L5: List and Tree Processing

CS1101S: Programming Methodology

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September 8, 2021

Where are we?

Module overview

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- Unit 1—Functional abstraction: SICP Chapter 1

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- Unit 1—Functional abstraction: SICP Chapter 1
- Unit 2—Data abstraction: SICP Chapter 2

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- Unit 1—Functional abstraction: SICP Chapter 1
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- Unit 3—State: SICP Chapter 3

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- Unit 1—Functional abstraction: SICP Chapter 1
- Unit 2—Data abstraction: SICP Chapter 2
- Unit 3—State: SICP Chapter 3
- Unit 4—Beyond: SICP Chapter 4

Unit 2

Lectures and Briefs

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- Intro to data abstraction: L4

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- Intro to data abstraction: L4
- List and Tree Processing: L5

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- Intro to data abstraction: L4
- List and Tree Processing: L5
- Language Processing: B5

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- Intro to data abstraction: L4
- List and Tree Processing: L5
- Language Processing: B5
- Symbolic Processing: L6

Unit 2

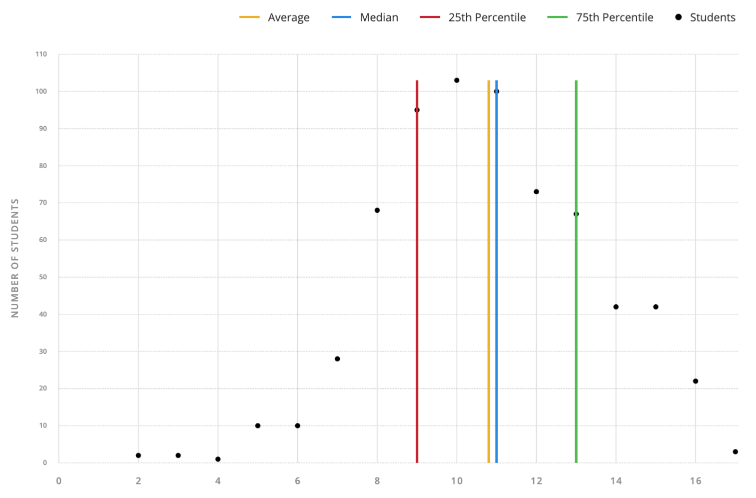
Lectures and Briefs

- Intro to data abstraction: L4
- List and Tree Processing: L5
- Language Processing: B5
- Symbolic Processing: L6
- Guest Lecture by Joel Low: B6

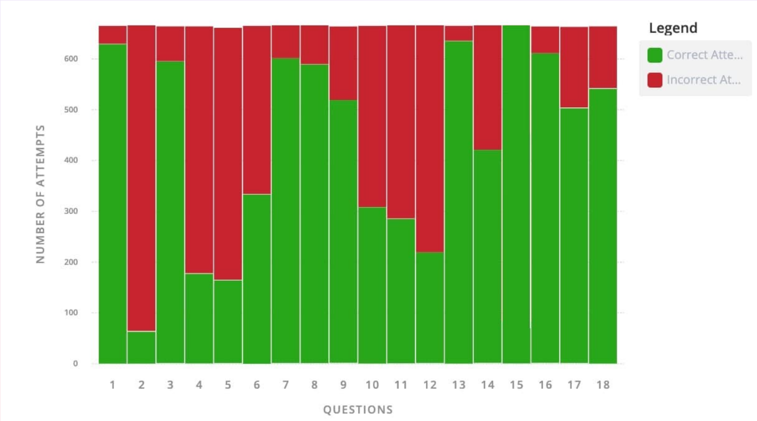
Some stock-taking

- Reading Assessment 1
- Unit 1 Survey

RA1: Results per student



RA1: Results per question



Reading Assessment 1: The hardest question

```
const x = 3;

function fun(x) {
    if (x % 2 === 0) {
        const z = 20;
    } else {
        const z = 30;
    }

    return x + y + z;
}

const y = 5;
const z = 10;
fun(x + y);
```

Unit 1 Survey

- Anonymous

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- 674 participants: 100%

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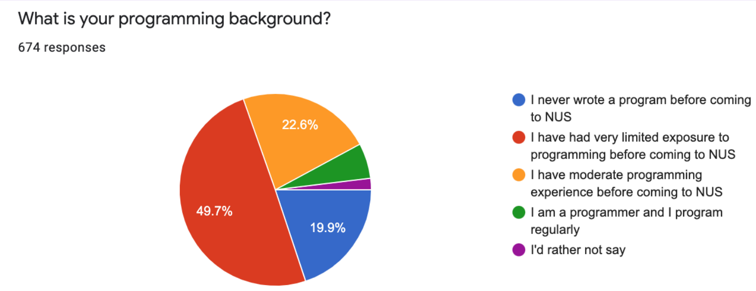
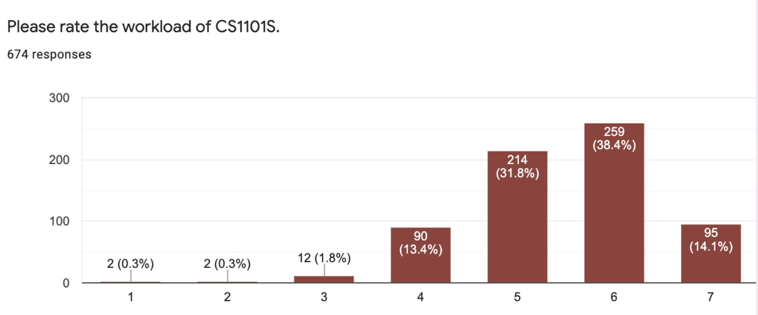
- We hear you!
- Many thanks for participating!

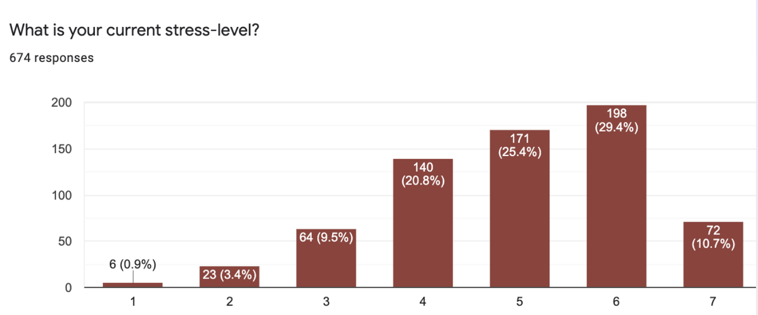
Unit 1 Survey: Programming Background



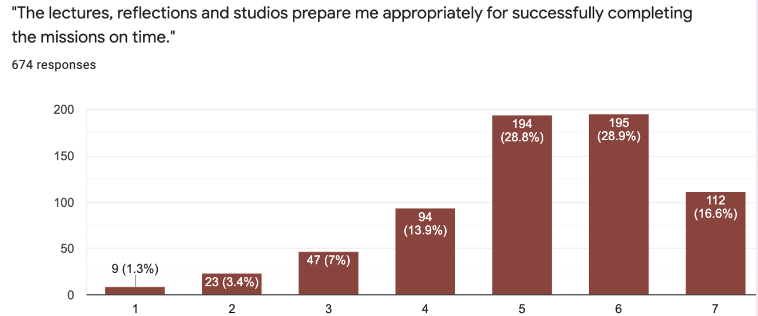
Unit 1 Survey: Workload



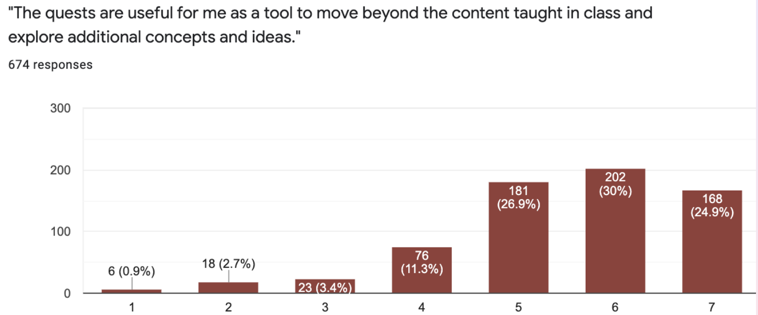
Unit 1 Survey: Stress Level



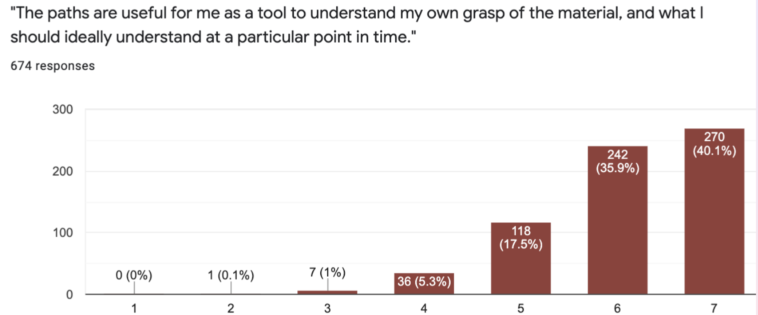
Unit 1 Survey: Preparation for Missions?



Unit 1 Survey: Quests



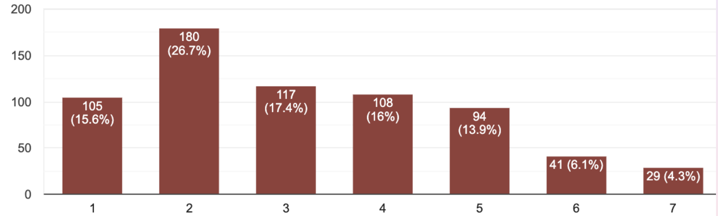
Unit 1 Survey: Paths



Unit 1 Survey: COVID

In your current view, how much are your studies in CS1101S affected by the COVID measures? (online-only lectures, reflections, social distancing etc)

674 responses



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- Learning attitude

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- pass/fail
- repetition allowed, also per topic

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- Other staff may check as well for repeated attempts.
- Try finish MC1 b4 Recess Week. (Great prep for Midterm!)

Contest: Beautiful Runes

1. List Processing (2.2.1)
   - Review: The `length` of a list
   - `append`
   - `reverse`
2. Continuation-Passing Style
3. Higher-order List Processing (2.2.1–2.2.3)
4. Trees and Tree Processing (2.2.2)

Computing the length of a list (2.2.1)

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```
function length(xs) {
  return is_null(xs)
      ? 0
      : 1 + length(tail(xs));
}
```

We can do this with an iterative process!

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```
function length(xs) {          // recursive
  return is_null(xs)
      ? 0
      : 1 + length(tail(xs));
}

function length_iter(xs) {  // iterative
  function len(xs, counted_so_far) {
    return is_null(xs)
        ? counted_so_far
        : len(tail(xs),
              counted_so_far + 1);
  }
  return len(xs, 0);
}
```

Appending two lists

Append `list(1, 3, 5)` and `list(2, 4)` results in

`list(1, 3, 5, 2, 4)`

Assumption: Both arguments are lists

Strategy for `append(xs, ys)`

If `xs` is empty, return `ys`.

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Strategy for `append(xs, ys)`

If `xs` is empty, return `ys`.

Otherwise, wishful thinking!

Append the tail of `xs` to `ys`

Form a pair of the head of `xs` and the result.

The same in Source

```
function append(xs, ys) {
  return is_null(xs)
      ? ys
      : pair(head(xs),
             append(tail(xs), ys));
}
```

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function append(xs, ys) {
  return is_null(xs)
      ? ys
      : pair(head(xs),
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```

Time complexity? Space complexity?

Reversing a list: First attempt

```
function reverse(xs) {
    return is_null(xs)
           ? null
           : pair(reverse(tail(xs)),
                  head(xs));
}
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What's wrong?

Result not a list.

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function reverse(xs) {
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           ? null
           : pair(reverse(tail(xs)),
                  head(xs));
}
```

What's wrong?
Result not a list.
We simply *reverse*
roles of head and tail.

Reversing a list: Correct but naive

```
function reverse(xs) {
    return is_null(xs)
        ? null
        : append(reverse(tail(xs)),
                 list(head(xs)));
}
```

Reversing a list: Correct but naive

```
function reverse(xs) {
    return is_null(xs)
        ? null
        : append(reverse(tail(xs)),
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}
```

Correct, but what about runtime?

Reversing a list efficiently

```
function reverse(xs) {
  function rev(original, reversed) {
    return is_null(original)
           ? reversed
           : rev(tail(original),
                 pair(head(original),
                      reversed));
  }
  return rev(xs,null);
}
```

Reversing a list efficiently

```
function reverse(xs) {
  function rev(original, reversed) {
    return is_null(original)
           ? reversed
           : rev(tail(original),
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  }
  return rev(xs,null);
}
```

Order of growth? Time? Space?

1. List Processing (2.2.1)
2. Continuation-Passing Style
   - Closer Look at `append`
   - Iterative process with `reverse`
   - Iterative process with Continuation Passing
3. Higher-order List Processing (2.2.1–2.2.3)
4. Trees and Tree Processing (2.2.2)

A closer look in Source at append

```
function append(xs, ys) {
    return is_null(xs)
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A closer look in Source at append

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function append(xs, ys) {
    return is_null(xs)
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                  append(tail(xs), ys));
}
```

Can we do this using an iterative process?

Iterative process, first attempt

```
function append_iter(xs, ys) {
  return is_null(xs)
      ? ys
      : append_iter(tail(xs),
                    pair(head(xs), ys));
}
```

Iterative process using reverse

```
function app_rev_iter(xs, ys) {
  return is_null(xs)
    ? ys
    : app_rev_iter(tail(xs), pair(head(xs), ys));
}
function append(xs, ys) {
  return append_rev_iter(
           reverse(xs), ys);
}
```

Iterative process using reverse

```
function app_rev_iter(xs, ys) {
  return is_null(xs)
    ? ys
    : app_rev_iter(tail(xs), pair(head(xs), ys));
}
function append(xs, ys) {
  return append_rev_iter(
           reverse(xs), ys);
}
```

Can we do this without reverse?

An iterative version of append

```
function append(xs, ys) {       // recursive proc
  return is_null(xs)
         ? ys
         : pair(head(xs),
                append(tail(xs), ys));
}
function app(current_xs, ys, c) {  // iter. proc
  return is_null(current_xs)
         ? c(ys)
         : app(tail(current_xs), ys,
               x => c(pair(head(current_xs), x)));
}
function append_iter(xs, ys) {
    return app(xs, ys, x => x);
}
```

Continuation-Passing Style

```
function app(current_xs, ys, c) {  // iter. proc
  return is_null(current_xs)
         ? c(ys)
         : app(tail(current_xs), ys,
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function append_iter(xs, ys) {
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Programming Pattern: CPS

Passing the deferred operation as a function in an extra argument is called "Continuation-Passing Style" (CPS).

Continuation-Passing Style

```
function app(current_xs, ys, c) {  // iter. proc
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}
```

Programming Pattern: CPS

Passing the deferred operation as a function in an extra argument is called "Continuation-Passing Style" (CPS).
We can convert *any* recursive function this way!

Recall L3-Excursion 2: a "divine" solution

```
function fractal_5(rune, n) {
    return n === 1
           ? rune
           : beside(rune,fractal_5(stack(rune,rune),
                                   n - 1));
}
```

Recall L3-Excursion 2: a "divine" solution with CPS

```
function fractal_5(rune, n) {
    return n === 1
        ? rune
        : beside(rune,fractal_5(stack(rune,rune),
                                  n - 1));
}
function frac(rune, n, c) {
    return n === 1
       ? c(rune)
       : frac(stack(rune, rune), n - 1,
              res => c(beside(rune, res)));
}
function fractal_5_iter(rune, n) {
    return frac(rune, n, rune => rune);
}
```

1. List Processing (2.2.1)
2. Continuation-Passing Style
3. Higher-order List Processing (2.2.1–2.2.3)
   - `map`
   - `accumulate`
   - `filter`
4. Trees and Tree Processing (2.2.2)

Map, reduce, filter

Advantage of functional programming

Results only depend on arguments.

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Functional programming in industry

FP has achieved widespread use in software industry.

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Set of abstractions that forms the core of many big data processing engines, such as Apache Hadoop.

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Terminology

Following SICP, we say *accumulate* instead of *reduce*.

Scaling a list (2.2.1)

Let us scale all elements of a list of numbers by a factor `f`.

```
function scale_list(xs, factor) {
  return is_null(xs)
      ? null
      : pair(factor * head(xs),
             scale_list(tail(xs),
                        factor));
}
```

Squaring a list

Let us *square* all elements of a list of numbers.

```
function square_list(xs) {
    const square = x => x * x;
    return is_null(xs)
        ? null
        : pair(square(head(xs)),
                 square_list(tail(xs)));
}
```

Abstraction: `map` (2.2.1)

Mapping means applying a given function `f` element-wise to a given list `xs`.

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function scale_list(xs, factor) {
  return map(x => factor * x, xs);
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function scale_list(xs, factor) {
  return map(x => factor * x, xs);
}

function square_list(xs) {
  return map(x => x * x, xs);
}
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Definition of map

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  return is_null(xs)
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Example: summing the elements of a list (2.2.3)

Problem

Compute the sum of all elements of a given list of numbers

Example: summing the elements of a list (2.2.3)

Problem

Compute the sum of all elements of a given list of numbers

```
function list_sum(xs) {
    return is_null(xs)
        ? 0
        : head(xs) + list_sum(tail(xs));
}
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Compute the sum of all elements of a given list of numbers

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```

Right-to-left folding

`list_sum(list(1,2,3,4))` computes
`1 + (2 + (3 + (4 + 0)))`.

accumulate: an abstraction for right-to-left folding

```
function list_sum(xs) { // programmed "by hand"
    return is_null(xs)
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        : head(xs) + list_sum(tail(xs));
}
```

accumulate: an abstraction for right-to-left folding

```
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    return is_null(xs)
        ? 0
        : head(xs) + list_sum(tail(xs));
}

function accumulate(f, initial, xs) {
  return is_null(xs)
    ? initial
    : f(head(xs),accumulate(f,initial,tail(xs)));
}
function list_sum(xs) {  // using accumulate
    return accumulate( (x, y) => x + y, 0, xs);
}
```

filter (2.2.3)

Problem: take only even elements of list of numbers

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```
filter(x => x % 2 === 0, list(1, 2, 3, 4, 5, 6));
```

filter (2.2.3)

Problem: take only even elements of list of numbers

```
filter(x => x % 2 === 0, list(1, 2, 3, 4, 5, 6));

function filter(pred, xs) {
  return is_null(xs)
       ? xs
       : pred(head(xs))
       ? pair(head(xs),
              filter(pred, tail(xs)))
       : filter(pred, tail(xs));
}
```

1. List Processing (2.2.1)
2. Continuation-Passing Style
3. Higher-order List Processing (2.2.1–2.2.3)
4. Trees and Tree Processing (2.2.2)
   - What are trees?
   - Higher-order Tree Processing
   - Counting Data Items
   - Syntax Trees

Trees (2.2.2)

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A list *of a certain type*

...is either `null` or a pair whose head is of that type and whose tail is a list of that type

Trees (2.2.2)

A list *of a certain type*

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A tree *of a certain type*

... is a list whose elements are of that type, or trees of that type.

Trees (2.2.2)

A list *of a certain type*

...is either `null` or a pair whose head is of that type and whose tail is a list of that type

A tree *of a certain type*

... is a list whose elements are of that type, or trees of that type.

Consider:

```
const tree = list(0, list(1,2), list(3,4), 5);
```

Trees (2.2.2)

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... is a list whose elements are of that type, or trees of that type.

Consider:

```
const tree = list(0, list(1,2), list(3,4), 5);
```

Caveat

Cannot consider `null` or pair as “certain type” for trees.

Scaling trees (2.2.2)

Example: scale each data item by a factor 10

```
const my_tree =
    list(1, list(2, list(3, 4), 5), list(6, 7));
```

```
scale_tree(my_tree, 10);
```

should have the same result as:

```
list(10,list(20,list(30,40),50),list(60,70));
```

Scaling trees: Idea

Recall: A *tree* is a list whose elements are data items, or trees.

Scaling trees: Idea

Recall: A *tree* is a list whose elements are data items, or trees.

Idea: Map over the list. If element is a data item, scale element.
If not: *scale tree*

.

Scaling trees: Implementation using list map

```
function scale_tree(tree, factor) {
    return map(sub_tree =>
                   ! is_list(sub_tree)
                   ? factor * sub_tree
                   : scale_tree(sub_tree, factor),
               tree);
}
```

Abstraction: Mapping over trees

```
function map_tree(f, tree) {
    return map(sub_tree =>
                   ! is_list(sub_tree)
                   ? f(sub_tree)
                   : map_tree(f, sub_tree),
               tree);
}
```

Scaling trees: Implementation using map_tree

```
function scale_tree(tree, factor) {
    return map_tree(data_item =>
                        data_item * factor,
                    tree);
}
```

.

Counting Data Items (2.2.2)

Task: Compute the number of data items in a given tree?

```
const tree = pair(list(1, 2), list(3, 4));
```

What is `count_data_items(tree)`?

.

Counting Data Items: Idea

Every tree is a list.

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Counting Data Items: Idea

Every tree is a list.

That list can be empty, in which case we return 0.

If the list is not empty, we add the *number of data items* of the head to the *number of data items* of the tail.

The head can be a tree, in which case we need to count *its* data items. If it's not a tree, it's a data item and we count 1.

Counting Data Items

```
function count_data_items(tree) {
  return is_null(tree)
         ? 0
         : ( is_list(head(tree))
             ? count_data_items(head(tree))
             : 1 )
           +
           count_data_items(tail(tree));
}
```

Counting Data Items

```
function count_data_items(tree) {
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}
```

Exercise

Design an abstraction that lets you count the elements using `(x, y) => x + y` and that lets you compute a list of elements using append

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- Goal: implement language processing tools

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- Implement language processors as data processors

Teaser for Lecture L11

The evaluator, which determines the meaning of statements in a programming language, is just another program.

Summary

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- Outlook: Brief B5: Overview of programming language processing