Threads and concurrency

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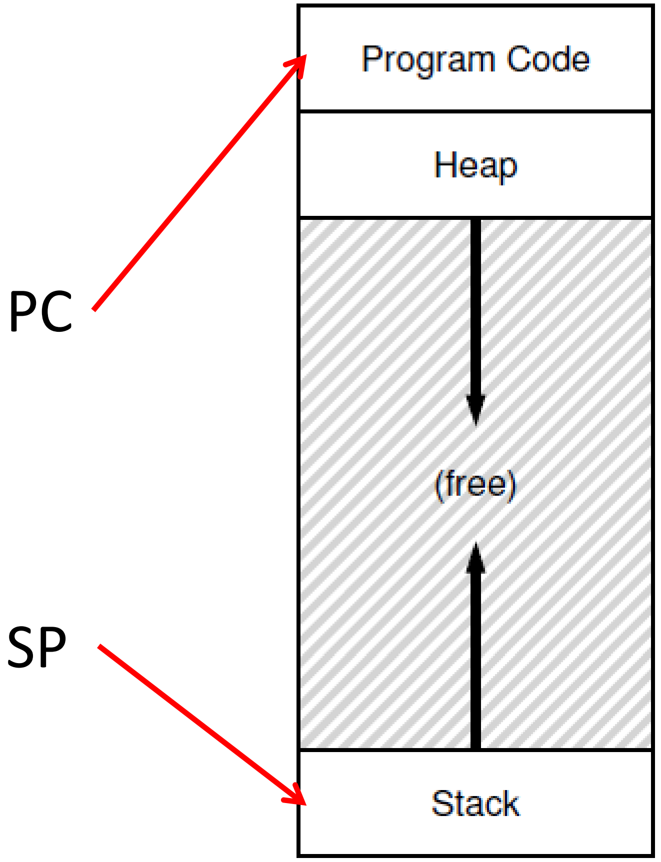
Processes and threads

- So, far we have studied single threaded programs
- Recap: process execution
  - CPU executes instruction by instruction, traps to OS as needed
  - PC points to next instruction to run
  - SP points to current top of stack
  - Other registers also with process context
- A program can also have multiple threads of execution
- What is a thread?



What are threads?

- Threads = light weight processes
- Why? A process may want to run multiple copies of itself
  - If one copy blocks due to blocking system call, another copy can still run
  - Multiple copies can run in parallel on multiple CPU cores
- Why not have multiple child processes running the same program?
  - Too much memory consumed by identical memory images
  - Needs IPC to share information across processes
- A process can create multiple threads (default: single thread)
  - Multiple threads share same memory image of process, saves memory
  - Threads run independently on same code (if one blocks, another can still run)
  - Threads can run in parallel on multiple cores at same time
  - Threads can share data more easily

Multi-threaded process

- A thread is like another copy of a process that executes independently from parent
- Threads shares the same code, global/static data, heap
- Each thread has separate stack for independent function calls
- Each thread has separate PC, running different code
- Each thread has separate CPU context during execution

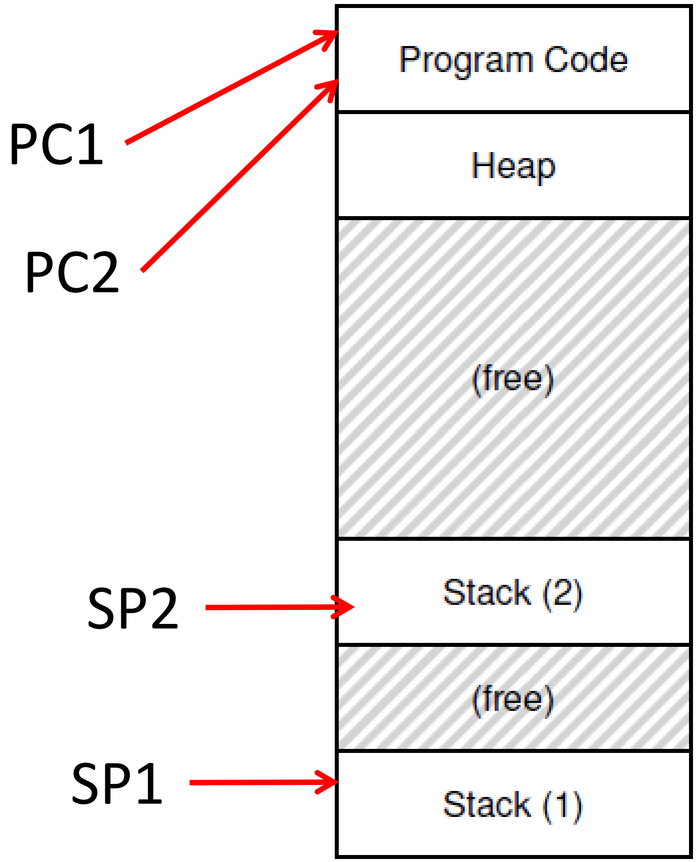


Image credit: OSTEP

Concurrency vs. parallelism

- 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
- With multiple threads, process can get better performance on multicore systems via parallelism
- Even if no parallelism (single core), concurrency of threads ensures effective use of CPU when one of the threads blocks (e.g., for I/O)

POSIX threads

- In Linux, POSIX threads (pthreads) library allows creation of multiple threads in a process
- Each thread is given a start function where its execution begins
  - Threads execute independently from parent after creation
  - Parent can wait for threads to finish (optional)
- Several such threading libraries exist in different programming languages

```
void f1() {
    …
}

void f2() {
    …
}

main() {
    …
    pthread_t t1, t2
    pthread_create(&t1, .., f1,..)
    pthread_create(&t2, .., f2,..)
    …

    pthread_join(t1, ..)
    pthread_join(t2, ..)

}
```

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)**

Scheduling threads

- OS schedules threads that are ready to run independently, 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, but kernel is aware of fewer threads
  - Multiple such user threads are seen as one thread by kernel, may not be scheduled in parallel for this reason
  - Why use user threads then? Ease of programming

Example: threads with shared data

- Shared global counter
- Two threads update same counter 10^7 times
- What is expected output after both threads finish?

```c

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)
```

Understanding shared data access

- The C code “counter = counter + 1” is compiled into multiple instructions
  - Load counter variable from memory into register
  - Increment register
  - Store register back into memory of counter variable

```
load counter → reg
reg = reg + 1
store reg → counter
```

Understanding shared data access

- What happens when two threads run this line of code concurrently?
  - Counter is 0 initially
  - T1 loads counter into register, increment reg
  - Context switch, register (value 1) saved
  - T2 runs, loads counter 0 from memory
  - T2 increments register, stores to memory
  - T1 resumes, stores register value to counter
  - Counter value rewritten to 1 again
  - Final counter value is 1, expected value is 2

T1

load counter → reg
reg = reg + 1
(context switch, save reg)

T2

load counter → reg
reg = reg + 1
store reg → counter

(resume, restore reg)
store reg → counter

Race conditions, critical sections

- Incorrect execution of code due to concurrency is called race condition
  - Due to unfortunate timing of context switches, atomicity of data update violated
- Race conditions happen when we have concurrent execution on shared data
  - Threads sharing common data in memory image of user processes
  - Processes in kernel mode sharing OS data structures
- We require mutual exclusion on some parts of user or OS code
  - Concurrent execution by multiple threads/processes should not be permitted
- Parts of program that need to be executed with mutual exclusion for correct operation are called critical sections
  - Present in multi-threaded programs, OS code
- How to access critical sections with mutual exclusion? Using locks (next topic)