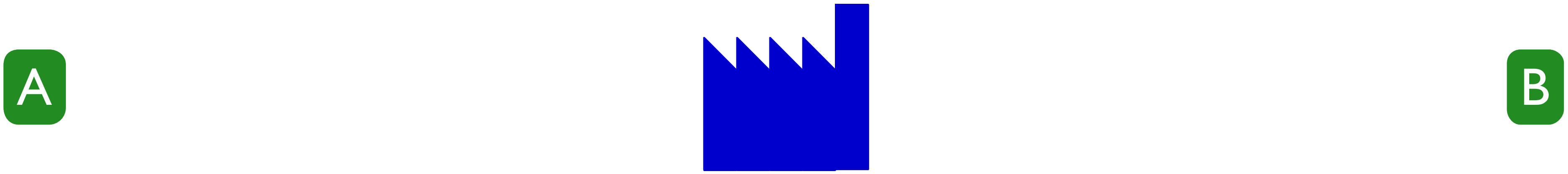
Introduction to Concurrency and Parallelism

Concurrency

Concurrency: two tasks, any order



Concurrency

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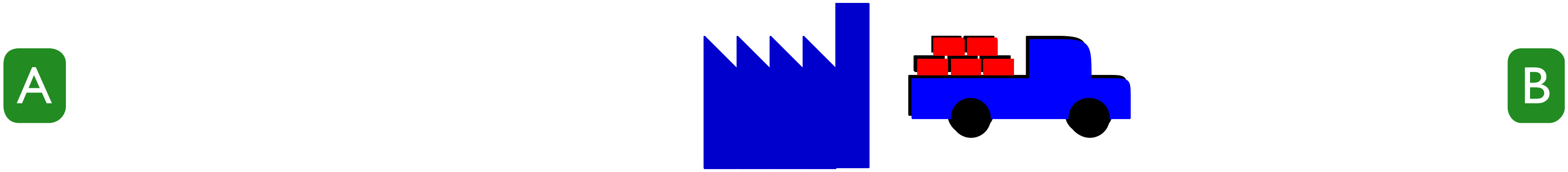

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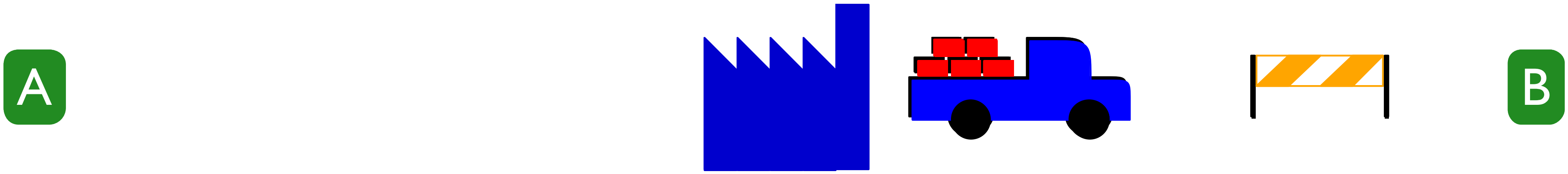

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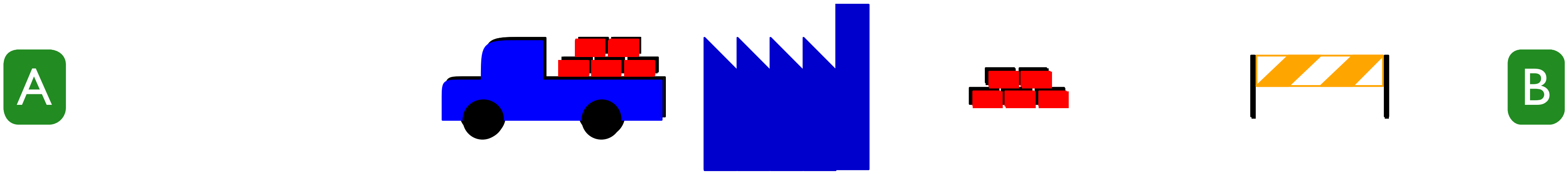

Concurrency

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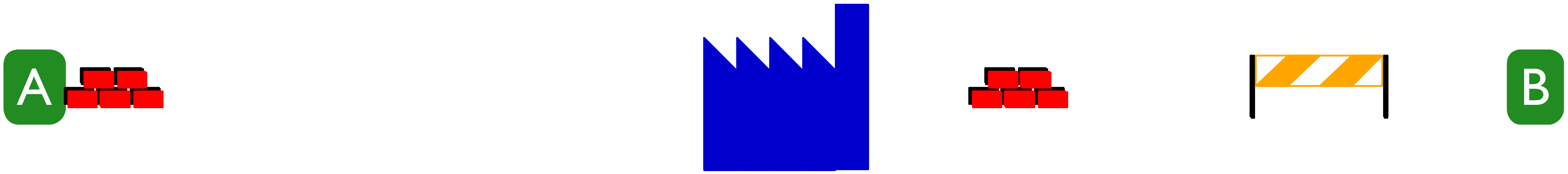
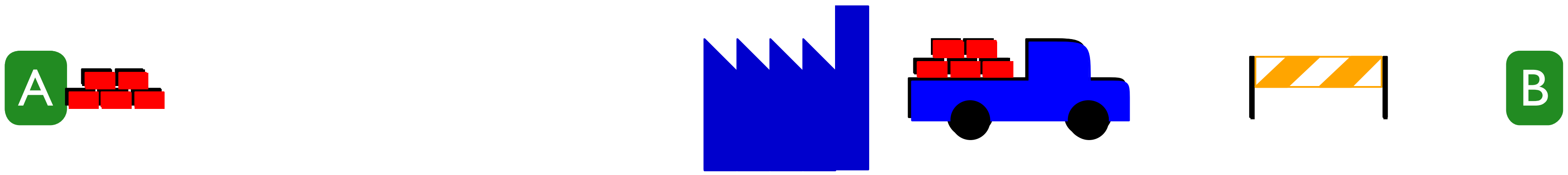


Concurrency

Concurrency: two tasks, any order

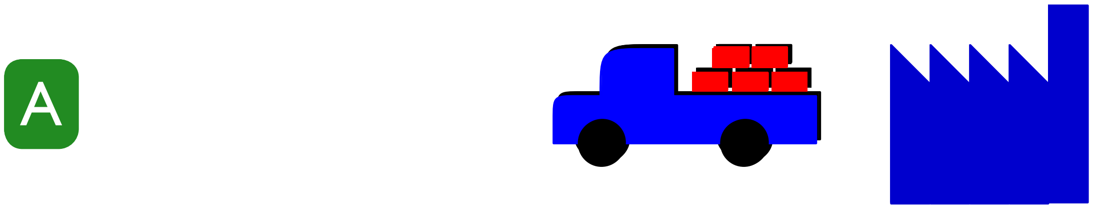


Concurrency is ***non-deterministic***

(whether A or B gets bricks first)

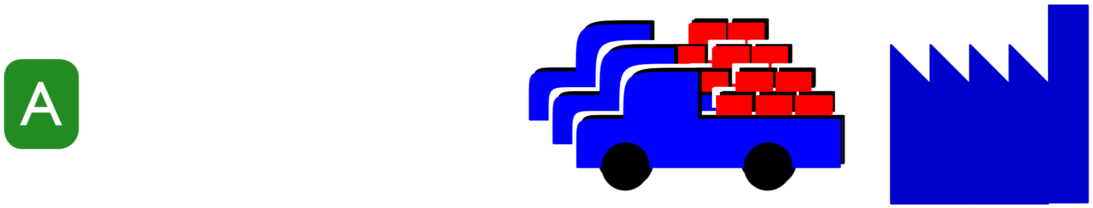
Parallelism

Parallelism: one task, faster



Parallelism

Parallelism: one task, faster

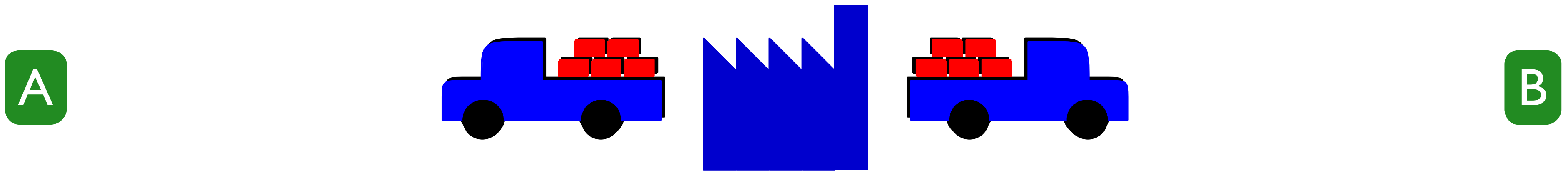


Parallelism can be ***deterministic***

(same bricks always delivered to A)

Parallelism vs. Concurrency

Bricks to both A and B as a single task:



Parallelism vs. Concurrency

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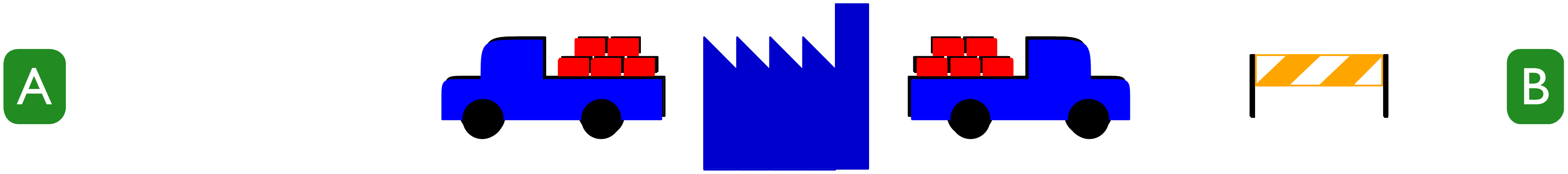

Parallelism vs. Concurrency

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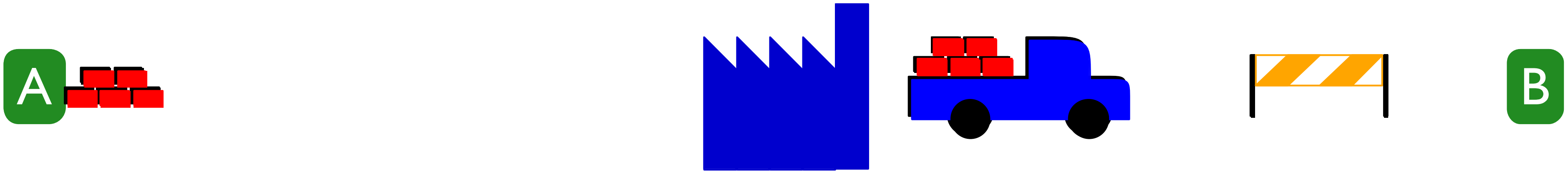
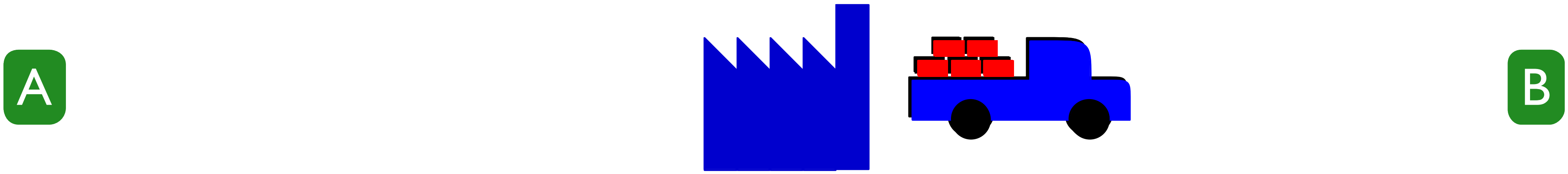


Parallelism may have internal concurrency!

Whether you see the concurrency depends on your layer of abstraction

Why Concurrency is Hard



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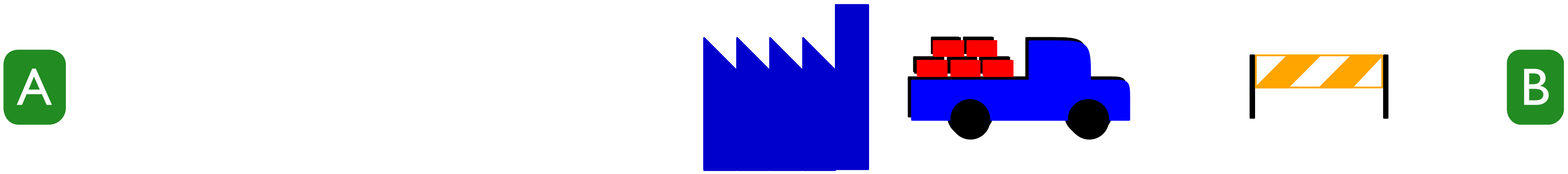
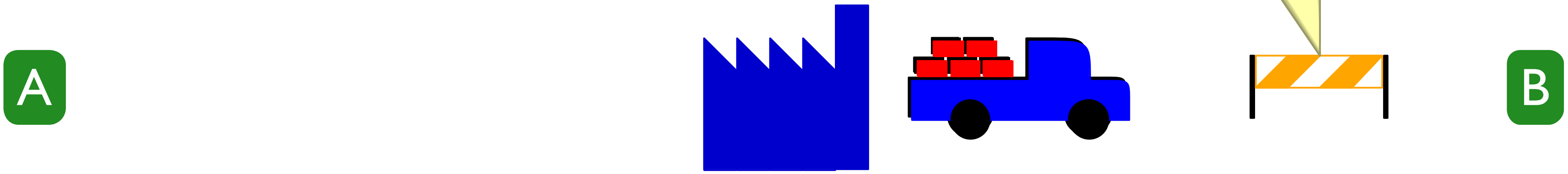
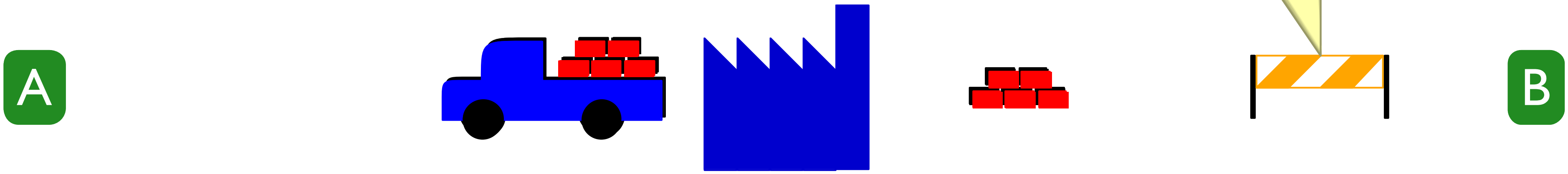


Why Concurrency is Hard

When barrier is removed, **`drive`**

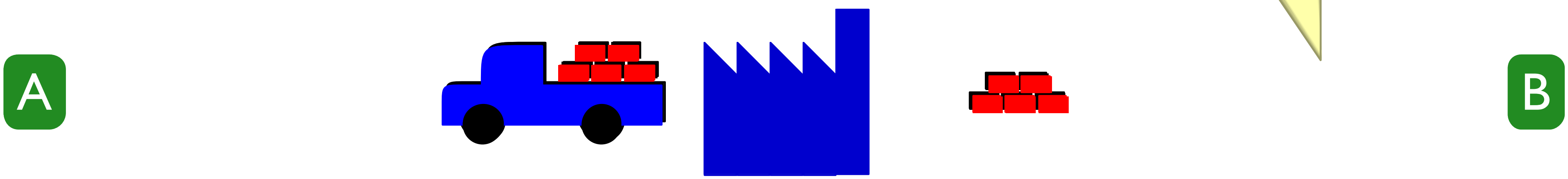


Why Concurrency is Hard



When barrier is removed, **`drive`**

Why Concurrency is Hard

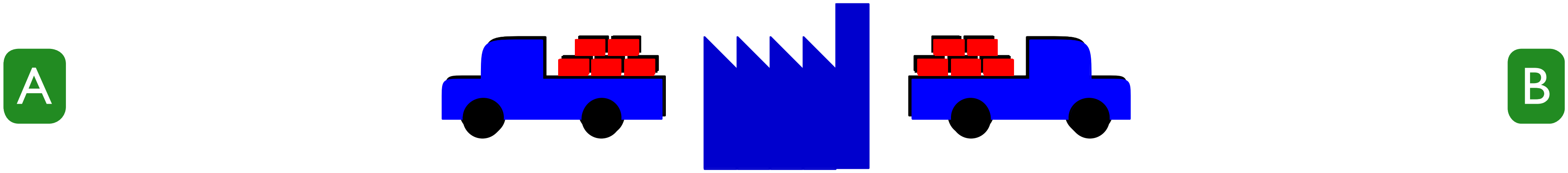


When barrier is removed, **`drive`**

`no such method: drive in:` 🧱

General problem: ***shared resources***

Why Parallelism is Hard: 1



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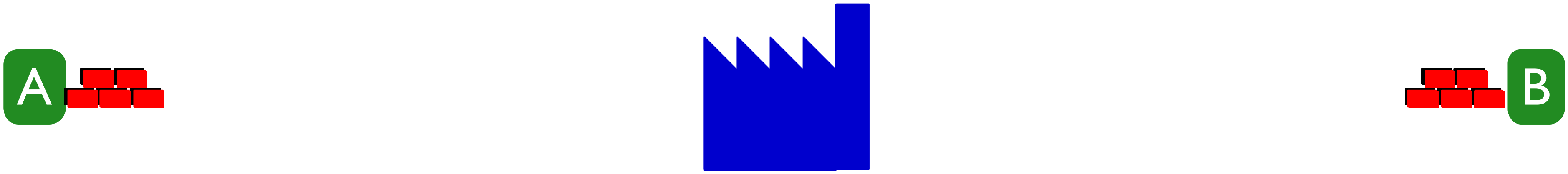

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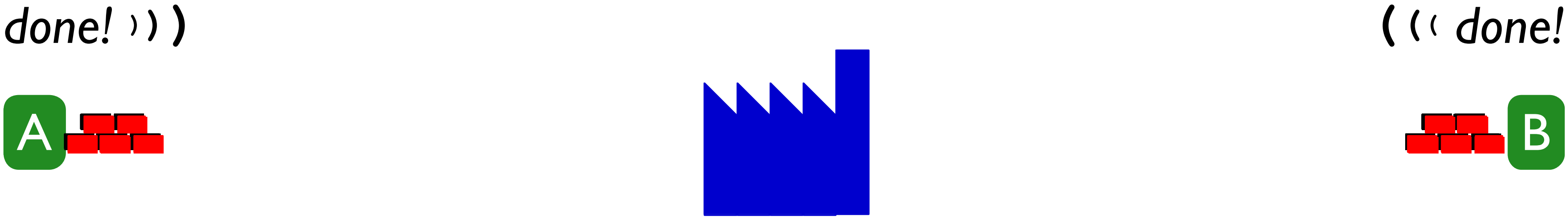

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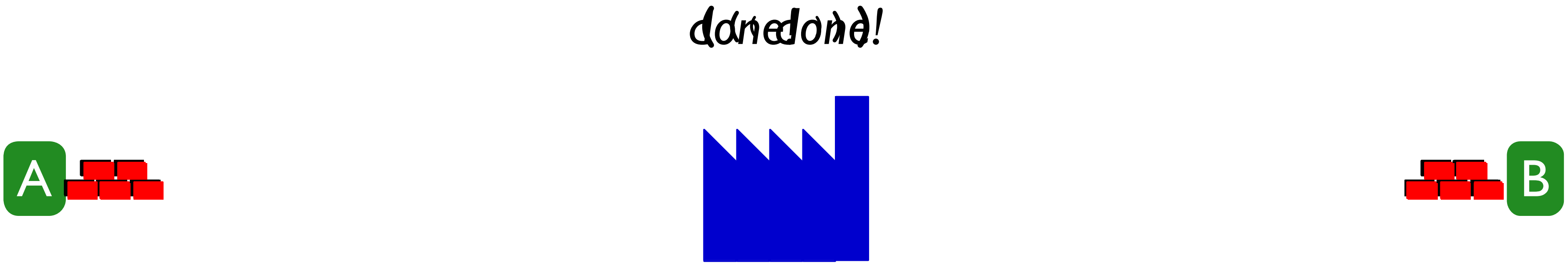
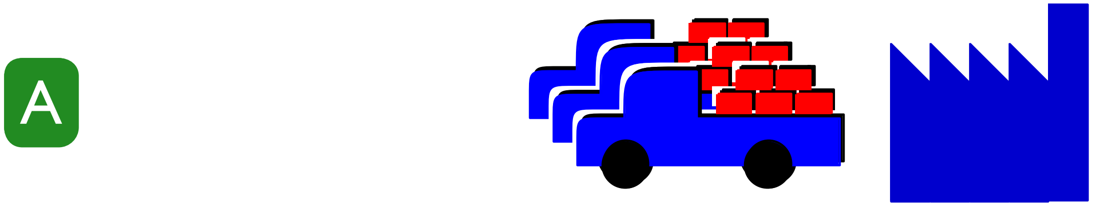


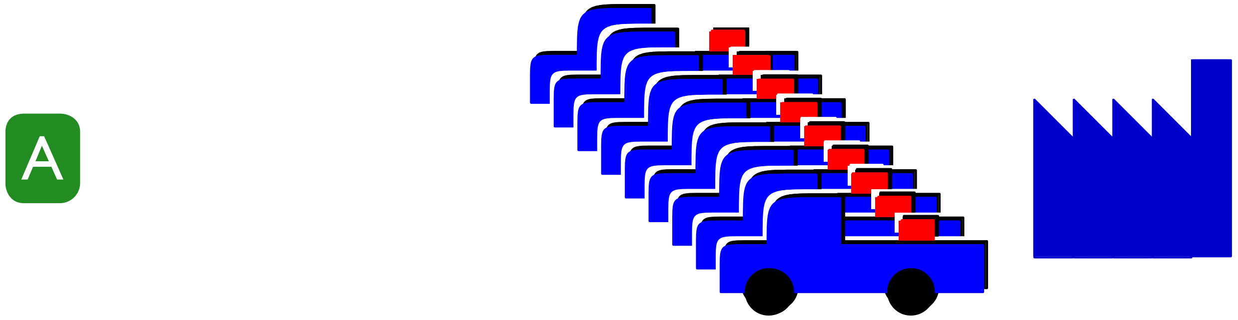
Concurrency is hard — including internal concurrency

“Systems” programmers deal with internal concurrency

Why Parallelism is Hard: 2



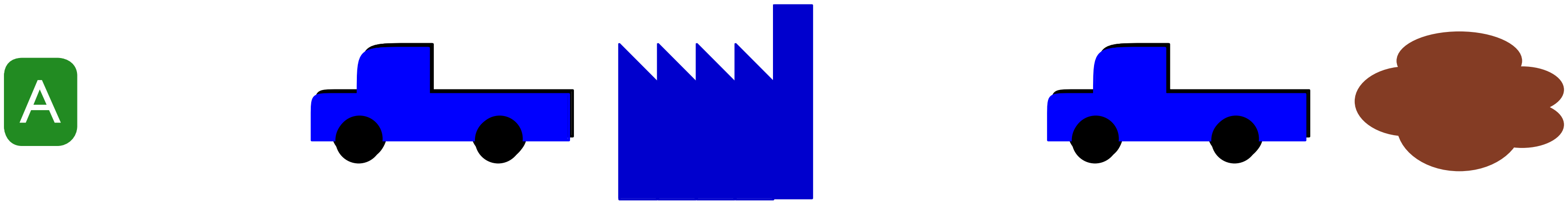
Why Parallelism is Hard: 2



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

```
(define (quicksort! vec n m)
  (when (> (- m n) 1)
    (let* ([pivot (vector-ref vec n)]
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            (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)
    (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

```
(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

```
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);
```

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

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

... and no guaranteed concurrency!