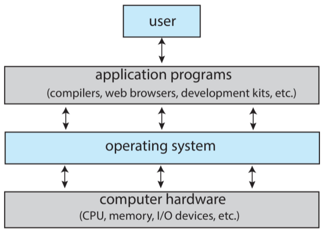
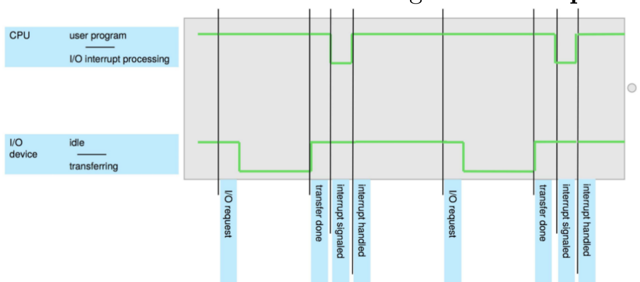
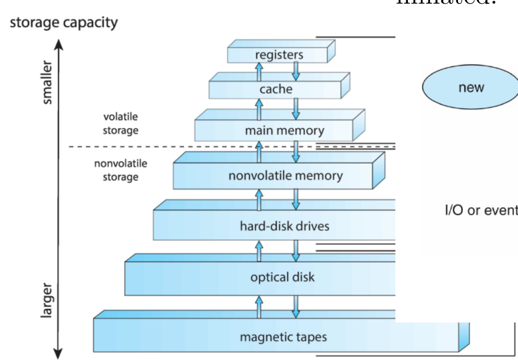
1 Operating System

OS = coordiantes use of hardware among various applications and users.



I/O devices and CPU can execute concurrently. The devices communicate with the CPU through **interrupts**.





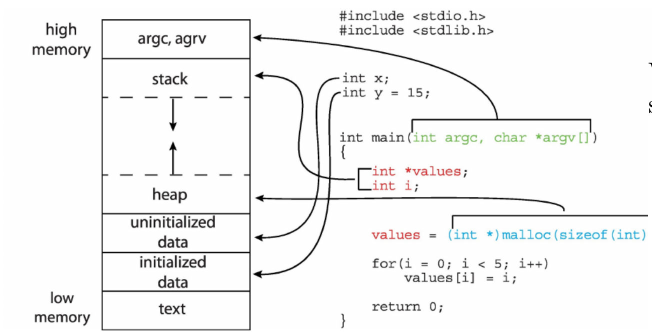
Memory structure:

2 Processes

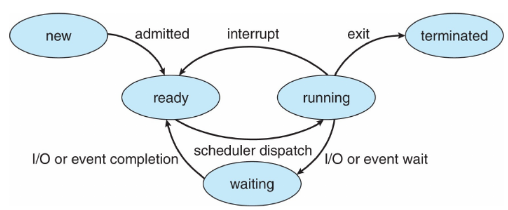
2.1 General

Process = program (executable / binary) in execution.
Program = passive entity stored on disk; Process = active entity loaded in memory.
Parts of a process:

- Text section (program code)
- Current activity (program counter and process registers)
- Stack (function parameters, local vars, ret addresses)
- Data section (global variables)
- Heap (dynamically alocated memory)



Process states: New, Running, Waiting, Ready, Terminated.

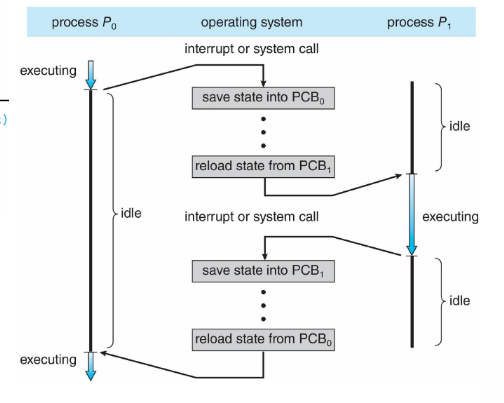


2.2 PCB

Information associated with each process (also called task control block)
PCB contents:

- Process state – running, waiting, etc.
- Program counter – location of instruction to next execute
- CPU registers – contents of all process-centric registers
- CPU scheduling information- priorities, scheduling queue pointers
- Memory-management information – memory allocated to the process
- Accounting information – CPU used, clock time elapsed since start, time limits
- I/O status information – I/O devices allocated to process, list of open files

When CPU switches context, the respective state stored in the PCB is loaded:



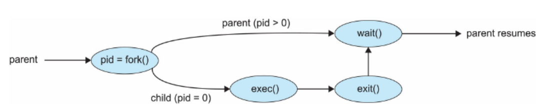
2.3 Process creation / termination

Parent process create children processes, which, in turn create other processes, forming a tree of processes.
Process is identified and managed via a process identifier (pid).

- fork() = syscall to create a new child process. Child's adress space is the same as parent. Returns 0 in the child process and PID of the child in parent.
- exec() = replace the child's adress space with another program.
- wait() = parent process calls wait() to wait for the child to terminate.

- exit() = process executes last statement and then asks the operating system to delete it.
- abort() = terminate the execution of children processes.
- waitpid() = waits for a specific child spawned by the process.

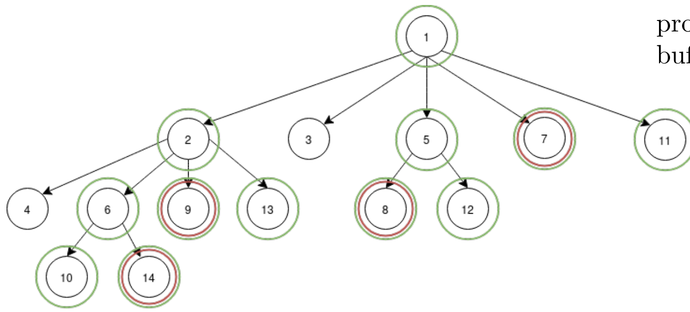
```
int main(int argc, char *argv[])
{
    pid_t pid = fork();
    if(pid < 0)
        return errno;
    else if(pid == 0)
    {
        //child
        char *argv[] = {"ls", NULL};
        execve("/bin/ls", argv, NULL);
        perror(NULL);
    }
    else
    {
        //parent
        wait(NULL);
        // child finished
    }
    return 0;
}
```



Exemplu arbore de procese: Câte procese și thread-uri sunt la final? Desenați arborescența de procese și thread-urile aferente.

```
fork()
if (fork()) {
    fork()
    if (!fork())
        pthread_create()
    else
        fork()
    pthread_create()
}
```

Sunt 14 procese si 16 thread-uri. Fiecare cerc este un thread format (prima data cele rosii, la linia 5, apoi cele verzi la linia 8).

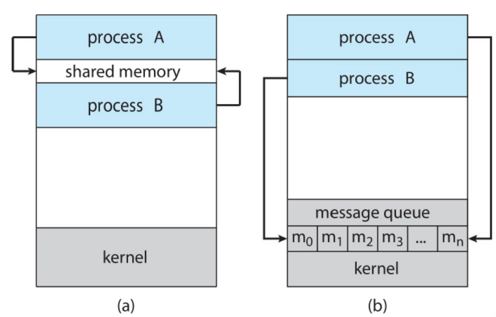


Zombie and Orphan processes:

- Zombie process = a process that has completed execution but still has an entry in the system process table. This happens because the parent didn't invoke wait().
- Orphan process = a living child whose parent has died. Could be because parent exited prematurely or intended in the case of daemons. The process is adopted by process with PID=1.

2.4 Interprocess Communication

Processes within a system may be independent or co-operating. Cooperating processes can affect or be affected by other processes for: sharing data, computation speedup, modularity, convenience.
Two models of IPC: Shared memory and Message passing.



2.4.1 Shared memory

Requires careful synchronization.
Producer-Consumer problem: producer process produces information that is consumed by a consumer process. Solved with shared memory by holding a buffer and in/out pointers.

- unbounded-buffer = Producer never waits; Consumer waits if there is no buffer to consume
- bounded-buffer = Producer must wait if all buffers are full; Consumer waits if there is no buffer to consume

Shared memory used in UNIX with shm_open() to create a shared memory segment and mapped it to a file descriptor via mmap.

2.4.2 Message passing

Processes communicate with each other without resorting to shared variables.
IPC facility provides two operations: **send(message)** and **receive(message)**

- Direct Communication = Processes must name each other explicitly: send (P, message) - send a message to process P, receive(Q, message) - receive a message from process Q
- Indirect Communication = Send and receive messages through mailbox: send(A, message) - send a message to mailbox A, receive(A, message) - receive a message from mailbox A

Message passing may be either blocking or non-blocking:

- Blocking (synchronous)
  - Blocking send = the sender is blocked until the message is received
  - Blocking receive = the receiver is blocked until a message is available
- Non-blocking (asynchronous)
  - Non-blocking send = the sender sends the message and continue
  - Non-blocking receive = the receiver receives a valid message / NULL

If both send and receive are blocking, we have a **rendezvous**.
As processes can not be synchronized perfectly, we make use of buffering (queue of messages attached to the link):

- Zero capacity: no messages are queued on a link. Sender must wait for receiver. (rendezvous)
- Bounded capacity: finite length of n messages. Sender must wait if link full.
- Unbounded capacity: infinite length. Sender never waits.

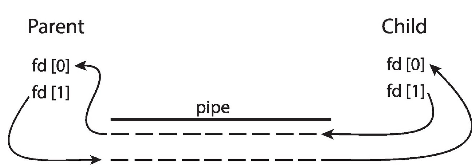
2.4.3 Signals

Signals can be send to a process:

- SIGINT (ctrl+c) = kills the process
- SIGSTOP (ctrl+z) = stops the process, moves it to background
- SIGSEGV = invalid memory accesed
- etc.

2.4.4 Pipes

Acts as a conduit allowing two processes to communicate.
Ordinary pipes (anonymous) = cannot be accessed from outside the process that created it. Typically, a parent process creates a pipe and uses it to communicate with a child process that it created.
Named pipes = can be accessed without a parent-child relationship.



2.4.5 Sockets

A socket is defined as an endpoint for communication. Concatenation of **IP address and port** (a number included at start of message packet to differentiate network services on a host).

loopback (127.0.0.1) = system on which process is running

2.4.6 RPCs

RPCs = remote procedure calls. Abstracts procedure calls between processes on networked systems Stubs = client-side proxy for the actual procedure on the server

The client-side stub locates the server and marshalls the parameters. The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server

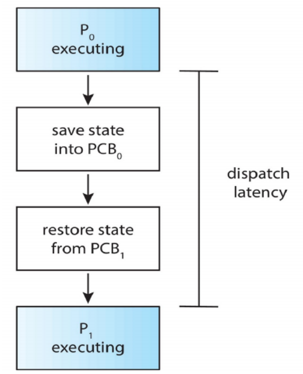
3 CPU Scheduling

How to schedule processes on the CPU efficently? Usually, CPU is a sequence of CPU bursts and I/O bursts (waiting time for I/O). A CPU scheduler selects a process and allocates a core to it.

- **Preemptive** = can postpone processes (put process in ready state / back in running state)
- **Non-preemptive** = once process has CPU, the process keeps it until the end or by switching to waiting.

Dispatcher = gives control of the CPU to the process selected by the CPU scheduler: switching context, switching to user mode, jumping to proper location in the user program to restart it.

Dispatch latency = time it takes for the dispatcher to stop one process and start another running.



Scheduling criteria:

- CPU utilization – keep the CPU as busy as possible
- Throughput – # of processes that complete their execution per time unit
- Turnaround time – amount of time to execute a particular process
- Waiting time – amount of time a process has been waiting in the ready queue
- Response time – amount of time it takes from when a request was submitted until the first response is produced.

3.1 FCFS

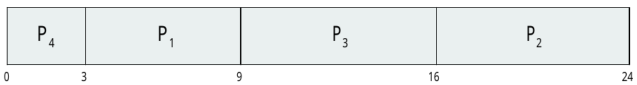
FCFS = First-Come, First-Served Put the processes on the CPU the order in which they request it. (this is non-preemptive) Convoy effect - short process behind long process (this results in optimal average waiting time)
Example: For processes with burst times $P_1 = 24$; $P_2 = 3$; $P_3 = 3$; This is the resulting Gantt Chart:

If the processes come in different order, it is better.

3.2 SJF

SJF = Shortest Job First Associate with each process the length of its next CPU burst. Use these lengths to schedule the process with the shortest time. Optimal average waiting time.

Non-Preemptive version: For processes with burst times $P_1 = 6$; $P_2 = 8$; $P_3 = 7$; $P_4 = 3$ This is the resulting Gantt Chart:



Determining the length of the next CPU-burst: ask the user to provide estimation / estimate ourselves.

Exponential averaging = Use length of previous CPU-burst and estimate the next one:

t_n = length on n-th CPU burst

τ_{n+1} = predicted next CPU burst

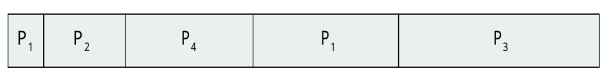
$\alpha, 0 \geq \alpha \leq 1$. Commonly $\alpha = \frac{1}{2}$

$\tau_{n+1} = \alpha t_n + (1-\alpha)\tau_n$

3.3 SRT

SRT = Shortest remaining time first

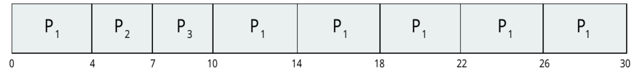
Preemptive version of SJF: For processes with arrival, burst times $P_1 = 0 \quad 8$; $P_2 = 1 \quad 4$; $P_3 = 2 \quad 9$; $P_4 = 3 \quad 5$ This is the resulting Gantt Chart:



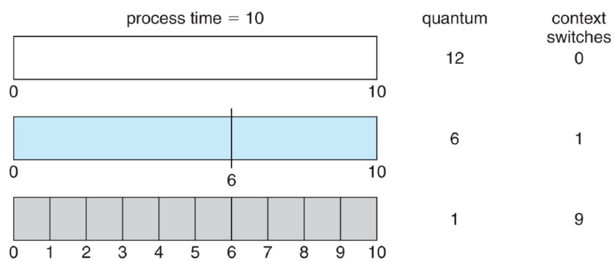
3.4 Round-Robin (RR)

Each process gets a small unit of CPU time (time quantum q). After this time has elapsed, the process is preempted and added to the end of the ready queue.

Preemptive RR: For processes with burst times: $P_1 = 24$; $P_2 = 3$; $P_3 = 3$ and q = 4, the Gantt chart is:



Choose q carefully, take into account context switches, and waiting time of processes:

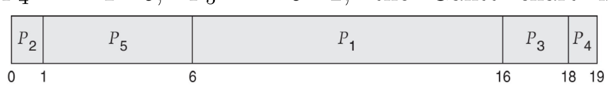


3.5 Priority Scheduling

A priority number (integer) is associated with each process. The CPU is allocated to the process with the highest priority (smallest integer = highest priority). SJF is priority scheduling.

Starvation = low priority processes may never execute. Can fix with **aging** = as time progresses increase the priority of the process.

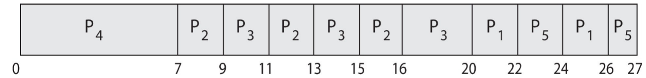
Non Preemptive Priority Scheduling: For processes with burst times and priority: $P_1 = 10 \quad 3$; $P_2 = 1 \quad 1$; $P_3 = 2 \quad 4$; $P_4 = 1 \quad 5$; $P_5 = 5 \quad 2$, the Gantt chart is:



3.6 Priority scheduling with Round Robin

Run the process with the highest priority. Processes with the same priority run round-robin.

Example: For processes with burst and priority: $P_1 = 4 \quad 3$; $P_2 = 5 \quad 2$; $P_3 = 8 \quad 2$; $P_4 = 7 \quad 1$; $P_5 = 3 \quad 3$ and $q = 2$

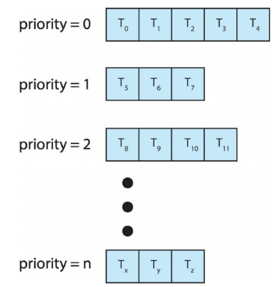


3.7 Multilevel Queue

The ready queue consists of multiple queues.

Each queue has it's own scheduling algorithm + method to determine which queue a process goes to.

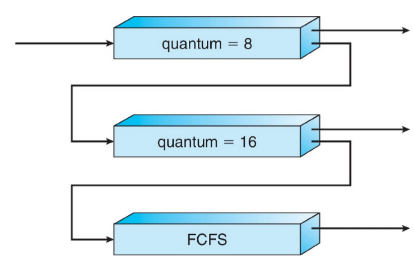
Example, multilevel queue by priority:



Multilevel Feedback Queue = A process can move between the various queues + method to determine which queue a process goes to + method to determine when to upgrade/demote process.

Example (Three queues):

- Q_0 = RR with q = 8ms
- Q_1 = RR with q = 16ms
- Q_2 = FCFS



When a process gains CPU, the process receives 8 ms. If it does not finish in 8 milliseconds, the process is moved to Q_1. If the process doesn't finish in 16 ms, it goes to FCFS.

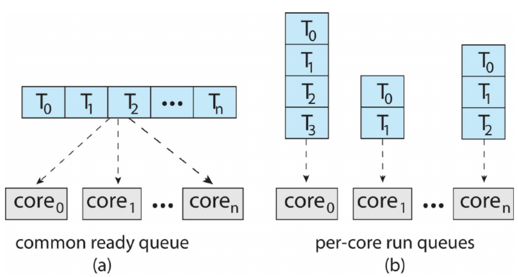
3.8 Thread scheduling

When threads are supported, threads are scheduled, not processes. Use the same algorithms.
Process-contention scope (PCS) = competition within the process. (on many-to-many / one-to-many threading models)
System-contention scope (SCS) = competition among all threads in system (on one-to-one models)

3.9 Scheduling on paralell systems

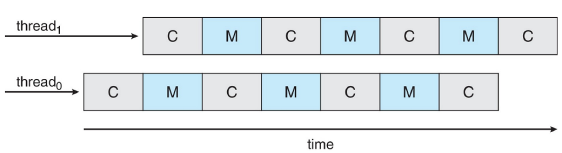
3.9.1 Multiple-Processor Scheduling

Symmetric multiprocessing (SMP) = each processor is self scheduling.
All threads may be in a common ready queue (a) or each processor may have its own private queue of threads (b).



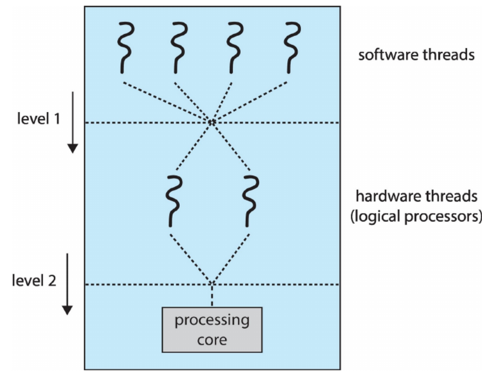
3.9.2 Multithreaded Mulitcore systems

Each core has 1 hardware threads. Then if one thread stalls, switch to another one. If they end up interleaved we have a speedup.



This is called Chip-multithread (hyperthreading) when you have multiple hardware threads on multiple cores. The systems sees each hw thread as a logical processor.
There are two levels of scheduling here:

- 1. The operating system deciding which software thread to run on a logical CPU
- 2. How each core decides which hardware thread to run on the physical core.



3.9.3 Load Balancing

: If the arhitecture is SMP, we need to keep all CPUs loaded for efficiency:

- **Load balancing** attempts to keep workload evenly distributed
- **Push migration** – periodic task checks load on each processor, and if found pushes task from overloaded CPU to other CPUs
- **Pull migration** – idle processors pulls waiting task from busy processor

3.9.4 Processor Affinity

When a thread has been running on one processor, the cache contents of that processor stores the memory accesses by that thread. This is called **Affinity**.
Load balancing may affect affinity.
Solutions:

- Soft affinity – the operating system attempts to keep a thread running on the same processor, but no guarantees.
- Hard affinity – allows a process to specify a set of processors it may run on.

3.10 Real-time systems

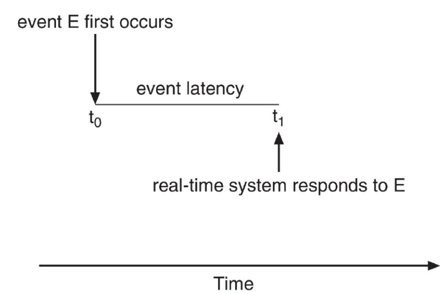
Soft real-time systems = Critical real-time tasks have the highest priority, but no guarantee as to when tasks will be scheduled

Hard real-time systems = task must be serviced by its deadline

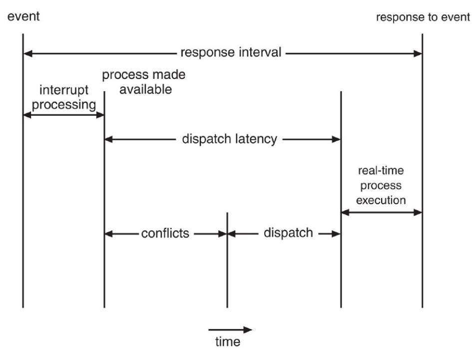
Event latency = the amount of time that elapses from when an event occurs to when it is serviced.

Two types of latencies affect performance:

- Interrupt latency = time from arrival of interrupt to start of routine that services interrupt.
- Dispatch latency – time for schedule to take current process off CPU and switch to another



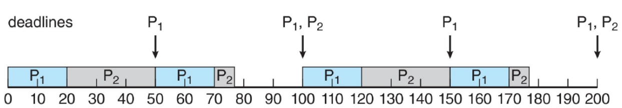
Interrupt latency consists of: 1) determining interrupt type and 2) switching the context.



Conflict phase of dispatch latency is: 1) preemption of any process running in kernel mode and 2) release by low-priority process of of resources needed by high-priority processes.

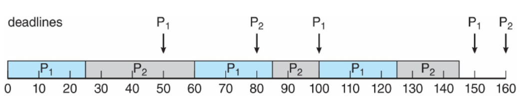
3.10.1 Real-time Priority-based Scheduling

For real-time scheduling, scheduler must support preemptive, priority- based scheduling.
Process may be periodic, have a processing time t, deadline d and period p. Rate of periodic task is $\frac{1}{p}$.
A priority is assigned based on the inverse of its period.



3.10.2 EDF

EDF = Earliest Deadline First Scheduling Priorities are assigned according to deadlines: The earlier the deadline, the higher the priority



3.10.3 Proportional Share Scheduling

T shares are allocated among all processes in the system
An application receives N shares where $N \leq T$.

This ensures each application will receive $\frac{N}{T}$ of the total processor time.

3.11 Little's formula

$n = \lambda \cdot W$.