Calculator

Announcements

Exceptions

Raise Statements

Python exceptions are raised with a raise statement

raise <expression>

<expression> must evaluate to a subclass of BaseException or an instance of one

Exceptions are constructed like any other object. E.g., TypeError('Bad argument!')

TypeError -- A function was passed the wrong number/type of argument

NameError -- A name wasn't found

KeyError -- A key wasn't found in a dictionary

RecursionError -- Too many recursive calls

(Demo)

Try Statements

Try statements handle exceptions

```
try:
    <try suite>
except <exception class> as <name>:
    <except suite>
...
```

Execution rule:

The <try suite> is executed first

If, during the course of executing the <try suite>,
an exception is raised that is not handled otherwise, and

If the class of the exception inherits from <exception class>, then

The <except suite> is executed, with <name> bound to the exception

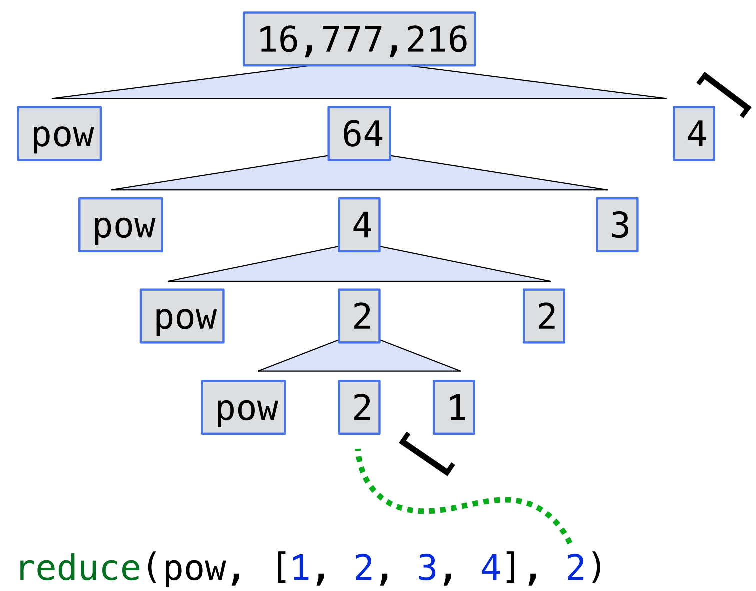
Example: Reduce

Reducing a Sequence to a Value

```
def reduce(f, s, initial):
    """Combine elements of s pairwise using f, starting with initial.

    E.g., reduce(mul, [2, 4, 8], 1) is equivalent to mul(mul(mul(1, 2), 4), 8).

    >>> reduce(mul, [2, 4, 8], 1)
    64
    """
```



`f` is ...
  a two-argument function

`s` is ...
  a sequence of values that can be the second argument

`initial` is ...
  a value that can be the first argument

(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! E.g.,

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

```
{{Short description|Public university in Berkeley, California}}
{{Redirect-distinguish|Berkeley University|Berkeley College|Berkeley College (Yale University)}}
{{Use American English|date=February 2019}}
{{Use mdy dates|date=November 2018}}
{{Infobox university
 | name                    = University of California, Berkeley
 | image                   = Seal of University of California, Berkeley.svg
 | motto                   = {{lang|la|[[Let there be light|Fiat lux]]}} ([[Latin]])
 | mottoeng                = "Let there be light"
}}
```

A programming language has:

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

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

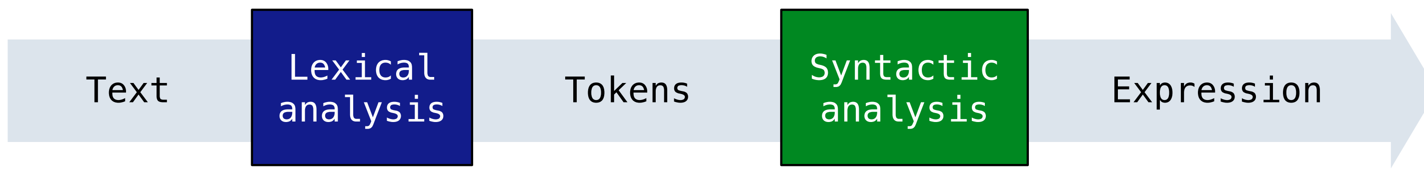
```
(+ (* 3 (+ (* 2 4) (+ 3 5))) (+ (- 10 7) 6))
```

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

(Demo)

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))
```

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

- 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)

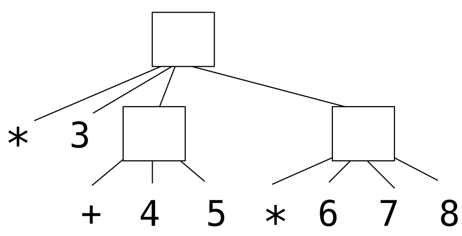
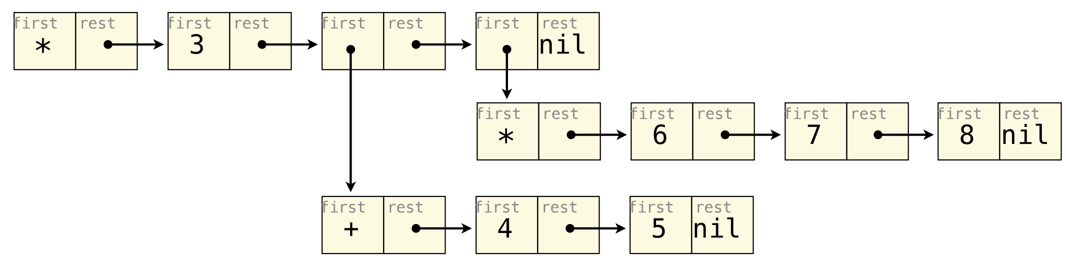
Calculator Syntax

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.

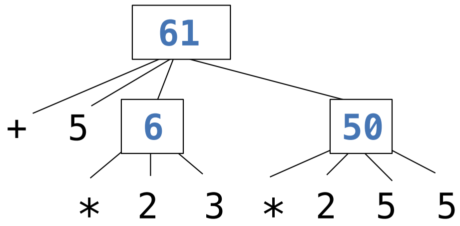
Call: A call expression evaluates to its argument values combined by an operator.

- **+:** 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 isinstance(exp, (int, float)):
        return exp
    elif isinstance(exp, Pair):
        arguments = exp.rest.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)

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

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)