Processes
Processes

• Process Concept
• Process Scheduling
• Operations on Processes
• Inter-process Communication
• Examples of IPC Systems
• Communication in Client-Server Systems
Objectives

• To introduce the notion of a process -- a program in execution, which forms the basis of all computation
• To describe the various features of processes, including scheduling, creation and termination, and communication
• To explore interprocess communication using shared memory and message passing
• To describe communication in client-server systems
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
• Multiple parts
  – The program code, also called text section
  – Current activity including program counter, processor registers
  – Stack containing temporary data
    • Function parameters, return addresses, local variables
  – Data section containing global variables
  – Heap containing memory dynamically allocated during run time
Process Concept (Cont.)

• Program is *passive* entity stored on disk *(executable file)*, process is *active*
  – Program becomes process when executable file loaded into memory

• Execution of program started via GUI mouse clicks, command line entry of its name, etc

• One program can be several processes
  – Consider multiple users executing the same program
Process in Memory
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**
- **scheduler dispatch**
- **I/O or event completion**

- **running**

- **waiting**
- **I/O or event wait**
Process Control Block (PCB)

Information associated with each process (also called task control block)
- Process state – running, waiting, etc
- Program counter – location of instruction to next execute
- CPU registers – contents of all process-centric registers
- CPU scheduling information - priorities, scheduling queue pointers
- Memory-management information – memory allocated to the process
- Accounting information – CPU used, clock time elapsed since start, time limits
- I/O status information – I/O devices allocated to process, list of open files
CPU Switch From Process to Process

process $P_0$  operating system  process $P_1$

executing  interrupt or system call

save state into PCB$_0$

interrupt or system call

reload state from PCB$_1$

save state into PCB$_1$

reload state from PCB$_0$

idle  executing

idle  idle

executing
Threads

• So far, process has a single thread of execution

• Consider having multiple program counters per process
  – Multiple locations can execute at once
    • Multiple threads of control -> threads

• Must then have storage for thread details, multiple program counters in PCB

• See next chapter
Process Representation in Linux

Represented by the C structure `task_struct`

```c
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 list_head children; /* this process's children */
struct files_struct *files; /* list of open files */
struct mm_struct *mm; /* address space of this process */
```
Process Scheduling

• Maximize CPU use, quickly switch processes onto CPU for time sharing
• **Process scheduler** selects among available processes for next execution on CPU
• Maintains **scheduling queues** of processes
  – **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
Representation of Process Scheduling

- **Queueing diagram** represents queues, resources, flows
Schedulers

• **Short-term scheduler** (or **CPU scheduler**) – selects which process should be executed next and allocates CPU
  – Sometimes the only scheduler in a system
  – Short-term scheduler is invoked frequently (milliseconds) ⇒ (must be fast)

• **Long-term scheduler** (or **job scheduler**) – selects which processes should be brought into the ready queue
  – Long-term scheduler is invoked infrequently (seconds, minutes) ⇒ (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 strives for good **process mix**
Addition of Medium Term Scheduling

- **Medium-term scheduler** can be added if degree of multiple programming needs to decrease
  - Remove process from memory, store on disk, bring back in from disk to continue execution: **swapping**
Multitasking in Mobile Systems

- Some mobile systems (e.g., early version of iOS) allow only one process to run, others suspended.
- Due to screen real estate, user interface limits iOS provides for a
  - Single **foreground** process—controlled via user interface.
  - Multiple **background** processes—in memory, running, but not on the display, and with limits.
  - Limits include single, short task, receiving notification of events, specific long-running tasks like audio playback.
- Android runs foreground and background, with fewer limits.
  - Background process uses a **service** to perform tasks.
  - Service can keep running even if background process is suspended.
  - Service has no user interface, small memory use.
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 via a **context switch**
  
• **Context** of a process represented in the PCB
• Context-switch time is overhead; the system does no useful work while switching
  – The more complex the OS and the PCB ➔ the longer the context switch

• Time dependent on hardware support
  – Some hardware provides multiple sets of registers per CPU ➔ multiple contexts loaded at once
Operations on Processes

• System must provide mechanisms for:
  – process creation,
  – process termination,
  – and so on as detailed next
Process Creation

• **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes

• Generally, process identified and managed via a **process identifier (pid)**

• Resource sharing options
  – Parent and children share all resources
  – Children share subset of parent’s resources
  – Parent and child share no resources

• Execution options
  – Parent and children execute concurrently
  – Parent waits until children terminate
A Tree of Processes in Linux

- init
  - pid = 1
  - sshd
    - pid = 3028
  - login
    - pid = 8415
  - kthread
    - pid = 2
    - sshd
      - pid = 3610
    - pdflush
      - pid = 200
    - khelper
      - pid = 6
  - tcsch
    - pid = 4005
  - emacs
    - pid = 9204
  - ps
    - pid = 9298
  - bash
    - pid = 8416
- ps
  - pid = 9298
- sshd
  - pid = 3028
- login
  - pid = 8415
- kthread
  - pid = 2
Process Creation (Cont.)

• Address space
  – Child duplicate of parent
  – Child has a program loaded into it

• UNIX examples
  – `fork()` system call creates new process

![Diagram showing the process creation process]

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

int main()
{
    pid_t pid;

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

    if (pid < 0) { /* error occurred */
        fprintf(stderr, "Fork Failed");
        return 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");
    }

    return 0;
}
Creating a Separate Process via Windows API

- CreateProcess() Fn
- Need to specify the program to load
- Requires 10 parameters
- STARTUPINFO
- PROCESS_INFO

```c
#include <stdio.h>
#include <windows.h>

int main(VOID)
{
    STARTUPINFO si;
    PROCESS_INFORMATION pi;

    /* allocate memory */
    ZeroMemory(&si, sizeof(si));
    si.cb = sizeof(si);
    ZeroMemory(&pi, sizeof(pi));

    /* create child process */
    if (!CreateProcess(NULL, /* use command line */
        "C:\WINDOWS\system32\mspaint.exe", /* command */
        NULL, /* don’t inherit process handle */
        NULL, /* don’t inherit thread handle */
        FALSE, /* disable handle inheritance */
        0, /* no creation flags */
        NULL, /* use parent’s environment block */
        NULL, /* use parent’s existing directory */
        &si, &pi))
    {
        fprintf(stderr, "Create Process Failed");
        return -1;
    }

    /* parent will wait for the child to complete */
    WaitForSingleObject(pi.hProcess, INFINITE);
    printf("Child Complete");

    /* close handles */
    CloseHandle(pi.hProcess);
    CloseHandle(pi.hThread);
}
```
Process Termination

• Process executes last statement and then asks the operating system to delete it using the `exit()` system call.
  – Returns status data from child to parent (via `wait()`)  
  – Process’ resources are deallocated by operating system

• Parent may terminate the execution of children processes using the `abort()` system call. Some reasons for doing so:
  – Child has exceeded allocated resources 
  – Task assigned to child is no longer required 
  – The parent is exiting and the operating systems does not allow a child to continue if its parent terminates
Process Termination

• Some operating systems do not allow child to exists if its parent has terminated. If a process terminates, then all its children must also be terminated.
  – **cascading termination.** All children, grandchildren, etc. are terminated.
  – The termination is initiated by the operating system.

• The parent process may wait for termination of a child process by using the `wait()` system call. The call returns status information and the pid of the terminated process
  \[
  \text{pid} = \text{wait}(&\text{status});
  \]

• If no parent waiting (did not invoke `wait()`) process is a **zombie**

• If parent terminated without invoking `wait`, process is an **orphan**
Multiprocess Architecture – Chrome Browser

• Many web browsers ran as single process (some still do)
  – If one web site causes trouble, entire browser can hang or crash

• Google Chrome Browser is multiprocess with 3 different types of processes:
  – **Browser** process manages user interface, disk and network I/O
  – **Renderer** process renders web pages, deals with HTML, Javascript. A new renderer created for each website opened
    • Runs in **sandbox** restricting disk and network I/O, minimizing effect of security exploits
  – **Plug-in** process for each type of plug-in
Interprocess Communication

• Processes within a system may be *independent* or *cooperating*

• Cooperating process can affect or be affected by other processes, including sharing data

• Cooperating processes need **interprocess communication (IPC)**

• Two models of IPC
  – Shared memory
  – Message passing
Communications Models

(a) Message passing.  (b) shared memory.
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;
```

• Solution is correct, but can only use BUFFER_SIZE-1 elements
Bounded-Buffer – Producer

item next_produced;
while (true) {
    /* produce an item in next produced */
    while (((in + 1) % BUFFER_SIZE) == out) ; /* do nothing */
    buffer[in] = next_produced;
    in = (in + 1) % BUFFER_SIZE;
}
Bounded Buffer – Consumer

```c
item next_consumed;
while (true) {
    while (in == out)
        ; /* do nothing */
    next_consumed = buffer[out];
    out = (out + 1) % BUFFER_SIZE;

    /* consume the item in next_consumed */
}
```
Interprocess Communication – Shared Memory

• An area of memory shared among the processes that wish to communicate
• The communication is under the control of the users processes not the operating system.
• Major issues is to provide mechanism that will allow the user processes to synchronize their actions when they access shared memory.
• Synchronization is discussed in great details in Chapter 5.
Interprocess Communication – 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
Message Passing (Cont.)

• If processes $P$ and $Q$ wish to communicate, they need to:
  – Establish a *communication link* between them
  – Exchange messages via send/receive

• Implementation issues:
  – How are links established?
  – Can a link be associated with more than two processes?
  – How many links can there be between every pair of communicating processes?
  – What is the capacity of a link?
  – Is the size of a message that the link can accommodate fixed or variable?
  – Is a link unidirectional or bi-directional?
• Implementation of communication link
  – Physical:
    • Shared memory
    • Hardware bus
    • Network
  – Logical:
    • Direct or indirect
    • Synchronous or asynchronous
    • Automatic or explicit buffering
Direct Communication

• Processes must name each other explicitly:
  – send \((P, message)\) – send a message to process P
  – receive \((Q, message)\) – receive a message from process Q

• Properties of communication link
  – Links are established automatically
  – A link is associated with exactly one pair of communicating processes
  – Between each pair there exists exactly one link
  – The link may be unidirectional, but is usually bidirectional
Indirect Communication

• Messages are directed and received from mailboxes (also referred to as ports)
  – Each mailbox has a unique id
  – Processes can communicate only if they share a mailbox

• Properties of communication link
  – Link established only if processes share a common mailbox
  – A link may be associated with many processes
  – Each pair of processes may share several communication links
  – Link may be unidirectional or bi-directional
Indirect Communication

• Operations
  – create a new mailbox (port)
  – send and receive messages through mailbox
  – destroy a mailbox

• Primitives are defined as:
  \texttt{send}(A, \textit{message}) – send a message to mailbox A
  \texttt{receive}(A, \textit{message}) – receive a message from mailbox A
Indirect Communication

• Mailbox sharing
  – $P_1$, $P_2$, and $P_3$ share mailbox A
  – $P_1$, sends; $P_2$ and $P_3$ receive
  – Who gets the message?

• Solutions
  – Allow a link to be associated with at most two processes
  – Allow only one process at a time to execute a receive operation
  – Allow the system to select arbitrarily the receiver. Sender is notified who the receiver was.
Synchronization

- Message passing may be either blocking or non-blocking
- **Blocking** is considered **synchronous**
  - **Blocking send** -- the sender is blocked until the message is received
  - **Blocking receive** -- the receiver is blocked until a message is available
- **Non-blocking** is considered **asynchronous**
  - **Non-blocking send** -- the sender sends the message and continue
  - **Non-blocking receive** -- the receiver receives:
    - A valid message, or
    - Null message

Different combinations possible
- If both send and receive are blocking, we have a **rendezvous**
Synchronization (Cont.)

- Producer-consumer becomes trivial

```c
message next_produced;
while (true) {
    /* produce an item in next produced */
    send(next_produced);
}
```

```c
message next_consumed;
while (true) {
    receive(next_consumed);

    /* consume the item in next consumed */
}
```
Buffering

- Queue of messages attached to the link.
- Implemented in one of three ways
  1. Zero capacity – no messages are queued on a link.
     Sender must wait for receiver (rendezvous)
  2. Bounded capacity – finite length of $n$ messages
     Sender must wait if link full
  3. Unbounded capacity – infinite length
     Sender never waits
Communications in Client-Server Systems

- Sockets
- Remote Procedure Calls
- Pipes
- Remote Method Invocation (Java)
Sockets

- A socket is defined as an endpoint for communication.
- Concatenation of IP address and port – a number included at start of message packet to differentiate network services on a host.
- The socket **161.25.19.8:1625** refers to port **1625** on host **161.25.19.8**.
- Communication consists between a pair of sockets.
- All ports below 1024 are well known, used for standard services.
- Special IP address 127.0.0.1 (loopback) to refer to system on which process is running.
Socket Communication

host X
(146.86.5.20)

socket
(146.86.5.20:1625)

web server
(161.25.19.8)

socket
(161.25.19.8:80)
Sockets in Java

- Three types of sockets
  - Connection-oriented (TCP)
  - Connectionless (UDP)
  - MulticastSocket class—data can be sent to multiple recipients

- Consider this “Date” server:

```java
import java.net.*;
import java.io.*;

public class DateServer
{
    public static void main(String[] args) {
        try {
            ServerSocket sock = new ServerSocket(6013);

            /* now listen for connections */
            while (true) {
                Socket client = sock.accept();

                PrintWriter pout = new
                PrintWriter(client.getOutputStream(), true);

                /* write the Date to the socket */
                pout.println(new java.util.Date().toString());

                /* close the socket and resume */
                /* listening for connections */
                client.close();
            }
        }
        catch (IOException ice) {
            System.err.println(ice);
        }
    }
}
```
Remote Procedure Calls

• Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
  – Again uses ports for service differentiation
• **Stubs** – client-side proxy for the actual procedure on the server
• The client-side stub locates the server and **marshalls** the parameters
• The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server
• On Windows, stub code compile from specification written in **Microsoft Interface Definition Language (MIDL)**
Remote Procedure Calls (Cont.)

• Data representation handled via **External Data Representation (XDL)** format to account for different architectures
  – **Big-endian** and **little-endian**

• Remote communication has more failure scenarios than local
  – Messages can be delivered *exactly once* rather than *at most once*

• OS typically provides a rendezvous (or **matchmaker**) service to connect client and server
Execution of RPC

- User calls kernel to send RPC message to procedure X.
- Kernel sends message to matchmaker to find port number.
- Kernel places port P in user RPC message.
- Kernel sends RPC message.
- Kernel receives reply, passes it to user.
- From: client To: server
  Port: matchmaker
  Re: address for RPC X
- Matchmaker receives message, looks up answer.
- From: server To: client
  Port: kernel
  Re: RPC X
  Port: P
- Matchmaker replies to client with port P.
- From: client To: server
  Port: port P
  <contents>
- Daemon listening to port P receives message.
- From: RPC To: client
  Port: P
  To: kernel
  <output>
- Daemon processes request and processes send output.

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Pipes

• Acts as a conduit allowing two processes to communicate

• Issues:
  – Is communication unidirectional or bidirectional?
  – In the case of two-way communication, is it half or full-duplex?
  – Must there exist a relationship (i.e., parent-child) between the communicating processes?
  – Can the pipes be used over a network?

• Ordinary pipes – cannot be accessed from outside the process that created it. Typically, a parent process creates a pipe and uses it to communicate with a child process that it created.

• Named pipes – can be accessed without a parent-child relationship.
Ordinary Pipes

- Ordinary Pipes allow communication in standard producer-consumer style.
- Producer writes to one end (the write-end of the pipe).
- Consumer reads from the other end (the read-end of the pipe).
- Ordinary pipes are therefore unidirectional.
- Require parent-child relationship between communicating processes.

- Windows calls these **anonymous pipes**.
- See Unix and Windows code samples in textbook.
Named Pipes

- Named Pipes are more powerful than ordinary pipes
- Communication is bidirectional
- No parent-child relationship is necessary between the communicating processes
- Several processes can use the named pipe for communication
- Provided on both UNIX and Windows systems
End of Chapter 3