Threads

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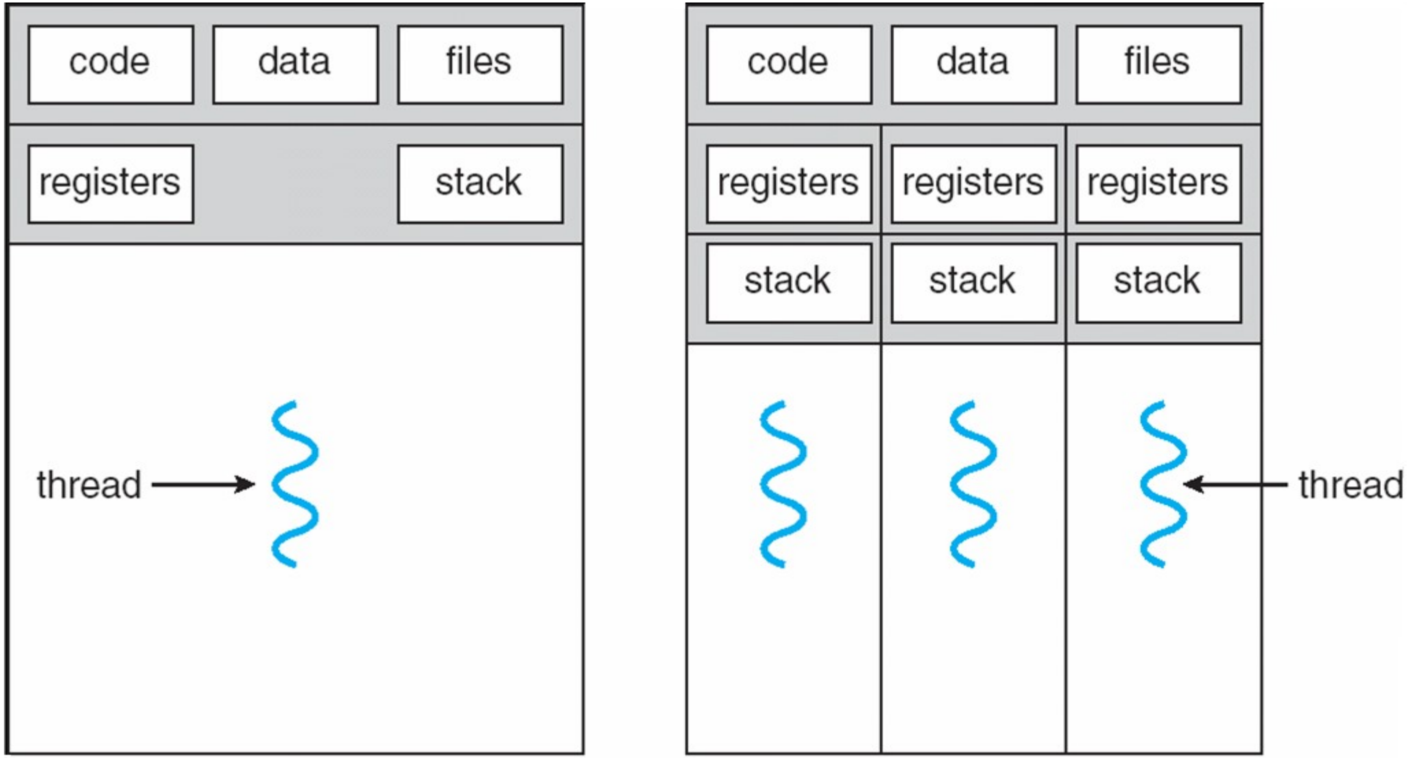
Threads

- thread — a fundamental unit of CPU utilization
  - A separate control flow within a program
  - set of instructions that execute “concurrently” with other parts of the code
  - Note the difference: Concurrency: progress at the same time, Parallel: execution at the same time
- Threads run within application
  - An application can be divided into multiple parts
  - Each part may be written to execute as a threads
- Let’s see an example

Threads

- 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, due to the very nature of threads
- Can simplify code, increase efficiency
- Kernels are generally multithreaded

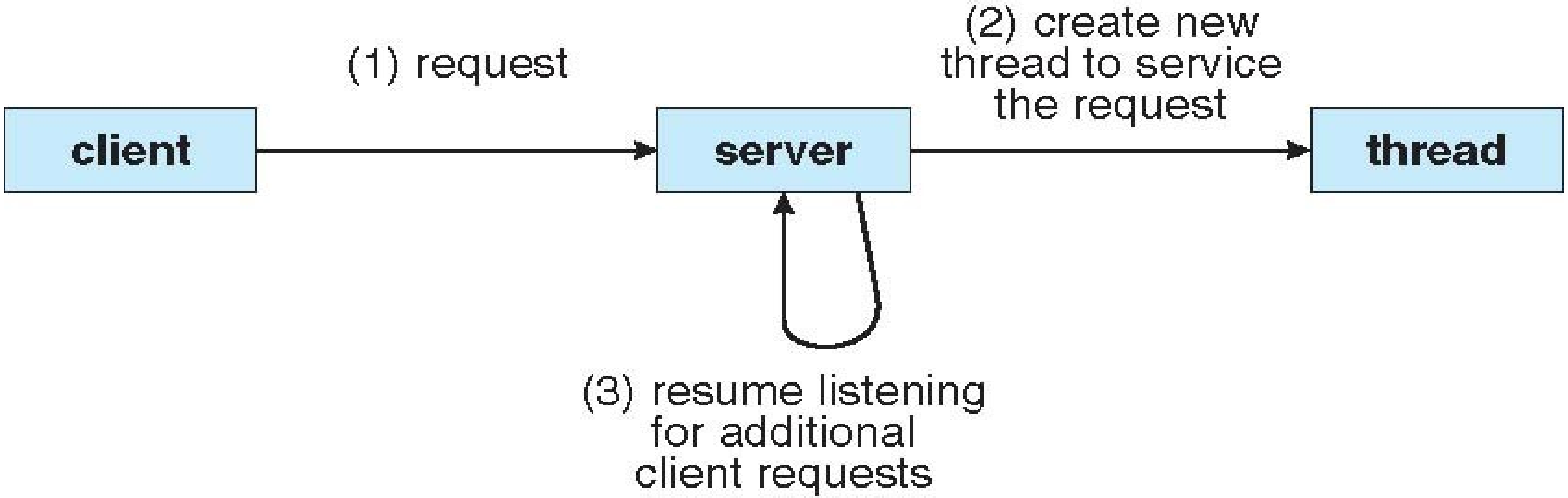
Single vs Mulththreaded process



single-threaded process

multithreaded process

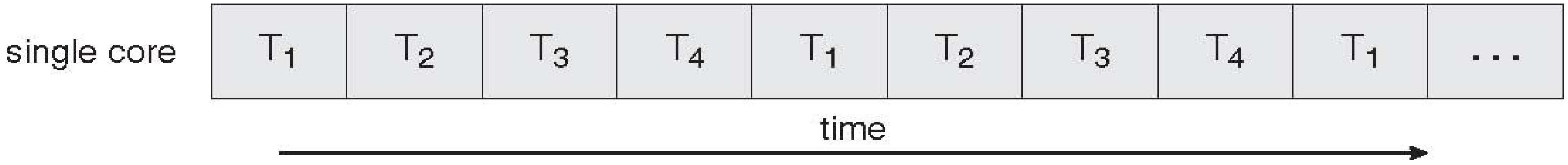
A mulththreaded server



Benefits of threads

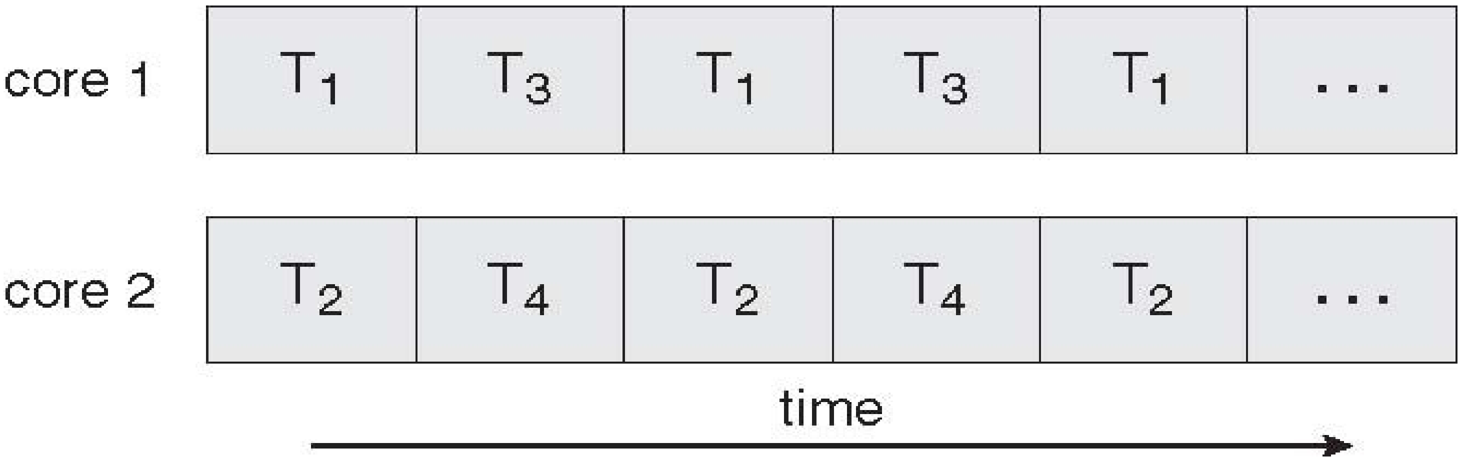
- Responsiveness
- Resource Sharing
- Economy
- Scalability

Single vs Multicore systems



Single core : Concurrency possible

Multicore : parallel execution possible



Multicore programming

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

User vs Kernel Threads

- 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

User threads vs Kernel Threads

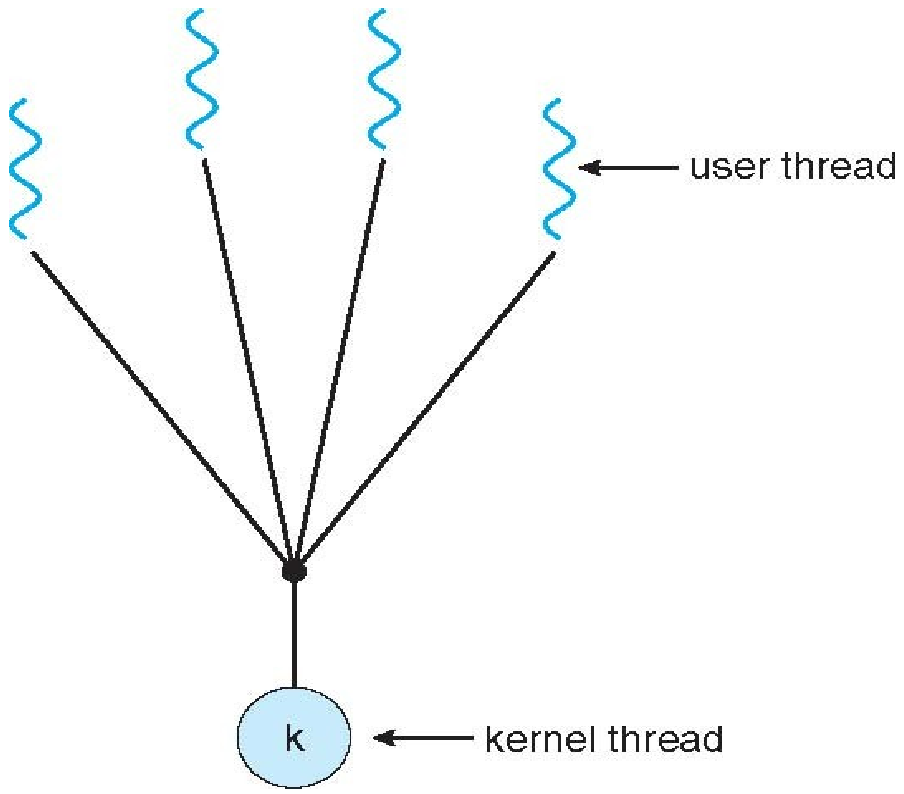
- User threads
  - User level library provides a “typedef” called threads
  - The scheduling of threads needs to be implemented in the user level library
  - Need some type of timer handling functionality at user level execution of CPU
    - OS needs to provide system calls for this
  - Kernel does not know that there are threads!

- Kernel Threads
  - Kernel implements concept of threads
  - Still, there may be a user level library, that maps kernel concept of threads to “user concept” since applications link with user level libraries
  - Kernel does scheduling!

Mulththreading models

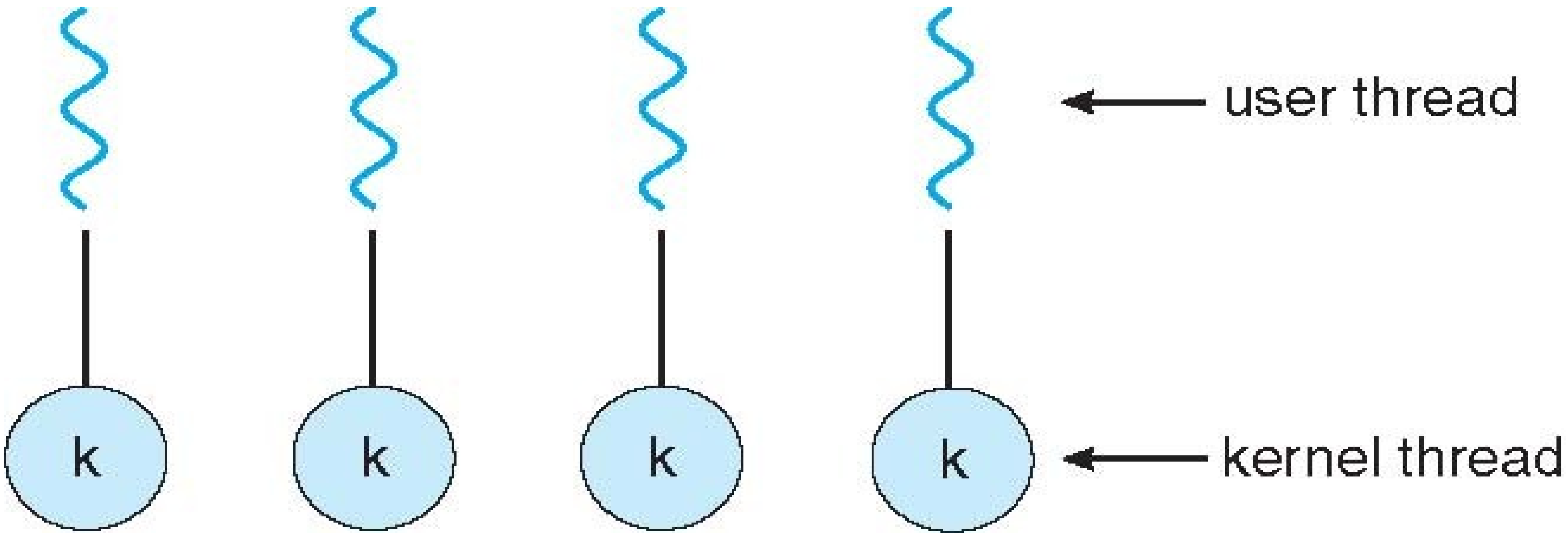
- How to map user threads to kernel threads?
  - Many-to-One
  - One-to-One
  - Many-to-Many
- What if there are no kernel threads?
  - Then only “one” process. Hence many-one mapping possible, to be done by user level thread library
  - Is One-One possible?

Many-One Model



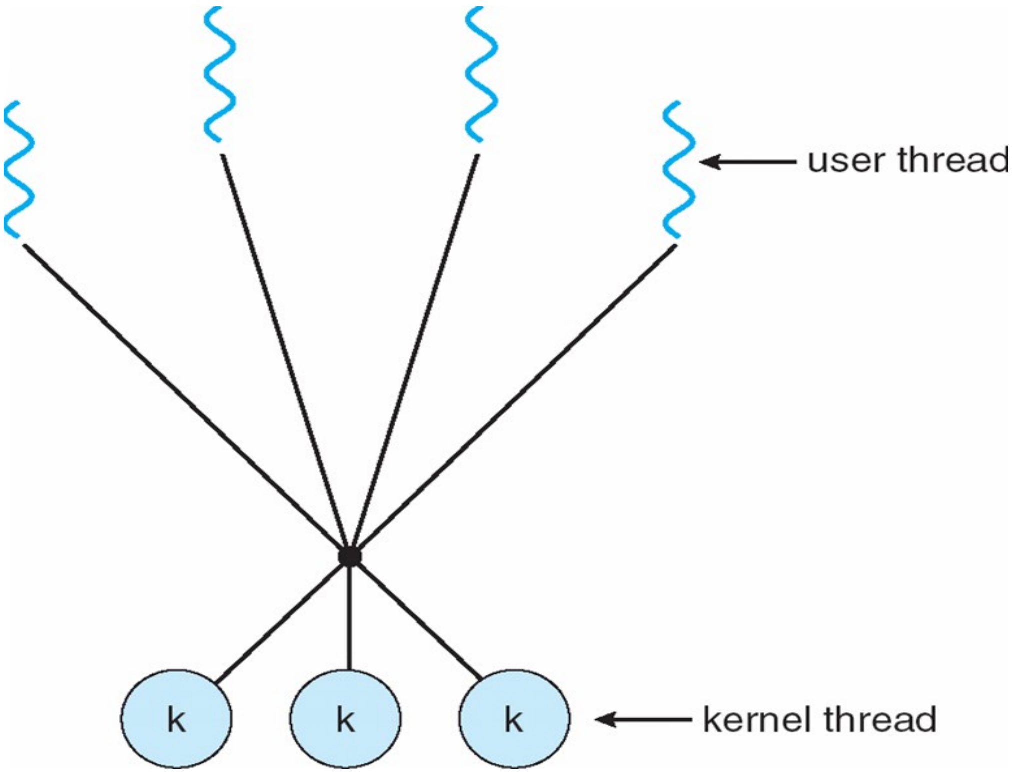
- **Many user-level threads mapped to single kernel thread**
- **Examples:**
  - **Solaris Green Threads**
  - **GNU Portable Threads**

One-One Model



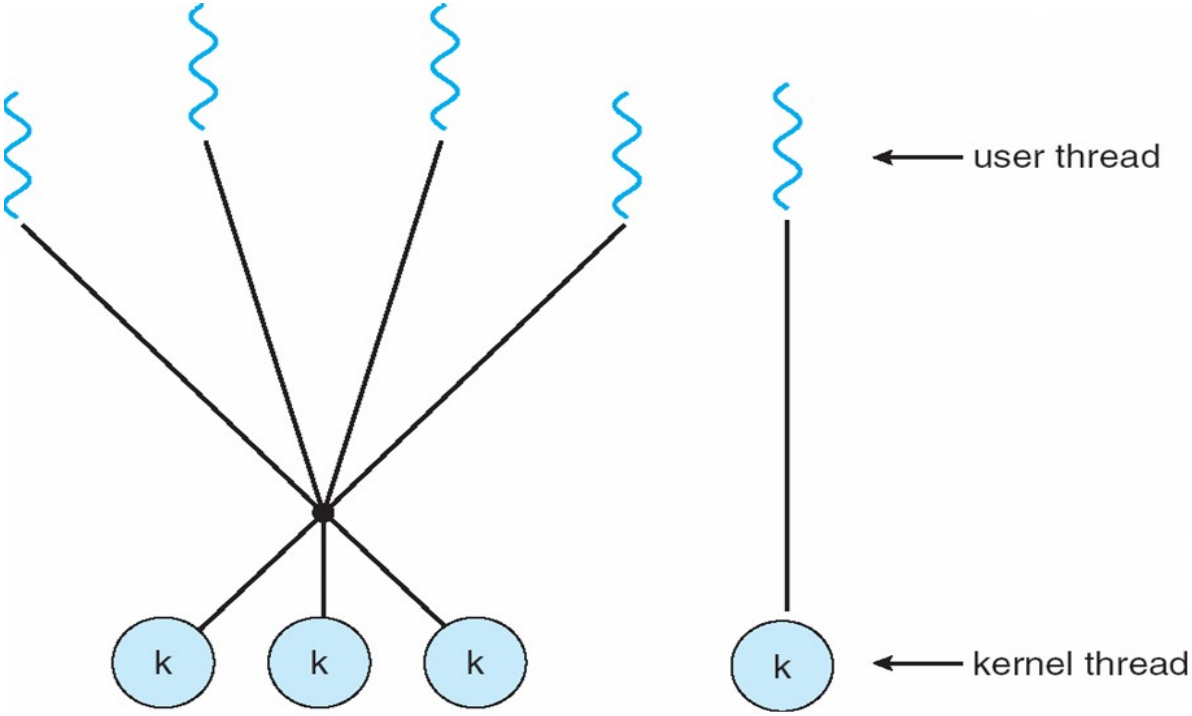
- **Each user-level thread maps to kernel thread**
- **Examples**
  - **Windows NT/XP/2000**
  - **Linux**
  - **Solaris 9 and later**

Many-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

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 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)
-

Demo of pthreads code

Demonstration on Linux – see the code, compile and execute it.

Other libraries

- **Windows threading API**
  - **CreateThread(...)**
  - **WaitForSingleObject(...)**
  - **CloseHandle(...)**
- **Java Threads**
  - **The Threads class**
  - **The Runnable Interface**

Issues with threads

- Semantics of fork() and exec() system calls
  - Does fork() duplicate only the calling thread or all threads?
- Thread cancellation of target thread
  - 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.

More on threads

Thread pools

- Some kernels/libraries can provide system calls to : Create a number of threads in a pool where they await work, assign work/function to a waiting thread
- 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 Local Storage (TLS)

- Thread-specific data, Thread Local Storage (TLS)
  - Not local, but global kind of data for all functions of a thread, more like “static” data
  - Create Facility needed for data private to thread
  - 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)
  - gcc compiler provides the storage class keyword thread for declaring TLS data

```
static __thread int threadID;
```

```
int arr[16];
int f() {
    a(); b(); c();
}
int g() {
    x(); y();
}
int main() {
    th_create(...,f,...);
    th_create(...,g,...);
}
//arr is visible to all of them!
//need data for only f,a,b,c
//need data for only g,x,y
```

Thread Local Storage (TLS) in pthreads

- **Functions**
  - `pthread_key_create`
  - `pthread_key_delete`
  - `pthread_setspecific`
  - `pthread_getspecific`
- **See**
  - thrd_specific.c file

Scheduler activations for threads

- 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 kernel threads

Scheduler activations for threads

Library

--

```
upcall_handler() {
  Create one more LWP and schedule threads on this;
}
th_setup(int n) {
   max_LSW = n;
   curr_LWP = 0;
   register_upcall(upcall_handler);
}
th_create(...., fn,....) {
   if(curr_LWP < max_LWP)
      create LWP;
   schedule fn on one of the LWP;
}
```

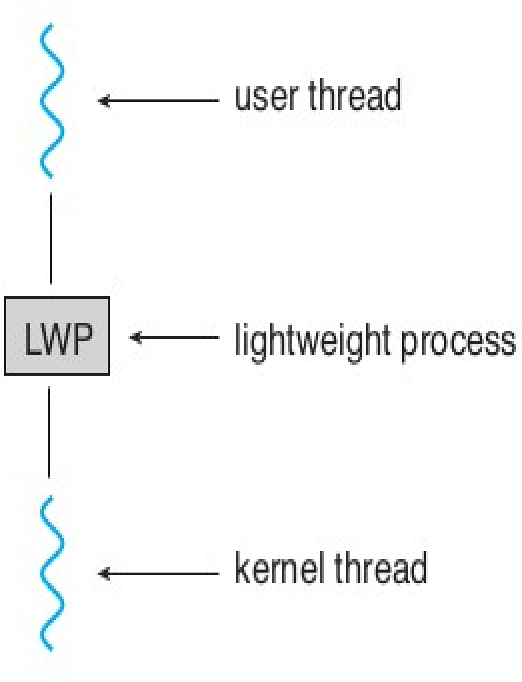
application

```
f() {
   scanf();
}
g() {
   recv();
}
h() {...}; i() {...}
main()
   th_setup(2);
   th_create(...,f,...);
   th_create(...,g,...);
   th_create(...,h,...);
   th_create(...,i,...);
}
```

Kernel

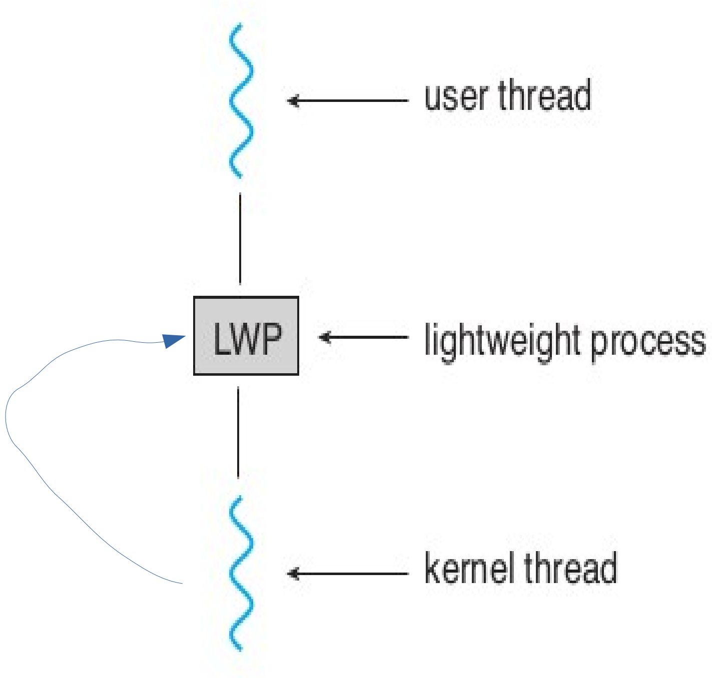
```
register_upcall(function f) {
    proc->upcall = f;
}
sys_write() {
// before calling sleep() going to block
myproc()->upcall();  // tricky!
}
```

Issues with threads



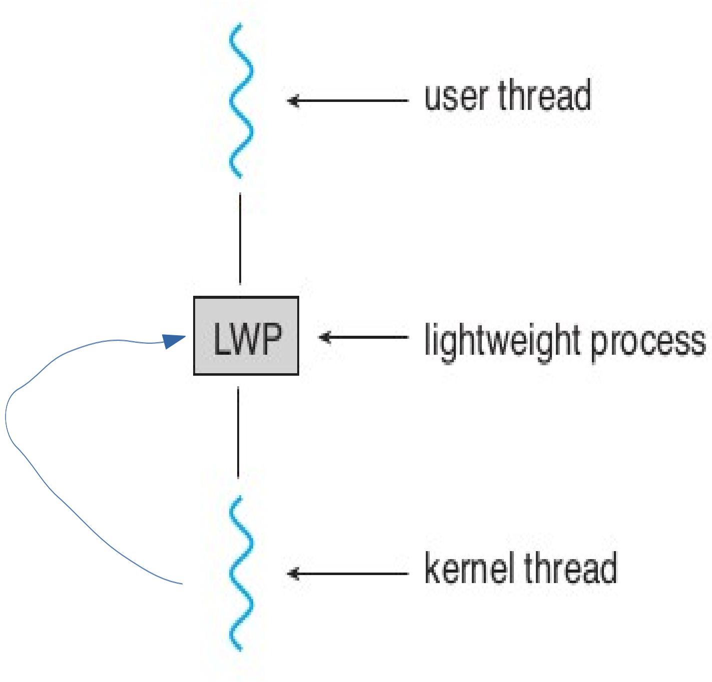
- Scheduler Activations: LWP approach
  - An intermediate data structure LWP
  - appears to be a virtual processor on which the application can schedule a user thread to run.
  - Each LWP attached to a kernel thread
  - Typically one LWP per blocking call, e.g. 5 file I/Os in one process, then 5 LWPs needed

Issues with threads



- **Scheduler Activations: LWP approach**
  - **Kernel needs to inform application about events like: a thread is about to block, or wait is over : this is ‘upcall’**
  - **This will help application relinquish the LWP or request a new LWP**

Issues with threads



- **Example NetBSD**
  - **“An Implementation of Scheduler Activations on the NetBSD Operating System”**
    - **https://web.mit.edu/nathanw/www/usenix/freenix-sa/freenix-sa.html**

Linux threads

- Only threads (called task), no processes!
- Process is a thread that shares many particular resources with the parent thread
- Clone() system call to create a thread

Linux threads

- clone() takes options to determine sharing on process create
- struct task_struct points to process data structures (shared or unique depending on clone options)
- fork() is a wrapper on top of clone()
  - Use 'strace' to see this.

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.

Issues in implementing threads project

- How to implement a user land library for threads?
- How to handle 1-1, many-one, many-many implementations?
- Identifying the support required from OS and hardware
- Identifying the libraries that will help in implementation

Issues in implementing threads project

- Understand the clone() system call completely
  - Try out various possible ways of calling it
  - Passing different options
  - Passing a user-land buffer as stack
- How to save and restore context?
  - C: setjmp, longjmp
  - Setcontext, getcontext(), makecontext(), swapcontext() functions
- Sigaction is more powerful than signal
  - Learn SIGALRM handling for timer and scheduler, timer_create() & timer_stop() system calls
- Customized data structure to store threads, and manage thread-lists for scheduling

Signals

Signals

- Signals are used in UNIX systems to notify a process that a particular event has occurred.
- Signal handling
  - Synchronous and asynchronous
- A signal handler (a function) is used to process signals
  - Signal is generated by particular event
  - Signal is delivered to a process
  - Then, signal is “handled” by the handler

Signals

- More about signals
  - Different signals are typically identified as different numbers
  - Operating systems provide system calls like kill() and signal() to enable processes to deliver and receive signals
  - Signal() - is used by a process to specify a “signal handler” – a code that should run on receiving a signal
  - Kill() is used by a process to send another process a signal
  - There are restrictions on which process can send which signal to other processes

Demo

- Let’s see a demo of signals with respect to processes
- Let’s see signal.h
  - /usr/include/signal.h
  - /usr/include/asm-generic/signal.h
  - /usr/include/linux/signal.h
  - /usr/include/sys/signal.h
  - /usr/include/x86_64-linux-gnu/asm/signal.h
  - /usr/include/x86_64-linux-gnu/sys/signal.h
- man 7 signal
- Important signals: SIGKILL, SIGUSR1, SIGSEGV, SIGALRM, SIGCLD, SIGINT, SIGPIPE, ...

Signal handling by OS

Process 12323 {

signal(19, abcd);

}

OS: sys_signal {

Note down that process 12323 wants to handle signal number 19 with function abcd

}

Process P1 {

kill (12323, 19) ;

}

OS: sys_kill {

Note down in PCB of process 12323 that signal number 19 is pending for you.

}

When process 12323 is scheduled, at that time the OS will check for pending signals, and invoke the appropriate signal handler for a pending signal.

Threads and Signals

- **Signal handling 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**