CS61A Lecture 22
Interpretation

Jom Magrotker
UC Berkeley EECS
July 25, 2012

Computer Science in the News

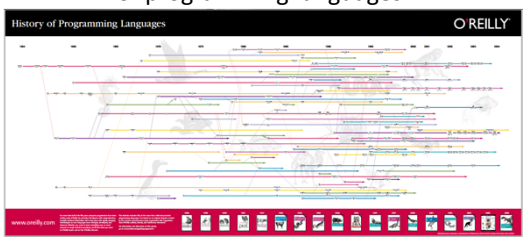
http://www.wired.co.uk/news/archive/2012-07/23/twitter-psychopaths

Today

- Interpretation: Basics
- Calculator Language
- Review: Scheme Lists

Programming Languages

Computer software today is written in a variety of programming languages.



http://oreilly.com/news/graphics/prog_lang_poster.pdf

Programming Languages

Computers can only work with 0s and 1s.

In *machine language*,

all data are represented as sequences of bits,

all statements are primitive instructions (ADD, DIV, JUMP) that can be interpreted directly by hardware.

Programming Languages

High-level languages like Python

allow a user to specify instructions in a more human-readable language, which eventually gets translated into machine language,

are evaluated in software, not hardware, and

are built on top of *low-level languages*, like C.

The details of the 0s and 1s are *abstracted* away.

How do we structure our programs? What functions do we need? What classes should we design?

Structure And Interpretation Of Computer Programs

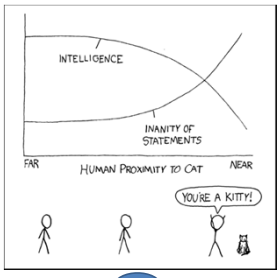
How can we make the computer understand our code? How does the computer currently understand our code?

The Treachery of Images (René Magritte)

http://upload.wikimedia.org/wikipedia/en/b/b9/MagrittePipe.jpg

Interpretation

What is a `kitty`?



http://imgs.xkcd.com/comics/cat_proximity.png
http://im.gloigster.com/media/5/18/37/45/18374576.jpg

Interpretation

`kitty` is a *word* made from `k`, `i`, `t` and `y`.

We ***interpret*** (or *give meaning to*) `kitty`, which is merely a string of characters, as the animal.

Similarly, `5 + 4` is simply a collection of characters: how do we get a computer to "understand" that `5 + 4` is an *expression* that ***evaluates*** (or produces a *value* of) 9?

Interpretation

```
>>>
```
What happens here?

The main question for this module is:

What exactly happens at the prompt for the interpreter?

More importantly, what *is* an interpreter?

Interpretation

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.

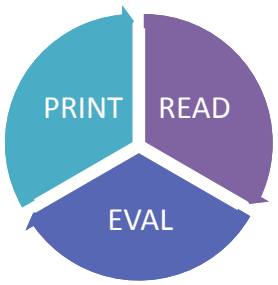
It allows a computer to *interpret* (or to "understand") strings of characters as expressions, and to work with resulting values.

Interpretation

Many interpreters will
read the input from the user,
evaluate the expression, and
print the result.

They repeat these three steps until stopped.

This is the ***read-eval-print loop (REPL)***.



Interpretation

Announcements

- Project 3 is due **Thursday, July 26**.
- Homework 11 is due **Friday, July 27**.

Please ***ask for help*** if you need to. There is a lot of work in the weeks ahead, so if you are ever confused, consult (in order of preference) your study group and Piazza, your TAs, and Jom.

Don't be clueless!

Announcements: Midterm 2

- Midterm 2 is **tonight**.
  - *Where*? 2050 VLSB.
  - *When*? 7PM to 9PM.
- Closed book and closed electronic devices.
- One 8.5" x 11" 'cheat sheet' allowed.
- Group portion is 15 minutes long.

Announcements: Midterm 2

The Calculator Language (or "Calc")

We will implement an interpreter for a very simple calculator language (or "Calc"):

```
calc> add(3, 4)
7
calc> add(3, mul(4, 5))
23
calc> +(3, *(4, 5), 6)
29
calc> div(3, 0)
ZeroDivisionError: division by zero
```

The Calculator Language (or "Calc")

The interpreter for the calculator language will be written in Python. This is our first example of using one language to write an interpreter for another.

This is not uncommon: this is how interpreters for new programming languages are written.

Our implementation of the Python interpreter was written in C, but there are other implementations in Java, C++, and even Python itself!

Syntax and Semantics of Calculator

How expressions are structured

What expressions mean

There are two types of expressions:

1. A ***primitive expression*** is a number.
2. A ***call expression*** is an operator name, followed by a comma-delimited list of operand expressions, in parentheses.

Syntax and Semantics of Calculator

Only four operators are allowed:

1. `add` (or `+`)
2. `sub` (or `-`)
3. `mul` (or `*`)
4. `div` (or `/`)

All of these operators are *prefix* operators: they are placed before the operands they work on.

Read-Eval-Print Loop

```
def read_eval_print_loop():
    while True:
        try:
            expression_tree = \
            calc_parse(input('calc> '))
        print(calc_eval(expression_tree))
        except ...:
            # Error-handling code not shown
```

READ

PRINT

EVAL

Read-Eval-Print Loop

```
def read_eval_print_loop():
    while True:
        try:
            expression_tree = \
            calc_parse(input('calc> '))
            print(calc_eval(expression_tree))
        except ...:
            # Error-handling code not shown
```

input prints the string provided and waits for a line of user input. It then returns the line.

Read

The function `calc_parse` reads a line of input as a string and ***parses*** it.

Parsing a string involves converting it into something more useful (and easier!) to work with.

Parsing has two stages:

tokenization (or ***lexical analysis***),

followed by ***syntactic analysis***.

Parsing

```
def calc_parse(line):
    tokens = tokenize(line)
    expression_tree = analyze(tokens)
    return expression_tree
```

TOKENIZATION

SYNTACTIC ANALYSIS

Parsing: Tokenization

Remember that a string is merely a sequence of characters: **tokenization** separates the characters in a string into ***tokens***.

As an analogy, for English, we use spaces and other characters (such as `.` and `,`) to separate tokens (or "words") in a string.

Parsing: Tokenization

Tokenization, or **lexical analysis**, identifies the **symbols** and **delimiters** in a string.

A ***symbol*** is a sequence of characters with meaning: this can either be a name (or an *identifier*), a literal value, or a reserved word.

A ***delimiter*** is a sequence of characters that defines the syntactic structure of an expression.

Parsing: Tokenization

This is the Python interpreter, *not* the interpreter for Calc.

```
>>> tokenize('add(2, mul(4, 6))')
['add', '(', '2', ',', 'mul',
 '(', '4', ',', '6', ')', ')']
```

Symbol: Operator name

Delimiter

Symbol: Literal

Delimiter

Parsing: Tokenization

For Calc, we can simply insert spaces and then split at the spaces.

```
def tokenize(line):
    spaced = line.replace('(', ' ( ')
    spaced = spaced.replace(')', ' ) ')
    spaced = spaced.replace(',', ' , ')
    return spaced.strip().split()
```

Removes leading and trailing white spaces.

Returns a list of strings separated by white space.

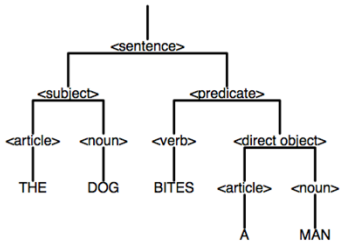
Parsing: Syntactic Analysis

Now that we have the tokens, we need to understand the structure of the expression:

What is the operator? What are its operands?

As an analog, in English, we need to determine the grammatical structure of the sentence before we can understand it.

PARSING: SYNTACTIC ANALYSIS



http://marvin.cs.uidaho.edu/Handouts/sentenceParse.png

PARSING: SYNTACTIC ANALYSIS

For English (and human languages in general), this can get complicated and tricky quickly:

```
Jom lectures to the student in the class
        with the cat.
The horse raced past the barn fell.
Buffalo buffalo Buffalo buffalo buffalo
    buffalo Buffalo buffalo.
```

Yes, this is a valid sentence.

PARSING: SYNTACTIC ANALYSIS

For Calc, the structure is much easier to determine.

Expressions in Calc can nest other expressions:

```
add(3, mul(4, 5))
```

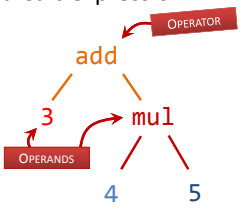
Calc expressions establish a hierarchy between operators, operands and nested expressions.

What is a useful data structure to represent hierarchical data?

PARSING: SYNTACTIC ANALYSIS

An ***expression tree*** is a hierarchical data structure that represents a Calc expression.

`add(3, mul(4, 5))` →



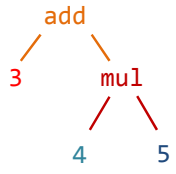
PARSING: SYNTACTIC ANALYSIS

String representing the operator of a Calc expression

List of either integers, floats, or other (children) Exp trees

```
class Exp:
    def __init__(self, operator, operands):
        self.operator = operator
        self.operands = operands
```


PARSING: SYNTACTIC ANALYSIS




```
Exp('add', [3,
        Exp('mul', [4, 5])])
```

Parsing: Syntactic Analysis

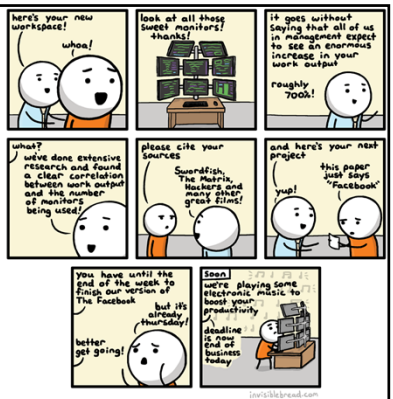
The function `analyze` takes in a list of tokens and constructs the expression tree as an `Exp` object.

It also changes the tokens that represent integers or floats to the corresponding values.

```
>>> analyze(tokenize('add(3, mul(4, 5))'))
Exp('add', [3, Exp('mul', [4, 5])])
```

(We will not go over the code for `analyze`.)

Break



http://invisiblebread.com/2012/06/new-workspace/
http://wondermark.com/wp-content/uploads/2012/07/sheep.gif

Read-Eval-Print Loop

```
def read_eval_print_loop():
    while True:
        try:
            expression_tree = \
            calc_parse(input('calc> '))
        print(calc_eval(expression_tree))
        except ...:
            # Error-handling code not shown
```

READ

PRINT

EVAL

Evaluation

Evaluation finds the value of an expression, using its corresponding expression tree.

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

Evaluation: Rules

- Primitive expressions (literals) 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.

Evaluation

```
def calc_eval(exp):
    if type(exp) in (int, float):
        return exp
    elif type(exp) == Exp:
        arguments = \
        list(map(calc_eval, exp.operands))
    return calc_apply(exp.operator,
                      arguments)
```

1. If the expression is a number, then return the number itself. Numbers are *self-evaluating*: they are their own values.

2. Otherwise, evaluate the arguments...

3. ... collect the values in a list ...

4. ... and then apply the operator on the argument values.

Evaluation

Why do we need to evaluate the arguments?

Some of them may be nested expressions!

We need to know what we are *operating with* (operator) and the values of all that we are *operating on* (operands), before we can completely evaluate an expression.

Apply

```
def calc_apply(operator, args):
    if operator in ('add', '+'):
        return sum(args)
    if operator in ('sub', '-'):
        if len(args) == 1:
            return -args[0]
        return sum(args[:1] + \
                   [-arg for arg in args[1:]])
    ...
```

If the operator is 'add' or '+', add the values in the list of arguments.

If the operator is 'sub' or '-', either return the negative of the number, if there is only one argument, or the difference of the arguments.

... and so on, for all of the operators that we want Calc to understand.

Apply

It may seem odd that we are using Python's addition operator to perform addition.

Remember, however, that we are interpreting an expression in *another language*. As we interpret the expression, we realize that we need to add numbers together.

The only way we know how to add is to use Python's addition operator.

Eval and Apply

Notice that `calc_eval` calls `calc_apply`, but before `calc_apply` can apply the operator, it needs to evaluate the operands. We do this by calling `calc_eval` on each of the operands.

`calc_eval` calls `calc_apply`,

which itself calls `calc_eval`.

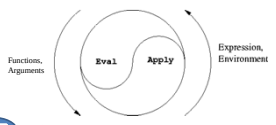
Mutual recursion!

Eval and Apply

The **eval-apply cycle** is essential to the evaluation of an expression, and thus to the interpretation of many computer languages. It is not specific to calc.

`eval` receives the expression (and in some interpreters, the environment) and returns a function and arguments;

`apply` applies the function on its arguments and returns another expression, which can be a value.



Read-Eval-Print Loop: We Are Done!

```
def read_eval_print_loop():
    while True:
        try:
            expression_tree = \
            calc_parse(input('calc> '))
        print(calc_eval(expression_tree))
        except ...:
            # Error-handling code not shown
```

With a small amount of code, we have a fully functioning interpreter for a new language!

READ

PRINT

EVAL

Three more Builtin Functions

`str(obj)` returns the string representation of an object `obj`.

It merely calls the `__str__` method on the object:

`str(obj)` is equivalent to `obj.__str__()`

`eval(str)` evaluates the string provided, as if it were an *expression* typed at the Python interpreter.

Three more Builtin Functions

`repr(obj)` returns the *canonical* string representation of the object `obj`.

It merely calls the `__repr__` method on the object:

`repr(obj)` is equivalent to `obj.__repr__()`

If the `__repr__` method is correctly implemented, then it will return a string, which contains an expression that, when evaluated, will return a new object equal to the current object.

In other words, for many classes and objects (including `Exp`), `eval(repr(obj)) == obj`.

Conclusion

- An interpreter is a function that, when applied to an expression, performs the actions required to evaluate that expression.
- We saw how to implement an interpreter for a simple calculator language, Calc.
- The *read-eval-print loop* reads user input, evaluates the expression in the input, and prints the resulting value.
- Reading also involves parsing user input into an expression tree.
- Evaluation works on the provided expression tree to obtain the value of the corresponding expression.
- ***Preview***: An interpreter for Python, written in Python.

Good Luck Tonight!

http://images.sodahead.com/polls/000240569/polls_awesome_3432_231682_answer_1_xlarge.jpeg