Section: LR Parsing

LR PARSING

LR(k) Parser

- bottom-up parser
- shift-reduce parser
- L means: reads input left to right
- R means: produces a rightmost derivation
- k - number of lookahead symbols

LR parsing process

- convert CFG to PDA
- Use the PDA and lookahead symbols
Convert CFG to PDA

The constructed NPDA:

- three states: s, q, f
  start in state s, assume z on stack
- all rewrite rules in state s,
  backwards
  rules pop rhs, then push lhs
  \((s, \text{lhs}) \in \delta(s, \lambda, \text{rhs})\)
  This is called a reduce operation.
- additional rules in s to recognize terminals
  For each \(x \in \Sigma, \ g \in \Gamma, \ (s, xg) \in \delta(s, x, g)\)
  This is called a shift operation.
- pop S from stack and move into state q
- pop z from stack, move into f, accept.
Example: Construct a PDA.

\[ S \rightarrow aSb \]
\[ S \rightarrow b \]
LR Parsing Actions

1. shift
   transfer the lookahead to the stack
2. reduce
   For $X \rightarrow w$, replace $w$ by $X$ on the stack
3. accept
   input string is in language
4. error
   input string is not in language

LR(1) Parse Table

- Columns:
  terminals, $\$ and variables
- Rows:
  state numbers: represent patterns in a derivation
LR(1) Parse Table Example

1) $S \rightarrow aSb$
2) $S \rightarrow b$

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>b</th>
<th>$</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>s2</td>
<td>s3</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>acc</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>s2</td>
<td>s3</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>r2</td>
<td>r2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>s5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>r1</td>
<td>r1</td>
<td></td>
</tr>
</tbody>
</table>

Definition of entries:

- $sN$ - shift terminal and move to state $N$
- $N$ - move to state $N$
- $rN$ - reduce by rule number $N$
- $\text{acc}$ - accept
- $\text{blank}$ - error
state = 0
push(state)
read(symbol)
entry = T[state,symbol]
while entry.action \neq accept do
    if entry.action == shift then
        push(symbol)
        state = entry.state
        push(state)
        read(symbol)
    else if entry.action == reduce then
        do 2*size_rhs times {pop()}
        state := top-of-stack()
        push(entry.rule.lhs)
        state = T[state,entry.rule.lhs]
        push(state)
    else if entry.action == blank then
        error
        entry = T[state, symbol]
    end while
if symbol \neq $ then error
Example:

Trace aabbb

```
5
b
3 4 4 5
b S S b
2 2 2 2 4 4
a a a a a S S
2 2 2 2 2 2 2 2 1
a a a a a a a a S
0 0 0 0 0 0 0 0 0 0
S: z z z z z z z z z z
L: a a b b b b b b b $ $
A: sh sh sh r sh r sh r acc
```
To construct the LR(1) parse table:

- Construct a dfa to model the top of the stack
- Using the dfa, construct an LR(1) parse table

To Construct the DFA

- Add $S' \rightarrow S$
- place a marker “_” on the rhs $S' \rightarrow _S$
- Compute closure($S' \rightarrow _S$).

Def. of closure:

1. $\text{closure}(A \rightarrow v_{xy}) = \{A \rightarrow v_{xy}\}$ if $x$ is a terminal.
2. $\text{closure}(A \rightarrow v_{xy}) = \{A \rightarrow v_{xy}\} \cup (\text{closure}(x \rightarrow _w) \text{ for all } w \text{ if } x \text{ is a variable.})
• The closure($S' \to _S$) is state 0 and “unprocessed”.

• Repeat until all states have been processed
  – unproc = any unprocessed state
  – For each $x$ that appears in $A \to u_xv$ do
  * Add a transition labeled “$x$” from state “unproc” to a new state with production $A \to u_xv$
  * The set of productions for the new state are: closure($A \to u_xv$)
  * If the new state is identical to another state, combine the states Otherwise, mark the new state as “unprocessed”

• Identify final states.
Example: Construct DFA

(0) \( S' \rightarrow S \)
(1) \( S \rightarrow aSb \)
(2) \( S \rightarrow b \)
Backtracking through the DFA

Consider aabbb

- Start in state 0.
- Shift “a” and move to state 2.
- Shift “a” and move to state 2.
- Shift “b” and move to state 3.
  Reduce by “S → b”
  Pop “b” and Backtrack to state 2.
- Shift “S” and move to state 4.
- Shift “b” and move to state 5.
  Reduce by “S → aSb”
  Pop “aSb” and Backtrack to state 2.
- Shift “S” and move to state 4.
- Shift “b” and move to state 5.
  Reduce by “S → aSb”
  Pop “aSb” and Backtrack to state 0.
Shift “S” and move to state 1.

- Accept. aabbb is in the language.
To construct LR(1) table from diagram:

1. If there is an arc from state1 to state2
   (a) arc labeled x is terminal or $ T[state1, x] = sh state2$
   (b) arc labeled X is nonterminal
       $ T[state1, X] = state2$

2. If state1 is a final state with $X \rightarrow w$
   For all a in $FOLLOW(X)$,
   $ T[state1,a] = reduce by X \rightarrow w$

3. If state1 is a final state with $S' \rightarrow S$
   $ T[state1,\$] = accept$

4. All other entries are error
Example: LR(1) Parse Table

(0) \( S' \rightarrow S \)
(1) \( S \rightarrow aSb \)
(2) \( S \rightarrow b \)

Here is the LR(1) Parse Table with extra information about the stack contents of each state.

<table>
<thead>
<tr>
<th>Stack contents</th>
<th>State number</th>
<th>Terminals</th>
<th>Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>(empty)</td>
<td>0</td>
<td>( S_2 ), ( S_3 )</td>
<td>(a, c)</td>
</tr>
<tr>
<td>( S )</td>
<td>1</td>
<td>( S_2 ), ( S_3 )</td>
<td>(a, c)</td>
</tr>
<tr>
<td>( a, a \times )</td>
<td>2</td>
<td>( S_2 ), ( S_3 )</td>
<td>(a, c)</td>
</tr>
<tr>
<td>( b + a \times b )</td>
<td>3</td>
<td>( S_3 ), ( R_2 ), ( R_2 )</td>
<td>(a, c)</td>
</tr>
<tr>
<td>( a \times S )</td>
<td>4</td>
<td>( S_5 )</td>
<td>(a, c)</td>
</tr>
<tr>
<td>( a \times S_6 )</td>
<td>5</td>
<td>( S_1 ), ( R_1 ), ( R_1 )</td>
<td>(a, c)</td>
</tr>
</tbody>
</table>
Actions for entries in LR(1) Parse table $T[\text{state, symbol}]$

Let entry $= T[\text{state, symbol}]$.

- If symbol is a terminal or $\$$
  - If entry is “shift state $i$”
    push lookahead and state $i$ on the stack
  - If entry is “reduce by rule $X \rightarrow w$”
    pop $w$ and $k$ states ($k$ is the size of $w$) from the stack.
  - If entry is “accept”
    Halt. The string is in the language.
  - If entry is “error”
    Halt. The string is not in the language.
• If symbol is nonterminal
  We have just reduced the rhs of a production $X \rightarrow w$ to a symbol. The entry is a state number, call it state$_i$. Push $T[\text{state}_i, X]$ on the stack.
Constructing Parse Tables for CFG’s with $\lambda$-rules

$A \rightarrow \lambda$ written as $A \rightarrow \lambda$

Example

\[
\begin{align*}
S & \rightarrow \text{dd}X \\
X & \rightarrow aX \\
X & \rightarrow \lambda
\end{align*}
\]

Add a new start symbol and number the rules:

\[
\begin{align*}
(0) & \quad S' \rightarrow S \\
(1) & \quad S \rightarrow \text{dd}X \\
(2) & \quad X \rightarrow aX \\
(3) & \quad X \rightarrow \lambda
\end{align*}
\]

Construct the DFA:
Construct the LR(1) Parse Table

<table>
<thead>
<tr>
<th></th>
<th>a</th>
<th>d</th>
<th>$</th>
<th>S</th>
<th>X</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td></td>
<td></td>
<td>$2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td>acc</td>
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</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td>$3</td>
<td></td>
<td></td>
</tr>
<tr>
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<td>$5</td>
<td>r3</td>
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<td>$5</td>
<td>r3</td>
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</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td>r2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Possible Conflicts:

1. Shift/Reduce Conflict
   Example:
   
   \[ A \rightarrow ab \]
   \[ A \rightarrow abcd \]

   In the DFA:
   
   \[ A \rightarrow ab_ \]
   \[ A \rightarrow ab_ cd \]

2. Reduce/Reduce Conflict
   Example:
   
   \[ A \rightarrow ab \]
   \[ B \rightarrow ab \]

   In the DFA:
   
   \[ A \rightarrow ab_ \]
   \[ B \rightarrow ab_ \]

3. Shift/Shift Conflict