18: Streams

CS1101S: Programming Methodology

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2 Streams: The Basics

3 Primes

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Module Plan

- Wed, 24/10: Streams
- Fri, 26/10: Hari Raya Haji
- Wed, 31/10: Meta-circular evaluator (Part I)
- Fri, 2/11: Meta-circular evaluator (Part II)
- Wed, 7/11: Practical exam
- Fri, 9/11: Death Cube Contest
- Wed, 14/11: Java
- Fri, 16/11: Wrapping up CS1101S (party?)

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The Basics

Remember Midterm Question 1

Represent E1 ? E2 : E3 as a function.

```
cond(E1, function() { return E2; },
         function() { return E3; })
```

where

```
function cond(x,y,z) {
    if (x) { return y(); } else { return z(); }
}
```

Delayed Evaluation

Main Idea

We delayed the evaluation of E2 and E3 until we had enough information to decide which one was needed.

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Instrument of delay

Functions allow us to describe an activity without actually doing the activity.

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Instrument of delay

Functions allow us to describe an activity without actually doing the activity.

Functions as Pickles

Like preserved vegetable or fruit, a function stores the activity and can be “opened” by applying it.

A Simple Example

```
function f(...) {
    var x = ...;
    return function() { return x + 10; };
}

// return y from computation
var y = f(...);

// two weeks later
var z = y();
```

Memoization with Lazy Evaluation

```
function memo_fun(fun) {
    var already_run = false;
    var result = undefined;
    return function() {
                if (! already_run) {
                    result = fun();
                    already_run = true;
                    return result;
                } else {
                    return result;
            }   };
}
```

Why don’t we always do this?

Nature of functions

Functions often have an *effect*, beyond the value they are computing

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Side effects

When we are talking about lazy evaluation, these effects are called *side effects*

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When we are talking about lazy evaluation, these effects are called *side effects*

Pure functional programming

Programming without side-effects. All values can be memoized.

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What does this function do?

```
function mystery(a, b) {
    function iter(count, sofar) {
        if (count > b) {
            return sofar;
        } else {
            if (prime(count)) {
                return iter(count + 1, count+sofar);
            } else {
                return iter(count + 1, sofar);
    }   }   }
    return iter(a, 0);
}
```

Sum of primes from a to b

```
function sum_primes(a, b) {
    function iter(count, sofar) {
        if (count > b) {
            return sofar;
        } else {
            if (prime(count)) {
                return iter(count + 1, count+sofar);
            } else {
                return iter(count + 1, sofar);
    }   }   }
    return iter(a, 0);
}
```

Also can?

```
function sum_primes(a, b) {
    return accumulate(function(x, y) {
                          return x + y;
                      },
                      filter(prime,
                             enum_list(a, b)));
}
```

Extreme example

```
head(tail(filter(prime,
                 enum_list(100, 1000000))));
```

What is wrong here?

Extreme example

```
head(tail(filter(prime,
                 enum_list(100, 1000000))));
```

What is wrong here?

We only need the first element of the list of 999901 numbers.

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Idea of streams

Delayed lists

Our pairs contain a data item as head (as usual), but a function as tail that can be activated when needed.

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Streams

A *stream* is either the empty list, or a pair whose tail is a nullary function that returns a stream.

Idea of streams

Delayed lists

Our pairs contain a data item as head (as usual), but a function as tail that can be activated when needed.

Streams

A *stream* is either the empty list, or a pair whose tail is a nullary function that returns a stream.

Stream discipline

Like list discipline, now using streams.

Simple example

```
function ones_stream() {
    return pair(1, ones_stream);
}

var ones = ones_stream();
head(ones); // 1
head(tail(ones)()); // 1
head(tail(tail(ones)())()); // 1
```

Convenient function

```
function stream_tail(stream) {
    return tail(stream)();
}

var ones = ones_stream();
head(ones); // 1
head(stream_tail(ones));
head(stream_tail(stream_tail(ones)));
```

Streams are lazy lists

```
function stream_ref(s, n) {
    if (n === 0) {
        return head(s);
    } else {
        return stream_ref(stream_tail(s), n - 1);
    }
}
```

Everything still works

```
function stream_map(f, s) {
  if (is_empty_list(s)) {
    return [];
  } else {
    return pair(f(head(s)),
                function() {
                  return stream_map(
                           f, stream_tail(s));
                });
} }
```

Everything still works

```
function stream_filter(p, s) {
  if (is_empty_list(s)) {
      return [];
  } else if (p(head(s))) {
      return pair(head(s),
                  function() {
                      return stream_filter(
                                 p,stream_tail(s));
                  });
  } else {
      return stream_filter(p,
                           stream_tail(s));
} }
```

Extreme example

```
head(stream_tail(stream_filter(
                              prime,
                              enum_stream(100,
                                          1000000))));
```

General idea

Only compute what is needed. Be *lazy* about it!

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More examples

```
function integers_from(n) {
    return pair(n,
                function() {
                    return integers_from(n + 1);
                });
}

var integers = integers_from(0);
head(integers);
head(stream_tail(integers));
head(stream_tail(stream_tail(integers)));
```

More examples

```
function divisible(x, y) {
    return x % y === 0;
}
no_fours =
stream_filter(function(x) {
                  return ! divisible(x, 4);
              },
              integers);
```

From streams to lists

```
function eval_stream(s, n) {
    if (n === 0) {
        return [];
    } else {
        return pair(head(s),
                    eval_stream(stream_tail(s),
                                n - 1));
    }
}
```

U still there?

```
stream_ref(no_fours,3);

stream_ref(no_fours,100);

eval_stream(no_fours,10);
```

Repeating sequence

Wanted

Stream containing 1, 2, 3, 1, 2, 3, 1, 2, 3,...

```
var rep123 =
pair(1,
     function() {
       return pair(2,
                   function() {
                     return pair(3,
                                 ???);
     });           });
```

Repeating sequence

Wanted

Stream containing 1, 2, 3, 1, 2, 3, 1, 2, 3,...

```
var rep123 =
pair(1,
     function() {
       return pair(2,
                   function() {
                     return pair(3,
                                 function() {
                                   return rep123;
                                 });
                   });
     });
```

More and more

Wanted

Stream containing 1, 1, 2, 1, 2, 3, 1, 2, 3, 4,...

```
function helper(a, b) {
    if (a > b) {
        return helper(1, 1 + b);
    } else {
        return pair(a,
                    function() {
                        return helper(a + 1, b);
                    });
    }
}
```

Stream Processing

Like lists except

- Wrap tail in function
- Use `stream_tail` instead of `tail`

Stream library

We need to write a stream library that provides stream versions of our list library functions: `stream_map`, `stream_filter` etc

Replace

Wanted

A function replace that creates a new stream by replacing in a given stream a particular value by another value.

Example

```
replace(more_and_more, 1, 0)

--> 0 0 2 0 2 3 0 2 3 4 0 2 3 4 5 ...
```

Replace

```
function replace(s, a, b) {
  return pair( (head(s) === a) ? b : head(s),
               function() {
                 return replace(stream_tail(s),
                                a, b);
               });
}
```

Challenge

Wanted

Write a function that when given a list returns a stream that repeats the list infinitely

Adding two streams

Wanted

Write a function that takes two streams and returns a stream that contains the pairwise sums

Adding two streams

Wanted

Write a function that takes two streams and returns a stream that contains the pairwise sums

Example

adding
1 2 3 4 5 6...
1 1 2 2 3 3...
should return
2 3 5 6 8 9...

Adding streams

```
function add_streams(s1, s2) {
  if (is_empty_list(s1) {
    return s2;
  } else {
    return pair(head(s1) + head(s2),
                function() {
                  return add_streams(
                           stream_tail(s1),
                           stream_tail(s2));
                });
} }
```

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Another example

```
var wat =
pair(0,
  function() {
    return pair(1,
                function() {
                  return add_streams(
                           wat,
                           stream_tail(wat));
                });
  });
```

Or another fib?

```
function fibgen(a, b) {
    return pair(a,
                function() {
                    return fibgen(b, a + b);
                });
}
var fibs = fibgen(0, 1);
```

Integers Revisited

```
var ones = pair(1, function() { return ones; });

var integers =
pair(1, function() {
          return add_streams(ones, integers);
        });
```

Iteration revisited

```
function improve(guess,x) {
    return average(guess,x / guess);
}
function sqrt_iter(guess,x) {
    if (good_enough(guess,x))
        return guess;
    else
        return sqrt_iter(improve(guess,x), x);
}
function sqrt(x) {
    return sqrt_iter(1.0,x);
}
```

Using streams for iteration

```
function sqrt_stream(x) {
  var guesses =
  pair(1.0,
       function() {
         return stream_map(
                  function(guess) {
                    return sqrt_improve(guess,x);
                  },
                  guesses)
       });
  return guesses;
}
```

Using streams for iteration

```
eval_stream(sqrt_stream(2), 6)
// 1
// 1.5
// 1.416666666666
// 1.414215686274
// 1.414213562374
// 1.414213562373
```