Operating Systems
CS2006

Lecture 9

Threads

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Background

Basic concepts

- **Multiprogramming:** Many processes one CPU. Interleaving between multiple processes. Process relinquish CPU itself.
- **Multiprocessing:** refers to more than one CPU. Systems can be both multiprogramming and multiprocessing at the same time.
- **Multitasking:** refers to modern operating systems doing preemption for switching processes/threads. OS gives a time quantum to each process/thread.
- **Time sharing:** When CPU time is being shared between processes, it is called time sharing system. Multiprogramming & multitasking systems are time sharing systems.
- **Multithreading:** is an execution model that allows a single process to have multiple code segments (threads) that run concurrently within the context of that process.

Motivation

- Most modern applications are multithreaded
- Threads run within application
- Multiple tasks with the application can be implemented by separate threads
  - MS Word
    - One thread for spell checking
    - One thread for output of keystrokes
- Process creation is heavy-weight while thread creation is light-weight
- Increases efficiency
- Kernels are generally multithreaded

Introduction

- Each process has
  1. Own Address Space
  2. Single thread of control
- A process model has two concepts:
  1. Resource grouping
  2. Execution
- Sometimes it is useful to separate them

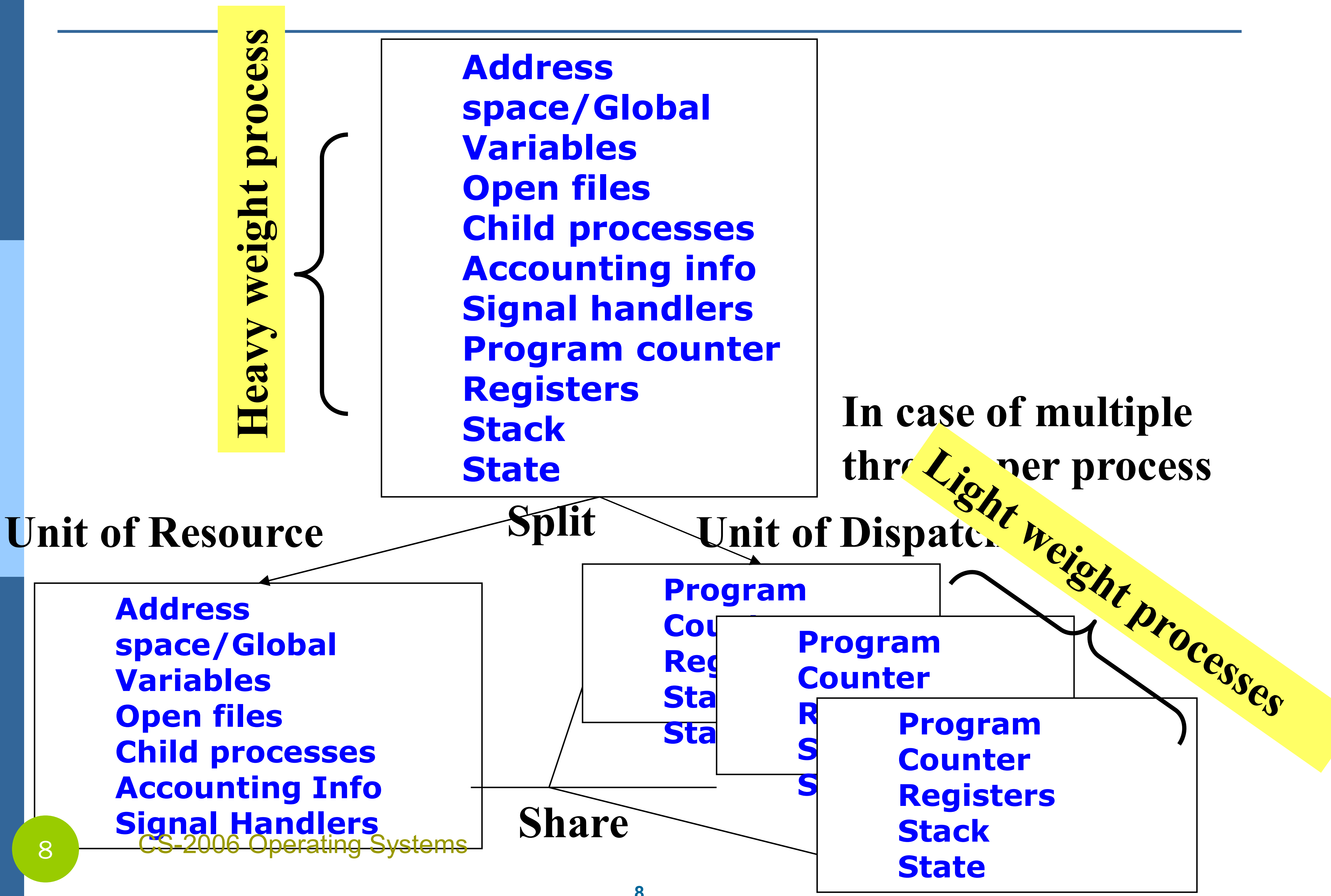
Unit of Resource Ownership

- A process has an
  - Address space
  - Open files
  - Child processes
  - Accounting information
  - Signal handlers
- If these are put together in a form of a process, can be managed more easily

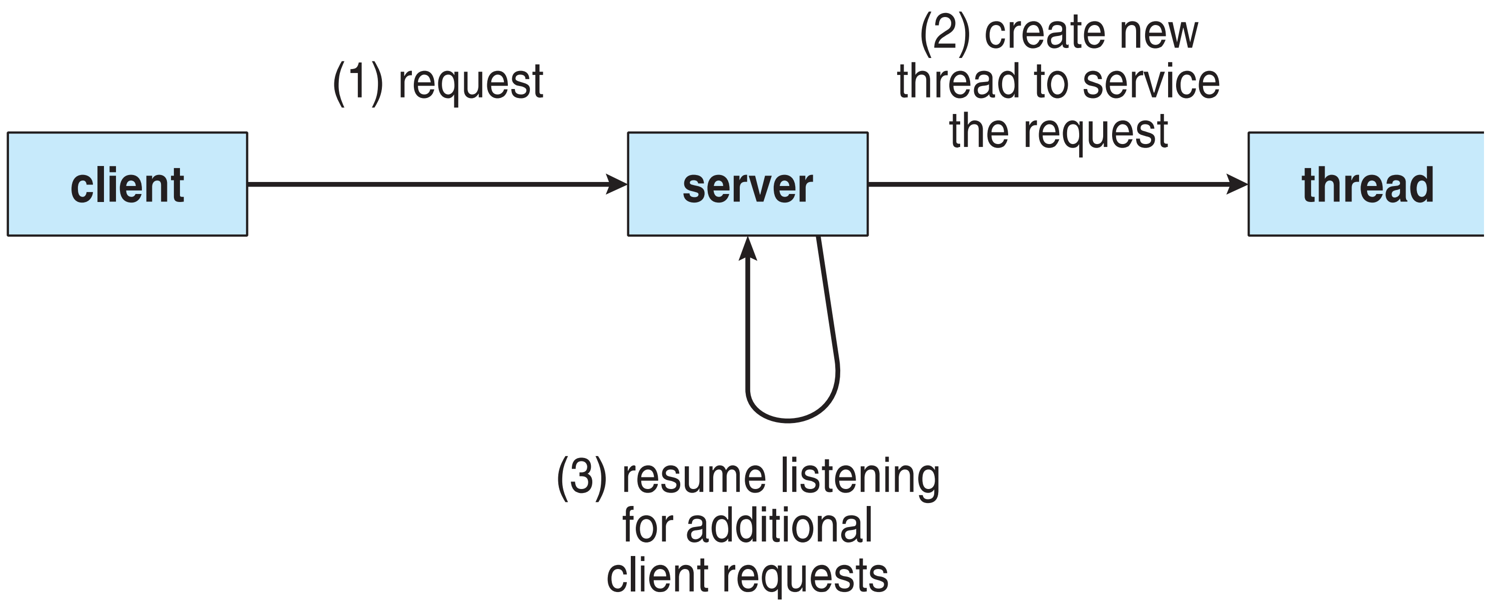
Unit of Dispatching

- Path of execution
  - Program counter: which instruction is running
  - Registers:
    - holds current working variables
  - Stack:
    - Contains the execution history, with one entry for each procedure called but not yet returned
  - State
- Processes are used to group resources together
- Threads are the entities scheduled for execution on the CPU
- Threads are also called ***lightweight*** process (LWP)

Its better to distinguish between the two concepts



Multithreaded Server Architecture

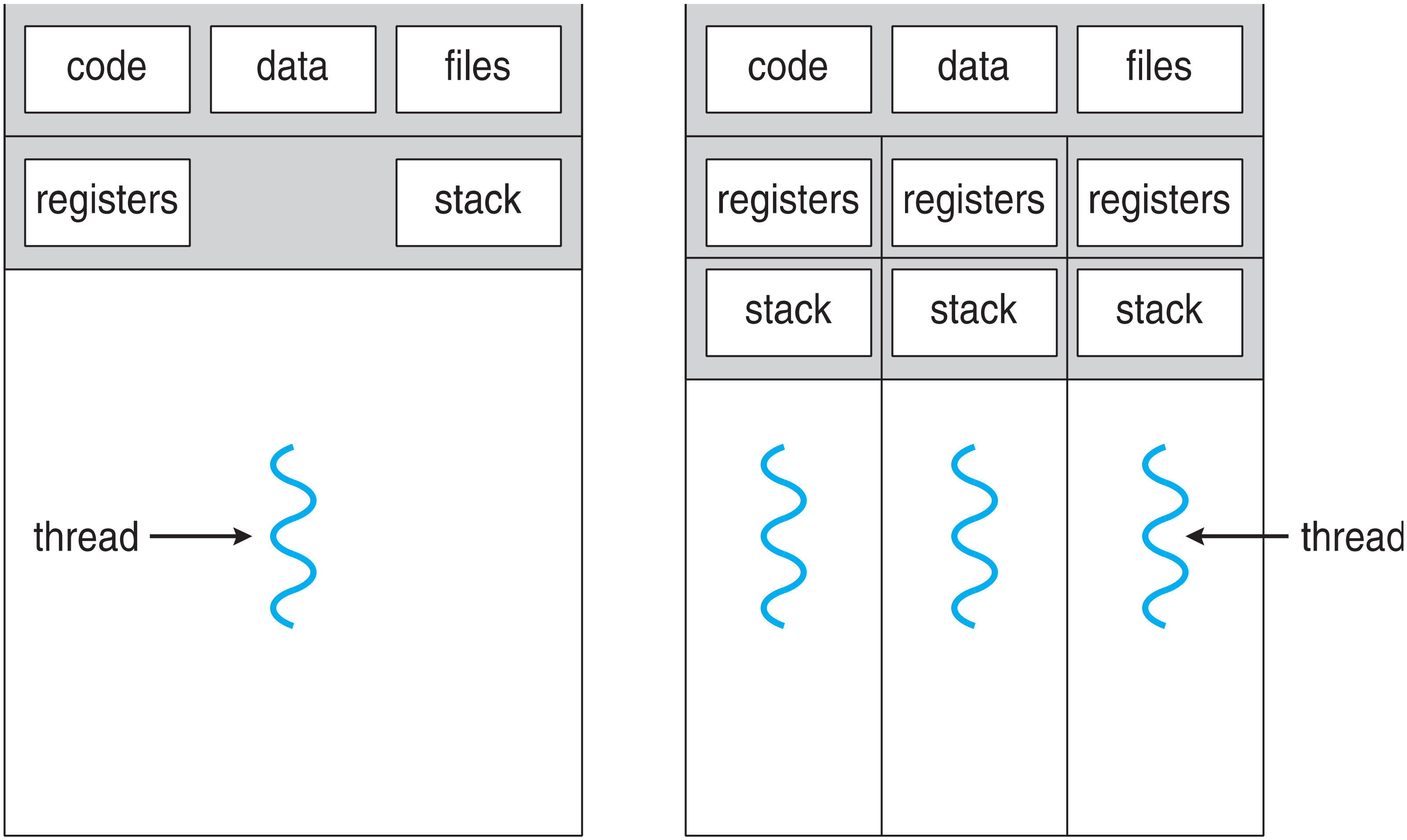


What are threads?

Thread

- A thread is a flow of execution through the process code.
- A thread will always belong to some process.
- A process can have multiple threads but starts with one only
- Threads share:
  - Same data as that of its process
  - Same code as that of its process
  - Same files as that of its process
- Each thread has its own
  - Register.
  - Stack.
  - Program Counter.

Single and Multithreaded Processes



single-threaded process

multithreaded process

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

Process vs. Thread

- Process is heavy weight or resource intensive.
- Process switching needs interaction with operating system.
- In multiple processes each process operates independently of the others.

- Thread is light weight, taking lesser resources than a process.
- Thread switching does not need to interact with operating system.
- One thread can read, write or change another thread's data.

Thread Properties

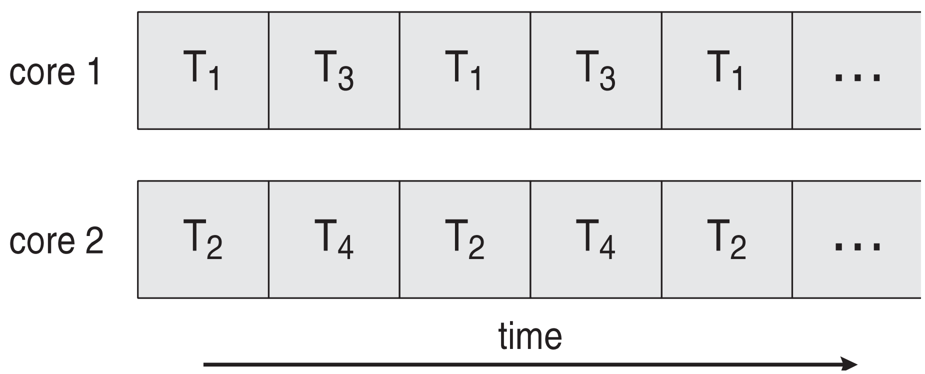
Multicore Programming

- **Multicore** or **multiprocessor** systems offer real speed up if multiple threads are used
- Programmers must accurately use threads
  - **Divide** independent problems and assign to threads
  - Keep a **balance** in dividing activities, do not overburden one or more threads
  - **Split Data** too**,** so threads can work in parallel
  - **Data** should be split properly, so that **dependency** among threads remains minimum
  - **Testing and debugging** of the multi threaded applications is difficult
- ***Parallelism*** implies a system can perform more than one task simultaneously
- ***Concurrency*** enables more than one task making progress

Concurrency vs. Parallelism

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

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



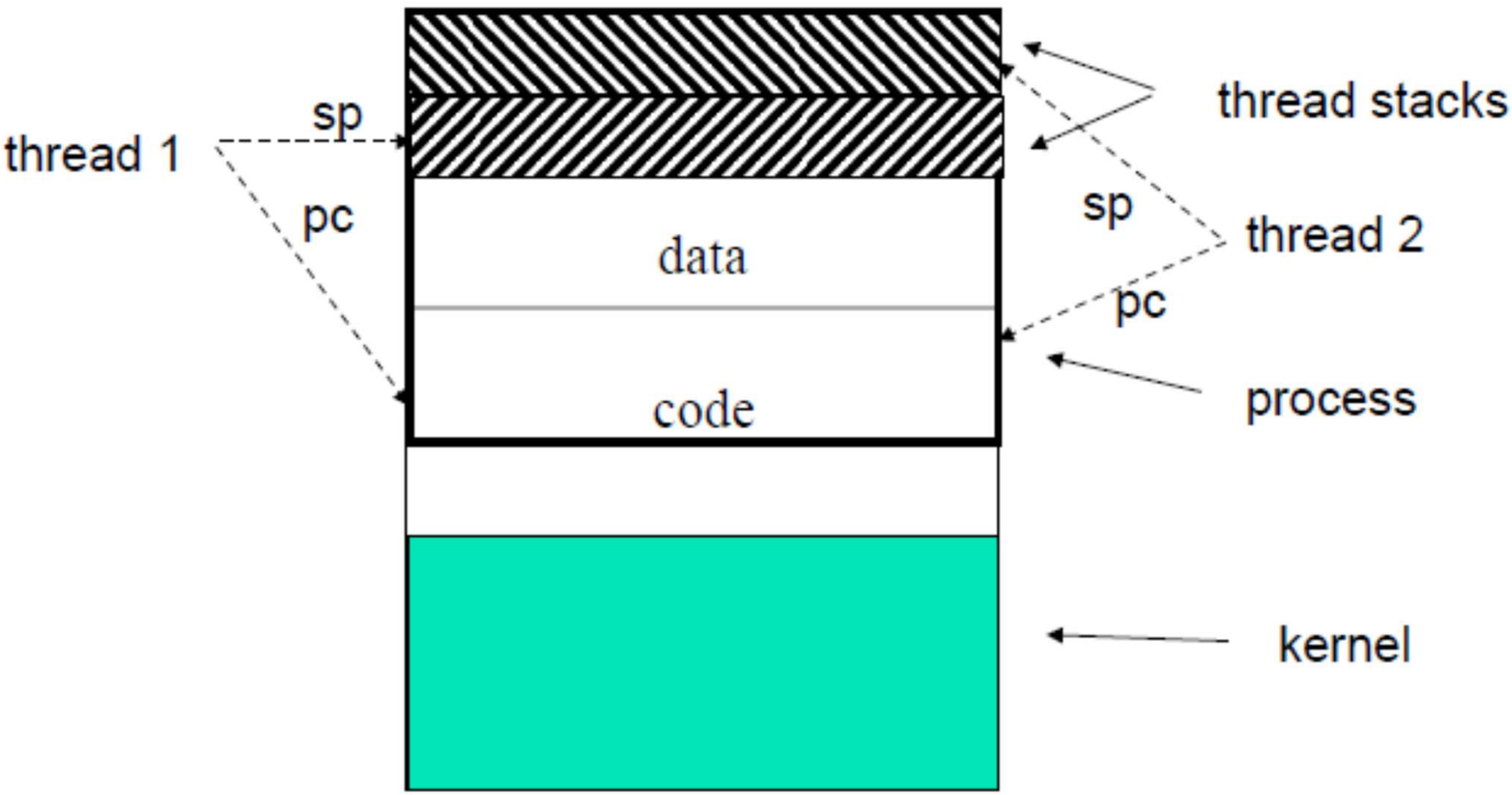
Multicore Programming (Cont.)

- 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
  - CPUs have cores as well as ***hardware threads***
  - Consider Oracle SPARC T4 with 8 cores, and 8 hardware threads per core

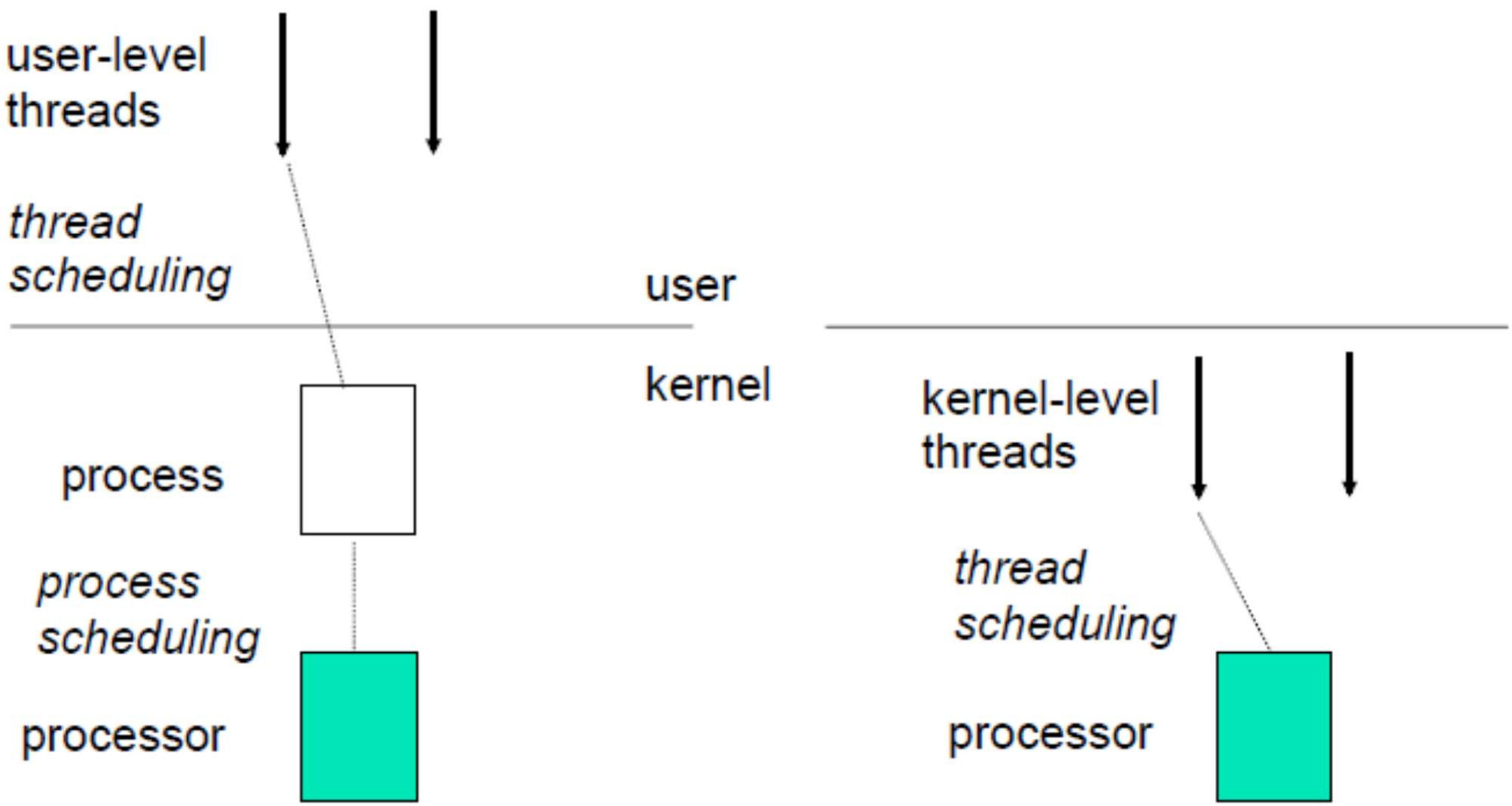
User Threads and Kernel Threads

- **User threads** - management done by user-level threads library
- The thread library contains code for creating and destroying threads, for passing message and data between threads, for scheduling thread execution and for saving and restoring thread contexts
- Three primary thread libraries:
  - POSIX **Pthreads**
  - Windows threads
  - Java threads
- **Kernel threads** - Operating System managed threads acting on kernel
- Examples – virtually all general purpose operating systems, including:
  - Windows
  - Solaris
  - Linux
  - Tru64 UNIX
  - Mac OS X

User-Level Thread Implementation



User-Level vs. Kernel-Level Threads



User-level threads vs. kernel-level threads

- User-level threads are faster to create and manage.
- Implementation is by a thread library at the user level.
- OS doesn’t recognize user level threads.
- Multi-threaded applications cannot take advantage of multiprocessing
- If one user level thread perform blocking operation then entire process will be blocked.

- Kernel-level threads are slower to create and manage.
- Operating system supports creation of Kernel threads.
- OS recognizes kernel-level threads
- Kernel routines themselves can be multithreaded.
- If one kernel thread perform blocking operation then another thread can continue execution.

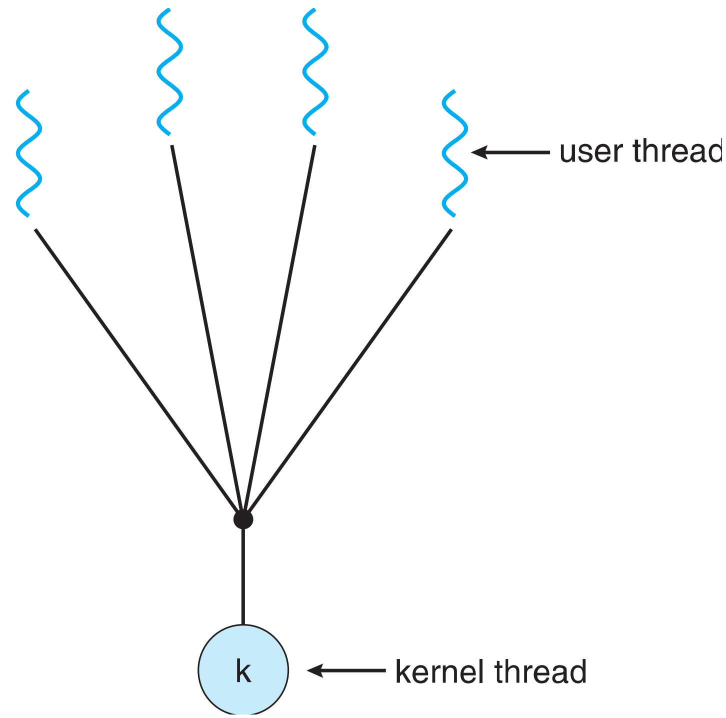
Multithreading Models

User-level threads can be implemented using any of the three models:

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

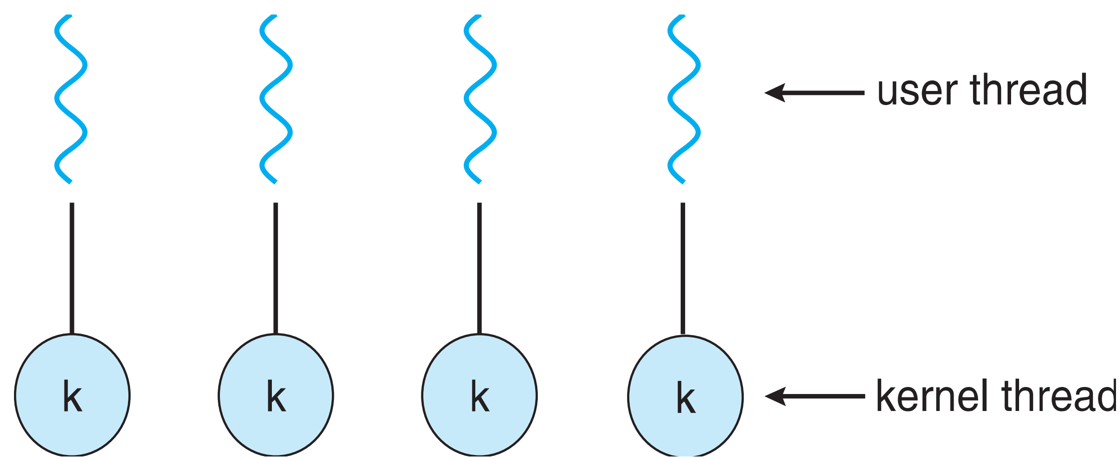
Many-to-One

- Synonym of user-level threads
- 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**



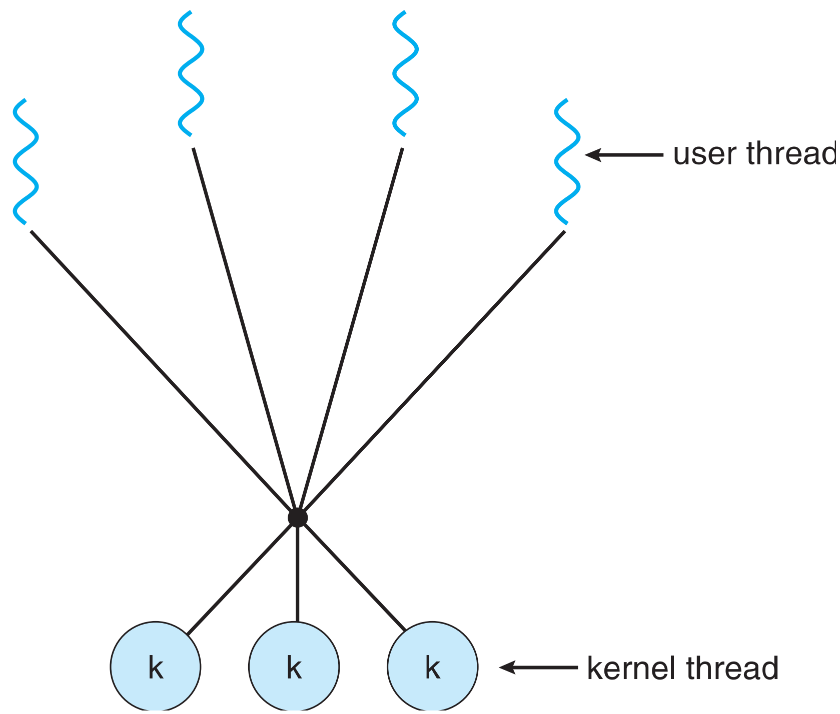
One-to-One

- Creating a user-level thread creates a kernel thread
- More concurrency than many-to-one
- One user-level thread is mapped onto one kernel level thread.
  - Even if one thread is blocked, others will still run
- Allows multiple threads to run on multiprocessor system
- Number of threads per process sometimes restricted due to overhead
- Examples
  - Windows
  - Linux
  - Solaris 9 and later



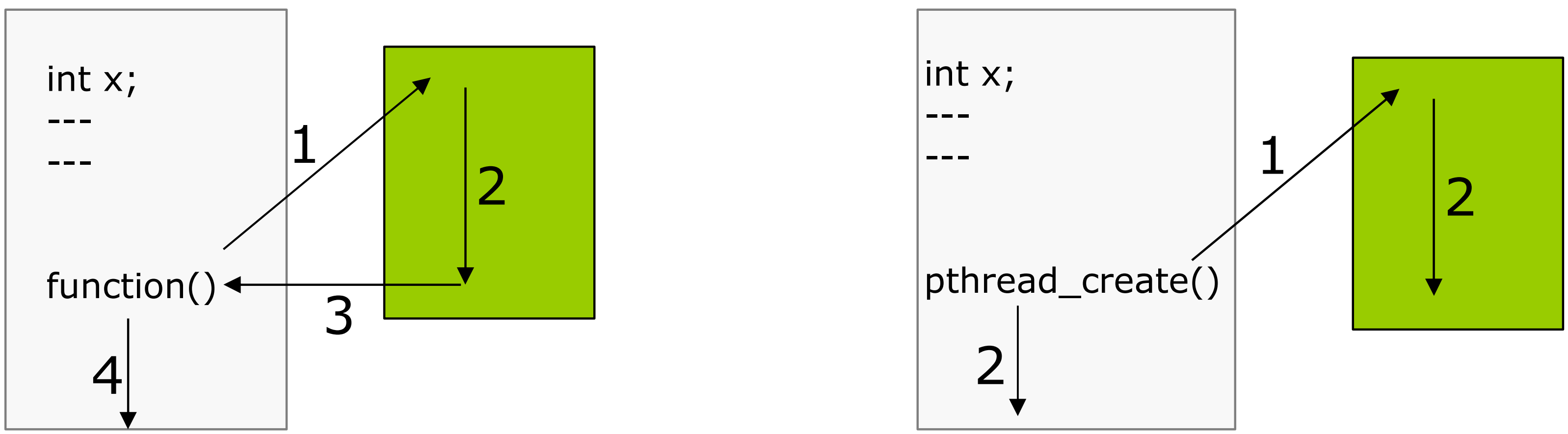
Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads
- The number of kernel level threads maybe equal to or less than user level threads
- Allows the operating system to create a sufficient number of kernel threads
- Many-to-one: suffered from lack of concurrency
- One-to-one: suffered from overhead of too many kernel level threads
- Many-to-many suffers from none



Threads In Action

C function call vs. thread creation



Creating a new thread

```
int pthread_create(
    pthread_t *thread,
    const pthread_attr_t *attr,
    void *(*start_routine) (void *), void *arg);
int pthread_join(
    pthread_t thread, // thread to join
    void **value_ptr  // store value returned by thread
);
int pthread_exit (void *retval);
int pthread_attr_init(pthread_attr_t *attr);
int pthread_attr_destroy(pthread_attr_t *attr);
unsigned int sleep(unsigned int seconds);
```

Practical work (explanation)

pthread_create(pthread_t* , NULL, void*, void*)

- First Parameter is pointer of thread ID it should be different for all threads.
- The second argument points to a pthread_attr_t structure whose contents are used at thread creation time to determine attributes for the new thread. Null means use default attr.
- Third parameter is address of function which we are going to use as thread.
- Forth parameter is argument to function. Only one is allowed.

Practical work (explanation)

pthread_join(i pthread_t , void**)

Pthread join is used in main program to wait for the end of a particular thread.

- First parameter is Thread ID of particular thread
- Second Parameter is used to catch return value from thread.

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

#define N 5

void *worker_thread(void *arg)
{
        printf("This is worker_thread #%ld\n", (long)arg);
        pthread_exit(NULL);
}

int main()
{
        pthread_t my_thread[N];

        long id;
        for(id = 1; id <= N; id++) {
                int ret =  pthread_create(&my_thread[id], NULL,
&worker_thread, (void*)id);
                if(ret != 0) {
                        printf("Error: pthread_create() failed\n");
                        exit(EXIT_FAILURE);
                }
        }

        pthread_exit(NULL);
}
```

Output

This is worker_thread #1
This is worker_thread #2
This is worker_thread #3
This is worker_thread #4
This is worker_thread #5

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

void * PrintHello(void * data)
{
    int my_data = (int)data;

    printf("\n Hello from new thread - got %d !\n", my_data);
    pthread_exit(NULL);
}

int main()
{
    int rc;
    pthread_t thread_id;

    int t = 11;

    rc = pthread_create(&thread_id, NULL, PrintHello, (void*)t);
    if(rc)
    {
      printf("\n ERROR: return code from pthread_create is %d \n", rc);
      exit(1);
    }
    printf("\n Created new thread (%u)... \n", thread_id);

    pthread_exit(NULL);
}
```

Output

Created new thread (4) ...
Hello from new thread - got 11

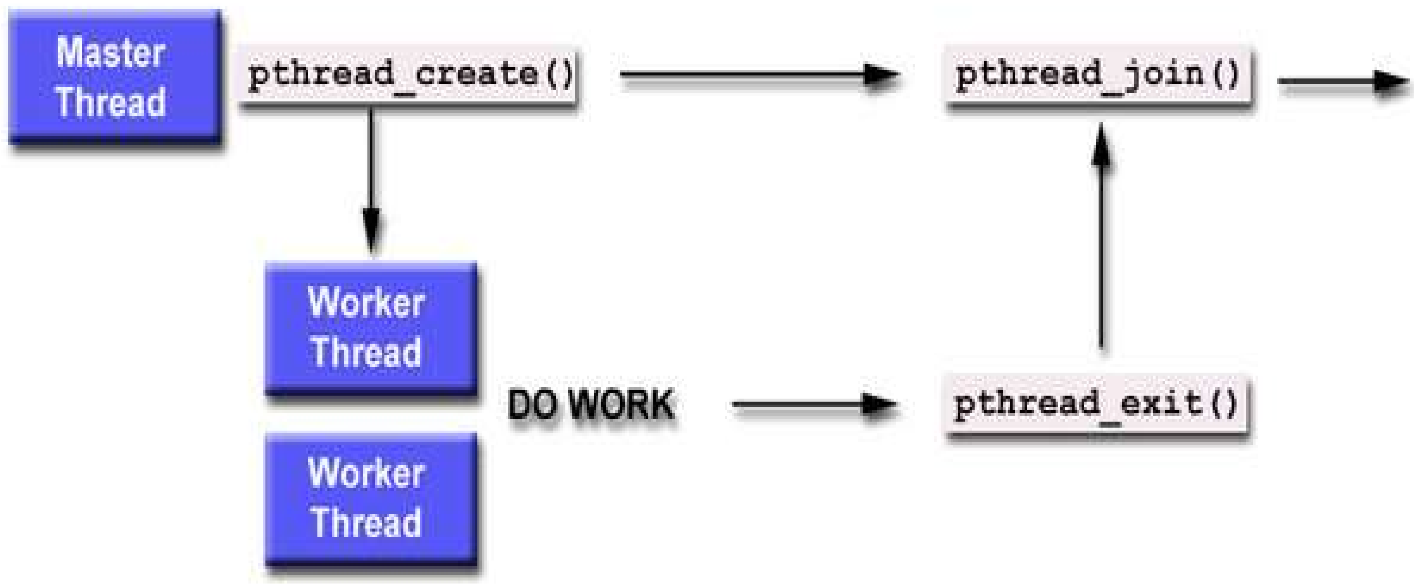
Questions

- What happens when a thread calls an exit() function?
- Can a function that is a part of the program be called from a thread?
- What happens when you call a fork() in a thread?
- What happens when you call pthread_exit() in the main thread?

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>
#include <unistd.h>
#include <errno.h>

void *functionC(void *);

int main ()
{
        int rc;
        pthread_t th;

        if(rc = pthread_create(&th, NULL, &functionC, NULL))
        {
                printf("Thread creation failed, return code %d, errno %d",
rc,                     errno);
        }

        printf("Main thread %lu: Sleeping for 20 seconds\n", pthread_self());
        fflush(stdout);
        sleep(20);
        pthread_exit(NULL);
        printf("Main thread %lu: This will not be printed as we already
called         pthread_exit\n", pthread_self());
        exit(0);
}

void *functionC(void *)
{
        printf("Thread %lu: Sleeping for 20 second\n", pthread_self());
        sleep(20);
        printf("Thread %lu: Came out of first and sleeping again\n",
pthread_self());
        sleep(20);
        printf("CThread %lu: Came out of second sleep\n", pthread_self());
}
```

Output

```
Main thread 140166909204288: Sleeping for 20 seconds
Thread 140166900684544: Sleeping for 20 second
Thread 140166900684544: Came out of first and sleeping again
CThread 140166900684544: Came out of second sleep
```


Master Thread
pthread_create()
pthread_join()
Worker Thread
Worker Thread
DO WORK
pthread_exit()

```
#include <stdio.h>
#include <unistd.h>
#include <stdlib.h>
#include <string.h>
#include <pthread.h>

void *thread_fnc(void * arg);

char thread_msg[] ="Hello Thread!";  // global

int main()
{
        int ret;
        pthread_t my_thread;
        void *ret_join;

        ret =  pthread_create(&my;_thread, NULL, thread_fnc, (void*) thread_msg);
        if(ret != 0) {
                perror("pthread_create failed\n");
                exit(EXIT_FAILURE);
        }
        printf("Waiting for thread to finish...\n");
        ret = pthread_join(my_thread, &ret_join);
        if(ret != 0) {
                perror("pthread_join failed");
                exit(EXIT_FAILURE);
        }
        printf("Thread joined, it returned %s\n", (char *) ret_join);
        printf("New thread message: %s\n",thread_msg);
        exit(EXIT_SUCCESS);
}

void *thread_fnc(void *arg)
{
        printf("This is thread_fnc(), arg is %s\n", (char*) arg);
        strcpy(thread_msg,"Bye!");
        pthread_exit("'Exit from thread'");
}
```

Output

```
Waiting for thread to finish...
This is thread_fnc(), arg is Hello Thread!
Thread joined, it returned 'Exit from thread'
New thread message: Bye!
```

Practice Problem

Write a program in which you are going to create a thread. The main thread will pass an integer value N to the newly spawned thread. This thread will sum the numbers starting from 1 till the number N. The main thread will display the updated `sum`. Remember that the main thread will have to wait for the spawned thread to complete its work.

SKELETON:

```
int sum;
void *runner(void *param);
main()
{
     pthread_create(tid, attr, runner, int_arg);
     Pthread_join(tid);
}
void * runner(void *param)
{
    sum…
    pthread_exit(sum);
}
```

Thread 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;
       }
```

Thread example cont.

```
if (atoi(argv[1]) < 0) {
fprintf(stderr,"%d must be >= 0\n",atoi(argv[1]));
return -1;
      }
/* 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);
}
```

Thread example cont

```
/* 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);
}
```

How to run: **./program 5**

Expected output: 15

Practice

- Write a program that gets the following problem solved in two threads.
  - (3 * 10) + (5 * 4)
  - First half via thread 1 and second half via thread 2
- Write the program in which you will search for the two halves of an int array for a value, each half using one thread.

Non-deliverable assignment

- Write a program in which you create a thread that calculates the factorial of a number n that is input by a user. The thread attributes must be changed are:
  - Scope
  - Scheduling priority
- Write a program that prints the first 15 numbers(starting from 1-15) each after a delay of one second using threads
- Why do we fork when we can thread?

Solution Practice example_1 1/5

```
#include <iostream>
#include<pthread.h>
#include<stdio.h>
using namespace std;
#include <string.h>

//agruments that we pass in the function
// we create struct if we have to pass multiple arguments
struct arg_struct {
    int arg1;
    int arg2;
};
```

Solution Practice example_1 2/5

```
//function that we use in threads
void* myFunc(void* arguments)
{

  struct arg_struct *args = (struct arg_struct *)arguments;

  int *new_ptr=new int;
  *new_ptr=args->arg1*args->arg2;
  pthread_exit( (void*) new_ptr);
  //do not use exit routine, it will terminate the whole process
}
```

Solution Practice example_1 3/5

```
int main()
{
 // creating id for thread
 pthread_t thread1_id,thread2_id;

//initializing variables
 struct arg_struct thread1_var;
 thread1_var.arg1=3;
 thread1_var.arg2=10;
 struct arg_struct thread2_var;
 thread2_var.arg1=5;
 thread2_var.arg2=4;
```

Solution Practice example_1 4/5

```
// creating threads
 if (pthread_create(&thread1_id, NULL, &myFunc,(void *)
   &thread1_var)==-1)
 {
    cout<<"Thread Creation Failed!"<<endl;
    return 1;
 }
if (pthread_create(&thread2_id, NULL, &myFunc,(void *)
   &thread2_var)==-1)
 {
    cout<<"Thread Creation Failed!"<<endl;
    return 1;
 }
```

Solution Practice example_1 5/5

```
  // variables to store the return value
  int *ptr_t1_ret,*ptr_t2_ret;
  // wait for the end of a particular thread
  pthread_join(thread1_id, (void**) &ptr_t1_ret);
  pthread_join(thread2_id, (void**) &ptr_t2_ret);
  // display result
  cout<<*ptr_t1_ret + *ptr_t2_ret;
}
```

Example 2

Solution Practice example_2 1/5

```
#include <iostream>
#include<pthread.h>
#include<stdio.h>
using namespace std;
#include <string.h>


//agruments that we pass in the function
// we create struct if we have to pass multiple arguments

struct arg_struct {
    int array[10]={1,2,3,4,5,6,7,8,9,10};
    int size=10;
    int search=11;
};
```

Solution Practice example_2 2/5

```
//function that we use in threads
// to search in 1st half
void* myFunc1(void* arguments)
{
  struct arg_struct *args = (struct arg_struct *)arguments;
  int *val_p=args->array;
  int *val=new int;
  int i = 0;
  for( i = 0; i < args->size/2; i++){
    if(val_p[i]==args->search){
       *val=val_p[i];
     }
  }
  pthread_exit( (void*) val);     }
```

Solution Practice example_2 3/5

```
// to search in 2nd half
void* myFunc2(void* arguments)
{
  struct arg_struct *args = (struct arg_struct *)arguments;
  int *val_p=args->array;
  int *val=new int;
  int i = 0;
  for( i = args->size/2; i < args->size; i++){
    if(val_p[i]==args->search){
       *val=val_p[i];
     }
  }
  pthread_exit( (void*) val); }
```

Solution Practice example_2 4/5

```
int main()
{
   // createing id for thread
  pthread_t thread1_id,thread2_id;
  struct arg_struct thread_var;

 // creating threads
  if (pthread_create(&thread1_id, NULL, &myFunc1,(void *) &thread_var)==-1)
  {
      cout<<"Thread Creation Failed!"<<endl;
      return 1;
  }
 if (pthread_create(&thread2_id, NULL, &myFunc2,(void *) &thread_var)==-1)
  {
      cout<<"Thread Creation Failed!"<<endl;
      return 1;
  }
```

Solution Practice example_2 5/5

```
// variables to store the return value
 int *ptr_t1_ret,*ptr_t2_ret;

 // wait for the end of a particular thread
 pthread_join(thread1_id, (void**) &ptr_t1_ret);
 pthread_join(thread2_id, (void**) &ptr_t2_ret);

 // display result
 if(*ptr_t1_ret>0){
    cout<<"found in first half of array";    }
 else if(*ptr_t2_ret>0){
    cout<<"found in 2nd half of array";   }
 else
    {cout<<"not found";}
}
```

Thanks