Threads, SMP, and Microkernels

Chapter 4

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Current View of Process

- Process is a program in execution
- It has
  - Execution environment
    - address space, registers, etc
  - Execution entity
    - Code
- Currently thought of as a singular unit

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Current View of a Process: Two Aspects

- *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

- However, these two characteristics are considered independently by the OS

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Rethinking the “Process”

- Thread - Unit of dispatching
  - Computational entity +
  - Thread-specific memory

- Process – Execution environment
  - Threads
  - Resources available to all threads
    - Memory, files

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Multithreading

Multiple threads of execution
within a single process

- MS-DOS supports a single thread
- UNIX supports multiple user processes but only supports one thread per process
- Windows, Solaris, Linux, Mach, and OS/2 support multiple threads within a process

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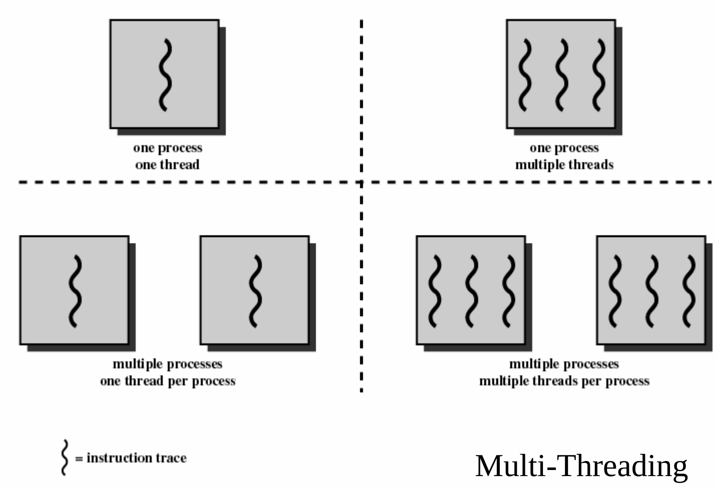

Multi-Threading

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Process? / Thread?

- Is there a difference in the way we NOW think about them?

  => YES!

- Loosely speaking
  - Thread is the computational unit
  - Process is the resources allocated to the thread, i.e., it's computational environment,
    - Well… almost
  - Threads execute within, and are considered elements of a process

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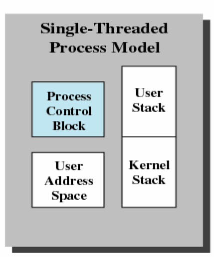
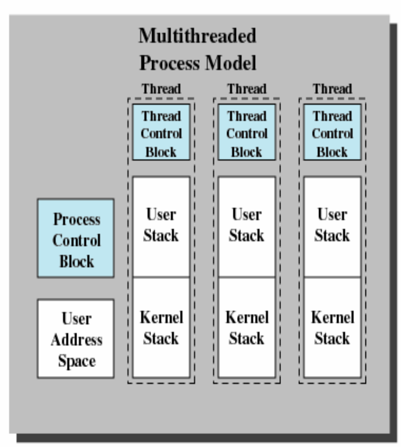
Process – Earlier Perspective



Process =
Computational unit +
Computational Environment

Process / Thread –
New Perspective



Thread

- Has an execution state (running, ready, etc.)
- Thread context saved when not running
- Has an execution stack
- Has some per-thread static storage for local variables

- Access to the memory and resources of its process
  - all threads of a process share this

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Process

- Have a virtual address space which holds the process image
  - Process Control Block
  - User address space
    - Thread accessible
  - Thread + thread components *
- Has protected access to processors, other processes, files, and I/O resources
  - Viz-a-viz the OS

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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

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Uses of Threads in a Single-User Multiprocessing System

- Foreground to background work
- Asynchronous processing
  - Computation + polling
- Speed of execution
  - Computation + I/O
- Modular program structure
  - threads ⇔ functions

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Process Implications w.r.t Threads

- Suspending a process involves suspending all threads of the process since all threads share the same address space
  - Does blocking a thread stop the process, and subsequently, all other processes?
    - ULT / KLT
- Termination of a process, terminates all threads within the process

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Thread States

- States associated with a change in thread state
  - Spawn
    - Spawn another thread
  - Block
  - Unblock
  - Finish
    - Deallocate register context and stacks

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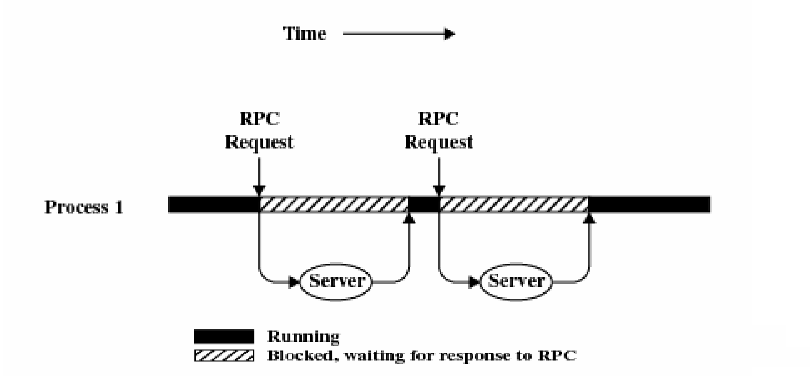
Remote Procedure Calls Using a Single Threaded Process



Remote Procedure Calls *Serialized*

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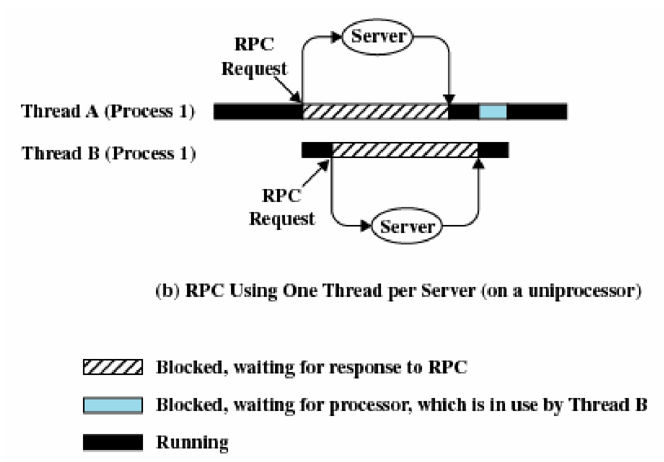
Remote Procedure Call Using a Multi-Threaded Process



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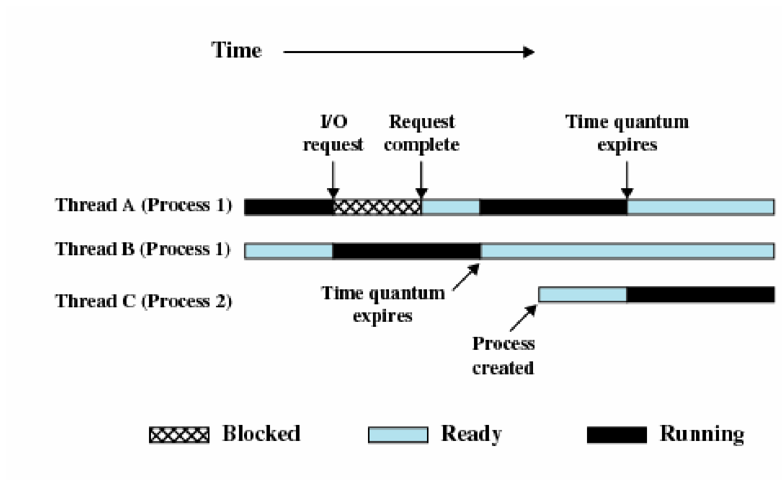
Multithreading / MultiProcessing



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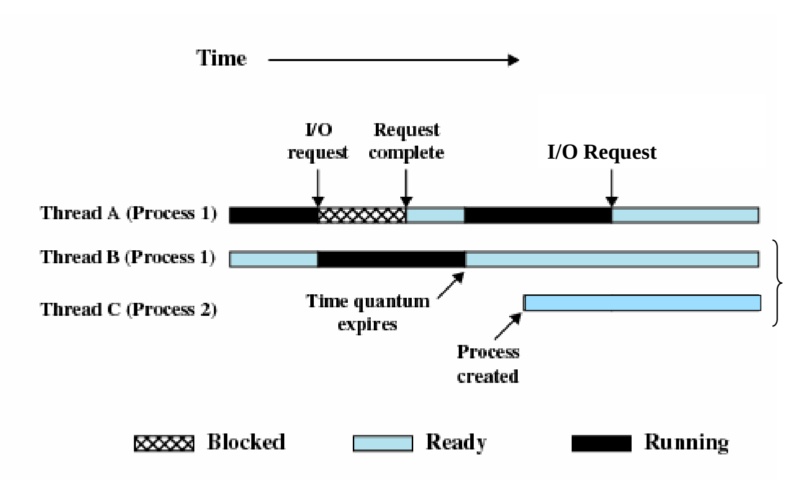
Multithreading / MultiProcessing



Who Should Get The Processor?

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User-Level vs. Kernel-Level Threads

- User-Level
  - OS Not aware of their existence
- Kernel-Level
  - OS IS Aware of their existence

- Considerations
  - Who Schedules them for execution?
  - Time Quantum allocation
    - At Process or Thread level?
  - Does Thread block cause Process to block?

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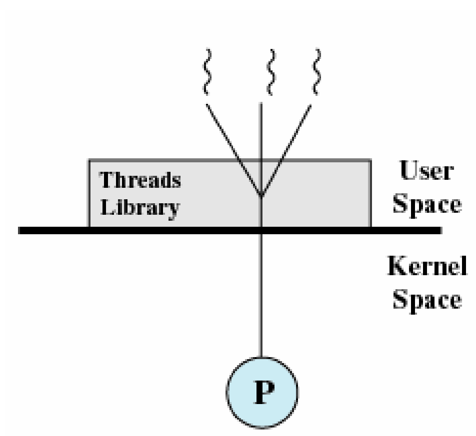
User-Level Threads



All thread management is done by the application

The kernel is not aware of the existence of threads

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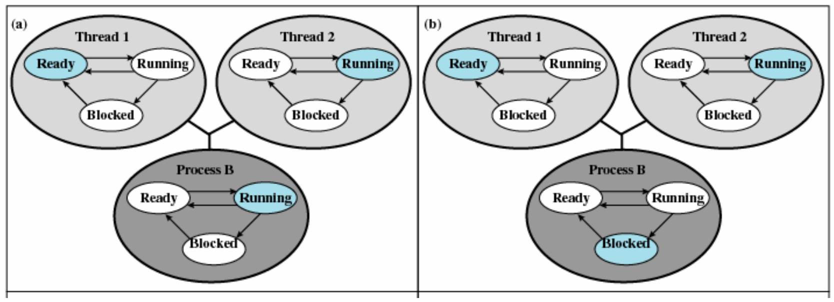
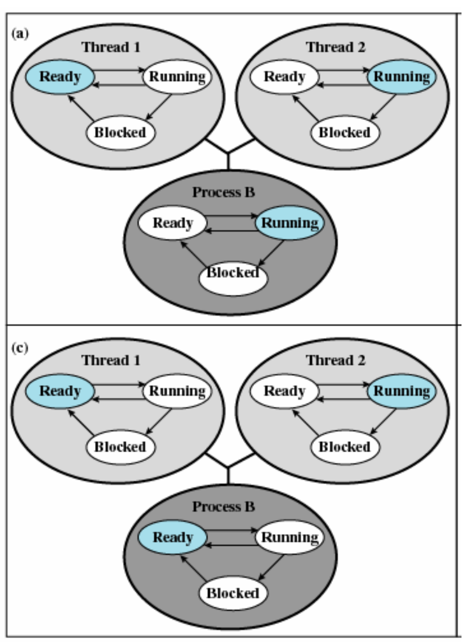


OS: Process B is executing
Application: Thread 2 is executing

Thread 2 requests I/O
OS perceives request from Process
OS Blocks **Process B**

Note: Thread 2 still in "running" State!

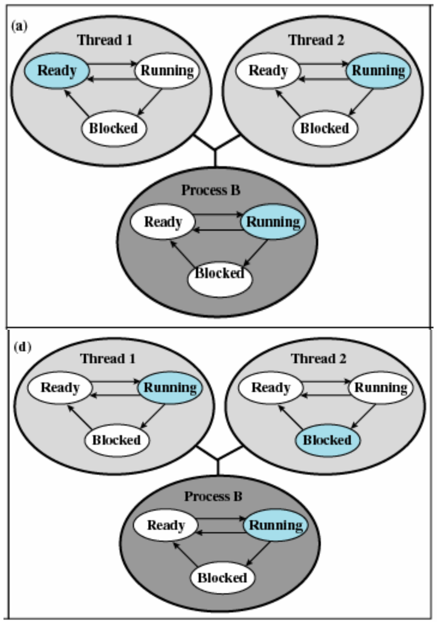
ULTs *explicitly* issue block or yield to change states



OS: Process B executing
App: Thread 2 executing

Quantum up for Process B
OS: Process B => Ready

Note:
 Thread 2 still in running state



OS: Thread B executing
App: Thread 2 executing

Thread 2 intentionally issues block

ULT Lib:
- Thread 2 => Blocked State
- Thread 1 => Running State

OS: Thread B still running
App: Thread 1 executing

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ULKs: The Good , The Bad

- Advantages
  - Thread level switching does not require kernel mode privildges (no Mode switching)
  - Scheduling can be application specific
  - ULT's can run on any OS
- Disadvantages
  - If a thread issues a system-level call that blocks thread, then entire Process blocks
  - Cannot take advantage of Multiprocessor environment, e.g. SMP

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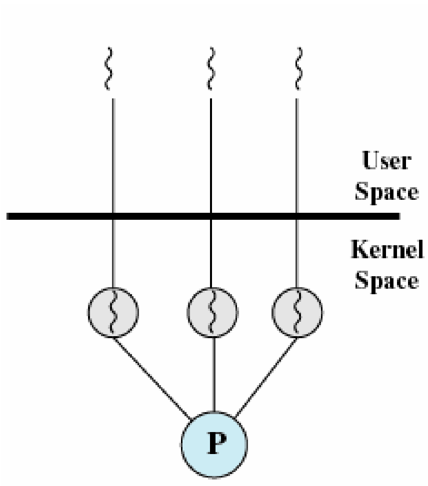
Kernel-Level Threads



Kernel maintains context information for *both* the process and the threads

Kernel (OS) schedules each thread individually

Windows uses this approach

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KLT: The Good, The Bad

- Advantages
  - Thread management done by OS Kernel
  - Scheduling at thread level, not process level
  - In a multiprocessor environement we can have true concurrency
  - If a thread issues a blocking system call, the other threads are not affected
- Disadvantages
  - Transfer of control form one thread to another expensive
    - Two Mode switches (U->K, K->U) : Context switch

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User-Level vs. Kernel-Level Threads (Revisited)

- User-Level: OS Not aware of their existence
- Kernel-Level: OS IS Aware of their existence

- Considerations
  - Who Schedules them for execution?
  - Time Quantum allocation
    - At Process or Thread level?
  - Does Thread block cause Process to block?

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Operational Overhead: ULK vs KLT

Table 4.1 Thread and Process Operation Latencies (µs) [ANDE92]

Operation	User-Level Threads	Kernel-Level Threads	Processes
Null Fork	34	948	11,300
Signal Wait	37	441	1,840

Null Fork: OH of creating a thread
Signal Wait: OH in synchronizing two process/thread together

Implications: KLTs are expensive

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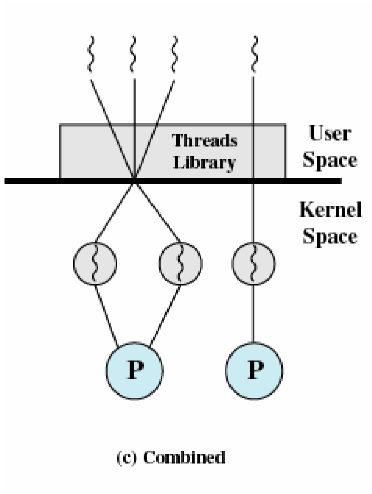
Combined Approaches Do Exist



SUN Solaris

Process created with single ULT thread running in user space

Additional ULT threads created in user space

ULTs are then mapped (transformed) into KLT – controlled by application programmer

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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

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Categories of Computer Systems

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

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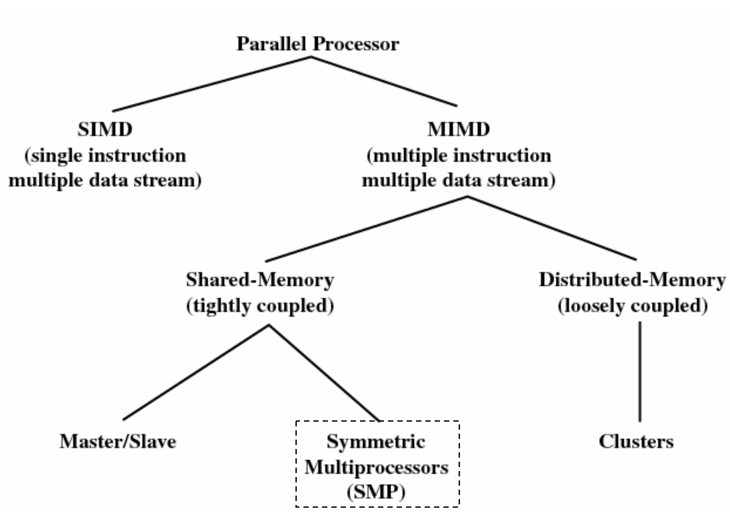
Parallel Processors: SIMD / MIMD



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Symmetric Multiprocessing

- Kernel can execute on any processor
- Kernel can be constructed as multiple processes/threads and execute concurrently

- Typically each processor does self-scheduling from the pool of available process or threads

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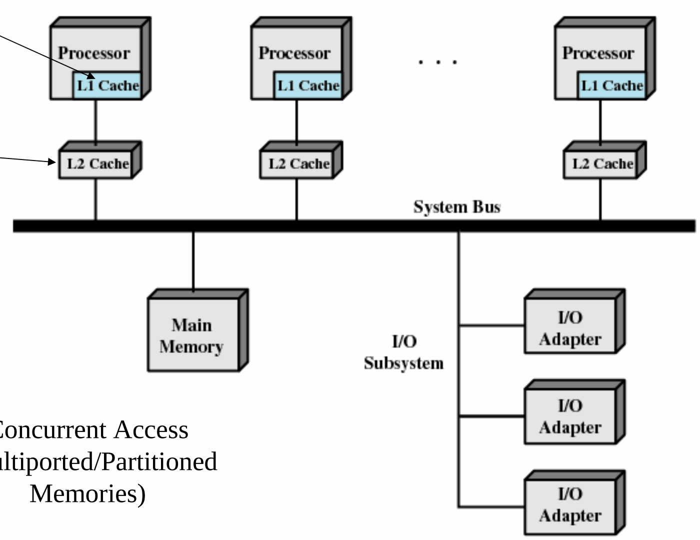
Memory & Cache Organization

On Processor Chip
(fastest)

On Motherboard
(Faster than accessing
memory)



Concurrent Access
(Multiported/Partitioned
Memories)

Multiprocessor Operating System Design Considerations

- Kernel processes need to be re-entrant
  - Simultaneous concurrent processes or threads
- Scheduling can be performed by more than one processor
  - Need to avoid conflicts
- Synchronization
  - Facility for mutual exclusion & event sequencing
- Memory management
  - Concurrent access
- Reliability and fault tolerance
  - Graceful degradation if one processor fails

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OS "Kernels"

- Monolithic
  - Lacked structure
  - Any procedure could call any other
  - OS/360 1Mill SLOC, Multics 20 Mill Slocs
- Layered
  - Structured, but everything still ran in Kernel mode
- Microkernels
  - Only essential run in Kernel mode
  - Remainder ran as services

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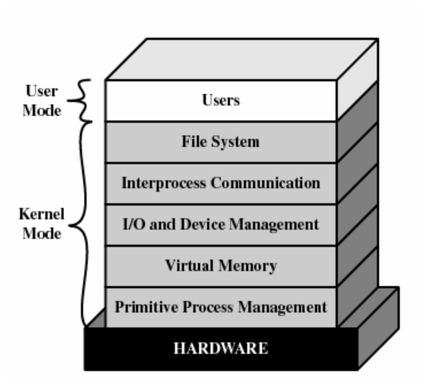
Layered Kernel



- Hierarchically organized
- Interaction between adjacent layers
- Most layers executed in Kernel mode
- Modifying code still a problem
- Security difficult (so many interfaces)

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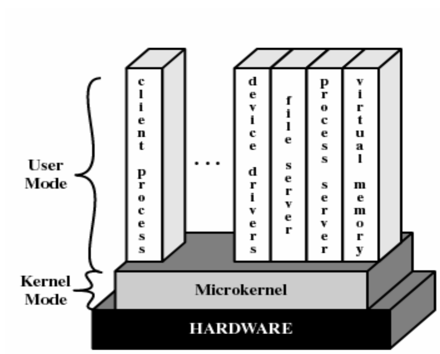
Microkernels



(b) Microkernel

- Small operating system core
- Contains only essential core OS functions
- Many traditional OS services now external subsystems
  - Device drivers
  - File systems
- Services implemented as server processes
  - Message passing

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Benefits of a Microkernel Organization

- Uniform interface on request made by a process
  - Don't distinguish between kernel-level and user-level services
  - All services are provided by means of message passing
- Extensibility
  - Allows the addition of new services
- Flexibility
  - New features easily added
  - Existing features can be subtracted

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Benefits of a Microkernel Organization

- Portability
  - Changes needed to port the system to a new processor is changed in the microkernel - not in the other services
- Reliability
  - Modular design
  - Small microkernel can be rigorously tested

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Benefits of Microkernel Organization

- Distributed system support
  - Message are sent without knowing what the target machine is

- Object-oriented operating system
  - Components are objects with clearly defined interfaces that can be interconnected to form software

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Microkernel Design

- Low-level memory management
  - Mapping each virtual page to a physical page frame

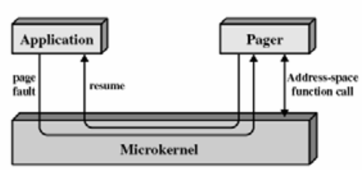

Figure 4.11 Page Fault Processing

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Microkernel Components

- Low-level memory management
  - Page fault initiates MK interupt
- Interprocess communication
  - Port-based communication
  - (sender, message)
- I/O and interrupt management

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Windows Processes

- Process & Thread separate concepts
- Threads are kernel-based
- ULTs achieved through library calls
- An executable process may contain one or more threads
- Both processes and thread objects have built-in synchronization capabilities

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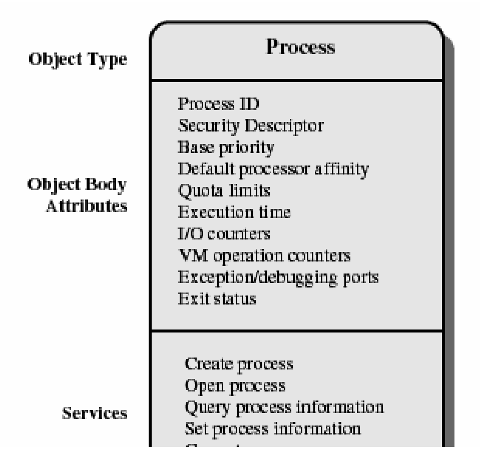
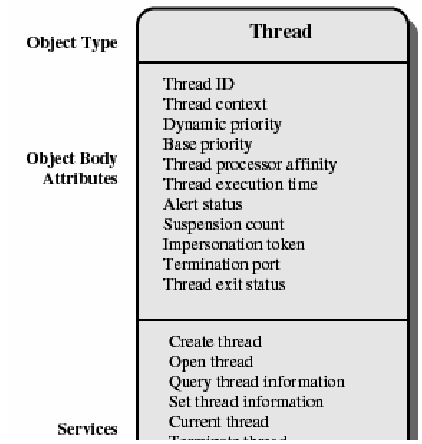
Windows Process Object



Windows Thread Object



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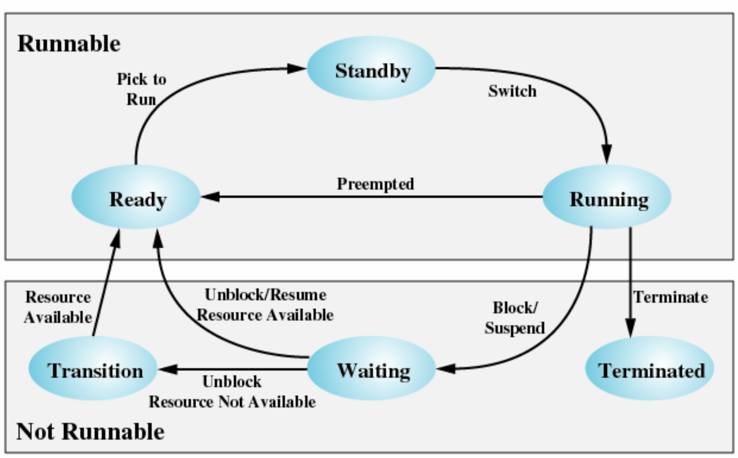
Windows Thread States



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Solaris (SUN)

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

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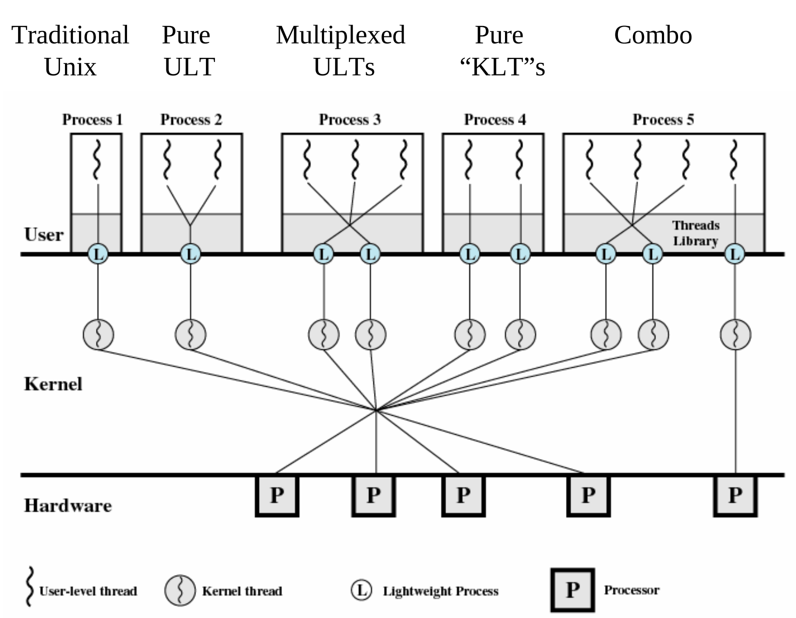

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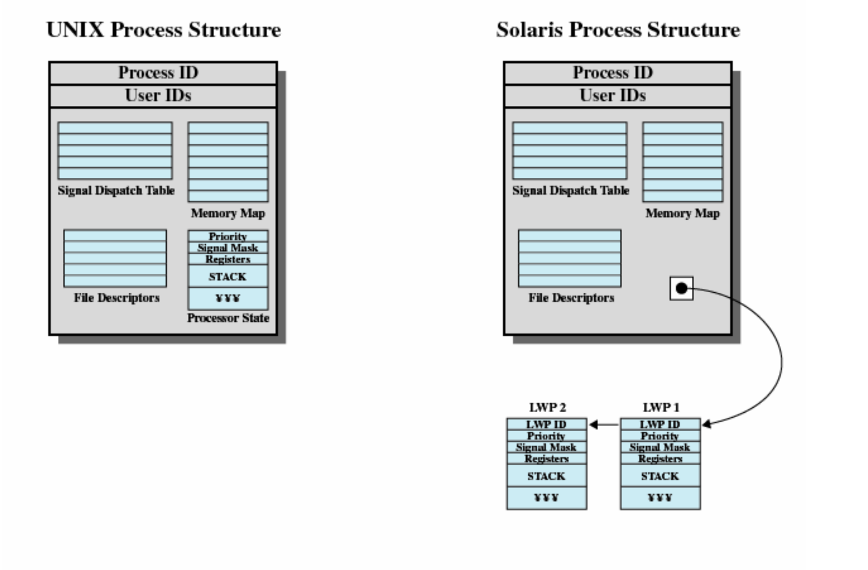

Figure 4.16 Process Structure in Traditional UNIX and Solaris [LEWI96]

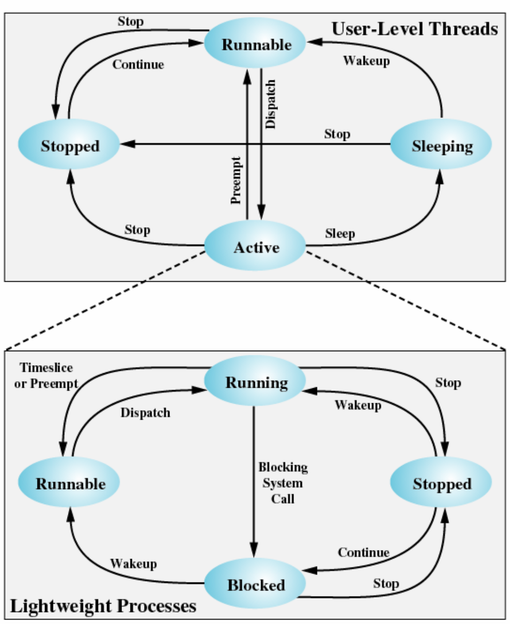

Figure 4.17 Solaris User-Level Thread and LWP States

Managed through application by calls to library routines

ULT can be in active state even if LWP is blocked
– no computation occurs

Managed by OS Kernel

Linux Process/Thread

- Classical view
  - Process and Thread viewed as one entity
  - Fork()
    - creates “copy” of parent process
    - Separate address space
- Modern view
  - Multithreading
  - Clone()
    - Shares address space, resources, code
    - Individual thread stack, PSW

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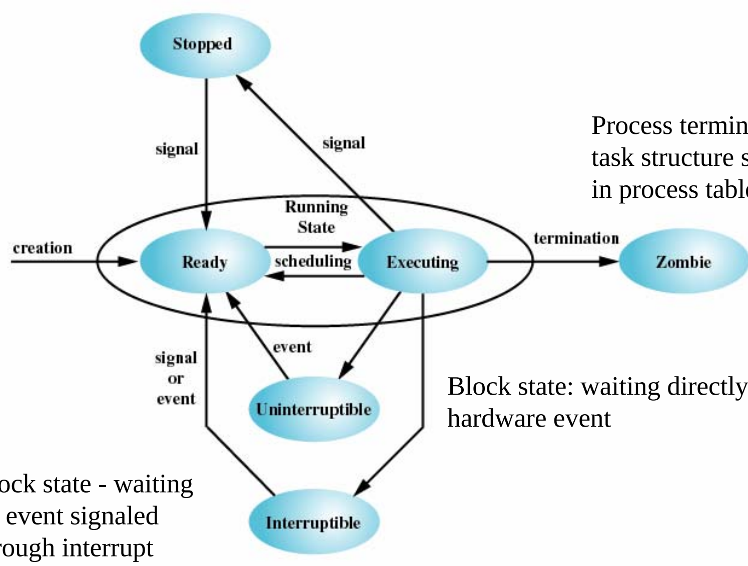
Linux Process/Thread Model



Process terminated, task structure still in process table

Block state: waiting directly on hardware event

Block state - waiting on event signaled through interrupt

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