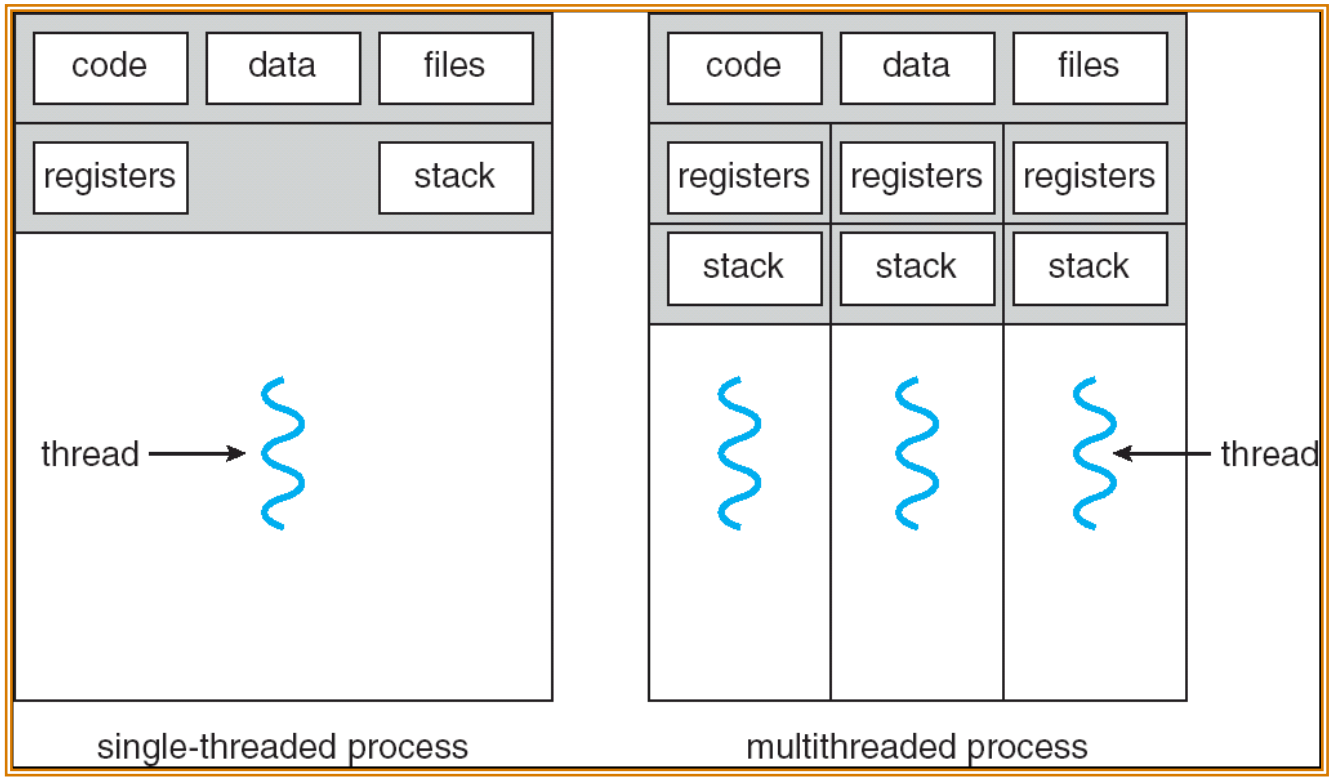
Single and multithreaded processes



Why threads?

- Express concurrency
  - Web server (multiple requests), Browser (GUI + network I/O + rendering), most GUI programs …

```
for(;;) {
    struct request *req = get_request();
    create_thread(process_request, req);
}
```

- Efficient communication
  - Using a separate process for each task can be heavyweight
- Leverage multiple cores (depends)
  - Unthreaded process can only run on a single CPU

Threads vs. Processes

- A thread has no data segment or heap
- A thread cannot live on its own, it must live within a process
- There can be more than one thread in a process, the first thread calls main() & has the process's stack
- Inexpensive creation
- Inexpensive context switching
- Efficient communication
- If a thread dies, its stack is reclaimed

- A process has code/data/heap & other segments
- A process has at least one thread

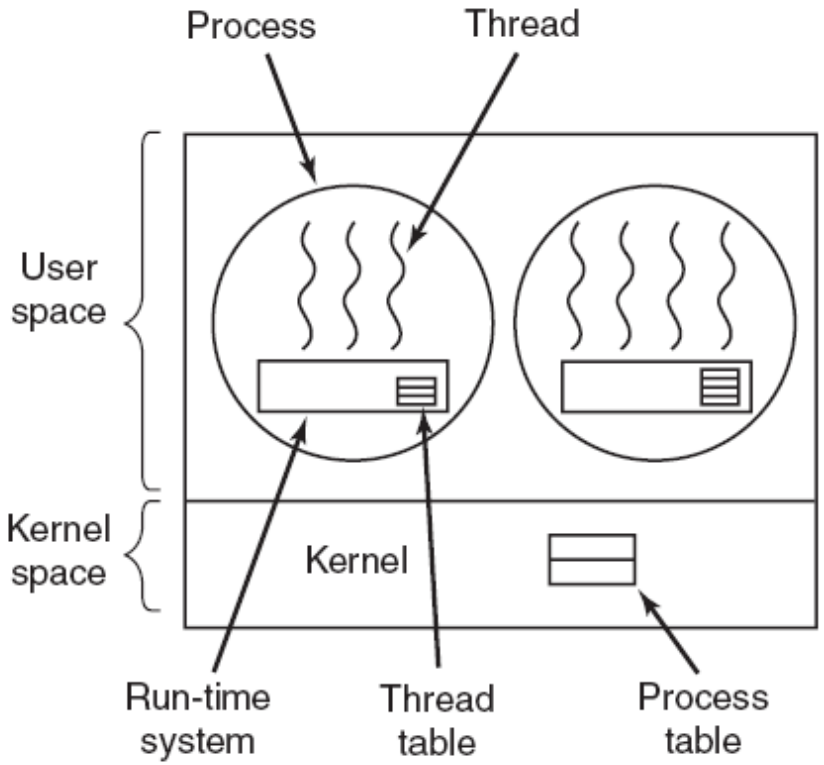
- Threads within a process share code/ data/heap, share I/O, but each has its own stack & registers

- Expensive creation
- Expensive context switching
- Interprocess communication can be expressive
- If a process dies, its resources are reclaimed & all threads die

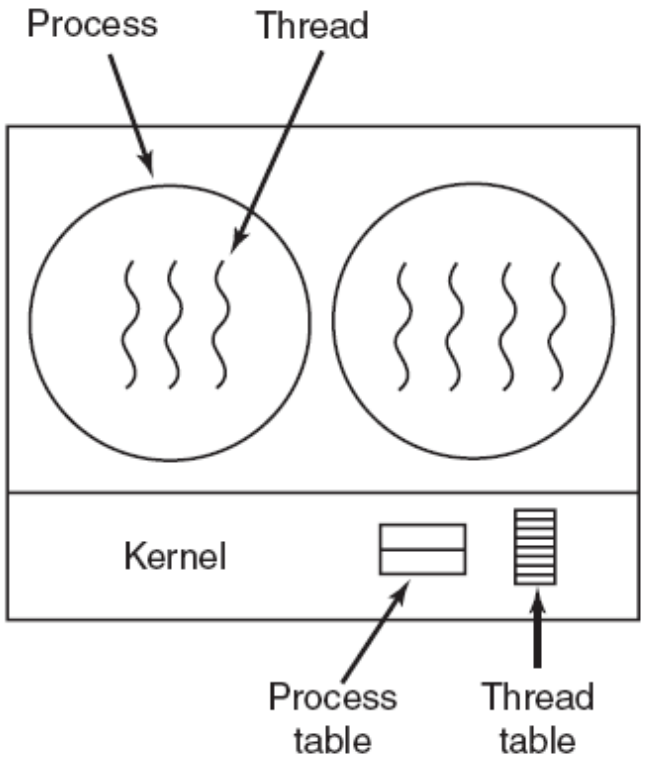
Multithreading models

- Where to support threads?
- User threads: thread management done by user-level threads library; kernel knows nothing
- Kernel threads: threads directly supported by the kernel
  - Virtually all modern OS support kernel threads

User vs. Kernel Threads



E.g., GreenThreads, any OS
(event ancient ones like DOS)



E.g., LinuxThreads, Solaris

Scheduling User Threads

- Non-preemptive Scheduling
  - No timer to make a thread yield the CPU
  - Threads must voluntarily yield control to let another thread run, e.g., pthread_yield()
  - Thread history isn't taken into account by scheduler
  - Threads are *co-operative*, not competitive
- Preemptive Scheduling
  - Can use signals to simulate interrupts, e.g., alarm
  - But then user code can't use alarm directly

User Thread Blocking

- What happens when a process does a read()?
  - Data needs to be fetched from disk
  - Kernel blocks the process (i.e., doesn't return) until disk read is done
  - Kernel unaware of thread structure: all user level threads will block as well!
- One solution: wrapper functions
  - Thread library contains alternate versions of syscalls
  - Check for blocking before calling the kernel
  - E.g., select() before read()
  - If the call will block, then schedule another thread
  - Complex – need to handle all blocking calls!

User vs. Kernel Threads (cont.)

User

- Pros: fast, no system call for creation, context switch
- Cons: kernel doesn't know ➔ one thread blocks, all threads in the process blocks
- Cons: can't benefit from multicore or multiple CPUS

Kernel

- Cons: slow, kernel does creation, scheduling, etc
- Pros: kernel knows ➔ one thread blocks, schedule another
- Pros: can fully utilize multiple cores/CPUs

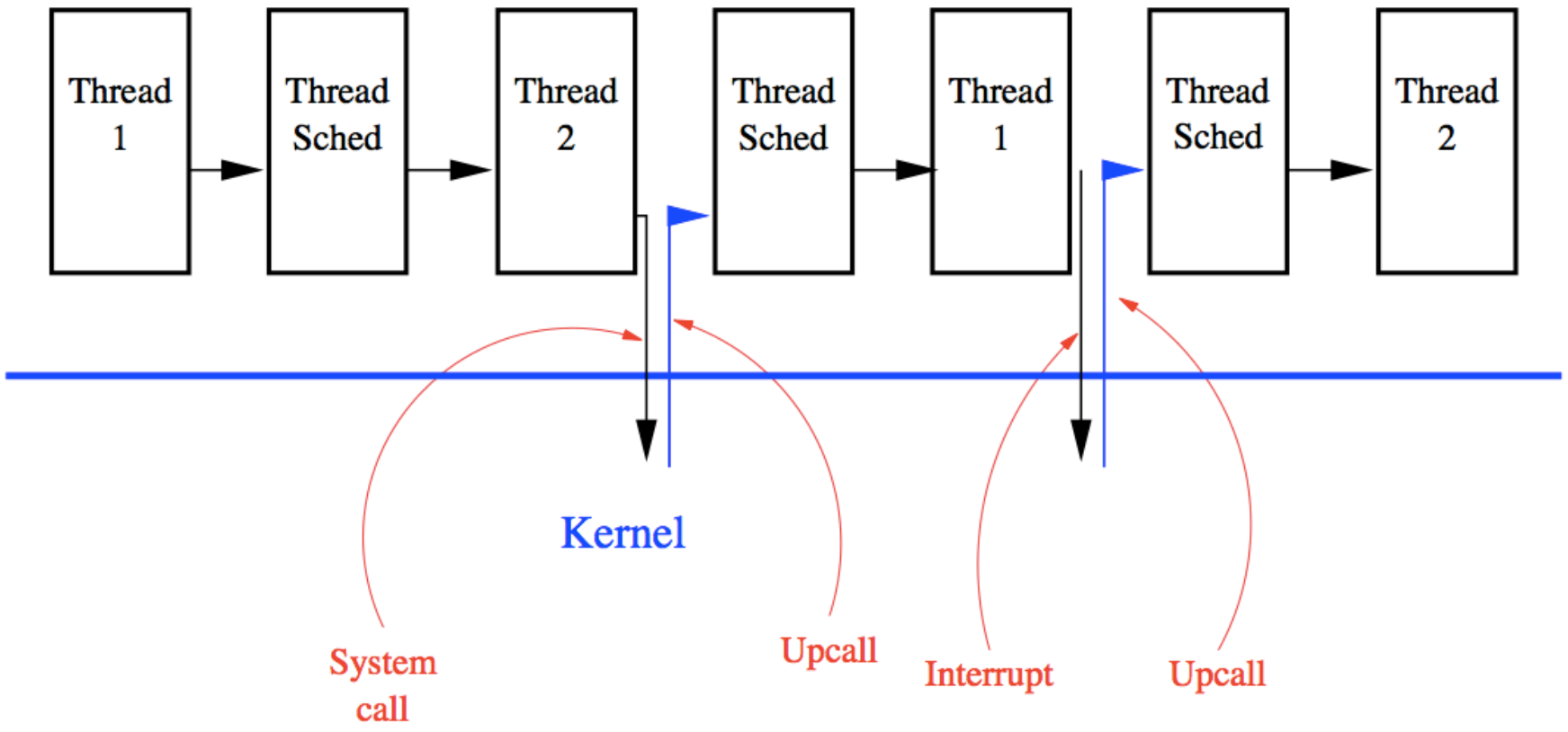
No free lunch!

Scheduler Activations

- Hybrid approach (Tru UNIX, NetBSD, some Mach, implementations for Linux)
  - Benefits of both user and kernel threads
  - Relies on upcalls (like signals)
- Scheduling done at user level
  - When a syscall is going to block, kernel informs user level thread manager via upcall
  - Thread manager can run another thread
  - When blocking call is done, kernel informs thread manager again

Reference: http://homes.cs.washington.edu/~bershad/Papers/p53-anderson.pdf ("Scheduler Activations: Effective Kernel Support for the User-Level Management of Parallelism")

Scheduler Activations

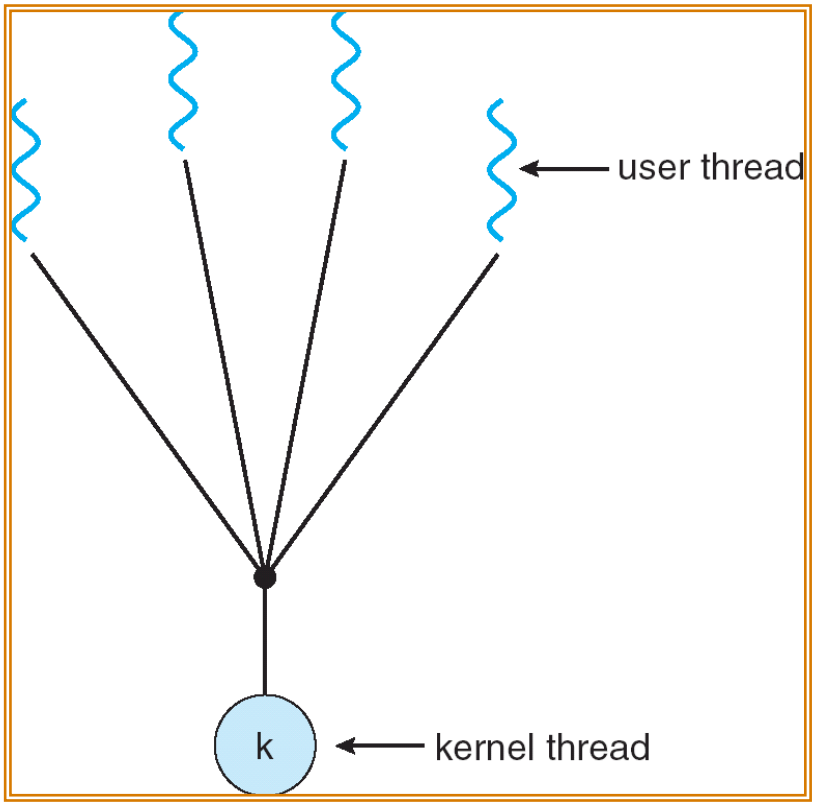


Multiplexing User-Level Threads

- A thread library must map user threads to kernel threads
- Big picture:
  - kernel thread: physical concurrency, how many cores?
  - User thread: application concurrency, how many tasks?
- Different mappings exist, representing different tradeoffs
  - Many-to-One: many user threads map to one kernel thread, i.e. kernel sees a single process
  - One-to-One: one user thread maps to one kernel thread
  - Many-to-Many: many user threads map to many kernel threads

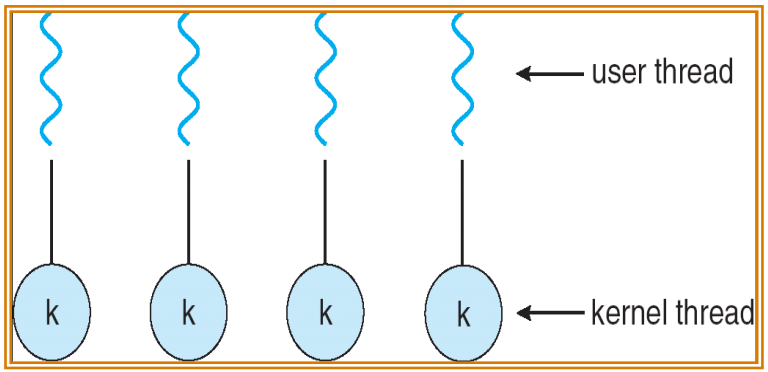
Many-to-One

- Many user-level threads map to one kernel thread
- Pros
  - Fast: no system calls required
  - Portable: few system dependencies
- Cons
  - No parallel execution of threads
    - All thread block when one waits for I/O



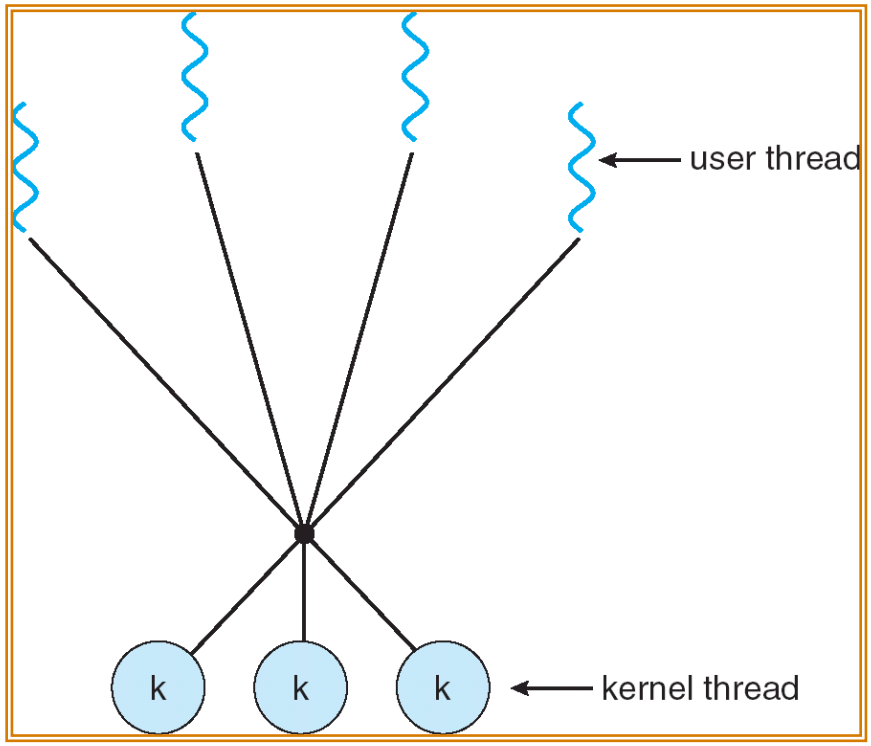
One-to-One

- One user-level thread maps to one kernel thread
- Pros: more concurrency
  - When one blocks, others can run
  - Better multicore or multiprocessor performance
- Cons: expensive
  - Thread operations involve kernel
  - Thread need kernel resources



Many-to-Many

- Many user-level threads map to many kernel threads (U >= K)
  - Supported in some versions of BSD and Windows
- Pros: flexible
  - OS creates kernel threads for physical concurrency
  - Applications creates user threads for application concurrency
- Cons: complex
  - Most programs use 1:1 mapping anyway



Thread pool

- Problem:
  - Creating a thread for each request: costly
    - And, the created thread exits after serving a request
  - More user request ➔ More threads, server overload
- Solution: thread pool
  - Pre-create a number of threads waiting for work
  - Wake up thread to serve user request --- faster than thread creation
  - When request done, don't exit --- go back to pool
  - Limits the max number of threads

Other thread design issues

- Semantics of fork() system calls
  - Does fork() duplicate only the calling thread or all threads?
    - Running threads? Threads trapped in system call?
  - Linux fork() copies only the calling thread
- Signal handling
  - Which thread to deliver signals to?
  - Segmentation fault kills process or thread?
- When using threads
  - Make sure to use re-entrant functions
  - Only stack variables for per-call data (no globals)
  - If you want globals? Use thread-local storage (pthread_key_create), or an array with one entry per-thread