Threads
(light weight processes)

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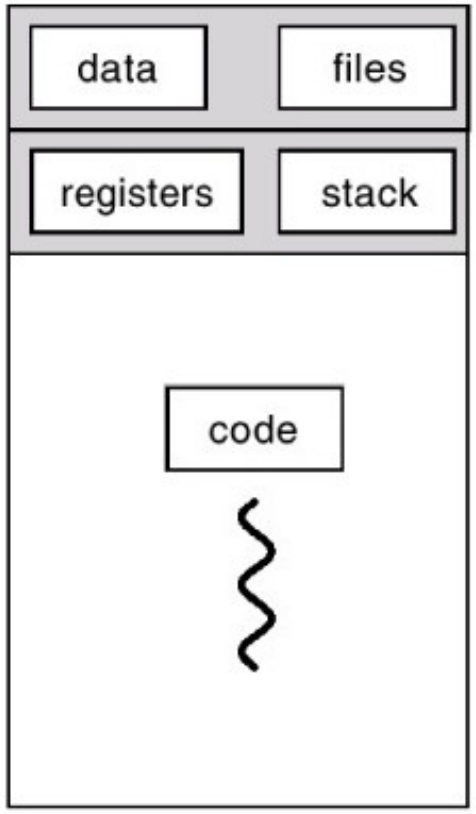
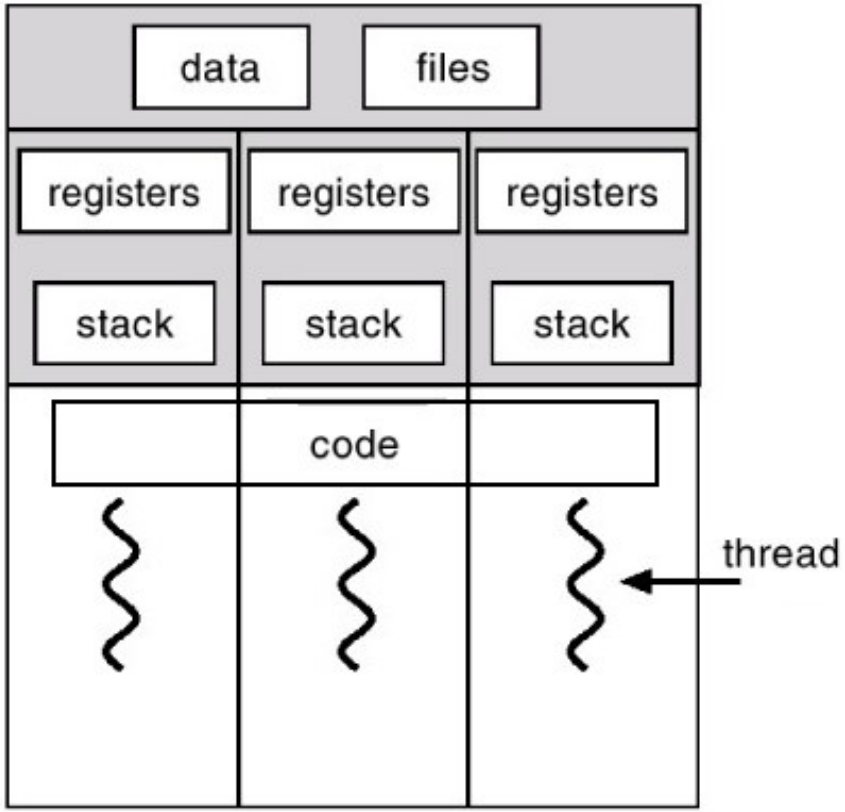
Processes

- Separate streams of execution
- Each process isolated from the other
- Process state contains
  - Process ID
  - Environment
  - Working directory.
  - Program instructions
  - Registers
  - Stack
  - Heap
  - File descriptors
- Created by the OS using fork
  - Significant overheads



Threads

- Separate streams of execution within a single process
- Threads in a process not isolated from each other
- Each thread state (thread control block) contains
  - Registers (including EIP, ESP)
  - stack



Why threads?

- Lightweight

Platform	fork()			pthread_create()		
	real	user	sys	real	user	sys
Intel 2.6 GHz Xeon E5-2670 (16 cores/node)	8.1	0.1	2.9	0.9	0.2	0.3
Intel 2.8 GHz Xeon 5660 (12 cores/node)	4.4	0.4	4.3	0.7	0.2	0.5
AMD 2.3 GHz Opteron (16 cores/node)	12.5	1.0	12.5	1.2	0.2	1.3
AMD 2.4 GHz Opteron (8 cores/node)	17.6	2.2	15.7	1.4	0.3	1.3
IBM 4.0 GHz POWER6 (8 cpus/node)	9.5	0.6	8.8	1.6	0.1	0.4
IBM 1.9 GHz POWER5 p5-575 (8 cpus/node)	64.2	30.7	27.6	1.7	0.6	1.1
IBM 1.5 GHz POWER4 (8 cpus/node)	104.5	48.6	47.2	2.1	1.0	1.5
INTEL 2.4 GHz Xeon (2 cpus/node)	54.9	1.5	20.8	1.6	0.7	0.9
INTEL 1.4 GHz Itanium2 (4 cpus/node)	54.5	1.1	22.2	2.0	1.2	0.6

Cost of creating 50,000 processes / threads
(https://computing.llnl.gov/tutorials/pthreads/)

- Efficient communication between entities
- Efficient context switching

Threads vs Processes

- A thread has no data segment or heap
- A thread cannot live on its own. It needs to be attached to a process
- There can be more than one thread in a process. Each thread has its own stack
- If a thread dies, its stack is reclaimed

- A process has code, heap, stack, other segments
- A process has at-least one thread.
- Threads within a process share the same I/O, code, files.
- If a process dies, all threads die.

Based on Junfeng Yang's lecture slides
http://www.cs.columbia.edu/~junfeng/13fa-w4118/lectures/l08-thread.pdf

pthread library

- Create a thread in a process

```
int pthread_create(pthread_t *thread,
                   const pthread_attr_t *attr,
                   void *(*start_routine) (void *),
                   void *arg);
```

Thread identifier (TID) much like

Pointer to a function, which starts execution in a different thread

Arguments to the function

- Destroying a thread

```
void pthread_exit(void *retval);
```

Exit value of the thread

pthread library contd.

- Join : Wait for a specific thread to complete

```
int pthread_join(pthread_t thread, void **retval);
```

TID of the thread to wait for

Exit status of the thread

what is the difference with wait()?

Example

```c
#include <pthread.h>
#include <stdio.h>

void *thread_fn(void *arg){
  long id = (long) arg;
  printf("Starting thread %ld\n", id);
  sleep(5);
  printf("Exiting thread %ld\n", id);
  return NULL;
}

int main(){
  pthread_t t1, t2;

  pthread_create(&t1, NULL, thread_fn, (void *)1);
  pthread_create(&t2, NULL, thread_fn, (void *)2);
  pthread_join(t1, NULL);
  pthread_join(t2, NULL);
  printf("Exiting main\n");
  return 0;
}
```

How many threads are there in this program? 3

Note. You need to link the pthread library

```
chester@optiplex:~/shared/OS/programs$ gcc threads.c -lpthread
chester@optiplex:~/shared/OS/programs$ ./a.out
Starting thread 1
Starting thread 2
Exiting thread 1
Exiting thread 2
Exiting main
```

Example

```c
#include <pthread.h>
#include <stdio.h>

void *thread_fn(void *arg){
  long id = (long) arg;
  printf("Starting thread %ld\n", id);
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int main(){
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  pthread_join(t2, NULL);
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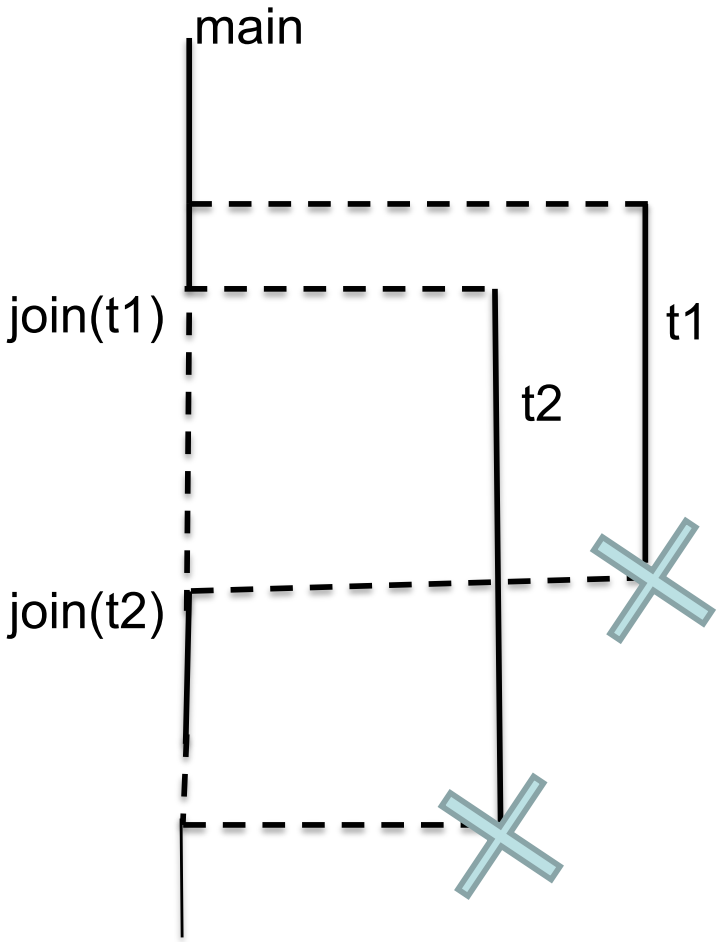
}
```



pthread_barrier

```
pthread_barrier_t barrier;

void *thread_fn(void *arg){
        long ld = (long) arg;
        printf ("Starting thread : %d\n", ld);

        sleep(5);
        printf ("%d: Hit Barrier A\n", ld);
        pthread_barrier_wait(&barrier);
        sleep(5);
        printf ("%d: Hit Barrier B\n", ld);
        pthread_barrier_wait(&barrier);

        exit(ld);
}

int main(){
        pthread_t t1, t2;

        pthread_barrier_init(&barrier, NULL, 3);

        printf("Creating threads\n");
        pthread_create(&t1, NULL, thread_fn, (void *)1);
        pthread_create(&t2, NULL, thread_fn, (void *)2);

        printf("0: Hit Barrier A\n");
        pthread_barrier_wait(&barrier);

        printf("0: Hit Barrier B\n");
        pthread_barrier_wait(&barrier);

        pthread_join(&t1, NULL);
        pthread_join(&t2, NULL);
        printf ("%d: Exit\n", 0);
}
```

Wait for 3 threads to hit the barrier

Define a barrier for 3 threads

pthread_barrier

```
pthread_barrier_t barrier;
```

```
void *thread_fn(void *arg){
        long ld = (long) arg;
        printf ("Starting thread : %d\n", ld);

        sleep(5);
        printf ("%d: Hit Barrier A\n", ld);
        pthread_barrier_wait(&barrier);
        sleep(5);
        printf ("%d: Hit Barrier B\n", ld);
        pthread_barrier_wait(&barrier);

        exit(ld);
}

int main(){
        pthread_t t1, t2;

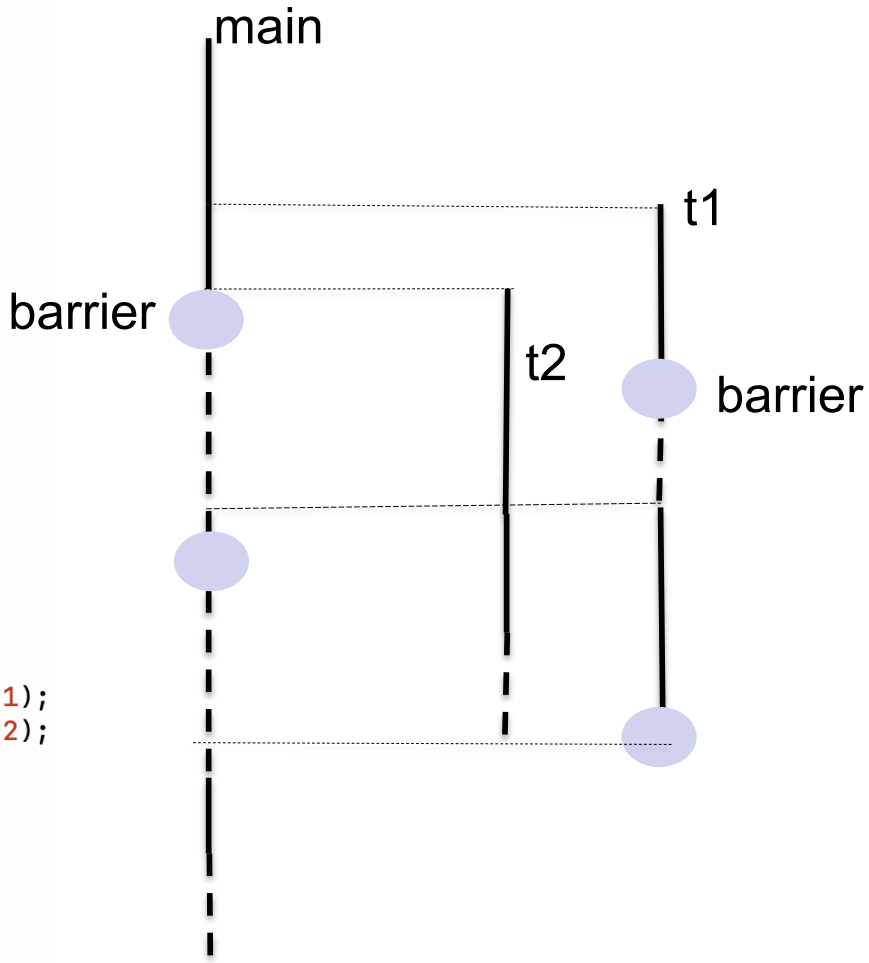
        pthread_barrier_init(&barrier, NULL, 3);

        printf("Creating threads\n");
        pthread_create(&t1, NULL, thread_fn, (void *)1);
        pthread_create(&t2, NULL, thread_fn, (void *)2);

        printf("0: Hit Barrier A\n");
        pthread_barrier_wait(&barrier);

        printf("0: Hit Barrier B\n");
        pthread_barrier_wait(&barrier);

        pthread_join(&t1, NULL);
        pthread_join(&t2, NULL);
        printf ("%d: Exit\n", 0);
}
```



pthread_barrier

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        long ld = (long) arg;
        printf ("Starting thread : %d\n", ld);

        sleep(5);
        printf ("%d: Hit Barrier A\n", ld);
        pthread_barrier_wait(&barrier);
        sleep(5);
        printf ("%d: Hit Barrier B\n", ld);
        pthread_barrier_wait(&barrier);

        exit(ld);
}

int main(){
        pthread_t t1, t2;

        pthread_barrier_init(&barrier, NULL, 3);

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        printf("0: Hit Barrier A\n");
        pthread_barrier_wait(&barrier);

        printf("0: Hit Barrier B\n");
        pthread_barrier_wait(&barrier);

        pthread_join(&t1, NULL);
        pthread_join(&t2, NULL);
        printf ("%d: Exit\n", 0);
}
```

```
chester@optiplex:~/work/riscv/tmp$ ./a.out
Creating threads
Starting thread : 1
Starting thread : 2
0: Hit Barrier A
1: Hit Barrier A
2: Hit Barrier A
0: Hit Barrier B
1: Hit Barrier B
2: Hit Barrier B
```

Other thread libraries

- Windows threads
- Boost (in C++)
- LinuxThreads
- OpenMP
- etc.

Who manages threads?

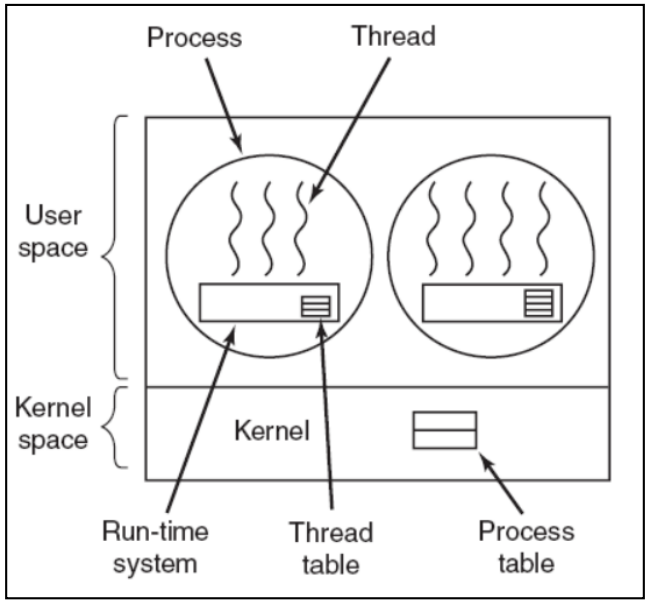
- Two strategies
  - User threads
    - Thread management done by user level thread library. Kernel knows nothing about the threads.
  - Kernel threads
    - Threads directly supported by the kernel.
    - Known as light weight processes.

User level threads

- Advantages:
  - Fast (really lightweight)

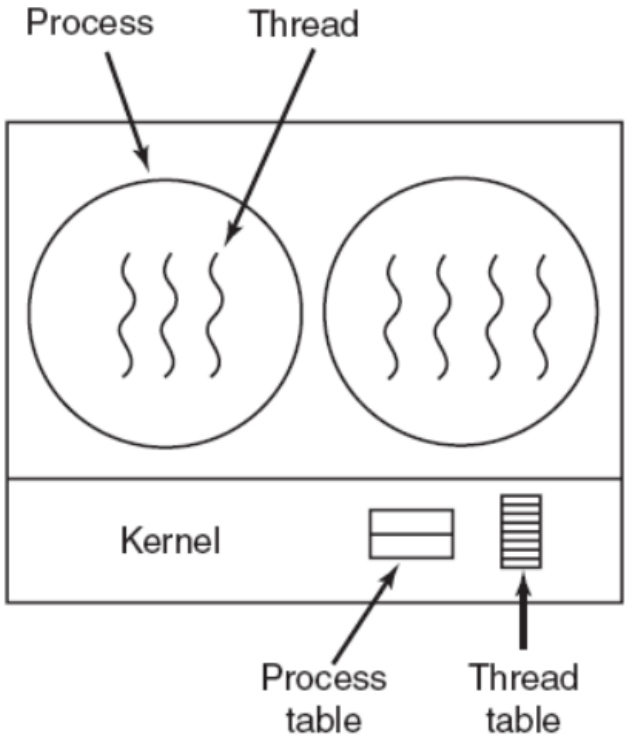
    (no system call to manage threads. The thread library does everything).
  - Can be implemented on an OS that does not support threading.
  - Switching is fast. No, switch from user to protected mode.

- Disadvantages:
  - Scheduling can be an issue. (Consider, one thread that is blocked on an IO and another runnable.)
  - Lack of coordination between kernel and threads. (A process with 1000 threads competes for a timeslice with a process having just 1 thread.)
  - Requires non-blocking system calls. (If one thread invokes a system call, all threads need to wait)



Kernel level threads

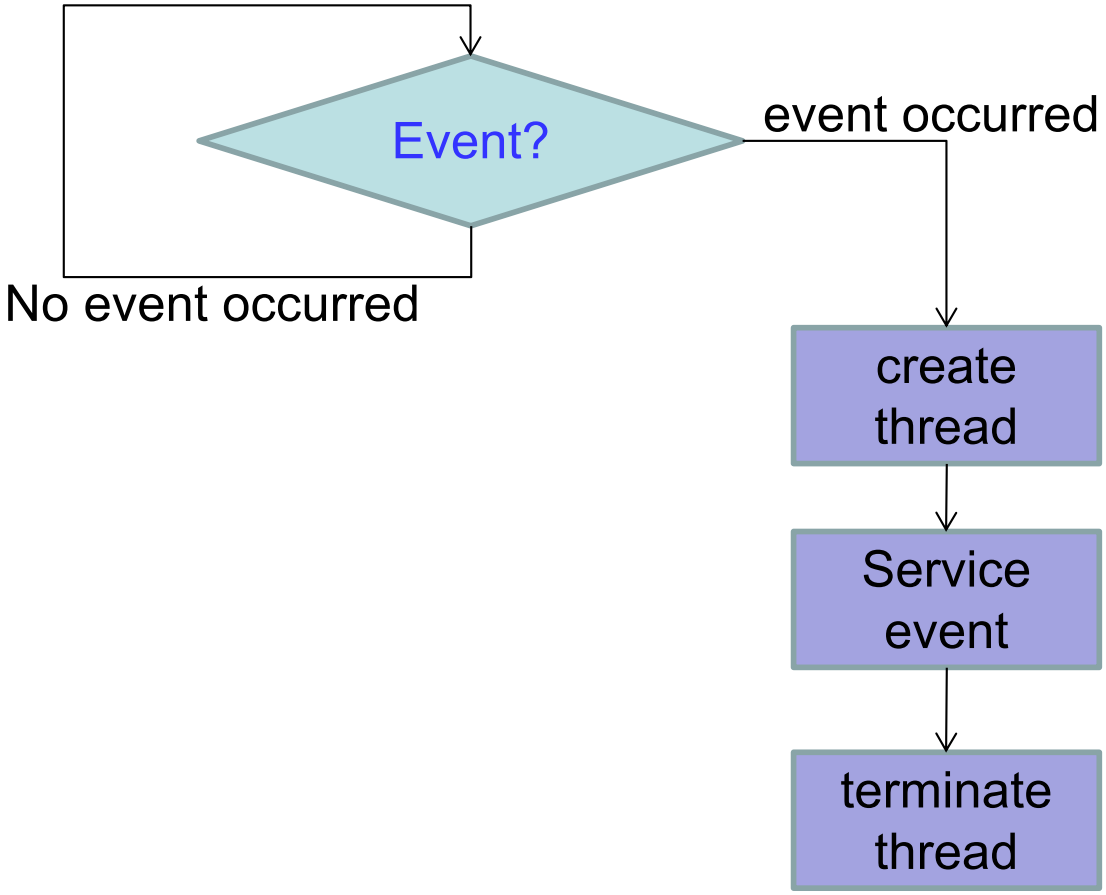
- Advantages:
  - Scheduler can decide to give more time to a process having large number of threads than process having small number of threads.
  - Kernel-level threads are especially good for applications that frequently block.
- Disadvantages:
  - The kernel-level threads are slow (they involve kernel invocations.)
  - Overheads in the kernel. (Since kernel must manage and schedule threads as well as processes. It require a full thread control block (TCB) for each thread to maintain information about threads.)



Threading issues

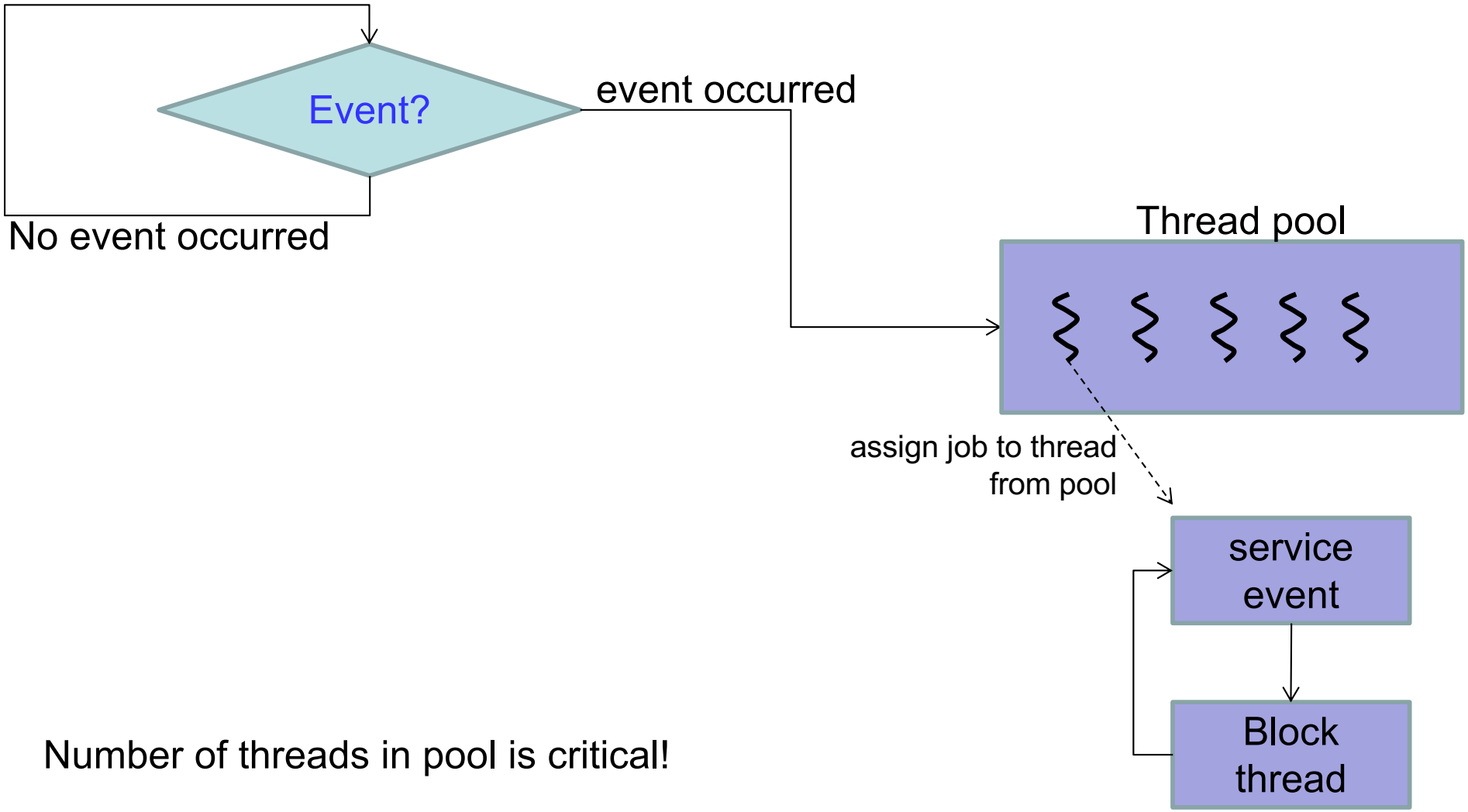
- What happens when a thread invokes fork?
  - Duplicate all threads?
    - Not easily done… other threads may be running or blocked in a system call
  - Duplicate only the caller thread?
    - More feasible.
- Segmentation fault in a thread. Should only the thread terminate or the entire process?

Typical usage of threads



Creating and terminating thread lead to overheads

Thread pools



Number of threads in pool is critical!