Introduction to Concurrency and Parallelism
Concurrency

**Concurrency**: two tasks, any order
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Concurrency is *non-deterministic*

(whether A or B gets bricks first)
Parallelism

*Parallelism*: one task, faster
Parallelism

**Parallelism:** one task, faster

Parallelism can be *deterministic*

(same bricks always delivered to A)
Parallelism vs. Concurrency

Bricks to both A and B as a single task:
Parallelism vs. Concurrency

Bricks to both A and B as a single task:
Parallelism vs. Concurrency

Bricks to both A and B as a single task:

Parallelism may have internal concurrency!

Whether you see the concurrency depends on your layer of abstraction
Why Concurrency is Hard
Why Concurrency is Hard
Why Concurrency is Hard

When barrier is removed, drive
Why Concurrency is Hard

When barrier is removed, drive
Why Concurrency is Hard

When barrier is removed, drive

no such method: drive in: 

General problem: shared resources
Why Parallelism is Hard: I
Why Parallelism is Hard: I
Why Parallelism is Hard: I

done! )))

A

B

( ( done!
Why Parallelism is Hard: I

doneda! doneda!

Concurrency is hard — including internal concurrency

“Systems” programmers deal with internal concurrency
Why Parallelism is Hard: 2
Why Parallelism is Hard: 2

It’s easy to ask for too much parallelism

(Each truck adds overhead)
Why Parallelism is Hard: 3

Dependencies limit parallelism

Algorithm designers deal with dependencies
Parallelism in an Algorithm

(define (quicksort! vec n m)
  (when (> (- m n) 1)
    (let* ([pivot (vector-ref vec n)]
           [pre
            (for/fold ([pre n]) ([i (in-range (add1 n) m)])
              (let ([v (vector-ref vec i)])
                (cond
                  [(< v pivot)
                   (vector-set! vec pre v)
                   (vector-set! vec i (vector-ref vec (add1 pre)))
                   (values (add1 pre))]
                  [else (values pre)])))]))
    (vector-set! vec pre pivot)
    ; Two recursive calls are independent:
    (quicksort! vec n pre)
    (quicksort! vec (add1 pre) m))))
Parallelism in an Algorithm

\[
\text{(define (quicksort! vec n m)}
\begin{align*}
& \text{ (when (> (- m n) 1))} \\
& \quad \text{ (let* ([pivot (vector-ref vec n)] [pre}
& \quad \text{ (for/fold ([pre n]) ([i (in-range (add1 n) m)])}
& \quad \text{ (let ([v (vector-ref vec i)])}
& \quad \text{ (cond}
& \quad \quad \text{ [(< v pivot) (vector-set! vec pre v) (vector-set! vec i (vector-ref vec (add1 pre))] (values (add1 pre))] [else (values pre)]))])}
& \quad \text{(vector-set! vec pre pivot) (parallel-begin ; ok, but... (quicksort! vec n pre) (quicksort! vec (add1 pre) m))})
\end{align*}
\]

Request too much parallelism $\Rightarrow$ management overload
Parallelism in an Algorithm

(define (quicksort! vec n m)
  (when (> (- m n) 1)
    (let* ([pivot (vector-ref vec n)]
          [pre
            (for/fold ([pre n]) ([i (in-range (add1 n) m)])
              (let ([v (vector-ref vec i)])
                (cond
                  [(< v pivot)
                    (vector-set! vec pre v)
                    (vector-set! vec i (vector-ref vec (add1 pre)))
                    (values (add1 pre))]
                  [else (values pre)])))))
      (vector-set! vec pre pivot)
      (if (> (- m n) (quotient (vector-length vec) 100)) ; ugh
        (parallel-begin
          (quicksort! vec n pre)
          (quicksort! vec (add1 pre) m))
        (begin
          (quicksort! vec n pre)
          (quicksort! vec (add1 pre) m))))))}
Concurrency vs. Parallelism

In principle:

**Parallelism ≠ Concurrency**

- Parallelism is for higher *throughput*
- Concurrency is for lower *latency*

In practice (for now):

**Parallelism ⇔ Concurrency**

- Parallelism via multiple processors
- Concurrency via multiple (virtual) processors
Threads

A **thread** is a virtual concurrent processor

• Racket: **thread** creates a thread

```scheme
(define a
  (thread (lambda () (printf "a\n"))))
(define b
  (thread (lambda () (printf "b\n"))))
(sync a)
(sync b)

... but no parallelism!
```
Threads

A **thread** is a virtual concurrent processor

- C: `pthread_create()` creates a thread

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

  ```c
  pthread_t a, b;
  pthread_create(&a, NULL, go, "a");
  pthread_create(&b, NULL, go, "b");

  pthread_join(a, NULL);
  pthread_join(b, NULL);
  ```
Futures

A **future** is a task that can run in parallel

- Racket: **future** creates a future

```
(define a
  (future (lambda () (+ 1 2))))
(define b
  (future (lambda () (+ 3 4))))
(touch a)
(touch b)
```

... but no guaranteed concurrency!
OpenMP Tasks

A **task** is a task that can run in parallel

- C + OpenMP: `#pragma omp task` creates a task

```c
#pragma omp task
v1 = add_one_plus_two();
#pragma omp task
v2 = add_three_plus_four();
```

... and no guaranteed concurrency!