Automated Code Generation using Dynamic Programming Techniques

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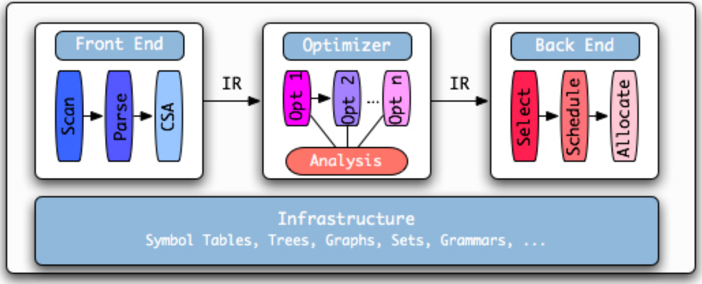
Outline

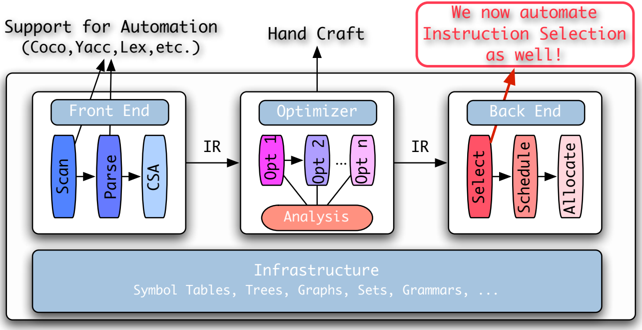
Why do we need Code Generation Tools?

- Writing a good compiler for a modern programming language is not easy...

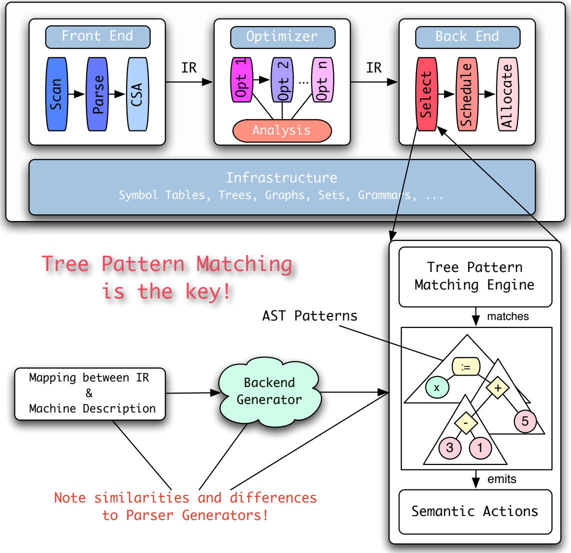


Tame Complexity through Automation!

- ...so we like to let tools figure out how to do the boringly mechanical parts, and only fill in the relevant bits and pieces.



Where and What is it good for?



What do we actually want to do?

- Given an IR in the form of an AST:
  - We **want** the following:
    - obviously we want to generate Machine Code
    - but the generated code should be optimal!
    - concentrate on the *essential* part of the problem, namely the task of generating code for AST trees and subtrees.
  - We **do not want**:
    - to clutter our code with boring tree traversals
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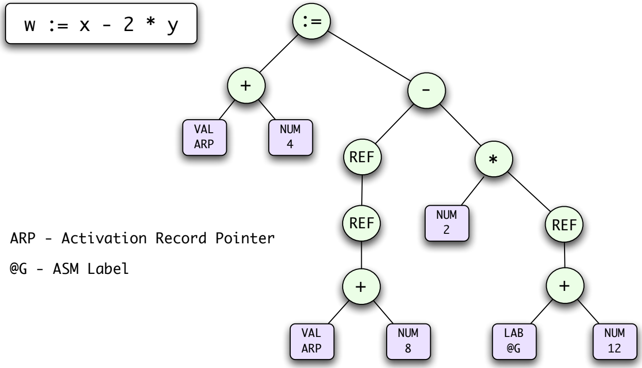
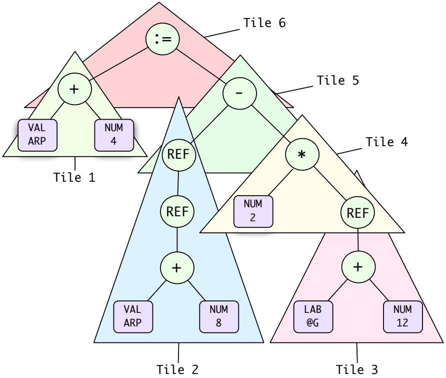
Code Generation Example

- Lets say we have an AST for the following operation and want to emit code for it:



- If we were to code this manually, we would probably do something like the following:



- Each tile corresponds to a sequence of operations
- If those operations are emitted in the appropriate order they *implement* the tree

So what's hard about this?

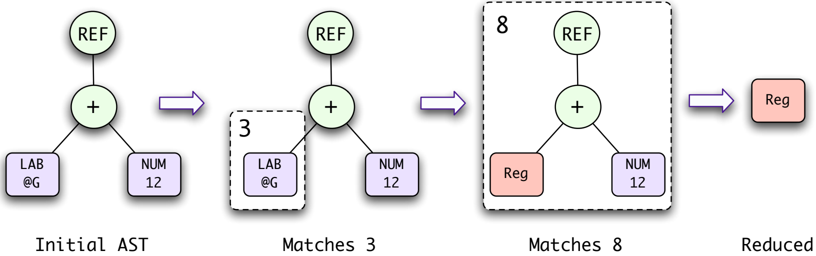
- Well, the hard part is to find the optimal set of tiles to tile the tree.
- In order to see why that is a problem we will *connect* tiles to AST subtrees by:
  - providing a set of **rewrite rules**
  - associate **code templates** with rewrite rules

Rewrite Rules with Code Templates for Abstract Syntax Tree

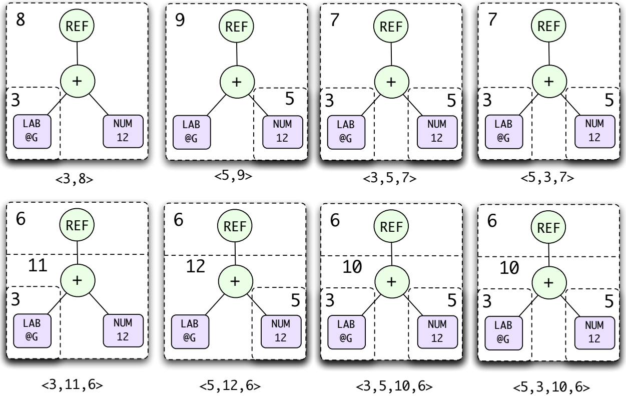
	Rewrite Rule	Code Template
1	$Goal \rightarrow Assign$	
2	$Assign \rightarrow \leftarrow(Reg_1, Reg_2)$	$store\ r_2 \rightarrow r_1$
3	$Reg \rightarrow LAB_1$	$loadI\ l_1 \rightarrow r_{new}$
4	$Reg \rightarrow VAL_1$	
5	$Reg \rightarrow NUM_1$	$load\ n_1 \rightarrow r_{new}$
6	$Reg \rightarrow REF(Reg_1)$	$load\ r_1 \rightarrow r_{new}$
7	$Reg \rightarrow REF(+(Reg_1, Reg_2))$	$loadAO\ r_1, r_2 \rightarrow r_{new}$
8	$Reg \rightarrow REF(+(Reg_1, NUM_2))$	$loadAI\ r_1, n_2 \rightarrow r_{new}$
9	$Reg \rightarrow REF(+(LAB_1, Reg_2))$	$loadAI\ r_2, l_1 \rightarrow r_{new}$
10	$Reg \rightarrow +(Reg_1, Reg_2))$	$add\ r_1, r_2 \rightarrow r_{new}$
11	$Reg \rightarrow +(Reg_1, NUM_2))$	$addI\ r_1, n_2 \rightarrow r_{new}$
12	$Reg \rightarrow +(LAB_1, Reg_2))$	$addI\ r_2, l_1 \rightarrow r_{new}$

Table: Modified example from **[Cooper & Torczon p.561]**

- Given the previous rewrite rules for our AST, lets consider **Tile 3** from our example and try to tile it:



- But there is a plethora of rewrite sequences (or tilings) for this trivial subtree!!!



- How do we select the optimal sequence of rewrite rules?
  - We need some metric which enables us to compare various selections of rewrite rules with each other.
    - **Solution:** *Annotate* rewrite rules with **costs**!
  - We need some clever algorithm to sort out the optimal rewrite sequence.
    - **Solution:** *Dynamic Programming* will do the trick!

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- Dynamic Programming is a method of solving problems exhibiting the following properties:
  - the approach for a given problem assumes a *recursive solution*, with a *bottom-up* evaluation of the solution.
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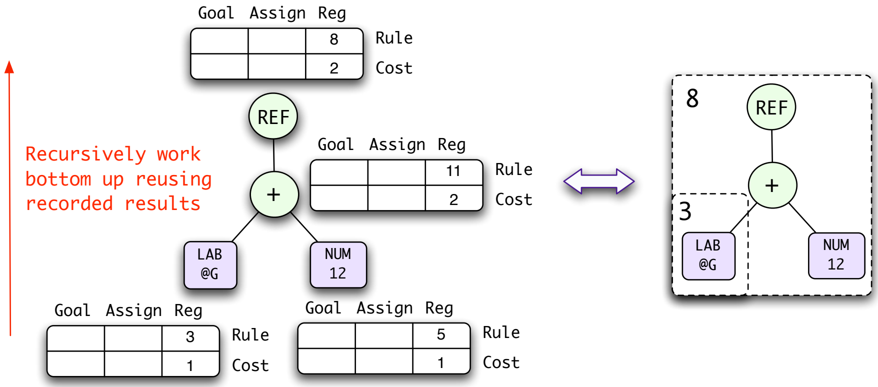
- One optimal solution for our previous tiling problem looks as follows:



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- We know how to optimally tile an AST using Dynamic Programming.
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- Tree Pattern Matching using Dynamic Programming works as follows:
  - *Two* passes over the AST:
    - **Pass 1:** Finds the optimal tiling of an AST using Dynamic Programming.
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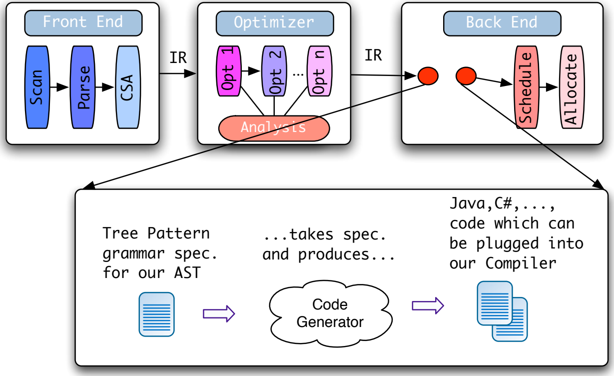
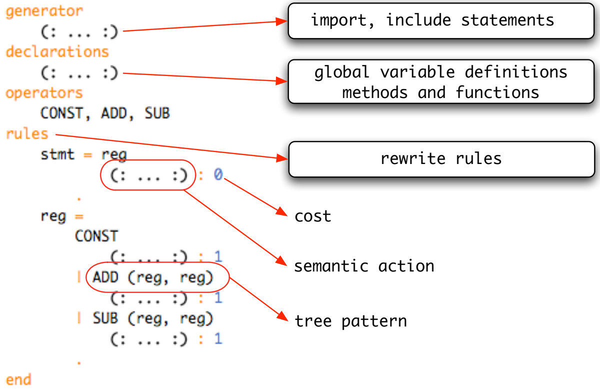
- Let's look at where our code generator is used in the compiler design process:



Tree Pattern Matching Language

- General Structure of a Grammar Specification:



- We have the following Node definition together with an example Abstract Syntax Tree:

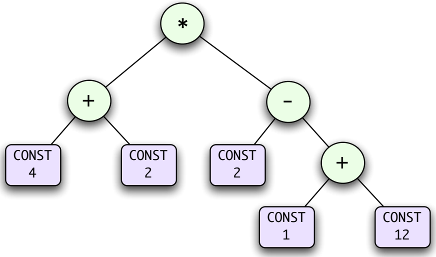
Node Kinds

```
public enum Kind {
    E_CONST,
    E_ADD,
    E_SUB,
    E_MULT
};
```

Node Datastructure

```
public class Node {
    Kind kind;
    String val;
    String result;
    Node left;
    Node right;
}
```

Example AST



Example 1

```
generator          -- Import Statements
    (:  import java.util.LinkedList;
        import comp.codegen.Reg;
        import comp.ast.Node;                              :)
declarations       -- General Declarations
    (: public LinkedList instrList = new LinkedList();    :)
operators          -- Operators (our Node Kinds)
    CONST(:E_CONST:), ADD(:E_ADD:),
    SUB(:E_SUB:), MULT(:E_MULT:)
rules              -- Production Rules
    reg  =  CONST c1    (:  c1.result = Reg.getNextReg();
                            instrList.add("loadI " +
                                          c1.val + "," +
                                          c1.result);
                        :) : 1
         |  ADD a1 ( reg r1, reg r2 )
                        (:  a1.result = Reg.getNextReg();
                            instrList.add("add " +
                                          r1.result + "," +
                                          r2.result + "," +
                                          a1.result);
                        :) : 1
         |  SUB s1 ( reg r1, reg r2 )
                        (:  s1.result = Reg.getNextReg();
                            instrList.add("sub " +
                                          r1.result + "," +
                                          r2.result + "," +
                                          s1.result);
                        :) : 1
         |  MULT m1 ( reg r1, reg r2 )
                        (: ... :) : 2
         .
end
```

Language Specification

- While the previous example looks nice at first sight, it is still quite cumbersome:
  - **Problem 1:** The way in which result registers are returned is by abusing the node class!
  - **Problem 2:** The list holding instructions is global!
- We can do much better than this!!!

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- We can use the **Attribute Grammar** formalism to correct our previous 'flaws':
  - **Solution to Problem 1:** The register production produces a *register* as its output and takes a list of *instructions* as its input to append its instructions to.
  - **Solution to Problem 2:** The instruction list is passed as a parameter and thus must not be declared as a 'global' class variable.
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Example 2

```
generator        -- Import Statements
    (:  import java.util.LinkedList;
        import comp.codegen.Reg;
        import comp.ast.Node;                                   :)
declarations     -- General Declarations (not needed now)
operators        -- Operators (our Node Kinds)
    CONST(:E_CONST:), ADD(:E_ADD:),
    SUB(:E_SUB:), MULT(:E_MULT:)
rules
    -- Production rules for registers:
    --      @out: produce a result register
    --      @in: list to add instructions to
    reg <: out String reg, List instr :>
        =
            CONST c1    (:  reg = Reg.getNextReg();
                            instr.add("loadI " +
                                        c1.val + "," +
                                        reg);
                        :) : 1
        |   ADD (   reg <: out r1, instr :> ,
                    reg <: out r2, instr :> )
                    (:  reg = Reg.getNextReg();
                        instr.add("add " +
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        |   SUB (   reg <: out r1, instr :> ,
                    reg <: out r2, instr :> )
                    (:  reg = Reg.getNextReg();
                        instr.add("sub " +
                                    r1 + "," +
                                    r2 + "," +
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                    :) : 1
        -- MULT pattern omitted
        .
end
```

- The simple example used up until now doesn't really convey the full power of the Tree Pattern Matching Language, namely:
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