CSE3221.3
Operating System Fundamentals

No.2

Process

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How OS manages CPU usage?

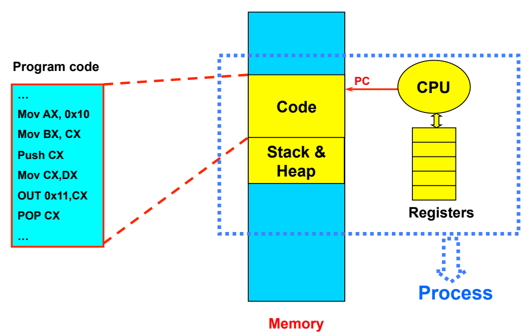
- How CPU is used?
  - Users use CPU to run programs
- In a multiprogramming system, a CPU always has several jobs running together.
- How to define a CPU job?
  - The important concept:

PROCESS

Process

- Process is a running program, a program in execution.
- Process is a basic unit of CPU activities, a process is a unit of work in a multiprogramming system.
- Many different processes in a multiprogramming system:
  - User processes executing user code
    - Word processor, Web browser, email editor, etc.
  - System processes executing operating system codes
    - CPU scheduling
    - Memory-management
    - I/O operation
- Multiple processes concurrently run in a CPU.

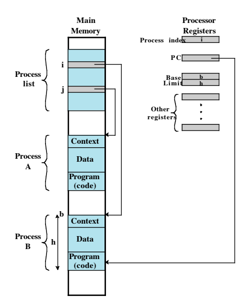
Process vs. Program Code



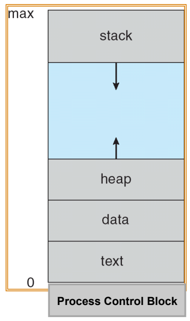
Process

- **A Process includes:**
  - **Text Section:** memory segment including program codes.
  - **Data Section:** memory segment containing global and static variables.
  - **Stack and Heap:** memory segment to save temporary data, such as local variable, function parameters, return address, ...
  - **Program Counter (PC):** the address of the instruction to be executed next.
  - **All CPU's Registers**

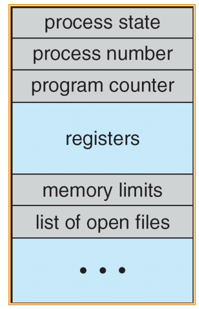
Process in Memory (I)



Process in Memory (II)



Data Structure to represent a Process: Process Control Block (PCB)

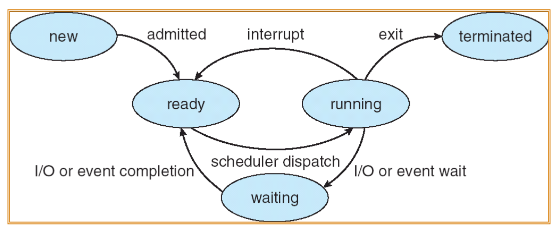


- **Process state**
- **Program counter (PC)**
- **CPU registers**
- **CPU scheduling information**
- **Memory-management information**
- **I/O status information**
- **Accounting information**

Linux PCB

```
struct task_struct {
    pid_t pid;   /* process identifier */
    long state;  /* state of the process */
    unsigned int time_slice; /*scheduling info*/
    struct task_struct *parent; /* parent process*/
    struct list_head children; /* all child processes*/
    struct files_struct *files; /* list of open files*/
    struct mm_struct *mm; /* memory space of process */
    …
    …
} ;
```

Process States

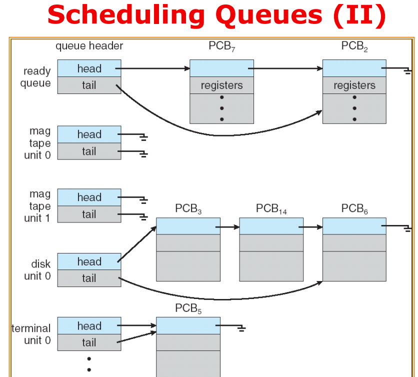


- **New:** the process is just being created
- **Running:** instructions are being executed by CPU
- **Waiting:** waiting for some event, I/O completion or a signal
- **Ready:** waiting to be assigned to CPU to run
- **Terminated:** it finished execution

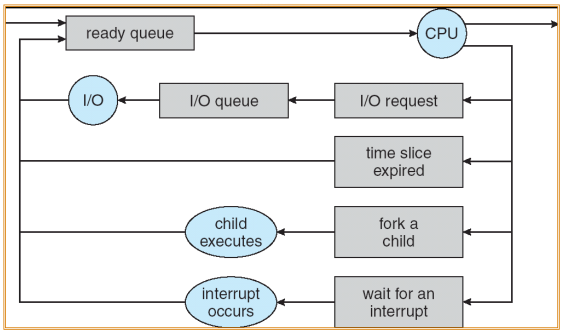
Scheduling Queues (I)

- Scheduling Queues:
  - List of processes competing for the same resource.
- Queues is generally implemented as linked lists.
- Each item in the linked list is PCB of a process, we extend each PCB to include a pointer to point to next PCB in the queue.
- In Linux, each queue is a doubly linked list of `task_struct`.
- Examples of scheduling queues:
  - Ready Queue: all processes waiting for CPU
  - Device Queues: all processes waiting for a particular device; Each device has its own device queue.

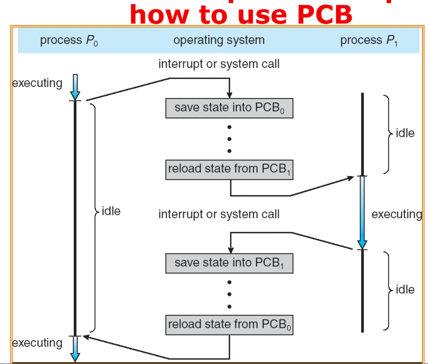
Scheduling Queues (II)



Queuing Diagram



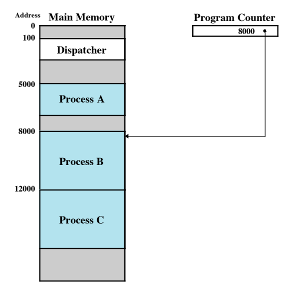
CPU Switch from process to process: how to use PCB



Context Switch

- Context Switch: switching the CPU from one process to another.
  - Saving the state of old process to its PCB.
  - CPU scheduling: select a new process.
  - Loading the saved state in its PCB for the new process.
- The context of a process is represented by its PCB.
- Context-switch time is pure overhead of the system, typically from 1–1000 microseconds, mainly depending on:
  - Memory speed.
  - Number of registers.
  - Existence of special instruction.
  - The more complex OS, the more to save.
- Context switch has become such a performance bottleneck in a large multiprogramming system:
  - New structure to reduce the overhead: THREAD.

Context Switch: example



Trace of Processes

(a) Trace of Process A	(b) Trace of Process B	(c) Trace of Process C
5000	8000	12000
5001	8001	12001
5002	8002	12002
5003	8003	12003
5004		12004
5005		12005
5006		12006
5007		12007
5008		12008
5009		12009
5010		12010
5011		12011

5000 = Starting address of program of Process A
8000 = Starting address of program of Process B
12000 = Starting address of program of Process C

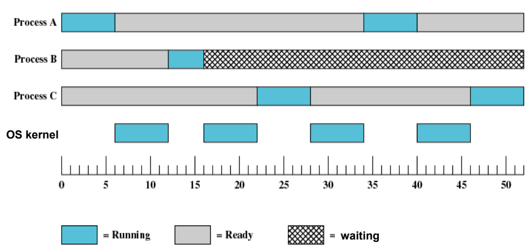
Trace of Processes

1	5000	27	12004
2	5001	28	12005
3	5002	----------	Time out
4	5003	29	100
5	5004	30	101
6	5005	31	102
----------	Time out	32	103
7	100	33	104
8	101	34	105
9	102	35	5006
10	103	36	5007
11	104	37	5008
12	105	38	5009
13	8000	39	5010
14	8001	40	5011
15	8002	----------	Time out
16	8003	41	100
----------	I/O request	42	101
17	100	43	102
18	101	44	103
19	102	45	104
20	103	46	105
21	104	47	12006
22	105	48	12007
23	12000	49	12008
24	12001	50	12009
25	12002	51	12010
26	12003	52	12011
		----------	Time out

100 = Starting address of dispatcher program

shaded areas indicate execution of dispatcher process;
first and third columns count instruction cycles;
second and fourth columns show address of instruction being executed

Process State



Process Scheduling: Schedulers

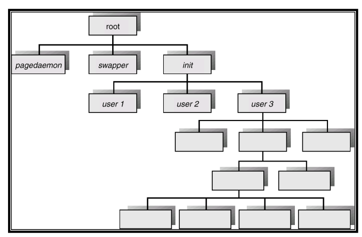
- The scheduler's role
- CPU scheduler (Short-term scheduler)
  - Select a process from ready queue to run once CPU is free.
  - Executed very frequently (once every 100 millisecond).
  - Must be fast enough for OS efficiency.
- Long-term Scheduler (Job scheduler):
  - Choose a job from job pool to load into memory to start.
  - Control the degree of multiprogramming – number of process in memory.
  - Select a good mix of I/O-bound processes and CPU-bound processes.

Operations on Processes (UNIX/Linux as an example)

- Process creation
- Process termination
- Inter-process communication (IPC)
- Multiple-process programming in Unix/Linux
  - Cooperating process tasks.
  - Important for multicore architecture

Process Creation(1)

- A process can create some new processes via a *create-process* system call:
  - Parent process / children process.
- All process in Unix form a tree structure.



Process Creation(2)

- Resource Allocation of child process
  - The child process get its resource from OS directly.
  - Constrain to its parent's resources.
- Parent status
  - The parent continues to execute concurrently with its children.
  - The parent waits until its children terminate.
- Initialization of child process memory space
  - Child process is a duplicate of its parent process.
  - Child process has a program loaded into it.
- How to pass parameters (initialization data) from parent to child?

UNIX Example: *fork()*

- In UNIX/Linux, each process is identified by its process number (*pid*).
- In UNIX/Linux, *fork()* is used to create a new process.
- Creating a new process with *fork():*
  - New child process is created by *fork().*
  - Parent process' address space is copied to new process' space (initially identical content in memory space).
  - Both child and parent processes continue execution from the instruction after *fork().*
  - Return code of *fork()* is different: in child process, return code is zero, in parent process, return code is nonzero (it is the process number of the new child process)
  - If desirable, another system call *execlp()* can be used by one of these two processes to load a new program to replace its original memory space.

Typical Usage of fork()

```
#include <stdio.h>
void main(int argc, char *argv[ ])
{
  int pid ;

  /* fork another process */
  pid = fork() ;

  if (pid < 0)  {  /* error occurred */
    fprintf(stderr, "Fork Failed!\n") ;
    exit(-1) ;
  }  else if (pid == 0)  { /* child process*/
    execlp("/bin/ls","ls",NULL) ;
  }  else {  /* parent process */
    /* parent will wait for the child to complete */
    wait(NULL) ;
    printf ("Child Complete\n") ;
    exit(0) ;
  }
}
```

Process Termination

- Normal termination:
  - Finishes executing its final instruction or call *exit()* system call.
- Abnormal termination: make system call *abort()*.
  - The parent process can cause one of its child processes to terminate.
    - The child uses too much resources.
    - The task assigned to the child is no longer needed.
    - If the parent exits, all its children must be terminated in some systems.
- Process termination:
  - The process returns data (output) to its parent process.
    - In UNIX, the terminated child process number is return by *wait()* in parent process.
  - All its resources are de-allocated by OS.

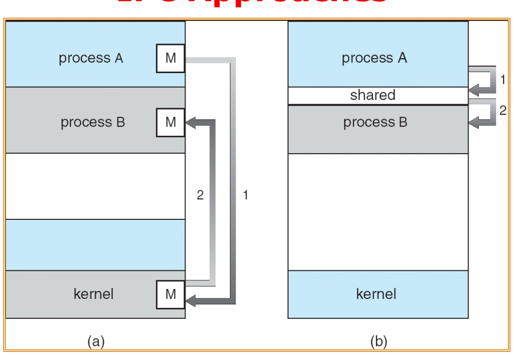
Multiple-Process Programming in Unix

- Unix system calls for process control:
  - *getpid()*: get process ID (*pid*) of calling process.
  - *fork()*: create a new process.
  - *exec()*: load a new program to run.
    - execl(char *pathname, char *arg0, …) ;
    - execv(char *pathname, char* argv[ ]) ;
    - execle(), execve(), execlp(), execvp()
  - *wait(), waitpid*(): wait child process to terminate.
  - *exit(), abort()*: a process terminates.

Cooperating Processes

- Concurrent processes executing in the operating system
  - Independent: runs alone
  - Cooperating: it can affect or be affected by other processes
- Why cooperating processes?
  - Information sharing
  - Computation speedup
  - Modularity
  - Convenience
- Inter-process communication (IPC) mechanism for cooperating processes:
  - Shared-memory
  - Message-passing

IPC Approaches



Inter-process Communication (IPC): Message Passing

- IPC with message passing provides a mechanism to allow processes to communicate and to synchronize their actions without sharing the same address space.
- IPC based on message-passing system:
  - Processes communication without sharing space.
  - Communication is done through the passing of messages.
  - At least two system calls:
    - *send*(message)
    - *receive*(message)
  - Message size: fixed vs. variable
  - Logical communication link:
    - Direct vs. indirect communication
    - Blocking vs. non-blocking
    - Buffering

Direct Communication

- Each process must explicitly name the recipient or sender of the communication.
  - *send*(P,message)
  - *Receive*(Q,message)
- A link is established between each pair of processes
- A link is associated with exactly two processes
- Asymmetric direct communication: no need for recipient to name the sender
  - *send*(P,message)
  - *receive*(&id,message): id return the sender identity
- Disadvantage of direct communication:
  - Limited modularity due to explicit process naming

Indirect Communication

- The messages are sent to and received from *mailbox.*
- *Mailbox* is a logical unit where message can be placed or removed by processes. (each mailbox has a unique id)
  - *send*(A,message): A is mailbox ID
  - *receive*(A,message)
- A link is established in two processes which share mailbox.
- A link may be associated with more than two processes.
- A number of different link may exist between each pair of processes.
- OS provides some operations (system calls) on mailbox
  - Create a new mailbox
  - Send and receive message through the mailbox
  - Delete a mailbox

Blocking vs. non-blocking in message-passing

- Message passing may be either blocking or non-blocking.
- Blocking is considered synchronous.
- Non-blocking is considered asynchronous.
- *send*() and *receive*() primitives may be either blocking or non-blocking.
  - Blocking send
  - Non-blocking send
  - Blocking receive
  - Non-blocking receive
- When both the *send* and *receive* are blocking, we have a *rendezvous* between the sender and the receiver.

Buffering in message-passing

- The buffering provided by the logical link:
  - Zero capacity: the sender must block until the recipient receives the message (no buffering).
  - Bounded capacity: the buffer has finite length. The sender doesn't block unless the buffer is full.
  - Unbounded capacity: the sender never blocks.

IPC in UNIX

- ★ Signals
- ★ Pipes
- Named pipe (FIFO)
- Message queues
- Shared memory
- Sockets
- others

Signal function in Unix

- Signal is a technique to notify a process that some events have occurred.
- The process has three choices to deal with the signal:
  - Ignore the signal
  - Let the default action occur.
  - Call a particular function when the signals occurs.
- *signal*() function: change the action function for a signal

```
#include <signal.h>
void (*signal(int signo, void (*func) (int )  ) ;
```

- *kill()* function: send a signal to another process

```
#include <sys/types.h>
#include <signal.h>
int kill (int pid, int signo) ;
```

Unix Signals

Name	Description	ANSI C	POSIX.1	SVR4	4.3+BSD	Default action
SIGABRT	abnormal termination (abort)	•	•	•	•	terminate w/core
SIGALRM	time out (alarm)		•	•	•	terminate
SIGBUS	hardware fault			•	•	terminate w/core
SIGCHLD	change in status of child		job	•	•	ignore
SIGCONT	continue stopped process		job	•	•	continue/ignore
SIGEMT	hardware fault			•	•	terminate w/core
SIGFPE	arithmetic exception	•	•	•	•	terminate w/core
SIGHUP	hangup		•	•	•	terminate
SIGILL	illegal hardware instruction	•	•	•	•	terminate w/core
SIGINFO	status request from keyboard				•	ignore
SIGINT	terminal interrupt character	•	•	•	•	terminate
SIGIO	asynchronous I/O			•	•	terminate/ignore
SIGIOT	hardware fault			•	•	terminate w/core
SIGKILL	termination		•	•	•	terminate
SIGPIPE	write to pipe with no readers		•	•	•	terminate
SIGPOLL	pollable event (poll)			•		terminate
SIGPROF	profiling time alarm (setitimer)			•	•	terminate
SIGPWR	power fail/restart			•		ignore
SIGQUIT	terminal quit character		•	•	•	terminate w/core
SIGSEGV	invalid memory reference	•	•	•	•	terminate w/core
SIGSTOP	stop		job	•	•	stop process
SIGSYS	invalid system call			•	•	terminate w/core
SIGTERM	termination	•	•	•	•	terminate
SIGTRAP	hardware fault			•	•	terminate w/core
SIGTSTP	terminal stop character		job	•	•	stop process
SIGTTIN	background read from control tty		job	•	•	stop process
SIGTTOU	background write to control tty		job	•	•	stop process
SIGURG	urgent condition			•	•	ignore
SIGUSR1	user-defined signal		•	•	•	terminate
SIGUSR2	user-defined signal		•	•	•	terminate
SIGVTALRM	virtual time alarm (setitimer)			•	•	terminate
SIGWINCH	terminal window size change			•	•	ignore
SIGXCPU	CPU limit exceeded (setrlimit)			•	•	terminate w/core
SIGXFSZ	file size limit exceeded (setrlimit)			•	•	terminate w/core

Example: signal in UNIX

```
#include <signal.h>

static void sig_int(int) ;

int main() {

  if(signal(SIGINT,sig_int)==SIG_ERR)
    err_sys("signal error") ;

  sleep(100) ;
}

void sig_int(int signo)
{
  printf("Interrupt\n") ;
}
```

- Event SIGINT: type the interrupt key (Ctrl+C)
- The default action is to terminate the process.
- Now we change the default action into printing a message to screen.

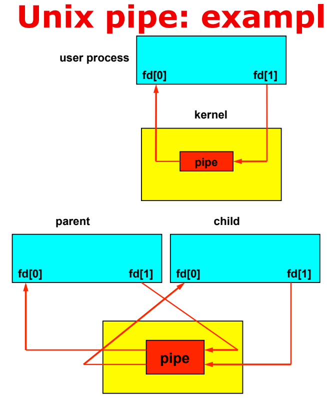
Unix Pipe

- Half-duplex; only between parent and child processes.
- Creating a pipe:
  - Call `pipe();`
  - Then call `fork();`
  - Close some ends to be a half-duplex pipe: `close()`.
- Communicate with a pipe:
  - Use `read()` and `write()`.

```
#include <unistd.h>

int pipe( int filedes[2] ) ;
```

Unix pipe: example



Unix Pipe: example

```
int main() {

   int n, fd[2] ;
   int  pid ;
   char  line[200] ;

  if( pipe(fd) < 0 )    err_sys("pipe error") ;

  if ( (pid = fork()) < 0 ) err_sys("fork error") ;
  else if ( pid > 0 )  {
      close(fd[0]) ;
      write(fd[1], "hello word\n", 12) ;
 } else  {
   close(fd[1]) ;
   n = read(fd[0], line, 200) ;
   write(STDOUT_FILENO, line, n) ;
}
 exit(0) ;
}
```

OS Global Control Structures

- Tables are constructed for each entity that operating system manages.
  - Process table: PCBs and process images.
  - Memory table: Allocation of main memory to processes; Protection attributes for access to shared memory regions.
  - File table: all opened files; location on hardware; current status.
  - I/O table: all I/O devices being used; status of I/O operations.
  - Scheduling queues.

Operating System Control Structures