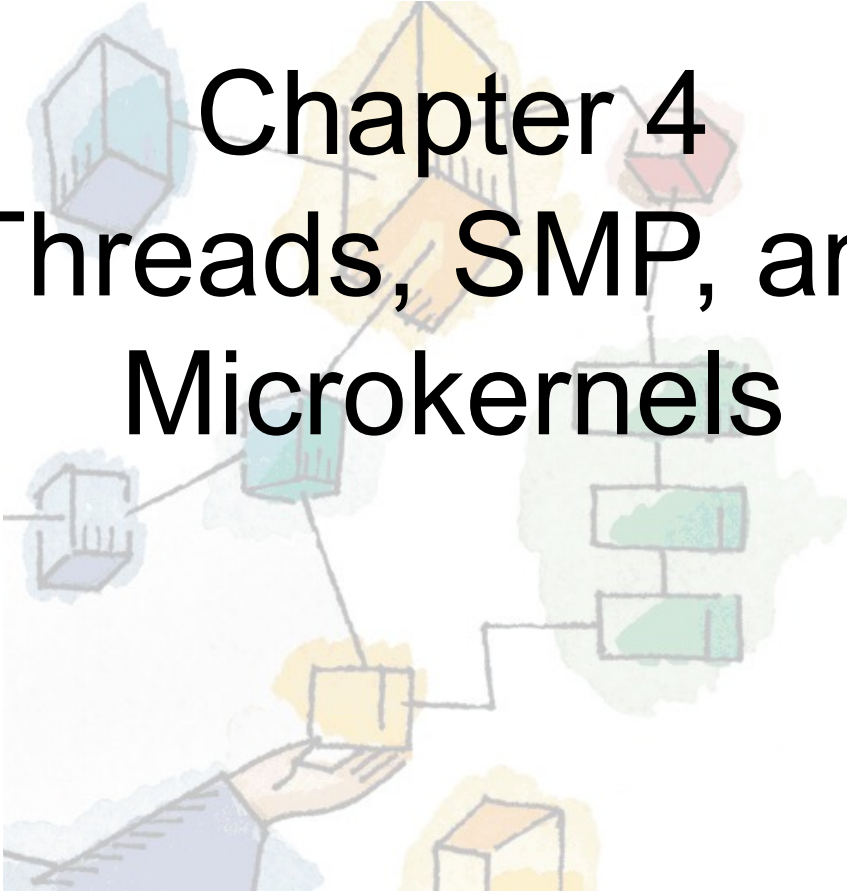


*Operating Systems:  
Internals and Design Principles, 6/E*  
William Stallings



# Chapter 4 Threads, SMP, and Microkernels

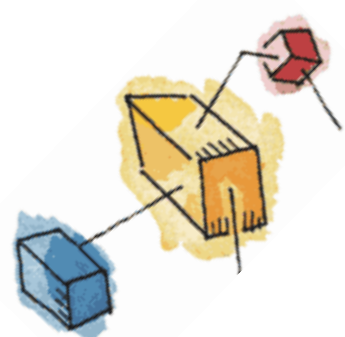


# Roadmap

## → Threads: Resource ownership and execution

- Symmetric multiprocessing (SMP).
- Microkernel
- Case Studies of threads and SMP:
  - Windows
  - Solaris
  - Linux

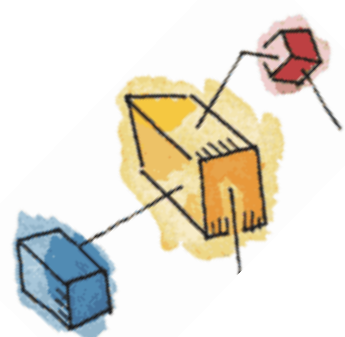




# Processes and Threads

- Processes have two characteristics:
  - **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

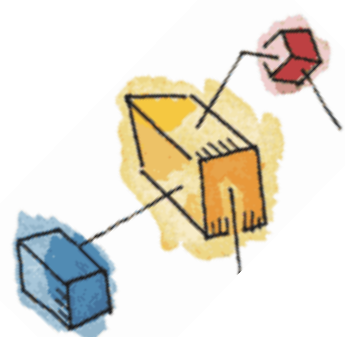




# Processes and Threads

- The unit of dispatching is referred to as a ***thread*** or lightweight process
- The unit of resource ownership is referred to as a process or ***task***





# Multithreading

- The ability of an OS to support multiple, concurrent paths of execution within a single process.

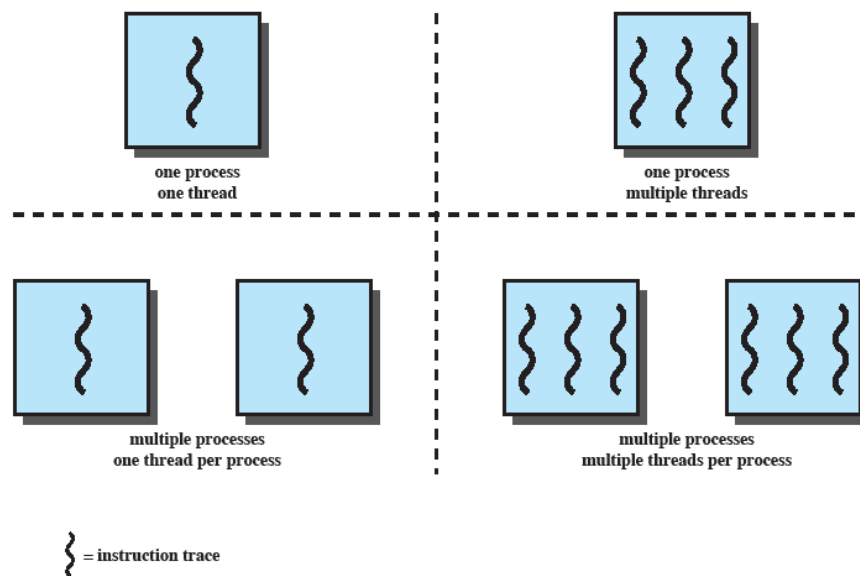


Figure 4.1 Threads and Processes [ANDE97]



# Single Thread Approaches

- MS-DOS supports a single user process and a single thread.
- Some UNIX, support multiple user processes but only support one thread per process

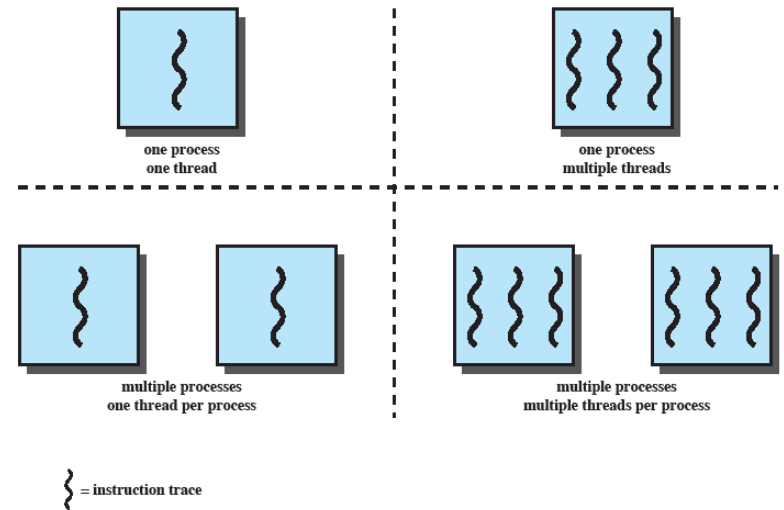


Figure 4.1 Threads and Processes [ANDE97]

# Multithreading

- Java run-time environment is a single process with multiple threads
- Multiple processes *and* threads are found in Windows, Solaris, and many modern versions of UNIX

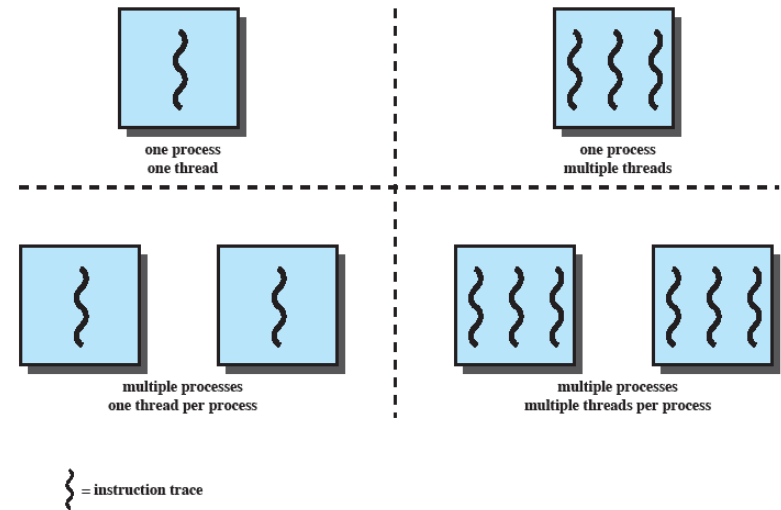


Figure 4.1 Threads and Processes [ANDE97]

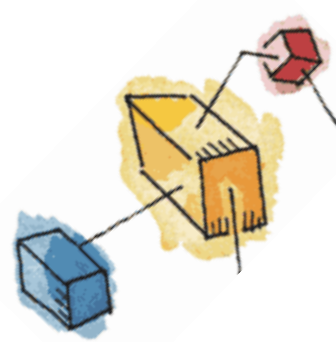


# Processes

- A virtual address space which holds the process image
- Protected access to
  - Processors,
  - Other processes,
  - Files,
  - I/O resources







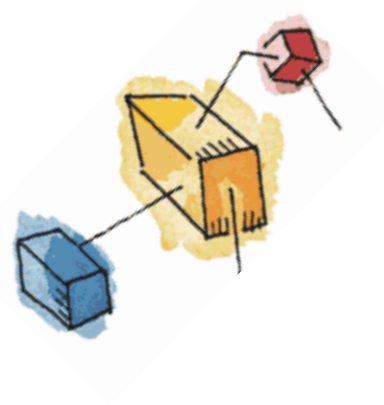
# One or More Threads in Process

- Each thread has
  - An execution state (running, ready, etc.)
  - Saved thread context when not running
  - An execution stack
  - Some per-thread static storage for local variables
  - Access to the memory and resources of its process (all threads of a process share this)



# One view...

- *One way to view a thread is as an independent program counter operating within a process.*





# Threads vs. processes

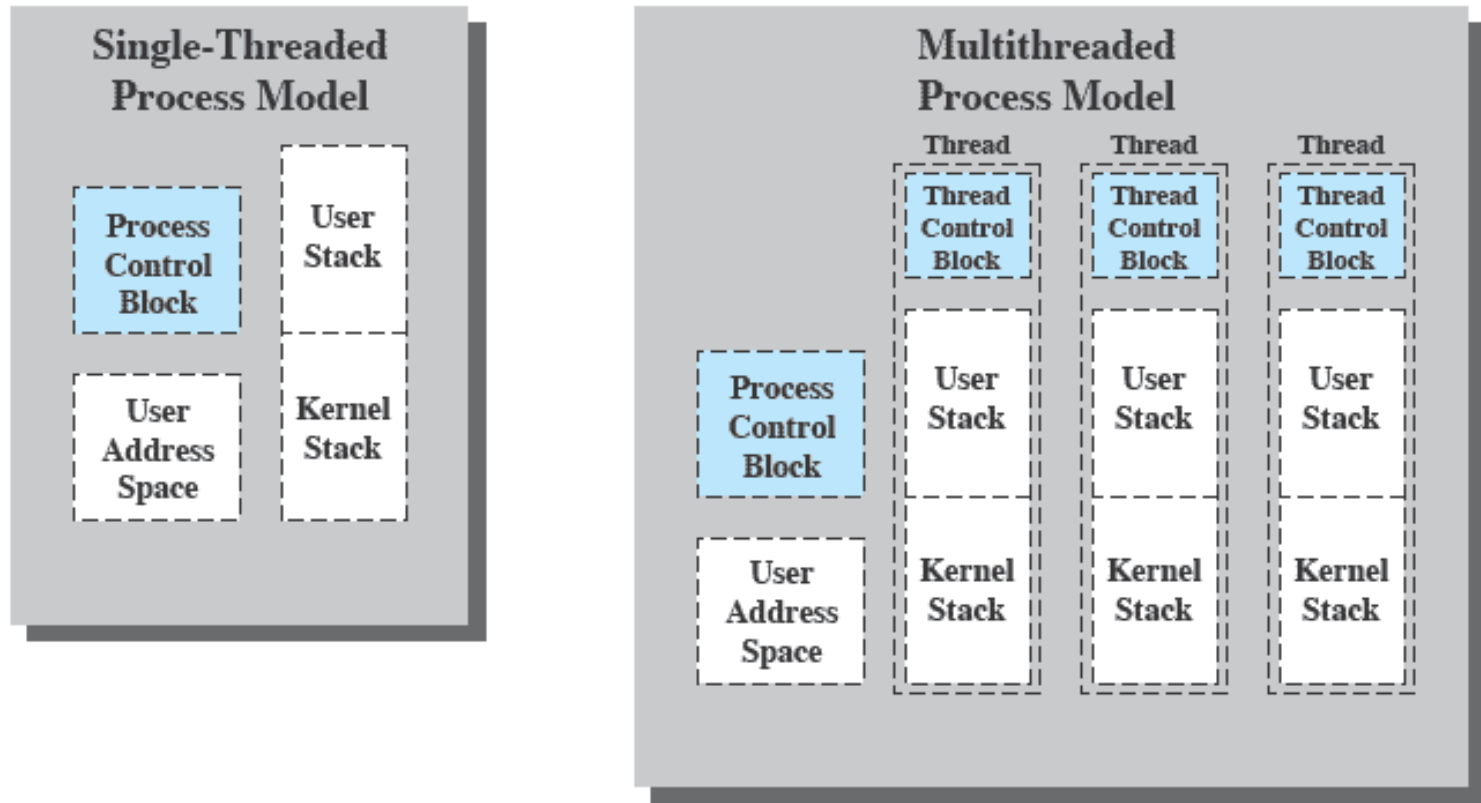
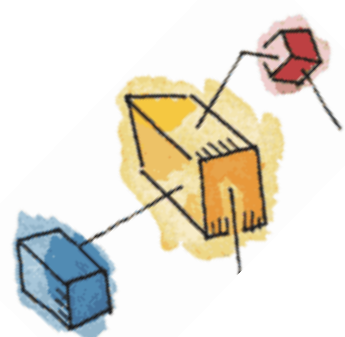


Figure 4.2 Single Threaded and Multithreaded Process Models





# Benefits of Threads

- Takes less time to create a new thread than a process
- Less time to terminate a thread than a process
- Switching between two threads takes less time than switching processes
- Threads can communicate with each other
  - without invoking the kernel





# Thread use in a Single-User System

- Foreground and background work
- Asynchronous processing
- Speed of execution
- Modular program structure





# Threads

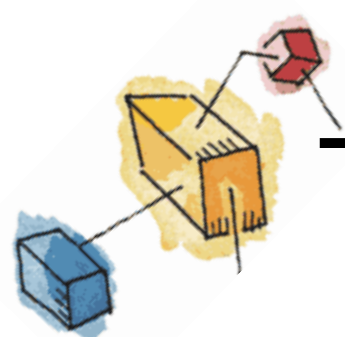
- Several actions that affect all of the threads in a process
  - The OS must manage these at the process level.
- Examples:
  - Suspending a process involves suspending all threads of the process
  - Termination of a process, terminates all threads within the process



# Activities similar to Processes

- Threads have execution states and may synchronize with one another.
  - Similar to processes
- We look at these two aspects of thread functionality in turn.
  - States
  - Synchronisation



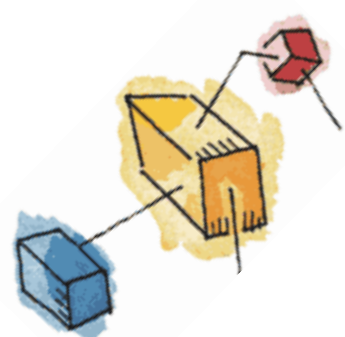


# Thread Execution States

- States associated with a change in thread state
  - Spawn (another thread)
  - Block
    - Issue: will blocking a thread block other, or *all*, threads
  - Unblock
  - Finish (thread)
    - Deallocate register context and stacks







# Example:

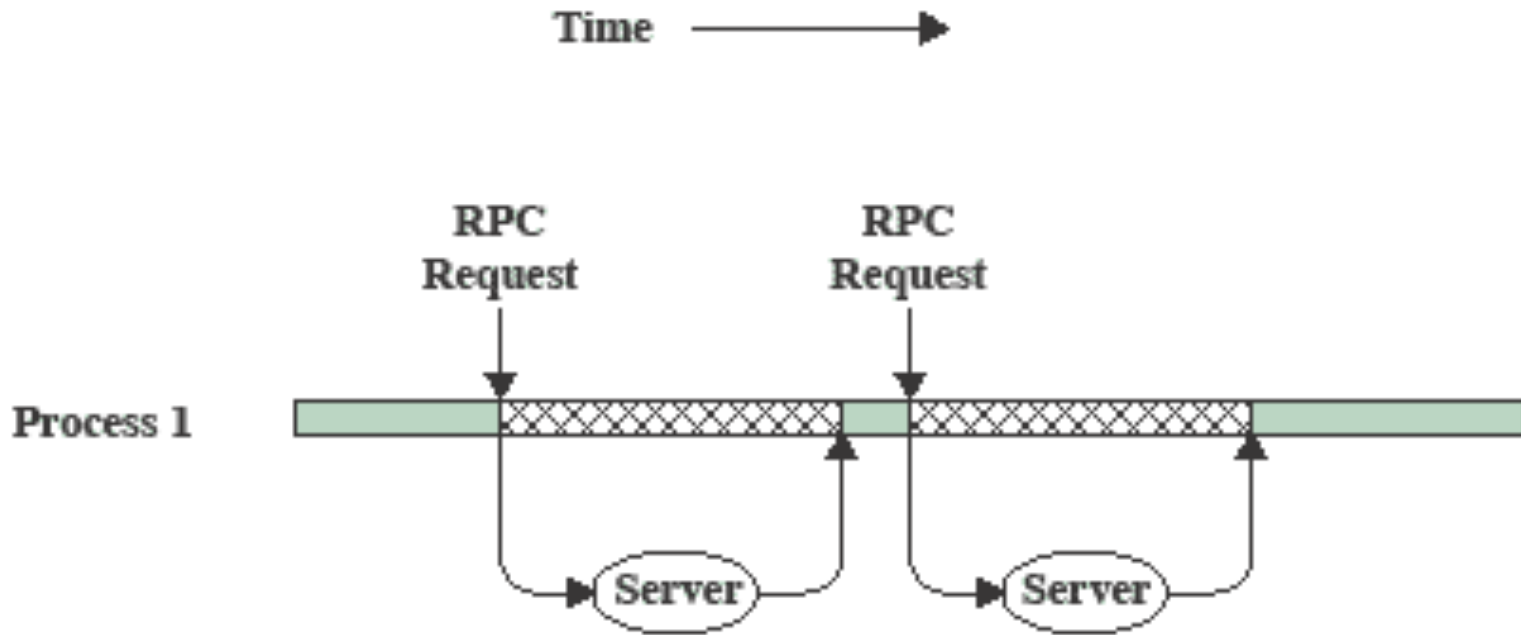
## Remote Procedure Call

- Consider:
  - A program that performs two remote procedure calls (RPCs)
  - to two different hosts
  - to obtain a combined result.



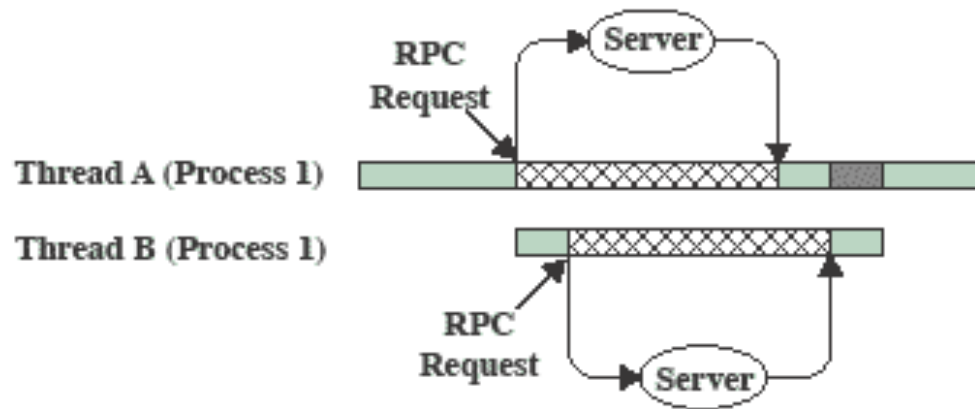
# RPC

## Using Single Thread






(a) RPC Using Single Thread

# RPC Using One Thread per Server



(b) RPC Using One Thread per Server (on a uniprocessor)

-  Blocked, waiting for response to RPC
-  Blocked, waiting for processor, which is in use by Thread B
-  Running

# Multithreading on a Uniprocessor

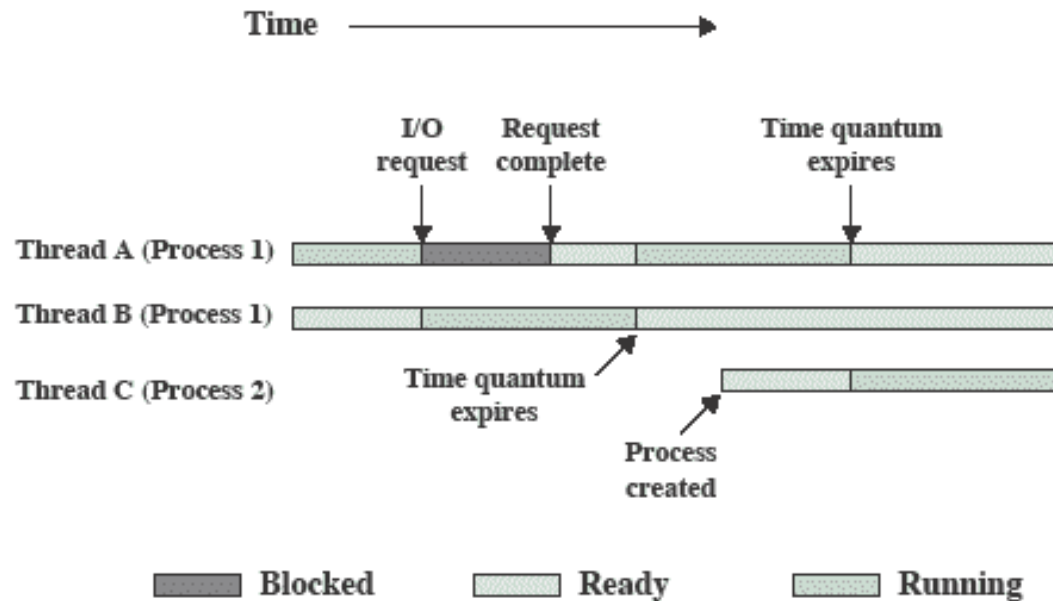


Figure 4.4 Multithreading Example on a Uniprocessor

# Adobe PageMaker

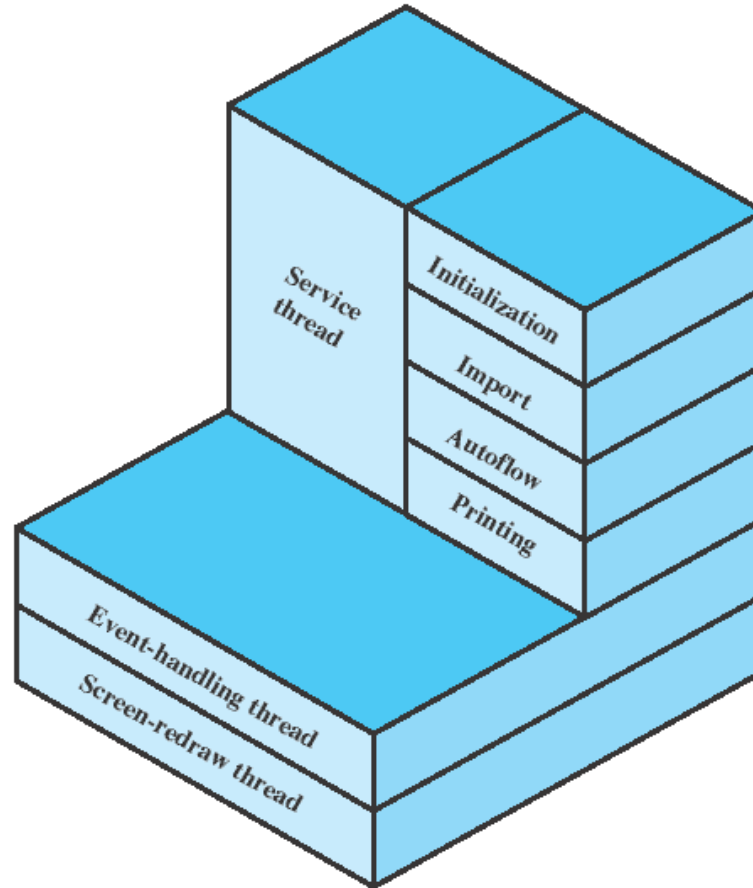
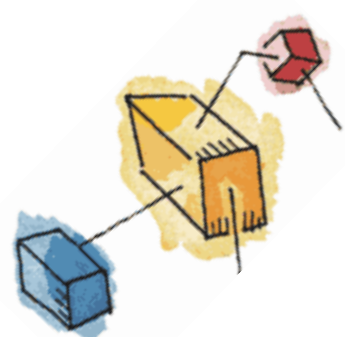


Figure 4.5 Thread Structure for Adobe PageMaker



# Categories of Thread Implementation

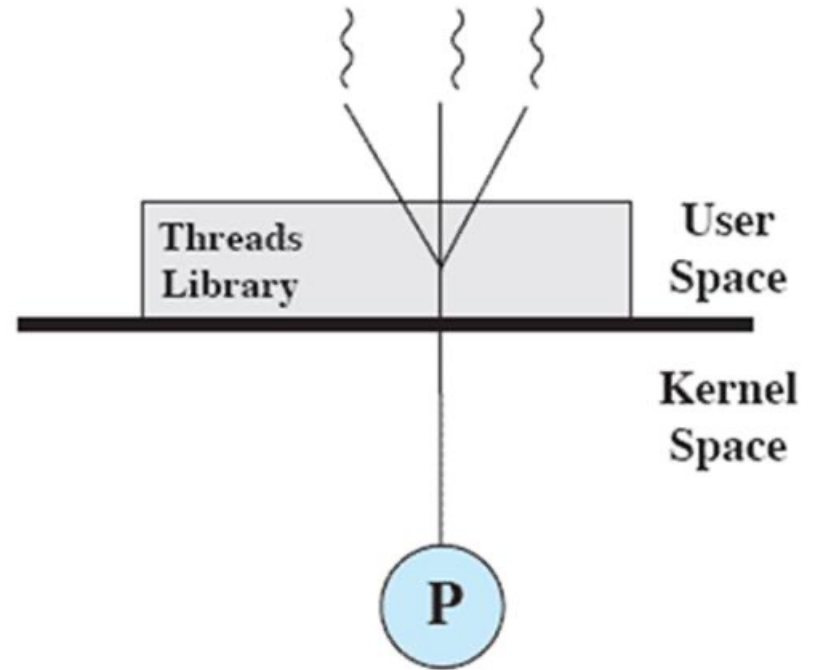
- User Level Thread (ULT)
- Kernel level Thread (KLT) also called:
  - kernel-supported threads
  - lightweight processes.





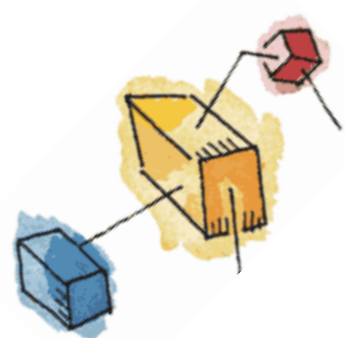
# User-Level Threads

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

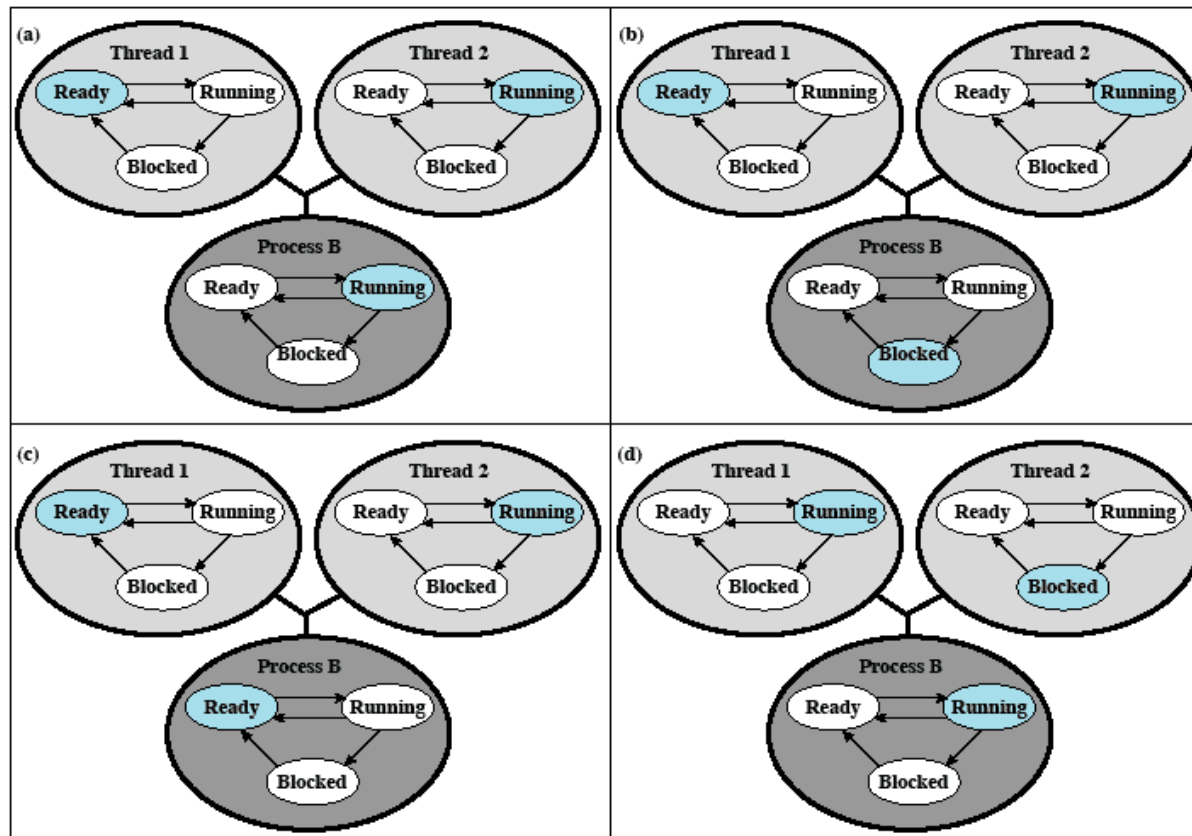


(a) Pure user-level





# Relationships between ULT Thread and Process States



Colored state  
is current state

Figure 4.7 Examples of the Relationships Between User-Level Thread States and Process States







# Kernel-Level Threads

- Kernel maintains context information for the process and the threads
  - No thread management done by application
- Scheduling is done on a thread basis
- Windows is an example of this approach

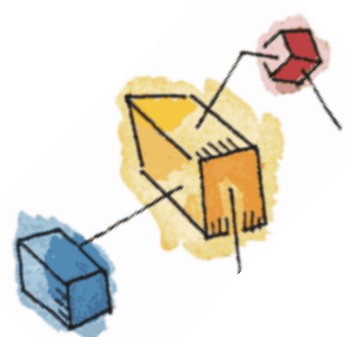


User Space

Kernel Space

(b) Pure kernel-level

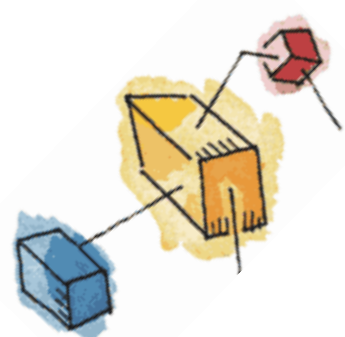




# Advantages of KLT

- 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 themselves can be multithreaded.

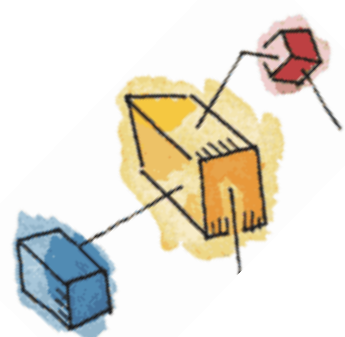




# Disadvantage of KLT

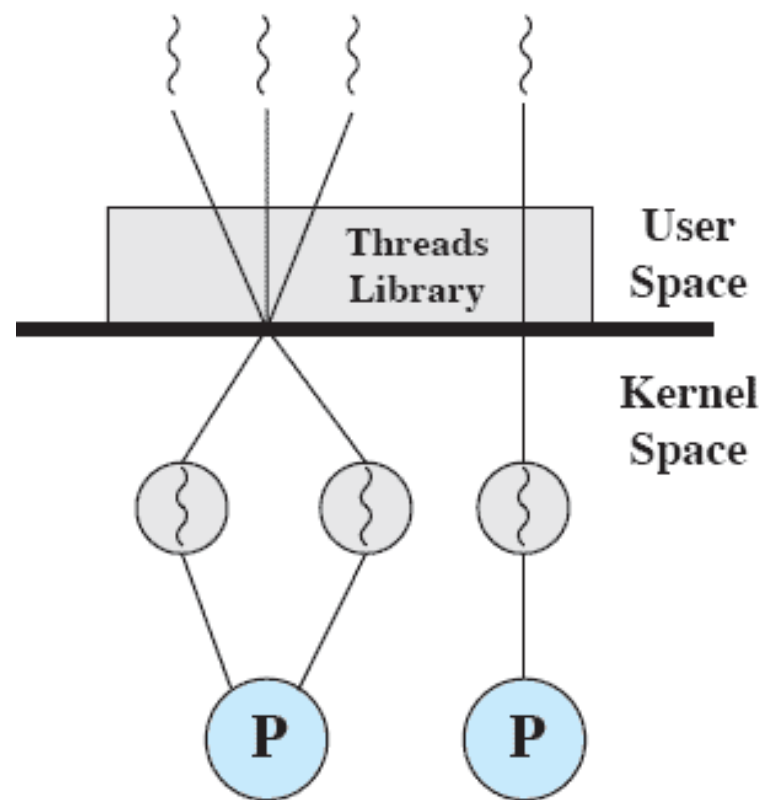
- The transfer of control from one thread to another within the same process requires a mode switch to the kernel





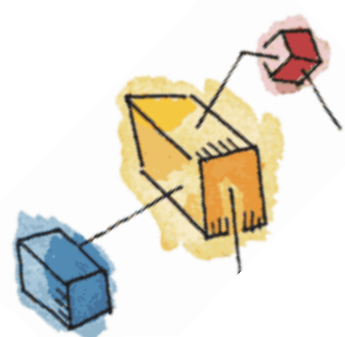
# Combined Approaches

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



(c) Combined





# Relationship Between Thread and Processes

Table 4.2 Relationship Between Threads and Processes

Threads:Processes	Description	Example Systems
1:1	Each thread of execution is a unique process with its own address space and resources.	Traditional UNIX implementations
M:1	A process defines an address space and dynamic resource ownership. Multiple threads may be created and executed within that process.	Windows NT, Solaris, Linux, OS/2, OS/390, MACH
1:M	A thread may migrate from one process environment to another. This allows a thread to be easily moved among distinct systems.	Ra (Clouds), Emerald
M:N	Combines attributes of M:1 and 1:M cases.	TRIX





# Roadmap

- Threads: Resource ownership and execution

→ Symmetric multiprocessing (SMP).

- Microkernel
- Case Studies of threads and SMP:
  - Windows
  - Solaris
  - Linux





# Traditional View

- Traditionally, the computer has been viewed as a sequential machine.
  - A processor executes instructions one at a time in sequence
  - Each instruction is a sequence of operations
- Two popular approaches to providing parallelism
  - Symmetric MultiProcessors (SMPs)
  - Clusters (ch 16)





# Categories of Computer Systems

- Single Instruction Single Data (SISD) stream
  - Single processor executes a single instruction stream to operate on data stored in a single memory
- Single Instruction Multiple Data (SIMD) stream
  - Each instruction is executed on a different set of data by the different processors







# Categories of Computer Systems

- Multiple Instruction Single Data (MISD) stream (Never implemented)
  - A sequence of data is transmitted to a set of processors, each of execute a different instruction sequence
- Multiple Instruction Multiple Data (MIMD)
  - A set of processors simultaneously execute different instruction sequences on different data sets



# Parallel Processor Architectures

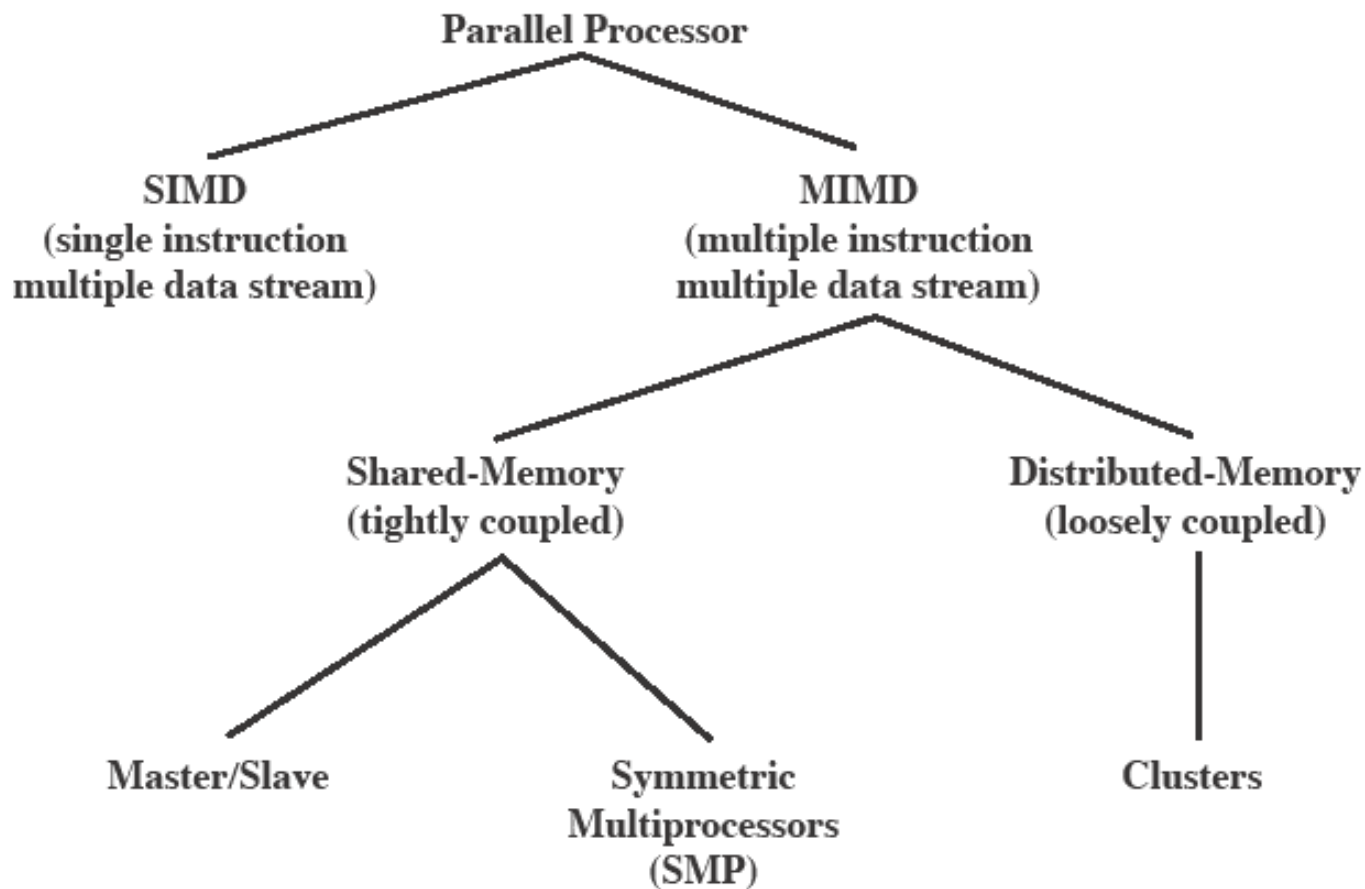
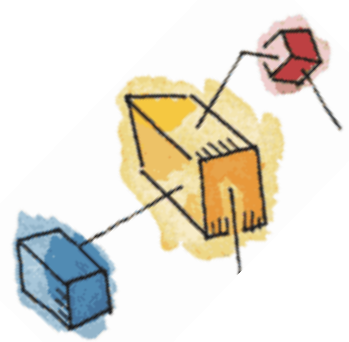


Figure 4.8 Parallel Processor Architectures

# Symmetric Multiprocessing

- Kernel can execute on any processor
  - Allowing portions of the kernel to execute in parallel
- Typically each processor does self-scheduling from the pool of available process or threads



# Typical SMP Organization

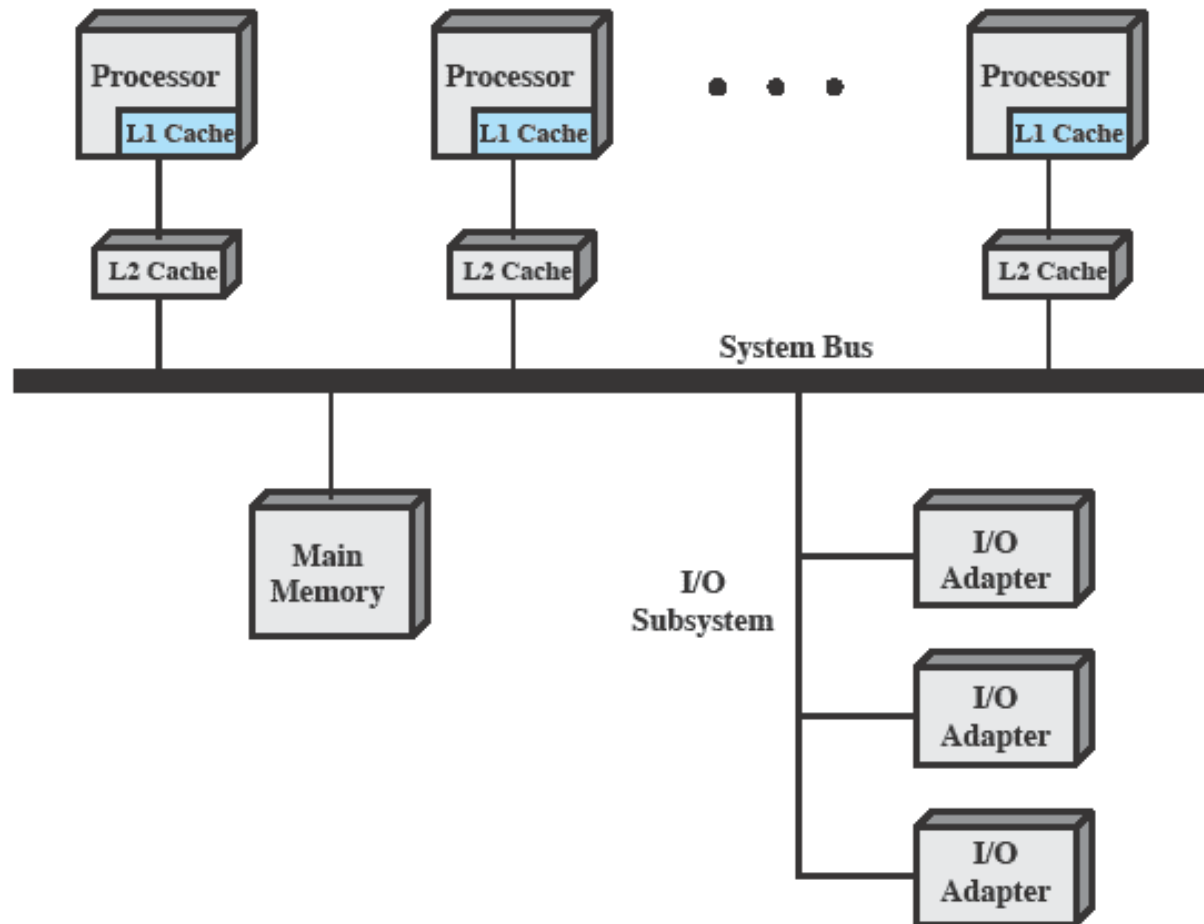
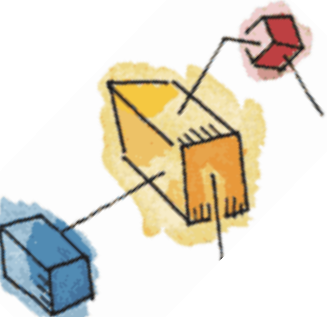


Figure 4.9 Symmetric Multiprocessor Organization



# Multiprocessor OS Design Considerations

- The key design issues include
  - Simultaneous concurrent processes or threads
  - Scheduling
  - Synchronization
  - Memory Management
  - Reliability and Fault Tolerance





# Roadmap

- Threads: Resource ownership and execution
- Symmetric multiprocessing (SMP).

## → Microkernel

- Case Studies of threads and SMP:
  - Windows
  - Solaris
  - Linux





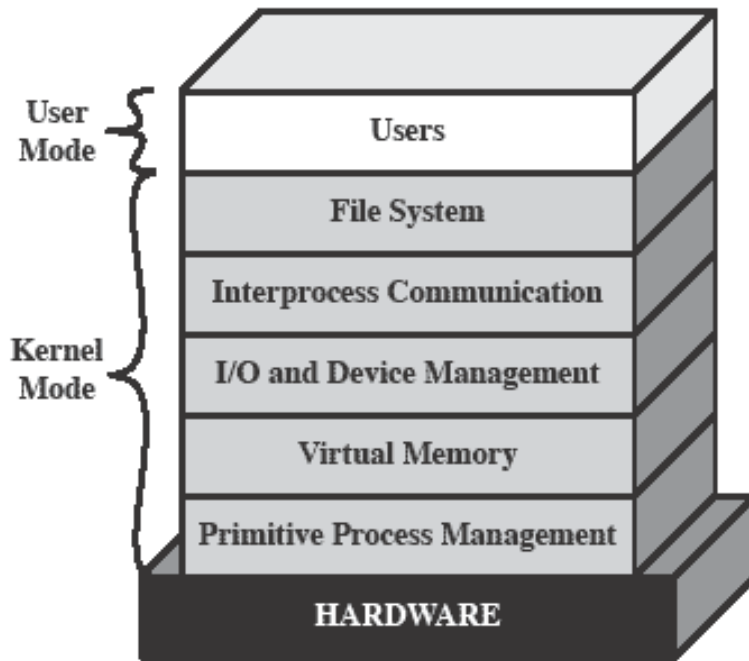
# Microkernel

The illustration shows a central yellow box representing the microkernel. It is connected by lines to three other boxes: a blue box on the left, a red box on the top right, and a smaller yellow box on the bottom right. This represents a modular system where various services are provided by separate user-space components.

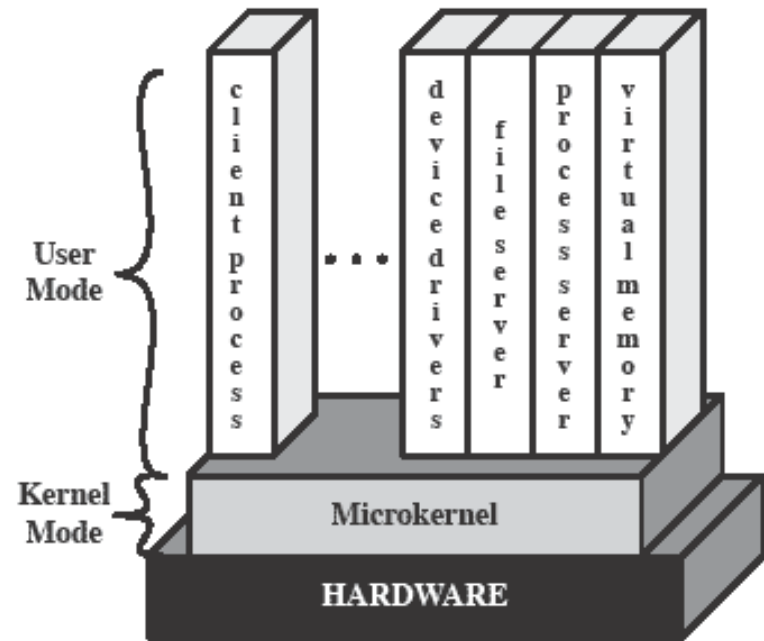
- A microkernel is a small OS core that provides the foundation for modular extensions.
- Big question is how small must a kernel be to qualify as a microkernel
  - *Must* drivers be in user space?
- In theory, this approach provides a high degree of flexibility and modularity.



# Kernel Architecture



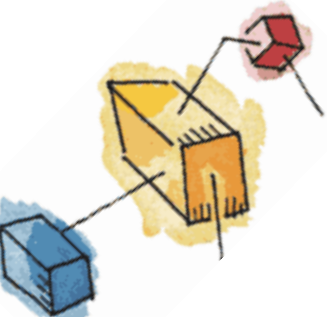
(a) Layered kernel



(b) Microkernel

Figure 4.10 Kernel Architecture





# Microkernel Design: Memory Management

- Low-level memory management - Mapping each virtual page to a physical page frame
  - Most memory management tasks occur in user space

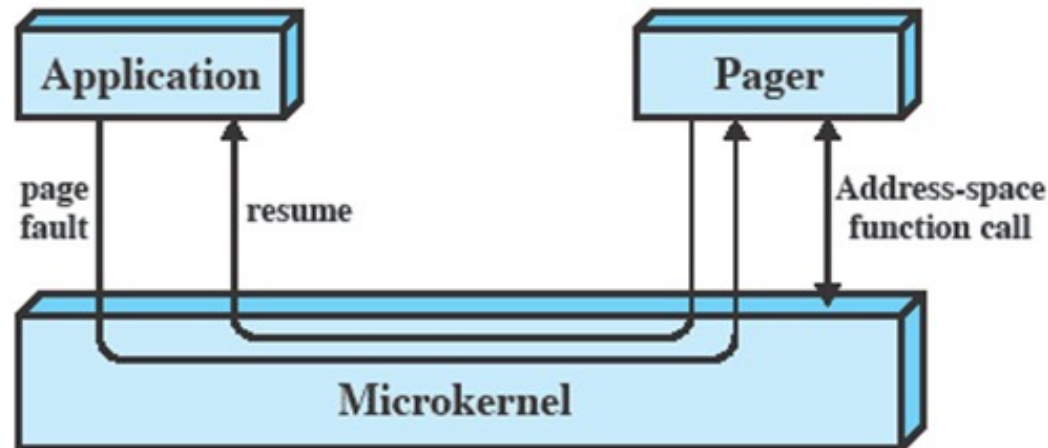
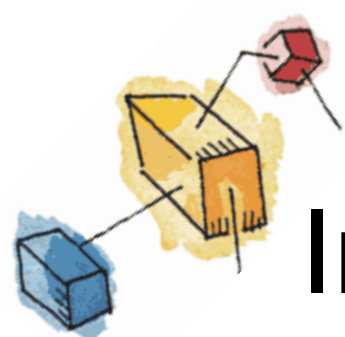


Figure 4.11 Page Fault Processing

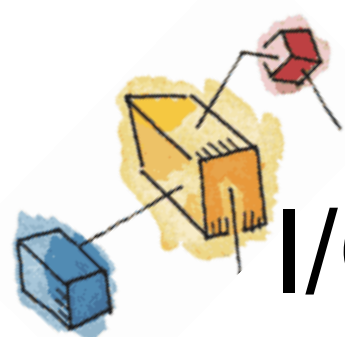




# Microkernel Design: Interprocess Communication

- Communication between processes or threads in a microkernel OS is via messages.
- A message includes:
  - A header that identifies the sending and receiving process and
  - A body that contains direct data, a pointer to a block of data, or some control information about the process.

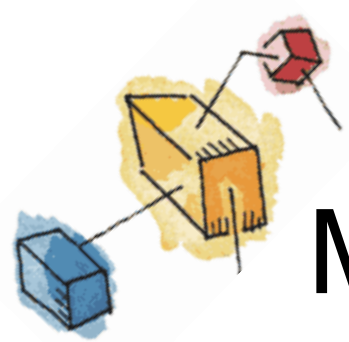




# Microkernel Design: I/O and interrupt management

- Within a microkernel it is possible to handle hardware interrupts as messages and to include I/O ports in address spaces.
  - a particular user-level process is assigned to the interrupt and the kernel maintains the mapping.





# Benefits of a Microkernel Organization

- Uniform interfaces on requests made by a process.
- Extensibility
- Flexibility
- Portability
- Reliability
- Distributed System Support
- Object Oriented Operating Systems





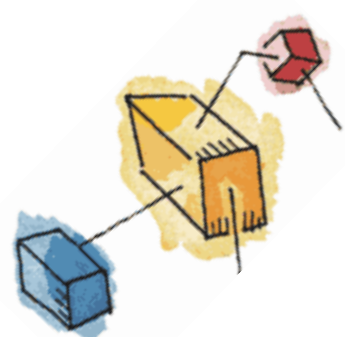
# Roadmap

- Threads: Resource ownership and execution
- Symmetric multiprocessing (SMP).
- Microkernel

## → Case Studies of threads and SMP:

- Windows
- Solaris
- Linux

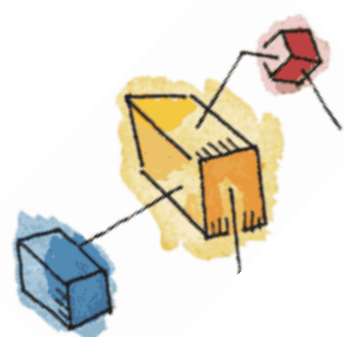




# Different Approaches to Processes

- Differences between different OS's support of processes include
  - How processes are named
  - Whether threads are provided
  - How processes are represented
  - How process resources are protected
  - What mechanisms are used for inter-process communication and synchronization
  - How processes are related to each other





# Windows Processes

- Processes and services provided by the Windows Kernel are relatively simple and general purpose
  - Implemented as objects
  - An executable process may contain one or more threads
  - Both processes and thread objects have built-in synchronization capabilities



# Relationship between Process and Resources

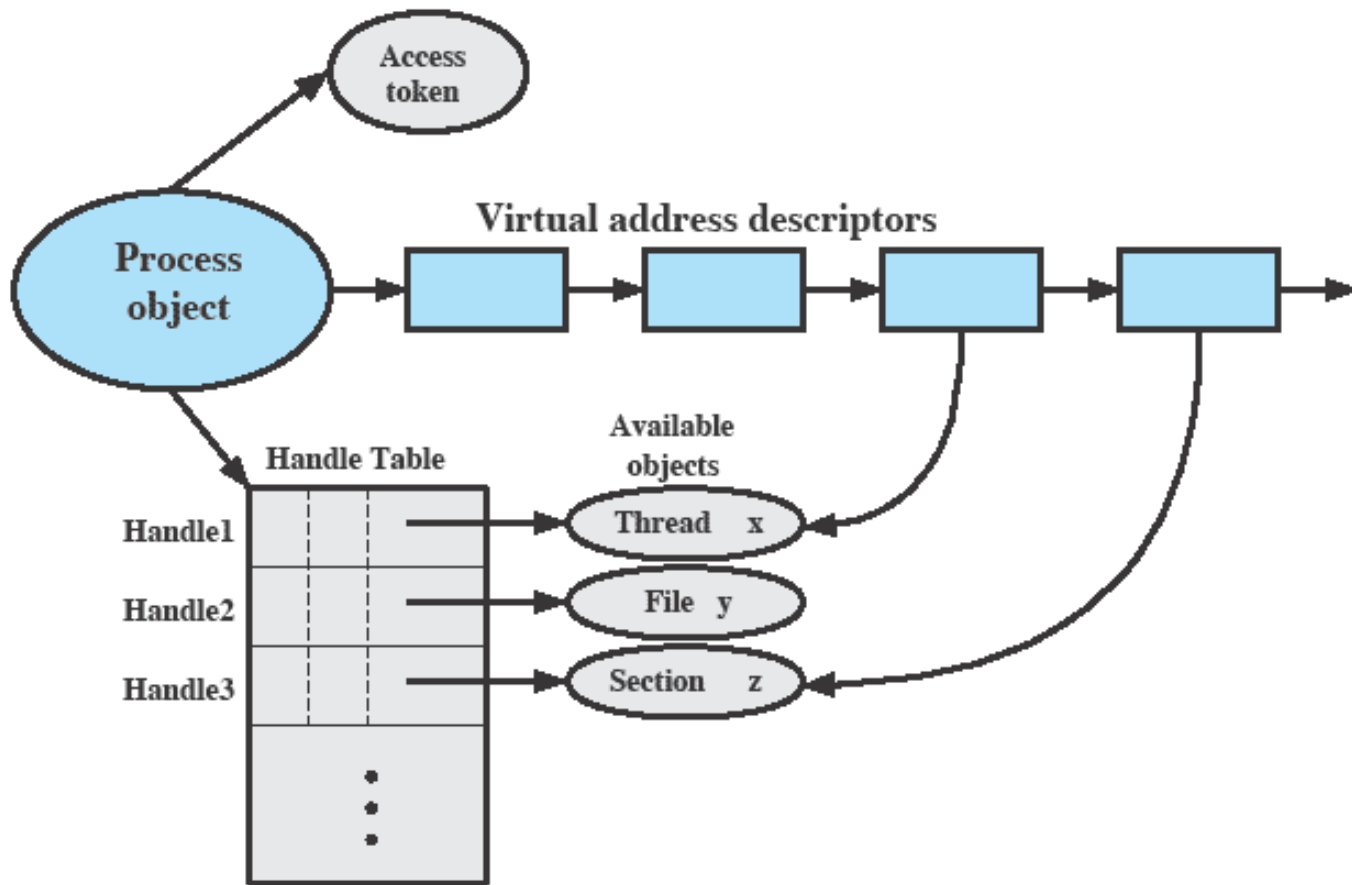


Figure 4.12 A Windows Process and Its Resources



# Windows Process Object

**Object Type**

**Process**

**Object Body  
Attributes**

Process ID  
Security Descriptor  
Base priority  
Default processor affinity  
Quota limits  
Execution time  
I/O counters  
VM operation counters  
Exception/debugging ports  
Exit status

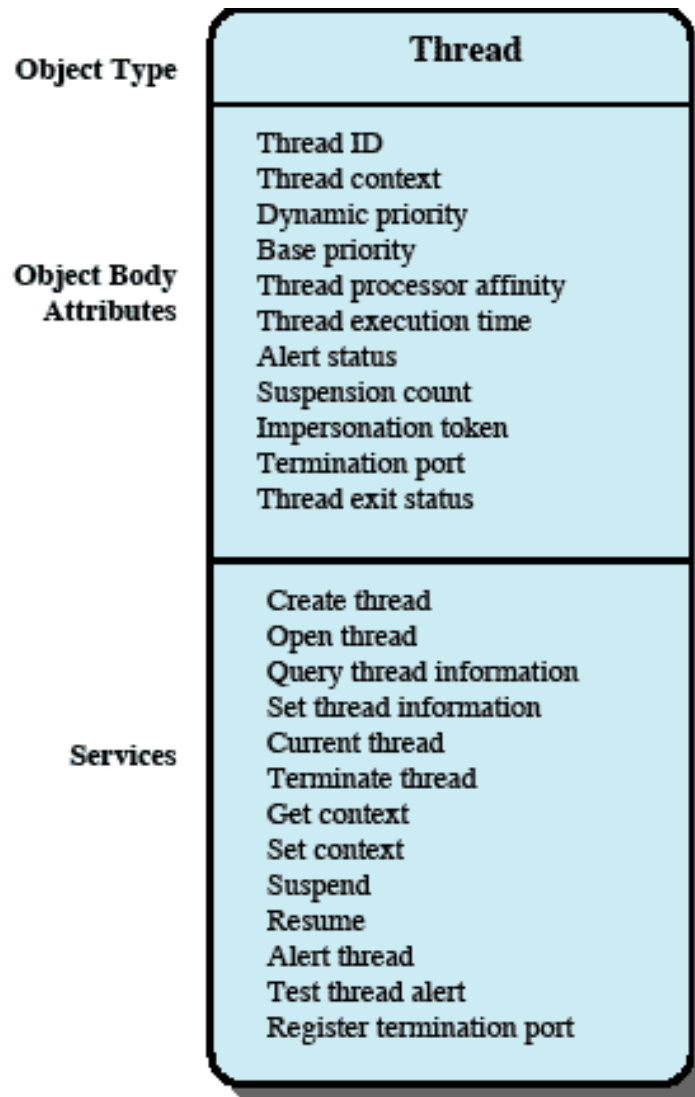
**Services**

Create process  
Open process  
Query process information  
Set process information  
Current process  
Terminate process


**(a) Process object**



# Windows Thread Object



(b) Thread object



# Thread States

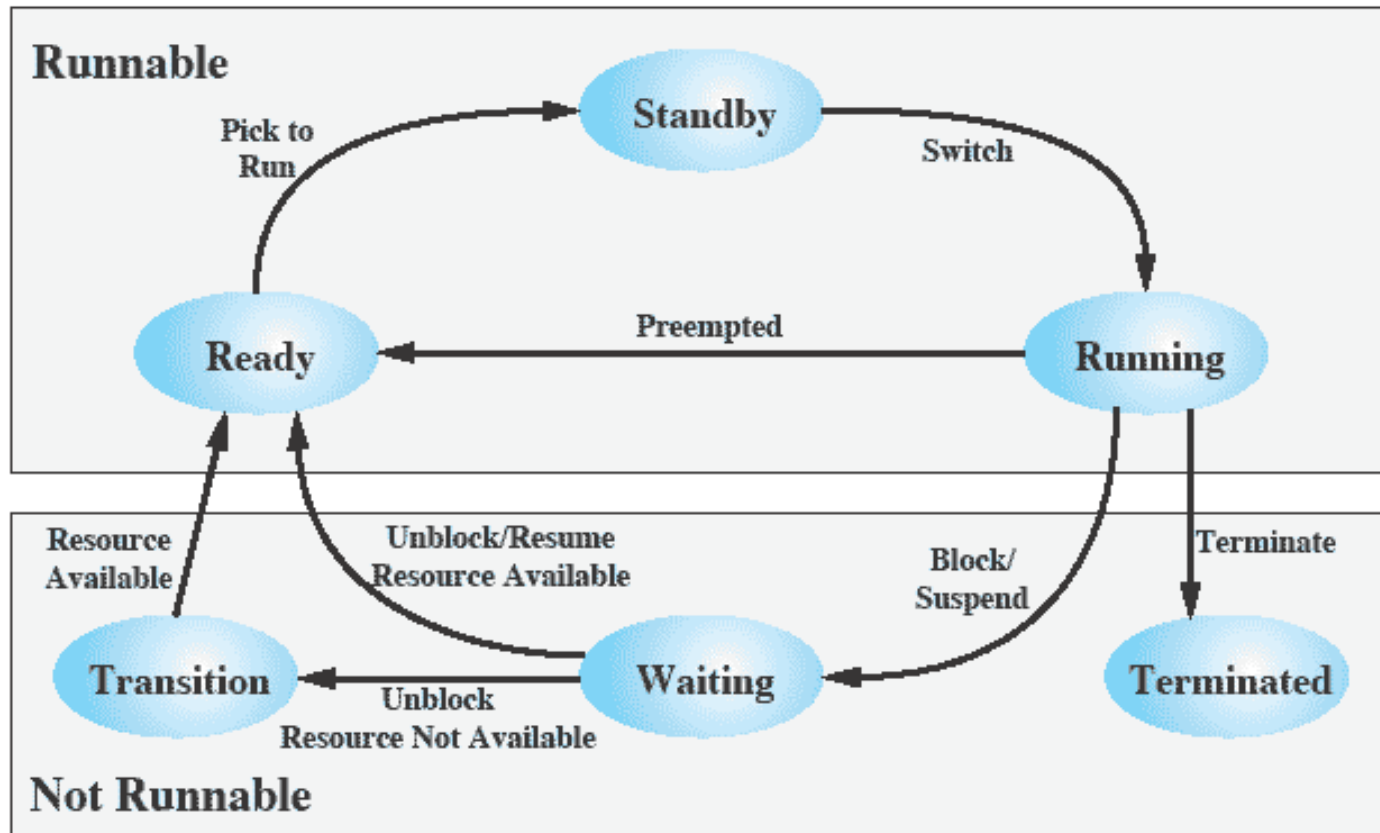
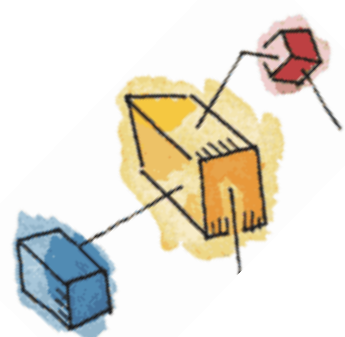


Figure 4.14 Windows Thread States



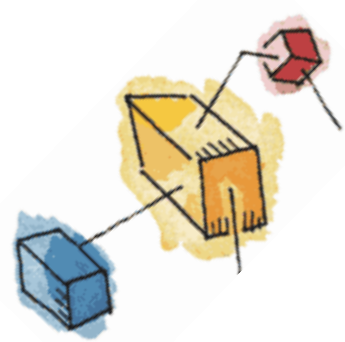
# Windows SMP Support

- **Threads can run on any processor**
  - But an application can restrict affinity
- **Soft Affinity**
  - The dispatcher tries to assign a ready thread to the same processor it last ran on.
  - This helps reuse data still in that processor's memory caches from the previous execution of the thread.
- **Hard Affinity**
  - An application restricts threads to certain processor



# Solaris

- Solaris implements multilevel thread support designed to provide flexibility in exploiting processor resources.
- Processes include the user's address space, stack, and process control block





# Solaris Process

- Solaris makes use of four separate thread-related concepts:
  - Process: includes the user's address space, stack, and process control block.
  - User-level threads: a user-created unit of execution within a process.
  - Lightweight processes: a mapping between ULTs and kernel threads.
  - Kernel threads



# Relationship between Processes and Threads

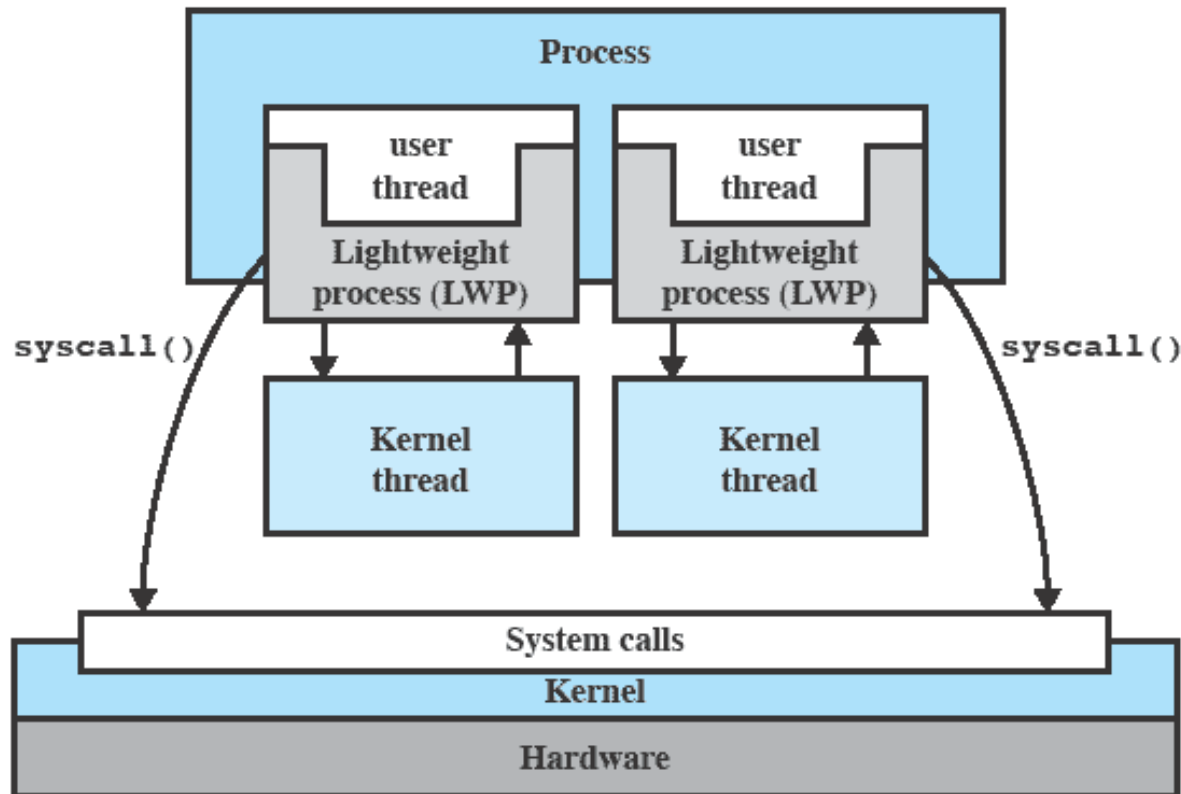
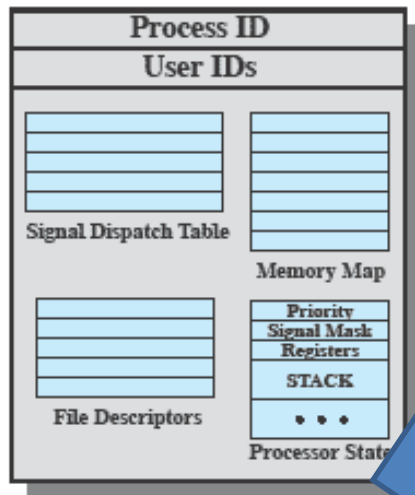


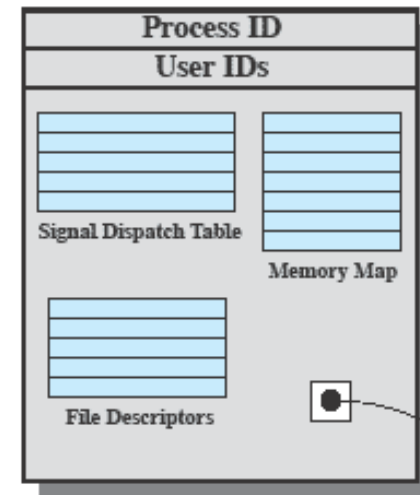
Figure 4.15 Processes and Threads in Solaris [MCDO07]

# Traditional Unix vs Solaris

UNIX Process Structure



Solaris Process Structure



Solaris replaces the processor state block with a list of LWPs

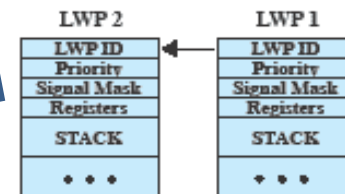


Figure 4.16 Process Structure in Traditional UNIX and Solaris [LEWI96]





# LWP Data Structure

- An LWP identifier
- The priority of this LWP
- A signal mask
- Saved values of user-level registers
- The kernel stack for this LWP
- Resource usage and profiling data
- Pointer to the corresponding kernel thread
- Pointer to the process structure



# Solaris Thread States

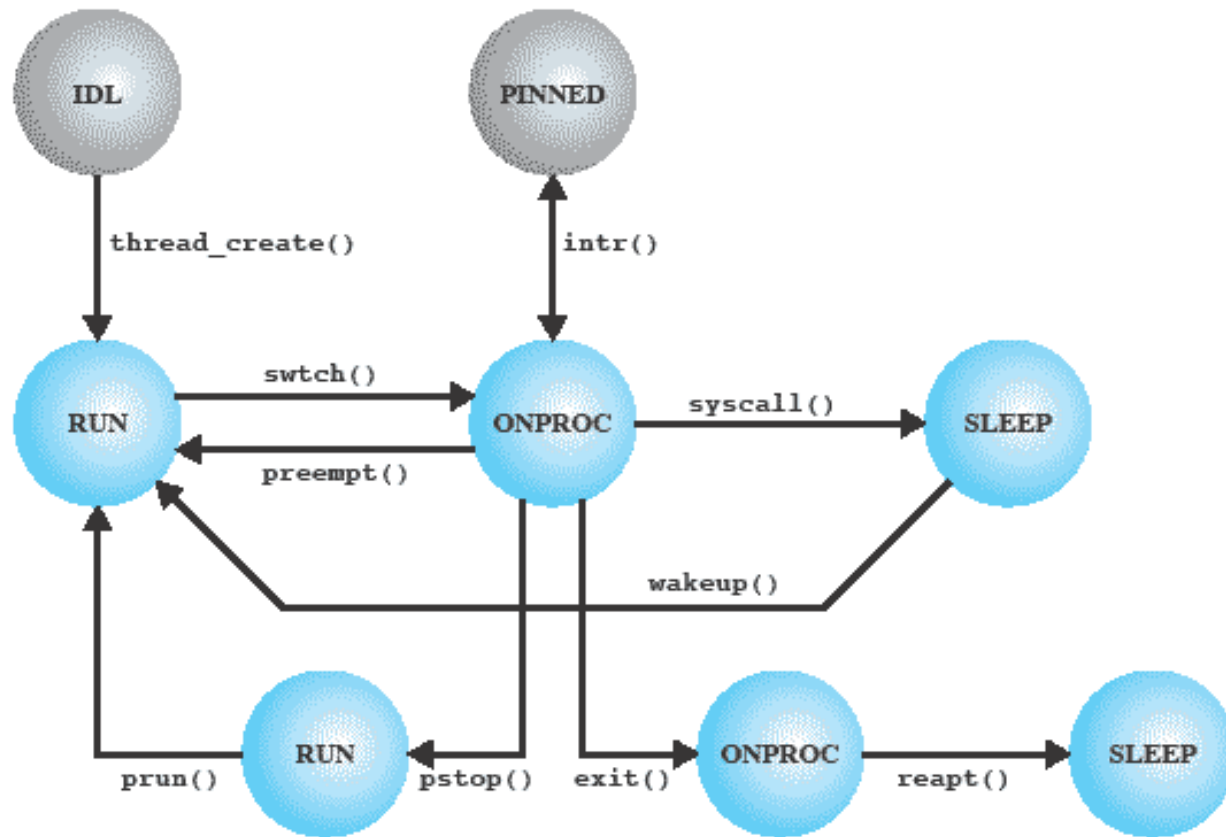


Figure 4.17 Solaris Thread States [MCDO07]

# Linux Tasks

- A process, or task, in Linux is represented by a `task_struct` data structure
- This contains a number of categories including:
  - State
  - Scheduling information
  - Identifiers
  - Interprocess communication
  - And others



# Linux Process/Thread Model

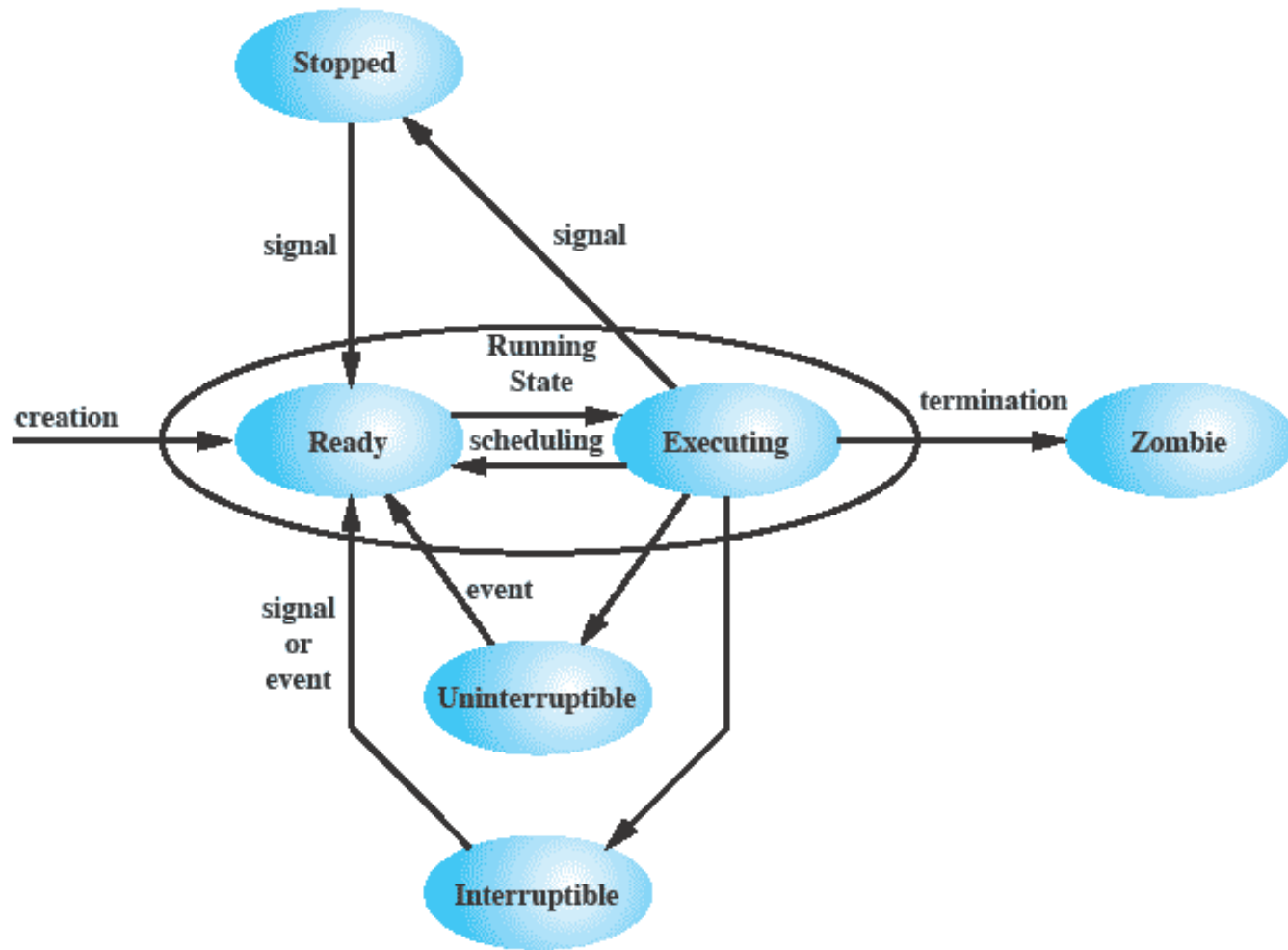


Figure 4.18 Linux Process/Thread Model