**Question 1.** (18 points) In FORTRAN, a floating-point numeric constant must contain a decimal point or an exponent or both to distinguish it from an integer. The exponent uses the letter `E` or `e` to indicate a single-precision constant and the letter `D` or `d` to indicate double-precision. A floating-point constant without an exponent is taken to be single precision. Some **examples** of floating-point constants: `3.14` `1.` `1.0` `01e2` `6.023D23` `3.5E-12` `1.0d+6` `.1e-001` `000.000d00` Some examples that are **not** floating-point constants: `17` (no decimal point or exponent), `1,000,000.00` (contains commas), `-17.0` (unary minus operator followed by a constant), `.e02` (no digits before the exponent), `e02` (an identifier, not a number).

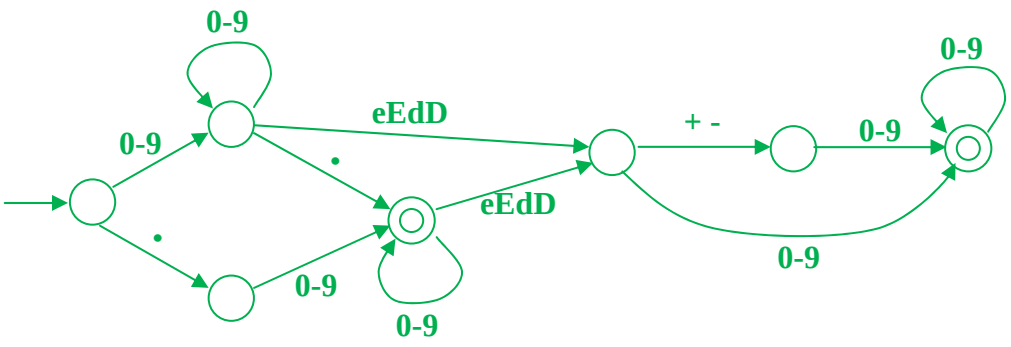
(a) (9 points) Give a regular expression for FORTRAN floating-point constants as described above. You may only use basic regular expression operators (concatenation `rs`, choice `r|s`, Kleene star `r*`) and the additional operators `r+` and `r?`. You may also specify character sets using the notation `[abw-z]`, and sets excluding specified characters `[^aeiou]`. Finally, you can name parts of the regular expression, like `vowel=[aeiou]`.

**dec = [ 0-9 ]+ . [ 0-9 ]* | [ 0-9 ]+**

**exp = [ eEdE ] [ + - ]? [0-9]+**

**float = {dec} {exp}? | [ 0-9 ]+ {exp}**

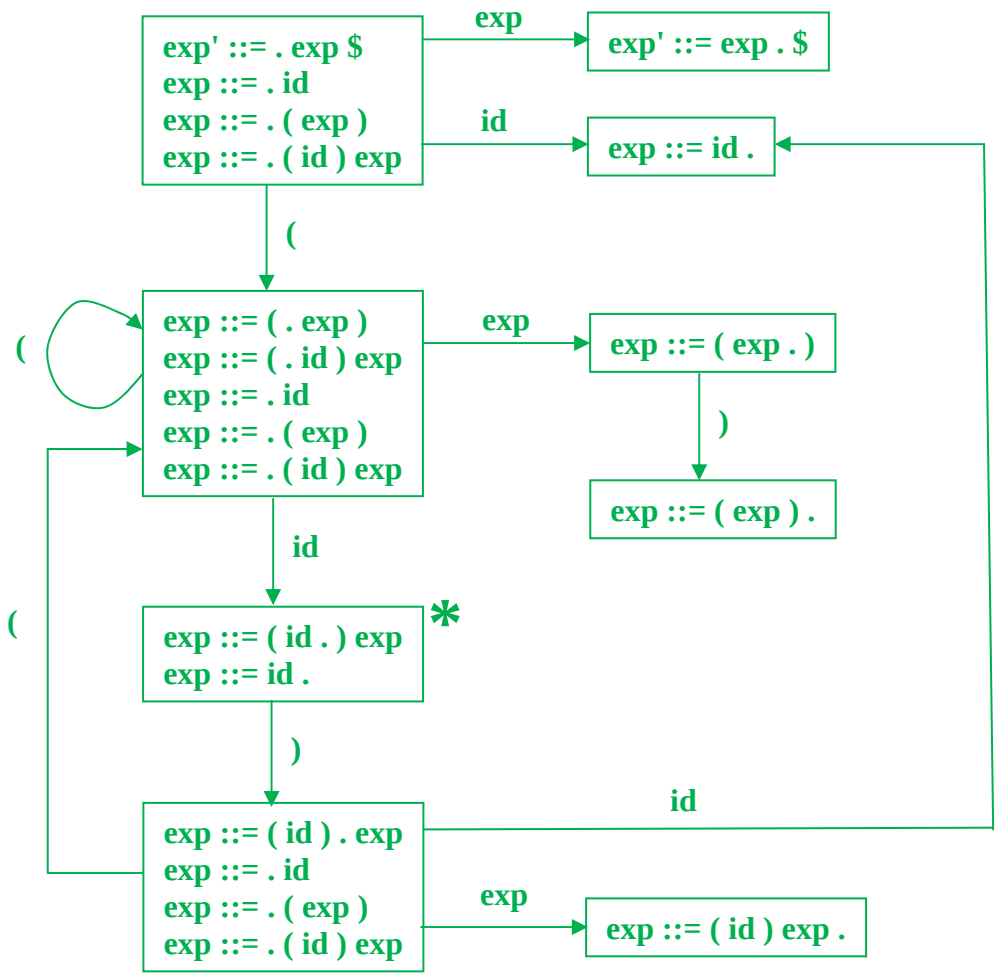
(b) (9 points) Draw a DFA (Deterministic Finite Automata) that recognizes FORTRAN floating-point constants as described in the problem and generated by the regular expression in your answer to part (a).



**Question 2.** (24 points) The you're-probably-not-surprised-to-see-it LR-parsing question. Here is a tiny grammar that gives the essence of expressions with optional parentheses and optional casts preceding the expression.

0. *exp'* ::= *exp* $
1. *exp* ::= `id`
2. *exp* ::= `(` *exp* `)`
3. *exp* ::= `(` `id` `)` *exp*

(a) (18 points) Draw the LR(0) state machine for this grammar. You do not need to write out the parser tables or first/follow/nullable sets, although you can do that if it helps you to answer the remaining parts of the question on the next page.




(continued on next page)

**Question 2. (cont.)** Grammar repeated from previous page for reference.

0. *exp′* ::= *exp* $
1. *exp* ::= `id`
2. *exp* ::= `(` *exp* `)`
3. *exp* ::= `(` `id` `)` *exp*

(b) (3 points) Is this grammar LR(0)? Why or why not?

**No. The state labeled * has a shift-reduce conflict.**

(c) (3 points) Is this grammar SLR? Why or why not?

**No. The grammar would be SLR if we could use the contents of FOLLOW(exp) to resolve the situation. But FOLLOW(exp) contains ')', so that doesn't get rid of the shift-reduce conflict in that state.**

**Question 3.** (16 points) Parsing tools. In CUP and similar tools we can use precedence declarations to resolve ambiguities and precedence issues in grammars. Here is a CUP specification for integer expressions with `PLUS` (`+`), `TIMES` (`*`), and `POWER` (`^`), where `PLUS` and `TIMES` associate to the left (i.e., `a+b+c` means `(a+b)+c`) and `POWER` (exponentiation) associates to the right (i.e., `a^b^c` means `a^(b^c)`). As usual, `TIMES` has higher precedence than `PLUS`, and `POWER` has the highest precedence. `INT` is the terminal symbol for integers.

```
precedence left PLUS;
precedence left TIMES;
precedence right POWER;

expr ::= expr PLUS expr | expr TIMES expr
      |  expr POWER expr | INT ;
```

For this problem, give an unambiguous context free grammar without precedence declarations that generates expressions with the same precedence and associativity as in the CUP specification above. You only need to give ordinary grammar rules – they do not need to be a properly formatted CUP specification.

(Hint: you may find it useful to introduce additional non-terminals into your grammar.)

**expr ::= term | expr PLUS term**

**term ::= expon | term TIMES expon**

**expon ::= INT | INT POWER expon**

Some short questions.

**Question 4.** (10 points) Compilers almost always do parsing and semantics/type checking in separate phases of the compiler. Give **two distinct** reasons why this separation into phases is done. Your reasons could be technical examples of things that can only be done in one phase but not the other, or engineering reasons why this is a good design, or similar persuasive arguments.

**Engineering: it is better modularity to separate the two jobs so the parser and semantics checker can each do one thing well. Easier to get right, easier to maintain, etc.**

**There are many things we need to check that aren't captured by a context-free specification. These either can't be done in the parser, or require a great deal of extra machinery or backtracking. Examples include checking whether variables are properly declared, checking for type compatibility in expressions and assignment statements, checking whether a method call has the right number and types of parameters, etc. Two of these reasons could have been used to answer the question.**

**Question 5.** (8 points) We suggested using at least two separate passes over the AST to check semantics and types in a MiniJava program. Why not do it in one pass? Is there some technical reason why two passes are needed or at least very helpful?

**In MiniJava, class names can be used before their classes are declared. A first pass to collect class names before a second pass doing detailed checking greatly simplifies the job. If we try to do it in one pass we have to be prepared to backtrack and recheck things once we find the declaration for a class whose name has been previously used.**

**Question 6.** (8 points) In full Java, the declaration of a field in a class can be preceded various modifiers. The possibilities are: `public, protected, private, static, final, transient,` and `volatile`. These modifiers may appear in any order. A compiler is required to check that in any single declaration no modifier appears more than once, and that at most one of the access modifiers `public`, `protected`, or `private` is used. Would it be best to put this check in the scanner, the parser, or in the static semantics part of the compiler? Give a technical justification for your answer.

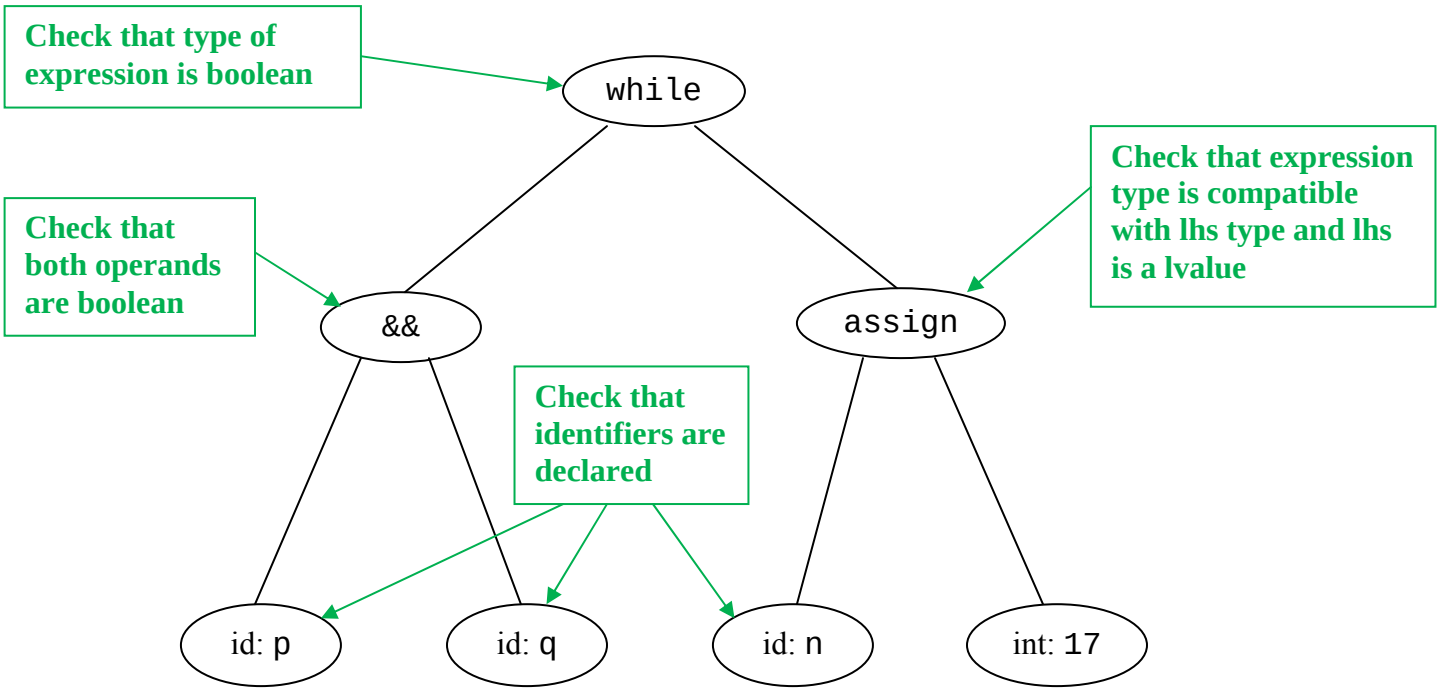
**The most reasonable place to do this is during the semantics pass.**

**The scanner can't do it since it has no context to interpret tokens.**

**It would be possible to construct a grammar that would accept only legal combinations of modifiers, but that would require an enormous number of rules to handle all possible permutations. It would be clumsy to put this in the parser, along with all of the redundant semantics action code associated with the grammar rules.**

**It's best to let the parser simply accept any sequence of modifiers, then have the semantics pass check that the rules about no duplicates are followed.**

**Question 7.** (16 points) Abstract syntax and semantics. Here is the abstract syntax for a fragment of a MiniJava program.




(a) (4 points) What is the Java source code that corresponds to this abstract syntax? i.e., what is the original concrete syntax fragment that the scanner and parser read to produce the above tree, including all necessary punctuation to make it legal Java code?

```
while (p && q)
  n = 17;
```

(b) (12 points) What checks need to be performed in the static semantics/typechecking phase of the compiler to verify that this abstract syntax is, in fact, legal and contains no type errors or other static semantics problems? A good way to show your answer is to annotate the above diagram to show the checks that need to be performed at each location in the AST. Or you can write your answer below.

**See diagram above.**