EECS3221.3
Operating System Fundamentals

No.2

Process

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How OS manages CPU usage?

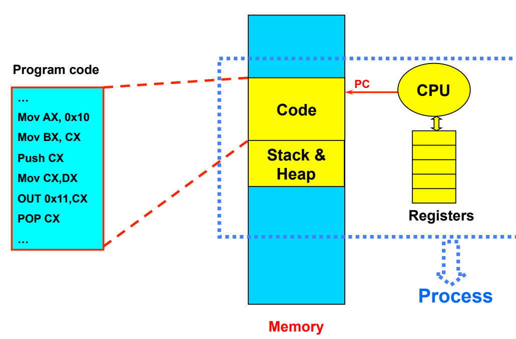
- How CPU is used?
  – Users use CPU to run programs
- In a multiprogramming system, a CPU always has several jobs running together.
- How to define a CPU job?
  – The important concept:

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.

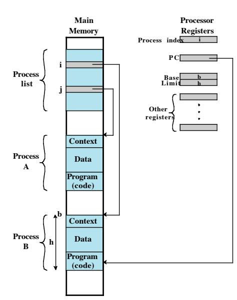
Process vs. Program Code



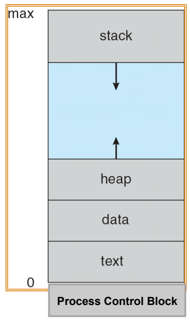
Process

- 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**

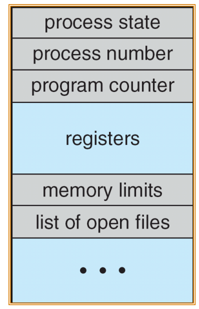
Process in Memory (I)



Process in Memory (II)



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

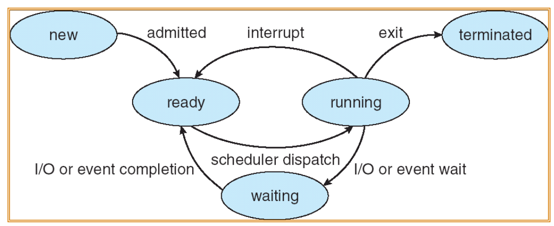


- **Process state**
- **Program counter (PC)**
- **CPU registers**
- **CPU scheduling information**
- **Memory-management information**
- **I/O status information**
- **Accounting information**

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

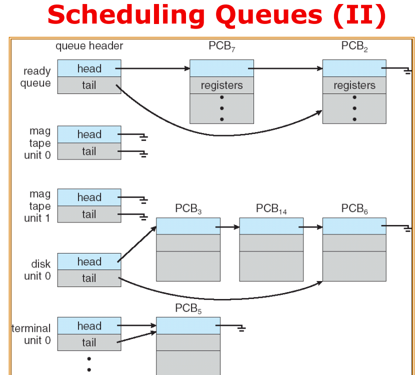


- **New:** the process is just being created
- **Running:** instructions are being executed by CPU
- **Waiting:** waiting for some event, I/O completion or a signal
- **Ready:** waiting to be assigned to CPU to run
- **Terminated:** it finished execution

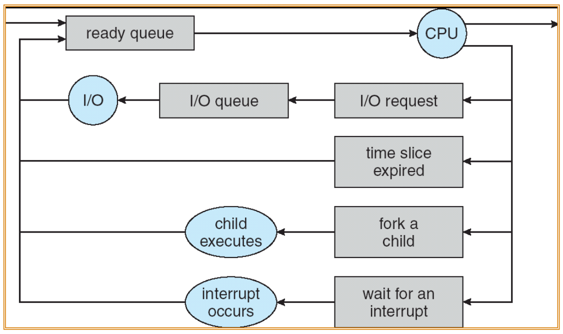
Scheduling Queues (I)

- **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.**

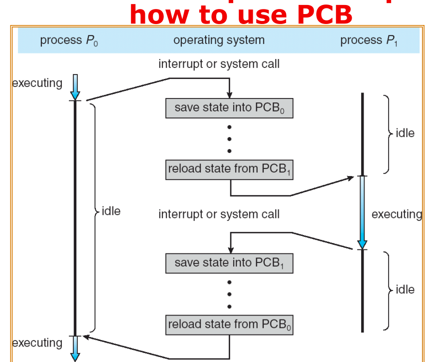
Scheduling Queues (II)



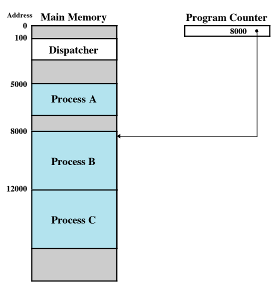
Queuing Diagram



CPU Switch from process to process: how to use PCB



Context Switch: 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

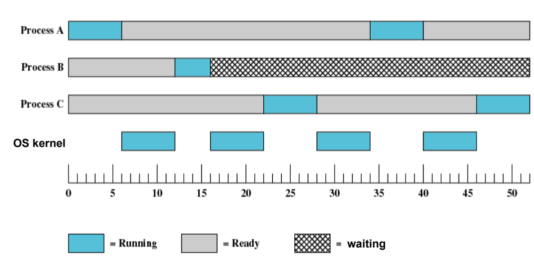
Trace of Processes

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



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.

Process Scheduling: Schedulers

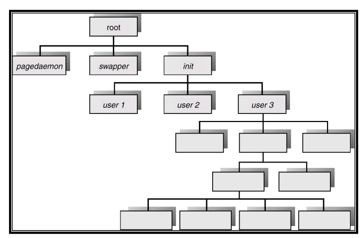
- The scheduler's role
- CPU scheduler (Short-term scheduler)
  - Select a process from ready queue to run once CPU is free.
  - Executed very frequently (once every 100 millisecond).
  - Must be fast enough for OS efficiency.
- Long-term Scheduler (Job scheduler):
  - Choose a job from job pool to load 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.

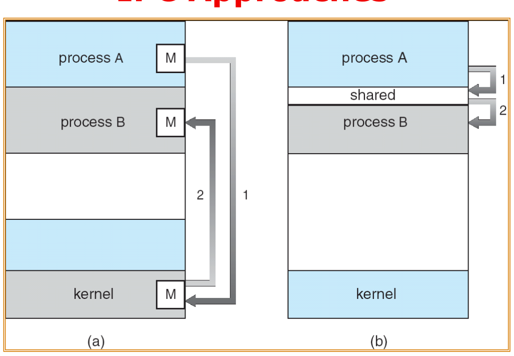
Multiple-Process Programming in Unix

- 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.

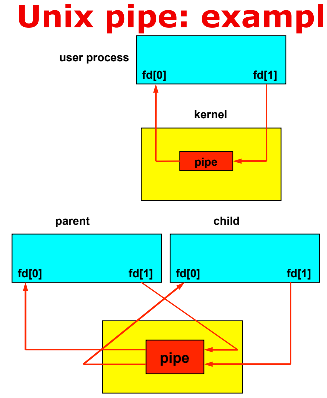
Unix Pipe

- 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