61A Lecture 27

Wednesday, October 31

Programming Languages

Computers have software written in many different languages.

Machine languages: statements can be interpreted by hardware

- All data are represented as sequences of bits
- All statements are primitive instructions

High-level languages: hide concerns about those details

- Primitive data types beyond just bits
- Statements/expressions can be non-primitive (e.g., calls)
- Evaluation process is defined in software, not hardware

High-level languages are built on top of low-level languages

Machine language | C | Python

Metalinguistic Abstraction

Metalinguistic abstraction: Establishing new technical languages (such as programming languages)

$$f(x) = x^2 - 2x + 1$$

$$\lambda f.(\lambda x.f(x\ x))(\lambda x.f(x\ x))$$

In computer science, languages can be *implemented*:

- An *interpreter* for a programming language is a function that, when applied to an expression of the language, performs the actions required to evaluate that expression.
- The *semantics* and *syntax* of a language must be specified precisely in order to build an interpreter.

The Scheme-Syntax Calculator Language

A subset of Scheme that includes:

- Number primitives
- Built-in arithmetic operators: +, –, *, /
- Call expressions

```
> (+ (* 3 5) (- 10 6))
19

> (+ (* 3
        (+ (* 2 4)
           (+ 3 5)))
     (+ (- 10 7)
        6))
57
```


Syntax and Semantics of Calculator

Expression types:

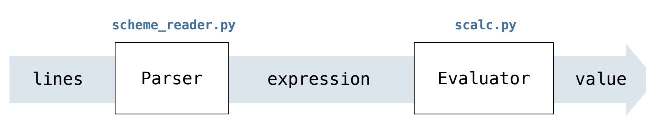
- A **call expression** is a Scheme list
- A **primitive expression** is an operator symbol or number

Operators:

- The + operator returns the sum of its arguments
- The – operator returns either
  - the additive inverse of a single argument, or
  - the sum of subsequent arguments subtracted from the first
- The * operator returns the product of its arguments
- The / operator returns the real-valued quotient of a dividend and divisor (i.e., a numerator and denominator)

Expression Trees

A basic interpreter has two parts: a *parser* and an *evaluator*



lines	expression	value
`'(+ 2 2)'`	`Pair('+', Pair(2, Pair(2, nil)))`	4

`'(* (+ 1'`
`'      (- 23)'`
`'      (* 4 5.6))'`
`'   10)'`
	`Pair('*', Pair(Pair('+', ...)))`
	printed as
	`(* (+ 1 (- 23) (* 4 5.6)) 10)`
		4

Lines forming a Scheme expression	A number or a Pair with an operator as its first element	A number

Syntactic Analysis

Syntactic analysis identifies the hierarchical structure of an expression, which may be nested.

Each call to scheme_read consumes the input tokens for exactly one expression.

```
'(', '+', 1, '(', '-', 23, ')', '(', '*', 4, 5.6, ')', ')'
```

Base case: symbols and numbers

Recursive call: scheme_read sub-expressions and combine them

Demo (http://inst.eecs.berkeley.edu/~cs61a/fa12/projects/scalc/scheme_reader.py.html)

Evaluation

Evaluation discovers the form of an expression and then executes a corresponding evaluation rule.

- Primitive expressions are evaluated directly.
- Call expressions are evaluated recursively:
  - Evaluate each operand expression
  - Collect their values as a list of arguments
  - *Apply* the named operator to the argument list

Demo

Applying Operators

Calculator has a fixed set of operators that we can enumerate

```
def calc_apply(operator, args):
    """Apply the named operator to a list of args."""
    if operator == '+':
        return ...
    if operator == '-':
        ...
    ...
```

Dispatch on operator name

Demo

Read-Eval-Print Loop

The user interface to many programming languages is an interactive loop, which

- Reads an expression from the user,
- Parses the input to build an expression tree,
- Evaluates the expression tree,
- Prints the resulting value of the expression.

Demo

Raising Application Errors

The sub and div operators have restrictions on argument number.

Raising exceptions in *apply* can identify such issues:

```
def calc_apply(operator, args):
    """Apply the named operator to a list of args."""
    ...
    if operator == '-':
        if len(args) == 0:
            raise TypeError(operator + ' requires at least 1 argument')
        ...
    ...
    if operator == '/':
        if len(args) != 2:
            raise TypeError(operator + ' requires exactly 2 arguments')
        ...
```


Handling Errors

The REPL handles errors by printing informative messages for the user, rather than crashing.

Demo

A well-designed REPL should not crash on any input!