Implementing threads

Module 4 self study material

Operating systems 2018

1DT044 and 1DT096

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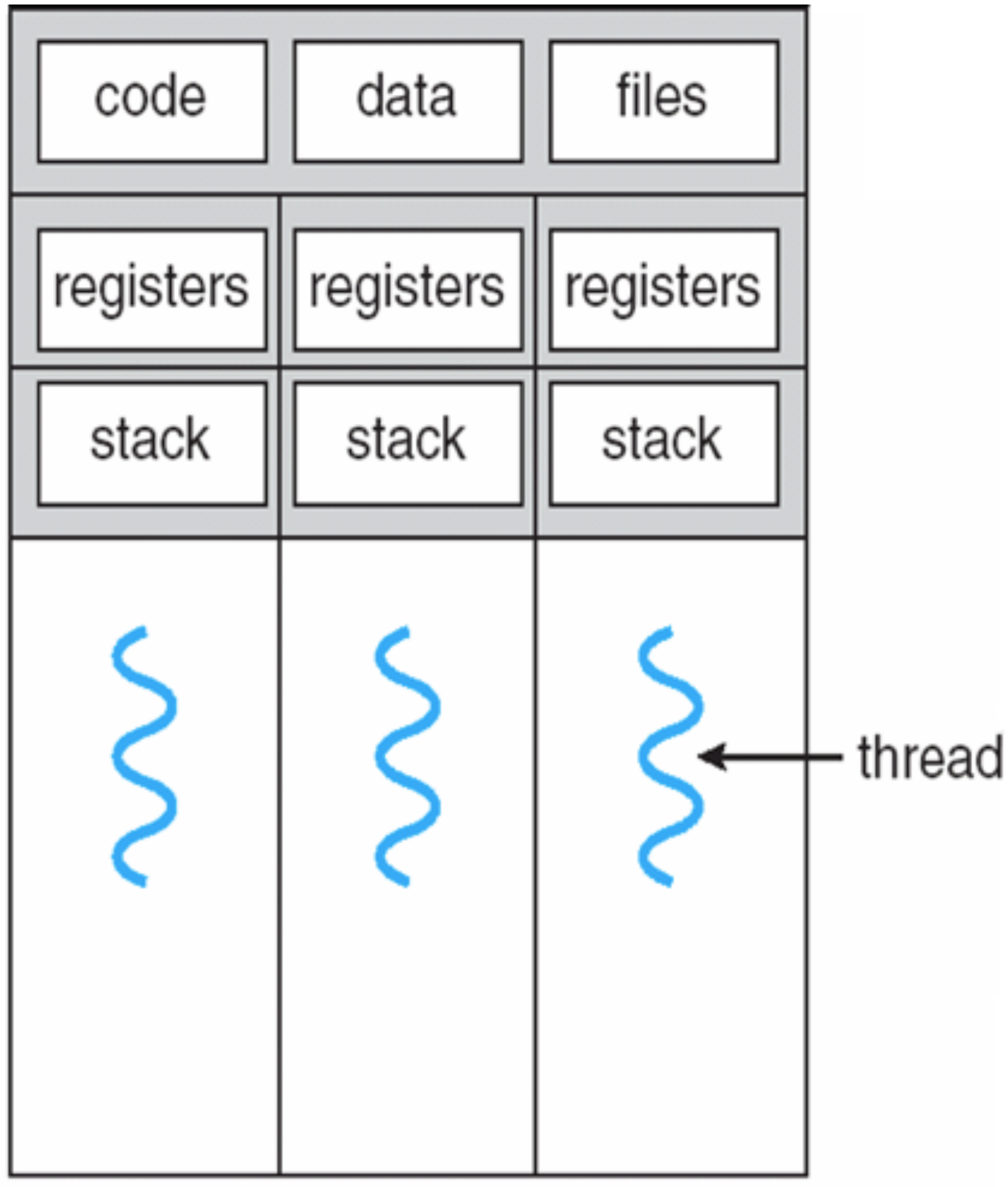
Implementing threads



multi-threaded process

What part of threading should be dealt with in **user space**?

What parts of threading should be dealt with in **kernel space**?

Threading models

Support for threads must be provided either at the **user** level **or** by the **kernel**.

4.2) Threading Models

Support for threads must be provided either at the user level or by the kernel.

User-level Threads

Supported above the kernel and are managed without kernel support.

User Mode

`mode bit = 1`

How are user level threads implemented?

How does user level threads relate to kernel threads?

Kernel Mode

`mode bit = 0`

Kernel-level Threads

Supported and managed directly by the operating system.

4.3) Thread Libraries

A thread library provides programmers with an API for creating and managing threads.

Two primary ways of implementing a thread library exists:

User-level Threads

All **code** and **data structures** for the library exist in user space.

Invoking a function in the API results in a **local function call** in user **space** and not a system call.

User Mode

`mode bit = 1`

Kernel Mode

`mode bit = 0`

Kernel-level Threads

All **code** and **data structures** for the library exists in **kernel space**.

Invoking a function in the API typically results in a **system call** to the kernel.

4.3) Thread Libraries

A Thread library provides programmers with an API for creating and managing threads.

Two primary ways of implementing a thread library exists:

User-level Threads

Library entirely in user space

Three primary thread libraries:

- ★ POSIX Pthreads
- ★ Win32 threads
- ★ Java threads

User Mode

`mode bit = 1`

Kernel Mode

`mode bit = 0`

Kernel-level Threads

Examples:

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

Kernel-level library supported by the OS

Kernel-level threads (issues)

Kernel-level threads (issues)

User space

- ★ The kernel knows about and manages all threads.
- ★ One process control block (PCP) per process.
- ★ One thread control block (TCB) per thread in the system.
- ★ Provide system calls to create and manage threads from user space.

Kernel space

Kernel-level threads advantages

User space

Advantages

- ★ The kernel has full knowledge of all threads.
- ★ Scheduler may decide to give more CPU time to a process having a large numer of threads.
- ★ Good for applications that frequently block.

Kernel space

Kernel-level threads disadvantages

User space

Disadvantages

- ★ Kernel manage and schedule all threads.
- ★ Significant overhead and increase in kernel complexity.
- ★ Kernel level threads are slow and inefficient compared to user level threads.
- ★ Thread operations are hundreds of times slower compared to user-level threads.

Kernel space

User-level threads (issues)

User space

Kernel space

User-level threads (issues)

User space

- ★ Threads managed entirely by the run-time system (user-level library).
- ★ Ideally, thread operations should be as fast as a function call.
- ★ The kernel knows nothing about user-level threads and manage them as if they where single-threaded processes.

Kernel space

User-level threads advantages

User space

Advantages

- ★ Can be implemented on an OS that does not suport kernel-level threads.
- ★ Does not require modifications of the OS.
- ★ **Simple representation:** (PC, registers, stack and small thread control block) all stored in the user-level process address space.
- ★ **Simple management:** Creating, switching and synchronizing threads done in user-space without kernel intervention.
- ★ **Fast and efficient:** switching threads not much more expensive than a function call.

Kernel space

Source: http://stackoverflow.com/a/18953760/3834375 2016-02-08

User-level threads disadvantages

User space

Disadvantages

★ Not a perfect solution (a trade off).

★ Lack of coordination between the user-level thread manager and the kernel.

★ OS may make poor decisions like:

- ✓ scheduling a process with idle threads
- ✓ blocking a process due to a blocking thread even though the process has other threads that can run
- ✓ giving a process as a whole one time slice irrespective of whether the process has 1 or 1000 threads
- ✓ unschedule a process with a thread holding a lock.

★ May require communication between the kernel and the user-level thread manager (scheduler activations) to overcome the above problems.

Kernel space

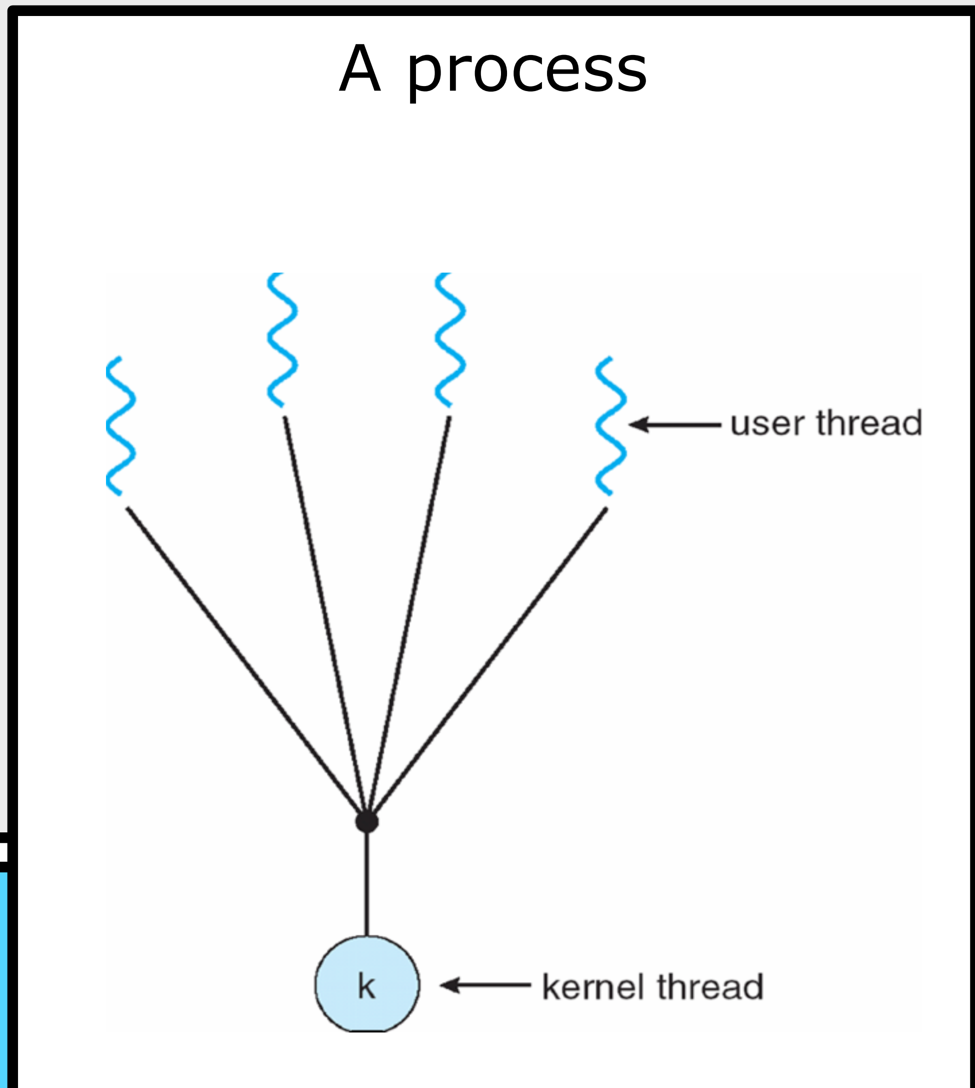
Implementing user-level threads

User space

Kernel space

Implementing many-to-one user-level threads

User space



If a process has 100,000 user-level threads but only one kernel thread, then the process can only run one user-level thread at a time because there is only one kernel-level thread associated with it.

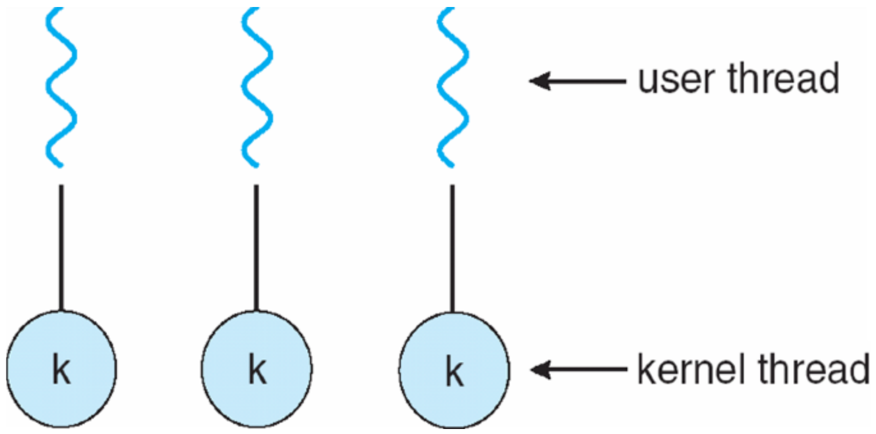
The kernel has no knowledge of user-level threads. From its perspective, a process is an opaque black box that occasionally makes system calls.

Kernel space

Implementing one-to-one user-level threads

User space

A process



If a process has multiple kernel-level threads, then it can potentially execute multiple instructions in parallel on a multicore machine.

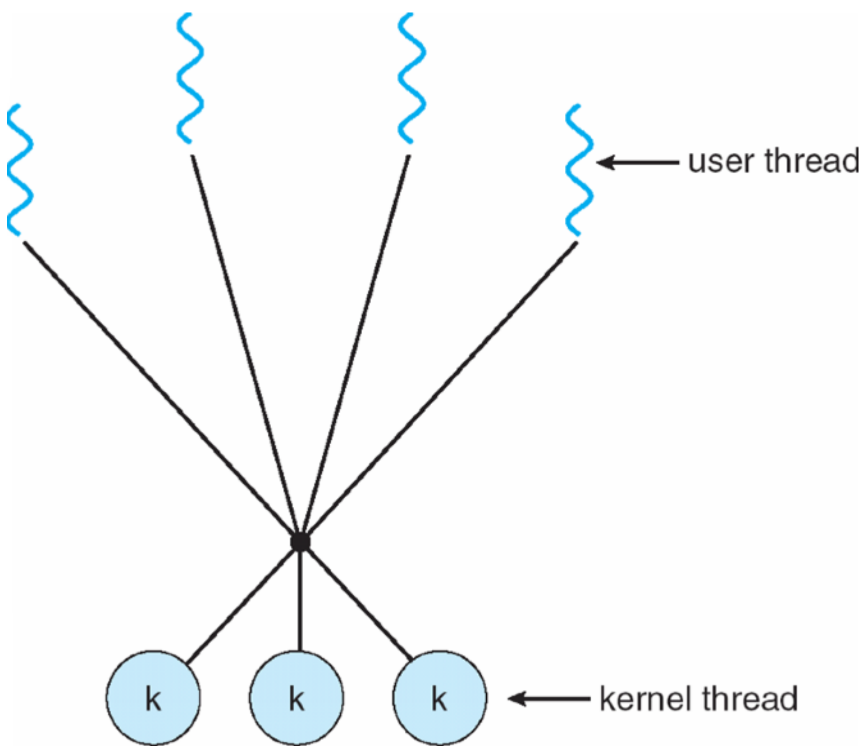
This models makes thread creation ”expensive” and most implementations restrict the number of threads supported by the system.

Kernel space

Implementing many-to-many user-level threads

User space

A process



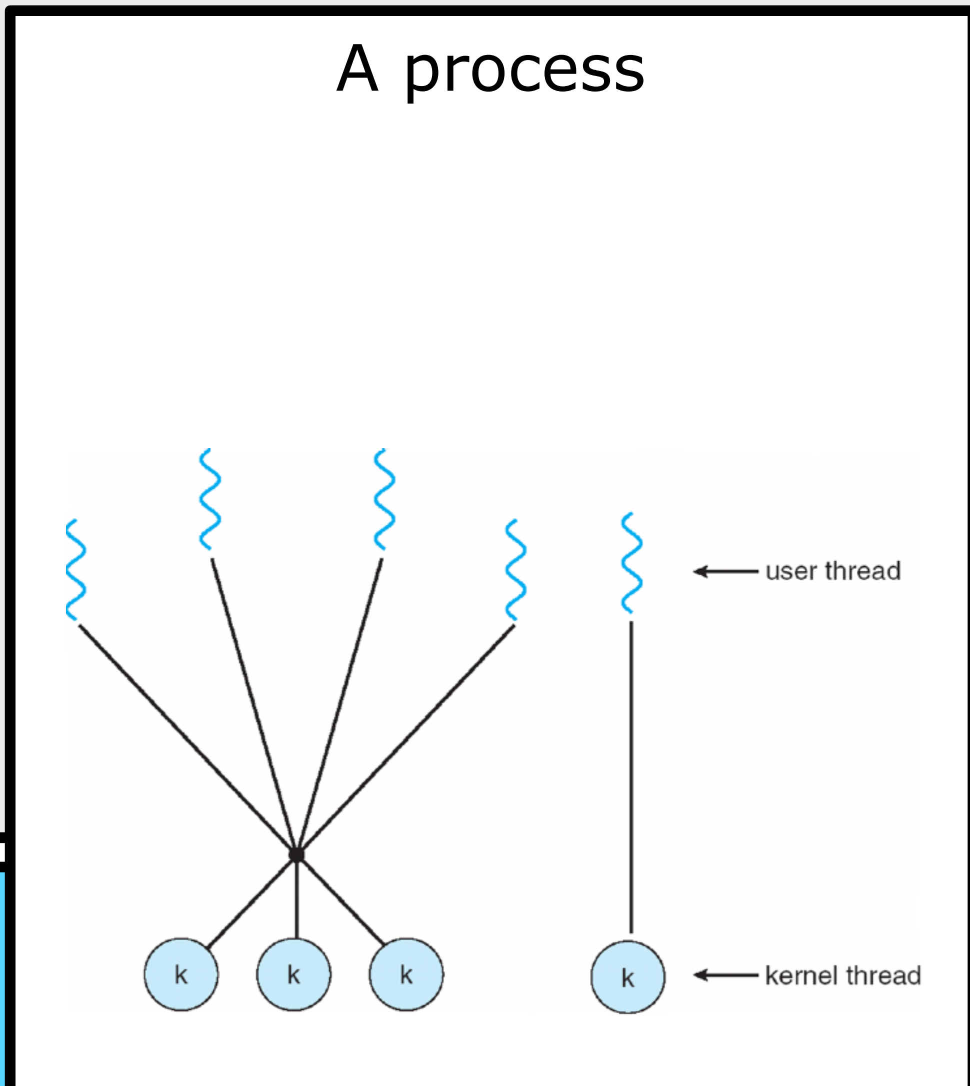
A process request some fixed number of kernel-level threads.

Multiple user level threads may execute in parallel, and the process can have fine-grained control over how threads execute.

Kernel space

Implementing two-level user-level threads

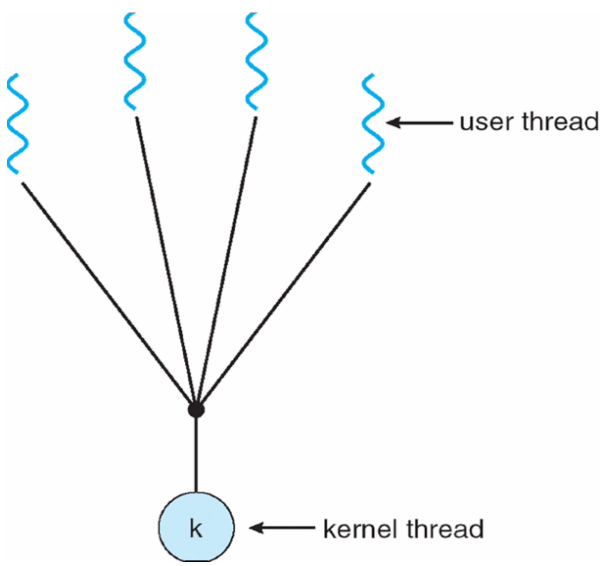
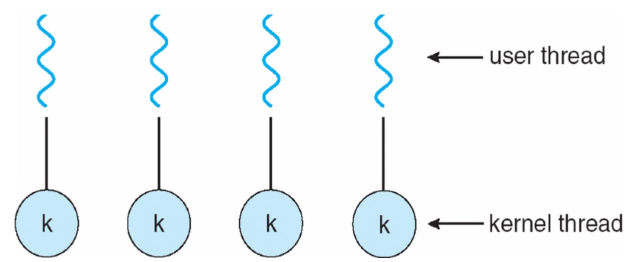
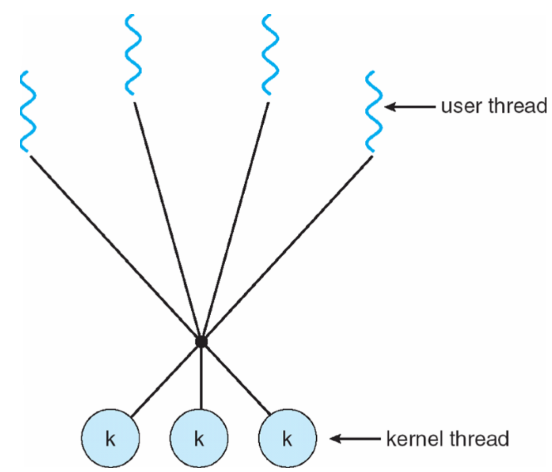
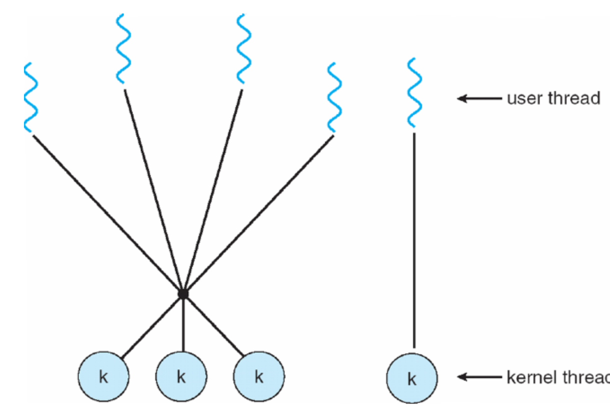
User space



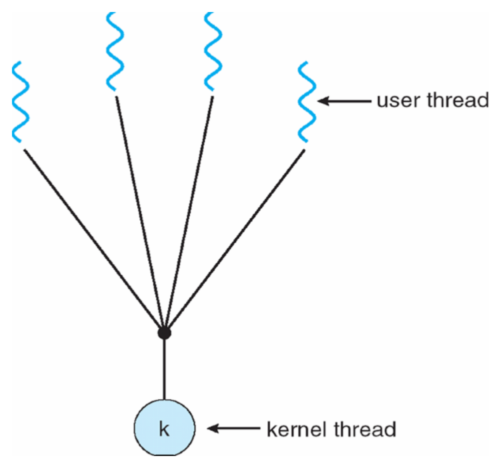
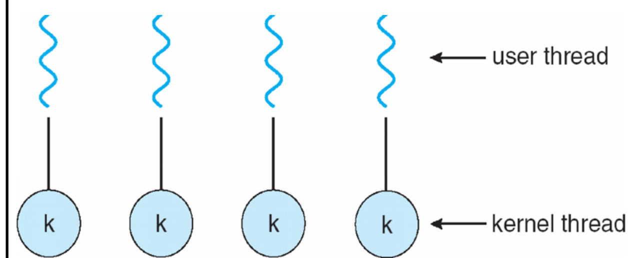
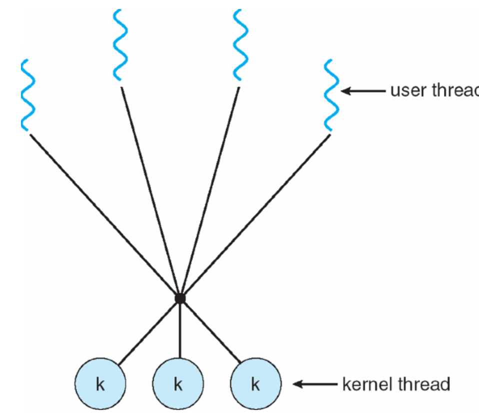
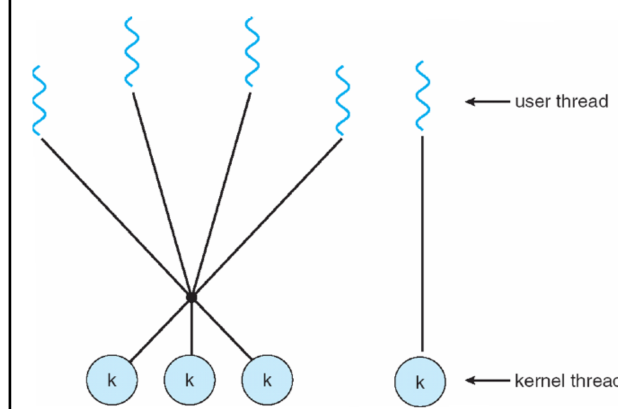
Similar to many-to-many, except that it allows a user thread to be bound to a kernel thread.

Kernel space

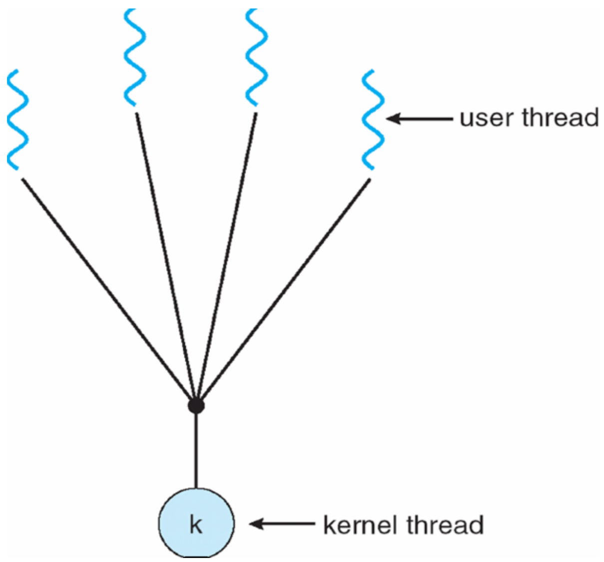
Multithreading models

Many-to-One	One-to-One	Many-to-Many	Two-level-model
			
Many user-level threads mapped to a single kernel thread. Thread management is done by the thread library in user space.	Each user-level thread maps to one kernel thread. This models makes thread creation "expensive" and most implementations restrict the number of threads supported by the system.	Allows many user level threads to be mapped to many kernel threads. Allows the operating system to create a sufficient number of kernel threads.	Similar to many-to-many, except that it allows a user thread to be bound to a kernel thread.

Multithreading models and blocking

Many-to-One	One-to-One	Many-to-Many	Two-level-model
			
Thread management is done by the thread library in user space but entire process will block if a thread makes a blocking system call. **One blocks all** Only one thread can access the kernel at a time, hence threads cannot run in parallel on multiprocessors.	Provides more concurrency than the many-to-one model by allowing another thread to run when a thread makes a blocking system call. **One blocks solely itself** Allows for threads to run in parallel on multiprocessors.	Multiplexes many user-level threads to a smaller or equal number of kernel threads. **One blocks some** A compromise between maný-to-one and one-to-one.	Similar to many-to-many, except that it allows a user thread to be bound to a kernel thread.

Multithreading models

<table>
<tr><th>Many-to-One</th><th>One-to-One</th><th>Many-to-Many</th><th>Two-level-model</th></tr>
<tr>
<td>
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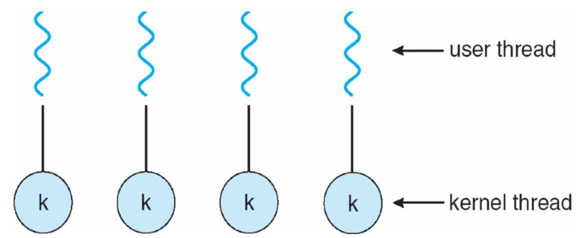
<td>
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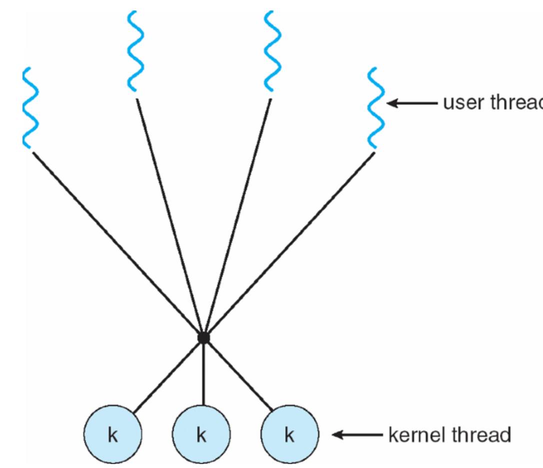
<td>
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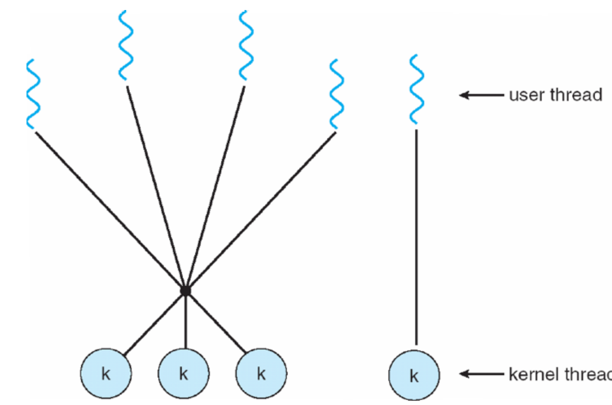
<td>
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<tr>
<td>Examples:

★ Solaris Green Threads
★ GNU Portable Threads</td>
<td>Examples:

★ Windows NT/ XP/2000
★ Linux
★ Solaris 9 and later</td>
<td>Examples:

★ Solaris prior to version 9
★ Windows NT/ 2000 with the ThreadFiber package</td>
<td>Examples:

★ IRIX
★ HP-UX
★ Tru64 UNIX
★ Solaris 8 and earlier</td>
</tr>
</table>

User-level thread scheduling

User space

Scheduling of user level thread among the available kernel-level threads done by user-level scheduler.

How to decide when to switch threads?

There are two main methods: **preemptive** & **cooperative**.

many-to-one	one-to-one	many-to-many	two-level

Kernel space

Preemptive user level thread scheduling

User space

In the **preemptive** model, you'll have something like a timer signal that causes execution flow to jump to a central dispatcher thread, which chooses the next thread to run.

many-to-one	one-to-one	many-to-many	two-level

Timer

Kernel space

Cooperative user-level thread scheduling

User space

In a cooperative model, threads **yield** to each other, either explicitly (e.g., by calling a yield() function you'll provide) or implicitly (e.g., requesting a lock held by another thread).

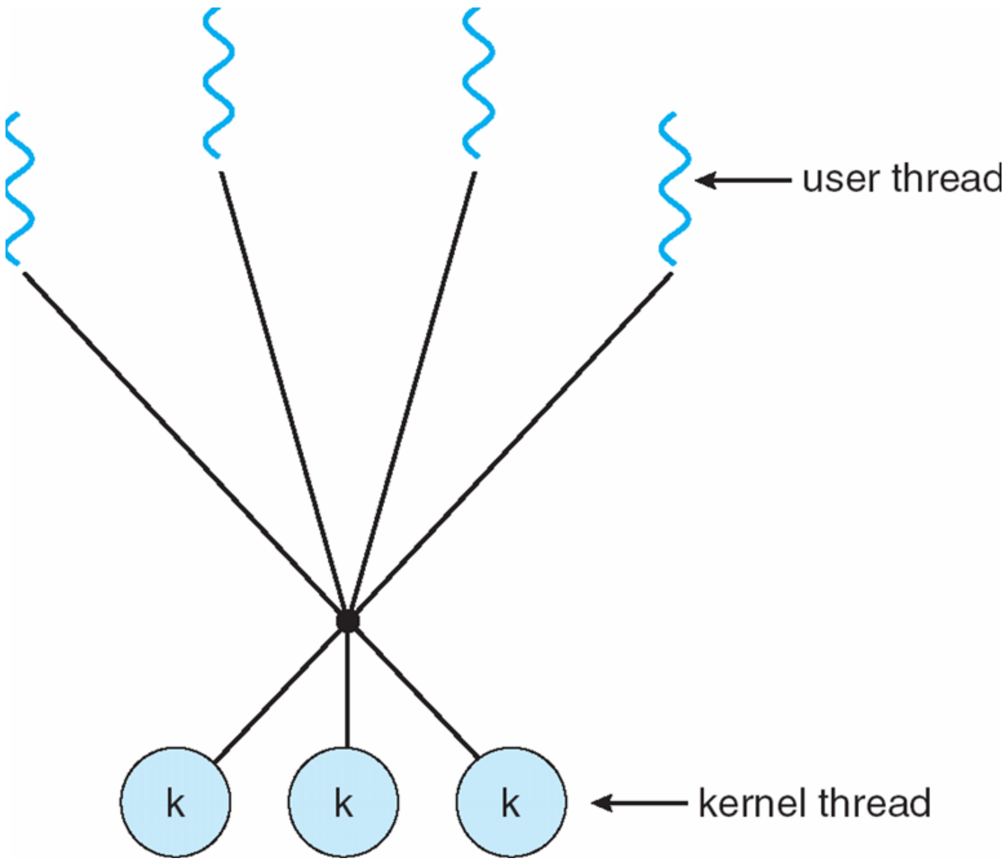
many-to-one	one-to-one	many-to-many	two-level

Kernel space

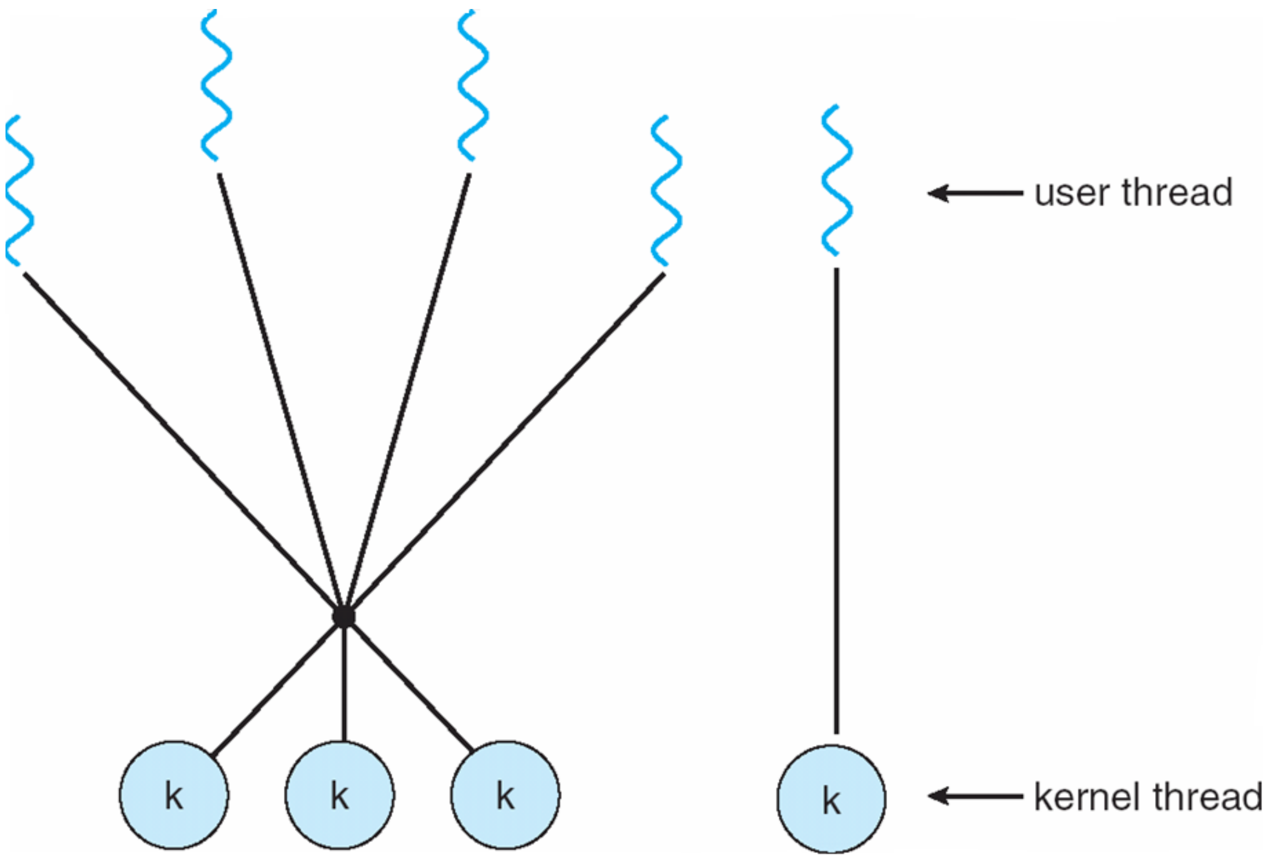
Scheduler activations (1)

Both Many-To-Many and Two-level models require communication to maintain the appropriate number of kernel threads allocated to the application.

Many-To-Many



Two-Level



Scheduler activations (2)

A scheduler activation notifies the user-level thread manager of kernel changes.

User space

Scheduler activations allows the user-level thread manager to make better decisions.

Scheduler activations provide **upcalls** - a communication mechanism from the kernel to the user-level thread library.

Kernel space

Scheduler activations (3)

Both Many-To-Many 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.

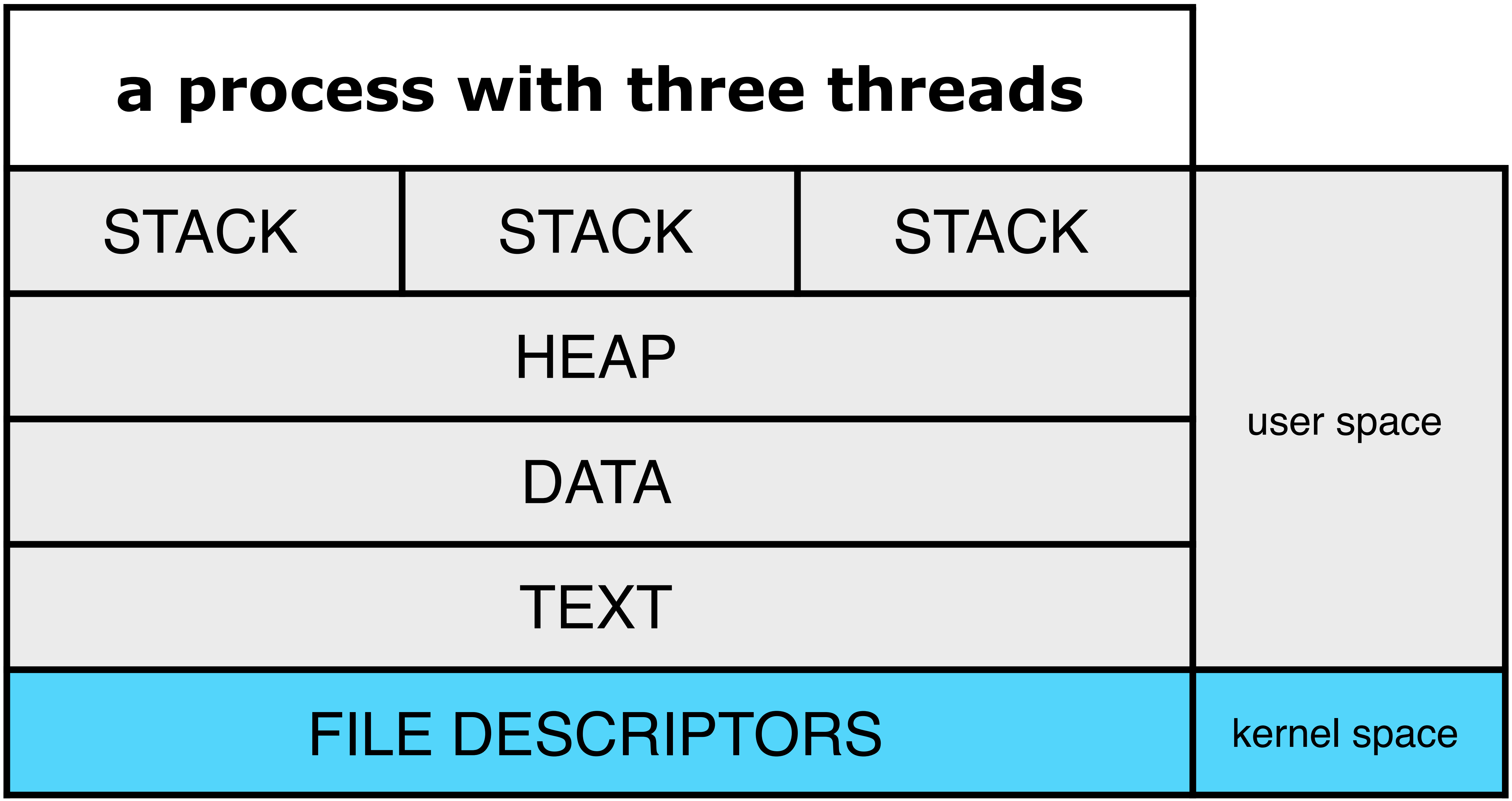
- Such coordination **allows the number of kernel threads to be dynamically adjusted** to help ensure the best performance.
- This communication allows an application to maintain the correct number of kernel threads

A scheduler activation notifies the user-level thread system of kernel changes:

- Number of processors assigned
- I/O interrupts
- Page faults

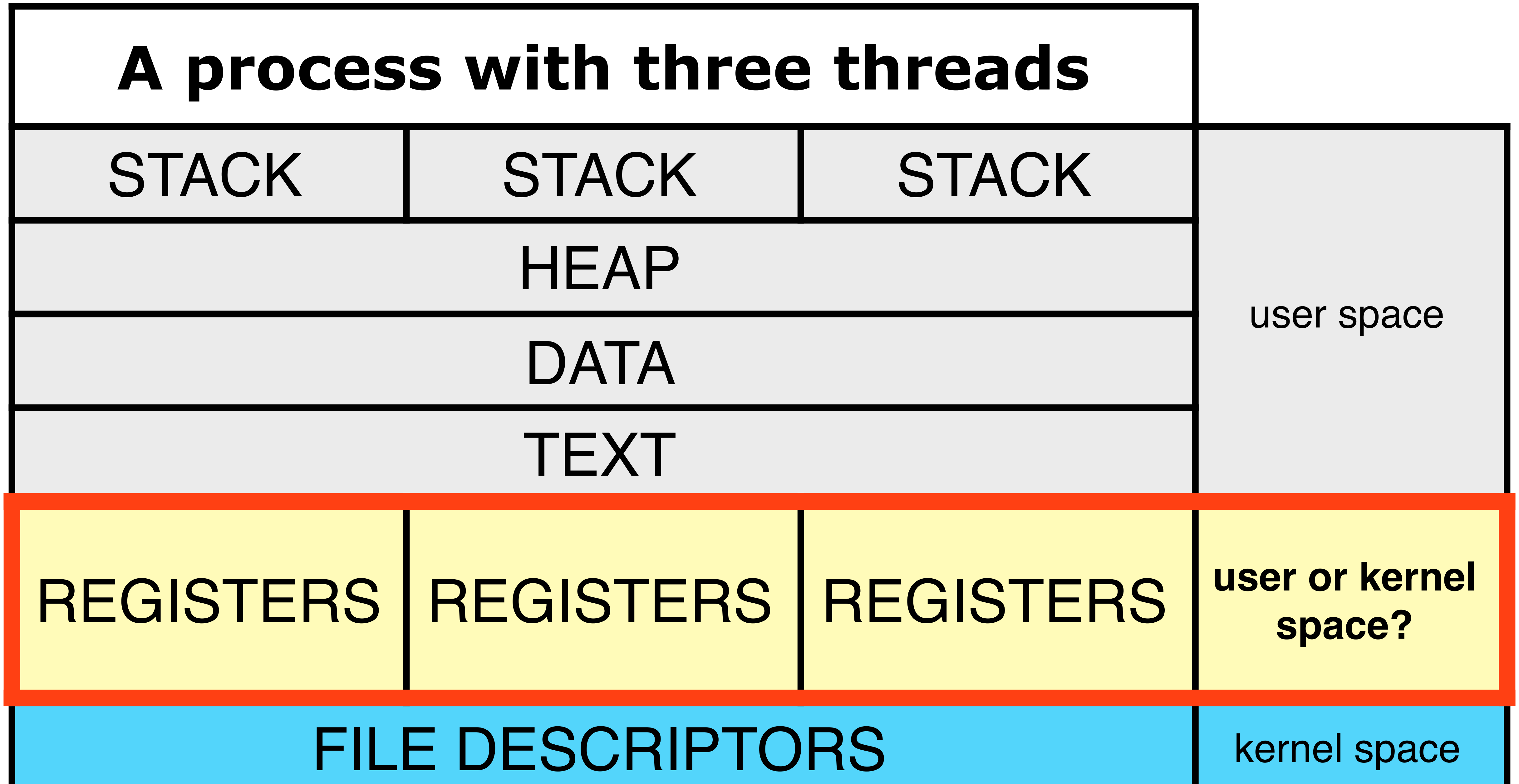
Thread resource management (1)

Threads share user space resources (heap, data and text). They also share kernel space resources (file descriptors). Each thread also have a private user level stack.



Thread resource management (2)

Each thread also needs private storage for registers (context).



User-level thread scheduling

User space

Scheduling of user level thread among the available kernel-level threads done by user-level scheduler.

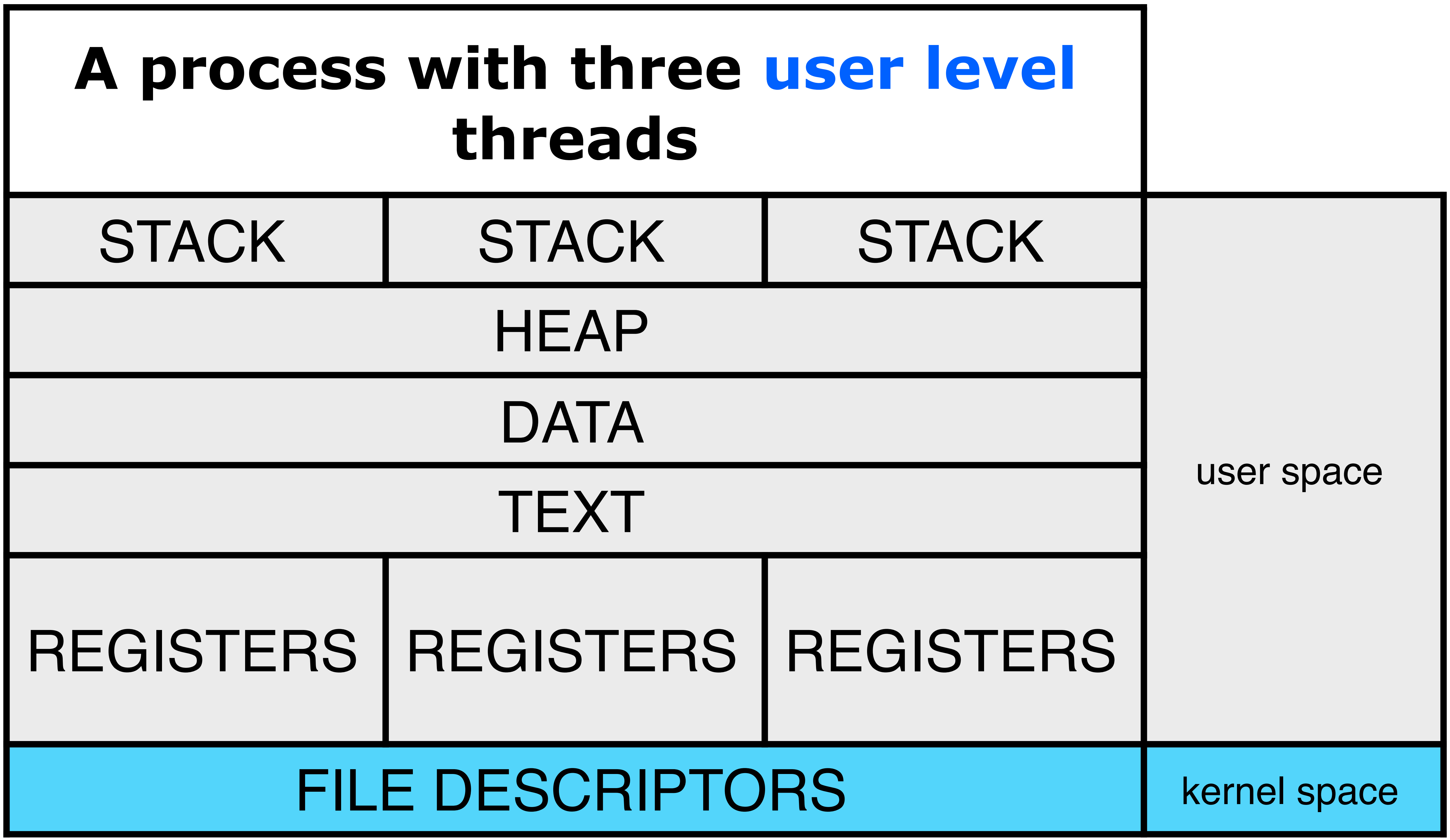
If scheduling of threads is done in user level, context (registers) must must be saved in user space!

many-to-one	one-to-one	many-to-many	two-level

Kernel space

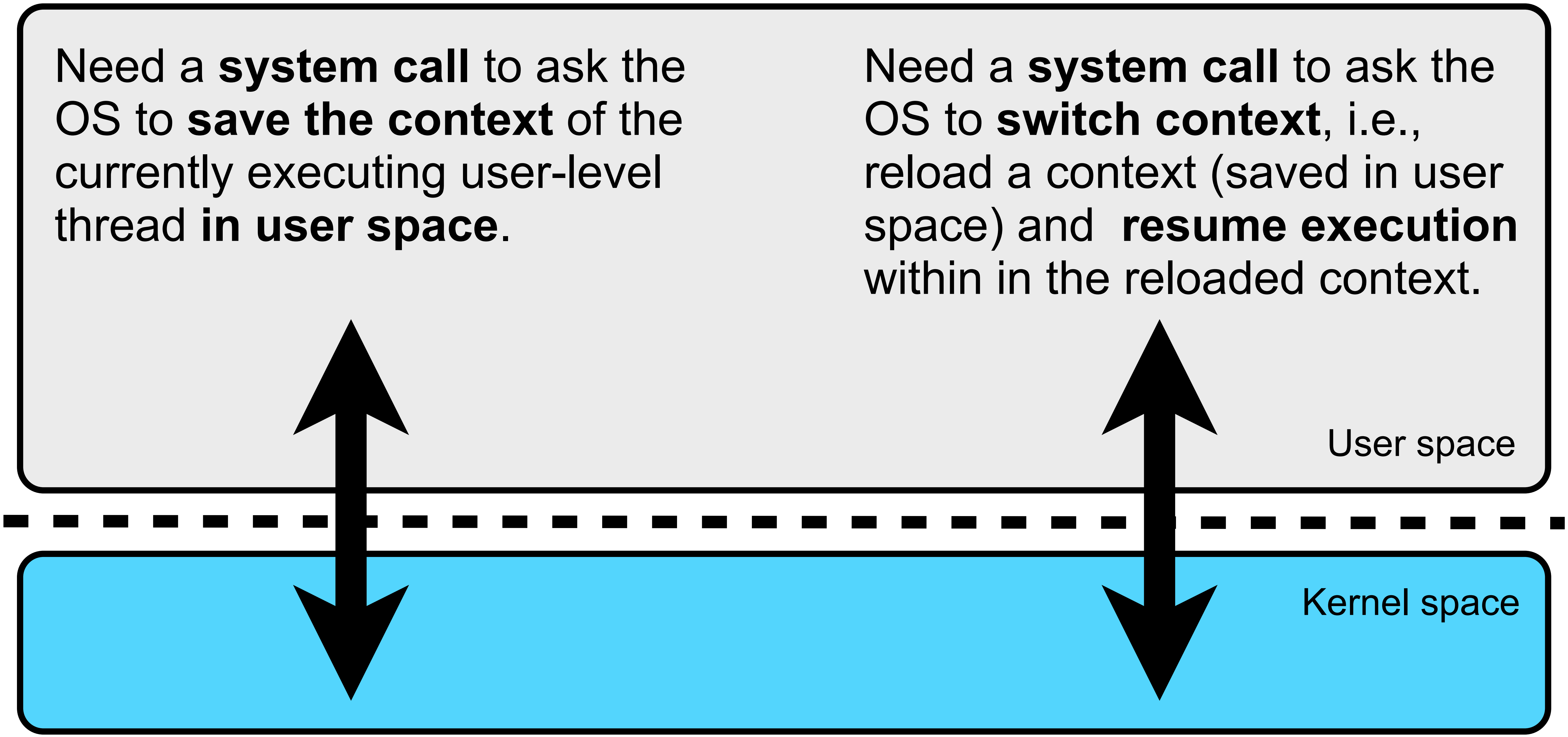
User level thread context

If scheduling of threads is done in user level, context (registers) must must be saved in user space!



User level thread context

A **machine-specific** representation of the saved **context** (the execution state) including all **registers** and **CPU flags**, the **instruction pointer**, and the **stack pointer**.



ucontext_t

The `<ucontext.h>` header defines the `ucontext_t` type as a structure that can be used to store the execution context of a user-level thread to user space.

Members of the ucontext_t structure		
Type	**Name**	**Description**
`mcontext_t`	`uc_mcontext`	A machine-specific representation of the saved **context** (the execution state) including all **registers** and **CPU flags**, the **instruction pointer**, and the **stack pointer**.
`stack_t`	`uc_stack`	The **stack** used by this context.
`sigset_t`	`uc_sigmask`	The set of **signals** that are **blocked** when this context is active.
`ucontext_t`	`*uc_link`	**Pointer** to the **context** that will be **resumed** when this context returns.

```
int getcontext(ucontext_t *ucp)
```

- ★ The getcontext() function shall initialize the structure pointed to by **ucp** to the current user context of the calling thread.
- ★ The ucontext_t type that **ucp** points to defines the user context and includes the contents of the calling thread's machine registers, the signal mask, and the current execution stack.
- ★ Upon successful completion, getcontext() shall return 0; otherwise, a value of -1 shall be returned.

```
void makecontext(
        ucontext_t *ucp,
        void (*func)(),
        int argc, …)
```

- ★ Modifies the context specified by **ucp**, which has been initialized using getcontext().
- ★ When this context is **resumed** using swapcontext() or setcontext(), program execution shall continue **by calling** **func**, passing it the arguments that follow **argc** in the makecontext() call.
- ★ Before a call is made to makecontext(), the application shall ensure that the context being modified has a stack allocated for it.
- ★ The application shall ensure that the value of **argc** matches the number of arguments of type int passed to **func**; otherwise, the behavior is undefined.

```
int swapcontext(
        ucontext_t *restrict oucp,
        const ucontext_t *restrict ucp)
```

- The swapcontext() function shall save the current context in the context structure pointed to by **oucp** and shall set the context to the context structure pointed to by **ucp**.
- When successful, swapcontext() does not return. (But we may return later, in case oucp is activated, in which case it looks like swapcontext() returns 0.) On error, swapcontext() returns -1 and sets errno appropriately.

Source: http://pubs.opengroup.org/onlinepubs/009695399/functions/makecontext.html 2016-02-08
http://linux.die.net/man/3/swapcontext 2016-02-08

In the C programming language, as of the C99 standard, restrict is a keyword that can be used in pointer declarations. The restrict keyword is a declaration of intent given by the programmer to the compiler. It says that for the lifetime of the pointer, only it or a value directly derived from it (such as pointer + 1) will be used to access the object to which it points. This limits the effects of pointer aliasing, aiding optimizations. If the declaration of intent is not followed and the object is accessed by an independent pointer, this will result in undefined behavior

Source: https://en.wikipedia.org/wiki/Restrict 2016-02-08

```
int setcontext(const ucontext_t *ucp)
```

- The setcontext() function shall restore the user context pointed to by **ucp**.
- A successful call to setcontext() shall not return; program execution resumes at the point specified by the ucp argument passed to setcontext().
- The ucp argument should be created either by a prior call to getcontext() or makecontext(), or by being passed as an argument to a signal handler.
- Upon successful completion, setcontext() shall not return; otherwise, a value of -1 shall be returned.