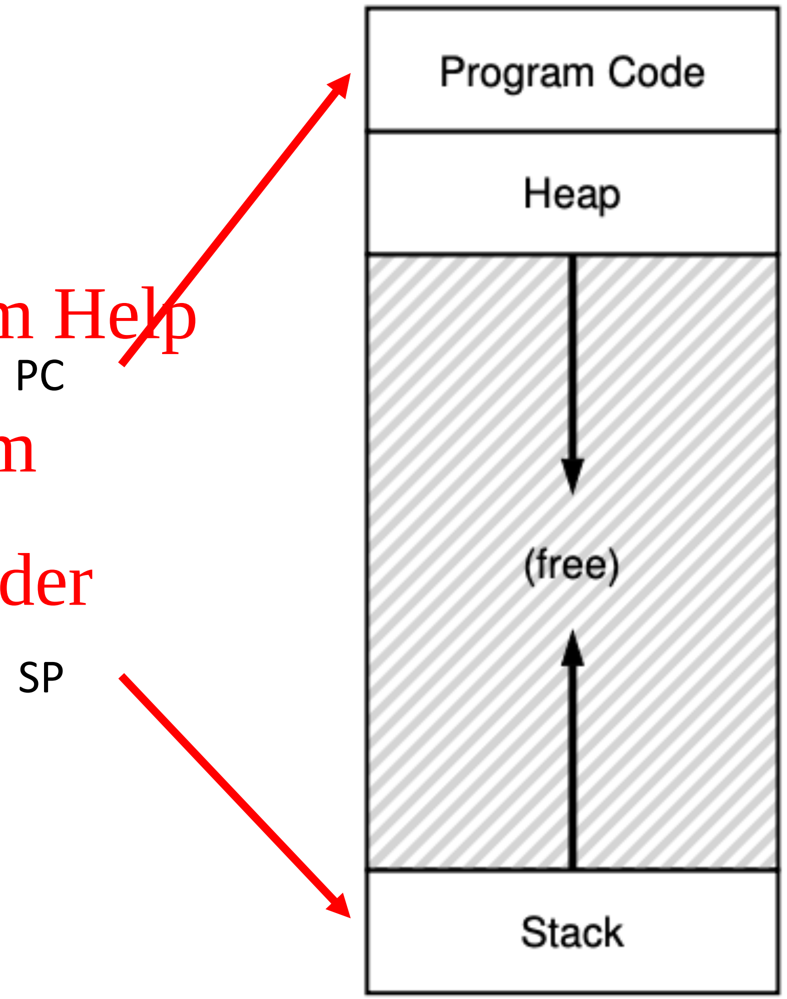
CS:3620 Operating Systems

Threads and Concurrency

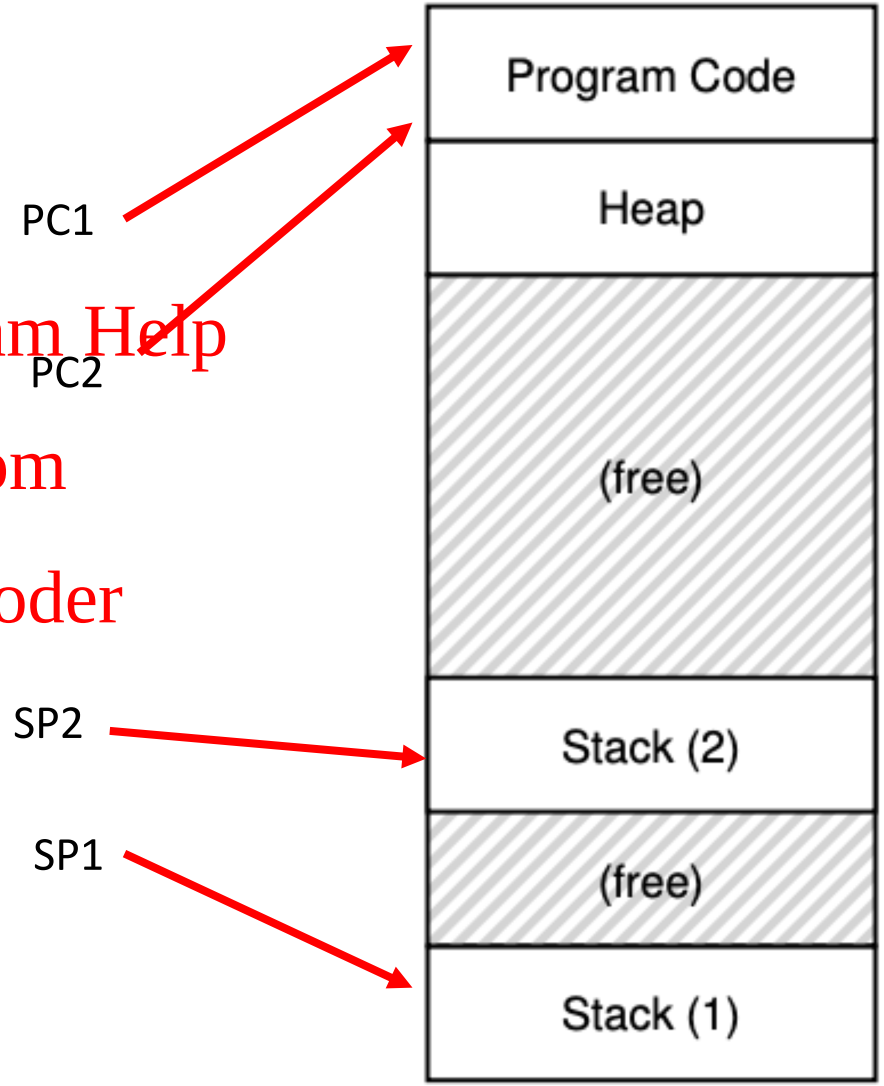
Single threaded process

- So, far we have studied single threaded programs
- Recap: process execution
  - PC points to current instruction being run
  - SP points to stack frame of current function call
- A program can also have multiple threads of execution
- What is a thread?



Multi threaded process

- A thread is like another copy of a process that executes independently
- Threads shares the same address space (code, heap)
- Each thread has separate PC
  - Each thread may run over different part of the program
- Each thread has separate stack for independent function calls



Process vs. threads

- Parent P forks a child C
  - P and C do not share any memory
  - Need complicated IPC mechanisms to communicate
  - Extra copies of code, data in memory

- Parent P executes two threads T1 and T2
  - T1 and T2 share parts of the address space
  - Global variables can be used for communication
  - Smaller memory footprint

- Threads are like separate processes, except they share the same address space

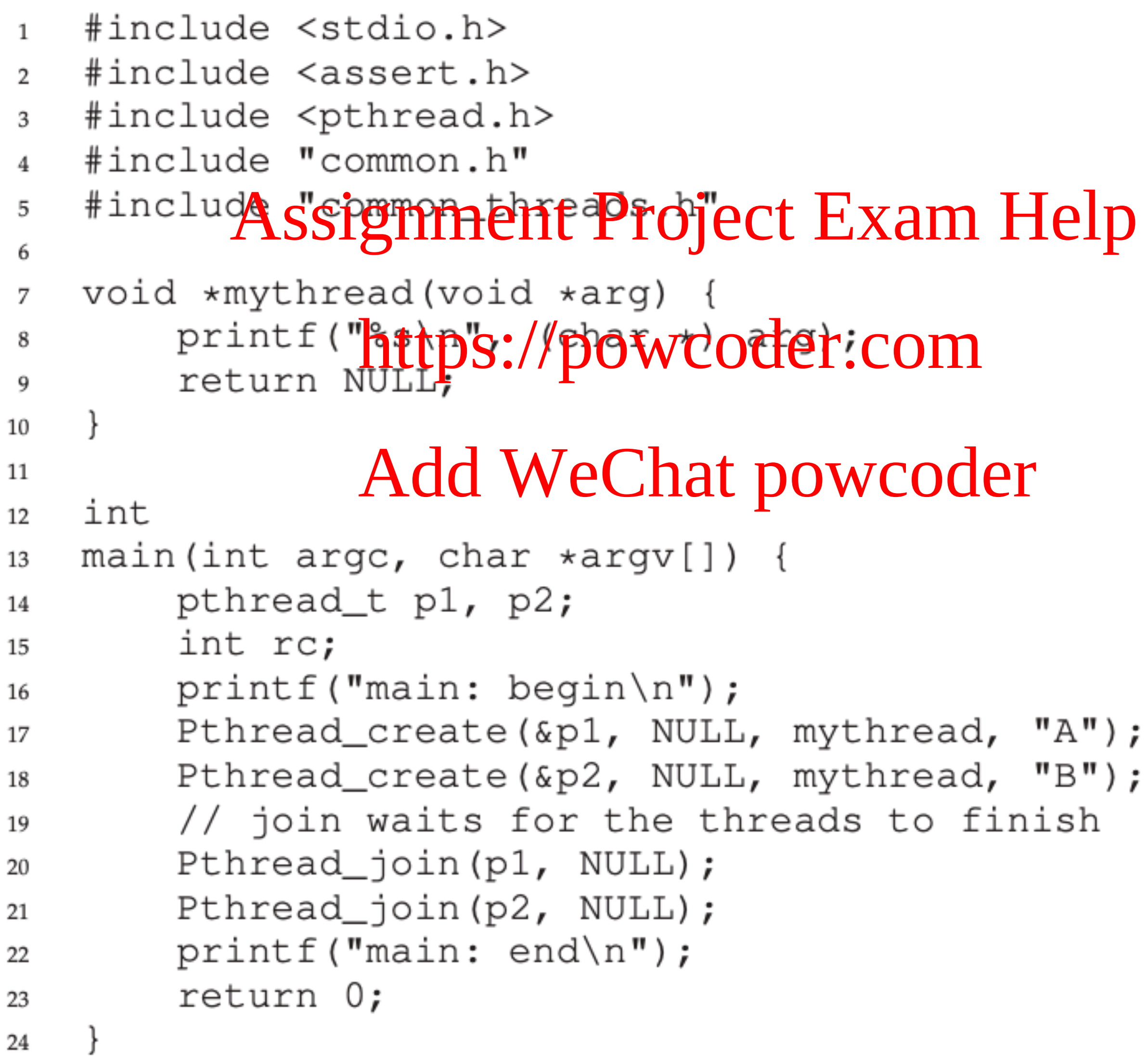
Why threads?

- Parallelism: a single process can effectively utilize multiple CPU cores
  - Understand the difference between concurrency and parallelism
  - Concurrency: running multiple threads/processes at the same time, even on single CPU core, by interleaving their executions
  - Parallelism: running multiple threads/processes in parallel over different CPU cores
- Even if no parallelism, concurrency of threads ensures effective use of CPU when one of the threads blocks (e.g., for I/O)

Scheduling threads

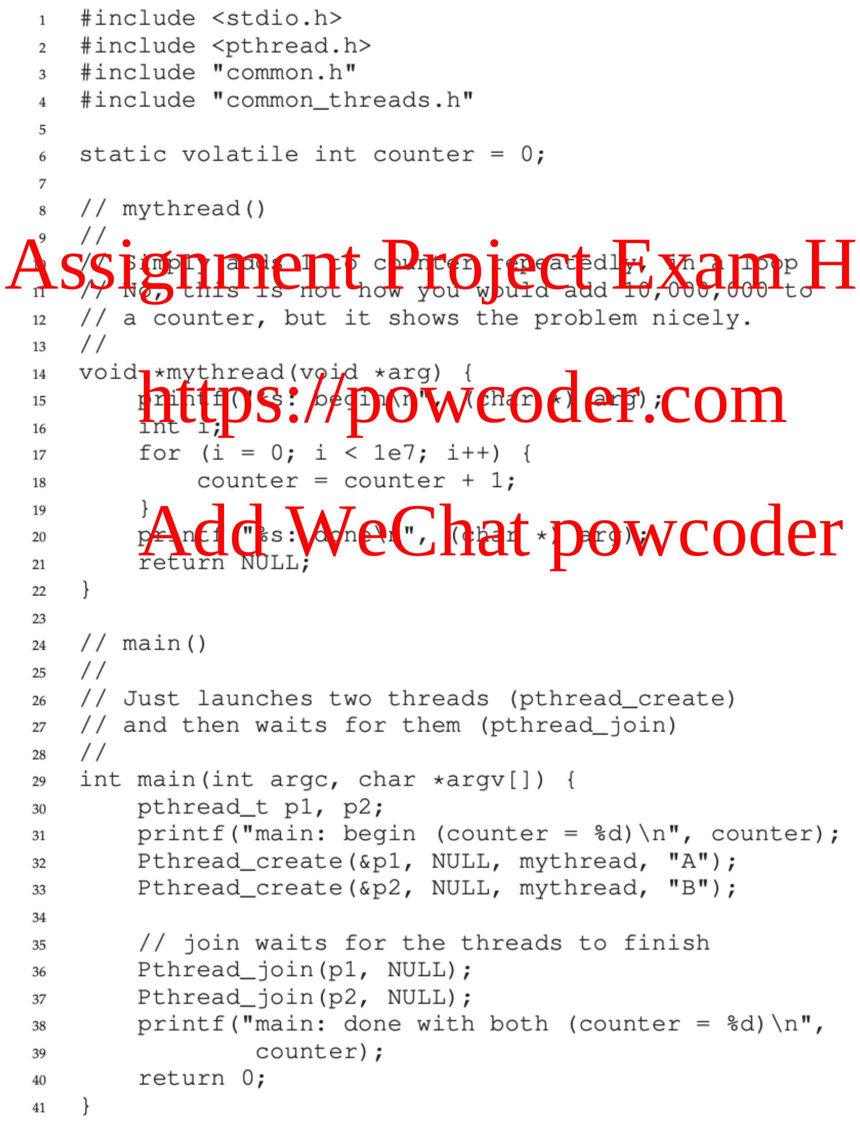
- OS schedules threads that are ready to run independently, much like processes
- The context of a thread (PC, registers) is saved into/restored from thread control block (TCB)
  - Every PCB has one or more linked TCBs
- Threads that are scheduled independently by kernel are called kernel threads
  - E.g., Linux pthreads are kernel threads
- In contrast, some libraries provide user-level threads
  - User program sees multiple threads
  - Library multiplexes larger number of user threads over a smaller number of kernel threads
  - Low overhead of switching between user threads (no expensive context switch)
  - But multiple user threads cannot run fully in parallel

Creating threads using pthreads API



```
#include <stdio.h>
#include <assert.h>
#include <pthread.h>
#include "common.h"
#include "common_threads.h"

void *mythread(void *arg) {
    printf("%s\n", (char *) arg);
    return NULL;
}

int
main(int argc, char *argv[]) {
    pthread_t p1, p2;
    int rc;
    printf("main: begin\n");
    Pthread_create(&p1, NULL, mythread, "A");
    Pthread_create(&p2, NULL, mythread, "B");
    // join waits for the threads to finish
    Pthread_join(p1, NULL);
    Pthread_join(p2, NULL);
    printf("main: end\n");
    return 0;
}
```

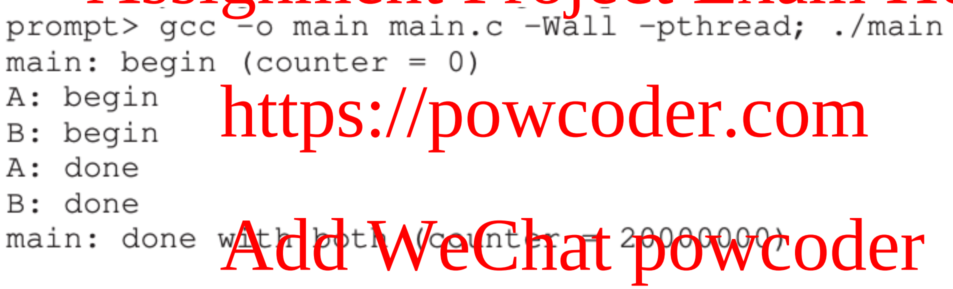
Example: threads with shared data



```
#include <stdio.h>
#include <pthread.h>
#include "common.h"
#include "common_threads.h"

static volatile int counter = 0;

// mythread()
//
// Simply adds 1 to counter repeatedly, in a loop
// No, this is not how you would add 10,000,000 to
// a counter, but it shows the problem nicely.
//
void *mythread(void *arg) {
    printf("%s: begin\n", (char *) arg);
    int i;
    for (i = 0; i < 1e7; i++) {
        counter = counter + 1;
    }
    printf("%s: done\n", (char *) arg);
    return NULL;
}

// main()
//
// Just launches two threads (pthread_create)
// and then waits for them (pthread_join)
//
int main(int argc, char *argv[]) {
    pthread_t p1, p2;
    printf("main: begin (counter = %d)\n", counter);
    Pthread_create(&p1, NULL, mythread, "A");
    Pthread_create(&p2, NULL, mythread, "B");

    // join waits for the threads to finish
    Pthread_join(p1, NULL);
    Pthread_join(p2, NULL);
    printf("main: done with both (counter = %d)\n",
            counter);
    return 0;
}
```

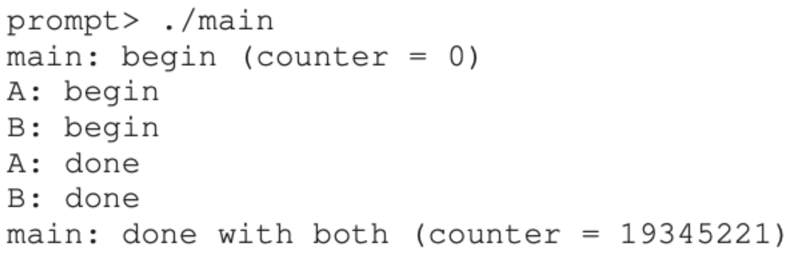
Threads with shared data: what happens?

- What do we expect? Two threads, each increments counter by 10^7, so 2X10^7



```
prompt> gcc -o main main.c -Wall -pthread; ./main
main: begin (counter = 0)
A: begin
B: begin
A: done
B: done
main: done with both (counter = 20000000)
```

- Sometimes, a lower value. Why?



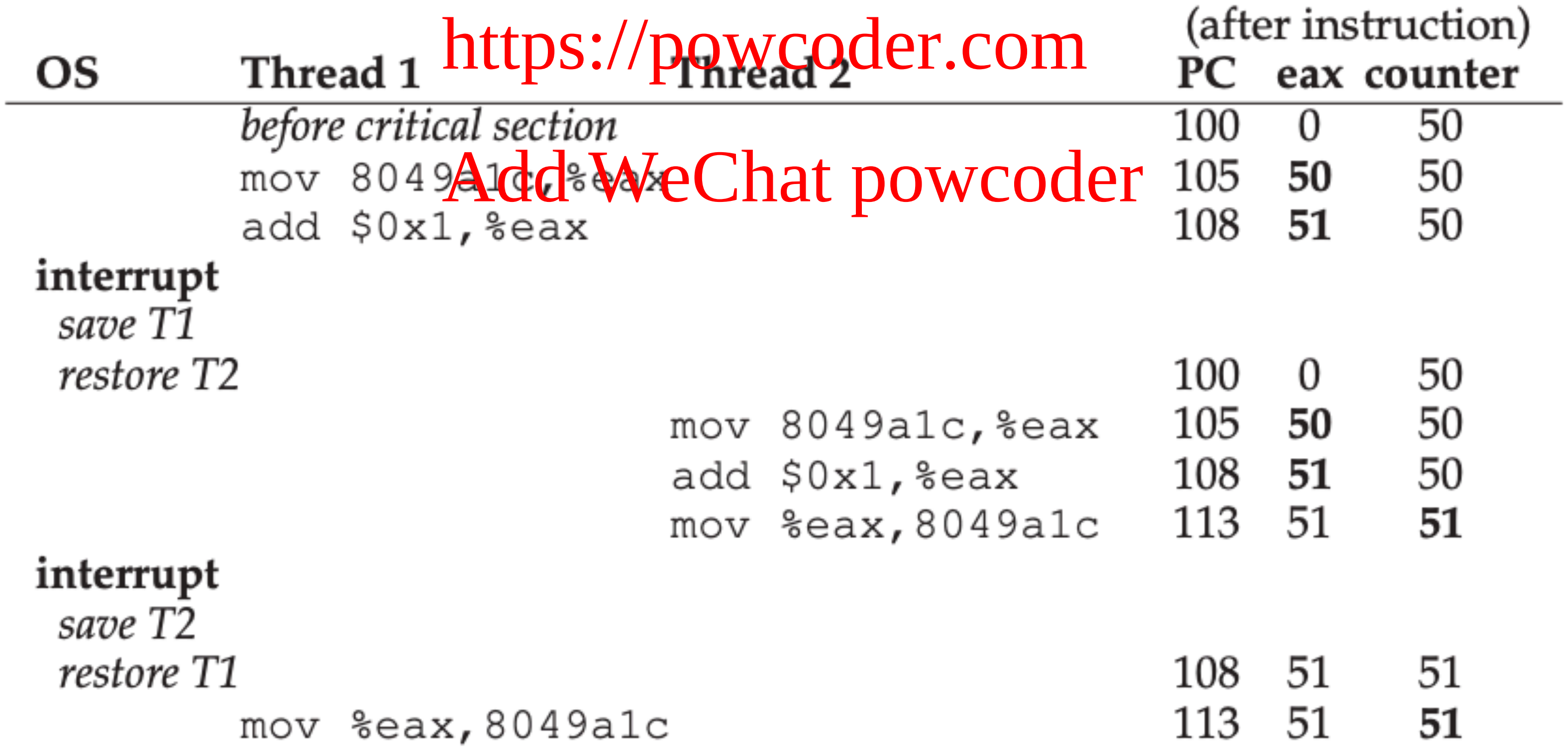
```
prompt> ./main
main: begin (counter = 0)
A: begin
B: begin
A: done
B: done
main: done with both (counter = 19345221)
```

What is happening?

- Assembly code of

counter = counter + 1

```
100: mov 0x8049a1c, %eax
105: add $0x1, %eax
108: mov %eax, 0x8049a1c
```



			(after instruction)		
OS	**Thread 1**	**Thread 2**	**PC**	**eax**	**counter**
	before critical section		100	0	50
	`mov 8049a1c,%eax`		105	**50**	50
	`add $0x1,%eax`		108	**51**	50
interrupt					
save T1					
restore T2			100	0	50
		`mov 8049a1c,%eax`	105	**50**	50
		`add $0x1,%eax`	108	**51**	50
		`mov %eax,8049a1c`	113	51	**51**
interrupt					
save T2					
restore T1			108	51	51
	`mov %eax,8049a1c`		113	51	**51**

Race conditions and synchronization

- What just happened is called a race condition
  - Concurrent execution can lead to different results
- Critical section: portion of code that can lead to race conditions
- What we need: mutual exclusion
  - Only one thread should be executing critical section at any time
- What we need: atomicity of the critical section
  - The critical section should execute like one uninterruptible instruction
- How is it achieved? Locks (topic of next lecture)

Disclaimer

- *These lecture slides are based on a slide set by Youjip Won (Hanyang University) and Mythili Vutukuru (IIT Bombay)*