Process (contd.)

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So far on processes

- What is a process?
- Structure of a process in memory
- Process control block (PCB)
- Process states
- Context switch

Process queues (for scheduling)

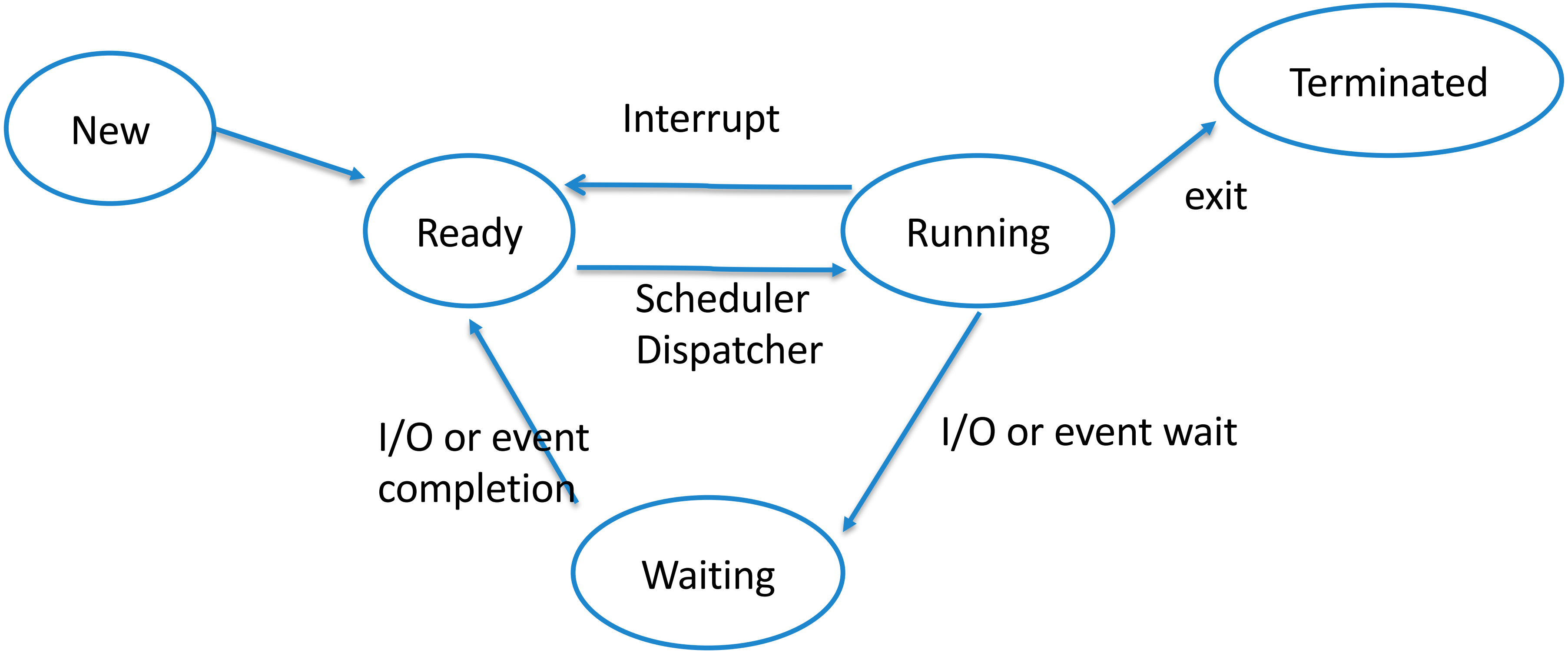
Process queues for scheduling

- Several scheduling queues exist in OS
  - A PCB is linked to one of the queues at any given tome
  - The PCBs in a queue are connected as a linked list

Characteristics of process queues

- Each I/O device has its own device queue
  - Contains (PCBs of) processes waiting for this device
- Each event also has its own queue
  - Contains processes waiting for this event
- Process scheduling can be represented as a queueing diagram
  - Queueing diagram represents queues, resources, flows
  - We will discuss actual scheduling algorithms later

Recap: Process state diagram



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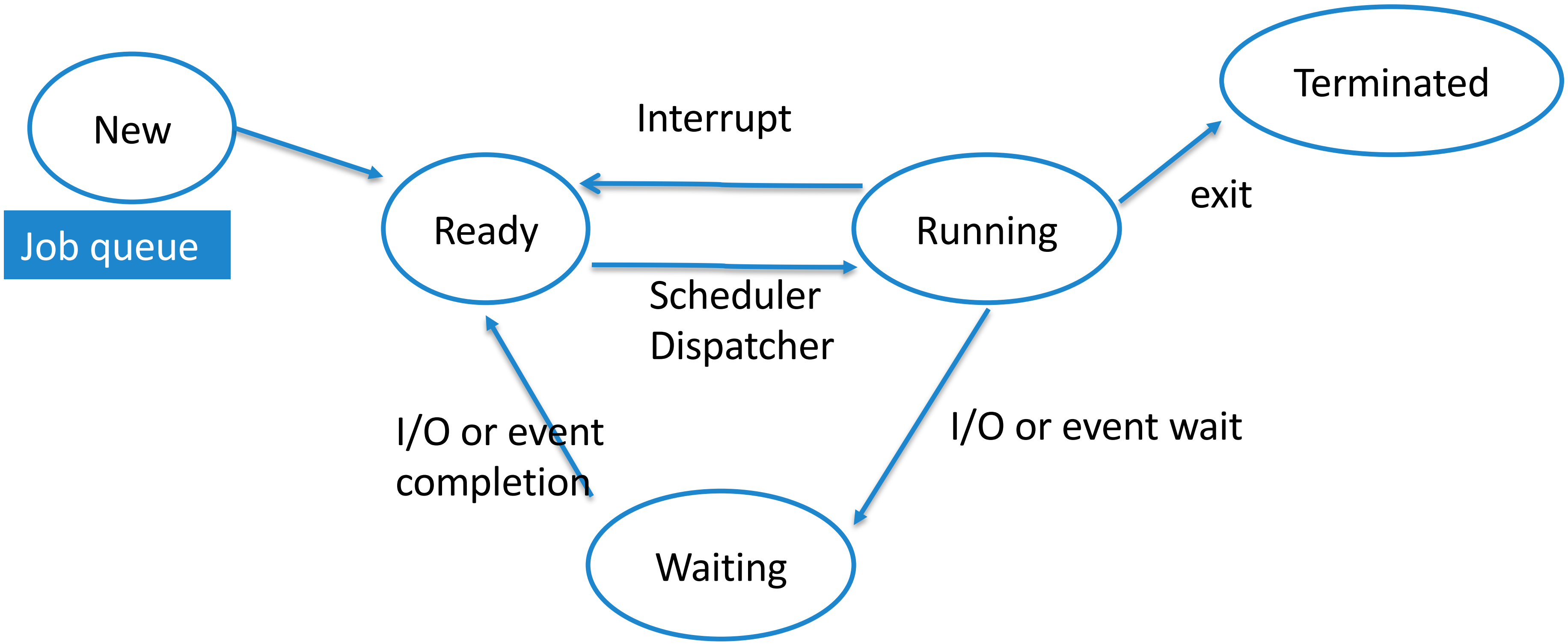

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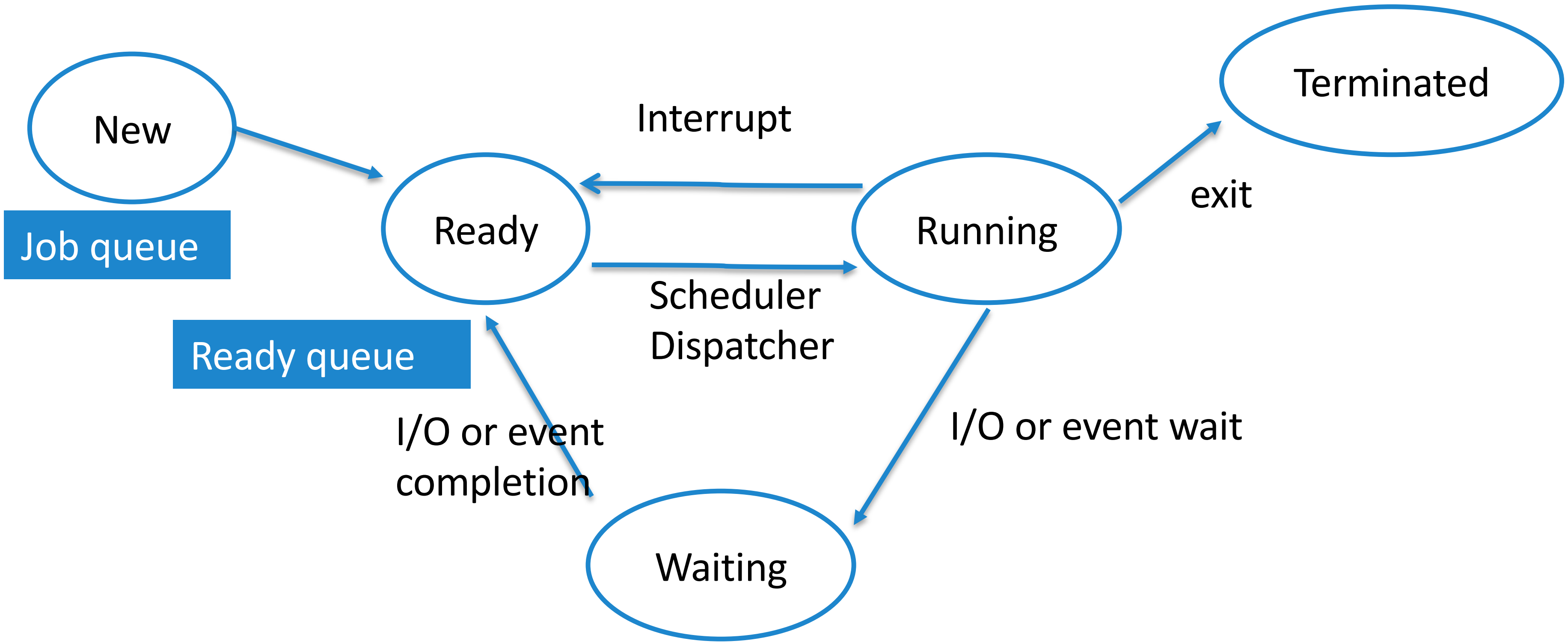
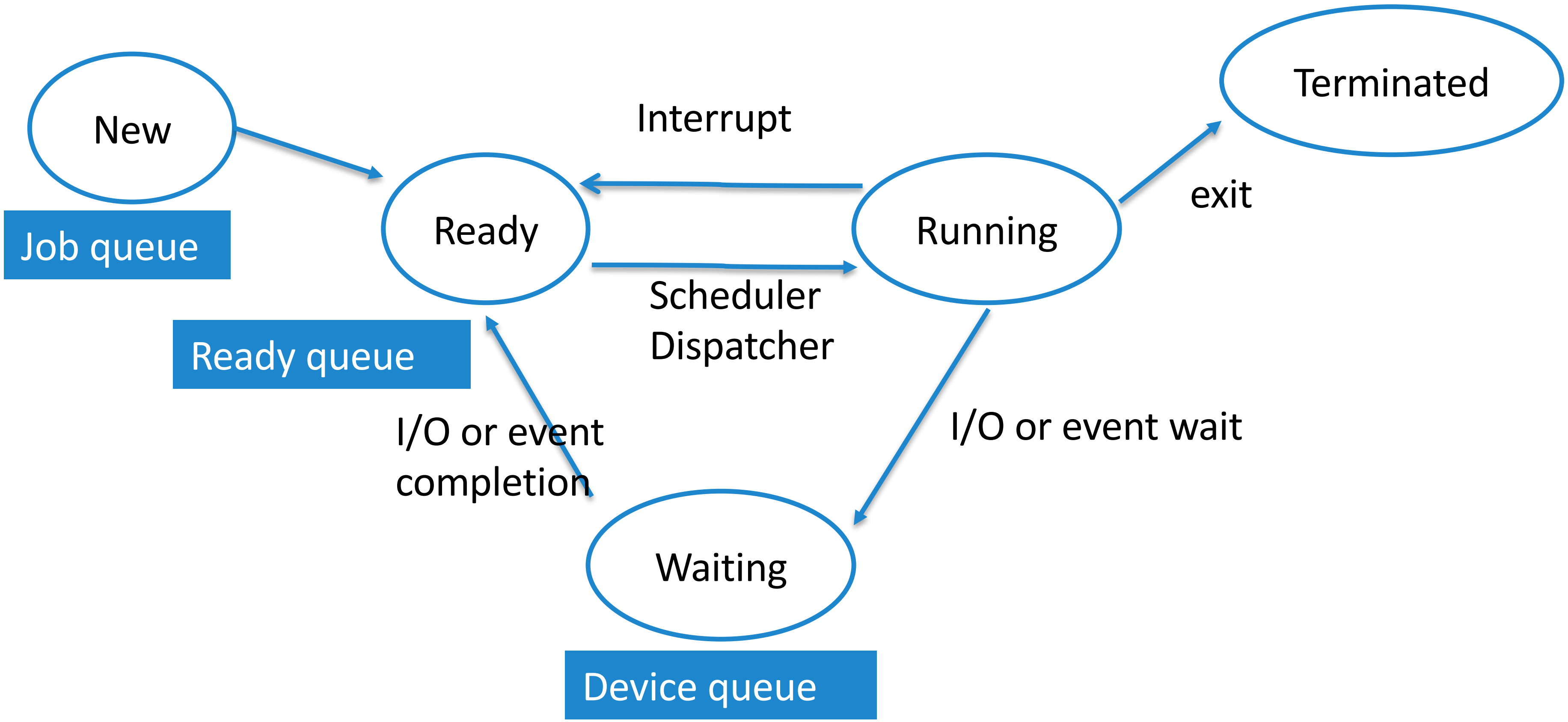


- The process scheduler selects a process from the ready queue for execution on the CPU
- Dispatcher: The kernel process that assigns the CPU to a process selected by the scheduler

Recap: Process state diagram

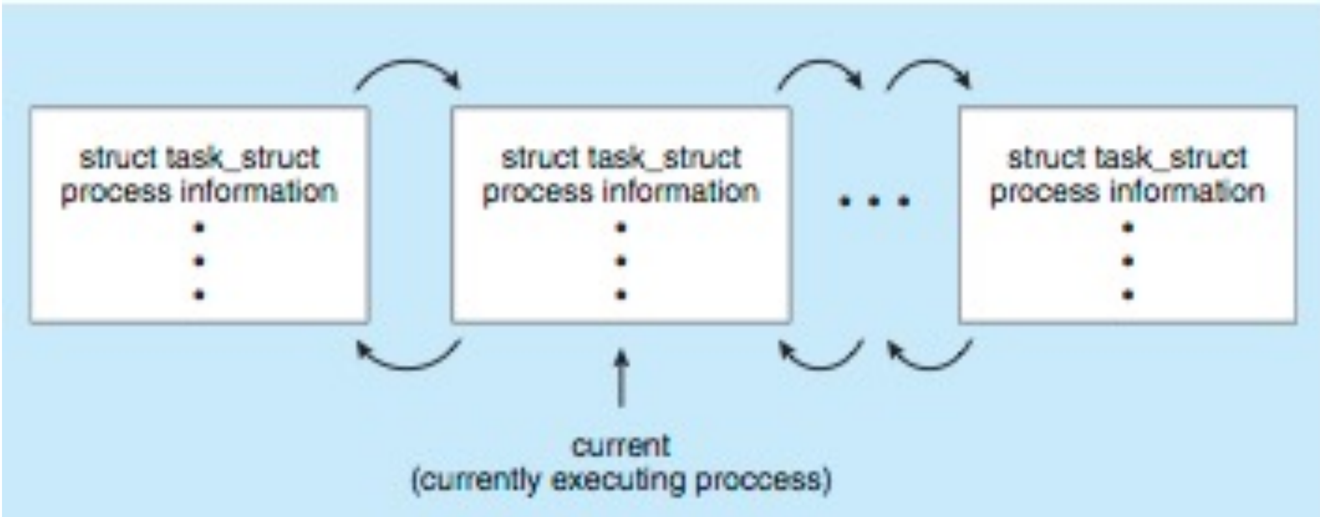


Process queue representation in Linux

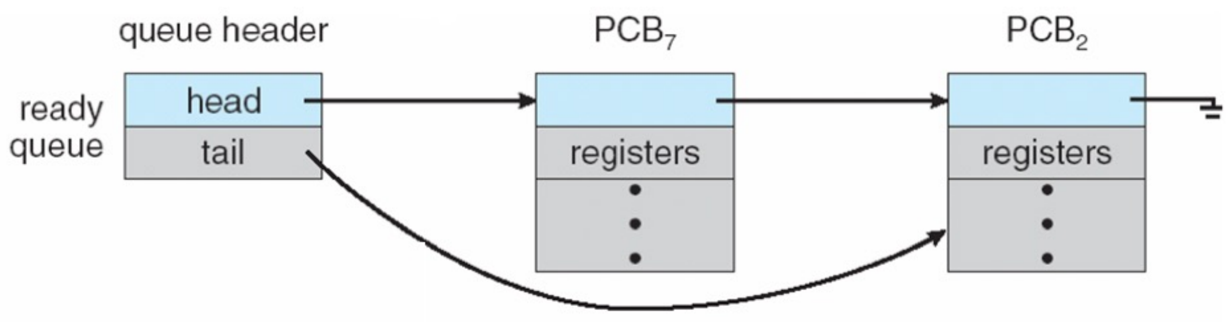
Represented by the C structure task_struct

```
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 task_struct *children; // this process's children
struct files_struct *files; // list of open files
struct mm_struct *mm; // address space of this pro
```

Doubly linked list



Structure of process queues



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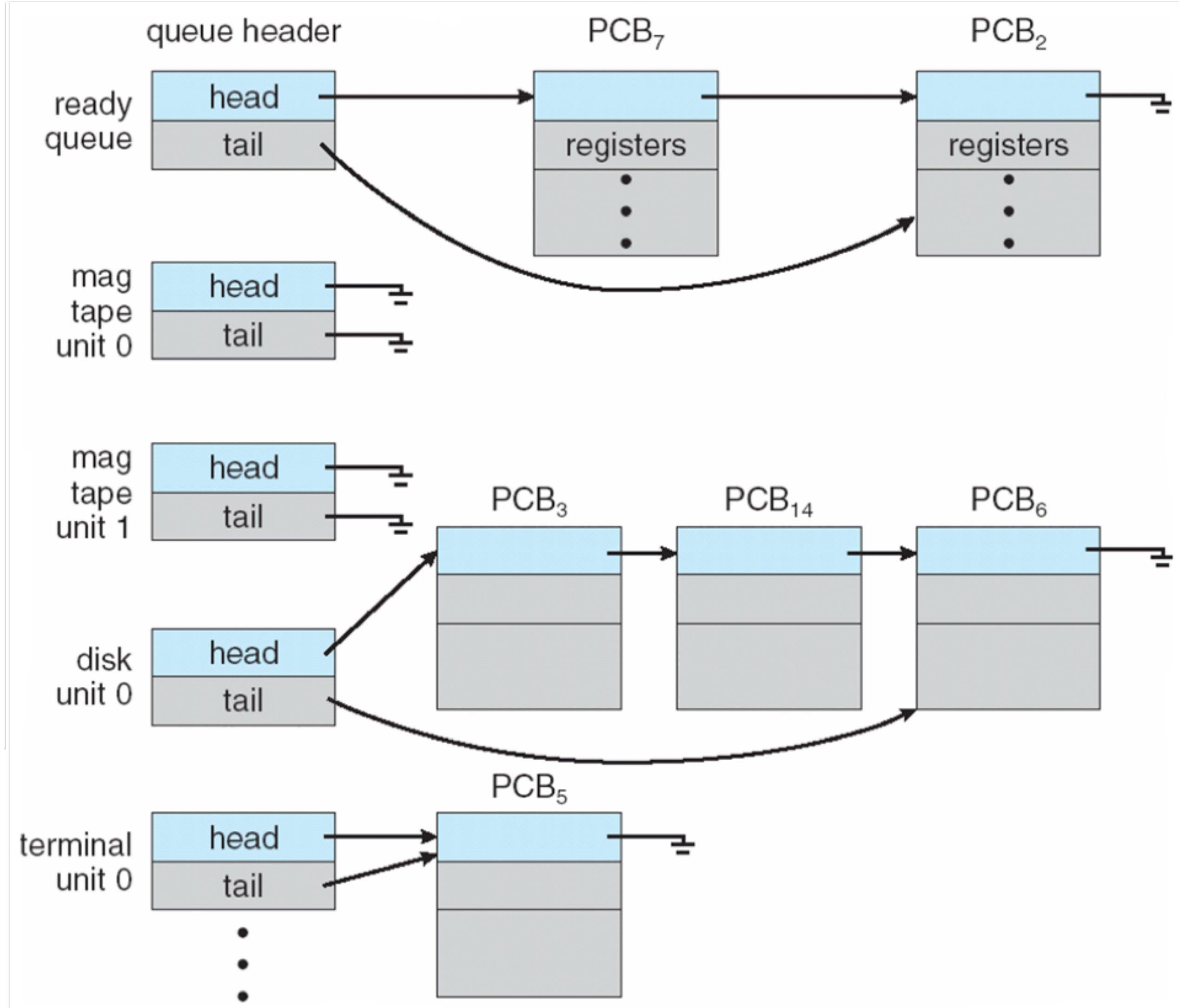
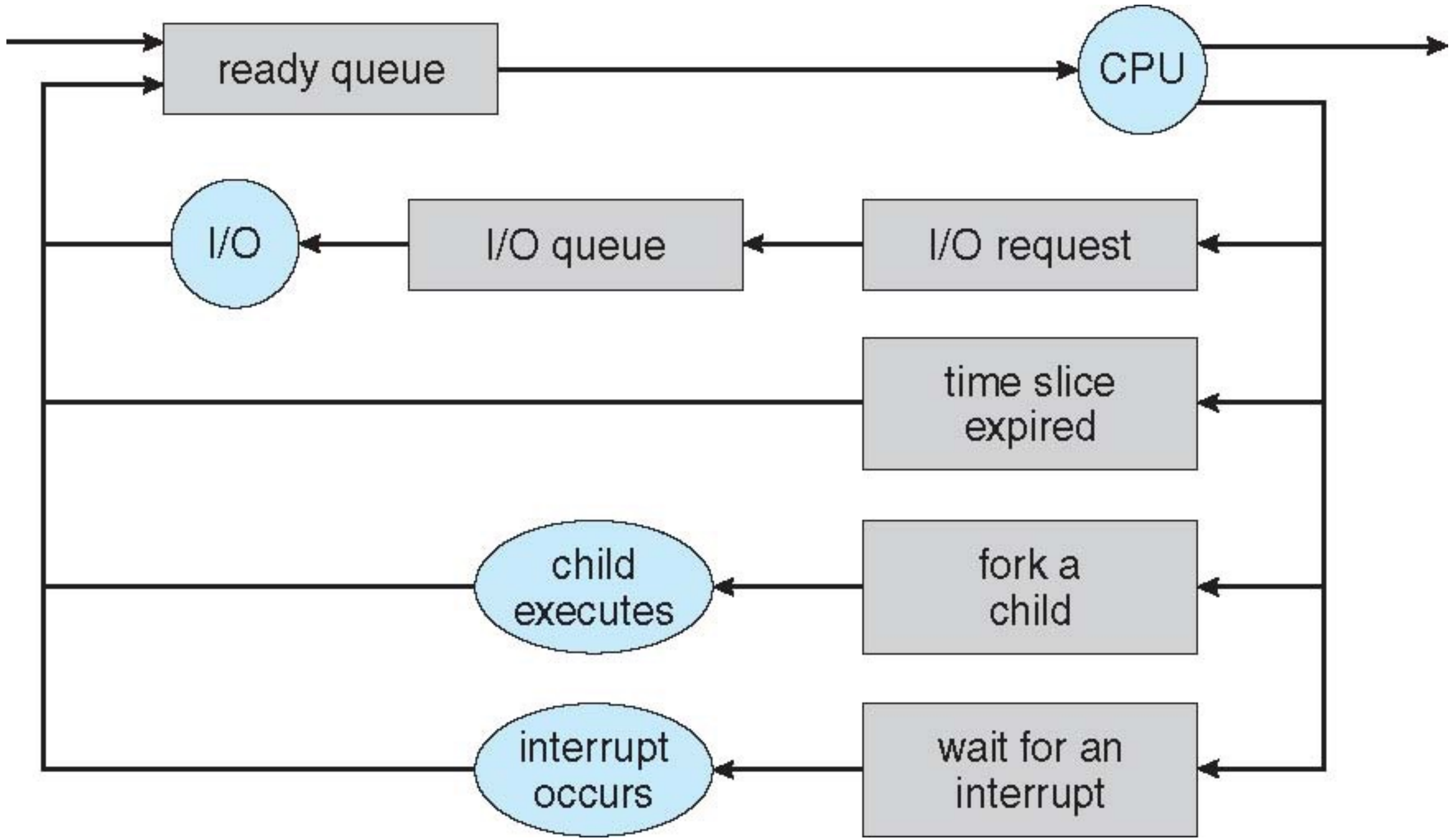


Representation of process scheduling



Operations on processes

Process creation

- During execution a process may create several new processes
  - The process that creates a new process: parent process
  - The new process created: child process
  - Parent process create children processes, which, in turn, can create other processes, forming a tree of processes
  - Each process has a unique process identifier (pid)
  - Other than the first process (init), all other processes are created by fork( ) system call

Process creation (contd.)

- Address space
  - Initially child is duplicate of parent
  - Child can later have a different program loaded into it
- In UNIX / Linux
  - fork() : creates a new process
  - exec(): replace new process's memory with new code

fork( ) system call

- If **fork()** returns a negative value, the creation of a child process was unsuccessful.

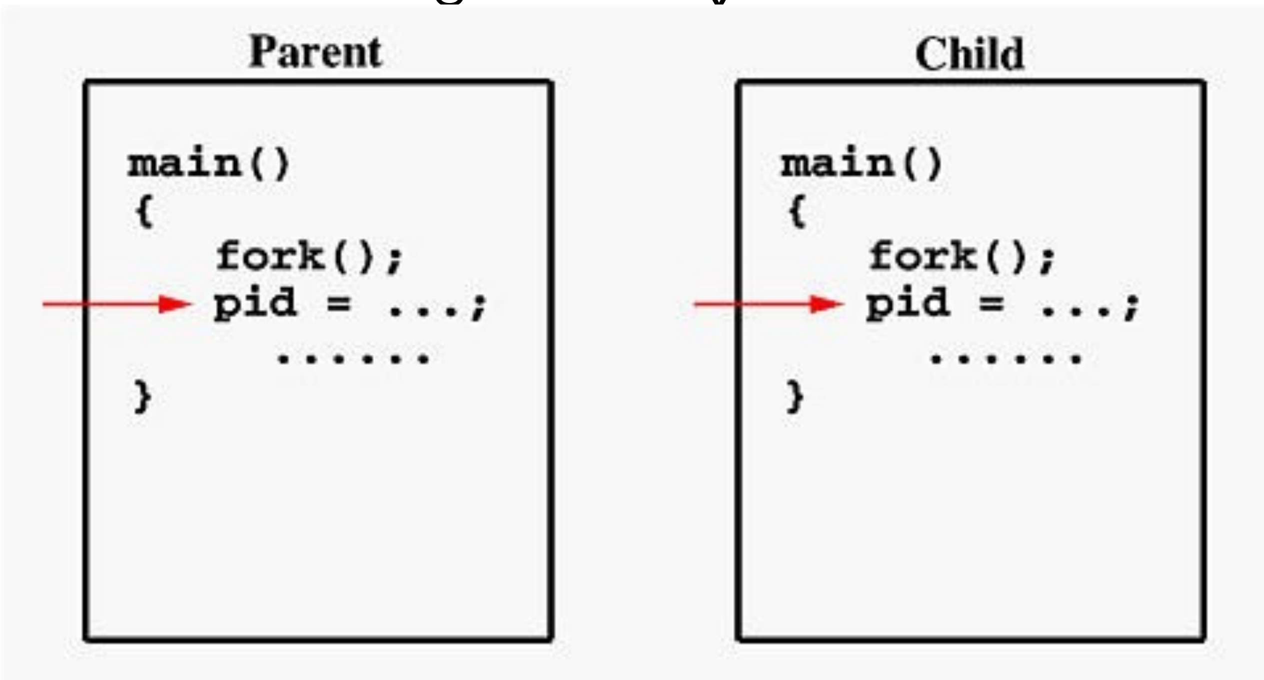
- **fork()** returns a zero to the newly created child process.

- **fork()** returns a positive value, the *process ID* of the child process, to the parent.

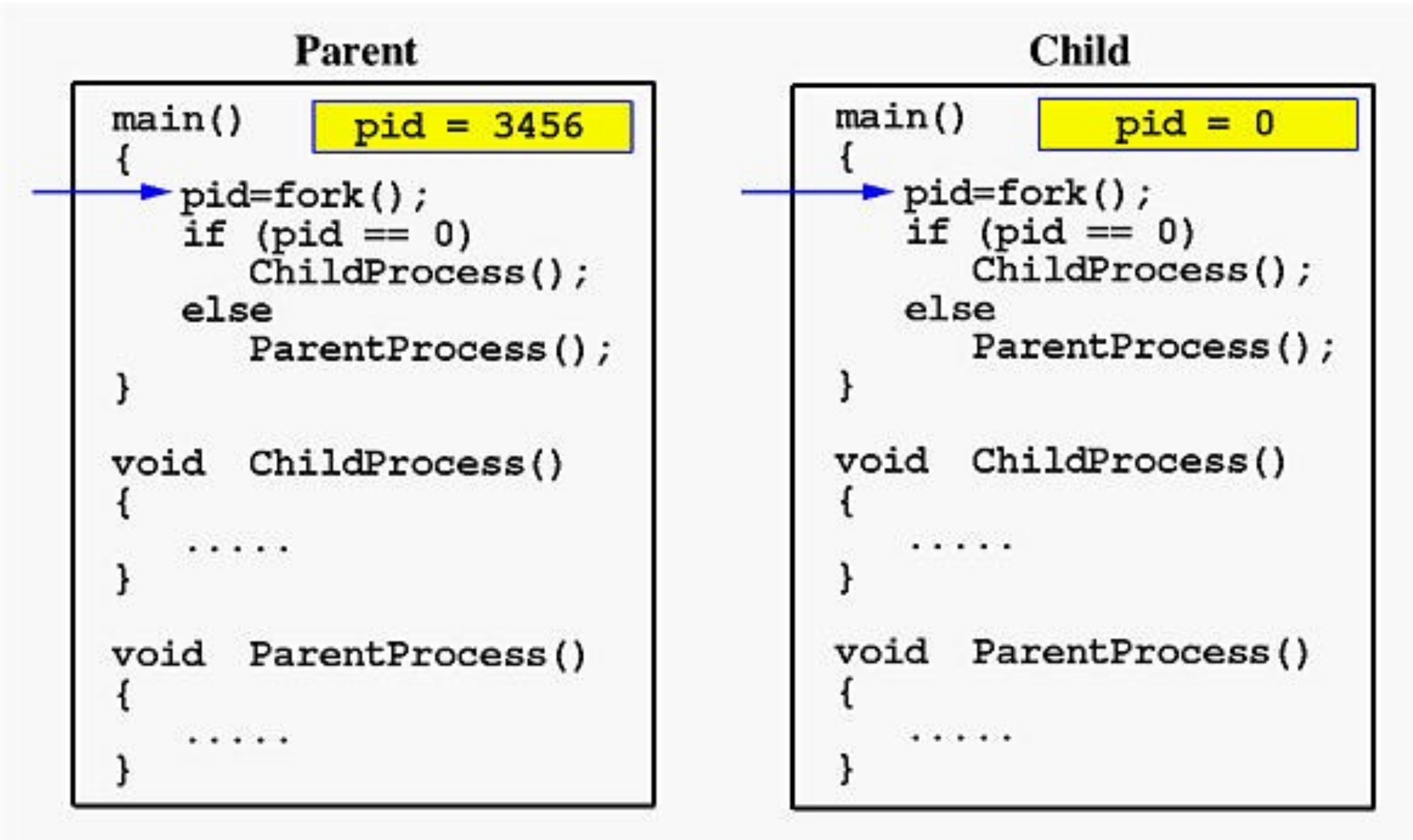
fork( ) system call

- If the call to **fork()** is executed successfully, the kernel will make an identical copy of the parent's address space, for use by the child.

- Both processes will start their execution at the next statement following the **fork()** call.



Make a child do something different than the parent – method 1



Make a child do something different than the parent – method 2

- exec( ) system call and its variants
  - Replaces the calling process (that calls exec) with another program
  - Calling process terminated; the specified program is loaded in the same address space and then executed
  - New process image has same process ID (pid), same file descriptors, etc
  - Several variants – execl, execle, execlp, execv, execve, execvp

Process waiting for a child

- A parent process can wait for a child to complete
  - Parent indicates to the kernel that it wants to wait, using the wait() system call
  - Parent execution is suspended; will be "ready" only after child terminates
  - If a child has already terminated, then the call returns immediately. Otherwise, block until a child terminates

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- Two variants
  - wait() - suspends execution of the current process until one of its children terminates
  - waitpid(pid) - suspends execution of the current process until the child specified by *pid* terminates

Process termination

- A child process executes last statement
  - exit() call for deleting the process
  - Return status data to parent via wait() if any parent is waiting for the termination of this process
  - Deallocate the resources

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<u>Child process</u>

.

.

exit(2) // Exit with status code

<u>Parent process</u>

pid_t pid;

int status;

.

pid = wait (&status) // pid of terminated child

Process creation and exec: example

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

int main()
{
pid_t pid;

    /* fork a child process */
    pid = fork();

    if (pid < 0) {
      fprintf(stderr, "Fork Failed");
      return 1;
    }
    else if (pid == 0) {
      execlp("/bin/ls","ls",NULL);
    }
    else {
      /* parent will wait for the child to complete */
      wait(NULL);
      printf("Child Complete");
    }

    return 0;
}
```

Error condition

child process

parent process

Process termination: Special cases

- In some OS
  - All child must terminate when a process terminates
  - Cascading termination: All children, grandchildren etc. must be terminated when a process terminates
  - OS takes care of this cascade

- Combinations of exit() and wait()
  - If no parent is waiting, then zombie process
  - If parent terminated without invoking wait() then orphan process

Zombie and orphan process

- Zombie process
  - A process that has terminated, but whose parent has not (yet) called wait()
  - All processes move to this state when they terminate, and remain there until parent calls wait()
  - Entry in process table removed only after calling wait()

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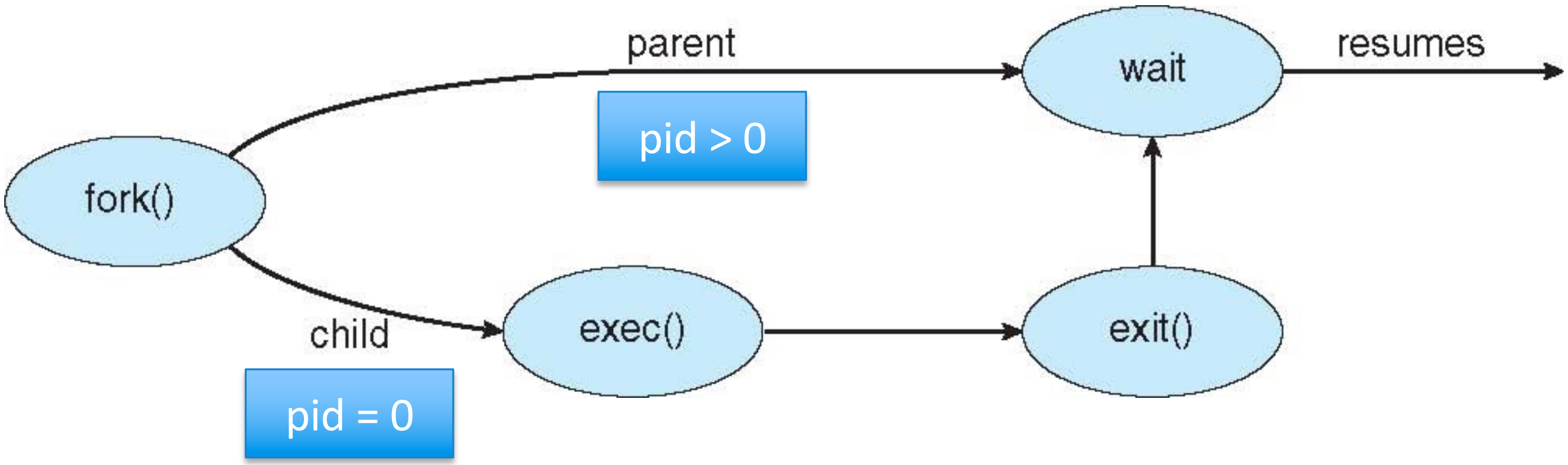
- Orphan process
  - parent terminated without invoking wait()
  - Immediately “init” process assigned as parent
  - “init” periodically invokes wait()

Usual workflow between parent & child



- Workflow can be different from what is shown
  - E.g., parent may or may not wait for the child
  - E.g., child may or may not use exec()

Inter Process Communication

Inter-process communication (IPC)

- Processes executing concurrently in OS may be independent or cooperating
- Cooperating process
  - Affect or be affected by other processes
  - Can share data
  - Speed-up in computation
  - Design can be modular

Inter-process communication (IPC)

- Processes executing concurrently in OS may be independent or cooperating
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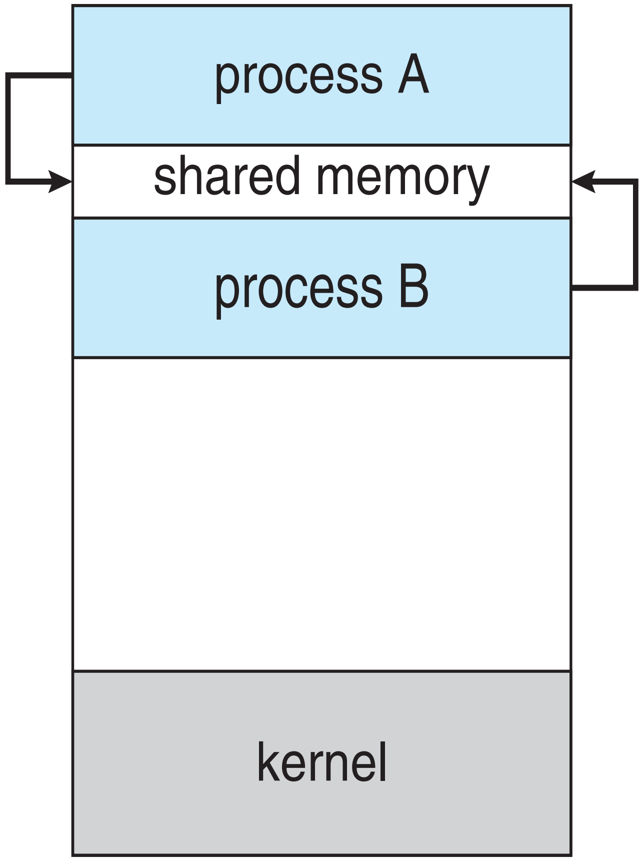
- Cooperating processes need IPC
  - Several types of IPC support provided by OS

Inter-process communication (IPC)

- Ways to do IPC
  - 1: shared memory - shmget(), shmcat(), shmaddr(), shmat(), shmdt(), shmctl()
  - 2: message passing (pipe) - pipe(), read(), write(), close()
  - 3: message passing (named pipe) - mkfifo(), read(), write(), close()
  - 4: over network - RPC or Remote Procedure Call, sockets

Shared memory system

Schematic for shared memory



Require the communicating processes to establish a region of shared memory

Relevant system calls in Linux / Unix
shmget( )
shmat( )
shmdt( )
shmctl( )

Let’s check the function calls

```
char *myseg;

key_t key; int shmid;

key = 235; // some unique id

shmid = shmget(key, 250, IPC_CREAT | 0666);

myseg = shmat(shmid, NULL, 0);

.
.
shmdt(myseg);
.
.
shmctl(shmid, IPC_RMID, NULL);
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Detach the memory segment from the address space of this process

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Create shared memory segment

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Detach the memory segment from the address space of this process

Mark the segment to be destroyed

Example: Producer consumer problem

- A producer process produces information that is consumed by the consumer process
  - Compiler produces assembly code consumed by assembler
  - Program produces lines to print, print spool consumes
  - The information is written to / read from a buffer

Example: Producer consumer problem

- A producer process produces information that is consumed by the consumer process
  - Compiler produces assembly code consumed by assembler
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  - The information is written to / read from a buffer

- Two variants
  - Bounded buffer: producer waits when buffer is full, consumer waits when buffer is empty
  - Unbounded buffer: consumer waits when buffer is empty

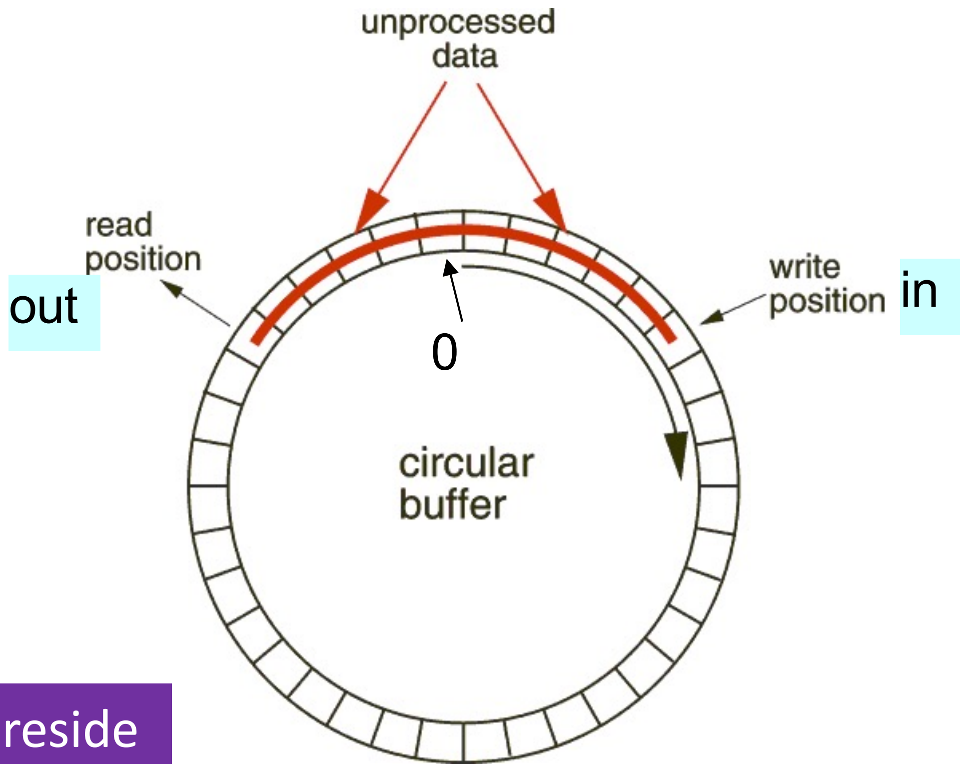
Producer consumer solution with bounded buffer

- Shared data: implemented as a circular array

```
#define BUFFER_SIZE 10
typedef struct {
   . . . // info to be shared
} item;

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

These variables reside in shared memory

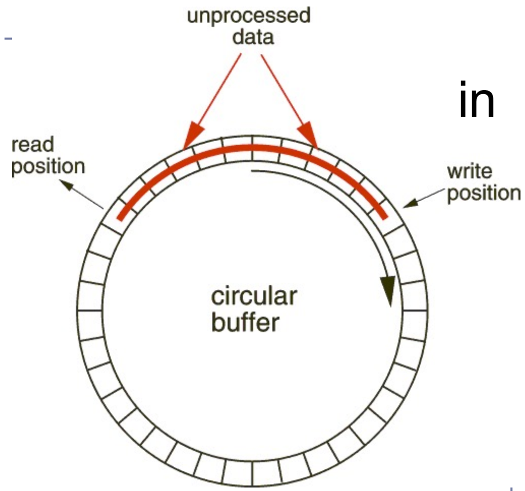


Key ideas

- Circular buffer
  - Index in: the next free position to write to
  - Index out: the next filled position to read from
- To check buffer full or empty:
  - Buffer empty: in==out
  - Buffer full: in+1 % BUFFER_SIZE == out
    - This scheme allows at most BUFFER_SIZE – 1 items in the buffer

Pseudo code

out




```
while (true) {
   /* Produce an item */

      while (( (in + 1) % BUFFER_SIZE) == out)

     ;   /* do nothing -- no free buffers */

    buffer[in] = newProducedItem;

    in = (in + 1) % BUFFER SIZE;

   }
```

Producer

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

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

Consumer

Solution is correct, but can only use BUFFER_SIZE-1 elements

Better utilization of buffer space

- Circular buffer (shared memory)
- Suppose that we want to use all buffer space:
  - an integer count: the number of filled buffers (shared memory)
  - Initially, count is set to 0.
  - incremented by producer after it produces a new buffer
  - decremented by consumer after it consumes a buffer.

Better utilization of buffer space: Pseudo code

Producer

```
while (true) {
    /*  produce an item
        and put in nextProduced  */
    while (count == BUFFER_SIZE)
     ; // do nothing
    buffer [in] = nextProduced;
    in = (in + 1) % BUFFER_SIZE;
    count++;
}
```

Consumer

```
while (true)  {
    while (count == 0)
      ; // do nothing
    nextConsumed =  buffer[out];
   out = (out + 1) % BUFFER_SIZE;
   count--;

   /*  consume the item in
     nextConsumed */
}
```

Message passing system

Basics of message passing

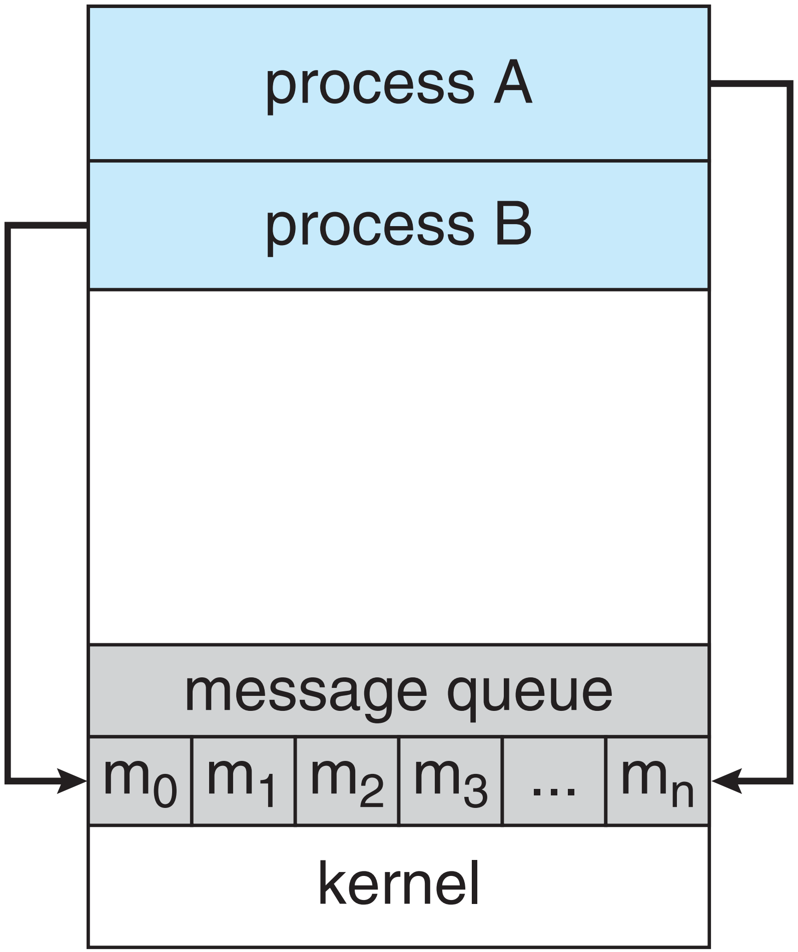
- Mechanism for processes to communicate and to synchronize their actions

- Message system – processes communicate with each other without resorting to shared variables

- IPC facility provides two operations:
  - **`send`**(*message*)
  - **`receive`**(*message*)

- The *message* size is either fixed or variable

Communication model



Ways for message passing

- Pipes
- Named pipes

Pipes

- Acts as a medium to allow two processes to communicate
  - Communication can be uni/bi-directional
  - Must there exist a relationship (i.e., parent-child) between the communicating processes?
  - Can the pipes be used over a network?

Ordinary pipes

- A message passing medium between related processes
  - Cannot be accessed from outside the process
  - Typically, a parent process creates a pipe and uses it to communicate with its child process
  - Pipes behave like FIFO queues
  - Read-write in pipe == producer-consumer
  - Producer writes to one end (the write-end of pipe)
  - Consumer reads from the other end (the read-end of pipe)
  - Unidirectional

Producer consumer in pipes

Producer

```
message next_produced;

while(TRUE){
   <produce and put data in next produced>
   ...
   send( next_produced);
}
```

Consumer

```
message next_consumed;

while(TRUE){
  receive(next_consumed);
  ...
  <data in next consumed>
}
```

Named pipes

- Accessed as files by processes
  - No parent-child relation is necessary
  - Still behave like FIFO queues (even called fifo)
  - Several processes can use the named pipe

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```
char* myfifo = '/tmp/myfifo';
mkfifo (myfifo, 0666); // creates the fifo or named pipe (a special file)
…
fd = open(myfifo, O_WRONLY);  // Process A
write(fd, …);    // Process A
close(fd);    // Process A
…
fd = open(myfifo, O_RDONLY);  // Process B
read(fd, …);    // Process B
close(fd);    // Process B
```

Named pipes

- Once you have created a FIFO special file / named pipe, any process can open it for reading or writing, in the same way as an ordinary file.
- However, it has to be open at both ends simultaneously before you can proceed to do any input or output operations on it.

Finally, for communication of two processes over network

- Sockets API
- Remote procedure call

Summary

- What is a process?
  - Structure of a process
  - Process states
  - Process control block
  - Context switch
- Queues for process scheduling
  - Ready queues, event queues, queueing diagram
- How does two processes talk?
  - Shared memory, pipe, named pipe