Programming Abstractions

Lecture 30: Promises

Stephen Checkoway

Promises

Some new Scheme special forms

`(delay exp)` returns an object called a *promise*, without evaluating `exp`

`(force promise)` evaluates the promised expression and returns its value

- A promised expression is evaluated only once, no matter how many times it is evaluated!

What does this code print?

```
(let* ([x 10]
       [f (λ () (add1 (* 3 x)))]
       [p (delay (add1 (* 3 x)))])
  (printf "(force p)=~s (f)=~s\n" (force p) (f))
  (set! x 4)
  (printf "(force p)=~s (f)=~s\n" (force p) (f)))
```

A.
```
(force p)=31 (f)=31
(force p)=31 (f)=16
```

B.
```
(force p)=31 (f)=31
(force p)=16 (f)=16
```

C.
```
(force p)=31 (f)=31
(force p)=16 (f)=31
```

D.
```
(force p)=31 (f)=31
(force p)=31 (f)=31
```

What happens if we comment out the first printf?

```
(let* ([x 10]
       [f (λ () (add1 (* 3 x)))]
       [p (delay (add1 (* 3 x)))])
  ; (printf "(force p)=~s (f)=~s\n" (force p) (f))
  (set! x 4)
  (printf "(force p)=~s (f)=~s\n" (force p) (f)))
```

A. `(force p)=31 (f)=16`

B. `(force p)=16 (f)=16`

C. `(force p)=16 (f)=31`

D. `(force p)=31 (f)=31`

E. `(force p)=16 (f)=16`

Example

```
(define foo
  (delay
    (begin
      (displayln "Promise is evaluated")
      2)))

(force foo) ; prints "Promise is evaluated"; returns 2
(force foo) ; returns 2
(force foo) ; returns 2
```

Example

```
(define foo
  (delay
    (begin
      (displayln "Promise is evaluated")
      2)))
```

`begin` not needed in Racket
`delay` allows arbitrary number of expressions

```
(force foo) ; prints "Promise is evaluated"; returns 2
(force foo) ; returns 2
(force foo) ; returns 2
```

Implementing delay and force

Before we talk about *why* we might want this, let's talk about how we can implement it

First attempt: define delay as a procedure that returns a procedure

```
(define (delay exp)
  (λ ()
    exp))

(define (force promise)
  (promise))
```

What goes wrong with this definition?

```
(define (delay exp)
  (λ ()
    exp))

(define (force promise)
  (promise))
```

A. When you know what goes wrong, select this choice

Evaluation isn't delayed

```
(delay
  (displayln "Lazy evaluation would be nice"))
```

Since `delay` was implemented as a procedure, its argument is evaluated when `delay` is called

`force` will correctly return the value, but it was already computed; we need to delay the computation until `force` is called

We need a macro!

Let's think about what we want

We want

```
(delay exp)
```

to become something like

```
(λ () exp)
```

Second attempt: define delay as a macro which produces a λ

```
(define-syntax delay
  (syntax-rules ()
    [(_ exp) (λ () exp)]))

(define (force promise)
  (promise))
```

Example

```
(define foo
  (delay
    (begin
      (displayln "This time, it's lazy!")
      10)))
```

This successfully defines foo as

```
(λ ()
  (begin
    (displayln "This time, it's lazy!")
    10))
```

and it doesn't evaluate until `(force foo)`

What goes wrong with this definition?

```
(define-syntax delay
  (syntax-rules ()
    [(_ exp) (λ () exp)]))

(define (force promise)
  (promise))
```

A. When you know what goes wrong, select this choice

Each time we force the promise, it's evaluated

```
(force foo) ; prints "This time it's lazy"; returns 10
(force foo) ; prints "This time it's lazy"; returns 10
(force foo) ; prints "This time it's lazy"; returns 10
```

We're going to need some mutation

We need to remember two things

- Has the promise been forced yet?
- If so, what was the value?

What we really want

We want

`(delay exp)`

to become something like

```
(let ([evaluated #f]
      [value 0])
  (λ ()
    (if evaluated
        value
        (begin
          (set! value exp)
          (set! evaluated #t)
          value))))
```

When the result is forced (i.e., called) the first time

- `exp` will be evaluated
- `value` will be set to the result
- `evaluated` will be set to `#t`
- `value` is returned

On subsequent calls

- value is returned

When would we use promises?

We can build an infinite data structure like an infinite list, tree, or graph

- An infinite list of primes
- The Fibonacci sequence

Concurrent execution

- Creating the promise starts a *thread* that performs the computation
- Forcing the promise causes the current thread to wait until the computing thread has finished before returning the answer

Promises in Racket

We're going to use Racket's promises

`(require racket/promise)` — Loads the library

`(delay body ...+)` — Returns a promise that when forced evaluates the body expressions

`(delay/thread body ...+)` — Starts evaluating the body expressions on another thread and returns a promise that when forced waits for the execution to complete and returns the value

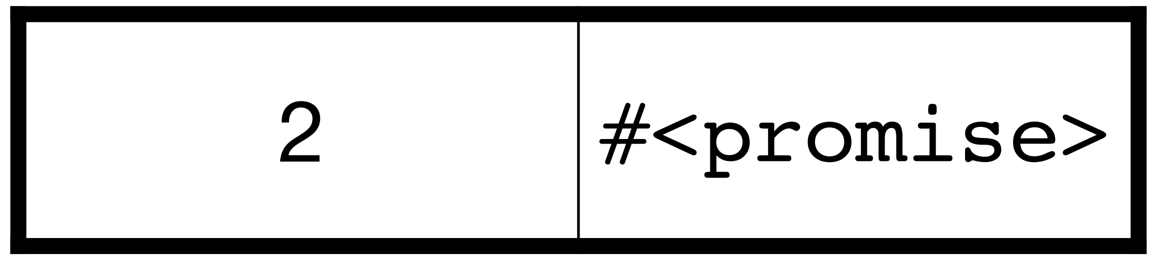
`(force promise)` — Force the promise

Let's build an infinite list of primes

First, we need to think about how we want to represent this

Let's use a `cons` cell where

- the `car` is a prime; and
- the `cdr` is a promise which will return the next `cons` cell



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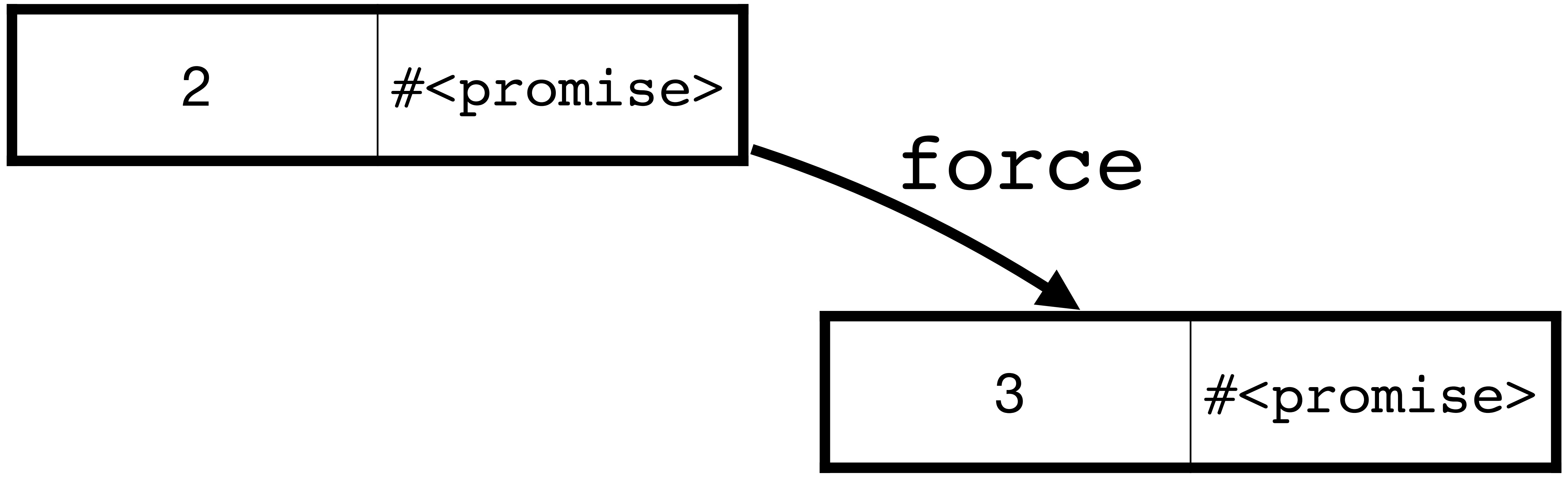

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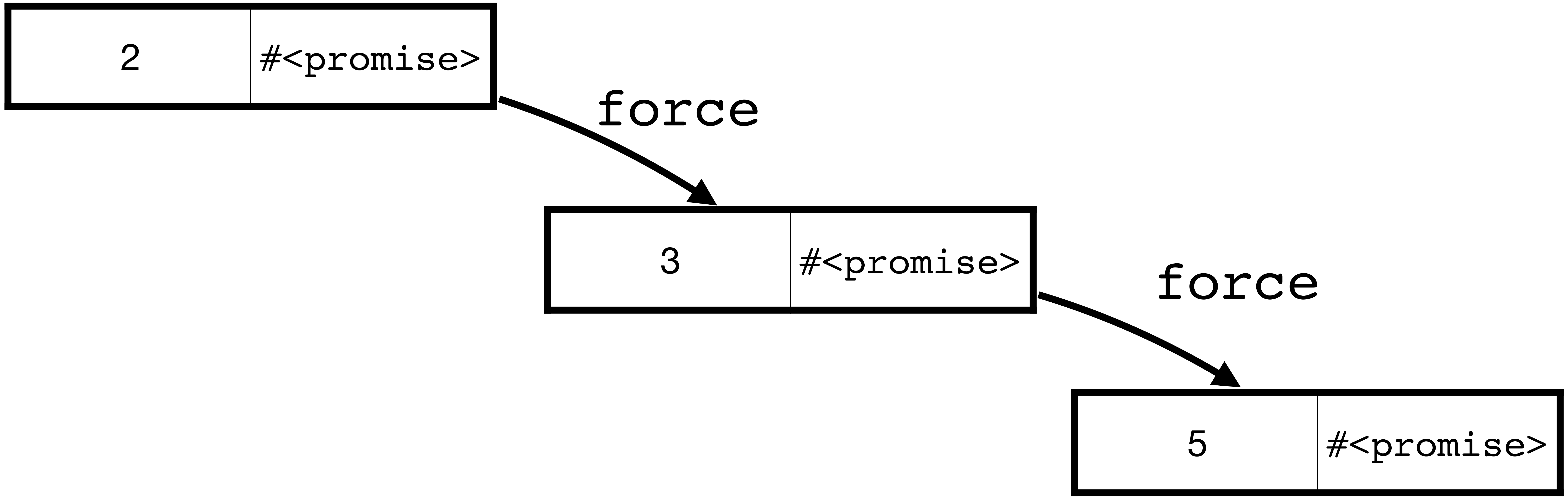

The uninteresting piece: checking primality

```
(define (prime? n)
  (cond [(= n 2) #t]
        [(even? n) #f]
        [else (not
                (ormap
                 (λ (m) (zero? (remainder n m)))
                 (range 3
                        (add1 (exact-floor (sqrt n)))
                        2)))]))
```

Does the simple thing and checks if dividing n by any odd m up to $\sqrt{n}$ gives remainder 0

The interesting piece: building the list

`next-prime` checks if n is prime and if so, returns a `cons` cell containing n and a promise to construct the next one; otherwise it recurses on n+2

```
(define (next-prime n)
  (cond [(prime? n) (cons n
                          (delay (next-prime (+ n 2))))]
        [else (next-prime (+ n 2))]))
```

`primes` returns a cons cell containing 2 and a promise to construct the next one

```
(define (primes)
  (cons 2
        (delay (next-prime 3))))
```

Infinite list in action!

```
> (define prime-lst (primes))
> prime-lst
'(2 . #<promise>)
> (force (cdr prime-lst))
'(3 . #<promise>)
> (force (cdr (force (cdr prime-lst))))
'(5 . #<promise>)
> prime-lst
'(2 . #<promise!(3 . #<promise!(5 . #<promise>)>)>)
```

Using our list

```
(define (print-until n prime-lst)
  (let ([prime (car prime-lst)])
    (if (<= prime n)
        (begin
          (displayln prime)
          (print-until n (force (cdr prime-lst))))
        prime-lst))) ; Return the remainder of the list
```

Using our list

```
> (print-until 15 prime-lst)
2
3
5
7
11
13
'(17 . #<promise>)
```

Concurrent execution

```
(require racket/promise)

(displayln "Before")

(define p (delay/thread
           (sleep 5)
           (displayln "Done!")
           42))

(displayln "During computation")
(force p)
(displayln "After")
```

What is the most likely output of

```
(define p1 (delay (println "Hello!")))
(define p2 (delay/thread (println "Goodbye!")))
(sleep 1) ; Wait one second
(force p1)
(force p2)
```

A. Hello!
   Goodbye!
   Hello!
   Goodbye!

B. Hello!
   Goodbye!

C. Goodbye!
   Hello!
   Hello!
   Goodbye!

D. Goodbye!
   Hello!

Promises in other languages

JavaScript has `async` which starts some potentially long-running calculation or (more typically) starts loading a resource from the Internet and returns a promise

This is paired with `await` which waits for the promise to finish computing/resource to download and returns the answer

Rust has something similar