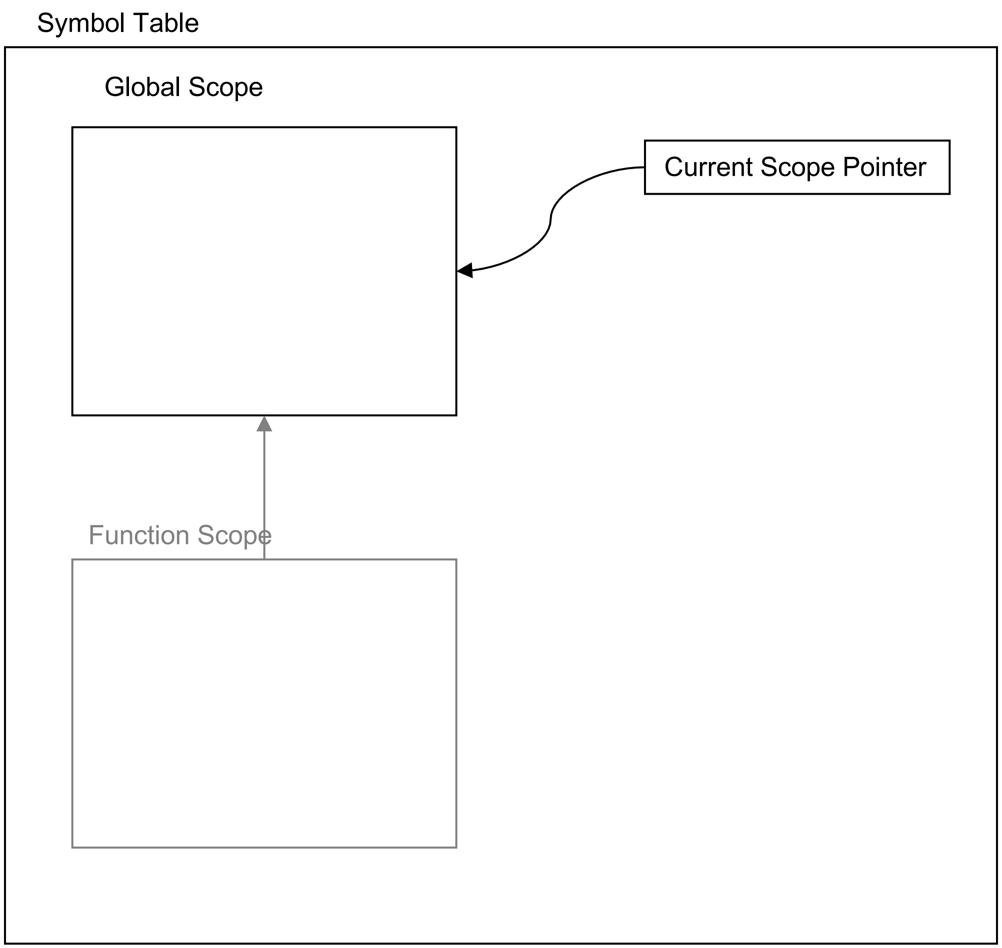
Interpreter Implementation

- 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

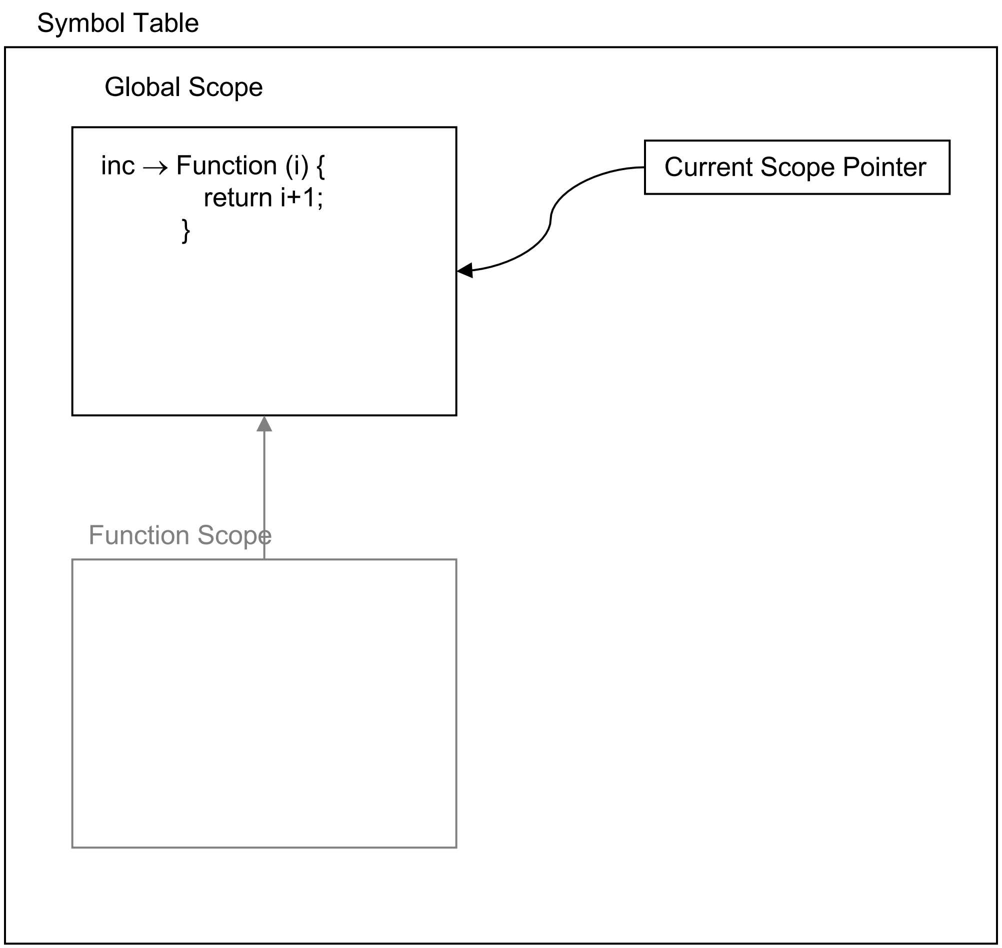
Interpreting Functions




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

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

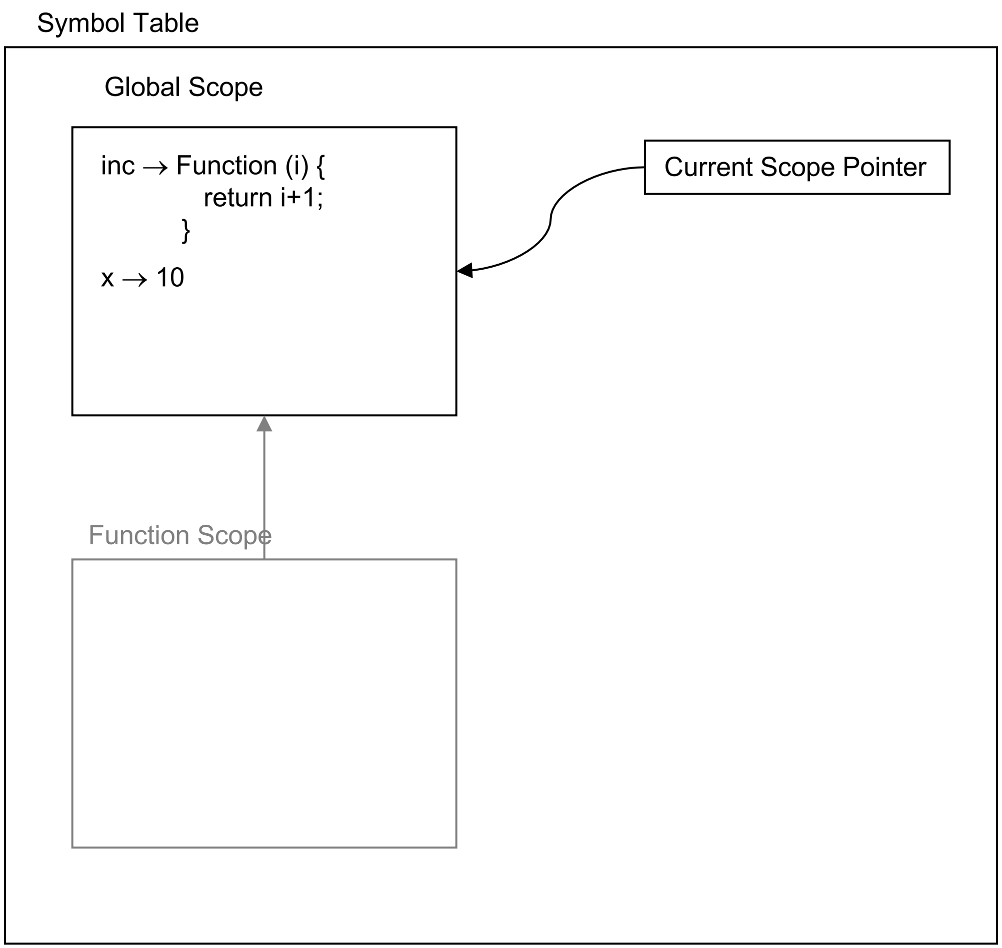
Interpreting Functions




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

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

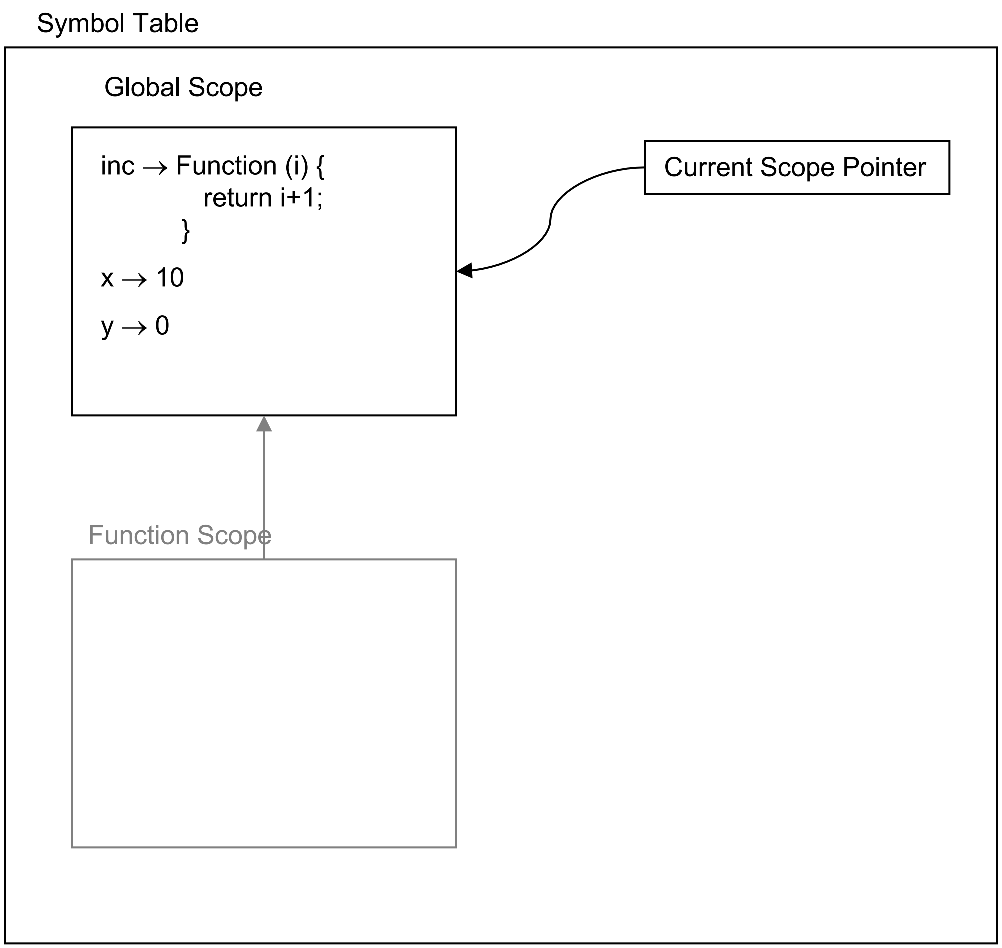
Interpreting Functions




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

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

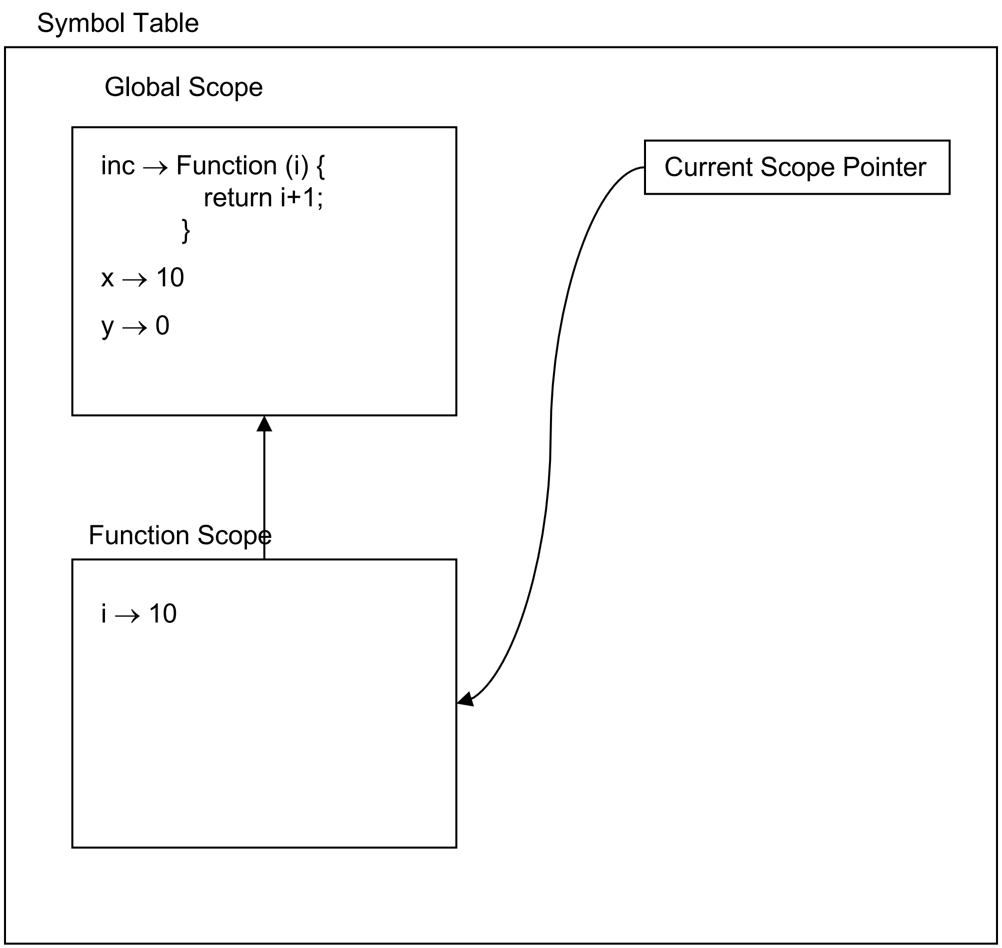
Interpreting Functions




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

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

Interpreting Functions



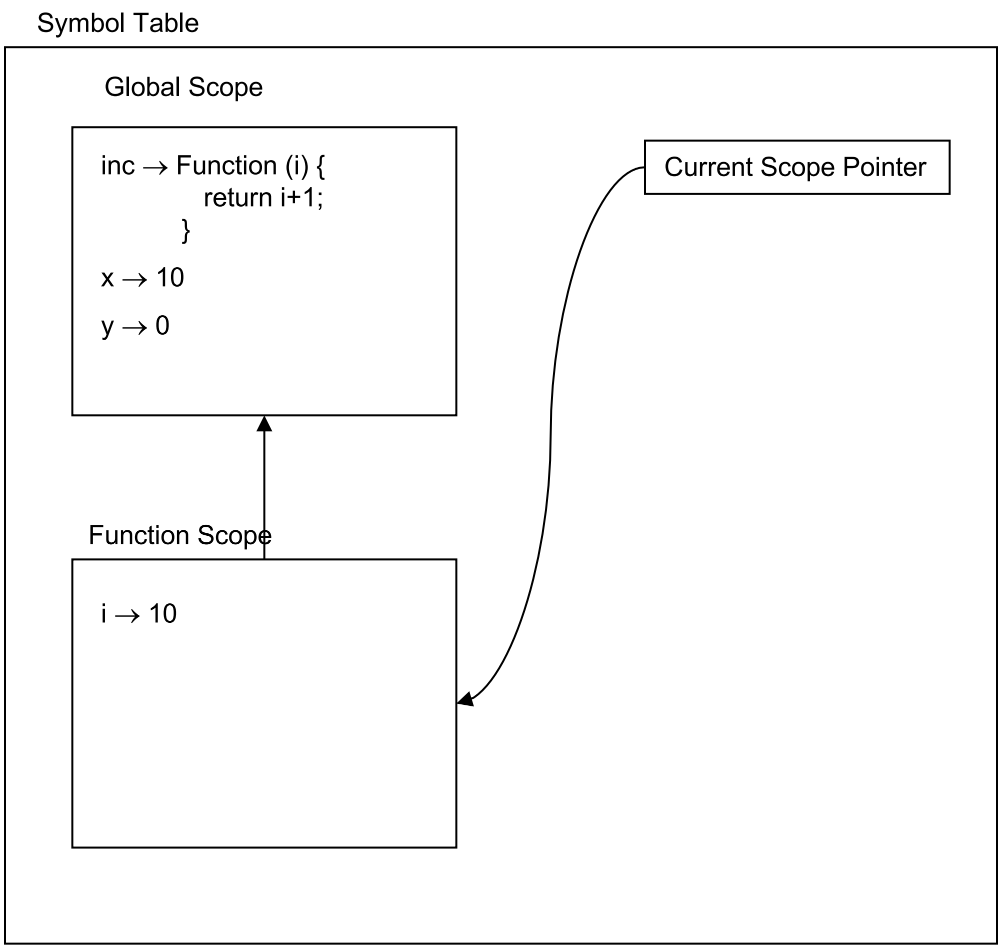

```
declare inc(i) {
    return i+1;
}

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

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

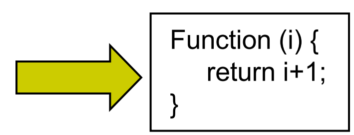
Setup the function call:
- lookup function name
- retrieve function body
- push new function scope
- init formal parameters with actual parameters

Interpreting Functions



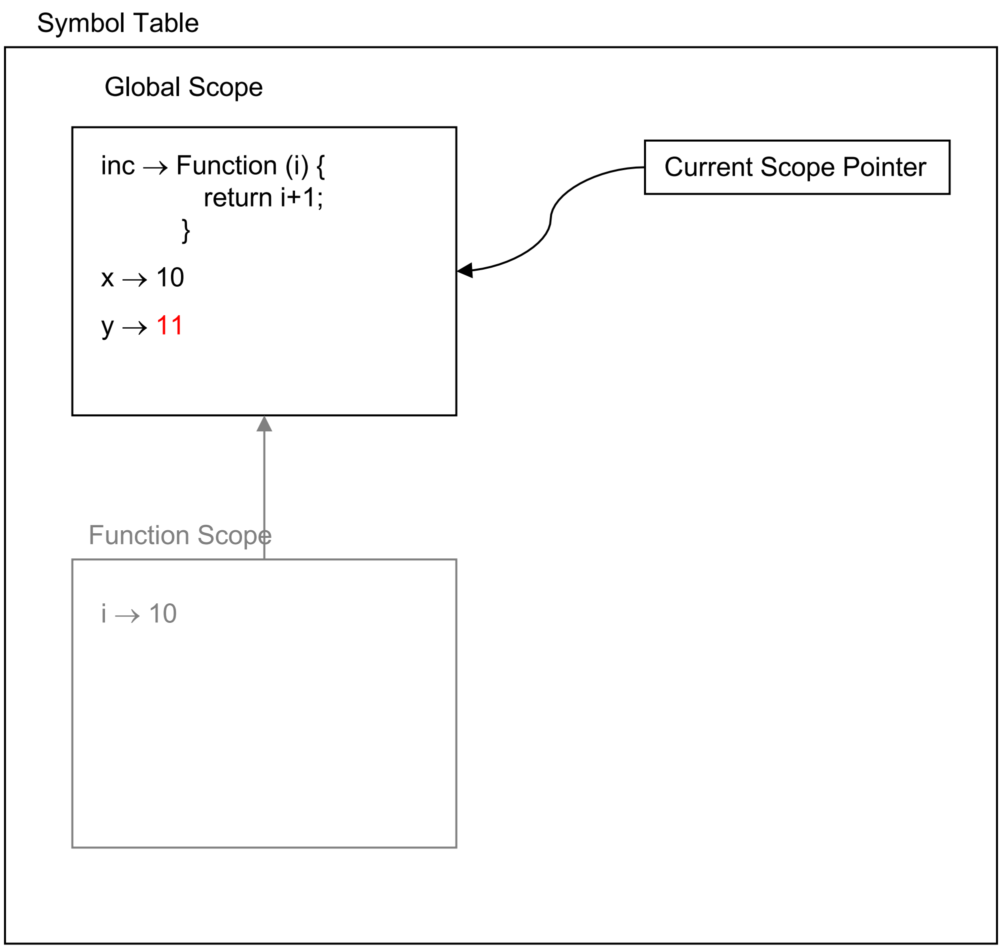

```
declare inc(i) {
    return i+1;
}

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



Execute the called function and compute return value.

Interpreting Functions

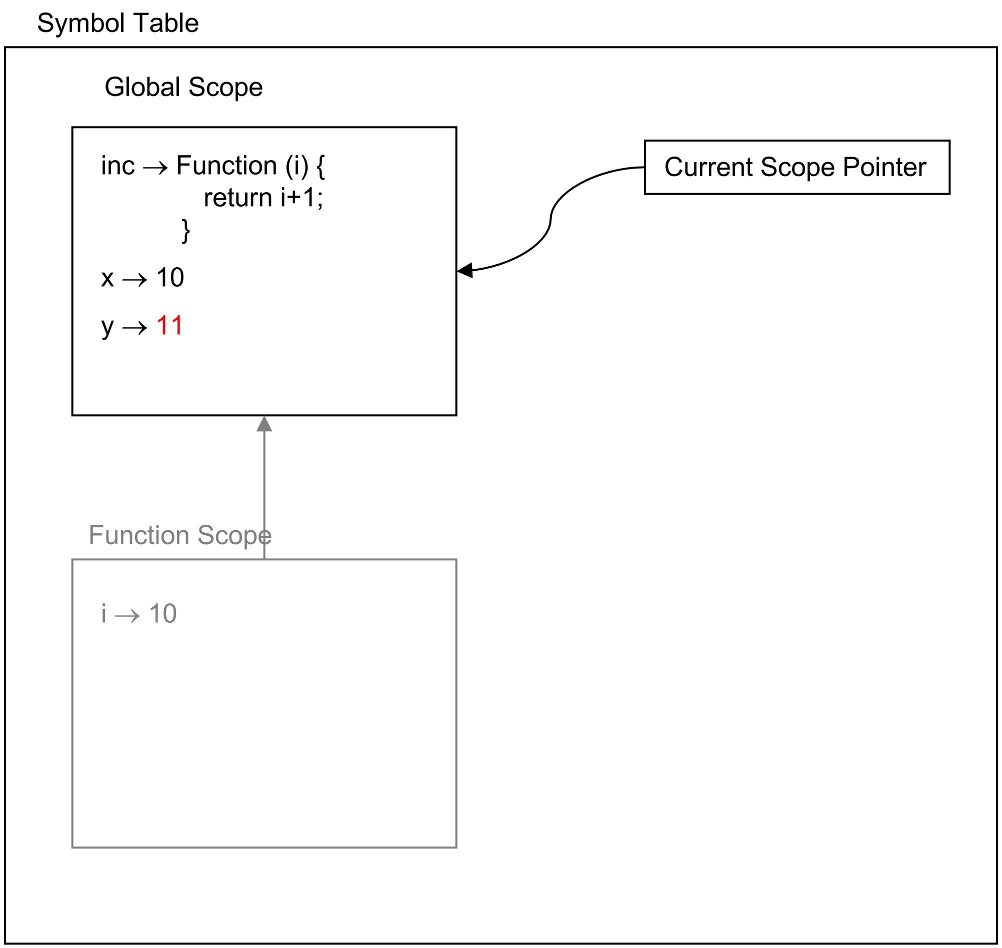



```
declare inc(i) {
    return i+1;
}

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

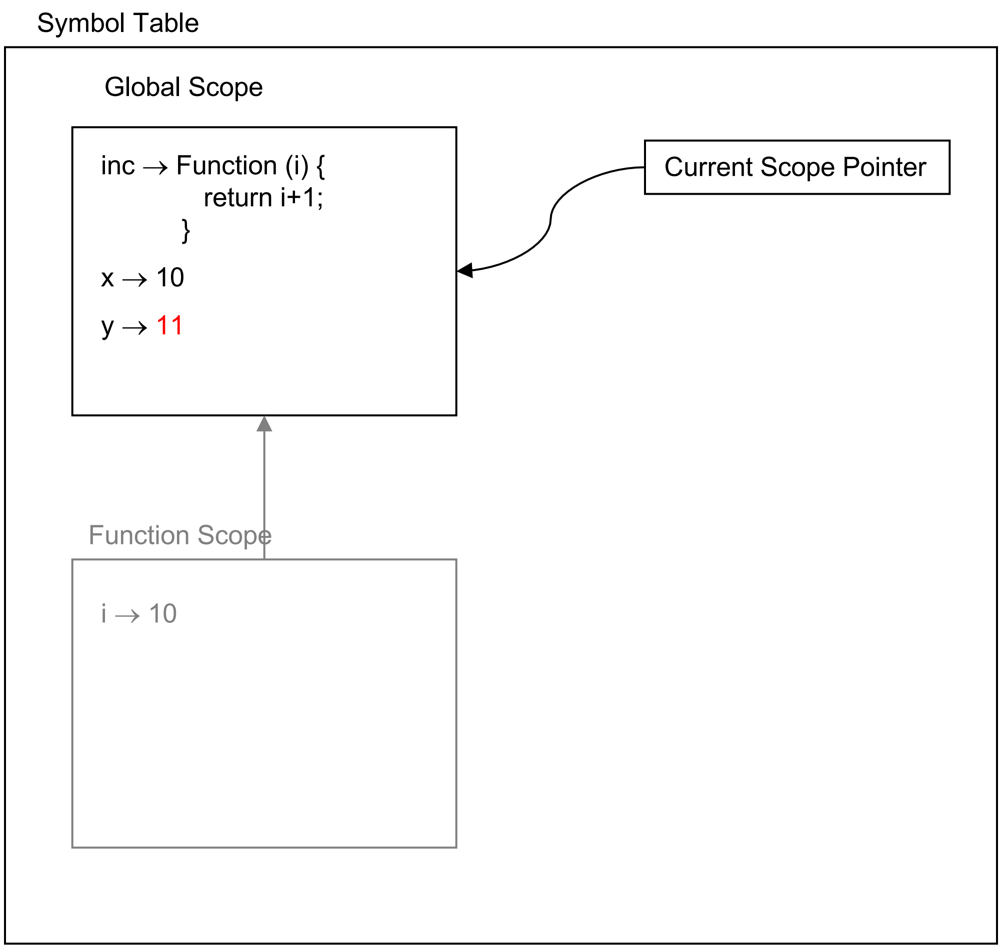



```
declare inc(i) {
    return i+1;
}

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

```
def p_stmt(p):
    '''
    stmt : DECLARE ID '(' opt_formal_args ')' stmt
         | DECLARE ID opt_init opt_semi
         | ID '=' exp opt_semi
         | GET ID opt_semi
         | PUT exp opt_semi
         | ID '(' opt_actual_args ')' opt_semi
         | RETURN opt_exp opt_semi
         | WHILE '(' exp ')' stmt
         | IF '(' exp ')' stmt opt_else
         | '{' stmt_list '}'
    '''
    if p[1] == 'declare' and p[3] == '(':
        p[0] = ('fundecl', p[2], p[4], p[6])
    elif p[1] == 'declare':
        p[0] = ('declare', p[2], p[3])
    elif is_ID(p[1]) and 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 is_ID(p[1]) and p[2] == '(':
        p[0] = ('callstmt', p[1], p[3])
    elif p[1] == 'return':
        p[0] = ('return', 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]))
```

```
def p_opt_formal_args(p):
    '''
    opt_formal_args : formal_args
                    | empty
    '''
    p[0] = p[1]

#############################################
def p_formal_args(p):
    '''
    formal_args : ID ',' formal_args
                | ID
    '''
    if (len(p) == 4):
        p[0] = ('seq', ('id', p[1]), p[3])
    elif (len(p) == 2):
        p[0] = ('seq', ('id', p[1]), ('nil',))
```

```
def p_opt_actual_args(p):
    '''
    opt_actual_args : actual_args
                    | empty
    '''
    p[0] = p[1]

#########################################
def p_actual_args(p):
    '''
    actual_args : exp ',' actual_args
                | exp
    '''
    if (len(p) == 4):
        p[0] = ('seq', p[1], p[3])
    elif (len(p) == 2):
        p[0] = ('seq', p[1], ('nil',))
```

```
def p_call_exp(p):
    '''
    exp : ID '(' opt_actual_args ')'
    '''
    p[0] = ('callexp', p[1], p[3])
```

Symbol Table

- The symbol table is extended to store two different kinds of objects:
  - Scalars
  - Functions
- It is also 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):
        # declare the scalar 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] = ('scalar', init)


    def declare_fun(self, sym, init):
        # declare a function 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 function in the current scope
        scope_dict = self.scoped_symtab[CURR_SCOPE]
        scope_dict[sym] = ('function', 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_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,
    'fundecl'  : fundecl_stmt,
    'declare'  : declare_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_exp,
    '-'        : minus_exp,
    '*'        : times_exp,
    '/'        : divide_exp,
    '=='       : eq_exp,
    '<='       : le_exp,
    'uminus'   : uminus_exp,
    'not'      : not_exp
}
```

Interp Walk

- 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;
```

Interp Walk

- 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;
```

```
(seq
   |(fundecl inc
   |   |(seq
   |   |   |(id i)
   |   |   |(nil))
   |   |(block
   |   |   |(seq
   |   |   |   |(return
   |   |   |   |   |(+
   |   |   |   |   |   |(id i)
   |   |   |   |   |   |(integer 1)))
   |   |   |   |(nil))))
   |(nil))
```

```
(seq
   |(declare y
   |   |(callexp inc
   |   |   |(seq
   |   |   |   |(integer 1)
   |   |   |   |(nil))))
   |(seq
   |   |(put
   |   |   |(id y))
   |   |(nil)))
```

Interp Walk

- Throwing the return value also solves the problem of terminating a deeply recursive computation on the AST!

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

```
(seq
   |(fundecl fact
   |   |(seq
   |   |   |(id x)
   |   |   |(nil))
   |   |(block
   |   |   |(seq
   |   |   |   |(if
   |   |   |   |   |(<=
   |   |   |   |   |   |(id x)
   |   |   |   |   |   |(integer 1))
   |   |   |   |   |(return
   |   |   |   |   |   |(integer 1))
   |   |   |   |   |(return
   |   |   |   |   |   |(*
   |   |   |   |   |   |   |(callexp fact
   |   |   |   |   |   |   |   |(seq
   |   |   |   |   |   |   |   |   |(-
   |   |   |   |   |   |   |   |   |   |(id x)
   |   |   |   |   |   |   |   |   |   |(integer 1))
   |   |   |   |   |   |   |   |   |(nil)))
   |   |   |   |   |   |   |(id x))))
   |   |   |   |(nil))))
   |(nil))
```

Interp Walk

```
def fundecl_stmt(node):

    try: # try the fundecl pattern without arglist
        (FUNDECL, name, (NIL,), body) = node
        assert_match(FUNDECL, 'fundecl')
        assert_match(NIL, 'nil')

    except ValueError: # try fundecl with arglist
        (FUNDECL, name, arglist, body) = node
        assert_match(FUNDECL, 'fundecl')

        context = state.symbol_table.get_config()
        funval = ('funval', arglist, body, context)
        state.symbol_table.declare_fun(name, funval)

    else: # fundecl pattern matched
        # no arglist is present
        context = state.symbol_table.get_config()
        funval = ('funval', ('nil',), body, context)
        state.symbol_table.declare_fun(name, funval)
```

```
def call_stmt(node):

    (CALLSTMT, name, actual_args) = node
    assert_match(CALLSTMT, 'callstmt')

    handle_call(name, actual_args)
```

```
def call_exp(node):
    # call_exp works just like call_stmt with the exception
    # that we have to pass back a return value

    (CALLEXP, name, args) = node
    assert_match(CALLEXP, 'callexp')

    return_value = handle_call(name, args)

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

    return return_value
```

```
def return_stmt(node):
    # if a return value exists the return stmt will record it
    # in the state object

    try: # try return without exp
        (RETURN, (NIL,)) = node
        assert_match(RETURN, 'return')
        assert_match(NIL, 'nil')

    except ValueError: # return with exp
        (RETURN, exp) = node
        assert_match(RETURN, 'return')

        value = walk(exp)
        raise ReturnValue(value)

    else: # return without exp
        raise ReturnValue(None)
```

Interp Walk

```
class ReturnValue(Exception):

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

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

```
def handle_call(name, actual_arglist):

    (type, val) = state.symbol_table.lookup_sym(name)

    if type != 'function':
        raise ValueError("{} is not a function".format(name))

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

    if len_seq(formal_arglist) != len_seq(actual_arglist):
        raise ValueError("function {} expects {} arguments".format(sym, len_seq(formal_arglist)))

    # set up the environment for static scoping and then execute the function
    actual_val_args = eval_actual_args(actual_arglist)   # evaluate actuals in current symtab
    save_symtab = state.symbol_table.get_config()        # save current symtab
    state.symbol_table.set_config(context)               # make function context current symtab
    state.symbol_table.push_scope()                      # push new function scope
    declare_formal_args(formal_arglist, actual_val_args) # declare formals in function scope

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

    state.symbol_table.pop_scope()                       # pop function scope
    state.symbol_table.set_config(save_symtab)           # restore original symtab config

    return return_value
```

Interp Walk

```
def eval_actual_args(args):

    if args[0] == 'nil':
        return ('nil',)

    elif args[0] == 'seq':
        # unpack the seq node
        (SEQ, p1, p2) = args

        val = walk(p1)

        return ('seq', val, eval_actual_args(p2))

    else:
        raise ValueError("unknown node type: {}".format(args[0]))
```

```
def declare_formal_args(formal_args, actual_val_args):

    if len_seq(actual_val_args) != len_seq(formal_args):
        raise ValueError("actual and formal argument lists do not match")

    if formal_args[0] == 'nil':
        return

    # unpack the args
    (SEQ, (ID, sym), p1) = formal_args
    (SEQ, val, p2) = actual_val_args

    # declare the variable
    state.symbol_table.declare_sym(sym, val)

    declare_formal_args(p1, p2)
```

Driver Function

```
def interp(input_stream):

    # initialize the state object
    state.initialize()

    # build the AST
    parser.parse(input_stream, lexer=lexer)

    # walk the AST
    #dump_AST(state.AST)
    walk(state.AST)
```

Testing the Interpreter

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

declare x = add(3,2);
put x;
'''
```

```
In [5]: interp(add)

        > 5
```

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

declare v;
get v;
put fact(v);
'''
```

```
In [9]: interp(factrec)

        Value for v? 3
        > 6
```

Assignment

- Assignment #7