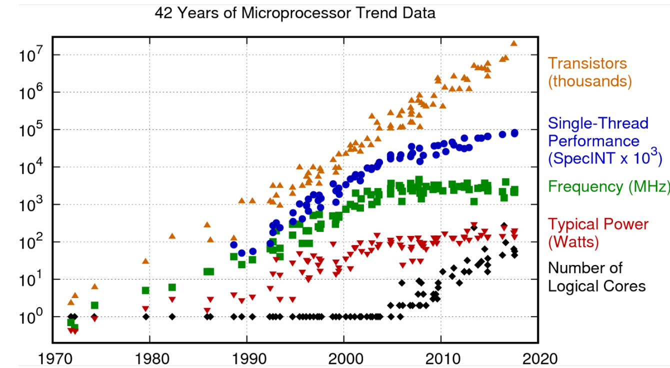
CS 240
Foundations of Computer Systems

WELLESLEY

Threads

Motivation: are *processes* all we need for useful concurrency?
Threads: Concurrency with shared memory

Why do we need concurrency?



M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten.
New plot and data collected for 2010-2017 by K. Rupp

Advantages/disadvantages of concurrent programs

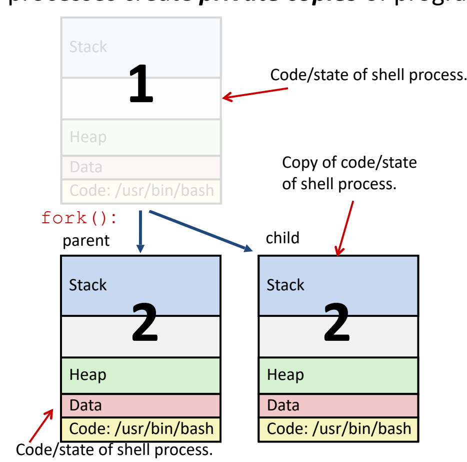
Advantages

- More responsive
  - Interacting with IO
- Higher performance
  - Computers have multiple cores
  - Make progress when one task waits

Disadvantages

- New kinds of bugs
  - Race conditions
  - Deadlock
- Much more difficult to test, debug

Recall: processes create ***private copies*** of program state

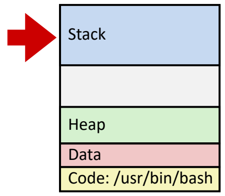


Why might we want *shared access* to program state?

Threads: distinct execution, shared memory

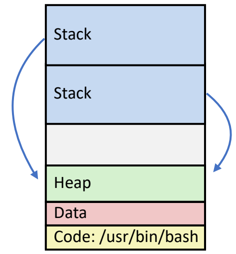
- Core idea: allow shared memory, but distinct/concurrent execution

Programs are just data: what data tracks execution?



Threads need distinct stacks & registers

Threads: distinct execution, shared memory



- OS and languages generally allow processes to run two or more functions simultaneously via threading.
- The stack segment is subdivided into 1 stack per thread
- The thread manager time slices and between threads
- Threads often called “lightweight processes”
- Each thread maintains its own stack, but all threads share the same text, data, and heap segments

Processes vs. Threads: what is shared?

	Processes	**Threads**
Stack	Not shared (private copies)	Not shared (subdivided)
Registers	Not shared (kernel tracks)	Not shared (kernel tracks)
Code (instruction memory)	Shared	Shared
Heap (dynamic memory)	Not shared (private copies)	Shared

A thread is an independent execution sequence within a single process, with **shared dynamic memory**

Processes vs. threads

Threads

- Easier coordination, operating on shared data
- Lower communication overhead

Processes

- Support for distinct programs/code (exec)
- Built-in memory protection

- Since threads have no memory protection, race conditions and deadlocks more likely

Race condition

ex

Thread 1	Thread 2
`x = x + 1`	`x = x * 2`

Assume `x = 2` before this code runs.

What possible values could `x` have after this code runs?

`pthreads` library

- ANSI C doesn't provide native support for threads.
- But **pthreads**, which comes with all standard UNIX distributions, provides thread support.
  - The primary **pthreads** data type is the **pthread_t**, which is a type used to manage the execution of a function within its own thread of execution.
  - The **pthreads** functions we'll need: **pthread_create** and **pthread_join**.

Examine introverts!

Key points of introverts

- Introverts declares an array of six **`pthread_t`** handles.
- The program initializes each **`pthread_t`** (via **`pthread_create`**) by installing **`recharge`** as the function each **`pthread_t`** should execute.
- All thread routines take a **`void *`** and return a **`void *`**.
- The **`pthread`** thread manager's attention, and we have very little control over what choices it makes when deciding what thread to run next.

pthread_join waits

- **pthread_join** is to threads what **waitpid** is to processes.
- The main thread of execution blocks until the child threads all exit. The second argument to **pthread_join** can be used to catch a thread routine's return value.
- If we don't care to receive it, we can pass in **NULL** to ignore it.

Sharing data

- Sharing data can be complicated and dangerous in concurrent execution, but often necessary.
- Concurrent programming often makes use of specific tools to control how data is shared between threads
  - Lockig/mutexes
  - Semaphores
  - Condition variables
  - Etc.

Examine robberBaronsBroken!

Something is wrong!

- How do we know?
  - Printing is out of order at the end
  - Negative value for the **stash**?
- Multiple threads are modifying the global variable **stash**
- Is it possible for two threads to evaluate **stash > 0** as True with only $10000 left and then both subtract from stash?
  - Yep! Say thread A evaluates **stash > 0** and then the thread manager switches to thread B before thread A subtracts the steal money from the **stash.**
  - Thread B executes fully bringing the stash to $0.
  - Thread A resumes execution and subtracts its $10000 bringing the total to -$10000.
  - Yikes!

Mutexes

- A mutex is a **mut**ual **ex**clusion object.
- It is a *locking* mechanism to protect shared data or critical regions of code so that only one thread can be permitted access.
- Here: protect the stash so that only one robber can modify it at a given time.
- We declare a mutex with **pthread_mutex_t**.
- To lock a piece of code, we use **pthread_mutex_lock().**
  - When a thread tries to acquire a lock, it will either take the lock if it is not being currently used or it will wait until the lock becomes available.
- To unlock a piece of code, we use **pthread_mutex_unlock().**
  - Only the thread that holds a lock can unlock it.

Examine robberBarons!