Processes
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* and *process* almost interchangeably

- Process – a program in execution; process execution must progress in sequential fashion

- A process includes:
  - program counter
  - stack
  - data section
Process in Memory

![Diagram showing process in memory with layers: text, data, heap, stack, and max.]}
Process State

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

- new
- admitted
- interrupt
- exit
- terminated
- ready
- running
- waiting

I/O or event completion
Scheduler dispatch
I/O or event wait
Process Control Block (PCB)

Information associated with each process

- Process state
- Program counter
- CPU registers
- CPU scheduling information
- Memory-management information
- Accounting information
- I/O status information
### Process Control Block (PCB)

<table>
<thead>
<tr>
<th>Feature</th>
</tr>
</thead>
<tbody>
<tr>
<td>process state</td>
</tr>
<tr>
<td>process number</td>
</tr>
<tr>
<td>program counter</td>
</tr>
<tr>
<td>registers</td>
</tr>
<tr>
<td>memory limits</td>
</tr>
<tr>
<td>list of open files</td>
</tr>
<tr>
<td>...</td>
</tr>
</tbody>
</table>
CPU Switch From Process to Process

<table>
<thead>
<tr>
<th>process $P_0$</th>
<th>operating system</th>
<th>process $P_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>executing</td>
<td>interrupt or system call</td>
<td></td>
</tr>
<tr>
<td></td>
<td>save state into PCB$_0$</td>
<td></td>
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<tr>
<td></td>
<td>...</td>
<td></td>
</tr>
<tr>
<td></td>
<td>reload state from PCB$_1$</td>
<td></td>
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<tr>
<td>idle</td>
<td>executing</td>
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</table>
Process Scheduling Queues

- **Job queue** – set of all processes in the system
- **Ready queue** – set of all processes residing in main memory, ready and waiting to execute
- **Device queues** – set of processes waiting for an I/O device
- Processes migrate among the various queues
Ready Queue And Various I/O Device Queues

- queue header
  - head
  - tail

- Ready queue
  - PCB₇
  - PCB₂

- mag tape unit 0
  - head
  - tail

- mag tape unit 1
  - head
  - tail
  - PCB₃
  - PCB₁₄
  - PCB₆

- disk unit 0
  - head
  - tail

- terminal unit 0
  - head
  - tail
  - PCB₅
Representation of Process Scheduling
Schedulers

- **Long-term scheduler** (or job scheduler) – selects which processes should be brought into the ready queue
- **Medium-term scheduler** – moves partially executed processes to/from disk storage to adjust the degree of multiprogramming
- **Short-term scheduler** (or CPU scheduler) – selects which process should be executed next and allocates CPU
Addition of Medium Term Scheduling

Medium term scheduler

- swap in
- partially executed swapped-out processes
- swap out

- ready queue
- CPU
- I/O
- I/O waiting queues

Long term Scheduler
Schedulers (Cont.)

- Short-term scheduler is invoked very frequently (milliseconds) ⇒ (must be fast)
- Medium-term scheduler is invoked less frequently
- Long-term scheduler is invoked very infrequently (seconds, minutes) ⇒ (may be slow)
- The medium-term and long-term schedulers control 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
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 overhead; the system does no useful work while switching.
- Time dependent on hardware support.
Process Creation

- Parent processes create child processes, which, in turn create other processes, forming a tree of processes.

- Possible kinds of 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/Linux examples**
  - `fork` system call creates new process
  - `exec` system call used after a `fork` to replace the process’ memory space with a new program
Process Creation

**Diagram:***

- **fork()**
  - Parent
  - Child

- **exec()**
  - Wait
  - Exit

- **wait**
  - Resumes
```c
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 */
        execvp("/bin/ls", "ls", NULL);
    }
    else { /* parent process */
        /* parent will wait for the child to complete */
        wait (NULL);
        printf ("Child Complete");
        exit(0);
    }
}
```
Process Termination

- Process executes last statement and asks the operating system to delete it (**exit**)
  - Output data from child to parent (via **wait**)
  - Process’ resources are deallocated by operating system

- Parent may terminate execution of children processes (**abort**)
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - If parent is exiting
    - Some operating system do not allow child to continue if its parent terminates
      - All children terminated - **cascading termination**
Cooperating Processes

- **Independent** process cannot affect or be affected by the execution of another process
- **Cooperating** process can affect or be affected by the execution of another process

- Advantages of process cooperation
  - Information sharing
  - Computation speed-up
  - Modularity
  - Convenience
Producer-Consumer Problem

- Paradigm for cooperating processes, *producer process* produces information that is consumed by a *consumer process*
  - *unbounded-buffer* places no practical limit on the size of the buffer
  - *bounded-buffer* assumes that there is a fixed buffer size
Bounded-Buffer – Shared-Memory Solution

- Shared data
  
  ```
  #define BUFFER_SIZE 10
  typedef struct {
     ... 
  } item;
  
  item buffer[BUFFER_SIZE];
  int in = 0;
  int out = 0;
  ```

- The following solution is correct, but can only use BUFFER_SIZE - 1 elements
while (true) {
    /* Produce an item */
    while (((in + 1) % BUFFER_SIZE) == out)
        ; /* do nothing -- no free buffers */
    buffer[in] = item;
    in = (in + 1) % BUFFER_SIZE;
}
Bounded Buffer – Remove() Method

```java
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;
}
```