Operating Systems

Input/Output

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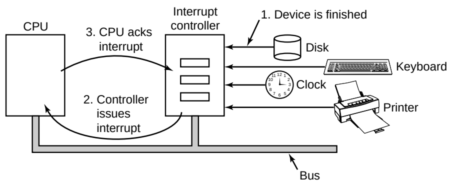
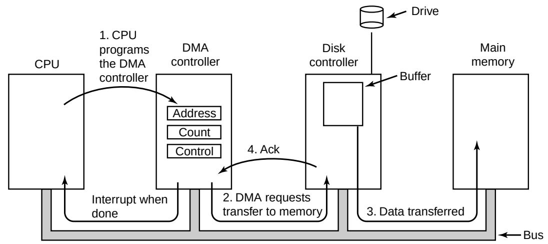
Interrupts Revisited (hardware level)



- √ when an I/O device has finished the work given to it, it causes an interrupt by asserting a signal on a bus line that it has been assigned,
- √ signal detected by the interrupt controller chip. If no other interrupts pending, the interrupt controller processes the interrupt immediately. If another one in progress or there is a simultaneous request on a higher-priority interrupt request line, continues to assert until serviced by the CPU.
- √ the controller puts a number on the address lines and asserts a signal that interrupts the CPU,
- √ that number used as an index into a table called the **interrupt vector** to start a corresponding interrupt service procedure,
- √ the service procedure in certain moment acknowledges the interrupt by sending some value to some controller's port. That enables the controller to issue other interrupts.

Direct Memory Access (DMA)



- √ DMA modules control data exchange between main mamory and external devices,
- √ usage of free bus time or (usually) delaying of the CPU for a one cycle from time to time to send a word by bus (**cycle stealing** and **burst mode**),
- √ only one interrupt after the whole transfer, avoidance of context switches,

Input/Output Handling

Division of I/O devices:

- √ **block devices**, read/write of each block possible independently,
- √ **character devices**, deliver stream of characters without division into blocks, not addressable, without seek operation,
- √ **communication/network devices** sometimes distinguished as a separate group because of their specificity,
- √ some devices, like **timers**, do not fit in to this classification scheme,

Differences in Input/Output Handling

Differencies in I/O handling:

- √ complexity of service,
- √ additional hardware support requirement,
- √ priorization of services,
- √ throughput unit,
- √ data representation,
- √ device response type,
- √ error handling,
- √ programming method.

Input/Output Programming Goals

- √ device independence,
- √ uniform naming,
- √ error handling – the closer the hardware the better,
- √ transfer type – synchronous/ asynchronous,
- √ buffering.

Communication with External Devices (I)

How processor communicates with control registers and how accesses external devices buffers. Two communication techniques:

1. **I/O ports**, with each control register some port with established number associated. Communication with special instructions:

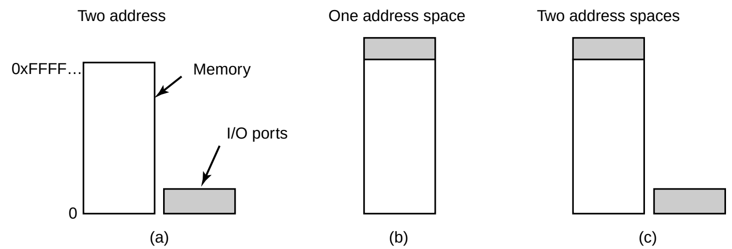
```
IN  REG, PORT
OUT PORT, REG
```

2. **memory-mapped I/O**
   - √ driver may be completely written in C, without any assembly code pieces, because access only via standard read/write calls,
   - √ no need for separate special protection mechanism,
   - √ faster testing of the contents of control registers,

   but

   - √ cache must be disabled for mapped region,
   - √ complicates the architecture with different type buses.

Communication with External Devices (II)



a. separate I/O and memory space,
b. memory-mapped I/O,
c. hybrid solution, i.e. Pentium architecture: 640kB - 1MB addresses reserved for external devices still having I/O ports space 0 – 64K.

Principles of I/O Software

Three ways of I/O communication/ programming:

1. programmed I/O (with polling, busy waiting behaviour),
2. interrupt-driven I/O,
3. I/O using DMA.

Programmed I/O

```
copy_from_user(buffer, p, count);               /* p is the kernel bufer */
for (i = 0; i < count; i++) {                   /* loop on every character */
      while (*printer_status_reg != READY) ;    /* loop until ready */
      *printer_data_register = p[i];            /* output one character */
}
return_to_user( );
```

An example of programmed I/O: steps in printing a string.

Interrupt-Driven I/O

```
copy_from_user(buffer, p, count);
enable_interrupts( );
while (*printer_status_reg != READY) ;
*printer_data_register = p[0];
scheduler( );
```

(a)

```
if (count == 0) {
     unblock_user( );
} else {
     *printer_data_register = p[i];
     count = count – 1;
      i = i + 1;
}
acknowledge_interrupt( );
return_from_interrupt( );
```

(b)

An example of an interrupt-driven I/O: writing a string to the printer.

a. code executed when the print system call is made,
b. interrupt service procedure.

I/O Using DMA

```
copy_from_user(buffer, p, count);
set_up_DMA_controller( );
scheduler( );
```

(a)

```
acknowledge_interrupt( );
unblock_user( );
return_from_interrupt( );
```

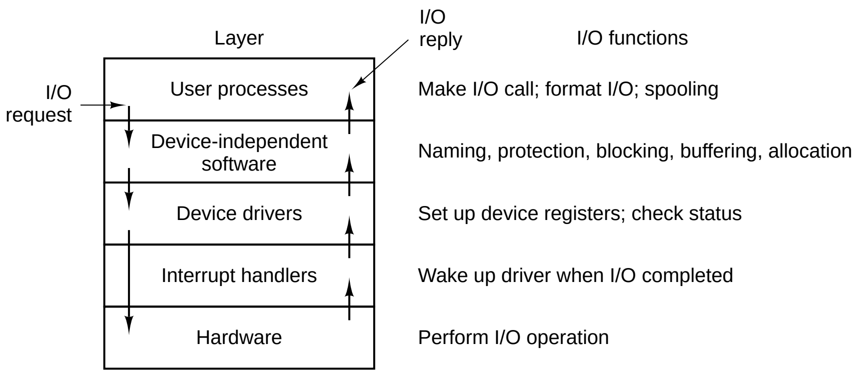
(b)

An example: of I/O using DMA: printing a string.

a. code executed when the print system call is made,
b. interrupt service procedure.

- √ advantage: reduction of number of interrupts from one per character to one per buffer printed,
- √ not always the best method – aspects of transfer scope size and relative speed of CPU and DMA controller.

I/O Software Layers



Device-Independent I/O Software

- √ uniform interfacing for device drivers,
- √ under Unix: naming devices with usage of **major** and **minor** numbers,
- √ protection against unauthorized access,
- √ providing a device-independent block size,
- √ buffering mechanisms (example: **double buffering**),
- √ management of accessability of devices,
- √ handling of allocation and releasing of devices,
- √ management of resource to user allocation,
- √ part of errors handling.

Disk Access Performance

- √ **seek time** the time ti move the arm to the proper track,
- √ **rotational delay/latency** the time for the proper sector to rotate under the head,
- √ **access time** seek time + rotational latency,
- √ seek time decides about performance,
- √ important role of the cache memory (replacement algorithms LRU, LFU).

Disk Arm Scheduling Algorithms

Because of requester:

RSS random scheduling,

FIFO the most fair one,

PRI with priorities,

LIFO *Last In First Out*, locality and resource usage maximization,

Because of service:

SSTF **shortest service time first** with the smallest move of arm,

SCAN **elevator algorithm**, the arm moves alternately in two directions (up and down) servicing all requests,

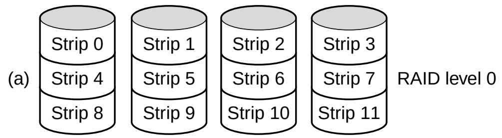
C-SCAN cyclic SCAN, servicing during the move only in one direction with a fast return to the start position.

Redundancy in Disk Service

RAID Redundant Array of Independent Disks – (formerly: Inexpensive) the name and classification originating from Berkeley University.

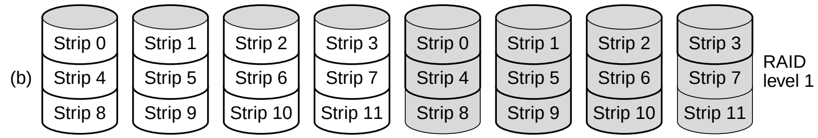
- a technique of creation of virtual disks (with logical volumes), with some features related to reliability, efficiency and serviceability, from a group of disks,
- data distributed over the matrix of disks,
- redundancy used to improve fault tolerance, especially tolerance to physical medium damage.
- RAID as opposed to (before) SLED (Single Large Expensive Disk) or (now) **JBOD** (Just a Bunch of Disks).

RAID Solutions (RAID 0)



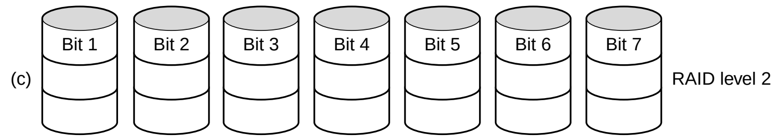
- no data redundancy,
- division into **concatenation** and **striping**,
- performane and flexibility improvement, low cost solution with lack of fault tolerance.

RAID Solutions (RAID 1)



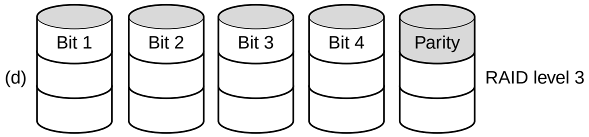
- **mirroring**, full data redundancy,
- from the point of fault tolerance the best solution,
- expensive solution.

RAID Solutions (RAID 2)



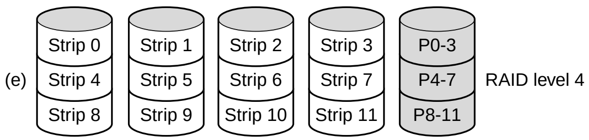
- correction code computed from data bits,
- usage of correction-detection codes (Hamming's code),
- expensive solution which requires many disks.

RAID Solutions (RAID 3)



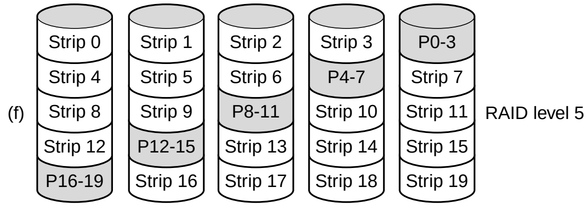
- analogoues to RAID 2, with parity bits instead of correction-detection codes,
- good throuhput in data size per time, poor performance in number of serviced requests in time.

RAID Solutions (RAID 4)



- RAID 4 – RAID 6, independent access to disks, independent requests may be serviced in parallel, better performance in number of serviced requests in time,
- striping with big stripes,
- parity computer on bit basis still requires read of a block.

RAID Solutions (RAID 5)



- striping with added parity bits,
- economical solution - redundancy costs exactly one disk,
- good read performance, noticable degradation of write performance,
- quality and efficiency of solution determined by the parameters tuning process.

RAID - Additional Aspects

- RAID 6, as RAID 5 with two independent parity bits (stripes),
- RAID $10 = 1 + 0$
- hardware RAID and software RAID,
- in common use RAID: 0, 1, 5, 1+0, 0+1,
- typical server configuration:
  - RAID 1 for small critical data (i.e. disks with operating system),
  - RAID 5 for huge databases (i.e. disks in some external matrix).