Last Class: CPU Scheduling

- Pre-emptive versus non-preemptive schedulers
- Goals for Scheduling:
  - Minimize average response time
  - Maximize throughput
  - Share CPU equally
  - Other goals?
- Scheduling Algorithms:
  - Selecting a scheduling algorithm is a policy decision - consider tradeoffs
    - FCS
    - Round-robin
    - SJF/SRTF
    - MLFQ
    - Lottery scheduler

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.

<table>
<thead>
<tr>
<th>Address Space</th>
<th>Thread</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS/DOS</td>
<td>![Thread Icon]</td>
</tr>
<tr>
<td>UNIX, Ultras</td>
<td>![Thread Icon]</td>
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<tr>
<td>Xerox Pilot, Embedded Systems</td>
<td>![Thread Icon]</td>
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<tr>
<td>Mach, Chorus, NT, Solaris</td>
<td>![Thread Icon]</td>
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</tbody>
</table>

Example Threaded Program

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

One possible memory layout:

```
  100  200  300  400  500  600  700  800  900  1000  1100  1200
  -----------
  |           |
  |           |
  |           |
  |           |
  |           |
  |           |
  |   Exec   |
  |   P      |
  |   SR     |
  |   Stack  |
  |   Page   |
  |   Mem    |
```

- 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:
```c
pthread_attr_init(&attr); /* set default attributes */
pthread_create(&tid, &attr, sum, &param);
```

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

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

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, ...).