

CSC2/455 Software Analysis and Improvement Intermediate Representations (IRs)

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URCS

January 23, 2019

Outline

Introduction

Midend

Miscellaneous

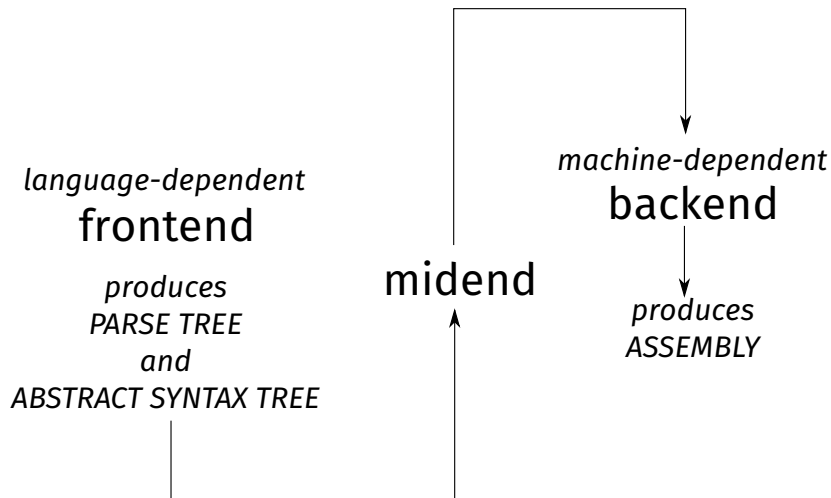
Outline

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Miscellaneous

Classic Compiler Architecture



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What does the midend do?

- ▶ Mostly language and machine independent analyses
- ▶ Majority of analyses run in this stage
- ▶ Multiple *intermediate representations* used
 - ▶ Starts from abstract syntax tree
 - ▶ Usually stops before instruction scheduling/register allocation
 - ▶ Examples: AST, CFG, DDG, PDG, etc.
- ▶ There is no *one* Intermediate Representation
 - ▶ although people have tried ...

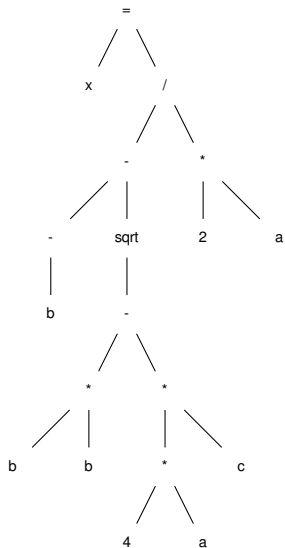
Running example

$$x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

In Python (assume `math.sqrt` is `sqrt`):

```
x = (-b - sqrt(b*b - 4 * a * c)) / (2*a)
```

Abstract Syntax Tree



AST as a list

```
ast = ['=',  
      ['x',  
       ['/',  
        ['-',  
         ['neg', 'b'],  
         ['sqrt',  
          ['-',  
           ['*', 'b', 'b'],  
           ['*',  
            ['*', '4', 'a'],  
            'c']  
          ]  
        ]  
       ]  
      ],  
      ['*', '2', 'a']  
     ]  
    ]
```

- ▶ What does this remind you of?

Slightly less LISPy

```
class Node(object):  
    operator = None  
    left = None  
    right = None
```

- ▶ Actual ASTs are not binary trees!
 - ▶ Will usually have list of descendants instead of left and right
 - ▶ descendants may be more specific, while may have condition and body

Linear Forms

- ▶ ASTs imply treewalking
 - ▶ Works best when manipulating source code
- ▶ Need lower level form “closer to machine”
 - ▶ Stack machines
 - ▶ 3 address code

Stack Machine

```
push b
push b
mul
push 4
push a
mul
push c
mul
sub
call sqrt
push b
neg
sub
push 2
push a
mul
div
pop x
```

Stack machines

- ▶ Compact in size
- ▶ Easy to execute
- ▶ BUT, fixed order of execution
 - ▶ Bad for parallelism
- ▶ Hard to analyze
- ▶ Nevertheless, widely used:
 - ▶ Java bytecode
 - ▶ WebAssembly

3 address code

- ▶ 3 “addresses”
 - ▶ Two source operands
 - ▶ One destination operand
- ▶ Addresses are actually *names* generated by compiler

Our example in 3 address code

Assume machine is not a strict load/store architecture:

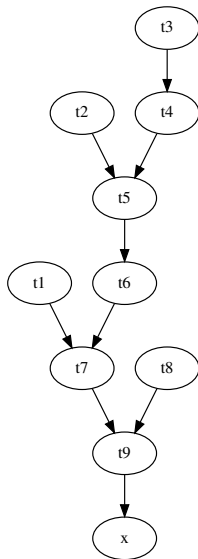
```
t1 ← -b  
  
t2 ← b * b  
t3 ← 4 * a  
t4 ← t3 * c  
t5 ← t2 - t4  
t6 ← sqrt(t5)  
  
t7 ← t1 - t6  
t8 ← 2 * a  
t9 ← t7 / t8  
  
x ← t9
```

(Here ' \leftarrow ' is \leftarrow , signifying assignment)

How do we produce stack machine code and 3 address code from the AST?

Data Dependence Graphs (DDGs)

- ▶ DDGs track “data flow” as an acyclic graph
- ▶ Strict (partial) order in which operations must be performed
 - ▶ Can't use a value that has not been calculated yet!
- ▶ But multiple orders may be allowed!
 - ▶ Topological sort
- ▶ Will revisit DDGs when we discuss instruction scheduling

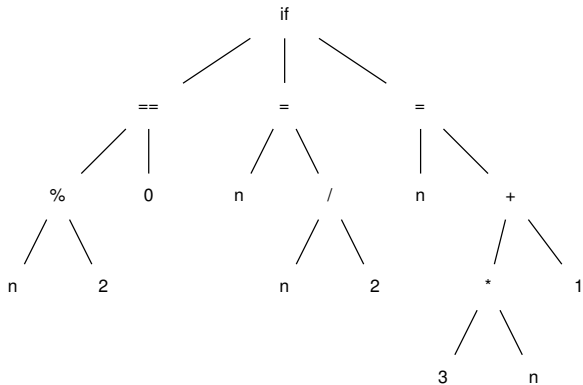


Control structures in 3 address code

What should the 3 address code for the code below look like?

```
if n % 2 == 0:  
    n = n / 2  
else:  
    n = 3 * n + 1
```

The AST for if



3 Address Code for if

```
t1 <- n % 2  
if (t1 != 0) goto L1
```

```
t2 <- n / 2  
n <- t2  
goto L2
```

L1:

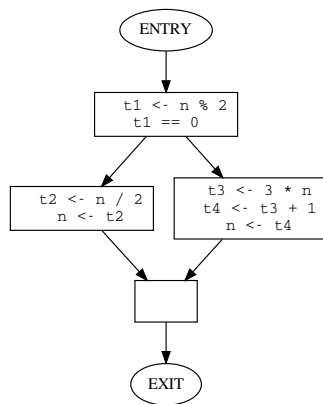
```
t3 <- 3 * n  
t4 <- t3 + 1  
n <- t4
```

L2:

- ▶ 3 address code can contain:
 - ▶ (simplified) conditional branches
 - ▶ unconditional branches

Control Flow Graphs (CFGs)

- ▶ “Hybrid” representation
 - ▶ Linear code + Graph structure
- ▶ Each node in the CFG is a “basic block”
 - ▶ Linear code
 - ▶ Single entry, single exit
 - ▶ “Straight-line code”
- ▶ Most common form for analysis



In this course

- ▶ We will write midend + some bits of a backend
- ▶ Input language: C
- ▶ Output language: C in 3 address form
 - ▶ Not assembly (maybe extra credit?)
- ▶ Using Python library `pyparser`

For assignments, make sure to review

- ▶ Basic data structures
 - ▶ lists
 - ▶ trees
 - ▶ graphs
- ▶ Basic data structure traversals
 - ▶ Infix, prefix, postfix
 - ▶ Depth-first, breadth-first
- ▶ And how to implement them in Python
 - ▶ Using Python standard libraries is fine

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Not-so-classic 'Compiler' Architectures

What is this code from TensorFlow doing?

```
a = tf.constant(2)
b = tf.constant(3)

with tf.Session() as sess:
    print("a=2, b=3")
    print("Addition with constants: %i" % sess.run(a+b))
    print("Multiplication with constants: %i" % sess.run(a*b))
```

https://github.com/aymericdamien/TensorFlow-Examples/blob/master/examples/1_Introduction/basic_operations.py

Metaprogramming

- ▶ TensorFlow API builds a graph
 - ▶ directed, acyclic
 - ▶ similar to the DDG
 - ▶ very common technique
- ▶ When `sess.run` is called, graph is compiled and executed
- ▶ Advantages:
 - ▶ No syntax, no parsing!
- ▶ Disadvantages:
 - ▶ ?

References

- ▶ Chapter 5 of Cooper and Turczon
 - ▶ Up to 5.4 in this lecture, but we will ultimately study the whole chapter
- ▶ (Optional) For a different perspective, Chapter 4 of Muchnick
 - ▶ Chapters 1–3 are essentially a recap of CSC 2/454