

Curs 8

LR(k) parsing

Terms

Reminder:

rhp = right handside of production

lhp = left handside of production

- Prediction – see LL(1)
- Handle = symbols from the head of the working stack that form (in order) a rhp
- ***Shift – reduce*** parser:
- **shift** symbols to form a handle
- When a rhp is formed – **reduce** to the corresponding lhp

LR(k)

- L = left – sequence is read from left to right
- R = right – use rightmost derivations
- k = length of prediction
- Enhanced grammar
- $G = (N, \Sigma, P, S)$
- $G' = (N \cup \{S'\}, \Sigma, P \cup \{S' \rightarrow S\}, S'), S' \notin N$

S' does NOT appear in any rhp

- **Definition 1:** If in a gfg $G = (N, \Sigma, P, S)$ we have

$S \xRightarrow{*}_r \alpha A w \Rightarrow_r \alpha \beta w$, where $\alpha \in (N \cup \Sigma)^*$, $A \in N$, $w \in \Sigma^*$, then

any prefix of sequence $\alpha\beta$ is called **live prefix** in G .

- **Definition 2:** **LR(k) item** is defined as $[A \rightarrow \alpha.\beta, u]$, where $A \rightarrow \alpha\beta$ is a production, $u \in \Sigma^k$ and describe the moment in which, considering the production $A \rightarrow \alpha\beta$, α was detected (α is in head of stack) and it is expected to detect β .

- **Definition 3:** LR(k) item $[A \rightarrow \alpha.\beta, u]$ is **valid for the live prefix** $\gamma\alpha$ if:

$$\begin{aligned} S &\xRightarrow{*}_r \gamma A w \Rightarrow_r \gamma \alpha \beta w \\ u &= \text{FIRST}_k(w) \end{aligned}$$

Definition 4: A cfg $G = (N, \Sigma, P, S)$ is LR(k), for $k \geq 0$, if

1. $S' \xRightarrow{*}_r \alpha A w \Rightarrow_r \alpha \beta w$
 2. $S' \xRightarrow{*}_r \gamma B x \Rightarrow_r \alpha \beta y$
 3. $\text{FIRST}_k(w) = \text{FIRST}_k(y)$
- $\Rightarrow \alpha = \gamma \text{ AND } A = B \text{ AND } x = y$

- $[A \rightarrow \alpha\beta., u]$ – rhp detected - apply reduce
- $[A \rightarrow \alpha.\beta, u]$ - shift

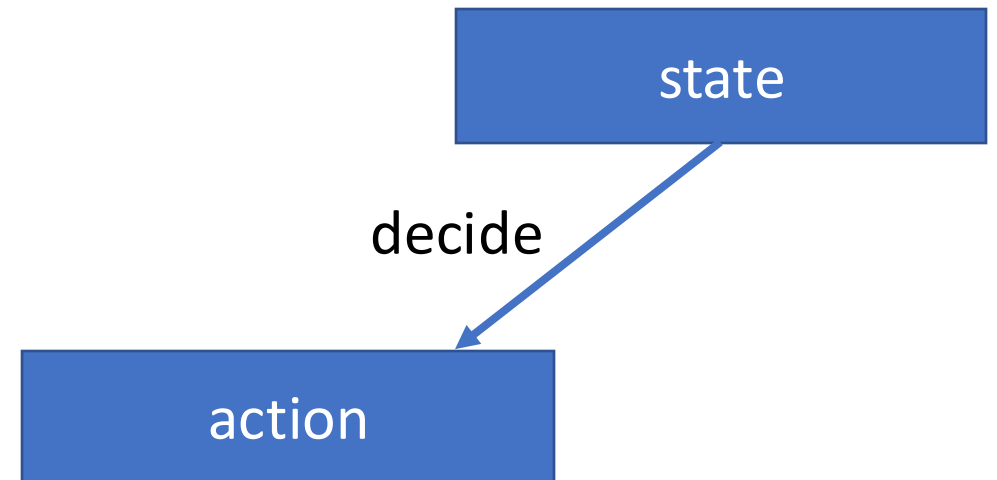
\Rightarrow Working stack:

$\$s_{\text{init}}X_1s_1 \dots X_ms_m$

where: \$ - mark empty stack

$X_i \in N \cup \Sigma$

s_i - states



LR(k) principle

- Current state
- Current symbol
- prediction

uniquely determines:

- Action to be applied
- Move to a new state

=> LR(k) table – 2 parts: **action** part + **goto** part

LR(k) parsing: LR(0), SLR, LR(1), LALR

- Define item
- Construct set of states
- Construct table

Executed 1 time

-
- Parse sequence based on moves between configurations

LR(0) Parser

- Prediction of length 0 (ignored)

1. LR(0) item: $[A \rightarrow \alpha.\beta]$

States

What a state contains?

- LR items
- *closure*

How many states? How to go from one state to another state?

- *goto*

- $[A \rightarrow \alpha.B\beta, u]$ valid for live prefix $\gamma\alpha \Rightarrow$

$$S \xRightarrow{*}_{dr} \gamma Aw \Rightarrow_{dr} \gamma\alpha B\beta w$$

$$u = FIRST_k(w)$$

- $B \rightarrow \delta \in P \Rightarrow S \xRightarrow{*} \gamma Aw \Rightarrow_{dr} \gamma\alpha B\beta w \Rightarrow_{dr} \gamma\alpha\delta\beta w.$

$\Rightarrow [B \rightarrow .\delta, u]$ valid for live prefix $\gamma\alpha$

2. Construct set of states

- What a state contains – Algorithm *closure_LR0*
- How to move from a state to another – Function *goto_LR0*
- Construct set of states – Algorithm *ColCan_LR0*

Canonical collection

Algorithm *Closure_LR(0)*

INPUT: I-element de analiză; G' - gramatica îmbogățită

OUTPUT: $C = \text{closure}(I)$;

$C := \{I\}$;

repeat

for $\forall [A \rightarrow \alpha.B\beta] \in C$ **do**

for $\forall B \rightarrow \gamma \in P$ **do**

if $[B \rightarrow \cdot\gamma] \notin C$ **then**

$C = C \cup [B \rightarrow \cdot\gamma]$

end if

end for

end for

until C nu se mai modifică

Function *goto*_{LR(0)}

$\text{goto} : P(\mathcal{E}_0) \times (N \cup \Sigma) \rightarrow P(\mathcal{E}_0)$

where \mathcal{E}_0 = set of LR(0) items

$\text{goto}(s, X) = \text{closure}(\{[A \rightarrow \alpha X \beta] \mid [A \rightarrow \alpha \cdot X \beta] \in s\})$

Algorithm *ColCan_LR(0)*

INPUT: G' - gramatica îmbogățită

OUTPUT: C - colecția canonică de stări

$C := \emptyset;$

$s_0 := closure(\{[S' \rightarrow .S]\})$

$C := C \cup \{s_0\};$

repeat

for $\forall s \in C$ **do**

for $\forall X \in N \cup \Sigma$ **do**

if $goto(s, X) \neq \emptyset$ and $goto(s, X) \notin C$ **then**

$C = C \cup goto(s, X)$

end if

end for

end for

until C nu se mai modifică

3. Construct LR(0) table

- one line for each state
- 2 parts:
 - Action: one column (for a state, action is unique because prediction is ignored)
 - Goto: one column for each symbol $X \in N \cup \Sigma$

Rules LR(0) table

1. *if $[A \rightarrow \alpha.\beta] \in s_i$ then **action**(s_i)=shift*
2. *if $[A \rightarrow \beta.] \in s_i$ and $A \neq S'$ then **action**(s_i)=reduce l , where l = number of production $A \rightarrow \beta$*
3. *if $[S' \rightarrow S.] \in s_i$ then **action**(s_i)=acc*
4. *if $\text{goto}(s_i, X) = s_j$ then **goto**(s_i, X) = s_j*
5. otherwise = **error**

Remarks

- 1) Initial state of parser = state containing $[S' \rightarrow .S]$
- 2) No shift from accept state:
if s is accept state then $\text{goto}(s, X) = \emptyset, \forall X \in N \cup \Sigma$.
- 3) *If in state s action is reduce then $\text{goto}(s, X) = \emptyset, \forall X \in N \cup \Sigma$.*
- 4) Argument G' : Let $G = (\{S\}, \{a, b, c\}, \{S \rightarrow aSbS, S \rightarrow c\}, S)$
states $[S \rightarrow aSbS.]$ and $[S \rightarrow c.]$ – accept / reduce ?

Remarks (cont)

- 5) A grammar is NOT LR(0) if the LR(0) table contains conflicts:
- shift – reduce conflict: a state contains items of the form $[A \rightarrow \alpha.\beta]$ and $[B \rightarrow \gamma.]$, yielding to 2 distinct actions for that state
 - reduce – reduce conflict: when a state contains items of the form $[A \rightarrow \alpha\beta.]$ and $[B \rightarrow \gamma.]$, in which the action is reduce, but with distinct productions

4. Define configurations and moves

- INPUT:

- Grammar $G' = (N \cup \{S'\}, \Sigma, P \cup \{S' \rightarrow S\}, S')$
- LR(0) table
- Input sequence $w = a_1 \dots a_n$

- OUTPUT:

if ($w \in L(G)$) ***then* string of productions**
***else* error & location of error**

LR(0) configurations

(α, β, π)

where:

- α = working stack
- β = input stack
- π = output (result)

Initial configuration:
 $(\$s_0, w\$, \varepsilon)$

Final configuration:
 $(\$s_{acc}, \$, \pi)$

Moves

1. Shift

if $\text{action}(s_m) = \text{shift}$ **AND** $\text{head}(\beta) = a_i$ **AND** $\text{goto}(s_m, a_i) = S_j$ **then**

$$(\$s_0 x_1 \dots x_m s_m, a_i \dots a_n \$, \pi) \vdash (\$s_0 x_1 \dots x_m s_m a_i s_j, a_{i+1} \dots a_n \$, \pi)$$

2. Reduce

if $\text{action}(s_m) = \text{reduce } l$ **AND** $(l) A \rightarrow x_{m-p+1} \dots x_m$ **AND** $\text{goto}(s_{m-p}, A) = s_j$ **then**

$$(\$s_0 \dots x_m s_m, a_i \dots a_n \$, \pi) \vdash (\$s_0 \dots x_{m-p} s_{m-p} A s_j, a_i \dots a_n \$, l \pi)$$

3. Accept

if $\text{action}(s_m) = \text{accept}$ **then** $(\$s_m, \$, \pi) = \text{acc}$

4. Error - otherwise

LR(0) Parsing Algorithm

INPUT:

- LR(0) table – conflict free
- grammar G' : production numbered
- - sequence = Input sequence $w = a_1 \dots a_n$

• OUTPUT:

if ($w \in L(G)$) *then* **string of productions**
else **error & location of error**

LR(0) Parsing Algorithm

```
state := 0;
alpha := '$s0'; beta := 'w$'; phi := ""; end := false
Repeat
    if action(state) = 'shift' then
        t = pop(beta);
        state = goto(state, t)
        push(t, state, alpha);
    else
```

```
        if action(state) = 'reduce l' then
            search_prod(t, rhp, lhp);
            pop(rhp, alpha);
            state = goto(head(alpha.state), lhp);
            push(lhp, state, alpha);
            push(t, phi);
        else
            if action(state) = 'accept' then
                write(" success", out);
                end := true;
            if action(state) = 'error' then
                write(" error")
                end := true
```

Until end