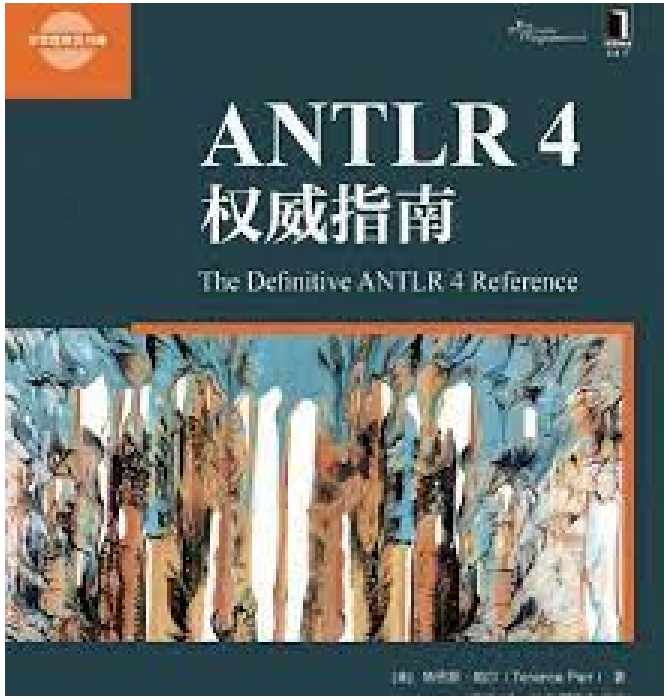
二、语法分析
(8. Adaptive $LL(*)$ 语法分析算法)

魏恒峰

hfwei@nju.edu.cn

2023 年 04 月 07 日



(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

(3) ANTLR 4 使用了一种名为 Adaptive $LL(*)$ 的新技术

(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

T. J. PARR
University of Minnesota, AHPCRC, 1100 Washington Ave S Ste 101, Minneapolis, MN 55415, U.S.A.
(email: parrt@acm.org)

AND

R. W. QUONG
School of Electrical Engineering, Purdue University, W. Lafayette, IN 47907, U.S.A.
(email: quong@ecn.purdue.edu)

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

Terence Parr
University of San Francisco
parrt@cs.usfca.edu

Kathleen Fisher *
Tufts University
kfisher@eecs.tufts.edu

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

Terence Parr
University of San Francisco
parrt@cs.usfca.edu

Sam Harwell
University of Texas at Austin
samharwell@utexas.edu

Kathleen Fisher
Tufts University
kfisher@eecs.tufts.edu

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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
     ;
```

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>
        )*
    ;
```

```
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
     ;
```

对应于一段递归函数 expr(int _p)

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

$1+2+3$　　$1+2*3$　　$1*2+3$

根本问题:

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。

parser-allstar/LRExprParen.g4

```
stat : expr ';' EOF;

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

```
expr[int _p]
    : (  '(' expr[0] ')'
       | INT
       | ID
      )
      (  {5 >= $_p}? '*' expr[6]
       | {4 >= $_p}? '+' expr[5]
      )*
    ;
```

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
     ;
```

```
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.

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Terence Parr
University of San Francisco
parrt@cs.usfca.edu

Sam Harwell
University of Texas at Austin
samharwell@utexas.edu

Kathleen Fisher
Tufts University
kfisher@eecs.tufts.edu

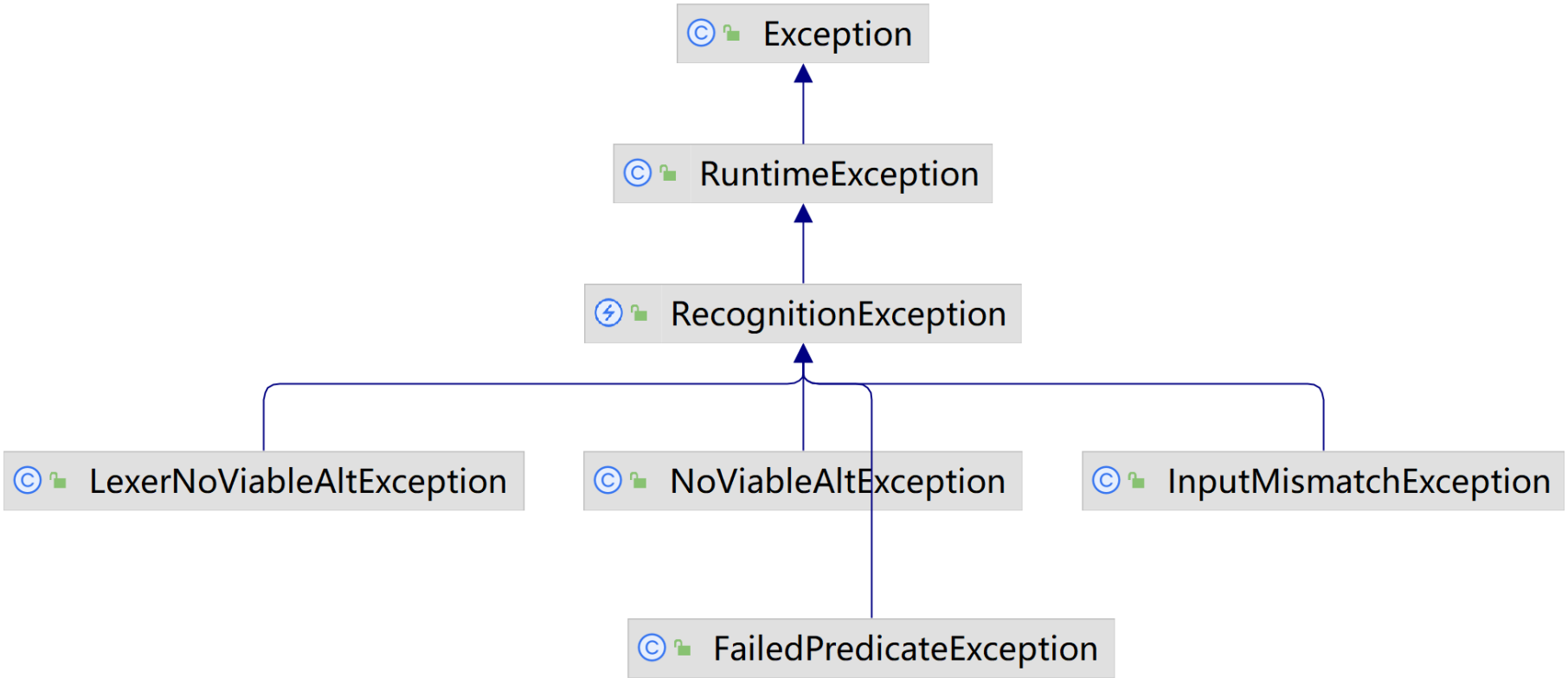
Appendix C: Left-recursion Elimination

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?


!
ERROR

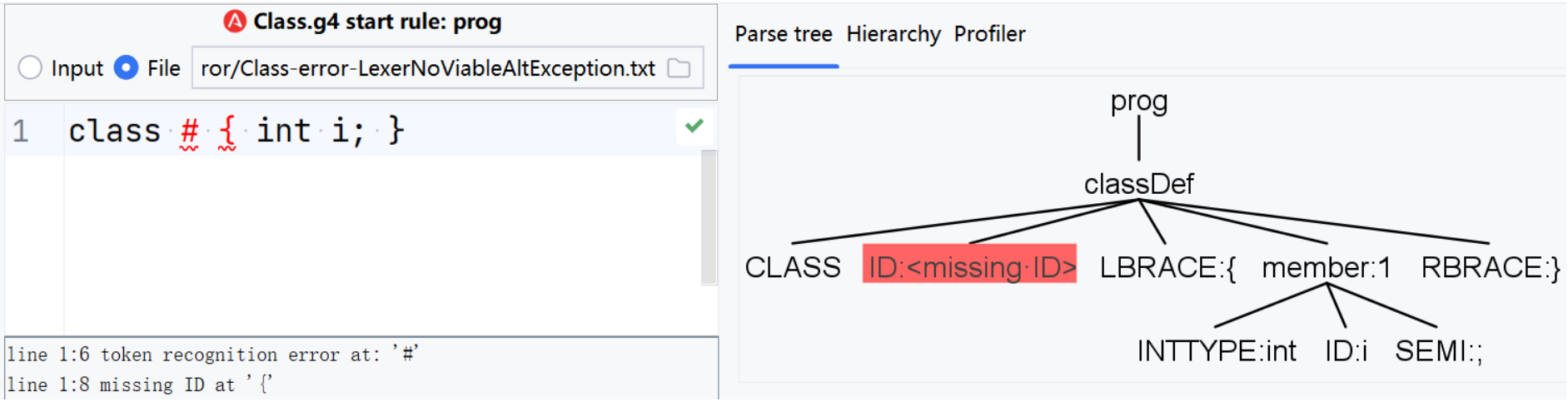
共四类词法、语法错误



`NoViableAltException` `InputMismatchException`

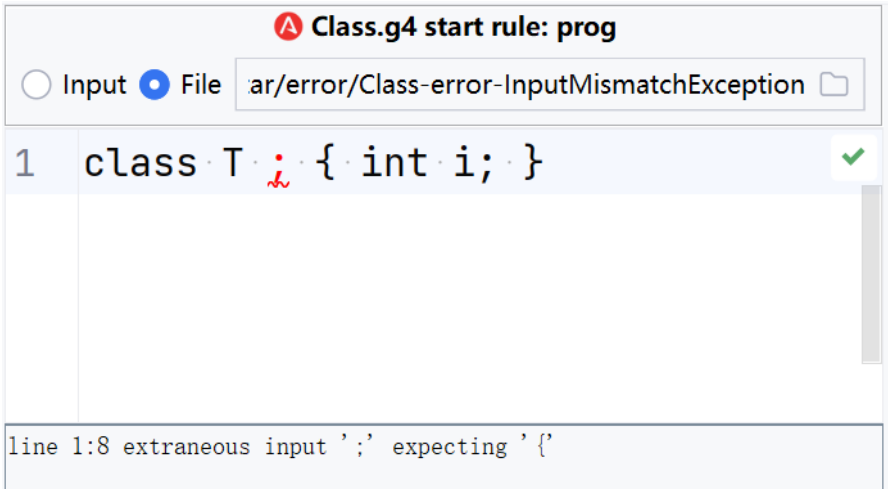
Class.g4

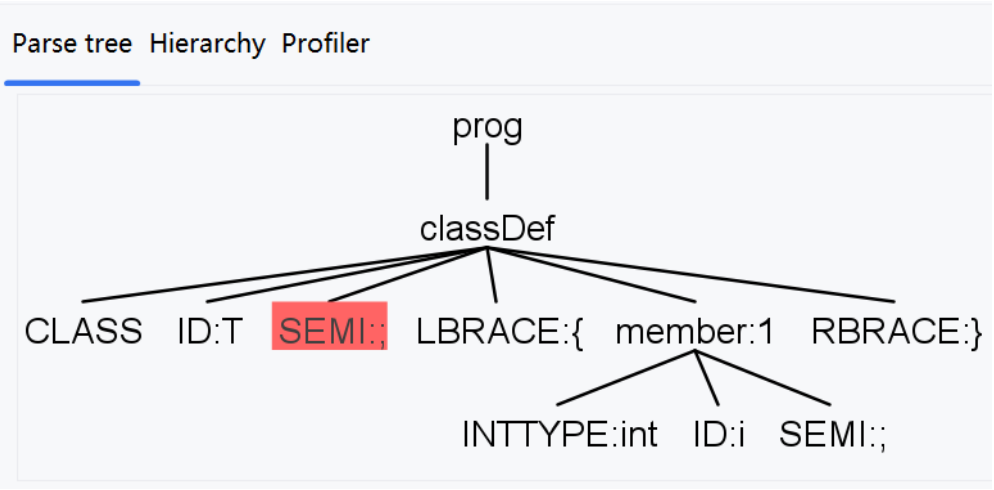
LexerNoViableAltException



遇到未知字符，出现词法错误

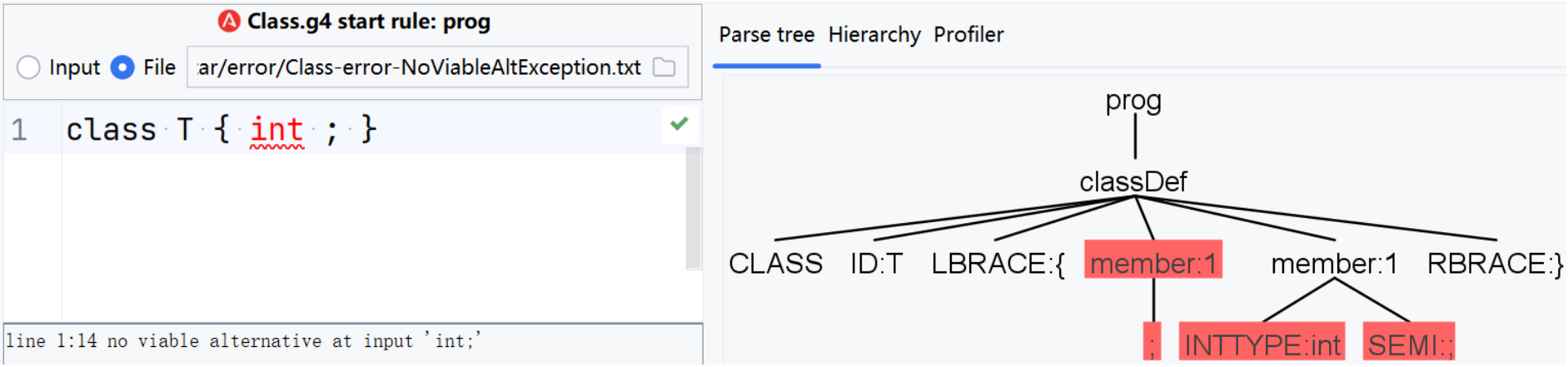
InputMismatchException





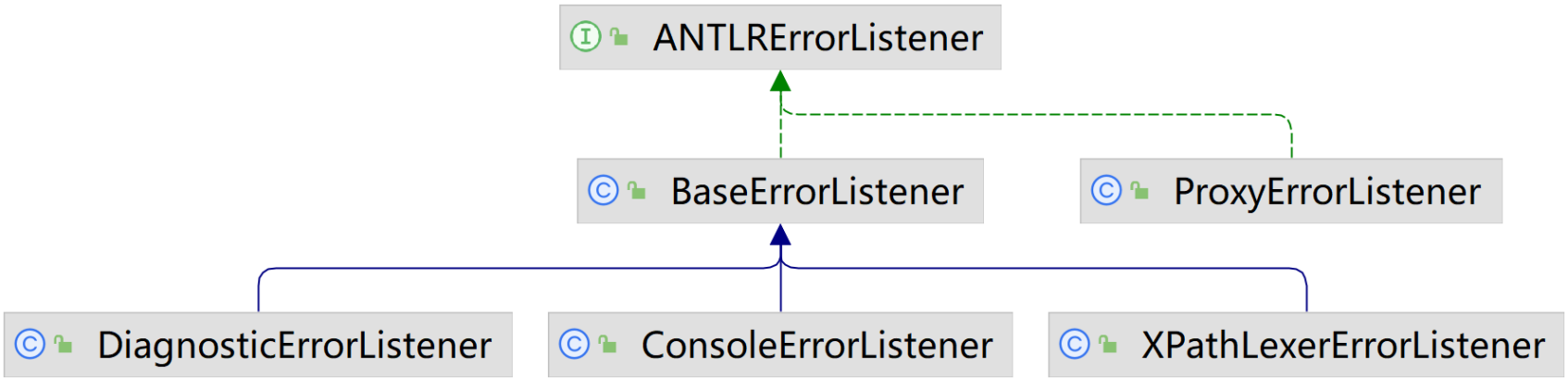
输入流中的当前词法单元与当前规则所期望的词法单元不匹配

NoViableAltException



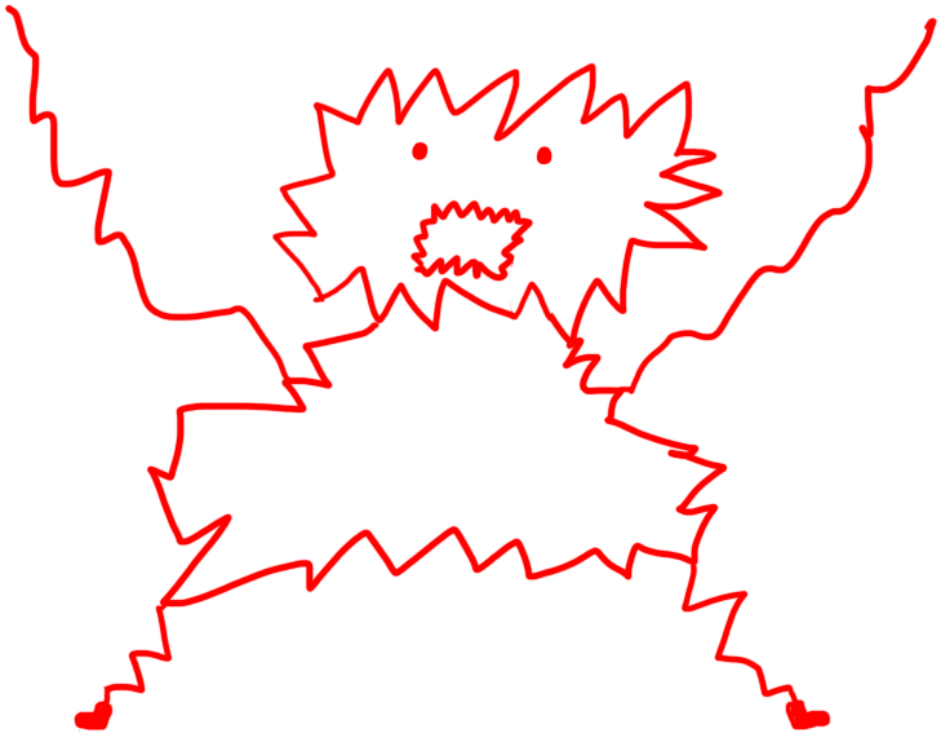
剩余输入不符合当前规则的任何一个备选分支

自定义错误报告消息



`syntaxError()`

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

四项基本原则:

(1) 特殊情况, 特殊处理

(2) 一般情况, 统一处理

(3) 统一处理, 精细控制

(4) 自定义错误处理策略

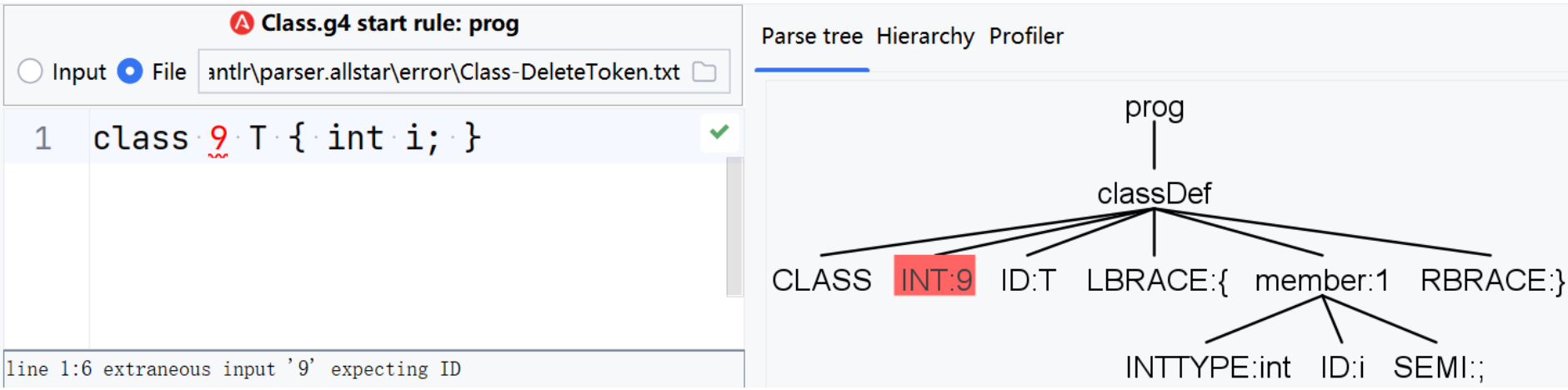
(1) 特殊情况, 特殊处理

如果**下一个词法单元**符合预期,

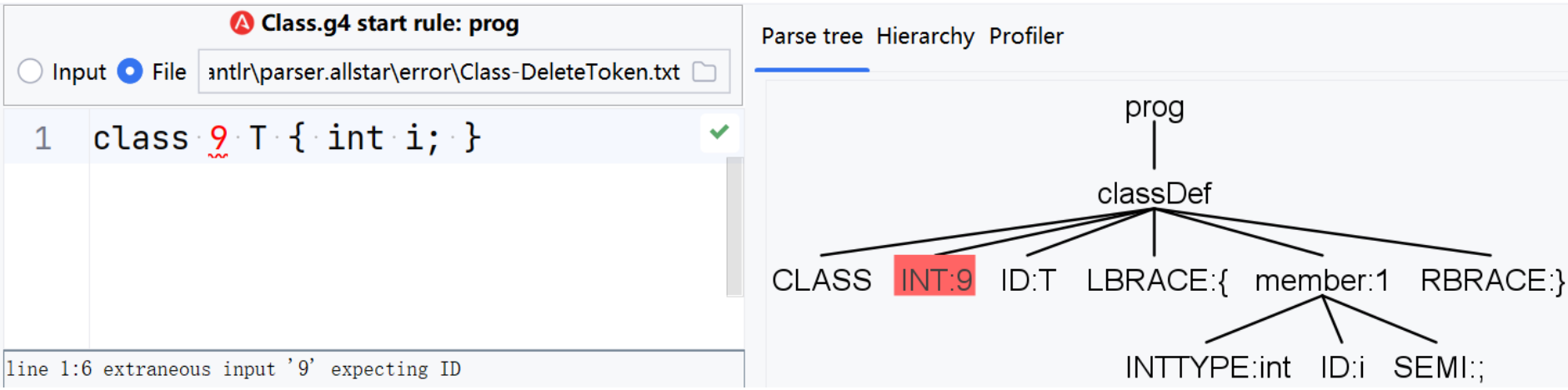
则采用 “单词法符号移除 (single-token deletion)”

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

单词法符号移除


Class.g4 start rule: prog
Input
File
antlr\parser.allstar\error\Class-DeleteToken.txt
1
class 9 T { int i; }
line 1:6 extraneous input '9' expecting ID
Parse tree
Hierarchy
Profiler
prog
classDef
CLASS
INT:9
ID:T
LBRACE:{
member:1
RBRACE:}
INTTYPE:int
ID:i
SEMI:;

单词法符号补全


Class.g4 start rule: prog
Input
File
antlr\parser.allstar\error\Class-DeleteToken.txt
1 class 9 T { int i; }
line 1:6 extraneous input '9' expecting ID
Parse tree
Hierarchy
Profiler
prog
classDef
CLASS
INT:9
ID:T
LBRACE:{
member:1
RBRACE:}
INTTYPE:int
ID:i
SEMI:;

(2) 一般情况, 统一处理

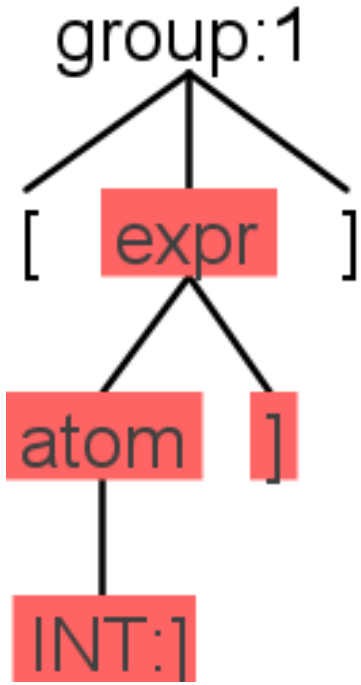
采用 “**同步-返回 (sync-and-return)**” 策略,

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

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

```
9   group : '[' expr ']'
10        | '(' expr ')'
11        ;
12
13  expr : atom '^' INT ;
14
15  atom : ID
16       | INT
17       ;
```

Group.g4



[]

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

(3) 统一处理, 精细控制

如何从子规则中优雅地恢复出来?

Class.g4 (member+)

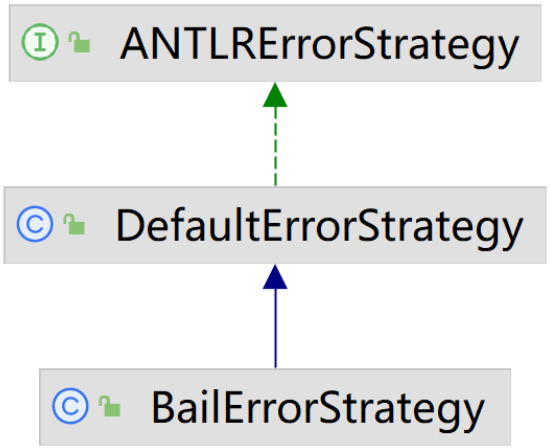
Class-Subrule-Start.txt ("单词法符号移除")

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

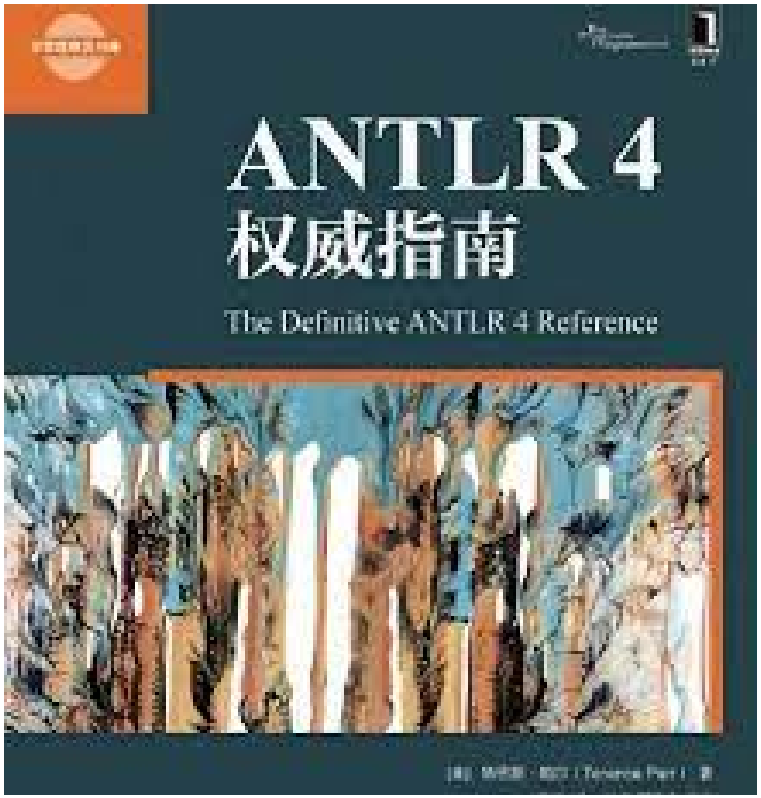
Class-Subrule-End.txt ("退出当前 classDef 规则")

(4) 自定义错误处理策略

比如, (已知语法正确) 关闭默认错误处理功能, 提高运行效率



比如, (出错代价太大) 在遇到第一个语法错误时, 就停止分析



第 9 章: 错误报告与恢复

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Terence Parr
University of San Francisco
parrt@cs.usfca.edu

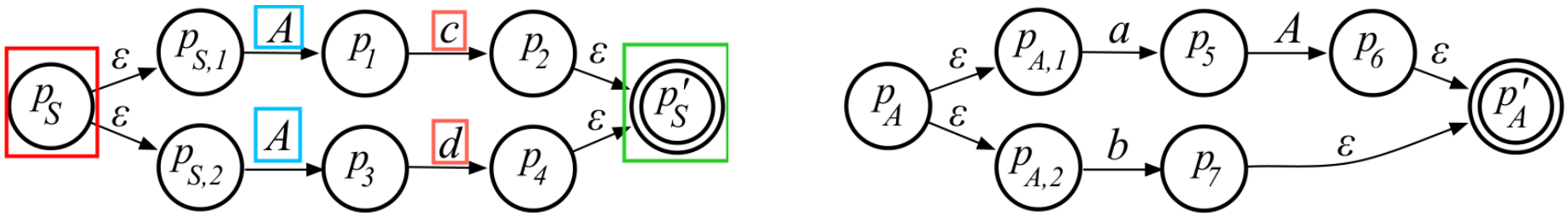
Sam Harwell
University of Texas at Austin
samharwell@utexas.edu

Kathleen Fisher
Tufts University
kfisher@eecs.tufts.edu

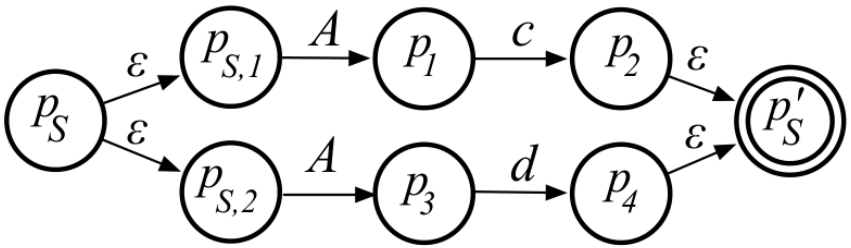
$$P{=}\{S \to Ac \,|\, Ad,\ \ A \to aA \,|\, b\}$$

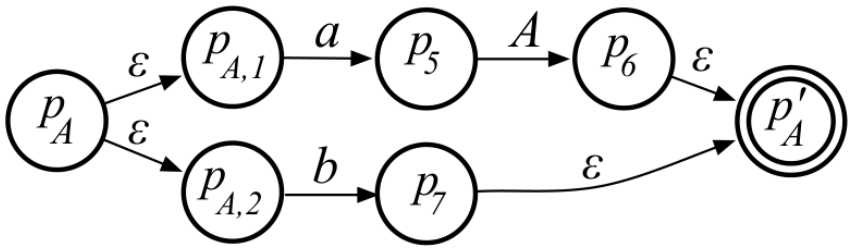
不是 $LL(1)$ 文法，也不是 $LL(k)$ 文法 $(\forall k \geq 1)$

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

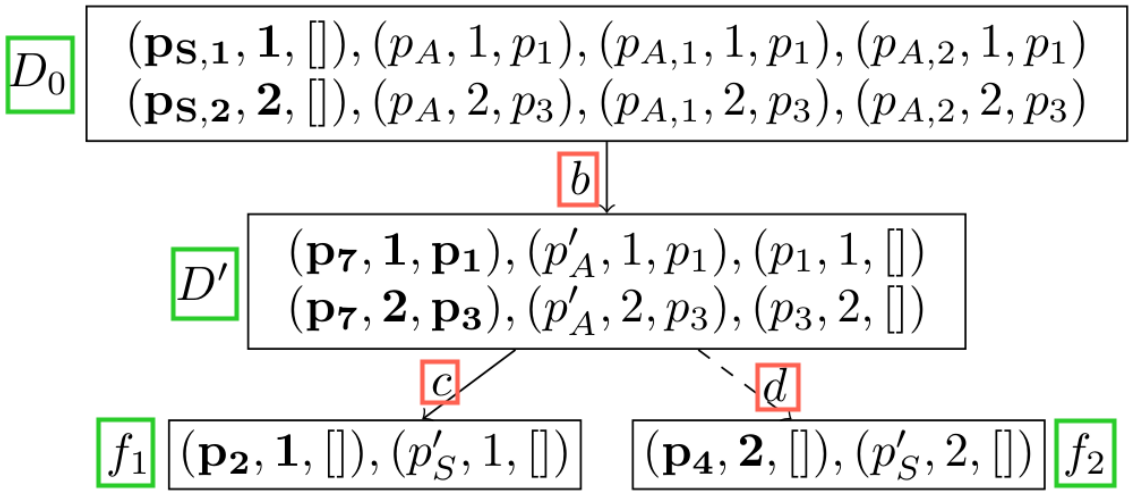


ATN: Augmented Transition Network



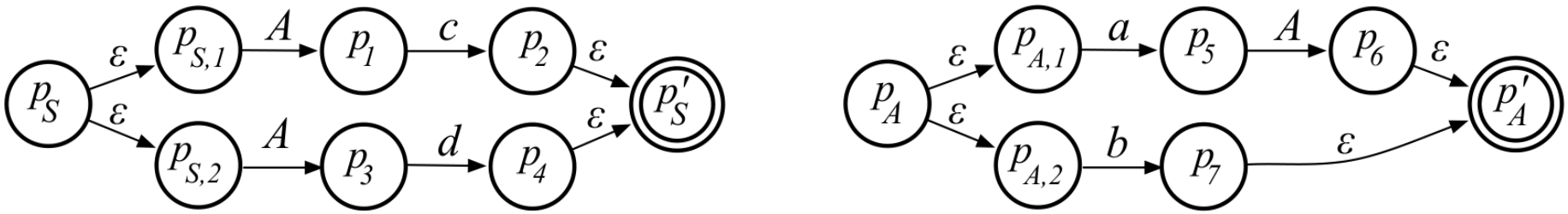


Incrementally and dynamically build up a **lookahead DFA** that **map lookahead phrases to predicated productions**.



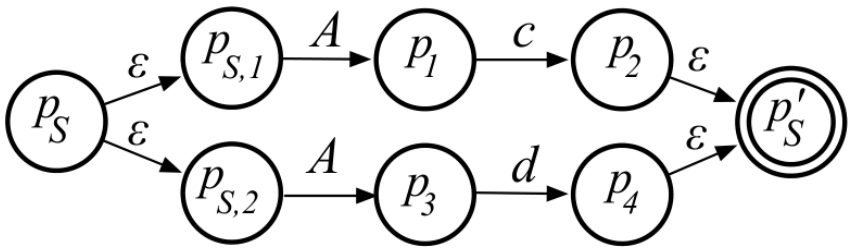
Upon bc and then bd

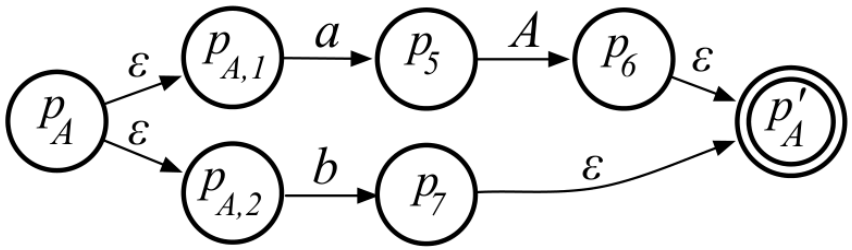
$$P=\{S \to Ac \mid Ad,\ \ A \to aA \mid b\}$$

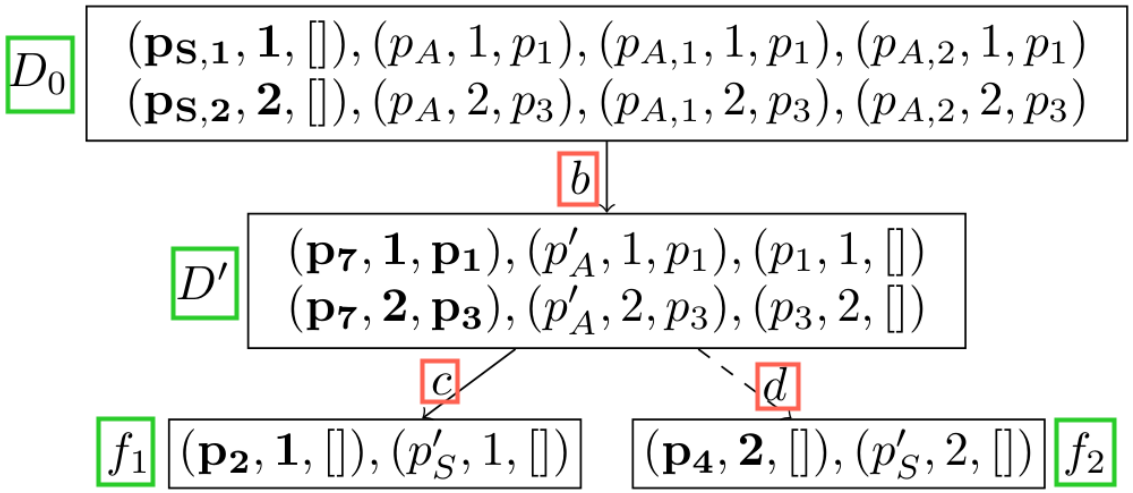


- Launch subparsers at a decision point, one per alternative productions.
- These subparsers run in pseudo-parallel to explore all possible paths.
- Subparsers die off as their paths fail to match the remaining input.
- Ambiguity: Multiple subparsers coalesce together or reach EOF.
- Resolution: The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

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







Upon bc and then bd

Move on terminals and **Closure** over ϵ and non-terminals

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University of San Francisco
parrt@cs.usfca.edu

Sam Harwell
University of Texas at Austin
samharwell@utexas.edu

Kathleen Fisher
Tufts University
kfisher@eecs.tufts.edu

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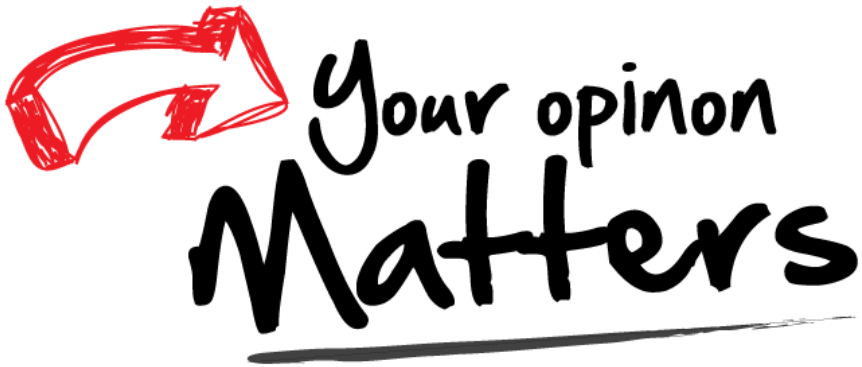
Thank
You!



Office 926

hfwei@nju.edu.cn