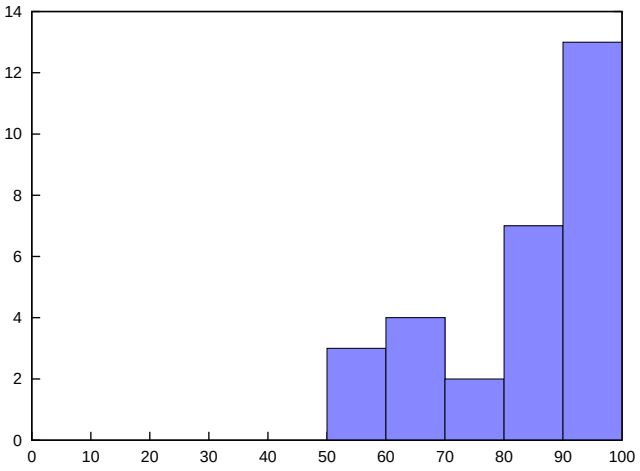
Department of Electrical Engineering and Computer Science

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

6.035 Spring 2013

Test I Solutions

Mean 83 Median 87 Std. dev 13.8203



I DFAs, NFAs, Regular Expressions and Context Free Grammars

For Questions 1 and 2, if a regular expression or context-free grammar can describe the language then provide one. Otherwise, write "N/A."

1. [4 points]: The language of matched parentheses.

Solution: CFG:

$$S \to \epsilon \tag{1}$$
$$S \to (S)S \tag{2}$$

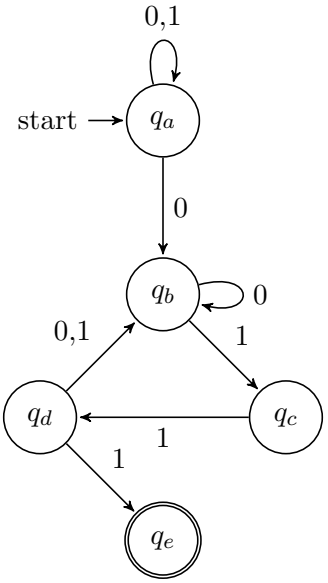
The grammar with $S \to (S)$ was also accepted since the question wasn't specific.

2. [4 points]: The language of even length strings over the alphabet $\{0, 1\}$. **Solution: Regular Expression: ((01)|(10))***

3. [4 points]: True or false: NFAs are more powerful (can recognize more languages) than DFAs. If false, explain. If true, give an example of a language that an NFA can parse that a DFA cannot.

Solution: False. Any NFA can be transformed into a DFA, although the DFA make take exponentially more space.

4. [8 points]: Give a regular expression for the following NFA:



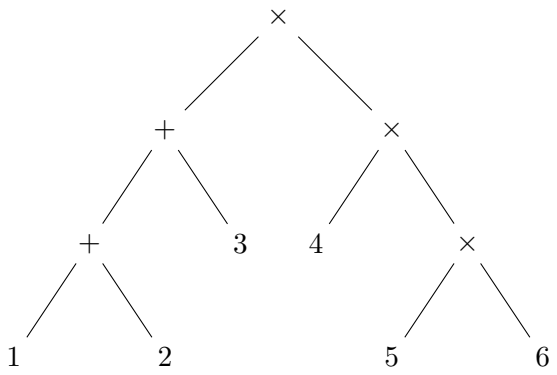
Solution: (0|1)*00*11((0|1)0*11)*1 (Other valid regexes accepted)

II Hacking the Grammar

For Questions 5 through 7, consider the following grammar for a language with expressions:

$E \to E + E$
$E \to E \times E$
$E \to c$
Where c is a number token.

5. [11 points]: Hack the grammar to give + higher precedence than $\times$, to make + left associative, and to make $\times$ right associative. The grammar should produce a parse tree for the string "$1+2+3\times4\times5\times6$" that reflects the evaluation order $(((1+2)+3)\times(4\times(5\times6)))$. This evaluation order is also reflected in the following abstract syntax tree:



Solution:

$$\begin{aligned} E \to & F \times E \\ | & F \\ F \to & F + c \\ | & c \end{aligned}$$

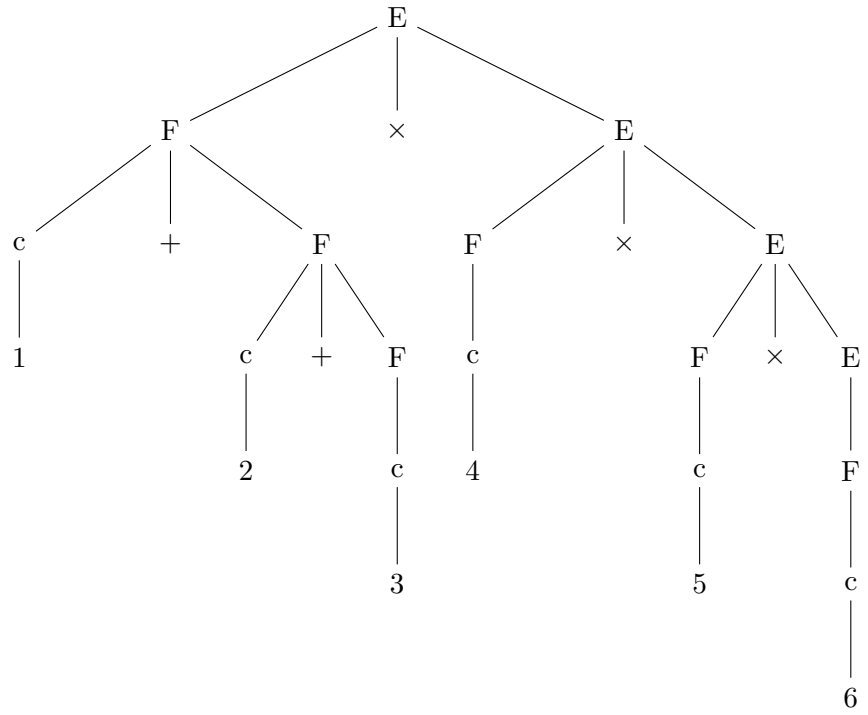
6. [11 points]: Remove left recursion from your answer to Question 5 to make the language parseable by a recursive descent parser with one token of lookahead. Do not worry about maintaining associativity.

Solution:

$$\begin{aligned} E \rightarrow & F \times E \\ & |F \\ F \rightarrow & c + F \\ & |c \end{aligned}$$

7. [6 points]: Removing left recursion from your grammar leads to weird parse trees. Draw the **parse tree** (not AST) your grammar from Question 6 would produce for the string $1 + 2 + 3 \times 4 \times 5 \times 6$.

Solution:



8. [6 points]: Eliminating Shift-Reduce Conflicts:
Consider the language defined by the following grammar (where S is the only nonterminal):

$S \rightarrow$ *if* a b
$S \rightarrow$ *if* a b *else* c

If you give this grammar to a parser generator that produces a shift-reduce parser with no lookahead, then the parser generator will say that there is a shift-reduce conflict. Rewrite the grammar to eliminate the conflict.

Solution:

Oops. Not possible. Points for everyone.

III Implementing Object-Orientation: Descriptors and Symbol Tables

Use the diagram on the next page to answer the following three questions about this fragment of an expression interpreter.

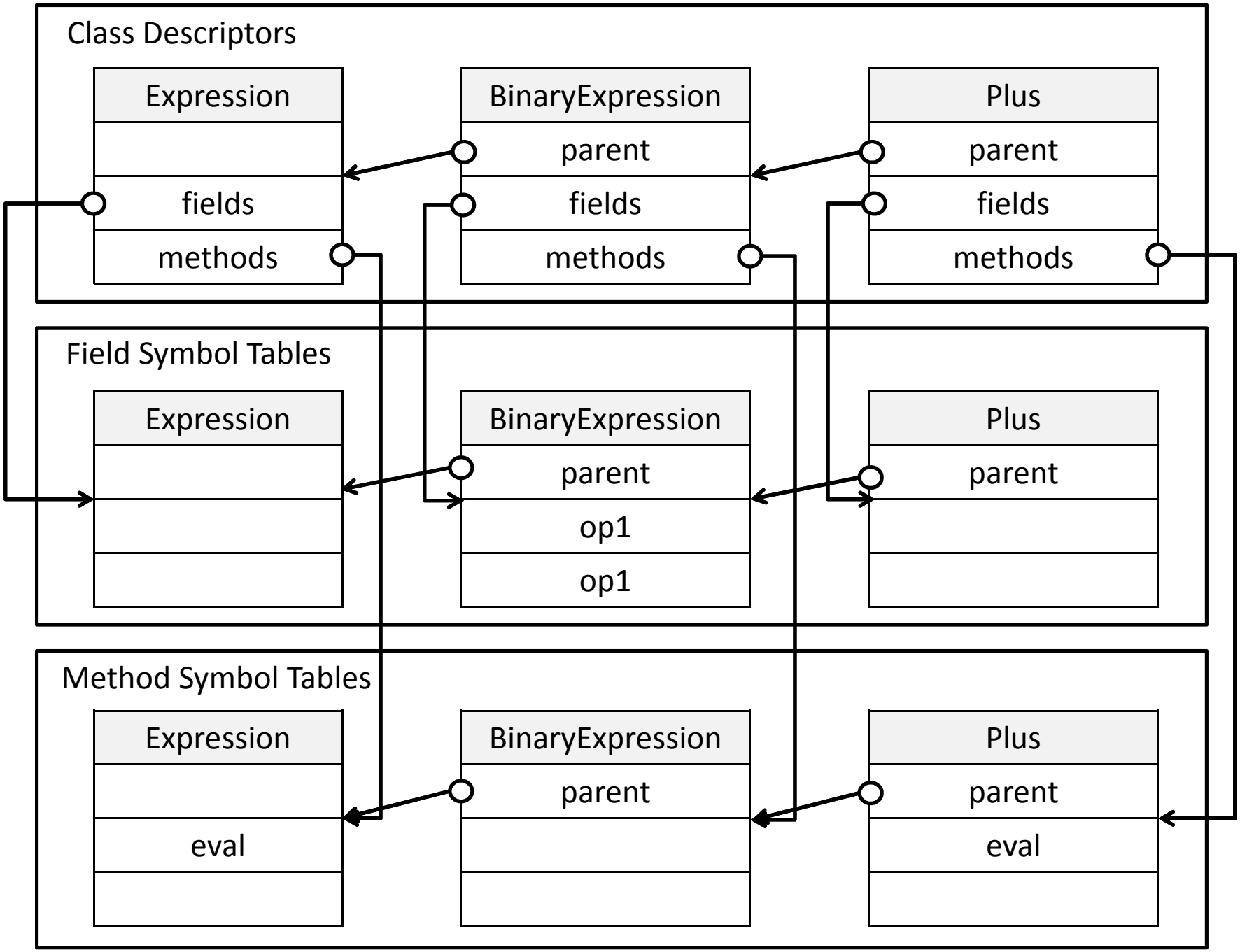
```
class Environment { ... }

abstract class Expression {
  abstract int eval(Environment env);
}

abstract class BinaryExpression extends Expression
{
  Expression op1, op2;
}

class Plus extends BinaryExpression
{
  int eval(Environment env) { return op1.eval(env) + op2.eval(env); }
}
```

9. [5 points]: Complete the entries of the class descriptors for each class. Use an arrow to connect the entry to a descriptor or symbol table where appropriate.

10. [5 points]: Complete the entries of the field symbol tables for each class. Use an arrow to connect the entry to a descriptor or symbol table where appropriate.

11. [5 points]: Complete the entries of the method symbol tables for each class. Use an arrow to connect the entry to a descriptor or symbol table where appropriate.

12. [5 points]: How does the method descriptor for a method with an `abstract` modifier differ from that of a method without the modifier?


Class Descriptors
Expression
fields
methods
BinaryExpression
parent
fields
methods
Plus
parent
fields
methods
Field Symbol Tables
Expression
BinaryExpression
parent
op1
op1
Plus
parent
Method Symbol Tables
Expression
eval
BinaryExpression
parent
Plus
parent
eval

IV Semantic Analysis

For this problem, you will write a semantic analyzer for the following simple language:

$$
\begin{array}{rcl}
P & \rightarrow & \mathit{Decls}\ E \\
\mathit{Decls} & \rightarrow & D\ \texttt{,}\ \mathit{Decls} \mid \epsilon \\
D & \rightarrow & \mathit{ID} = \texttt{read\_int} \mid \mathit{ID} = \texttt{read\_float} \mid \mathit{ID} = \texttt{read\_string} \\
E & \rightarrow & \mathit{INT} \mid \mathit{FLOAT} \mid \mathit{STRING} \mid \mathit{ID} \mid \mathit{concat}(E, E) \mid E + E
\end{array}
$$

The language consists of a sequence of variable declarations and a single expression consisting of constants (integer, float, and string), variable references, string concatenation, and addition. The keywords `read_int`, `read_float`, and `read_string` read a value of the given type from the user.

Implement a semantic analyzer in pseudo-code for the program element specified in each question. Your implementation should compute the `type` *attribute* of the given production. For example, the implementations for P and Decls are as follows:

$P \rightarrow \mathit{Decls}\ E$

```
{ P.type = (Decls.type == "void") ?  E.type : Decls.type; }
```

$\mathit{Decls} \rightarrow D\ \texttt{,}\ \mathit{Decls}_1$

```
{ Decls.type = (D.type == "void") ? Decls1.type : D.type; }
```

$\mathit{Decls} \rightarrow \epsilon$

```
{ Decls.type = "void"; }
```

- Use the types “int”, “float”, “str”, and “void”.
- Use the type “err” when the program has a semantic error. Do not throw an exception.
- Use a global symbol table that you can manipulate and access with the functions `void add(string name, string type)` and `string lookup(string name)`. `lookup` returns `null` if the symbol hasn't been defined.

13. [6 points]: Variable Declaration.

Goal: set `D.type` appropriately.

Semantic Rules:

- Each variable is declared at most once.
- The type of a variable is the type of the value assigned to it from the input.
- Semantically correct declarations have type "void".

Assume: `ID.value` contains the name of the variable.

$D \rightarrow ID$ = `read_int`

```
{
  string t = lookup(ID.value);
  if (t == null) {
    add(ID.value, "int");
    D.type = "void";
  } else {
    D.Type = "err";
  }
}
```

14. [2 points]: Constant Expression.

Goal: set `E.type` appropriately.

Semantic Rule: a constant has its given type (e.g., an integer has type "int").

$E \rightarrow STRING$

```
{
  E.type = "str";
}
```

15. [4 points]: Variable Reference Expression.

Goal: set `E.type` appropriately.

Semantic Rules:

- A referenced variable must be declared.
- The type of a variable reference is the declared type of the variable.

Assume: `ID.value` contains the name of the variable.

$E \rightarrow ID$

```
{
  string t = lookup(ID.value);
  E.type =  (t != null) t : "err";
}
```

16. [6 points]: String Concatenation Expression.

Goal: set `E.type` appropriately.

Semantic Rule: string concatentation operates only on string operands.

Assume: `E1.type` and `E2.type` have already been recursively computed by the analyzer.

$E \rightarrow concat(E_1, E_2)$

```
{
  if (E1.type == "str" && E2.type == "str") {
    E.type = "str";
  } else {
    E.type = "err";
  }
}
```

17. [8 points]: Addition Expression.

Goal: set `E.type` appropriately.

Semantic Rules:

- Addition operates only on integer and float operands.
- If one operand is a float, then the result of the addition is a float.

Assume: `E1.type` and `E2.type` have already been recursively computed by the analyzer.

$E \rightarrow E_1 + E_2$

```
{
  if (E1.type == "err" || E2.type == "err")
  {
    E.type = "err";
  } else if (E1.type == "str" || E2.type == "str") {
    E.type = "err";
  } else if (E1.type == "float" || E2.type == "float") {
    E.type = "float";
  } else {
    E.type = "int";
  }
}
```