

MASSACHUSETTS INSTITUTE OF TECHNOLOGY  
 Department of Electrical Engineering and Computer Science  
 6.001—Structure and Interpretation of Computer Programs  
 Spring 2004

**Recitation 23**  
**Analysis**

## Static Analysis

```
(define (analyze-variable exp)
  (lambda (env) (lookup-variable-value exp env)))

(define (analyze-definition exp)
  (let ((var (definition-variable exp))
        (vproc (analyze (definition-value exp))))
    (lambda (env)
      (define-variable! var (vproc env) env)
      'ok)))

(define (analyze-application exp)
  (let ((fproc (analyze (operator exp)))
        (aprocs (map analyze (operands exp))))
    (lambda (env)
      (execute-application (fproc env)
                           (map (lambda (aproc) (aproc env))
                                aprocs)))))

(define (execute-application proc args)
  (cond ((primitive-procedure? proc)
        (apply-primitive-procedure proc args))
        ((compound-procedure? proc)
         ((procedure-body proc)
          (extend-environment (procedure-parameters proc)
                             args
                             (procedure-environment proc))))
        (else
         (error "Unknown procedure type -- EXECUTE-APPLICATION"
                proc))))
```

1. Assuming that `analyze` is extended to include `((let? exp) (analyze-let exp))`, implement `analyze-let`:

```
(define (analyze-let exp)
```

## Streams

1. `(cons-stream a b)` - equivalent to `(cons a (delay b))`
2. `(stream-car c)` - equivalent to `(car c)`
3. `(stream-cdr c)` - equivalent to `(force (cdr c))`

### Simple Streams:

Zeros: `(0 0 0 0 0 0 ....`

```
(define zeros
```

Ones: `(1 1 1 1 1 1 ....`

```
(define ones
```

Natural numbers (called ints): `(1 2 3 4 5 6 ....`

```
(define ints
```

### Stream operators

We'd like to be able to operate on streams to modify them and combine them with other streams. For example, to do element-wise addition or multiplication:

```
(define (add-streams s1 s2) (map2-stream + s1 s2))
(define (mul-streams s1 s2) (map2-stream * s1 s2))
(define (div-streams s1 s2) (map2-stream / s1 s2))
```

Write `map2-stream`:

```
(define (map2-stream op s1 s2)
```

Another possible operation is multiplying every element of the stream by a constant factor:

```
(define (scale-stream x s)
```

Implement the stream of factorials, which goes (1 1 2 6 24 120 ...):

```
(define facts
```

## Power Series

We can approximate functions by summing terms of an appropriate power series. A power series has the form:

$$\sum a_n x^n = a_0 + a_1 x + a_2 x^2 + a_3 x^3 + \dots$$

By selecting appropriate  $a_n$ , the series converges to the value of a function. One particularly useful function for which this is the case is  $e^x$  which has the following power series:

$$e^x = 0! + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \dots$$

Since power series involve an infinite summation, of which we might only care about the first couple terms, they are an excellent problem to tackle with streams. The stream will encode the coefficients  $a_n$ . For example, to represent the function  $f(x) = 3$ , we'd use a stream whose first element was 3, and the rest are zeros. The following two procedures come in handy:

```
(define (powers x)
  (cons-stream x (scale-stream x (powers x))))

(define (sum-series s x n)
  (define (sum-helper s sum n)
    (if (= n 0)
        sum
        (sum-helper (stream-cdr s) (+ sum (stream-car s)) (- n 1))))
  (sum-helper (mul-streams s (powers x))))
```

Write an expression that computes a stream to represent the power series that converges to  $f(x) = 2x + 5$ :

```
(define two-x-plus-five
```

Write an expression that computes the stream for  $e^x$ :

```
(define e-to-the-x
```

To compute  $e^5$  using 20 terms, we'd call `(sum-series e-to-the-x 5 20)`.

Since the stream represents a function, we can write operations which work on functions and try to implement them in terms of the coefficients of the series. One such operation is integration. The integral of an infinite polynomial is also an infinite polynomial, but the coefficients will be different. In particular, we'll want our integration function to return a stream whose constant term (first element) is missing, as it can't actually compute it from the series.

```
(define (integrate-series s)
```

Write a new definition of  $e^x$  using `integrate-series` (Hint: what is the integral of  $e^x$ ?)

```
(define e-to-the-x
```

Given that we can build  $e^x$  this way, implement `sin` and `cos` in a similar fashion:

```
(define sine  
(define cosine
```

**Bonus Round Problem:** Another operation is function multiplication. This involves multiplying two infinite polynomials, which is not the same as `mul-streams`, as that only does elementwise multiplication.

```
(define (mul-series s1 s2)
```

Then this should look interestingly simple:

```
(add-streams (mul-series sine sine)  
             (mul-series cosine cosine))
```