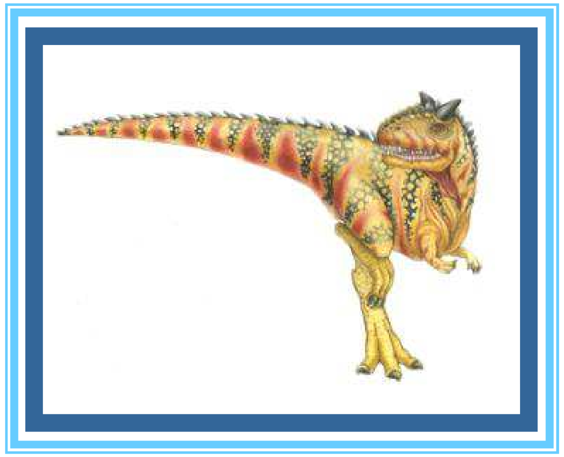
Topic 2: Processes



- Chapter 3: Process Concept
- Chapter 4: Multithreaded Programming
- Chapter 5: Process Scheduling

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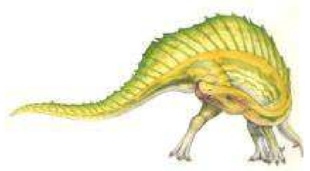
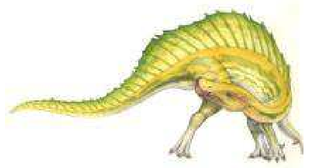


Objectives

- 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 introduce the notion of a thread — a fundamental unit of CPU utilization that forms the basis of multithreaded computer systems
- To introduce CPU scheduling, which is the basis for multiprogrammed operating systems
- To describe various CPU-scheduling algorithms



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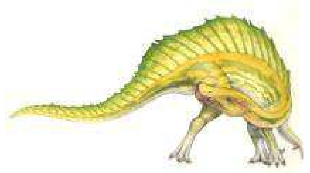
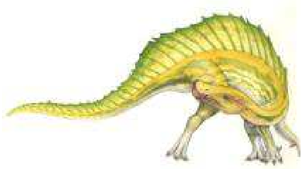


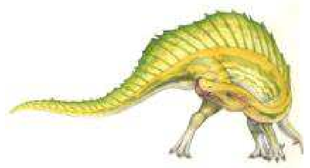
Process Concept

- An operating system executes a variety of programs
- Program:
  - description of how to perform an activity (algorithm)
  - instructions and static data values
  - static file (image)
- Process:
  - a program in execution; process execution must progress in sequential fashion
  - a snapshot of a program in execution
  - an instance of a program running in a computer



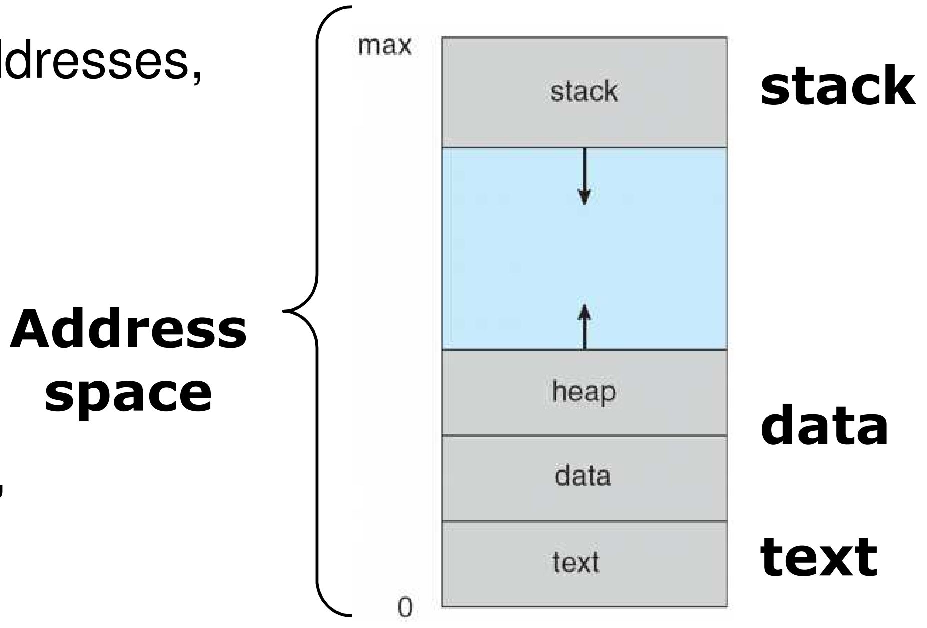
Process Concept

- A process is the basic unit of execution in an operating system
  - Each process has a number, its process identifier (pid)
- Different processes may run different instances of the same program



Process requirements

- At a minimum, process execution requires following resources:
  - Memory to contain the program code (**text section**) and data
  - **Stack** containing temporary data
    - Function parameters, return addresses, local variables
  - A set of CPU registers to support execution
    - CPU state (registers, Program Counter (PC), Stack Pointer (SP), etc)
    - operating system state (open files, accounting statistics etc)



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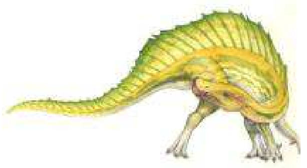
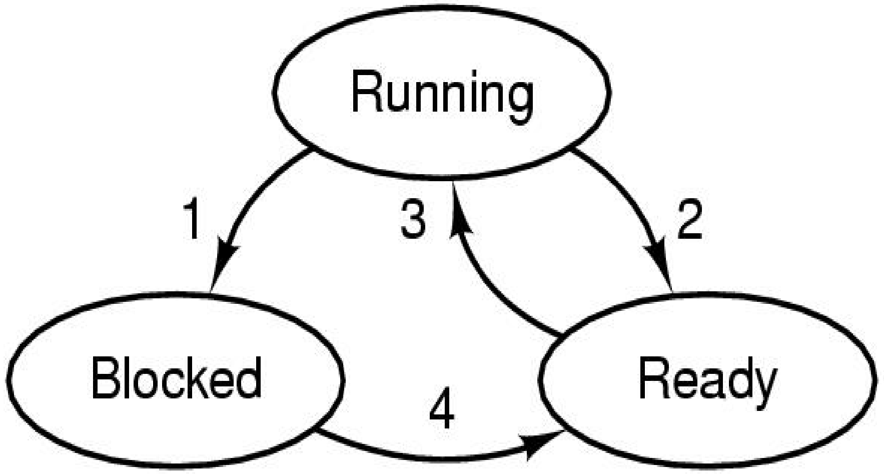
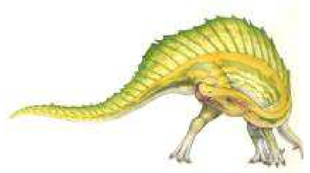


Process states

- As a process executes, it changes **state**
- Possible process states
  - **running**: instructions are being executed
  - **blocked (waiting)**: the process is waiting for some event to occur
  - **ready**: the process is waiting to be assigned to a processor

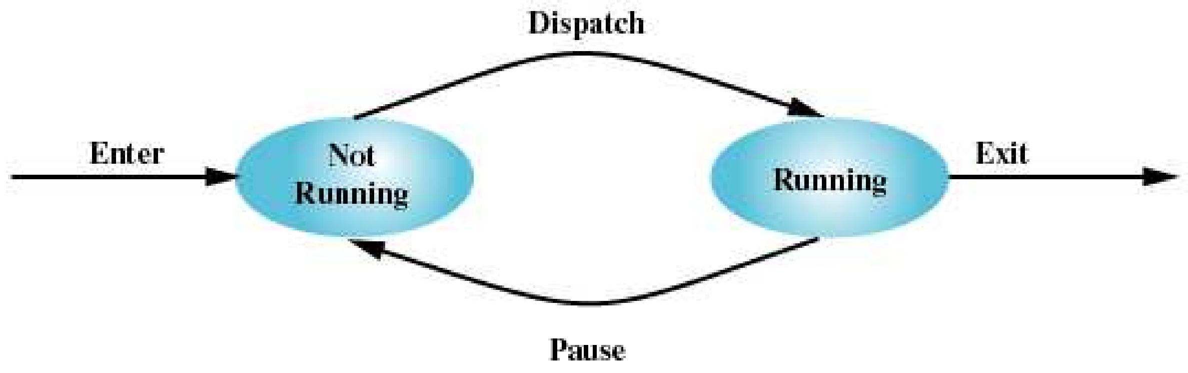


1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available



Two-State Process Model

- Process may be in one of two states
  - Running
  - Not-running

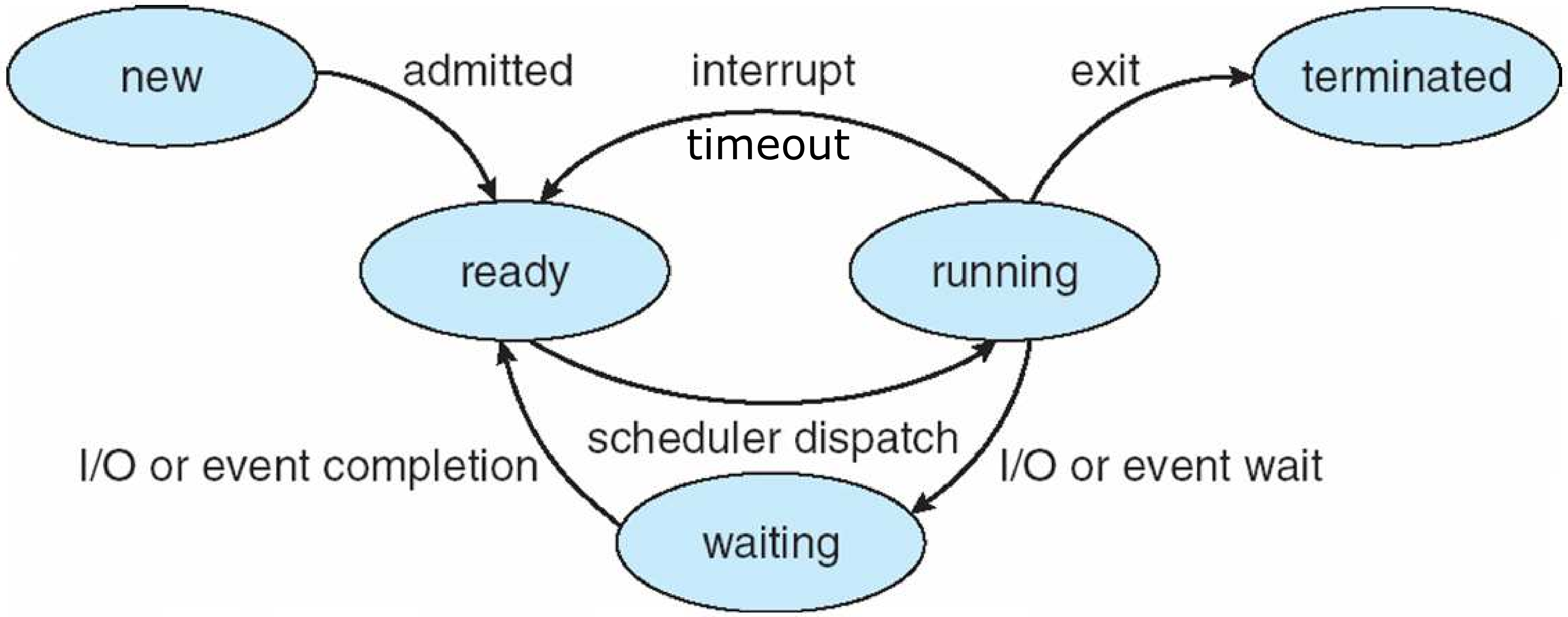


(a) State transition diagram

Source: Operating Systems. W. Stallings Fig. 3.5

Five-State Process Model

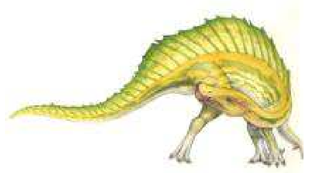
- States:
  - **new**: The process is being created
  - **running**: Instructions are being executed
  - **waiting (blocked)**: The process is waiting for some event to occur
  - **ready**: The process is waiting to be assigned to a processor
  - **terminated**: The process has finished execution



Source: Operating System Concepts. A. Silberschatz. Fig. 3.2

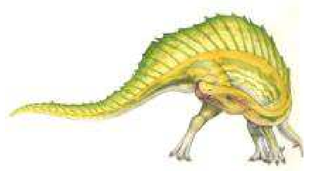
Swapped and Suspended Processes

- Processor is faster than I/O so all processes could be waiting for I/O
  - Swap these processes to disk to free up more memory
    - More processes can be executed
- System overloaded
  - blocked state becomes suspend state when swapped to disk
- Two new states
  - Blocked/Suspend
  - Ready/Suspend

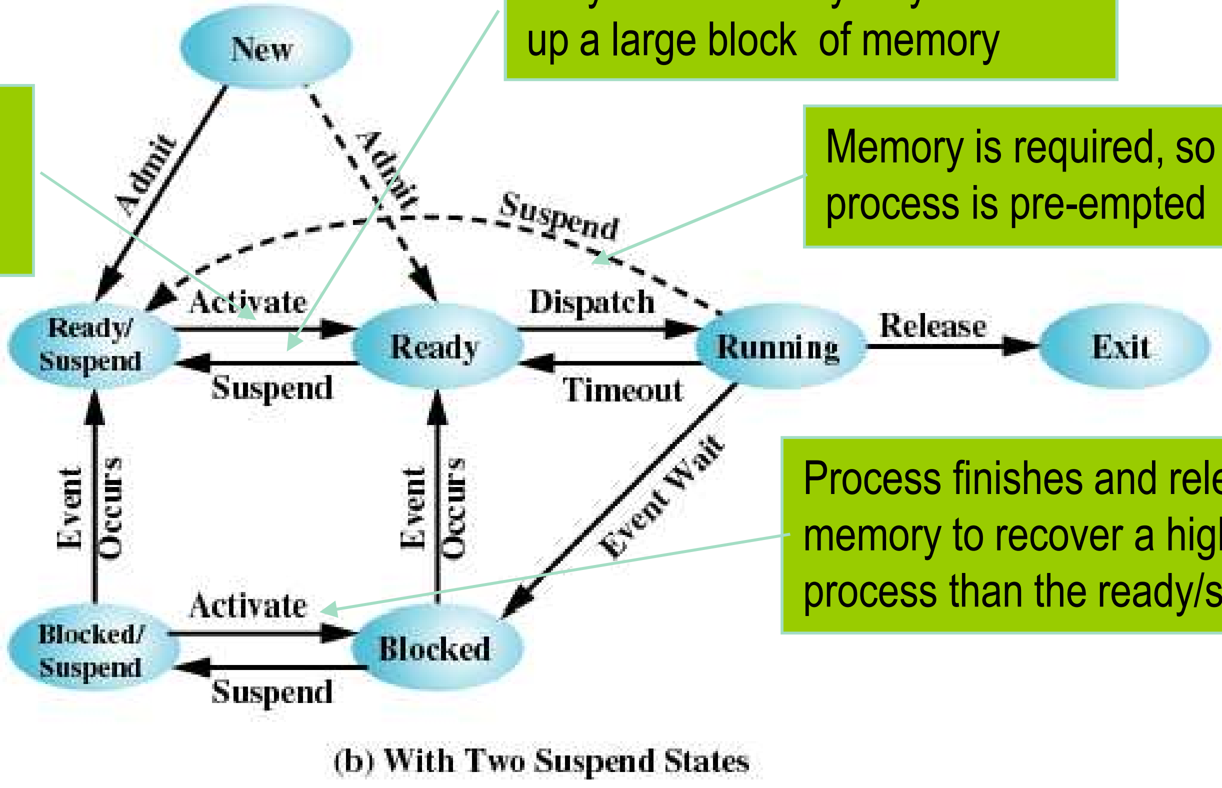


Reasons for Process Suspension

- Swapping: OS needs to release memory to bring in a ready process
- Protection: OS may suspend a process suspected of causing a problem
- User request: may whish to suspend execution for debugging reasons
- Timing: process executed periodically, and suspended while waiting the next round
- Others



Suspended Processes



Only if it is the only way to free up a large block of memory

No ready processes or ready processes with less priority

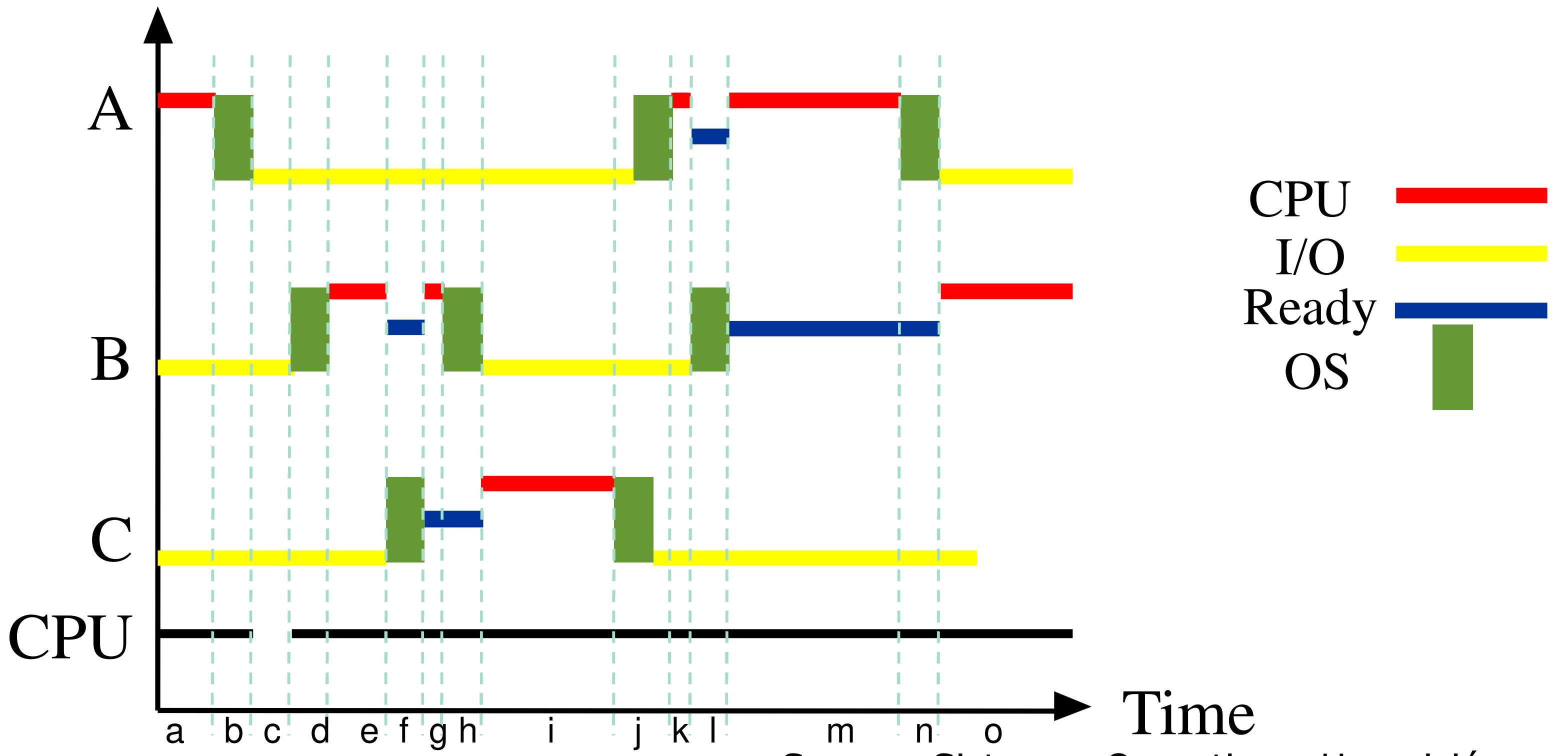
Memory is required, so process is pre-empted

Process finishes and releases enough memory to recover a higher priority process than the ready/suspended ones

Figure 3.9 Process State Transition Diagram with Suspend States

Source: Operating Systems. W. Stallings

Process Tracking



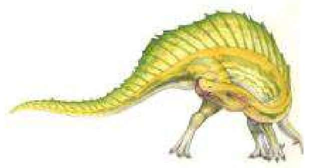
Source: Sistemas Operativos. Una visión aplicada.

a: A in CPU, B y C blocked
b: A calls the OS for I/O
c: All processes blocked (CPU idle)
d: B I/O finishes (awake and dispatch)
e: B in execution
f: C I/O finishes (awake), B ready
g: B still in CPU and C ready
h: B performs syscall. OS dispatches C and blocks B

i: C in CPU, A y B blocked
j: C calls the OS for I/O and A awakes
k: A in execution
l: I/O interrup. calls OS to wake up B
m: A still in Run and B watis for ready
n: A blocks
o: B starts to run

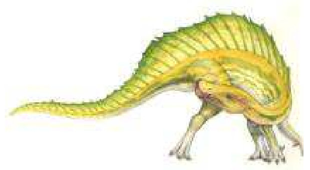
CPU always busy except in c

Contents



Process Control Block

- What happens if the processor switches from process A to process B?
  - The processor needs information to get back to execute process A
  - Operating systems need a information structure

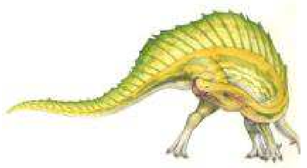


Process Control Block

- What happens if the processor switches from process A to process B?
  - The processor needs information to get back to execute process A
  - Operating systems need a information structure

$\Downarrow$

Process Control Block (PCB)



Process Control Block

- What happens if the processor switches from process A to process B?
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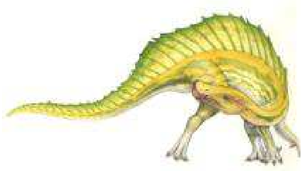
Process Control Block (PCB)

Context Switch



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

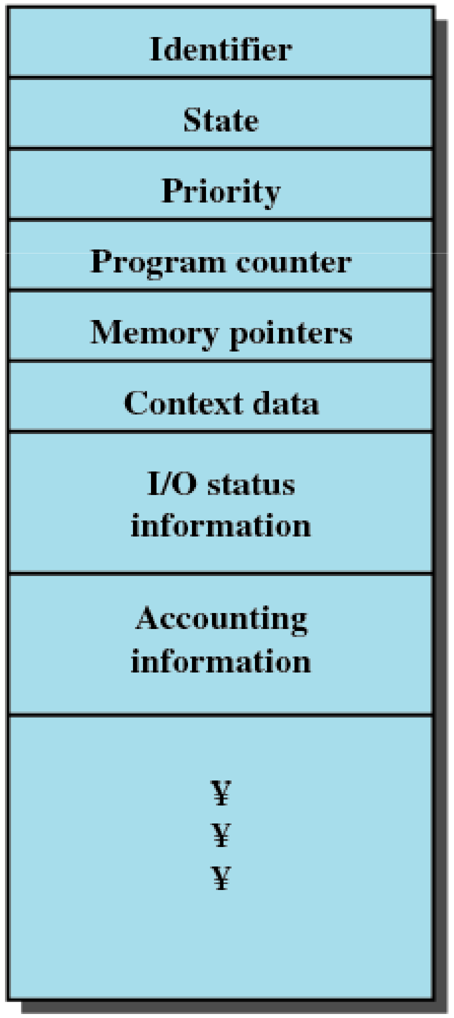
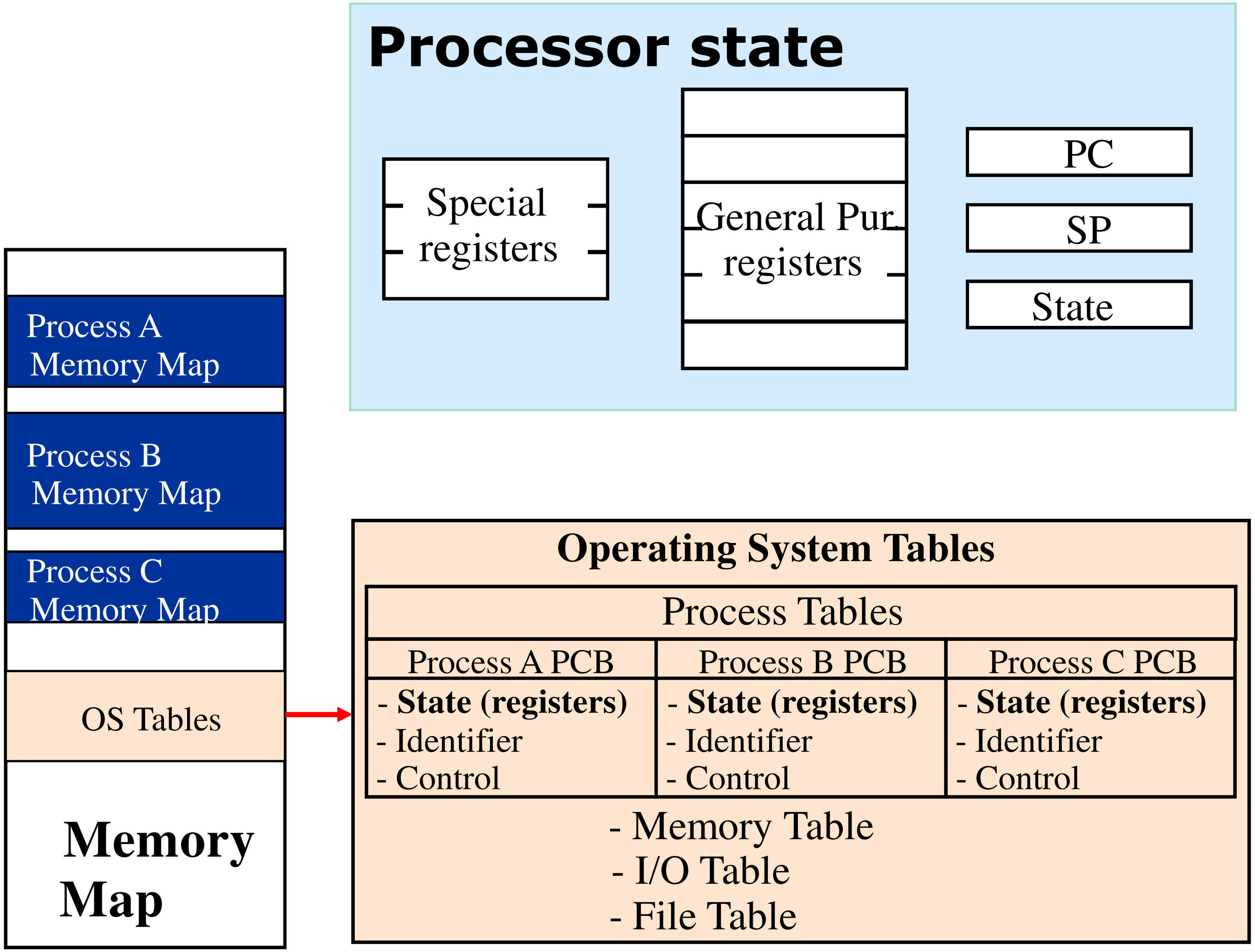


Figure 3.1 Simplified Process Control Block

Source: Operating Systems. W. Stallings

Process Information



Source: Sistemas Operativos. Una visión aplicada.

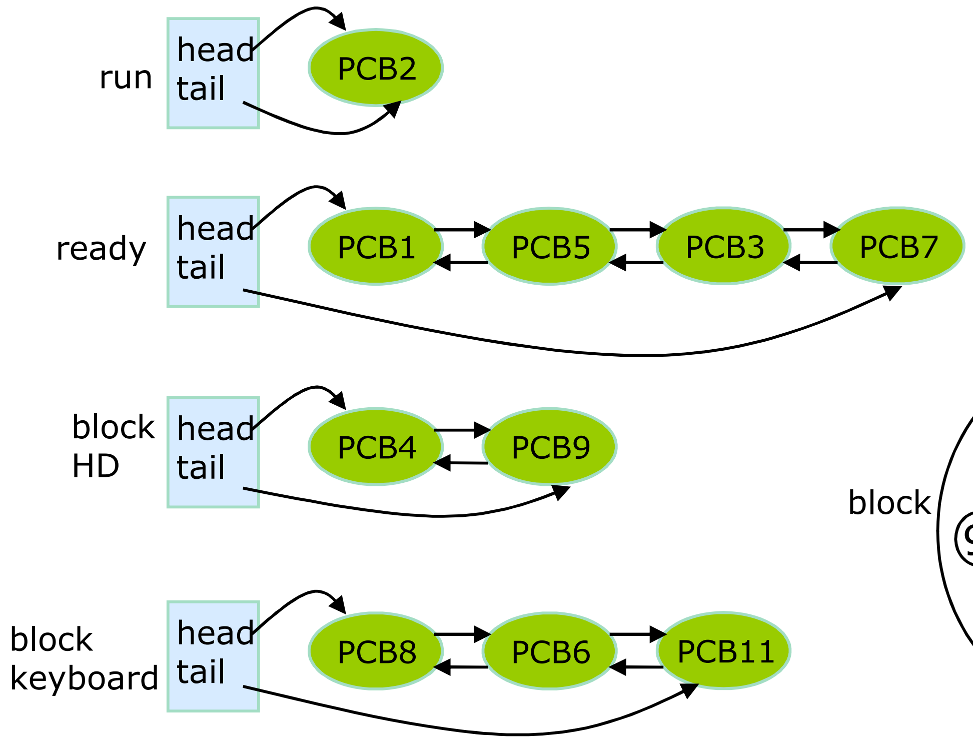
What does define a process?

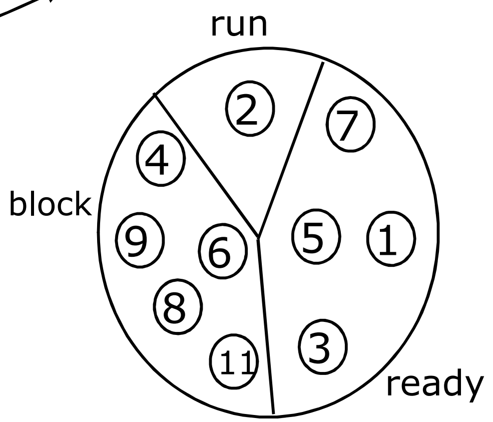
- State of the *processor*
  - Data of the registers of the processor
- Core image
  - Data of the memory segments (code, data and stack)
- Information/status of each process
  - Process Control Block (PCB)

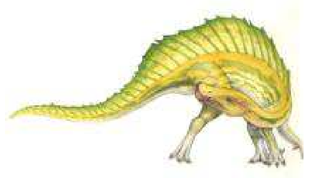
Process Image

Process organization

- Processes organization
  - Process lists of a certain type
    - Run: as many processes as processors
    - Ready: sorted list by the scheduler
    - Block: several non sorted lists
      - It speeds up the search of the process to wake up

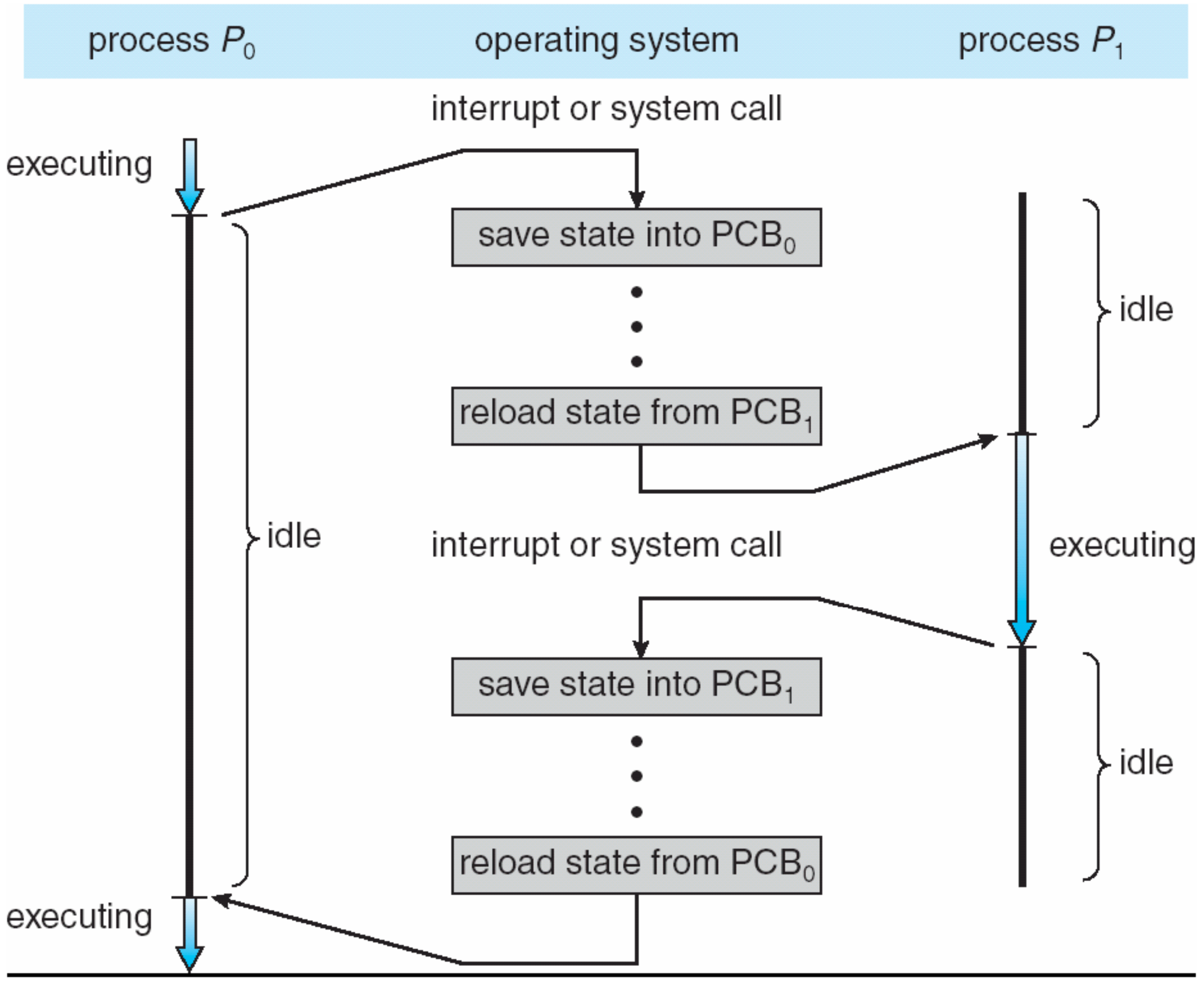






CPU Switch From Process to Process

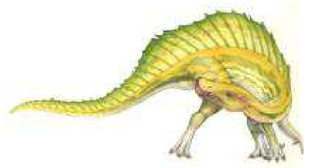
- The PCB is saved when a process is removed from the CPU and another process takes its place (context switch).



Source: Operating System Concepts. A. Silberschatz. Fig. 3.4

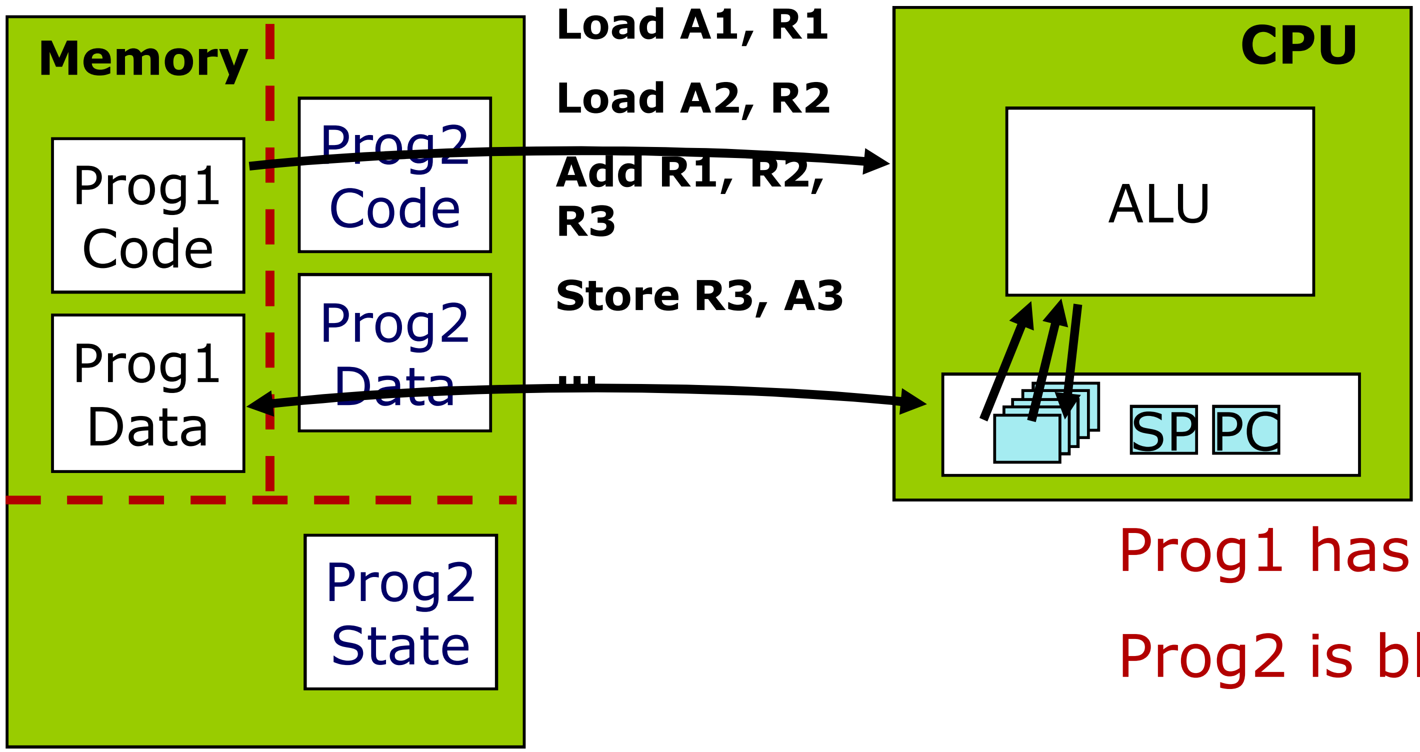
Context Switch

- 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 $\rightarrow$ the longer the context switch
- Time dependent on hardware support.
  - Varies from 1 to 1000 microseconds



Switching among multiple processes

- Program instructions operate on operands in memory and (temporarily) in registers

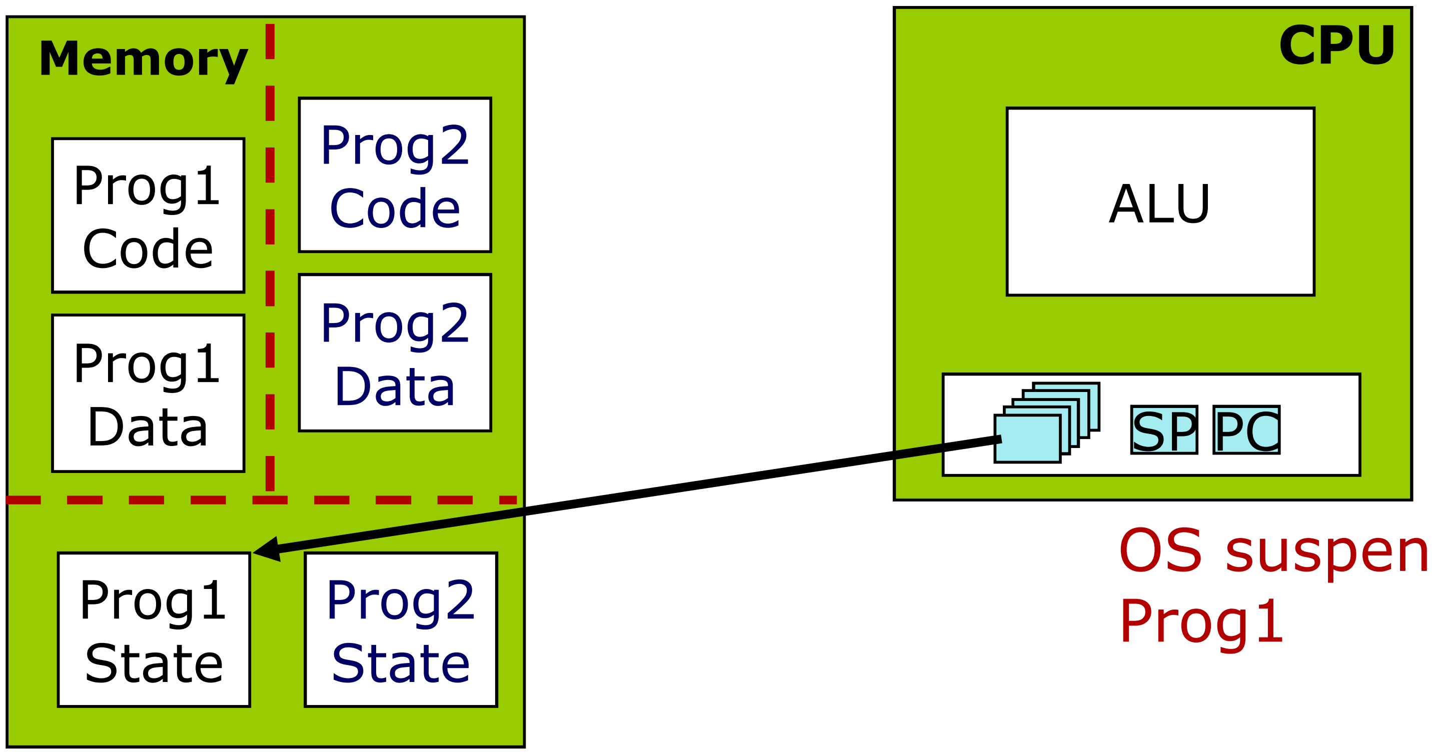


Prog1 has CPU

Prog2 is blocked

Switching among multiple processes

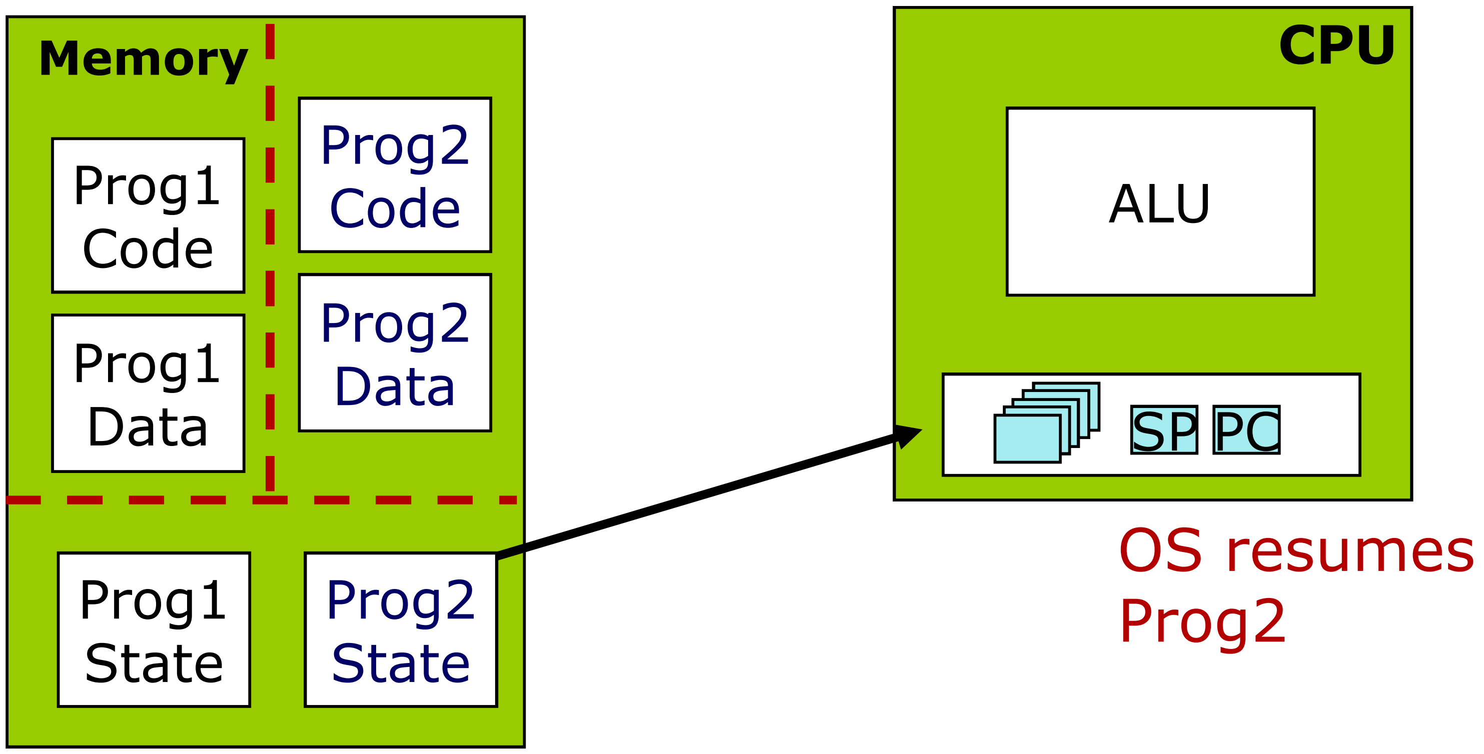
- Saving all the information about a process allows a process to be *temporarily suspended* and later *resumed* from the same point



OS suspends Prog1

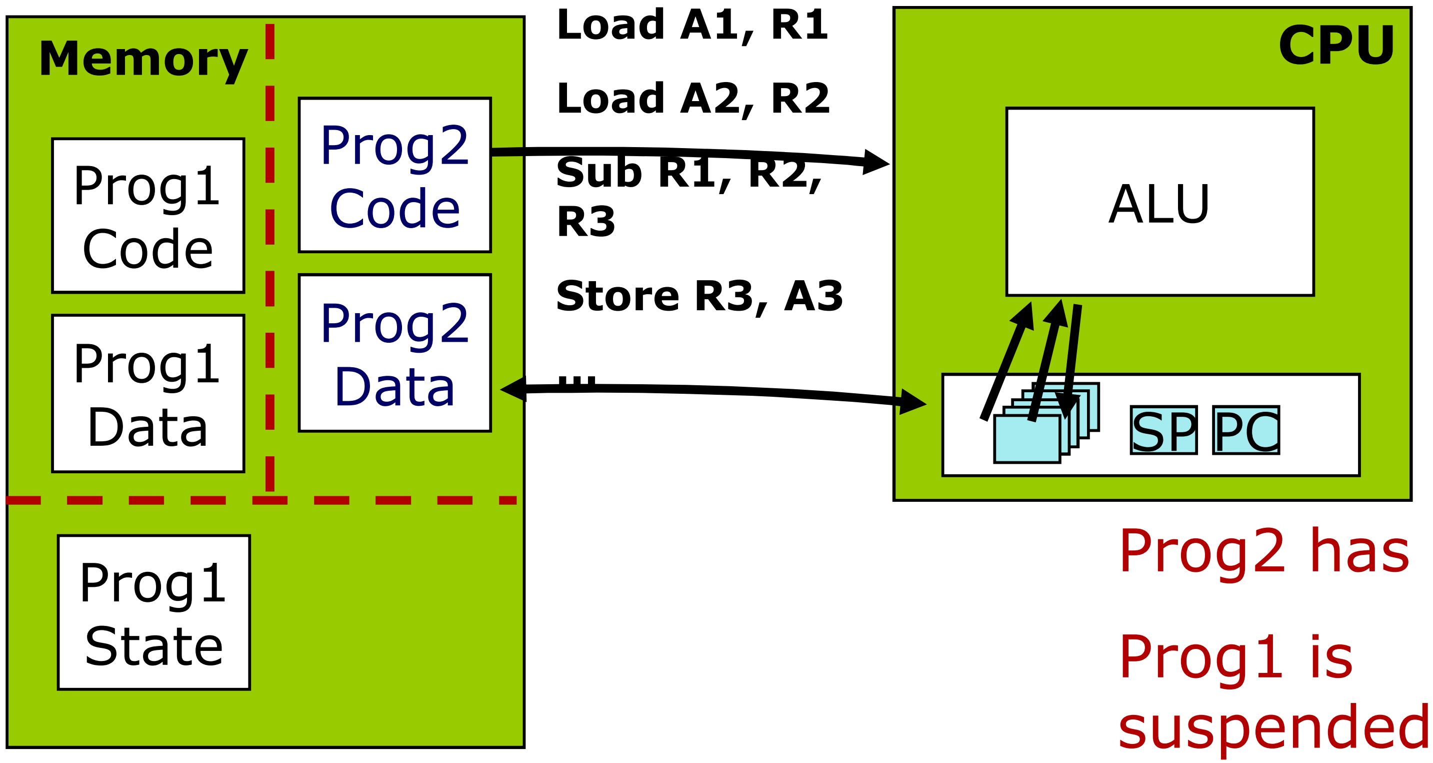
Switching among multiple processes

- Saving all the information about a process allows a process to be *temporarily suspended* and later *resumed*



Switching among multiple processes

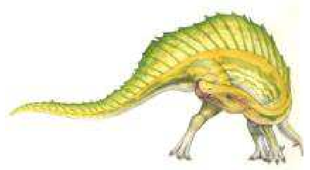
- Program instructions operate on operands in memory and in registers



Prog2 has CPU

Prog1 is suspended

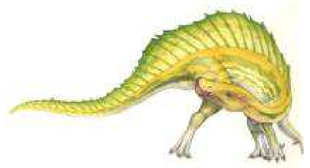
Contents



How do processes get created?

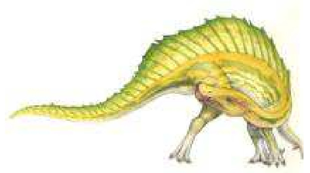
Principal events that cause process creation

- System initialization
- Initiation of a batch job
- User request to create a new process
- Execution of a process creation system call from another process



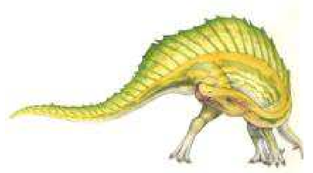
Process Creation

- **Parent** process create **children** processes, which, in turn create other processes, forming a **tree** of processes
  - special system calls for communicating with and waiting for child processes
  - each process is assigned a unique identifying number or **process ID** (**PID**)
- 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



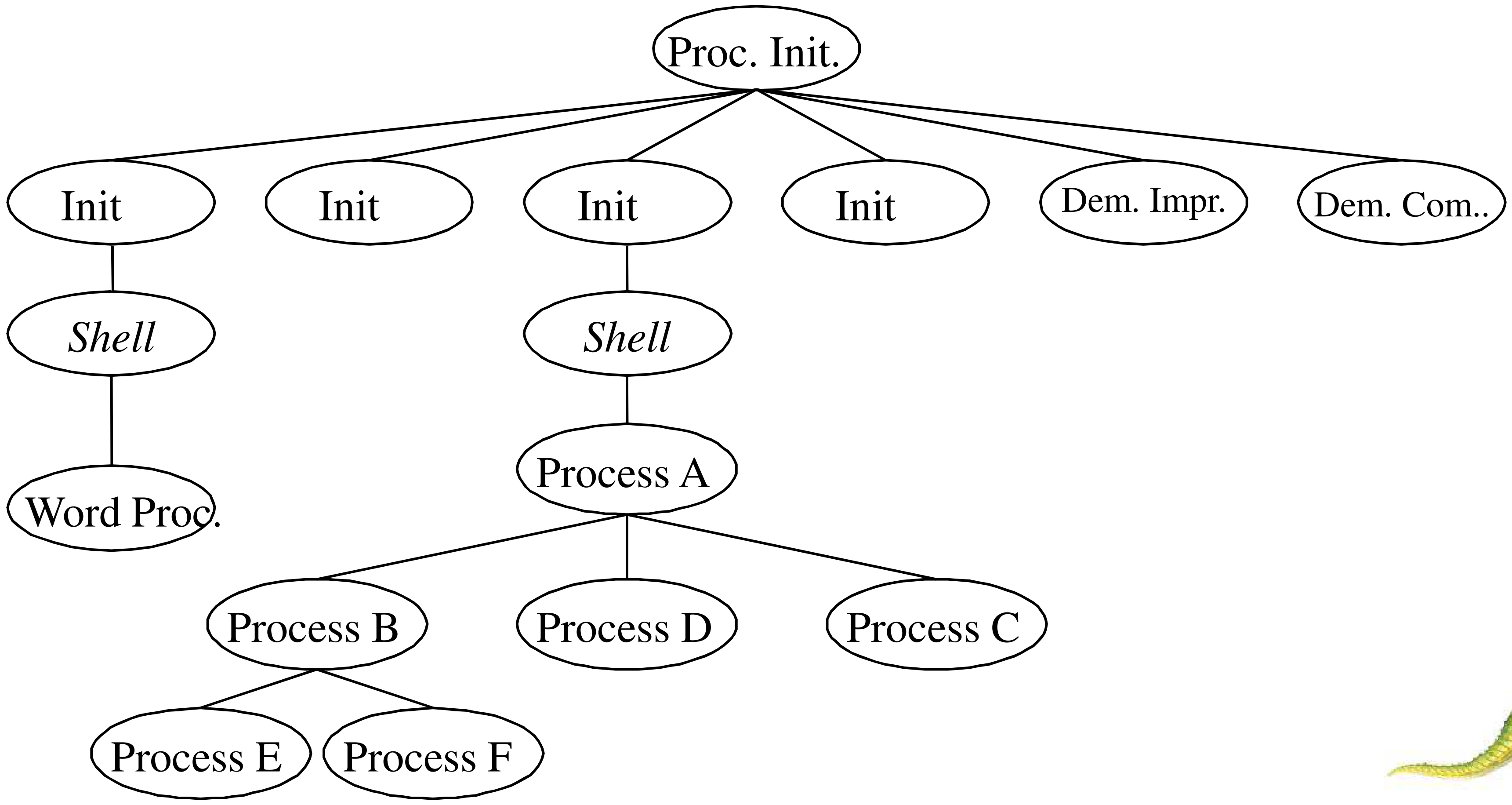
Process Creation (Cont)

- Address space
  - Child duplicate of parent (UNIX)
    - Child has copy of parent’s address space
      - Enables easy communication between the two
      - The child process’ memory space is replaced with a new program which is then executed. Parent can wait for child to complete or create more processes
  - Child has a program loaded into it directly (Windows or DEC VMS)
- Child processes can create their own child processes
  - Forms a hierarchy
  - UNIX calls this a "process group"
  - Windows has no concept of process hierarchy
    - all processes are created equal



A tree of processes in Unix

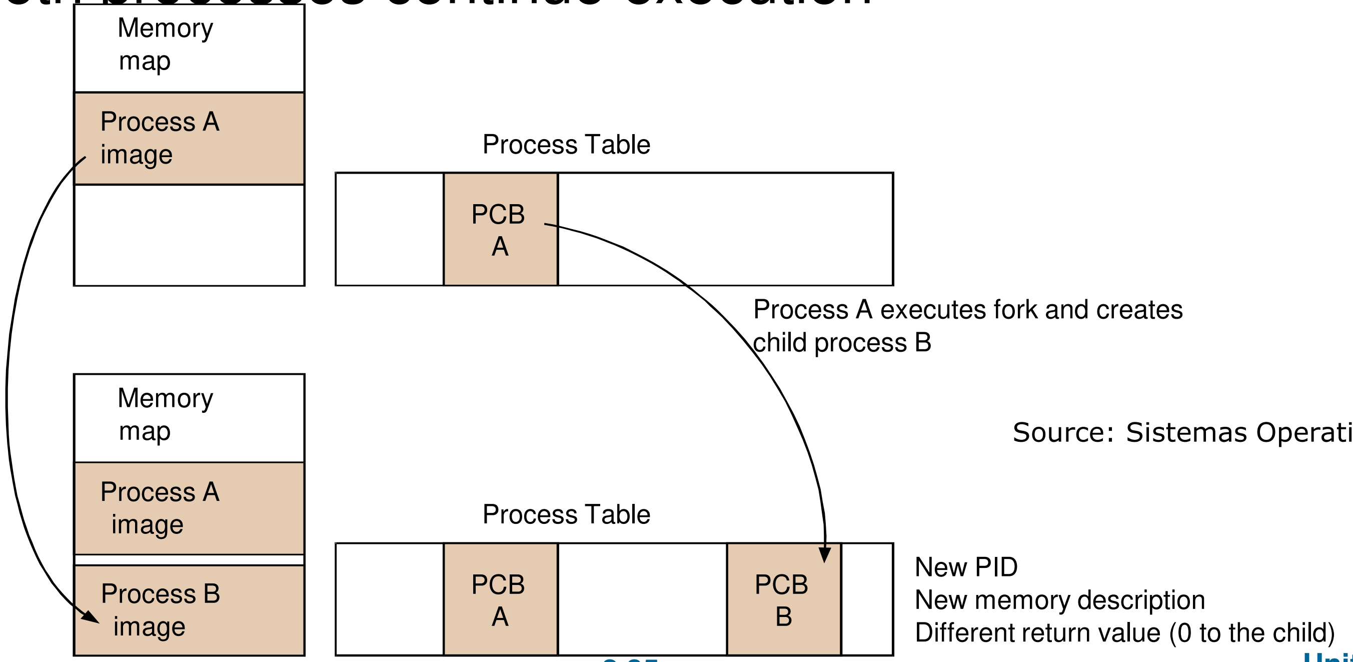
- The first process is Init ()
- Init creates login daemons
- Login becomes a shell
- Using the shell user spawns new processes



Source: Sistemas Operativos. Una visión aplicada.

Process creation in UNIX (POSIX)

- Process creation: `fork` and `exec`
  - `pid_t fork(void)` system call
    - creates new process which has a copy of the address space of the original process and returns in both processes (parent and child), but with a different return value:
      - **0 to child, pid's child to parent and -1 in error case**
    - Simplifies parent-child communication
    - Both processes continue execution



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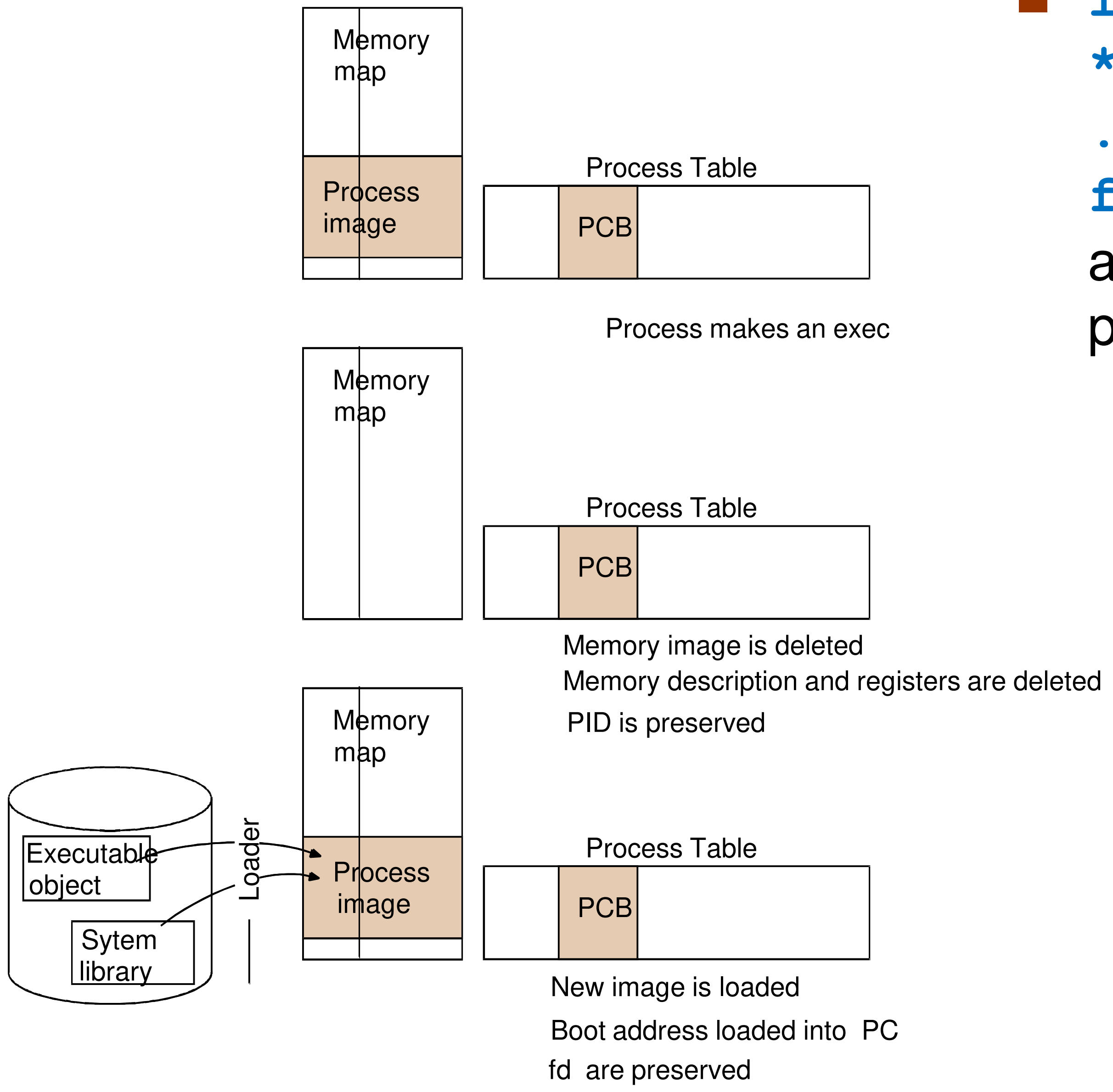
Process creation in Unix



Source: Sistemas Operativos. Una visión aplicada.

- `int execlp(const char *file, const char *arg, ...)` system call used after a `fork()` to replace the process' address space with a new program
  - Loads a binary file into memory and starts execution
  - Parent can then create more children processes or issue a `wait()` system call to move itself off the ready queue until the child completes

C Program Forking Separate Process

```
#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 */
       execlp("/bin/ls","ls",NULL);
    }
    else { /* parent process */
       /* parent will wait for the child to complete */
       wait(NULL);
       printf("Child Complete");
    }

    return 0;
}
```

Example: process creation in UNIX

csh (pid = 22)

```
…

pid = fork()
if (pid == 0) {
   // child…
   …
   exec(“ls”…);
   }
else {
   // parent
   wait();
   }
…
```

Process creation in UNIX example

csh (pid = 22)

```
…

pid = fork()
if (pid == 0) {
   // child…
   …
   exec("ls"…);
   }
else {
   // parent
   wait();
   }
…
```

csh (pid = 24)

```
…

pid = fork()
if (pid == 0) {
   // child…
   …
   exec("ls"…);
   }
else {
   // parent
   wait();
   }
…
```

Process creation in UNIX example

csh (pid = 22)

```
…

pid = fork()
if (pid == 0) {
   // child…
   …
   exec("ls"…);
   }
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   // parent
   wait();
   }
…
```

csh (pid = 24)

```
…

pid = fork()
if (pid == 0) {
   // child…
   …
   exec("ls"…);
   }
else {
   // parent
   wait();
   }
…
```

Process creation in UNIX example

csh (pid = 22)

```
…

pid = fork()
if (pid == 0) {
   // child…
   …
   exec("ls"…);
   }
else {
   // parent
   wait();
   }
…
```

csh (pid = 24)

```
…

pid = fork()
if (pid == 0) {
   // child…
   …
   exec("ls"…);
   }
else {
   // parent
   wait();
   }
…
```

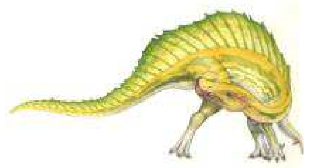
Process creation in UNIX example

csh (pid = 22)

```
…

pid = fork()
if (pid == 0) {
   // child…
   …
   exec(“ls”…);
   }
else {
   // parent
   wait();
   }
…
```

ls (pid = 24)

```
//ls program

main(){

   //look up dir

   …

}
```

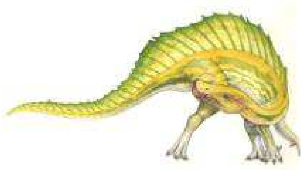


Creating a Separate Process via Windows API

```
#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);
}
```

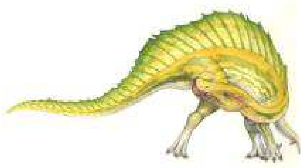
Others POSIX services

- All processes have a unique process id
  - `getpid()`, `getppid()` system calls allow processes to get their information
    - `pid_t getpid(void)` —returns the process ID of the calling process
    - `pid_t getppid(void)` –returns the parent process ID of the calling process



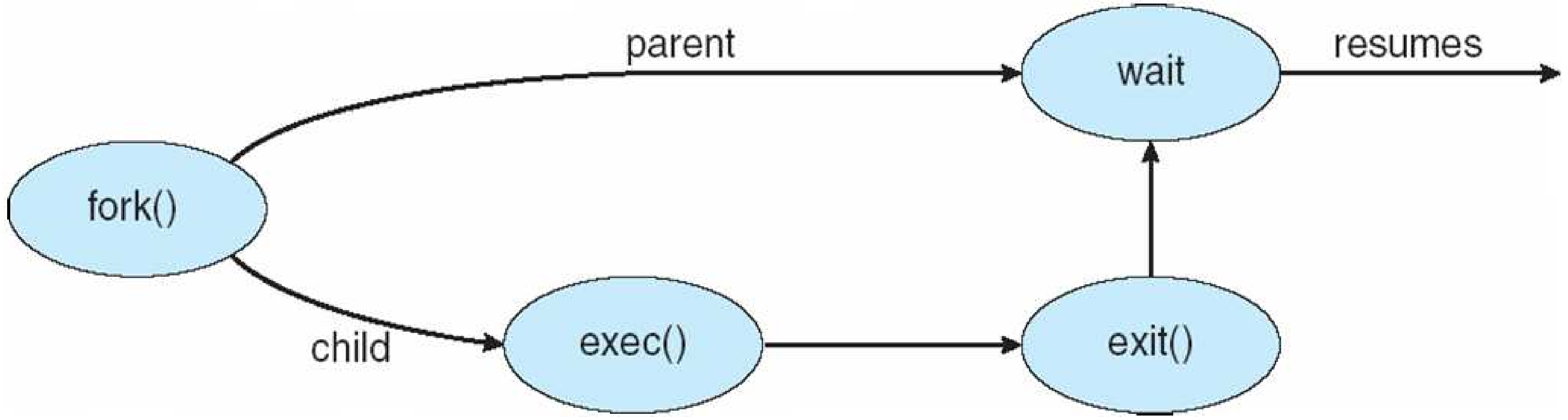
Process Termination

- Process executes last statement and asks the operating system to delete it by using the `exit()` system call
  - Process may return a status value to parent via `wait()`
  - Process' resources are deallocated by operating system
- Parent may terminate execution of children processes `abort()` in UNIX
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - Parent is exiting
    - Some operating systems do not allow child to continue if its parent terminates - `cascading termination`



Process Termination in Unix

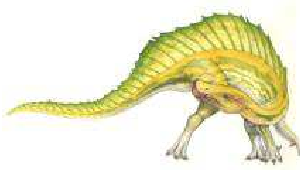
- In UNIX, a process can be terminated via the **`exit`** system call.
  - Parent can wait for termination of child by the **`wait`** system call
  - **`wait`** returns the process identifier of a terminated child so that the parent can tell which child has terminated



Source: Operating System Concepts. A. Silberschatz. Fig. 3.10

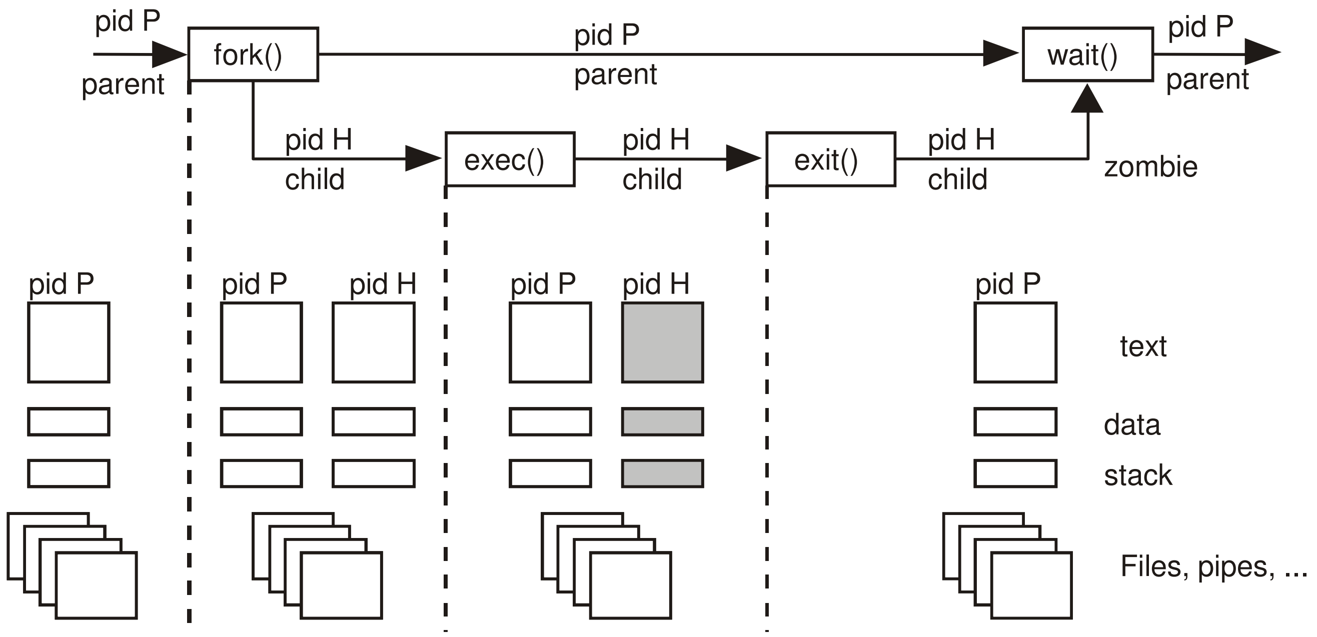
Wait() and Exit() (POSIX services)

- `int exit (int status);`
  - Arguments: code of returning to the parent
  - Description:
    - It finishs process execution
    - It closes all fd
    - It releases all process resources



Wait() and Exit() (POSIX services)

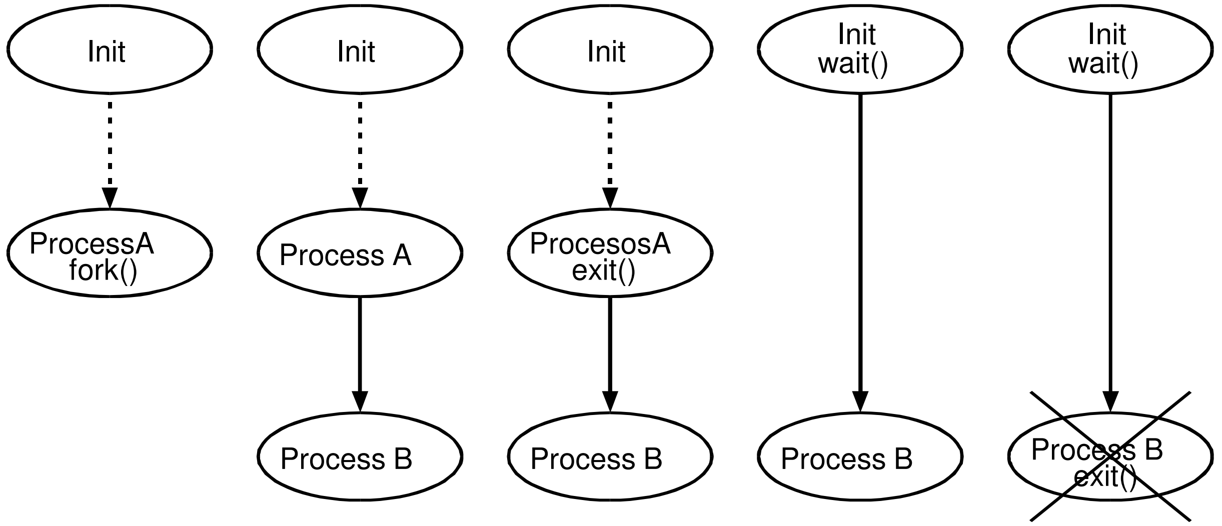
- `pid_t  wait (int *status);`
  - Arguments: returns the exit status of the child
  - Description:
    - This system call suspends execution of the calling process until one of its children terminates (a parent can wait till its child finishes)
    - It returns pid and exit status of the child (-1 in error case)



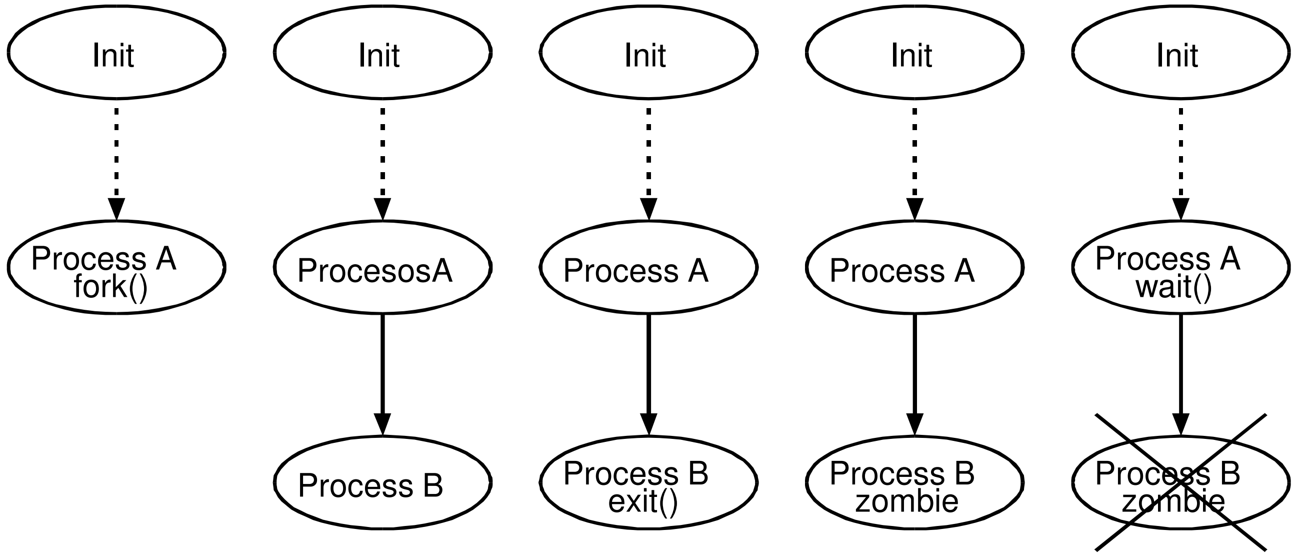
Source: Sistemas Operativos. Una visión aplicada.

Process Termination in Unix

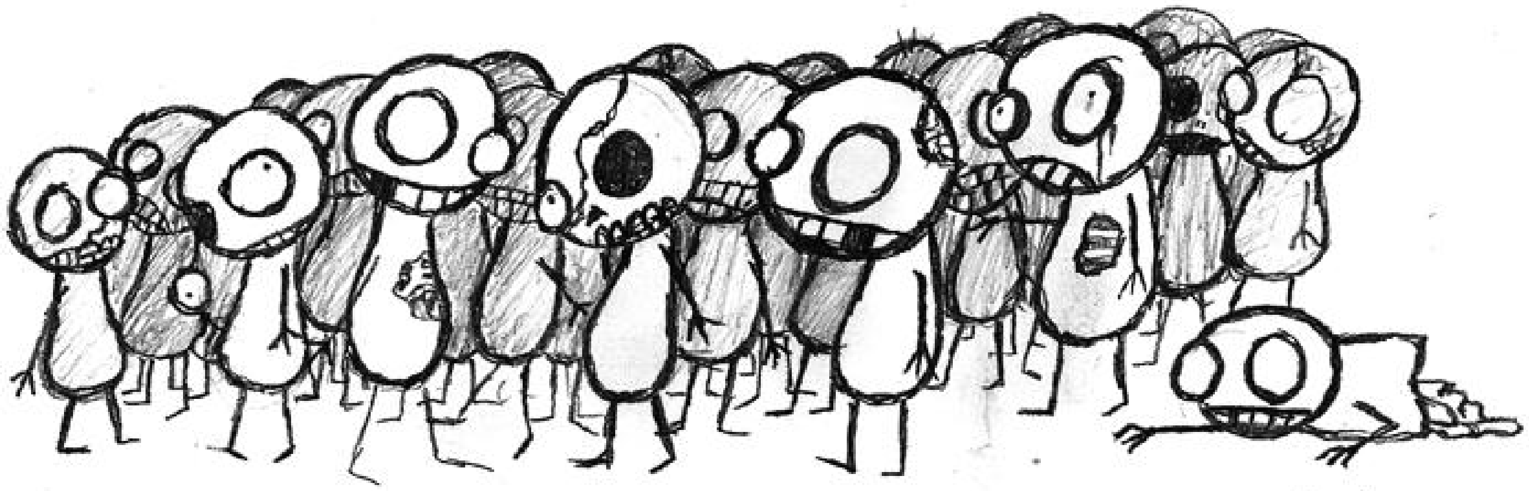
- If a parent terminates, all children are assigned the **init** process as their new parent



- Zombie: childrens terminate (exit) and father doesn't call to wait



Source: Sistemas Operativos. Una visión aplicada.

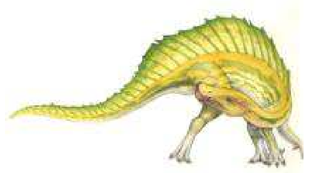


Source: https://ninefold.com/blog/2014/11/25/threads/

Example: process creation in UNIX

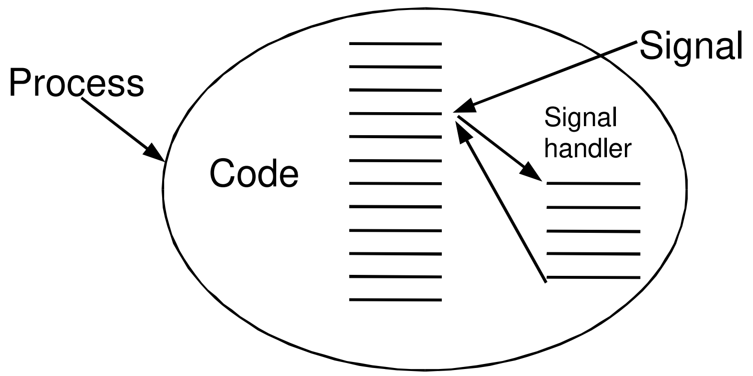
- A process launches command “ls –l”

```
#include <sys/types.h>
#include <stdio.h>
/* program executes command ls -l */
main() {
   pid_t pid;
   int status;
   pid = fork();
   if (pid == 0)    { /* child process */
      execlp("ls","ls","-l",NULL);
      exit(-1);
   }
   else          /* parent process */
     while (pid != wait(&status));
   exit(0);
}
```



Signal Handling

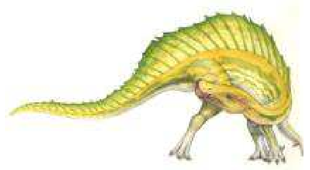
- Signals are used in UNIX systems to notify a process that a particular event has occurred
- Process termination, signaling
  - *signal(), kill()* system calls allow a process to be terminated or have specific signals sent to it
- The signals are process interrupts
  - Signals are sent:
    - From process to process with kill
    - From OS to a process



Source: Sistemas Operativos. Una visión aplicada.

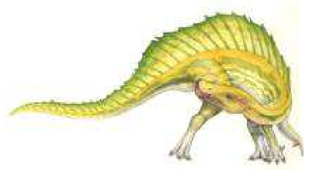
Signal Handling

- Types of signals (kill –l shows the list)
  - SIGKILL -9- (Kill : terminate immediately)
  - SIGTERM -15- (Termination : request to terminate)
  - SICHLD -17- (Child process terminated, stopped or continued)
  - SIGCONT -18- (Continue if stopped)
  - SIGSTOP -19- (Stop executing temporarily)
  - SIGTTIN -21. (Background process attempting to read from tty)
  - SIGTTOU -22- (Background process attempting to write to tty)



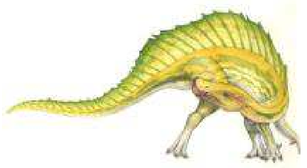
Signal Handling

- **Signals** are used in UNIX systems to notify a process that a particular event has occurred.
- A **signal handler** is used to process signals
  1. Signal is generated by particular event
  2. Signal is delivered to a process
  3. Signal is handled by one of two signal handlers:
     1. default
     2. user-defined
- Every signal has **default handler** that kernel runs when handling signal
  - **User-defined signal handler** can override default



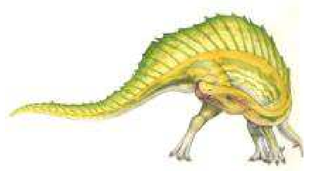
Signal Handling in Unix

- Signal handlers can be installed with the `signal()` system call.
  - When the signal is intercepted, the signal handler is invoked
- If a signal handler is not installed for a particular signal, the default handler is used.
- The process can also specify two default behaviors, without creating a handler:
  - ignore the signal (SIG_IGN)
  - use the default signal handler (SIG_DFL)
- The `sigprocmask()` call can be used to block and unblock delivery of signals.



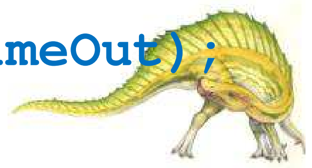
Handling Signals (POSIX)

- `int kill(pid_t pid, int sig)`
  - It sends to the process “pid” the signal “sig”
- `int sigaction(int sig, struct sigaction *act, struct sigaction *oact)`
  - It allows to specify the action to be taken when the signal “sig” is received
- `int pause(void)`
  - It blocks the process until the reception of a signal
- `unsigned int alarm(unsigned int seconds)`
  - It generates the reception of signal SIGALARM after “seconds” seconds
- `sigprocmask(int how, const sigset_t *set, sigset_t *oset)`
  - It is used to explore or modify the signal mask of a process



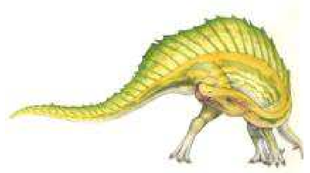
Win32 services

- To create a process
  - `BOOL CreateProcess(….);`
- To finish the execution of a process
  - `VOID ExitProcess(UINT nExitCode);`
- To obtain the end code of a process
  - `BOOL GetExitCodeProcess(HANDLE hProcess, LPDWORD lpdwExitCode);`
- To finish the execution of another process
  - `BOOL TerminateProcess(HANDLE hProcess, UINT uExitCode);`
- To wait till the end of a process
  - `DWORD WaitForSingleObject(HANDLE hObject, DWORD dwTimeOut);`
  - `DWORD WaitForMultipleObjects(DWORD cObjects, LPHANDLE lphObjects, BOOL fWaitAll, DWORD dwTimeOut);`



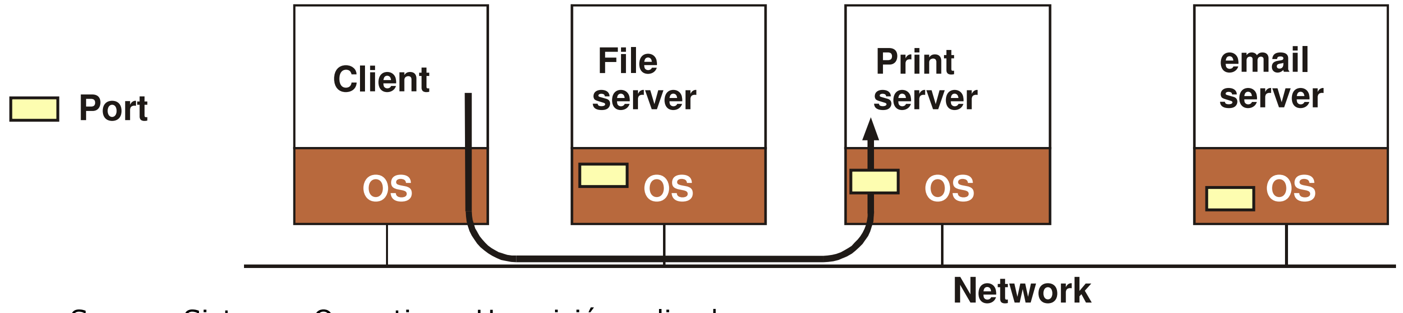
Summary (POSIX & Win32 APIs)

- Process identification
  - `getpid, GetCurrentProcessId`
- Process environment variables
  - `getenv, GetEnvironmentStrings`
  - Path, home directory, working directory, personal directory
- Process creation: `fork, CreateProcess`
  - Program transformation: `exec`
- Waiting for termination of a process: `wait, WaitForSingleObject, WaitForMultipleObjects`
- Process termination: `exit, ExitProcess`
- Send signal to process: `kill, TeminateProcess`



Daemon processes (or System Agents)

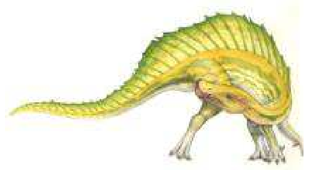
- Special processes:
  - Running in background
  - Non related to a terminal or login process
  - Waiting for an event (client request)
  - Perform a specified operation at predefined times
- Characteristics:
  - Start at the boot time
  - Don’t die
  - Usually waiting for an event
  - Don’t make the job, they create other process or threads
  - Can be in a different machine to the client



Source: Sistemas Operativos. Una visión aplicada.

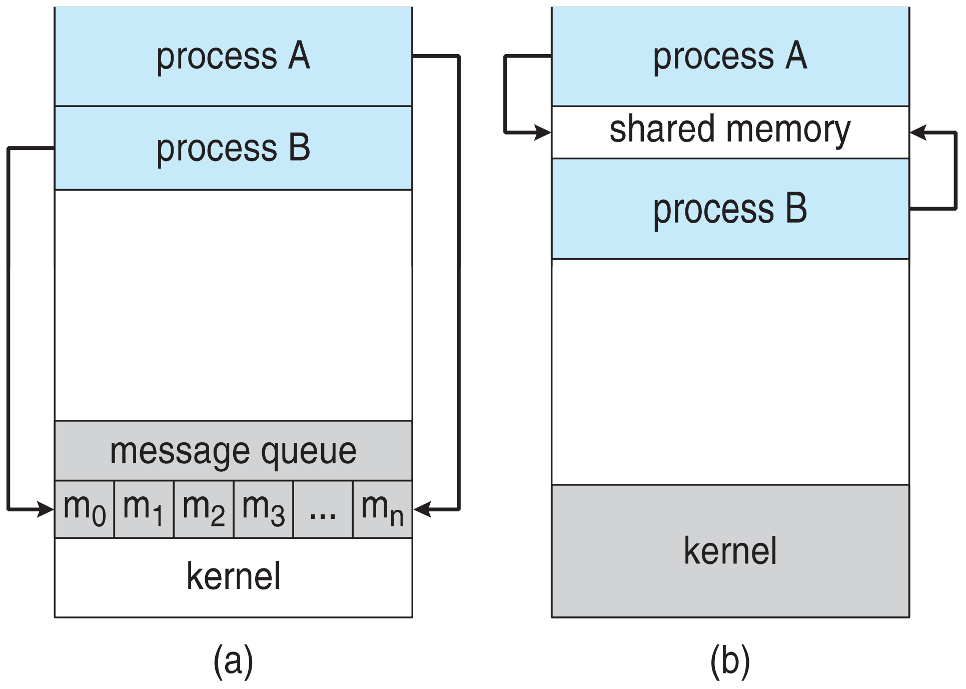
Cooperating Processes

- **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 via parallel sub-tasks
  - Modularity by dividing system functions into separate processes
  - Convenience - even an individual may want to edit, print and compile in parallel
- Cooperating processes need an **interprocess communication** (**IPC**) mechanism to exchange data
- Two models of IPC
  - Shared memory
  - Message passing



Interprocess Communication

- Message passing
  - useful for small amounts of data
  - easier to implement than shared memory
  - requires system calls and thus intervention of the kernel
- Shared memory
  - maximum speed (speed of memory) and convenience
  - system calls required only to establish the shared memory regions; further I/O does not require the kernel

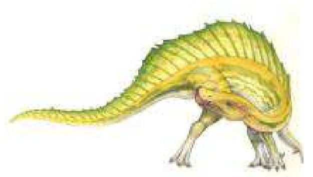


Source: Operating System Concepts. A. Silberschatz. Fig. 3.12

Contents

Process handicaps

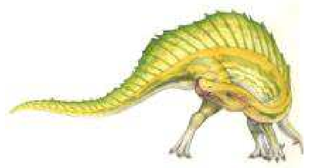
- There are applications, parallel by nature, that need to share the same address space:
  - Data base servers
  - Transaction processing monitors
  - Network protocols processing
  - Etc.
- ***Parallelism*** implies a system can perform more than one task simultaneously
- It is non easy to perform parallelism using process
  - Process creation is heavy-weight (usage of memory, context switch overhead) and time consuming
  - Interprocess communication is costly



From Process to Threads

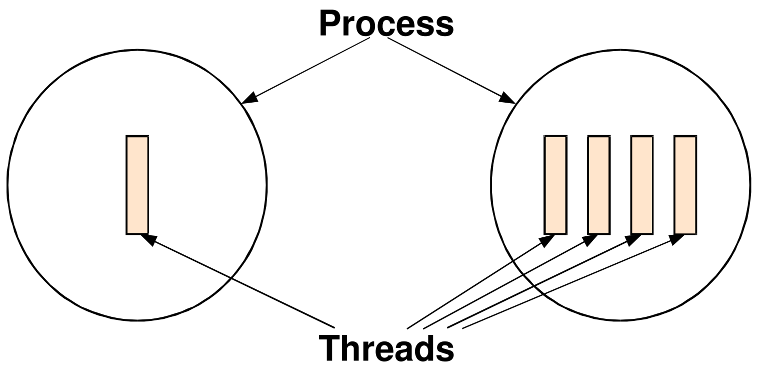
- Processes have two characteristics:
  - Unit of scheduling/execution (control flow):
    - Execution state, dispatching priority, instructions to be executed
  - Unit of resource ownership:
    - address space, allocated resources (files, I/O channels, I/O devices, main memory)
- A new model of execution different from process concept:

Threads



Thread concept

- Idea: Split the process into two entities
  - Thread: only the unit of Scheduling/Execution (control flow)
  - Process: the unit of Resource ownership + thread
- More than one control flow (thread) “live” in a same address space
  - It is allowed several executions with the same program (code and data) and OS resources

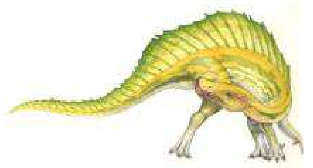


Source: Sistemas Operativos. Una visión aplicada.

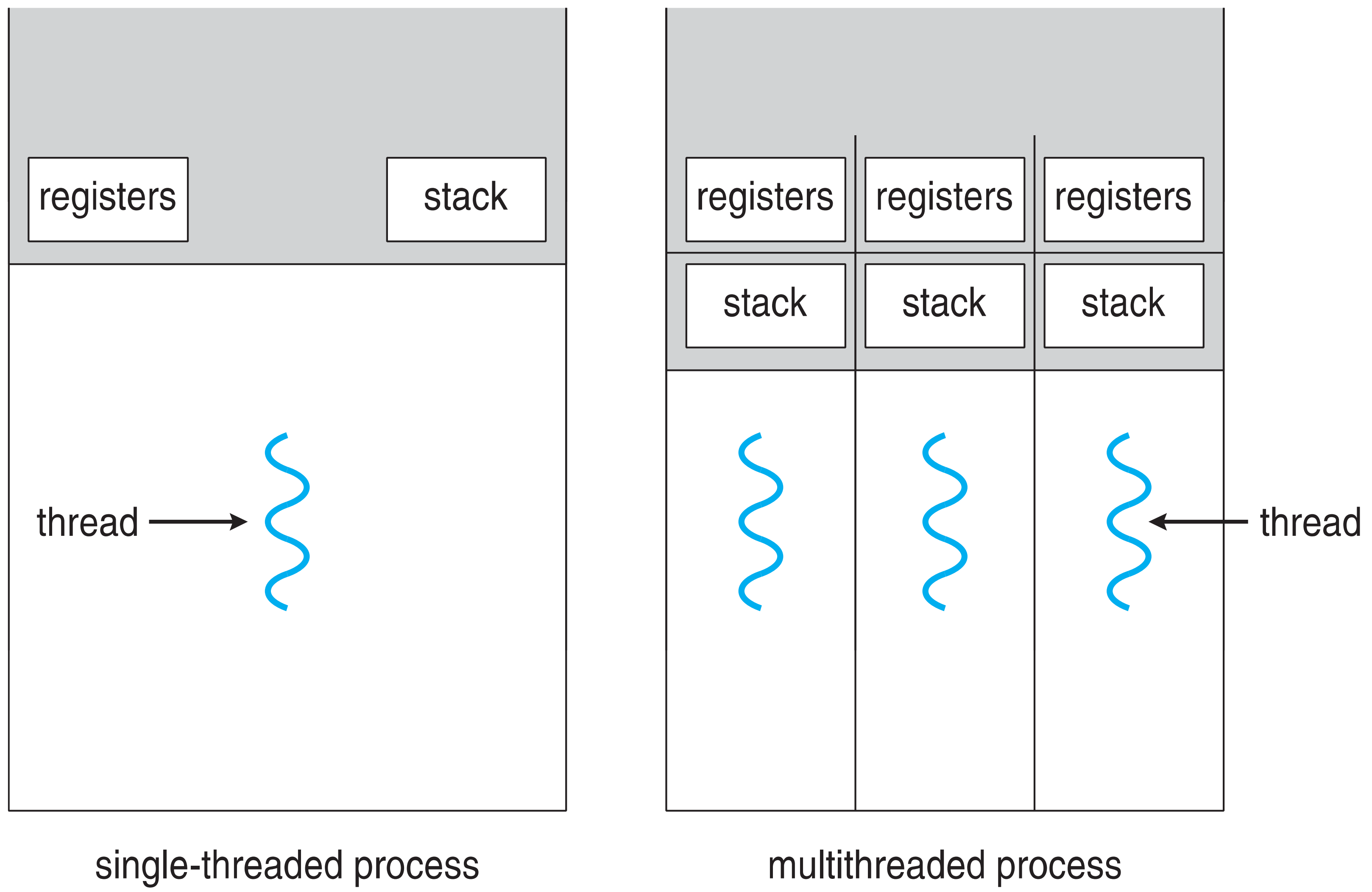
Thread definition

- A *thread* is the entity within a process that can be scheduled for execution
- A thread is sometimes called a **lightweight process**
  - It is comprised over a thread ID, program counter, a register set and a stack
  - It has an execution state (Running, Ready, etc.) and some static storage for local variables
  - When not running, the thread context is saved
  - It shares with other threads belonging to the same process its code section, data section and other OS resources (e.g., open files), signals, global variables, child processes,…
  - A process that has multiples threads can do more than one task at a time
- Each process is started with a single thread, but can create additional threads from any of its threads

Thread information

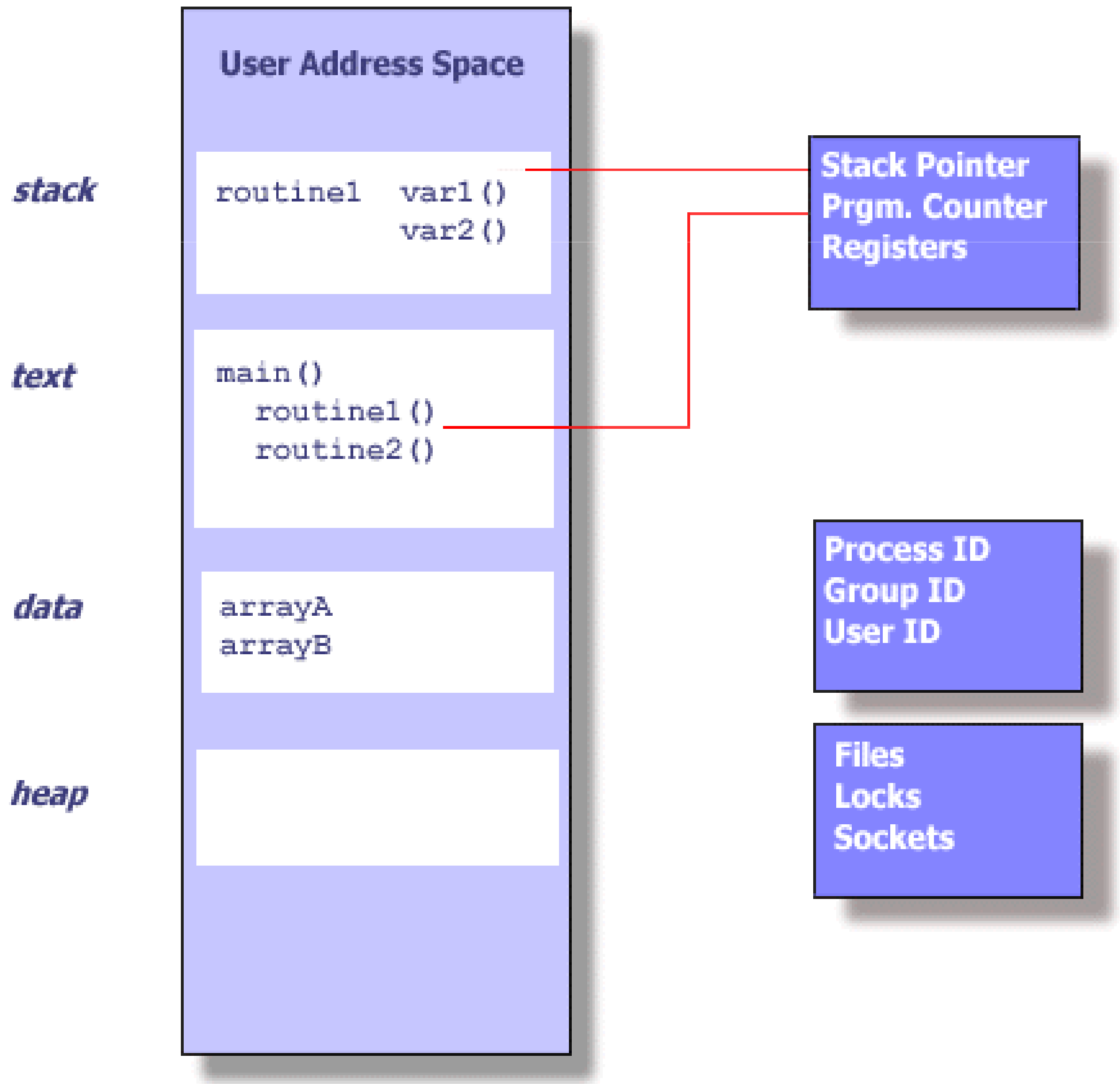


Single and Multithreaded Processes

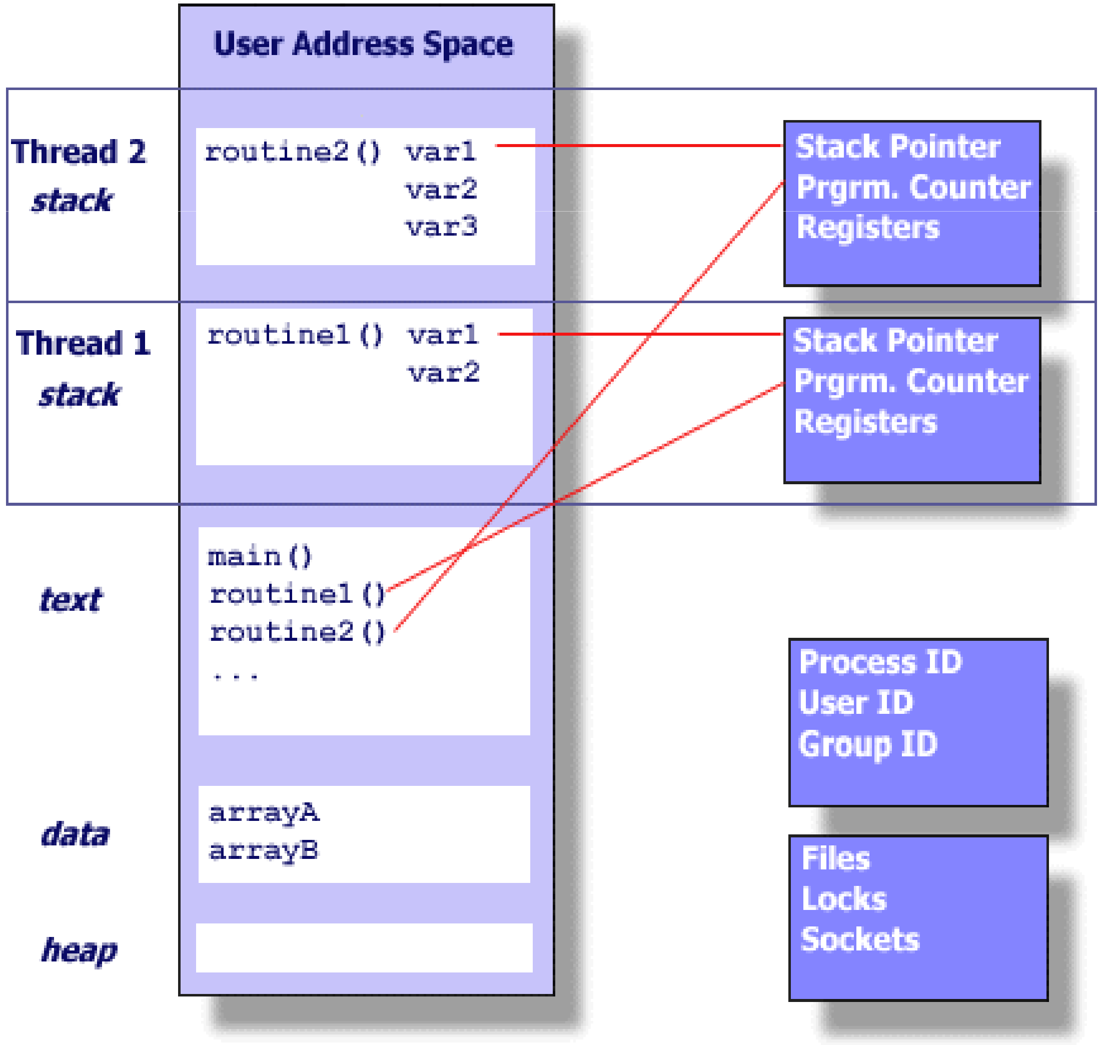


Source: Operating System Concepts. A. Silberschatz. Fig. 4.1

Single thread state within a process

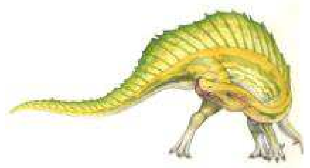


Multiple threads in an address space



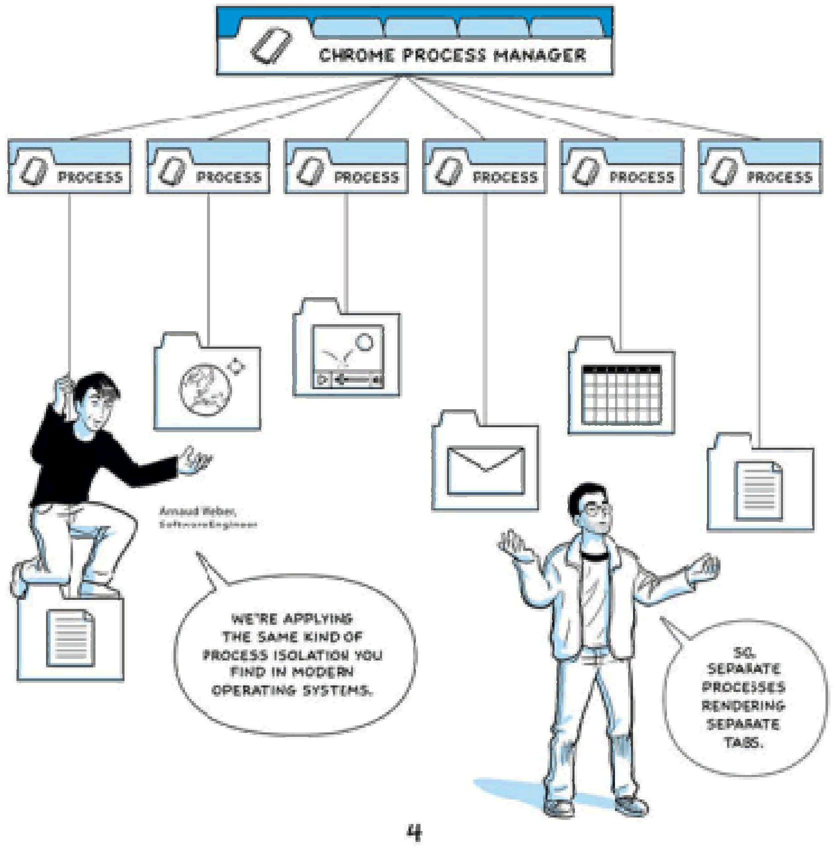
Nowadays…

- Most modern applications are multithreaded
- Threads run within application
- Multiple tasks with the application can be implemented by separate threads
  - Web-browser: one to display images, another to retrieve data from the network, …
  - Word processor: spell checking, display graphics, read keystrokes from the user
  - Web server: answer a network request
- Kernels are generally multithreaded



Although….

- Tabs in web-browsers are:
  - Threads:
    - they share memory but some of them can modify some local variable and harm/affect the other tabs
  - Process:
    - They don't share memory and, thus, they are more reliable
    - Each tab in Chrome and Firefox runs a process


CHROME PROCESS MANAGER
PROCESS
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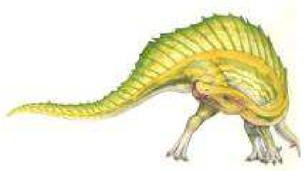
PROCESS
PROCESS
Arnaud Weber, Software Engineer
WE'RE APPLYING THE SAME KIND OF PROCESS ISOLATION YOU FIND IN MODERN OPERATING SYSTEMS.
SO, SEPARATE PROCESSES RENDERING SEPARATE TABS.
4

Source: http://impl.emented.com/2008/09/02/chrome-googles-first-steps-towards-an-operating-system/

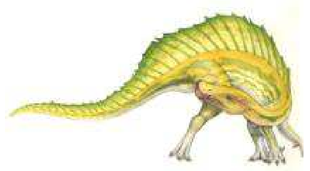
Multithreading concept

- **Multithreading**:
  - Multiple threads per Process
  - The **ability of an OS** to support multiple concurrent threads executing within a single process



Multithreading Benefits

- **Responsiveness –** may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing –** threads share resources of process, easier than shared memory or message passing
- **Economy –** cheaper than process creation, thread switching lower overhead than context switching
  - Process creation is heavy-weight while thread creation is light-weight
- **Scalability –** process can take advantage of multiprocessor architectures
- Can simplify code, increase efficiency



Multithreaded Environments

- Single-threaded approach:
  - A single thread of execution per process (thread concept not recognized)
    - Ex.: MS-DOS
  - Multiple processes with one thread per process
    - Ex.: UNIX
- Multithreaded approach:
  - One process with multiple threads
    - Ex.: Java
  - Multiple process with multiple threads
    - Ex.: Linux, Windows, Solaris,…

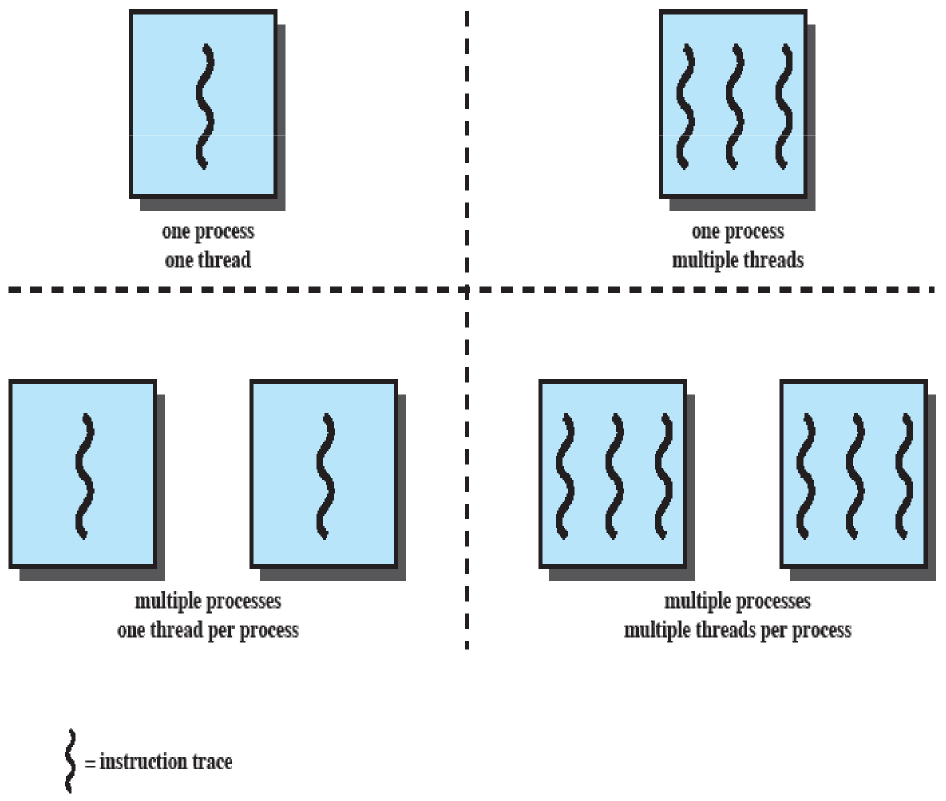
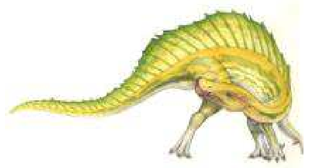


Figure 4.1 Threads and Processes [ANDE97]

Source: Operating Systems. W. Stallings

Thread Control Block

- As a process each thread has its own Thread Control Block:
  - thread ID
  - program counter
  - execution state (Running, Ready, etc.)
  - scheduling information
  - context saved (when not running),…



Threads information

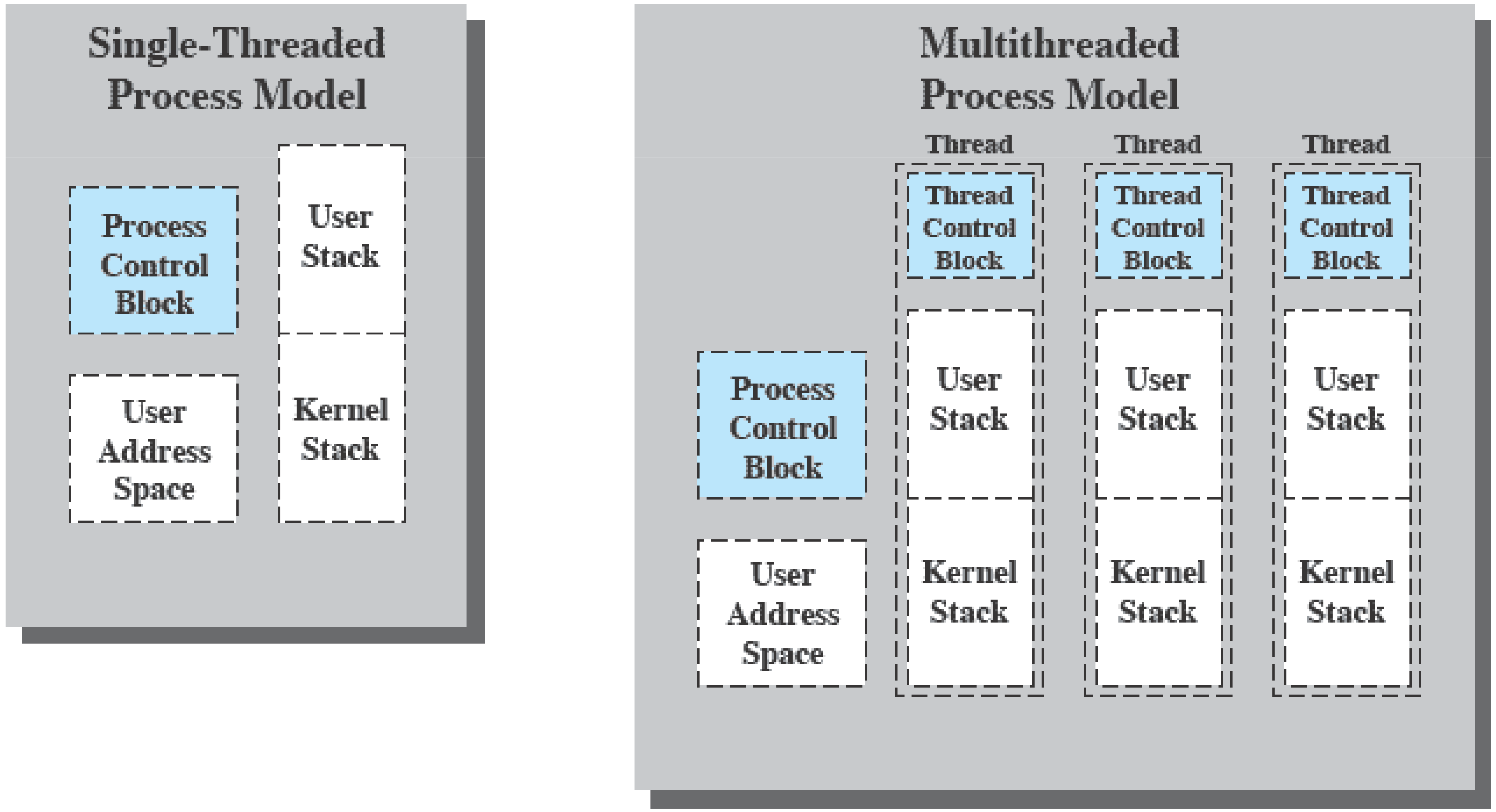
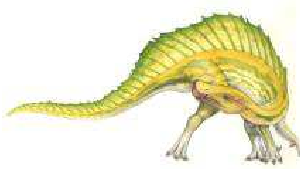


Figure 4.2 Single Threaded and Multithreaded Process Models

Source: Operating Systems. W. Stallings

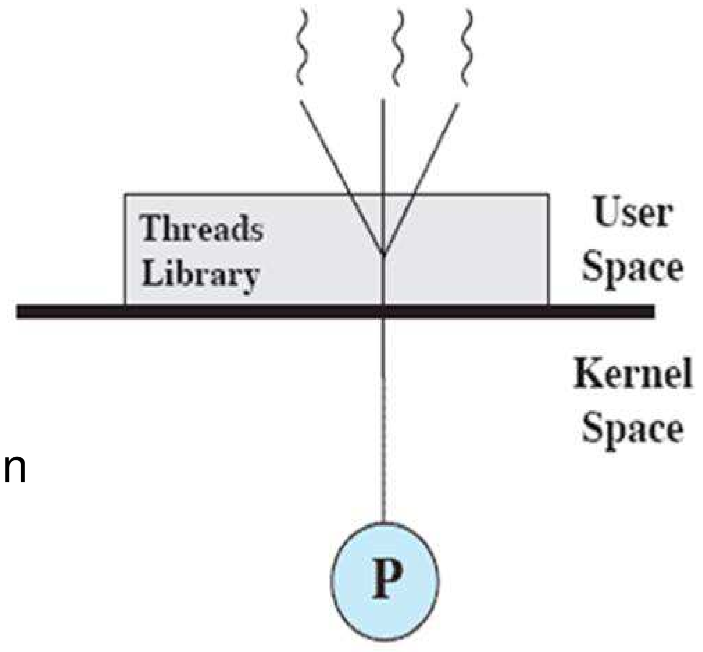
Types of Threads

- Two types:
  - User Level Thread (ULT)
  - Kernel level Thread (KLT)



User-Level Threads (ULTs)

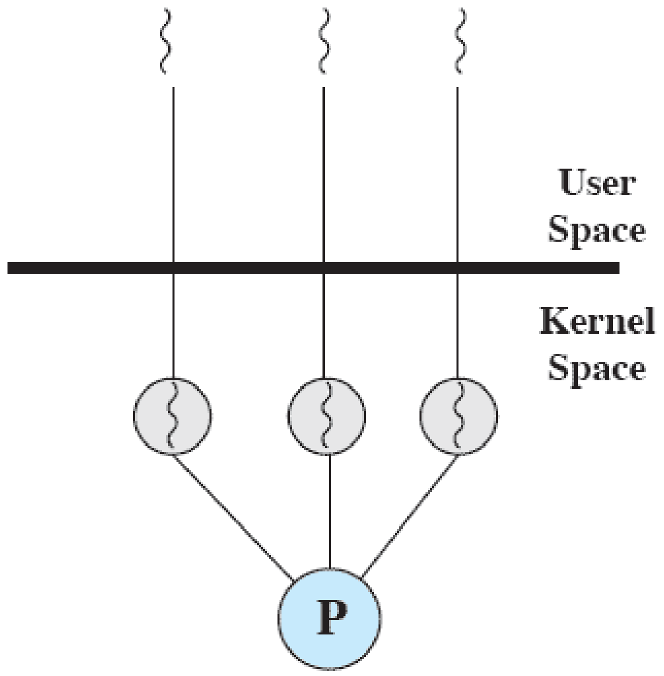
- All thread management is done by the application (library)
- The kernel is not aware of the existence of threads
- **Advantages**:
  - Thread switching does not require kernel mode privileges
  - Scheduling can be application specific (doesn't depend on OS)
  - ULTs can run on any OS (while library is available)
- **Disadvantages**:
  - If a thread is blocked, then all of the threads within the process are blocked
  - ULTs **cannot** take advantage of multiprocessing (multi-processor or multi-core)



(a) Pure user-level

Source: Operating Systems. W. Stallings

Kernel-Level Threads (KLTs)



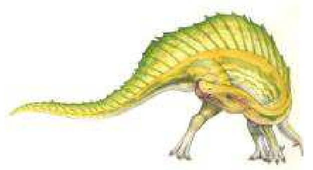
(b) Pure kernel-level

Source: Operating Systems. W. Stallings

- Thread management is done by the kernel
  - no thread management is done by the application
  - Windows, Linux , OS/2 and Mac OS X are examples of this approach

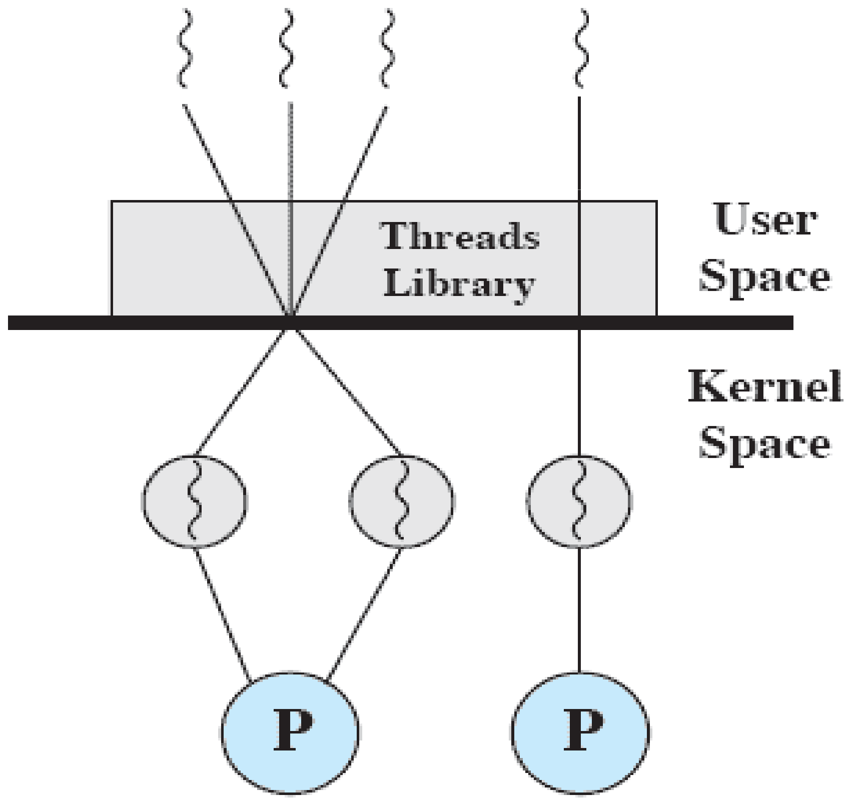
Kernel-Level Threads (KLTs)

- **Advantages**:
  - The kernel can simultaneously schedule multiple threads from the same process on multiple processors
  - If one thread in a process is blocked, the kernel can schedule another thread of the same process
  - Kernel routines can be multithreaded
- **Disadvantages**:
  - Slower to create and manage than user threads
  - The transfer of control from one thread to another within the same process requires a mode switch to the kernel
  - Scheduling by the OS (not by the application)



Combined Approaches

- Thread creation is done in the user space
- Bulk of scheduling and synchronization of threads is by the application
- Previous versions to Solaris 9 are an example



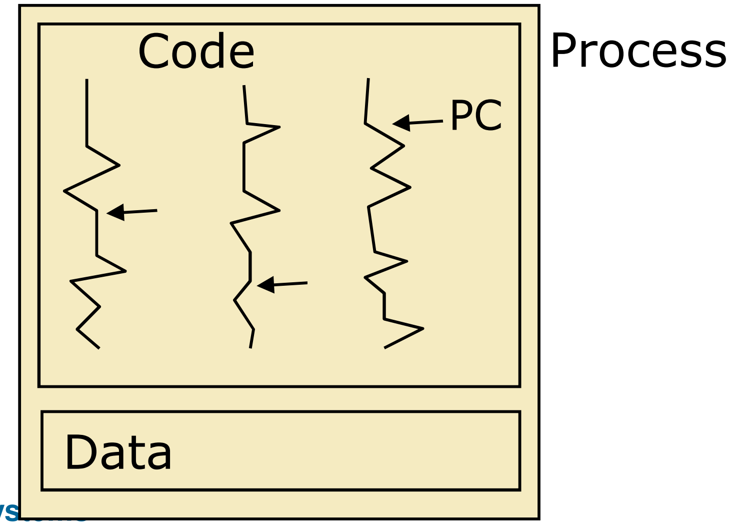
(c) Combined

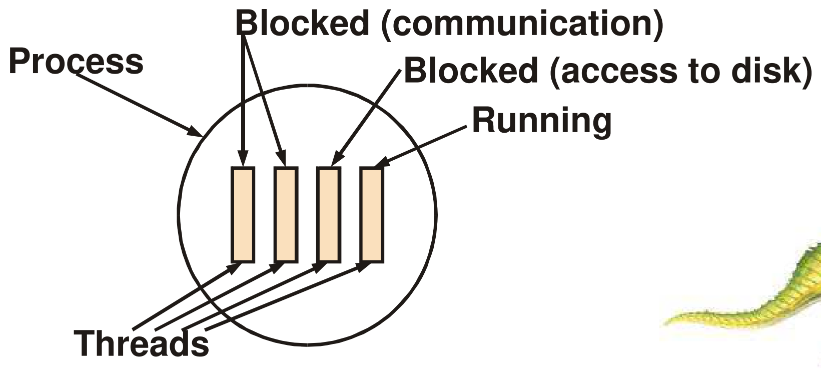
Source: Operating Systems. W. Stallings

Thread Execution States

- States for a thread: running, ready, blocked
- KLTs: several processors $\Rightarrow$ several threads running

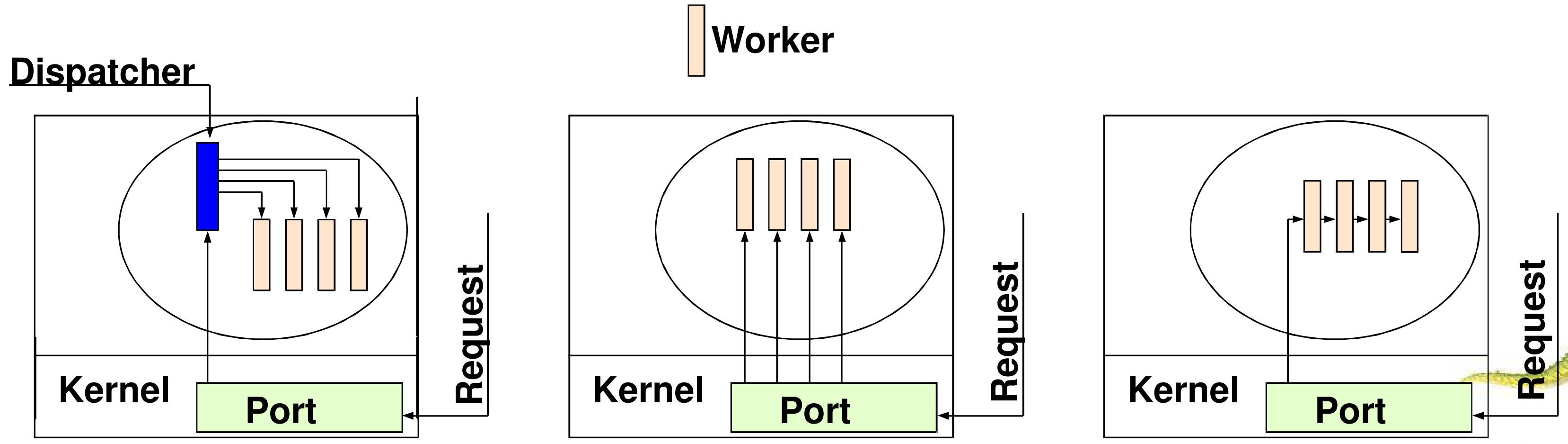
ULTs	KLTs
Run: one thread running and none blocked	Run: if at least one thread is running
Ready: all threads ready (no thread runnig nor blocked)	Ready: none thread running and some ready
Block: if any thread blocked	Block: if all threads blocked





Multithreaded Server Architecture

- Server designs using threads:
  - Dispatcher worker model/Delegation model
    - A central thread (boss/dispatcher) creates the threads (workers), assigning each worker a task
  - Peer-to-peer model
    - All the threads have an equal working status
  - Pipeline thread model
    - Each thread performs part of the work



Source: Sistemas Operativos. Una visión aplicada.

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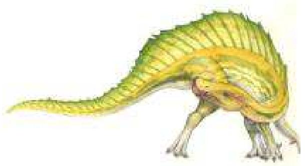
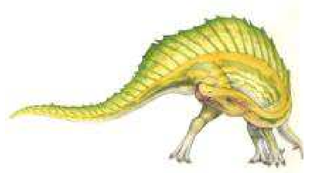


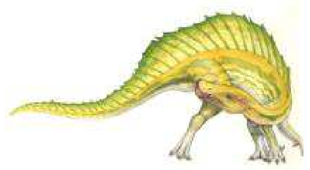
Thread Libraries

- Thread library provides programmer with API for creating and managing threads
- Two primary ways of implementing
  - Library entirely in user space
  - Kernel-level library supported by the OS
- Three main libraries in use
    - POSIX threads (Pthreads)
    - Win32 threads
    - Java threads



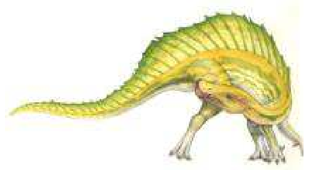
Pthreads

- POSIX Threads (Pthreads)
  - ISO/IEEE standard
  - API specifies behavior of the thread library, implementation is up to development of the library
  - Available on many UNIX-like systems



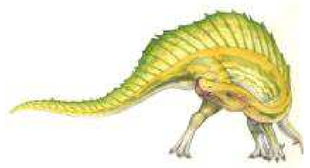
Pthreads services

- `int pthread_attr_init (pthread_attr_t *attr)`
  - It allows to initialize the attributes of the threads to be used
  - The attributes allow to specify: stack size, priority, scheduling policy, etc.
- `int pthread_create (pthread_t *thread, const pthread_attr_t  *attr, void *(*func)(void *), void *arg)`
  - It creates a thread that executes "func" with argument "arg" and attributes specified by "attr“ and returns new thread ID in “thread”
  - If argument “attr” specified as NULL, the attributes will be set as default (including thread created as non independent)
- `int pthread_attr_setdetachstate (pthread_attr_t *attr, int detachstate)`
  - It defines if a thread is independent or not

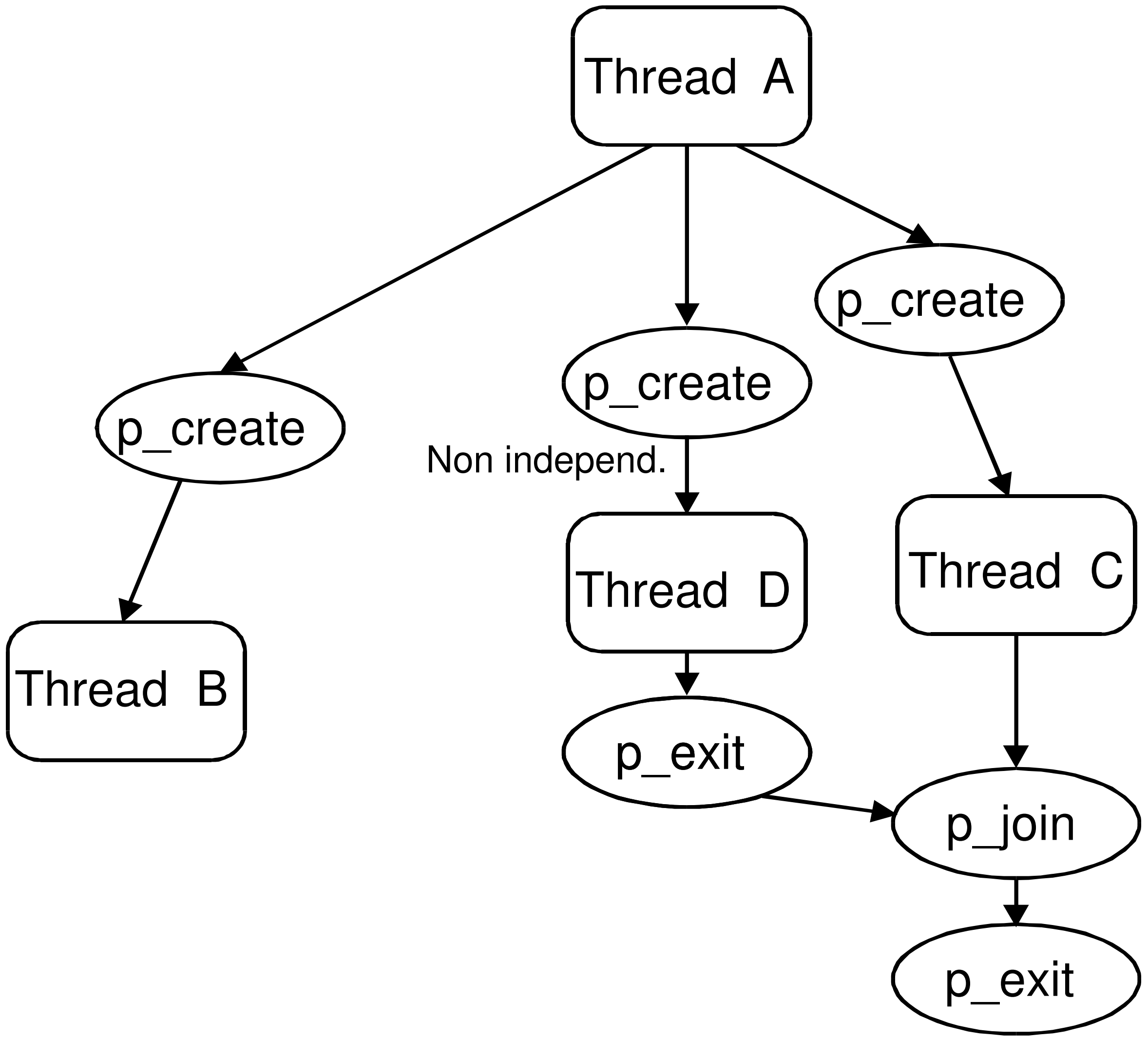


Pthreads services

- `int pthread_join (pthread_t thid, void **value)`
  - It suspends execution of the thread until the thread with ID "thid" finishes
  - It returns the termination status of the thread with ID “thid”
  - One way of synchronizing between threads
- `int pthread_exit (void *value)`
  - It allows a thread to terminate its execution, returning its termination status to any joining thread
- `pthread_t pthread_self (void)`
  - It returns the calling thread ID



Thread hierarchy



Source: Sistemas Operativos. Una visión aplicada.

An example Pthreads program

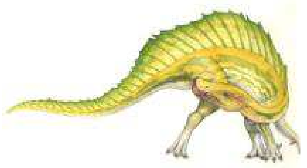
```
#include <pthread.h>
#include <stdio.h>
#define NUM_THREADS 5

void *PrintHello(void *threadid)
{
  printf("\n%d: Hello World!\n", threadid);
  pthread_exit(NULL);
}

int main (int argc, char *argv[])
{
  pthread_t threads[NUM_THREADS];
  int rc, t;
  for(t=0; t<NUM_THREADS; t++)
  {
    printf("Creating thread %d\n", t);
    rc = pthread_create(&threads[t], NULL, PrintHello, (void *)t);
    if (rc)
    {
      printf("ERROR; return code from pthread_create() is %d\n", rc);
      exit(-1);
    }
  }
  pthread_exit(NULL);
}
```

Program Output

```
Creating thread 0
Creating thread 1
0: Hello World!
1: Hello World!
Creating thread 2
Creating thread 3
2: Hello World!
3: Hello World!
Creating thread 4
4: Hello World!
```

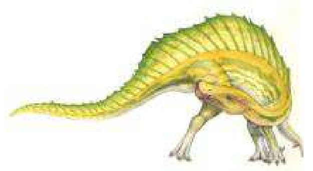


Windows Thread API

- Creates a thread

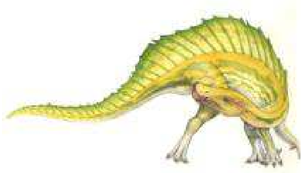
  -
    ```
    BOOL CreateThread (
    LPSECURITY_ATTRIBUTES lpsa,
    DWORD cbStack,
    LPTHREAD_START_ROUTINE lpStartAddr;
    LPVOID lpvThreadParam,
    DWORD fdwCreate,
    LPDWORD lpIdThread);
    ```
- Ends the calling thread

  -
    ```
    VOID ExitThread(DWORD dwExitCode);
    ```



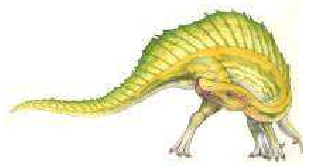
Contents

- **Process**
  - Process concept
  - Process states
  - Process Control Block (PCB)
  - Operations on Processes
- **Threads**
  - Thread concept
  - Libraries to create threads
- **Operating System Examples**
- **CPU scheduling**



Operating System Examples

- UNIX SVR4
- Linux Thread
- Windows Threads



Unix Process States

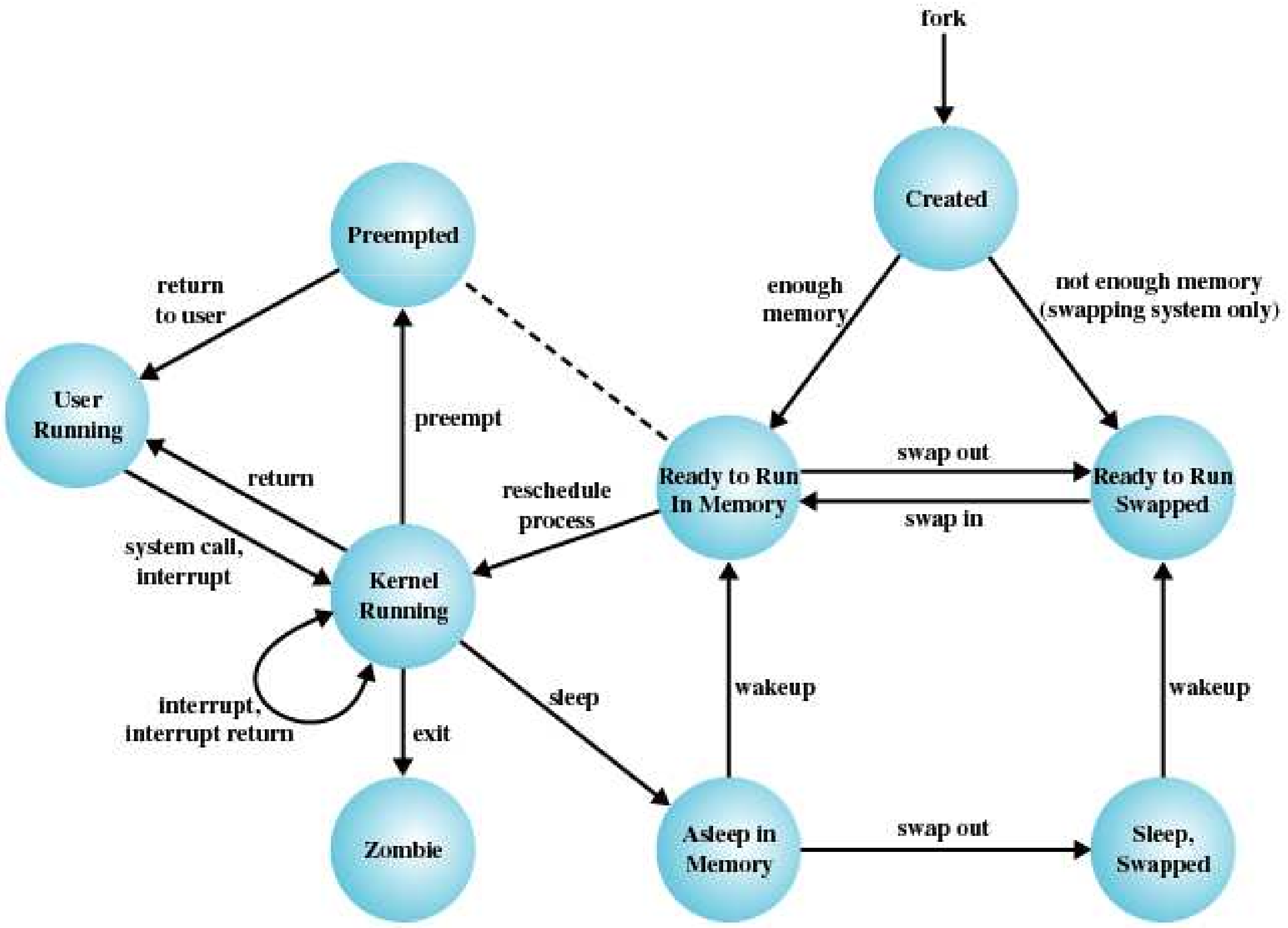


Figure 3.17 UNIX Process State Transition Diagram

Source: Operating Systems. W. Stallings

UNIX process states

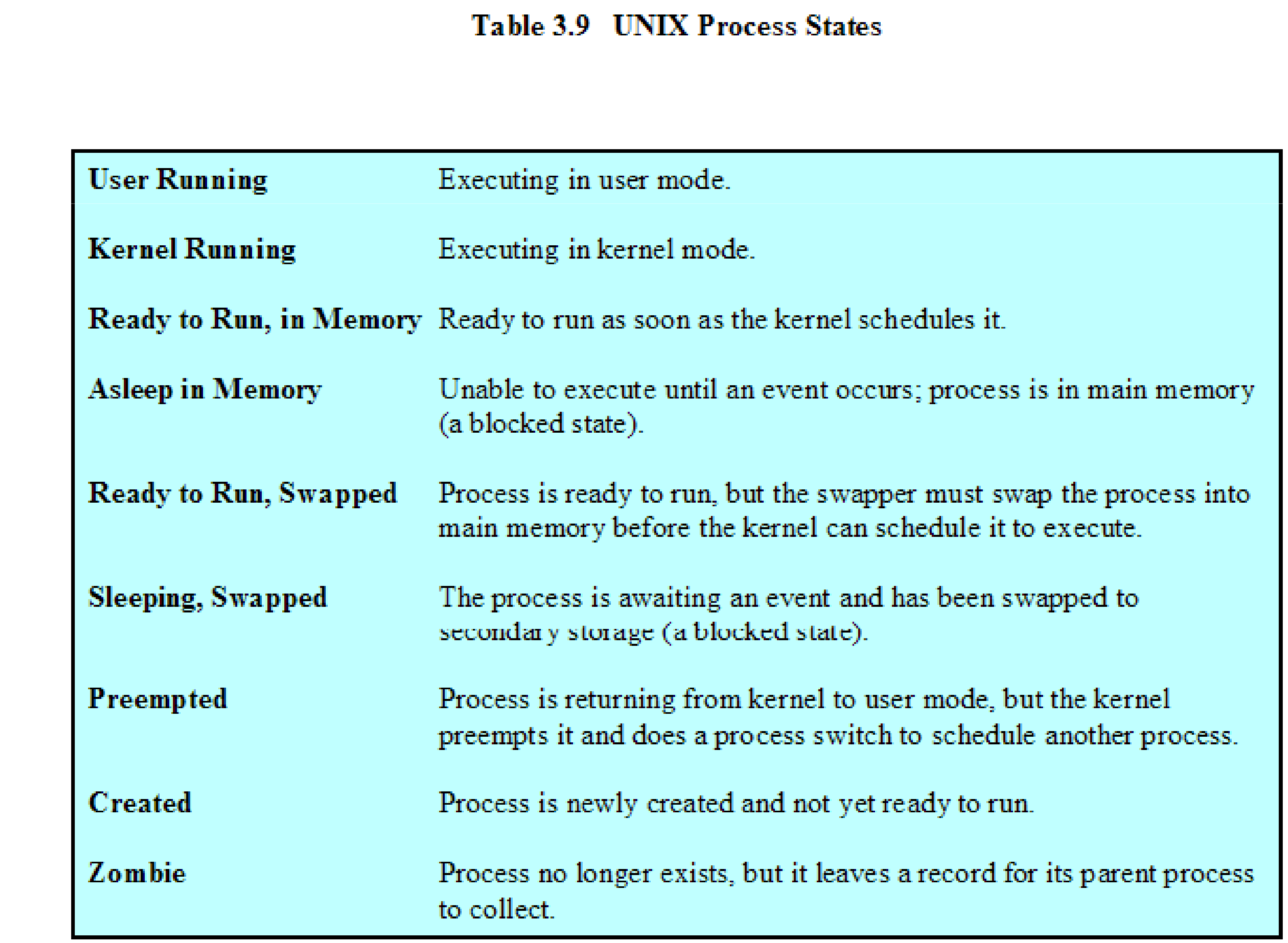
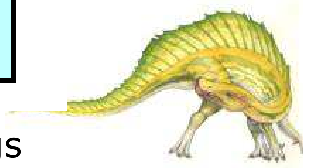


Table 3.9 UNIX Process States

User Running	Executing in user mode.
Kernel Running	Executing in kernel mode.
Ready to Run, in Memory	Ready to run as soon as the kernel schedules it.
Asleep in Memory	Unable to execute until an event occurs; process is in main memory (a blocked state).
Ready to Run, Swapped	Process is ready to run, but the swapper must swap the process into main memory before the kernel can schedule it to execute.
Sleeping, Swapped	The process is awaiting an event and has been swapped to secondary storage (a blocked state).
Preempted	Process is returning from kernel to user mode, but the kernel preempts it and does a process switch to schedule another process.
Created	Process is newly created and not yet ready to run.
Zombie	Process no longer exists, but it leaves a record for its parent process to collect.

Source: Operating Systems. W. Stallings



Linux Process/Thread States

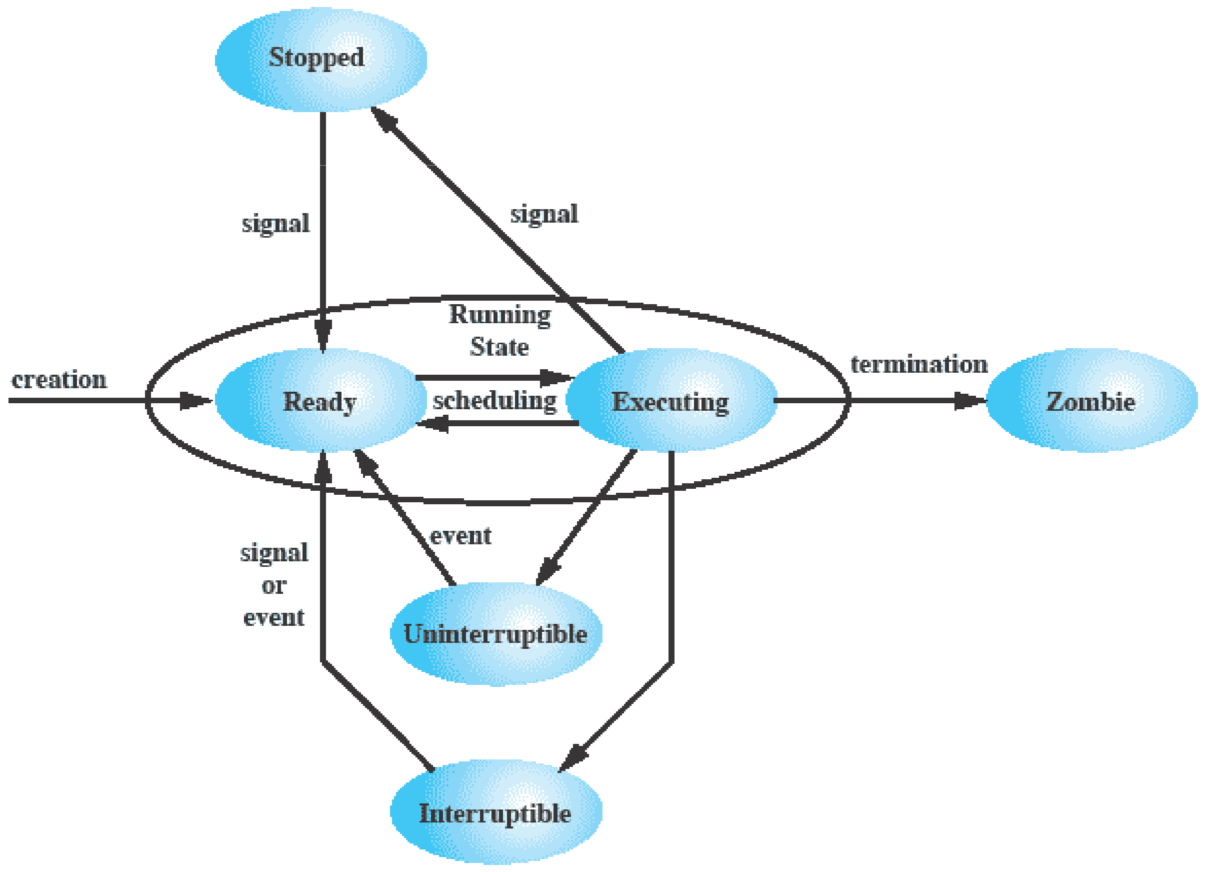
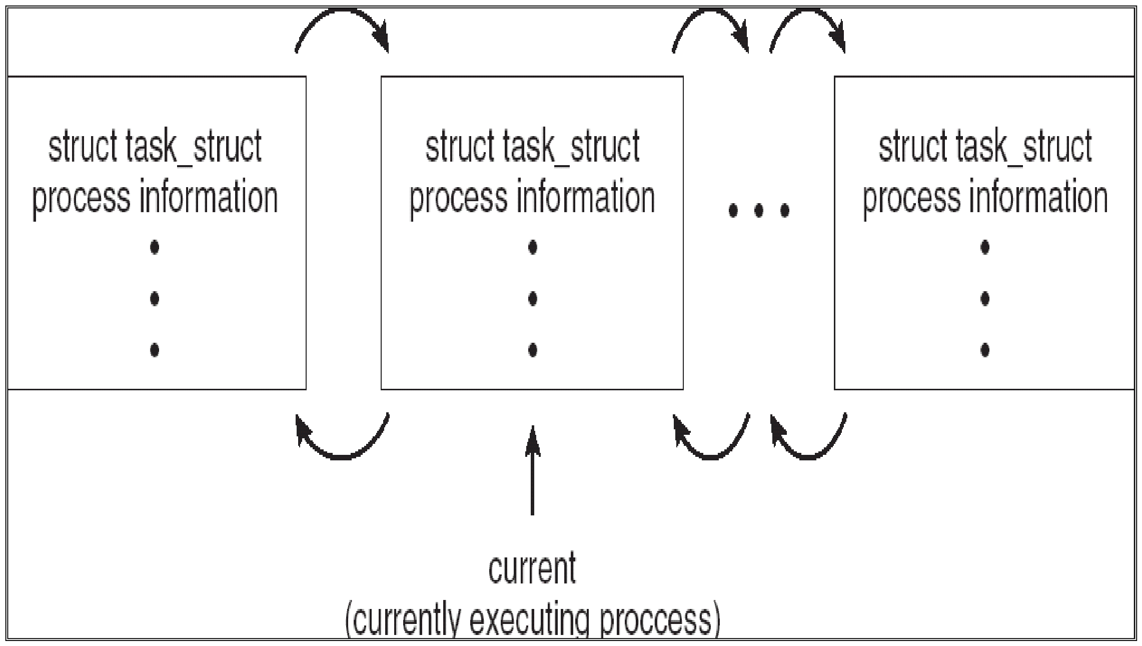


Figure 4.18 Linux Process/Thread Model

Source: Operating Systems. W. Stallings

Active processes in Linux

- The process control block in Linux is represented by the C structure ***task_struct***
  - State of the process
  - Scheduling and memory management information
  - List of open files
  - Pointers to the process' parent and any of its children
- All active processes are represented using a doubly linked list of *task_struct* and the kernel maintains a pointer to the process currently executing



Source: Operating System Concepts. A. Silberschatz.

Linux Threads

- Linux refers to them as ***tasks*** rather than ***threads***
- Thread creation is done through **`clone()`** system call
- **`clone()`** allows a child task to share the address space of the parent task (process)
  - Flags control behavior

flag	meaning
`CLONE_FS`	File-system information is shared.
`CLONE_VM`	The same memory space is shared.
`CLONE_SIGHAND`	Signal handlers are shared.
`CLONE_FILES`	The set of open files is shared.

Source: Operating System Concepts. A. Silberschatz. Fig. 4.15

Windows Process/Thread States

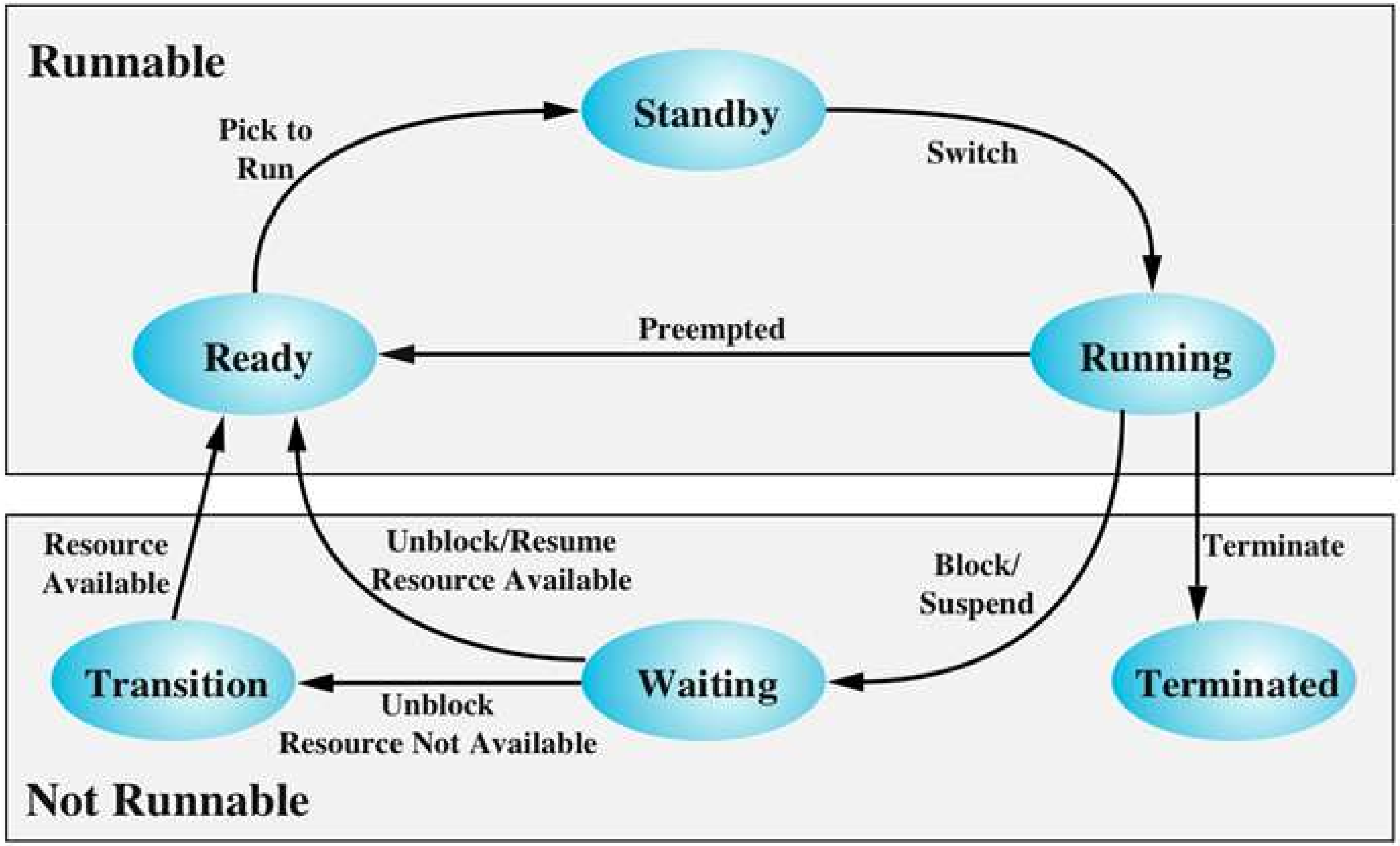
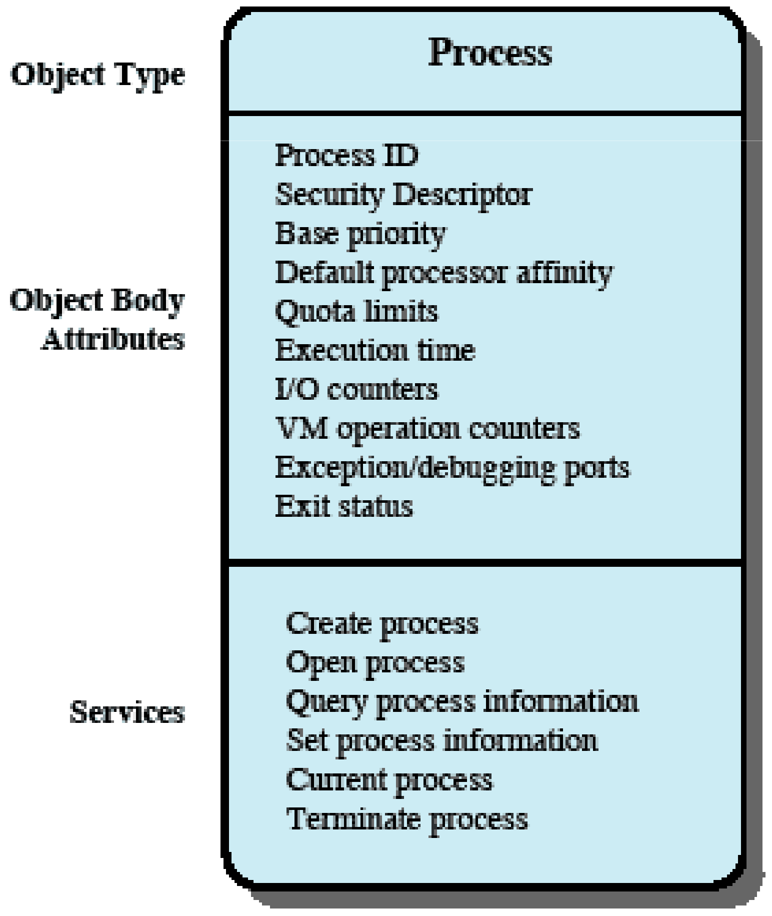


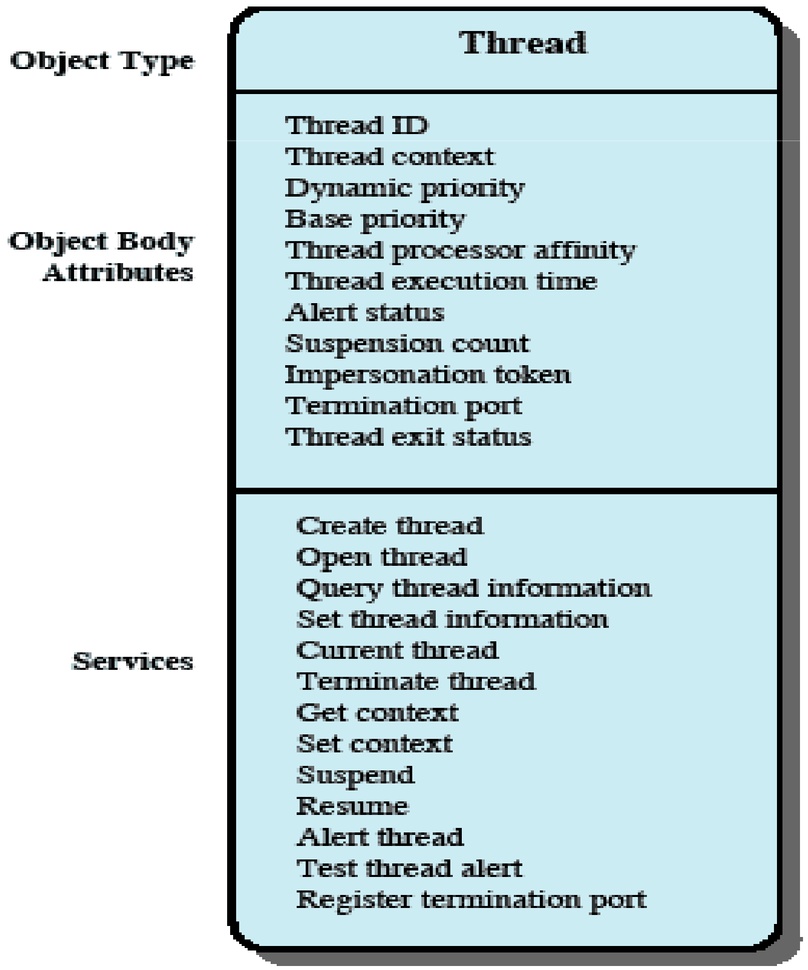
Figure 4.14 Windows Thread States

Source: Operating Systems. W. Stallings

Windows Process and Thread Objects



(a) Process object



(b) Thread object

Source: Operating Systems. W. Stallings

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