61A Lecture 25

Monday, November 4

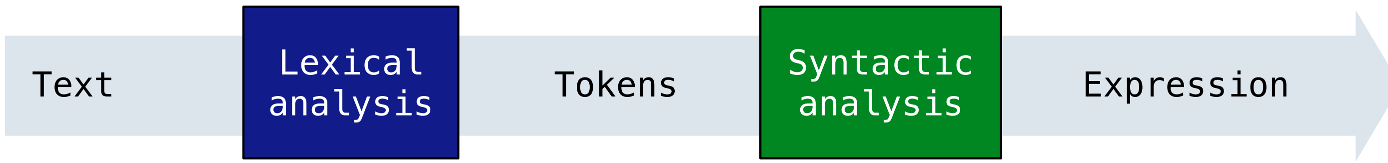
Announcements

- Homework 7 due Tuesday 11/5 @ 11:59pm.
- Project 1 composition revisions due Thursday 11/7 @ 11:59pm.
  - Instructions are posted on the course website (submit proj1revision)
- Homework 8 due Tuesday 11/12 @ 11:59pm.
  - All problems must be solved in Scheme
  - Make sure that you know how to use the Scheme interpreter by attending lab this week!
- An improved final exam score can partially make up for low midterm scores.
  - This policy will only affect students who might not otherwise pass the course.
- Example for today: http://composingprograms.com/examples/scalc/scalc.html

Parsing

Parsing

A Parser takes text and returns an expression.




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

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

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

printed as

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

tokenize_line(line)
in scheme_tokens.py

scheme_read(source)
scheme_reader.py

(Demo)

Recursive Syntactic Analysis

A predictive recursive descent parser inspects only *k* tokens to decide how to proceed, for some fixed *k*.

In Scheme, k is 1. The open-parenthesis starts a combination, the close-parenthesis ends a combination, and other tokens are primitive expressions.

Can English be parsed via predictive recursive descent?

sentence subject

The horse ~~raced~~ past the barn fell.

ridden

(that was)

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 are primitive expressions.

Recursive call: scheme_read all sub-expressions and combine them.

(Demo)

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.

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! *Homoiconic* means 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

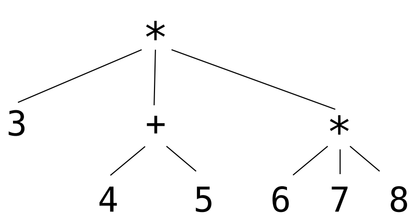
A call expression is a combination that begins with an operator (+, -, *, /) followed by 0 or more expressions: (+ 1 2 3), (/ 3 (+ 4 5))

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

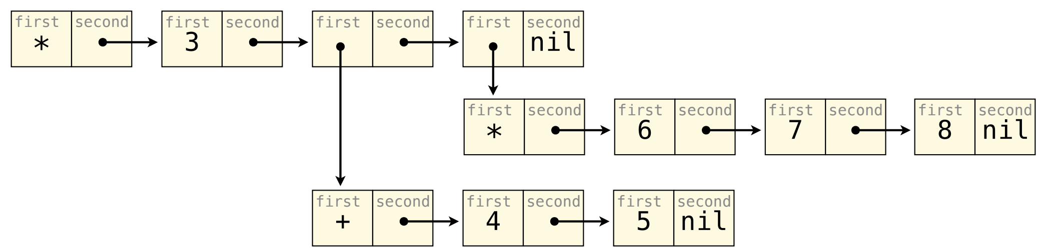
Expression

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

Expression Tree



Representation as Pairs



Calculator Semantics

The value of a calculator expression is defined recursively.

Primitive: A number evaluates to itself.

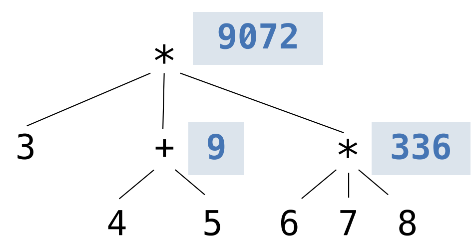
Call: A call expression evaluates to its argument values combined by an operator.

- **+**: 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

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

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
```

(Demo)

Language Semantics

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

Interactive Interpreters

Read-Eval-Print Loop

The user interface for many programming languages is an interactive interpreter.

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

(Demo)

Raising Exceptions

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

Example exceptions

- **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")

(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.

(Demo)