COP 4610

Operating System Principles

Lecture 5 – Processes / Threads

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Recap

- Processes
  - What is a process?
  - What is in a process control block?
  - Contrast stack, heap, data, text.
  - What are process states?
  - Which queues are used in an OS?
  - What does the scheduler do?
  - What is a context switch?
  - What is the producer/consumer problem?
  - What is IPC?

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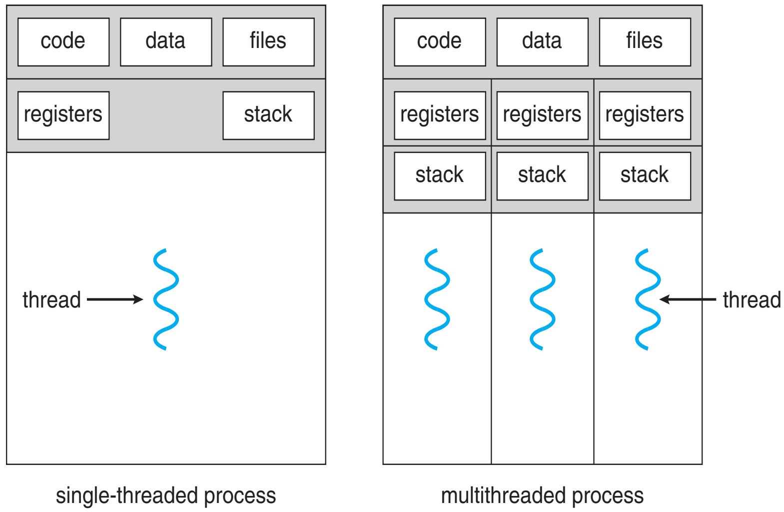
Lecture Overview: Threads

- Overview
- Multicore Programming
- Multithreading Models
- Thread Libraries
- Implicit Threading
- Threading Issues
- Operating System Examples

Definition

- Process: group resources together
- Thread: entity scheduled for execution in a process
- **“Single sequential stream of instructions within a process”**
- “Lightweight process”

Thread of Execution



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Thread vs. Process

- Threads have their own:
  - Thread ID (TID) (compare to PID)
  - Program counter (PC)
  - Register set
  - Stack
- Threads commonly share:
  - Code section (text)
  - Data section
  - Resources (files, signals, etc.)

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Why Threads?

- Enable **multi-tasking** within an app
  - Update display
  - Fetch data
  - Spell checking
  - Answer a network request
- Reduced **cost** ("lightweight" process)
  - Processes are heavy to create
  - IPC for threads cheaper/easier than processes
- Can "simplify" code & increase efficiency
- Kernels are generally multithreaded (different threads provide different OS services)

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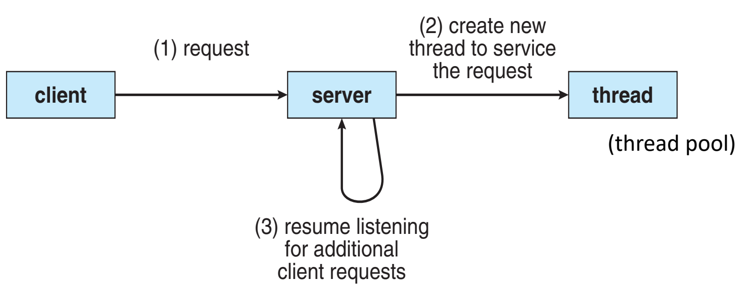
Multi-Threaded Server



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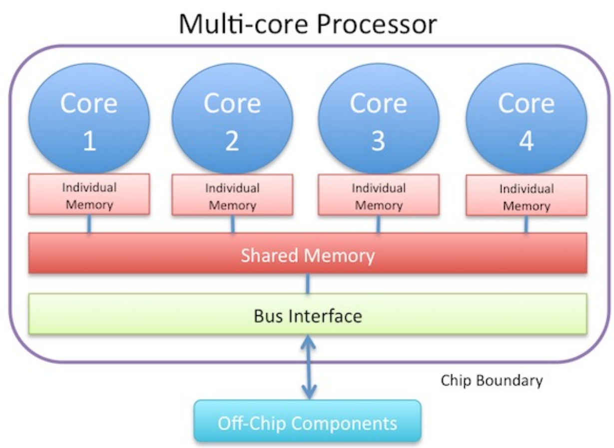
Benefits

- **Responsiveness –** may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing –** threads share resources of process, easier than shared memory or message passing
- **Economy –** cheaper than process creation, thread switching lower overhead than context switching
- **Scalability –** process can take advantage of multiprocessor architectures

Multicore Systems



Multicore Programming

- **Multicore** systems putting pressure on programmers; challenges include:
  - **Dividing activities** (which tasks to parallelize)
  - **Balance** (if/how to parallelize tasks)
  - **Data splitting** (how to divide data)
  - **Data dependency** (thread synchronization)
  - **Testing and debugging** (how to test different execution paths)
- ***Parallelism*** implies a system can perform more than one task simultaneously
- ***Concurrency*** supports more than one task making progress
  - Single processor/core, scheduler providing concurrency

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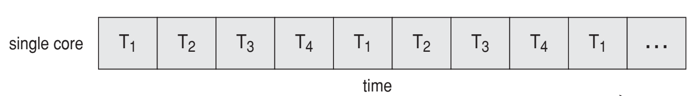
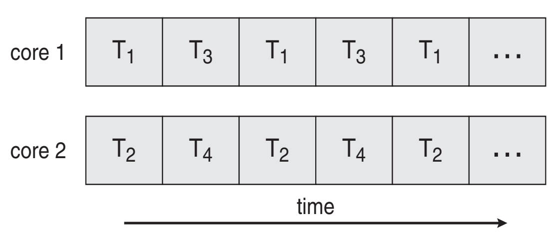
Concurrency vs. Parallelism

- **Concurrent execution on single-core system**



- **Parallelism on a multi-core system**



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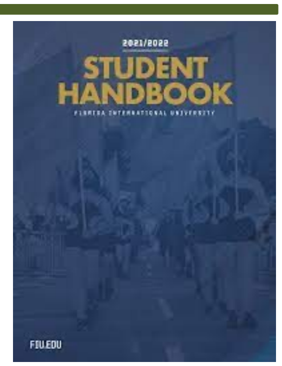
Multicore Programming

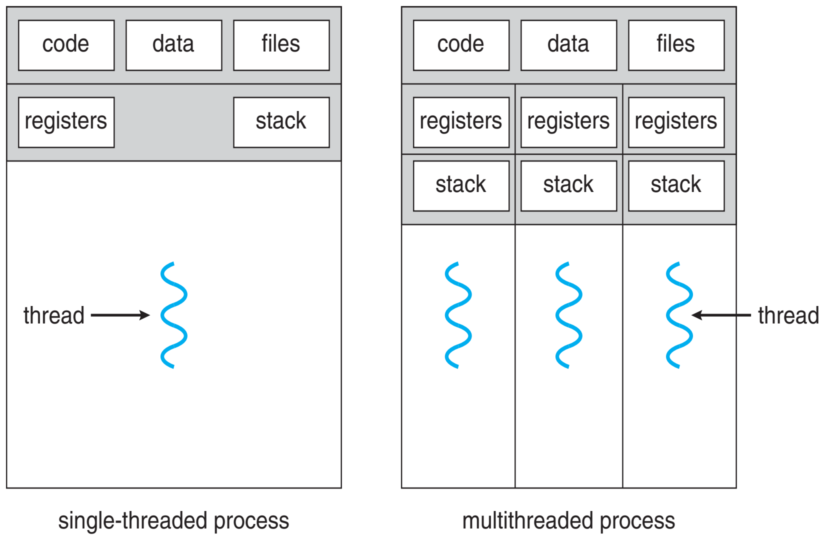
- Types of parallelism
  - **Data parallelism** – distributes subsets of the same data across multiple cores, same operation on each
  - **Task parallelism** – distributing threads across cores, each thread performing unique operation
- As # of threads grows, so does architectural support for threading ("hyperthreading")
  - CPUs have cores as well as ***hardware threads***
  - Consider Oracle SPARC T4 with 8 cores and 8 hardware threads per core

Data vs. Task Parallelism

- Count number of times each character in alphabet occurs
- Data Parallelism
  - Thread 1 does page 1-100
  - Thread 2 does page 100-200
- Task Parallelism
  - Thread 1 does letters A-M, all pages
  - Thread 2 does letters N-Z, all pages



Single and Multithreaded Processes



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User Threads and Kernel Threads

- **User threads** - management done by user-level threads library
- Three primary thread libraries:
  - POSIX **Pthreads**
  - Win32 threads
  - Java threads

- **Kernel threads** - Supported by the Kernel, **"schedulable entity"**
- Examples – virtually all general-purpose operating systems, including:
  - Windows
  - Solaris
  - Linux
  - Tru64 UNIX
  - Mac OS X

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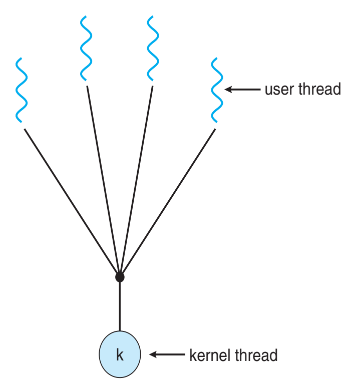
Multithreading Models

- Many-to-One
- One-to-One
- Many-to-Many

Many-to-One

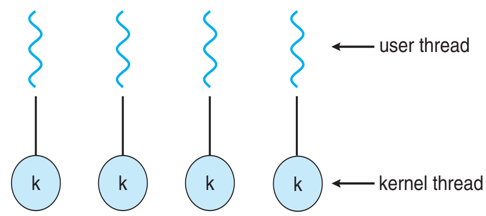
- Many user-level threads mapped to single kernel thread
- One thread blocking causes all to block
- Multiple threads may not run in parallel on multicore system because only one may be in kernel at a time
- Few systems currently use this model
- Examples:
  - Solaris Green Threads
  - GNU Portable Threads



One-to-One

- Each user-level thread maps to kernel thread
- Creating a user-level thread creates a kernel thread
- More concurrency than many-to-one
- Number of threads per process sometimes restricted due to overhead

- Examples
  - Windows NT/XP/2000
  - Linux
  - Solaris 9 and later



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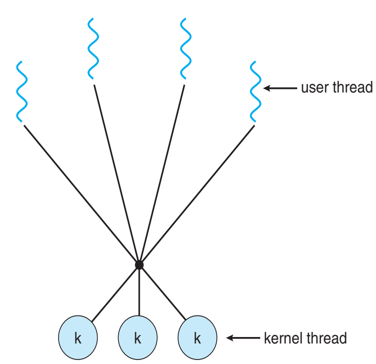
Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads

- Allows the operating system to create a sufficient number of kernel threads

- Solaris prior to version 9

- Windows NT/2000 with the *ThreadFiber* package



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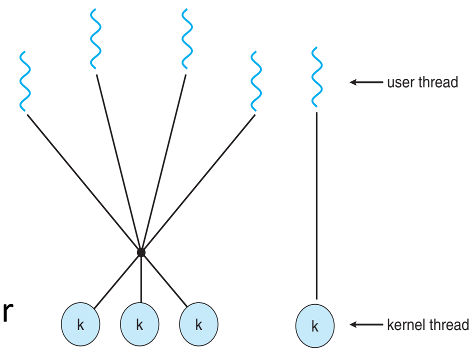
Two-level Model

- Similar to M:M, except that it allows a user thread to be **bound** to kernel thread
- Examples
  - IRIX
  - HP-UX
  - Tru64 UNIX
  - Solaris 8 and earlier



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
- ***Specification***, not ***implementation***
- 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)

Pthreads Example

```
#include <pthread.h>
#include <stdio.h>

int sum; /* this data is shared by the thread(s) */
void *runner(void *param); /* threads call this function */

int main(int argc, char *argv[])
{
  pthread_t tid; /* the thread identifier */
  pthread_attr_t attr; /* set of thread attributes */

  if (argc != 2) {
    fprintf(stderr,"usage: a.out <integer value>\n");
    return -1;
  }
  if (atoi(argv[1]) < 0) {
    fprintf(stderr,"%d must be >= 0\n",atoi(argv[1]));
    return -1;
  }
```

Pthreads Example (Cont.)

```
   /* get the default attributes */
   pthread_attr_init(&attr);
   /* create the thread */
   pthread_create(&tid,&attr,runner,argv[1]);
   /* wait for the thread to exit */
   pthread_join(tid,NULL);

   printf("sum = %d\n",sum);
}

/* The thread will begin control in this function */
void *runner(void *param)
{
   int i, upper = atoi(param);
   sum = 0;

   for (i = 1; i <= upper; i++)
      sum += i;

   pthread_exit(0);
}
```

Figure 4.9 Multithreaded C program using the Pthreads API.

Linux Threads

- Linux refers to them as ***tasks*** rather than ***threads***
- Thread creation is done through **`clone()`** system call
- **`clone()`** allows a child task to share the address space of the parent task (process)
  - Flags control behavior

flag	meaning
`CLONE_FS`	File-system information is shared.
`CLONE_VM`	The same memory space is shared.
`CLONE_SIGHAND`	Signal handlers are shared.
`CLONE_FILES`	The set of open files is shared.

Recap

- What is a thread? Why would one use a thread?
- How does a thread differ from a process?
- What are pthreads?
- What is a kernel thread?
- How does task parallelism differ from data parallelism?