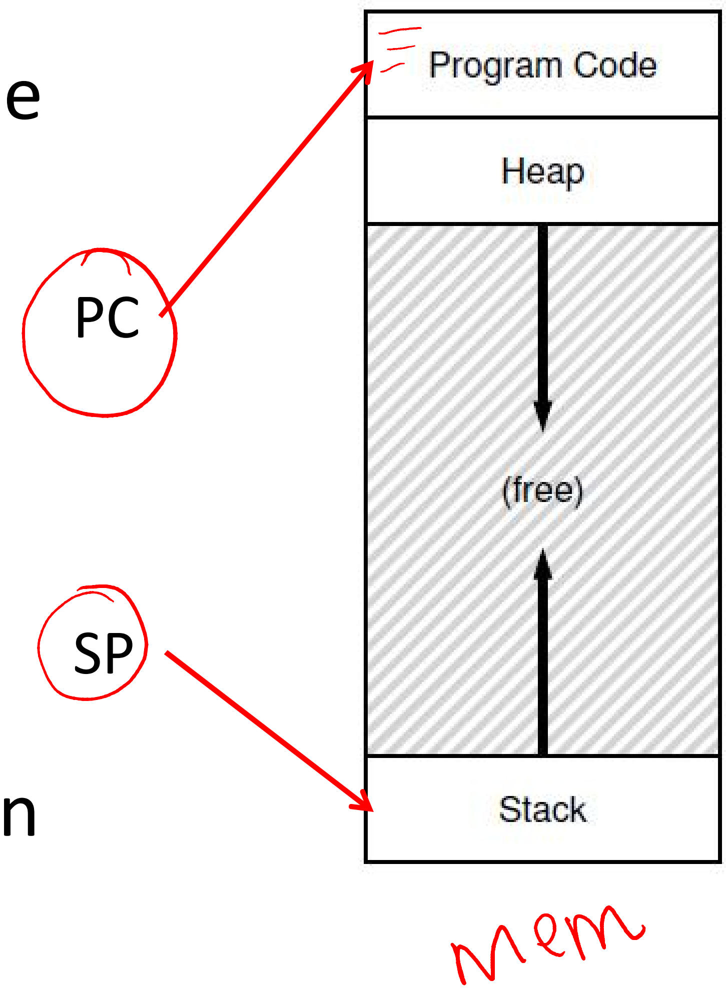
Lecture 12: Threads and Concurrency

Mythili Vutukuru
IIT Bombay

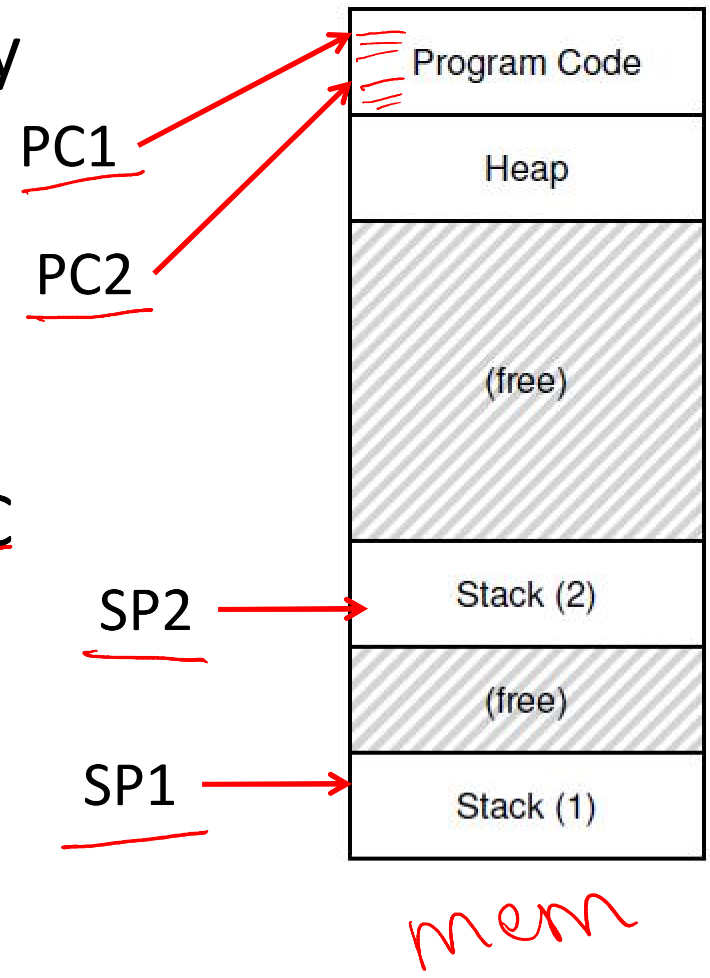
Single threaded process

- 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?

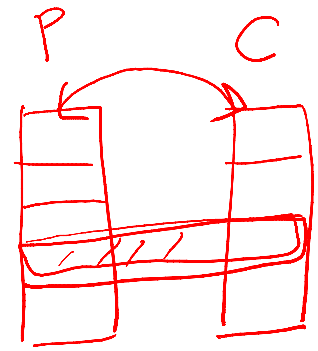


Multi threaded process

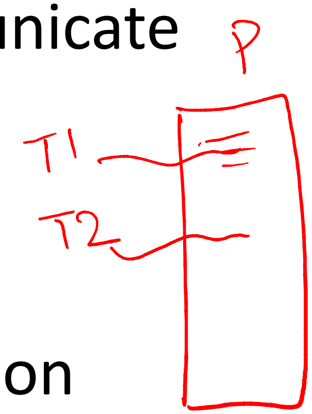
- A thread is like another copy of a process that executes independently
- Threads shares the same address space (code, heap)
- Each thread has separate PC
  - Each thread may run over different part of the program
- Each thread has separate stack for independent function calls



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



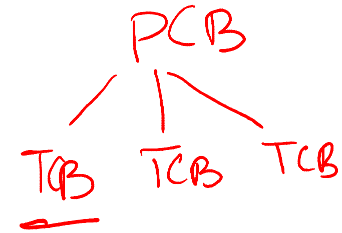
- Parent P executes two threads T1 and T2
  - T1 and T2 share parts of the address space
  - Global variables can be used for communication
  - Smaller memory footprint
- Threads are like separate processes, except they share the same address space

Why threads?

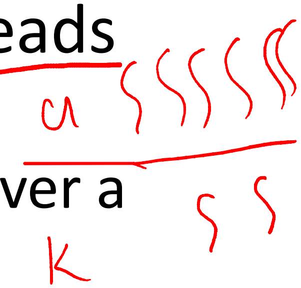
- Parallelism: a single process can effectively utilize multiple CPU cores
  - Understand the difference between concurrency and parallelism
  - Concurrency: running multiple threads/processes at the same time, even on single CPU core, by interleaving their executions
  - Parallelism: running multiple 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 in parallel



Creating threads using pthreads API

```c
#include <stdio.h>
#include <assert.h>
#include <pthread.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");
    rc = pthread_create(&p1, NULL, mythread, "A"); assert(rc == 0);
    rc = pthread_create(&p2, NULL, mythread, "B"); assert(rc == 0);
    // join waits for the threads to finish
    rc = pthread_join(p1, NULL); assert(rc == 0);
    rc = pthread_join(p2, NULL); assert(rc == 0);
    printf("main: end\n");
    return 0;
}
```

Figure 26.2: **Simple Thread Creation Code (t0.c)**

Example: threads with shared data

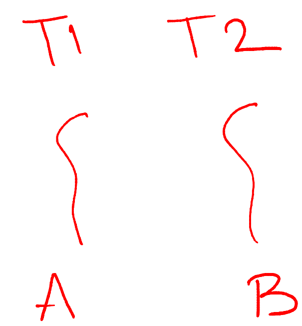
```

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
prompt> ./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
```

OS	Thread 1	Thread 2	(after instruction) PC	%eax	counter
	before critical section		100	0	50
	mov 0x8049a1c, %eax		105	**50**	50
	add $0x1, %eax		108	**51**	50
interrupt					
save T1's state					
restore T2's state			100	0	50
		mov 0x8049a1c, %eax	105	**50**	50
		add $0x1, %eax	108	**51**	50
		mov %eax, 0x8049a1c	113	51	**51**
interrupt					
save T2's state					
restore T1's state			108	51	51
	mov %eax, 0x8049a1c		113	51	**51**

Figure 26.7: **The Problem: Up Close and Personal**

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)