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Operating Systems and System Administration

Lecture 04

Introduction to Threads

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Motivation

- Most modern applications are multithreaded
- Threads run within application
- Multiple tasks with the application can be implemented by separate threads
  - Update display
  - Fetch data
  - Spell checking
  - Answer a network request
- Process creation is heavy-weight while thread creation is light-weight
- Can simplify code, increase efficiency
- Kernels are generally multithreaded

Threads

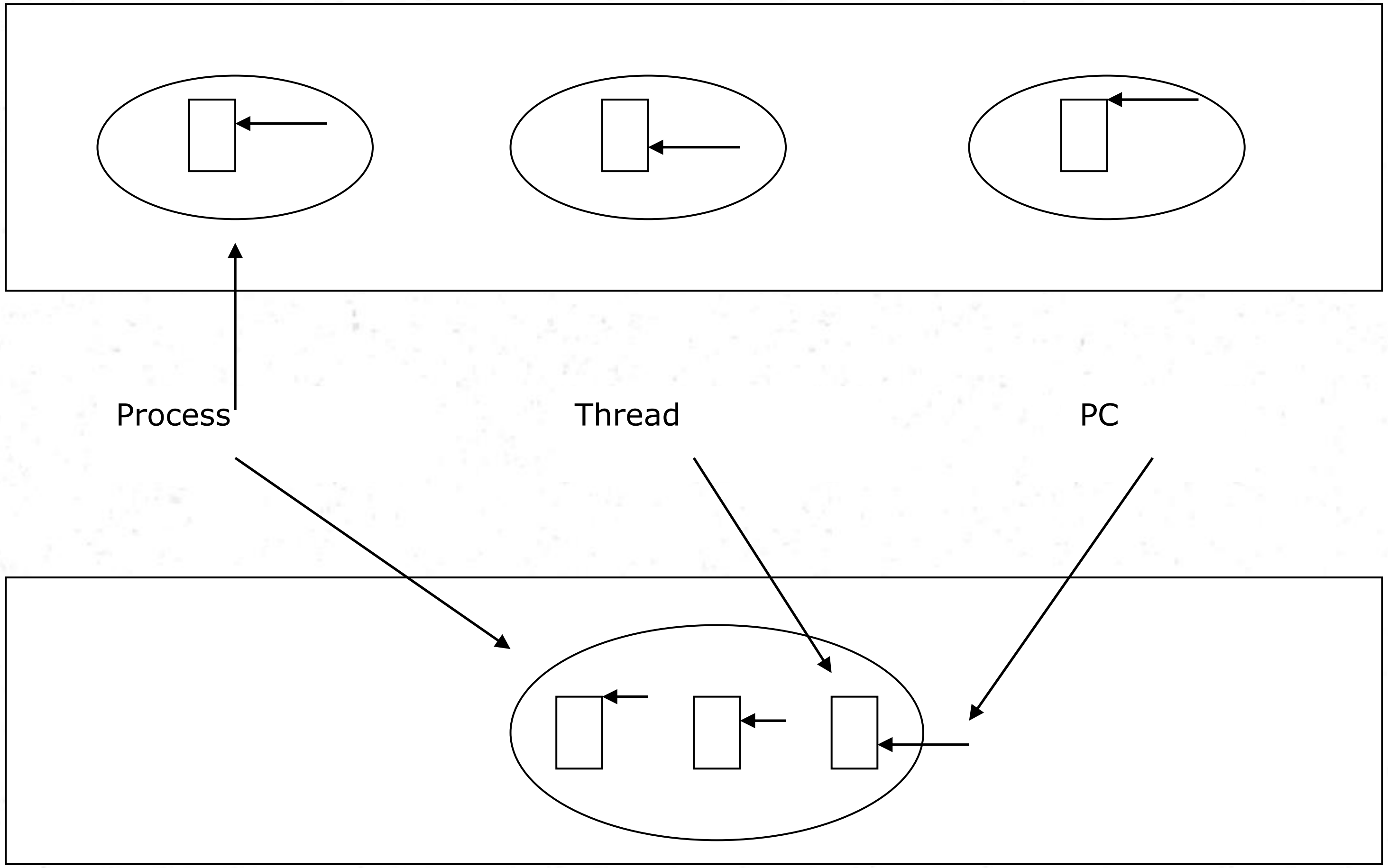
- A thread of control is an independent sequence of execution of program code in a process.
- A thread (or lightweight process) is a basic unit of CPU utilization.
  - A traditional process (or heavyweight process) is equal to a task with one thread.
- A traditional process has a single thread that has sole possession of the process's memory and other resources → context switch becomes performance bottleneck
  - Threads are used to avoid the bottleneck.
  - Threads share all the process's memory, and other resources.
- Threads within a process:
  - are generally invisible from outside the process.
  - are scheduled and executed independently in the same way as different single-threaded processes.
- On a multiprocessor, different threads may execute on different processors
  - On a uni-processor, threads may interleave their execution arbitrarily.

Threads (cont.)

- Threads operate, in many respects, in the same manner as processes:
  - Threads can be in one of several states: ready, blocked, running, or terminated, etc.
  - Threads share CPU; only one thread at a time is running.
  - A thread within a process executes sequentially, and each thread has its own PC and Stack.
  - Thread can create child threads, can block waiting for system calls to complete
    - if one thread is blocked, another can run.
- One major different with process: threads are not independent of one another
  - all threads can access every address in the task → a thread can read or write any other thread’s stack.
  - There is no protection between threads (within a process);
    - however this should not be necessary since processes may originate from different users and may hostile to one another while threads (within a process) should be designed (by same programmer) to assist one another.

Threads (cont.)

Three processes with one thread each

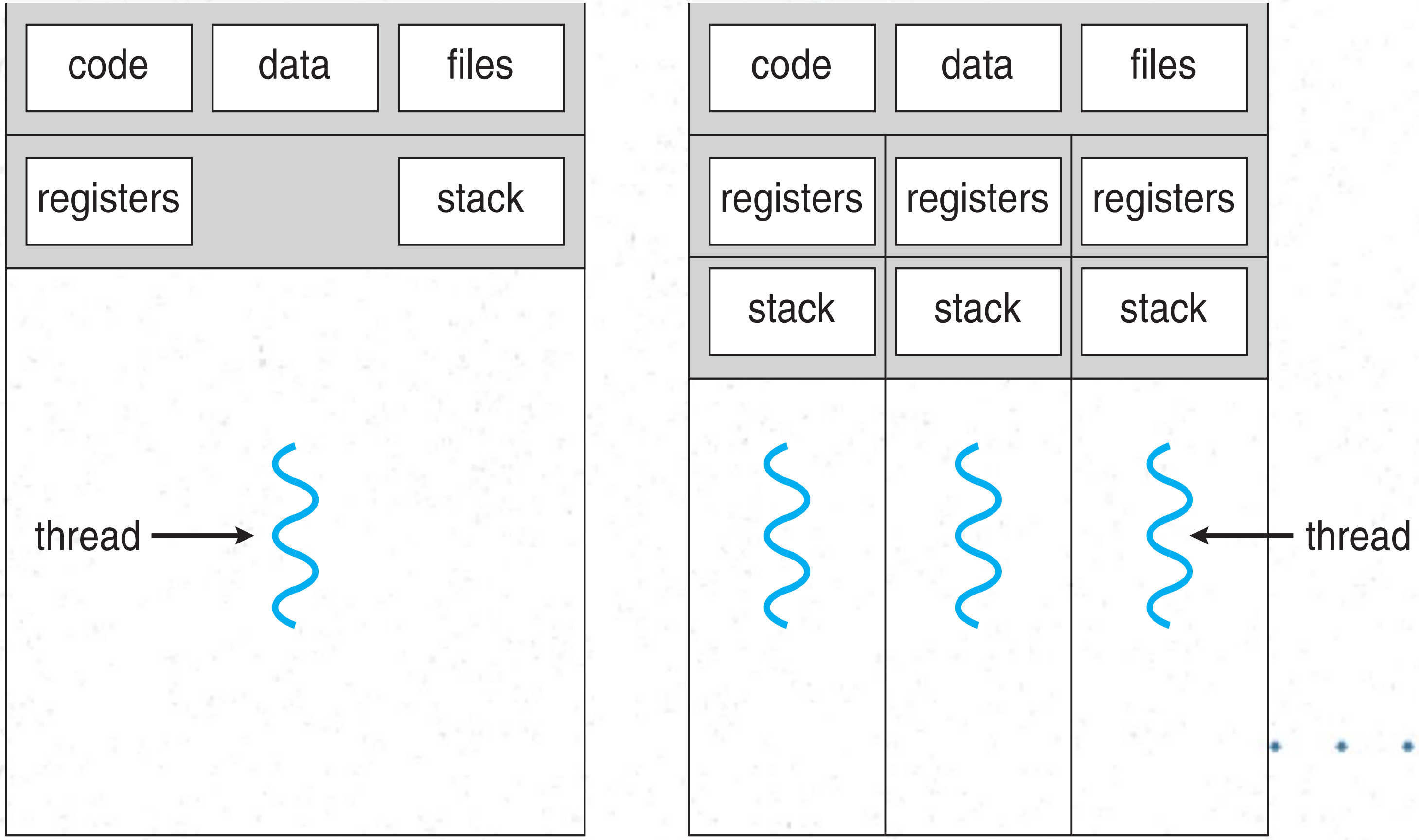


One process with three threads

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

Single and Multithreaded Processes



single-threaded process

multithreaded process

User Threads and Kernel Threads

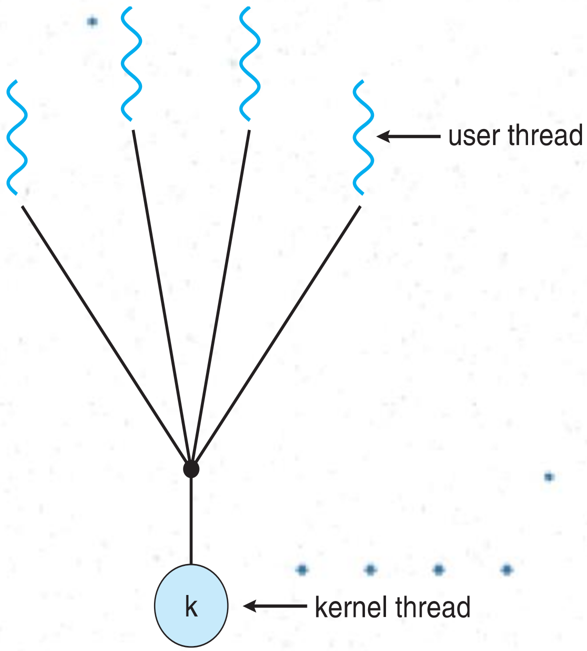
- **User threads** - management done by user-level threads library
- Three primary thread libraries:
  - POSIX **Pthreads**
  - Windows threads
  - Java threads
- **Kernel threads** - Supported by the Kernel
- Examples – virtually all general purpose operating systems, including:
  - Windows
  - Solaris
  - Linux
  - Tru64 UNIX
  - Mac OS X

Multithreading Models

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

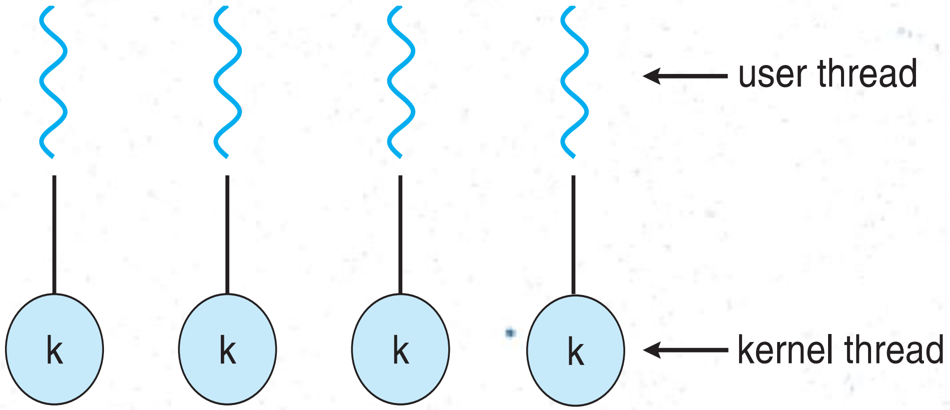
Many-to-One

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



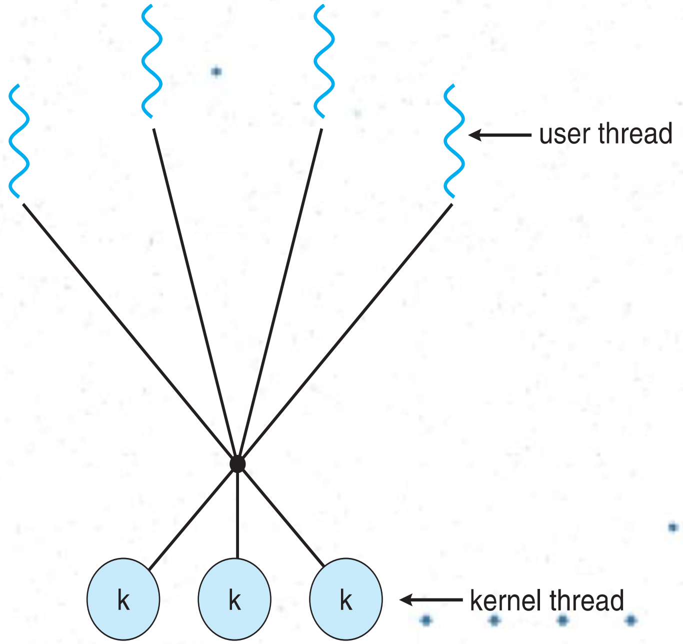
One-to-One

- 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
  - Linux
  - Solaris 9 and later



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 with the *ThreadFiber* package



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)

Thread Pools

- Create a number of threads in a pool where they await work
- Advantages:
  - Usually slightly faster to service a request with an existing thread than create a new thread
  - Allows the number of threads in the application(s) to be bound to the size of the pool
  - Separating task to be performed from mechanics of creating task allows different strategies for running task
    - i.e.Tasks could be scheduled to run periodically

Signal Handling

- **Signals** are used in UNIX systems to notify a process that a particular event has occurred.
- A **signal handler** is used to process signals
  1. Signal is generated by particular event
  2. Signal is delivered to a process
  3. Signal is handled by one of two signal handlers:
     1. default
     2. user-defined
- Every signal has **default handler** that kernel runs when handling signal
  - **User-defined signal handler** can override default
  - For single-threaded, signal delivered to process

Signal Handling (Cont.)

- Where should a signal be delivered for multi-threaded?
  - Deliver the signal to the thread to which the signal applies
  - Deliver the signal to every thread in the process
  - Deliver the signal to certain threads in the process
  - Assign a specific thread to receive all signals for the process

Thread Cancellation

- Terminating a thread before it has finished
- Thread to be canceled is **target thread**
- Two general approaches:
  - **Asynchronous cancellation** terminates the target thread immediately
  - **Deferred cancellation** allows the target thread to periodically check if it should be cancelled

Thread Example

```c
#include <stdio.h>
#include <pthread.h>
#define NUM_THREADS 4

void *hello (void *arg) { /* thread main */
    printf("Hello Thread\n");
    return 0;
}

int main (void) {
    int i;
    pthread_t tid[NUM_THREADS];
    for (i = 0; i < NUM_THREADS; i++) { /* create/fork threads */
        pthread_create(&tid[i], NULL, hello, NULL);
    }
    for (i = 0; i < NUM_THREADS; i++) { /* wait/join threads */
        pthread_join(tid[i], NULL);
    }
    return 0;
}
```

```
#include<pthread.h> #include <stdio.h>
/* Producer/consumer program illustrating conditional variables */ /* Size of shared buffer */       #define BUF_SIZE 3
int buffer[BUF_SIZE];                                          /* shared buffer */
int add=0;                                                     /* place to add next element */
int rem=0;                                                     /* place to remove next element */
int num=0;                                                     /* number elements in buffer */
pthread_mutex_t m=PTHREAD_MUTEX_INITIALIZER;          /* mutex lock for buffer */
pthread_cond_t c_cons=PTHREAD_COND_INITIALIZER; /* consumer waits on this cond var */
pthread_cond_t c_prod=PTHREAD_COND_INITIALIZER; /* producer waits on this cond var */
void *producer(void *param);
void *consumer(void *param);
main (int argc, char *argv[])
{           pthread_t tid1, tid2;                         /* thread identifiers */
            int i; /* create the threads; may be any number, in general */
            if (pthread_create(&tid1,NULL,producer,NULL) != 0) {
                        fprintf (stderr, "Unable to create producer thread\n"); exit (1); }
            if (pthread_create(&tid2,NULL,consumer,NULL) != 0) {
                        fprintf (stderr, "Unable to create consumer thread\n"); exit (1);
            }
            /* wait for created thread to exit */
            pthread_join(tid1,NULL);
            pthread_join(tid2,NULL);
            printf ("Parent quiting\n"); }
}
```

```
/* Produce value(s) */
void *producer(void *param)
{
        int i;
        for (i=1; i<=20; i++) {
                /* Insert into buffer */
                pthread_mutex_lock (&m);
                if (num > BUF_SIZE) exit(1);        /* overflow */
                while (num == BUF_SIZE)                        /* block if buffer is full */
                        pthread_cond_wait (&c_prod, &m);
                /* if executing here, buffer not full so add element */
                buffer[add] = i;
                add = (add+1) % BUF_SIZE;
                num++;
                pthread_mutex_unlock (&m);
                pthread_cond_signal (&c_cons);
                printf ("producer: inserted %d\n", i);  fflush (stdout);
        }
        printf ("producer quiting\n");  fflush (stdout);
}
```

```c
/* Consume value(s); Note the consumer never terminates */
void *consumer(void *param)
{
        int i;
        while (1) {
                pthread_mutex_lock (&m);
                if (num < 0) exit(1);   /* underflow */
                while (num == 0)                /* block if buffer empty */
                        pthread_cond_wait (&c_cons, &m);
                /* if executing here, buffer not empty so remove element */
                i = buffer[rem];
                rem = (rem+1) % BUF_SIZE;
                num--;
                pthread_mutex_unlock (&m);
                pthread_cond_signal (&c_prod);
                printf ("Consume value %d\n", i);  fflush(stdout);
        }
}
```

Thank you