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

Cooperating Processes: Producers and Consumers

n = 100 //max outstanding items
in = 0
out = 0

producer

```
repeat forever{
  …
  nextp = produce item
  while in+1 mod n = out
        do no-opt
  buffer[in] = nextp
  in = in+1 mod n
}
```

consumer

```
repeat forever{
              //Make sure buffer not empty
  while in = out do no-opt
  nextc = buffer[out]
  out = out+1 mod n
  …
  consume nextc
}
```

- Producers and consumers can communicate using *message passing* or *shared memory*

Communication using Message Passing

```
main()
  …
  if (fork() != 0) producerSR;
  else consumerSR;
end
```

```
producerSR
        repeat
          …
          produce item nextp
          …
          send(nextp, consumer)
```

```
consumerSR
        repeat
          receive(nextc, producer)
          …
          consume item nextc
          …
```


Message Passing

- Distributed systems typically communicate using message passing
- Each process needs to be able to name the other process.
- The consumer is assumed to have an infinite buffer size.
- A bounded buffer would require the tests in the previous slide, and communication of the **in** and **out** variables (**in** from producer to consumer, **out** from consumer to producer).
- OS keeps track of messages (copies them, notifies receiving process, etc.).

➔How would you use message passing to implement a single producer and multiple consumers?

Communication using Shared Memory

- Establish a mapping between the process's address space to a named memory object that may be shared across processes
- The mmap(…) systems call performs this function.
- Fork processes that need to share the data structure.

Shared Memory Example

```
main()
  …
  mmap(..., in, out, PROT_WRITE, PROT_SHARED, …);
  in = 0;
  out = 0;
  if (fork != 0) produce();
  else consumer();
end
```

```
producer
        repeat
          …
          produce item nextp
          …
          while in+1 mod n = out do no-opt
          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
          …
```

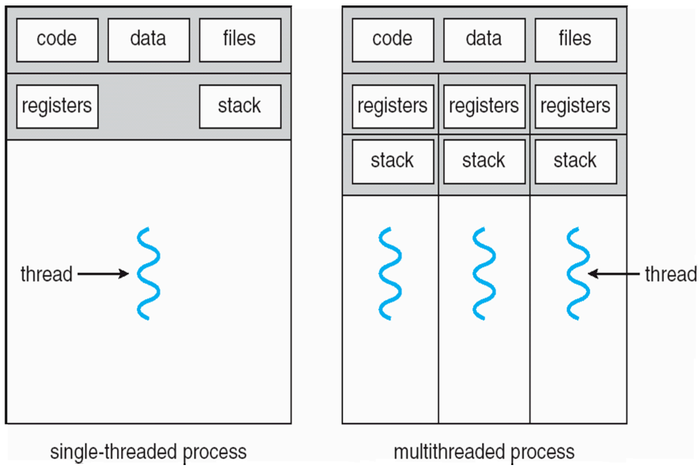
Today: Threads

- 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

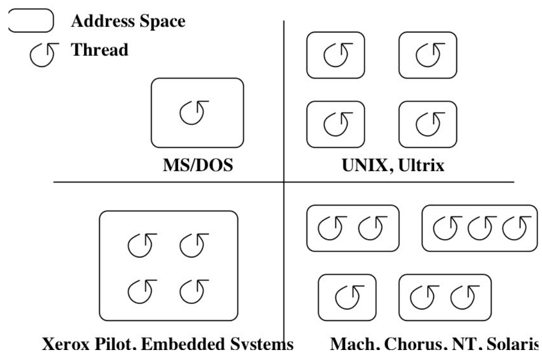
- **A process** defines the address space, text, resources, etc.,
- **A thread** defines a single sequential execution stream within a process (PC, stack, registers).
- Threads extract the *thread of control* information from the process
- Threads are bound to a single process.
- Each process may have 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

Single and Multithreaded Processes



Classifying Threaded Systems

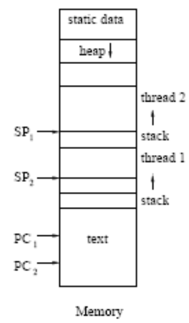
Operating Systems can support one or many address spaces, and one or many threads per address space.



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

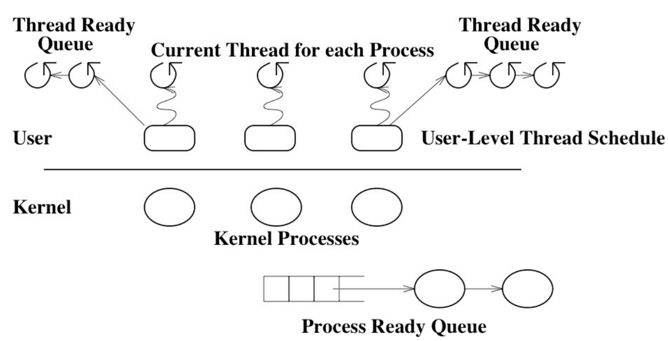
- **A kernel thread**, also known as a **lightweight process**, is a thread that the operating system knows about.
- Switching between kernel threads of the same process requires a small context switch.
  - The values of registers, program counter, and stack pointer must be changed.
  - Memory management 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

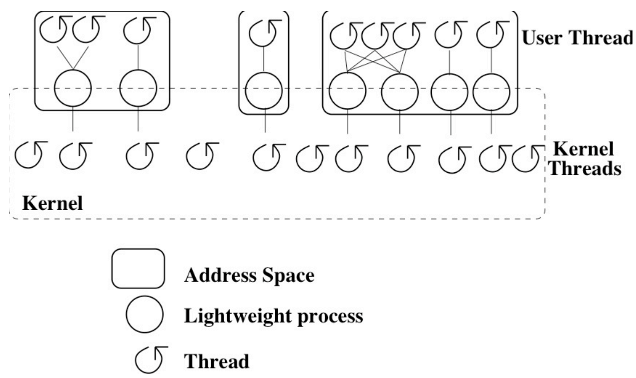
- There is no context switch involved when switching threads.
- User-level thread scheduling is more flexible
  - A user-level code can define a problem dependent thread scheduling policy.
  - Each process might use a different scheduling algorithm for its own threads.
  - A thread can voluntarily give 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

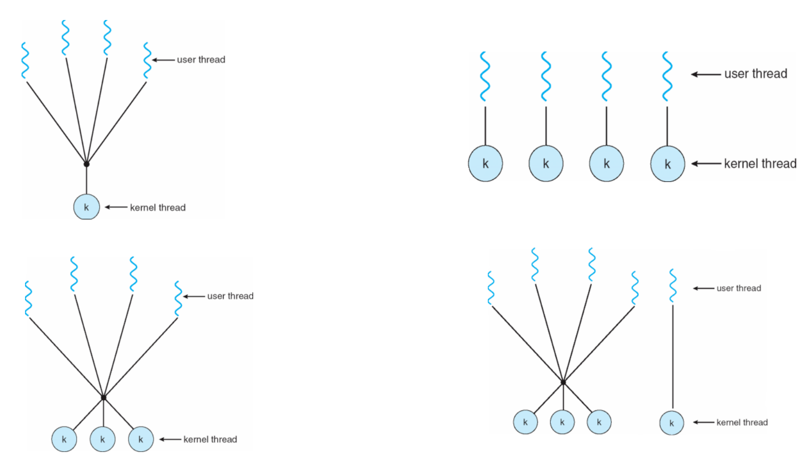
User-Level Threads: Disadvantages

- 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

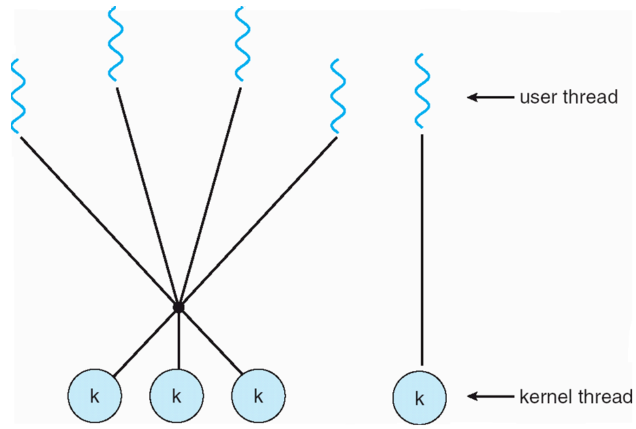


Threading Models



- Many-to-one, one-to-one, many-to-many and two-level

Two-level Model



Thread Libraries

- Thread library provides programmer with API for creating and managing threads
- Two primary ways of implementing
  - Library entirely in user space
  - Kernel-level library supported by the OS

Pthreads

- May be provided either as user-level or kernel-level
- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization
- API specifies behavior of the thread library, implementation is up to development of the library
- Common in UNIX operating systems (Solaris, Linux, Mac OS X)

- WIN32 Threads: Similar to Posix, but for Windows

Java Threads

- Java threads are managed by the JVM

- Typically implemented using the threads model provided by underlying OS

- Java threads may be created by:

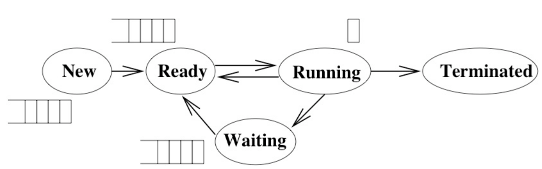
  - Extending Thread class
  - Implementing the Runnable interface

Examples

```
Pthreads:
    pthread_attr_init(&attr);  /* set default attrributes */
    pthread_create(&tid, &attr, sum, &param);

Win32 threads
ThreadHandle  = CreateThread(NULL, 0, Sum, &Param, 0, &ThreadID);


Java Threads:

Sum sumObject = new Sum();
Thread t = new Thread(new Summation(param, SumObject));
t.start();  // start the thread
```


Scheduling Processes

- **Multiprogramming**: 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
  - minimize overhead (OS overhead, context switching)
  - 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.

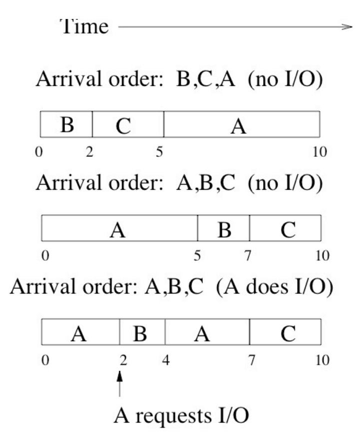
Lottery Scheduling: Jobs get tickets and scheduler randomly picks winning ticket.

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, ...).