语法分析
(3. Adaptive $LL(*)$ 语法分析算法)

魏恒峰

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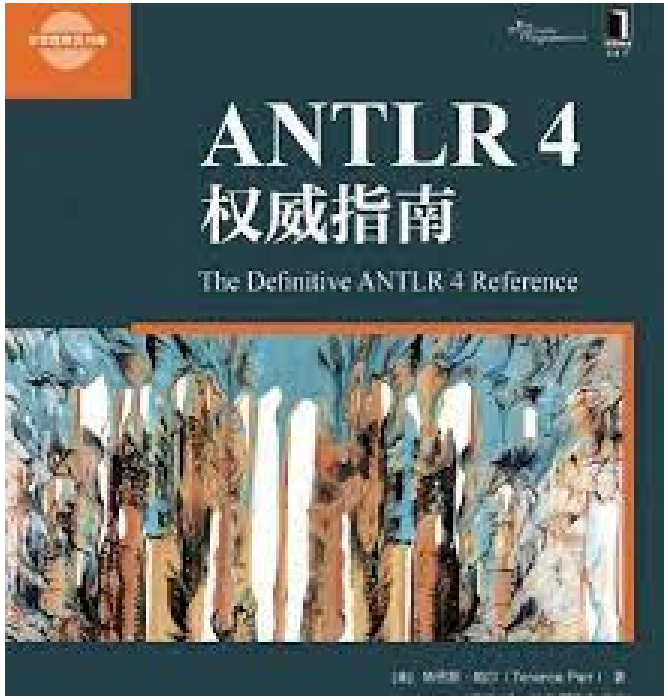
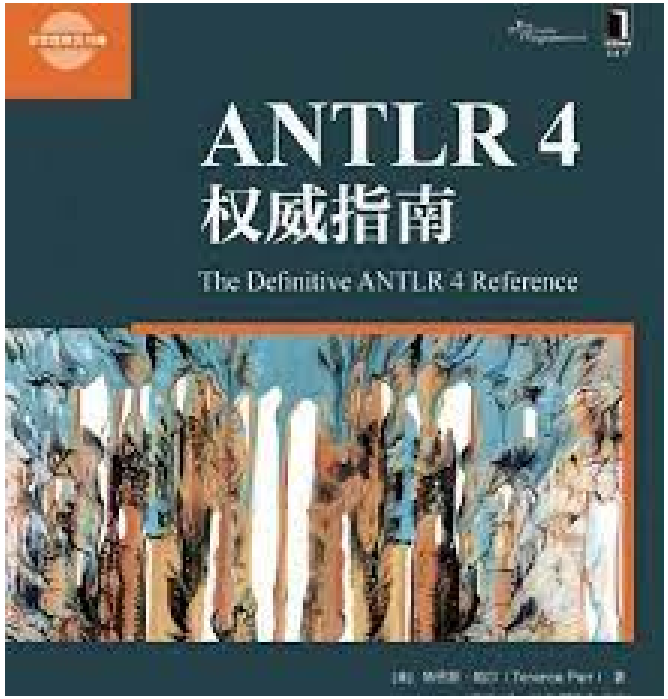
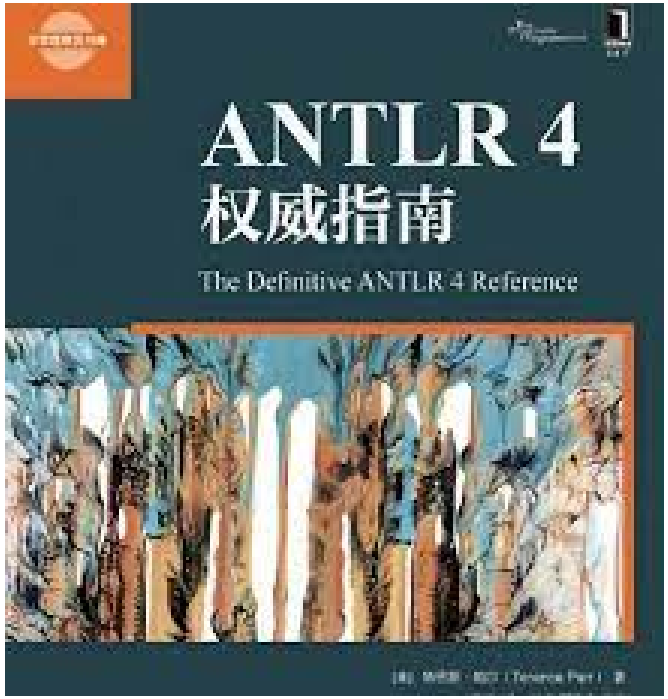
2022 年 11 月 30 日


ANTLR 4
权威指南
The Definitive ANTLR 4 Reference

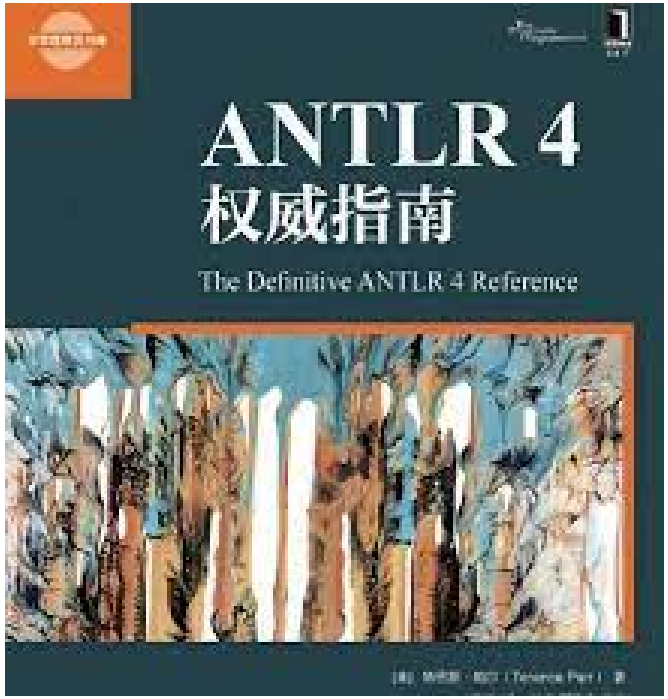


(1) ANTLR 4 自动将类似 `expr` 的左递归规则重写成非左递归形式



(1) ANTLR 4 自动将类似 `expr` 的左递归规则重写成非左递归形式

(2) ANTLR 4 提供优秀的错误报告功能和复杂的错误恢复机制



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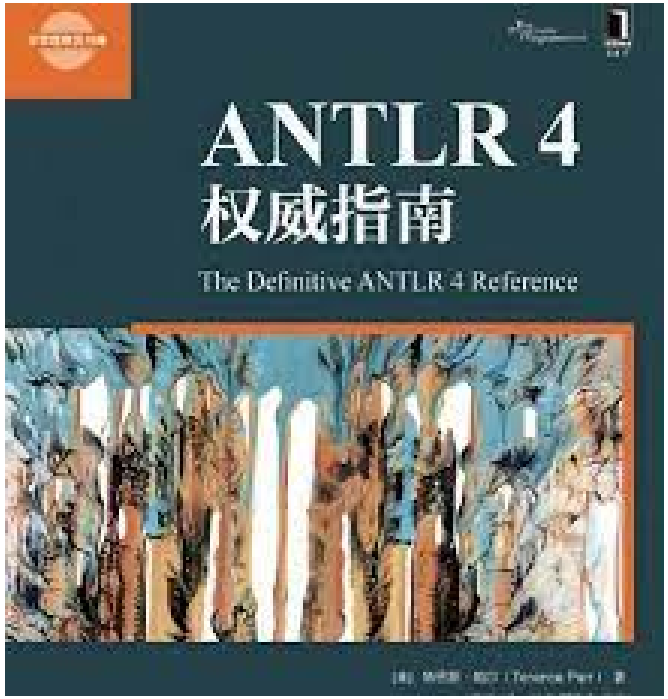

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(4) ANTLR 4 几乎能处理任何文法 (二义性文法✓　间接左递归✗)

(1995 2011 2014)

ANTLR: A Predicated-$LL(k)$ Parser Generator

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(email: parrt@acm.org)

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***LL(*)*: The Foundation of the ANTLR Parser Generator**

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Adaptive *LL(*)* Parsing: The Power of Dynamic Analysis

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ANTLR 4 是如何处理**直接左递归与优先级**的?

parser-allstar/LRExpr.g4

```
stat : expr ';' EOF;

expr : expr '*' expr
     | expr '+' expr
     | INT
     | ID
     ;
```

根本原因:

究竟是在 expr 的**当前调用**中匹配下一个运算符,

还是让 expr 的**调用者**匹配下一个运算符。

根本原因:

究竟是在 expr 的**当前调用**中匹配下一个运算符,

还是让 expr 的**调用者**匹配下一个运算符。

```
antlr4 LRExpr -Xlog
```

```
2021-11-25 17:44:23:815 left-recursion LogManager.java:25 expr
    :   ( {} INT<tokenIndex=45>
        | ID<tokenIndex=51>
        )
        (
          {precpred(_ctx, 4)}?<p=4> '*'<tokenIndex=27> expr<tokenIndex=29,p=5>
                | {precpred(_ctx, 3)}?<p=3> '+'<tokenIndex=37> expr<tokenIndex=39,p=4>
        )*
    ;
```

```
2021-11-25 17:44:23:815 left-recursion LogManager.java:25 expr
    :   ( {} INT<tokenIndex=45>
        | ID<tokenIndex=51>
        )
        (
          {precpred(_ctx, 4)}?<p=4> '*'<tokenIndex=27> expr<tokenIndex=29,p=5>
                | {precpred(_ctx, 3)}?<p=3> '+'<tokenIndex=37> expr<tokenIndex=39,p=4>
        )*
    ;
```

```
stat : expr ';' EOF;

expr : expr '*' expr
     | expr '+' expr
     | INT
     | ID
     ;
```

```
expr[int _p]
    : (  INT
      | ID
      )
      (  {4 >= $_p}? '*' expr[5]
       | {3 >= $_p}? '+' expr[4]
      )*
    ;
```

expr[int _p]

```
stat : expr ';' EOF;

expr : expr '*' expr
     | expr '+' expr
     | INT
     | ID
     ;
```

```
expr[int _p]
    : (   INT
      | ID
      )
      (   {4 >= $_p}? '*' expr[5]
      | {3 >= $_p}? '+' expr[4]
      )*
    ;
```

$1+2+3$ $1+2*3$ $1*2+3$

parser-allstar/LRExprParen.g4

```
stat : expr ';' EOF;

expr : expr '*' expr
     | expr '+' expr
     | '(' expr ')'
     | INT
     | ID
     ;
```

parser-allstar/LRExprUS.g4

```
stat : expr ';' EOF;

expr : '-' expr
     | expr '!'
     | expr '+' expr
     | ID
     ;
```

```
expr[int _p]
    : (    ID
         | '-' expr[4]
      )
      (    {3 >= $_p}? '!'
         | {2 >= $_p}? '+' expr[3]
      )*
    ;
```

$-a!!$ $\quad$ $-a + b!$

```
stat : expr ';' EOF ;
expr : <assoc = right> expr '^' expr
     | expr '+' expr
     | INT
     ;
```

```
stat : expr ';' EOF ;
expr : <assoc = right> expr '^' expr
     | expr '+' expr
     | INT
     ;
```

```
expr[int _p]
    : ( INT )
    (    {3 >= $_p}? '^' expr[3]
       | {2 >= $_p}? '+' expr[3]
    )*
    ;
```

$$1 \hat{} 2 \hat{} 3 + 4$$

For *left-associative* operators, the right operand gets **one more** precedence level than the operator itself.

Adaptive *LL(*)* Parsing: The Power of Dynamic Analysis

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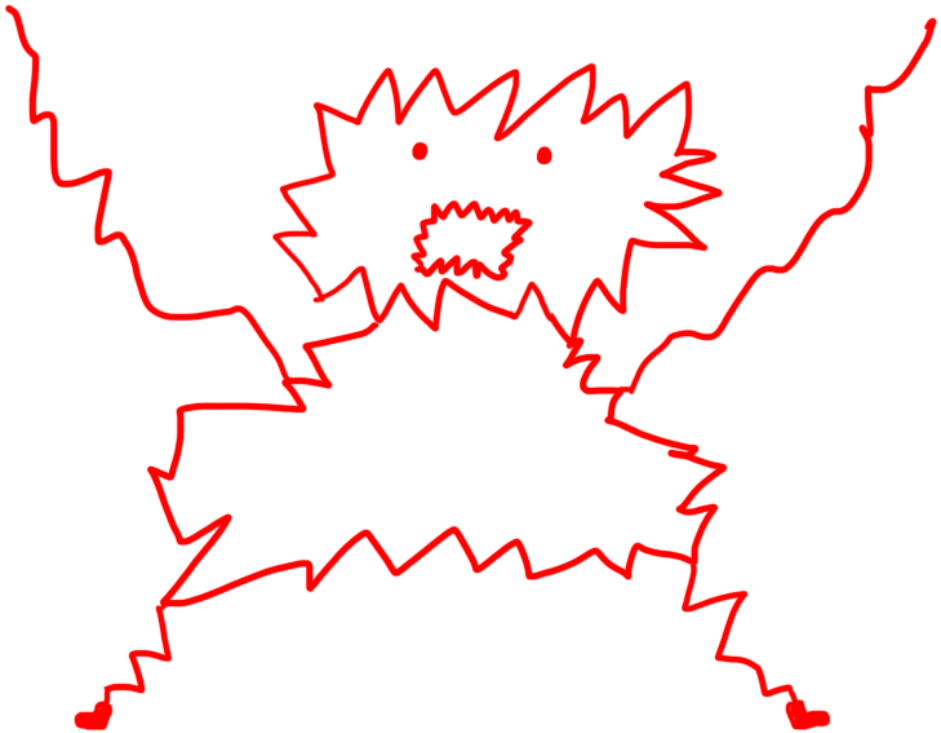
Appendix C: Left-recursion Elimination

For *right-associative* operators, the right operand gets **the same** precedence level as the current operand.

ANTLR 4 是如何进行**错误报告与恢复**的?

报错、**恢复**、继续分析



恐慌/应急 (Panic) 模式: 假装成功、调整状态、继续进行

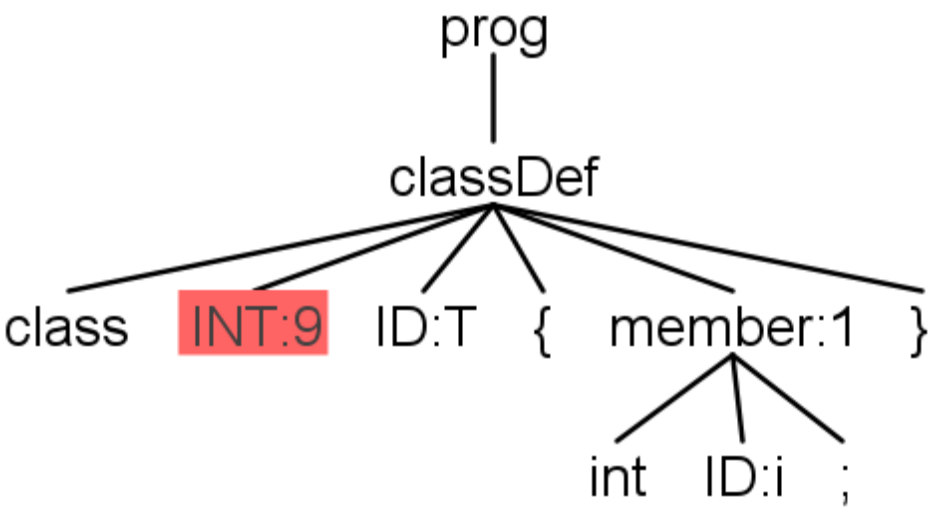
如果**下一个词法单元**符合预期,

则采用 “单词法符号移除 (single-token deletion)”

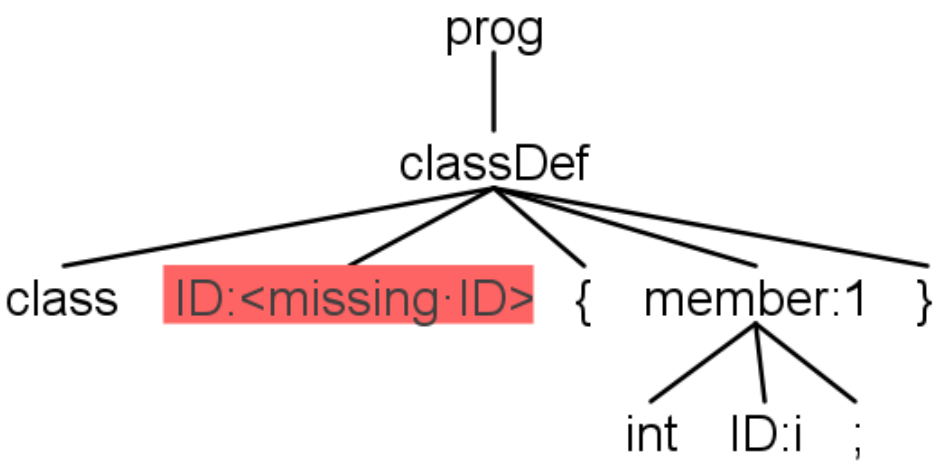
或 “单词法符号补全 (single-token insertion)” 策略

`Class.g4`

Class-DeleteToken.txt



Class-AddToken.txt

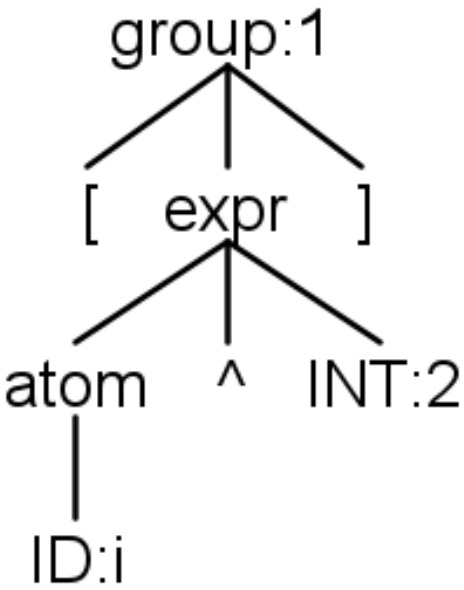


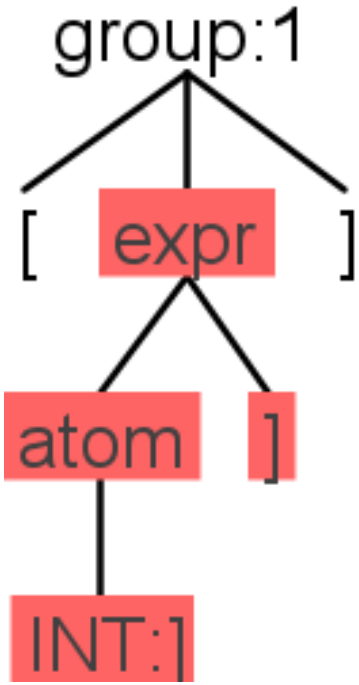
采用 “**同步-返回 (sync-and-return)**” 策略,

使用 “重新同步集合 (resynchronization set)” 从当前规则中恢复

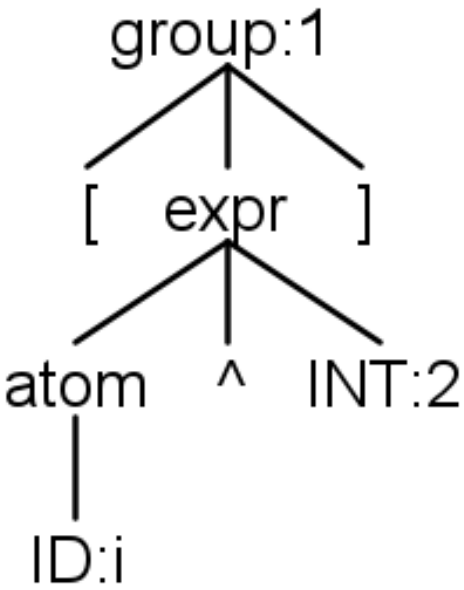
`Group.g4`

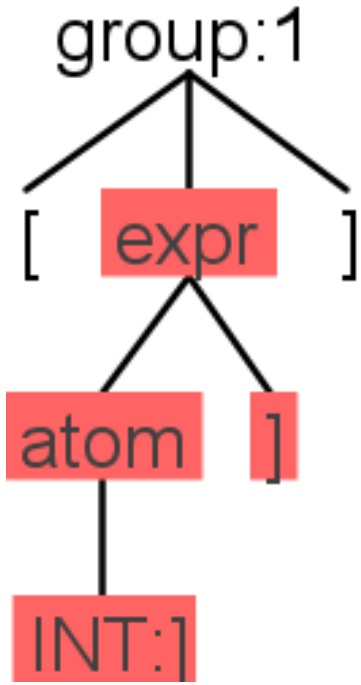
$\textsc{Following}(\{\texttt{expr}, \texttt{atom}\}) = \{\texttt{\^{}}, \texttt{]}\}$ $\textsc{Following}(\{\texttt{expr}\}) = \{\texttt{]}\}$





$\textsc{Following}(\{\texttt{expr}, \texttt{atom}\}) = \{\texttt{\^{}}, \texttt{]}\}$ $\textsc{Following}(\{\texttt{expr}\}) = \{\texttt{]}\}$





注意 $\textsc{Follow}$ (静态) 集合与 $\textsc{Following}$ (动态) 集合的区别

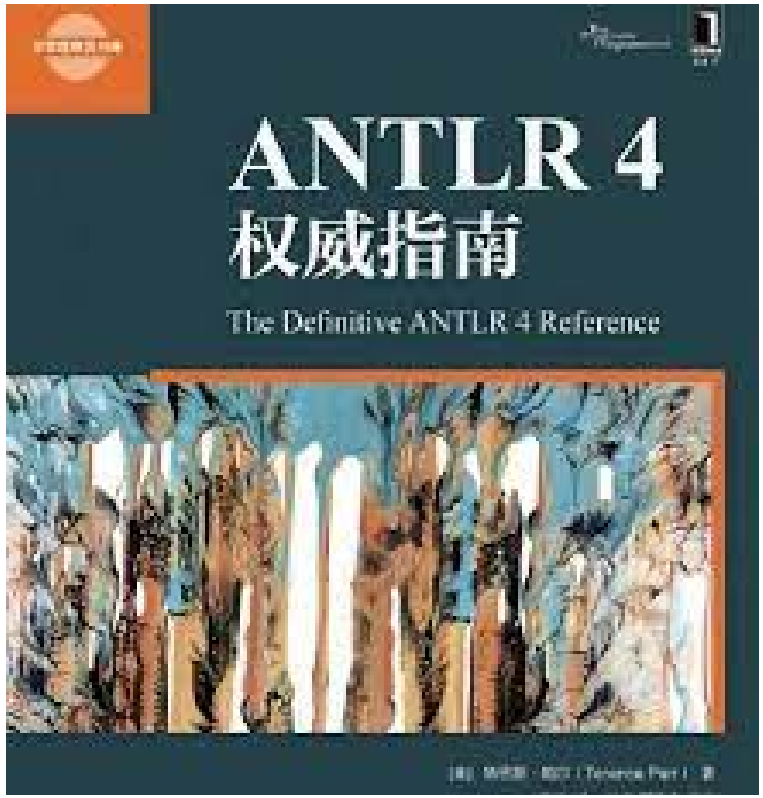
如何从子规则中优雅地恢复出来?

Class.g4 (member+)

Class-Subrule-Start.txt ("单词法符号移除")

Class-Subrule-Loop.txt ("另一次 member 迭代")

Class-Subrule-End.txt ("退出当前 classDef 规则")

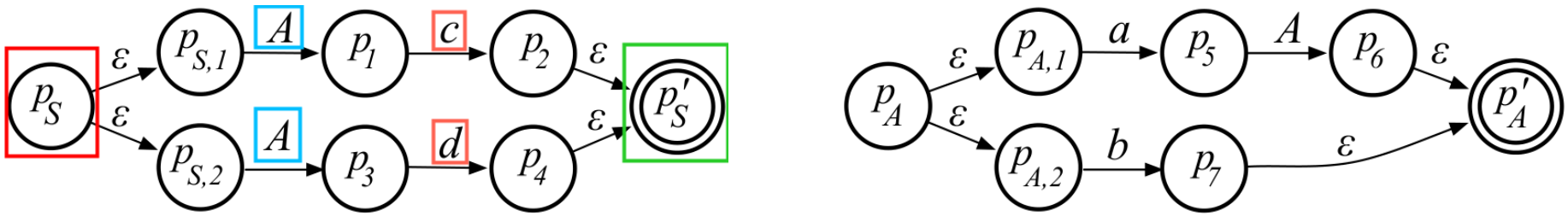


第 9 章: 错误报告与恢复

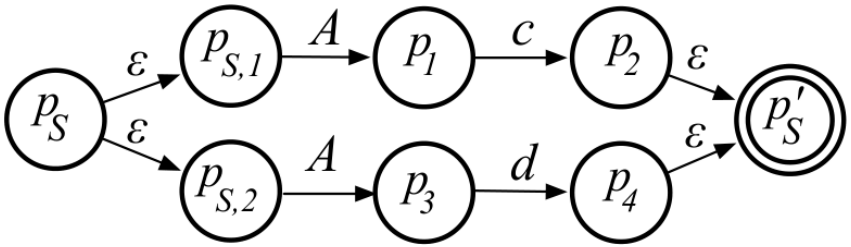
$$P{=}\{S \to Ac \,|\, Ad,\ \ A \to aA \,|\, b\}$$

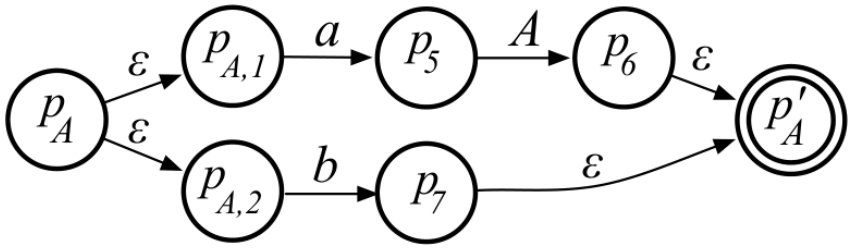
不是 $LL(1)$ 文法，也不是 $LL(k)$ 文法 $(\forall k \geq 1)$

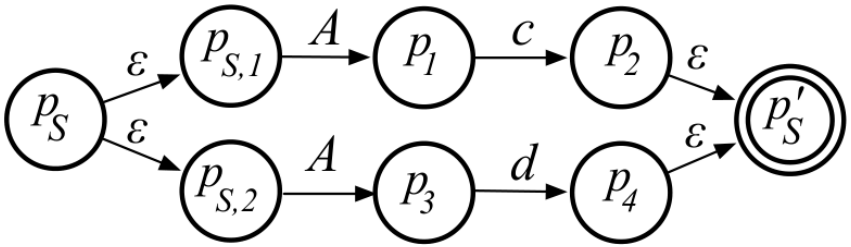
$$P=\{S \to Ac \mid Ad,\quad A \to aA \mid b\}$$

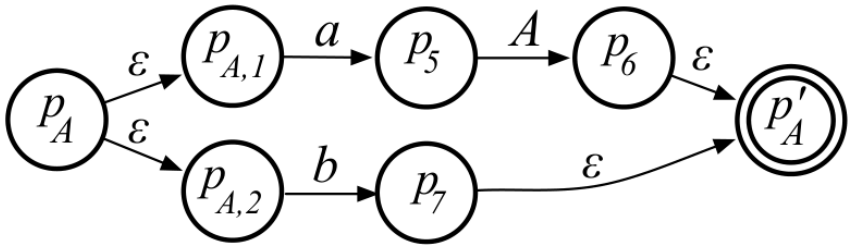


ATN: Augmented Transition Network

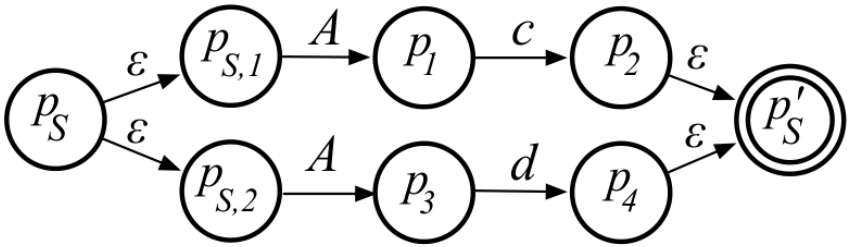

p_S
ε
ε
$p_{S,1}$
$p_{S,2}$
A
A
p_1
p_3
c
d
p_2
p_4
ε
ε
p'_S

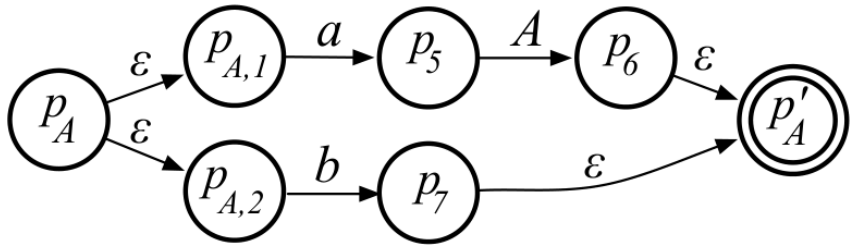

p_A
ε
ε
$p_{A,1}$
$p_{A,2}$
a
b
p_5
p_7
A
p_6
ε
ε
p'_A





Incrementally and dynamically build up a ***lookahead DFA*** that map lookahead phrases to predicated productions.





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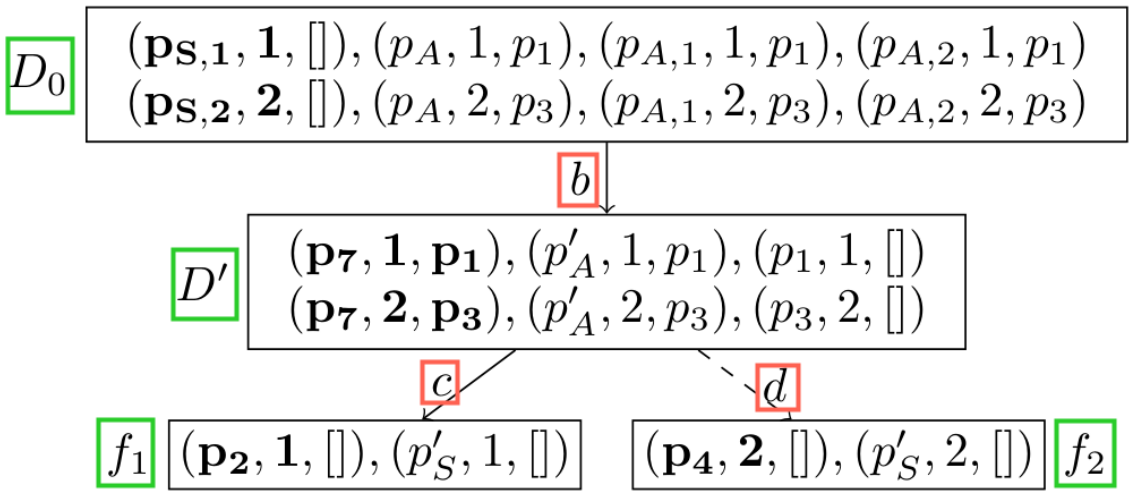
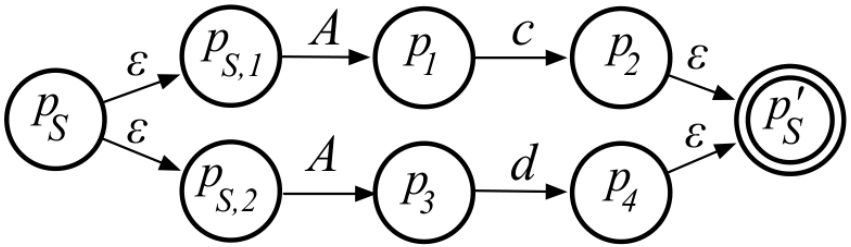
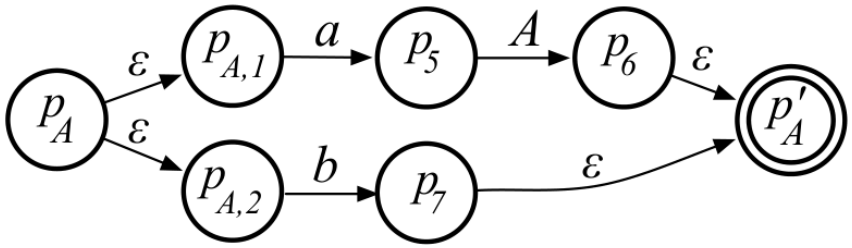
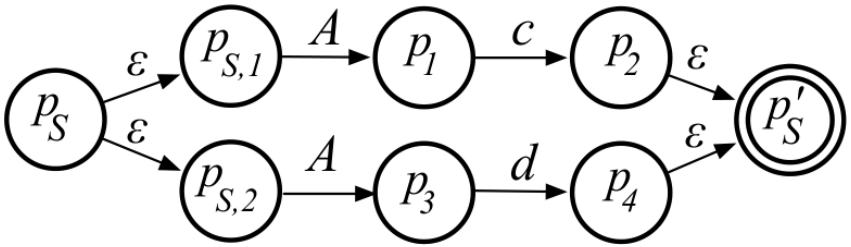
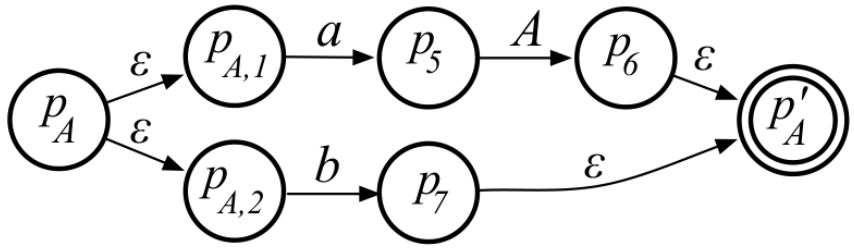




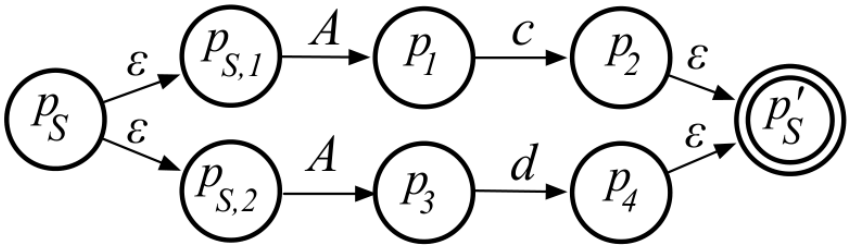


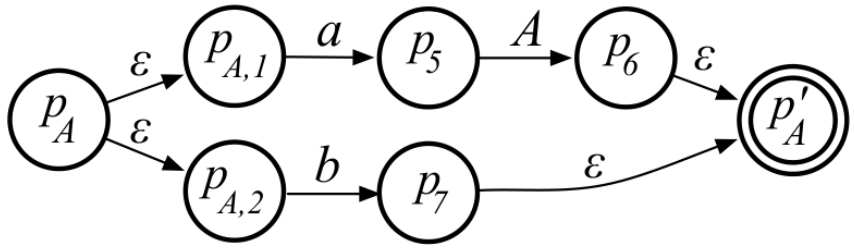
- Launch subparsers at a decision point, one per alternative productions.



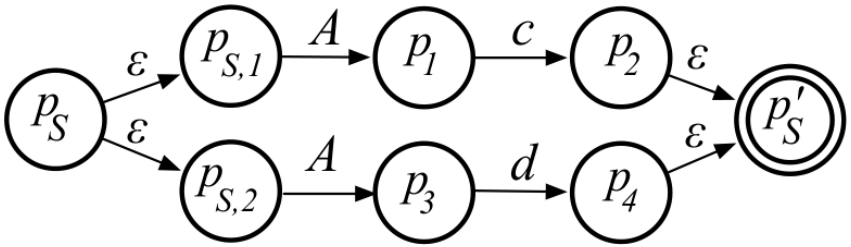


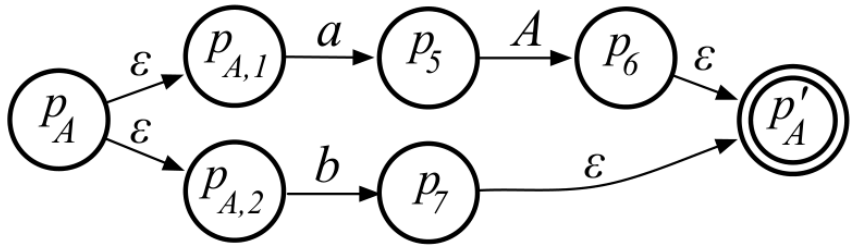
- Launch subparsers at a decision point, one per alternative productions.
- These subparsers run in pseudo-parallel to explore all possible paths.



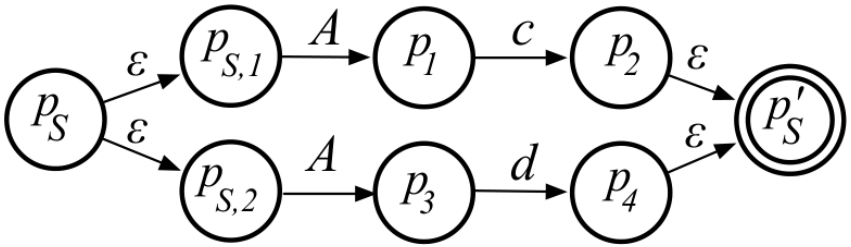


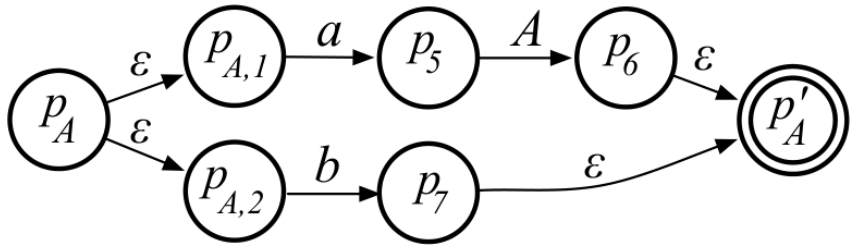
- Launch subparsers at a decision point, one per alternative productions.
- These subparsers run in pseudo-parallel to explore all possible paths.
- Subparsers die off as their paths fail to match the remaining input.



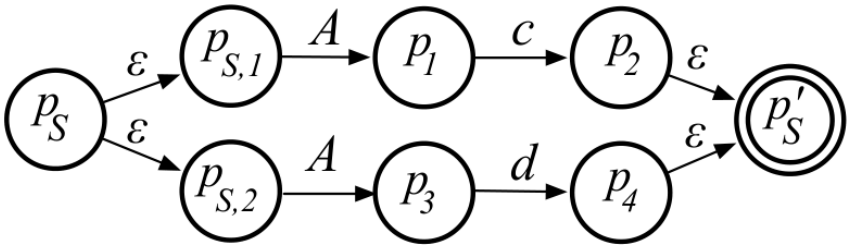


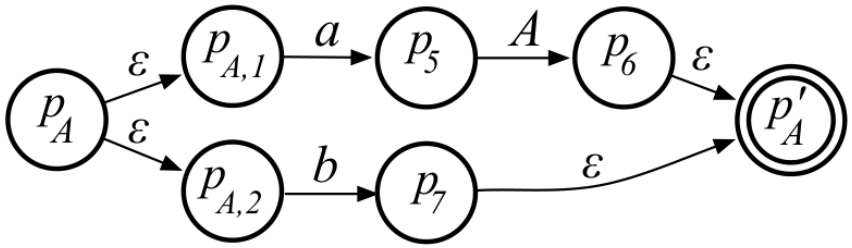
- Launch subparsers at a decision point, one per alternative productions.
- These subparsers run in pseudo-parallel to explore all possible paths.
- Subparsers die off as their paths fail to match the remaining input.
- Ambiguity: Multiple subparsers coalesce together or reach EOF.

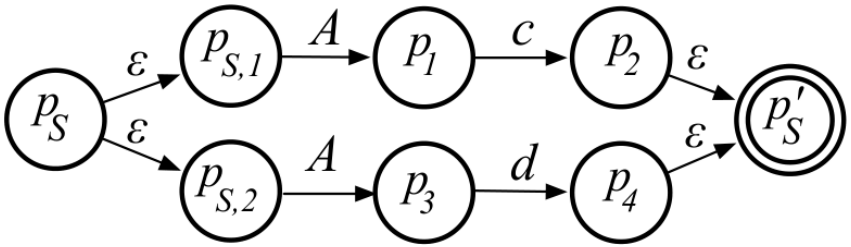


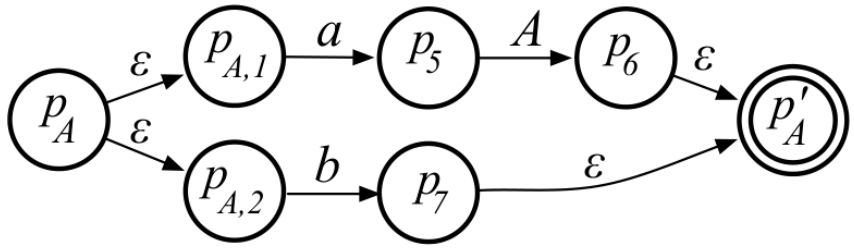


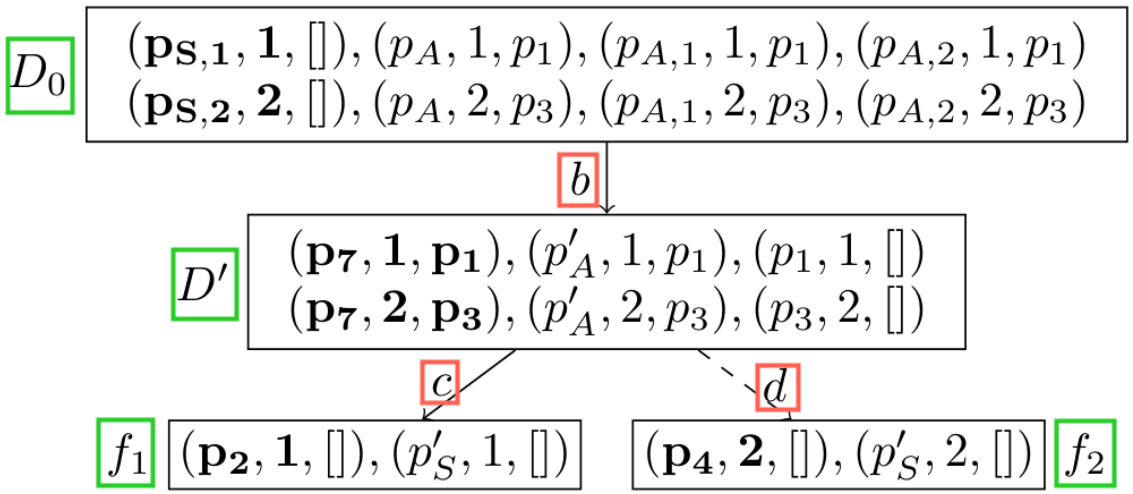
- Launch subparsers at a decision point, one per alternative productions.
- These subparsers run in pseudo-parallel to explore all possible paths.
- Subparsers die off as their paths fail to match the remaining input.
- Ambiguity: Multiple subparsers coalesce together or reach EOF.
- Resolution: The first production associated with a surviving subparser.


p_S
ε
ε
$p_{S,1}$
$p_{S,2}$
A
A
p_1
p_3
c
d
p_2
p_4
ε
ε
p'_S

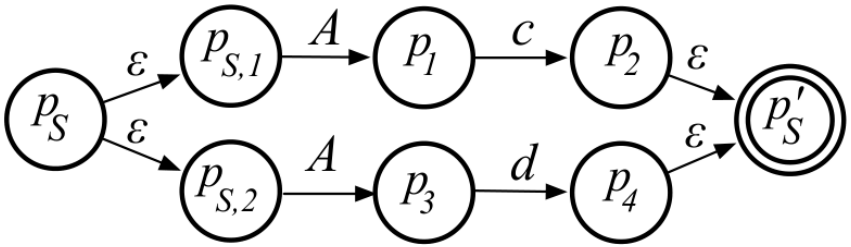

p_A
ε
ε
$p_{A,1}$
$p_{A,2}$
a
b
p_5
p_7
A
p_6
ε
ε
p'_A

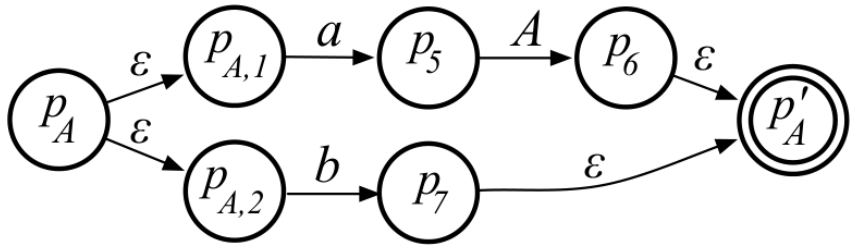


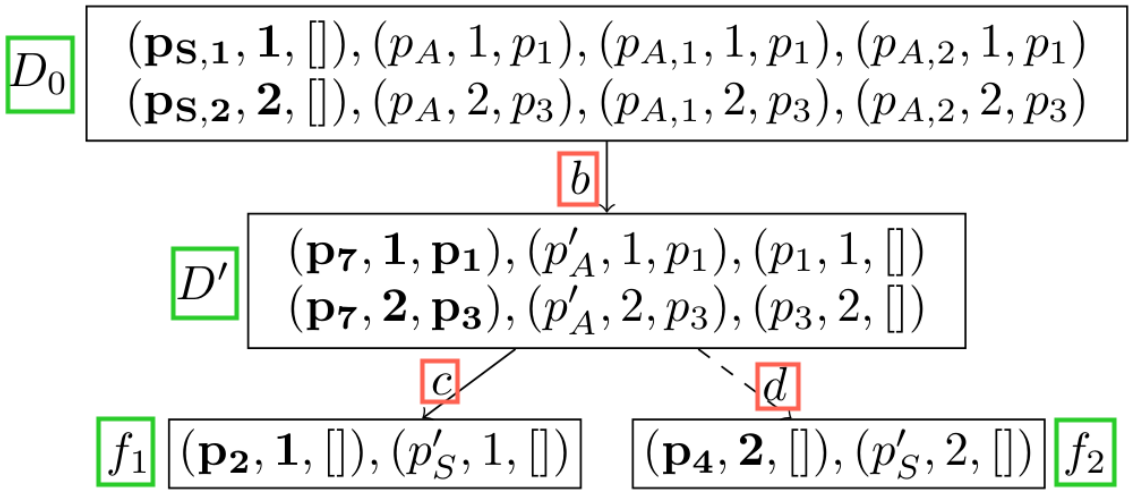




Upon bc and then bd







Upon bc and then bd

move-closure!!!

Adaptive *LL(*)* Parsing: The Power of Dynamic Analysis

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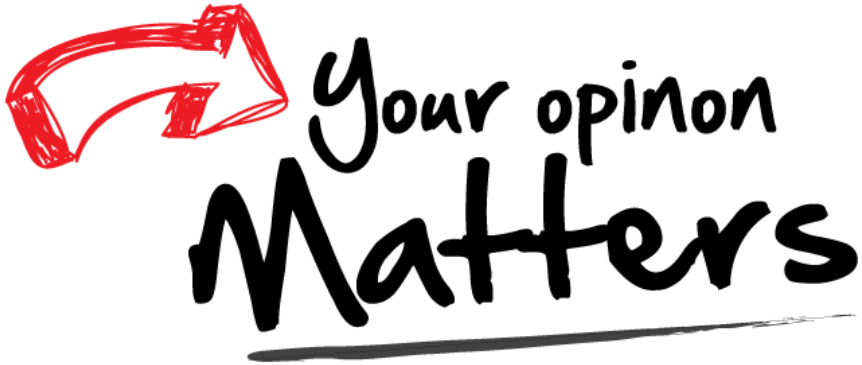
Thank
You!



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