Processes & Threads

Managing Concurrency in Computer Systems

Process Management

- **Process management deals with several issues:**
  - **what are the units of execution**
  - **how are those units of execution represented in the OS**
  - **how is work scheduled in the CPU**
  - **what are possible execution states, and how does the system move from one to another**

The Process

- **Basic idea is the *process*:**
  - **process is the unit of execution**
  - **it's the unit of scheduling**
  - **it's the dynamic (active) execution context (as opposed to a program, which is static)**
- **A process is sometimes called a *job* or a *task* or a *sequential process.***
- **A sequential process is a program in execution; it defines the sequential, instruction-at-a-time execution of a program.**

What's in a Process?

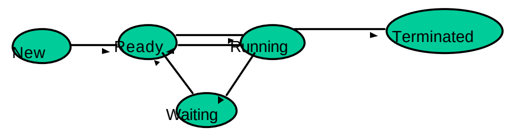
- **A process consists of at least:**
  - **the code for the running program**
  - **the data for the running program**
  - **an execution stack tracing the state of procedure calls made**
  - **the Program Counter, indicating the next instruction**
  - **a set of general-purpose registers with current values**
  - **a set of operating system resources (open files, connections to other programs, etc.)**
- **The process contains all the state for a program in execution.**

Process State

- There may be several processes running the same program (e.g., an editor), but each is a distinct process with its own representation.
- Each process has an *execution state* that indicates what it is currently doing, e.g.,:
  - ready: waiting to be assigned to the CPU
  - running: executing instructions on the CPU
  - waiting: waiting for an event, e.g., I/O completion
- As a program executes, it moves from state to state

5

Process State Changing



Processes move from state to state as a result of actions they perform (e.g., system calls), OS actions (rescheduling), and external actions (interrupts)

6

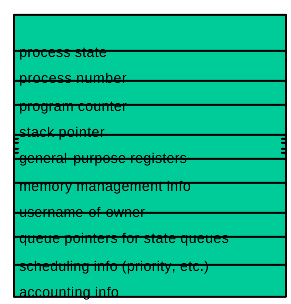
Process Data Structures

- At any time, there are many processes in the system, each in its particular state.
- The OS must have data structures representing each process: this data structure is called the <u>PCB</u>:
  - *Process Control Block*
- The PCB contains all of the info about a process.
- The PCB is where the OS keeps all of a process' hardware execution state (PC, SP, registers) when the process is not running.

7

PCB

The PCB contains the entire state of the process



8

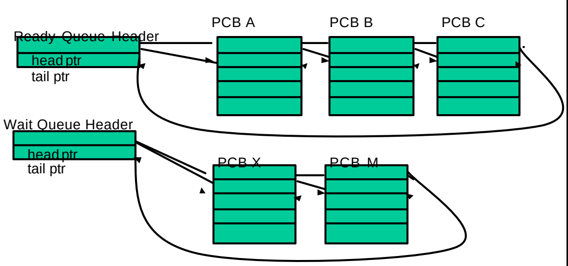
PCBs and Hardware State

- When a process is running its Program Counter, stack pointer, registers, etc., are loaded on the CPU (I.e., the processor hardware registers contain the current values)
- When the OS stops running a process, it saves the current values of those registers into the PCB for that process.
- When the OS is ready to start executing a new process, it loads the hardware registers from the values stored in that process' PCB.
- The process of switching the CPU from one process to another is called a ***context switch***. Timesharing systems may do 100s or 1000s of context switches a second!

State Queues

- The OS maintains a collection of queues that represent the state of all processes in the system.
- There is typically one queue for each state, e.g., ready, waiting for I/O, etc.
- Each PCB is queued onto a state queue according to its current state.
  - As a process changes state, its PCB is unlinked from one queue and linked onto another.

State Queues



There may be many wait queues, one for each type of wait (specific device, timer, message,...).

PCBs and State Queues

- PCBs are data structures, dynamically allocated in OS memory.
- When a process is created, a PCB is allocated to it, initialized, and placed on the correct queue.
- As the process computes, its PCB moves from queue to queue.
- When the process is terminated, its PCB is deallocated.

Cooperating Processes

- Processes can be independent or they can be cooperating to accomplish a single job.
- Cooperating processes can be used:
  - to gain speedup by overlapping activities or performing work in parallel
  - to better structure an application as a small set of cooperating processes
  - to share information between jobs
- Sometimes processes are structured as a pipeline where each produces work for the next stage that consumes it, and so on.

13

Processes and Threads

- A full process includes numerous things:
  - an address space (defining all the code and data pages)
  - OS resources and accounting information
  - a "thread of control", which defines where the process is currently executing (basically, the PC and registers)
- Creating a new process is costly, because of all of the structures (e.g., page tables) that must be allocated
- Communicating between processes is costly, because most communication goes through the OS

14

Parallel Programs

- Suppose I want to build a parallel program to execute on a multiprocessor, or a web server to handle multiple simultaneous web requests. I need to:
  - create several processes that can execute in parallel
  - cause *each* to map to the *same* address space (because they're part of the same computation)
  - give each its starting address and initial parameters
  - the OS will then schedule these processes, in parallel, on the various processors
- Notice that there's a lot of cost in creating these processes and possibly coordinating them. There's also a lot of duplication, because they all share the same address space, protection, etc……

15

"Lightweight" Processes

- What's similar in these processes?
  - They all share the same code and data (address space)
  - they all share the same privileges
  - they share almost everything in the process
- What don't they share?
  - Each has its own PC, registers, and stack pointer
- Idea: why don't we separate the idea of process (address space, accounting, etc.) from that of the minimal "thread of control" (PC, SP, registers)?

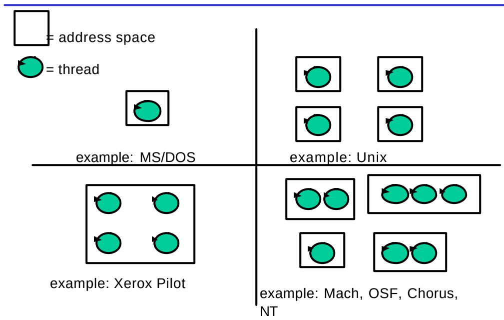
16

Threads and Processes

- Some newer operating systems (Mach, Chorus, NT) therefore support two entities:
  - the process, which defines the address space and general process attributes
  - the thread, which defines a sequential execution stream within a process
- A thread is bound to a single process. For each process, however, there may be many threads.
- Threads are the unit of scheduling; processes are *containers* in which threads execute.

17

How different OSs support threads



18

Separation of Threads and Processes

- Separating threads and processes makes it easier to support multi-threaded applications
- Concurrency (multi-threading) is useful for:
  - improving program structure
  - handling concurrent events (e.g., web requests)
  - building parallel programs
- So, multi-threading is useful even on a uniprocessor.
- But, threads, even when supported separately from processes in the kernel, are too slow.

19

Kernel Threads

- Kernel threads still suffer from performance problems.
- Operations on kernel threads are slow because:
  - a thread operation still requires a kernel call
  - kernel threads may be overly general, in order to support needs of different users, languages, etc.
  - the kernel doesn't trust the user, so there must be lots of checking on kernel calls

20

User-Level Threads

- **To make threads really fast, they should be implemented at the <u>user</u> level**
- **A user-level thread is managed entirely by the run-time system (user-level code that is linked with your program).**
- **Each thread is represented simply by a PC, registers, stack and a little control block, managed in the user's address space.**
- **Creating a new thread, switching between threads, and synchronizing between threads can all be done without kernel involvement.**

21

(Old) Example of thread performance

	Ultrix	Topaz	FastThreads
Fork	11320	1208	39
Signal/Wait	1846	229	52

(performance on a 3 MIPS processor, in microseconds)

•Ultrix: 1 thread per address space

•Topaz: multiple threads per address space

•FastThreads: multiple user threads per address space

22

Example U-L Thread Interface

t = thread_fork(initial context)
  create a new thread of control

thread_stop()
  stop the calling thread, sometimes called thread_block

thread_start(t)
  start the named thread

thread_yield()
  voluntarily give up the processor

thread_exit()
  terminate the calling thread, sometimes called thread_destroy.

23