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The answers must be the original work of the author. While discussion with others is permitted and encouraged, the final work should be done individually. You are not allowed to work in groups. You are allowed to build on the material supplied in the class. Any other source must be specified clearly.

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1. (10+ 15+ 15 points) Consider the following grammar  $G$  over  $\Sigma = \{a, b, d, e, f\}$ .

$$S \rightarrow aaBS \mid aCbCC$$

$$B \rightarrow bB \mid b$$

$$C \rightarrow DE$$

$$D \rightarrow dDe \mid \lambda$$

$$E \rightarrow fE \mid \lambda$$

**Part a.** Transform the grammar into  $G_1$  so that the recursion to the start symbol is removed.

**Part b.** Show the set of nullable variables in the **new grammar**  $G_1$ .

**Part c.** Construct an essentially noncontracting grammar  $G_L$  (with a non-recursive start symbol) equivalent to  $G_1$ .

2. (10+15+15 points) Consider the following grammar:

$$S \rightarrow aSb \mid DEF \mid f$$

$$D \rightarrow EF \mid abEF$$

$$E \rightarrow eEff \mid \lambda$$

$$F \rightarrow ffFe \mid \lambda$$

**a.** Transform the grammar into  $G_1$  so that the recursion to the start symbol is removed.

**b.** Show the set of nullable variables in  $G_1$ .

**c.** Construct an essentially noncontracting grammar  $G_2$  (with a non-recursive start symbol) equivalent to  $G_1$ .

3. (10+10 points) Consider the following grammar  $G$ . Note that the grammar does not contain  $\lambda$ -rules except at  $S$ .

$$S \rightarrow aSb \mid DEF \mid D \mid \lambda$$

$$D \rightarrow E \mid EF \mid abEF$$

$$E \rightarrow eEff \mid a \mid F$$

$$F \rightarrow ffFe \mid a$$

**a.** Use algorithm 4.3.1 to construct the CHAIN sets for the variables in  $V$ .

**b.** Construct an equivalent grammar  $G_c$  that does not contain chain rules.