An Optimizing Compiler

- The big difference between interpreters and compilers is that compilers have the ability to think about how to translate a source program into target code in the most effective way.
- Usually that means trying to translate the program in such a way that it executes as fast as possible on the target machine.
- This usually implies either one or both of the following tasks:
  - Rewrite the AST so that it represents a more efficient program – Tree Rewriting
  - Reorganize the generated instructions so that they represent the most efficient target program possible
- This is referred to as *Optimization*.
- There are many optimization techniques available to compilers in addition to the two mentioned above:
  - Register allocation, loop optimization, common subexpression elimination, dead code elimination, *etc*

An Optimizing Compiler

- In our optimizing compiler we study:
  - Tree rewriting in the context of *constant folding,* and
  - Target code optimization in the context of *peephole optimization*.

Tree Rewriting

- So far our applications only have looked at the AST as an immutable data structure
  - Bytecode interpreter used it to execute instructions
  - The Cuppa1 interpreter used it as an abstract representation of the original program
  - PrettyPrinter used it to regenerate programs
- But there are many cases where we actually want to transform the AST
  - Consider constant folding

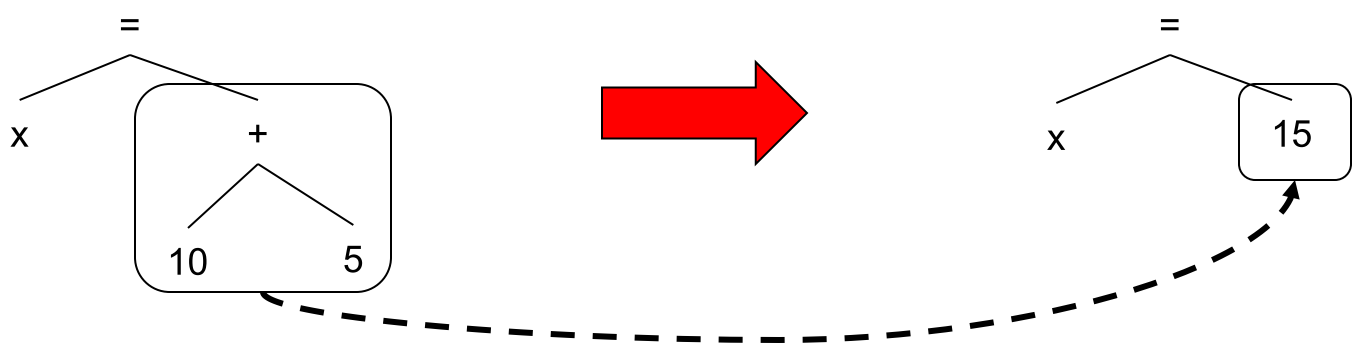
Constant Folding

- Constant folding is an optimization that tries to find arithmetic operations in the source program that can be performed at *compile time* rather than runtime.

Constant Folding

- In constant folding we look at the operations in arithmetic expressions and if the operands are constants then we perform the operation and replace the AST with a result node.

x = 10 + 5 $\rightarrow$ x = 15



Constant Folding

- One way to view constant folding is as a AST rewriting.
- Here the AST for the expression 10 + 5 is replaced by an AST node for the constant 15.
- In order to accomplish this we need to walk the AST for a Cuppa1 program and look for patterns that allow us to rewrite the tree.
- This is very similar to code generation tree walker where we walked the tree and looked for AST patterns that we could translate into Exp1bytecode.
- The big difference being that in the constant folder we will be *returning the rewritten tree from the tree walker* rather than bytecode as in the code generator.

Constant Folding

Consider:

cuppa1_cc_fold.py

```
In [45]: from grammar_stuff import assert_match, dump_AST
         from cuppa1_cc_fold import *

In [46]: # %load -s plus_exp code/cuppa1_cc_fold.py
         def plus_exp(node):

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

             ltree = walk(c1)
             rtree = walk(c2)

             # if the children are constants -- fold!
             if ltree[0] == 'integer' and rtree[0] == 'integer':
                 return ('integer', ltree[1] + rtree[1])

             else:
                 return ('+', ltree, rtree)
```

```
In [47]: plus_node = ('+', ('integer', 10), ('integer', 1))
         dump_AST(plus_node)

         (+
           |(integer 10)
           |(integer 1))

In [48]: plus_exp(plus_node)

Out[48]: ('integer', 11)
```

Constant Folding

Consider:

```
# %load -s eq_exp code/cuppa1_cc_fold.py
def eq_exp(node):

    (OP, c1, c2) = node
    assert_match(OP, '==')

    ltree = walk(c1)
    rtree = walk(c2)

    # if the children are constants -- fold!
    if ltree[0] == 'integer' and rtree[0] == 'integer':
        return ('integer', 1 if ltree[1] == rtree[1] else 0)

    else:
        return ('==', ltree, rtree)
```

cuppa1_cc_fold.py

```
def assign_stmt(node):

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

    exp_tree = walk(exp)

    return ('assign', name, exp_tree)
```

```
def seq(node):

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

    stmt_tree = walk(s1)
    list_tree = walk(s2)

    return ('seq', stmt_tree, list_tree)
```

Constant Folding

Consider:

cuppa1_cc_fold.py

```
#########################################################################
# walk
#########################################################################
def walk(node):
    node_type = node[0]

    if node_type in dispatch_dict:
        node_function = dispatch_dict[node_type]
        return node_function(node)

    else:
        raise ValueError("walk: unknown tree node type: " + node_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,
    'uminus'  : uminus_exp,
    'not'     : not_exp,
    'paren'   : paren_exp,
    '+'       : plus_exp,
    '-'       : minus_exp,
    '*'       : mult_exp,
    '/'       : div_exp,
    '=='      : eq_exp,
    '<='      : le_exp

}
```

Constant Folding

Let's try our walker on our assignment statement example to see if it does what we claim it does,

In [50]:
```
stmt = ('assign', 'x', ('+', ('integer', 10), ('integer', 5)))
dump_AST(stmt)
```

```
(assign x
  |(+
  |  |(integer 10)
  |  |(integer 5)))
```

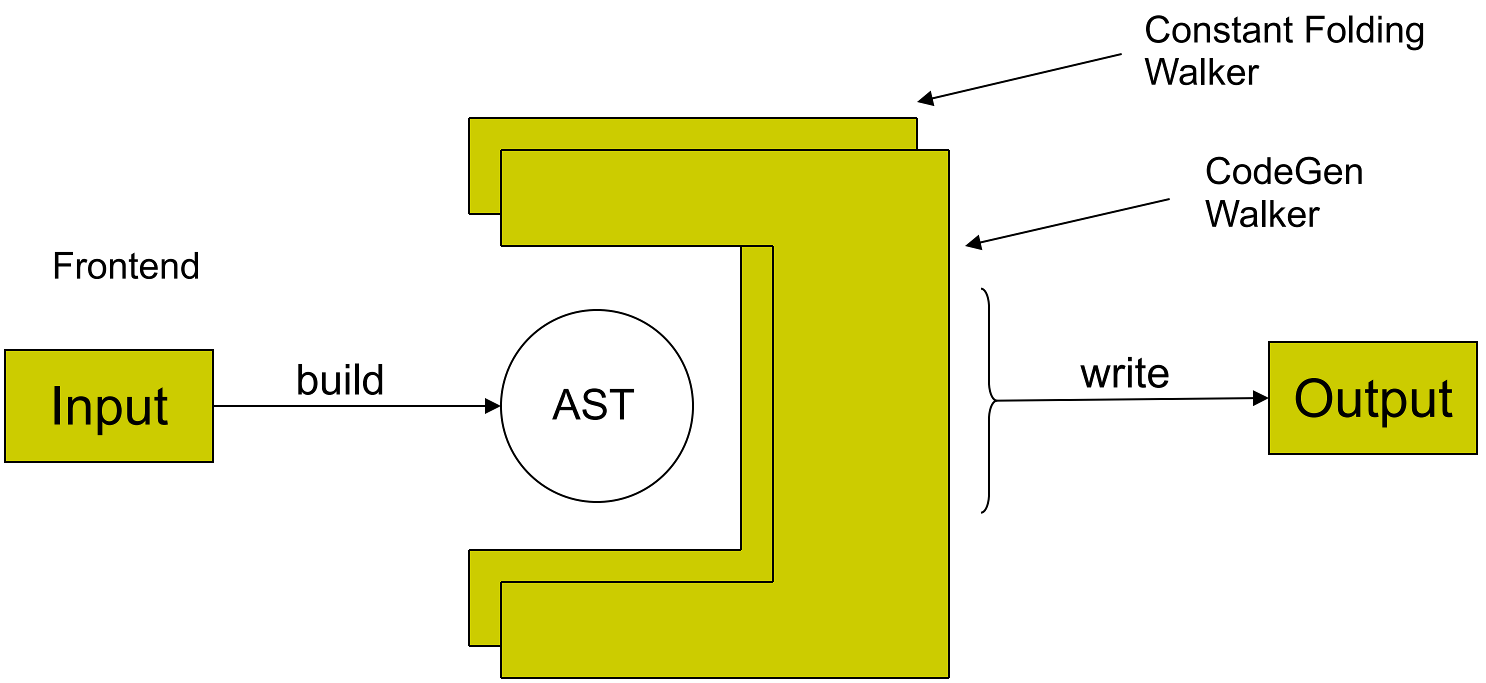
In [51]:
```
from cuppa1_cc_fold import walk as fold
```

In [52]:
```
new_stmt = fold(stmt)
dump_AST(new_stmt)
```

```
(assign x
  |(integer 15))
```

Compiler Architecture

- As an example we insert a constant folding tree rewriting phase into our Cuppa1 compiler as a tree walker.



Peephole Code Optimization

- A peephole optimizer improves the generated code by reorganizing the generated instructions.
- If you recall the code generator for our Cuppa1 compiler translates Cuppa1 AST patterns into Exp1bytecode patterns and simply composes the generated bytecode patterns into a list of instructions.
- That can lead to very silly looking code.

Peephole Code Optimization

Consider:

```
In [53]: from cuppa1_examples import fact

In [54]: print(fact)

         get x;
         y = 1;
         while (1 <= x)
         {
               y = y * x;
               x = x - 1;
         }
         put y;
```

```
In [55]: bytecode = cc1(fact)

In [56]: print(bytecode)
                   input x ;
                   store y 1 ;
         L13:
                   jumpF (<= 1 x) L14 ;
                   store y (* y x) ;
                   store x (- x 1) ;
                   jump L13 ;
         L14:
                   noop ;
                   print y ;
                   stop ;
```

Really Silly!

Peephole Code Optimization

```
In [55]: bytecode = cc1(fact)

In [56]: print(bytecode)
                input x ;
                store y 1 ;
         L13:
                jumpF (<= 1 x) L14 ;
                store y (* y x) ;
                store x (- x 1) ;
                jump L13 ;
         L14:
                noop ;
                print y ;
                stop ;
```

```
In [57]: new_bytecode = \
         '''
             input x ;
             store y 1 ;
         L13:
             jumpF (<= 1 x) L14 ;
             store y (* y x) ;
             store x (- x 1) ;
             jump L13 ;
         L14:
             print y ;
             stop ;
         '''
```

There is a rule for that:

```
L:
    noop
    <other instruction>

=>

L:
    <other instruction>
```

Peephole Code Optimization

Consider:

```
In [58]: print_even = \
'''
get x
r = x - 2*(x/2)
if (not r)
  if (x <= 10)
    put x
'''
```

```
In [60]: bytecode = cc1(print_even)

In [61]: print(bytecode)
        input x ;
        store r (- x (* 2 (/ x 2))) ;
        jumpF !r L15 ;
        jumpF (<= x 10) L16 ;
        print x ;
L16:
        noop ;
L15:
        noop ;
        stop ;
```

Even Sillier!

Peephole Code Optimization

```
In [60]: bytecode = cc1(print_even)

In [61]: print(bytecode)
                   input x ;
                   store r (- x (* 2 (/ x 2))) ;
                   jumpF !r L15 ;
                   jumpF (<= x 10) L16 ;
                   print x ;
         L16:
                   noop ;
         L15:
                   noop ;
                   stop ;
```

There is a rule for that:

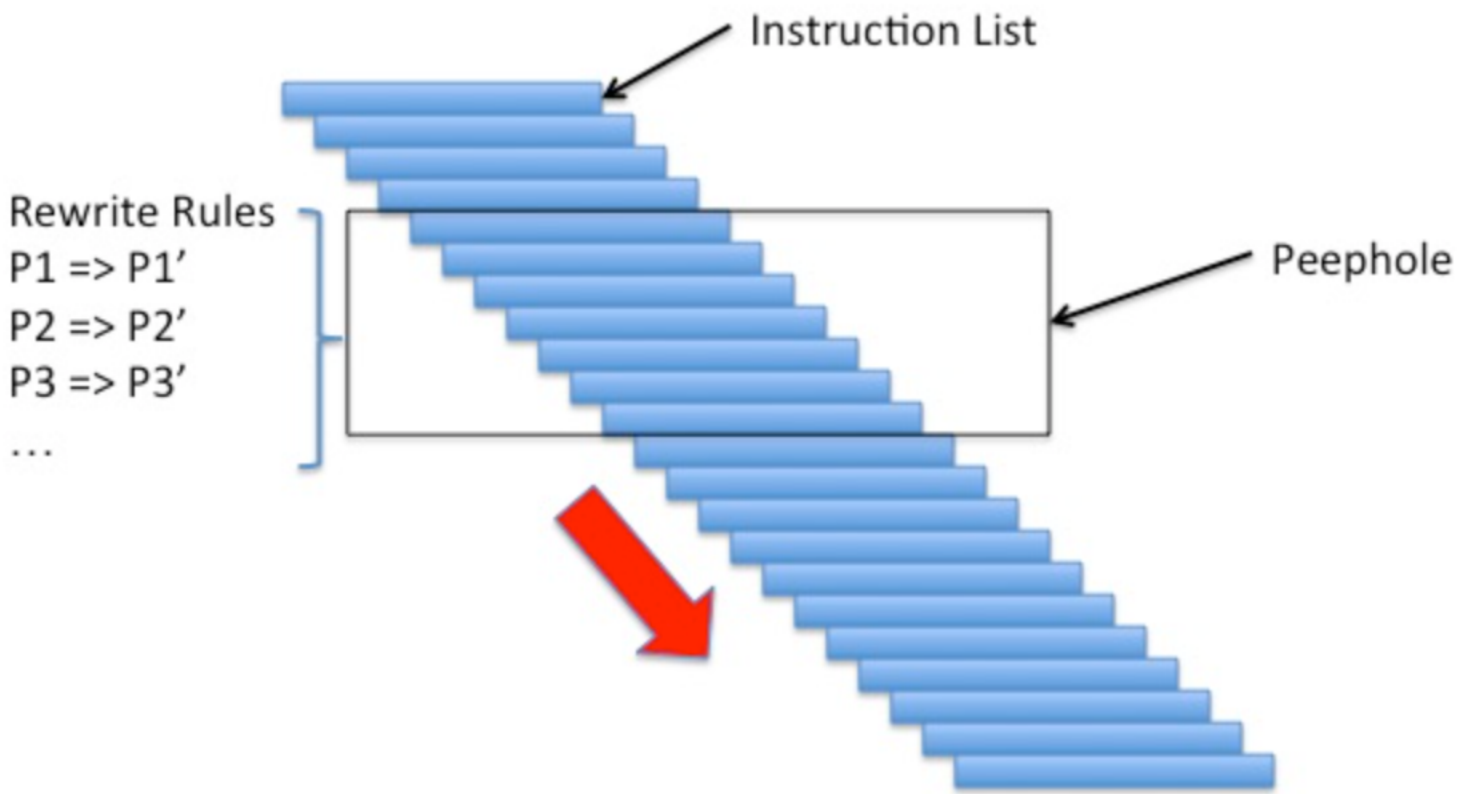
```
L1:
     noop
L2:
     <other instruction>
=>


L2:   -- with L1 backpatched to L2
     <other instruction>
```

```
In [62]: new_bytecode = \
         '''
         input x ;
             store r (- x (* 2 (/ x 2))) ;
             jumpF !r L15 ;
             jumpF (<= x 10) L15 ;
             print x ;
         L15:
             stop ;
         '''
```

Peephole Code Optimization

- One way to think of a peephole optimizer is as a window (the peephole) which we slide across the generated instructions *repeatedly* and apply *rewrite rules* like the ones we developed above to the code within the window.
- The peephole optimizer terminates once no longer any code is being rewritten.
- The repeated nature of the process is necessary because applying one rewrite rule to the instruction list can expose opportunities to apply other rewrite rules.
- So we need to keep sliding the window across the instructions until no further rewrites are possible.

Peephole Code Optimization



Peephole Code Optimization

Rewrite Rules:

cuppa1_cc_output.py

```
# rewrite rule:
# *L:
#       noop
#       <some other instr>
# =>
# *L:
#       <some other instr>
if pattern_fits(3, ix, instr_stream) and \
   label_def(curr_instr) and \
   relative_instr(1, ix, instr_stream)[0] == 'noop' and \
   not label_def(relative_instr(2, ix, instr_stream)):
     # delete noop
     instr_stream.pop(ix+1)
     change = True
```

```
# rewrite rule:
# *L1:
#    noop
#  L2:
# =>
# *L2:  -- with L1 backpatched to L2 in instr_stream
elif pattern_fits(3, ix, instr_stream) and \
     label_def(curr_instr) and \
     relative_instr(1, ix, instr_stream)[0] == 'noop' and \
     label_def(relative_instr(2, ix, instr_stream)):
    label1 = get_label_from_def(curr_instr)
    label2 = get_label_from_def(relative_instr(2, ix, instr_stream))
    backpatch_label(label1, label2, instr_stream)
    instr_stream.pop(ix)
    instr_stream.pop(ix)
    change = True
```

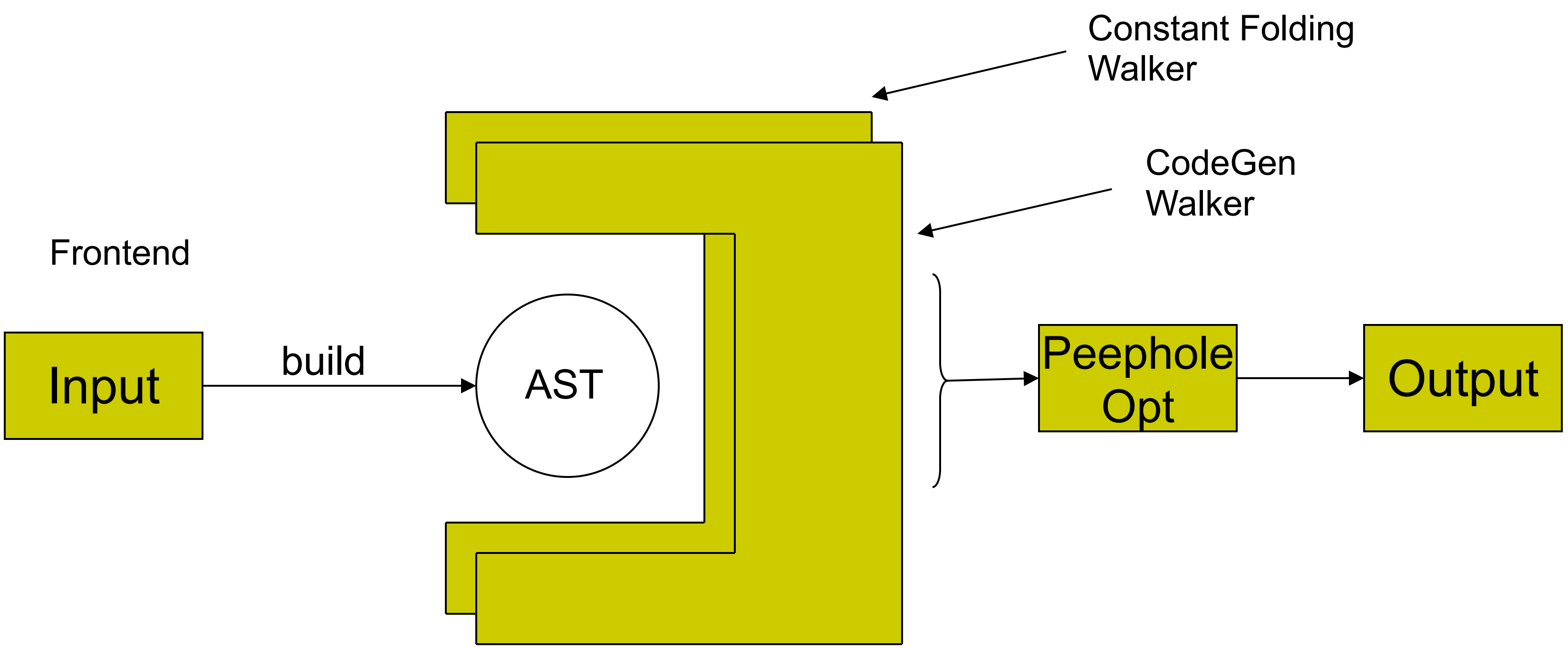
Peephole Code Optimization

```
########################################################################
# apply peephole optimization.  The instruction tuple format is:
#   (instr_name_str, [param_str1, param_str2, ...])
def peephole_opt(instr_stream):

  ix = 0
    change = False

    while(True):

        curr_instr = instr_stream[ix]

        ### compute some useful predicates on the current instruction
        is_first_instr = ix == 0
        is_last_instr = ix+1 == len(instr_stream)
        has_label = True if not is_first_instr and label_def(instr_stream[ix-1]) else False

<** rewrite rules here **>

        ### advance ix
        if is_last_instr and not change:
            break

        elif is_last_instr:
            ix = 0
            change = False

        else:
            ix += 1
```

cuppa1_cc_output.py

Optimizing Compiler Architecture

- We insert our peephole optimizer between the code generator and the output phase



Optimizing Compiler

Top-level Driver Function

```
from cuppa1_lex import lexer
from cuppa1_frontend_gram import parser
from cuppa1_state import state
from cuppa1_cc_codegen import walk as codegen
from cuppa1_cc_fold import walk as fold
from cuppa1_cc_output import output
from cuppa1_cc_output import peephole_opt

def cc(input_stream, opt = False):

    # initialize the state object
    state.initialize()

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

    # run the constant fold optimizer
    if opt:
        state.AST = fold(state.AST)

    # generate the list of instruction tuples
    instr_stream = codegen(state.AST) + [('stop',)]

    # run the peephole optimizer
    if opt:
        peephole_opt(instr_stream)

    # output the instruction stream
    bytecode = output(instr_stream)

    return bytecode
```

cuppa1_cc.py