Chapter 3 – Process Concepts

Outline

Objectives

- After reading this chapter, you should understand:
  - the concept of a process.
  - the process life cycle.
  - process states and state transitions.
  - process control blocks (PCBs)/process descriptors.
  - how processors transition between processes via context switching.
  - how interrupts enable hardware to communicate with software.
  - how processes converse with one another via interprocess communication (IPC).
  - UNIX processes.

3.1 Introduction

- Computers perform operations concurrently
  - For example, compiling a program, sending a file to a printer, rendering a Web page, playing music and receiving e-mail
  - Processes enable systems to perform and track simultaneous activities
  - Processes transition between process states
  - Operating systems perform operations on processes such as creating, destroying, suspending, resuming and waking

3.1.1 Definition of Process

- A program in execution
  - A process has its own address space consisting of:
    - Text region
      - Stores the code that the processor executes
    - Data region
      - Stores variables and dynamically allocated memory
    - Stack region
      - Stores instructions and local variables for active procedure calls

3.2 Process States: Life Cycle of a Process

- A process moves through a series of discrete process states:
  - *Running* state
    - The process is executing on a processor
  - *Ready* state
    - The process could execute on a processor if one were available
  - *Blocked* state
    - The process is waiting for some event to happen before it can proceed
- The OS maintains a *ready* list and a *blocked* list to store references to processes not running

3.3 Process Management

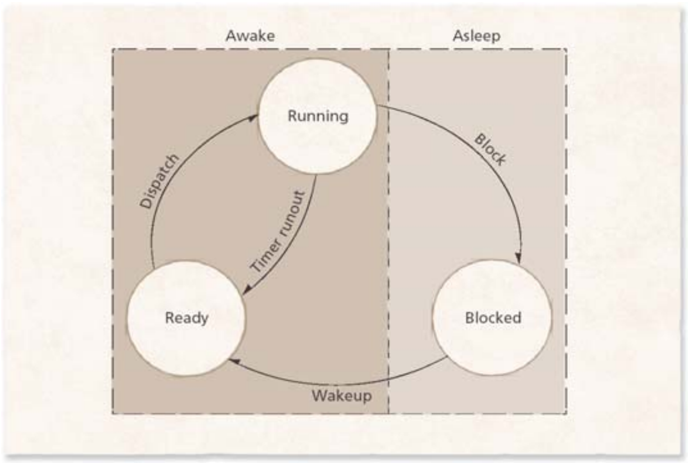
- Operating systems provide fundamental services to processes including:
  - Creating processes
  - Destroying processes
  - Suspending processes
  - Resuming processes
  - Changing a process's priority
  - Blocking processes
  - Waking up processes
  - Dispatching processes
  - Interprocess communication (IPC)

3.3.1 Process States and State Transitions

- Process states
  - The act of assigning a processor to the first process on the ready list is called dispatching
  - The OS may use an interval timer to allow a process to run for a specific time interval or quantum
  - Cooperative multitasking lets each process run to completion
- State Transitions
  - At this point, there are four possible state transitions
    - When a process is dispatched, it transitions from *ready* to *running*
    - When the quantum expires, it transitions from *running* to *ready*
    - When a process blocks, it transitions from *running* to *blocked*
    - When the event occurs, it transitions from *blocked* to *ready*

3.3.1 Process States and State Transitions

Figure 3.1 Process state transitions.



3.3.2 Process Control Blocks (PCBs)/Process Descriptors

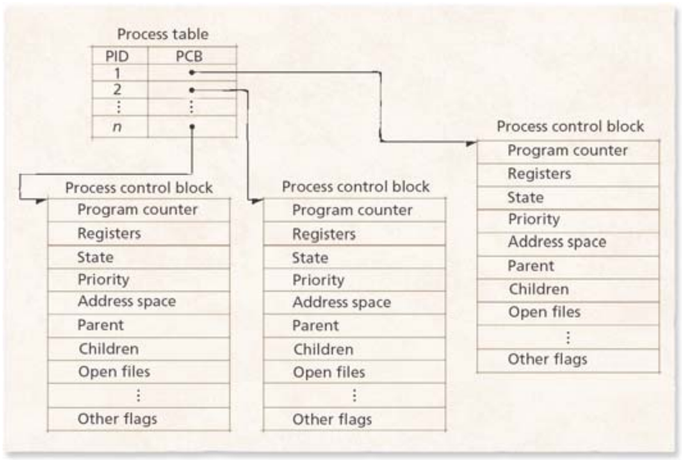
- PCBs maintain information that the OS needs to manage the process
  - Typically include information such as
    - Process identification number (PID)
    - Process state
    - Program counter
    - Scheduling priority
    - Credentials
    - A pointer to the process's parent process
    - Pointers to the process's child processes
    - Pointers to locate the process's data and instructions in memory
    - Pointers to allocated resources

3.3.2 Process Control Blocks (PCBs)/Process Descriptors

- Process table
  - The OS maintains pointers to each process's PCB in a system-wide or per-user process table
  - Allows for quick access to PCBs
  - When a process is terminated, the OS removes the process from the process table and frees all of the process's resources

3.3.2 Process Control Blocks (PCBs)/Process Descriptors

Figure 3.2 Process table and process control blocks.

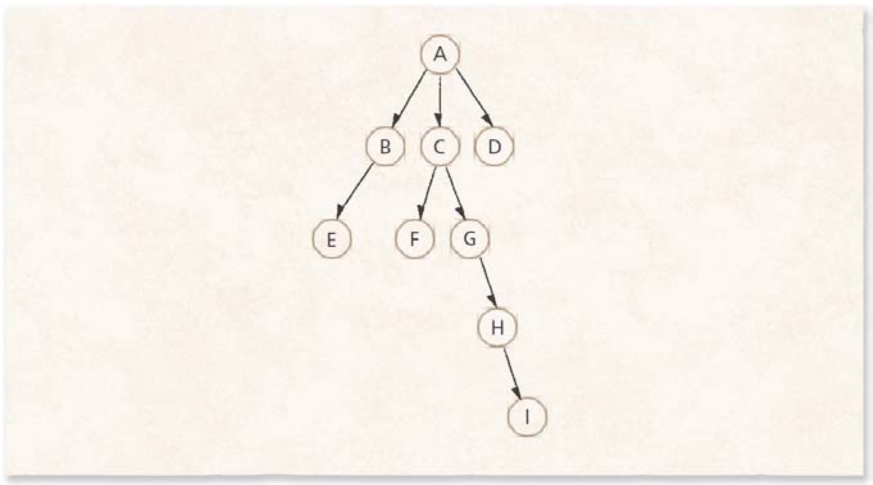


3.3.3 Process Operations

- A process may spawn a new process
  - The creating process is called the parent process
  - The created process is called the child process
  - Exactly one parent process creates a child
  - When a parent process is destroyed, operating systems typically respond in one of two ways:
    - Destroy all child processes of that parent
    - Allow child processes to proceed independently of their parents

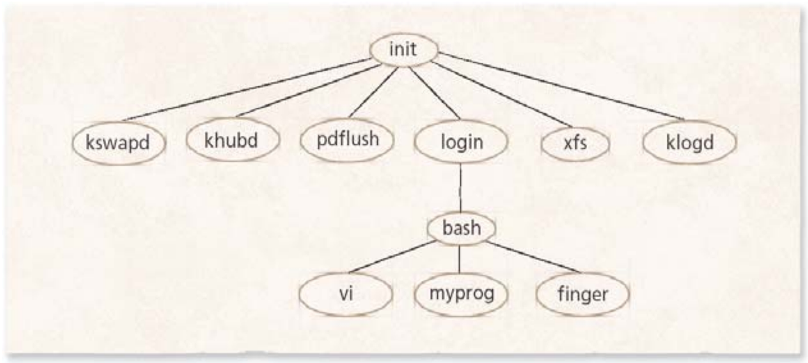
3.3.3 Process Operations

Figure 3.3 Process creation hierarchy.



3.3.3 Process Operations

Figure 3.4 Process hierarchy in Linux.

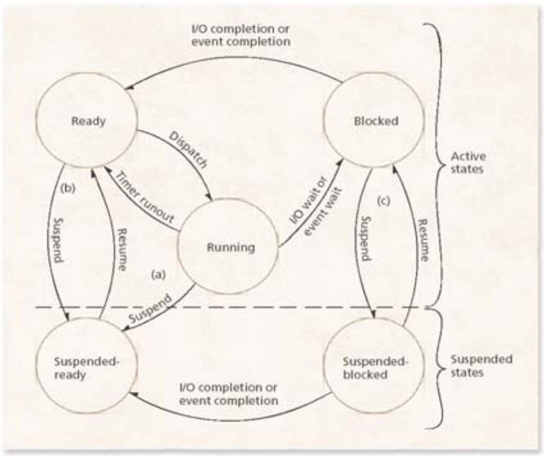


3.3.4 Suspend and Resume

- Suspending a process
  - Indefinitely removes it from contention for time on a processor without being destroyed
  - Useful for detecting security threats and for software debugging purposes
  - A suspension may be initiated by the process being suspended or by another process
  - A suspended process must be resumed by another process
  - Two suspended states:
    - *suspendedready*
    - *suspendedblocked*

3.3.4 Suspend and Resume

Figure 3.5 Process state transitions with suspend and resume.

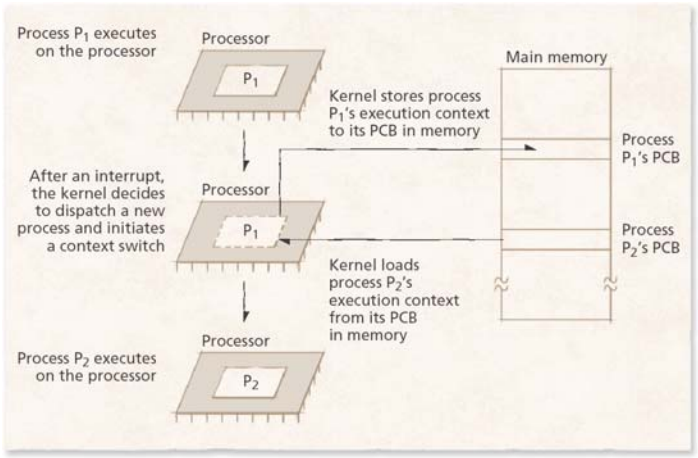


3.3.5 Context Switching

- Context switches
  - Performed by the OS to stop executing a *running* process and begin executing a previously *ready* process
  - Save the execution context of the *running* process to its PCB
  - Load the *ready* process's execution context from its PCB
  - Must be transparent to processes
  - Require the processor to not perform any "useful" computation
    - OS must therefore minimize context-switching time
  - Performed in hardware by some architectures

3.3.5 Context Switching

Figure 3.6 Context switch.


Process P₁ executes on the processor
Processor
P₁
Main memory
Kernel stores process P₁'s execution context to its PCB in memory
Process P₁'s PCB
After an interrupt, the kernel decides to dispatch a new process and initiates a context switch
Processor
P₁
Process P₂'s PCB
Kernel loads process P₂'s execution context from its PCB in memory
Processor
Process P₂ executes on the processor
P₂

3.4 Interrupts

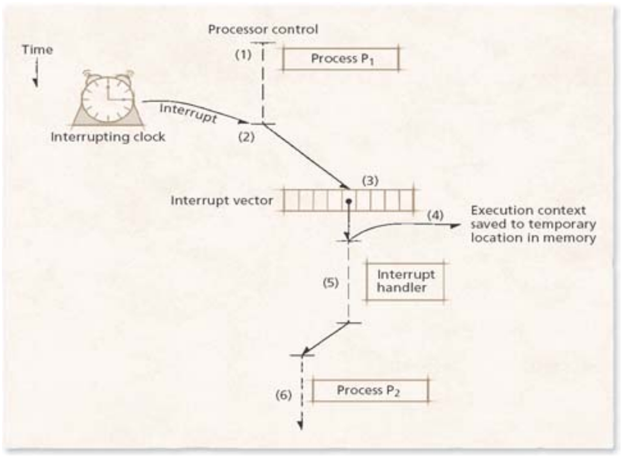
- Interrupts enable software to respond to signals from hardware
  - May be initiated by a running process
    - Interrupt is called a trap
    - Synchronous with the operation of the process
    - For example, dividing by zero or referencing protected memory
  - May be initiated by some event that may or may not be related to the running process
    - Asynchronous with the operation of the process
    - For example, a key is pressed on a keyboard or a mouse is moved
  - Low overhead
- Polling is an alternative approach
  - Processor repeatedly requests the status of each device
  - Increases in overhead as the complexity of the system increases

3.4.1 Interrupt Processing

- Handling interrupts
  - After receiving an interrupt, the processor completes execution of the current instruction, then pauses the current process
  - The processor will then execute one of the kernel's interrupt-handling functions
  - The interrupt handler determines how the system should respond
  - Interrupt handlers are stored in an array of pointers called the interrupt vector
  - After the interrupt handler completes, the interrupted process is restored and executed or the next process is executed

3.4.1 Interrupt Processing

Figure 3.7 Handling interrupts.

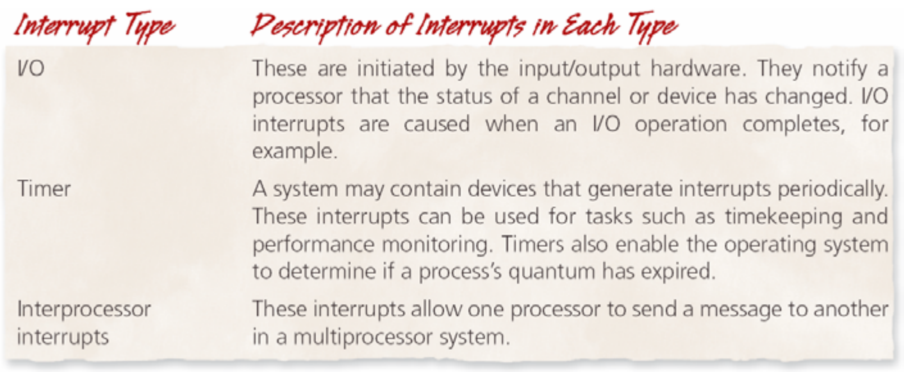


3.4.2 Interrupt Classes

- Supported interrupts depend on a system's architecture
  - The IA-32 specification distinguishes between two types of signals a processor may receive:
    - Interrupts
      - Notify the processor that an event has occurred or that an external device's status has changed
      - Generated by devices external to a processor
    - Exceptions
      - Indicate that an error has occurred, either in hardware or as a result of a software instruction
      - Classified as faults, traps or aborts

3.4.2 Interrupt Classes

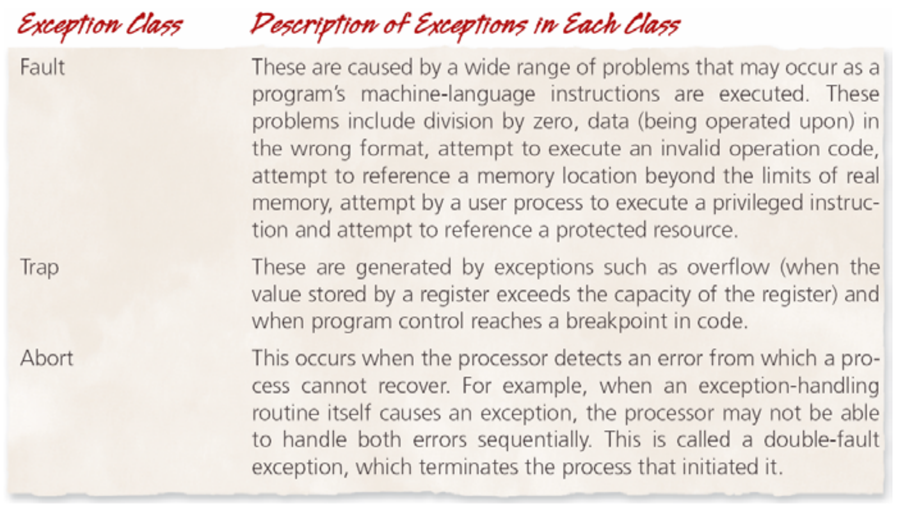
Figure 3.8 Common interrupt types recognized in the Intel IA-32 architecture.



Interrupt Type	Description of Interrupts in Each Type
I/O	These are initiated by the input/output hardware. They notify a processor that the status of a channel or device has changed. I/O interrupts are caused when an I/O operation completes, for example.
Timer	A system may contain devices that generate interrupts periodically. These interrupts can be used for tasks such as timekeeping and performance monitoring. Timers also enable the operating system to determine if a process's quantum has expired.
Interprocessor interrupts	These interrupts allow one processor to send a message to another in a multiprocessor system.

3.4.2 Interrupt Classes

Figure 3.9 Intel IA-32 exception classes.



Exception Class	Description of Exceptions in Each Class
Fault	These are caused by a wide range of problems that may occur as a program's machine-language instructions are executed. These problems include division by zero, data (being operated upon) in the wrong format, attempt to execute an invalid operation code, attempt to reference a memory location beyond the limits of real memory, attempt by a user process to execute a privileged instruction and attempt to reference a protected resource.
Trap	These are generated by exceptions such as overflow (when the value stored by a register exceeds the capacity of the register) and when program control reaches a breakpoint in code.
Abort	This occurs when the processor detects an error from which a process cannot recover. For example, when an exception-handling routine itself causes an exception, the processor may not be able to handle both errors sequentially. This is called a double-fault exception, which terminates the process that initiated it.

3.5 Interprocess Communication

- Many operating systems provide mechanisms for interprocess communication (IPC)
  - Processes must communicate with one another in multiprogrammed and networked environments
    - For example, a Web browser retrieving data from a distant server
  - Essential for processes that must coordinate activities to achieve a common goal

3.5.1 Signals

- Software interrupts that notify a process that an event has occurred
  - Do not allow processes to specify data to exchange with other processes
  - Processes may catch, ignore or mask a signal
    - Catching a signal involves specifying a routine that the OS calls when it delivers the signal
    - Ignoring a signal relies on the operating system's default action to handle the signal
    - Masking a signal instructs the OS to not deliver signals of that type until the process clears the signal mask

3.5.2 Message Passing

- Message-based interprocess communication
  - Messages can be passed in one direction at a time
    - One process is the sender and the other is the receiver
  - Message passing can be bidirectional
    - Each process can act as either a sender or a receiver
  - Messages can be blocking or nonblocking
    - Blocking requires the receiver to notify the sender when the message is received
    - Nonblocking enables the sender to continue with other processing
  - Popular implementation is a pipe
    - A region of memory protected by the OS that serves as a buffer, allowing two or more processes to exchange data

3.5.2 Message Passing

- IPC in distributed systems
  - Transmitted messages can be flawed or lost
    - Acknowledgement protocols confirm that transmissions have been properly received
    - Timeout mechanisms retransmit messages if acknowledgements are not received
  - Ambiguously named processes lead to incorrect message referencing
    - Messages are passed between computers using numbered ports on which processes listen, avoiding this problem
  - Security is a significant problem
    - Ensuring authentication

3.6 Case Study: UNIX Processes

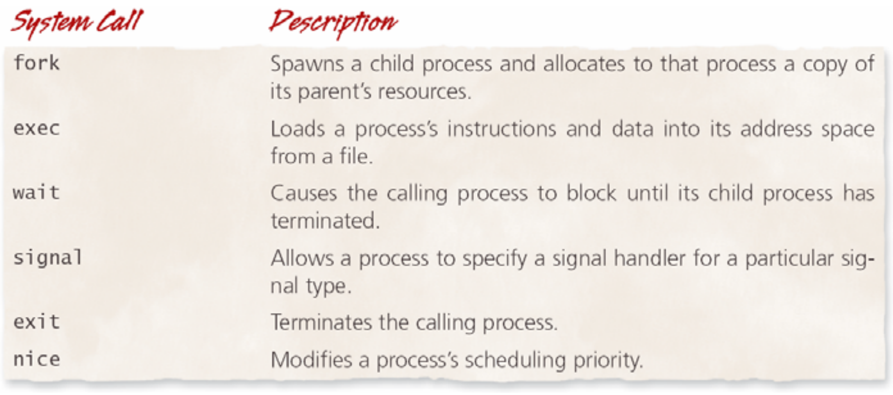
- UNIX processes
  - All processes are provided with a set of memory addresses, called a virtual address space
  - A process's PCB is maintained by the kernel in a protected region of memory that user processes cannot access
  - A UNIX PCB stores:
    - The contents of the processor registers
    - PID
    - The program counter
    - The system stack
  - All processes are listed in the process table

3.6 Case Study: UNIX Processes

- UNIX processes continued
  - All processes interact with the OS via system calls
  - A process can spawn a child process by using the fork system call, which creates a copy of the parent process
    - Child receives a copy of the parent's resources as well
  - Process priorities are integers between -20 and 19 (inclusive)
    - A lower numerical priority value indicates a higher scheduling priority
  - UNIX provides IPC mechanisms, such as pipes, to allow unrelated processes to transfer data

3.6 Case Study: UNIX Processes

Figure 3.10 UNIX system calls.



System Call	Description
`fork`	Spawns a child process and allocates to that process a copy of its parent's resources.
`exec`	Loads a process's instructions and data into its address space from a file.
`wait`	Causes the calling process to block until its child process has terminated.
`signal`	Allows a process to specify a signal handler for a particular signal type.
`exit`	Terminates the calling process.
`nice`	Modifies a process's scheduling priority.