Ch 5: Processor Management

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Processor Management

- Threads *Implementation*
  - lock/mutex implementation on multiprocessors
- Interrupts
- Scheduling
- Linux/Windows Scheduler

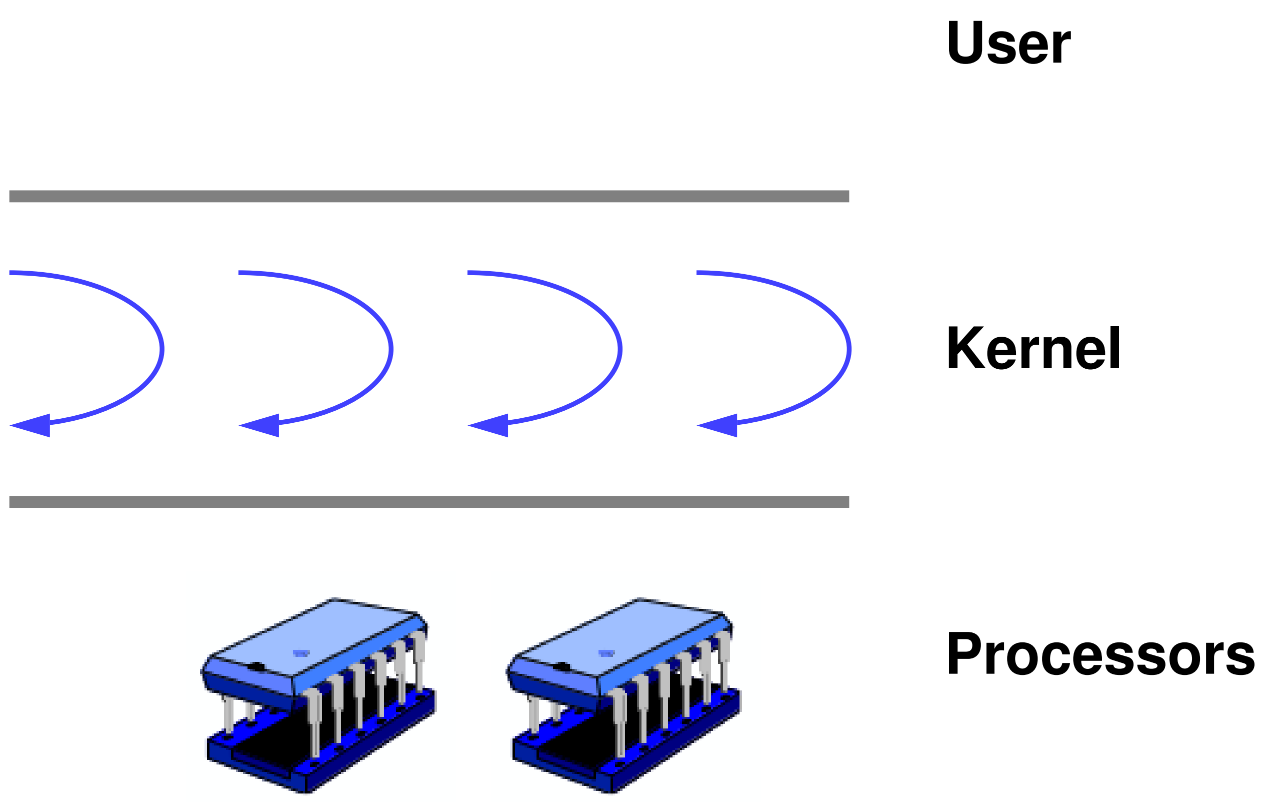
5.1 Threads Implementations

- *Strategies*
- A Simple Thread Implementation
- Multiple Processors

Threads Implementation

- The ultimate goal of the OS is to support user-level applications
  - we will discuss various strategies for supporting threads
- Where are operations on threads implemented?
  - in the kernel?
  - or in user-level library?
- Approaches
  - one-level or 1×1 model (threads are implemented in the kernel)
    - variable-weight processes
  - two-level model (threads are implemented in user library)
    - $N \times 1$
    - $M \times N$
  - scheduler activations model

One-Level Model (1 $\times$ 1)



One-Level Model (1×1)

- The simplest and most direct approach is the *one-level model*
  - all aspects of the *thread implementation* are *in the kernel*
    - i.e., all thread routines (e.g., `pthread_mutex_lock`) called by user code are all system calls
  - each *user thread* is mapped to a *kernel thread*

- If a thread calls `pthread_create()`
  - it's a system call, so it traps into the kernel
  - the kernel creates a thread control block
    - associate it with the process control block
  - the kernel creates a kernel and a user stack for this thread

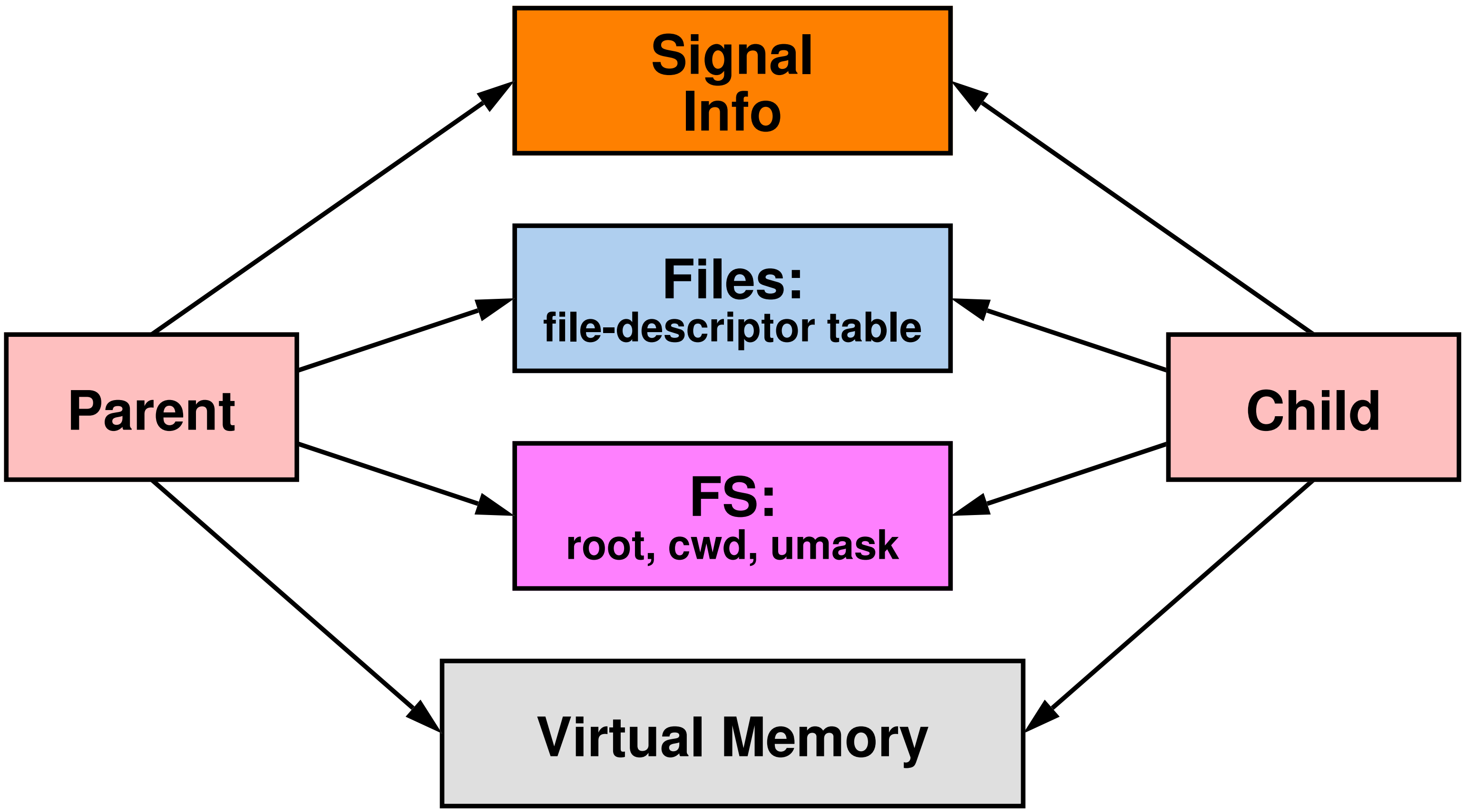
- What about `pthread_mutex_lock()`
  - why does it have to be done in the kernel?
  - it's not necessary to protect the threads from each other!
    - you definitely don't need the kernel to protect threads from each other

One-Level Model (1 × 1)

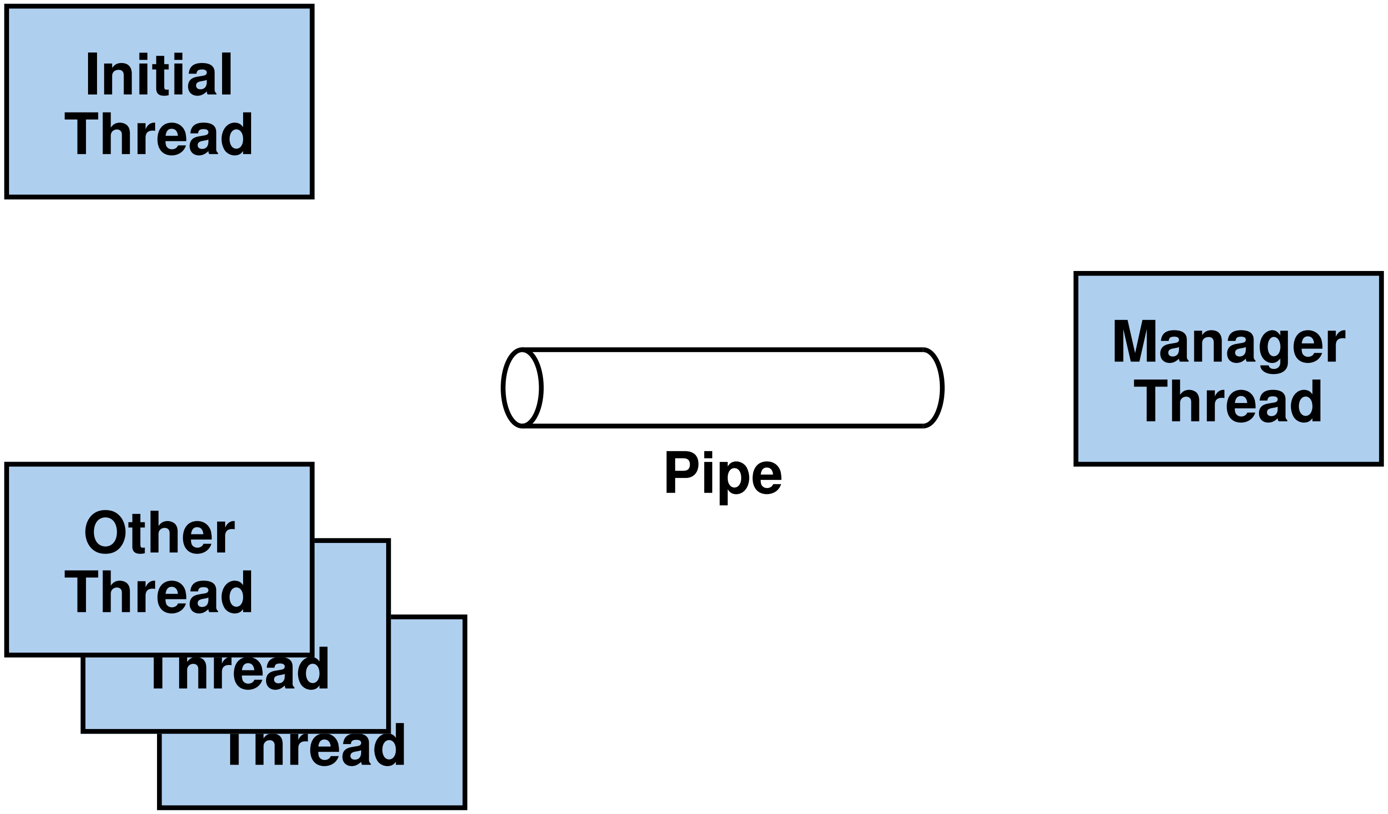
- Problem: system calls are expensive
  - if `pthread_mutex_lock` finds the mutex available, it should return quickly (and lock the mutex)
    - if this can be done in user code, it can be 20 times faster (for the case where the mutex is available)
    - in Win32 threads, an equivalent of a mutex is represented in a user-level data structure
      - if such an object is not locked, it returns quickly
      - if such an object is locked, it makes a system call and blocks in the kernel
- Does it happen a lot that `pthread_mutex_lock` finds the mutex available?
  - think about your warmup2

Variable-Weight Processes

- Variant of one-level model
- Portions of parent process selectively *copied* into or *shared* with child process
- Children created using `clone()` system call



Linux Threads (pre 2.6)



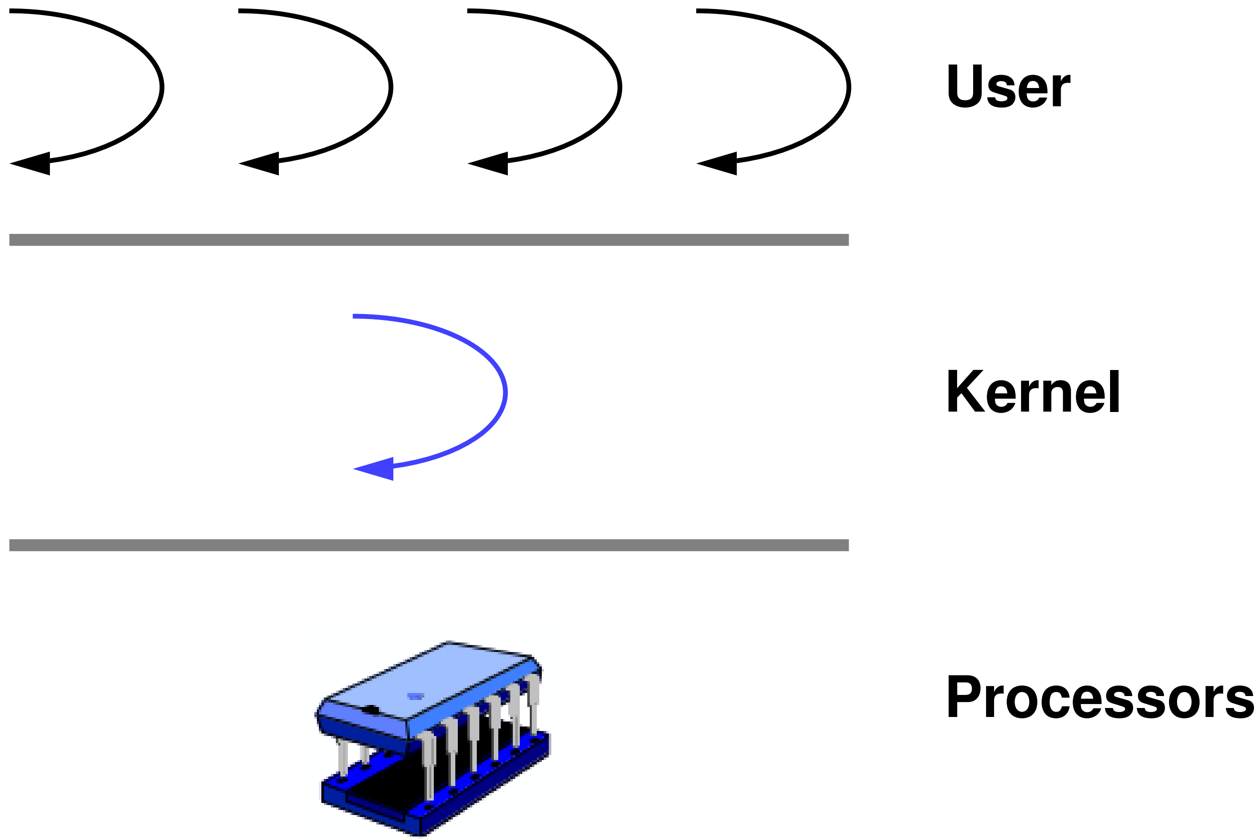
NPTL in Linux 2.6

- Native POSIX-Threads Library
  - full POSIX-threads semantics on improved variable-weight processes
  - threads of a "process" form a *thread group*
    - `getpid()` returns process ID of first thread in group
    - any thread in group can wait for any other to terminate
    - signals to process delivered by kernel to any thread in group
  - new kernel-supported synchronization construct: *futex* (fast user-space mutex)
    - used to implement mutexes, semaphores, and condition variables

Two-Level Model

- In the two-level model, a user-level library plays a major role
  - what an user-level application perceives as a thread is implemented within user-level library code
- Two versions
  - single kernel thread (per user process)
  - multiple kernel threads (per user process)

Two-Level Model - One Kernel Thread (N × 1)



- This is one of the earliest ways of implementing threads
  - threads are implemented entirely in the user level
    - thread control block, mutex in user space
    - thread stack allocated by user library code
  - mostly done on uniprocessors

Two-Level Model - One Kernel Thread (N $\times$ 1)

- Within a process, user threads are multiplexed not on the processor, but on a kernel-supported thread
  - the OS multiplexes kernel threads (or equivalently, processes) on the processor
  - kernel does *not* know about *the existance of user threads*
    - there are really no "kernel threads" in these systems
- User thread creation
  - a stack and a thread control block is allocated
  - thread is put on a queue of runnable threads
    - wait for its turn to become the running thread
- Synchronization implementation
  - relative straightforward
  - e.g., mutex (one queue per mutex)
    - if a thread must block, it simply queues itself on a wait queue and calls context-switch routine to pass control to the first thread on the runnable queue

Two-Level Model - One Kernel Thread ($N \times 1$)

- **Major advantage**
  - fast, because no system calls for thread-related APIs
- **Major disadvantage**
  - what if a thread makes a system call (for a non-thread-related API)?
    - it gets blocked in the kernel
    - no other user thread in the process can run
  - also, there is no true parallelism within a process even when more CPUs are available

Coping ...

```
ssize_t read(int fd, void *buf, size_t count)
{
  ssize_t ret;
  while (1) {
    if ((ret = real_read(fd, buf, count)) == -1) {
      if (errno == EWOULDBLOCK) {
        sem_wait(&FileSemaphore[fd]);
        continue;
      }
    }
    break;
  }
  return(ret);
}
```

- Solution is to have a non-blocking `read()` called `real_read()`
  - `real_read()` either returns immediately with data in `buf`
  - or returns immediately with an error code in `errno`
    - `EWOULDBLOCK` means that a real `read()` would block, i.e., data is not ready to be read

Coping ...

```
ssize_t read(int fd, void *buf, size_t count)
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  ssize_t ret;
  while (1) {
    if ((ret = real_read(fd, buf, count)) == -1) {
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        sem_wait(&FileSemaphore[fd]);
        continue;
      }
    }
    break;
  }
  return(ret);
}
```
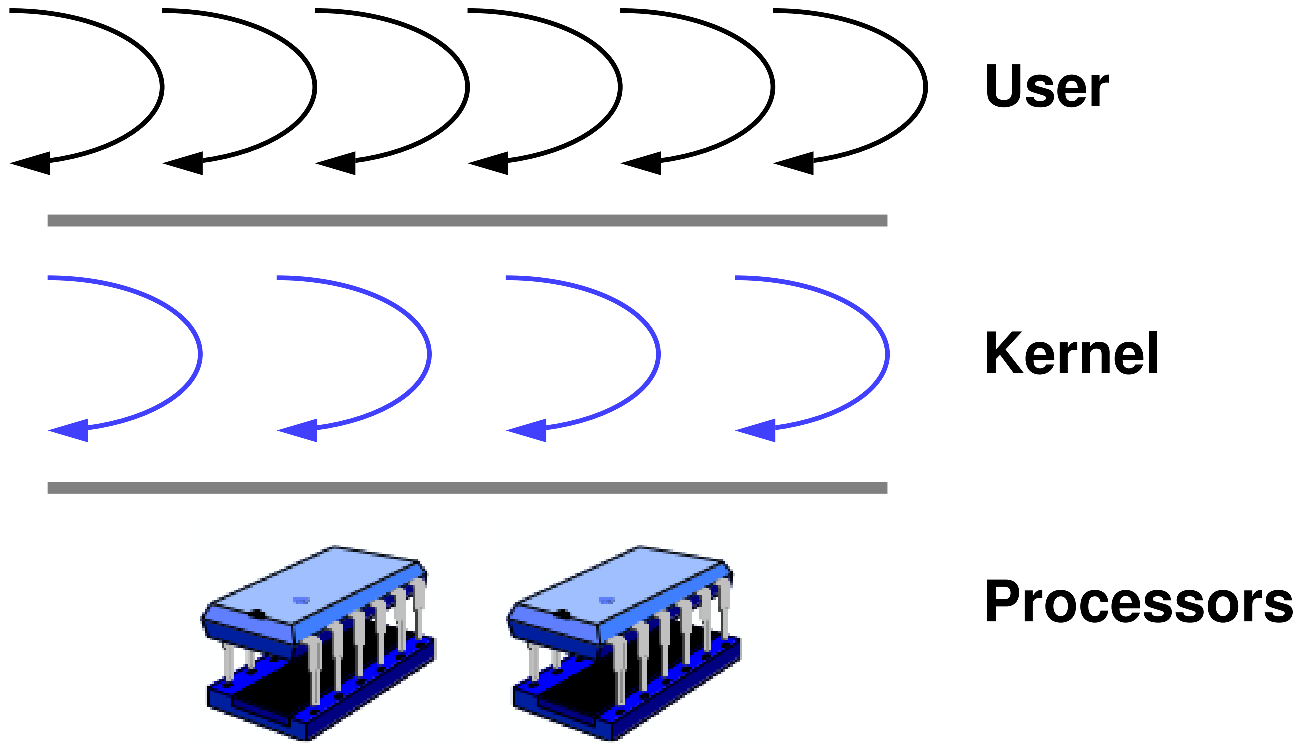
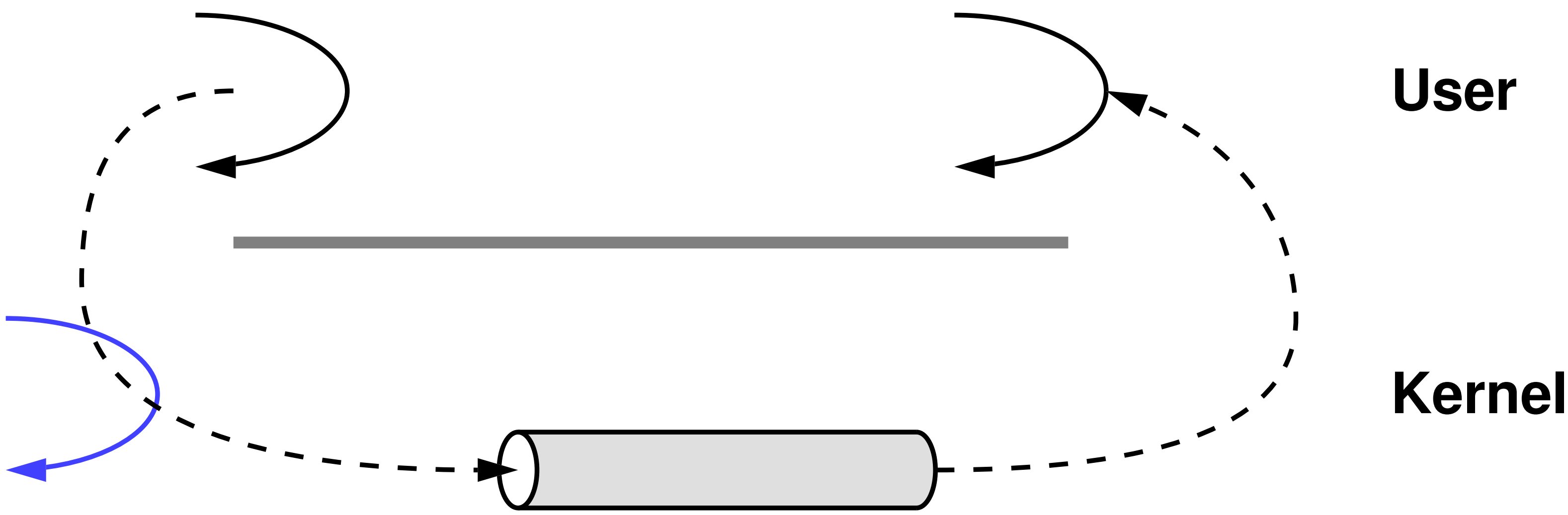

- One semaphore for each open file
  - perhaps a signal handler will invoke `sem_post()` when data is ready to be read
- Major drawback
  - only works for some I/O objects - not a general solution

Two-Level Model: Multiple Kernel Threads ($M \times N$)



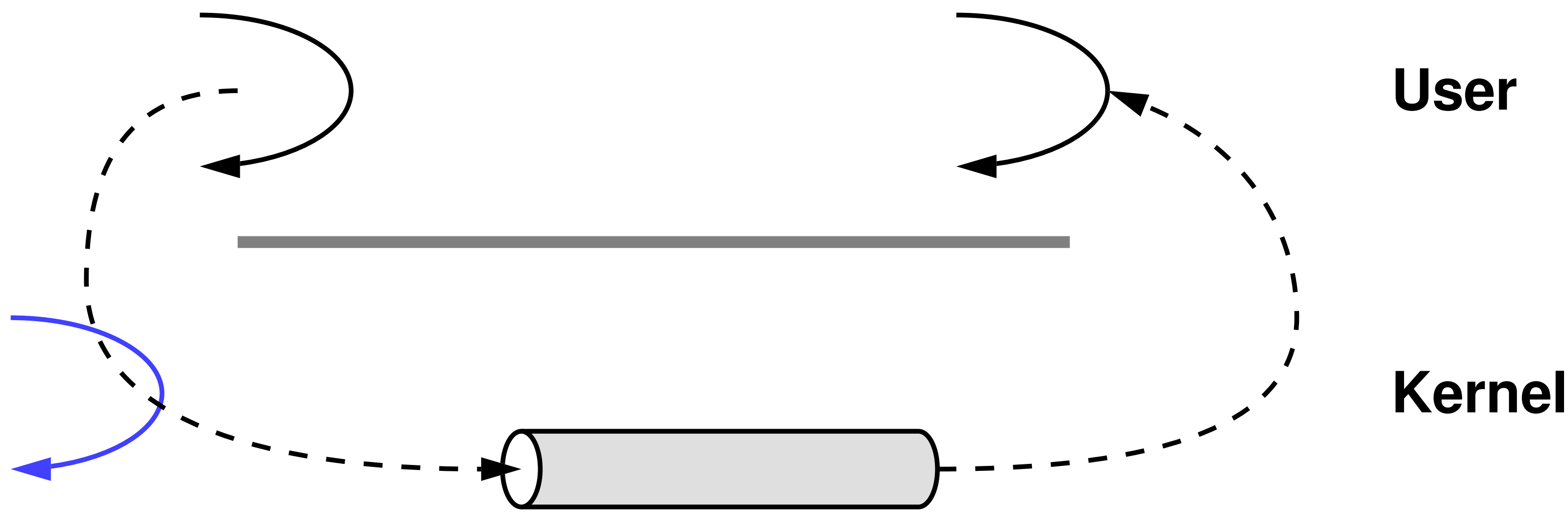
- This is called the ***M-to-N model***
- Implementation is similar to the two-level model with a single kernel thread
  - no system calls for thread-related APIs
  - if we don't have enough kernel threads per user process, we end up having the same problem with the N-to-1 model

Deadlock



- Ex: two threads are communicating using a pipe (this is essentially a kernel implementation of the producer-consmer problem)
  - first user thread writes to a full pipe and get blocked in the kernel
    - first thread just happened to use the last kernel thread
    - 2nd thread wants to read the pipe to unblock the first thread, but cannot because no kernel thread left

Deadlock



- Solaris solution: automatically create a new kernel thread
  - an obvious solution

Problems With Two-level Model

- Two-level model does not solve the I/O blocking problem
  - if there are *N* kernel threads and if *N* user threads are blocked in I/O
    - no other user threads can make progress
    - Solaris solution basically goes back to one-level model
- Another problem: *Priority Inversion*
  - user-level thread schedulers are not aware of the kernel-level thread scheduler
    - it may know the number of kernel threads
  - how can the user-level scheduler talk to the kernel-level scheduler?
    - people have tried this, but it's complicated
  - it's possible to have a higher priority user thread scheduled on a lower priority kernel thread and vice versa
- Will address these problems a little later with Scheduler Activations Model