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• Midterm survey due Monday 11/10 @ 11:59pm (Thanks!)
Programming Languages
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```python
def square(x):
    return x * x
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| def square(x):
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from dis import dis
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```

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To create a new programming language, you either need a:

- **Specification:** A document describe the precise syntax and semantics of the language.
- **Canonical Implementation:** An interpreter or compiler for the language.
Calculator

(Demo)
The Pair Class

The Pair class represents Scheme pairs and lists. A list is a pair whose second element is either a list or nil.
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class Pair:
    """A Pair has two instance attributes: first and second.
    For a Pair to be a well-formed list,
    second is either a well-formed list or nil.
    Some methods only apply to well-formed lists.
    """
    def __init__(self, first, second):
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(1 2 . 3)
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Traceback (most recent call last):
  ...  
TypeError: length attempted on improper list
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Scheme expressions are represented as Scheme lists! Source code is data
Calculator Syntax
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Expression | Expression Tree | Representation as Pairs
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(* 3 (+ 4 5) (* 6 7 8)) | ![Expression Tree Diagram] | ![Representation as Pairs Diagram]
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```
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```plaintext
(* 3
  (+ 4 5)
  (* 6 7 8))
```
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Expression: (* 3 (+ 4 5) (* 6 7 8))

Expression Tree:
```
  *  
  /   
(*/  
  /   
(*  
  /   
(*  
  /   
(+  
  /   
    */ 
    /  
    (*  
    /   
    (*  
    /   
    (*  
    /   
    3    9    
    4    5    6    7    8)
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```
9
(* 3(+ 4 5)(* 6 7 8))
```

```
Expression

(* 3
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Expression Tree

3
  +
  4 5
  9

(*)
  (* 6 7 8)

336
  6 7 8
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Expression

\[(\ast\ 3 \\
\ (+\ 4\ 5) \\
\ (*\ 6\ 7\ 8))\]

Expression Tree

```
            * 9072
           /    /
          3    +    *
         /  \
        4   5   9    336
       /   /    /    /
      6   7   8
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Evaluation
The Eval Function
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It is a generic function that dispatches on the type of the expression (primitive or call).

```
def calc_eval(exp):
    if type(exp) in (int, float):
        return exp
    elif isinstance(exp, Pair):
        arguments = exp.second.map(calc_eval)
        return calc_apply(exp.first, arguments)
    else:
        raise TypeError
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Recursive call returns a number for each operand
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        arguments = exp.second.map(calc_eval)
        return calc_apply(exp.first, arguments)
    else:
        raise TypeError
```

Language Semantics

**A number evaluates...**

* to itself

**A call expression evaluates...**

* to its argument values combined by an operator
The Eval Function

The eval function computes the value of an expression, which is always a number.

It is a generic function that dispatches on the type of the expression (primitive or call).

Implementation

```python
def calc_eval(exp):
    if type(exp) in (int, float):
        return exp
    elif isinstance(exp, Pair):
        arguments = exp.second.map(calc_eval)
        return calc_apply(exp.first, arguments)
    else:
        raise TypeError
```

Language Semantics

- **A number evaluates...**
  to itself
- **A call expression evaluates...**
  to its argument values

combined by an operator
Applying Built-in Operators
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The `apply` function applies some operation to a (Scheme) list of argument values.
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In calculator, all operations are named by built-in operators: +, −, *, /
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In calculator, all operations are named by built-in operators: +, −, *, /

```
def calc_apply(operator, args):
    if operator == '+':
        return reduce(add, args, 0)
    elif operator == '-':
        ...
    elif operator == '*':
        ...
    elif operator == '/':
        ...
    else:
        raise TypeError
```
Applying Built-in Operators

The apply function applies some operation to a (Scheme) list of argument values.

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<table>
<thead>
<tr>
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</tr>
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<tbody>
<tr>
<td>def calc_apply(operator, args):</td>
<td>+:</td>
</tr>
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<td></td>
</tr>
<tr>
<td>return reduce(add, args, 0)</td>
<td></td>
</tr>
<tr>
<td>elif operator == '-':</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>elif operator == '*':</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>elif operator == '/':</td>
<td></td>
</tr>
<tr>
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    else:
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```

Language Semantics

+:

*Sum of the arguments*
Applying Built-in Operators

The apply function applies some operation to a (Scheme) list of argument values.

In calculator, all operations are named by built-in operators: +, −, *, /

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    ...
  elif operator == '*':
    ...
  elif operator == '/':
    ...
  else:
    raise TypeError | +:  
  Sum of the arguments  
−:  
  ...  
|                  |

```
  ```
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(Demo)
```
Interactive Interpreters
Read-Eval-Print Loop
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The user interface for many programming languages is an interactive interpreter.
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Read-Eval-Print Loop

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(Demo)
Raising Exceptions
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Exceptions are raised within lexical analysis, syntactic analysis, eval, and apply.
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Example exceptions
Raising Exceptions

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Example exceptions

- **Lexical analysis**: The token 2.3.4 raises ValueError("invalid numeral")
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(Demo)
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(Demo)