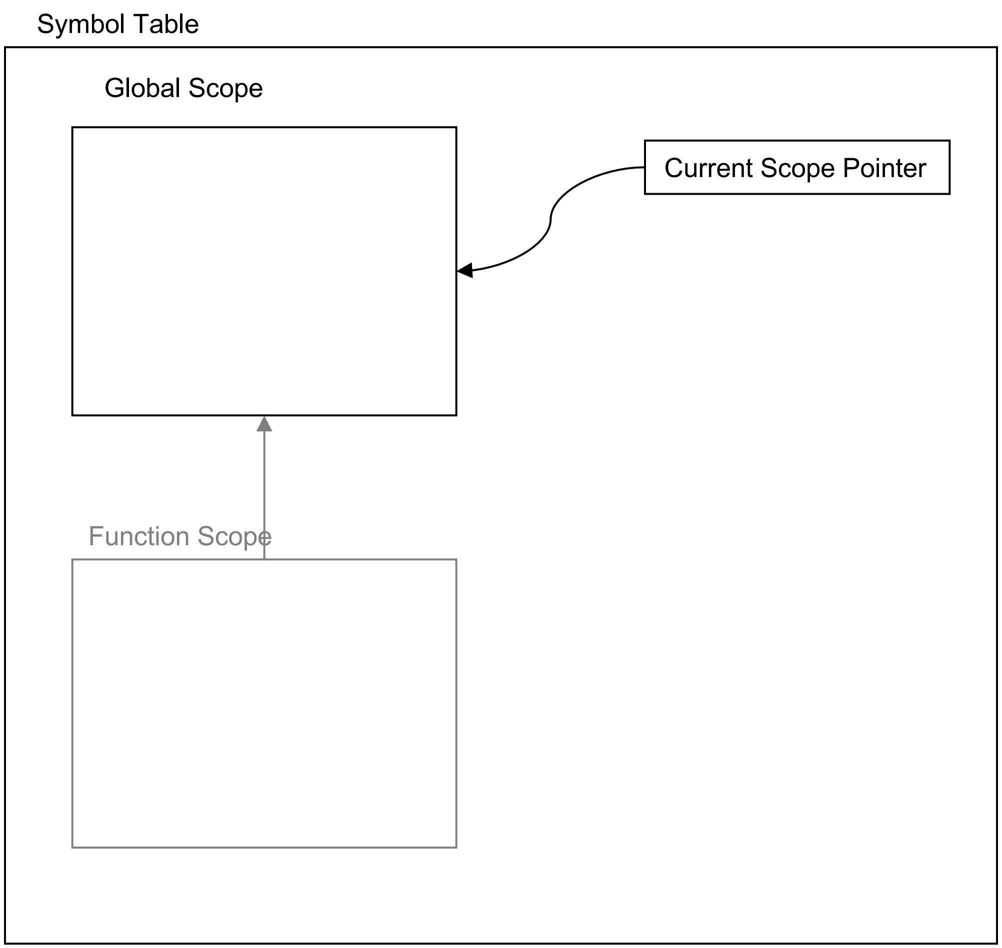
Interpreter Implementation

- The crucial insight to implementing functions is that function names act just like variable names - they are the key into a symbol lookup table.
  - During function declaration we enter the function name into the symbol table
  - During a function call we search for the function name in the symbol table
- The second important insight is that the function body is the value that we store with the function name in the symbol table.
  - During a function call we lookup the function name in the symbol table and return the function body for interpretation.
- The symbol table is extended to distinguish between scalar values and function values

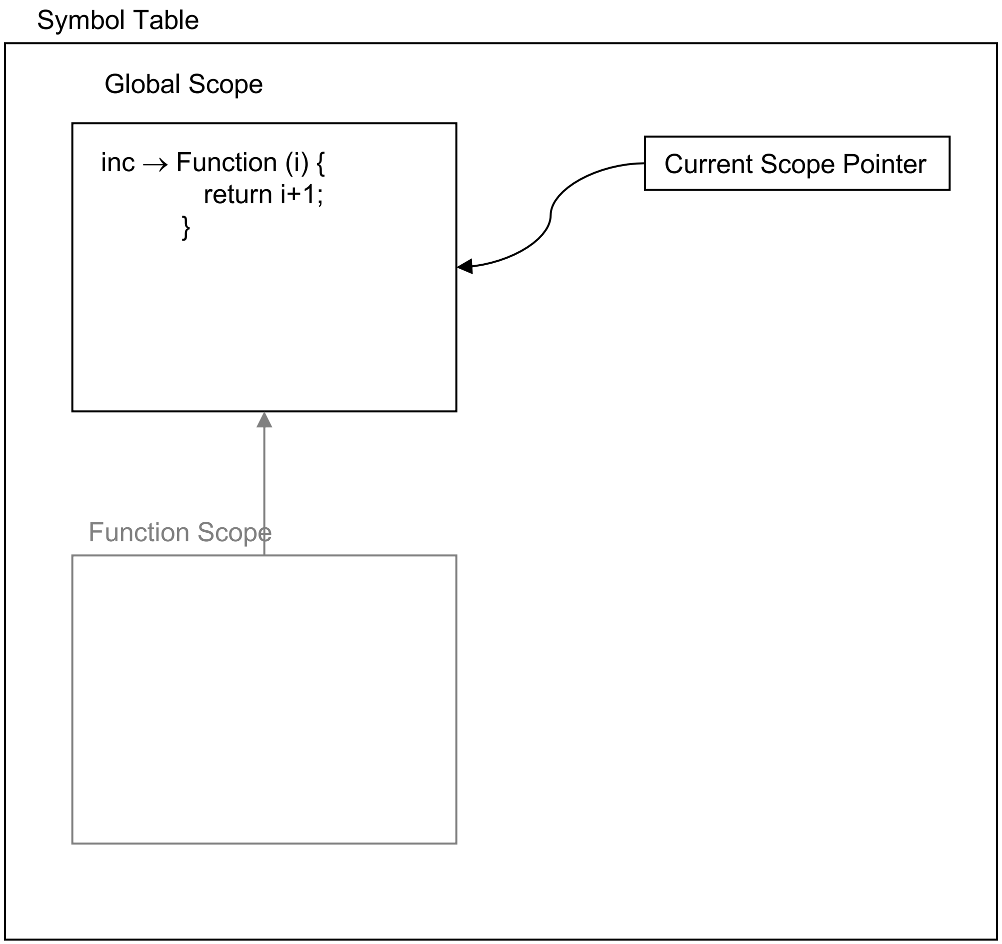
Interpreting Functions




```
declare inc(i) {
    return i+1;
}

declare x = 10;
declare y;
y = inc(x);
put y;
```

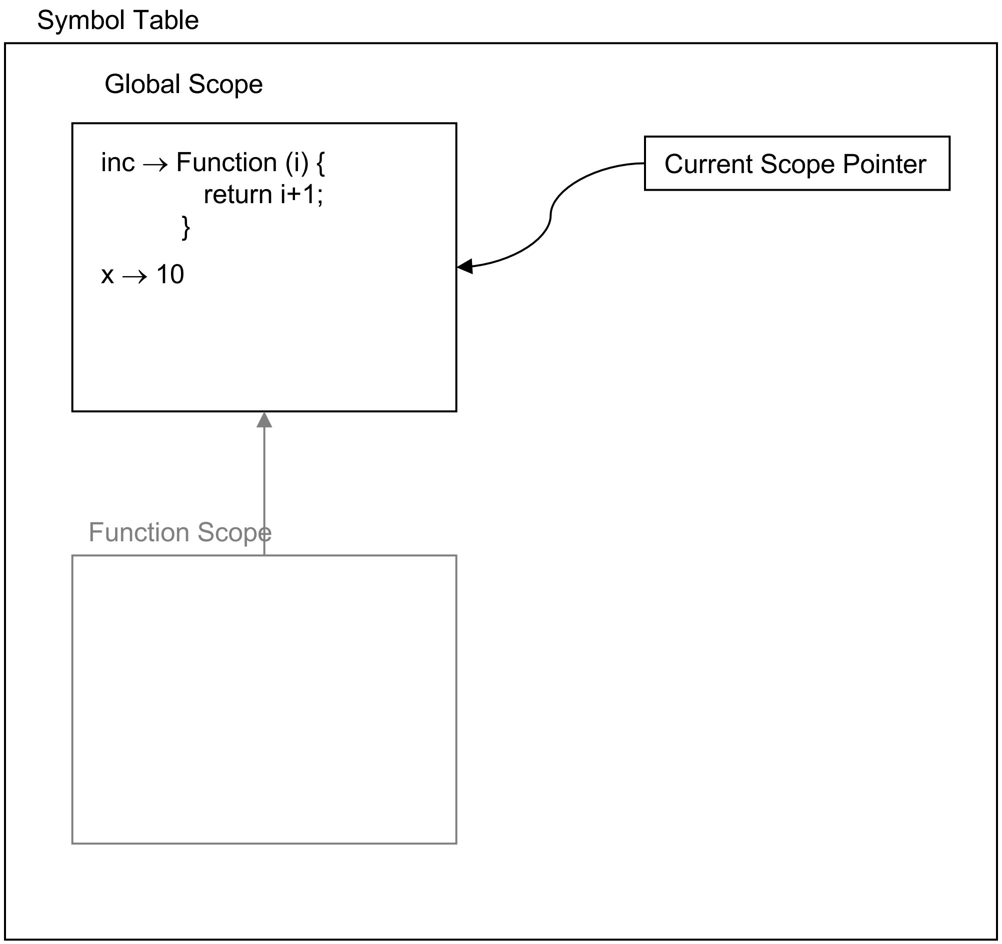
Interpreting Functions




```
declare inc(i) {
    return i+1;
}

declare x = 10;
declare y;
y = inc(x);
put y;
```

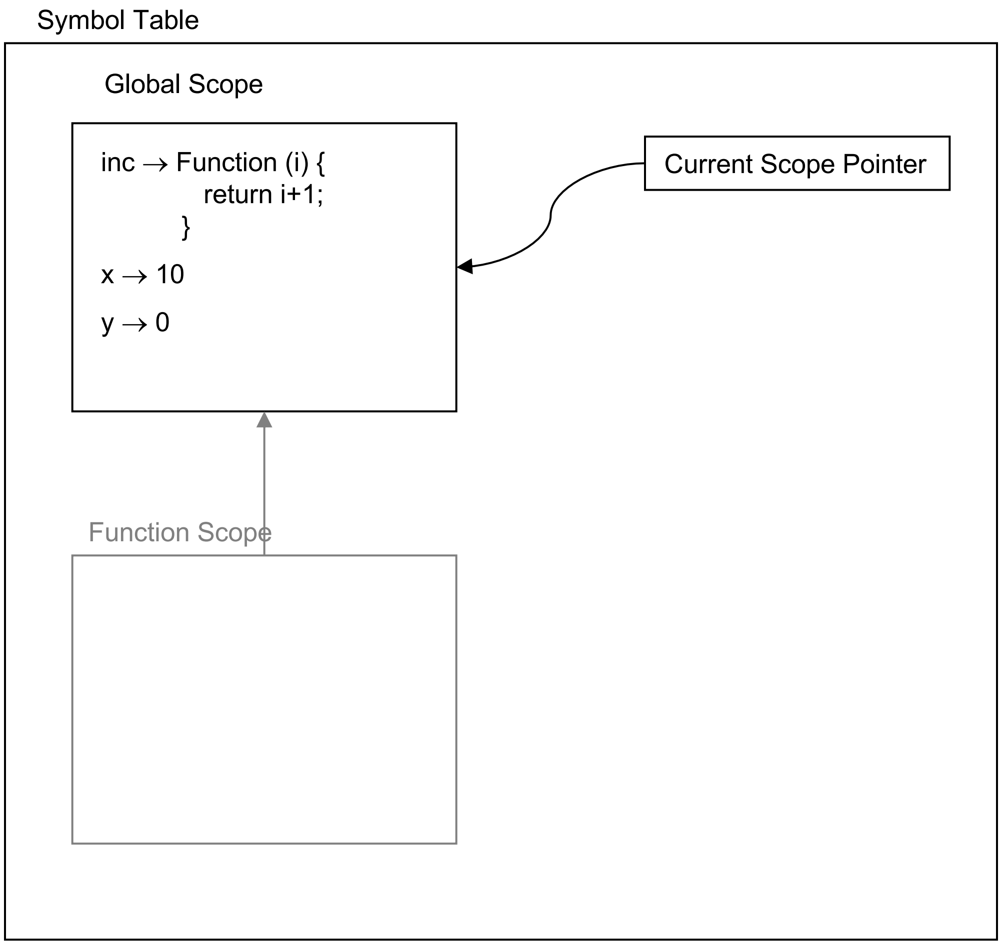
Interpreting Functions



declare inc(i) {
    return i+1;
}

declare x = 10;
declare y;
y = inc(x);
put y;

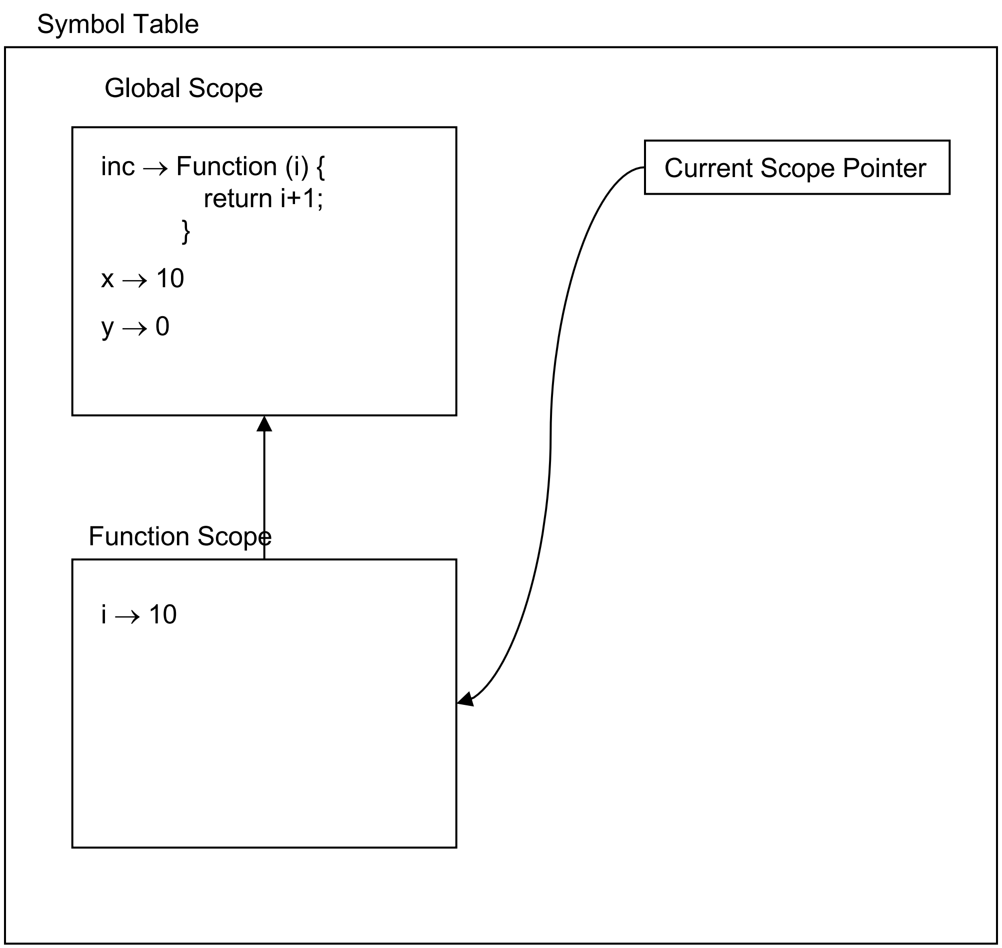
Interpreting Functions




```
declare inc(i) {
    return i+1;
}

declare x = 10;
declare y;
y = inc(x);
put y;
```

Interpreting Functions



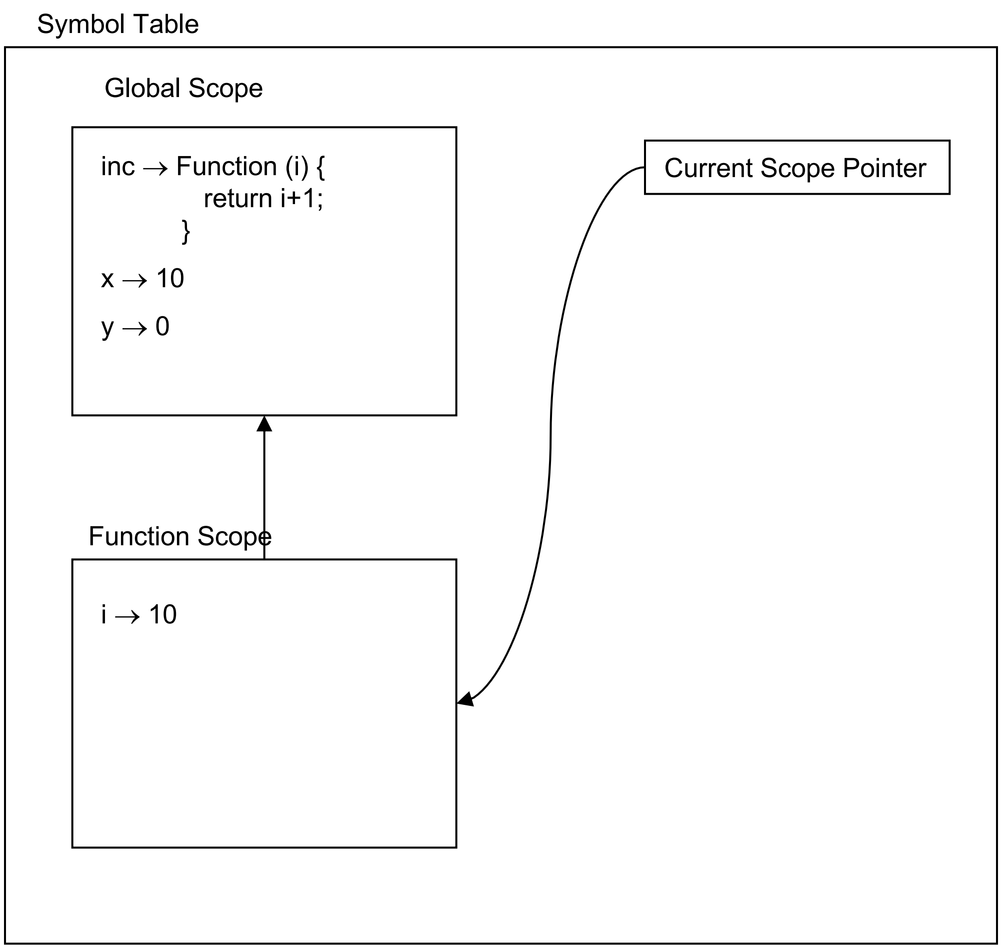

```
declare inc(i) {
    return i+1;
}

declare x = 10;
declare y;
y = inc(x);
put y;
```

```
Function (i) {
    return i+1;
}
```

Setup the function call:
- lookup function name
- retrieve function body
- push new function scope
- init formal parameters with actual parameters

Interpreting Functions



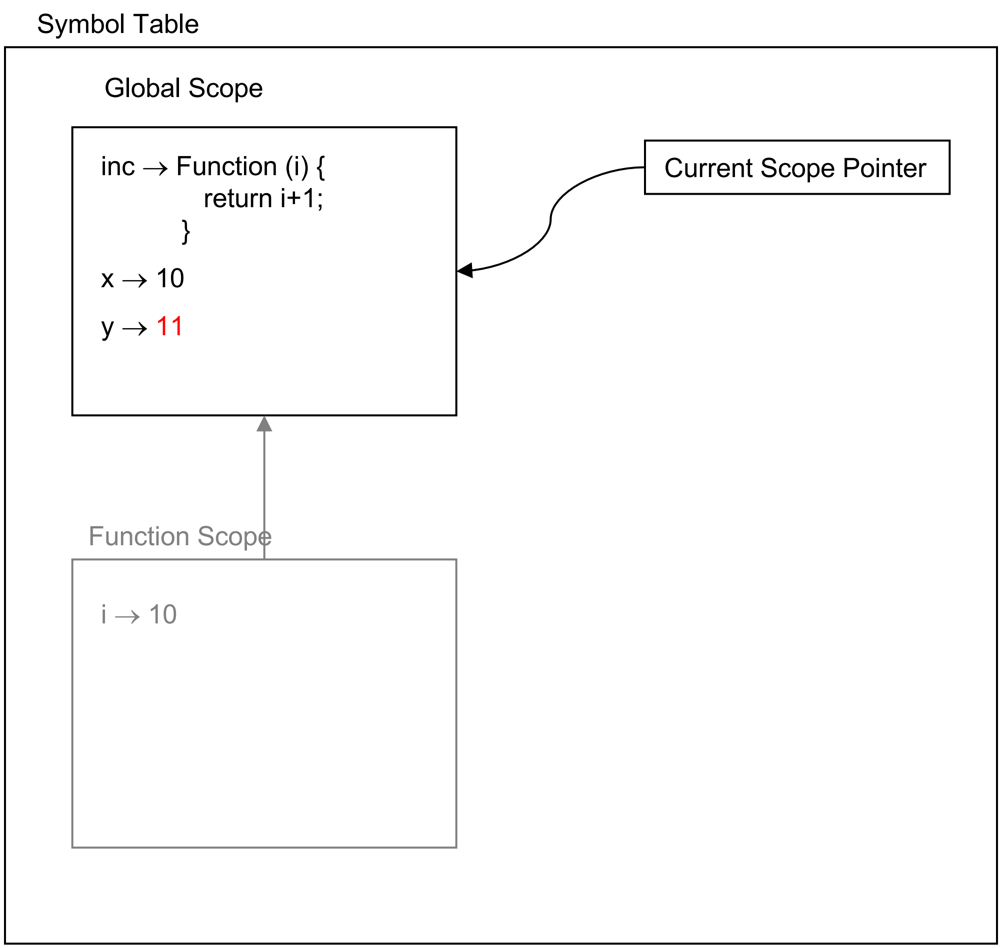

```
declare inc(i) {
    return i+1;
}

declare x = 10;
declare y;
y = inc(x);
put y;
```

```
Function (i) {
    return i+1;
}
```

Execute the called function and compute return value.

Interpreting Functions

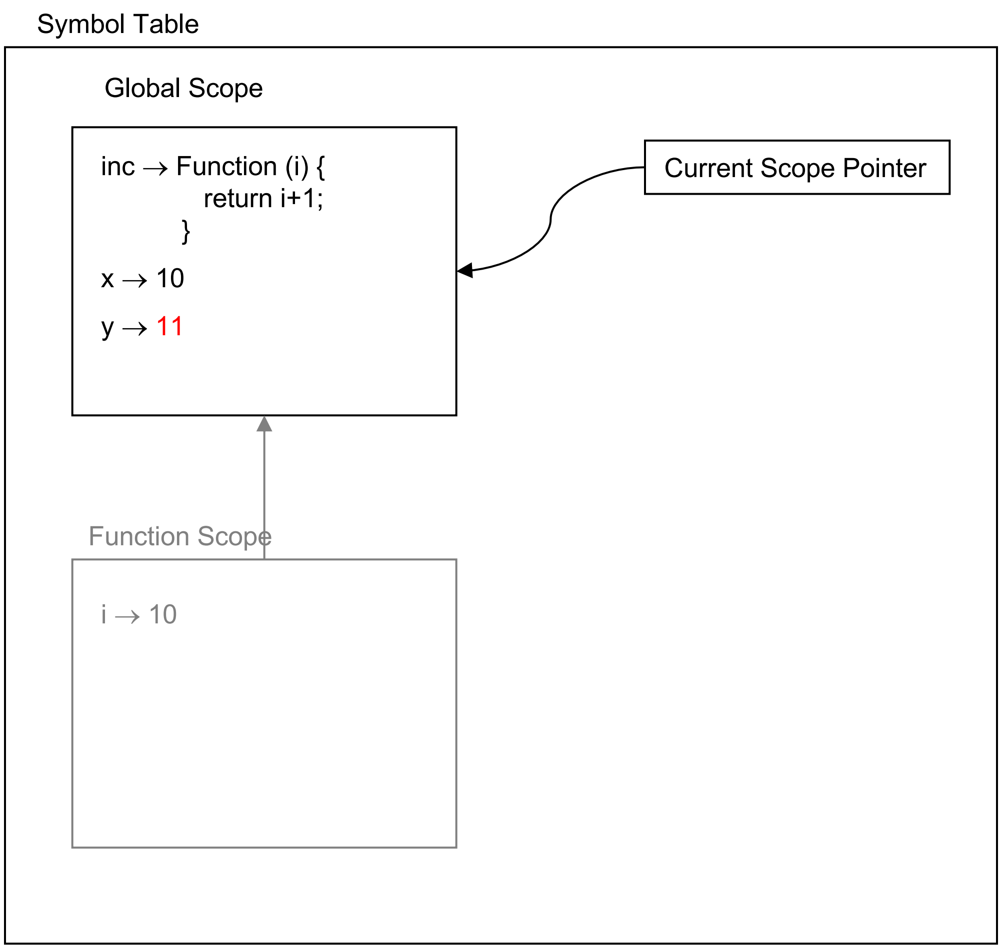



```
declare inc(i) {
    return i+1;
}

declare x = 10;
declare y;
y = inc(x);
put y;
```

Exit the called function:
- pop the function scope
- store the return value in y

Interpreting Functions

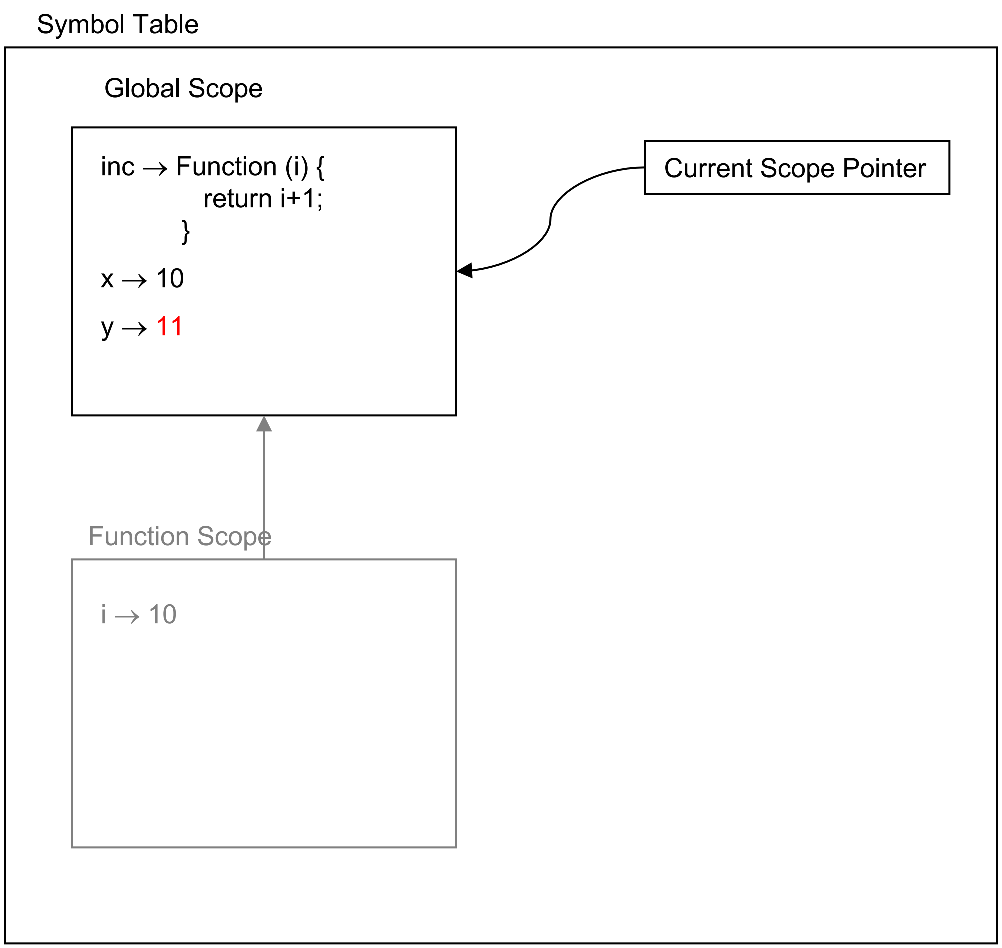



```
declare inc(i) {
    return i+1;
}

declare x = 10;
declare y;
y = inc(x);
put y;
```

Execute the put statement ⇒ 11

Interpreting Functions




```
declare inc(i) {
    return i+1;
}

declare x = 10;
declare y;
y = inc(x);
put y;
```

Interpreting Functions

- Note that we use the function value just like we would use the value of a variable, but instead of using it in some arithmetic expression we simply interpret the body of the function in order to compute a return value.

Cuppa3 Frontend

Listing 8.2: An LL(1) grammar for the Cuppa3 language.

```
stmt_list : (stmt)*

stmt : declare ID decl_suffix
     | ID id_suffix
     | get ID ;?
     | put exp ;?
     | return exp? ;?
     | while \( exp \) stmt
     | if \( exp \) stmt (else stmt)?
     | \{ stmt_list \}

decl_suffix : \( formal_args? \) stmt
            | = exp ;?
            | ;?

id_suffix : \( actual_args? \) ;?
          | = exp ;?

exp : exp_low
exp_low : exp_med ((== | =<) exp_med)*
exp_med : exp_high ((\+ | -) exp_high)*
exp_high : primary ((\* | /) primary)*

primary : INTEGER
        | ID (\( actual_args? \))?
        | \( exp \)
        | - primary
        | not primary

formal_args : ID (, ID)*
actual_args : exp (, exp)*

ID : <any valid variable name>
INTEGER : <any valid integer number>
```

Cuppa3 Frontend

- The frontend is like all of our other Cuppa LL(1) frontends
  - we construct an AST using a parser constructed from an LL(1) grammar.
- We will concentrate on the three new features outlined in the previous slide.

Cuppa3 Frontend

```
stmt : declare ID decl_suffix

decl_suffix : \( formal_args? \) stmt
            | = exp ;?
            | ;?
```

```
def decl_suffix(stream):
    if stream.pointer().type in ['LPAREN']:
        stream.match('LPAREN')
        if stream.pointer().type in ['ID']:
            args = formal_args(stream)
        else:
            args = ('LIST', [])
        stream.match('RPAREN')
        body = stmt(stream)
        return ('FUNCTION', args, body )
    elif stream.pointer().type in ['ASSIGN']:
        stream.match('ASSIGN')
        e = exp(stream)
        if stream.pointer().type in ['SEMI']:
            stream.match('SEMI')
        return e
    else:
        if stream.pointer().type in ['SEMI']:
            stream.match('SEMI')
        return ('INTEGER', 0)
```

```
def stmt(stream):
    if stream.pointer().type in ['DECLARE']:
        stream.match('DECLARE')
        id_tok = stream.match('ID')
        e = decl_suffix(stream)
        if e[0] == 'FUNCTION':
            (FUNCTION, args, body) = e
            return ('FUNDECL', ('ID', id_tok.value), args, body)
        else:
            return ('VARDECL', ('ID', id_tok.value), e)
    elif ...
```

Cuppa3 Frontend

```
declare add(a,b)
{
    return a+b;
}

declare x;
```

```
(STMTLIST
   |[
   |   |(FUNDECL
   |   |   |(ID add)
   |   |   |(LIST
   |   |   |   |[
   |   |   |   |   |(ID a)
   |   |   |   |   |(ID b)])
   |   |   |(BLOCK
   |   |   |   |(STMTLIST
   |   |   |   |   |[
   |   |   |   |   |   |(RETURN
   |   |   |   |   |   |   |(PLUS
   |   |   |   |   |   |   |   |(ID a)
   |   |   |   |   |   |   |   |(ID b)))])))
   |   |(VARDECL
   |   |   |(ID x)
   |   |   |(INTEGER 0))])
```

Cuppa3 Frontend

```
stmt : ID id_suffix

id_suffix : \( actual_args? \) ;?
          | = exp ;?
```

```
def stmt(stream):
    ...
    elif stream.pointer().type in ['ID']:
        id_tok = stream.match('ID')
        e = id_suffix(stream)
        if e[0] == 'LIST':
            return ('CALLSTMT', ('ID', id_tok.value), e)
        else:
            return ('ASSIGN', ('ID', id_tok.value), e)
    elif ...
```

```
def id_suffix(stream):
    if stream.pointer().type in ['LPAREN']:
        stream.match('LPAREN')
        if stream.pointer().type in ['INTEGER','ID','LPAREN','MINUS','NOT']:
            args = actual_args(stream)
        stream.match('LPAREN')
        if stream.pointer().type in ['SEMI']:
            stream.match('SEMI')
        return args
    elif stream.pointer().type in ['ASSIGN']:
        stream.match('ASSIGN')
        e = exp(stream)
        if stream.pointer().type in ['SEMI']:
            stream.match('SEMI')
        return e
    else:
        raise SyntaxError("id_suffix: syntax error at {}"
                          .format(stream.pointer().value))
```

```
# actual_args : {INTEGER,ID,LPAREN,MINUS,NOT} exp ({COMMA} COMMA exp)*
def actual_args(stream):
    if stream.pointer().type in ['INTEGER','ID','LPAREN','MINUS','NOT']:
        e = exp(stream)
        ll = [e]
        while stream.pointer().type in ['COMMA']:
            stream.match('COMMA')
            e = exp(stream)
            ll.append(e)
        return ('LIST', ll)
    else:
        raise SyntaxError("actual_args: syntax error at {}"
                          .format(stream.pointer().value))
```

Cuppa3 Frontend

```
f(2,3);
g = 5;
```

```
(STMTLIST
  |[
  |   |(CALLSTMT
  |   |   |(ID f)
  |   |   |(LIST
  |   |   |   |[
  |   |   |   |   |(INTEGER 2)
  |   |   |   |   |(INTEGER 3)]))
  |   |(ASSIGN
  |   |   |(ID g)
  |   |   |(INTEGER 5))])
```

Cuppa3 Frontend

```
primary : ID (\( actual_args? \))?
```

```
def primary(stream):
    ...
    elif stream.pointer().type in ['ID']:
      id_tk = stream.match('ID')
      if stream.pointer().type in ['LPAREN']:
          stream.match('LPAREN')
         if stream.pointer().type in ['INTEGER','ID','LPAREN','MINUS','NOT']:
              args = actual_args(stream)
          else:
              args = ('LIST', [])
          stream.match('RPAREN')
          return ('CALLEXP', ('ID', id_tk.value), args)
      else:
          return ('ID', id_tk.value)
    elif ...
```

```
# actual_args : {INTEGER,ID,LPAREN,MINUS,NOT} exp ({COMMA} COMMA exp)*
def actual_args(stream):
    if stream.pointer().type in ['INTEGER','ID','LPAREN','MINUS','NOT']:
        e = exp(stream)
        ll = [e]
        while stream.pointer().type in ['COMMA']:
            stream.match('COMMA')
            e = exp(stream)
            ll.append(e)
        return ('LIST', ll)
    else:
        raise SyntaxError("actual_args: syntax error at {}"
                          .format(stream.pointer().value))
```

Cuppa3 Frontend

```
x = f(2,3) + y;
```

```
(STMTLIST
   |[
   |   |(ASSIGN
   |   |   |(ID x)
   |   |   |(PLUS
   |   |   |   |(CALLEXP
   |   |   |   |   |(ID f)
   |   |   |   |   |(LIST
   |   |   |   |   |   |[
   |   |   |   |   |   |   |(INTEGER 2)
   |   |   |   |   |   |   |(INTEGER 3)]))
   |   |   |   |(ID y)))])
```

Cuppa3 Frontend

```
stmt : return exp? ;?
```

```
def stmt(stream):
    if stream.pointer().type in ['DECLARE']:…
    elif stream.pointer().type in ['ID']:…
    elif stream.pointer().type in ['GET']:…
    elif stream.pointer().type in ['PUT']:…
    elif stream.pointer().type in ['RETURN']:
        stream.match('RETURN')
        if stream.pointer().type in ['INTEGER','ID','LPAREN','MINUS','NOT']:
            e = exp(stream)
        else:
            e = ('NIL',)
        if stream.pointer().type in ['SEMI']:
            stream.match('SEMI')
        return ('RETURN', e)
    elif stream.pointer().type in ['WHILE']:…
    elif stream.pointer().type in ['IF']:…
    elif stream.pointer().type in ['LCURLY']:…
    else:…
```

Cuppa3 Frontend

```
declare inc(x) return x+1;
```

```
(STMTLIST
  |[
  |   |(FUNDECL
  |   |   |(ID inc)
  |   |   |(LIST
  |   |   |   |[
  |   |   |   |   |(ID x)])
  |   |   |(RETURN
  |   |   |   |(PLUS
  |   |   |   |   |(ID x)
  |   |   |   |   |(INTEGER 1))))])
```

Symbol Table

- The symbol table is extended so that we can manipulate scopes in order to implement *static scoping*

Symbol Table

cuppa3_symtab.py

```
class SymTab:


    def __init__(self):
        self.scoped_symtab = [{}]

    def get_config(self):
        # we make a shallow copy of the symbol table
        return list(self.scoped_symtab)

    def set_config(self, c):
        self.scoped_symtab = c

    def push_scope(self):
              …

    def pop_scope(self):
              …

    def declare_sym(self, sym, init):
               …

    def declare_fun(self, sym, init):
               …

    def lookup_sym(self, sym):
              …

    def update_sym(self, sym, val):
              …
```

Interp Walker

Good News: the interpretation of the AST is the same as for Cuppa2 except for the nodes shown with the red arrow.

cuppa3_interp_walk.py

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

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

# a dictionary to associate tree nodes with node functions
dispatch = {
    'STMTLIST': stmtlist,
    'NIL'     : nil,
    'FUNDECL' : fundecl_stmt,
    'VARDECL' : vardecl_stmt,
    'ASSIGN'  : assign_stmt,
    'GET'     : get_stmt,
    'PUT'     : put_stmt,
    'CALLSTMT': call_stmt,
    'RETURN'  : return_stmt,
    'WHILE'   : while_stmt,
    'IF'      : if_stmt,
    'BLOCK'   : block_stmt,
    'INTEGER' : integer_exp,
    'ID'      : id_exp,
    'CALLEXP' : call_exp,
    'PAREN'   : paren_exp,
    'PLUS'    : plus_exp,
    'MINUS'   : minus_exp,
    'MUL'     : mul_exp,
    'DIV'     : div_exp,
    'EQ'      : eq_exp,
    'LE'      : le_exp,
    'UMINUS'  : uminus_exp,
    'NOT'     : not_exp
}
```

Interpreting Declarations

- We now have two types of values that we need to store in the symbol table
  - Integer values
  - Function values
- We tag the values that we store in the symbol table with appropriate type tags
  - Traditionally this is called a ‘symbol table record’
  - For us it is just a tuple of type tag and value

Interpreting Declarations

```
def vardecl_stmt(node):

    (VARDECL, (ID, name), init_val) = node

    value = walk(init_val)
    symtab.declare(name, ('INTEGER', value))
    return None
```

Function context needed for static scoping

```
def fundecl_stmt(node):

    (FUNDECL, (ID, name), arglist, body) = node

    context = symtab.get_config()
    funval = ('FUNVAL', arglist, body, context)
    symtab.declare(name, funval)
    return None
```

Interpreting Assignments

- The fact that we are binding tuples into the symbol table affects assignment statements
- We have to bind tuples into the symbol table for assigned values.

```
def assign_stmt(node):

    (ASSIGN, (ID, name), exp) = node

    value = walk(exp)
    symtab.update_sym(name, ('INTEGER', value))

    return None
```

Interpreting Identifier Expressions

- Variables that appear in expressions return values
- Before we can return a value, we need to unpack the structure bound into the symbol table

```
def id_exp(node):

    (ID, name) = node

    val = symtab.lookup_sym(name)

    if val[0] != 'INTEGER':
        raise ValueError("{} is not an integer".format(name))

    return val[1]
```

Interpreting Function Calls

- The difference between call statements and call expressions:
  - Call statements – return value of a function is ignored
  - Call expressions – function has to provide a return value

Note: the return value of functions called as statement is ignored. Consider:

```
declare f () {
    put(1001);
    return 1001;
}

f();
```

```
declare inc(i)
{
    return i+1;
}

declare x = 10;
declare y;
y = inc(x);
put y;
```

Interpreting Function Calls

- How do we get function return values to the call site?
  - We *throw* them!

```
declare inc(i)
{
     return i+1;
}

declare y = inc(1);
put y;
```

```
(STMTLIST
  |[
  |   |(FUNDECL
  |   |   |(ID inc)
  |   |   |(LIST
  |   |   |   |[
  |   |   |   |   |(ID i)])
  |   |   |(BLOCK
  |   |   |   |(STMTLIST
  |   |   |   |   |[
  |   |   |   |   |   |(RETURN
  |   |   |   |   |   |   |(PLUS
  |   |   |   |   |   |   |   |(ID i)
  |   |   |   |   |   |   |   |(INTEGER 1)))])))
  |   |(VARDECL
  |   |   |(ID y)
  |   |   |(CALLEXP
  |   |   |   |(ID inc)
  |   |   |   |(LIST
  |   |   |   |   |[
  |   |   |   |   |   |(INTEGER 1)])))
  |   |(PUT
  |   |   |(ID y))])
```

Interpreting Function Calls

```
def call_stmt(node):

    (CALLSTMT, (ID, name), actual_args) = node

    handle_call(name, actual_args)

    return None
```

```
def call_exp(node):

    (CALLEXP, (ID, name), actual_args) = node

    return_value = handle_call(name, actual_args)

    if return_value is None:
        raise ValueError("No return value from function {}".format(name))

    return return_value
```

```
def return_stmt(node):

    (RETURN, exp) = node

    value = walk(exp)
    raise ReturnValue(value)
```

```
class ReturnValue(Exception):

    def __init__(self, value):
        self.value = value

    def __str__(self):
        return(repr(self.value))
```

```
def nil(node):

    (NIL,) = node

    # do nothing!
    return None
```

Interpretin

```python
def handle_call(name, actual_arglist):
    '''
    handle calls for both call-statements and call-expressions.
    '''

    val = symtab.lookup_sym(name)

    if val[0] != 'FUNVAL':
        raise ValueError("{} is not a function".format(name))

    # unpack the funval tuple
    (FUNVAL, formal_arglist, body, context) = val

    # set up the environment for static scoping and then execute the function
    actual_val_args = eval_actual_args(actual_arglist)
    save_symtab = symtab.get_config()
    symtab.set_config(context)
    symtab.push_scope()
    declare_formal_args(formal_arglist, actual_val_args)

    # execute function
    return_value = None
    try:
        walk(body)
    except ReturnValue as val:
        return_value = val.value

    # NOTE: popping the function scope is not necessary because we
    # are restoring the original symtab configuration
    symtab.set_config(save_symtab)

    return return_value
```

'handle_call' our function call work horse

Interpreting Function Calls

```python
def eval_actual_args(args):
    '''
    Walk the list of actual arguments, evaluate them, and
    return a list with the evaluated actual values
    '''
    (LIST, ll) = args

    outlist = []
    for e in ll:
        v = walk(e)
        outlist.append(('INTEGER', v))

    return ('LIST', outlist)
```

```python
def declare_formal_args(formal_args, actual_val_args):
    '''
    Walk the formal argument list and declare the identifiers on that
    list using the corresponding actual args as initial values.
    NOTE: this is where we implement by-value argument passing
    '''
    (LIST, fl) = formal_args
    (LIST, avl) = actual_val_args

    if len(fl) != len(avl):
        raise ValueError("actual and formal argument lists do not match")

    for ((ID, f), v) in zip(fl, avl):
        symtab.declare(f, v)
```

Driver Function

```
def interp(input_stream, dump=False, exceptions=False):
    try:
        symtab.initialize()
        ast = parse(input_stream)
        if dump:
            dumpast(ast)
        else:
            walk(ast)
    except Exception as e:
        if exceptions:
            raise e # rethrow for visibility
        else:
            print("error: "+str(e))
    return None
```

Testing the Interpreter

```
// recursive implementation of factorial
declare fact(x)
{
     if (x =< 1)
        return 1;
     else
        return x * fact(x-1);
}

// ask the user for input
declare v;
get v;
put fact(v);
```

```
$ python3 cuppa3_interp.py fact.txt
Value for v? 3
6
$
```

Assignment

- Assignment #5 – see BrightSpace