Multithreading

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CS31202 / CS30002

Topics for this lecture

- What is a thread?
- Why do you need threads?
- How are threads used in real-world?
- Multithreading models
- POSIX Pthread library

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- Multiple tasks within an application can be implemented by separate threads, e.g., in a word processor
  - Update display
  - Respond to keystrokes from user
  - Spell checking

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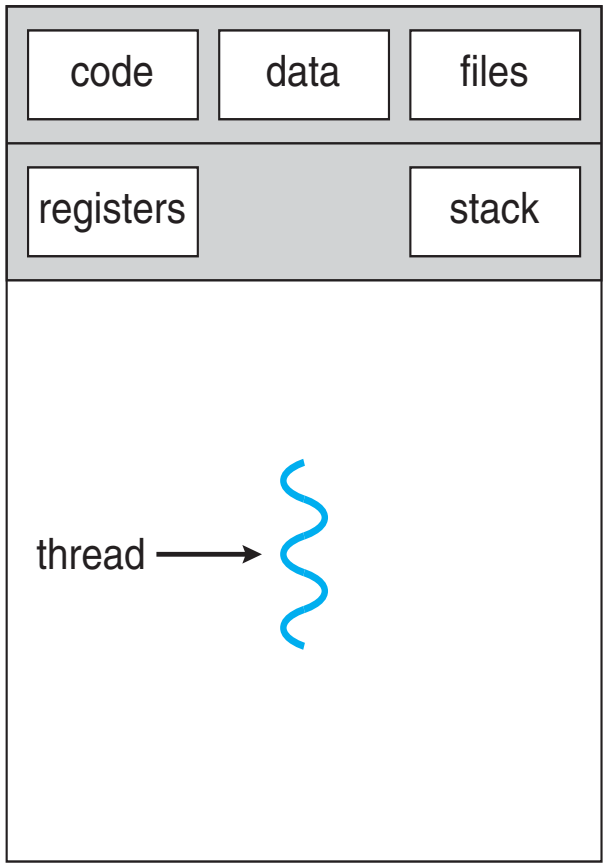
- Can be considered a basic unit of CPU utilization
  - Unique thread ID, Program counter (PC), register set & stack
  - Shares with other threads from same process the code section, data section and other OS resources like open files
  - Essentially all threads of the same process share the same virtual memory address space

Comparison: single and multi threaded processes



single-threaded process

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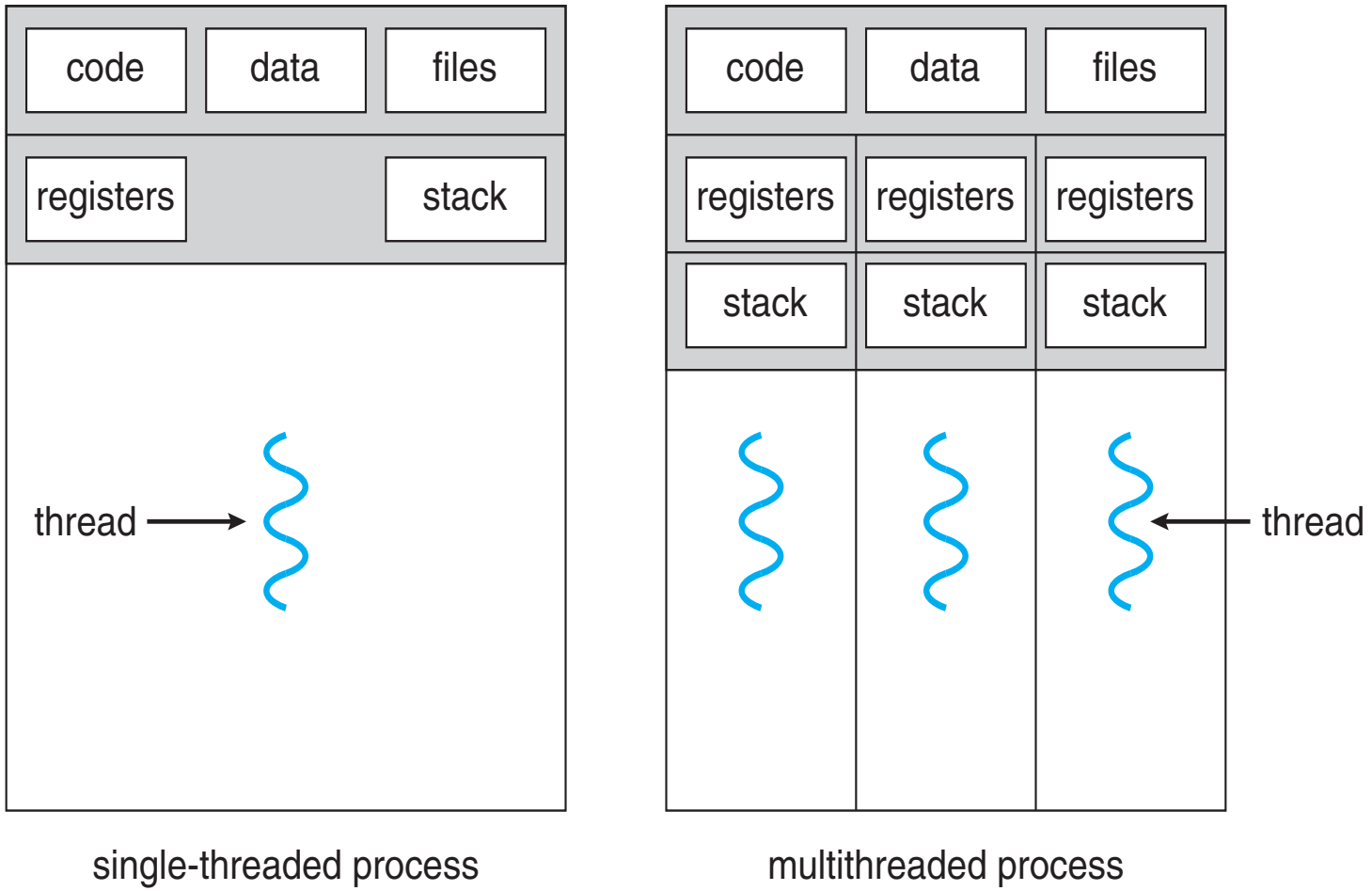

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Processes Have…

- A virtual address space which holds the process image

- Protected access to processors, other processes (inter-process communication), files, and other I/O resources

While Threads...

- Have execution state (running, ready, etc.)
- Save thread context (e.g. program counter) when not running
- Have private storage for local variables and execution stack
- Have shared access to the address space and resources (files etc.) of their process
  - when one thread alters (non-private) data, all other threads (of the process) can see this
  - threads communicate via shared variables
  - a file opened by one thread is available to others

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- Thread creation: Process creation is **heavy-weight** while thread creation is **light-weight** (10-30 times faster than process creation)
- Better scalability for multiprocessor / multicore architecture

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Application benefits of threads

- Consider an application that consists of several independent parts that do not need to run in sequence
- Each part can be implemented as a thread
- Whenever one thread is blocked waiting for I/O, execution could switch to another thread of the same application (instead of switching to another process)

Thread: The applications

- A typical application is implemented as a separate process with multiple threads of control
  - Ex 1: A web browser
  - Ex 2: A web server
  - Ex 3: An OS

Thread example 1: Web browser

- Think of a web browser (e.g., chrome)
  - Thread 1: retrieve data
  - Thread 2: display image or text (render)
  - Thread 3: waiting for user input (your password)
  - …

Thread example 2: Web server

- A single instance of web server (apache tomcat, nginx) may be required to perform several similar tasks
  - One thread accepts request over network (continues listening for new connection requests)
  - New threads service requests: one thread per request
  - The main process creates these threads

Thread example 3: OS

- Most OS kernels are multithreaded
  - Several threads operate in kernel
  - Each thread performing a specific task
  - E.g., managing memory, managing devices, handling interrupts etc.

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User-Level Threads (ULT) (ex. Java)

- Kernel not aware of the existence of threads
- Thread management handled by thread library in user space
- No mode switch (kernel not involved)

- However all part of same PCB (kernel only knows PCB)
  - I/O in one thread could block the entire process!

ULT : Pros and cons

Advantages

- Thread switching does not involve the kernel: no mode change: fast
- Scheduling can be application specific: choose the best algorithm for the situation.
- Can run on any OS. We only need a thread library

Disadvantages

- Most system calls are blocking for processes. So all threads within a process will be implicitly blocked

So lets take help of kernel …

Kernel-Level Threads (KLT)

Ex: Windows NT, Windows 2000, OS/2

- All thread management is done by kernel
- No thread library; instead an API to the kernel thread facility
- Kernel maintains context information for the process and the threads
- Switching between threads requires the kernel
- Kernel does Scheduling on a thread basis

KLT: Pros and cons

Advantages

- Blocking at thread level, not process level
  - If a thread blocks, the CPU can be assigned to another thread in the same process

Disadvantages

- Thread switching always involves the kernel. This means 2 mode switches per thread switch
- So it is slower compared to User Level Threads

- ULT = +fast - blocking
- KLT = -slow +non-blocking

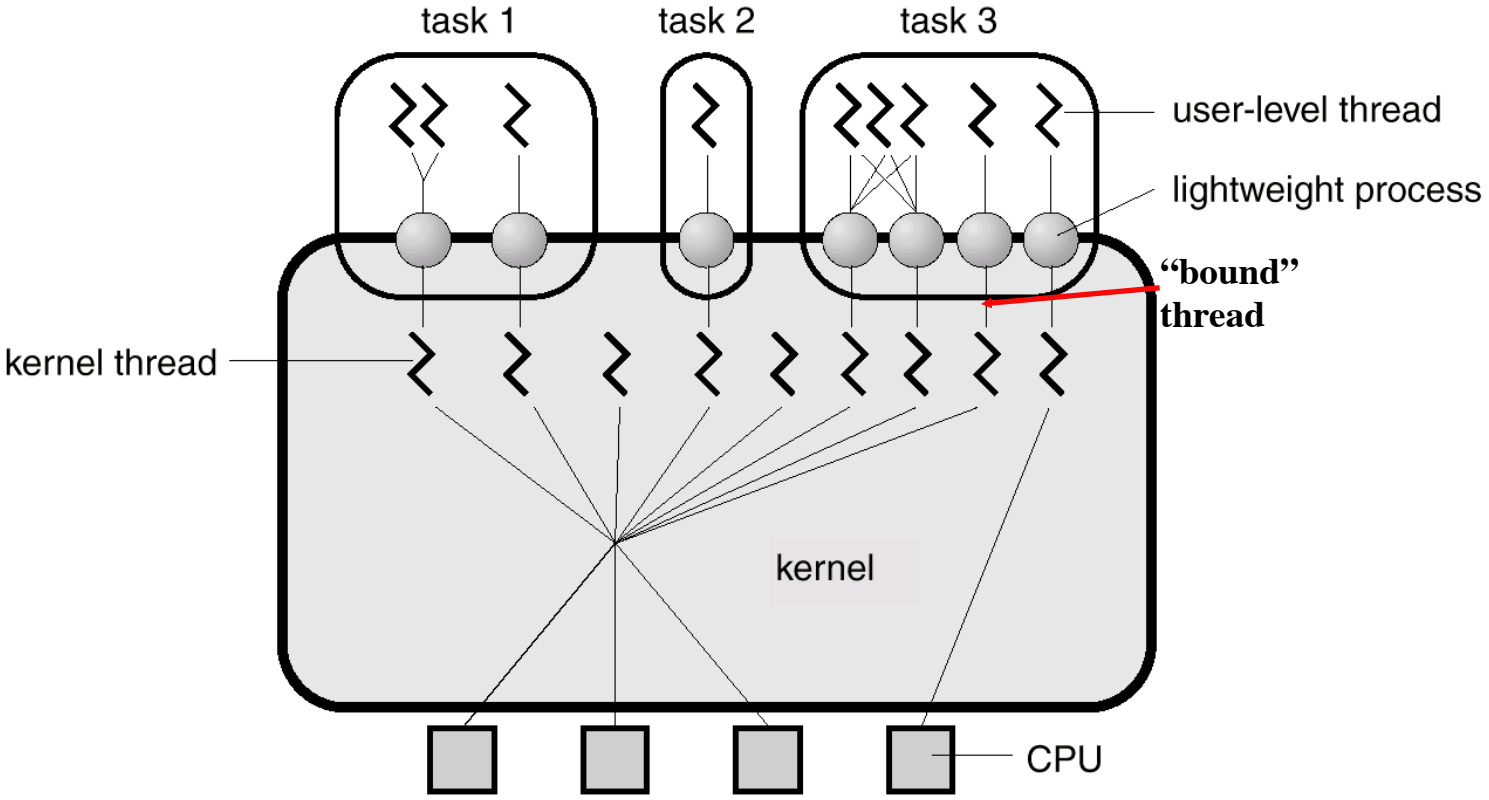
Solution: Combine ULT & KLT

- Thread creation done in the user space
- Bulk of thread scheduling and synchronization done in user space
- ULT's mapped onto KLT's
  - The programmer may adjust the number of KLTs
- KLT's may be assigned to processors
- Combines the best of both approaches
  - Cost?

Solaris strategy: ULT + KLT

- Process includes the user's address space, stack, and process control block
- User-level threads (threads library)
  - invisible to the OS
  - are the interface for application parallelism
- Kernel threads
  - the unit that can be dispatched on a processor
- Lightweight processes (LWP)
  - each LWP supports one or more ULTs and maps to exactly one KLT

Solaris Threads



- Task 2 is equivalent to a pure ULT approach (= Old Unix)
- Tasks 1 and 3 map one or more ULT's onto a fixed number of LWP's (&KLT's)
- Task 3 maps a single ULT to a single LWP bound to a CPU

Solaris: Light-Weight Processes

- A UNIX process consists mainly of an address space and a set of LWPs that share the address space
- Each LWP is like a virtual CPU and the kernel schedules the LWP by the KLT that it is attached to

Solaris: Kernel Level Threads

- Only objects scheduled within the system
- May be multiplexed on the CPU's or tied to a specific CPU
- Each LWP is tied to a kernel level thread

Solaris: User Level Threads

- Share the execution environment of the task
  - Same address space, instructions, data, file (any thread opens file, all threads can read).
- Can be tied to a LWP or multiplexed over multiple LWPs
- Represented by data structures in address space of the task – but kernel knows about them indirectly via LWPs

Combination of ULT and KLT

- Run-time library (RTL) ties together
- Multiple threads handled by RTL
- If 1 thread makes system call, LWP makes call, LWP will block, all threads tied to LWP will block
- Any other thread in same task will not block.

User threads and kernel threads

- User threads: managed by user-level threads library
  - A few well-established primary thread libraries
  - POSIX Pthreads, Windows threads, Java threads

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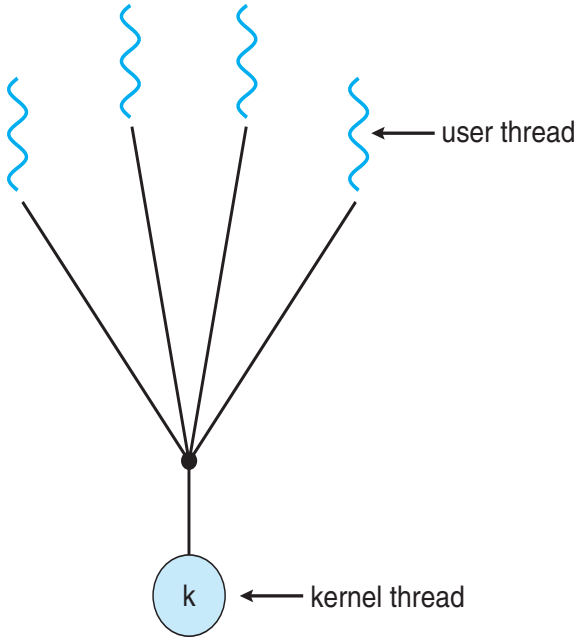
User threads will ultimately need kernel thread support

Multithreading Models

- There are multiple models to map user threads to kernel threads
  - Many-to-One
  - One-to-One
  - Many-to-Many

Many-to-One

- Many user-level threads mapped to single kernel thread
- User threads managed by thread library in user space
- Blocking call by one thread causes all threads in process to block
- Multiple threads may not run in parallel on multicore system because only one can access kernel at a time
- Old model: Only few systems currently use this model



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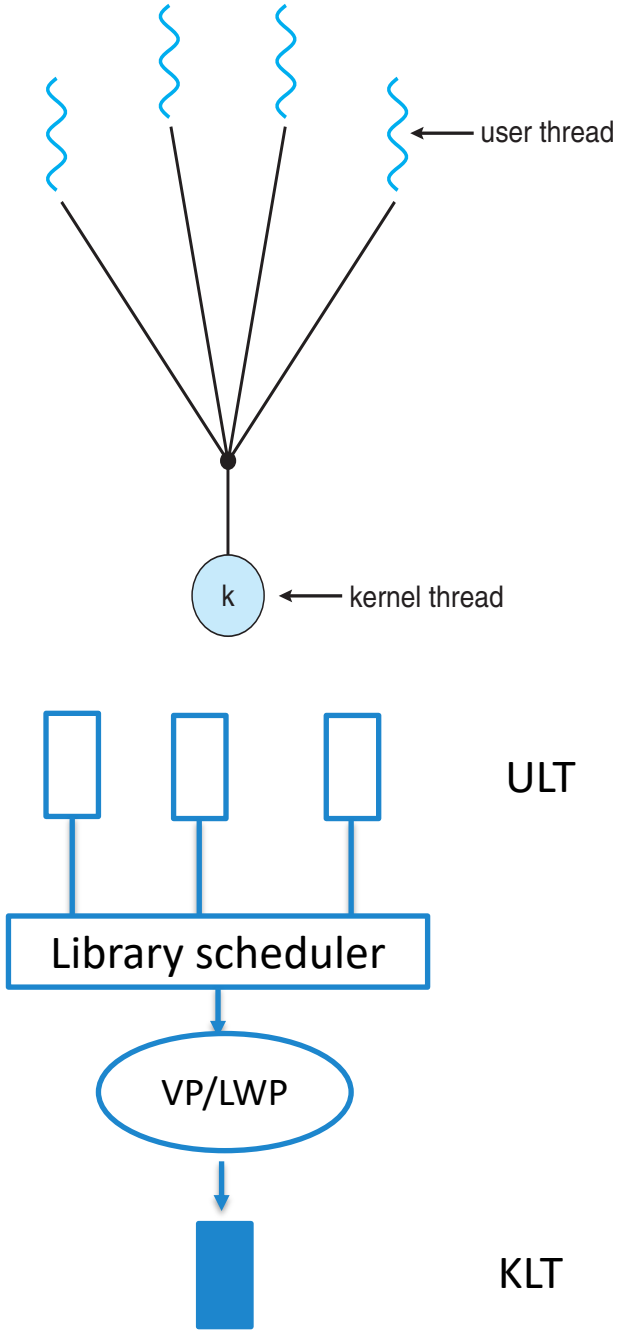
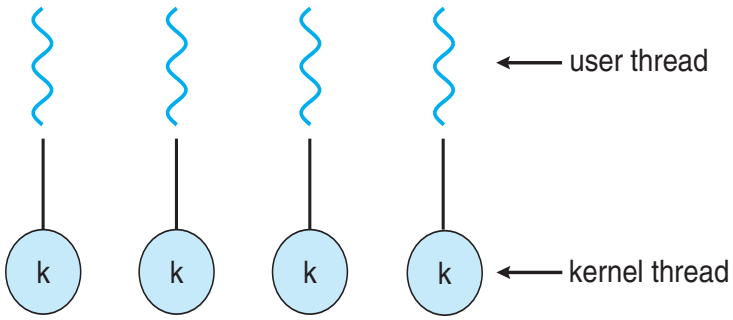


One-to-One

- Each user-level thread maps to one kernel thread
- A user-level thread creation -> a kernel thread creation
- More concurrency than many-to-one (even if one thread makes a blocking system call, others can run)
- #threads per process sometimes restricted due to overhead on kernel (of creating kernel threads)
- Windows, Linux



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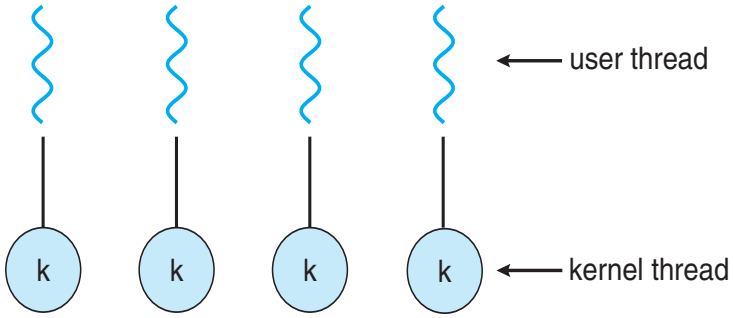
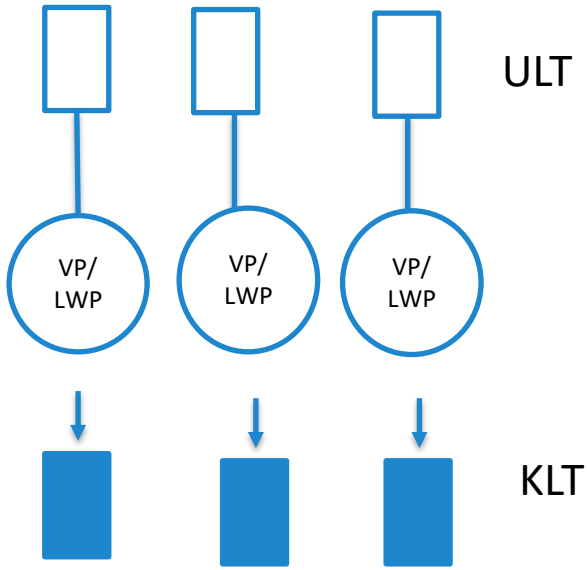
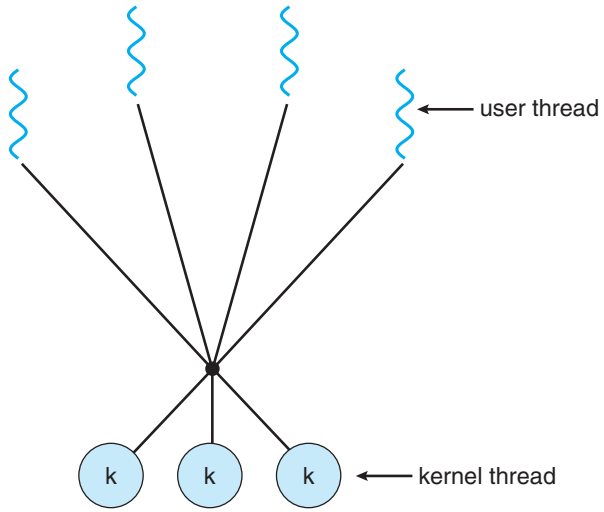




Many-to-Many Model

- Allows many user-level threads to be mapped to several (a smaller or equal number of) kernel threads
- Allows the OS to create a sufficient number of kernel threads
- If one thread performs a blocking system call, kernel can schedule another thread for execution
- Windows with the *ThreadFiber* package



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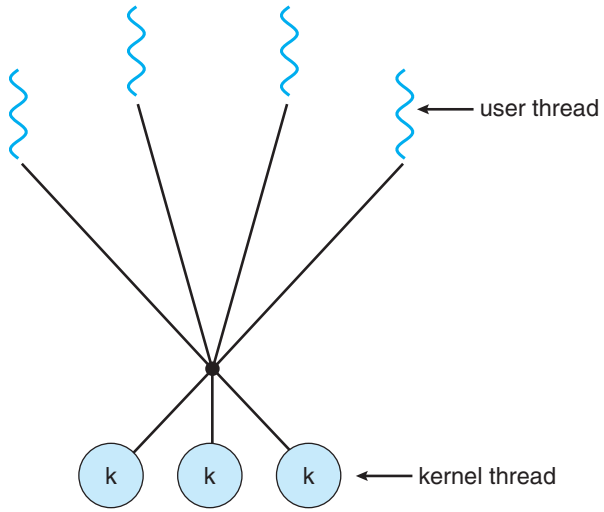

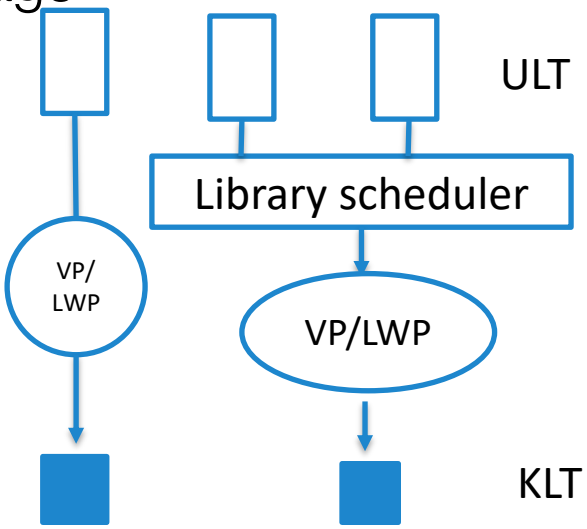

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Thread library

- Provides the programmer with an API for creating and managing threads
- Two ways of implementation
  - Provide the library in the user-space (all code and data structures of the library exist in user-space)
  - Provide a kernel-level library (code and data structures of the library exist in kernel-space; invoking a library function results in a system call)
- Some popular thread libraries: POSIX Pthreads, Windows, Java

Two strategies for using threads

- Asynchronous threading
  - Parent thread creates one or more child threads, and resumes execution
  - Parent and child threads execute concurrently (each thread runs independent of others)
  - Parent need not know when child threads terminate
  - Typically, very little data sharing between threads

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- Synchronous threading
  - Parent thread creates one or more child threads, and then waits for all child threads to terminate before it resumes
  - Also called fork-join strategy
  - Typically involves significant data sharing among threads (e.g., parent combines results computed by child threads)

POSIX Pthreads: basics

- Actually a standard / specification (IEEE 1003.1c) that defines an API for thread creation and synchronization
  - POSIX: Portable Operating System Interface
  - Family of standards for maintaining OS compatibility
  - Basically, tells OS what function calls need to be supported
  - Increases portability
- All major thread libraries in unix are POSIX compatible

POSIX Pthreads: basics

- Include `pthread.h` in the main source file
- Compile program with `-lpthread`
  - `gcc -o test test.c -lpthread`
  - Otherwise, may not report compilation errors but calls will fail
- Global data: Any variable/data declared globally are shared among all threads of the same process
- Local data: Data local to a function stored in stack. Since each thread has own stack, each thread has own copy
- Threads begin execution in a specified function

POSIX Pthreads: an example

- A separate thread is created that calculates the sum of N natural numbers (N is an input)
- The parent thread waits for the child thread to end

The code

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#include<stdio.h>
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int main(int argc, char *argv[]){
        pthread_t tid;  // identifier for the thread that we will create
        pthread_attr_t attr;  // will store attributes of the thread (e.g., stack size)
        pthread_attr_init (&attr); // get default attributes




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        pthread_exit(0); // terminate the thread
}
```

You can also create many threads

```
#include<stdio.h>
#include<pthread.h>
#define N_THR 10
Int sum; // data shared over threads

void *runner (void *param); // child process calls this

int main(int argc, char *argv[]){
        pthread_t mythreads[N_THR];
        …
        …
        for (int i=0; i< N_THR; i++)
                pthread_create(&mythreads[i], &attr, runner, argv[1]); // create the threads



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exit() Vs. pthread_exit()

- exit() kills all threads
  - Including the main() thread
  - pthread_exit() only kills the running thread but keep the task alive

Thread Attributes

- Type: `pthread_attr_t` (see previous example)
- Attributes define the state of the new thread
- State: system scope, joinable, stack size, inheritance
- Default behaviors with `NULL` in `pthread_create()`

```
int pthread_attr_init(&attr);
pthread_attr_{set/get}{attribute}
```

- Example:

```
pthread_attr_t attr;
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