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

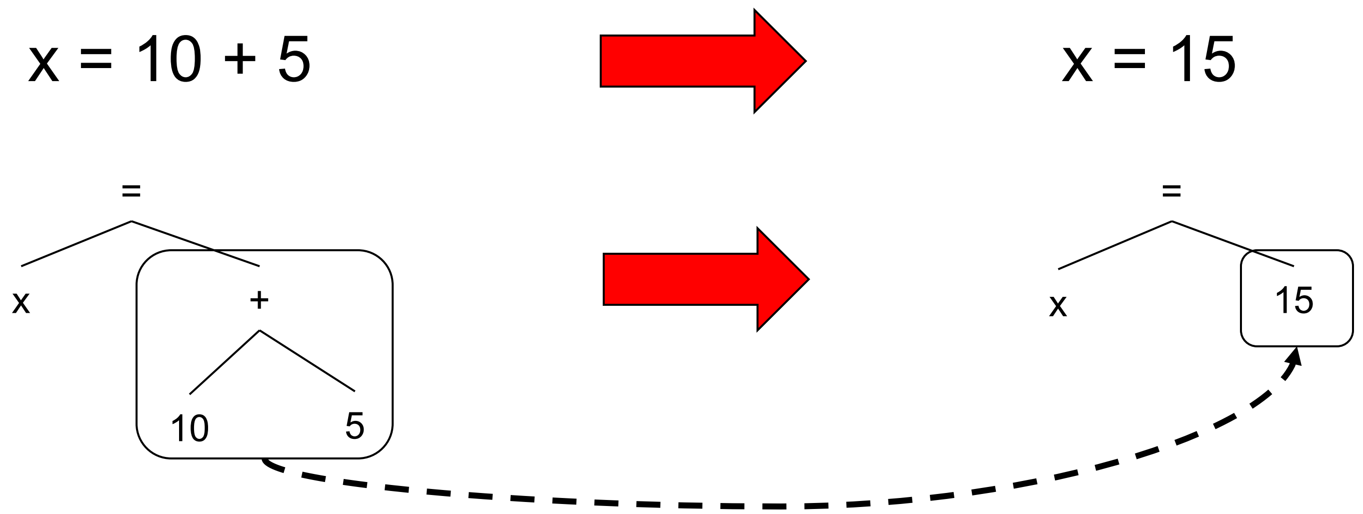
- So far our applications only have looked at the AST as an immutable data structure
  - Bytecode interpreter used it to execute instructions
  - The Cuppa1 interpreter used it as an abstract representation of the original program
  - PrettyPrinter used it to regenerate programs
- But there are many 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.



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.

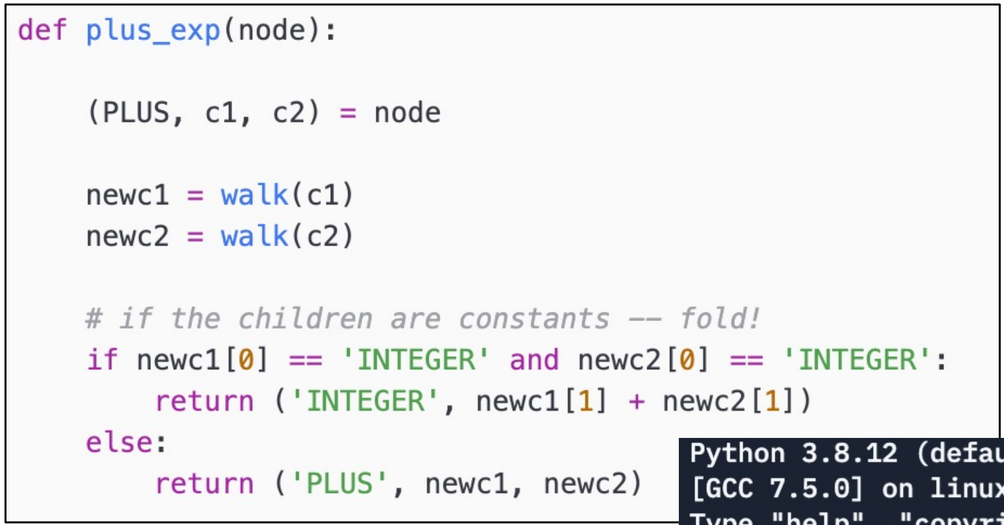
Constant Folding Walker

```python
def walk(node):
    node_type = node[0]
    if node_type in dispatch:
        node_function = dispatch[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 = {
    'STMTLIST'  : stmtlst,
    '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'      : plus_exp,
    'MINUS'     : minus_exp,
    'MUL'       : mult_exp,
    'DIV'       : div_exp,
    'EQ'        : eq_exp,
    'LE'        : le_exp,
}
```

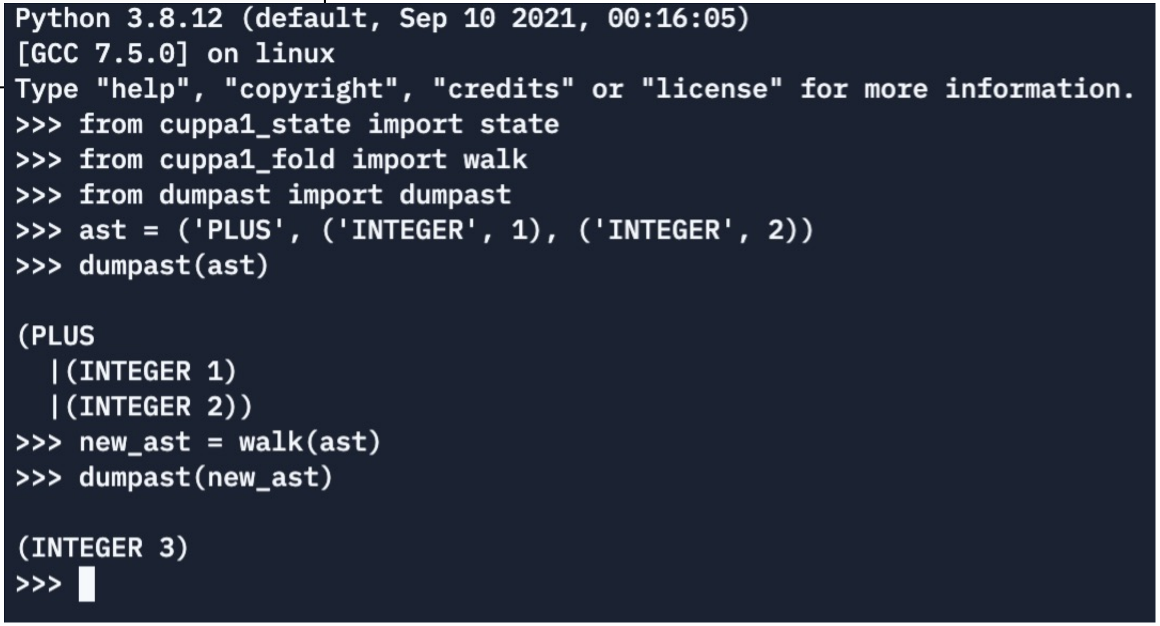
cuppa1_fold.py

Constant Folding Walker

cuppa1_fold.py



```python
def plus_exp(node):

    (PLUS, c1, c2) = node

    newc1 = walk(c1)
    newc2 = walk(c2)

    # if the children are constants -- fold!
    if newc1[0] == 'INTEGER' and newc2[0] == 'INTEGER':
        return ('INTEGER', newc1[1] + newc2[1])
    else:
        return ('PLUS', newc1, newc2)
```



```
Python 3.8.12 (default, Sep 10 2021, 00:16:05)
[GCC 7.5.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>> from cuppa1_state import state
>>> from cuppa1_fold import walk
>>> from dumpast import dumpast
>>> ast = ('PLUS', ('INTEGER', 1), ('INTEGER', 2))
>>> dumpast(ast)

(PLUS
  |(INTEGER 1)
  |(INTEGER 2))
>>> new_ast = walk(ast)
>>> dumpast(new_ast)

(INTEGER 3)
>>> 
```

Constant Folding Walker

```
def eq_exp(node):

    (EQ, c1, c2) = node

    newc1 = walk(c1)
    newc2 = walk(c2)

    # if the children are constants -- fold!
    if newc1[0] == 'INTEGER' and newc2[0] == 'INTEGER':
        return ('INTEGER', 1 if newc1[1] == newc2[1] else 0)
    else:
        return ('EQ', newc1, newc2)
```

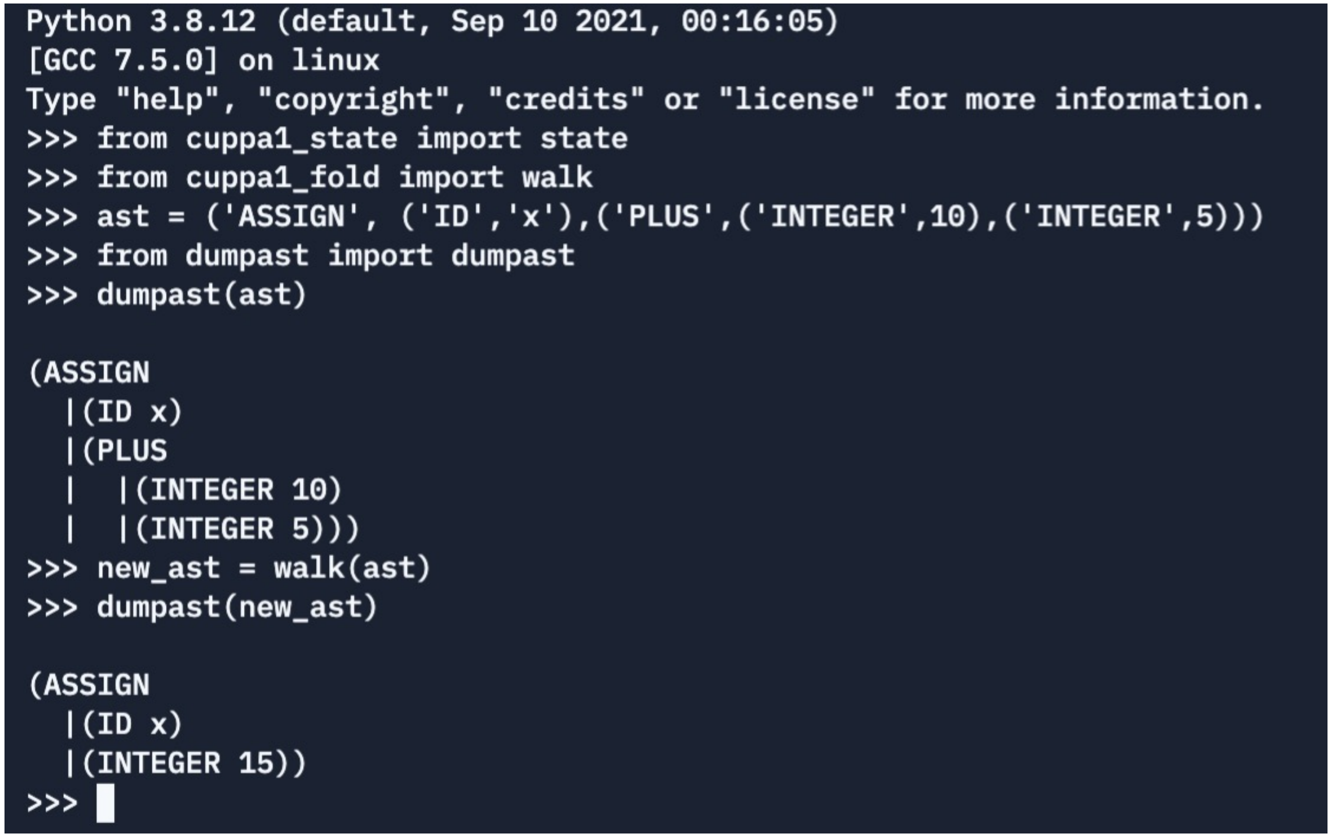
cuppa1_fold.py

```
def assign_stmt(node):

    (ASSIGN, name_tree, exp) = node

    newexp = walk(exp)

    return ('ASSIGN', name_tree, newexp)
```

```
def stmtlst(node):

    (STMTLIST, lst) = node

    newlst = []
    for stmt in lst:
        newlst.append(walk(stmt))
    return ('STMTLIST', newlst)
```

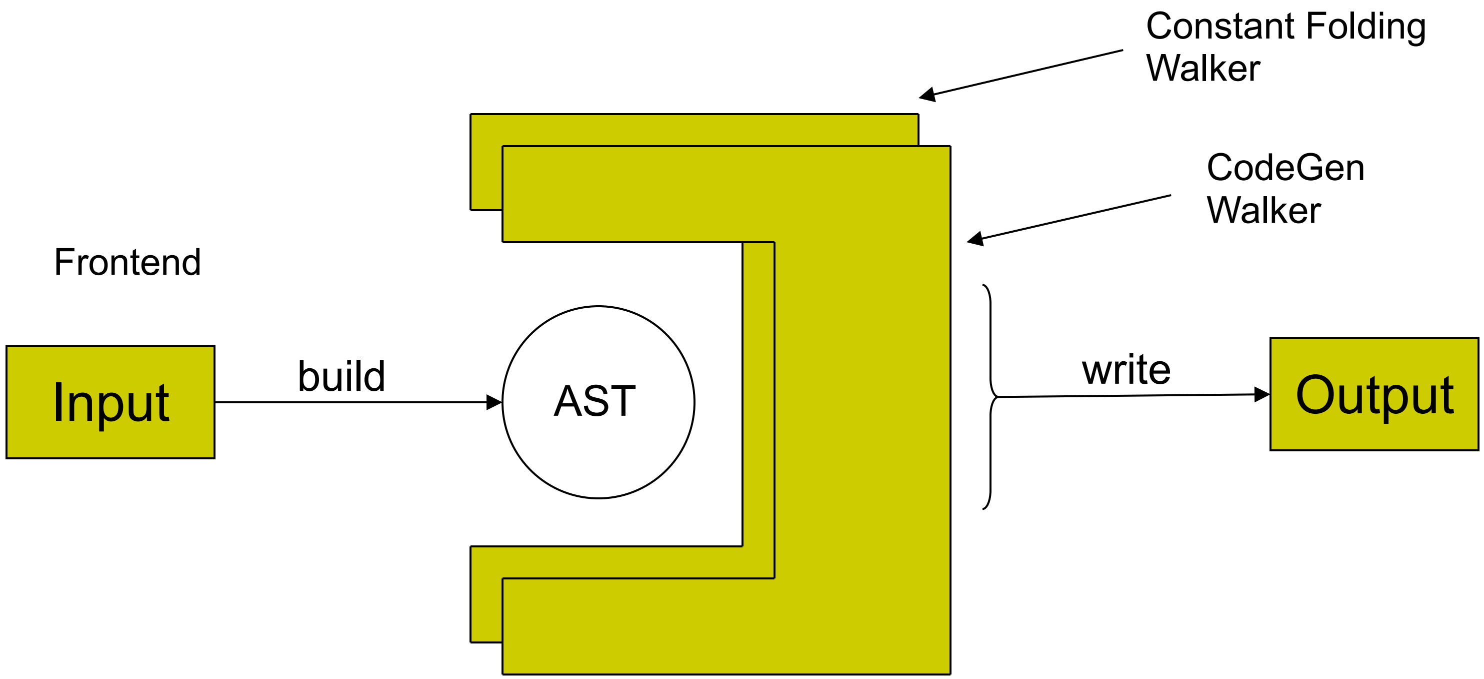
Constant Folding

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


```
Python 3.8.12 (default, Sep 10 2021, 00:16:05)
[GCC 7.5.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>> from cuppa1_state import state
>>> from cuppa1_fold import walk
>>> ast = ('ASSIGN', ('ID','x'),('PLUS',('INTEGER',10),('INTEGER',5)))
>>> from dumpast import dumpast
>>> dumpast(ast)

(ASSIGN
  |(ID x)
  |(PLUS
  |   |(INTEGER 10)
  |   |(INTEGER 5)))
>>> new_ast = walk(ast)
>>> dumpast(new_ast)

(ASSIGN
  |(ID x)
  |(INTEGER 15))
>>> 
```

Compiler Architecture

- We insert our 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:

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

```
          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

```
          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 ;
```

```
     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:

```
get x
r = x - 2*(x/2)
if (not r)
  if (x <= 10)
    put x
...
```

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

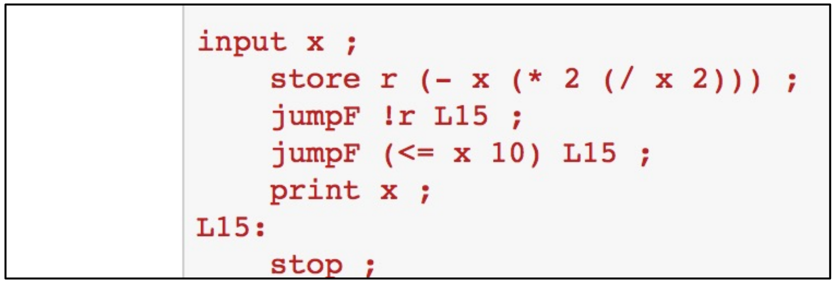
Even Sillier!

Peephole Code Optimization

There is a rule for that:

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


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

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

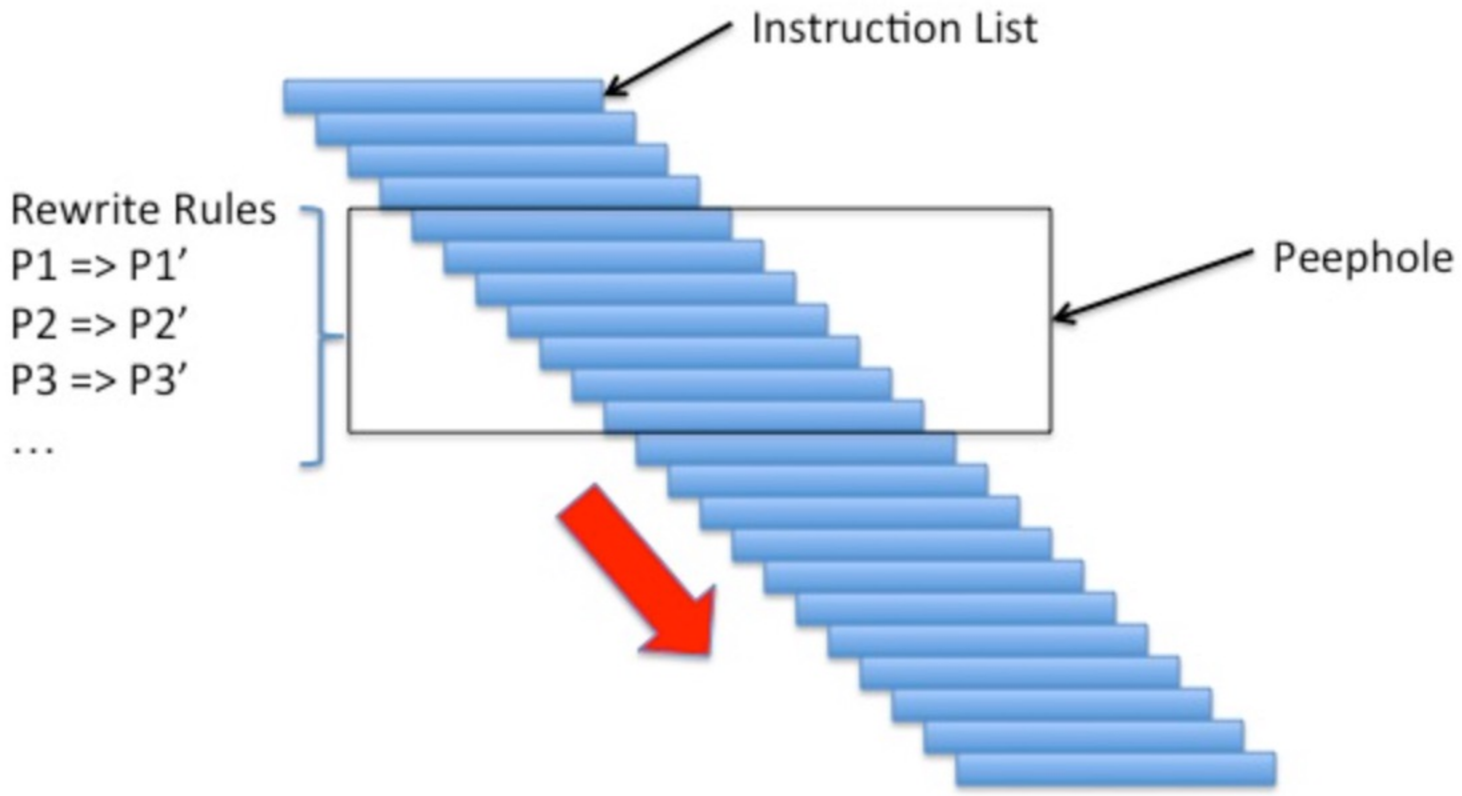


```
input x ;
    store r (- x (* 2 (/ x 2))) ;
    jumpF !r L15 ;
    jumpF (<= x 10) L15 ;
    print x ;
L15:
    stop ;
```

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.

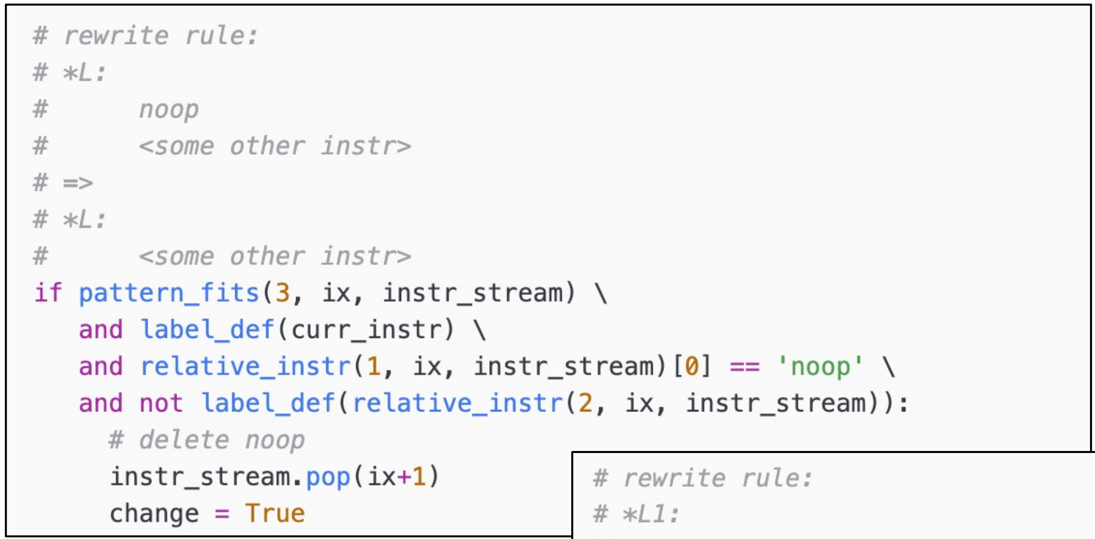
Peephole Code Optimization



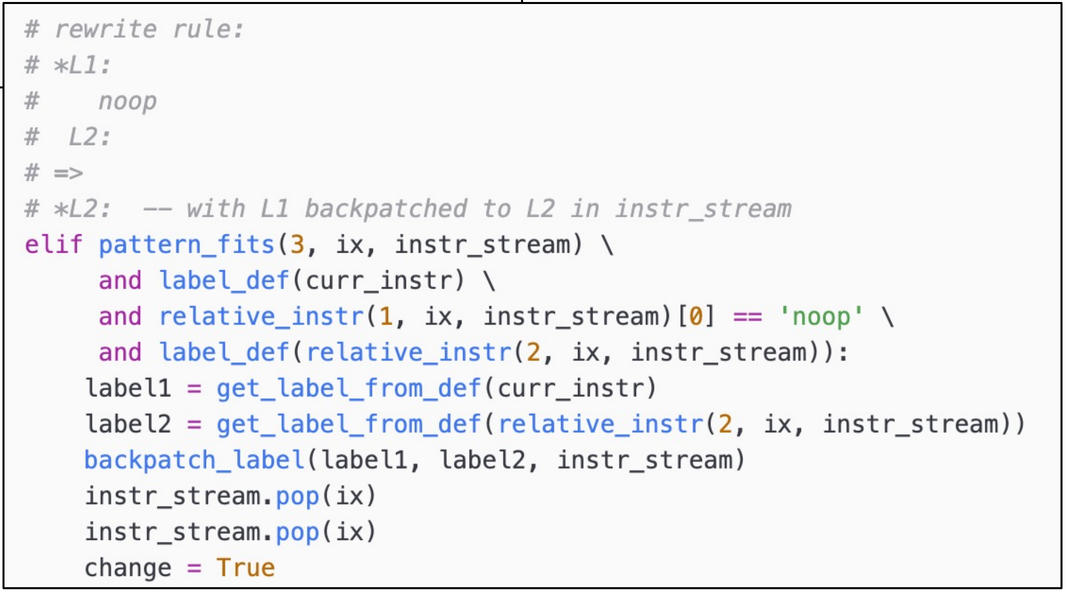
Peephole Code Optimization

Rewrite Rules:

cuppa1_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
```

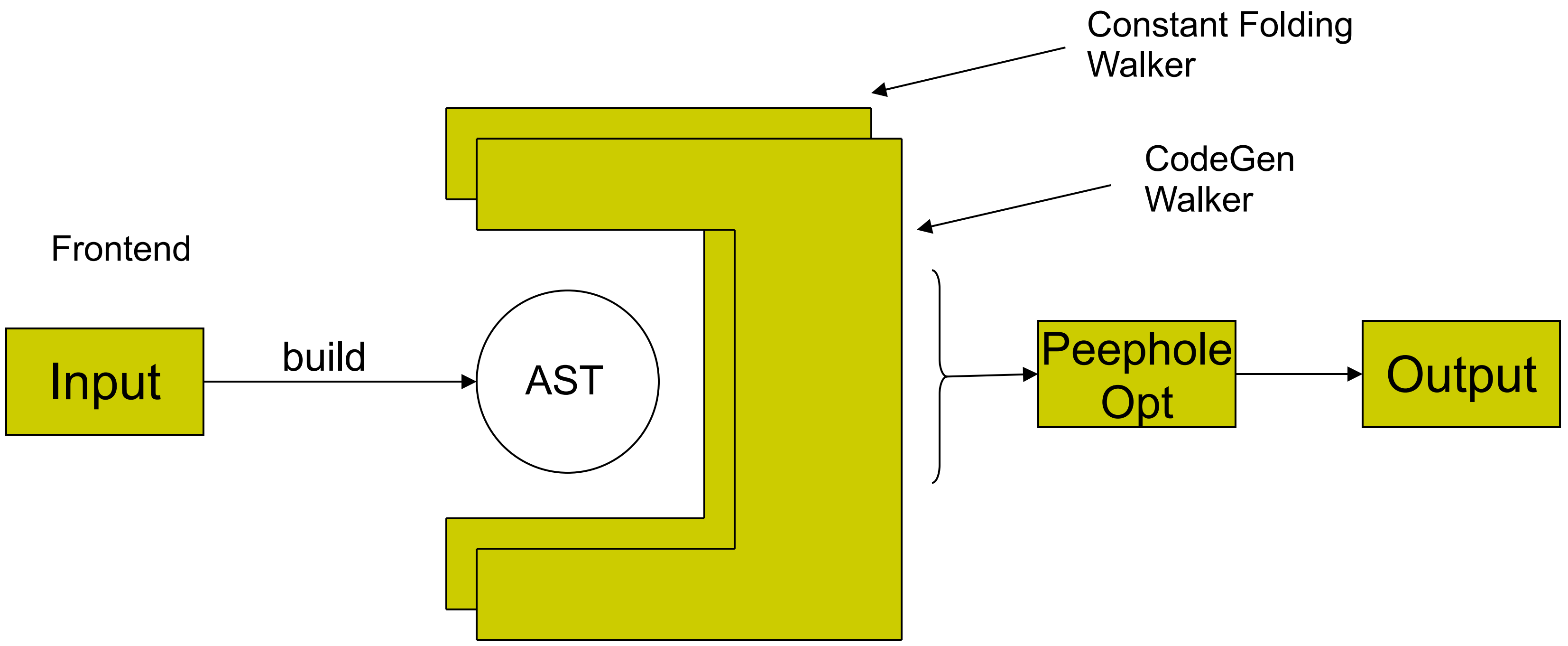
Peephole Code Optimization

```
#########################################################################
# 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_output.py

Optimizing Compiler Architecture

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



Optimizing Compiler

Top-level Driver Function

cuppa1_cc.py

```
from argparse import ArgumentParser
from cuppa1_fe import parse
from cuppa1_codegen import walk as codegen
from cuppa1_fold import walk as fold
from cuppa1_output import output
from cuppa1_output import peephole_opt

def cc(input_stream, opt = False):
    try:
        ast = parse(input_stream)
        if opt:
            ast = fold(ast) # constant fold optimizer
        instr_stream = codegen(ast) + [('stop',)]
        if opt:
            peephole_opt(instr_stream) # peephole optimizer
        bytecode = output(instr_stream)
        return bytecode
    except Exception as e:
        print('error: ' + str(e))
        return None
```

Testing the Compiler

```
$ cat even.txt
get x
r = x - 2*(x/2) // integer division!
if (not r)
  if (x =< 10)
    put x

$ python3 cuppa1_cc.py -O -o even.bc even.txt
$ cat even.bc
  input x ;
  store r - x * 2 / x 2 ;
  jumpf !r L1 ;
  jumpf =< x 10 L1 ;
  print x ;
L1:
  stop ;
$
```