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Question 1. (12 points, 4 each) Regular expressions.

(a) Describe the set of strings generated by the regular expression

```
((xy*x) | (yx*y))*
```

In any order, 0 or more pairs of x's with 0 or more y's between them, or pairs of y's with 0 or more x's between them.

(b) Write a regular expression that generates all non-empty strings of `a`'s, `b`'s, and `c`'s where the first `c` (if any) appears after the first `a` (if there are any `a`'s in the string).

b*a(a|b|c)* | (b|c)+

(c) Write a regular expression that generates all non-empty strings of `a`'s and `b`'s that ***don't*** contain the contiguous substring `baa`.

a*(a|b|ba)(b|ba)*

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Question 2. (12 points) Context-free grammars

Consider the following grammar.

S ::= SA | Ba
A ::= Ab | B
B ::= aA | c

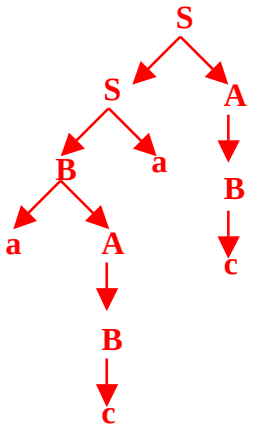
(a) (3 points) List the terminal, nonterminal, and start symbols for this grammar.

Terminals: **a b c**

Non-terminals: **S A B**

Start symbol: **S**

(b) (6 points) Draw the parse tree for the sentence `acac`.



(c) (3 points) Give a leftmost derivation of the sentence `acac`.

S => SA => BaA => aAaA => aBaA => acaA => acaB => acac

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Question 3. (8 points) Stack machine hacking.

The Java virtual machine (JVM) defines an instruction set for a stack machine, and it is instructions for this machine that are contained in Java .class files. This question is about generic stack machines, as discussed in class.

Recall that most of the operations in a stack machine take their operands off the top of the expression stack and push the result onto the stack in their place. Typical operations are:

pushval *offset*	push contents of variable at given offset in the stack frame
pushaddr *offset*	push memory address of variable with given stack frame offset
pushconst *val*	push constant integer *val* onto stack
assign	store top of stack value at location whose address is underneath it on the stack; pop both
pop	pop unneeded value from stack
dup	push duplicate copy of value currently on top of the stack
swap	interchange top two values on the stack
add	addition
mul	multiplication

Suppose we're generating code in a method with the following symbol table.

Variable	Offset
p	12
q	4
z	8

Write the stack machine code corresponding to the following statements. For full credit, the operands of expressions should be pushed from left to right (i.e., push the 12 first when evaluating the last expression).

```
q = 17;
p = 42;
z = 12 * ((p*q) + 4*q+ p);
```

```
pushaddr    4
pushconst   17
assign
pushaddr    12
pushconst   42
assign
```

```
pushaddr    8
pushconst   12
pushval     12
pushval     4
mul
pushconst   4
pushval     4
mul
add
pushval     12
add
mul
assign
```

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Question 4. (14 points) Java hacking.

Write a complete Java program that makes a copy of a text file. The file name should be given on the command line (or equivalent, depending on your development environment), and can be accessed as the first element of the `String` array parameter of method `main`. The copy of the file should be named `copy of` *originalfilename*, where *originalfilename* is the file name taken from the command line.

For full credit, you must copy the file a line at a time (`readLine`), not character by character, and you should use the appropriate reader and writer classes.

```
public class Copy {

    public static void main(String args[ ]) {
        String sourceFileName = args[0];
        String copyFileName   = "copy of " + sourceFileName;

        try {
            BufferedReader in  = new BufferedReader(newFileReader(sourceFileName));
            PrintWriter    out = new PrintWriter(new FileWriter(copyFileName));

            String line = in.readLine( );
            while (line != null) {
                out.println(line);
                line = in.readLine( );
            }
        } catch (IOException e) {
            System.err.println(("Error while copying: " + e);
        }
    }
}
```

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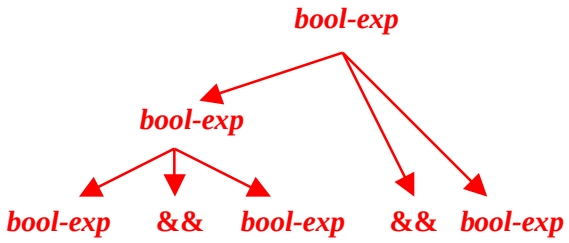
Question 5. (10 points) Language hacking (context-free grammars again).

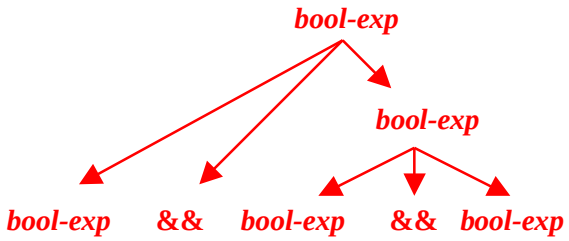
One of your colleagues proposes to extend D by adding logical and (`&&`) to the grammar as follows:

bool-exp ::= *rel-exp* | ! (*rel-exp*) | *bool-exp* `&&` *bool-exp*

(a) (6 points) Show that this extension makes the grammar ambiguous.

Easiest way to answer this is to draw two separate parse trees for the same expression:





(b) (4 points) Fix the grammar so it contains logical and, but is not ambiguous.

Here's one possible fix:

***bool-exp* ::= *rel-exp* | ! (*rel-exp*) | *bool-exp* && *rel-exp* | *bool-exp* && ! (*rel-exp*)**

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Question 6. (20 points) x86 hacking.

Here is yet another version of factorial written in D.

```
int fact(int n) { return factaux(1,2,n); }

int factaux(int result, int next, int n) {
   int answer;
   if (next > n)
      answer = result;
   else
      answer = factaux(result*next, next+1, n);
   return answer;
}
```

The goal of this problem is to write an x86 assembly language version of function `factaux` **only**. Use the standard Win32 conventions for function calls, **except** push the function arguments from *left to right*, as you did in your D compiler.

(a) (6 points) Draw a picture showing the local stack frame layout during execution of function `factaux`. This is the layout after the function prologue code has been executed, just before execution of the `if` statement. Be sure to show where registers `ebp` and `esp` point in the stack frame, the location of each parameter and local variable, and their numeric offsets from `ebp`.

+16	**result**	
+12	**next**	
+8	**n**	
+4	**return address (saved eip)**	
0	**saved ebp**	**← ebp**
-4	**answer**	**← esp**

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Question 6 (cont).

(b) (14 points) Translate `factaux` to x86 assembly language. You don't have to imitate your compiler precisely and generate really bad code; straightforward x86 code is fine, as long as it uses the registers properly and obeys the x86 conventions used by the D compiler for stack layout, function calls, etc. Also, don't omit any statements – be sure to actually store a value in variable `answer`, for instance. It will help us read your answer if you include the source code as comments near the corresponding x86 code. The D code is repeated here for reference.

```
int factaux(int result; int next; int n) {
   int answer;
   if (next > n)
      answer = result;
   else
      answer = factaux(result*next, next+1, n);
   return answer;
}
```

There are obviously many ways to do this. This solution moves local variables to registers before doing arithmetic, which isn't strictly necessary on the x86, but which is typical of more modern processor architectures.

```
d$factaux:  push  ebp            ; function prologue
            mov   ebp,esp
            sub   esp,4          ; allocate local variables
            mov   eax,[ebp+12]   ; compare  next:n
            mov   ecx,[ebp+8]
            cmp   eax,ecx
            jng   L1             ; jump if next <= n
            mov   eax,[ebp+16]   ; answer = result;
            mov   [ebp-4],eax
            jmp   L2             ; else
L1:         mov   eax,[ebp+16]   ; push result*next
            mov   ecx,[ebp+12]
            imul  eax,ecx
            push  eax
            mov   eax,[ebp+12]   ; push next+1
            add   eax,1          ;  (or inc eax)
            push  eax
            mov   eax,[ebp+8]    ; push n
            push  eax
            call  d$factaux      ; recursive call of factaux
            add   esp,12         ; pop arguments
            mov   [ebp-4],eax    ; finish assignment answer = factaux(...);
L2:         mov   eax,[ebp-4]    ; return answer;  (result in eax)
            mov   esp,ebp        ; restore registers
            pop   ebp
            ret                  ; return to caller
```

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Question 7. (14 points) Compiler hacking.

C, C++, and Java all contain a *conditional expression* that has the syntax

condition ? *expression1* : *expression2*

This is very much like the `if` expression in Scheme. The Boolean expression *condition* is evaluated. If it is true, then *expression1* is evaluated and its value is the value of the entire conditional expression. If *condition* evaluates to false, then *expression2* is evaluated and its value is the value of the conditional expression. **Only one** of *expression1* and *expression2* is evaluated; the other is not evaluated.

Example: This statement compares the values in `x` and `y` and stores the larger value in `max`.

```
max = x > y ? x : y;
```

For this problem, we will add a rule to the D grammar for conditional expressions, and your job is to write a method to compile it. The new grammar rule is

conditional-exp ::= *bool-exp* ? *exp* : *exp*

Complete the definition of method `conditionalExp` in the parser class on the next page so it compiles *conditional-exp*s. The parser class contains an instance variable that holds the next unprocessed token from the input program, and a function that calls the scanner to read the next token. Use these to access the tokens from the source program - don't call the scanner directly. It also contains a method to write generated code to the output file. Use this to generate code; don't use `writeln` directly. The parameter to function `boolExp` is the label to which control should be transferred in the condition evaluates to false. Finally, function `newLabel` is available to create unique strings that can be used as labels in the generated code as needed.

Hint: You may find it helpful to sketch out the parsing and code generation separately before you write your solution.

Reference information: You should assume that classes representing tokens, EchoIO, and the scanner are available for your use, as described in the compiler project handouts.

```
// description of a single lexical token
 class Token {
   public int kind;   // kind of token (see constants below)
   public int val;    // if kind=INT, then val=value of the integer

                                       // lexical classes:
   public static int INT       = 0;    //   integer constant
   public static int QUESTION  = 1;    //   ? symbol
   public static int COLON     = 2;    //   : symbol
     ...                               //   ... etc. ...
   public static int EOF       = 99;   //   end of input
                                       // (returned by scanner
                                       //   when no more tokens
 }                                     //   are available)
```

```
// parser
class Parser {
   EchoIO eio;          // I/O interface [ initialized elsewhere ]
   Scanner scan;        // Scanner [ initialized elsewhere ]
   ...
   Token tok;           // next unprocessed token from source program

   // update tok by advancing to the next token in the source program
   void nextTok() { tok = scan.nextToken(); }

   // write generated code s to output
   void gen(String s) { eio.println(s); }

   // return unique string that can be used as an assembly lang. label
   String newLabel() { ... }

   // compile bool-exp and generate a conditional jump to falseTarget
   // if the bool-exp evaluates to false
   void boolExp(String falseTarget) { ... }

   // compile bool-exp ? exp : exp
   void conditionalExp( ) {

      String falseTarget = newLabel();
      String endLabel    = newLabel();

      boolExp(falseTarget);
      nextTok();                  // skip ?
      exp();
      gen("  jmp  " + endLabel);
      nextTok( );                 // skip :
      gen(falseTarget + ":");
      exp();
      gen(endLabel + ":");

   }
}
```