Lecture 21: Interpreters I

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Announcements

Roadmap

Introduction

Functions

Data

Mutability

Objects

Interpretation

Paradigms

Applications

- This week (Interpretation), the goals are:
  - To learn a new language, Scheme, in two days!
  - To understand how interpreters work, using Scheme as an example

Programming Languages (demo)

- Computers can execute programs written in many different programming languages. How?
- Computers only deal with *machine languages* (0s and 1s), where statements are direct commands to the hardware
- Programs written in languages like Python are *compiled*, or translated, into these machine languages
- Python programs are first compiled into Python *bytecode*, which has the benefit of being system-independent
- You can look at Python bytecode using the `dis` module

Python 3

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

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

Python 3 Bytecode

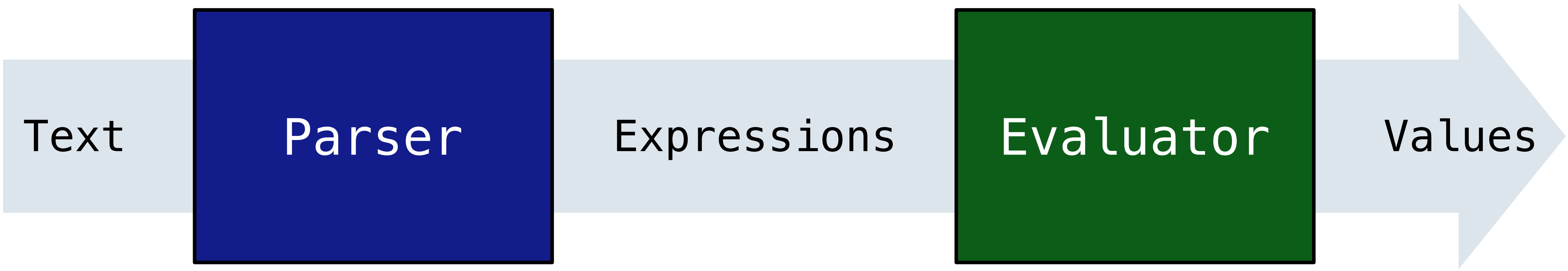
```
LOAD_FAST          0 (x)
LOAD_FAST          0 (x)
BINARY_MULTIPLY
RETURN_VALUE
```

Interpretation

- Compilers are complicated, and the topic of future courses
- In this course, we will focus on *interpreters*, programs that execute other programs written in a particular language
- The Python interpreter is a program written in C
  - After compiling it to machine code, it can be run to interpret Python programs
- The last project in this course is to write a Scheme interpreter in Python
  - The Scheme interpreter can then be run using the Python interpreter to interpret Scheme programs
- To create a new programming language, we either need a:
  - *Specification* of the syntax and semantics of the language
  - *Canonical implementation* of either a compiler or interpreter for the language

The Scheme Interpreter

- An interpreter for Scheme must take in text (Scheme code) as input and output the values from interpreting the text



- The job of the parser is to take in text and perform *syntactic analysis* to convert it into expressions that the evaluator can understand
- The job of the evaluator is to read in expressions and perform *semantic analysis* to evaluate the expressions and output the corresponding values

Calculator (demo)

- Building an interpreter for a language is a lot of work
- Today, we'll build an interpreter for a subset of Scheme
  - We will support +, -, *, /, integers, and floats
- We will call this simple language Calculator
- In lab, discussion, and next lecture, we will look at more complicated examples

```
calc> (/ (+ 8 7) 5)
3.0
```

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

Parsing

From text to expressions

Parsing

- The parser converts text into expressions


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

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

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

printed as

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

- Iterative process
- Checks number of parentheses
- Checks for malformed tokens
- Determines types of tokens

- Tree-recursive process
- Processes tokens one by one
- Checks parenthesis structure
- Returns expression as a Pair

Lexical Analysis (demo)

- Tokenization takes in a string and converts it into a list of tokens by splitting on whitespace
  - This step also removes excess whitespace

- An error is raised if the number of open and closed parentheses are unequal

- Each token is checked iteratively to ensure it is valid
  - For Calculator, each token must be a parenthesis, an operator, or a number
  - Otherwise, an error is raised

Syntactic Analysis (demo)

- Syntactic analysis uses a *read function to* identify the hierarchical structure of an expression
- Each call to the read function consumes the input tokens for exactly one expression, and returns the expression

```
def read_exp(tokens):
    """Returns the first calculator expression."""
    ...

def read_tail(tokens):
    """Reads up to the first mismatched close parenthesis."""
    ...
```

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

Resulting expression:

Evaluation

From expressions to values

Evaluation (demo)

- Evaluation is performed by an *evaluate function*, which takes in an expression (the output of our parser) and computes and returns the value of the expression
  - In Calculator, the value is always an operator or a number

- If the expression is primitive, we can return the value of the expression directly

- Otherwise, we have a call expression, and we follow the rules for evaluating call expressions:
  1. *Evaluate* the operator to get a function
  2. *Evaluate* the operands to get its values
  3. *Apply* the function to the values of the operands to get the final value
  - This hopefully looks very familiar!

The Evaluate and Apply Functions

```
def calc_eval(exp):
    if isinstance(exp, Pair):
        return calc_apply(calc_eval(exp.first),
                          list(exp.second.map(calc_eval)))
    elif exp in OPERATORS:
        return OPERATORS[exp]
    else:
        return exp

def calc_apply(op, args):
    return op(*args)
```

- Why define `calc_apply`? It's not really necessary, since the Calculator language is so simple
  - For real languages, applying functions is more complex
  - With user-defined functions, the apply function has to call the evaluate function! This mutual recursion is called the *eval-apply loop*

Putting it all together

A Calculator interactive interpreter!

The Read-Eval-Print Loop (demo)

- Interactive interpreters all follow the same interface:
    1. Print a prompt
    2. *Read* text input from the user
    3. Parse the input into an expression
    4. *Evaluate* the expression into a value
    5. Report any errors, if they occur, otherwise
    6. *Print* the value and return to step 1

- This is known as the read-eval-print loop (REPL)

Handling Exceptions (demo)

- Various exceptions may be raised throughout the REPL:
  - **Lexical analysis:** The token `2.3.4` raises **`SyntaxError`**
  - **Syntactic analysis:** A misplaced `)` raises **`SyntaxError`**
  - **Evaluation:** No arguments to `-` raises **`TypeError`**

- An interactive interpreter prints information about each error that occurs
- 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

Summary

- We built an interpreter today!
  - It was for a very simple language, but the same ideas and principles will allow us to build an interpreter for Scheme, a much more complicated language
  - More complicated examples are coming soon

- Interpreters are separated into a *parser* and an *evaluator*
  - The parser takes in text input and outputs the corresponding expressions, using *tokens* as a midpoint
  - The evaluator takes in an expression and outputs the corresponding value
  - The *read-eval-print loop* completes our interpreter