1. (10 points) Write a regular expression or regular expressions that generate the following sets of strings.

(a) (5 points) All strings containing a's, b's, and c's with at least one a and at least one b.

[abc]*a[abc]*b[abc]* | [abc]*b[abc]*a[abc]*

(b) (5 points) All strings of 0's and 1's with at most one pair of consecutive 1's.

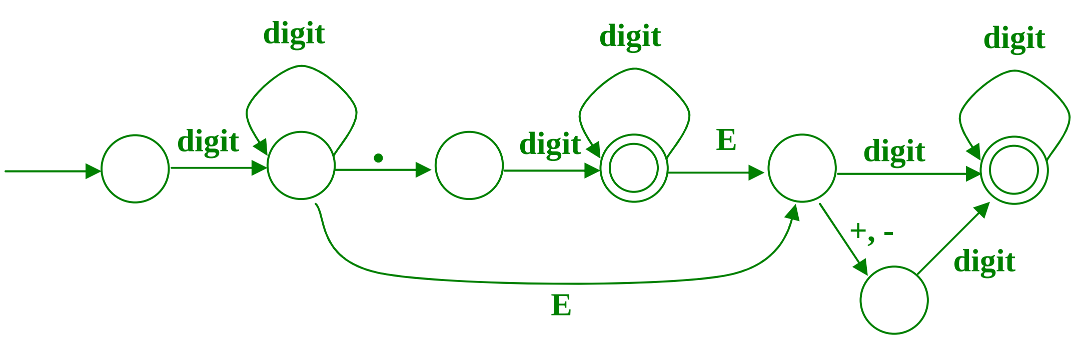
Here are two possible solutions

(0|10)*1?1?(0|01)* 　　　 **1 | (0|10)*11(0|01)***

2. (8 points) Pascal defined real (floating-point) numeric constants as follows:

digit ::= [0-9]
digits ::= *digit*+
real ::= *digits* . *digits* | *digits* . *digits* E *scalefactor* | *digits* E *scalefactor*
scalefactor ::= *digits* | (+ | -) *digits*

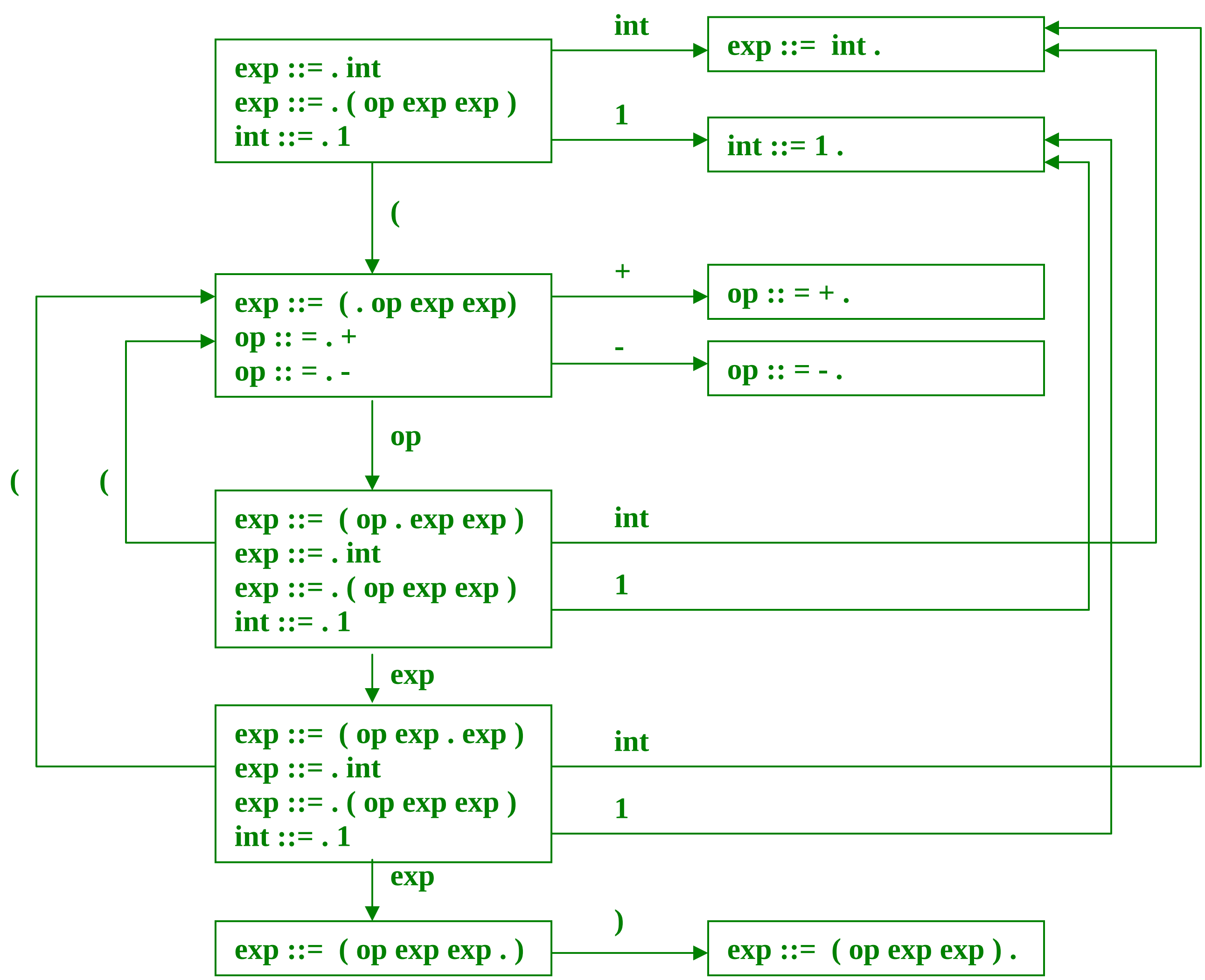
Draw a DFA that accepts real constants as defined above. (You don't need to construct an NFA and use algorithms to convert it to a DFA – just draw a suitable DFA diagram.)



3. (12 points) (LR parsing) In languages like Scheme, arithmetic expressions are written as parenthesized lists beginning with an operator followed by the operands. Here is a simple grammar for expressions involving addition and subtraction and the single integer constant 1.

exp ::= *int* | (*op exp exp*)
op ::= + | -
int ::= 1

(a) (10 points) Construct the LR(0) state machine for this grammar.



(b) (2 points) Is this grammar LR(0)? Why or why not?

Yes. There are no shift-reduce or reduce-reduce conflicts.

4. (6 points) Some experimental programming languages include an *n*+1/2 loop with the following syntax:

```
repeat
  statement1
while ( exp )
  statement2
end
```

The semantics of this loop is that *statement1* is executed then the conditional expression *exp* is evaluated. If *exp* is false, the loop terminates, otherwise, if it is true, *statement2* is executed and the loop repeats starting with *statement1*.

Give the x86 code shape for this loop using a style similar to that used in lecture for other statements and conditional expressions.

Here's a straightforward solution that leaves the parts of the loop in the same order they appear in the source code.

loop:
    statement1
    exp
    $\text{jmp}_{\text{false}}$ done
    statement2
    jmp loop
done:

It's also possible to rearrange the order to get rid of the unconditional jump that's executed each iteration in the above code.

    jmp start
continue:
    statement2
start:
    statement1
    exp
    jmp_{true} continue

5. (12 points) Suppose we want to add the following conditional statement to MiniJava:

> `ifequal` (*exp1*, *exp2*)
>   *statement1*
> `smaller`
>   *statement2*
> `larger`
>   *statement3*

The meaning of this is that *statement1* is executed if the integer expressions *exp1* and *exp2* are equal; *statement2* is executed if *exp1* < *exp2*, and *statement3* is executed if *exp1* > *exp2*.

(a) (5 points) Give context-free grammar production(s) for the `ifequal` statement that allows either or both of the "`smaller`" and "`larger`" parts of the statement to be omitted. If both the "`smaller`" and "`larger`" parts of the statement appear, they should appear in that order.

Here are two solutions. The first one uses ε-productions

> ***stmt*** **::= ifequal (** ***exp*** **,** ***exp*** **)** ***stmt optsmaller optlarger***
> ***optsmaller*** **::= smaller** ***stmt*** **| ε**
> ***optlarger*** **::= larger** ***stmt*** **| ε**

The other one is more brute-force but doesn't include any ε-productions.

> ***stmt*** **::= ifequal (** ***exp*** **,** ***exp*** **)** ***stmt***
> **| ifequal (** ***exp*** **,** ***exp*** **)** ***stmt*** **smaller** ***stmt***
> **| ifequal (** ***exp*** **,** ***exp*** **)** ***stmt*** **larger** ***stmt***
> **| ifequal (** ***exp*** **,** ***exp*** **)** ***stmt*** **smaller** ***stmt*** **larger** ***stmt***

(b) (5 points) Is the grammar with your production(s) from part (a) ambiguous? If not, argue informally why not; if it is ambiguous, give an example that shows that it is.

Yes. This grammar has the same sort of problem as the "dangling else" in the usual grammar for conditional statements. There are two possible ways to derive, for example,

> **ifequal (** ***exp*** **,** ***exp*** **) ifequal (** ***exp*** **,** ***exp*** **)** ***stmt*** **smaller** ***stmt***

A derivation can be given where the "smaller" part is associated with the second "ifequal", and another can be given that associates it with the first "ifequal".

(c) (2 points) When compiling this statement, what rule(s) or condition(s) should the type checker verify?
We need to check that the two expressions both have type integer.

6. (5 points) Suppose we have two classes `B` and `D`, where `D` is a subclass (derived class) of `B`, and these classes contain the methods shown below.

```
class B {
   void f() { … }
   void g() { … }
   void h() { … }
}

class D extends B {
   void k() { … }
   void g() { … }
}
```

Recall that our convention is that in generated x86 assembly code, the label for a method m in class `C` is `C$m`.

Show what the generated virtual method dispatch tables for classes `B` and `D` would look like in x86 assembly language. (Hint: this is supposed to be an easy question – don't over-analyze it.)

```
B$$   dd   0     ; no superclass
      dd   B$f
      dd   B$g
      dd   B$h

D$$   dd   B$$
      dd   B$f
      dd   D$g
      dd   B$h
      dd   D$k
```

A key point here is that the subclass method table must have pointers to the first three methods (f, g, and h) in the same order that they appear in the superclass table.

7. (12 points) Write an x86 assembly-language version of the following C function. Your answer doesn't need to use exactly the same code shape presented in class for the various statements and expressions (i.e., it only needs to be legal x86 code that works properly), but you do need to use the C function-calling conventions properly, i.e., push arguments onto the stack, set up a new stack frame, etc., and you must include assembly language code for all statements given here (i.e., don't omit the assignment to the local variable a, for example).

```
int factorial(int n) {
   int a;
   a = n;
   if (a <= 1) {
      return 1;
   } else {
      return a * factorial(a-1);
   }
}
```

```
factorial: push  ebp              ; function prologue
           mov   ebp,esp
           sub   esp,4
           mov   eax,[ebp+8]      ; a = n;
           mov   [ebp-4],eax
           cmp   eax,1            ; a ? 1 (a still in eax)
           jg    else
           mov   eax,1            ; a<=1 here, return 1
           mov   esp,ebp
           pop   ebp
           ret                    ; (no jmp needed)
else:      sub   eax,1            ; a-1 (a still in eax here)
           push  eax              ; factorial(a-1)
           call  factorial
           add   esp,4            ; pop argument
           imul  eax,[ebp-4]      ; factorial(a-1) * a in eax
           mov   esp,ebp          ; return
           pop   ebp
           ret
```