Department of Computer Science Columbia University

Sample Final – COMS W4115

Programming Languages and Translators

Wednesday, April 30, 2014 75 minutes

Closed book, no aids. Each question is worth 20 points.

1. Let *G* be the grammar

$$S \rightarrow A\ a\ A\ b \mid B\ b\ B\ a$$
$$A \rightarrow \varepsilon$$
$$B \rightarrow \varepsilon$$

   a) Is *G* LL(1)? Explain.
   b) Is *G* SLR(1)? Explain.

2. Consider the grammar `G: E -> E + E | E – E | a`.

   a) Construct all the different parse trees for `a - a + a`.
   b) Construct an equivalent unambiguous grammar that makes the operators + and – left associative and of the same precedence.
   c) Draw the parse tree according to your grammar for the input string `a - a + a`.
   d) Construct a syntax directed definition using your grammar that maps infix expressions into abstract syntax trees (ASTs).
   e) Show the AST that gets generated for the input string `a - a + a`.

3. a) Construct three-address code for the following program fragment. State what assumptions you are making.

```
prod = 0.0;
for (i = 0; i < 10; i++)
   prod = prod + a[i] * b[i];
```

   b) Construct a flow graph for your three-address code.

4. Draw a block diagram showing the six phases of a typical optimizing compiler. Describe the representation of the program before and after each phase. Which phase takes the most time when compiling a program?

5. Lambda calculus

a) Reduce the following lambda calculus expression into normal form using both normal order evaluation and applicative order evaluation:

$$\lambda z.\ (\ (\ \lambda x.\ (+\ x\ 3\ )\ )\ (\ \lambda y.\ (*\ y\ y\ )\ (a\ )\ )\ )$$

b) Let F be the lambda expression $\lambda t.\ (\lambda x.\ t(x\ x))\ (\lambda x.\ t(x\ x))$. Evaluate the expression FG where G is any lambda expression. What sort of behavior does F exhibit?