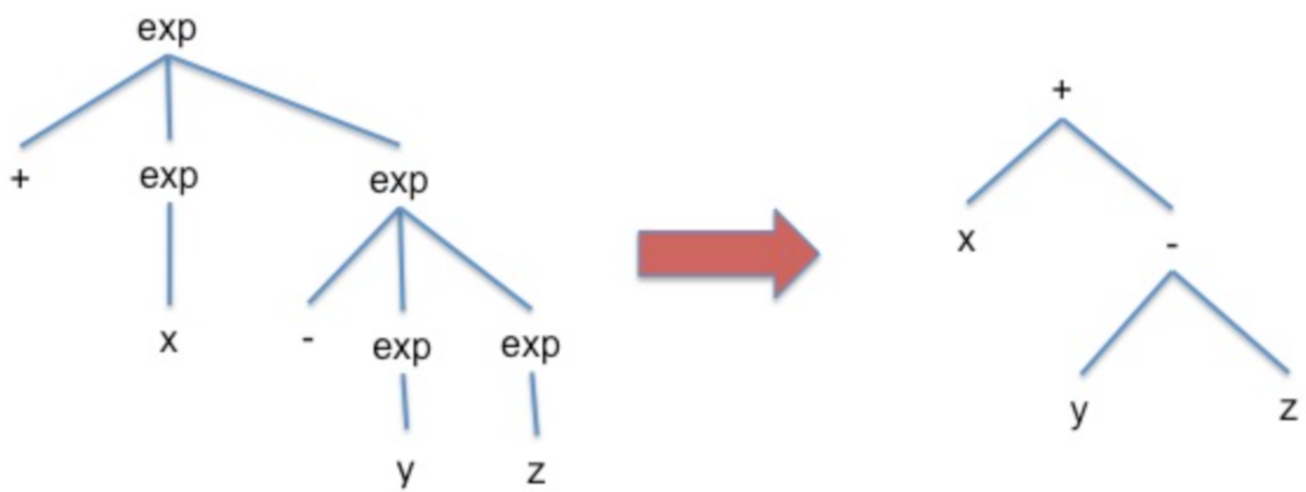
Abstract Syntax Trees

- Our Exp1bytecode language was so straightforward that the best IR was an abstract representation of the instructions
- In more complex languages, especially higher level languages it usually not possible to design such a simple IR
- Instead we use Abstract Syntax Trees (ASTs)

Abstract Syntax Trees

- One way to think about ASTs is as parse trees with all the derivation information deleted



Parse Tree

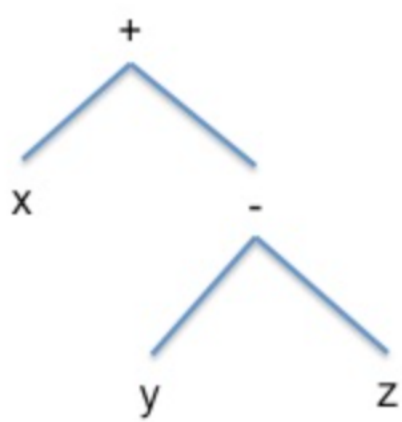
Abstract Syntax Tree

Abstract Syntax Trees

- Because every valid program has a parse tree, it is always possible to construct an AST for every valid input program.
- In this way ASTs are the IR of choice because it doesn't matter how complex the input language, there will always be an AST representation.
- Besides being derived from the parse tree, AST design typically follows three rules of thumb:
  - *Dense*: no unnecessary nodes
  - *Convenient*: easy to understand, easy to process
  - *Meaningful*: emphasize the operators, operands, and the relationship between them; emphasize the computations

Tuple Representation of ASTs

- A convenient way to represent AST nodes is with the following structure,
  - (TYPE [, child1, child2,...])
- A tree node is a tuple where the first component represents the type or name of the node followed by zero or more components each representing a child of the current node.
- Consider the abstract syntax tree for + x - y x,




```
In [2]: ast = ('+', 'x', ('-', 'y', 'z'))
```

```
In [3]: from grammar_stuff import dump_AST
        dump_AST(ast)

(+ x
  |(- y z))
```

The Cuppa1 Language

- Our next language is a simple high-level language that supports structured programming with ‘if’ and ‘while’ statements.
- However, it has no scoping and no explicit variable declarations.

The Cuppa1 Language

```
program : stmt_list

stmt_list : stmt stmt_list
          | empty

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

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
```

Infix Expressions!

```
// list of integers
get x;
while (1 <= x)
{
        put x;
        x = x - 1;
}
```

Precedence & Associativity Table:

```
precedence = (
               ('left', 'EQ', 'LE'),
               ('left', 'PLUS', 'MINUS'),
               ('left', 'TIMES', 'DIVIDE'),
               ('right', 'UMINUS', 'NOT')
             )
```

The Cuppa1 Language

cuppa1_gram.py

```
# grammar for Cuppa1

from ply import yacc
from cuppa1_lex import tokens, lexer

# set precedence and associativity
# NOTE: all arithmetic operator need to have tokens
#       so that we can put them into the precedence table
precedence = (
       ('left', 'EQ', 'LE'),
       ('left', 'PLUS', 'MINUS'),
       ('left', 'TIMES', 'DIVIDE'),
       ('right', 'UMINUS', 'NOT')
      )


def p_grammar(_):
  '''
    program : stmt_list

    stmt_list : stmt stmt_list
        | empty

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

    opt_else : ELSE stmt
        | empty

  opt_semi : ';'
        | empty
…
```

The Parser Specification

```
…
    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
  '''
  pass

def p_empty(p):
    'empty :'
  pass

def p_error(t):
    print("Syntax error at '%s'" % t.value)

### build the parser
parser = yacc.yacc()
```

The Cuppa1 Language

cuppa1_lex.py

```
# Lexer for Cuppa1

from ply import lex

reserved = {
  'get'  : 'GET',
  'put'  : 'PUT',
  'if'   : 'IF',
  'else' : 'ELSE',
  'while' : 'WHILE',
  'not'  : 'NOT'
}

literals = [';','=','(',')','{','}']

tokens = [
      'PLUS','MINUS','TIMES','DIVIDE',
      'EQ','LE',
      'INTEGER','ID',
      ] + list(reserved.values())

t_PLUS   = r'\+'
t_MINUS  = r'-'
t_TIMES  = r'\*'
t_DIVIDE = r'/'
t_EQ     = r'=='
t_LE     = r'<='

t_ignore = ' \t'
...
```

The Lexer Specification

```
…
def t_ID(t):
  r'[a-zA-Z_][a-zA-Z_0-9]*'
    t.type = reserved.get(t.value,'ID')    # Check for reserved words
    return t

def t_INTEGER(t):
  r'[0-9]+'
    return t

def t_COMMENT(t):
  r'//.*'
  pass

def t_NEWLINE(t):
  r'\n'
  pass

def t_error(t):
    print("Illegal character %s" % t.value[0])
  t.lexer.skip(1)

# build the lexer
lexer = lex.lex(debug=0)
```

Testing our Parser

In [4]:
```
from cuppa1_gram import parser
from cuppa1_lex import lexer
```

```
Generating LALR tables
WARNING: 1 shift/reduce conflict
```

In [6]:
```
fact = \
'''
get x;
y = 1;
while (1 <= x)
{
      y = y * x;
      x = x - 1;
}
put y;
'''

parser.parse(fact, lexer=lexer)
```

In [7]:
```
loop = "while (1) {}"

parser.parse(loop, lexer=lexer)
```

Notice the shift/reduce conflict!

The error is due to the if-then-else statement with the optional else.

The default action for shift/reduce conflicts is to always **shift**.

That is exactly right for us!

The Cuppa1 Frontend

- A frontend is a parser that
  1. Constructs an AST
  2. Fills out some rudimentary information in a symbol table

cuppa1_state.y

```
class State:
    def __init__(self):
        self.initialize()

    def initialize(self):
        # symbol table to hold variable-value associations
        self.symbol_table = {}

        # when done parsing this variable will hold our AST
        self.AST = None

state = State()
```

We use the State to maintain the program AST and a symbol table.

AST: Statements

cuppa1_frontend_gram.py

```
def p_stmt(p):
  '''
    stmt : ID '=' exp opt_semi
         | GET ID opt_semi
         | PUT exp opt_semi
         | WHILE '(' exp ')' stmt
         | IF '(' exp ')' stmt opt_else
         | '{' stmt_list '}'
  '''
  if p[2] == '=':
    p[0] = ('assign', p[1], p[3])
    state.symbol_table[p[1]] = None
  elif p[1] == 'get':
    p[0] = ('get', p[2])
    state.symbol_table[p[2]] = None
  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]))
```

```
def p_opt_else(p):
  '''
    opt_else : ELSE stmt
             | empty
  '''
  if p[1] == 'else':
    p[0] = p[2]
  else:
    p[0] = p[1]
```

```
def p_empty(p):
    'empty :'
    p[0] = ('nil',)
```

Consider:
stmt : ID '=' exp opt_semi

Gives rise to the following actions:
`p[0] = ('assign', p[1], p[3])`
`state.symbol_table[p[1]] = None`

Consider the rule: IF '(' exp ')' stmt opt_else
What does the tuple tree look like for the various shapes of the 'if' statement?

AST: Statement Lists & Programs

cuppa1_frontend_gram.py

```
def p_prog(p):
  '''
    program : stmt_list
  '''
  state.AST = p[1]
```

Save the construct AST in the state!

```
def p_stmt_list(p):
  '''
    stmt_list : stmt stmt_list
       | empty
  '''
  if (len(p) == 3):
    p[0] = ('seq', p[1], p[2])
  elif (len(p) == 2):
    p[0] = p[1]
```

Statement lists are 'nil' terminated 'seq' terms.

```
def p_empty(p):
  '''
    empty :
  '''
  p[0] = ('nil',)
```

AST: Expressions

cuppa1_frontend_gram.py

```
def p_binop_exp(p):
  '''
  exp : exp PLUS exp
      |exp MINUS exp
      | exp TIMES exp
      |exp DIVIDE exp
      |exp EQ exp
      |exp LE exp
  '''
  p[0] = (p[2], p[1], p[3])
```

This should look familiar, same structure as for the expressions in exp1bytecode language.

```
#########################################################################
def p_integer_exp(p):
    '''
    exp : INTEGER
    '''
    p[0] = ('integer', int(p[1]))

#########################################################################
def p_id_exp(p):
    '''
    exp : ID
    '''
    p[0] = ('id', p[1])

#########################################################################
def p_paren_exp(p):
    '''
    exp : '(' exp ')'
    '''
    p[0] = ('paren', p[2])

#########################################################################
def p_uminus_exp(p):
    '''
    exp : MINUS exp %prec UMINUS
    '''
    p[0] = ('uminus', p[2])

#########################################################################
def p_not_exp(p):
    '''
    exp : NOT exp
    '''
    p[0] = ('not', p[2])

#########################################################################
```

Running the Frontend

In [16]:
```
from cuppa1_frontend_gram import parser
from cuppa1_lex import lexer
from cuppa1_state import state
from grammar_stuff import dump_AST
```

In [17]:
```
state.initialize()
parser.parse("get x; put x", lexer=lexer)
```

In [18]:
```
dump_AST(state.AST)
```

```
(seq
  |(get x)
  |(seq
  |   |(put
  |   |   |(id x))
  |   |(nil)))
```

In [19]:
```
state.symbol_table
```

Out[19]:
```
{'x': None}
```

Running the Frontend

In [20]:
```
state.initialize()
parser.parse("get x; x = x + 1; put x", lexer=lexer)
```

In [21]:
```
dump_AST(state.AST)
```

```
(seq
  |(get x)
  |(seq
  |  |(assign x
  |  |  |(+
  |  |  |  |(id x)
  |  |  |  |(integer 1)))
  |  |(seq
  |  |  |(put
  |  |  |  |(id x))
  |  |  |(nil))))
```

In [22]:
```
state.symbol_table
```

Out[22]:
```
{'x': None}
```

Running the Frontend

In [23]:
```
state.initialize()
parser.parse("while (1) {}", lexer=lexer)
```

In [24]:
```
dump_AST(state.AST)
```

```
(seq
  |(while
  |   |(integer 1)
  |   |(block
  |   |   |(nil)))
  |(nil))
```

Running the Frontend

```
In [25]: state.initialize()
         parser.parse("get x; if (0 <= x) put 1", lexer=lexer)
```

```
In [26]: dump_AST(state.AST)
```

```
(seq
   |(get x)
   |(seq
   |   |(if
   |   |   |(<=
   |   |   |   |(integer 0)
   |   |   |   |(id x))
   |   |   |(put
   |   |   |   |(integer 1))
   |   |   |(nil))
   |   |(nil)))
```

Running the Frontend

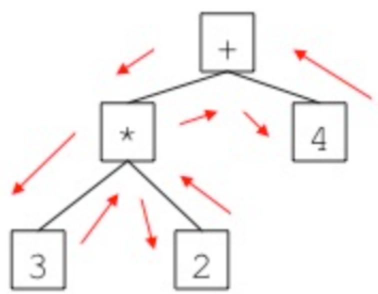
```
In [27]: parser.parse("get x; if (0 <= x) put 1 else put 2", lexer=lexer)

In [28]: dump_AST(state.AST)

(seq
  |(get x)
  |(seq
  |  |(if
  |  |  |(<=
  |  |  |  |(integer 0)
  |  |  |  |(id x))
  |  |  |(put
  |  |  |  |(integer 1))
  |  |  |(put
  |  |  |  |(integer 2)))
  |  |(nil)))
```

Processing ASTs: Tree Walking

- The recursive structure of trees gives rise to an elegant way of processing trees: *tree walking*.
- A tree walker typically starts at the root node and traverses the tree in a depth first manner.

Processing ASTs: Tree Walking

Consider the following:



In [34]:
```
ast = ('+', ('*', ('integer', 3), ('integer', 2)), ('integer', 4))
```

In [35]:
```
from grammar_stuff import dump_AST

dump_AST(ast)
```

```
(+
  |(*
  |  |(integer 3)
  |  |(integer 2))
  |(integer 4))
```

Processing ASTs:

```
def const(node):
    # pattern match the constant node
    (INTEGER, val) = node

    # return the value as an integer value
    return int(val)

def add(node):
    # pattern match the tree node
    (ADD, left, right) = node

    # recursively call the walker on the children
    left_val = walk(left)
    right_val = walk(right)

    # return the sum of the values of the children
    return left_val + right_val

def mult(node):
    # pattern match the tree node
    (MULT, left, right) = node

    # recursively call the walker on the children
    left_val = walk(left)
    right_val = walk(right)

    # return the product of the values of the children
    return left_val * right_val
```

A simple tree walker for our expression tree

```
dispatch_dict = {
    '+' : add,
    '*' : mult,
    'integer' : const
}
```

```
def walk(node):
    # first component of any tree node is its type
    t = node[0]

    # lookup the function for this node
    node_function = dispatch_dict[t]

    # now call this function on our node and capture the return value
    val = node_function(node)

    return val
```

Processing ASTs: Tree Walking

A simple tree walker for our expression tree

```
In [34]: ast = ('+', ('*', ('integer', 3), ('integer', 2)), ('integer', 4))
```

```
In [35]: from grammar_stuff import dump_AST

         dump_AST(ast)
```

```
(+
  |(*
  |  |(integer 3)
  |  |(integer 2))
  |(integer 4))
```

```
In [39]: print(walk(ast))
```

```
10
```

We just interpreted the expression tree!!!

Processing ASTs: Tree Walking

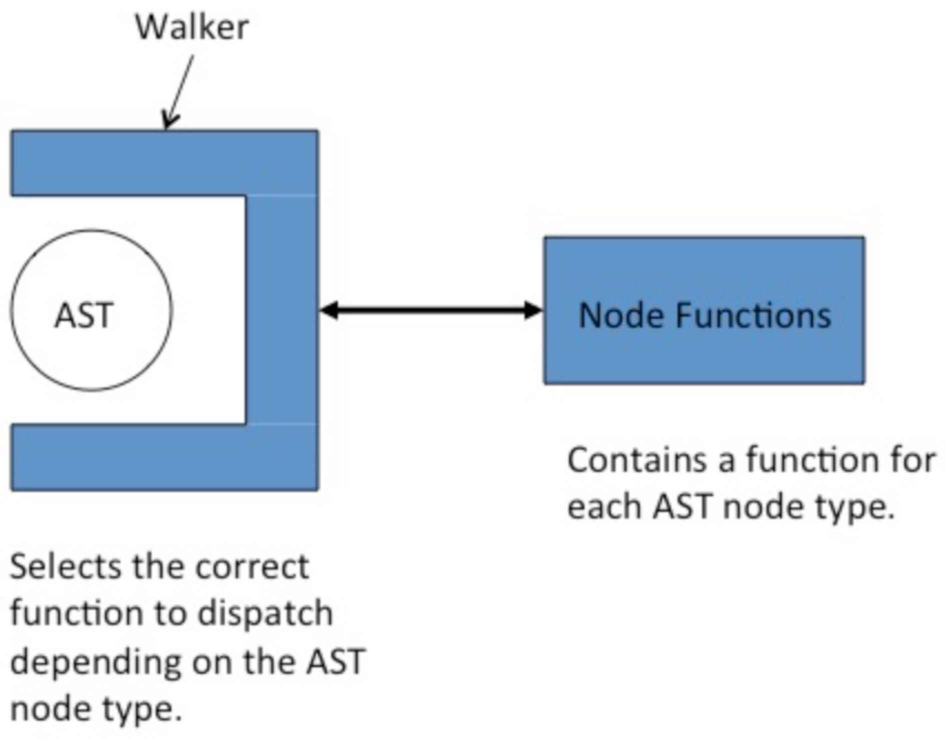
A simple tree walker for our expression tree

```
def const(node):
    # pattern match the constant node
    (INTEGER, val) = node

    # return the value as an integer value
    return int(val)

def add(node):
    # pattern match the tree node
    (ADD, left, right) = node

    # recursively call the walker on the children
    left_val = walk(left)
    right_val = walk(right)

    # return the sum of the values of the children
    return left_val + right_val

def mult(node):
    # pattern match the tree node
    (MULT, left, right) = node

    # recursively call the walker on the children
    left_val = walk(left)
    right_val = walk(right)

    # return the product of the values of the children
    return left_val * right_val
```

- Notice that this scheme mimics what we did in the syntax directed interpretation schema,
- But now we interpret an expression tree rather than the implicit tree constructed by the parser.

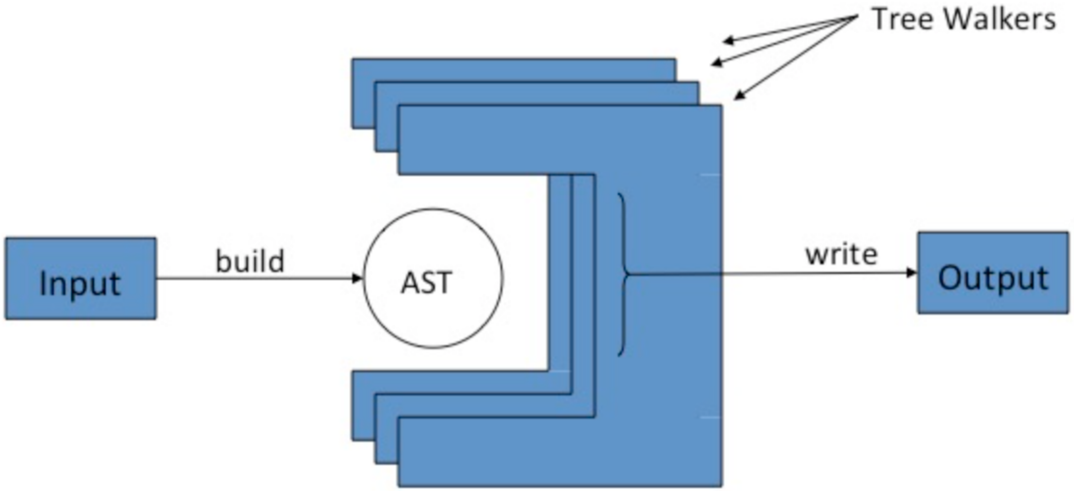
Tree Walkers are Plug'n Play

- Tree walkers exist completely separately from the AST.
- Tree walkers plug into the AST and process it using their node functions.

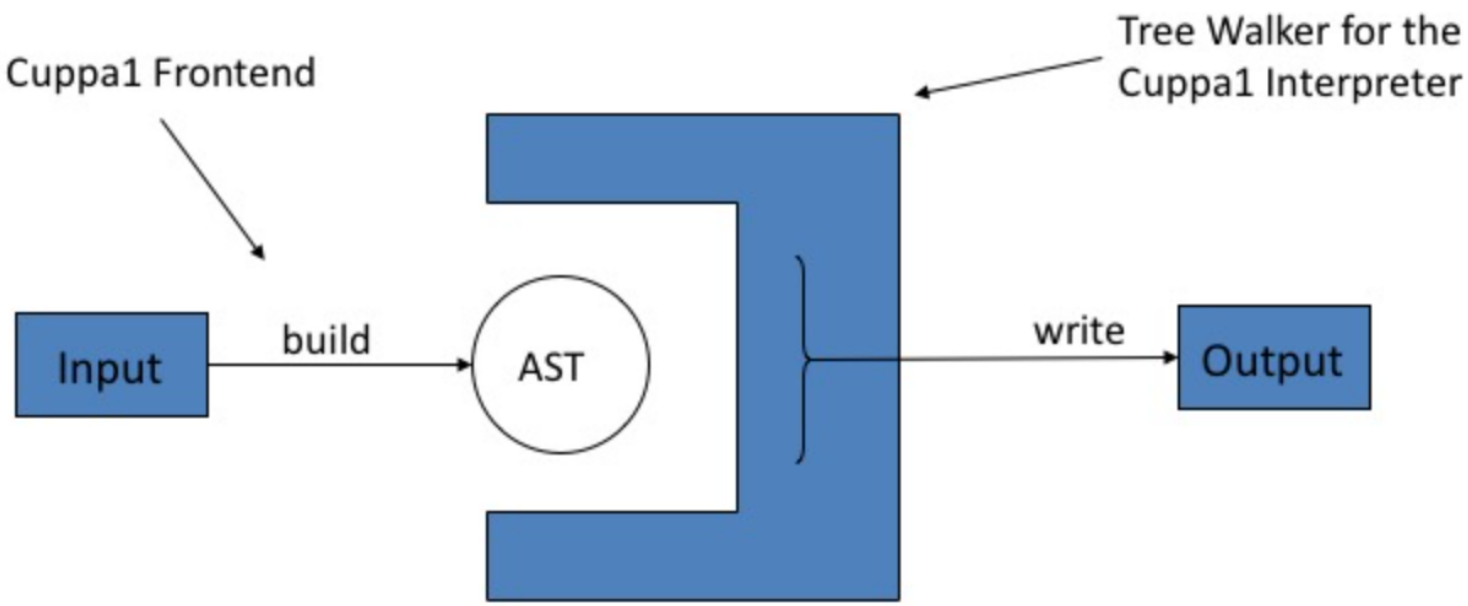


Tree Walkers are Plug'n Play

- There is nothing to prevent us from plugging in multiple walkers during the processing of an AST, each performing a distinct phase of the processing.



An Interpreter for Cuppa1



An Interpreter for Cuppa1

cuppa1_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,
    '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
}
```

An Interpreter for Cuppa1

cuppa1_interp_walk.py

```
def assign_stmt(node):

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

    value = walk(exp)
    state.symbol_table[name] = value
```

```
def seq(node):

    (SEQ, stmt, stmt_list) = node
    assert_match(SEQ, 'seq')

    walk(stmt)
    walk(stmt_list)
```

```
def while_stmt(node):

    (WHILE, cond, body) = node
    assert_match(WHILE, 'while')

    value = walk(cond)
    while value != 0:
        walk(body)
        value = walk(cond)
```

```
def if_stmt(node):

    try: # try the if-then pattern
        (IF, cond, then_stmt, (NIL,)) = node
        assert_match(IF, 'if')
        assert_match(NIL, 'nil')

    except ValueError: # if-then pattern didn't match
        (IF, cond, then_stmt, else_stmt) = node
        assert_match(IF, 'if')

        value = walk(cond)
        if value != 0:
            walk(then_stmt)
        else:
            walk(else_stmt)
        return

    else: # if-then pattern matched
        value = walk(cond)
        if value != 0:
            walk(then_stmt)
        return
```

```
def plus_exp(node):

    (PLUS,c1,c2) = node
    assert_match(PLUS, '+')

    v1 = walk(c1)
    v2 = walk(c2)

    return v1 + v2
```

An Interpreter for Cuppa1

```python
from argparse import ArgumentParser
from cuppa1_lex import lexer
from cuppa1_frontend_gram import parser
from cuppa1_state import state
from cuppa1_interp_walk import walk

def interp(input_stream):

    # initialize the state object
    state.initialize()

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

    # walk the AST
    walk(state.AST)

if __name__ == "__main__":
    # parse command line args
    aparser = ArgumentParser()
    aparser.add_argument('input')

    args = vars(aparser.parse_args())

    f = open(args['input'], 'r')
    input_stream = f.read()
    f.close()

    # execute interpreter
    interp(input_stream=input_stream)
```

cuppa1_interp.py

```
In [49]: interp("get x; x = x + 1; put x")

Value for x? 3
> 4

In [50]: from cuppa1_examples import *

In [51]: print(list)

// list of integers
get x
while (1 <= x)
{
    put x;
    x = x + - 1;
    i = x
}

In [52]: interp(list)

Value for x? 5
> 5
> 4
> 3
> 2
> 1
```

A Pretty Printer with a Twist

- Our pretty printer will do the following things:
  - It will read the Cuppa1 programs and construct an AST
  - It will compute whether a particular variable is used in the program
  - It will output a pretty printed version of the input script but <u>will flag assignment/get statements to variables which are not used in the program</u>

➔This cannot be accomplished in a syntax directed manner – therefore we need the AST

PrettyPrinting the Language

```
program : stmt_list

stmt_list : stmt stmt_list
          | empty

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

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
```

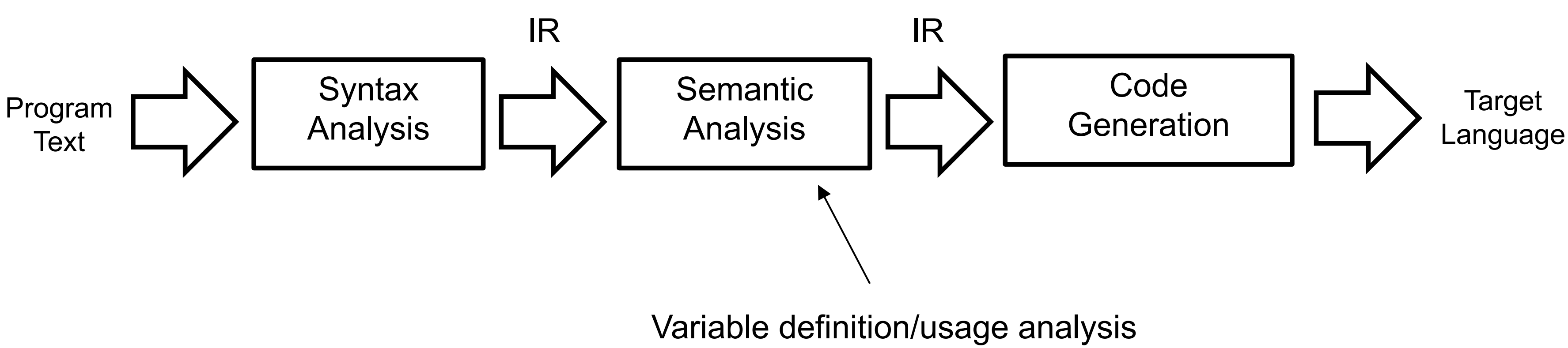
```
// list of integers
get x;
i = x;
while (1 <= x) {
      put x;
      x = x - 1;
}
```

```
get x
i = x  // -- var i unused --
while ( 1 <= x )
{
    put x
    x = x - 1
}
```

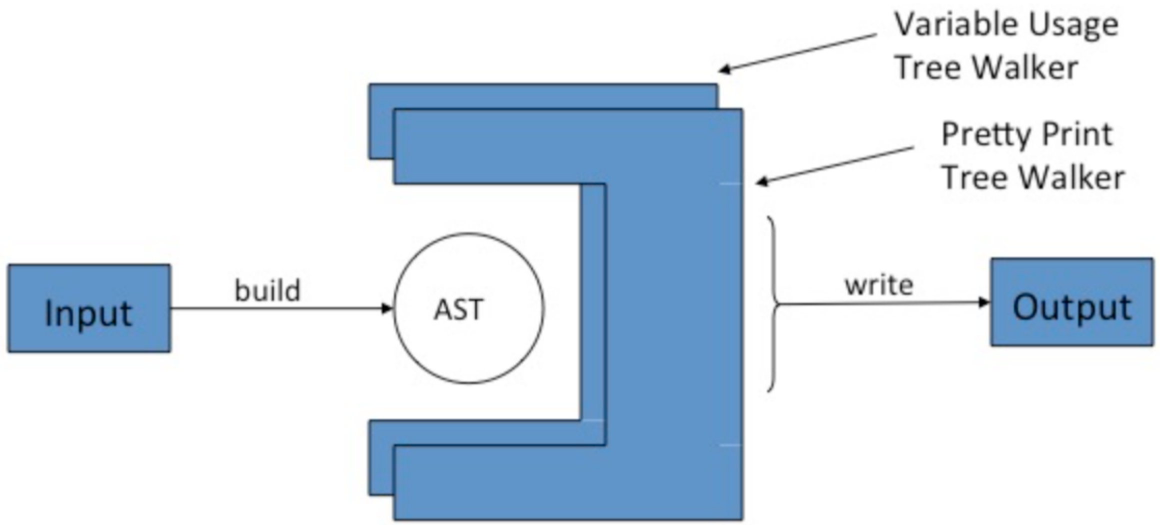
☞ We need an IR because usage will always occur after definition – cannot be handled by a syntax directed pretty printer.

The Pretty Printer is a Translator!

- The Pretty Printer with a Twist fits neatly into our translator class
  - Read input file and construct AST/Collect info
  - Generate output code, flagging unused assignments



Pretty Printer Architecture



Frontend + 2 Tree Walkers

PP1: Variable Usage

- The first pass of the pretty printer walks the AST and looks for variables in expressions
  - only those count as usage points.
- A peek at the tree walker for the first pass,
  cuppa1_pp1_walk.py
  shows that it literally just walks the tree doing nothing until it finds a variable in an expression.
- If it finds a variable in an expression then the node function for id_exp marks the variable in the symbol table as used,

PP1: Variable Usage

```
def assign_stmt(node):

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

    walk(exp)
```

```
def while_stmt(node):

    (WHILE, cond, body) = node
    assert_match(WHILE, 'while')

    walk(cond)
    walk(body)
```

Just Walking the Tree!

```
def integer_exp(node):

    (INTEGER, value) = node
    assert_match(INTEGER, 'integer')
```

```
def binop_exp(node):

    (OP, c1, c2) = node
    if OP not in ['+', '-', '*', '/', '==', '<=']:
        raise ValueError("pattern match failed on " + OP)

    walk(c1)
    walk(c2)
```

PP1: Variable Usage

But…

```
def id_exp(node):

    (ID, name) = node
    assert_match(ID, 'id')

    # we found a use scenario of a variable, if the variable is defined
    # set it to true
    if name in state.symbol_table:
        state.symbol_table[name] = True
```

PP1: Variable Usage

- Recall that when the frontend finds a definition of a variable as an
  - assignment statement or a
  - get statement
- it enters the variable into the symbol table and initializes it with None.

```
def p_stmt(p):
    '''
    stmt : ID '=' exp opt_semi
         | GET ID opt_semi
         | PUT exp opt_semi
         | WHILE '(' exp ')' stmt
         | IF '(' exp ')' stmt opt_else
         | '{' stmt_list '}'
    '''
    if p[2] == '=':
        p[0] = ('assign', p[1], p[3])
        state.symbol_table[p[1]] = None
    elif p[1] == 'get':
        p[0] = ('get', p[2])
        state.symbol_table[p[2]] = None
    ...
```

PP1: Variable Usage

Testing the tree walker

```
In [86]: from cuppa1_frontend_gram import parser
         from cuppa1_lex import lexer
         from cuppa1_pp1_walk import walk as pp1_walk
         from cuppa1_state import state
         state.initialize()

In [87]: parser.parse("get x", lexer=lexer)

In [88]: pp1_walk(state.AST)

In [89]: state.symbol_table

Out[89]: {'x': None}
```

```
In [90]: state.initialize()

In [91]: parser.parse("get x; put x", lexer=lexer)

In [92]: pp1_walk(state.AST)

In [93]: state.symbol_table

Out[93]: {'x': True}
```

PP2: Pretty Print Tree Walker

- The tree walker for the second pass walks the AST and compiles a formatted string that represents the pretty printed program.

```
def seq(node):

    (SEQ, s1, s2) = node
    assert_match(SEQ, 'seq')

    stmt = walk(s1)
    list = walk(s2)

    return stmt + list
```

Concatenate the string for stmt with the string from the rest of the Seq list.

Recall that programs are nil terminated Seq lists of statements:

```
('seq',
    <Stmt1>,
    ('seq',
        <Stmt2>,
        ('nil',)))
```

PP2: Pretty Print Tree Walker

```
def assign_stmt(node):

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

    exp_code = walk(exp)

    code = indent() + name + ' = ' + exp_code

    if not state.symbol_table[name]:
        code += ' // *** '+ name + ' is not used ***'

    code += '\n'
    return code
```

```
def binop_exp(node):

    (OP, c1, c2) = node
    if OP not in ['+', '-', '*', '/', '==', '<=']:
        raise ValueError("pattern match failed on " + OP)

    lcode = walk(c1)
    rcode = walk(c2)

    code = lcode + ' ' + OP + ' ' + rcode

    return code
```

```
def while_stmt(node):
    global indent_level

    (WHILE, cond, body) = node
    assert_match(WHILE, 'while')

    cond_code = walk(cond)

    indent_level += 1
    body_code = walk(body)
    indent_level -= 1

    code = indent() + 'while (' + cond_code + ')\n' + body_code

    return code
```

Indent() and indent_level keep track of the code indentation for formatting purposes.

Top Level Function of PP

```
#!/usr/bin/env python
# Cuppa1 pretty printer

from sys import stdin
from cuppa1_frontend_gram import parser
from cuppa1_lex import lexer
from cuppa1_state import state
from cuppa1_pp1_walk import walk as pp1_walk
from cuppa1_pp2_walk import walk as pp2_walk
from cuppa1_pp2_walk import init_indent_level

def pp(input_stream = None):

    # if no input stream was given read from stdin
    if not input_stream:
        input_stream = stdin.read()

    # initialize the state object and indent level
    state.initialize()
    init_indent_level()

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

    # walk the AST
    pp1_walk(state.AST)
    code = pp2_walk(state.AST)

    # output the pretty printed code
    print(code)

if __name__ == "__main__":
    # execute only if run as a script
    pp()
```

Top level function

The Cuppa1 PP

Testing the pretty printer

```
In [79]: from cuppa1_pp import pp

In [80]: pp("get x; while (1 <= x) { put x; x = x + - 1; i = x }")
get x
while (1 <= x)
{
    put x
    x = x + -1
    i = x // *** i is not used ***
}
```

Assignment

- Assignment #5 – see webpage.