بسم اللّه الرّحمن الرّحیم

دانشگاه صنعتی اصفهان ـ دانشکدهٔ مهندسی برق و کامپیوتر
(نیم‌سال تحصیلی ۴۰۲۲)

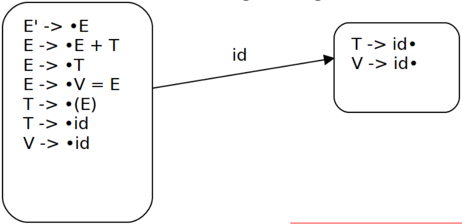
کامپایلر

حسین فلسفین

مثالی دیگر از یک گرامر که LR(0) نیست اما SLR(1) هست

```
E' -> E
E  -> E + T  | T | V = E
T  -> (E) | id
V  -> id
```

Here are the first two LR(0) configurating sets entered if id is the first token of the input.

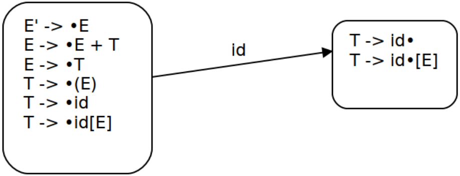


In an LR(0) parser, the set on the right has a reduce-reduce conflict. However, an SLR(1) parser will compute Follow(T) = { +) $ } and Follow(V) = { = } and thus can distinguish which reduction to apply depending on the next input token. The modified grammar is SLR(1).

مثالی دیگر از یک گرامر که LR(0) نیست اما SLR(1) هست

```
E' -> E
E  -> E + T  | T
T  -> (E) | id | id[E]
```

Here are the first two LR(0) configurating sets entered if id is the first token of the input.



In an LR(0) parser, the set on the right has a shift-reduce conflict. However, an SLR(1) will compute Follow(T) = { +)] $ } and only enter the reduce action on those tokens. The input [will shift and there is no conflict. Thus this grammar is SLR(1) even though it is not LR(0).

More Powerful LR Parsers

We shall extend the previous LR parsing techniques to use one symbol of lookahead on the input. There are two different methods:

1. The "canonical-LR" or just "LR" method, which makes full use of the lookahead symbol(s). This method uses a large set of items, called the $\mathrm{LR}(1)$ *items.*

2. The "lookahead-LR" or "LALR*" method, which is based on the* $\mathrm{LR}(0)$ *sets of items, and has many fewer states than typical parsers based on the* $\mathrm{LR}(1)$ *items. By carefully introducing lookaheads into the* $\mathrm{LR}(0)$ *items, we can handle many more grammars with the* LALR *method than with the* SLR *method, and build parsing tables that are no bigger than the* SLR *tables.* LALR *is the method of choice in most situations.*

$\mathrm{LR}(1)$ *items;* $\mathrm{LR}(1)$ *parsing table*

Even more powerful than SLR *is the* $\mathrm{LR}(1)$ *parsing algorithm. Most programming languages whose syntax is describable by a context-free grammar have an* $\mathrm{LR}(1)$ *grammar. The algorithm for constructing an* $\mathrm{LR}(1)$ *parsing table is similar to that for* $\mathrm{LR}(0)$*, but the notion of an item is more sophisticated.*

> *An* $\mathrm{LR}(1)$ *item consists of a grammar production, a right-hand-side position (represented by the dot), and a lookahead symbol.*

The idea is that an item $[A \to \alpha \bullet \beta, x]$ *indicates that the sequence* α *is on top of the stack, and at the head of the input is a string derivable from* βx*.*

Canonical LR(1) *Items*

We shall now present the most general technique for constructing an LR parsing table from a grammar. Recall that in the SLR *method, state i calls for reduction by $A \to \alpha$ if the set of items I_i contains item $[A \to \alpha\bullet]$ and input symbol a is in* $\mathrm{FOLLOW}(A)$*. In some situations, however, when state i appears on top of the stack, the viable prefix $\beta\alpha$ on the stack is such that βA cannot be followed by a in any right-sentential form. Thus, the reduction by $A \to \alpha$ should be invalid on input a.*

It is possible to carry more information in the state that will allow us to rule out some of these invalid reductions by $A \to \alpha$. By splitting states when necessary, we can arrange to have each state of an LR parser indicate exactly which input symbols can follow a handle α for which there is a possible reduction to A.

The extra information is incorporated into the state by redefining items to include a terminal symbol as a second component. The general form of an item becomes $[A \to \alpha \bullet \beta, a]$, where $A \to \alpha\beta$ is a production and a is a terminal or the right end-marker $\$$. We call such an object an $\mathrm{LR}(1)$ item. The 1 refers to the length of the second component, called the lookahead of the item.

Lookaheads that are strings of length greater than one are possible, of course, but we shall not consider such lookaheads here.

The $\mathrm{LR}(1)$ ***technique does not rely on*** FOLLOW ***sets, but rather keeps the specific lookahead with each item. We will write an*** $\mathrm{LR}(1)$ ***item thus:*** $[A \to \alpha \bullet \beta, S]$***, in which*** S ***is the set of tokens that can follow this specific item. When the dot has reached the end of the item, as in*** $[A \to \alpha\beta\bullet, S]$***, the item is an acceptable reduce item only if the lookahead at that moment is in*** S***; otherwise the item is ignored.***

The $\mathrm{LR}(1)$ Canonical Collection

The $\mathrm{LR}(1)$ parsing tables, ACTION and GOTO, for a grammar G are derived from a DFA for recognizing the possible handles for a parse in G. This DFA is constructed from what is called an $\mathrm{LR}(1)$ canonical collection, in turn a collection of sets of items of the form

$$[Y \to \alpha \bullet \beta, a]$$

where $Y \to \alpha\beta$ is a production rule in the set of productions P, α and β are (possibly empty) strings of symbols, and a is a lookahead. The item represents a potential handle. The $\bullet$ is a position marker that marks the top of the stack, indicating that we have parsed the α and still have the β ahead of us in satisfying the Y. The lookahead symbol, a, is a token that can follow Y (and so, $\alpha\beta$) in a legal right-most derivation of some sentence.

☞ *If the position marker comes at the start of the right-hand side in an item, $[Y \rightarrow \bullet\alpha\beta, a]$ the item is called a possibility. One way of parsing the Y is to first parse the α and then parse the β, after which point the next incoming token will be an a. The parse might be in the following configuration:*

Stack: $\$\gamma$ **Input:** $ua\ldots$

where $\alpha\beta \Rightarrow^* u$, where u is a string of terminals.

☞ *If the position marker comes after a string of symbols α but before a string of symbols β in the right-hand side in an item, $[Y \rightarrow \alpha \bullet \beta, a]$ the item indicates that α has been parsed (and so is on the stack) but that there is still β to parse from the input:*

Stack: $\$\gamma\alpha$ **Input:** $va\ldots$

where $\beta \Rightarrow^* v$, where v is a string of terminals.

☞ ***If the position marker comes at the end of the right-hand side in an item, $[Y \to \alpha\beta \bullet , a]$ the item indicates that the parser has successfully parsed $\alpha\beta$ in a context where Ya would be valid, the $\alpha\beta$ can be reduced to a Y, and so $\alpha\beta$ is a handle. That is, the parse is in the configuration***

Stack: $\$\gamma\alpha\beta$ ***Input:*** $a \ldots$

and the reduction of $\alpha\beta$ would cause the parser to go into the configuration

Stack: $\$\gamma Y$ ***Input:*** $a \ldots$

مجموعهٔ aهای نظیر آیتم‌های $[A \to \alpha\bullet, a]$ همواره زیرمجموعهٔ $\mathrm{FOLLOW}(A)$ است

The lookahead has no effect in an item of the form $[A \to \alpha \bullet \beta, a]$, where β is not ε, but an item of the form $[A \to \alpha\bullet, a]$ calls for a reduction by $A \to \alpha$ only if the next input symbol is a. Thus, we are compelled to reduce by $A \to \alpha$ only on those input symbols a for which $[A \to \alpha\bullet, a]$ is an $\mathrm{LR}(1)$ item in the state on top of the stack. The set of such a's will always be a subset of $\mathrm{FOLLOW}(A)$, but it could be a proper subset, as in Example 4.51.

Computing the Closure of a Set of Items

SetOfItems $\text{CLOSURE}(I)$ {
    repeat
        for (each item $[A \to \alpha{\cdot}B\beta, a]$ in I)
            for (each production $B \to \gamma$ in G')
                for (each terminal b in $\text{FIRST}(\beta a)$)
                    add $[B \to {\cdot}\gamma, b]$ to set I;
    until no more items are added to I;
    return I;
}

Closure(I) =
  repeat
    for any item $(A \to \alpha.X\beta, z)$ in I
      for any production $X \to \gamma$
        for any $w \in \text{FIRST}(\beta z)$
          $I \leftarrow I \cup \{(X \to .\gamma,\ w)\}$
  until I does not change
  return I

Computing GOTO

SetOfItems $\text{GOTO}(I, X)$ {
    initialize J to be the empty set;
    for (each item $[A \to \alpha{\cdot}X\beta, a]$ in I)
        add item $[A \to \alpha X{\cdot}\beta, a]$ to set J;
    return $\text{CLOSURE}(J)$;
}

Goto$(I, X) =$
  $J \leftarrow \{\}$
  for any item $(A \to \alpha.X\beta,\ z)$ in I
    add $(A \to \alpha X.\beta,\ z)$ to J
  return Closure(J).

Computing the $\mathrm{LR}(1)$ *Collection*

```
void items(G') {
      initialize C to {CLOSURE({[S' → ·S, $]})};
      repeat
            for ( each set of items I in C )
                  for ( each grammar symbol X )
                        if ( GOTO(I, X) is not empty and not in C )
                              add GOTO(I, X) to C;
      until no new sets of items are added to C;
}
```