Chapter 3: Processes-Concept

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Chapter 3: Processes-Concept

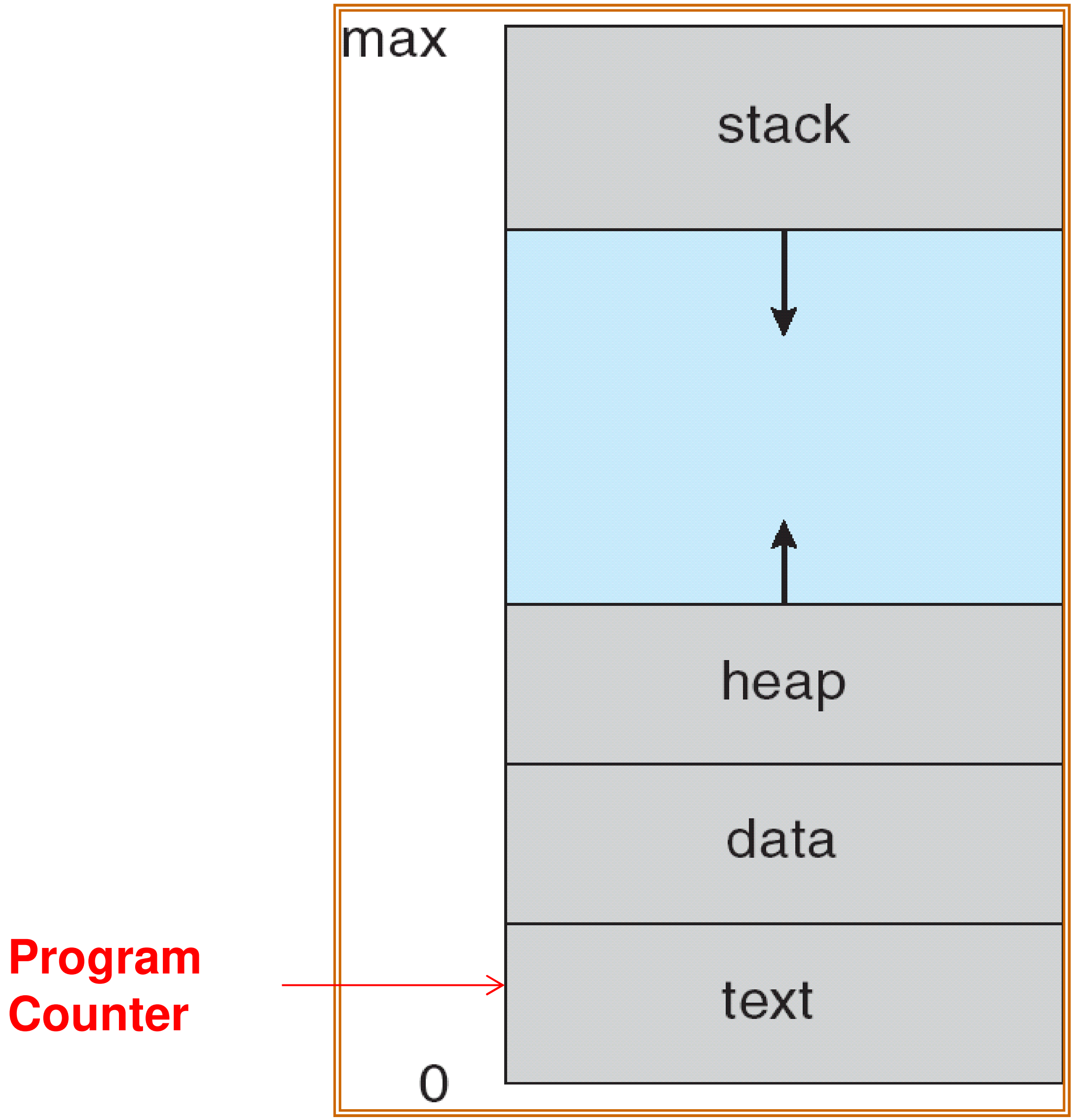
- Process Concepts
- Process Schedulers
- Operations on Processes
- Inter-process Communication
- Examples of IPC Systems

PROCESS CONCEPTS

Process Concept

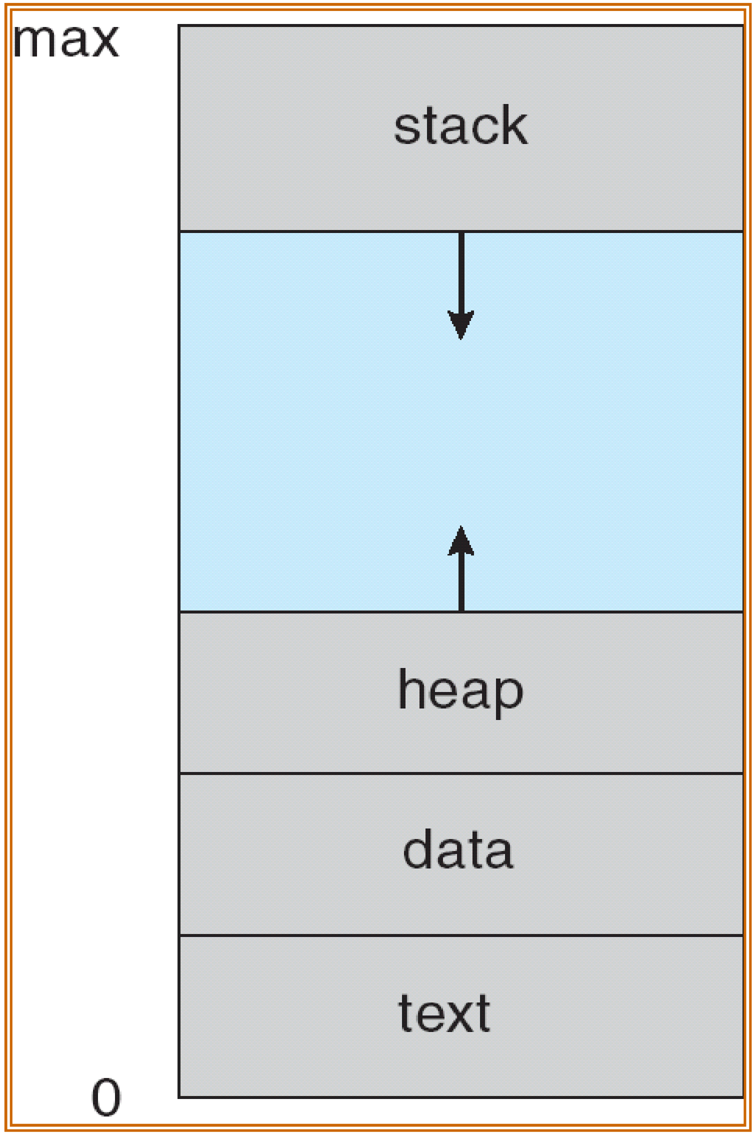
- An operating system executes a variety of programs:
  - Batch system – jobs
  - Time-shared systems – user programs or tasks
  - Textbook uses the terms job, task, and process almost interchangeably
- Process – a program in execution; process execution must progress in sequential fashion
  - Process: active,   program: passive
- A process includes:
  - Text section
  - Stack section
  - Data section
    - BSS and variables with initial values
  - Heap
  - Program counter and other CPU registers

Process in Memory (virtual addr space)



Where the variables below are allocated from?

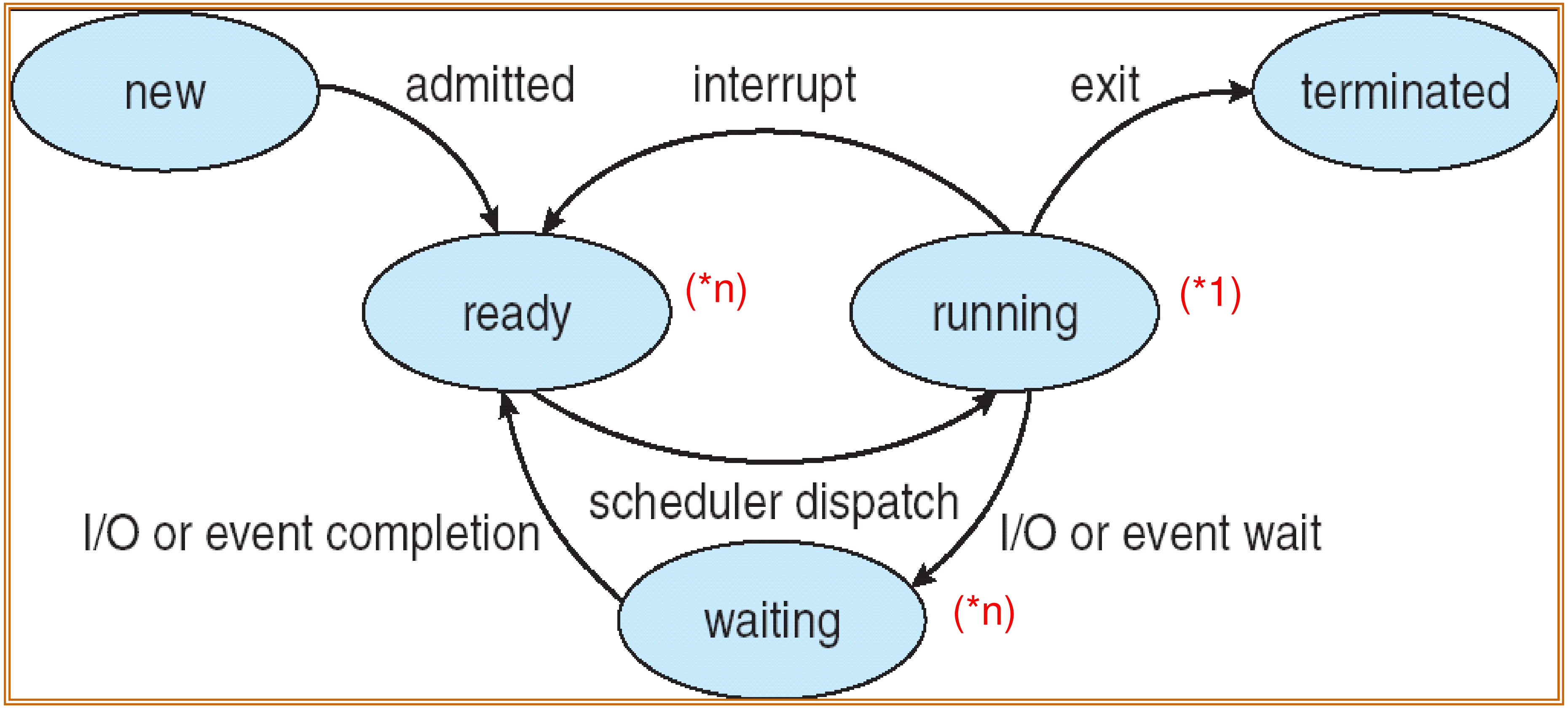
```
int i;

int foo(int x)
{
      int *y;

      i=0;
      y=(int *)malloc(100);
}
```



Process State

- As a process executes, it changes state
  - new: The process is being created
  - running: Instructions are being executed
  - ready: The process is waiting to be assigned to a processor
  - waiting: The process is waiting for some event to occur
  - terminated: The process has finished execution

Diagram of Process State



- A running process voluntarily leaves the running state
- Running → waiting: the running process requests a system service that can not be immediately fulfilled
  - Triggered by traps (calling the kernel for I/O service)

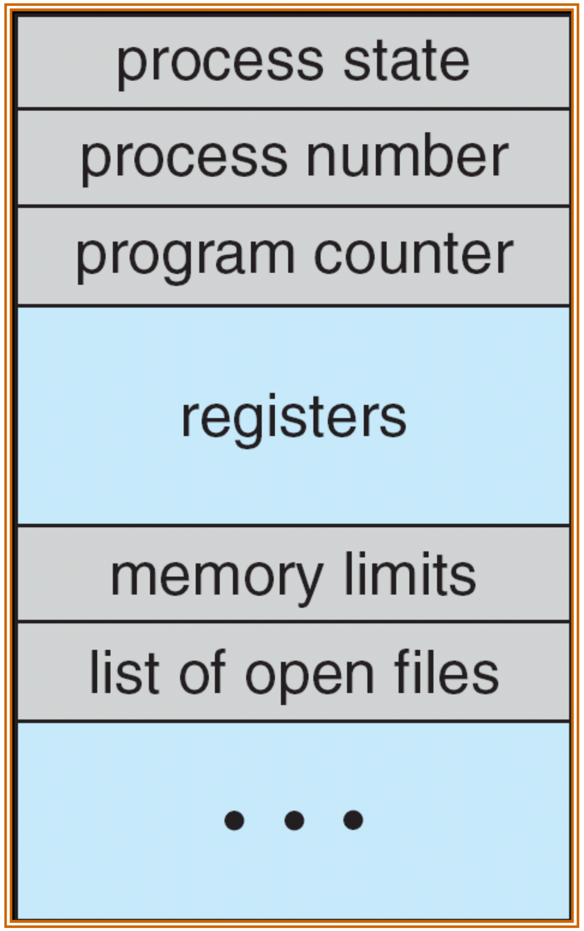
- When a running process involuntarily leaves the running state
- Running → ready: the running process runs out its time quota under time sharing.
  - Triggered by timer interrupts
- Running → ready, case 2: IO interrupts make a high-priority process ready and the running process is preempted by the high-priority process
  - Triggered by I/O interrupts

- Hardware interrupts can trigger which one(s) of the following transitions?
  1. Running → ready
  2. Running → waiting
  3. Waiting → ready

- What is the state transition of
  - Starting an synchronous I/O
  - Process resume
  - Process suspend?

Process Control Block (PCB)

- Information associated with each process
  - Process state
  - Saved CPU registers values
  - CPU scheduling info (e.g., priority)
  - Memory-management information (e.g., segment table and page-table base register)
  - I/O status info (e.g., opened files)
  - Etc

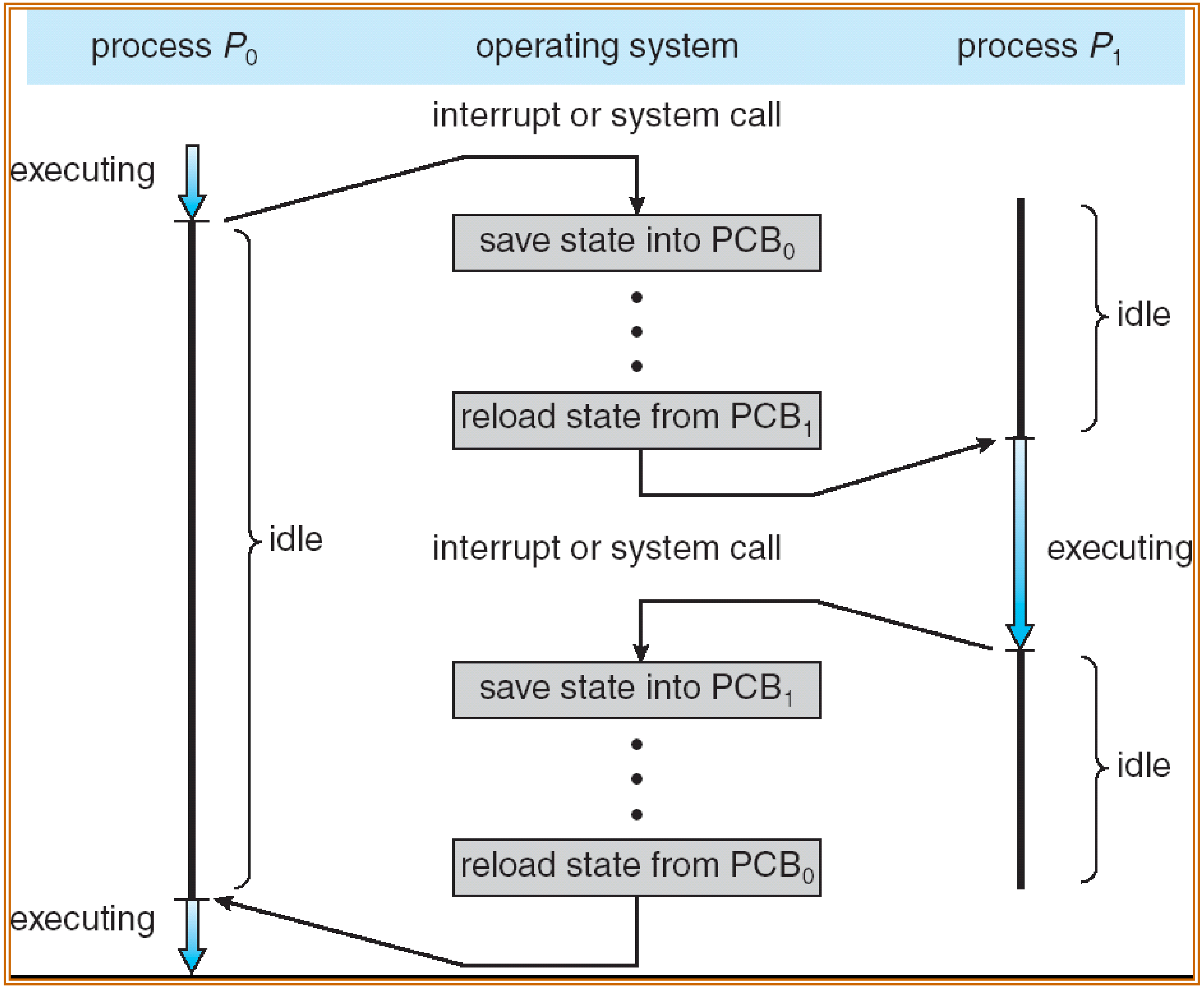


Context Switch

- When CPU switches to another process, the system must save the state of the old process and load the saved state for the new process
- Context-switch time is an overhead; the system does no useful work while switching
- Time dependent on hardware
  - Roughly 2000 ns/cxtsw on Intel 5150 (2.66 GHz)
  - And the subsequent costs of pipeline stall and cache pollution

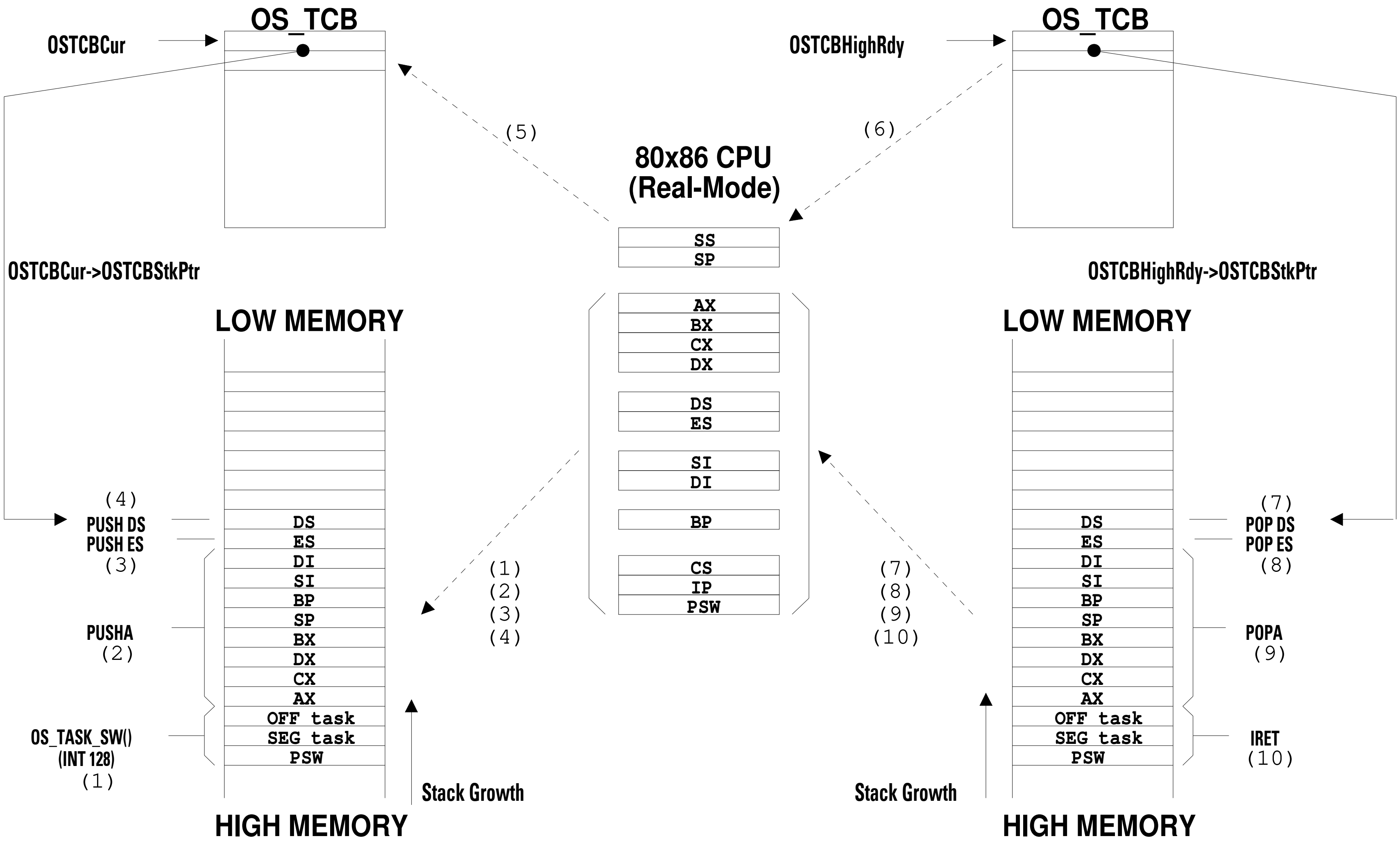
http://blog.tsunanet.net/2010/11/how-long-does-it-take-to-make-context.html

CPU Switch From Process to Process



Example: Context Switch in uC/OS-2

```
;*********************************************************************************************************
*
;                                  PERFORM A CONTEXT SWITCH (From task level)
;                                           void OSCtxSw(void)
;
; Note(s): 1) Upon entry,
;             OSTCBCur     points to the OS_TCB of the task to suspend
;             OSTCBHighRdy points to the OS_TCB of the task to resume
;
;          2) The stack frame of the task to suspend looks as follows:
;
;                 SP -> OFFSET  of task to suspend    (Low memory)
;                       SEGMENT of task to suspend
;                       PSW     of task to suspend    (High memory)
;
;          3) The stack frame of the task to resume looks as follows:
;
;                 OSTCBHighRdy->OSTCBStkPtr --> DS                               (Low memory)
;                                               ES
;                                               DI
;                                               SI
;                                               BP
;                                               SP
;                                               BX
;                                               DX
;                                               CX
;                                               AX
;                                               OFFSET  of task code address
;                                               SEGMENT of task code address
;                                               Flags to load in PSW             (High memory)
;*********************************************************************************************************
*
```



OS_TCB
OSTCBCur
OSTCBCur->OSTCBStkPtr
LOW MEMORY
(4)
PUSH DS
PUSH ES
(3)
PUSHA
(2)
OS_TASK_SW()
(INT 128)
(1)
DS
ES
DI
SI
BP
SP
BX
DX
CX
AX
OFF task
SEG task
PSW
Stack Growth
HIGH MEMORY
(5)
80x86 CPU
(Real-Mode)
SS
SP
AX
BX
CX
DX
DS
ES
SI
DI
BP
CS
IP
PSW
(1)
(2)
(3)
(4)
(6)
(7)
(8)
(9)
(10)
OS_TCB
OSTCBHighRdy
OSTCBHighRdy->OSTCBStkPtr
LOW MEMORY
(7)
POP DS
POP ES
(8)
POPA
(9)
IRET
(10)
DS
ES
DI
SI
BP
SP
BX
DX
CX
AX
OFF task
SEG task
PSW
Stack Growth
HIGH MEMORY

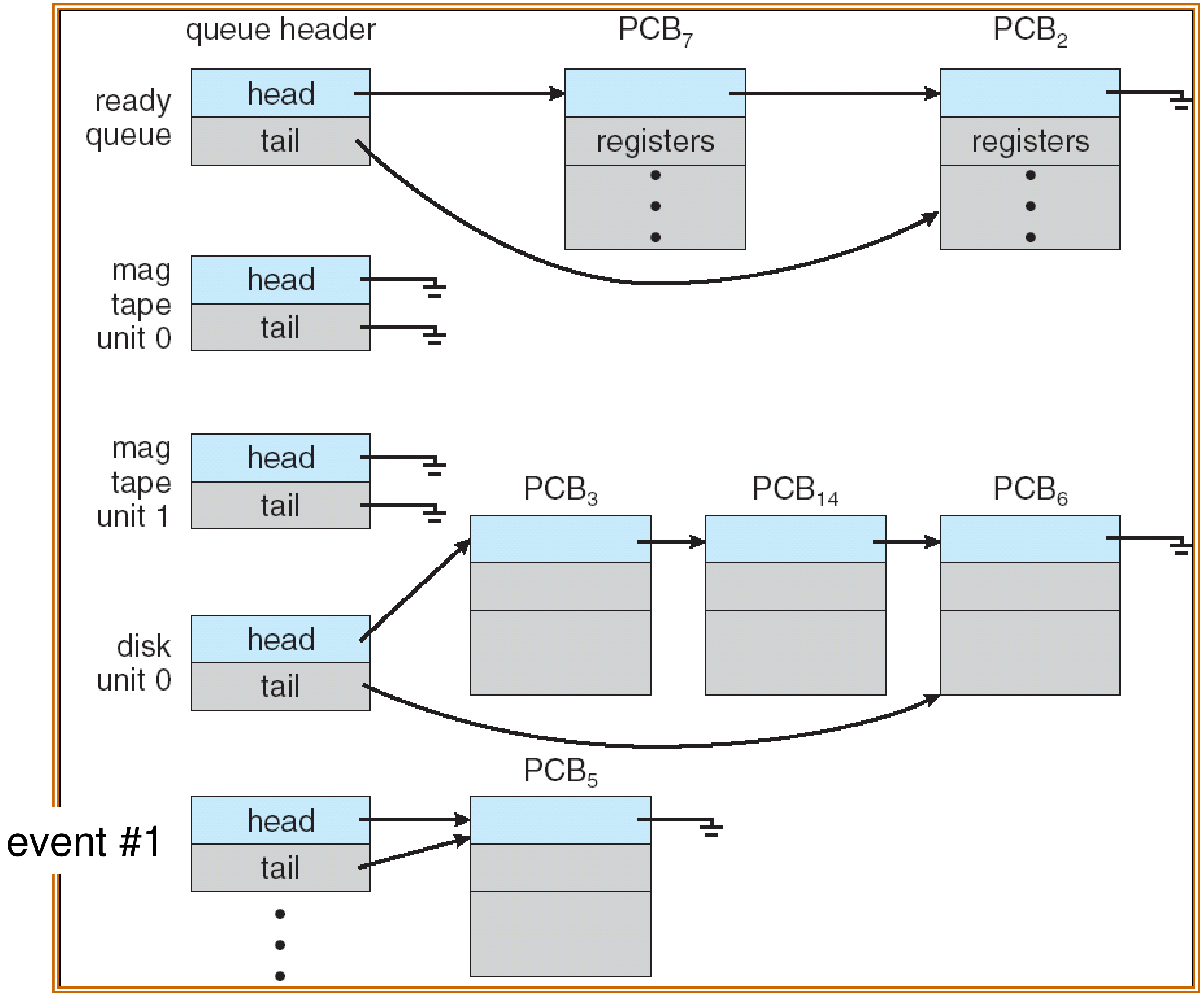
```
_OSCtxSw    PROC    FAR
;
            PUSHA                                   ; Save current task's context
            PUSH    ES                              ;
            PUSH    DS                              ;
;
            MOV     AX, SEG _OSTCBCur               ; Reload DS in case it was altered
            MOV     DS, AX                          ;
;
            LES     BX, DWORD PTR DS:_OSTCBCur      ; OSTCBCur->OSTCBStkPtr = SS:SP
            MOV     ES:[BX+2], SS                   ;
            MOV     ES:[BX+0], SP                   ;
;
            CALL    FAR PTR _OSTaskSwHook           ; Call user defined task switch hook
;
            MOV     AX, WORD PTR DS:_OSTCBHighRdy+2 ; OSTCBCur = OSTCBHighRdy
            MOV     DX, WORD PTR DS:_OSTCBHighRdy   ;
            MOV     WORD PTR DS:_OSTCBCur+2, AX     ;
            MOV     WORD PTR DS:_OSTCBCur, DX       ;
;
            MOV     AL, BYTE PTR DS:_OSPrioHighRdy  ; OSPrioCur = OSPrioHighRdy
            MOV     BYTE PTR DS:_OSPrioCur, AL      ;
;
            LES     BX, DWORD PTR DS:_OSTCBHighRdy  ; SS:SP = OSTCBHighRdy->OSTCBStkPtr
            MOV     SS, ES:[BX+2]                   ;
            MOV     SP, ES:[BX]                     ;
;
            POP     DS                              ; Load new task's context
            POP     ES                              ;
            POPA                                    ;
;
            IRET                                    ; Return to new task
;
_OSCtxSw    ENDP
```

PROCESS SCHEDULING

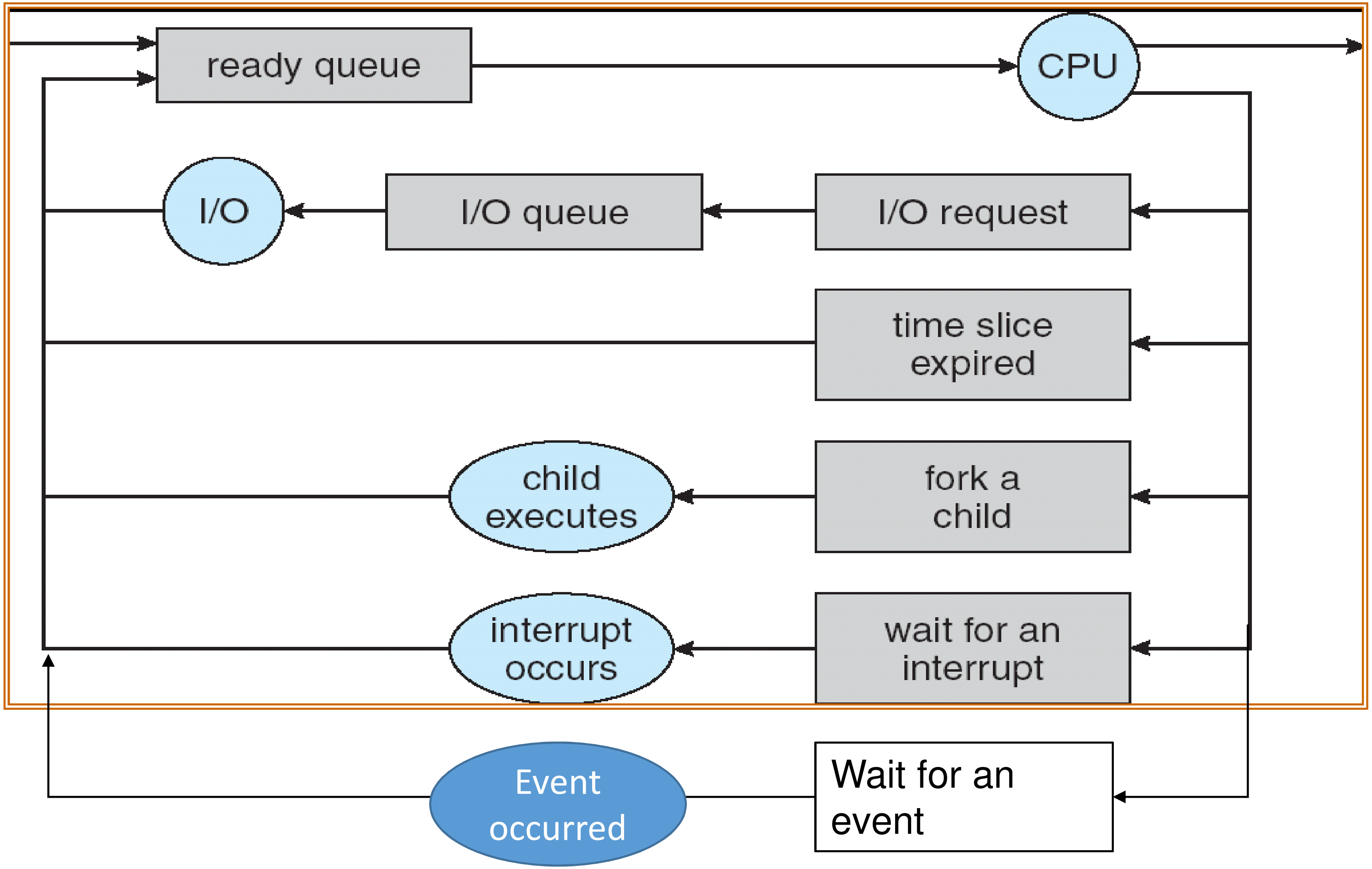
Process Scheduling Queues

- Ready queue – set of all processes residing in main memory, ready for execution
- Device queues – set of processes waiting for an I/O device
- Event queues – set of processes waiting for an event (e.g., semaphore)
- Processes migrate among the various queues

Various Process Queues



Representation of Process Scheduling



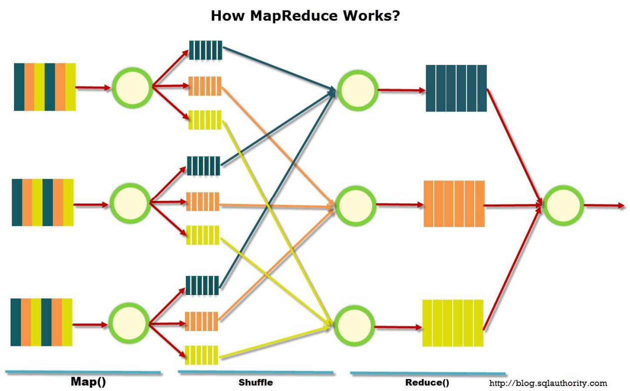
Schedulers

- Long-term scheduler (or job scheduler) – selects which processes should be brought into the ready queue
- Short-term scheduler (or CPU scheduler) – selects which process should be executed next and allocates CPU

Schedulers (Cont.)

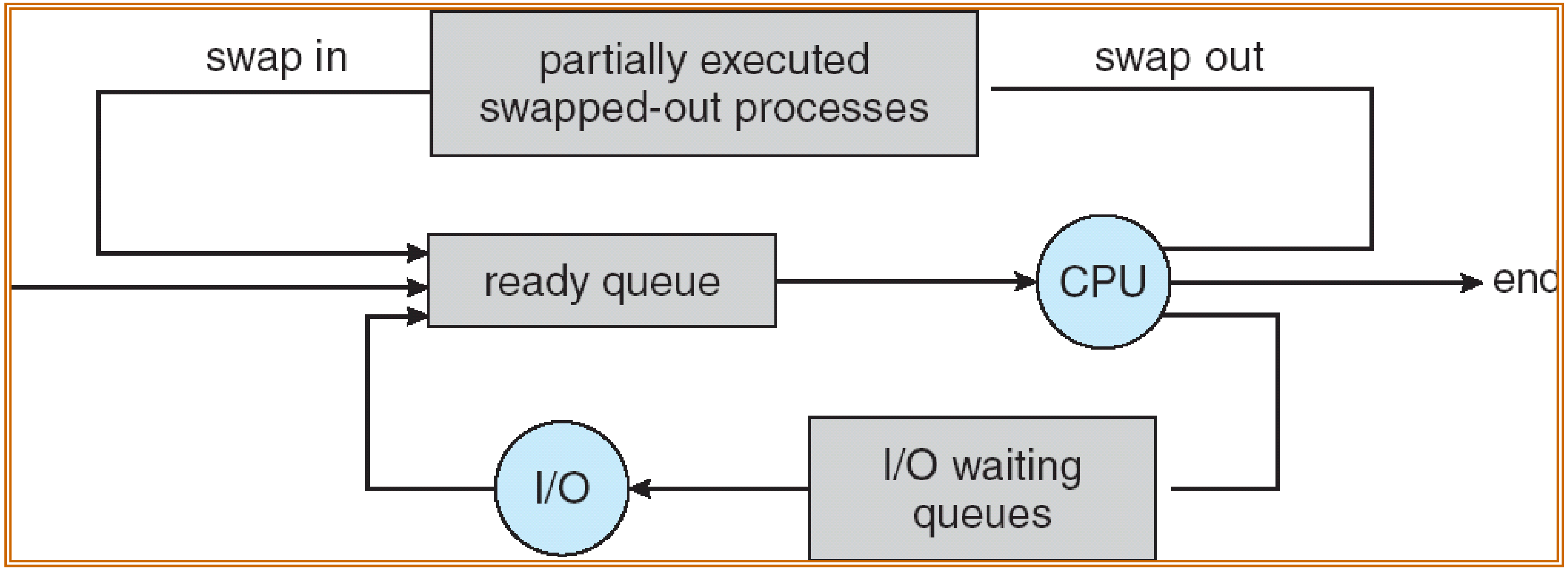
- Short-term scheduler is invoked very frequently (milliseconds) $\Rightarrow$ (must be fast)
- Long-term scheduler is invoked very infrequently (seconds, minutes) $\Rightarrow$ (may be slow)
- The long-term scheduler controls the degree of multiprogramming
- Processes can be described as either:
  - I/O-bound process – spends more time doing I/O than computations, many short CPU bursts
  - CPU-bound process – spends more time doing computations; few very long CPU bursts

Long-Term Scheduler



- In batch-processing systems, the long-term scheduler is to make a good mix of I/O bound processes and CPU-bound processes
  - Modern batch processing example: MapReduce
- Timesharing systems do not have long-term schedulers
  - The degree of multiprogramming is limited by physical limitation (e.g., RAM space)
  - The user will give up if the system cannot launch any more processes

Addition of Medium Term Scheduling



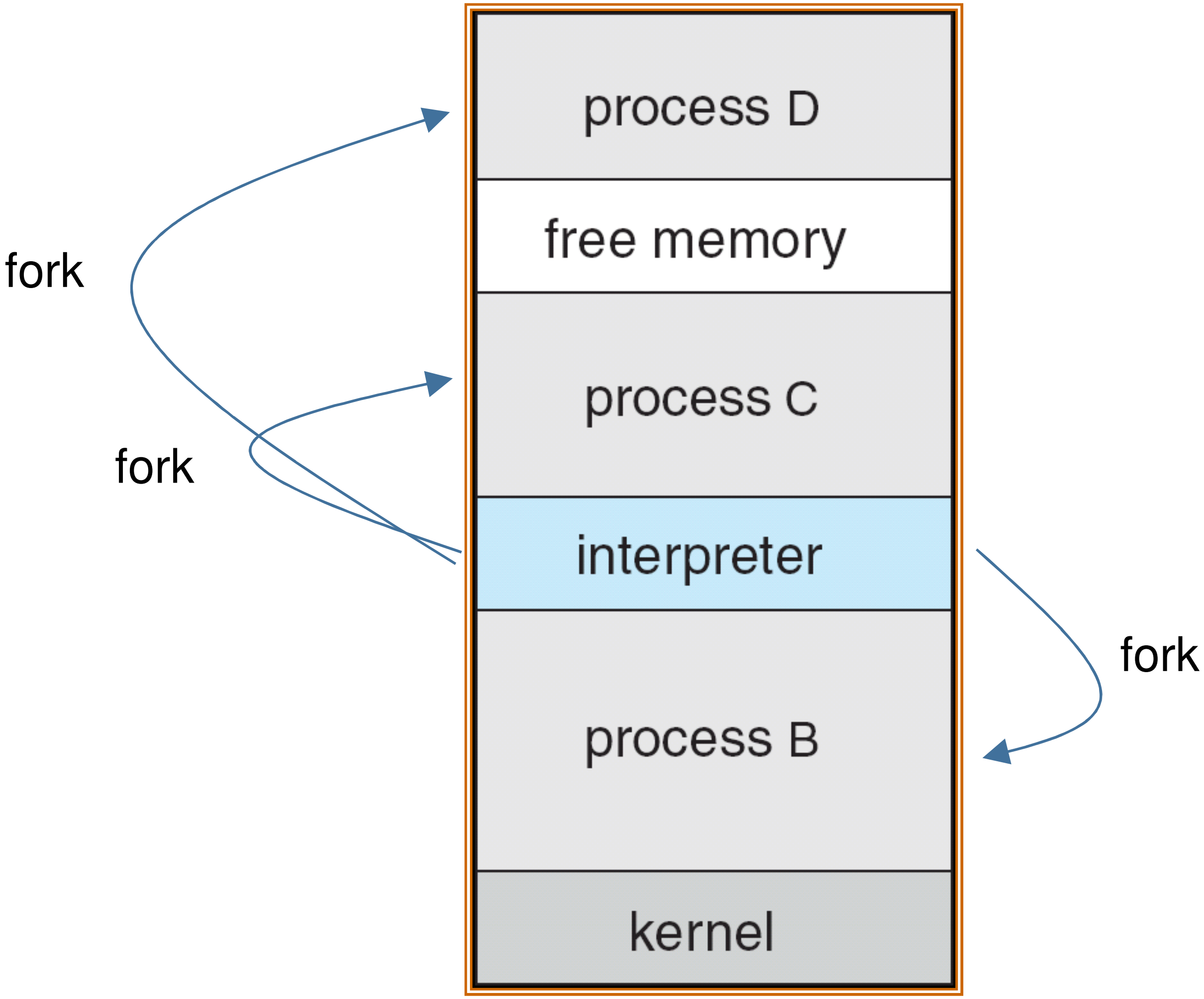
Swapping out: "saving" the memory image of a process (to a disk) to give memory space to new processes

Checklist

- Long term scheduler
- Short term scheduler
- Mid term scheduler
- I/O-bound and CPU-bound processes

OPERATIONS ON PROCESSES (CREATION & TERMINATION)

Physical Memory Layout of a Multiprogramming System (No Paging)



Process Creation

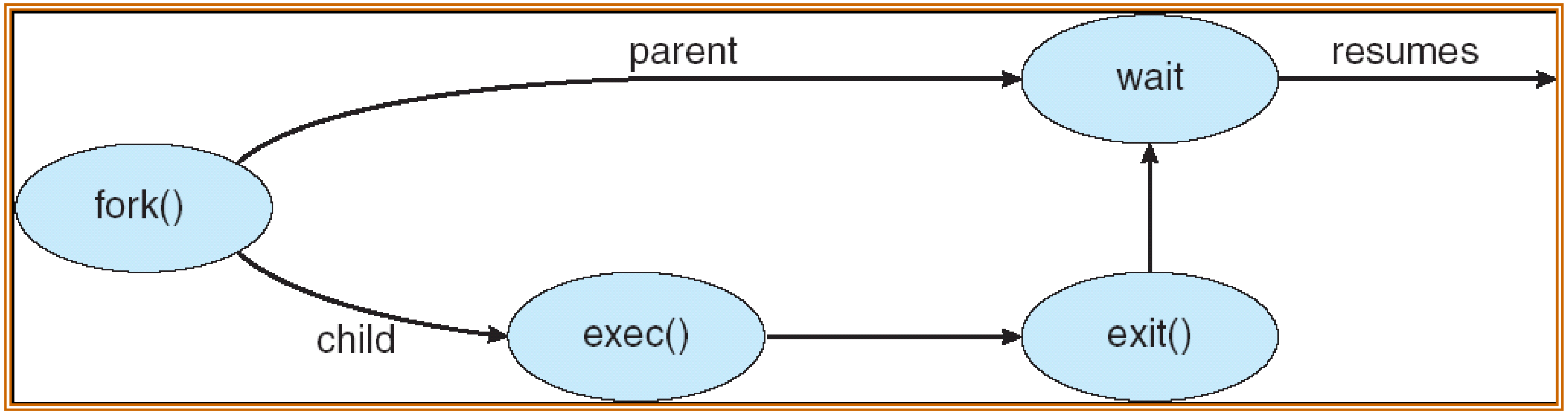
- Parent process create children processes, which, in turn create other processes, forming a tree of processes
- Resource sharing
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution
  - Parent and children execute concurrently
  - Parent waits until children terminate

Process Creation (Cont.)

- Address space
  - Child duplicate of parent
  - Child has a program loaded into it
- UNIX examples
  - fork system call creates new process (clone the calling process)
  - exec system call used after a fork to replace the process' memory space with a new program

- Right after fork():
  - The child is an exact copy of the parent

Process Creation



C Program Forking Separate Process (in UNIX)

Parent and child see different return values!!!

```
int main()
{
    pid_t  pid;
    /* fork another process */
    pid = fork();
    if (pid < 0) { /* error occurred */
              fprintf(stderr, "Fork Failed");
              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");
              exit(0);
    }
}
```

The child won't return here after exec()

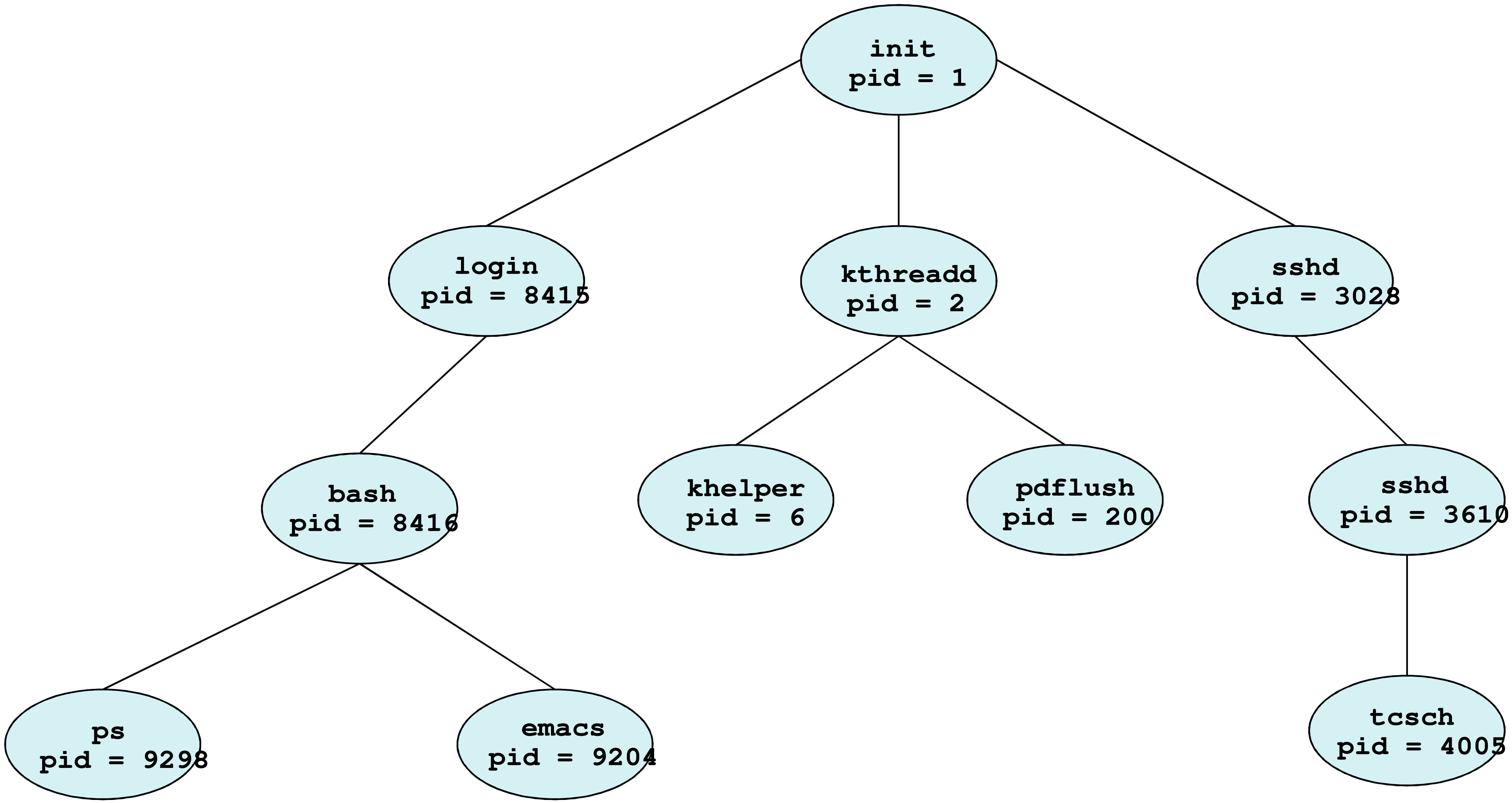
The parent has child's pid so it can kill the child (if necessary)

Address Spaces of Parent and Child Processes

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int x=0;

int main()
{
        pid_t  pid;
        /* fork another process */
        pid = fork();
        if (pid < 0) { /* error occurred */
                fprintf(stderr, "Fork Failed");
                exit(-1);
        }
        else if (pid == 0) { /* child process */
                x++;
                exit(0);
        }
        else { /* parent process */
                /* parent will wait for the child to complete */
                wait (NULL);
                printf ("%d",x);
                exit(0);
        }
}
```

What is the output of this program?

A Tree of Processes in Linux



Process Termination

- Process executes last statement and asks the operating system to delete it (exit)
  - Output data from child to parent (via wait())
  - Synchronous termination
- Parent may terminate execution of its children
  - Sending a signal (SIGKILL) to a child
  - Asynchronous termination

Orphan Processes and Zombie Processes

- A zombie (defunct) process
  - A process that has terminated (all resources released) but its return value has not been retrieved by its parent yet
  - It will not be deleted from the process table (!)
- An orphan process
  - A process whose parent process has terminated
  - Linux: an orphan will be adopted by process 0 (init)
  - Process 0 (init) will wait (/retrieve the return value) of an orphan
- Zombie implies orphan? Orphan implies zombie?

A Zombie Child Process

```
#include <stdio.h>
#include <sys/types.h>

main(){

        if(fork()==0){
                // child process
                printf("child pid=%d\n", getpid());
                exit(0)
        }

        // parent process
        sleep(20);   // let the child print the message
        printf("parent pid=%d \n", getpid());
        exit(0);
}
```

After the child terminates, it becomes a zombie until being adopted and read by init.

fork() then exec()

- fork() requires to make a copy of the current process, but the following exec() replaces the address space
- The copying is efficiently implemented through memory mapping, with the assistance of MMU
- Use vfork() instead of fork() if the CPU is not equipped with an MMU

vfork(): parent and child share most resources

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int x=0;

int main()
{
        pid_t  pid;
        /* fork another process */
        pid = vfork();
        if (pid < 0) { /* error occurred */
                fprintf(stderr, "Fork Failed");
                exit(-1);
        }
        else if (pid == 0) { /* child process */
                x++;     // often, here calls exec()
                _exit(0);
        }
        else { /* parent process */
                /* parent will wait for the child to complete */
                wait (NULL);
                printf ("%d",x);
                exit(0);
        }
}
```

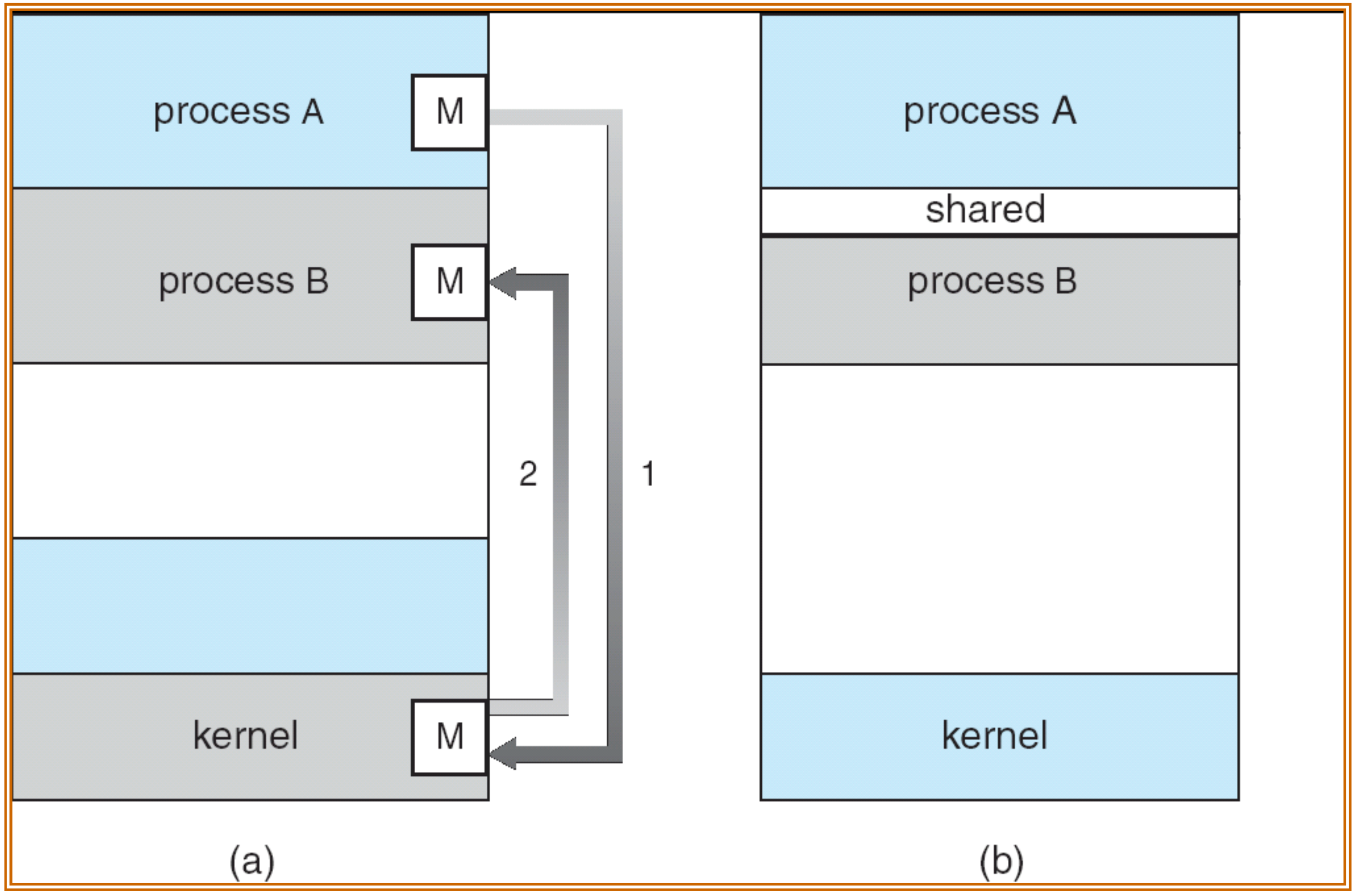
What is the output of this program?

INTER-PROCESS COMMUNICATION

Cooperating Processes

- Advantages of process cooperation
  - Information sharing
  - Computation speed-up
  - Modularity
  - Convenience
  - UX improvement

Communications Models



Message passing **Shared memory**

IPC- SHARED MEMORY

Shared Memory

- Linux offers the following system calls for shared memory management
  - shmget() – create a block of shared memory
  - shmat() – attach shared memory to the current process’s address space
  - shmdt() – detach shared memory from the current process’s address space
  - shmctl() – control shared memory (including delete)
- Let assume that a piece of shared memory has been setup between two processes

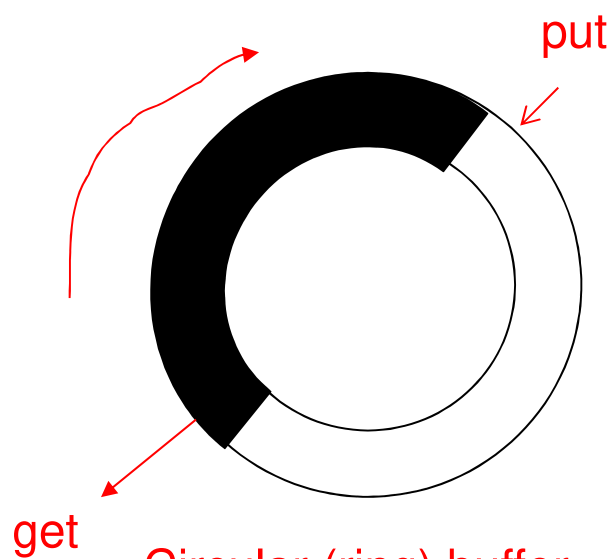
Producer-Consumer Problem

- Paradigm for cooperating processes, a producer process produces information that is consumed by a consumer process
  - The two processes run concurrently
- Objective:
  - to synchronize a producer and a consumer via shared memory
- Issues:
  - The buffer size is limited – no overwriting and null reading

Bounded-Buffer – Shared-Memory Solution

- Shared data

```
#define BUFFER_SIZE 10
typedef struct {
        . . .
} item;

item buffer[BUFFER_SIZE];
int in = 0;
int out = 0;
```



Circular (ring) buffer

- Solution is correct, but can only use BUFFER_SIZE-1 elements
- What are the conditions for buffer full and buffer empty?

Bounded-Buffer – Insert() Method

```
while (true) {

      /* Produce an item */
      while (( (in + 1) % BUFFER SIZE count)  == out)
           ;   /* do nothing -- no free buffers */

      buffer[in] = item;
      in = (in + 1) % BUFFER SIZE;
}
```

Bounded Buffer – Remove() Method

```
while (true) {

     while (in == out)
        ; // do nothing -- nothing to consume

     // remove an item from the buffer
     item = buffer[out];
     out = (out + 1) % BUFFER SIZE;
     return item;
}
```

Bounded Buffer Problem

- Data corruption?
- Performance issue?
- Why not to use a free-slot counter?

IPC- MESSAGE PASSING

Interprocess Communication (IPC)

- Mechanism for processes to communicate and to synchronize their actions
- Message system – processes communicate with each other without resorting to shared variables
- IPC facility provides two operations:
  - send(message) – message size fixed or variable
  - receive(message)
- If P and Q wish to communicate, they need to:
  - establish a communication link between them
  - exchange messages via send/receive
- Implementation of communication link
  - physical (e.g., shared memory, hardware bus)
  - logical (e.g., logical properties)

Interprocess Communication (IPC)

- Messages can be buffered in the link
  - P→[link <buffer>]→Q

- P will be *blocked* on sending if the link buffer is full
- Q will be *blocked* on receiving if the link buffer is empty

Example: Linux Pipe

- A basic mechanism for IPC
  - Widely used, e.g., “ls | more”
  - A process “ls”, a process “more”, and a pipe between them
- The system call pipe() creates a pipe
  - Receiver must close the output side, and receives from the input side
  - Sender must close the input side, and write to the output side
  - A pipe is created and configured by the parent process

```c
#include <stdio.h>
#include <unistd.h>
#include <sys/types.h>

int main(void)
{
        int     fd[2], nbytes;
        pid_t   childpid;
        char    string[] = "Hello, world!\n";
        char    readbuffer[80];

        pipe(fd);      // create the pipe before calling fork()

        if((childpid = fork()) == -1)
        {
                perror("fork");
                exit(1);
        }
```

```
        if(childpid == 0)
        {
                /* Child process closes up input side of pipe */
                close(fd[0]);

                /* Send "string" through the output side of pipe */
                write(fd[1], string, (strlen(string)+1));
                exit(0);
        }
        else
        {
                /* Parent process closes up output side of pipe */
                close(fd[1]);

                /* Read in a string from the pipe */
                nbytes = read(fd[0], readbuffer, sizeof(readbuffer));
                printf("Received string: %s", readbuffer);
        }

        return(0);
}
```

UNIX Signals

- Signals are used in UNIX systems to notify a process that a particular event has occurred
- A signal handler is used to process signals
  - Signal is generated by particular event
  - Signal is delivered to a process
  - Signal is handled
- Analogy
  - Interrupts for CPU (async or sync)
  - Signals for processes (async or sync)
  - Many signals, but not all, have a counterpart in terms of interrupts

Signal Handling

- Synchronous signals
  - A signal that is delivered to the process caused the event
  - E.g., divide overflow and memory-access violations
- Asynchronous signals
  - A signal that is delivered to a process other than the signaling process
  - E.g., the kill signal
- Signal handlers
  - Default handlers
  - User-defined handlers (using signal() or sigaction())

UNIX Signal Example

- Synchronous signals
  - SIGSEGV : Memory protection fault
  - SIGFPE : Arithmetic fault, including divided by zero
- Asynchronous signals
  - SIGKILL : Kill a process
  - SIGSTOP : Suspend a process
  - SIGCHLD: ???

Handling SIGSEGV on your own

```
#include <stdio.h>
#include <stdlib.h>
#include <signal.h>

void sigsegv_handler(int sig) {
        printf("Received segmentation violation (SIGSEGV). \n");
        exit(0);
}

int main() {
        int *null_pointer=(int *)NULL;
        signal(SIGSEGV,sigsegv_handler);

        printf("About to segfault:\n");
        *null_pointer=0;

        printf(“Shouldn’t be here!\n");
        return 1;
}
```

Handling SIGSEGV on your own

```
void action(int sig, siginfo_t* siginfo, void* context)
{
    sig=sig; siginfo=siginfo;

    // get execution context
    mcontext_t* mcontext = &((ucontext_t*)context)->uc_mcontext;

    uint8_t* code = (uint8_t*)mcontext->gregs[REG_EIP];
    if (code[0] == 0x88 && code[1] == 0x10) { // mov %dl,(%eax)
        mcontext->gregs[REG_EIP] += 2; // skip it!
        return;
    }
}
main()
{
    ...
    sigaction(SIGSEGV, ...);
    ...
    for (int i = 0; i < 10; i++) { ((unsigned char*)0)[i] = i; }
}
```


http://stackoverflow.com/questions/6981702/how-to-write-a-segmentation-fault-handler-so-that-the-faulty-instruction-is-not

End of Chapter 3