CSE 323: Operating System Design
Thread

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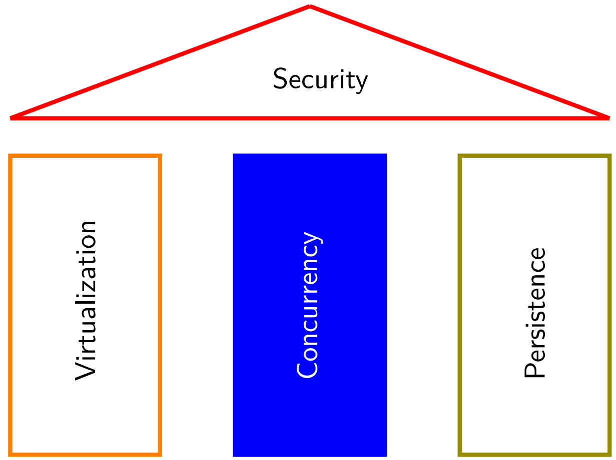
Concurrency



Lecture Topics

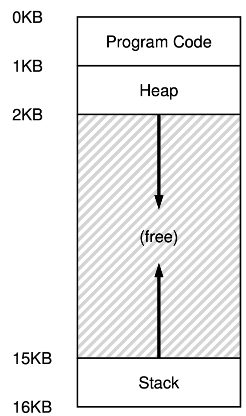
- Thread abstraction
- Multi-threading challenges
- Key concurrency terms and definitions

This slide deck covers chapters 26 and 27 in OSTEP.

[**Credits**: Portions of the content are adapted from slides based on the OSTEP book by Prof. Youjip Won (Hanyang University) and Prof. Mythili Vutukuru (IIT Bombay), with thanks.]

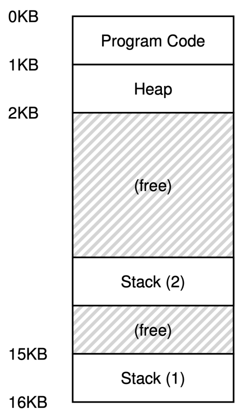
Threads: Executions context

- Threads are independent execution context
  - similar to processes
  - EXCEPT they share the same address space
- We only had one thread in a process so far
  - single-threaded program
  - one Program Counter (PC)
  - one Stack Pointer (SP)



Multi-threaded Process

- **What happens if we want multiple threads in parallel?**
  - shared address space but separate execution stream
  - is that possible with a shared stack or PC?
  - each thread has separate stack and PC
    - leading to independent function calls
    - able to execute different parts
  - code and heap segments are still shared



- ***user-level threads***: scheduled by thread library in user space
- ***kernel-level threads***: scheduled directly by the OS

Threads & Concurrency

Concurrency vs Parallelism

- **Concurrency**: multiple processes/threads making progress during the same time period
  - Possibly on a single core by interleaving executions
  - Better CPU utilization (e.g., when one thread is blocked on I/O, another runs)
- **Parallelism**: running multiple processes in parallel over multiple CPU cores
  - A single process can achieve paralellism with multiple threads

How do they communicate?

- Processes need complicated Inter-Process Communication
- Extra memory footprint for IPC
- Threads can do it by simply using global variables (shared)
- **Question:** When to use threads vs processes?

Creating Threads

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

#include "common.h"
#include "common_threads.h"

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

```c
int main(int argc, char *argv[]) {
    if (argc != 1) {
      fprintf(stderr, "usage: main\n");
      exit(1);
    }

    pthread_t p1, p2;
    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;
}
```


Shared data is useful but not so simple!

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

// shared global variables
int max;
volatile int counter = 0;
// ^ no caching on register

void *mythread(void *arg) {
  char *letter = arg;
  int i; // on stack
         // (private per thread)
  printf("%s: begin \
          [addr of i: %p]\n",
          letter, &i);
  for (i = 0; i < max; i++) {
    counter = counter + 1;
    // shared: only one
  }
  printf("%s: done\n", letter);
  return NULL;
}
```

```c
int main(int argc, char *argv[]) {
  if (argc != 2) {
    fprintf(stderr, \
    "usage: main-first <loopcount>\n");
    exit(1);
  }
  max = atoi(argv[1]);

  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 \
        [counter: %d] \
        [should: %d]\n",
        counter, max*2);
  return 0;
}
```

Will the final count always be $2 \times$ max?

Uncontrolled Scheduling

- assembly instructions for `counter = counter + 1` (in x86)

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

[Critical Section] consider a context switch after 'add'.

			(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

Concurrency Terms

Race Condition

Concurrent execution of threads leading to different results depending on the order of execution. Such programs are *indeterminate*, producing different outputs across runs.

Critical Section

Portion of code resulting in a race condition, usually by accessing a *shared* resource (e.g., a variable or data structure).

Mutual Exclusion

Guarantees a single thread executes a critical section at a time, preventing race conditions. [**Atomicity**]
Next: We need to design synchronization primitives for **mutex**.