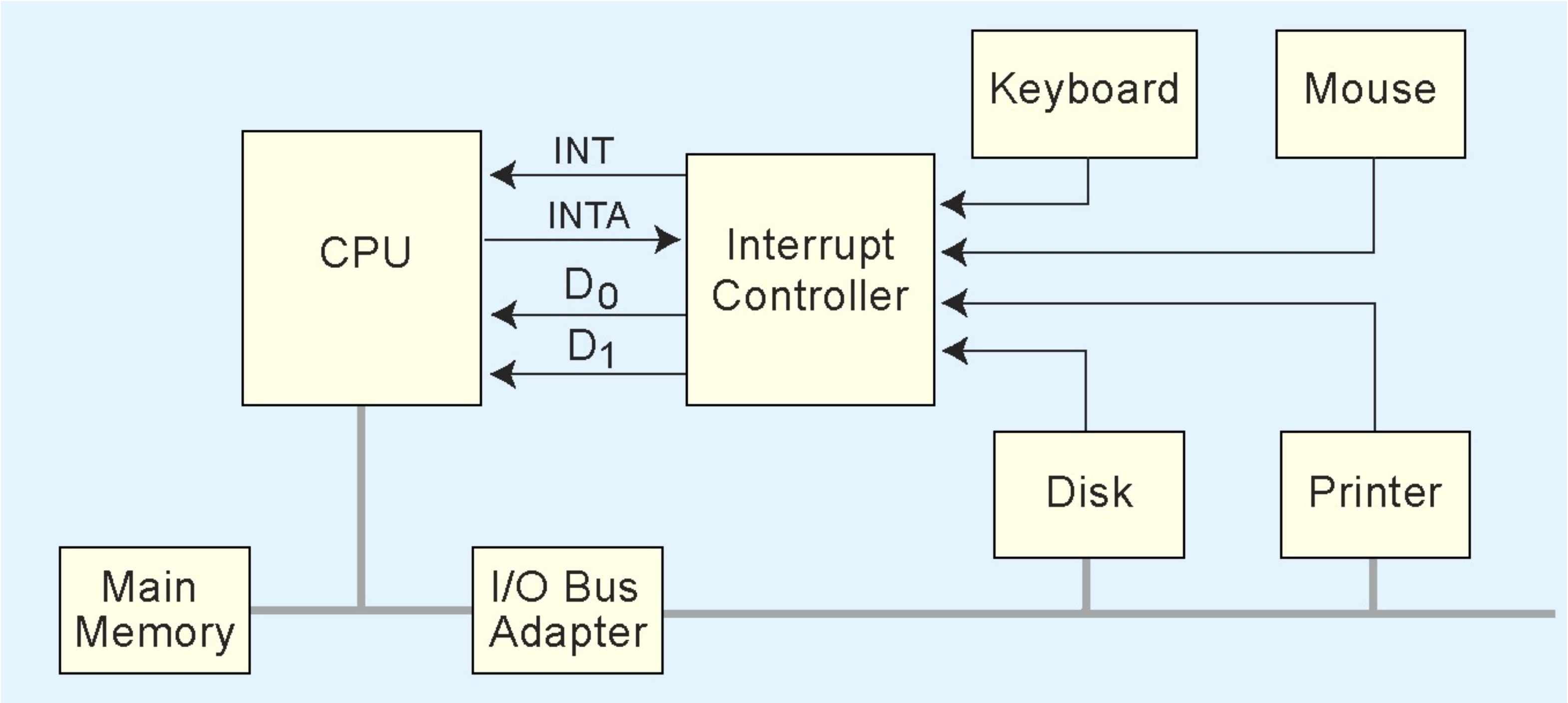
Control of I/O

- I/O can be controlled in **five** general ways.
  - *Programmed I/O* reserves **a register for each I/O** device. Each register is continually polled **to detect data arrival**.
  - *Interrupt-Driven I/O* allows the CPU to do other things until I/O is requested.
  - *Memory-Mapped I/O* **shares memory address** space between **I/O devices** and **program memory**.
  - *Direct Memory Access (DMA)* offloads I/O processing to a special-purpose **chip** that takes **care of the details**.
  - *Channel I/O* uses dedicated I/O processors.

Programmed I/O

An idealized I/O subsystem that uses interrupts.

Each device connects its interrupt line to the **interrupt controller**.



The controller signals the CPU when any of the interrupt lines are Asserted.

Interrupt Vectors

- The status of the interrupt signal is checked at the top of the **fetch-decode-execute** cycle.
- The **particular code** that is executed whenever an interrupt occurs is determined by a **set of addresses** called ***interrupt vectors*** that are stored in low memory.
- The system state is saved **before** the **I**nterrupt **S**ervice **R**outine (ISR) is executed and is restored **afterward**.

Interrupt Service Routine (ISR):

CPU halt normal operation and jump to a specific location in memory called ISR.

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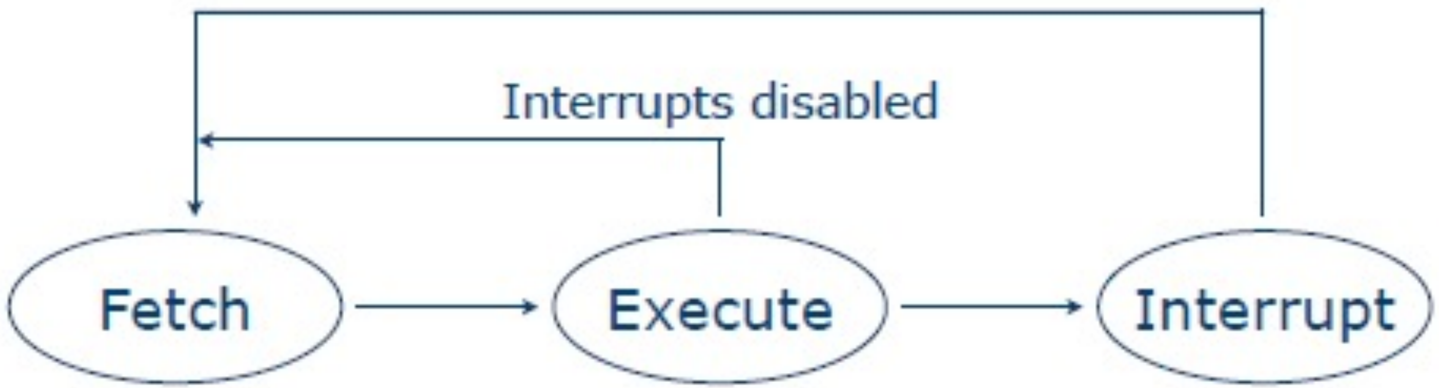
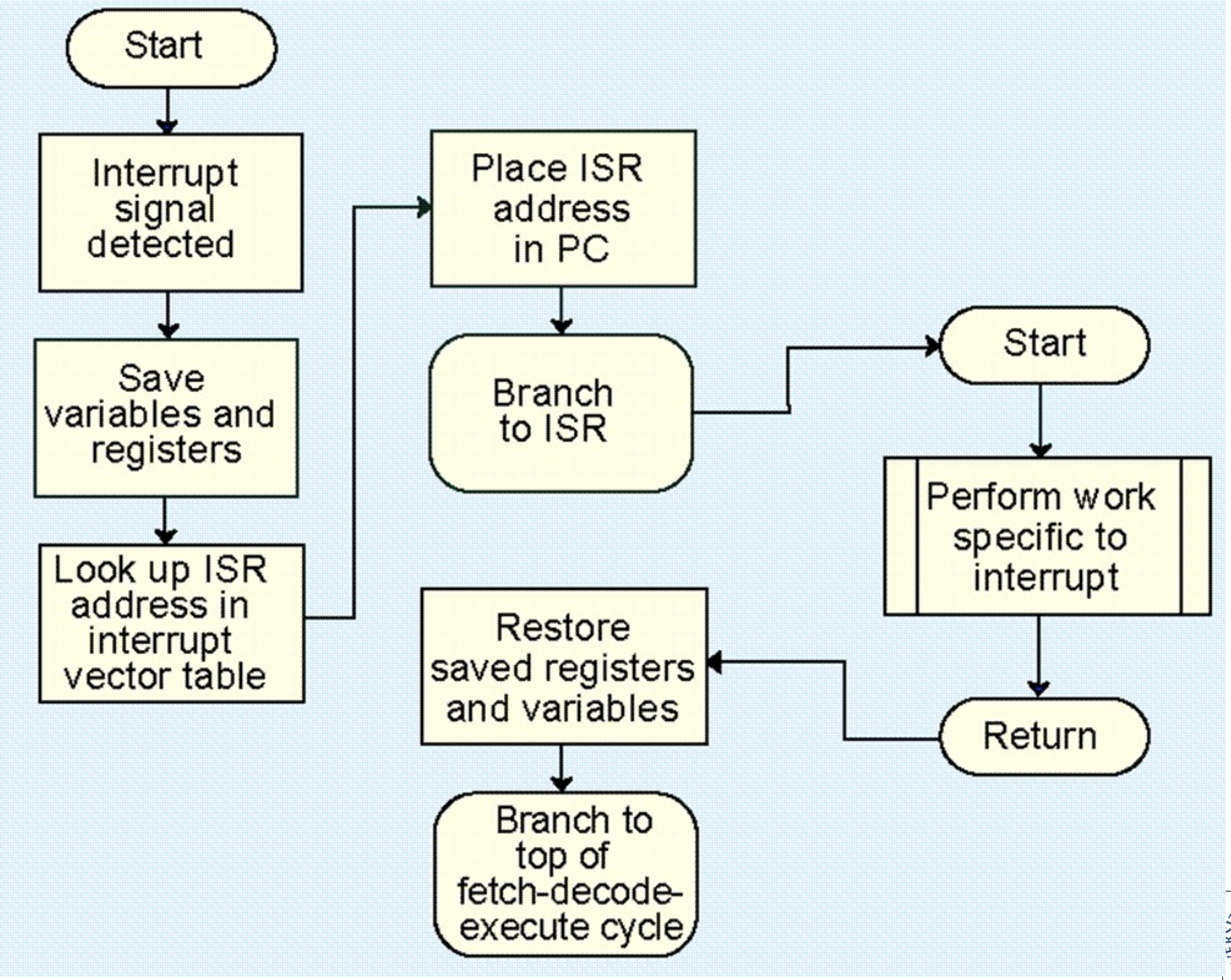
Instruktionscykeln med interrupts



Interrupt-Driven I/O



Interrupt Service Routine (ISR):

CPU halt normal operation and jump to a specific location in memory called ISR.

Memory-mapped I/O

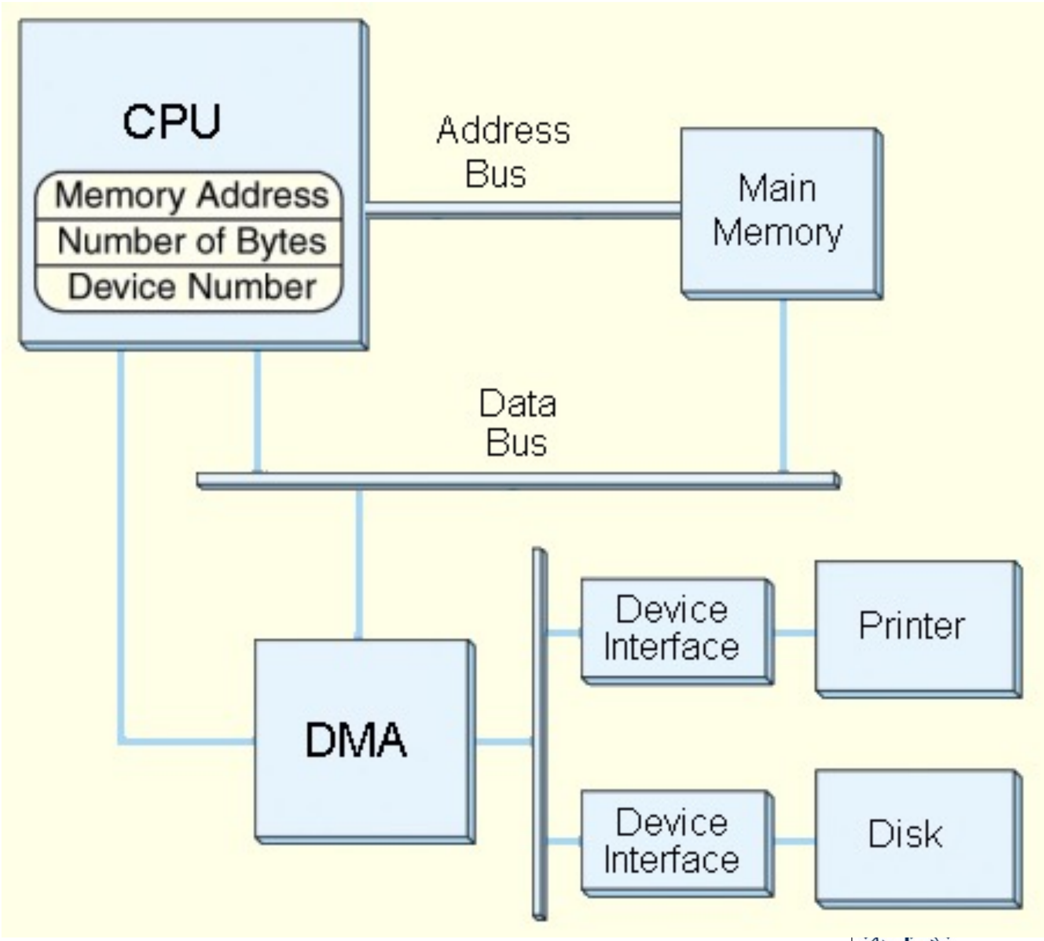
- In memory-mapped I/O devices and main memory **share the same address space**.
  - Each **I/O device** has **its own reserved block** of memory.
  - Memory-mapped I/O therefore **looks just like a memory access** from the point of view of the CPU.
  - The **same instructions to move data to and from both I/O and memory**, greatly simplifying system design.

Direct Memory Access I/O

This is a DMA configuration.

Notice that the DMA and the CPU share the bus.

The DMA **runs at a higher priority and steals memory cycles** from the CPU.

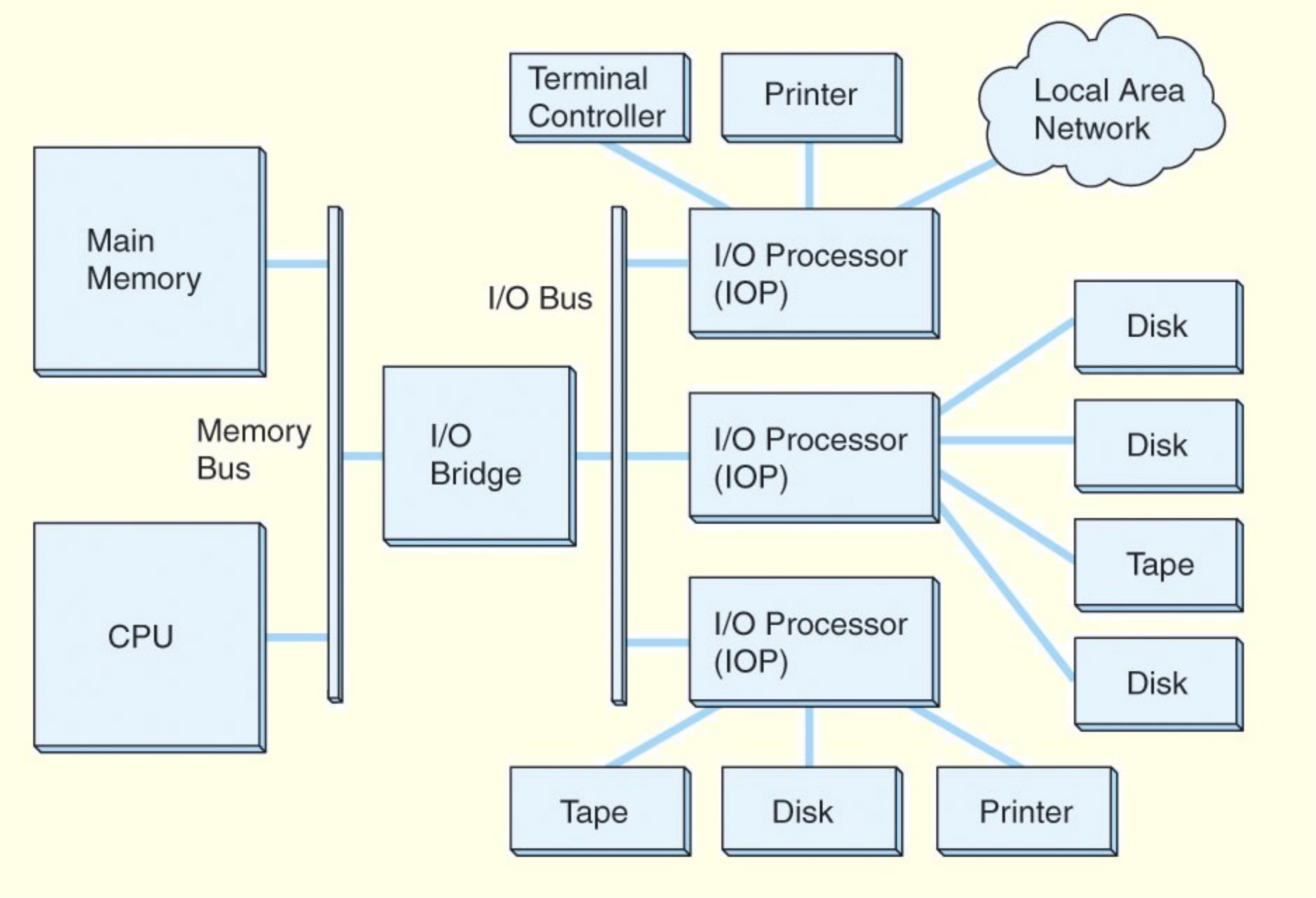


Channel-attached I/O

- In very large systems employ Channel-attached I/O
- One or more I/O processors (IOPs) that control various channel paths.
- Slower devices such as terminals and printers are combined (*multiplexed*) into a single faster channel.
- Distinguished from DMA by the intelligence of the IOPs.
- The IOP **negotiates protocols**, issues device commands, translates storage coding to memory coding, and can transfer entire files or groups of files independent of the host CPU.

Channel-attached I/O

A channel I/O configuration



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I/O Architectures

- **Character I/O devices** process one byte (or character) at a time.
  - Examples **include modems, keyboards, and mice**.
  - **Keyboards** are usually connected through an **interrupt-driven I/O system**.
- **Block I/O devices** handle bytes in groups.
  - Most mass storage devices (disk and tape) are block I/O devices.
  - Block I/O systems are most efficiently connected through DMA or channel I/O.

I/O BUSES

- **I/O buses**, unlike memory buses, operate asynchronously. Requests for bus access must be arbitrated among the devices involved.
- **Bus control** lines **activate** the devices when they are needed, raise signals when errors have occurred, and reset devices when necessary.
- The number of data lines is the ***width*** of the **bus**.
- A bus **clock** coordinates activities and provides bit cell boundaries.

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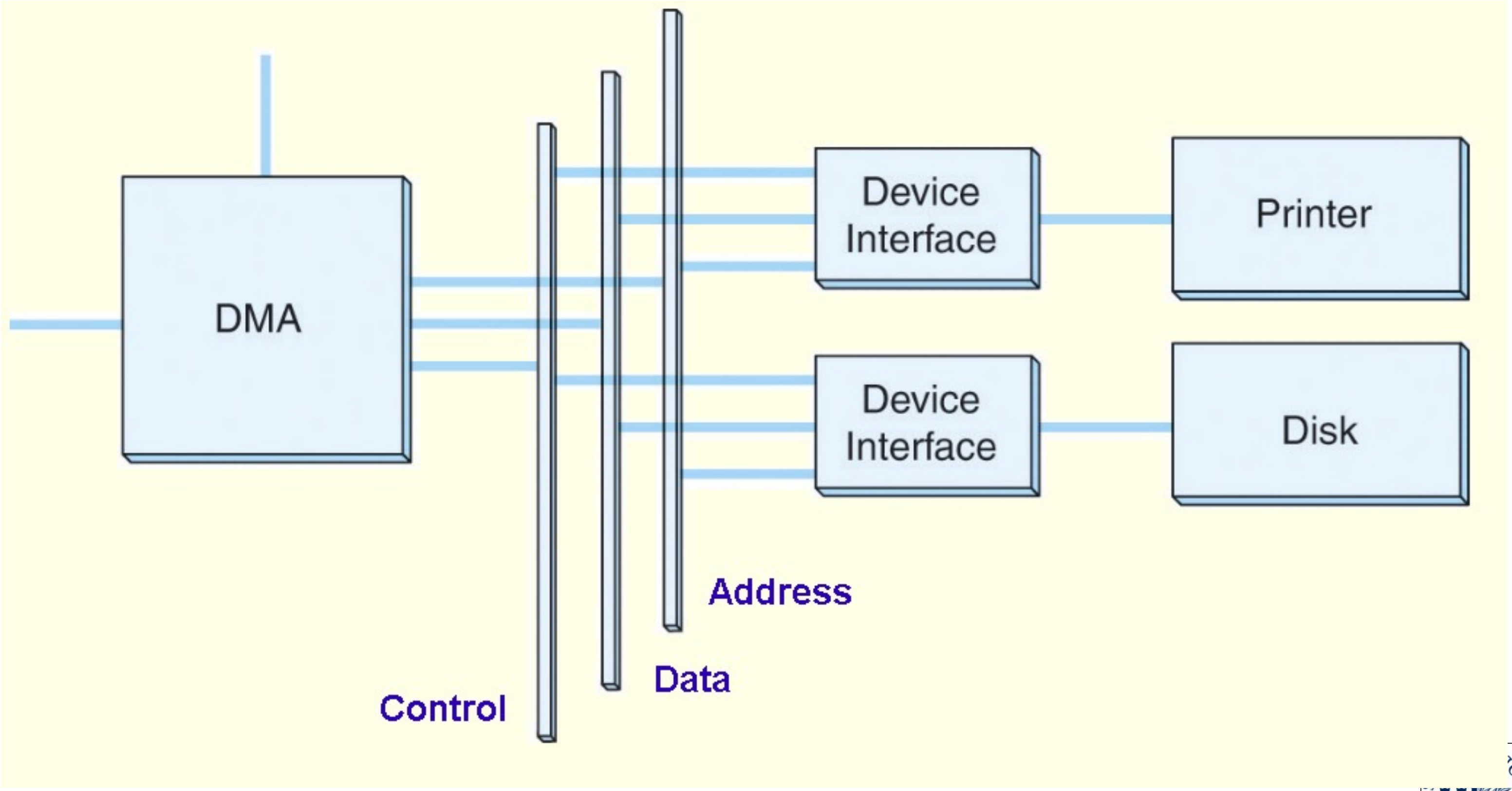
GDMA I/O

This is a **Generic DMA** configuration showing how the DMA circuit connects to a data bus.



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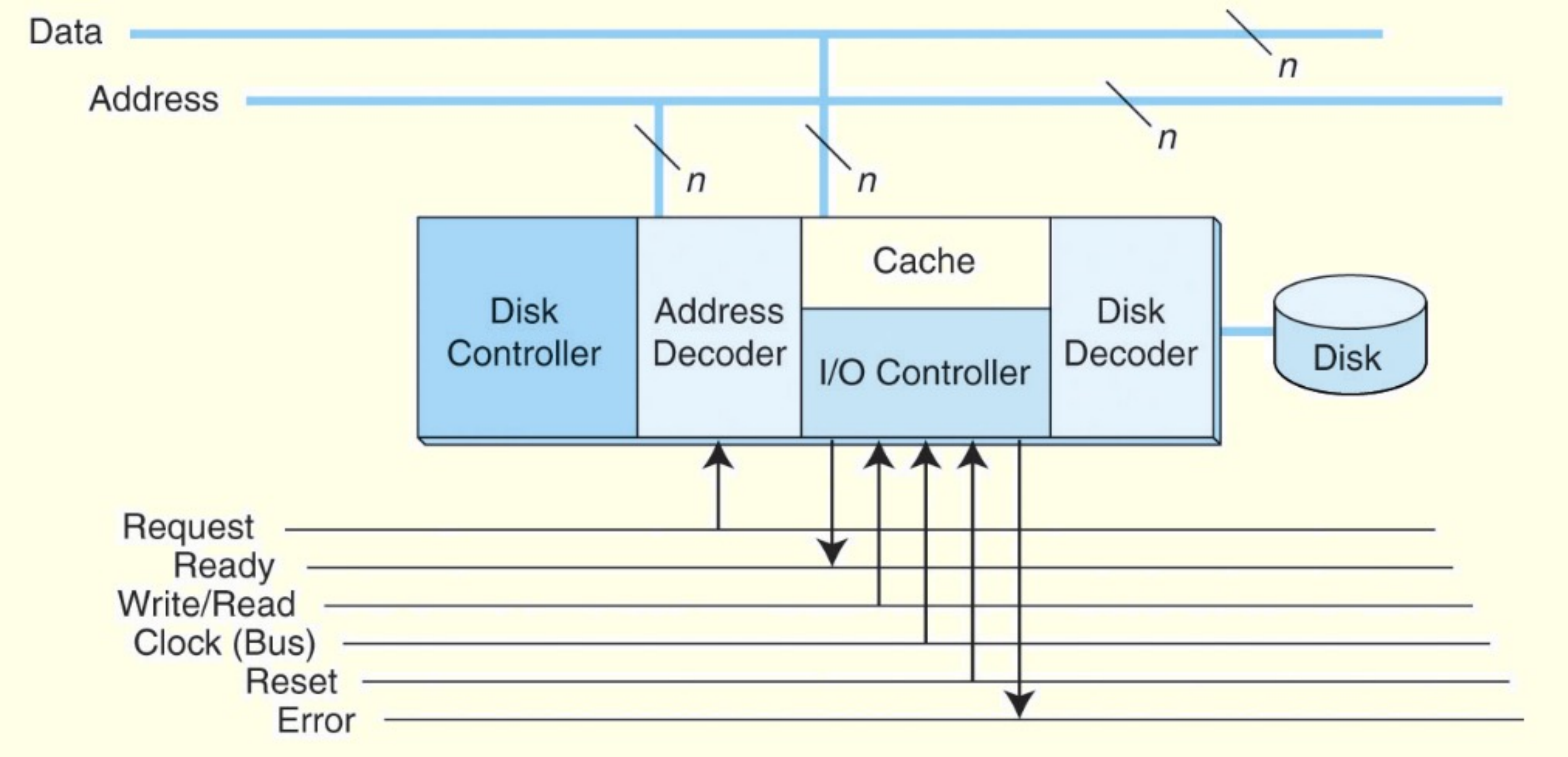
Connecting Buses to I/O devices

This is how a bus connects to a disk drive.



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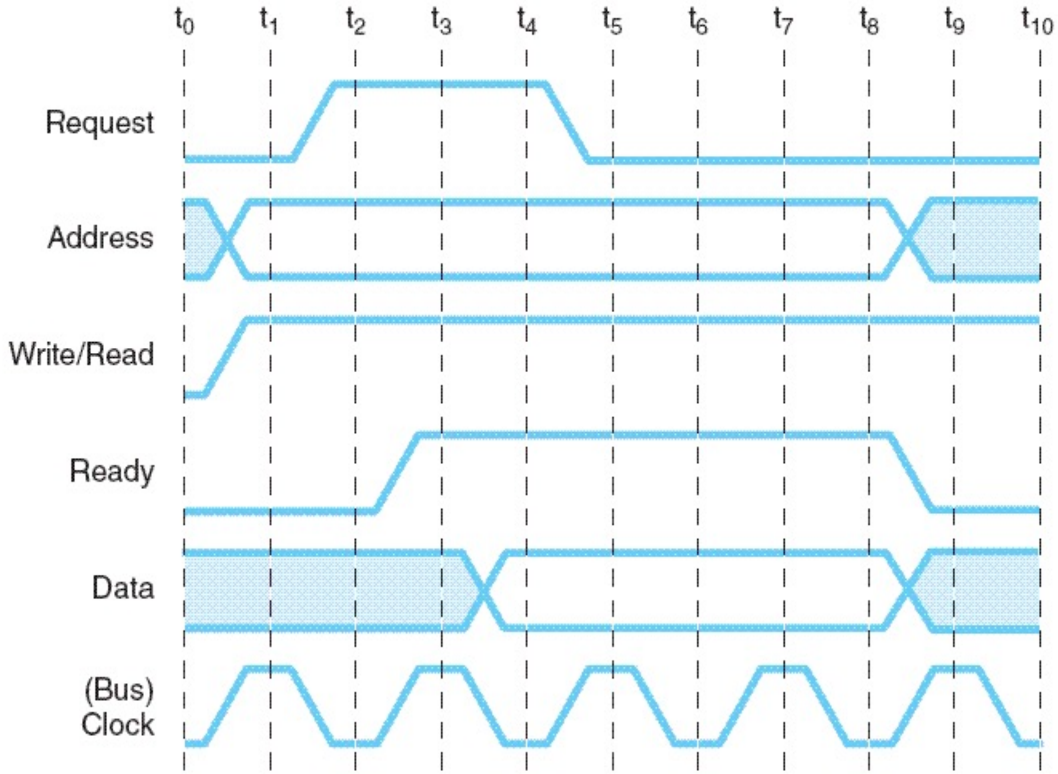
Timing diagrams, such as this one, define bus operation in detail.



Time	Salient Bus Signal	Meaning
t_0	Assert Write	Bus is needed for writing (not reading)
t_1	Assert Address	Indicates where bytes will be written
t_2	Assert Request	Request write to address on address lines
t_3	Assert Ready	Acknowledges write request, bytes placed on data lines
t_4–t_7	Data Lines	Write data (requires several cycles)
t_8	Lower Ready	Release bus

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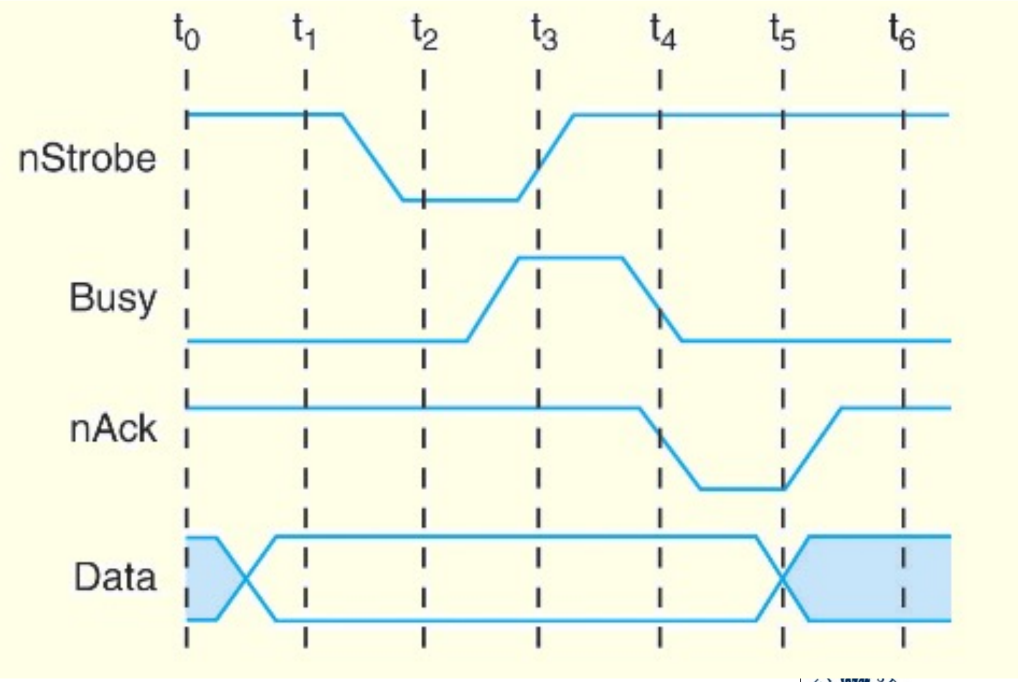
Data Transmission Modes

- **Bytes** can be conveyed from one point to another by sending their encoding signals simultaneously using *parallel data transmission* or by sending them one **bit** at a time in *serial data transmission*.

  – Parallel data transmission for a printer resembles the signal protocol of a memory bus:



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Data Transmission Modes

- In parallel data transmission, the interface requires one conductor for each bit.
- Parallel cables are **fatter than serial** cables.
- Compared with parallel data interfaces, serial communications interfaces:
  - Require fewer conductors.
  - Are less susceptible to attenuation.
  - Can transmit data farther and faster.

Serial communications interfaces are suitable for time-sensitive (*isochronous*) data such as voice and video.

Optical Disks

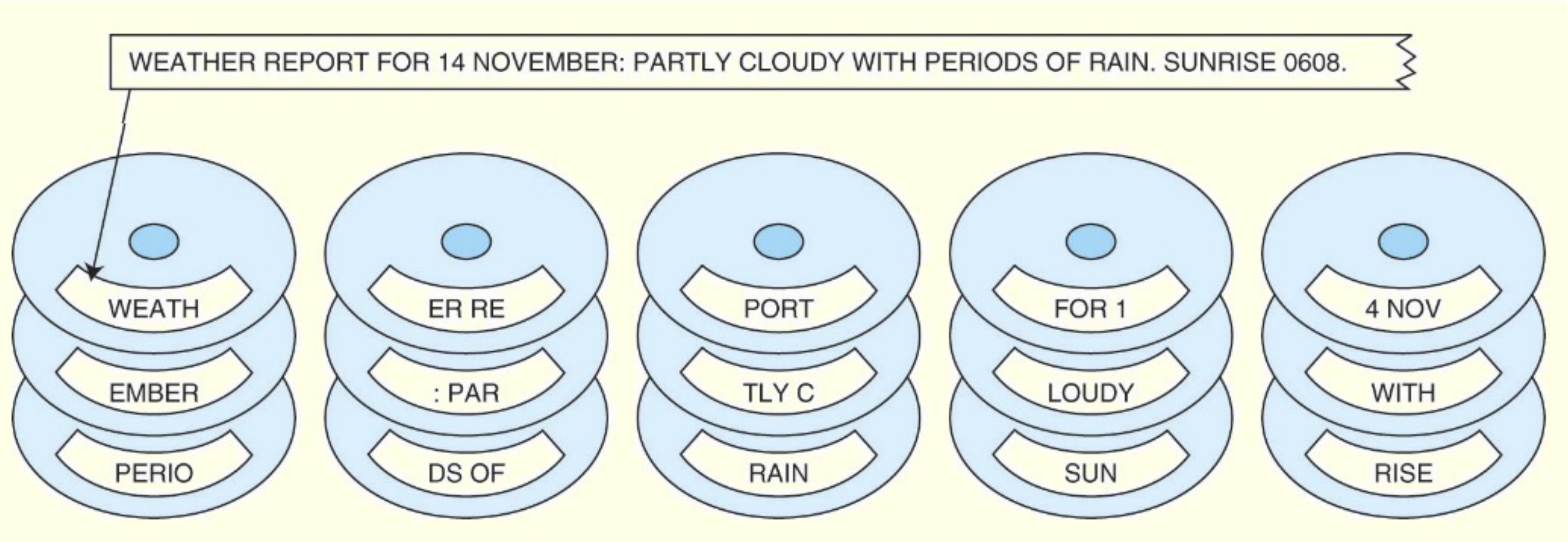
- Optical disks provide large storage capacities very inexpensively.
- They come in a number of varieties including CD-ROM, DVD, and WORM.
- Many large computer installations produce document output on optical disk rather than on paper. This idea is called COLD-- *Computer Output Laser Disk*.
- It is estimated that optical disks can endure for a hundred years. Other media are good for only a decade-- at best.

RAID

- RAID, an acronym for ***R**edundant **A**rray of **I**ndependent **D**isks* was invented to address problems of disk reliability, cost, and performance.
- In RAID, data is stored across many disks, with extra disks added to the array to provide error correction (redundancy).
- The inventors of RAID, David Patterson, Garth Gibson, and Randy Katz, provided a RAID taxonomy that has persisted for a quarter of a century, despite many efforts to redefine it.

RAID

- RAID Level 0, also known as *drive spanning*, provides improved performance, but no redundancy.
  - Data is written in blocks across the entire array



  - The disadvantage of RAID 0 is in its low reliability (låg tillförlitlighet).

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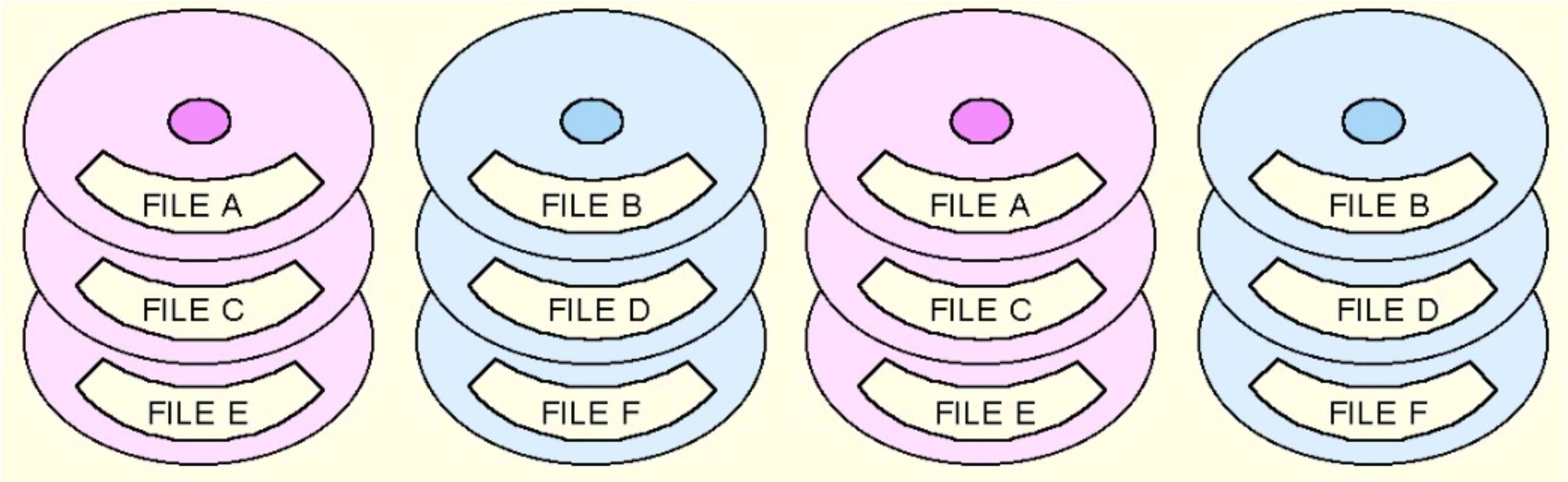
RAID

- RAID Level 1, also known as *disk mirroring*, provides 100% redundancy, and good performance.
  - Two matched sets of disks contain the same data.



  - The disadvantage of RAID 1 is cost.

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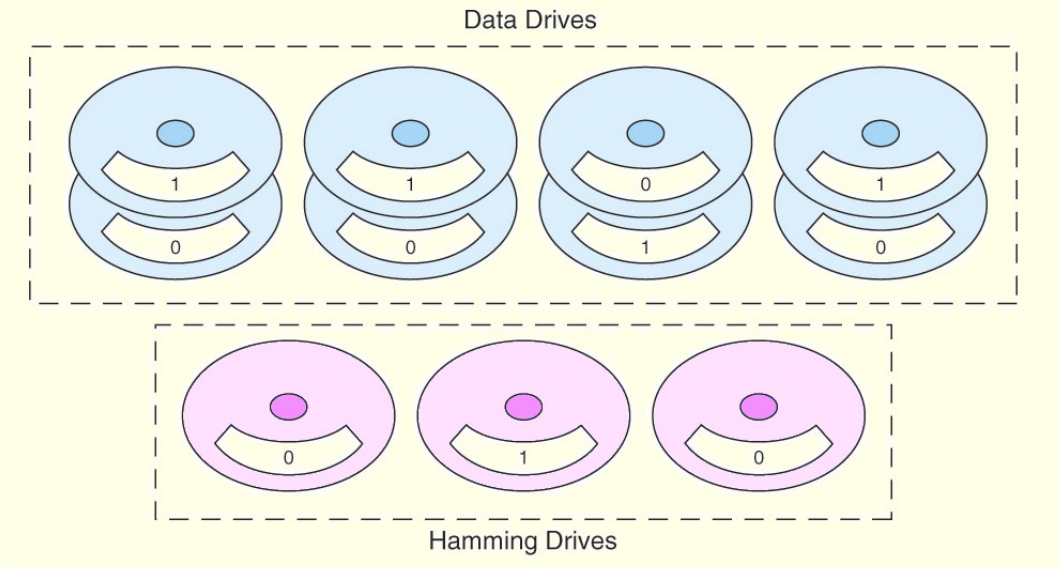
RAID

- A RAID Level 2 configuration consists of a set of data drives, and a set of Hamming code drives.
  - Hamming code drives provide error correction for the data drives.



  - RAID 2 performance is poor and the cost is relatively high.

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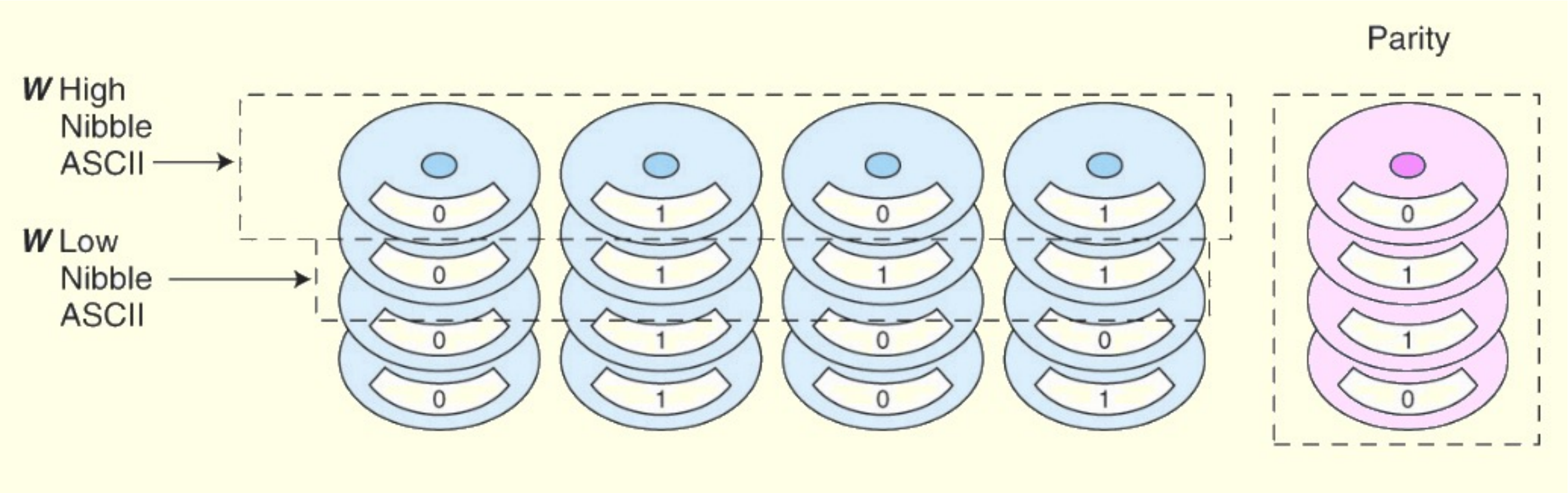
RAID

- RAID **Level 3** stripes bits across a set of data drives and provides a separate disk for parity.
  - Parity is the **XOR** of the data bits.



  - RAID 3 is not suitable for commercial applications, but is good for personal systems.

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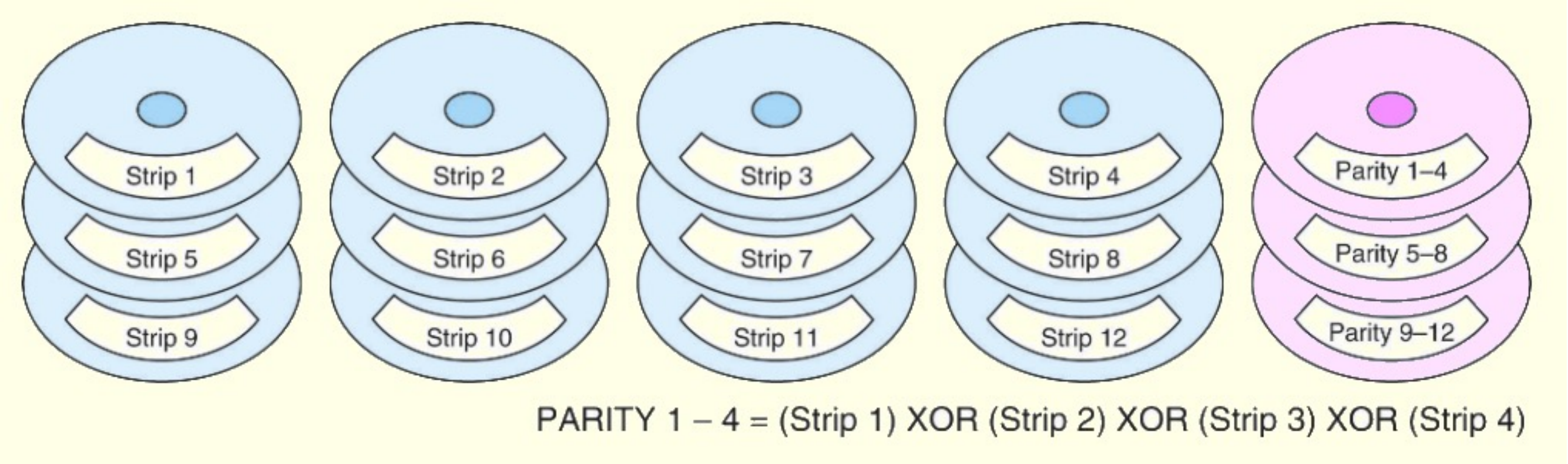
RAID

- RAID **Level 4** is like adding parity disks to RAID 0.
  - Data is written in blocks across the data disks, and a parity block is written to the redundant drive.



  - RAID 4 would be **feasible if all record blocks** were the **same size**.

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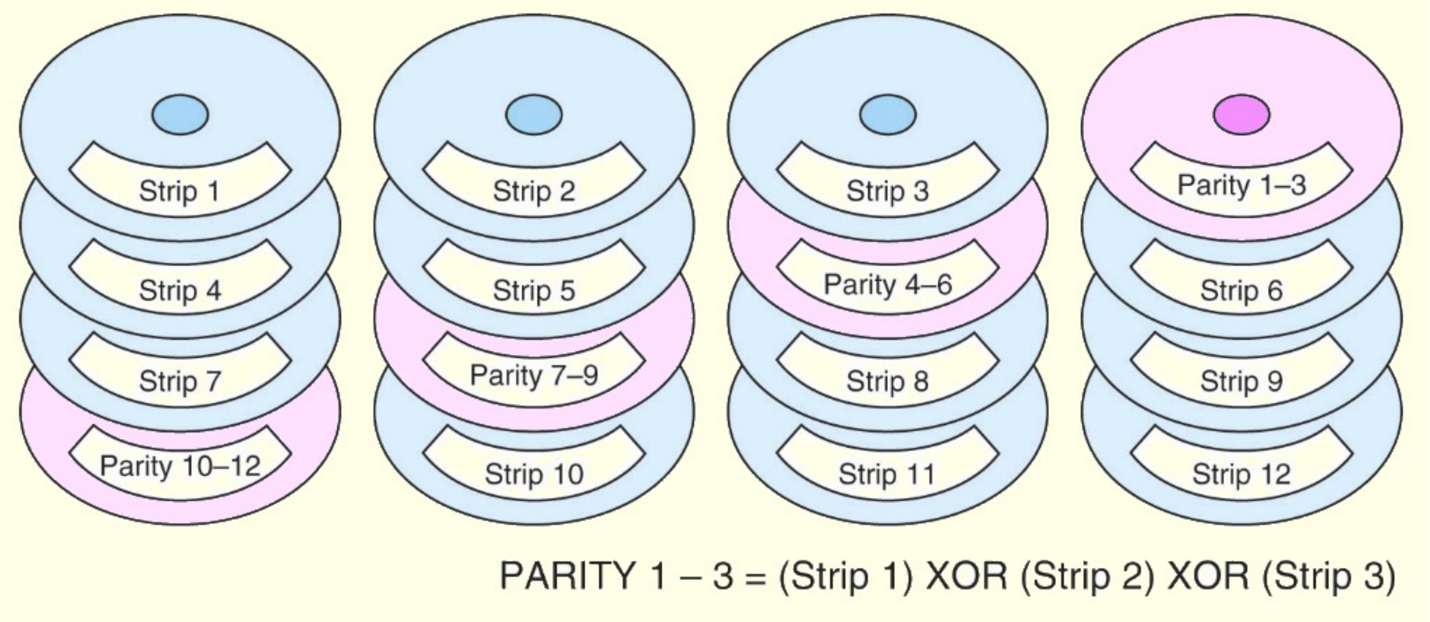
RAID

- RAID **Level 5** is RAID 4 with distributed parity.
  - With distributed parity, some accesses can be serviced concurrently, giving good performance and high reliability.



  - RAID 5 is used in many commercial systems.

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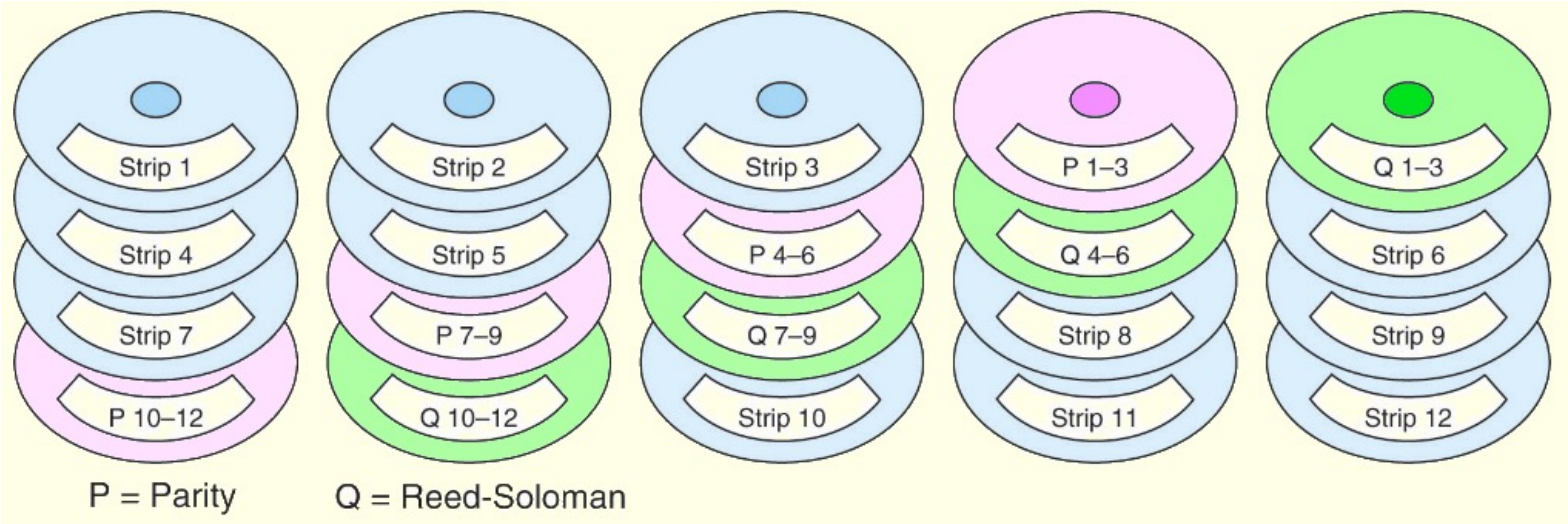
RAID

- RAID **Level 6** carries two levels of error protection over striped data: Reed-Soloman and parity.
  - It can tolerate the loss of two disks.



  - **RAID 6** is write-intensive, but highly fault-tolerant.

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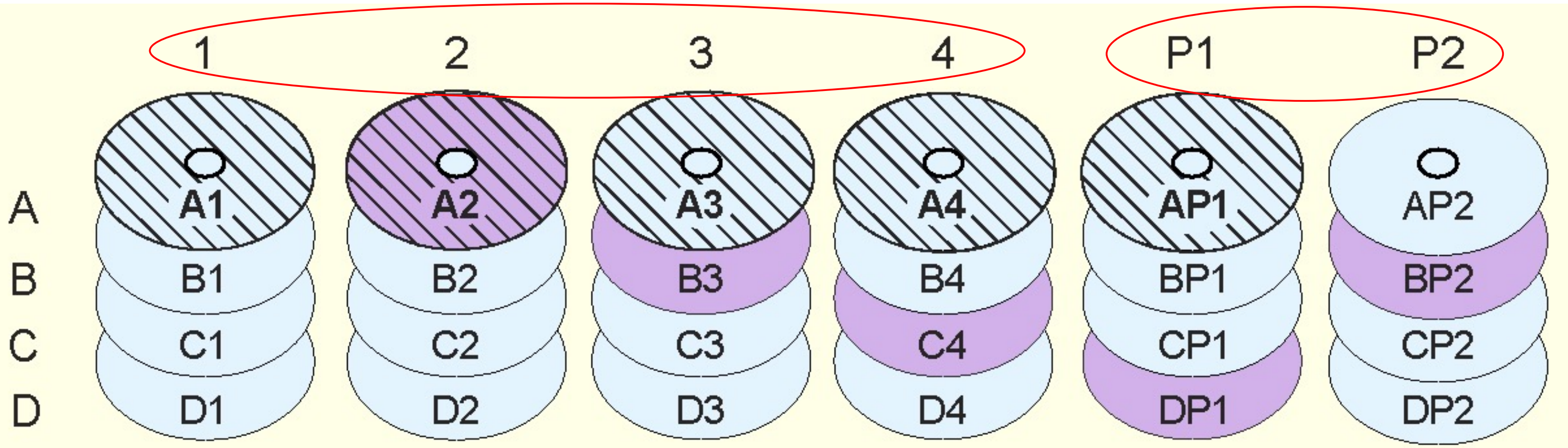
RAID

- Double Parity RAID (**RAID DP**) employs pairs of over-lapping parity blocks that provide linearly independent parity functions.



$$AP1 = A1 \oplus A2 \oplus A3 \oplus A4$$
$$BP1 = B1 \oplus B2 \oplus B3 \oplus B4$$
$$CP1 = C1 \oplus C2 \oplus C3 \oplus C4$$
$$DP1 = D1 \oplus D2 \oplus D3 \oplus D4$$

$$AP2 = A1 \oplus B2 \oplus C3 \oplus D4$$
$$BP2 = A2 \oplus B3 \oplus C4 \oplus DP1$$
$$CP2 = A3 \oplus B4 \oplus CP1 \oplus D1$$
$$DP2 = A4 \oplus BP1 \oplus C1 \oplus D2$$

SSD Raid 101: The essentials of flash storage and Raid

- **Raid in flash array products**

Read more:

- https://www.computerweekly.com/feature/SSD-Raid-101-The-essentials-of-flash-storage-and-Raid?src=5780423&asrc=EM_ERU_99100674&utm_content=eru-rd2-rcpB&utm_medium=EM&utm_source=ERU&utm_campaign=20180820_ERU%20Transmission%20for%2008/20/2018%20(UserUniverse:%202632457)

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The Future of Data Storage

- Future exponential gains in data storage most likely will occur through the use of totally new technologies.
- Research into finding suitable replacements for magnetic disks is taking place on several fronts.
- Some of the more interesting technologies include:
  - Biological materials
  - Holographic systems and
  - Micro-electro-mechanical devices.

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The Future of Data Storage

- Present day biological data storage systems combine organic compounds such as proteins or oils with inorganic (magentizable) substances.
- Early prototypes have encouraged the expectation that densities of $1 Tb/in^2$ are attainable.
- Of course, the ultimate biological data storage medium is DNA.
  - Trillions of messages can be stored in a tiny strand of DNA.
- Practical DNA-based data storage is most likely decades away.

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Harvard Researchers Can Store All the Data Humans Make in a Year on 4 grams of DNA

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Forget that hard drive humming inside your computer – the most efficient memory storage device on the planet might be locked up in each and every cell in your body. Scientists have been chasing down the idea of DNA memory storage for years now, and a team from Harvard may have finally broken the idea wide open.

According to a report out of Harvard Medical School, a research team has exceeded the previous limits of DNA storage by about 1,000 times – meaning they were able to encode researcher George Church's book onto a space the size of a thumbnail some 70 billion times. DNA storage works, in essence, just like regular binary storage, only the bases (TGAC) stand for a different value (T and G =1, A and C = 0). You can read stored data like you would read a normal genome — not the quickest way to read, but getting quicker every day. The result is a method of storing data so dense that it makes most modern tech seem like wasted space.

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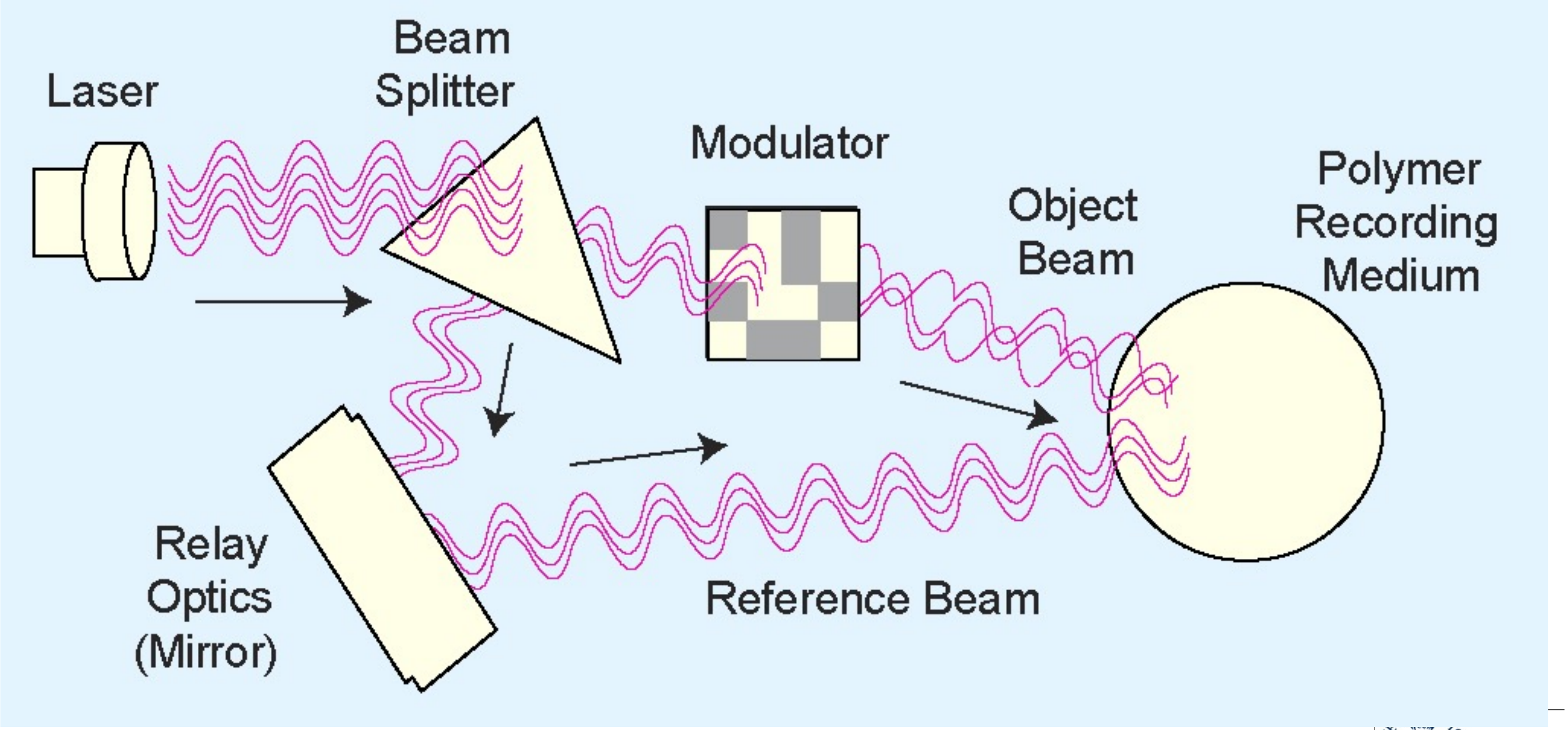
The Future of Data Storage

- Holographic storage uses a pair of laser beams to etch a three-dimensional hologram onto a polymer medium.



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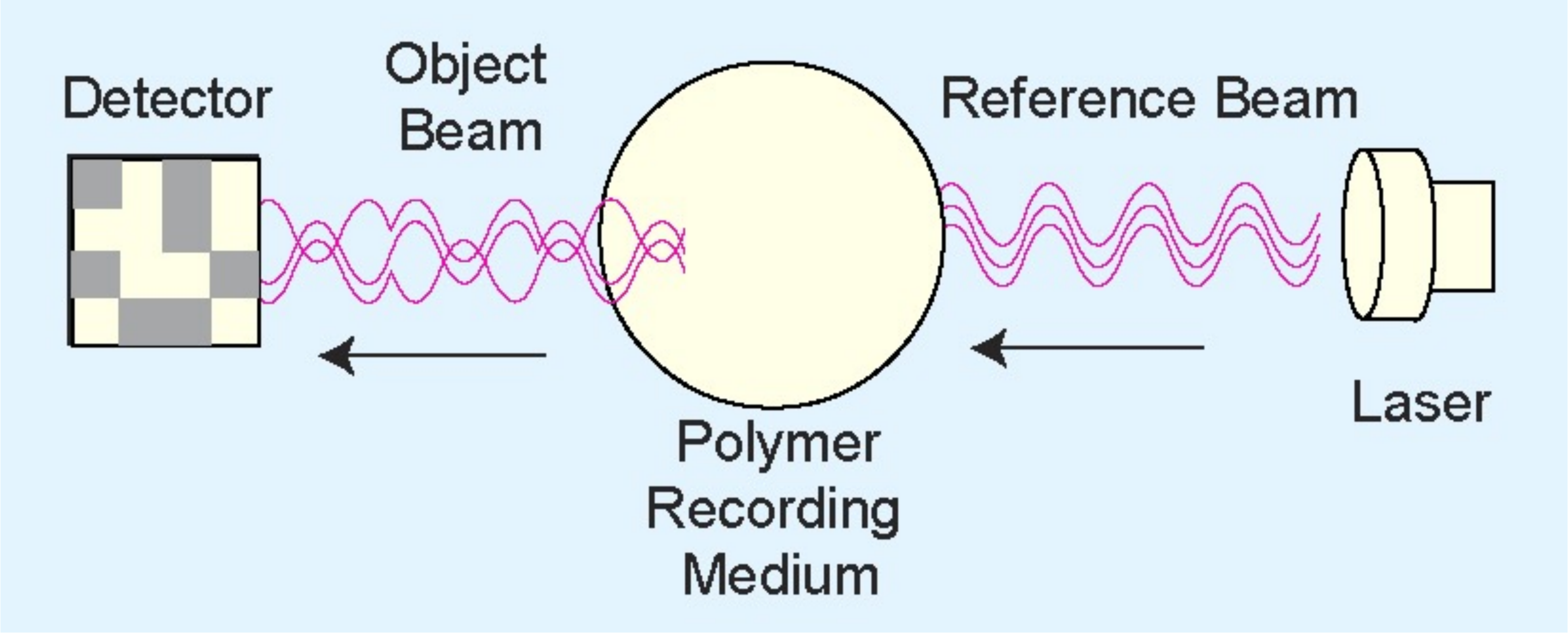
The Future of Data Storage

- Data is retrieved by passing the reference beam through the hologram, thereby reproducing the original coded object beam.



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The Future of Data Storage

- Because holograms are three-dimensional, tremendous data densities are possible.
- Experimental systems have achieved over 30Gb/in^2, with transfer rates of around 1GBps.
- In addition, holographic storage is content addressable.
  - This means that there is no need for a file directory on the disk. Accordingly, access time is reduced.
- The major challenge is in finding an inexpensive, stable, rewriteable holographic medium.

Summary

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