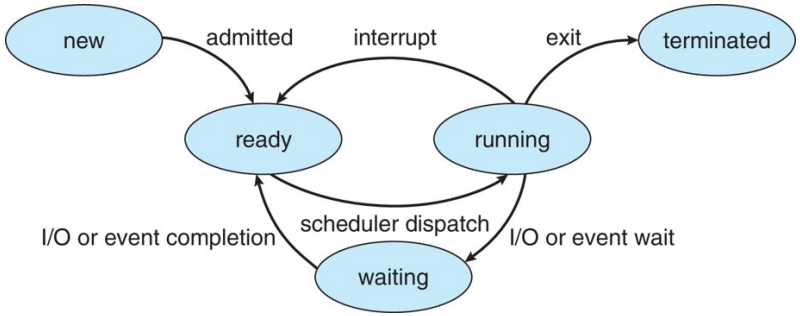
PROCESS

- An efficient and interactive OS which should fully satisfy the user need and effectively utilize the resources of the system can only be realized through *concurrency*, *parallelism* and *virtualization*.
- The key to realize this goal is the *Process*; which is by definition An instance of a program in execution. The concept of the Process is one of the most successful ideas in computer system.

All users programs and applications need to run in the context of a process. The key abstractions that a process provides to the application are

- An independent *logical control flow* – an illusion that the program has got the exclusive use of the processor
- A *private address space* – an illusion that the program has exclusive use of the memory system.

DIFFERENT STATES OF A PROCESS



- START: A new process is created and admitted to the READY state.
- READY: The process is ready to run and getting a processor shortly.
- RUNNING: The process is running in a processor.
- WAITING: wait for I/O or an event to be completed. On completion it is again ready to run
- TERMINATED: exit normally on completion or abnormally (error exit or killed)

For a better understanding of the ideas and various implementation issues involving processes requires a background on exceptional control flow (ECF).

Concurrent Flows

Logical flow may take different forms in computer systems. Exception handlers, processes, signal handlers, threads; etc.

- A logical flow whose execution overlaps in time with another flow is known as *concurrent flow*
- And the flows are said to run *concurrently* e.g., A and B are concurrent but B and C are not.
- Multiple flows running concurrently is known as *concurrency*
- The notion of a process taking turn with other processes is also known as *multitasking*
- Each time period that a process executes a portion of its flow is called a *time slice*
- *Multitasking* is also referred to as *time slicing*

Concurrent Flows contd.

- Idea of concurrent flow is *independent* of the number of processor cores or the computers that the flows are running on
- If the two flows *overlap* in time they are concurrent even if they are running on the same processor

However, we will, sometimes, find it useful to identify a proper subset of concurrent flows known as *Parallel flows*. If two flows are running concurrently on different cores or computers at the same time

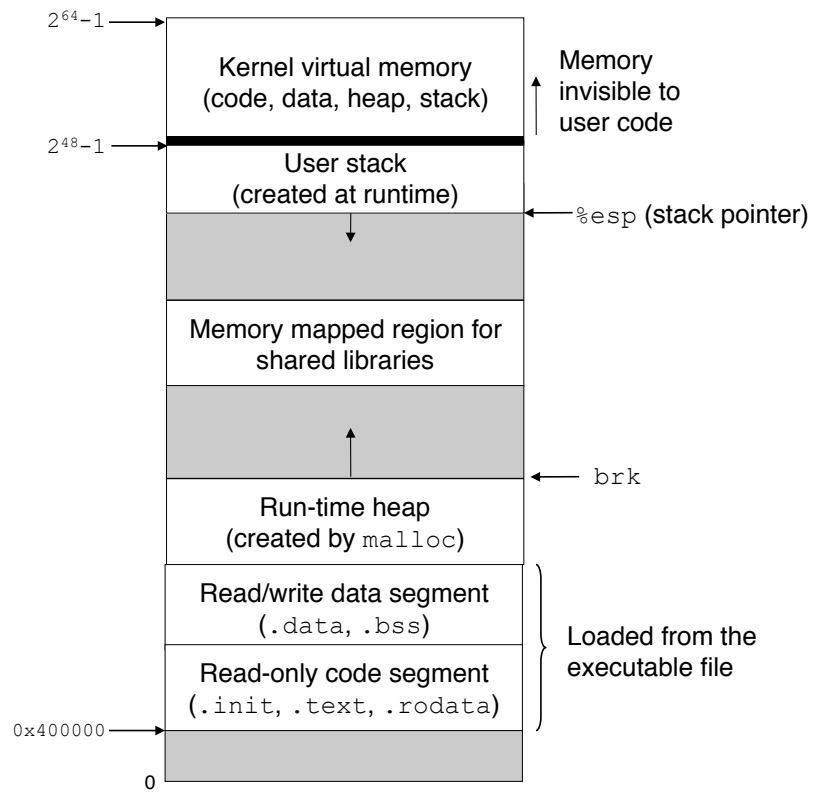
- we say that they are *parallel flows*, and
  - are running in *Parallel*, and
  - have *Parallel execution*

Private Address Space

A process provides each program with its own *private address space*; i.e.,

- It has exclusive use of the system's address space
- A byte located in an address in this space cannot be in general read or written by others

The content of the memory locations of each private space is different but their genral organisational structures are same



User and kernel mode

In order to provide the kernel a full proof process abstraction the processor must restrict the application from executing some instructions as well as the portions of the address space that it can access. This is provided by having at least two different mode of operations; namely, the *User* and the *Kernel* mode. A mode bit in a register is set/reset to move from user to kernel mode and vice-versa.

- privilege instructions like change mode bits, halt the processor or initiating I/O are not permitted in the user mode; and
- direct access to kernel to code and data in the kernel space is not allowed; any such attempt results in fatal protection fault; and
- it must access kernel code and data via the system call interface

User and kernel mode contd.

A process running an application is initially in user mode and the only way to change the mode from user to kernel is via exception; such as (i) an *interrupt*, (ii) a *fault* or (iii) a *trapping system call*
When an exception occurs, the control is passed to the exception handler and

- the mode is changed to kernel and the handler runs in kernel mode
- after the exception processing the control is passed to the application code with a switch of mode bit to user mode again.

In Linux the */proc* filesystem exports contents of many kernel data structures as a hierarchy of text files that an application can read. [Try seeing /proc/cpuinfo or /proc/process-id/maps; Now in Linux a */sys* filesystem exports additional low level information like devices and buses]

Context Switches

Kernel implements *multitasking* using a high-level form of ECF known as *context switch* – built on the lower level ECFs'. The kernel maintains a context for each process – the context is the state that the kernel needs to restart a preempted process. It contains the values of the object in the processor programming models (Registers), user and kernel stacks and various kernel data structures such as

- A *page table* – that characterises the address space; and
- A *Process table* – contains information about the current process; and
- A *File table* – contains information about the files that the process has opened

At certain points during execution of a process (running state), the kernel can decide to preempt the current process and restart a previously preempted process. This act is known as *scheduling* and handled by the kernel code, called the *scheduler*.

Context Switches contd.

When the kernel selects a new process to run we say that the process is *scheduled* – the kernel preempts the currently running process and transfers control to the new process to run by doing a *context switch* that (i) saves the context of the current process, (ii) restores the context of the previously preempted process, and (iii) passes control to this newly restored process.

A context switch can occur

- while the kernel is executing a system call on behalf of the user. If the system call blocks because it is waiting for some event to occur, then the kernel can put the current process to sleep and and switch to another process. For example for a read system call that requires a disk acess the kernel may run another process instead of the long wait for the data arriving from the disk.
- An explicit request to put the calling process to sleep using a *sleep* system call

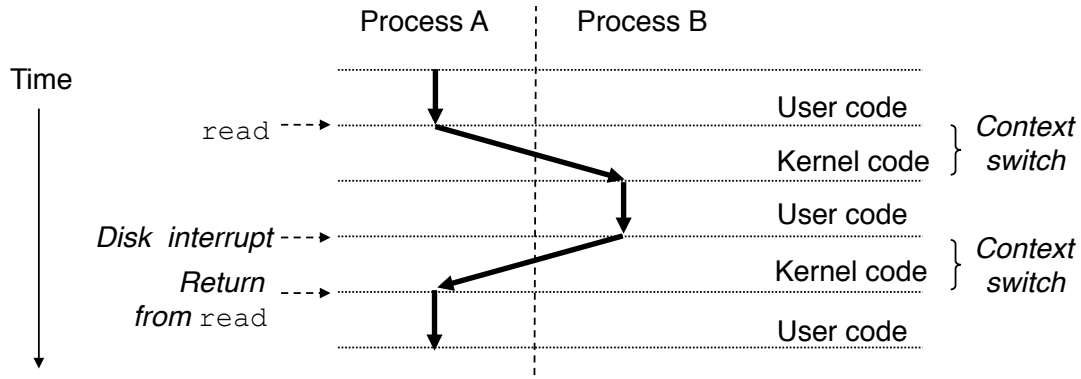
Context Switches contd.

In general, even if the system call does not block, the kernel can opt for a context switch rather than returning to the calling process.
A context switch can also occur as

- a result of an interrupt – say a timer interrupt (controlling the time slicing) deciding the current process has run for too long and chose another to run.

Next we see graphically a context switch between two concurrent processes A and B where A is running in user mode and traps to the kernel by a read system call. The trap handler in the kernel requests a DMA transfer from the disk controller and arranges an interrupt by the disk when the data transfer is done.

Context Switches Anatomy.



- the kernel was running process A in user mode before the read system call
- during the first part of the switch the kernel is executing instruction in kernel mode on behalf of process A (there is no kernel process)
- then kernel starts executing on behlf of process B (in kernel mode) and finally
- kernel is allows Process B to run in user mode
- On completion of DMA there is another context switch and finally kernel is running process A from where it left off until the next exception.

Process Control System Calls: UNIX

```
#include <sys/types.h>
#include <unistd.h>
pid_t  fork(void);  // returns 0 to Child;
// pid of the child to parent, -1 on error
```

The fork() function is used by the calling process to create a new running chid process. fork() characteristics are

- call once, return twice (always a 0 to the chid and a +ve inetger to the parent)
- concurrent execution (parent and child are concurrent processes)
- duplicate but separate address space (address space of each is separate but identical just after fork() – however with time changes are expected as they are two different processes.
- shared files (child inherits all theparent's opened files)

The charcateristics would be best understood by analysis a simple program given next [pid stands for process id and pid_t is defined as an integer]

understanding fork()

```
int main() { pid_t pid; int x = 1;
pid = Fork();  /* A wrapper for fork() explained  shorly */
     if (pid == 0){/* child */ printf("Child: x= %d\n", ++x);
             exit(0);  }
      /* Parent */
     printf(" Parent: x = %d\n", --x);
     exit(0);
}
```

Output of the program would be
Parent: x = 0
Child: x = 2
or; it could be
Child: x = 2
Parent: x = 0

Understanding fork()

- Call once – returns twice
  - as parent and child running concurrently – the return value of 0 to child and pid of the child to the parent helps identifying in which you are in; parent or chid
- Concurrent execution
  - Output sequence could be anything for the concurrent processes; may be different in different runs. As no ordering of execution sequence can be predicted in general.
- Duplicate but separate address space
  - After fork() – in the seprate but private address space everything is identical; so the value of x is 1 in both the cases. Finally, in parent we have decreased the value of x to 0 and in the child it has been increased from 1 to 2
- Shared files
  - Child inherits all the open files of the parent; in this case the child inherits stdout from the parent. Thus both the parent and child to produce their output to stdout; i.e., the VDU.

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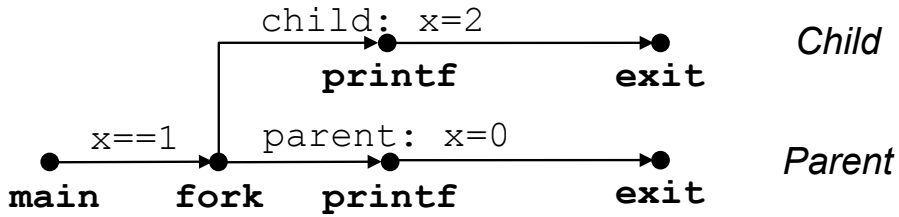
Understanding fork() contd.

As the fork() call is slightly tricky we may take help of a process graph as shown below graphically describing the previous program that increments a variable x in child and decrements the same in parent.

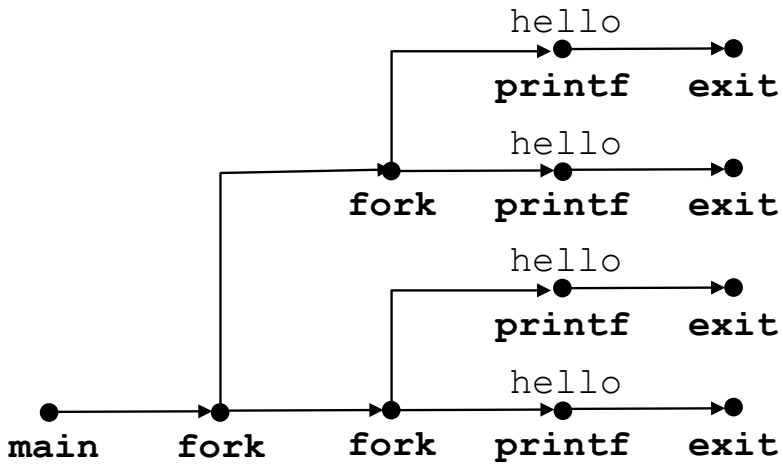


The precedence graph that captures the partial ordering of the program statement. Each vertex 'a' corresponds to the execution of a program statement. Each graph begins with a vertices representing the parent process calling main(). The arrows indicate the logical flows statement by statement up to the exit.

Program examples: Understanding fork() contd.

Take another example

```
int main() {fork(); fork(); printf("hello\n"); exit 0}
```



Here two consecutive calls to the fork() function results in four process (children) with the same code running as evidend from the graph; and we get four "hello" messages; however – the order of execution of the prcesses is random (we'll see this later through other examples)

Program examples: Understanding fork() contd.

Take another example

```
int main() { int a = 9;
  if ( fork() == 0)
printf("p1: a=%d\n", a--);
  printf("p2: a =%d\n", a++); exit (0);}
```

As fork() return 0 to the child – the first printf instruction would be executed after fork return to the child followed by 2nd printf instruction by the child again and exit. However, parent code will not reach the first printf (as pid is a positive integer) and the 2nd printf would be executed by the parent only once. So, the output would be
p1: a= 9;
p2: a= 8;
p2: a = 9; (note that the print order may change in different runs)

Using wrapper – system call error handling

Unix system calls encountering error responds by

- returning -1; and
- set the global integer variable *errno* to indicate what went wrong

PROGRAMMERS SHOULD ALWAYS CHECK FOR ERRORS.
Programmers skips error checking as it bloats the code and making it a bit uncomprehending. Here is the solution – a wrapper.

```
(A) if ((pid = fork()) < 0 ) {
fprintf(stderr, "fork error: %s\n", strerror(errno)); }
```

We can have a clean slate by using the error-reporting function

```
void unix_error(char *msg) {
 fprintf(stderr, %s: %s\n", msg, strerror(errno));
     exit(0);}  and then
 (B)    if (( pid = fork() < 0) unix_error("fork error");
```

Using wrapper – conts.

Finally, the error handling wrapper (say, Fork()) for the fork() system call

```
pid_t Fork(void)
{
pid_t pid;

if ( pid = fork()) < 0)
unix_error("Fork error");

    return pid;
}
With this wrapper, our call including the error checking is

 (C)      pid = Fork(); /* clean and unbloated */
```

For the ease of comprehension –the first letter of the function is capitalized from 'f' to 'F' – may be followed as a convention

Getting process ID – we have two call

```
#include <sys/types.h>
#include <unistd.h>
   pid_t  getpid(void);  /* returns  pid
                         of the calling process */
   pid_t      getppid(void); /* returns pid of the parent
                         of the calling process */
```

Terminating a process

```
#include <stdlib.h>
   void  exit(int status); /* you may return an exit
                                 status to the caller */
```

The other ways to terminate a process is through a signal or when you return from the main

Reaping a child process

When a process terminates the

- kernel does not remove it immediately from the system.
- The kernel waits until it is reaped by its parent
- When it is reaped by its parent the kernel returns the exit status to its parent
- And discards the terminated process – and then it does not exist

A terminated process yet to be reaped by its parent is known as a *Zombie*; i.e., a living corpse as depicted in folklores. When a parent process terminates, the kernel arranges for the init process (the ancestor of every process created by the kernel with pid 1 and that never terminate) to adopt the orphaned children. And finally the kernel arranges for the init process to reap them.

waitpid() function

```
#includes  <sys/types.h>
#include <sys/wait.h>
pid_t  waitpid(pid_t pid, int *statusp, int options);
/* returns PID of the child; 0 (if WNOHANG) & -1 on error  */
```

By default (options = 0) *waitpid* suspends execution of the calling process until a child process in its wait set terminates. If a process in the wait set has already terminated – waitpid returns immediately. The parent gets the pid of the terminated child that causes the waitpid to return.

Reaping a child process contd.

Members of the wait set can be determined by the pid argument.

- if pid $>$ 0; wait set is the singleton child process whose pid is passed.
- if pid $=$ -1; wait set consists of all of the child processes of the parent

On error (say, the caller has no child) it returns -1 and sets *errno* to ECHILD. If waitpid is interrupted by a signal (more later) it sets the *errno* to EINTR.

wait() function

It is a simpler version of the complicated *waitpid()* function

```
#includes  <sys/types.h>
#include <sys/wait.h>
pid_t  wait(int *statusp);
/* returns PID of the child if OK or  -1 on error */
```

Calling wait(&status) is equivalent to calling waitpid(-1, &status, 0).

Program examples: Understanding fork() and waitpid()

```
int main(){
if (fork() == 0) {printf("9"); fflush(stdout);}
else {printf("0"); fflush(stdout);
    waitpid(-1, NULL,0);
    }
printf("3"); fflush(stdout);
printf("6"); exit(0);
}
```

What is the output of this program? Try predicting the output using the precendence graph.

Putting Processes to Sleep and Pause

The **Sleep** and **Pause** function suspends a process for a specified period of time.

```
#include <unistd.h>
unsigned in sleep(unsigned int sec);
/* returns: 0 if time is already elapsed else  seconds left to
to make a prematured exit */
```

The **pause()** function is useful which puts a proces to sleep until it receives a signal.

```
int pause(void);  /* always returns -1 */
```

A wakeup wrapper for sleep function that prints a mesage on wake up.

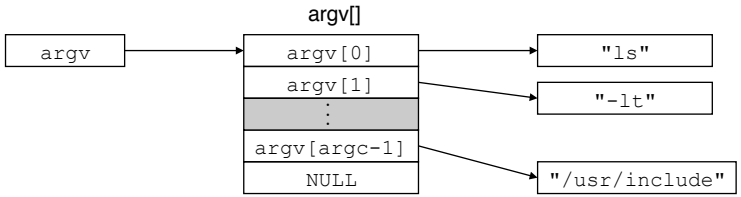
```
unsigned int wakeup(unsigned int secs)
{unsigned int rc = sleep(secs);
  printf("Woke up at %d secs.\n", secs - rc +1); return rc;}
```

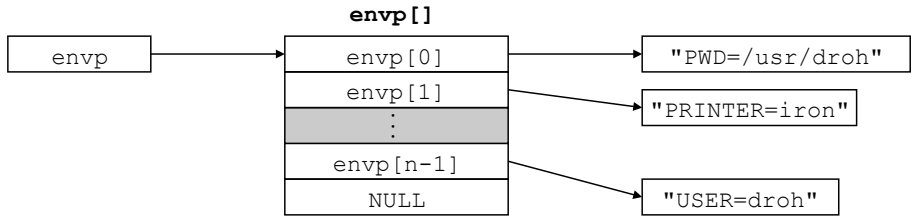
Loading and running a program in the context of a process

Execve() function is used to load and run users program.

```
#include <unistd.h>
int execve(const char *filename, const char *argv[],
     const char *envp[]);  /* Returns -1 on error
                              otherwise does not  return */
```

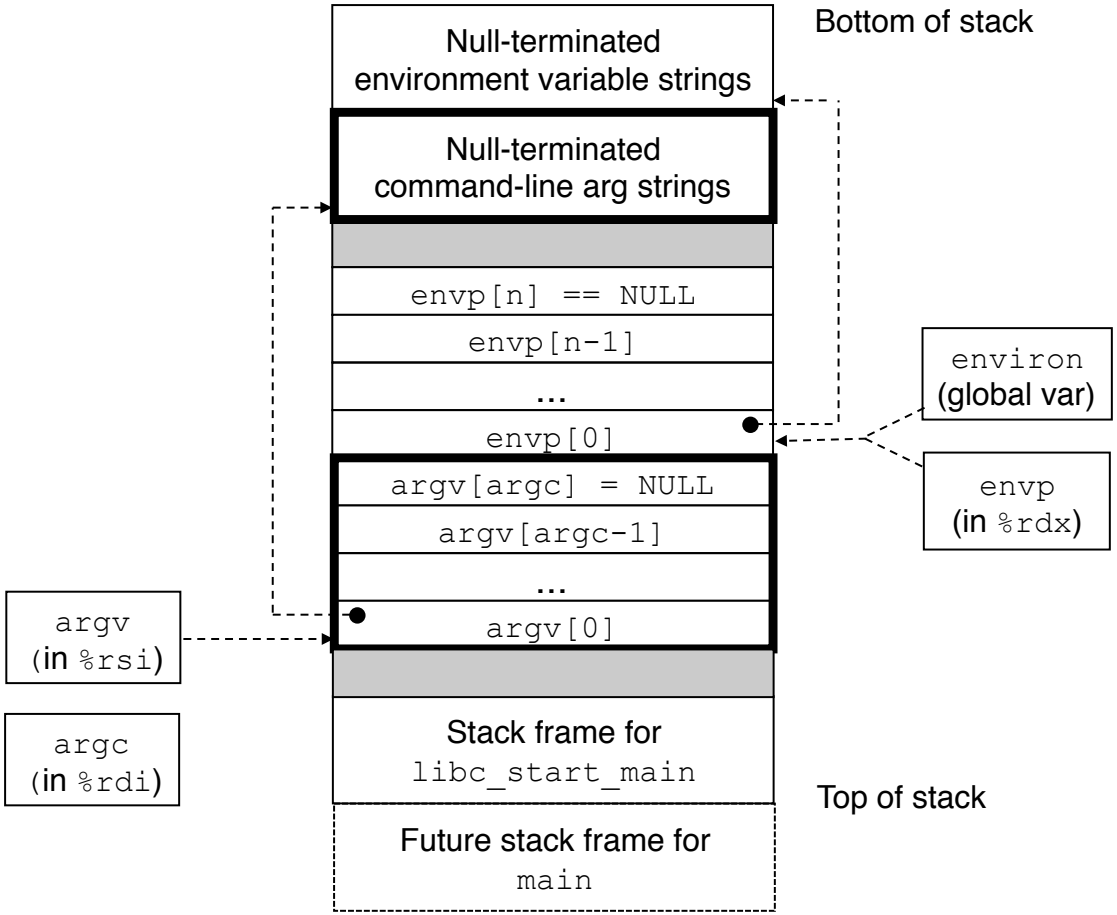
Organisations of the argument and environment variable lists





After loading the program execve calls the start up code which sets up the stack and passes control to the main routine having the form shown below
int main(int argc, char *argv[], char *envp[]);

User's stack at start



libc_start_main is the startup code that calls main(). Note that register rsi and rdx (x86-64 registers) point to the argv and envp strings while argc is available in rdi.

Running a Program: fork() and execve()

- Unix shell and Web servers make frequent use of the fork() and execve() functions to run programs
- The shell is an application level program that runs another program on behalf of the user using the following steps
  - Reads a Command Line from the user
  - Parse the command line; and
  - Runs the program on behalf of the user

Next is an example of a main() routine of a simple shell which prints a prompt and waits for user input through *stdin* and then evaluates the command line to take action

Running a Program contd.

```
#define MAXARGS 128   // appropriate .h files to
// be included before this
void eva(char *cmdline); // function prototypes
int  parseline(char *buf, char *argv[]);
int builtin_command(char *argv[]);


int main() { char cmdline[MAXLINE];
while(1){ printf("Ready>");
       fgets(cmdline, MAXLINE, stdin); // Read commandline
     if ( feof(stdin))
exit(o);
eval(cmdline); /* evaluate the commandline
```

The next is the Evaluate routine

Running a Program contd.

```
void eva(char *cmdline){
char *argv[MAXARGS]; // Argument list execve()
char buf[MAXLINE]; // holds modified command line
int bg; /* background job? */ pid_t pid // process id

strcpy (buf, cmdline); bg = parseline(buf, argv);
   if (argv[0] == NULL) return;
    if (!builtin_command(argv)){// expecting users executable
if (( pid = Fork()) == 0) { // let the child runs user program
if (execve(argv[0], argv, environ) < 0) {
printf("Command not found\n"); exit(0); } }
if(!bg) {
int status;
if (waitpid(pid, &status, 0) < 0)
unix_error("waitpid error"):
     } else printf("%d %s ", pid, cmdline); } return; }
```

Running a Program contd.

If the first argument is a bult-in comman – run it

```
int builtin_command(char *argv[])
{
if (!strcmp(argv[0], "quit")); exit (0);
   if (!strcmp(argv[0], "&")); return 1;

   return 0; // not a built-in command
}
```

Running a Program contd.

```
int  parseline(char *buf, char *argv[]){ // parse command line
 and build argv array
char *delim; /* points to first space delim.*/ int argc; int bg;
buf[strlen(buf) - 1] = ' '; // replace trailing '\n' with space
while(*buf && (*buf == ' ')) buf++ // skip past leading spaces
argc = 0; // build argvs'
 while ((delim = strchr(buf,' '))){ argv[argc++]=buf;*delim = '\0';
buf = delim + 1;
 while(*buf && (*buf == ' ')) buf++;} // skip past trailing
spacesargv[argc] = NULL;
    if (argc == 0) return 1; // ignore blank line
   if (( bg = (*argv[argc-1] == '&')) != 0) // should job in
 the bg mode
argv[--argc] = NULL;
    return bg;
}
```

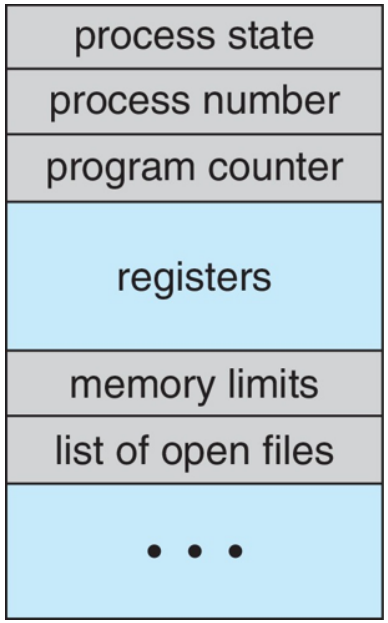
Program Vs. Process

- A program
  - is a collection of code and data and
  - may be stored as an object file on the disk or as a segment in an address space
- A process
  - is an instance of a program in execution and
  - a program always runs in the context of a process
- The fork() function creates a new process (the child) and
  - runs the same program in a new child process; and
  - this child process is a duplicated of the parent
- The execve() function does not create a new process rather
  - it loads and runs a new program in the context of a current process by overwriting the address space of the current process; and
  - the new program still has the same pid and enjoys the inherietence of all the file descriptors that were open at the time of calling execve

Process Control I Block (PCB)

Each process in the system is represented by a PCB containing essential information that includes

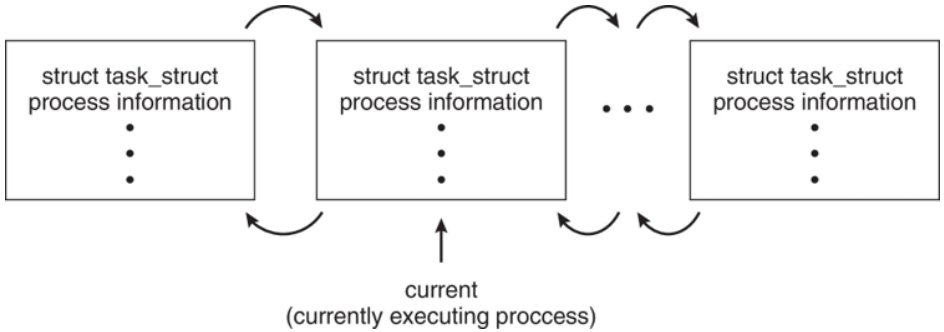
- Process state (running, waiting etc.) , Process number, PC and registers
- CPU-scheduling information – priorities, scheduling queue pointers
- Memory management informatiuon – memory allocated to the process
- I/O status information– I/O devices allocated to the process, list of open files
- Accounting information — CPU time used, clock time elapsed since start, time limits



Process representaton : UNIX

Represented by the C structure `task_struct`

```
pid t_pid;                    /* process identifier */
long state;                   /* state of the process */
unsigned int time_slice       /* scheduling information */
struct task_struct *parent;/* this process's parent */
struct list_head children; /* this process's children */
struct files_struct *files;/* list of open files */
struct mm_struct *mm;         /* address space of this
process */
```



Process Scheduling

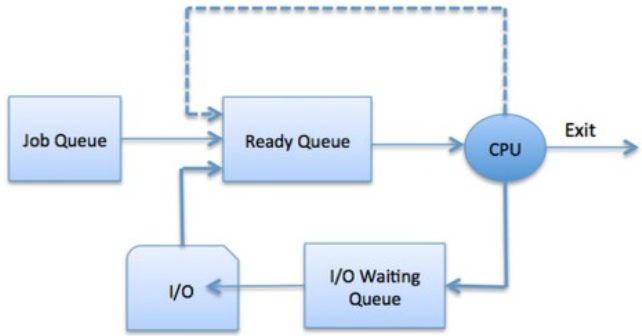
Process scheduling is an essential part of a Multiprogramming operating systems. Such operating systems allow more than one process to be loaded into the executable memory at a time and the loaded process shares the CPU using time multiplexing.

- It is the activity of the process manager that does the removal of the running process from the CPU and the selection of another process on the basis of a particular strategy.
- Several scheduling algorthms are used depending on several factors. However, the objective is more or less same for all the cases – utilising the CPU, unbiased quick response to the user, and last but not the least – completion of the jobs ASAP

Process Scheduling Queues

The OS keeps all the PCBs in process scheduling queues. Note that there are mutiple queues – separate queue for seprate state (ready, wait etc.). There may be a Job Queue that contains all the PCBs. The two most important queues are the

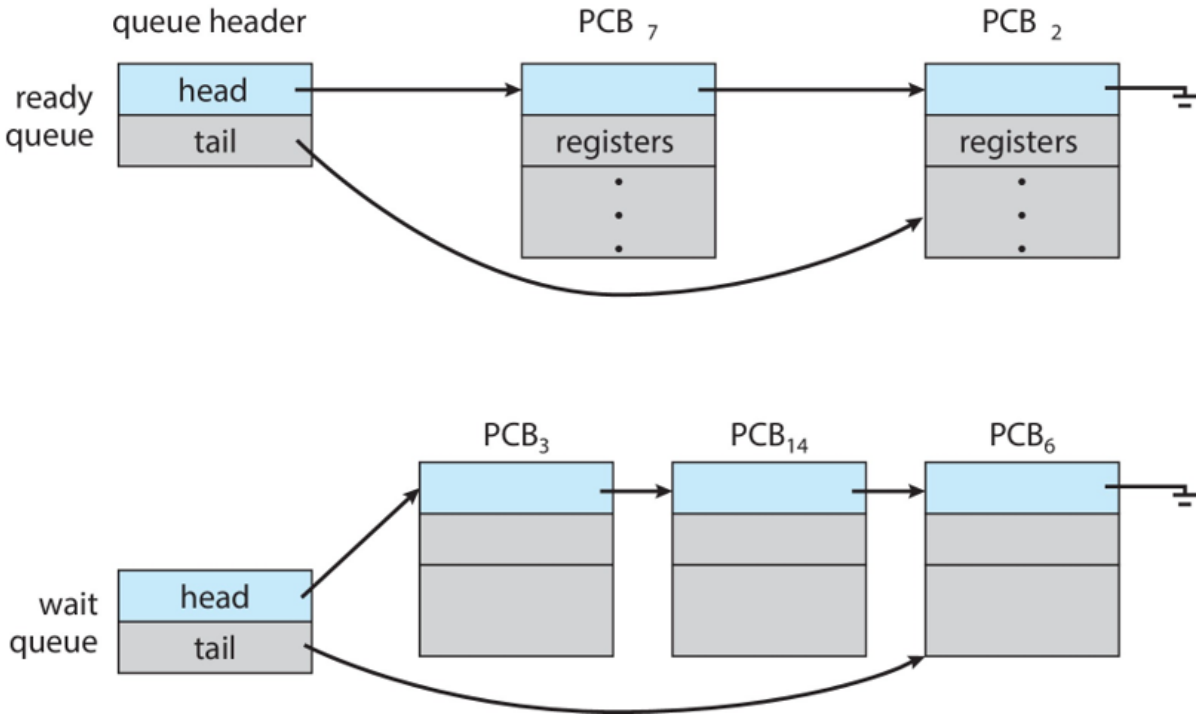
- Ready queue – set of all processes in main memeory that are ready and to execute.
- Wait queue – set of process waiting for an I/O or event completion
  The diagram shows the migration of processes between various queues as the process state changes from one to another. [note: Running state is fused to CPU]



Migration

Ready and Wait Queues

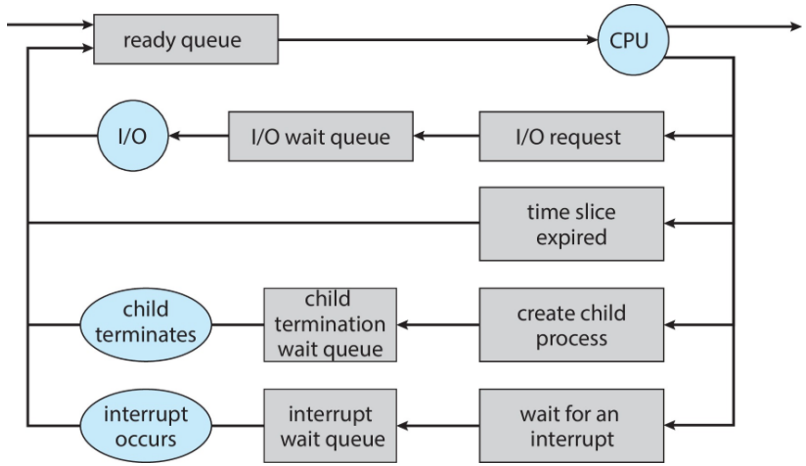
The ready and wait queues are implemented as linked list as shown in the figures. Queue headers point to the first PCB of the list. Each PCB has a link field to connect the subsequent PCB.



A more elaborate queueing dioagram is shown in the next figure that shows multiple wait queues.

Process – scheduling contd.

A new process is immediately put to the ready queue and it is then dispathced (selected to run). After that one of the several events can happen.



- The process issues an I/O request and moved to I/O wait queue
- The process creates a child and goes to the wait queue awaiting termination of the child
- A process may be interrupted (this includes timer interrupt for elapsed time slice) and placed to the ready queue.

Schedulers

The main task is to select the jobs to be submitted into the system and to decide which process to run. Schedulers are of three types:

- Long term
  - Also known as job scheduler that determines which program is to be selected (loaded in memory) for running. The objective is to maintain an optimised mix of I/O bound and CPU bound jobs running with a high and stable degree of multiprogramming.
  - Long term schedulers are not used in a time-sharing system
- Short term
  - Also known as CPU scheduler or dispatchers that determines which of the process gets the CPU from the ready queue.
  - Primary objective is to improve the system performance
- Mid-term
  - It is a part of the swapping activity that determines the process to be suspended and rolled-out from the memoryto the secondary device.
  - It reduces the degree of multiprogramming and improve process mix.

Schedulers : Comparison

No.	Long-term	Short-term	Medium-term
1	Job-scheduler	CPU scheduler	Swapping scheduler
2	Controls degree of Multiprogramming	Does not control degree of Multiprogramming	Reduce degree of Multiprogramming
3	Absent in time-sharing	Minimal in Time-sharing	Part of Time-sharing
4	Select job from a pool for execution	Select one of the ready processes	roll-in process and execution resumes

CPU Scheduling

CPU is the most importanat resource of the OS and its scheduling is central to the OS design. The task of the CPU scheduler is primarily selecting one of the ready processes to be selected for running.

- Process execution consists of an alternating cycle of CPU execution (*CPU burst*) and I/O wait (*I/O Burst*).
- Usually we have a few long CPU bursts (CPU intensive programs) and many short CPU bursts (I/O intensive program).
- So an optimum mix of these cycles is necessary for a better performance.

CPU Scheduling contd.

CPU scheduling decisions depend on the following four circumstances

1. Process is switching from running to wait (I/O request or wait() call)
2. Running to ready – due to an interrupt
3. waiting to ready – e.g., on completion of I/O
4. Termination

For case 1 and 4 scheduler has nothing to do in terms of scheduling except choosing a process to run. So, any scheduling taking place in case 1 or 4 is known to be non-preemptive (or co-operating) i.e., once it is running it releases the CPU by switching to wait state or terminating – otherwise preemptive (case 2 and 3).
All modern OS use pre-emptive scheduling for better performance; However, preemption leads to other consideration like prevention of race condition etc.

CPU Scheduling Criteria

CPU scheduling strategies are based on the following

- CPU utilisation – more is better (40 to 90% is common)
- Throughput – more is better (No. of processes completed per unit time)
- Turnaround time – less is better (time of submission to completion for a particulart process. Total time spent on ready, wait and running)
- Waiting time – Sum total of the time spent in ready queue (Note that scheduling is not affecting the CPU time or the I/O wait time – however it directly affacting the time spent in the ready queue). SO, less is better.
- Response time – For interactive systems (mostly are) turnaround time may not be the best criterion. Time from submission of the request to get the first response is more important than the time it takes to output the response. So, less is better.

Scheduling : Algorithms

There are six popular process scheduling algorithms

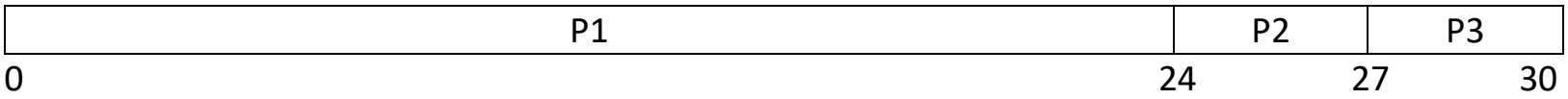
- First-Come, First-Served (FCFS) Scheduling
- Shortest-Job-Next/Shortest job first (SJN/SJF) Scheduling
- Priority Scheduling
- Shortest Remaining Time (Preemptive version of SJN)
- Round Robin(RR) Scheduling
- Multiple-Level Queues Scheduling

FRIST COME FIRST SERVED : FCFS

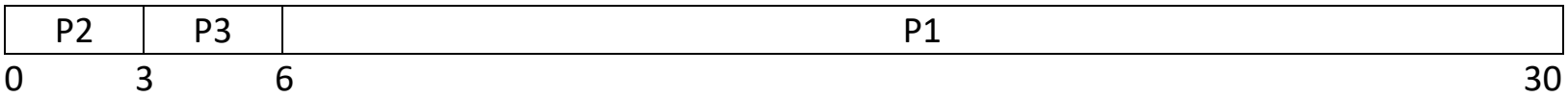
Simplest

- The 1st process waiting in the ready qureue is assigned the CPU first
- Non-preemptive
- Easy to implement with a FIFO queue
- Average wait time is high – also depends on the order of arrival of the processes.
- Usually a poor CPU and I/O utilisation

Gantt chart for FCFS with three processes. Note that a drastic reduction in average wait time; it is (0+24+ 27)/3 = 17 unit



Gantt chart for FCFS with the same number of processes but different order. Note that a drastic reduction in average wait time; it is (0+3+6)/3 = 3

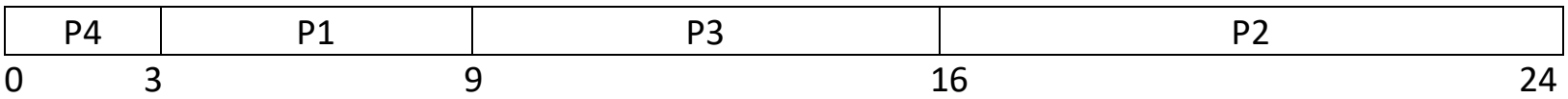


SHORTEST JOB FIRST: SJF

- Allocates the CPU to the next job with shortest CPU burst time (more appropriately the "shortest next CPU burst time")
- Non-preemptive
- Average wait time is less
- Usually a better CPU and I/O utilisation
- Cannot be directly implemented for CPU scheduling unless we can predict the next burst using exponential average of the measured lengths of the previous CPU bursts.

For four processes (P1: 6; P2: 8; P3 : 7 and P4: 3) with different CPU bursts the Gantt chart reveals reduction of wait time.

Average wait time is (0+3+9+16)/4 = 7 units. The same is 10.5 for FCFS



Computing Exponential Average

We may use the formula

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

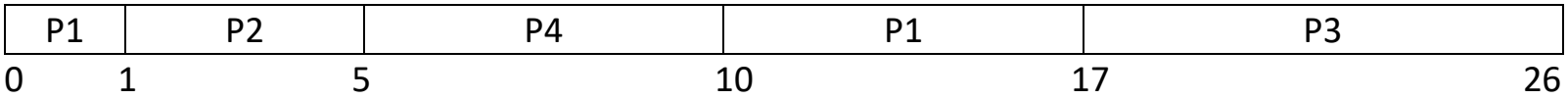
where τ_{n+1} is the prediction for (n+1)th burst where t_n is the time taken for nth burst and α is a constant set between 0 and 1.

- t_n contains the recent information and τ_n contains the past history
- Setting of α to $\frac{1}{2}$ is a prudent choice

SHORTEST REMAINING TIME NEXT

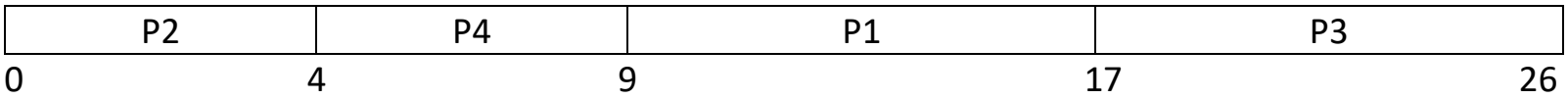
In SJF the process runs to the completion of the current CPU burst. We can have a preemptive version of the SJF; that is SRTN. Let us consider four processes with their arrival and burst time as follows.

Process	Arrival Time	Burst Time
P1	0	8
P2	1	4
P3	2	9
P4	3	5



P2 comes after 1 unit and P1 is pre-empted as P2 would take 4 units against 7 units more for P1. This way P4 is allocated after 5^{th} time unit; followed by P1 again at 10^{th} and finally P3 at 17^{th}.

The average wait time is ((10-1) + (1-1) + (17-2) + (5-3))/4 = 6.5 units while a Non preemptive SJF would results in average wait time of 7.75 units(i.e., 0 + 4+ 9 +17)/4 = 7.75 units as shown in the Gantt chart below.



ROUND ROBIN

Preemptive form of FCFS is Round Robin.

- A time quantum of 10 to 100 ms is allowed as a time slice
- The ready queue is treated as a circular one. For implementation it would simply be a FIFO where new process is added at the tail and the front one is allocated a CPU time-slice.

Two things can happen after the dispatcher puts the front from ready to running

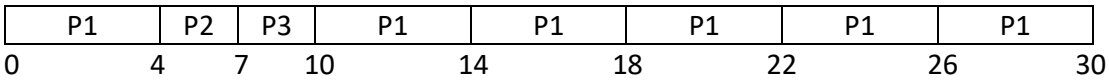
- The process may not need the allocated quantum releases the CPU voluntarily
- Time quatum elapsed and the process is interrupted by the timer for a context switch and the process is put to the end of the ready queue. It is imperative that the front process in the FIFO gets the CPU.

ROUND ROBIN (RR) contd.

The average wait time of RR may often be long as disclosed from the chart. An example with three processes in the ready list (P1 : 24; P2 : 3 and P3 : 3) shows the result where the time slice is 4 units.
P1 gets the CPU first and preempted after 4 such quantum. Then we get P2 running to its completion requireing only 3 quantum; so is P3. So, after 10th P1 gets the slot again 5 times in succession as there were no more in the ready queue.
The performance of the RR depends a lot on the time quantum.

- A large time quantum leads it towards FCFS
- A short time quatum increases overhead from context switching

Gantt chart for three processes (P1:20; P2: 3 and P3: 3)



The average wait time is (0+6 + 4 + 7)/3 = 5.67 units

ROUND ROBIN (RR) contd.

Considering a single process that requires 10 CPU burst and time quantum of 12, 6 and 1, respectively, for three cases we get 0, 1 and 9 context switches as shown below.

In general the time quantum should be high enough with respect to the context switch time for a better performance. Context switching time is typically around 10 Microsecond against the time quantum of 10 to 100 ms in all modern systems. Taking the average of time quantum as 50 ms; the context stwitching time is $1/5000$ of it.

ROUND ROBIN (RR) contd.

The time quantum has an effect on the average turn around time.

- Short time-quantum does not reduce the turnaround time substantially.

Process	CPU Burst	Time quantum	Average Turnaround Time
P1	6	1	11
P2	3	2	11.5
P3	1	3	10.85
P4	7	4	11.5
		5	12.25
		6	10.5
		7	10.5

In general the average turnaround time improves if 80% (and above) of the next CPU-burst is less than the time quantum allowed.

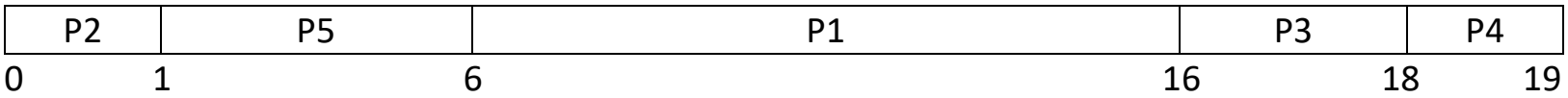
Priority Scheduling contd.

- Highest priority process gets the CPU first. Equal priority processes are scheduled using FCFS
- Priority scheduling is a special case of SJF where the priority is the inverse of the next predicted CPU burst

For the following five processes arrived at time 0 has the following priority (0 – highest and n-1 is the lowest priority)

Process	CPU Burst	Priority
P1	10	3
P2	1	1
P3	2	4
P4	1	5
P5	5	2

The average wait time is 8.2 unit time



Priority Scheduling contd.

Priority can be internally or externally defined

- Internal Priority
  - Use some measurable quantities; like
    - Time limit
    - Memory requirements
    - Ratio of CPU and I/O burst
    - Number of open files; etc.
- External Priority; outside the realm of the OS; like
  - Fee paid to use the system
  - Emergent work (from the authority), etc.

Priority scheduling can be preemptive or nonpreemptive. when a new process with higher priority arrives –

- For a premeeptive system it would make the new process running by preempting the current one,
- For a non-preemptive case the new process would be put to the head of the ready queue.

Priority Scheduling contd.

A major problem of priority scheduling is starvation (indefinite blocking) where a low priority process may not get the CPU at all due to continuous arrival of higher priority processes. A low priority process may run if the system gets some respite in odd-hours or the system crashes/user lost all hope of the work being done and walk out. Solutions to this problem is

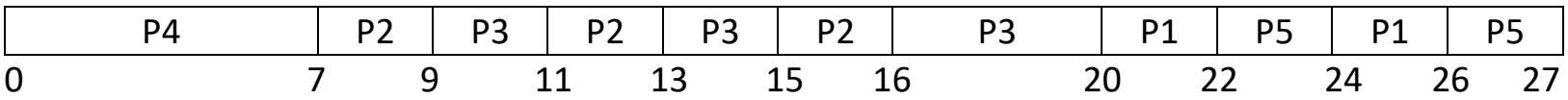
- Aging – improving the priority of the low priority processes at regular intervals
- Combining the priority and RR such that highest priority process runs and same priority processes uses RR

Priority Scheduling contd.

For five processes shown below we will examine the proposal of using a combination of Priority with RR.

Process	CPU Burst	Priority
P1	4	3
P2	5	2
P3	8	2
P4	7	1
P5	3	3

The average wait time for a time slice of 2 units is 14.2 unit.



Multi-level Queue Scheduling

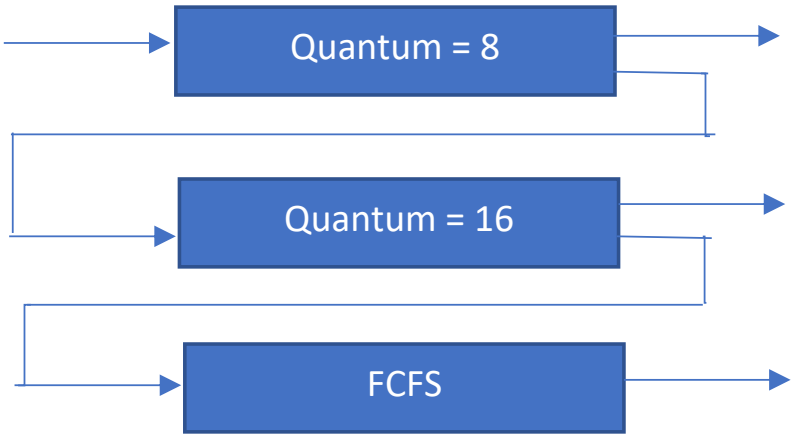
Here the key idea is to have seprate queues for each distinct priority and the scheduler allocates the CPU to a process from the highest priority queue. Scheduling performance is better with priority and RR combined. A prioriy is assigned to a process and the process is kept in that queue during its lifetime; a less flexible but easy to implement approach. The queues may formed as per the process type as assigning priority usually depends on good prediction logic.

Certain processes have an inherently higher priority than others; for example if we may have four queues (higher to lower priority), namely, i) Real-time processes ii) System processes; iii) Interactive processes; and iv) batch processes. Here we could maintain 4 different queues and go for PR and RR combined. Note that a higher priority queue has got absolute priority from the lower priority queues. This means if the real-time process queue is empty then only we can run a process from the system process queue. Moreover, a process from the lower priority group may be preempted to make room for a process just arrived in a higher priority queue.

Multi-level Queue Scheduling contd.

Multi-level feedback queue allows inter-queue movement by dynamic change in priority of a process

- The key idea is to separate the processes as per their CPU burst charcateristics with different queue with different time-slices
- Process asking for more CPU bursts moves to lower priority queue with higher time quantum
- This approach automatically leaves I/O bound and interactive processes with short CPU bursts in high priority queues
- Additionally aging may be applied for processes in the lower priority queue to move-up



Multi-level Queue Scheduling contd.

In a nutshell the following are the key points for a multi-level queue scheduling

- How many queues?
- Scheduling method for each queue
- Method to upgrade (or downgrade) a process from one to another queue; etc.

Technically this is the most complex scheduling algorithm and perhaps the best as we have a lot of scopes to configure for a particular need. Computation of too many scheduling parameters may be counter-productive.