SICP

God's Programming Book

Lecture-23 Calculator

Calculator

Slides Adapted from cs61a of UC Berkeley

Programming Languages

Programming Languages

A computer typically executes programs written in many different programming languages

Machine languages: statements are interpreted by the hardware itself

- A fixed set of instructions invoke operations implemented by the circuitry of the central processing unit (CPU)
- Operations refer to specific hardware memory addresses; no abstraction mechanisms

High-level languages: statements & expressions are interpreted by another program or compiled (translated) into another language

- Provide means of abstraction such as naming, function definition, and objects
- Abstract away system details to be independent of hardware and operating system

Python 3

```
def square(x):
    return x * x
```

```
from dis import dis
dis(square)
```

Python 3 Byte Code

```
LOAD_FAST                0 (x)
LOAD_FAST                0 (x)
BINARY_MULTIPLY
RETURN_VALUE
```

Metalinguistic Abstraction

A powerful form of abstraction is to define a new language that is tailored to a particular type of application or problem domain

Type of application: Erlang was designed for concurrent programs. It has built-in elements for expressing concurrent communication. It is used, for example, to implement chat servers with many simultaneous connections

Problem domain: The MediaWiki mark-up language was designed for generating static web pages. It has built-in elements for text formatting and cross-page linking. It is used, for example, to create Wikipedia pages

Metalinguistic Abstraction

A programming language has:

- **Syntax**: The legal statements and expressions in the language
- **Semantics**: The execution/evaluation rule for those statements and expressions

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

Parsing

Reading Scheme Lists

A Scheme list is written as elements in parentheses:

```
(<element_0> <element_1> ... <element_n>)
```

A Scheme list

Each <element> can be a combination or primitive

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

The task of parsing a language involves coercing a string representation of an expression to the expression itself

Parsing

A Parser takes text and returns an expression

Text → **Lexical analysis** → Tokens → **Syntactic analysis** → Expression

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

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

```
Pair('+', Pair(1, ...))
```

printed as

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

Lexical analysis:

- Iterative process
- Checks for malformed tokens
- Determines types of tokens
- Processes one line at a time

Syntactic analysis:

- Tree-recursive process
- Balances parentheses
- Returns tree structure
- Processes multiple lines

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

Scheme-Syntax 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.

```
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):
        self.first = first
        self.second = second
```

```
>>> s = Pair(1, Pair(2, Pair(3, nil)))
>>> print(s)
(1 2 3)
>>> len(s)
3
>>> print(Pair(1, 2))
(1 . 2)
>>> print(Pair(1, Pair(2, 3)))
(1 2 . 3)
>>> len(Pair(1, Pair(2, 3)))
Traceback (most recent call last):
...
TypeError: length attempted on improper list
```

Scheme expressions are represented as Scheme lists! Source code is data

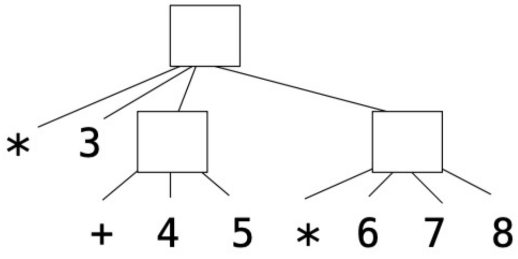
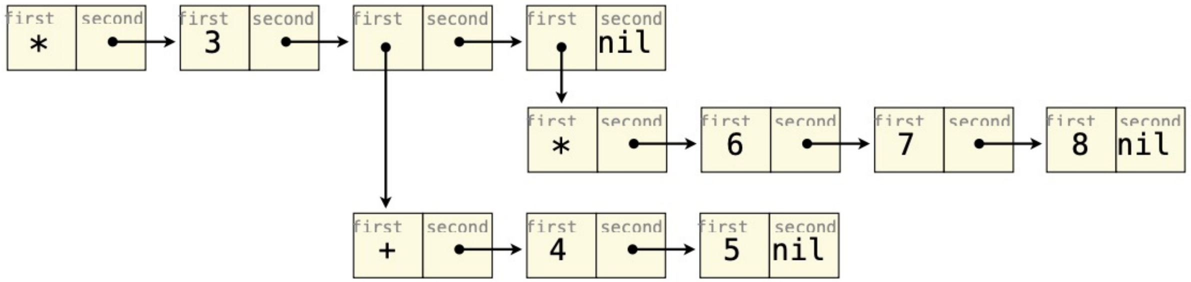
Calculator Syntax

The Calculator language has primitive expressions and call expressions. (That's it!)

A primitive expression is a number: 2 -4 5.6

A call expression is a combination that begins with an operator (+, -, *, /) followed by 0 or more expressions: (+ 1 2 3) (/ 3 (+ 4 5))

Expressions are represented as Scheme lists (Pair instances) that encode tree structures.

Expression	**Expression Tree**	**Representation as Pairs**
`(* 3 (+ 4 5) (* 6 7 8))`		

Calculator Semantics

The value of a calculator expression is defined recursively.

Primitive: A number evaluates to itself.

Call: A call expression evaluates to its argument values combined by an operator.
+: Sum of the arguments

*****: Product of the arguments

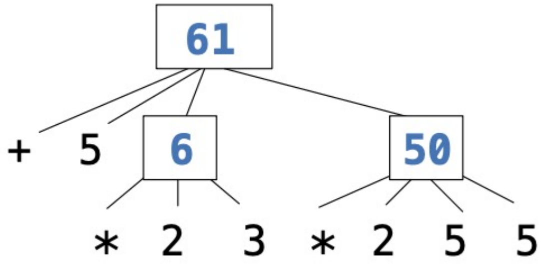
-: If one argument, negate it. If more than one, subtract the rest from the first.

/: If one argument, invert it. If more than one, divide the rest from the first.

Expression

```
(+ 5
   (* 2 3)
   (* 2 5 5))
```

Expression Tree



Evaluation

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

```
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
```

Recursive call returns a number for each operand

'+', '-', '*', '/'

A Scheme list of numbers

Language Semantics

A number evaluates...

to itself

A call expression evaluates...

to its argument values

combined by an operator

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: +, -, *, /

Implementation

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

Language Semantics

```
+:
   Sum of the arguments
-:
   ...
...
```

Interactive Interpreters

Read-Eval-Print Loop

The user interface for many programming languages is an interactive interpreter

1. Print a prompt
2. **Read** text input from the user
3. Parse the text input into an expression
4. **Evaluate** the expression
5. If any errors occur, report those errors, otherwise
6. **Print** the value of the expression and repeat

Raising Exceptions

Exceptions are raised within lexical analysis, syntactic analysis, eval, and apply

<u>Example exceptions</u>

- **Lexical analysis**: The token 2.3.4 raises ValueError("invalid numeral")
- **Syntactic analysis**: An extra) raises SyntaxError("unexpected token")
- **Eval**: An empty combination raises TypeError("() is not a number or call expression")
- **Apply**: No arguments to - raises TypeError("- requires at least 1 argument")

Handling Exceptions

An interactive interpreter prints information about each error

A well-designed interactive interpreter should not halt completely on an error, so that the user has an opportunity to try again in the current environment

Thanks for Listening