Processes and Threads

Chapter 3 and 4

Operating Systems:
Internals and Design Principles, 9/E
William Stallings

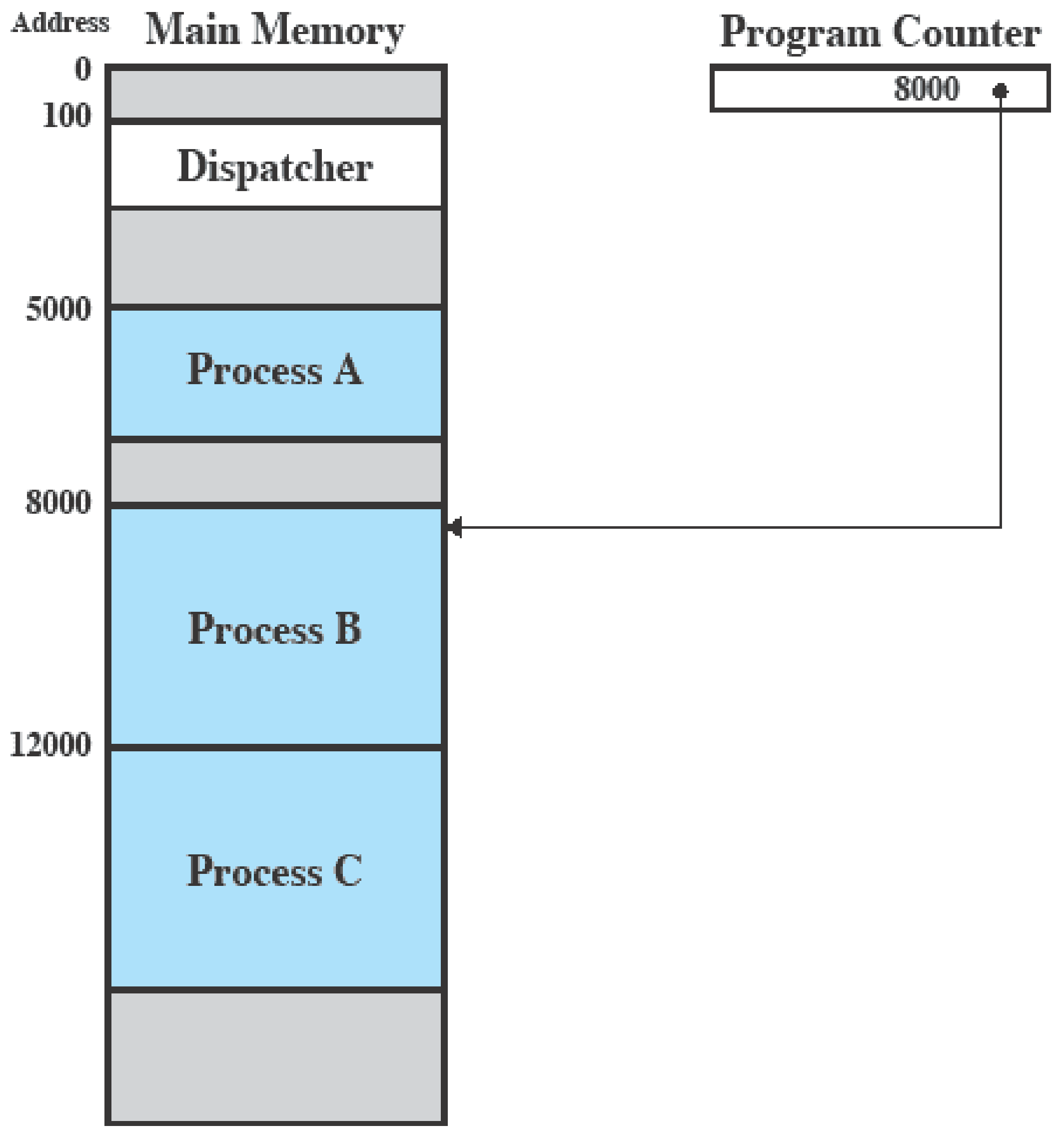
Process

- A program in execution
- An instance of a program running on a computer (cooking vs. recipe)
- The entity that can be assigned to and executed on a processor
- A unit of activity characterized by the **execution** of a sequence of instructions, a current **state**, and an associated set of system **resources**

Requirements of an Operating System

- Interleave the execution of multiple processes – **multiprogramming** -, to maximize processor utilization while providing reasonable response time
- Allocate resources to processes
- Support interprocess communication and user creation of processes

Example Execution



Combined Trace of Processes

1	5000
2	5001
3	5002
4	5003
5	5004
6	5005
------------------- Timeout	
7	100
8	101
9	102
10	103
11	104
12	105
13	8000
14	8001
15	8002
16	8003
-------------- I/O Request	
17	100
18	101
19	102
20	103
21	104
22	105
23	12000
24	12001
25	12002
26	12003
27	12004
28	12005
------------------- Timeout	
29	100
30	101
31	102
32	103
33	104
34	105
35	5006
36	5007
37	5008
38	5009
39	5010
40	5011
------------------- Timeout	
41	100
42	101
43	102
44	103
45	104
46	105
47	12006
48	12007
49	12008
50	12009
51	12010
52	12011
------------------- Timeout	

Interleaving

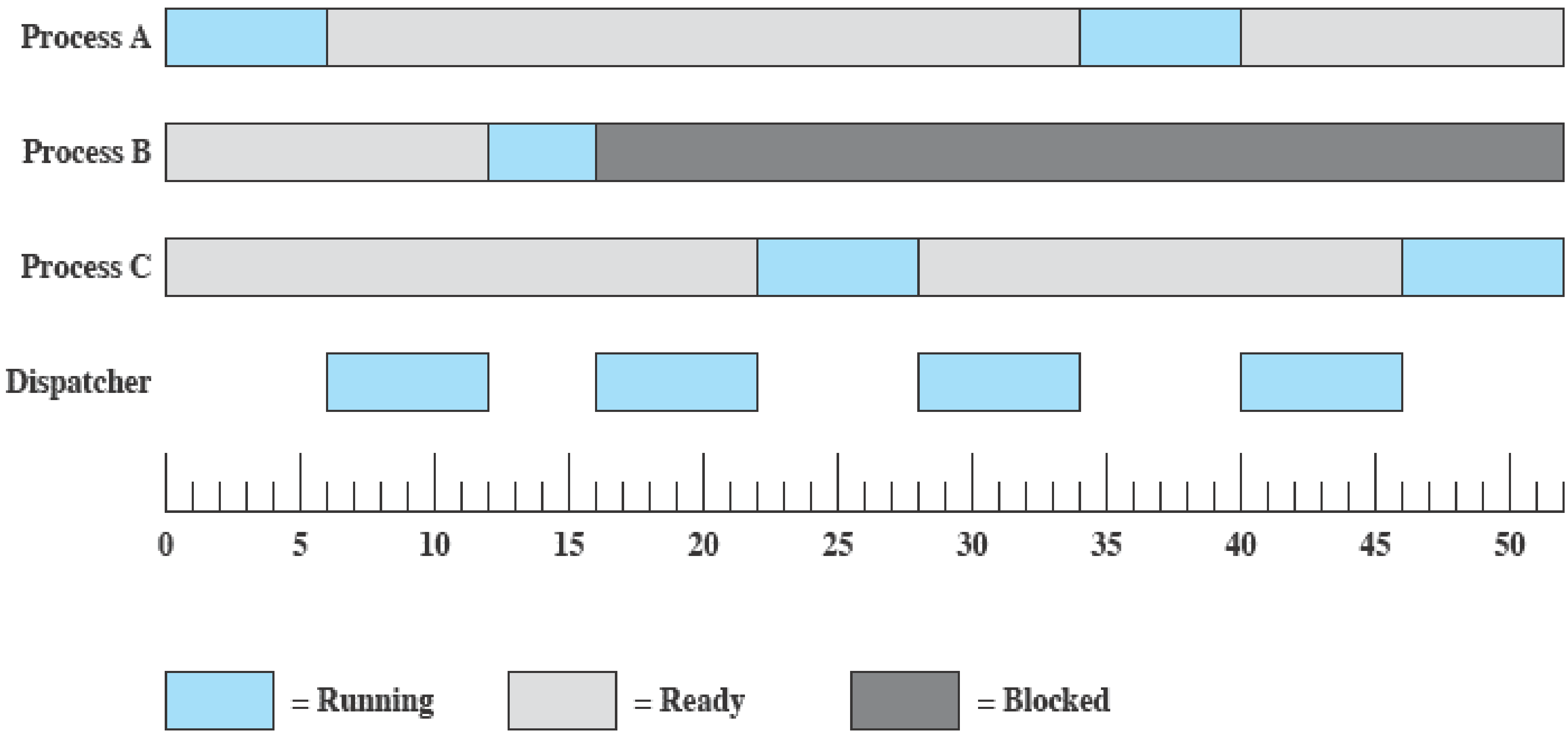
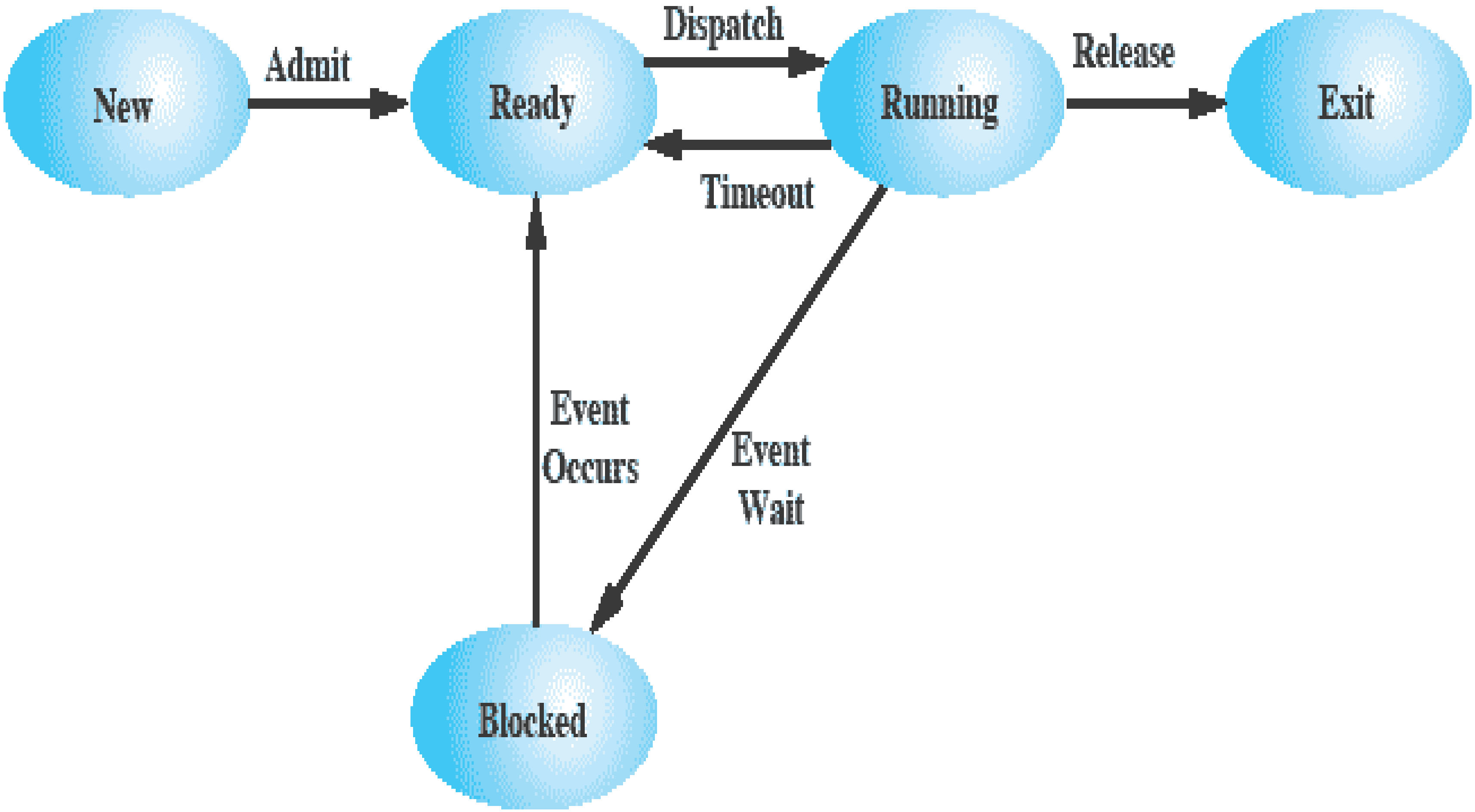


Figure 3.7 Process States for Trace of Figure 3.4

Five-State Process Model



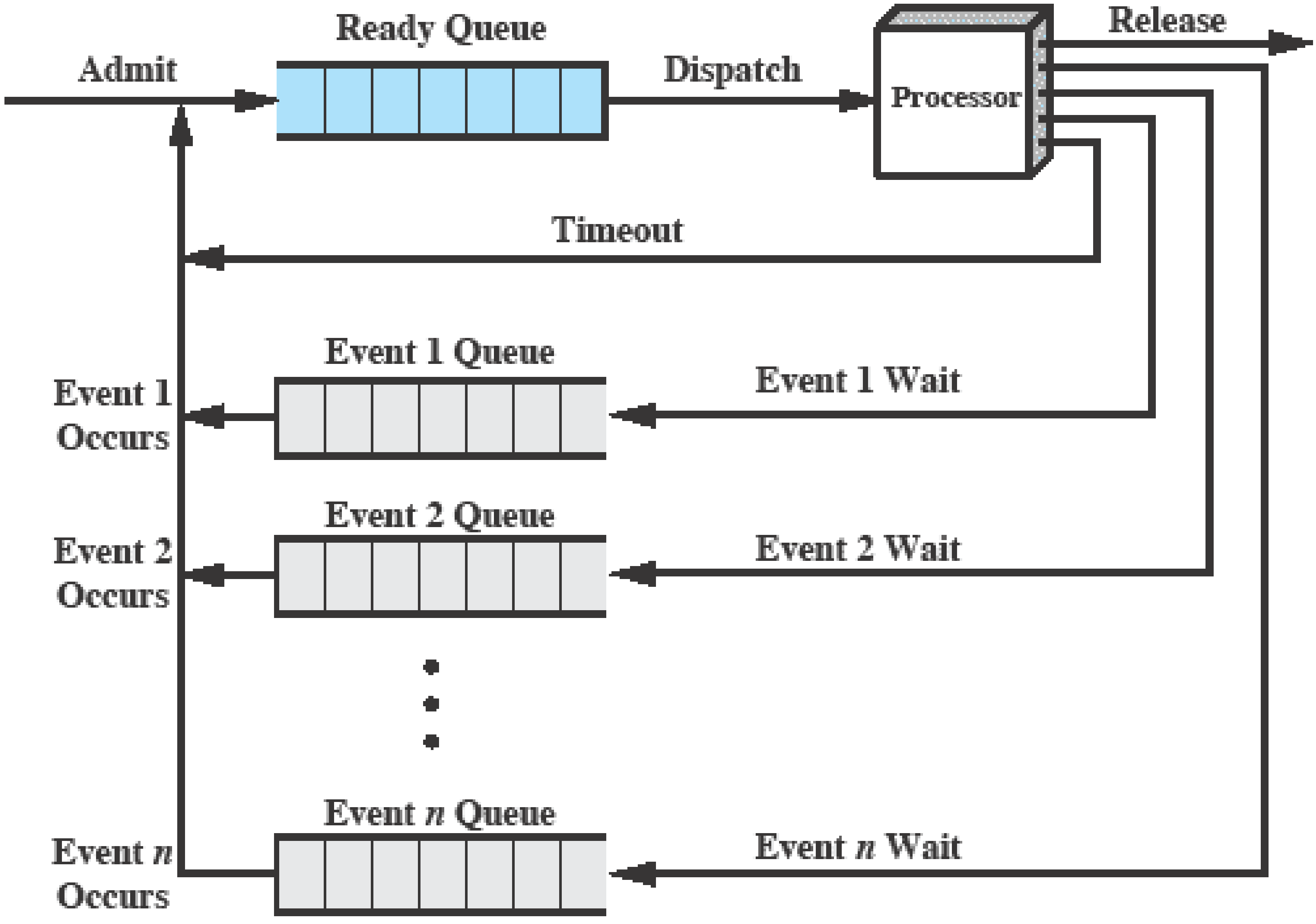
Process Creation

- New batch job
- Interactive logon
- Created by OS to provide a service
- Spawned by existing process – UNIX: fork + exec

Process Termination

- Normal completion
- Time limit exceeded
- Privileged instructions in user mode
- Parent termination
- Operator or OS intervention (e.g. deadlock)
- Errors
  - memory unavailable
  - bounds violation
  - protection error
  - arithmetic error
  - I/O failure

Multiple Blocked Queues



Suspended Processes

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

Two Suspend States

Operating System Control Structures

- Information about the current status of processes and resources
- Tables are constructed for each entity the operating system manages: memory table, I/O table, file table

Memory Tables

- Allocation of main memory to processes
- Allocation of secondary memory to processes
- Protection attributes for access to shared memory regions
- Information needed to manage virtual memory (page table)

I/O Tables

- I/O device is available or assigned
- Status of I/O operation
- Location in main memory being used as the source or destination of the I/O transfer

File Tables

- Existence of files
- Location on secondary memory
- Current status
- Attributes
- Sometimes this information is maintained by a file management system

OS Control Tables

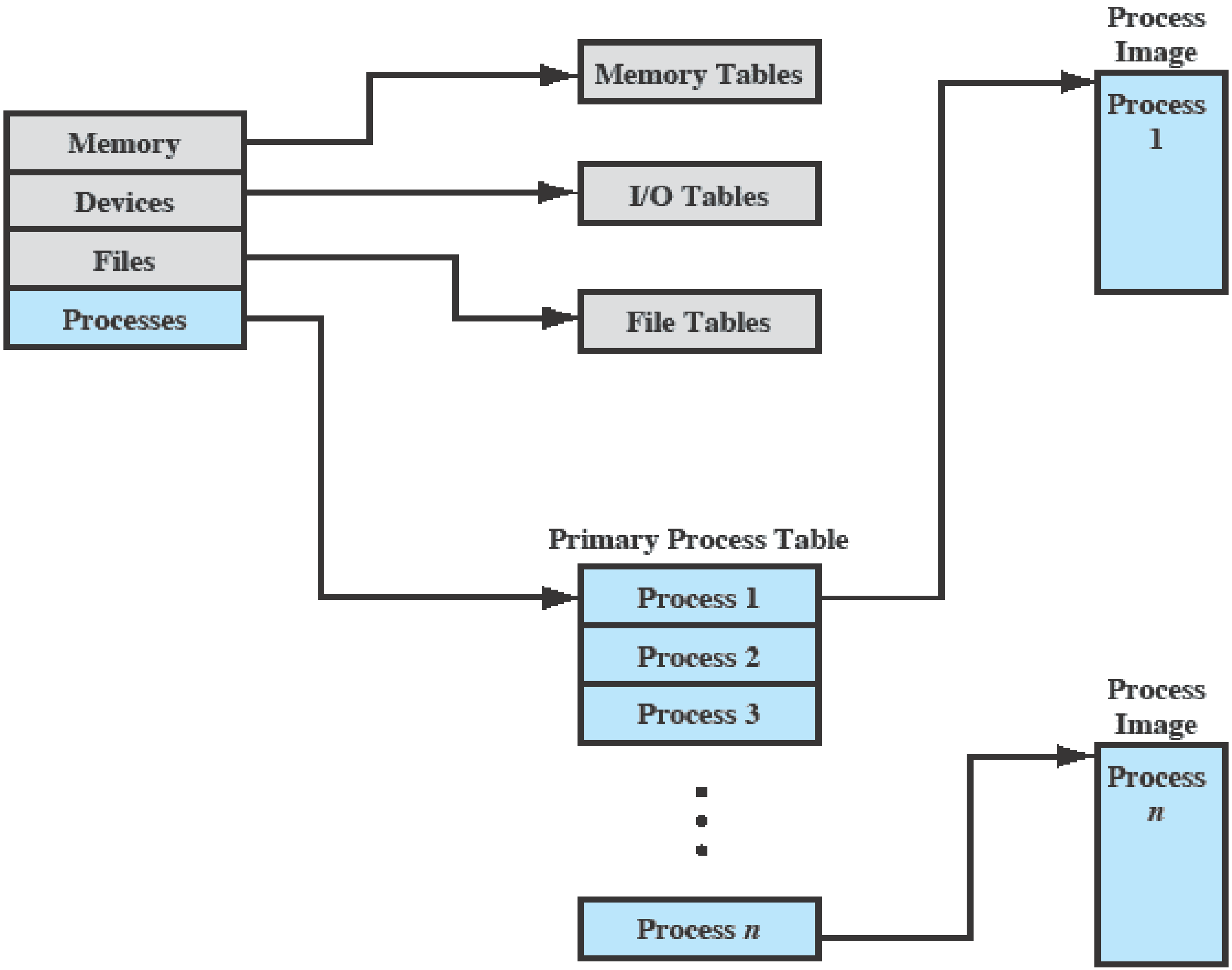


Figure 3.11 General Structure of Operating System Control Tables

Process Table – Process Control Block

- Identifiers: process id, parent process, user id
- User-visible registers
- Control and status registers: PC, PSW
- Stack pointer
- Scheduling and state info: process state, priority, used CPU time, event (waiting for)
- Process privileges
- Memory management: pointers to segments, page table
- Resource ownership and utilization

Modes of Execution

- User mode
  - Less-privileged mode
  - User programs typically execute in this mode
- System mode, control mode, or kernel mode
  - More-privileged mode
  - Kernel of the operating system
- Mode switch

Process Creation

- Assign a unique process identifier
- Allocate memory space for the process
- Initialize process control block
- Set up appropriate linkages (e.g. put process in scheduling queue)
- Create or expand other data structures (e.g. CPU time, page table)

When to Switch Process

Clock interrupt: process has executed for the maximum allowable time slice

I/O interrupt

Memory fault: memory address is in virtual memory so it must be brought into main memory – requires I/O

Trap: error or exception occurred; may cause process to be moved to Exit state

Supervisor/system call, e.g., such as file open

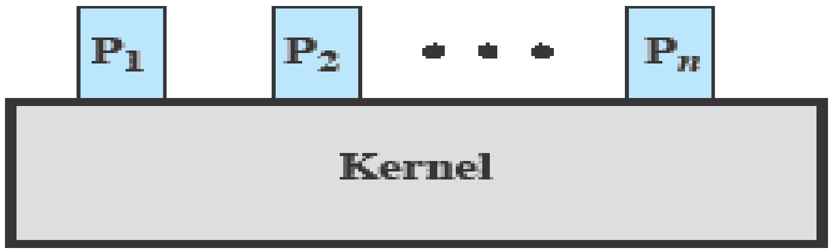
Change of Process State

1. Save context of processor including program counter and other registers
2. Update the process control blocks
3. Move process into appropriate queue – ready; blocked; ready/suspend
4. Run the scheduler to select another process for execution
5. Update the process control block
6. Restore context of the selected process

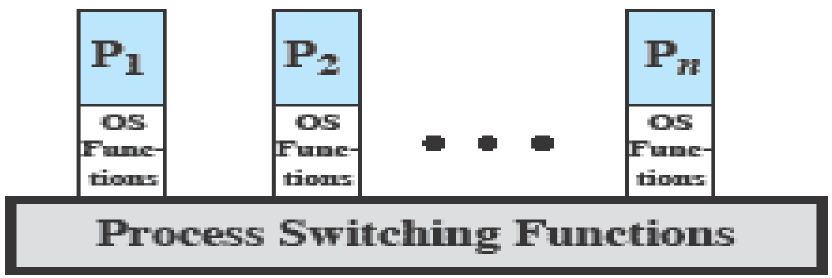
Execution of the Operating System

- Non-process Kernel
  - Execute kernel outside of any process
  - Operating system code is executed as a separate entity that operates in privileged mode – monolithic OS
- Execution within user processes
  - Operating system software within context of a user process, e.g. scheduler
- Process-based operating system
- Implement the OS as a collection of system processes – modular OS

Execution of the Operating System



(a) Separate kernel



(b) OS functions execute within user processes

(c) OS functions execute as separate processes

Processes and Threads

- Resource ownership - process includes a virtual address space to hold the process image
- Scheduling/execution- follows an execution path that may be interleaved with other processes
- These two characteristics are treated independently by the operating system

Threads

Process =

resource grouping (code, data, open files, etc.) +

execution (program counter, registers, stack)

Multithreading:

- multiple execution takes place in the same process environment
- co-operation by sharing resources (address space, open files, etc.)

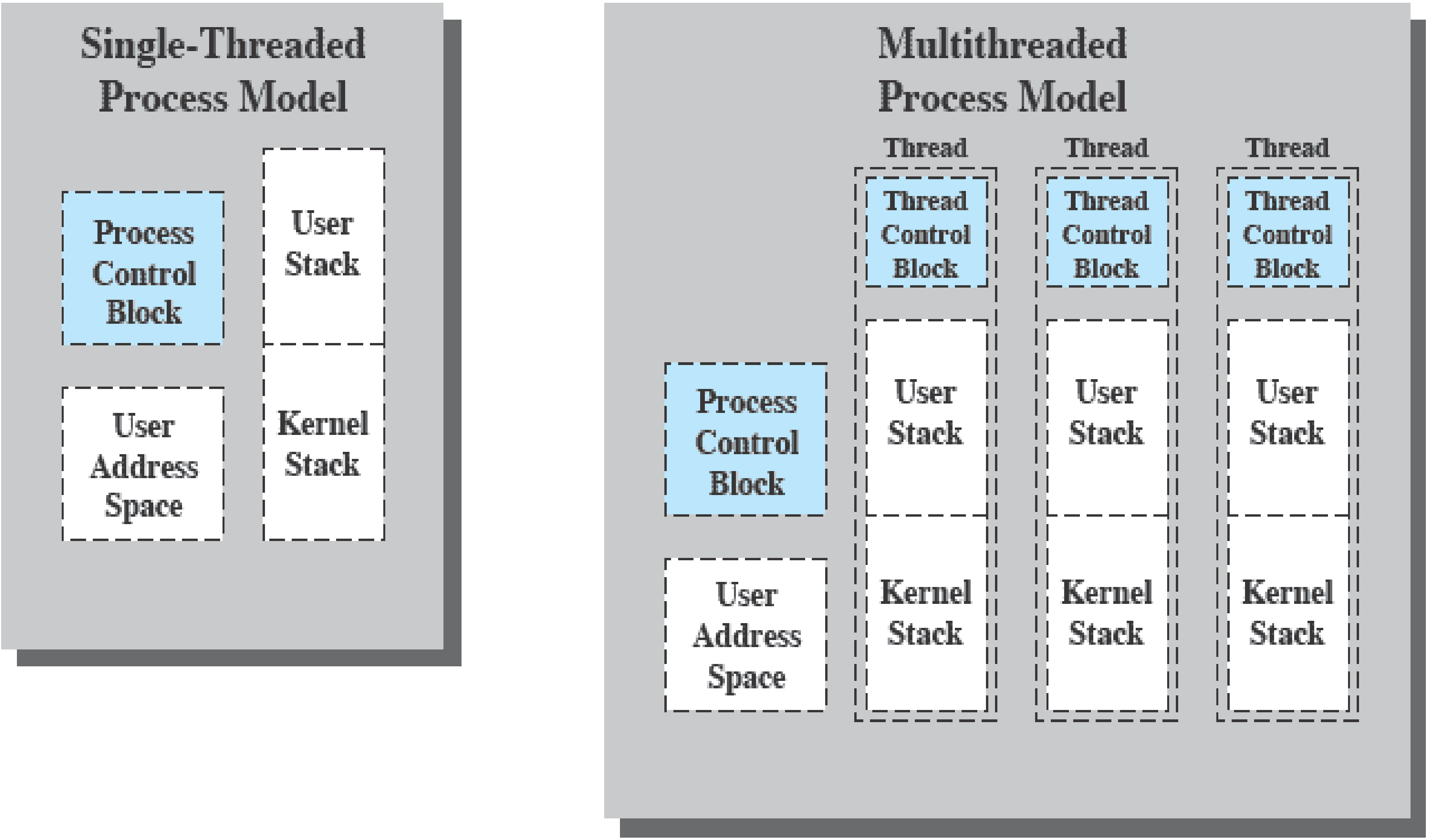
The Thread Model

Per process items	Per thread items
Address space	Program counter
Global variables	Registers
Open files	Stack
Child processes	State
Pending alarms	
Signals and signal handlers	
Accounting information	

Left: Items shared by all threads in a process

Right: Items private to each thread

Threads


Single-Threaded Process Model
Process Control Block
User Stack
User Address Space
Kernel Stack
Multithreaded Process Model
Thread
Thread
Thread
Thread Control Block
Thread Control Block
Thread Control Block
Process Control Block
User Stack
User Stack
User Stack
User Address Space
Kernel Stack
Kernel Stack
Kernel Stack

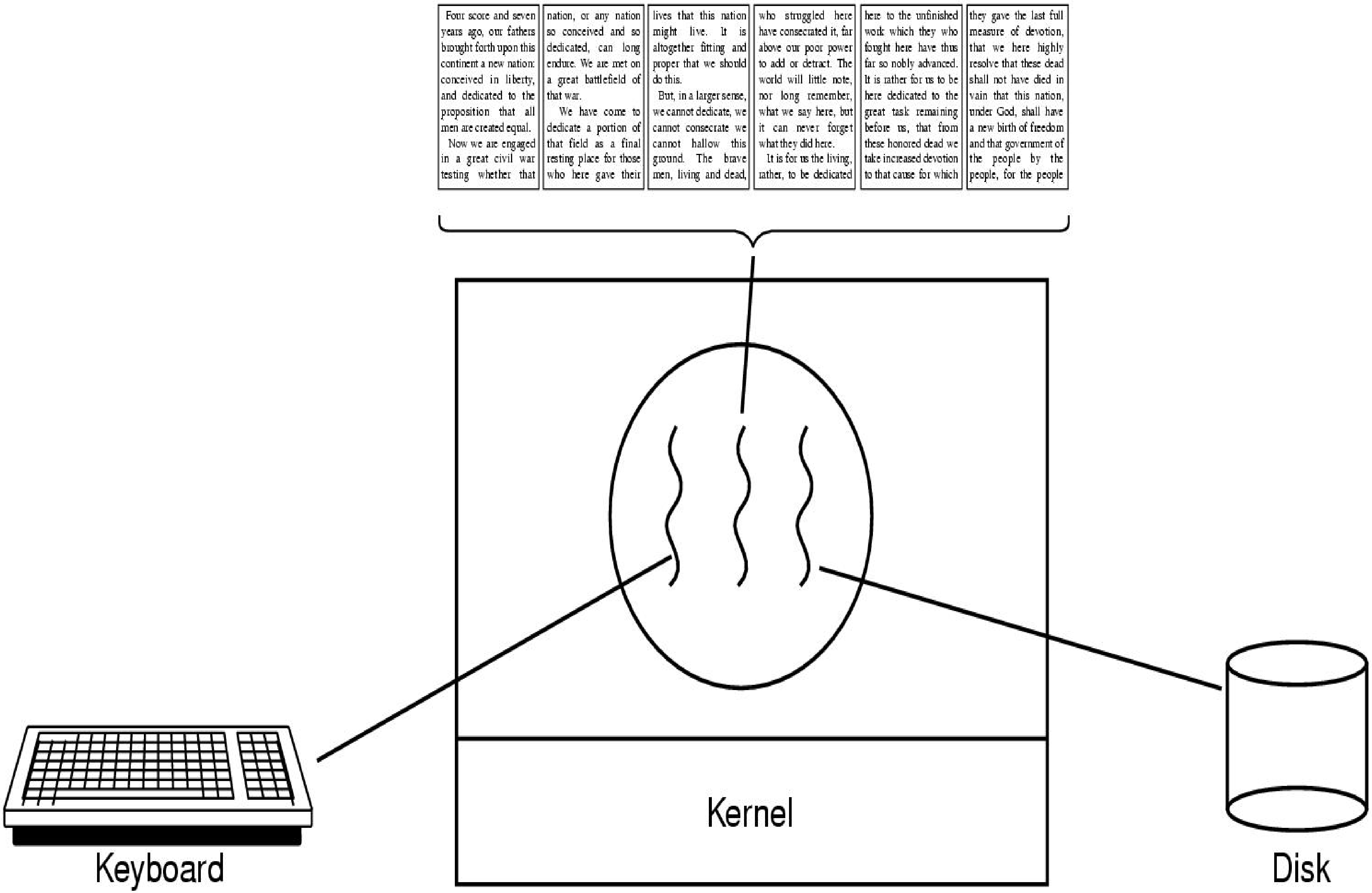
Benefits of Threads

- Takes less time to create a new thread than a process
- Less time to terminate a thread than a process
- Less time to switch between two threads within the same process
- Since threads within the same process share memory and files, they can communicate with each other without invoking the kernel

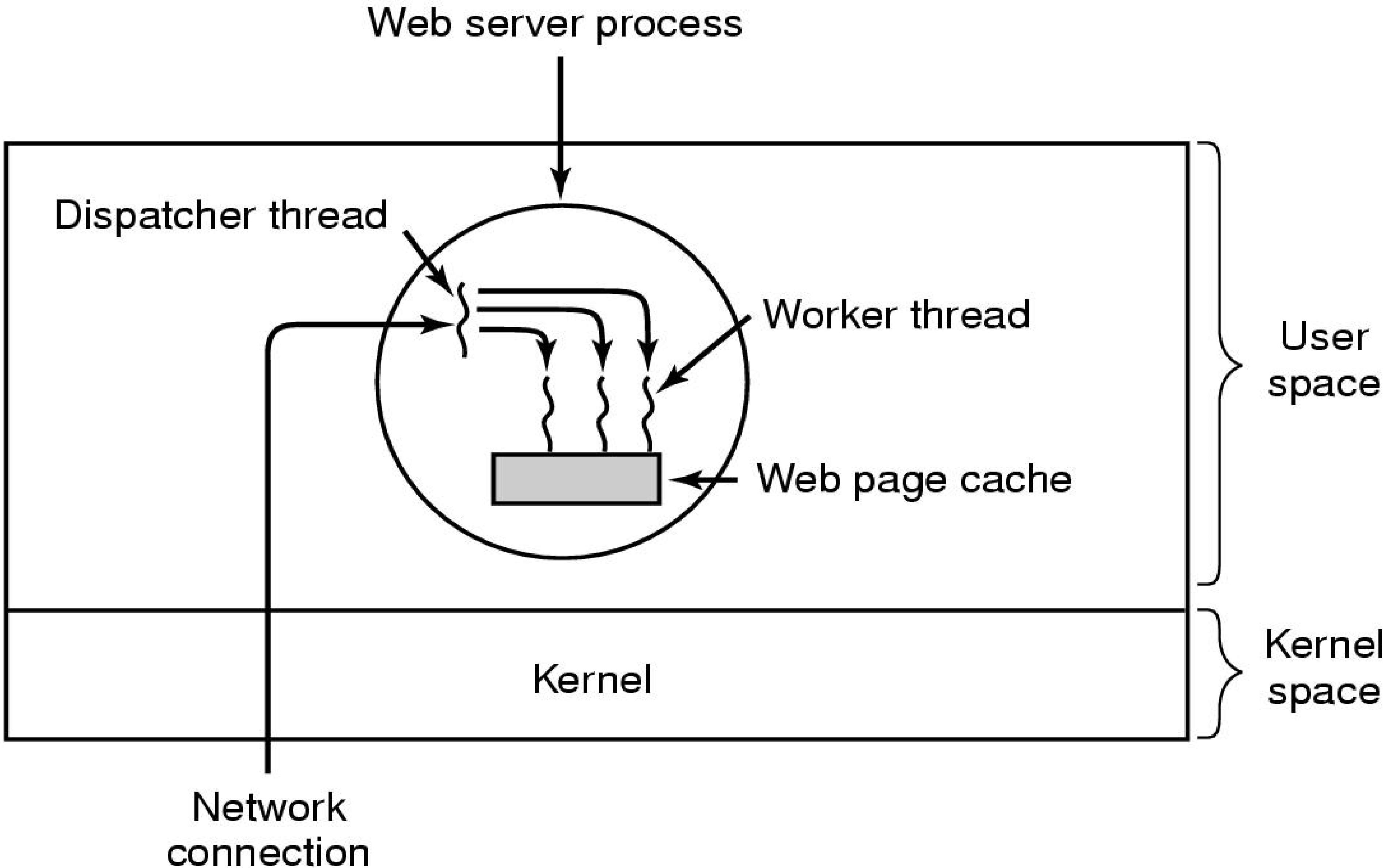
Uses of Threads in a Single-User Multiprocessing System

- Foreground and background work
- Speed of execution, e.g. blocked and running threads in one process
- Modular program structure
- Specific scheduling algorithms

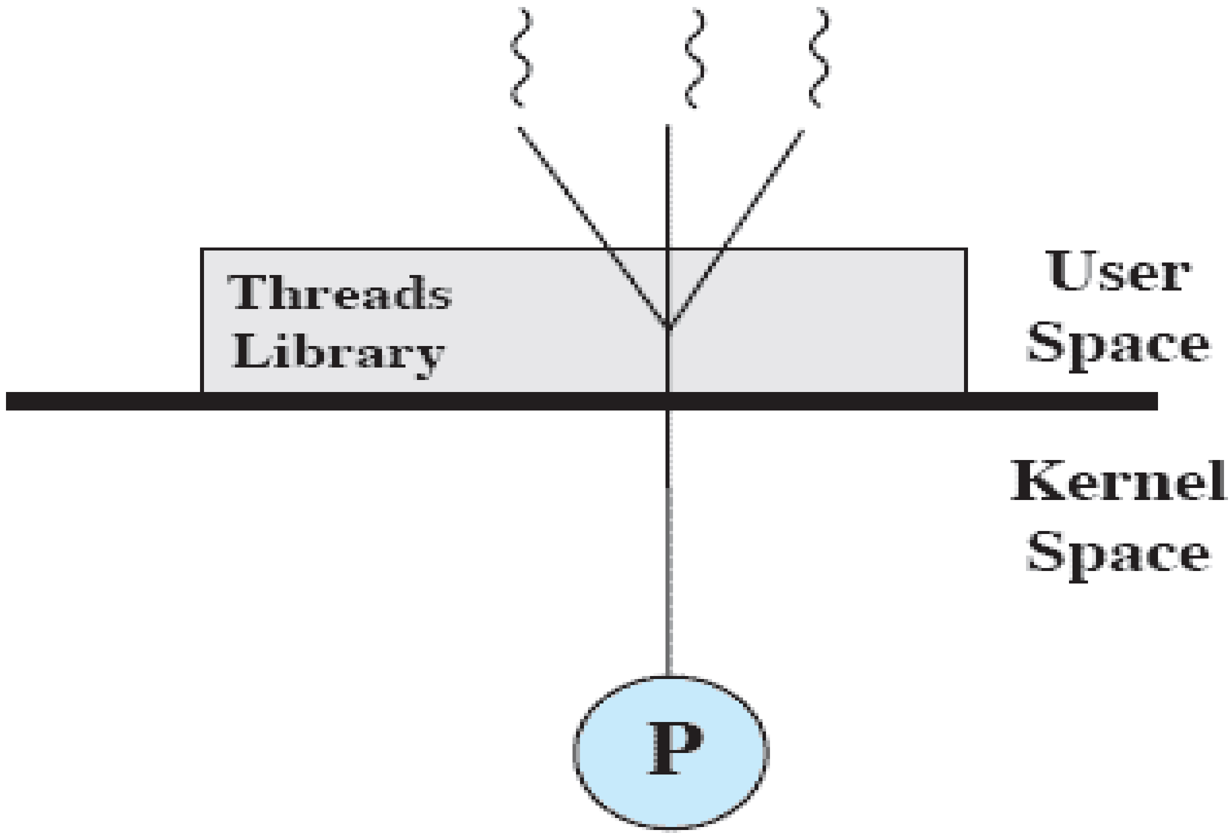
A word processor with three threads



A multithreaded Web server



User-Level Threads



(a) Pure user-level

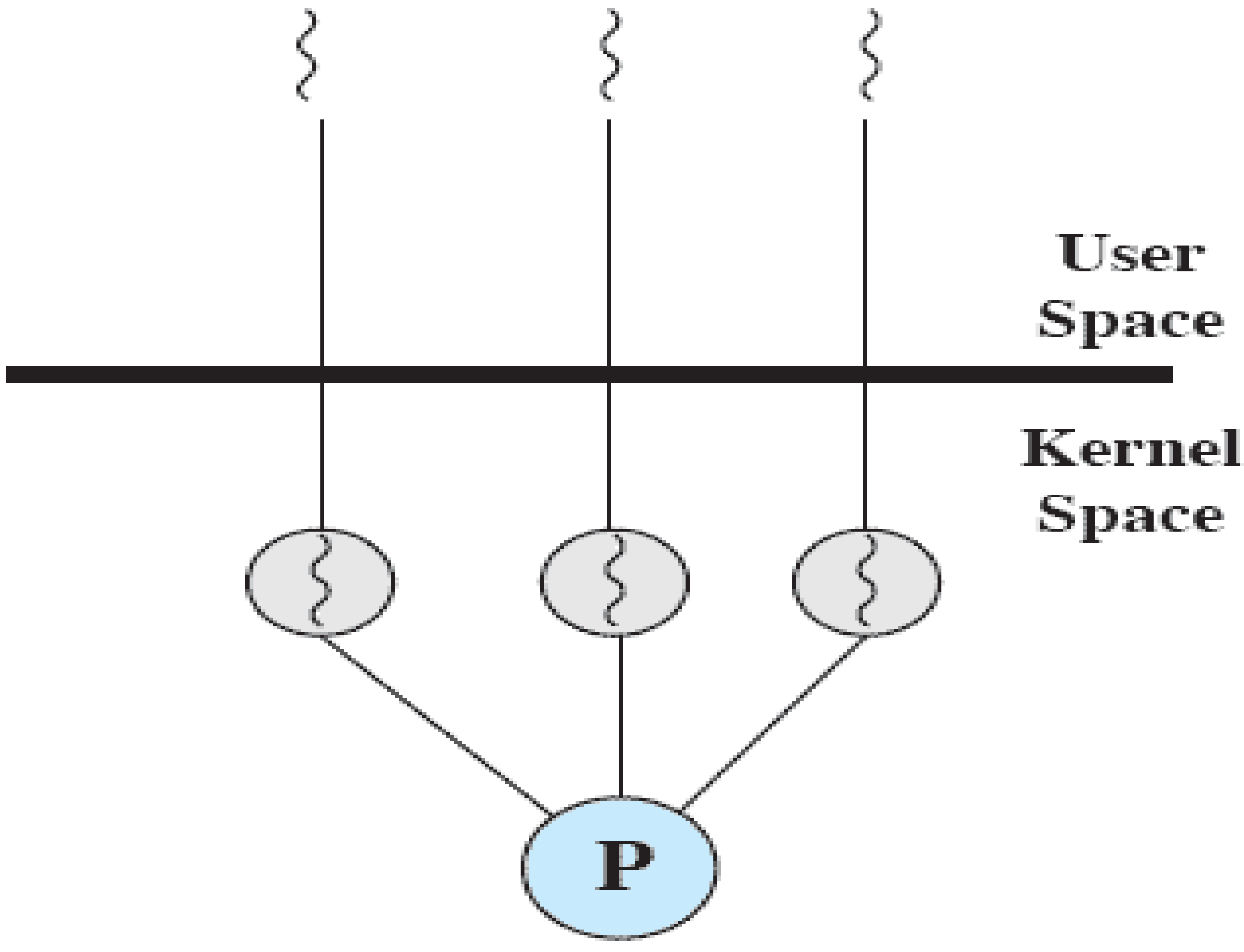
User-Level Threads

- All thread management is done by the application
- The kernel is not aware of the existence of threads
- Blocking system call!!!

Kernel-Level Threads

- Windows is an example of this approach
- Kernel maintains context information for the process and the threads
- Scheduling is done on a thread basis

Kernel-Level Threads

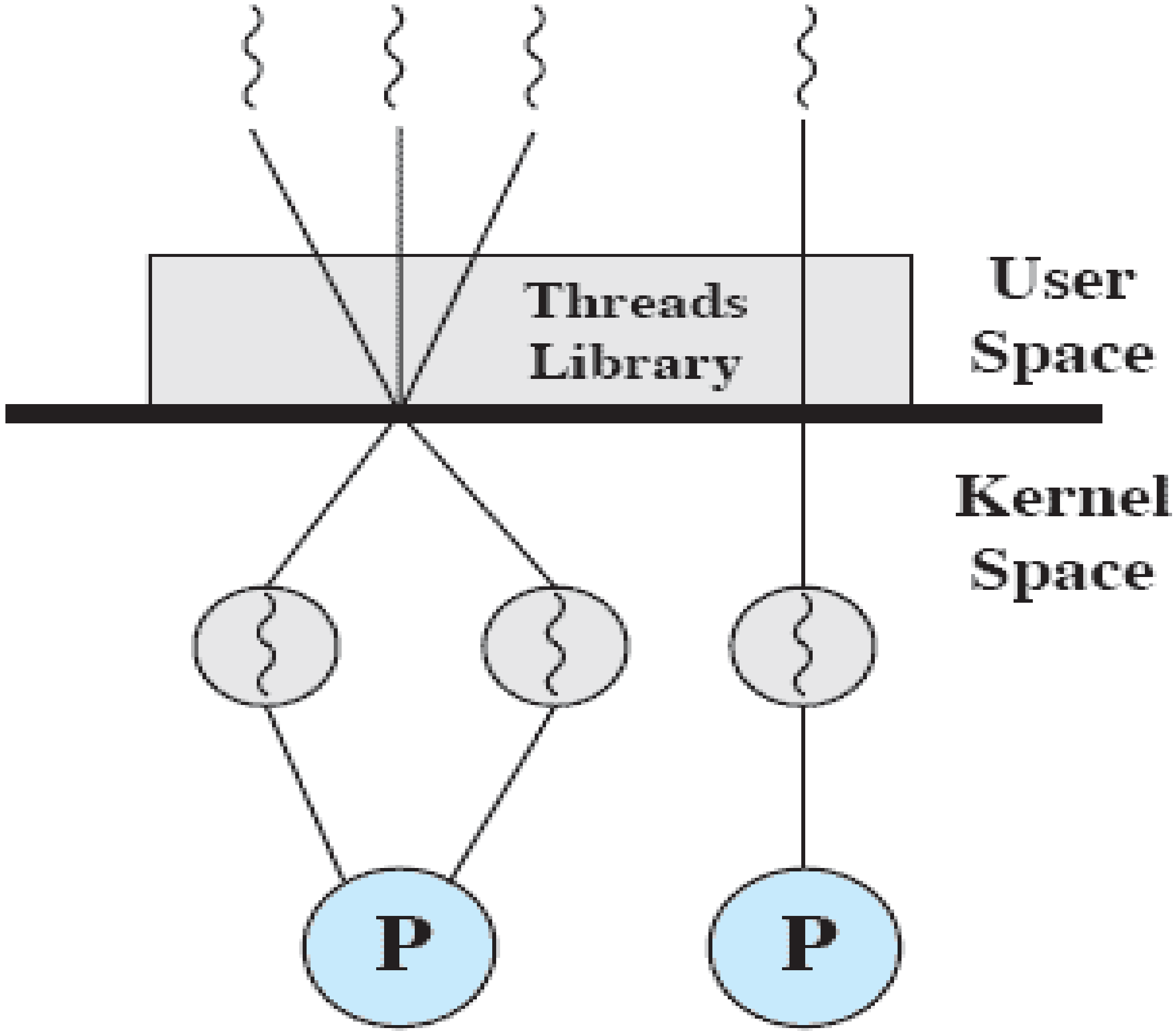


(b) Pure kernel-level

Combined Approaches

- Example is Solaris
- Thread creation done in the user space
- Bulk of scheduling and synchronization of threads within application

Combined Approach



Solaris

- Process includes the user's address space, stack, and process control block
- User-level threads
- Lightweight processes (LWP)
- Kernel threads

Processes and Threads in Solaris

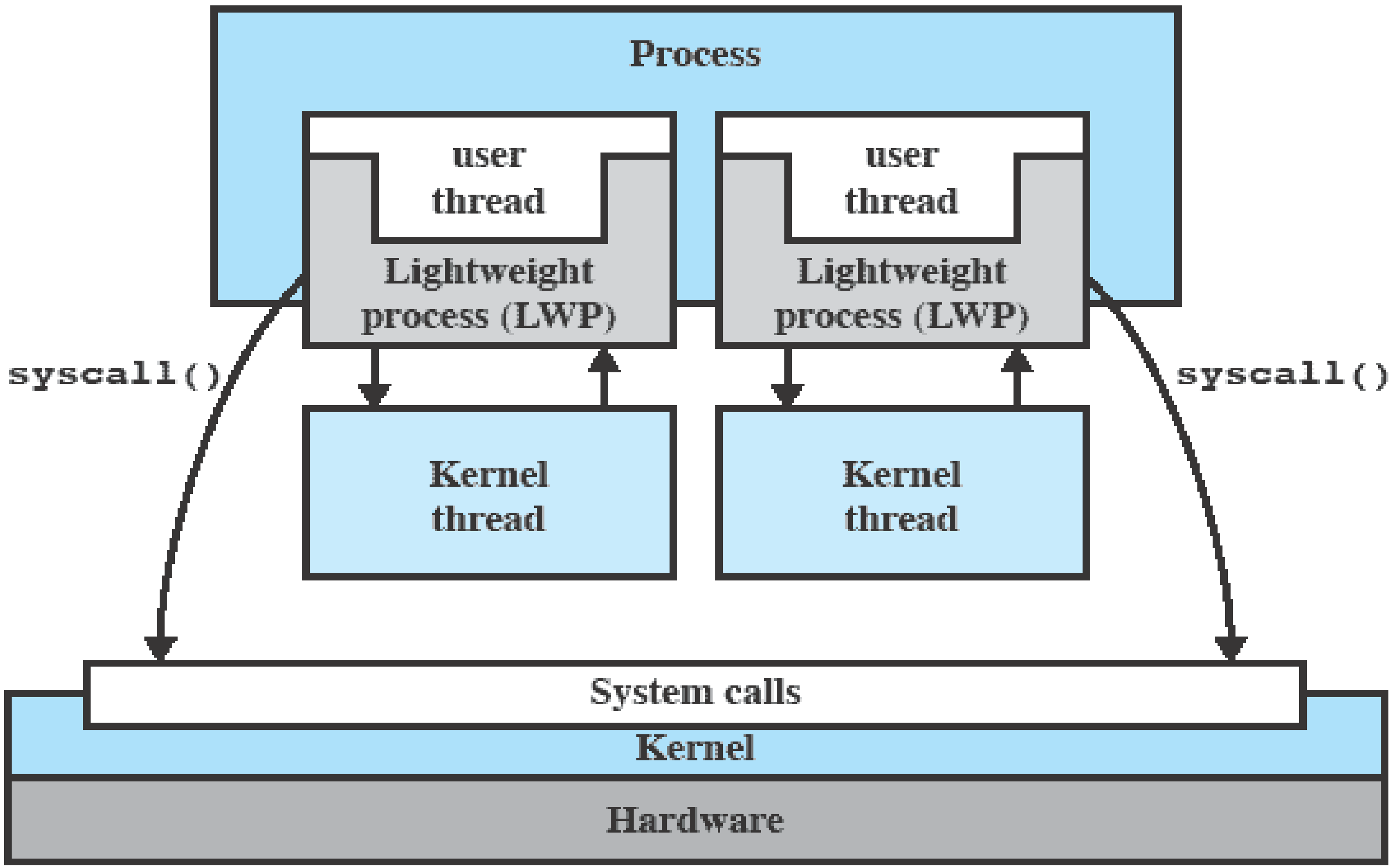
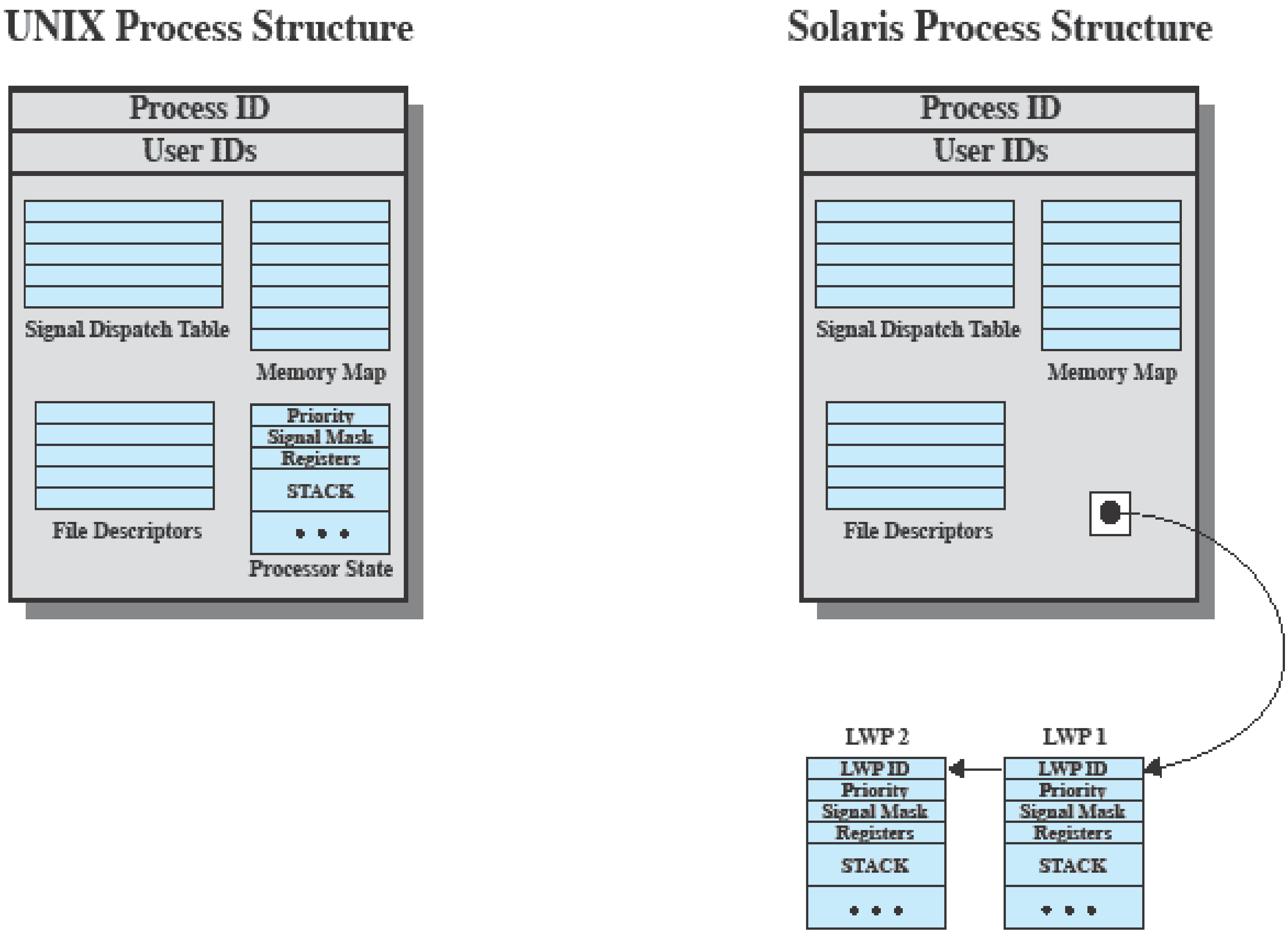


Figure 4.15 Processes and Threads in Solaris [MCDO07]

LWP Data Structure

- Identifier
- Priority
- Signal mask
- Saved values of user-level registers
- Kernel stack
- Resource usage and profiling data
- Pointer to the corresponding kernel thread
- Pointer to the process structure

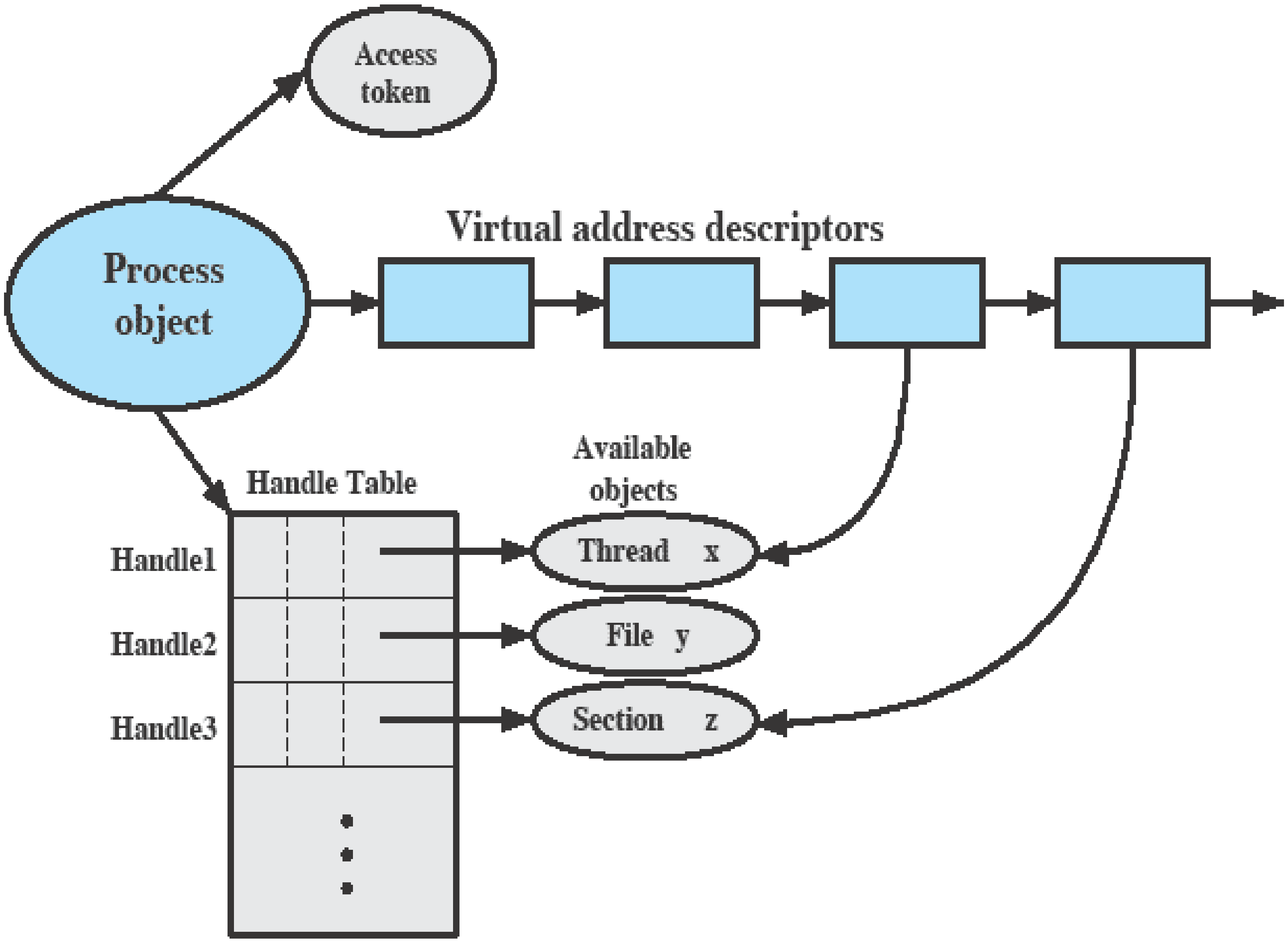
Process Structure



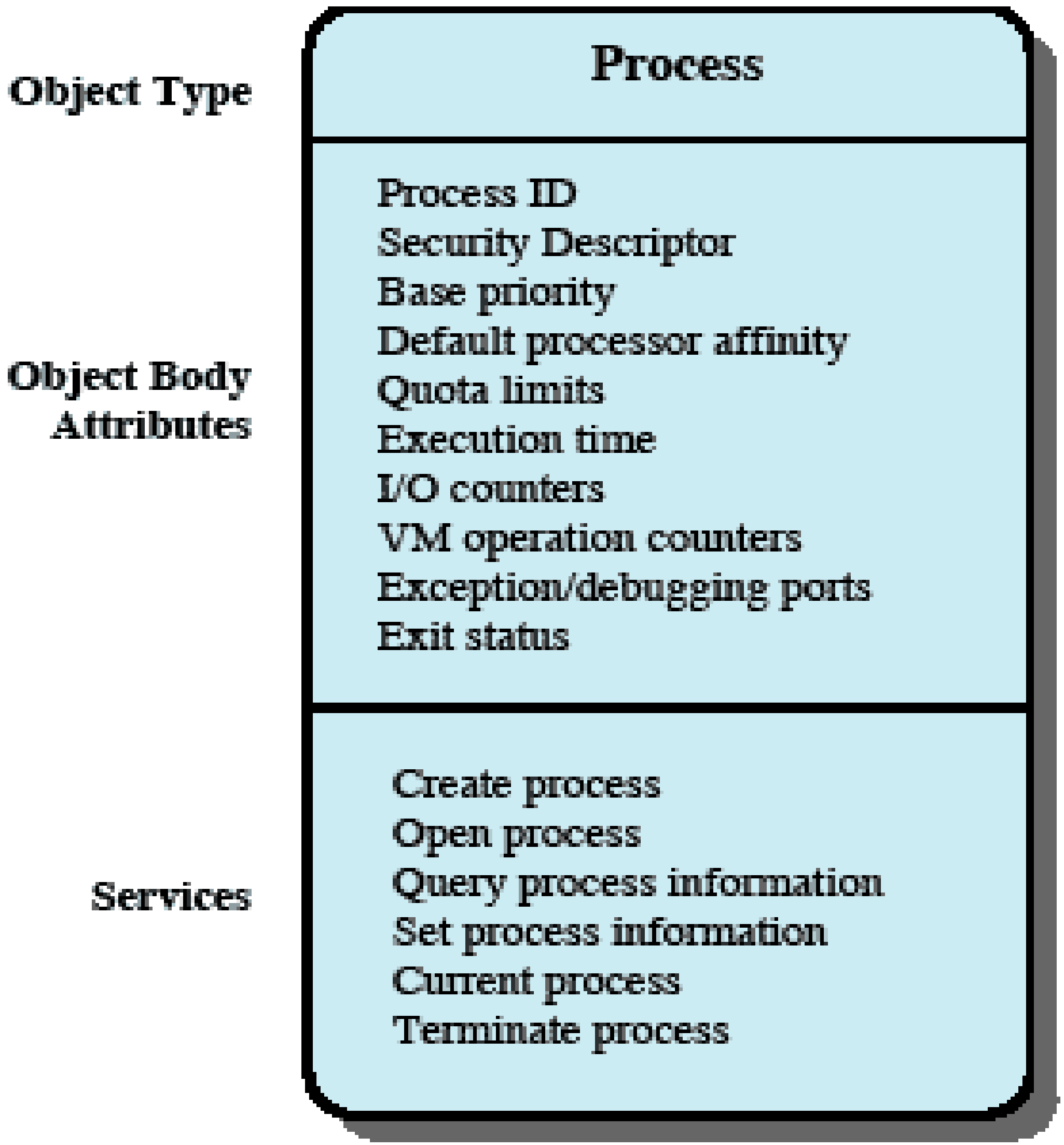
Windows Processes

- Implemented as objects
- An executable process may contain one or more threads
- Both processes and thread objects have built-in synchronization capabilities

Windows Processes



Windows Process Object - Job



Windows Thread Object

Object Type	**Thread**
Object Body Attributes	Thread ID Thread context Dynamic priority Base priority Thread processor affinity Thread execution time Alert status Suspension count Impersonation token Termination port Thread exit status
Services	Create thread Open thread Query thread information Set thread information Current thread Terminate thread Get context Set context Suspend Resume Alert thread Test thread alert Register termination port

Thread States