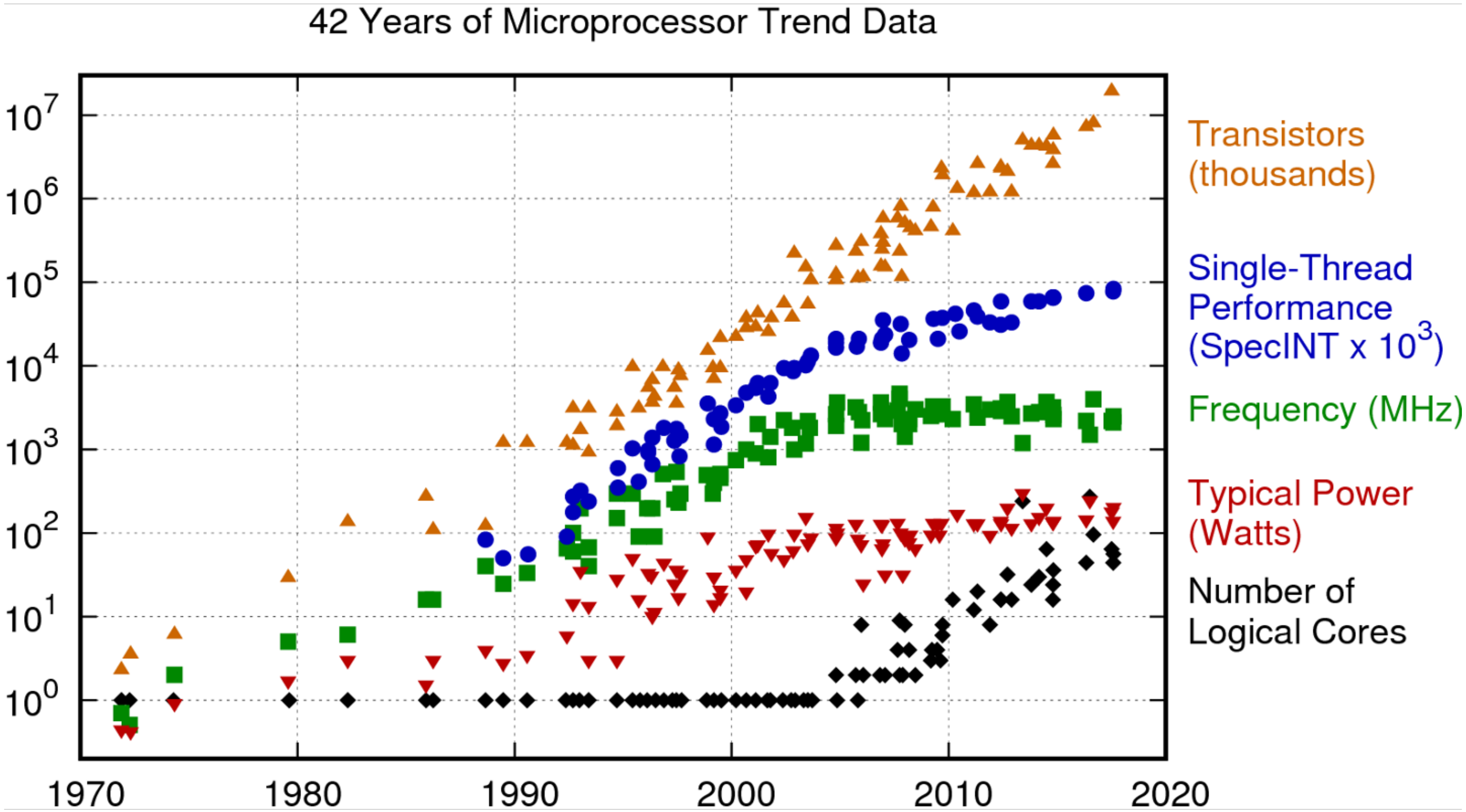
Threads

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

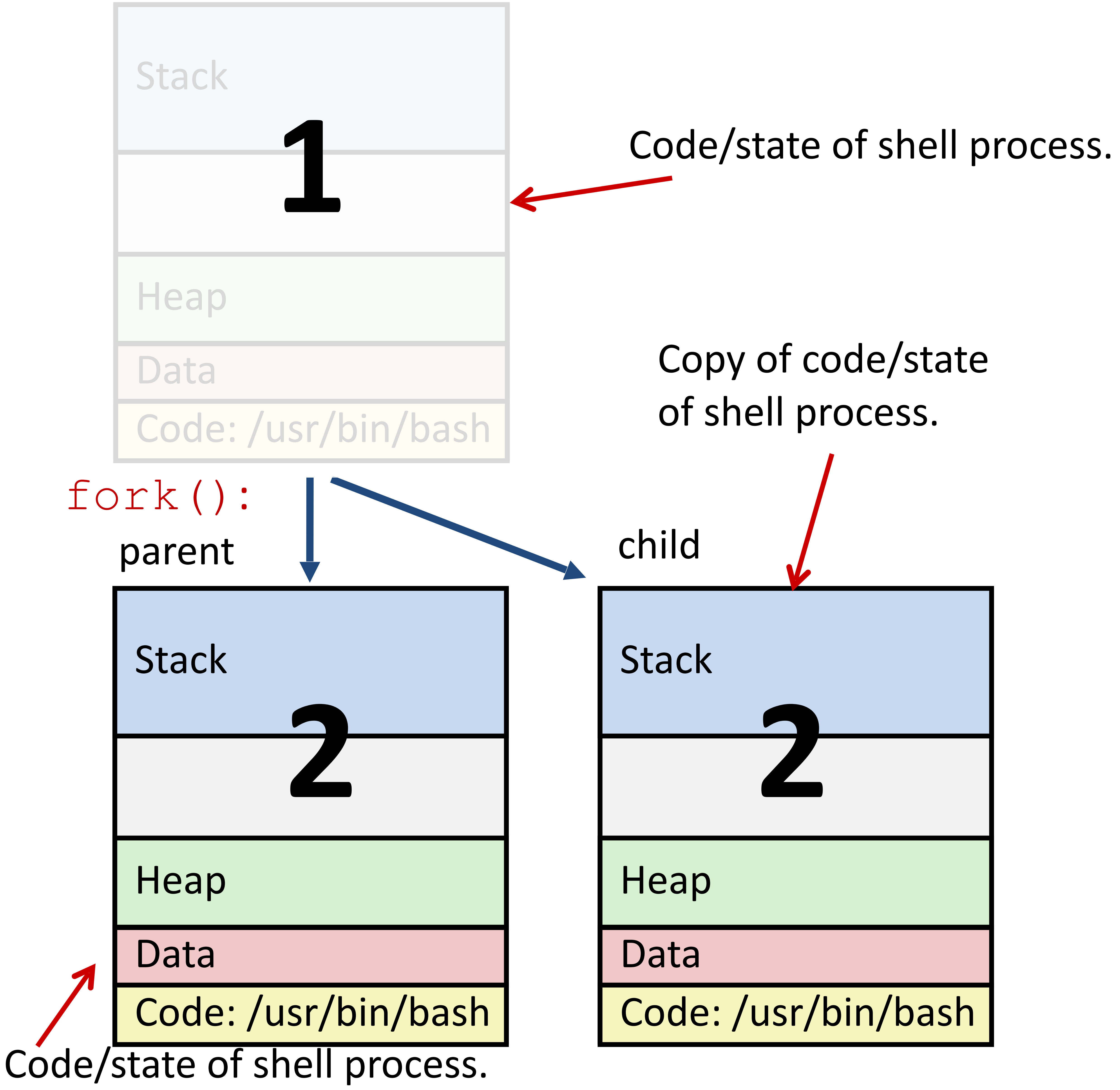
Advantages

- 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

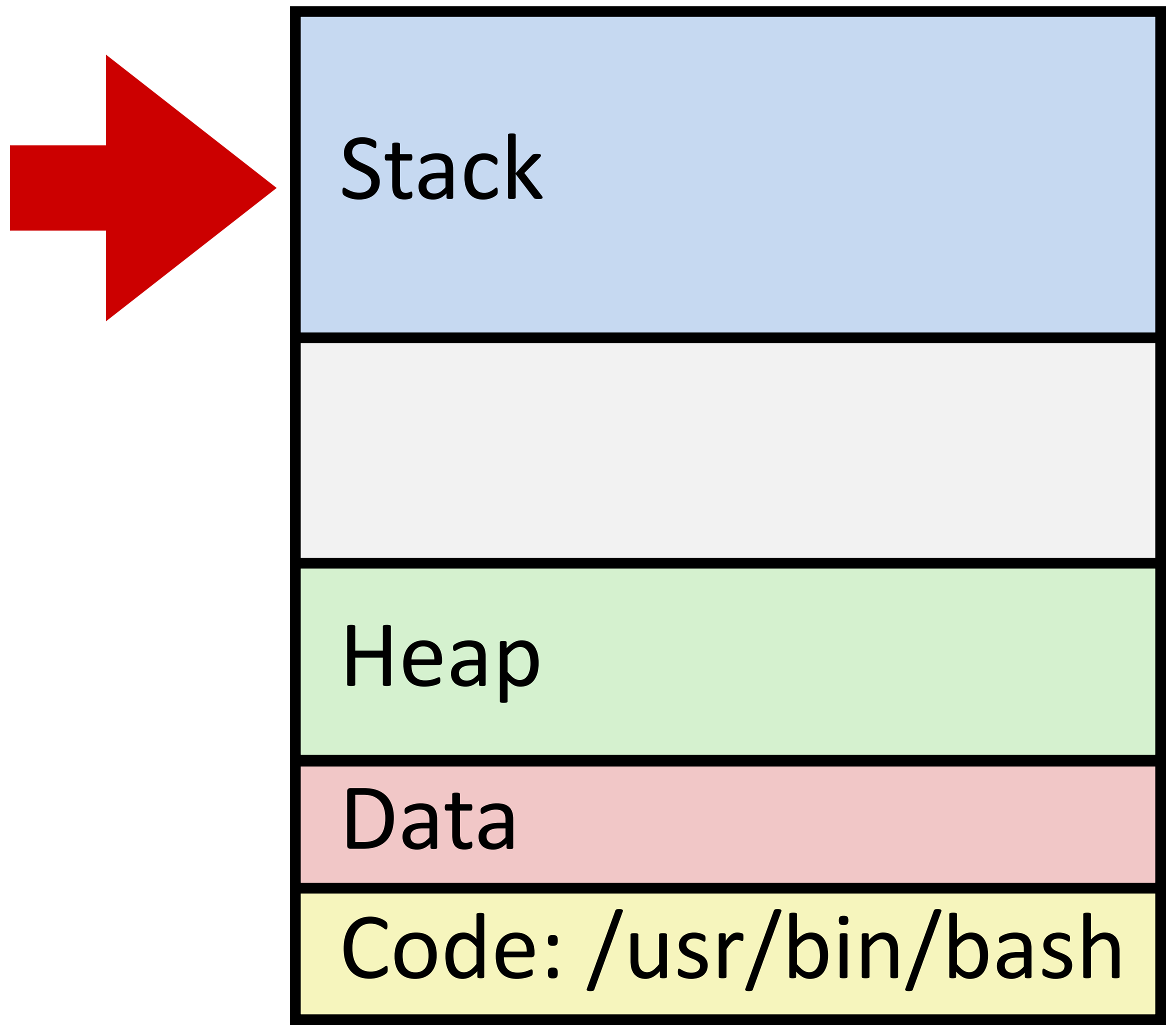


Why might we want *shared access* to program state?

Threads: distinct execution, shared memory

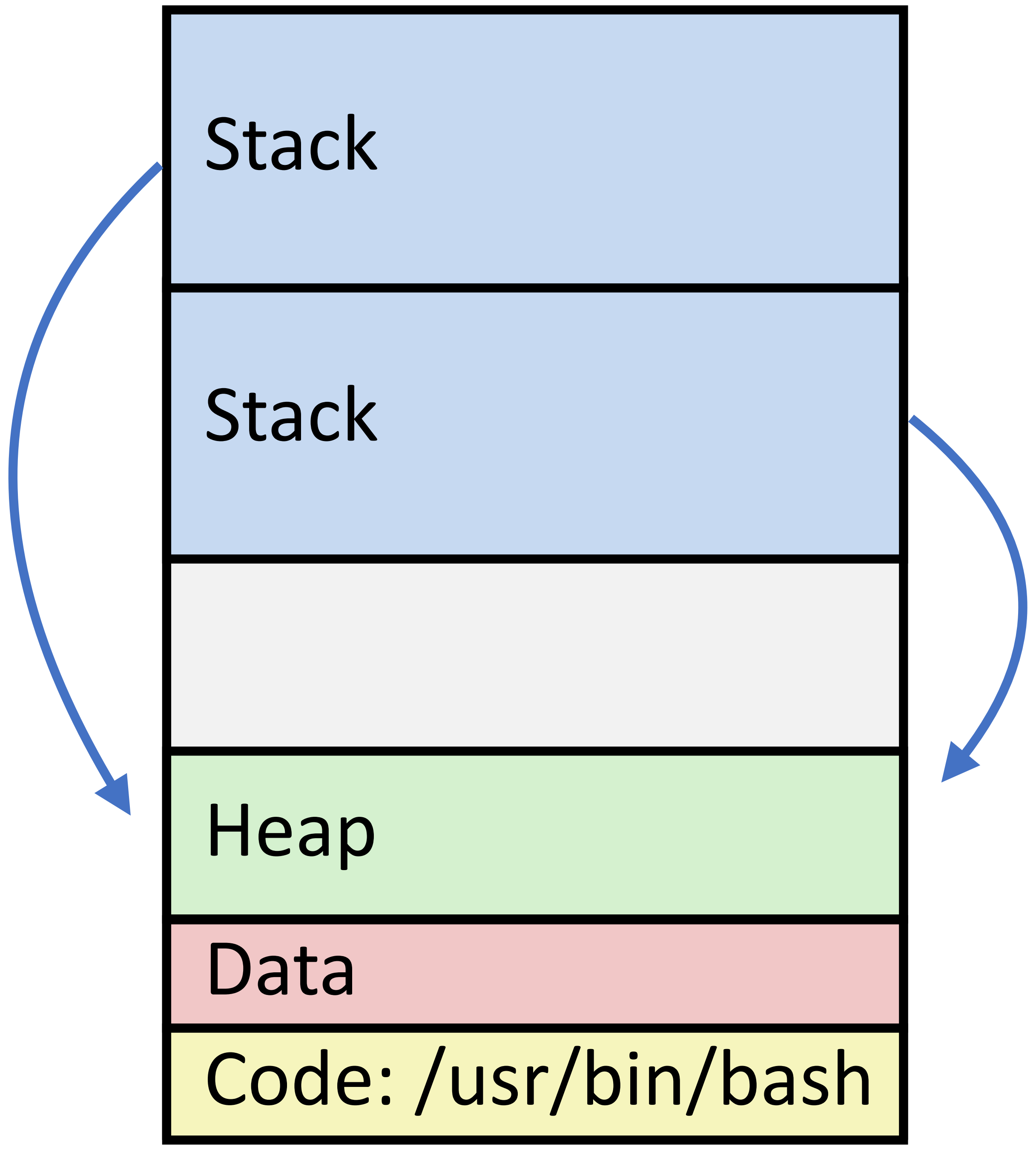
- Core idea: allow shared memory, but distinct/concurrent execution

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

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

Processes

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

Race condition

ex

Thread 1

```
x = x + 1
```

Thread 2

```
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!