Unit OS4: Scheduling and Dispatch

4.1. The Concept of Processes and Threads

Roadmap for Section 4.1.

- The Process Concept
- Thread States
- Context Switches
- Approaches to CPU Scheduling
- Multithreading Models

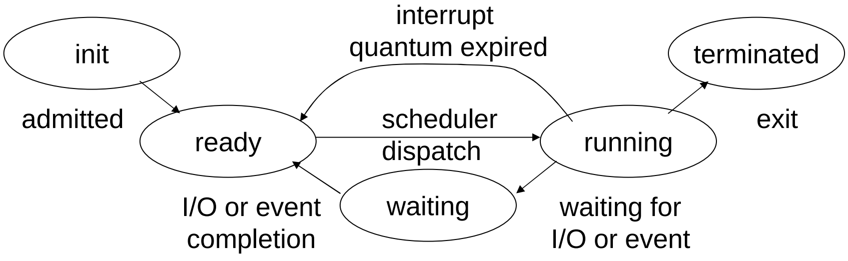
Process Concept

- An operating system executes programs:
  - Batch system – jobs
  - Time-shared systems – user programs or tasks
- Process – a program in execution
  - Process execution must progress sequentially
- A process includes:
  - CPU state (one or multiple threads)
  - Text & data section
  - Resources such as open files, handles, sockets
- Traditionally, processes used to be units of scheduling (i.e. no threads)
  - However, like most modern operating systems, Windows schedules threads
  - Our discussion assumes thread scheduling

3

Thread States

- Five-state diagram for thread scheduling:
  - **init**: The thread is being created
  - **ready**: The thread is waiting to be assigned to a CPU
  - **running**: The thread's instructions are being executed
  - **waiting**: The thread is waiting for some event to occur
  - **terminated**: The thread has finished execution



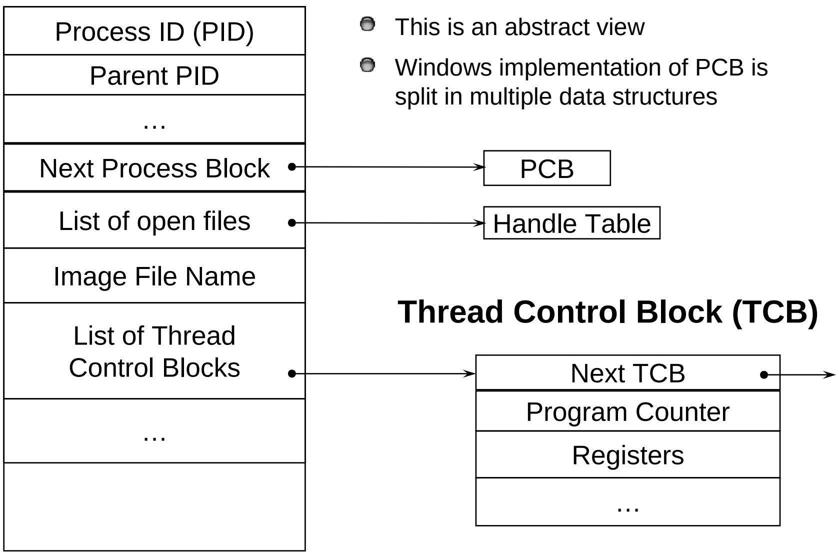
4

Process and Thread Control Blocks

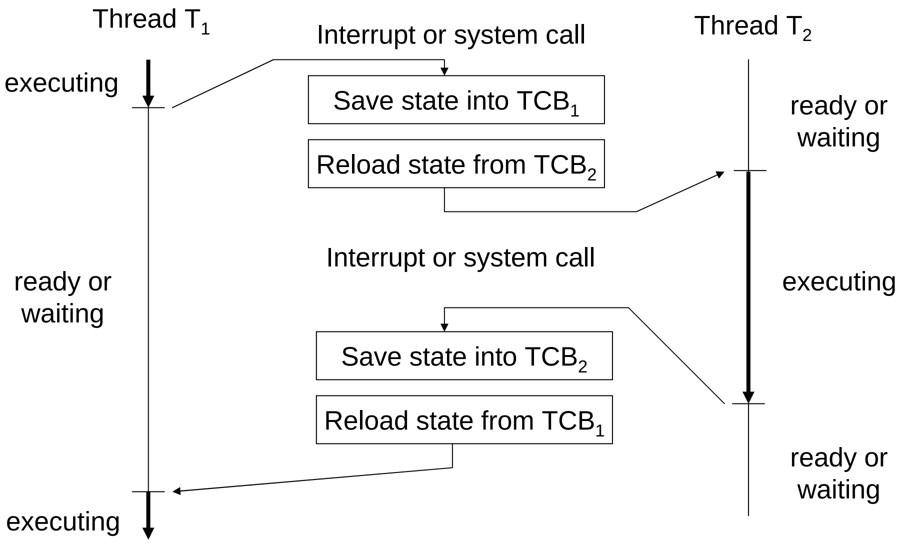
- Information associated with each process: Process Control Block (PCB)
  - Memory management information
  - Accounting information
  - Process-global vs. thread-specific
- Information associated with each thread: Thread Control Block (TCB)
  - Program counter
  - CPU registers
  - CPU scheduling information
  - Pending I/O information

Process Control Block (PCB)

- This is an abstract view
- Windows implementation of PCB is split in multiple data structures



CPU Switch from Thread to Thread



Context Switch

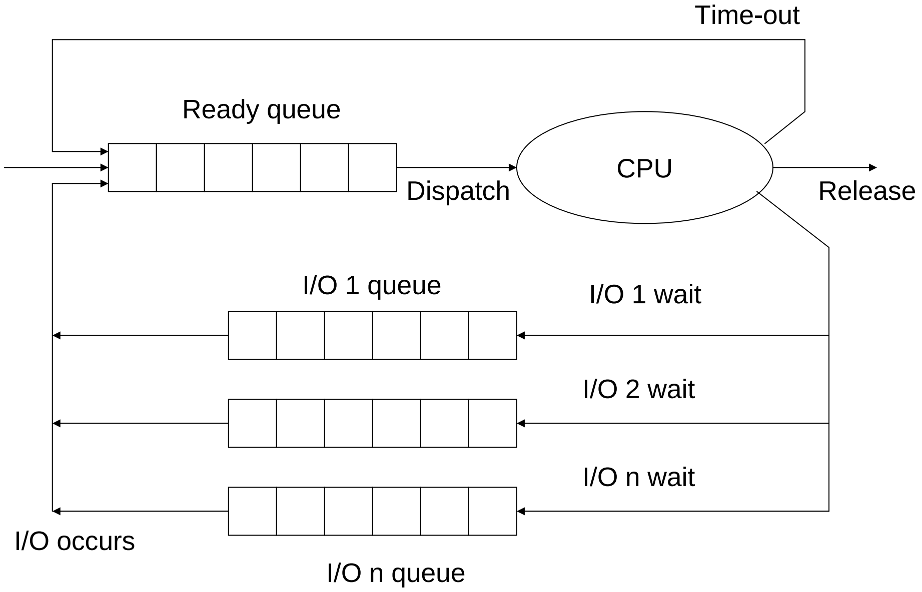
- When CPU switches to another thread, the system must save the state of the old thread and load the saved state for the new thread
- Context-switch time is overhead; the system does no useful work while switching
- Thread context-switching can be implemented in kernel or user mode
- Interaction with memory management (MMU) is required when switching between threads in different processes

Thread Scheduling Queues

- Ready queue
  - Maintains set of all threads ready and waiting to execute
  - There might be multiple ready queues, sorted by priorities
- Device queue
  - Maintains set of threads waiting for an I/O device
  - There might be multiple queues for different devices
- Threads migrate between the various queues

9

Ready Queue and I/O Device Queues



10

Optimization Criteria

- CPU scheduling uses heuristics to manage the tradeoffs among contradicting optimization criteria.
- Schedulers are optimized for certain workloads
  - Interactive vs. batch processing
  - I/O-intense vs. compute-intense
- Common optimization criteria:
  - Maximize CPU utilization
  - Maximize throughput
  - Minimize turnaround time
  - Minimize waiting time
  - Minimize response time

11

Basic Scheduling Considerations

- What invokes the scheduler?
- Which assumptions should a scheduler rely on?
- What are its optimization goals?

Rationale:

  - Multiprogramming maximizes CPU utilization
  - Thread execution experiences cycles of compute- and I/O-bursts
  - Scheduler should consider CPU burst distribution

12

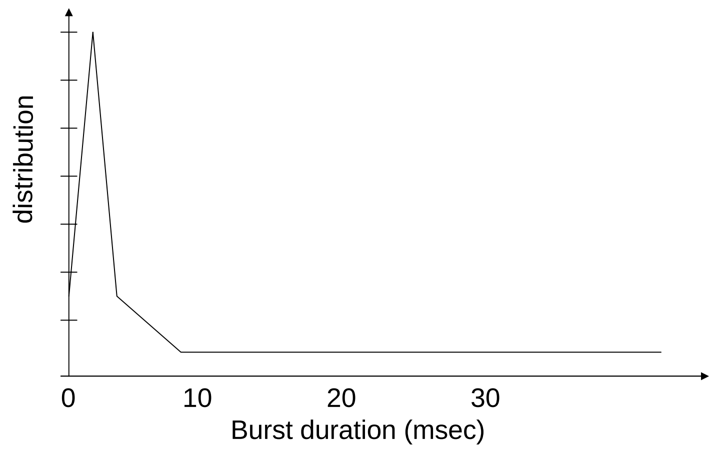
Alternating Sequence of CPU and I/O Bursts

Threads can be described as either:

- I/O-*bound* – spends more time doing I/O than computations, many short CPU bursts
- *CPU-bound* – spends more time doing computations; few very long CPU bursts

… load val inc val read file	CPU burst
wait for I/O	I/O burst
inc count add data, val write file	CPU burst
wait for I/O	I/O burst
load val inc val read from file	CPU burst
wait for I/O …	I/O burst

Histogram of CPU-burst Times



- Many short CPU bursts are typical
- Exact figures vary greatly by process and computer

Schedulers

- Long-term scheduler (or job scheduler)
  - Selects which processes with their threads should be brought into the ready queue
  - Takes memory management into consideration (swapped-out processes)
  - Controls degree of multiprogramming
  - Invoked infrequently, may be slow
- Short-term scheduler (or CPU scheduler)
  - Selects which threads should be executed next and allocates CPU
  - Invoked frequently, must be fast
- Windows has no dedicated long-term scheduler

CPU Scheduler

- Selects from among the threads in memory that are ready to execute, and allocates the CPU to one of them
- CPU scheduling decisions may take place when a thread:
  1. Switches from running to waiting state
  2. Switches from running to ready state
  3. Switches from waiting to ready
  4. Terminates
- Scheduling under 1 and 4 is *nonpreemptive*
- All other scheduling is *preemptive*

Dispatcher

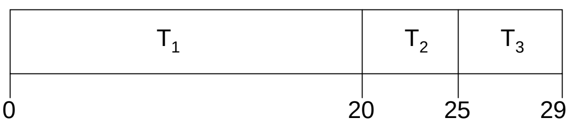
- Dispatcher module gives control of the CPU to the thread selected by the short-term scheduler; this involves:
  - switching context
  - switching to user mode
  - jumping to the proper location in the user program to restart that program
- *Dispatch latency* – time it takes for the dispatcher to stop one thread and start another running.
- Windows scheduling is event-driven
  - No central dispatcher module in the kernel

Scheduling Algorithms: First-In, First-Out (FIFO)

- Also known as First-Come, First-Served (FCFS)

Thread	Burst Time
T_1	20
T_2	5
T_3	4

- Suppose that the threads arrive in the order: T_1 , T_2 , T_3
  - The Gantt Chart for the schedule is:



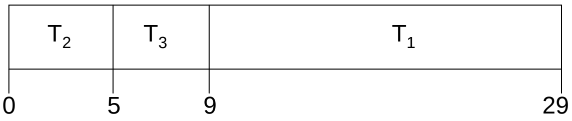
- Waiting time for T_1 = 0; T_2 = 20; T_3 = 25
- Average waiting time: (0 + 20 + 25)/3 = 15
- *Convoy effect*: short thread behind long threads experience long waiting time

FIFO Scheduling (Cont.)

Suppose that the threads arrive in the order

T_2 , T_3 , T_1 .

- The Gantt chart for the schedule is:



- Waiting time for T_1 = 9; T_2 = 0; T_3 = 5
- Average waiting time: (9 + 0 + 5)/3 = 4.66
- Much better than previous case

Scheduling Algorithms: Round Robin (RR)

- Preemptive version of FIFO scheduling algorithm
  - Each thread gets a small unit of CPU time (*time quantum*), usually 10-100 milliseconds
  - After this time has elapsed, the thread is preempted and added to the end of the ready queue
  - Each of *n* ready thread gets 1/*n* of the CPU time in chunks of at most quantum *q* time units at once
  - Of *n* ready threads, no one waits more than (*n*-1)*q* time units
- Performance
  - *q* large ⇒ FIFO
  - *q* small ⇒ *q* must be large with respect to context switch, otherwise overhead is too high

Example of RR with Quantum = 10

Thread	Burst Time
T_1	23
T_2	7
T_3	38
T_4	14

- Assuming all threads have same priority, the Gantt chart is:

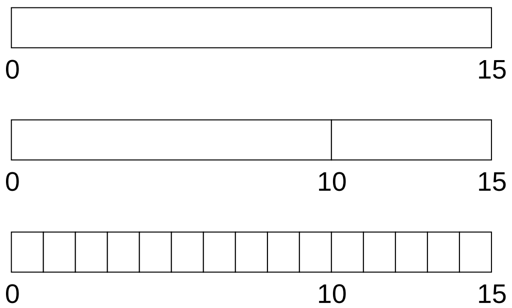
T_1	T_2	T_3	T_4	T_1	T_3	T_4	T_1	T_3	T_3

0 10 17 27 37 47 57 61 64 74 82

- Round-Robin favors CPU-intense over I/O-intense threads
- Priority-elevation after I/O completion can provide a compensation
- Windows uses Round-Robin with a priority-elevation scheme

Shorter quantum yields more context switches

Thread execution time: 15



quantum	context switches
20	0
10	1
1	14

- Longer quantum yields shorter average turnaround times

Scheduling Algorithms: Priority Scheduling

- A priority number (integer) is associated with each thread
- The CPU is allocated to the thread with the highest priority
  - Preemptive
  - Non-preemptive

23

Priority Scheduling - Starvation

Starvation is a problem:

- low priority threads may never execute

Solutions

1) Decreasing priority & aging: the Unix approach
   - Decrease priority of CPU-intense threads
   - Exponential averaging of CPU usage to slowly increase priority of blocked threads

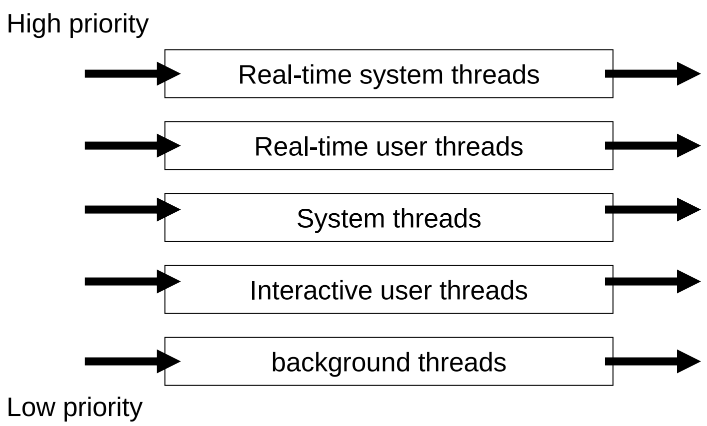
2) Priority Elevation: the Windows/VMS approach
   - Increase priority of a thread on I/O completion
   - System gives starved threads an extra burst

24

Multilevel Queue

- Ready queue is partitioned into separate queues:
  - Real-time (system, multimedia)
  - Interactive
- Queues may have different scheduling algorithm,
  - Real-Time – RR
  - Interactive – RR + priority-elevation + quantum stretching
- Scheduling must be done between the queues
  - Fixed priority scheduling (i.e., serve all from real-time threads then from interactive)
    - Possibility of starvation
  - Time slice – each queue gets a certain amount of CPU time which it can schedule amongst its threads;
    - CPU reserves

Multilevel Queue Scheduling



- Windows uses strict Round-Robin for real-time threads
- Priority-elevation can be disabled for non-RT threads

Process Creation

- Parent process creates children processes, which create other processes, forming a tree of processes
  - Processes start with one initial thread
- Resource sharing models
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources
- Execution
  - Parent's and children's' threads execute concurrently
  - Parent waits until children terminate

27

Process Creation (Cont.)

- How to set up an address space
  - Child can be duplicate of parent
  - Child may have a program loaded into it
- UNIX example
  - **fork()** system call creates new process
  - **exec()** system call used after a **fork** to replace the process' memory space with a new program
- Windows example
  - **CreateProcess()** system call create new process and loads program for execution

28

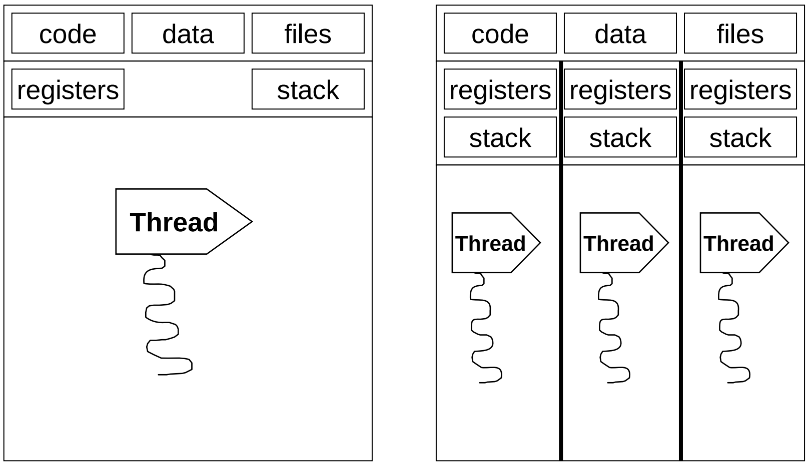
Processes Tree on a UNIX System

Prozess-ID	Prozessname	Threads	% CPU
0	kernel_task	32	1,40
1	init	1	0,00
193	WindowServer	2	4,40
1876	PowerPoint	2	30,90
1874	Microsoft Word	1	15,40
358	Aktivitäts-Anzeige	2	11,90
361	pmTool	1	2,90
1898	Bildschirmfoto	3	9,90
356	Terminal	4	1,90
364	login	1	0,00
366	tcsh	1	0,00
415	su	1	0,00
416	tcsh	1	0,00

Process Termination

- Last thread inside a process executes last statement and returns control to operating system (**exit**)
  - Parent may receive return code (via **wait**)
  - Process' resources are deallocated by operating system
- Parent may terminate execution of children processes (**kill**)
  - Child has exceeded allocated resources
  - Task assigned to child is no longer required
  - Parent is exiting
    - Operating system typically does not allow child to continue if its parent terminates (depending on creation flags)
    - Cascading termination inside process groups

Single and Multithreaded Processes



single-threaded multi-threaded

31

Benefits of Multithreading

- Higher Responsiveness
  - Dedicated threads for handling user events
- Simpler Resource Sharing
  - All threads in a process share same address space
- Utilization of Multiprocessor Architectures
  - Multiple threads may run in parallel

32

User Threads

- Thread management within a user-level threads library
  - Process is still unit of CPU scheduling from OS kernel perspective
- Examples
  - POSIX *Pthreads*
  - Mach *C-threads*
  - Solaris *threads*
  - *Fibers* on Windows

Kernel Threads

- Supported by the Kernel
  - Thread is unit of CPU scheduling
- Examples
  - Windows
  - Solaris
  - OSF/1
  - Linux - Tasks can act like threads by sharing kernel data structures

Multithreading Models

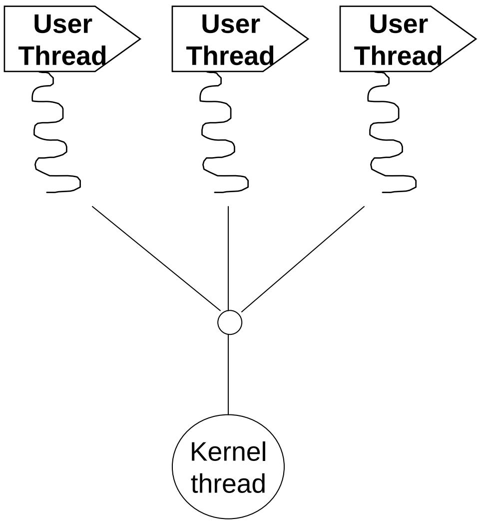
How are user-level threads mapped on kernel threads?

- Many-to-One
  - Many user-mode threads are mapped on a single kernel thread
- One-to-One
  - Each user-mode thread is represented by a separate kernel thread
- Many-to-Many
  - A set of user-mode threads is being mapped on another set of kernel threads

35

Many-to-One Model

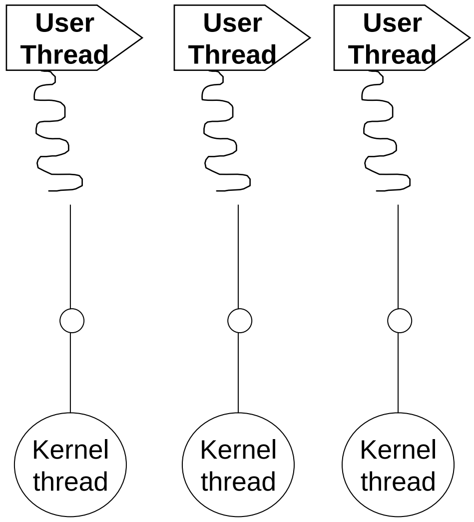
- Many user-level threads are mapped to a single kernel thread
- Used on systems that do not support kernel threads
- Example:
  - POSIX Pthreads
  - Mach C-Threads
  - Windows Fibers



36

One-to-One Model

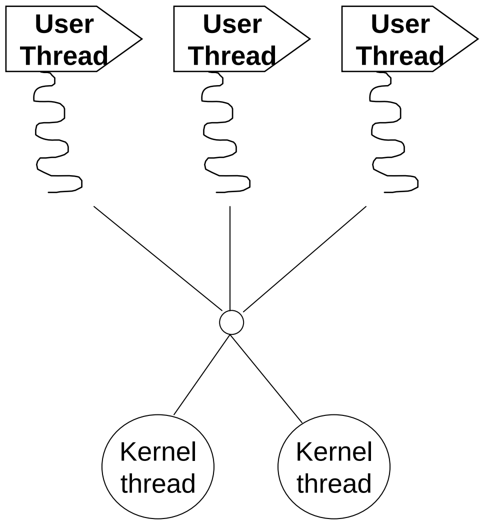
- Each user-level thread maps to kernel thread
- Examples
  - Windows threads
  - OS/2 threads



37

Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads.
- Allows the operating system to create a sufficient number of kernel threads.
- Example
  - Solaris 2



38

Problems with Multithreading

- Semantics of fork()/exec() or CreateProcess() system calls
- Coordinated termination
- Signal handling
- Global data, errno, error handling
- Thread specific data
- Reentrant vs. non-reentrant system calls

39

Pthreads

- a POSIX standard (IEEE 1003.1c) API for thread creation and synchronization
- API specifies behavior of the thread library, not an implementation
- Implemented on many UNIX operating systems
- Services for Unix (SFU) implement PThreads on Windows

40

Further Reading

- Abraham Silberschatz, Peter B. Galvin, Operating System Concepts, John Wiley & Sons, 6th Ed., 2003;
  - Chapter 4 - Processes
  - Chapter 5 - Threads
  - Chapter 6 - CPU Scheduling
- Mark E. Russinovich and David A. Solomon, Microsoft Windows Internals, 4th Edition, Microsoft Press, 2004.
  - Chapter 6 - Processes, Thread, and Jobs (from pp. 289)

41