Scope & Symbol Table

- Most modern programming languages have some notion of scope.
- Scope defines the "lifetime" of a program symbol.
- If a symbol is no longer accessible then we say that it is "out of scope."
- The simplest scope is the "block scope."
- With scope we need a notion of variable declaration which allows us to assert in which scope the variable is visible or accessible.

Cuppa2

- We extend our Cuppa1 language with variable declarations of the form

  declare x = 10;

- Declares the variable x in the current scope and initializes it to the value 10
- If the current scope is the global (outermost) scope then we call x a “global” variable.

Cuppa2 Grammar

cuppa2_gram.py

```
program : stmt_list

stmt_list : stmt stmt_list
          | empty

stmt : DECLARE ID opt_init opt_semi
     | ID '=' exp opt_semi
     | GET ID opt_semi
     | PUT exp opt_semi
     | WHILE '(' exp ')' stmt
     | IF '(' exp ')' stmt opt_else
     | '{' stmt_list '}'

opt_init : '=' exp
         | empty

opt_else : ELSE stmt
         | empty

opt_semi : ';'
         | empty

exp : exp PLUS exp
    | exp MINUS exp
    | exp TIMES exp
    | exp DIVIDE exp
    | exp EQ exp
    | exp LE exp
    | INTEGER
    | ID
    | '(' exp ')'
    | MINUS exp %prec UMINUS
    | NOT exp
...
```

Cuppa2 Frontend

cuppa2_frontend_gram.py

```
def p_stmt(p):
    '''
    stmt : DECLARE ID opt_init opt_semi
         | ID '=' exp opt_semi
         | GET ID opt_semi
         | PUT exp opt_semi
         | WHILE '(' exp ')' stmt
         | IF '(' exp ')' stmt opt_else
         | '{' stmt_list '}'
    '''
    if p[1] == 'declare':
        p[0] = ('declare', p[2], p[3])
    elif p[2] == '=':
        p[0] = ('assign', p[1], p[3])
    elif p[1] == 'get':
        p[0] = ('get', p[2])
    elif p[1] == 'put':
        p[0] = ('put', p[2])
    elif p[1] == 'while':
        p[0] = ('while', p[3], p[5])
    elif p[1] == 'if':
        p[0] = ('if', p[3], p[5], p[6])
    elif p[1] == '{':
        p[0] = ('block', p[2])
    else:
        raise ValueError("unexpected symbol {}".format(p[1]))
```

Cuppa2

- We can now write properly scoped programs
- Consider:

```
declare x = 1;
{
  declare x = 2;
  put x;
}
{
  declare x = 3;
  put x;
}
put x;
```

Variable Shadowing

- An issue with scoped declarations is that inner declarations can “overshadow” outer declarations
- Consider:

```
declare x = 2;
{
    declare x = 3;
    {
        declare y = x + 2;
        put y;
    }
}
```

What is the output of the program once it is run?

Variable update

- A variable update can be outside of our current scope.
- Consider

```
declare x = 2;
{
      declare y = 3;
      x = y + x;
      put x;
}
put x;
```

Symbol Tables

- To deal with programs like that we need something more sophisticated for variable lookup than a dictionary.

☞ *a dictionary stack*

- This stack needs to be able to support the following functionality
  - Declare a variable (insertion)
  - Lookup a variable
  - Update a variable value

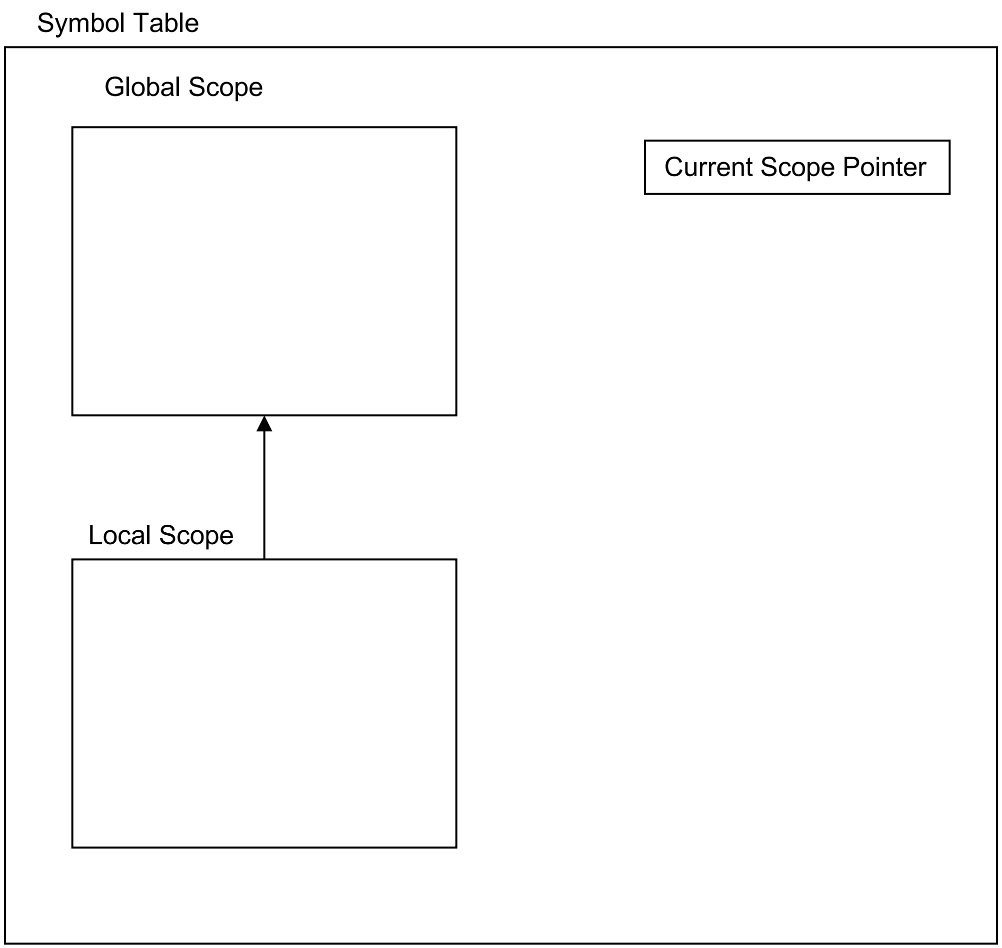
Semantic Rules for Variable Declarations

- Here are the rules which we informally used in the previous examples:
  - The ‘declare’ statement inserts a variable declaration into the current scope
    - a variable lookup returns a variable value from the current scope or the surrounding scopes
  - Every variable needs to be declared before use
  - No variable can be declared more than once in the current scope.

Symbol Tables

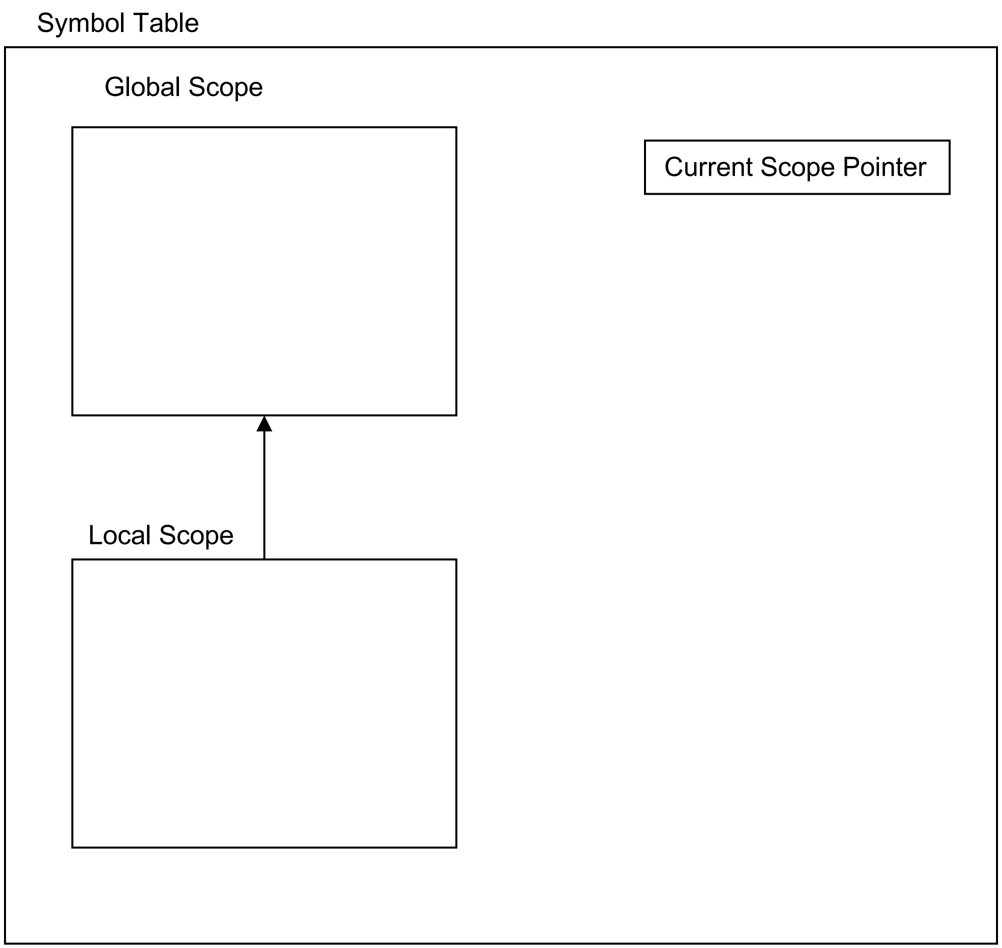
- Design:
  - we have a class SymTab that:
    - Holds a stack of scopes
      - scoped_symtab
    - Defines the interface to the symbol table
      - push_scope, pop_scope, declare_sym, *etc*
  - By default, SymTab is initialized with a single scope on the stack – *the global scope.*

Symbol Tables



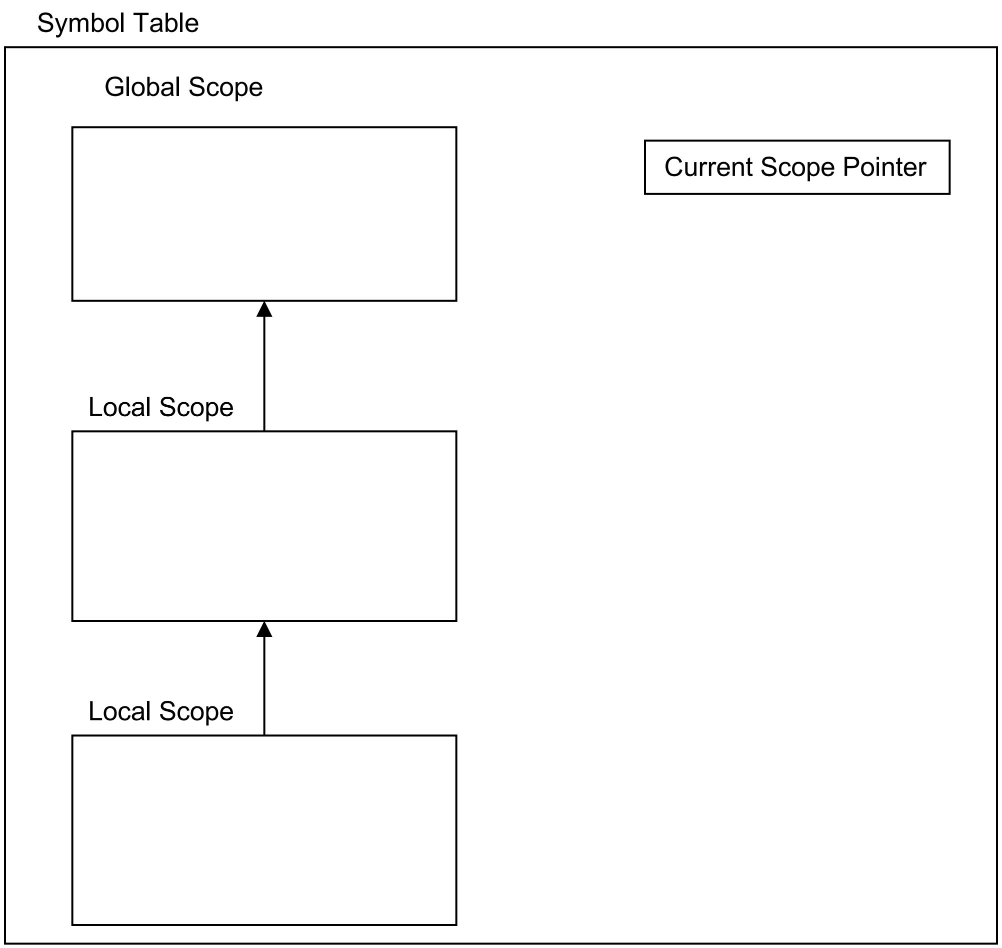

```
declare x = 2;
{
    declare y = 3;
    x = y + x;
    put x;
}
put x;
```

Symbol Tables




```
declare x;
get x;
If (0 <= x)
{
    declare i = x;
    put i;
}
else
{
    declare j = -1 * x;
    put j;
}
put x;
```

Symbol Tables




```
declare x = 2;
{
    declare x = 3;
    {
        declare y = x + 2;
        put y;
    }
}
```

Symbol

cuppa2_symtab.py

```
CURR_SCOPE = 0

class SymTab:

    #-------
    def __init__(self):
        # global scope dictionary must always be present
        self.scoped_symtab = [{}]

    #-------
    def push_scope(self):
        # push a new dictionary onto the stack - stack grows to the left
        self.scoped_symtab.insert(CURR_SCOPE,{})

    #-------
    def pop_scope(self):
        # pop the left most dictionary off the stack
        if len(self.scoped_symtab) == 1:
            raise ValueError("cannot pop the global scope")
        else:
            self.scoped_symtab.pop(CURR_SCOPE)

    #-------
    def declare_sym(self, sym, init):
        # declare the symbol in the current scope: dict @ position 0
        …

    #-------
    def lookup_sym(self, sym):
        # find the first occurence of sym in the symtab stack
        # and return the associated value
        …

    #-------
    def update_sym(self, sym, val):
        # find the first occurence of sym in the symtab stack
        # and update the associated value
        …
```

Symbol Tables

```
def declare_sym(self, sym, init):
       # declare the symbol in the current scope: dict @ position 0

       # first we need to check whether the symbol was already declared
       # at this scope
       if sym in self.scoped_symtab[CURR_SCOPE]:
           raise ValueError("symbol {} already declared".format(sym))

       # enter the symbol in the current scope
       scope_dict = self.scoped_symtab[CURR_SCOPE]
       scope_dict[sym] = init
```

```
def lookup_sym(self, sym):
     # find the first occurence of sym in the symtab stack
     # and return the associated value


     n_scopes = len(self.scoped_symtab)


     for scope in range(n_scopes):
         if sym in self.scoped_symtab[scope]:
             val = self.scoped_symtab[scope].get(sym)
             return val


     # not found
     raise ValueError("{} was not declared".format(sym))
```

Symbol Tables

```
def update_sym(self, sym, val):
    # find the first occurence of sym in the symtab stack
    # and update the associated value


    n_scopes = len(self.scoped_symtab)


    for scope in range(n_scopes):
        if sym in self.scoped_symtab[scope]:
            scope_dict = self.scoped_symtab[scope]
            scope_dict[sym] = val
            return


    # not found
    raise ValueError("{} was not declared".format(sym))
```

Interpret Walker

Note: Same as Cuppa1 interpreter except for the addition of the declaration statement and additional functionality in block statements and variable expressions.

cuppa2_interp_walk.py

```
#########################################################################
# walk
#########################################################################
def walk(node):
    # node format: (TYPE, [child1[, child2[, ...]]])
    type = node[0]

    if type in dispatch_dict:
        node_function = dispatch_dict[type]
        return node_function(node)
    else:
        raise ValueError("walk: unknown tree node type: " + type)

# a dictionary to associate tree nodes with node functions
dispatch_dict = {
    'seq'     : seq,
    'nil'     : nil,
    'declare' : declare_stmt,
    'assign'  : assign_stmt,
    'get'     : get_stmt,
    'put'     : put_stmt,
    'while'   : while_stmt,
    'if'      : if_stmt,
    'block'   : block_stmt,
    'integer' : integer_exp,
    'id'      : id_exp,
    'paren'   : paren_exp,
    '+'       : plus_exp,
    '-'       : minus_exp,
    '*'       : times_exp,
    '/'       : divide_exp,
    '=='      : eq_exp,
    '<='      : le_exp,
    'uminus'  : uminus_exp,
    'not'     : not_exp
}
```

Interpret Walker

```
def declare_stmt(node):

    try: # try the declare pattern without initializer
        (DECLARE, name, (NIL,)) = node
        assert_match(DECLARE, 'declare')
        assert_match(NIL, 'nil')

    except ValueError: # try declare with initializer
        (DECLARE, name, init_val) = node
        assert_match(DECLARE, 'declare')

        value = walk(init_val)
        state.symbol_table.declare_sym(name, value)

    else: # declare pattern matched
        # when no initializer is present we init with the v
        state.symbol_table.declare_sym(name, 0)
```

```
def block_stmt(node):

    (BLOCK, stmt_list) = node
    assert_match(BLOCK, 'block')

    state.symbol_table.push_scope()
    walk(stmt_list)
    state.symbol_table.pop_scope()
```

```
def get_stmt(node):

    (GET, name) = node
    assert_match(GET, 'get')

    s = input("Value for " + name + '? ')

    try:
        value = int(s)
    except ValueError:
        raise ValueError("expected an integer value for " + name)

    state.symbol_table.update_sym(name, value)
```

```
def assign_stmt(node):

    (ASSIGN, name, exp) = node
    assert_match(ASSIGN, 'assign')

    value = walk(exp)
    state.symbol_table.update_sym(name, value)
```

That’s it – everything else is the same as the Cuppa1 interpreter!

Syntactic vs Semantic Errors

- Grammars allow us to construct parsers that recognize the syntactic structure of languages.
- Any program that does not conform to the structure prescribed by the grammar is rejected by the parser.
- We call those errors "syntactic errors."

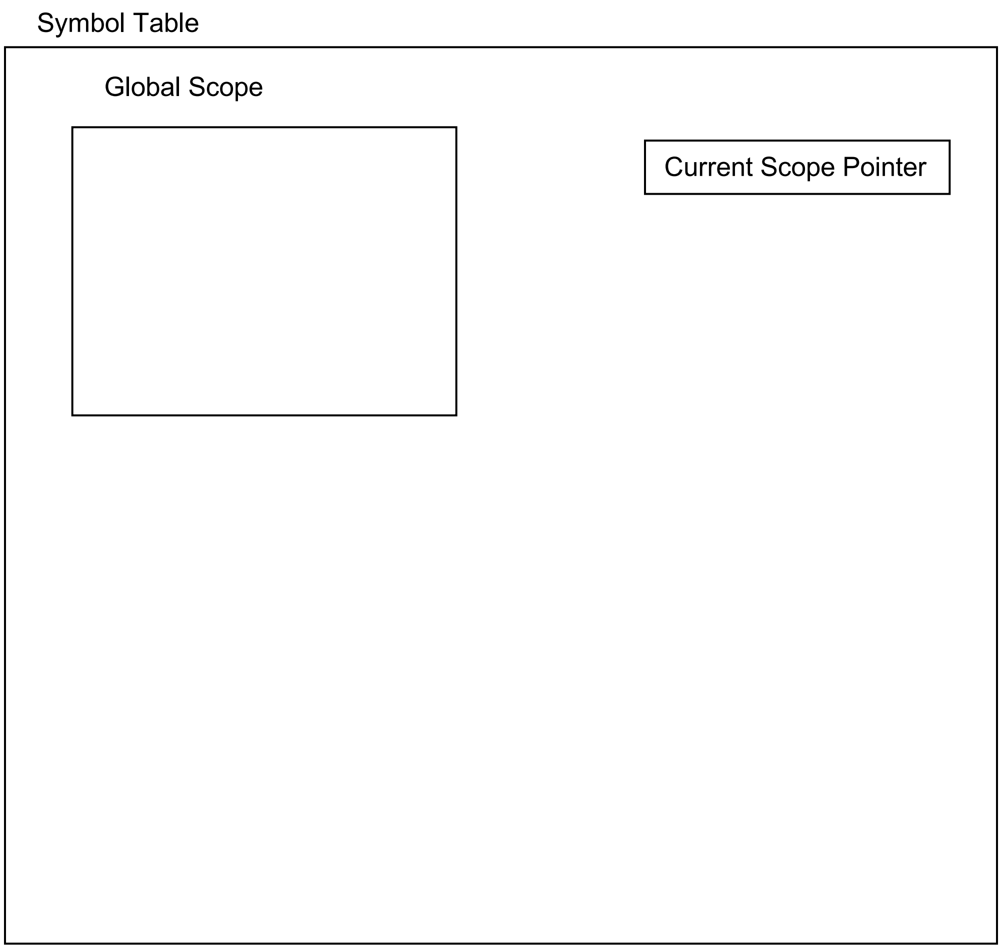
Syntactic vs Semantic Errors

- Semantic errors are errors in the behavior of the program and cannot be detected by the parser.
- Programs with semantic errors are usually syntactically correct
- A certain class of these semantic errors can be caught by the interpreter/compiler. Consider:

```
declare x = 10;
put x + 1;
declare x = 20;
put x + 2;
```

- Here we are redeclaring the variable 'x' which is not legal in many programming languages.
- Many other semantic errors cannot be detected by the interpreter/compiler and show up as "bugs" in the program.

Symbol Tables

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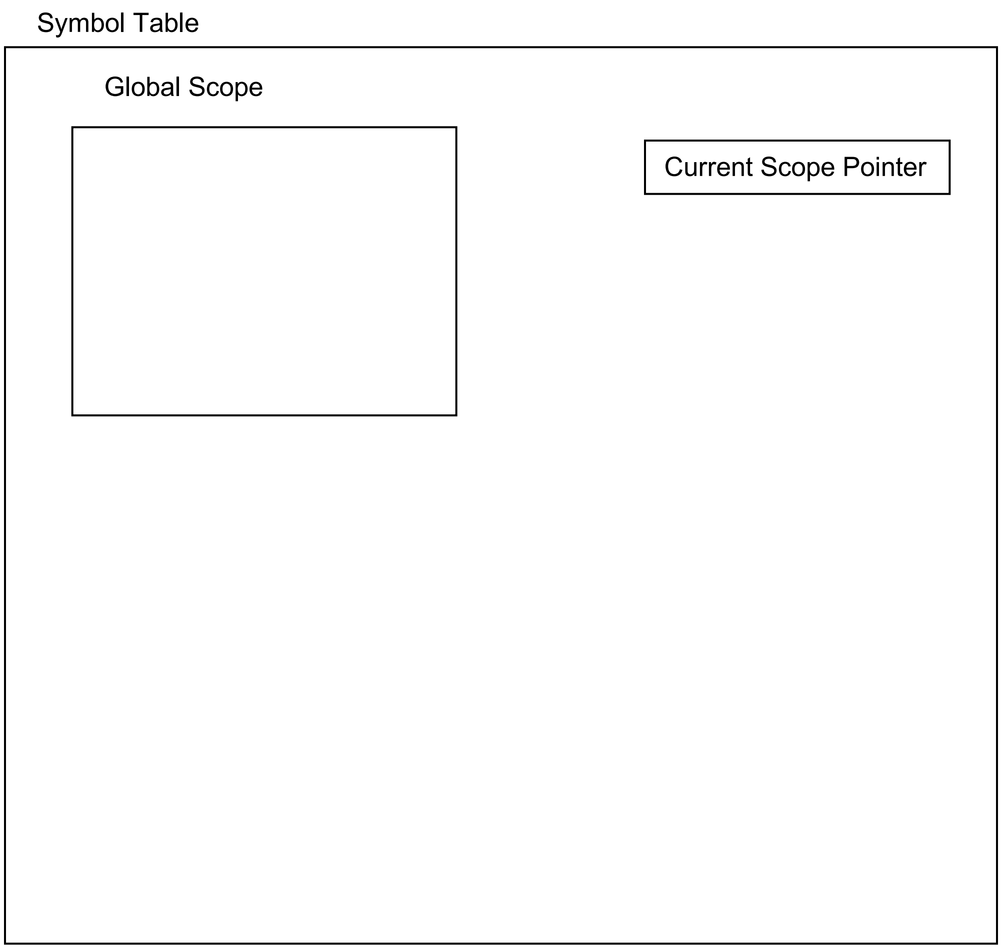
declare x = 10;
put x + 1;
declare x = 20;
put x + 2;
```

Symbol Tables




```
x = x + 1;
put x;
```