



CS3281 / CS5281

Concurrent Programming

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Fall 2025

**Some lecture slides borrowed and adapted from CMU's
"Computer Systems: A Programmer's Perspective"*



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Motivation

- Idea: Use multiple processes to “collaborate” to accomplish work faster
 - A process may be able to run while another waits for some event
 - e.g., when a web server receives a request from a client, it creates a child process to service the request
 - The web server may be very busy, receiving many requests. Process creation is time consuming and uses a lot of resources. It is not worth the time and resource because the new process does the same tasks as the other processes

Motivation

- Idea: Use multiple threads in a process to do the work
 - Divide up work between two or more threads
 - For example, the web server listens for the client requests. When a request is made, the server creates a new thread to service the request. The server resumes listening for the additional requests

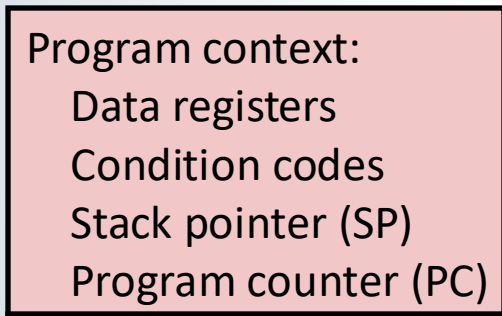
Terminology

- Concurrent programming: a programming paradigm in which multiple tasks are executed in overlapping periods
 - Enables multiple operations to be executed concurrently (or in parallel) without adversely affecting the final outcome
- Benefits
 - Speed & responsiveness
 - Better resource utilization
 - Scalability in modern architectures

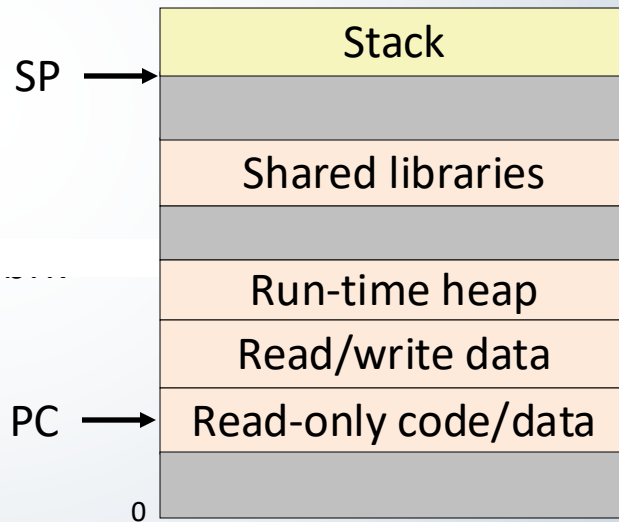
Traditional View of a Process

- Process = process context + code, data, and stack

Process context



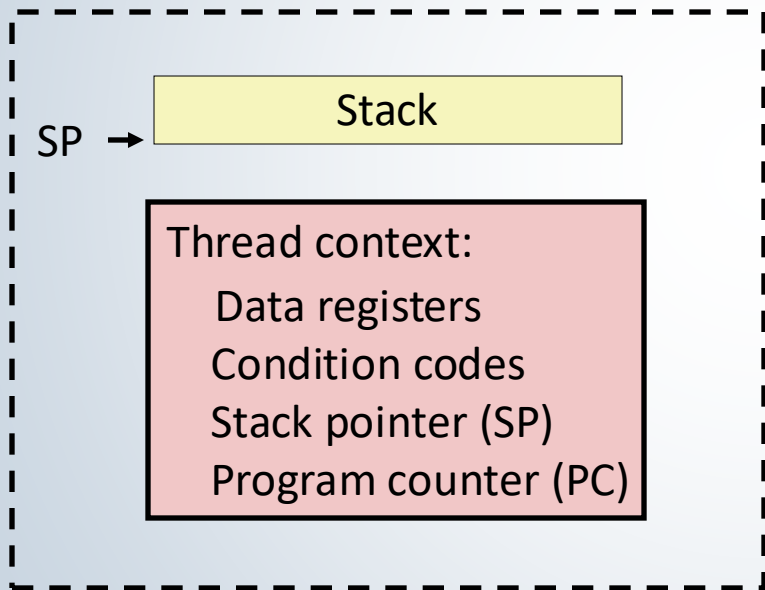
Code, data, and stack



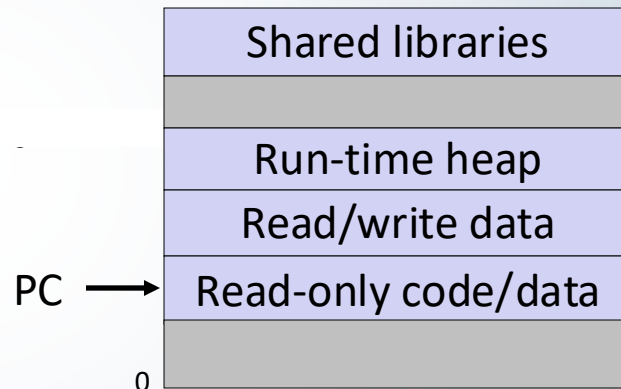
Alternate View of a Process

- Process = thread + code and data

Thread



Code and data



A Process with Multiple Threads

- Multiple threads can be associated with a process
 - Each thread has its own logical control flow
 - Each thread shares the same code and data (unlike processes)
 - Each thread has its own stack for local variables
 - but not protected from other threads – why?
 - Each thread has its own thread id (TID)

Thread 1 (main thread)

stack 1

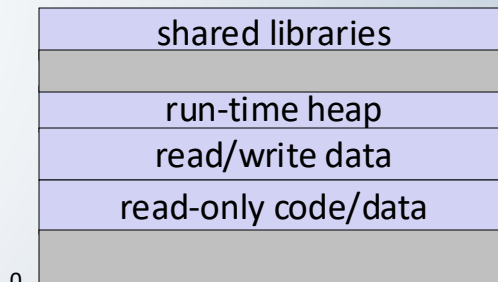
Thread 1 context:
Data registers
Condition codes
SP1
PC1

Thread 2 (peer thread)

stack 2

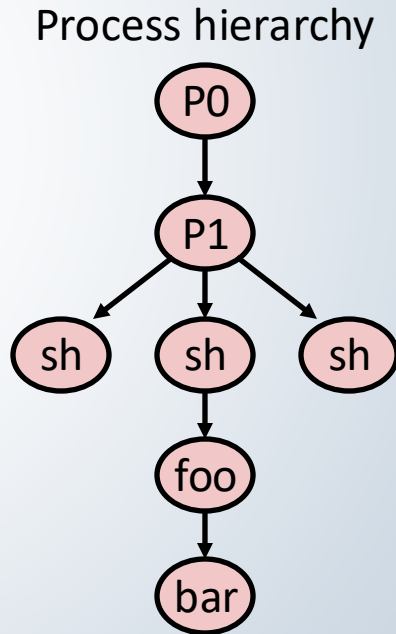
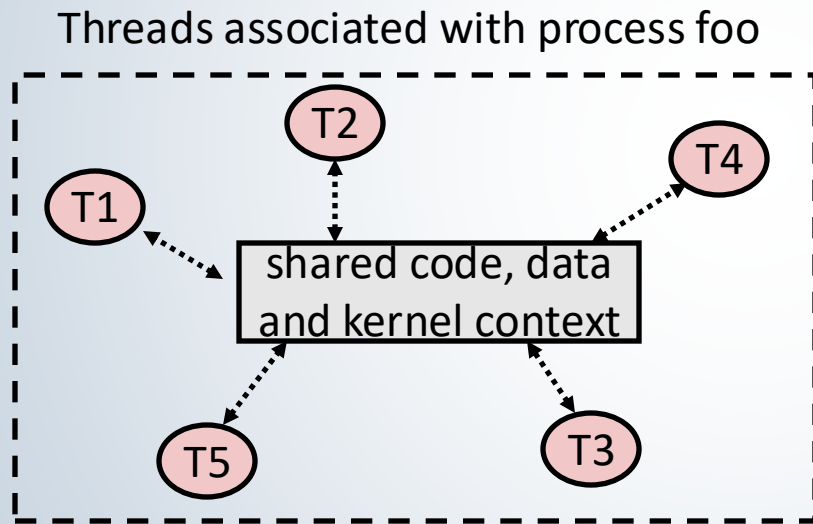
Thread 2 context:
Data registers
Condition codes
SP2
PC2

Shared code and data



Logical View of Threads

- Threads associated with process form a pool of peers
 - Unlike processes, which form a tree hierarchy

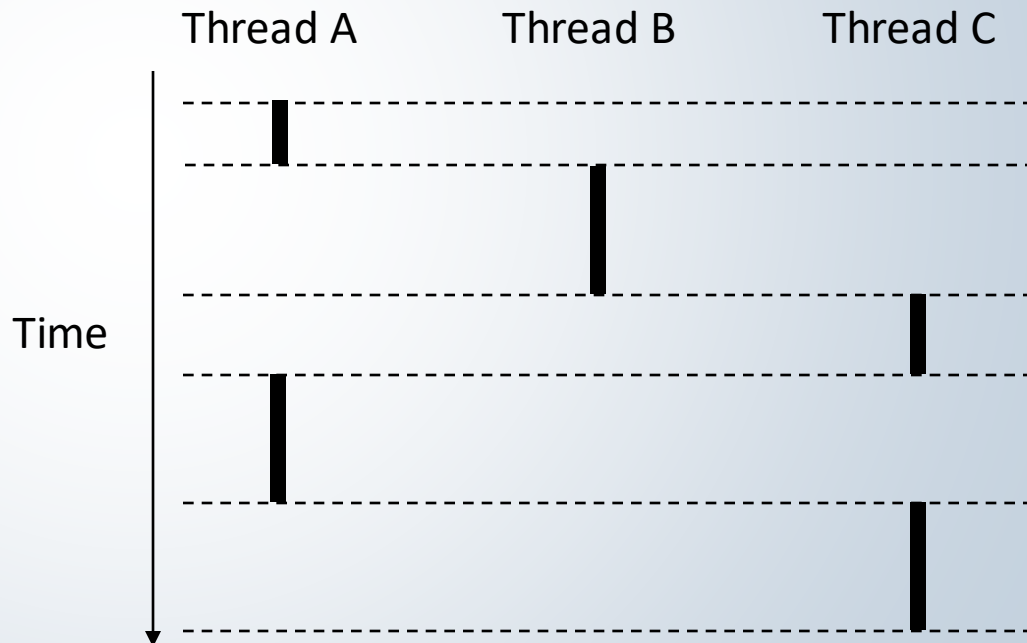


Concurrent Threads

- Two threads are *concurrent* if their flows overlap in time
- Otherwise, they are sequential
- Examples:
 - Concurrent: A & B, A&C
 - Sequential: B & C

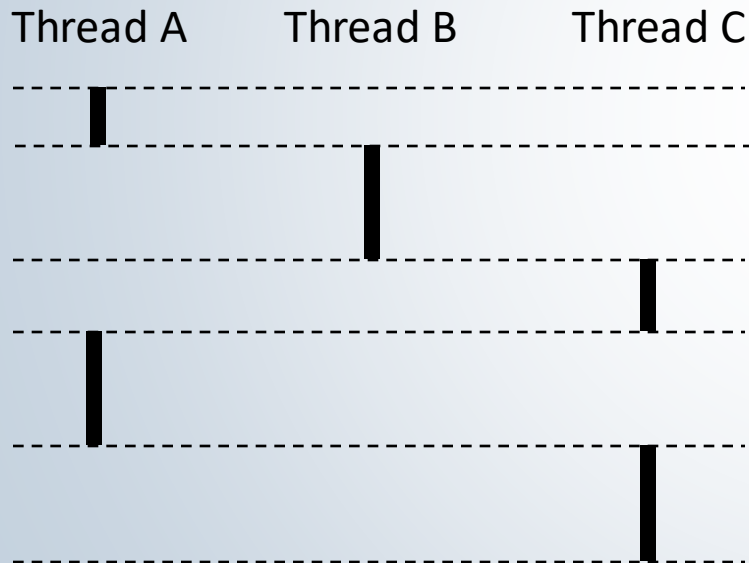
An application has a user interface
Main thread (A) receives user actions
Peer thread (B) processes the inputs

```
main() {  
    while(true) {  
        check_for_UI_interactions();  
        process_UI_actions();  
    }  
}
```

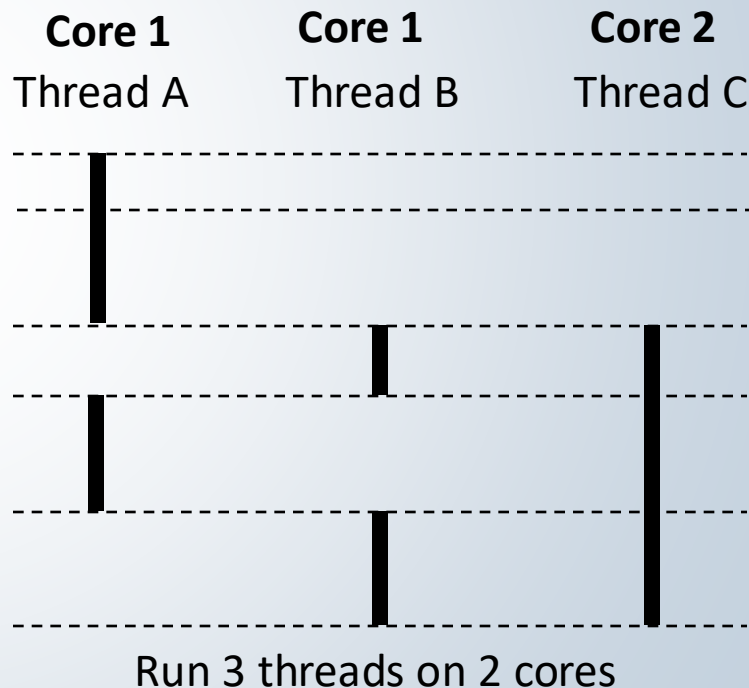


Concurrent Thread Execution

- Single Core Processor
 - Simulate parallelism by time slicing



- Multi-Core Processor
 - Can have parallelism



Threads vs. Processes

- How threads and processes are similar
 - Each has its own logical control flow
 - Each can run concurrently with others (possibly on different cores)
 - Each is context switched
- How threads and processes are different
 - Threads share all code and data (except local stacks)
 - Processes (typically) do not
 - Threads are somewhat less expensive than processes
 - Process control (creating and reaping) twice as expensive as thread control
 - Linux numbers:
 - ~20K cycles to create and reap a process
 - ~10K cycles (or less) to create and reap a thread
 - Switching between threads of the same process is faster than switching between processes

Posix Threads (pthreads) Interface

- *Pthreads*: Standard interface for ~60 functions that manipulate threads from C programs
 - Creating and reaping threads
 - `pthread_create()`
 - `pthread_join()`
 - Determining your thread ID
 - `pthread_self()`
 - Terminating threads
 - `pthread_cancel()`
 - `pthread_exit()`
 - `exit()` [terminates all threads]
 - Synchronizing access to shared variables
 - `pthread_mutex_init`
 - `pthread_mutex_[un]lock`

The pthreads “Hello, World” Program

```
// hello.c - Pthreads "hello, world" program
```

```
#include "csapp.h"
```

```
void *thread(void *vargp);
```

```
int main()
```

```
{
```

```
pthread_t tid;
```

```
Pthread_create(&tid, NULL, thread, NULL);
```

```
exit(0);
```

```
}
```

hello.c

Thread ID

Thread attributes
(usually NULL)

Thread routine

Thread arguments
(void *p)

```
void *thread(void *vargp) /* thread routine */
```

```
{
```

```
printf("Hello, world!\n");
```

```
return NULL;
```

```
}
```

hello.c

The pthreads "Hello, World" Program

```
// hello.c - Pthreads "hello, world" program
```

```
#include "csapp.h"
```

```
void *thread(void *vargp);
```

```
int main()
```

```
{
```

```
    pthread_t tid;
```

```
    Pthread_create(&tid, NULL, thread, NULL);
```

```
    Pthread_join(tid, NULL);
```

```
    exit(0);
```

```
}
```

hello.c

Thread ID

Thread attributes
(usually NULL)

Thread routine

Thread arguments
(void *p)

Return value
(void **p)

```
void *thread(void *vargp) /* thread routine */
```

```
{
```

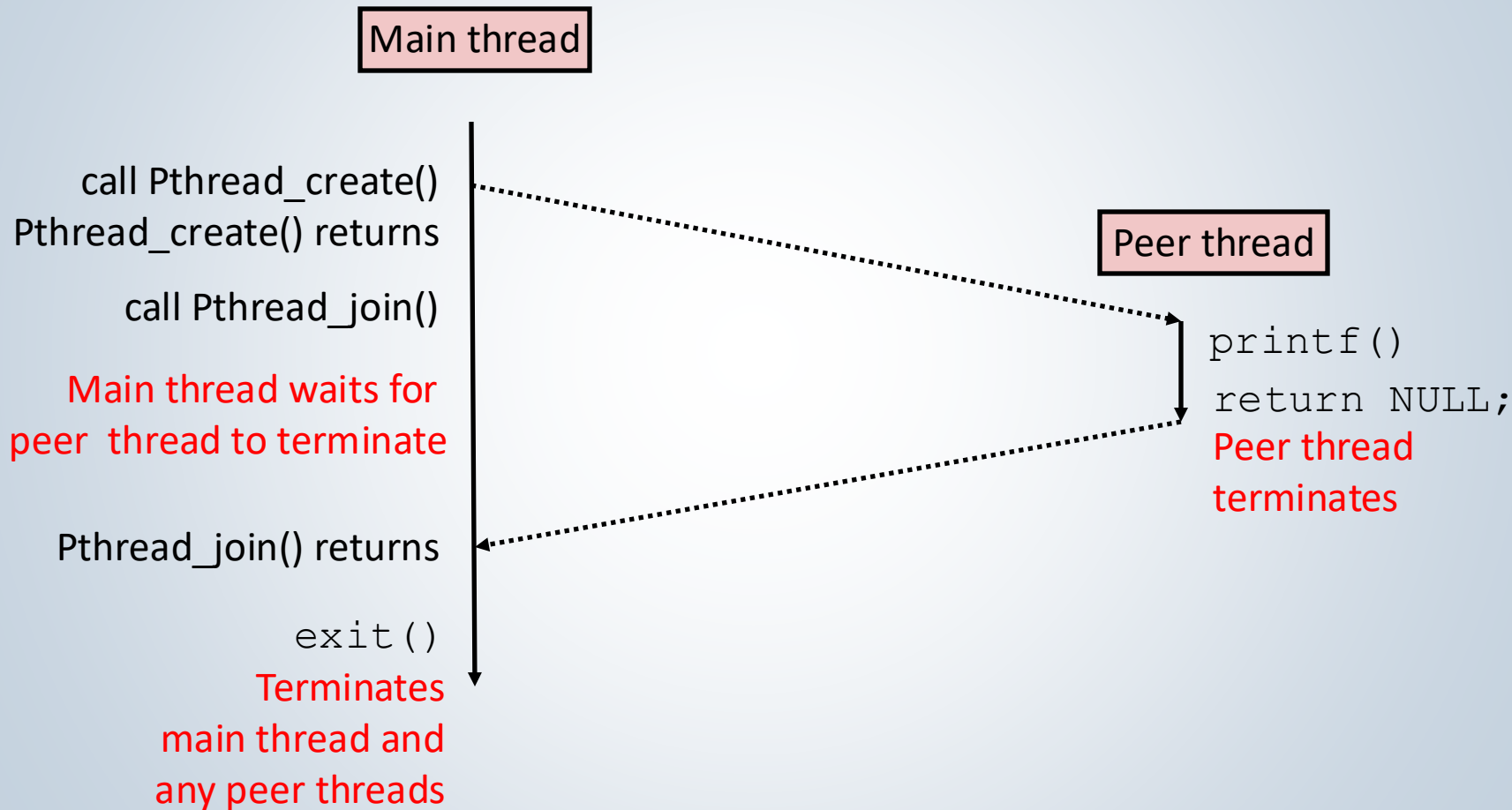
```
    printf("Hello, world!\n");
```

```
    return NULL;
```

```
}
```

hello.c

Execution of Threaded “Hello, World”



Issues with Threads

- Must be “detached” to avoid memory leak
 - At any point in time, a thread is either *joinable* or *detached*
 - *Joinable* thread can be reaped and killed by other threads
 - must be reaped (with `pthread_join`) to free memory resources
 - *Detached* thread cannot be reaped or killed by other threads
 - resources are automatically reaped on termination
 - Default state is joinable
 - use `pthread_detach(pthread_self())` to make detached
- Must be careful to avoid unintended sharing
 - For example, passing pointer to main thread’s stack
 - `pthread_create(&tid, NULL, thread, (void *)buffer);`
- All functions called by concurrent thread must be *thread-safe*
 - (next lecture)

Pros and Cons of Thread-Based Designs

- + Easy to share data structures between threads
 - e.g., logging information, file cache
- + Threads are more efficient than processes
- – Unintentional sharing can introduce subtle and hard-to-reproduce errors!
 - The ease with which data can be shared is both the greatest strength and the greatest weakness of threads
 - Hard to know which data should be shared vs. private
 - Hard to detect by testing
 - Probability of bad “race” outcome very low
 - But nonzero!
 - Future lectures