Concurrency

*Concurrency*: two tasks, any order
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Concurrency:

two tasks, any order
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Concurrency

Concurrent: two tasks, any order

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: \textit{shared resources}
Why Parallelism is Hard: I
Why Parallelism is Hard: I
Why Parallelism is Hard: I
Why Parallelism is Hard: I

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)
    (define pivot (vector-ref vec n))
    (define 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)))]
            [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

(define (quicksort! vec n m)
 (when (> (- m n) 1)
   (define pivot (vector-ref vec n))
   (define 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)
   (parallel-begin ; ok, but...
     (quicksort! vec n pre)
     (quicksort! vec (add1 pre) m)))))

Request too much parallelism ⇒ management overload
Parallelism in an Algorithm

(define (quicksort! vec n m)
  (when (> (- m n) 1)
    (define pivot (vector-ref vec n))
    (define 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)))]
            [else (values pre)])))
      (vector-set! vec pre pivot)
    (if (> (- m n) (quotient (vector-length vec) 100))
      (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;
}

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

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

See also parallel  `quicksort.c`
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!

See also parallel **quicksort.rkt**
OpenMP Tasks

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

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

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

  ... and no guaranteed concurrency!

See `quicksort-omp.c`

See `graph.c` for `#pragma omp parallel` for
Parallel Map

\[
\begin{align*}
  & v_1 \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \\
  & f \quad f \quad f \quad f \quad f \quad f \quad f \quad f \quad f \\
  & a_1 \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \downarrow \\
\end{align*}
\]
Parallel Reduce

... for any associative ⊕
Parallel Reduce

Leaves must be big enough to be worthwhile
MapReduce

*MapReduce* is parallel map and then parallel reduce
Parallel Scan