| CMSC 22610<br>Winter 2009 | Implementation of<br>Computer Languages - I | Homework 3<br>February 5, 2009 |
|---|---|---|

# Homework 3

**Due: February 19, 2009**

1. Give unambiguous grammars (and do not use Extended BNF) for the following languages:

   (a) Non-empty palindromes over the terminals $\{\texttt{0}, \texttt{1}\}$.

   (b) The language denoted by the regular expression $(\texttt{a} \cdot \texttt{b}^* \cdot \texttt{a}) \mid (\texttt{b} \cdot \texttt{a}^* \cdot \texttt{b})$ (over the alphabet $\{\texttt{a}, \texttt{b}\}$).

   (c) Strings where all **a**s preceed all **b**s and there are strictly more **a**s than **b**s over the terminals $\{\texttt{a}, \texttt{b}, \texttt{c}\}$.

   Hint: One way of verifying that a grammar is unambiguous is to run it through ML-Yacc or ML-Antlr and get no conflicts.

2. Consider the following grammar:

| Function-style prefix with $\{\wedge, \vee\}$-lists | | |
|---|---|---|
| $\hat{S}$ | $\rightarrow$ | $P$ **$** |
| $P$ | $\rightarrow$ | *var* |
| $P$ | $\rightarrow$ | $\neg$ **(** $P$ **)** |
| $P$ | $\rightarrow$ | $\wedge$ **(** $L$ **)** |
| $P$ | $\rightarrow$ | $\vee$ **(** $L$ **)** |
| $L$ | $\rightarrow$ | |
| $L$ | $\rightarrow$ | $P\ K$ |
| $K$ | $\rightarrow$ | |
| $K$ | $\rightarrow$ | **,** $P\ K$ |

   (a) Draw the *derivation tree* for the string $\wedge$ **(** $a$ **,** $\vee$ **(** $b$ **,** $\neg$ **(** $c$ **) ) )** **$**.

   (b) Compute $Nullable$, $First$, and $Follow$ for each non-terminal in the grammar. Use Figure 1.

   (c) Compute the $LL(1)$ parse table for the grammar. Use Figure 2.

   (d) Show the execution of the $LL(1)$ parsing algorithm when parsing the string $\wedge$ **(** $a$ **,** $\neg$ **(** $b$ **) ) $**. Use Figure 3.

   (e) The canonical $LR(0)$ states for the grammar are given in Figure 4. Compute the $LR(0)$ $Goto$ function for the grammar. Use Figure 5.

   (f) Compute the $LR(0)$ action and goto tables for the grammar. Use Figures 6 and 7. Is the grammar $LR(0)$?

   (g) Compute the $SLR$ action table for the grammar. Use Figure 8. (Recall: the $SLR$ goto table is the same as the $LR(0)$ goto table in Problem 2f.) Is the grammar $SLR$?

   (h) Show the execution of the $SLR$ parsing algorithm when parsing the string $\wedge$ **(** $a$ **,** $\neg$ **(** $b$ **) ) $**. Use Figure 9.

## Document history

**February 10, 2009**

Figure 4: $I_9 = \{[\underline{P \ \rightarrow \ \neg \ \texttt{(} \ . \ P \ \texttt{)}}]\} \Rightarrow I_9 = \{[\underline{P \ \rightarrow \ \wedge \ \texttt{(} \ L \ \texttt{)} \ .}]\}$

**February 5, 2009** Original version

| | *Nullable* | *First* | *Follow* |
|---|---|---|---|
| $\hat{S}$ | | | |
| $P$ | | | |
| $L$ | | | |
| $K$ | | | |

Figure 1: *Nullable*, *First*, *Follow* (for Problem 2b)



| | *var* | $\neg$ | $\wedge$ | $\vee$ | `(` | `)` | `,` | `$` |
|---|---|---|---|---|---|---|---|---|
| $\hat{S}$ | | | | | | | | |
| $P$ | | | | | | | | |
| $L$ | | | | | | | | |
| $K$ | | | | | | | | |

Figure 2: $LL(1)$ parse table (for Problem 2c)

| Stack | Input | Action |
|---|---|---|
| $\hat{S}$ | $\dot{\wedge}$ `(` $a$ `,` $\neg$ `(` $b$ `))` `$` | parse $\hat{S} \rightarrow P$ `$` |
| `$` $P$ | $\dot{\wedge}$ `(` $a$ `,` $\neg$ `(` $b$ `))` `$` | |
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Figure 3: Execution of $LL(1)$ parsing the string $\wedge$ `(` $a$ `,` $\neg$ `(` $b$ `))` `$` (for Problem 2d)

$$
\begin{aligned}
I_0 &= \{\underline{[\hat{S} \rightarrow . P \,\$]}, [P \rightarrow . var], [P \rightarrow . \neg \,(\, P \,)], [P \rightarrow . \wedge \,(\, L \,)], [P \rightarrow . \vee \,(\, L \,)]\} \\
I_1 &= \{\underline{[P \rightarrow var .]}\} \\
I_2 &= \{\underline{[P \rightarrow \neg . \,(\, P \,)]}\} \\
I_3 &= \{\underline{[P \rightarrow \wedge . \,(\, L \,)]}\} \\
I_4 &= \{\underline{[P \rightarrow \vee . \,(\, L \,)]}\} \\
I_5 &= \{\underline{[\hat{S} \rightarrow P . \,\$]}\} \\
I_6 &= \{\underline{[P \rightarrow \neg \,(\, . P \,)]}, [P \rightarrow . var], [P \rightarrow . \neg \,(\, P \,)], [P \rightarrow . \wedge \,(\, L \,)], [P \rightarrow . \vee \,(\, L \,)]\} \\
I_7 &= \{\underline{[P \rightarrow \wedge \,(\, . L \,)]}, [L \rightarrow .], [L \rightarrow . P\, K], [P \rightarrow . var], [P \rightarrow . \neg \,(\, P \,)], [P \rightarrow . \wedge \,(\, L \,)], [P \rightarrow . \vee \,(\, L \,)]\} \\
I_8 &= \{\underline{[P \rightarrow \vee \,(\, . L \,)]}, [L \rightarrow .], [L \rightarrow . P\, K], [P \rightarrow . var], [P \rightarrow . \neg \,(\, P \,)], [P \rightarrow . \wedge \,(\, L \,)], [P \rightarrow . \vee \,(\, L \,)]\} \\
I_9 &= \{\underline{[P \rightarrow \wedge \,(\, L \,) .]}\} \\
I_{10} &= \{\underline{[L \rightarrow P . K]}, [K \rightarrow .], [K \rightarrow . \,,\, P\, K]\} \\
I_{11} &= \{\underline{[P \rightarrow \wedge \,(\, L . \,)]}\} \\
I_{12} &= \{\underline{[P \rightarrow \vee \,(\, L . \,)]}\} \\
I_{13} &= \{\underline{[P \rightarrow \neg \,(\, P . \,)]}\} \\
I_{14} &= \{\underline{[K \rightarrow \,, . P\, K]}, [P \rightarrow . var], [P \rightarrow . \neg \,(\, P \,)], [P \rightarrow . \wedge \,(\, L \,)], [P \rightarrow . \vee \,(\, L \,)]\} \\
I_{15} &= \{\underline{[L \rightarrow P\, K .]}\} \\
I_{16} &= \{\underline{[P \rightarrow \vee \,(\, L \,) .]}\} \\
I_{17} &= \{\underline{[P \rightarrow \neg \,(\, P \,) .]}\} \\
I_{18} &= \{\underline{[K \rightarrow \,, P . K]}, [K \rightarrow .], [K \rightarrow . \,,\, P\, K]\} \\
I_{19} &= \{\underline{[K \rightarrow \,, P\, K .]}\}
\end{aligned}
$$

Figure 4: Canonical $LR(0)$ states (for Problems 2e, 2f, 2g)

| | *Goto* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *var* | $\neg$ | $\wedge$ | $\vee$ | **(** | **,** | **)** | $\hat{S}$ | $P$ | $L$ | $K$ |
| $I_0$ | $I_1$ | $I_2$ | $I_3$ | $I_4$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $I_5$ | $\emptyset$ | $\emptyset$ |
| $I_1$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $I_2$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $I_6$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |
| $I_3$ | | | | | | | | | | | |
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| $I_{17}$ | | | | | | | | | | | |
| $I_{18}$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $I_{14}$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $I_{19}$ |
| $I_{19}$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ | $\emptyset$ |

Figure 5: $LR(0)$ $Goto$ function (for Problem 2e)

| | Action | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *var* | $\neg$ | $\wedge$ | $\vee$ | **(** | **,** | **)** | **$** |
| $I_0$ | s $I_1$ | s $I_2$ | s $I_3$ | s $I_4$ | | | | |
| $I_1$ | r $P \rightarrow var$ | r $P \rightarrow var$ | r $P \rightarrow var$ | r $P \rightarrow var$ | r $P \rightarrow var$ | r $P \rightarrow var$ | r $P \rightarrow var$ | r $P \rightarrow var$ |
| $I_2$ | | | | | s $I_6$ | | | |
| $I_3$ | | | | | | | | |
| $I_4$ | | | | | | | | |
| $I_5$ | | | | | | | | |
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| $I_{19}$ | | | | | | | | |

Figure 6: $LR(0)$ action table (for Problem 2f)

| | Goto | | | |
|---|---|---|---|---|
| | $\hat{S}$ | $P$ | $L$ | $K$ |
| $I_0$ | | g $I_5$ | | |
| $I_1$ | | | | |
| $I_2$ | | | | |
| $I_3$ | | | | |
| $I_4$ | | | | |
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Figure 7: $LR(0)$ goto table (for Problem 2f)

| | Action | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *var* | $\neg$ | $\wedge$ | $\vee$ | **(** | **,** | **)** | **$** |
| $I_0$ | s $I_1$ | s $I_2$ | s $I_3$ | s $I_4$ | | | | |
| $I_1$ | | | | | | | | |
| $I_2$ | | | | | | | | |
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Figure 8: $SLR$ action table (for Problem 2g)

| Stack | Input | Action |
|---|---|---|
| $I_0$ | $\dot{\wedge}$ `(` $a$ `,` $\neg$ `(` $b$ `)` `)` `$` | shift $I_3$ |
| $I_0\ I_3$ | $\dot{\texttt{(}}$ $a$ `,` $\neg$ `(` $b$ `)` `)` `$` | |
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Figure 9: Execution of $SLR$ parsing the string $\wedge$ `(` $a$ `,` $\neg$ `(` $b$ `)` `)` `$` (for Problem 2h)