BITS, PILANI – K. K. BIRLA GOA CAMPUS

Operating Systems

by

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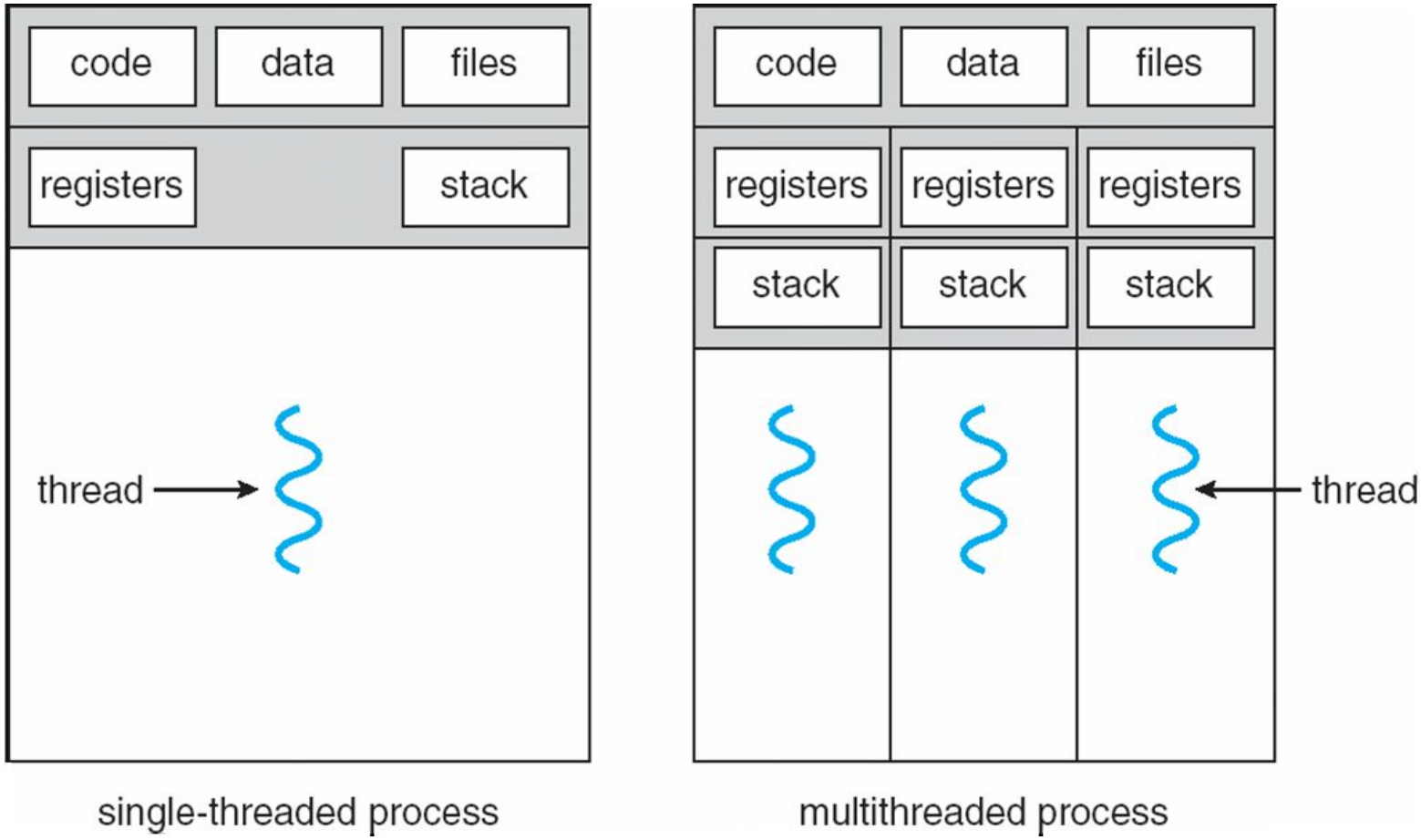
Lecture 17

Multithreaded Programming

Processes and Threads

PROCESSES	THREADS
Multiple simultaneous Programs	Multiple simultaneous Functions
Independent memory space	Shared memory space
Independent open file-descriptors	Shared open file-descriptors

Single and Multithreaded Processes



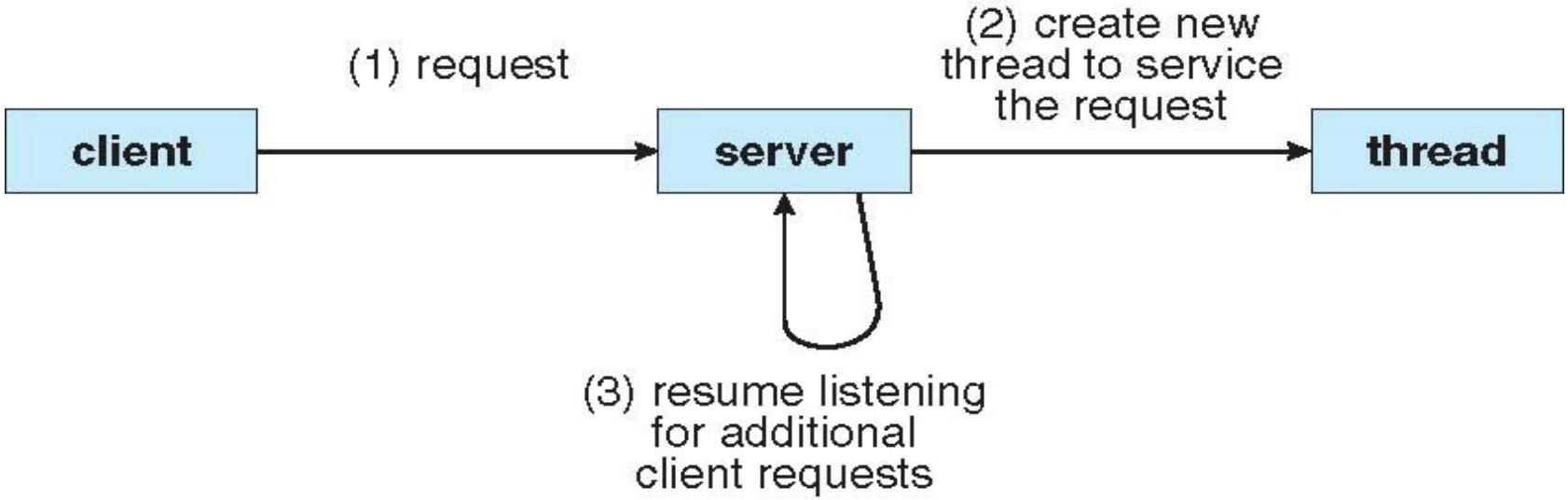
single-threaded process

multithreaded process

Motivation

- 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

Multithreaded Server Architecture



a Thread

- A *thread (or lightweight process) is a basic unit*

of CPU utilization; it consists of:

  - Thread ID
  - program counter
  - register set, stack pointer
  - stack space for local variables and return addresses
  - Signal mask
  - Priority
  - Return value : errno

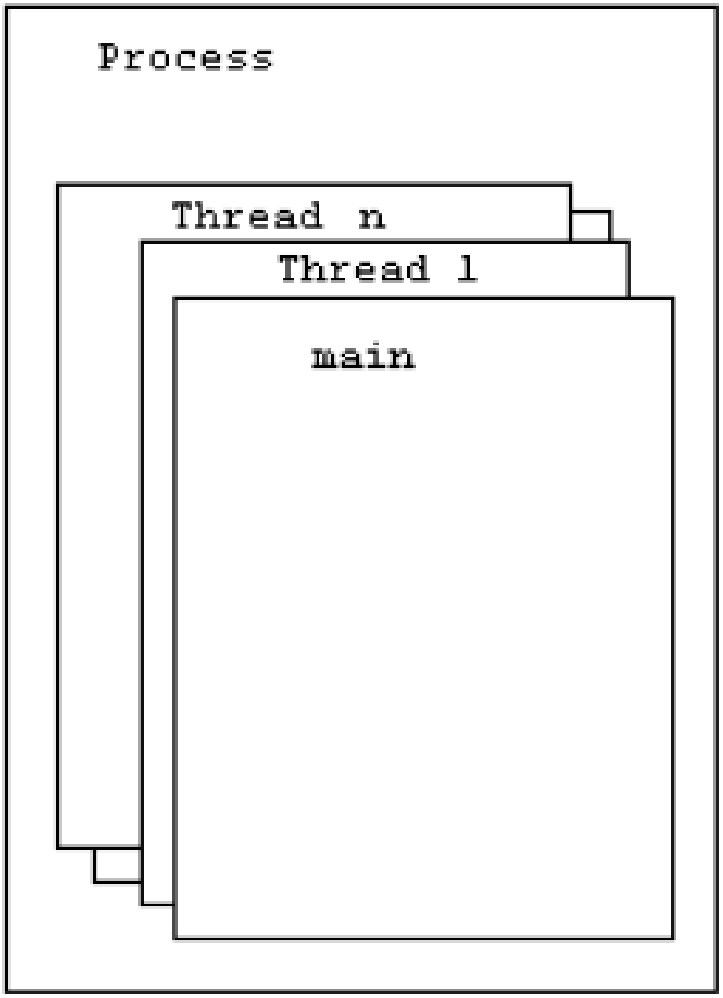
- A thread shares with its peer threads its:
  - Code section
  - Global data section
  - Operating-system resources
  - Process instructions
  - Open files (descriptors)
  - Signal and signal handlers
  - Current working directory
  - User and group id
- And is collectively know as a *task.*

- A traditional or *heavyweight process is equal* to a task with one thread

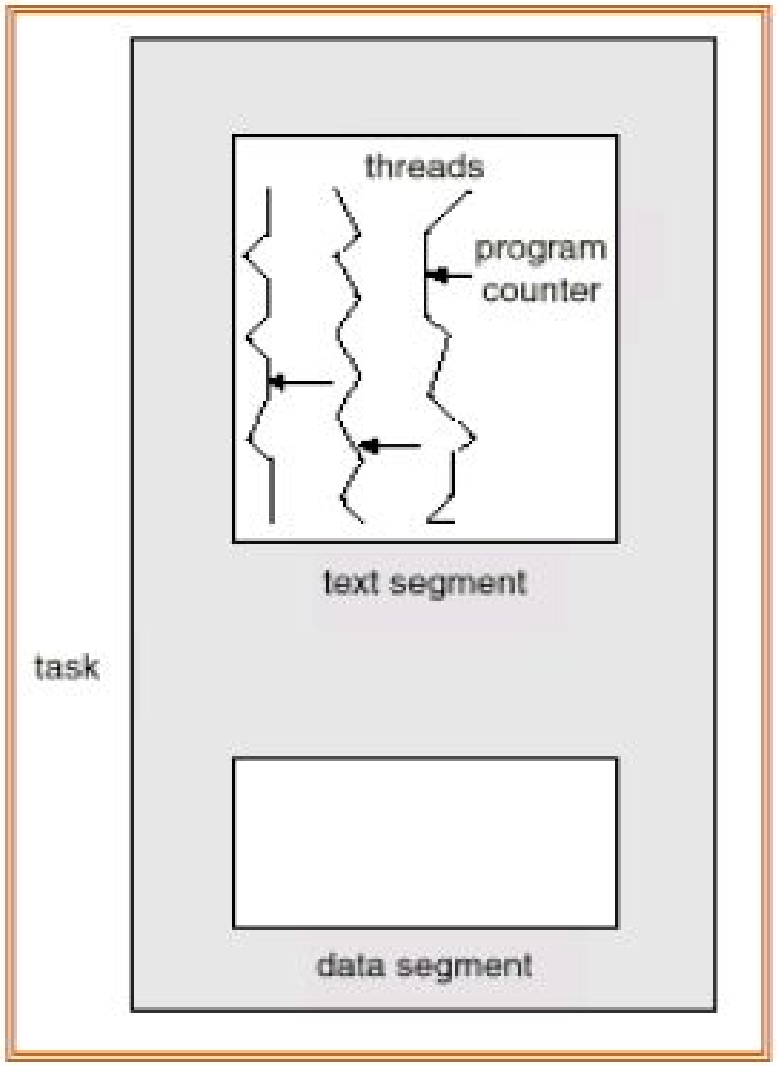
- Unlike process thread does not maintain a list of created threads.

- It does not know the thread created it also

a Process



Multiple threads within a task



Local to a thread

- Thread ID
- program counter
- register set, stack pointer
- stack space for local variables
- return addresses
- Signal mask
- Priority
- Return value : errno

Global to all threads

- Code section
- Global data section
- Operating-system resources
- Process instructions
- Open files (descriptors)
- Signal and signal handlers
- Current working directory
- User and group id

Benefits

- **Responsiveness**
  - Even if one thread is blocked other threads can continue execution
- **Resource Sharing**
  - Sharing memory & other resources of the process it belongs to
- **Economy**
  - It is more economical to create & context switch threads
- **Utilization of multiprocessor architectures**
  - Increases multi threading (threads can run parallel)

Benefits contd…

- Takes less time to create a new thread than a process
- Less time to terminate a thread than a process
- Less time to switch between two threads within the same process
- Since threads within the same process share memory and files, they can communicate with each other without invoking the kernel

pthread

- #include <pthread.h>
- Define a worker function

  void *func(void *args) { }
- Initialize pthread _attr_t

  pthread_attr_t attr;

  pthread _attr _init(attr);
- Create a thread

  pthread _t thread;

  pthread_create(&thread, &attr, worker function, arg);
- Exit current thread

  pthread_exit(status)

Compiling

- Use -pthread

pthread examples

Lecture 18

Multithreaded Programming

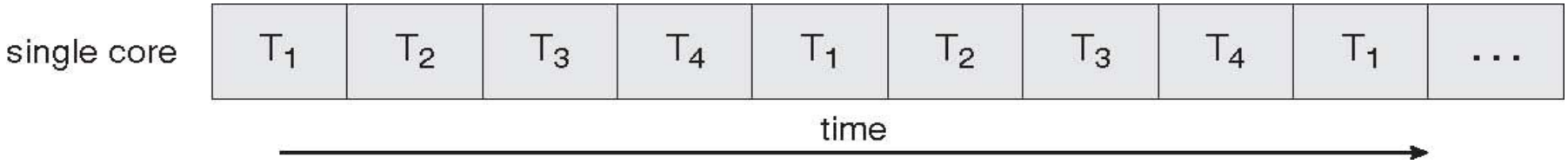
Thread Management

- **int pthread_detach(pthread_t *thread*);**
  - The **pthread_detach**() function marks the thread identified by *thread* as detached. When a detached thread terminates, its resources are automatically released back to the system without the need for another thread to join with the terminated thread.
  - The following statement detaches the calling thread:
    - pthread_detach(pthread_self());

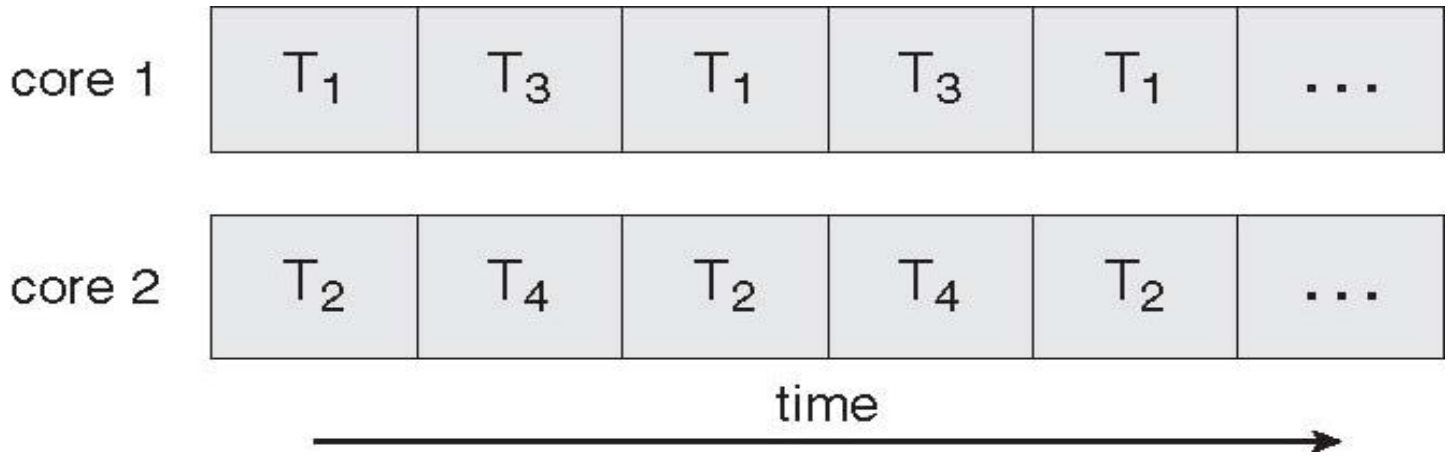
Thread Management

- **int pthread_join(pthread_t** *thread*, **void *****retval*);
  - The **pthread_join**() function waits for the thread specified by *thread* to terminate.
  - If that thread has already terminated, then **pthread_join**() returns immediately. The thread specified by *thread* must be joinable.
  - If *retval* is not NULL, then **pthread_join**() copies the exit status of the target thread (i.e., the value that the target thread supplied to pthread_exit(3)) into the location pointed to by **retval*.
  - If the target thread was canceled, then **PTHREAD_CANCELED** is placed in **retval*.
  - If multiple threads simultaneously try to join with the same thread, the results are undefined. If the thread calling **pthread_join**() is canceled, then the target thread will remain joinable (i.e., it will not be detached).

Concurrent Execution on a Single-core System



Parallel Execution on a Multicore System



Multicore Programming

- Multicore systems putting pressure on programmers, challenges include:
  - **Dividing activities**
  - **Balance**
  - **Data splitting**
  - **Data dependency**
  - **Testing and debugging**

Types of Parallelism

- Data Parallelism
- Task Parallelism

User Threads

- Thread management done by user-level threads library

- Three primary thread libraries:
  - POSIX **Pthreads**
  - Win32 threads
  - Java threads

Kernel Threads

- Supported by the Kernel

- Examples
  - Windows XP/2000
  - Solaris
  - Linux
  - Tru64 UNIX
  - Mac OS X

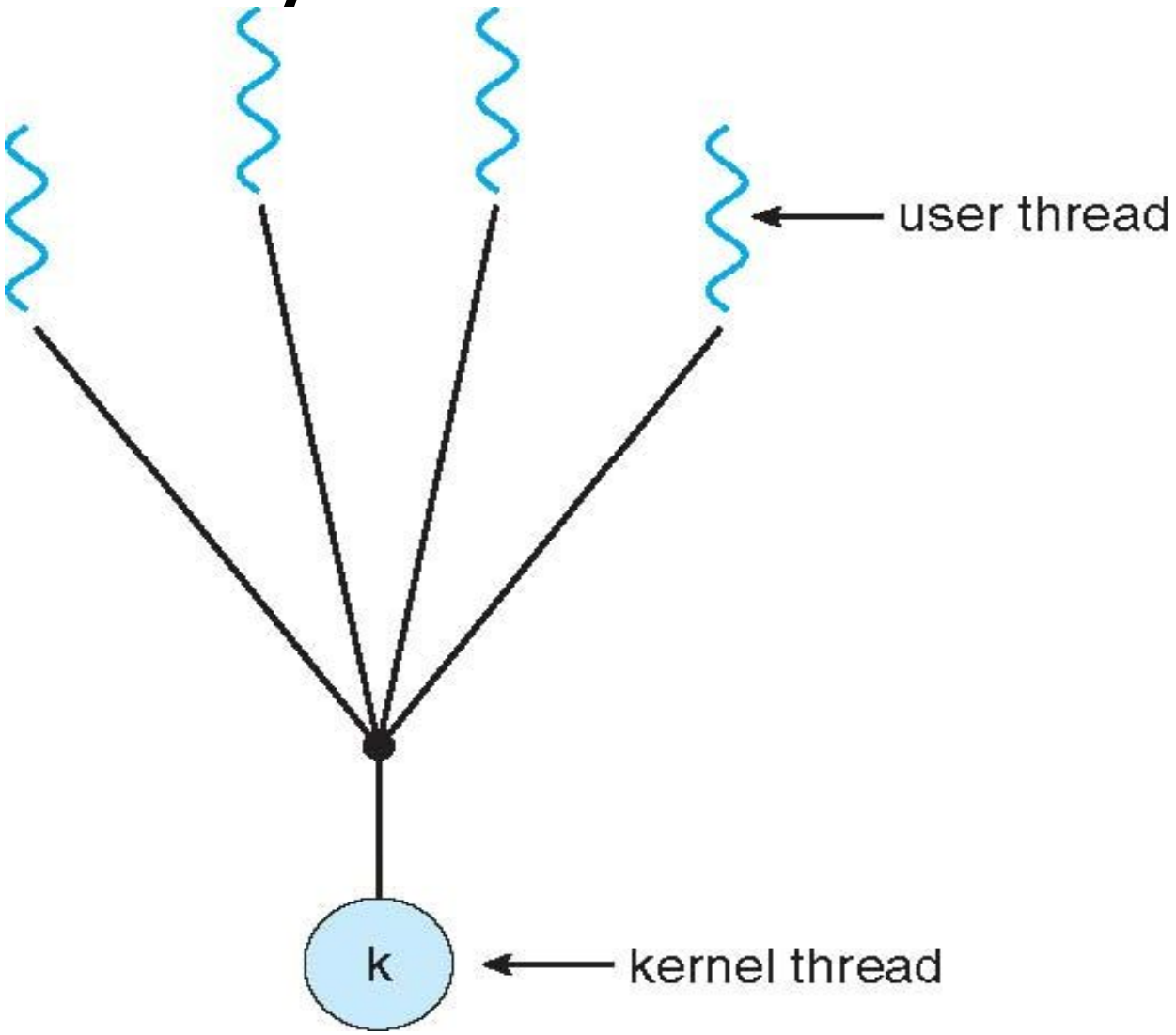
Multithreading Models

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

Many-to-One

- Many user-level threads mapped to single kernel thread
- Shortcomings
  - If a thread makes a blocking system call entire process is blocked
  - Multiple threads are unable to read in parallel on MP
- Examples:
  - **Solaris Green Threads**
  - **GNU Portable Threads**

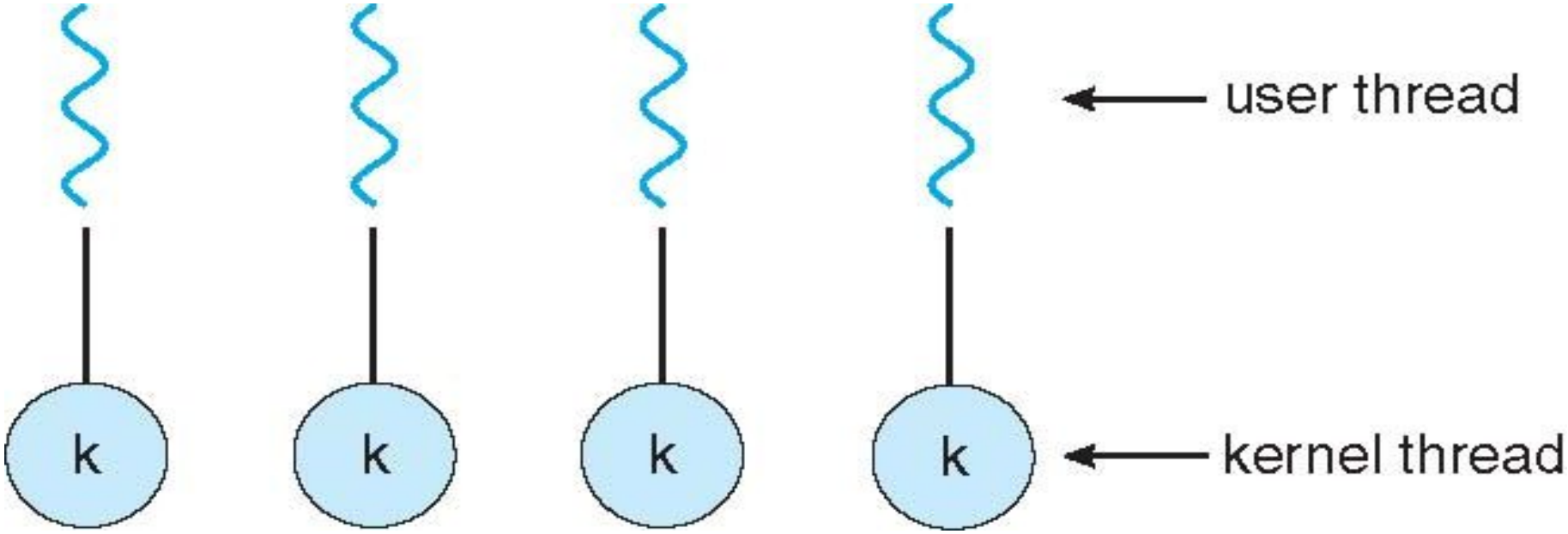
Many-to-One Model



One-to-One

- Each user-level thread maps to kernel thread
- Allow multiple threads to run in parallel on MP, also when a thread makes a blocking system call
- Only drawback is creating a user thread requires creating the corresponding kernel thread
- Examples
  - Windows NT/XP/2000
  - Linux
  - Solaris 9 and later

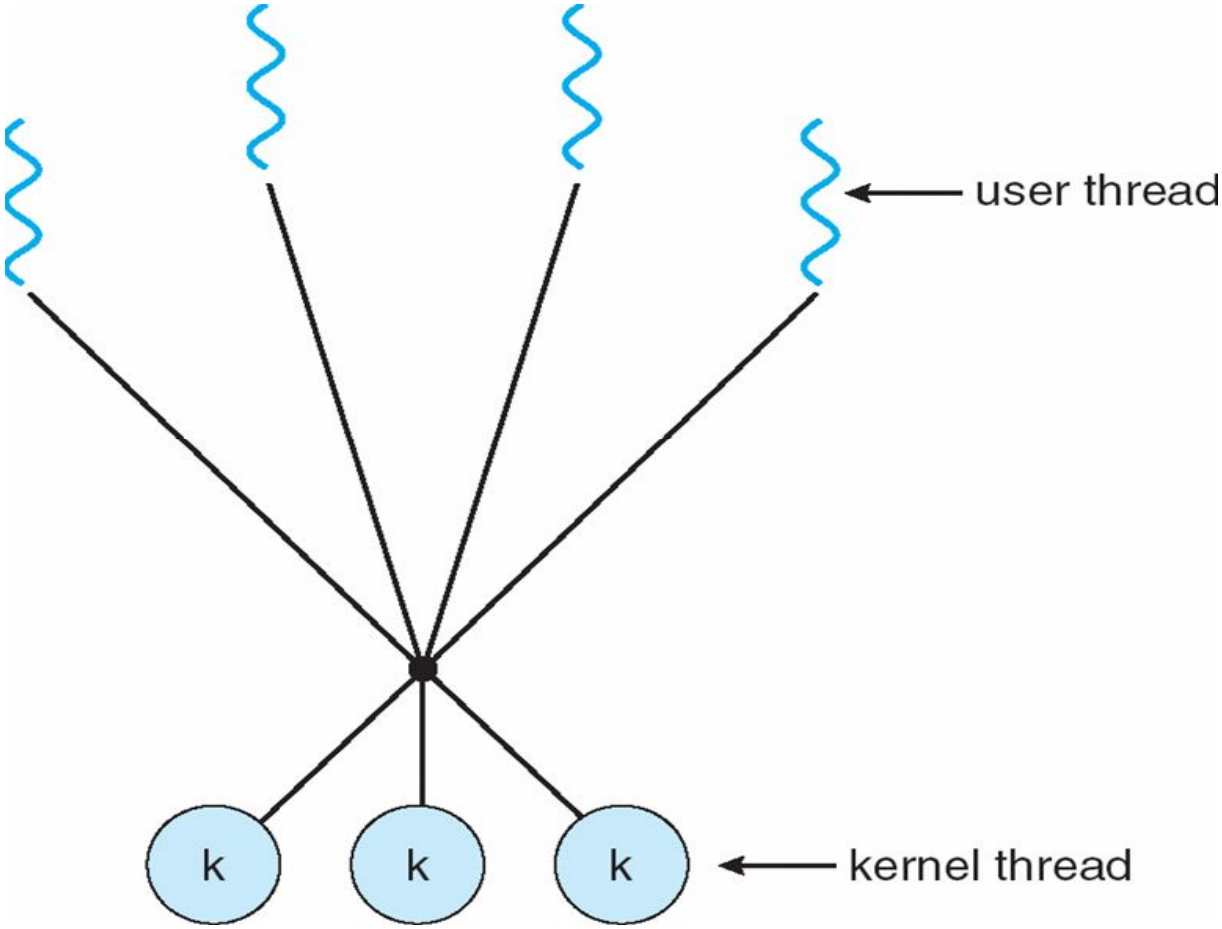
One-to-one Model



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
- Kernel threads can run in parallel on MP, also when a thread performs a blocking system call
- Examples
  - Solaris prior to version 9
  - Windows NT/2000 with the *ThreadFiber* package

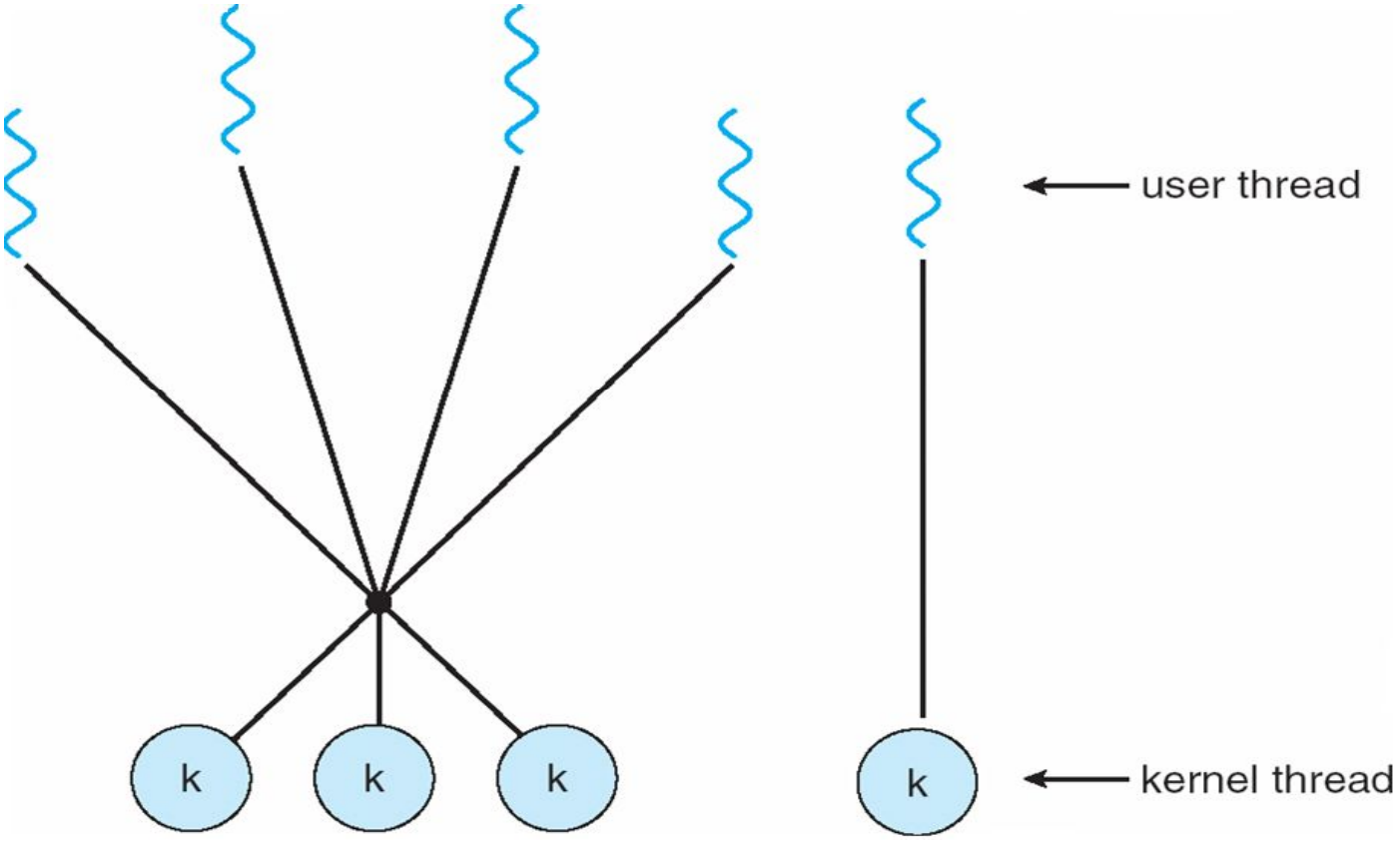
Many-to-Many Model



Two-level Model

- Variation on M:N model,
- Multiplexes many user level thread to a smaller or equal number of kernel threads
- Examples
  - IRIX
  - HP-UX
  - Tru64 UNIX
  - Solaris 8 and earlier

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 (like local function call)
  - Kernel-level library supported by the OS (system call)

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)

Threading Issues

- Semantics of **fork()** and **exec()** system calls

Q: If one thread forks, is the entire process copied, or is the new process single-threaded?

A: System dependant.

A: If the new process execs right away, there is no need to copy all the other threads. If it doesn't, then the entire process should be copied.

A: Many versions of UNIX provide multiple versions of the fork call for this purpose.

Thread Cancellation

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

Signal Handling

- Signals are used in UNIX systems to notify a process that a particular event has occurred.
- Signal may be received **Synchronously or Asynchronously**
- 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 (Default signal handler/user defined signal handler)

Signal Handling

Q: When a multi-threaded process receives a signal, to what thread should that signal be delivered?

A: There are four major options:

- 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

- Uses system call kill(pthread_t pid, int signal) and pthread_kill(pthread_t tid, int signal)

Lecture 19

Multithreaded Programming

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

Thread Specific Data

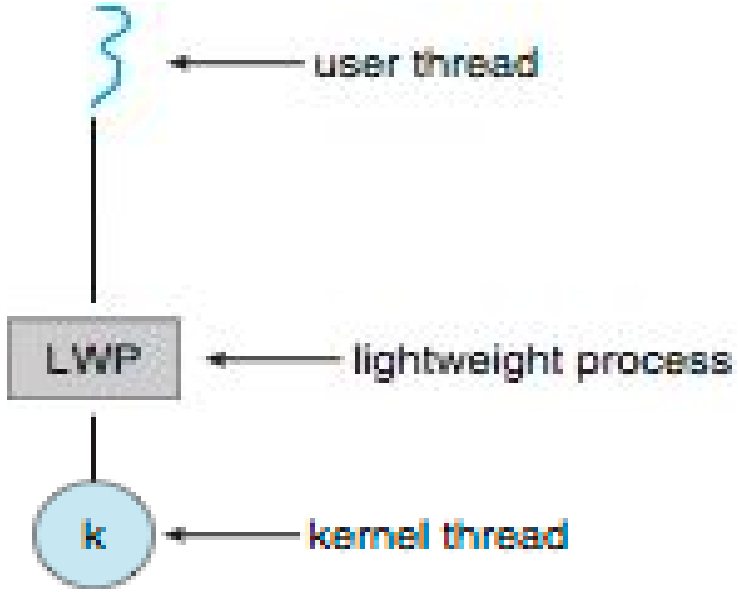
- Allows each thread to have its own copy of data

- Useful when you do not have control over the thread creation process (i.e., when using a thread pool)

Scheduler Activations

- Both M:M and Two-level models require communication to maintain the appropriate number of kernel threads allocated to the application
- Scheduler activations provide **upcalls** - a communication mechanism from the kernel to the thread library
- This communication allows an application to maintain the correct number of kernel threads

Lightweight Processes



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)
- `struct task_struct` points to process data structures (shared or unique)

Linux Threads

- `fork()` and `clone()` system calls
- Doesn't distinguish between process and thread
  - Uses term ***task*** rather than thread
- `clone()` takes options to determine sharing on process create
- `struct task_struct` points to process data structures (shared or unique)

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.

Thread Scheduling

- Distinction between user-level and kernel-level threads

- Many-to-one and many-to-many models, thread library schedules user-level threads to run on LWP
  - Known as **process-contention scope (PCS)** since scheduling competition is within the process

- Kernel thread scheduled onto available CPU is **system-contention scope (SCS)** – competition among all threads in system

Pthread Scheduling

- API allows specifying either PCS or SCS during thread creation
  - PTHREAD SCOPE PROCESS schedules threads using PCS scheduling
  - PTHREAD SCOPE SYSTEM schedules threads using SCS scheduling.

Pthread Scheduling API

```
#include <pthread.h>
#include <stdio.h>
#define NUM THREADS 5
int main(int argc, char *argv[])
{
     int i;
    pthread t tid[NUM THREADS];
    pthread attr t attr;
    /* get the default attributes */
    pthread attr init(&attr);
    /* set the scheduling algorithm to PROCESS or SYSTEM */
    pthread attr setscope(&attr, PTHREAD_SCOPE_SYSTEM);
    /* set the scheduling policy - FIFO, RT, or OTHER */
    pthread attr setschedpolicy(&attr, SCHED_OTHER);
    /* create the threads */
    for (i = 0; i < NUM THREADS; i++)
            pthread create(&tid[i],&attr,runner,NULL);
```

Pthread Scheduling API

```
    /* now join on each thread */
    for (i = 0; i < NUM THREADS; i++)
        pthread join(tid[i], NULL);
}
 /* Each thread will begin control in this function */
void *runner(void *param)
{
    printf("I am a thread\n");
    pthread exit(0);
}
```