Threads

Today

- Why threads
- Thread model & usage
- Implementing threads
- Scheduler activations
- Making single-threaded code multithreaded

Next time

- CPU Scheduling

The problem with processes

- A process consists of (at least):
  - An address space
  - The code for the running program
  - The data for the running program
  - An execution stack and stack pointer (SP)
    - Traces state of procedure calls made
  - The program counter (PC), indicating the next instruction
  - A set of general-purpose processor registers and their values
  - A set of OS resources
    - open files, network connections, sound channels, …
- A lot of concepts bundled together!

The problem with processes

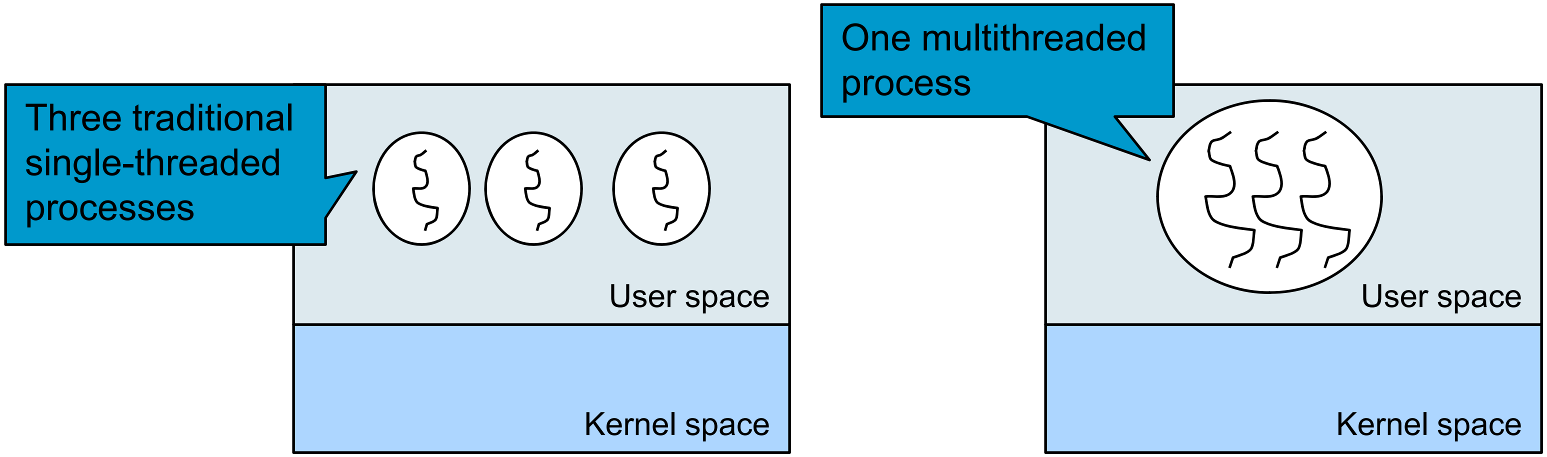
- Many programs need to perform largely independent tasks that do not need to be serialized
  - e.g. web server, text editor, database server, …
- In each of these examples
  - Everybody wants to run the same code
  - Everybody wants to access the same data
  - Everybody has the same privileges
  - Everybody uses the same resources (open files, network connections, etc.)
- But you'd like to have multiple HW execution states:
  - An execution stack & SP
  - PC indicating the next instruction
  - A set of general-purpose processor registers & their values

How can we get this?

- Given the process abstraction as we know it
  - fork several processes
  - cause each to map to the *same* address space to share data
    - see the `shmget()` system call for one way to do this (kind of)
- Not very efficient
  - Space: PCB, page tables, etc.
  - Time: creating OS structures, fork and copy addr space, etc.
- Some equally bad alternatives for some of the cases:
  - Entirely separate web servers
  - Asynchronous programming (non-blocking I/O) in the web client (browser)

The thread model

- Traditionally
  - Process = 1 address space + 1 thread of execution
  - Process = resource grouping + execution stream
    - Resources: program text, data, open files, child processes, pending alarms, accounting info, …
- Key idea with threads
  - Separate the concept of a process (address space, etc.)
  - From that of a minimal "thread of control" (execution state)



The thread model

- Concurrency & parallelism
  - Concurrency – what's possible with infinite processors
    - Provided at the
      - System level: Kernel recognizes multiple threads of control within a process & schedules them independently
      - Application level: Through user-level thread library; a good structuring tool
  - Parallelism – your actual degree of parallel exec.
- Threads states ~ processes states
- One stack per thread – w/ one frame per procedure called but not yet returned from
- Common calls
  - `thread_create()`
  - `thread_exit()`
  - `thread_wait()`
  - `thread_yield()` *(why would you need this?)*

The thread model

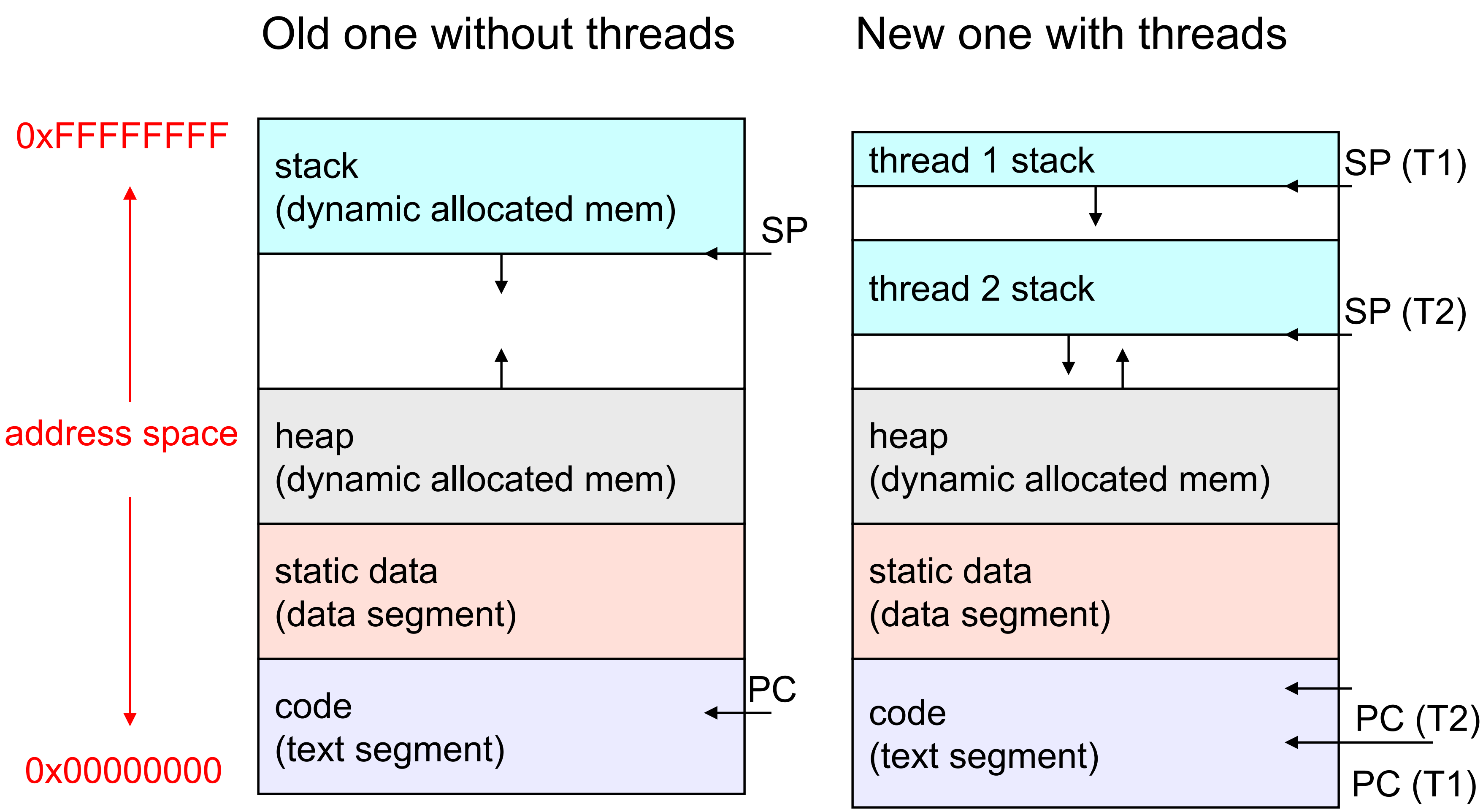
- Share and private items

Per process	**Per thread**
Address space	Program counter
Global variables	Registers
Open files	Stack
Child processes	State
Pending alarms	
Signals and signal handlers	
Accounting information	

- No protection bet/ threads

  (Should they be?)

Old and new process address space

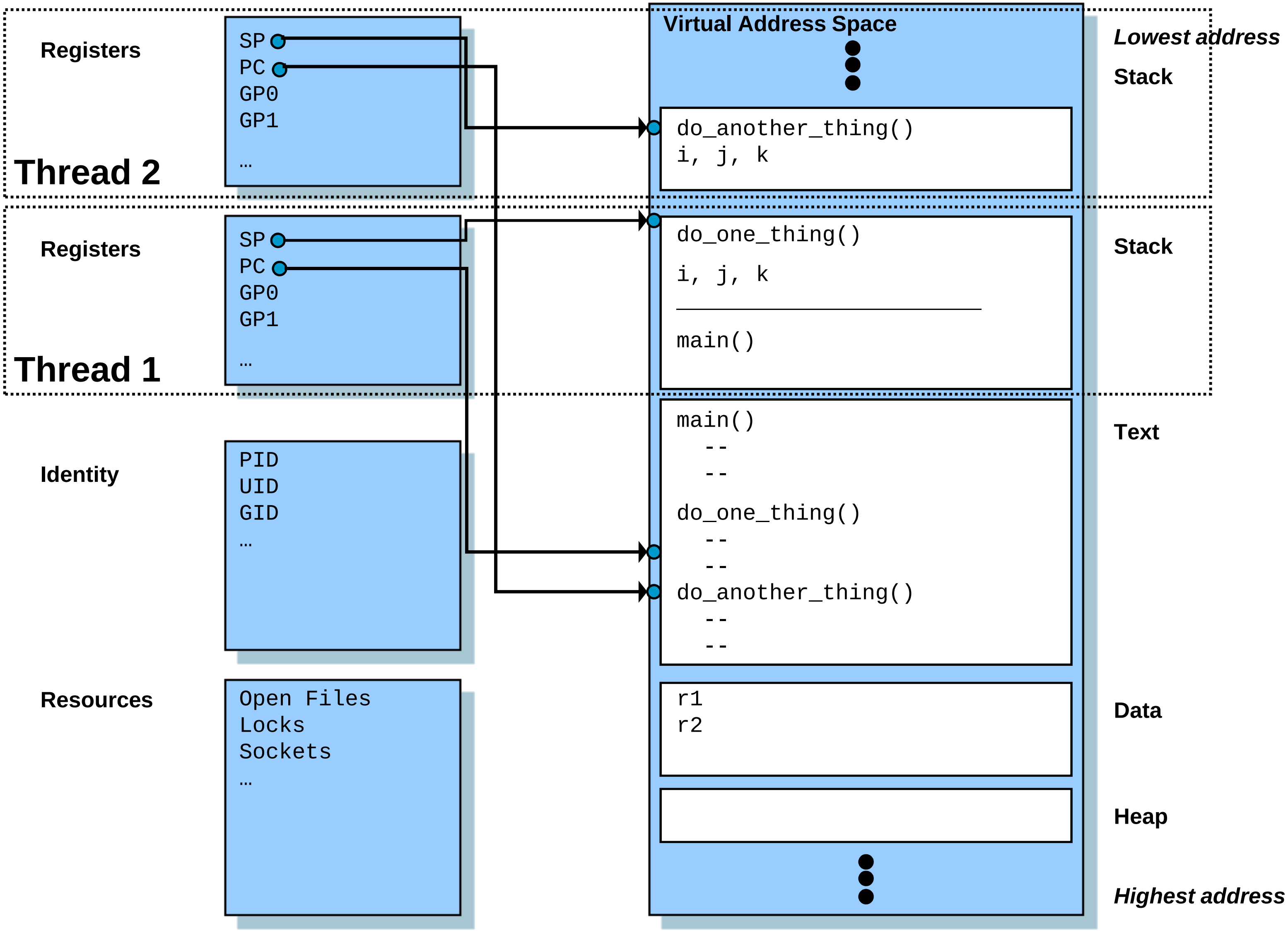


A simple example

```
int r1 = 0, r2 = 0;

void do_one_thing(int *ptimes)
{
  int i, j, k;

  for (i = 0; i < 4; i++) {
    printf(“doing one\n”);
    for (j = 0; j < 1000; j++)
      x = x + i;
    (*ptimes)++;
} /* do_one_thing! */

void do_another_thing(int *ptimes)
{
  int i, j, k;

  for (i = 0; i < 4; i++) {
    printf(“doing another\n”);
    for (j = 0; j < 1000; j++)
      x = x + i;
    (*ptimes)++;
} /* do_another_thing! */
```

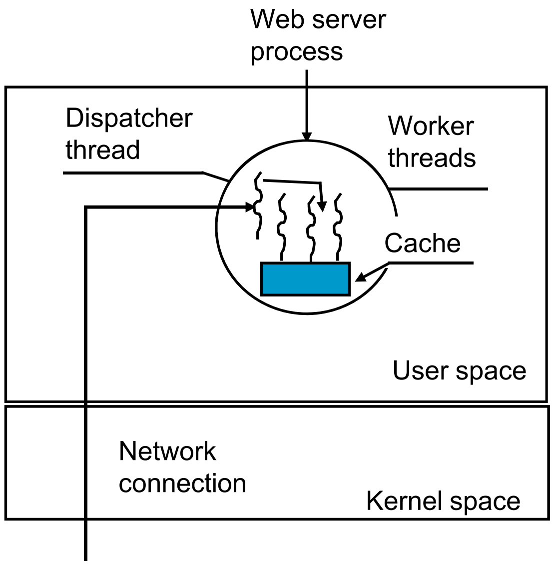
```
void do_wrap_up(int one, int
    another)
{
  int total;
  total = one + another;
  printf(“wrap up: one %d, another
    %d and total %d\n”, one,
    another, total);
}

int main (int argc, char *argv[])
{
  do_one_thing(&r1);
  do_another_thing(&r2);
  do_wrap_up(r1,r2);
  return 0;
} /* main! */
```

Layout in memory & threading



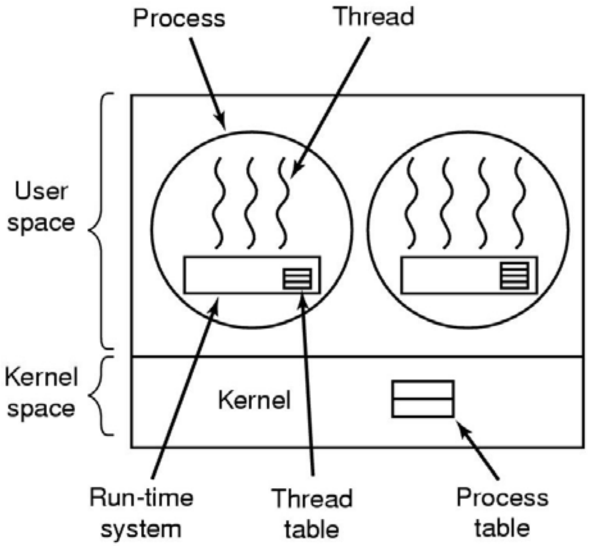
Using threads

- Reasons for threads
  - Simpler programming model when application has multiple, concurrent activities
  - Easy/cheaper to create/destroy than processes since they have no resources attached to them
  - With good mix of CPU and I/O bound activities, better performance
  - Even better if you have multiple CPUs
- A web server
  - Single-threaded: no parallelism, blocking system calls
  - Event-driven: parallelism, nonblocking system calls, interrupts
  - Multithreaded: parallelism, blocking system calls



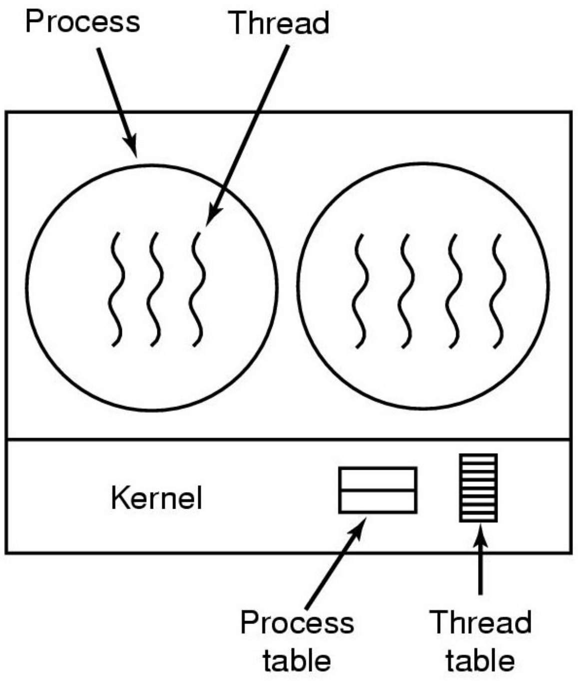
Implementing threads in user space

- Kernel unaware of threads – no modification required (many-to-one model)
- Run-system: a collection of procedures
- Each process needs its own thread table
- Pros
  - Thread switch is very fast
  - No need for kernel support
  - Customized scheduler
  - Each process ~ virtual processor
- Cons - 'real world' factors
  - Multiprogramming, I/O, Page faults
  - Blocking system calls?



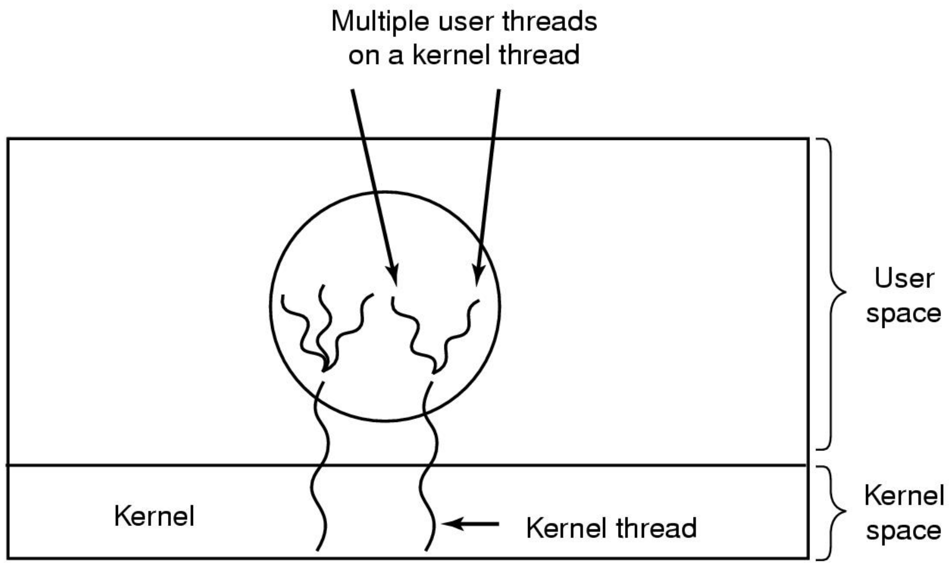
Implementing threads in the kernel

- One-to-one model
- No need for runtime system
- No wrapper for system calls
- Creating threads is more expensive – recycle
- System calls are expensive



Hybrid thread implementations

- Trying to get the best of both worlds
- Multiplexing user-level threads onto kernel- level threads (many-to-many model)
- One popular variation – two-level model (you can bound a user-level thread to a kernel one)



Costs of threads (creation)

Creation time	User-level threads	LWP/Kernel-level threads	Processes
SPARCstation 2, Solaris	52μsec	350μsec	1700μsec
700MHz Pentium, Linux 2.2.*	4.5μsec create/join	94μsec create/join	251μsec fork/exit

Scheduler activations*

- Goal
  - Functionality of kernel threads &
  - Performance of user-level threads
  - Without special non-blocking system calls
- Problem : needed control & scheduling information distributed bet/ kernel & each app's address space
- Basic idea
  - When kernel finds out a thread is about to block, *upcalls* the runtime system (activates it at a known starting address)
  - When kernel finds out a thread can run again, upcalls again
  - Run-time system can now decide what to do
- Pros – fast & smart
- Cons – upcalls violate layering approach

*Anderson et al., "Scheduler Activations: effective Kernel Support for the User-level Management of Parallelism," SOSP, Oct. 1991.

Thread libraries

- Pthreads – POSIX standard (IEEE 1003.1c) API for thread creation & synchronization
  - API specifies behavior of the thread library, implementation is up to the developers of the library
  - Common in UNIX OSs (Solaris, Linux, Mac OS X)
- Win32 threads – slightly different (more complex API)
- Java threads
  - Managed by the JVM
  - May be created by
    - Extending Thread class
    - Implementing the Runnable interface
  - Implementation model depends on OS (1-to-1 in Windows but many-to-many in early Solaris)

Multithreaded C/POSIX

```
/* shared by thread(s) */
int sum;

/* runner: the thread */
void *runner(void *param)
{
  int i, upper = atoi(param);
  sum = 0;
  for (i = 1; i < upper; i++)
    sum += 1;
  pthread_exit(0);
} /* runner! */
```

$$sum = \sum_{i=0}^{N} i$$

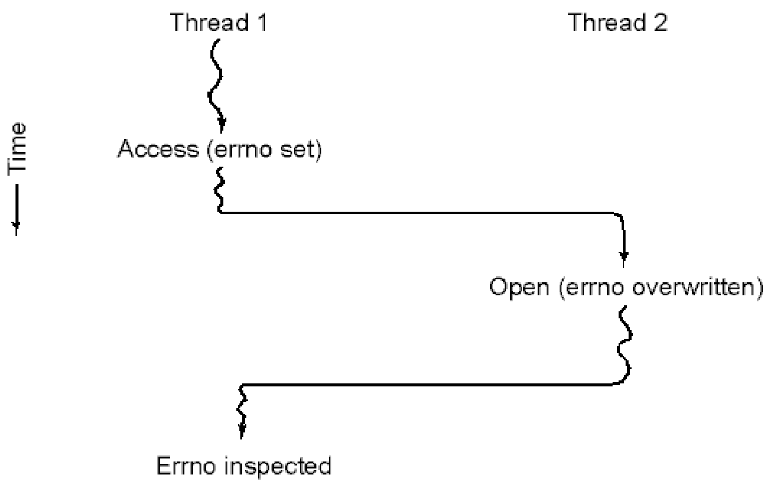
```
int main (int argc, char *argv[])
{
  pthread_t tid;   /* thread id */

  /* set of thread attrs */
  pthread_attr_t attr;

  if (argc != 2 || atoi(argv[1]) < 0) {
    fprintf (stderr, "usage: %s
   <int>\n", argv[0]);
    exit(1);
  }

  /* get default attrs */
  pthread_attr_init(&attr);
  pthread_create(&tid, &attr, runner,
   argv[1]);

  /* wait to exit */
  pthread_join(tid, NULL);
  printf("sum = %d\n", sum);
  exit(0);
} /* main! */
```

Complications with threads

- Semantics of fork() & exec() system calls
  – Duplicate all threads or single-threaded child by default?
  – Are you planning to invoke exec()?
- Other system calls (closing a file, lseek, cwd, …?)
- Signal handling, handlers and masking
  1. Send signal to each thread – too expensive
  2. Appoint a master thread per process – asymmetric threads
  3. Send signal to an arbitrary thread (`control C`?)
  4. Use heuristics to pick thread (SIGSEGV & SIGILL – caused y thread, SIGTSTP & SIGINT – caused by external events)
  5. Create a new thread to handle each signal – situation specific
- Visibility of threads
- Stack growth

Single-threaded to multithreaded

- Threads and global variables
  - An example problem



  - Prohibit global variables? Legacy code?
  - Assign each thread its own global variables
    - Allocate a chunk of memory and pass it around
    - Create new library calls to create/set/destroy global variables

Single-threaded to multithreaded

- Many library procedures are not reentrant
- Re-entrant: *able to handle a second call while not done with previous one*

  e.g. assemble msg in a buffer before sending it
- Solutions
  - Rewrite library?
  - Wrappers for each call?
- Signal handling

OS: Linux threads

- Refers to as tasks rather than processes or threads
- No distinction between processes/threads
- Thread creation is done through `clone()`
- `clone()` allows a child task to share the address space of the parent task (process)
- Some `clone()` flags:
  - CLONE_FS – Share FS info
  - CLONE_VM – Share memory
  - CLONE_SIGHAND – Share handlers
  - CLONE_FILES – Shared set of open files
- `clone()` called with all flags ~ `pthread_create()`
- `clone()` without any ~ `fork()`
- Possible due to task representation: a struct with pointers to others where info is kept

Summary

- You really want multiple threads per address space
- Kernel threads are more efficient than processes, but they're still not cheap
  – all operations require a kernel call and parameter verification
- User-level threads are:
  – Really fast
  – Great for common-case operations, but
  – Can suffer in uncommon cases due to kernel obliviousness
- Scheduler activations are a good answer
- Next time
  – Multiple processes in the ready queue, but only one processor … which you should you pick next?