Last Class: Processes

- A process is the unit of execution.
- Processes are represented as Process Control Blocks in the OS
  - PCBs contain process state, scheduling and memory management information, etc
- A process is either New, Ready, Waiting, Running, or Terminated.
- On a uniprocessor, there is at most one running process at a time.
- The program currently executing on the CPU is changed by performing a context switch
- Processes communicate either with message passing or shared memory

Today: Threads

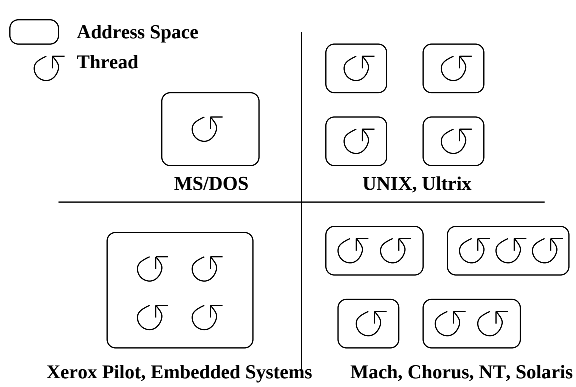
- What are threads?
- Where should we implement threads? In the kernel? In a user-level threads package?
- How should we schedule threads (or processes) onto the CPU?

Processes versus Threads

- **A process** defines the address space, text, resources, etc.,
- **A thread** defines a single sequential execution stream within a process (PC, stack, registers).
- Threads extract the *thread of control* information from the process
- Threads are bound to a single process.
- Each process may have multiple threads of control within it.
  - The address space of a process is shared among all its threads
  - No system calls are required to cooperate among threads
  - Simpler than message passing and shared-memory

Classifying Threaded Systems

Operating Systems can support one or many address spaces, and one or many threads per address space.



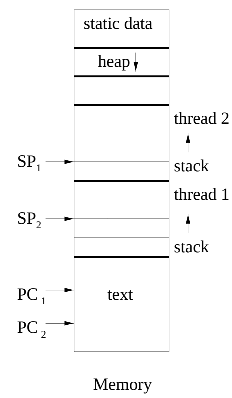
Example Threaded Program

```
main()
    global in, out, n, buffer[n];
    in = 0; out = 0;
    fork_thread (producer());
    fork_thread (consumer());
end

producer
    repeat
        nextp = produced item
        while in+1 mod n = out do no-op
        buffer[in] = nextp; in = (in+1) mod n

consumer
    repeat
        while in = out do no-op
        nextc = buffer[out]; out = (out+1) mod n
        consume item nextc
```

One possible memory layout:



- Forking a thread can be a system call to the kernel, or a procedure call to a thread library (user code).

Kernel Threads

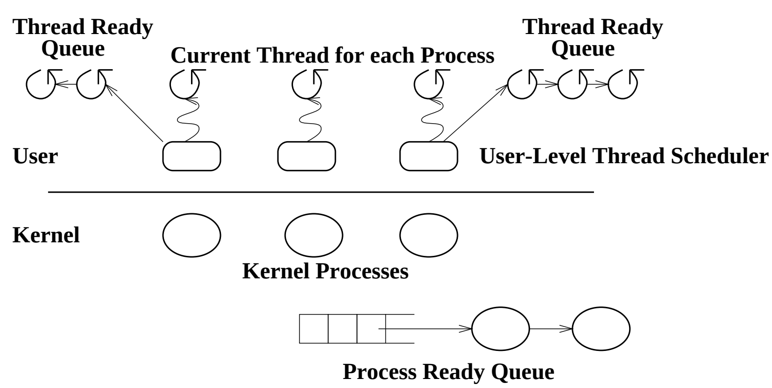
- A **kernel thread**, also known as a **lightweight process**, is a thread that the operating system knows about.
- Switching between kernel threads of the same process requires a small context switch.
  - The values of registers, program counter, and stack pointer must be changed.
  - Memory management information does not need to be changed since the threads share an address space.
- The kernel must manage and schedule threads (as well as processes), but it can use the same process scheduling algorithms.

⇒ Switching between kernel threads is slightly faster than switching between processes.

User-Level Threads

- A **user-level thread** is a thread that the OS does *not* know about.
- The OS only knows about the process containing the threads.
- The OS only schedules the process, not the threads within the process.
- The programmer uses a *thread library* to manage threads (create and delete them, synchronize them, and schedule them).

User-Level Threads



User-Level Threads: Advantages

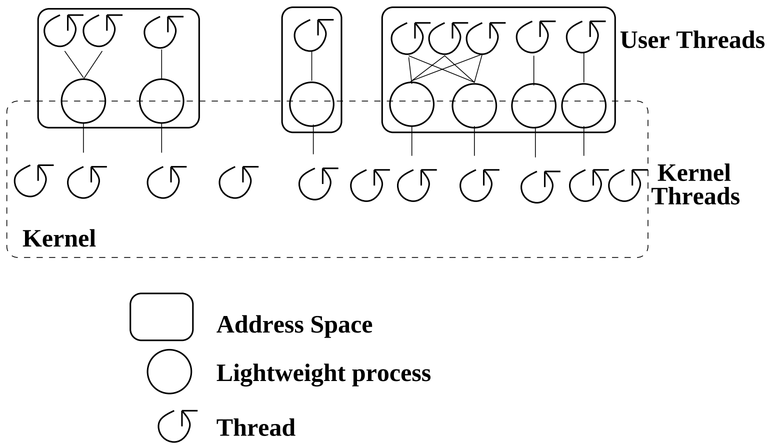
- There is no context switch involved when switching threads.
- User-level thread scheduling is more flexible
  - A user-level code can define a problem dependent thread scheduling policy.
  - Each process might use a different scheduling algorithm for its own threads.
  - A thread can voluntarily give up the processor by telling the scheduler it will *yield* to other threads.
- User-level threads do not require system calls to create them or context switches to move between them

⇒ User-level threads are typically much faster than kernel threads

User-Level Threads: Disadvantages

- Since the OS does not know about the existence of the user-level threads, it may make poor scheduling decisions:
  - It might run a process that only has idle threads.
  - If a user-level thread is waiting for I/O, the entire process will wait.
  - Solving this problem requires communication between the kernel and the user-level thread manager.
- Since the OS just knows about the process, it schedules the process the same way as other processes, regardless of the number of user threads.
- For kernel threads, the more threads a process creates, the more time slices the OS will dedicate to it.

Example: Kernel and User-Level Threads in Solaris



More Examples of Kernel and User-Level Threads

Ultrix: 1 thread per address space

Topaz: multiple kernel threads per address space

FastThreads: multiple user threads per address space

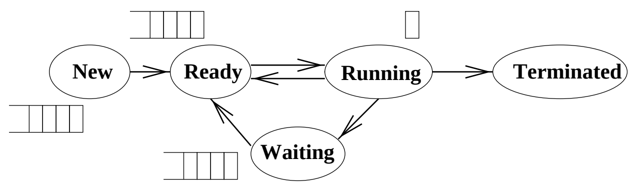
	Ultrix	Topaz	FastThreads
Fork	11,320	1208	39
Signal/Wait	1846	229	52

Operation times in Microseconds on a MIPS 3000

⇒ User-level thread operations are orders of magnitude faster than similar kernel thread operations

Scheduling Processes

- **Multiprocessing:** running more than one process at a time enables the OS to increase system utilization and throughput by overlapping I/O and CPU activities.
- Process Execution State



- All of the processes that the OS is currently managing reside in one and only one of these state queues.

Scheduling Processes

- **Long Term Scheduling::** How does the OS determine the degree of multiprogramming, i.e., the number of jobs executing at once in the primary memory?
- **Short Term Scheduling:** How does (or should) the OS select a process from the ready queue to execute?
  - Policy Goals
  - Policy Options
  - Implementation considerations

Short Term Scheduling

- The kernel runs the scheduler at least when
  1. a process switches from running to waiting,
  2. an interrupt occurs, or
  3. a process is created or terminated.
- **Non-preemptive system:** the scheduler must wait for one of these events
- **Preemptive system:** the scheduler can interrupt a running process

Criteria for Comparing Scheduling Algorithms:

CPU Utilization The percentage of time that the CPU is busy.

Throughput The number of processes completing in a unit of time.

Turnaround time The length of time it takes to run a process from initialization to termination, including all the waiting time.

Waiting time The total amount of time that a process is in the ready queue.

Response time The time between when a process is ready to run and its next I/O request.

Scheduling Policies

Ideally, choose a CPU scheduler that optimizes all criteria simultaneously (utilization, throughput,..), but this is not generally possible

Instead, choose a scheduling algorithm based on its ability to satisfy a policy

- Minimize average response time - provide output to the user as quickly as possible and process their input as soon as it is received.
- Minimize variance of response time - in interactive systems, predictability may be more important than a low average with a high variance.
- Maximize throughput - two components
  1. minimize overhead (OS overhead, context switching)
  2. efficient use of system resources (CPU, I/O devices)
- Minimize waiting time - give each process the same amount of time on the processor. This might actually increase average response time.

Scheduling Policies:

Simplifying Assumptions

- One process per user
- One thread per process
- Processes are independent

  Researchers developed these algorithms in the 70's when these assumptions were more realistic, and it is still an open problem how to relax these assumptions.

Scheduling Algorithms: A Snapshot

FCFS: First Come, First Served

Round Robin: Use a time slice and preemption to alternate jobs.

SJF: Shortest Job First

Multilevel Feedback Queues: Round robin on each priority queue.

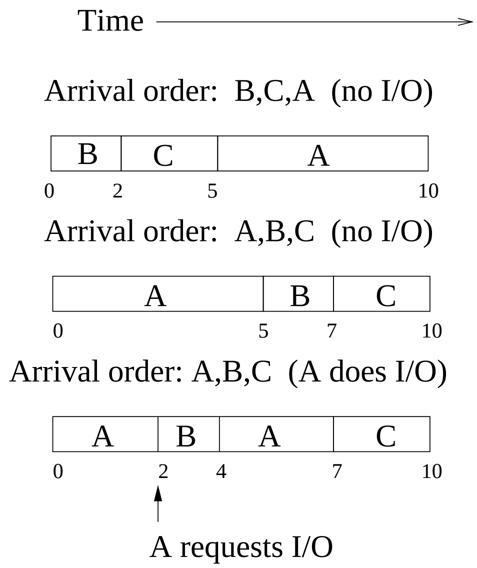
Lottery Scheduling: Jobs get tickets and scheduler randomly picks winning ticket.

Scheduling Policies

FCFS: First-Come-First-Served (or FIFO: First-In-First-Out)

- The scheduler executes jobs to completion in arrival order.
- In early FCFS schedulers, the job did not relinquish the CPU even when it was doing I/O.
- We will assume a FCFS scheduler that runs when processes are blocked on I/O, but that is non-preemptive, i.e., the job keeps the CPU until it blocks (say on an I/O device).

FCFS Scheduling Policy: Example



- If processes arrive 1 time unit apart, what is the average wait time in these three cases?

FCFS: Advantages and Disadvantages

Advantage: simple

Disadvantages:

- average wait time is highly variable as short jobs may wait behind long jobs.
- may lead to poor overlap of I/O and CPU since CPU-bound processes will force I/O bound processes to wait for the CPU, leaving the I/O devices idle

Summary

- Thread: a single execution stream within a process
- Switching between user-level threads is faster than between kernel threads since a context switch is not required.
- User-level threads may result in the kernel making poor scheduling decisions, resulting in slower process execution than if kernel threads were used.
- Many scheduling algorithms exist. Selecting an algorithm is a policy decision and should be based on characteristics of processes being run and goals of operating system (minimize response time, maximize throughput, ...).