61A Lecture 26

Announcements

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

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

validating there are no errors and creating a nested hierarchical structure

Parsers must validate that expressions are well-formed.

(Demo)
http://composingprograms.com/examples/scalc/scheme_reader.py.html

see 26_scalc/scheme_reader.py

```
> 1
1
1
> (1 2)
(1 2)
Pair(1, Pair(2, nil))
> (1 2 3)
(1 2 3)
Pair(1, Pair(2, Pair(3, nil)))
> (+ 1 2 3)
(+ 1 2 3)
Pair('+', Pair(1, Pair(2, Pair(3, nil))))
> (+
    1 2
            3)
(+ 1 2 3)
Pair('+', Pair(1, Pair(2, Pair(3, nil))))
```

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))
```

ignore the white space

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

symbol / number

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

```
> ((1 2) 3)
((1 2) 3)
Pair(Pair(1, Pair(2, nil)), Pair(3, nil))
```

scheme_read calls read_tail

read_tail calls scheme_read, leading to the first element of Pair

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)

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

(Demo)

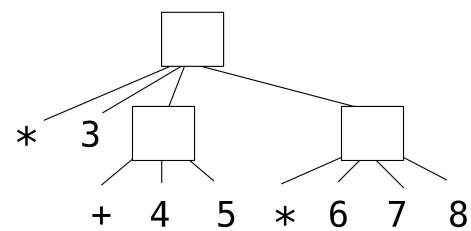
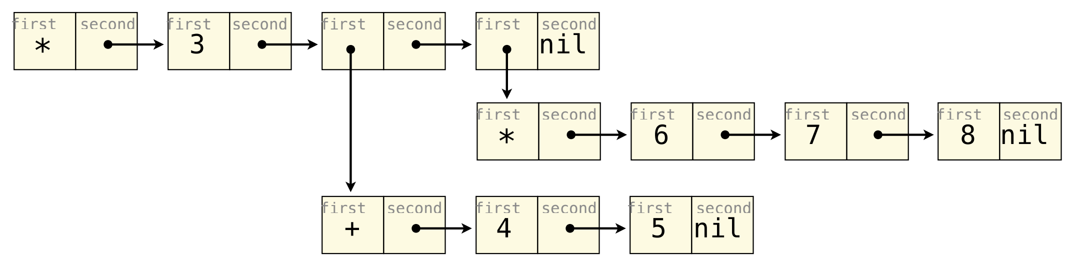
Calculator Syntax

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))`		


```
(* 3
   (+ 4 5)
   (* 6 7 8))
```

Calculator Semantics

The value of a calculator expression is defined recursively.

Primitive: A number evaluates to itself.

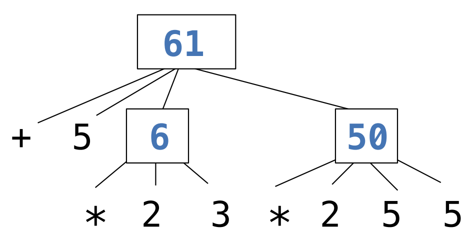
Call: A call expression evaluates to its argument values combined by an operator.

- **+**: 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
-:
  ...
...

(Demo)

see 26_scalc/scalc.py

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

(Demo)

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")

TypeError for a specific operand

(Demo)

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

by using While True in front of try ... except ... except ...return

Handling exceptions happen at one place, while raising exceptions happen at all kinds of places.

(Demo)