Infinite Streams

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Infinitely Long Streams

We can use streams to represent infinitely long sequences:

\[
\text{(define (integers-starting-from n)} \text{)} \\
\hspace{1cm} \text{(cons-stream n (integers-starting-from (+ n 1)))}
\]

\[
\text{(define integers (integers-starting-from 1))}
\]

Then we can filter these infinite sequences, just as before:

\[
\text{(define (divisible? x y)} \text{)} \\
\hspace{1cm} \text{(= (remainder x y) 0) )}
\]

\[
\text{(define no-sevens} \text{)} \\
\hspace{1cm} \text{(stream-filter (lambda (x) (not (divisible? x 7))) integers))}
\]
If we define

\[
\text{(define (stream-ref stream n)} \\
\quad \text{(if (= n 0)} \\
\qquad \text{(stream-car stream)} \\
\qquad \text{(stream-ref (stream-cdr stream) (- n 1)))}}
\]

then \text{(stream-ref no-sevens 100)} will evaluate to 117. Here is a neat way to produce the Fibonacci sequence:

\[
\text{(define (fibgen a b)} \\
\quad \text{(cons-stream a (fibgen b (+ a b)))}}
\]

\[
\text{(define fibs (fibgen 0 1))}
\]
Getting Prime Numbers

- The sieve of Eratosthenes is an efficient way to produce prime numbers.
- Given a prime number, filter out all of its multiples.
- Of the remaining numbers, the next one is the next prime.
- Repeat...
- Start from 2.
Here is how we get the primes, using a form of the sieve of Eratosthenes:

```
(define (sieve stream)
  (cons-stream
   (stream-car stream)
   (sieve (stream-filter
            (lambda (x)
               (not (divisible? x (stream-car stream))))
            (stream-cdr stream))))

(define primes (sieve (integers-starting-from 2)))
```

You can now try evaluating (stream-ref primes 50).
(define ones (cons-stream 1 ones))

(define (add-streams s1 s2)
  (stream-map + s1 s2))

(define integers (cons-stream 1
  (add-streams ones integers)))

(define fibs
  (cons-stream 0
    (cons-stream 1
      (add-streams (stream-cdr fibs) fibs))))
(define (scale-stream stream factor)
  (stream-map (lambda (x) (* x factor)) stream))

(define double (cons-stream 1 (scale-stream double 2)))
Defining Streams Implicitly

;;; prime numbers -- really clever, 
;;; and efficient because it only 
;;; checks divisibility by numbers less than sqrt(n).

(define primes
  (cons-stream
   2
   (stream-filter prime? (integers-starting-from 3))))

(define (prime? n)
  (define (iter ps)
    (cond ((> (square (stream-car ps)) n) #t)
          ((divisible? n (stream-car ps)) #f)
          (else (iter (stream-cdr ps))))
    (iter primes))

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CS450 - Structure of Higher Level Languages
If we want to produce infinite streams of pairs we’ll run into a problem because the “looping” must range over an infinite set.

For example, suppose we want to produce the stream of pairs of all integers \((i, j)\) with \(i < j\) such that \(i + j\) is prime.

If \textit{int-pairs} is the sequence of all pairs of integers \((i, j)\) with \(i < j\), we can do the following:

\[
\text{(stream-filter (lambda (pair)
    (prime? (+ (car pair) (cadr pair))))
    int-pairs)}
\]

(we assume every pair is a list)
More generally, suppose we have two streams $S = (S_i)$ and $T = (T_j)$, and imagine the infinite rectangular array

$$(S_0, T_0) \ (S_0, T_1) \ (S_0, T_2) \ldots$$
$$(S_1, T_0) \ (S_1, T_1) \ (S_1, T_2) \ldots$$
$$(S_2, T_0) \ (S_2, T_1) \ (S_2, T_2) \ldots$$

We wish to generate a stream that contains all the pairs in the array that lie on or above the diagonal, i.e., the pairs

$$(S_0, T_0) \ (S_0, T_1) \ (S_0, T_2) \ldots$$
$$(S_1, T_1) \ (S_1, T_2) \ldots$$
$$(S_2, T_2) \ldots$$

If both $S$ and $T$ are the streams of integers, this will be our desired int-pairs.
In general, the stream of pairs (pairs S T) is composed of three parts:

- the pair \((S_0, T_0)\), the rest of the pairs in the first row, and the remaining pairs:

\[
\begin{array}{c|cc}
(S_0, T_0) & (S_0, T_1) & (S_0, T_2) \\
\hline
(S_1, T_1) & (S_1, T_2) \\
& (S_2, T_2) \\
\end{array}
\]

- The third piece in this decomposition (pairs that are not in the first row) is (recursively) the pairs formed from \((\text{stream-cdr } S)\) and \((\text{stream-cdr } T)\).

- Also note that the second piece (the rest of the first row) is

\[
(\text{stream-map (lambda (x) (list (stream-car s) x)) (stream-cdr t)})
\]
Thus we can form our stream of pairs as follows:

```
(define (pairs s t)
  (cons-stream
    (list (stream-car s) (stream-car t))
    (<combine-in-some-way>
      (stream-map (lambda (x) (list (stream-car s) x))
        (stream-cdr t))
      (pairs (stream-cdr s) (stream-cdr t))))))
```

We must find a way to combine the two inner streams.

One idea is to use the stream analog of the list append:

```
(define (stream-append s1 s2)
  (if (stream-null? s1) s2
    (cons-stream (stream-car s1)
      (stream-append (stream-cdr s1) s2))))
```
Streams of Infinite Pairs

- This is unsuitable for infinite streams because it takes all the elements from the first stream before incorporating the second stream.
- In particular, if we try to generate all pairs of positive integers using

\[(\text{pairs integers integers})\]

our stream will first run through all pairs with the first integer equal to 1, and will never produce pairs with any other value of the first integer.
- We need to devise an order of combination that ensures that every element will eventually be reached if we let our program run long enough.
Interleave takes elements alternately from the two streams.
Every element of the second stream will eventually find its way into the interleaved stream, even if the first stream is infinite.
We can thus generate the required stream of pairs as

(define (pairs s t)
  (cons-stream
   (list (stream-car s) (stream-car t))
   (interleave
    (stream-map (lambda (x) (list (stream-car s) x))
                (stream-cdr t))
    (pairs (stream-cdr s) (stream-cdr t))))

(define (interleave s1 s2)
  (if (stream-null? s1) s2
     (cons-stream (stream-car s1)
                  (interleave s2 (stream-cdr s1))))

)