Code Generation

Part VI

Phases In a Compiler

- A modern compiler is usually partitioned into three major parts:
  1. The front-end – Responsible for validating that the program is legal in the source language.
  2. The "middle-end" – Optimizations.
  3. The back-end – Generating a program in the target language, usually some form of machine code.

More on Phases

- The first phase has to be tailored for the particular language to compile but is really independent of the machine to compile to.
- The last phase has to be tailored for the machine to compile to but is to a large extent independent of the source language.
- Some optimizations are dependent on the source language or the target language, but most optimizations are independent.

Intermediate Representation

- An intermediate representation (IR) can make the front-end and the back-end truly independent.
- This will make it possible to reuse parts of the compiler in other projects.
  - By plugging in different back-ends we can get compilers for different machines (SPARC, x86, JVM, EVM)
  - By plugging in different front-ends we can get compilers for different languages (Expressive, Java, C, C++)

Intermediate Representation

- The intermediate representation has to be carefully designed.
  - It should support constructs for several different programming languages (functions, objects, types).
  - It should be easy to map to several different target machines.
- There are several common ways to structure the IR.
  - 3-address instructions, Control Flow Graphs (CFG), Expression-Trees, Static Single Assignment (SSA)

Optimization

- The IR is ideal for optimizing on:
  - Unnecessary syntactical constructs have been removed.
  - Strange machine specific peculiarities have not been introduced.
- By using the IR for our optimization phases we can reuse optimizations in other compilers we write. ;)

Project Note

- In the project we are not going to do any optimizations (or porting).
- Hence, for Expressive we will not use an intermediate representation.
- Instead we will generate (virtual) machine code directly.

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7 Compilation A 28.05.03 http://lamp.epfl.ch/teach/eg/compilation/2003/html/

The Target Language

- In order to generate code we need to know the target language.
- In our project the target language is the assembly language of a virtual machine called EVM (the Expressive Virtual Machine).
- Before describing code generation in detail we will take a detour and look at the EVM.

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Code Generation

- The task of the code generator is to select machine instructions for each construct in the IR (or the AST in our case).
- In Java this can be done by applying a visitor on the tree nodes.
- In functional languages it can be done by pattern matching on tree nodes.

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Designing The Code Generator

- Given:
  - A target language – The EVM in our case.
  - An intermediate representation in the form of a tree – the AST in our case
- Find:
  - For each node in the source tree find a combination of instructions in the target language.

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The Generator

```
public class Generator implements
 Visitor, expressive.evm.Instructions {
  final Global global;
  final PrintWriter out;
  final Code code = new Code();

  public Generator(Global global,
                   PrintWriter out) {
    this.global = global;
    this.out = out;
  }

  public void generate(Tree tree) {
    tree.apply(this);
  }
…
```

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Bottom up Design

- Lets try to design the code generator from the bottom up. That is, we will start with leaves in the AST and then work our way up.
- Since the target machine is a stack machine we will want to get the result of each expression on the top of the stack.
- We will use the Visitor pattern over the AST.
- We assume we have a function emit which produces code for the target.

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Literals

- The literals in the AST can contain either a string or an integer.
- Since string literals can only occur in a `prints` node we will ignore them for now.
- For a value what we want to do is to push it onto the top of the stack.

Code for Literals

```
public void caseLiteral(Literal tree) {

  if (tree.str != null) // String or int lit?
    global.fatal(tree.pos,
      "Cannot generate code for a string literal");

  code.emit(PUSH, tree.value);
}
```


Identifiers

- Identifiers represents uses of variables.
- Variables will be stored in memory.
- Each identifier is associated with a symbol.
- The symbol can keep track of where in memory the variable is stored – let's assume it does.

Identifiers (cont)

- We need to get the contents of the variable from the memory to the top of the stack.
- The `LOAD` instruction does this, assuming we know the memory position.

Code for Identifiers

```
public void caseIdent(Ident tree) {
  // id

  code.emit(LOAD,
            tree.symbol.getOffset());

}
```


Assignment

- The assignment node consists of an identifier and an expression:
  `id := expr`
- The statement should store the value of `expr` to the memory location of `id`.
- We assume we can call `generate` to generate code for an expression.
- We assume that the value of the evaluated expression will be on the top of the stack.
- All we need to do is emit code for storing the top of the stack to memory with `STORE mempos`.

Code for Assignment

```
public void caseAssign(Assign tree) {
  // id := expr

  // Recursive call to generate code
  //  for the expression expr.
  generate(tree.rhs);

  // Code for storing the result in memory
  //  at the location of id.
  code.emit(STORE, tree.symbol);
}
```


Code

- We have assumed that we have an emit function and that each symbol is allocated to a memory position.
- This is handled by the Code class.
- We keep a vector of emitted instructions, and a count of used memory positions.

The Code Class

```
public class Code implements
   expressive.evm.Instructions {

 private final Vector/*<int>*/ code = new Vector();
 private int memSize = 0;
…
 public Code emit(int instr) {
   code.add(new Integer(instr));
   return this;
 }

 public Code emit(int instr, int arg) {
  emit(instr);
  return emit(arg);
 }
```


The Magic in Code

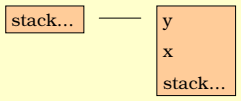
```
public Code emit(int instr, Symbol sym) {
  return emit(instr, declareVar(sym));
}

public int declareVar(Symbol sym) {
  // Offset -1 indicate unallocated symbol.
  if (sym.getOffset() < 0)
    sym.setOffset(memSize++);

  return sym.getOffset();
}
```


Operators

- The operators can be constant (`TRUE`, `FALSE`), unary (`NOT expr`) or binary (`expr ADD expr`, etc).
- For the binary operators we want the right hand side (y) on the top of the stack and the left hand side (x) below that on the stack.



Operators

- We can use `generate` to generate code for the sub trees, first left (x), then right (y).
- Then we just have to figure out what each operation should do.
- Most ops have a direct correspondence in the EVM.

Booleans

- In the EVM Booleans are represented by the integer 0 for false and any other integer for true.
- This means that we can implement the Boolean operators:
  - `! expr` (`NOT x => x = 0`)
  - `Expr | expr` (`x OR y => x + y`)
  - `Expr & expr` (`x AND y => x * y`)
- As:

NOT x:	x OR y:	x AND y:
`PUSH 0`	`ADD`	`MUL`
`CMPE`		

If

- To generate code for if we will need to use control flow instructions.
- For

  "`if Cond {Statements1} else {Statements2}`"

  we need to first generate code that evaluates `Cond`.

  Then we need to generate code that checks if `Cond` is false (=0) and if so jumps over all the statements in Statements1.

Labels

- In order to easily jump to some point in the code the Code class provides labels.
  - `getLabel()` returns a new label.
  - `markLabel(Label label)` marks the label to point to the current location in the code.
- For the implementation look in Code.java.

...If again

- Armed with labels we can make the following outline for the generated code for `if Cond {Statements1} else {Statements2}`

```
Code for Cond
JZ elseL // Jump if Cond=0 i.e. false
Code for Statements1
elseL:
Code for Statements2
```


...and again

- We do not want to execute the code for `Statements2` after `Statements1` if `Cond` is true:

```
Code for Cond
JZ elseL // Jump if Cond=0 i.e. false
Code for Statements1
GOTO exitL // Skip Statements2
elseL:
Code for Statements2
exitL:
```


Code for if

```
public void caseIf(If tree) {
  // if Cond {Statements1} [else {Statements2}]
  Code.Label elseL = code.getLabel();
  Code.Label exitL = code.getLabel();

  generate(tree.cond);        // Code for Cond
  code.emit(JZ, elseL);       // JZ elseL // Jump if Cond=0 i.e. false
  generate(tree.thenp);       // Code for Statements1
  if (tree.elsep.length > 0)
      code.emit(GOTO, exitL);// GOTO exitL // Skip Statements2
  code.markLabel(elseL);      // elseL:
  if (tree.elsep.length > 0) {
      generate(tree.elsep);   // Code for Statements2
      code.markLabel(exitL); // exitL:
  }
}
```

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That's about it

- You will get Code.java and a skeleton for Generator.java.
- You will have to figure out how to handle `caseProg`, `caseWhile`, and `caseIO` nodes by yourself.
- You will also have to finish `caseOP`.