Principles of Compiler Construction

线性文法不一定递归

match--shift
derive--reduce
key:找到适合reduce的串

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Lecture 6. Operator Precedence Parsing (OPP)

1. Bottom-Up Parsing
2. Abstract Model for Shift-Reduce Parsing
3. Operator-Precedence Parser
4. What Have We discarded?
5. Does OPP Disappear?

1. Bottom-Up Parsing

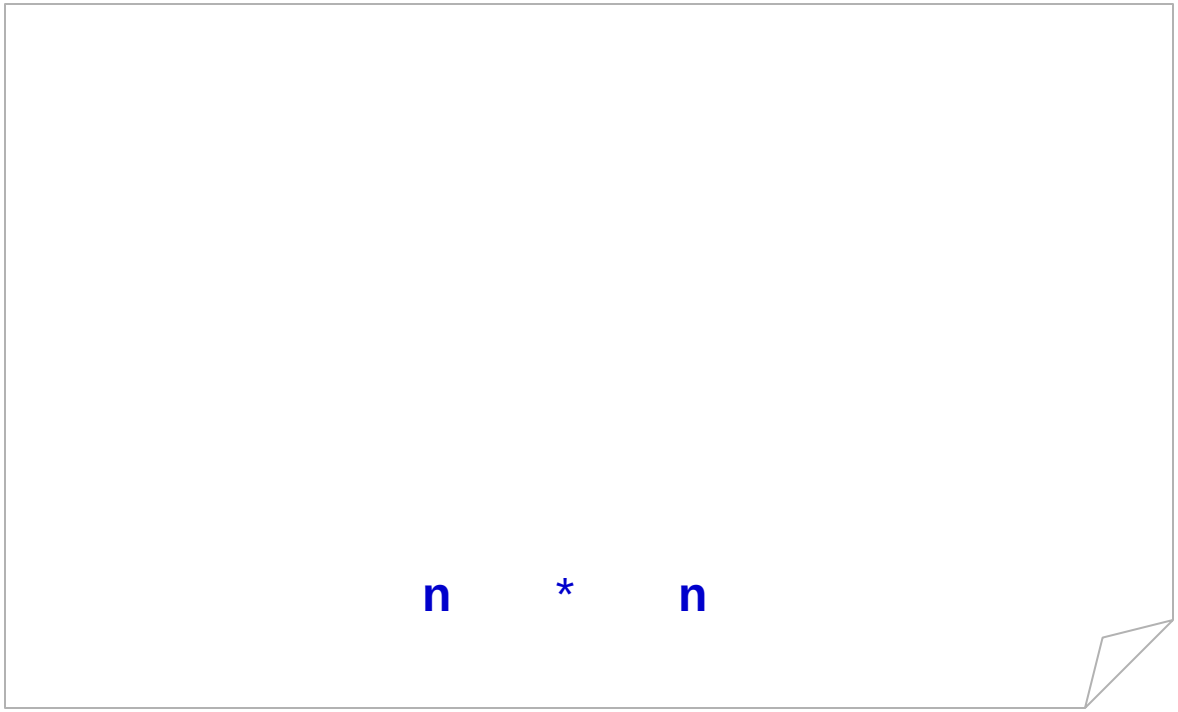
- A motivating example
  - Construct a parse tree beginning at the leaves and working up towards the root.
  - For the grammar

$$E \rightarrow E + T \mid T$$

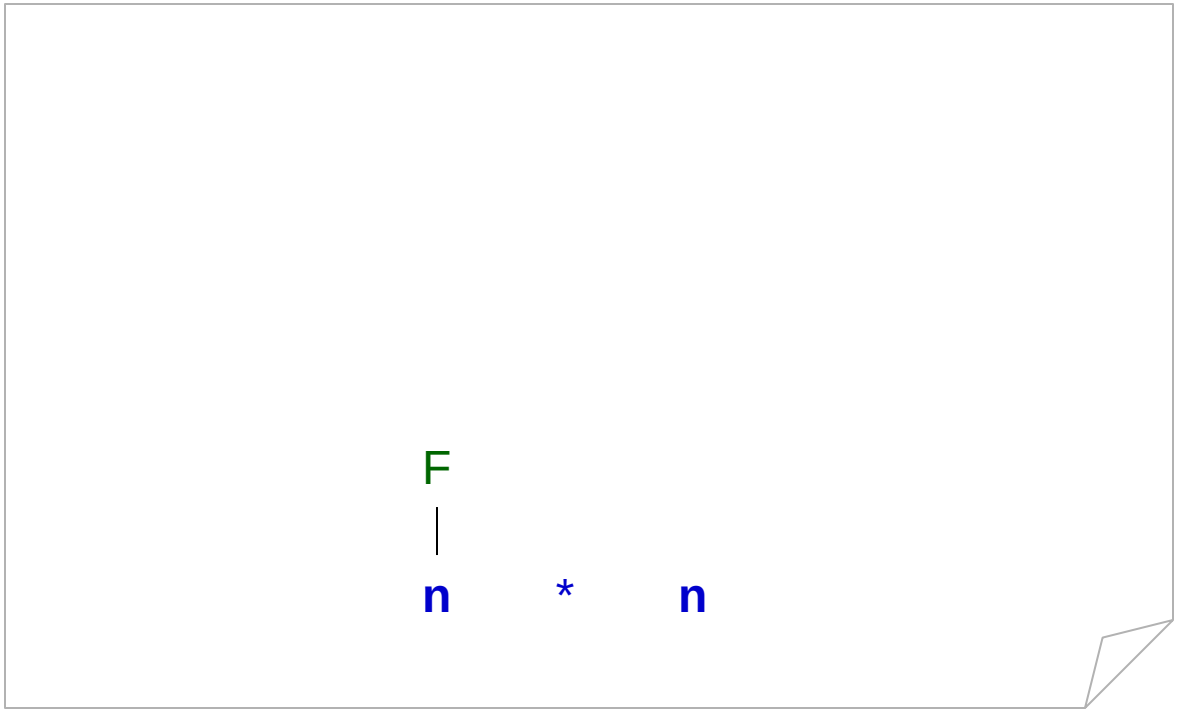
$$T \rightarrow T * F \mid F$$

$$F \rightarrow (E) \mid \mathbf{n}$$

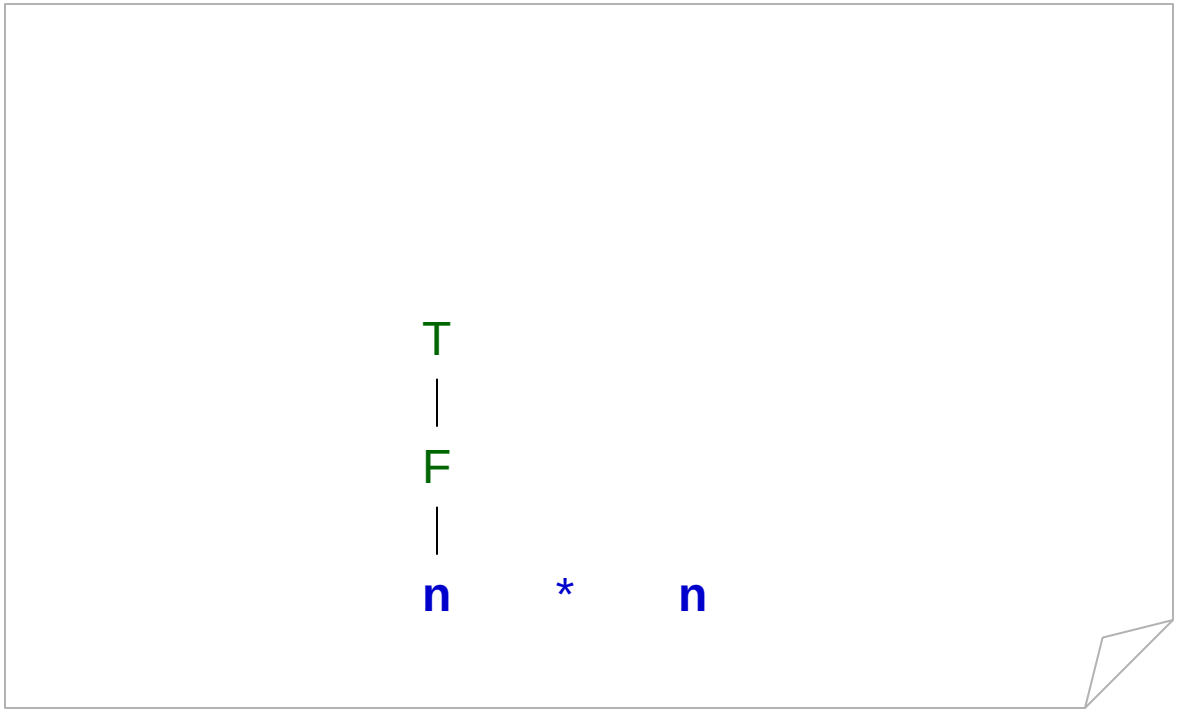
- Begin with leaves: **n * n**



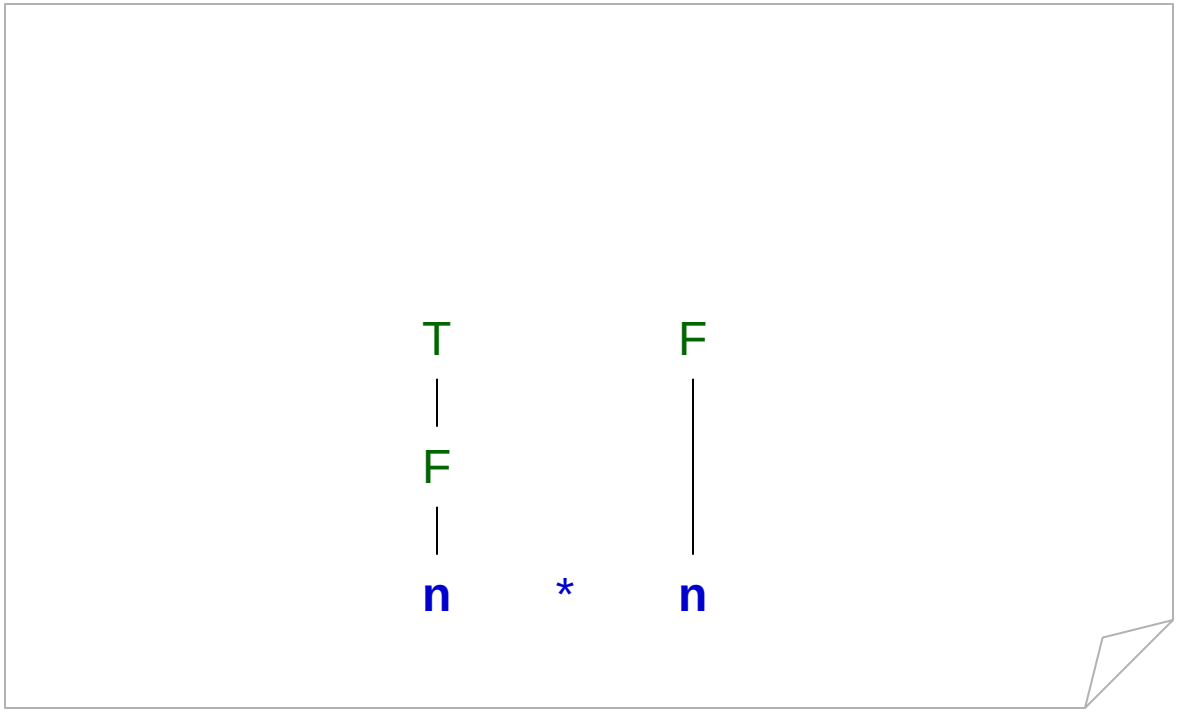
- The 1st **n** is the handle, after reduction we have the right sentential form: **F * n**



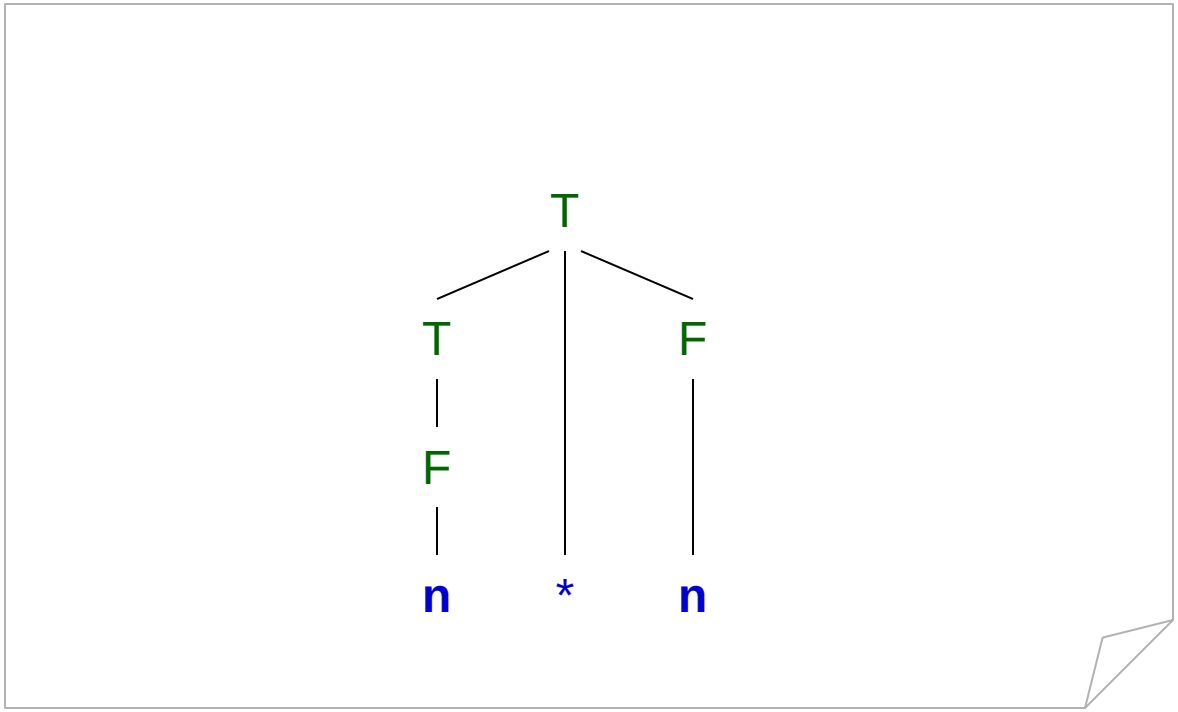
- **F** is the handle and we have: **T * n**



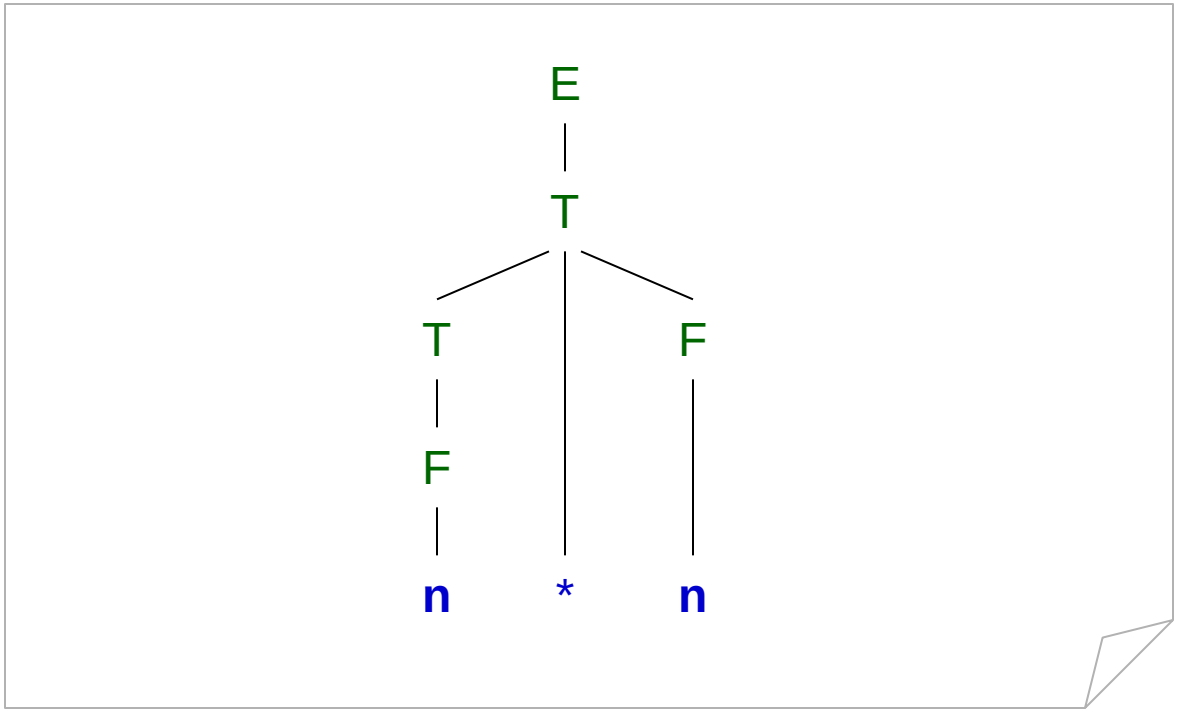
- **n** is the handle in **T * n**, we have: **T * F**



- **T * F** is the handle



- **T** is the handle



One More Example

- For the grammar

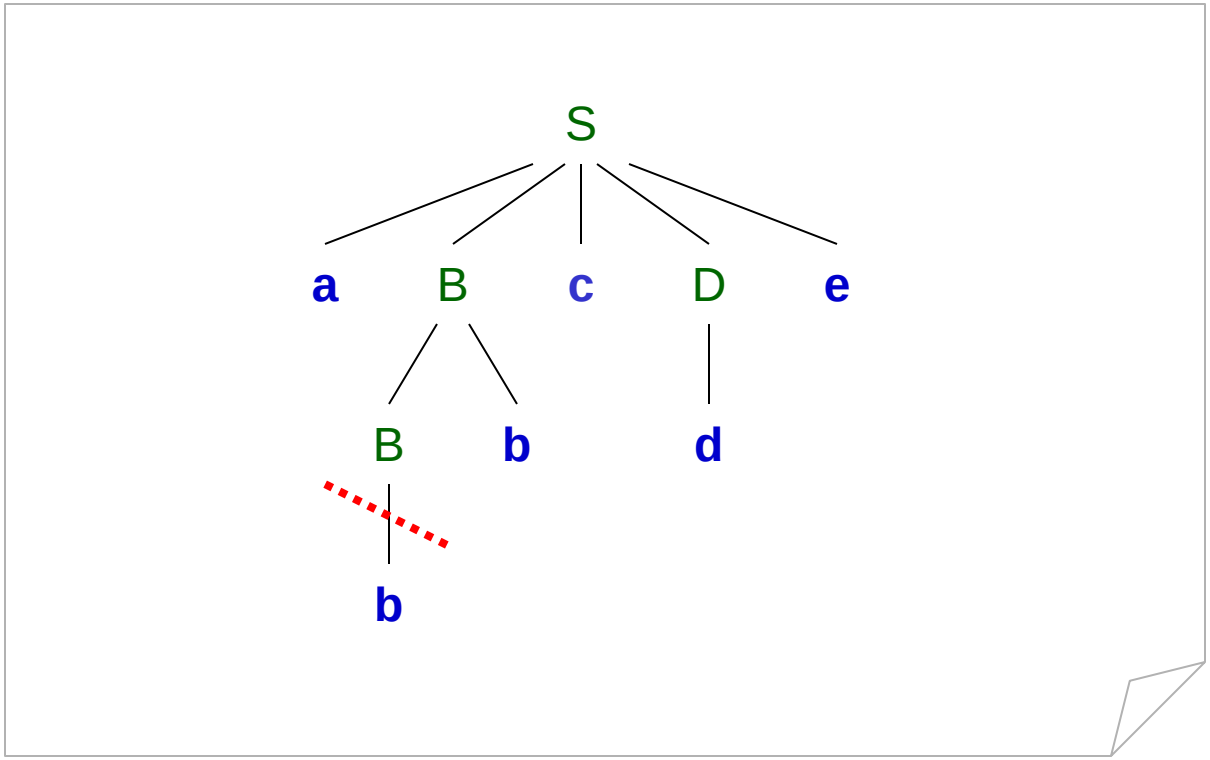
$$S \rightarrow \mathbf{a}\ B\ \mathbf{c}\ D\ \mathbf{e}$$

$$B \rightarrow B\ \mathbf{b} \mid \mathbf{b}$$

$$D \rightarrow \mathbf{d}$$

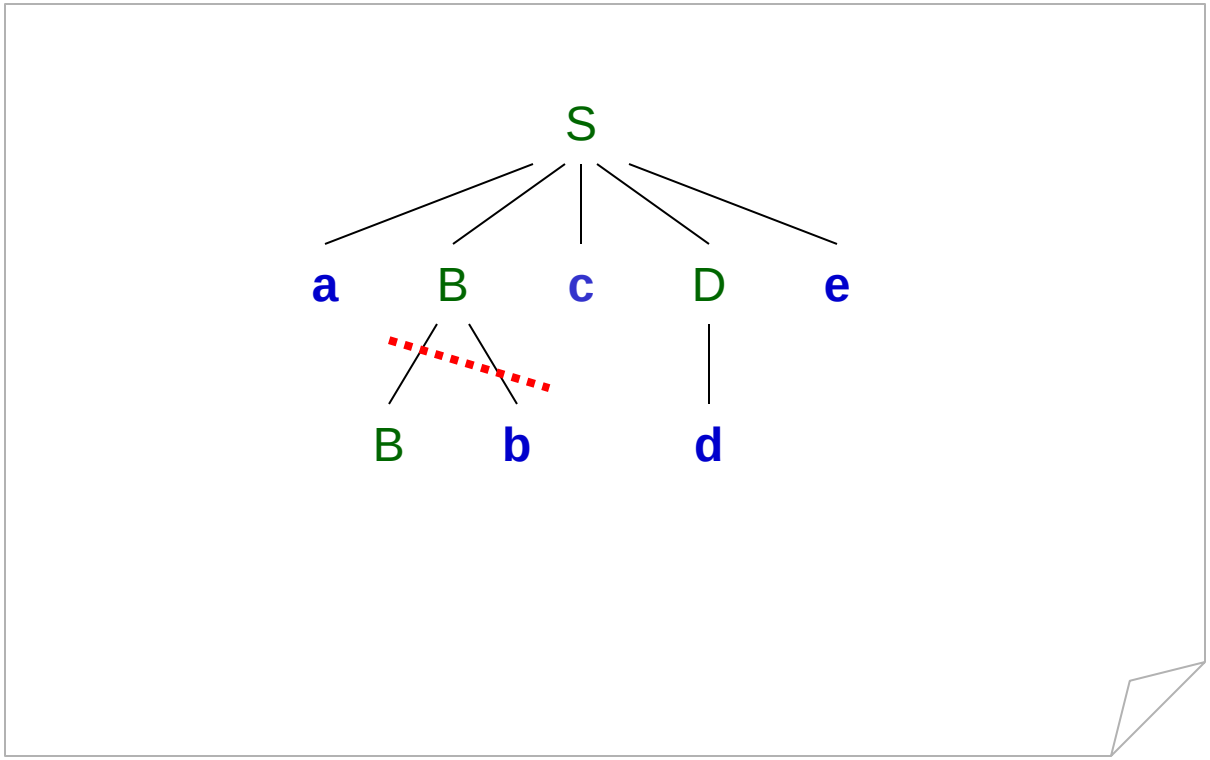
句柄：最左的两层子树

- Reduction = handle (**b**) pruning



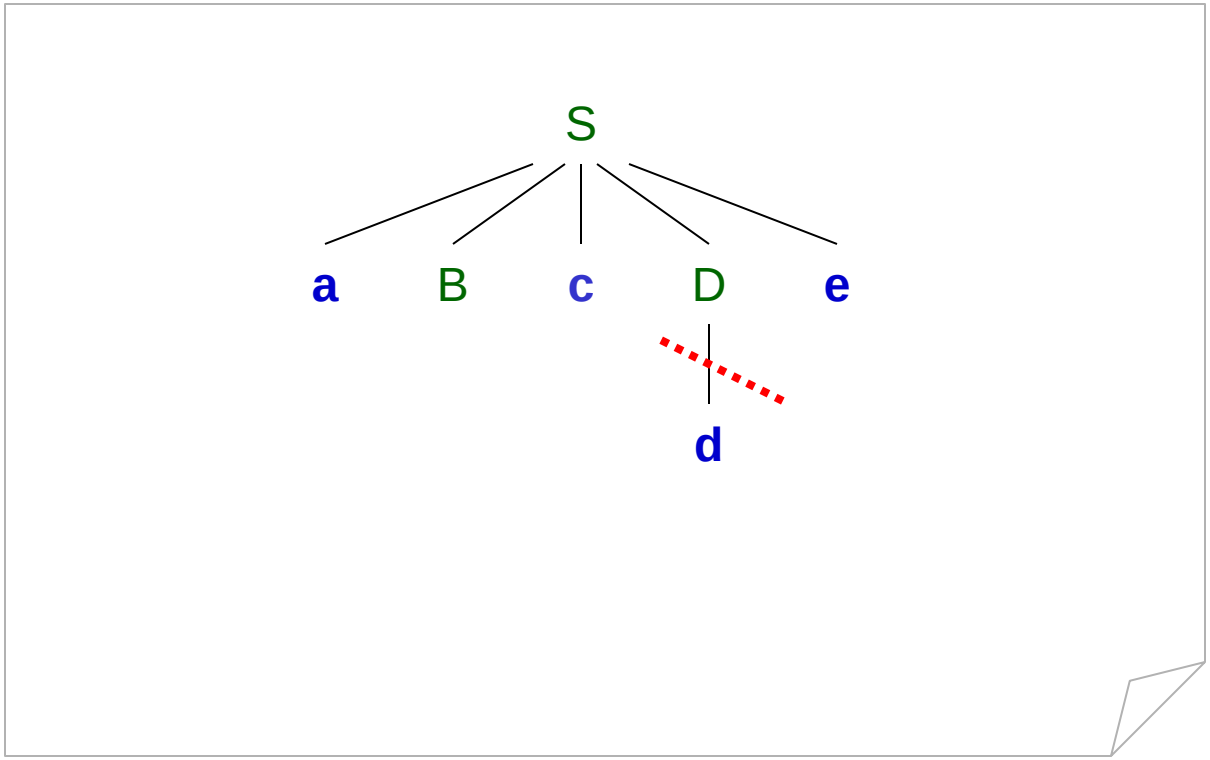
Right sentential form: **a b b c d e**

- **Bb** is the handle



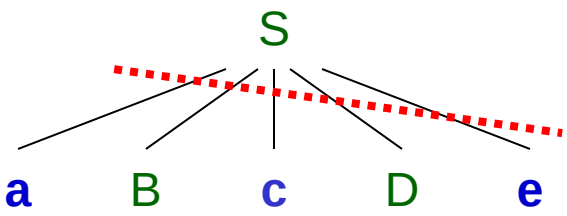
Right sentential form: **a B b c d e**

- **d** is the handle



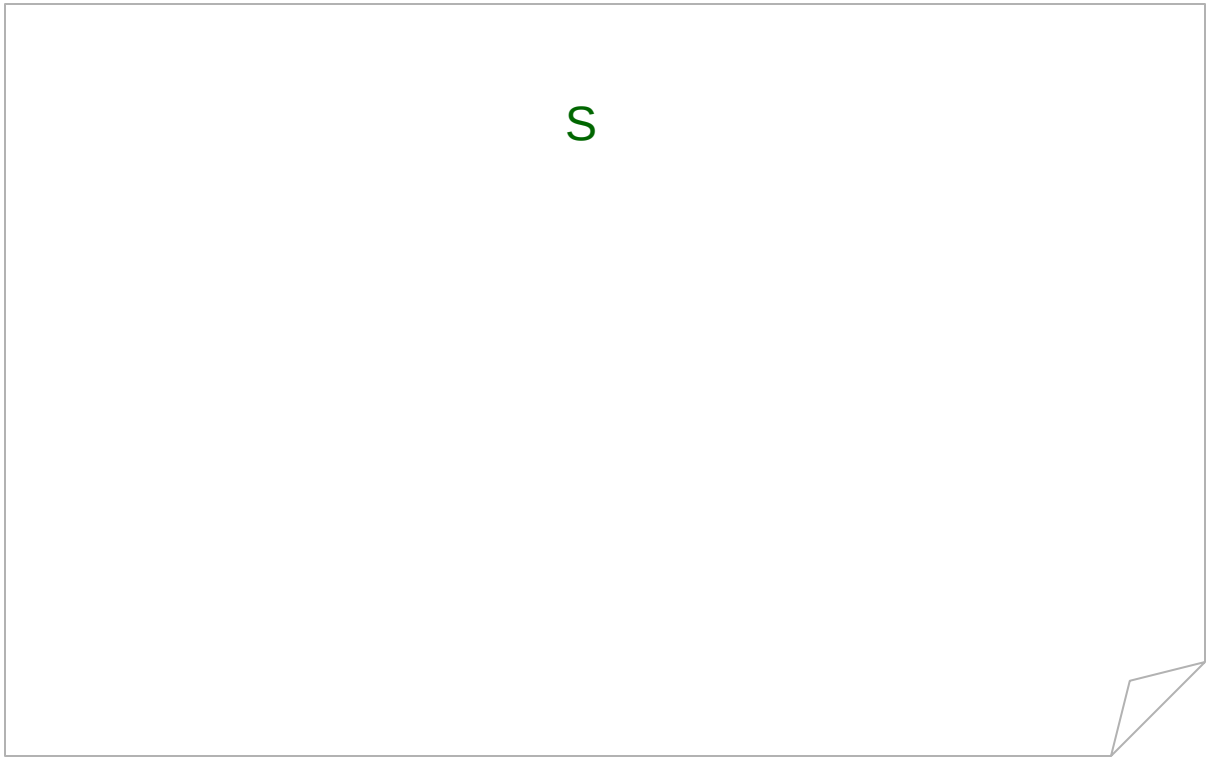
Right sentential form: **a B c d e**

- **aBcDe** is the handle



Right sentential form: **a B c D e**

- Successfully reduced to the root



Right sentential form: **S**

和top-down结合

Review

- Reducable string in a sentential form
  - Handle of a **right** sentential form
    - If $S \Rightarrow^*_{rm} \alpha A \omega \Rightarrow_{rm} \alpha\beta\omega$, then
    - production $A \rightarrow \beta$ in the position following α is a handle of $\alpha\beta\omega$.
  - Properties
    - The substring to the right of the handle (i.e. ω in the previous definition) must contain only terminals.
      - Note that it is a right-most (rm) derivation.

规范句型

Review (cont')

- Handle in a parse tree
  - A left-most two-level subtree.
  - Not practical. Only helpful to understand the concept.
- Critical problem in bottom-up parsing
  - How to find a reducable string in a sentential form?
    - LR parsing: handle (left-most simple phrase)
    - OPP: left-most prime phrase

最左直接短语

子树可能好几层

必须含有终结符号

最左素短语

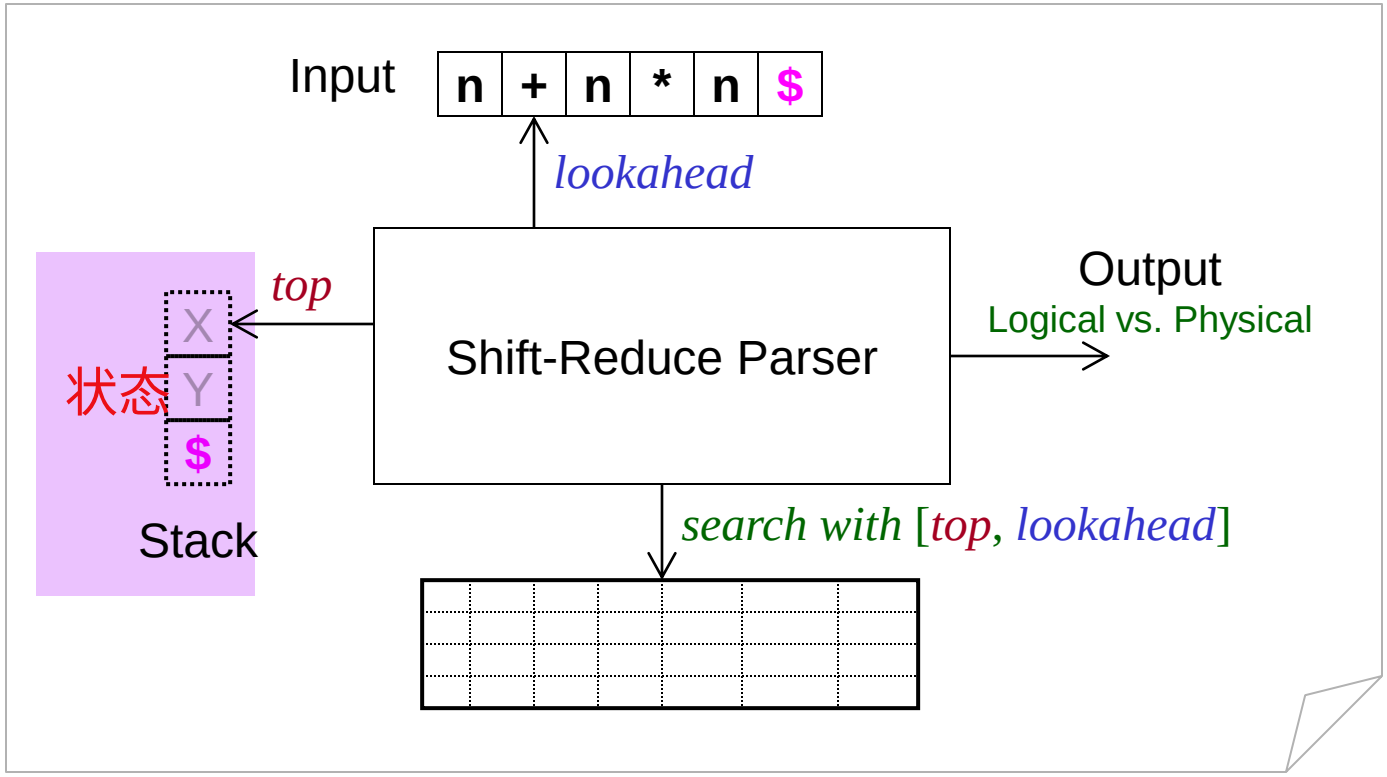
2. Abstract Model for Shift-Reduce Parsing

`match-derive parser`

- Symmetric to LL(1) parsing
  - Table-driven approach
    - Parsing decision making based on a table
    - LL(1) parsing table vs.
      - Operator-precedence relation table
      - LR(0)/SLR(1)/LALR(1)/LR(1) parsing table
  - Explicit stack
    - Top-down parsing: [**$**S, ω**$**] $\Rightarrow$ [**$**, **$**]
    - Bottom-up parsing: [**$**, ω**$**] $\Rightarrow$ [**$**S, **$**]
  - Actions
    - Top-down parsing: match-derive
    - Bottom-up parsing: shift-reduce

An Abstract Model

- A shift-reduce parser



A Motivating Example

- Given the previous grammar

  $S \rightarrow \mathbf{a}\ B\ \mathbf{c}\ D\ \mathbf{e}$

  $B \rightarrow B\ \mathbf{b} \mid \mathbf{b}$

  $D \rightarrow \mathbf{d}$

- For the previous sentence

  a b b c d e

A Motivating Example (cont')

Step	Stack	Input	Action	Output
1	**$**	**a b b c d e $**	shift	
2	**$ a**	**b b c d e $**	shift	
3	**$ a b**	**b c d e $**	reduce	B → **b**
4	**$ a** B	**b c d e $**	shift	
5	**$ a** B **b**	**c d e $**	reduce	B → B **b**
6	**$ a** B	**c d e $**	shift	
7	**$ a** B **c**	**d e $**	shift	
8	**$ a** B **c d**	**e $**	reduce	D → **d**
9	**$ a** B **c** D	**e $**	shift	
10	**$ a** B **c** D **e**	**$**	reduce	S → **a** B **c** D **e**
11	**$** S	**$**	accept	

More Motivating Examples

- Given the **ambiguous** grammar for expressions

$$E \rightarrow E + E \mid E * E \mid (E) \mid n$$

- For the following sentence

$$n + n * n$$

More Motivating Examples (cont')

Step	Stack	Input	Action	Output
1	**$**	**n + n * n $**	shift	
2	**$ n**	**+ n * n $**	reduce	E → **n**
3	**$** E	**+ n * n $**	shift	
4	**$** E **+**	**n * n $**	shift	
5	**$** E **+ n**	*** n $**	reduce	E → **n**
6	**$** E **+** E	*** n $**	shift	
7	**$** E **+** E *****	**n $**	shift	
8	**$** E **+** E *** n**	**$**	reduce	E → **n**
9	**$** E **+** E ***** E	**$**	reduce	E → E ***** E
10	**$** E **+** E	**$**	reduce	E → E **+** E
11	**$** E	**$**	accept	

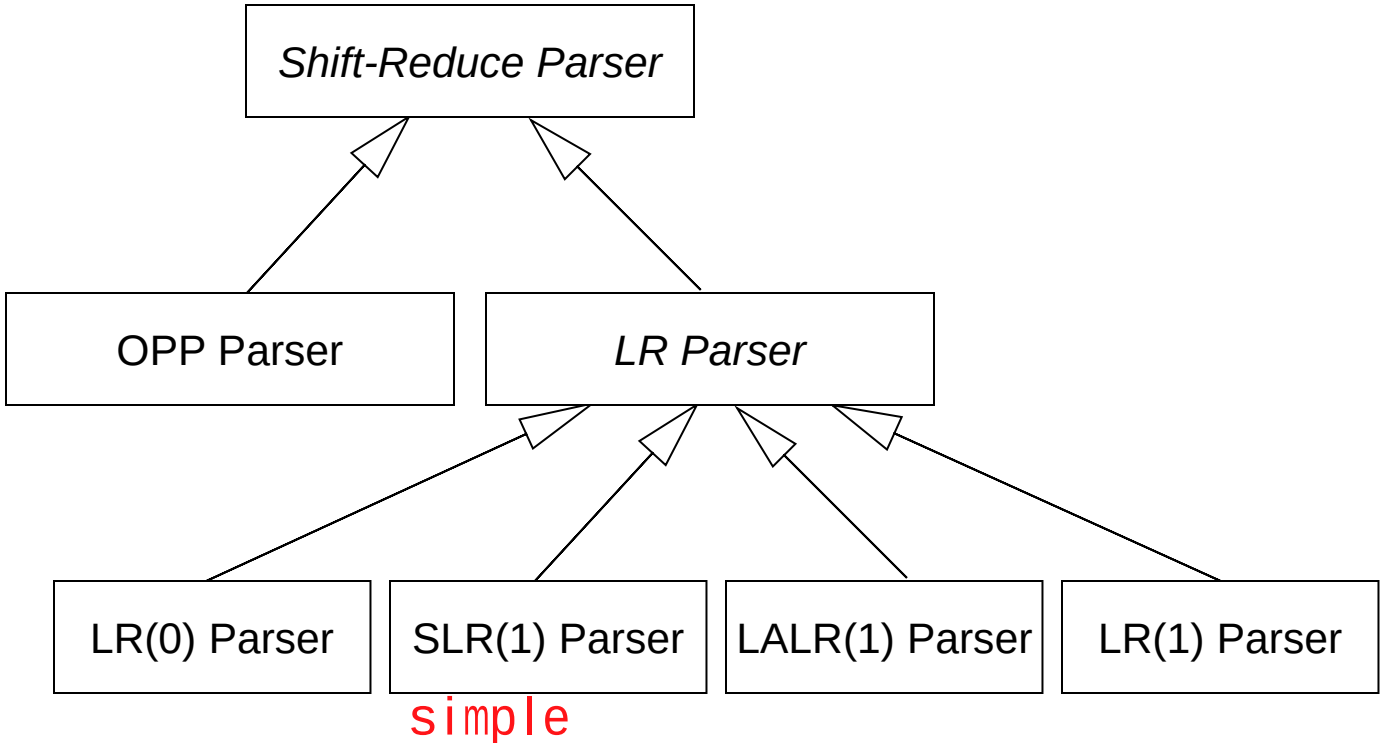
What Is Abstract in the Model?

- What is the form of the parsing table?
  - Operator-precedence relation table
  - LR parsing table
- What is the contents of the stack?
  - Operators opp
  - Parsing states 实质是状态的转换 LR
- How to determine a reducable substring on the top of the stack?
  - Left-most prime phrase opp
  - Handles LR

可能有多层，不止两层

Concrete Implementations

- Implementations of the abstract model for shift-reduce parsing

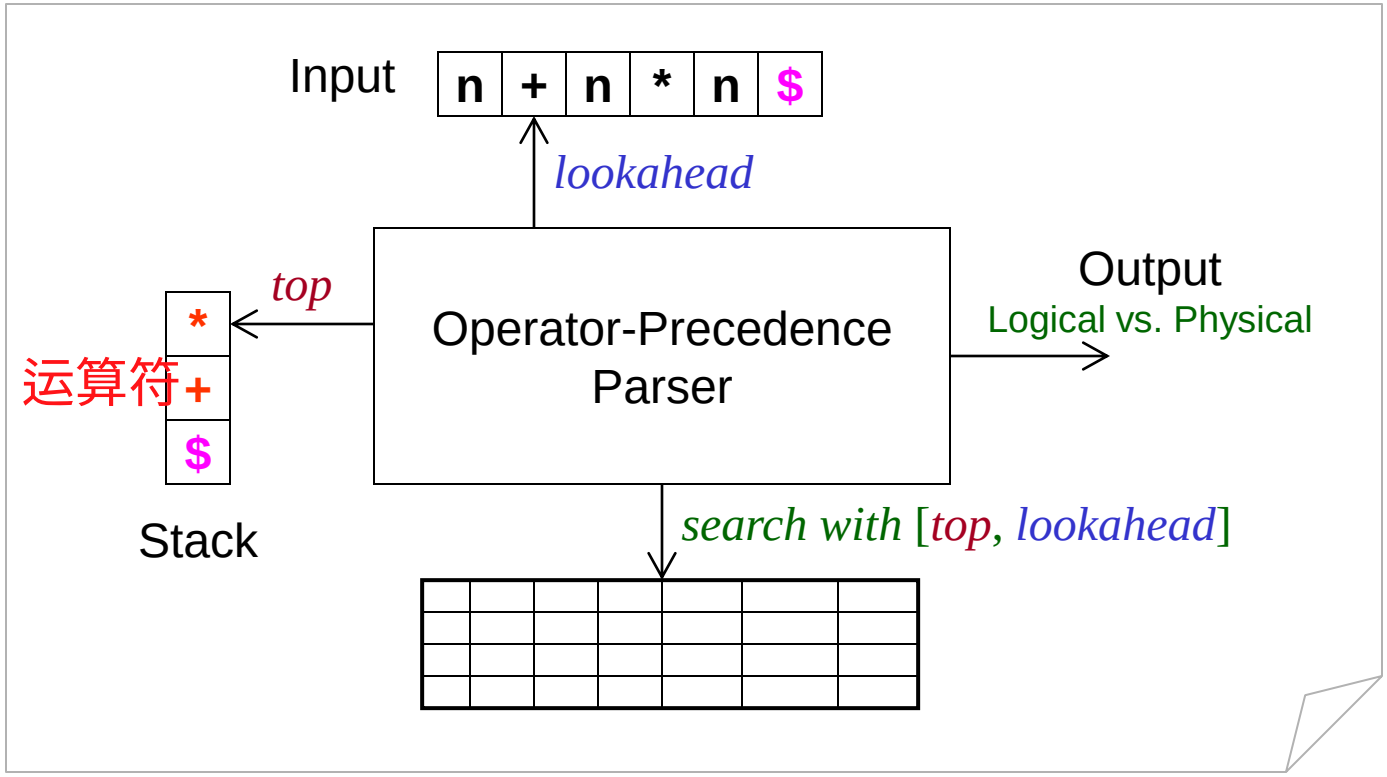


3. Operator-Precedence Parser

- Concrete implementations
  - Parsing table
    - Operator-precedence relations
  - Explicit stack
    - Operators
  - Reducable substring
    - Left-most prime phrases

A Concrete Model for OPP Parser

- Operator Precedence Parser



Operator Grammar

- A small but important class of grammars
  - There is no ε-production.
  - No production has two adjacent nonterminals.
- For example
  - Not an operator grammar

$$E \rightarrow E\,A\,E \mid (\,E\,) \mid -E \mid \mathbf{id}$$

$$A \rightarrow + \mid - \mid * \mid / \mid \wedge$$

  - An operator grammar

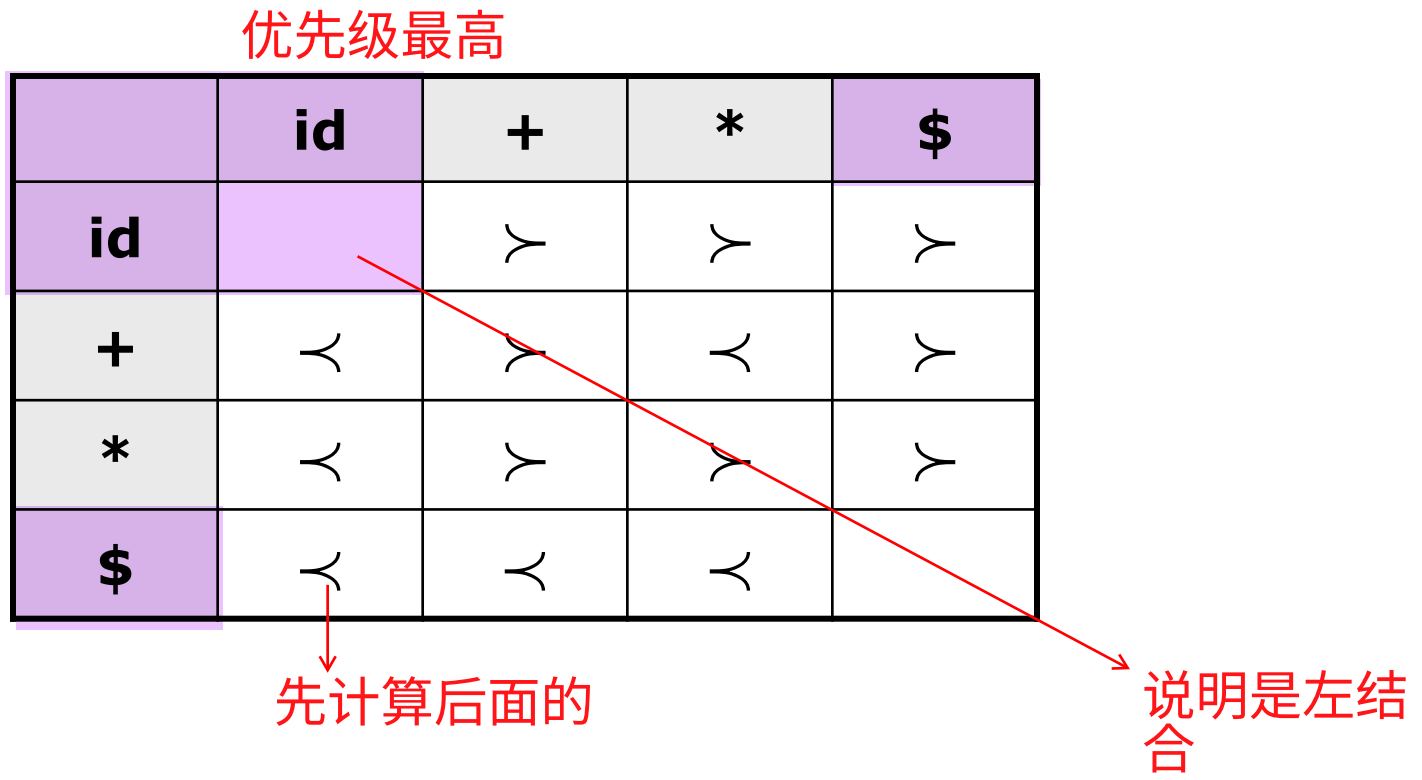
$$E \rightarrow E+E \mid E-E \mid E*E \mid E/E \mid E\wedge E$$

$$\mid \quad (\,E\,) \mid -E \mid \mathbf{id}$$

Operator-Precedence

- Three precedence relations
  - a $\prec$ b 表示运算的顺序
  - a $\equiv$ b
  - a $\succ$ b
- Properties of the binary relation
  - Non-reflexive: "+ $\equiv$ +" is not true. 无自反性
  - Non-symmetric: "+ $\succ$ –", but "– $\succ$ +". 无对称性
  - Non-transitive: "> $\succ$ <" & "< $\succ$ =", but "= $\succ$ >" 无传递性
  - A partial relation 部分是不定义的

Operator-Precedence Ralation Table



OPP

Parsing Algorithm

```
initialize();
for (;;) {
    if (top == $ && lookahead == $)  accept();
    topOp = stack.topMostTerminal();
    if (topOp ≺ lookahead || topOp ≡ lookahead) {  // shift
        stack.push(lookahead);
        lookahead = scanner.getNextToken();
    } else if (topOp ≻ lookahead) {  // reduce
        do {
            topOp = stack.pop();
        } while (stack.topMostTerminal() ≻ || ≡ topOp);
    } else  error();
}
```

opp里面是operater，所以没有S

（与）一起pop

Parsing a Sentence

查前面优先级表

Step	Stack	Input	Reference	Action	Output
1	**$**	**n + n * n $**	**$ ≺ n**	shift	
2	**$ n**	**+ n * n $**	**n ≻ +**	reduce	E → **n**
3	**$** E	**+ n * n $**	**$ ≺ +**	shift	
4	**$** E **+**	**n * n $**	**+ ≺ n**	shift	
5	**$** E **+ n**	*** n $**	**n ≻ ***	reduce	E → **n**
6	**$** E **+** E	*** n $**	**+ ≺ ***	shift	
7	**$** E **+** E *****	**n $**	*** ≺ n**	shift	
8	**$** E **+** E *** n**	**$**	**n ≻ $**	reduce	E → **n**
9	**$** E **+** E ***** E	**$**	*** ≻ $**	reduce	E → E * E
10	**$** E **+** E	**$**	**+ ≻ $**	reduce	E → E **+** E
11	**$** E	**$**		accept	

实际上，栈里只有操作符和$

一个运算有两个operator是两个是=

More Practical OPP Table

	+	–	*	/	^	id	(	)	$
+	⋗	⋗	⋖	⋖	⋖	⋖	⋖	⋗	⋗
–	⋗	⋗	⋖	⋖	⋖	⋖	⋖	⋗	⋗
*	⋗	⋗	⋗	⋗	⋖	⋖	⋖	⋗	⋗
/	⋗	⋗	⋗	⋗	⋖	⋖	⋖	⋗	⋗
^	⋗	⋗	⋗	⋗	⋖	⋖	⋖	⋗	⋗
id	⋗	⋗	⋗	⋗	⋗			⋗	⋗
(	⋖	⋖	⋖	⋖	⋖	⋖	⋖	≡	
)	⋗	⋗	⋗	⋗	⋗			⋗	⋗
$	⋖	⋖	⋖	⋖	⋖	⋖	⋖		

直接代替为操作

Another Form of OPP Table

	+	–	*	/	^	id	(	)	$
+	reduce	reduce	shift	shift	shift	shift	shift	reduce	reduce
–	reduce	reduce	shift	shift	shift	shift	shift	reduce	reduce
*	reduce	reduce	reduce	reduce	shift	shift	shift	reduce	reduce
/	reduce	reduce	reduce	reduce	shift	shift	shift	reduce	reduce
^	reduce	reduce	reduce	reduce	shift	shift	shift	reduce	reduce
id	reduce	reduce	reduce	reduce	reduce			reduce	reduce
(	shift	shift	shift	shift	shift	shift	shift	shift	
)	reduce	reduce	reduce	reduce	reduce			reduce	reduce
$	shift	shift	shift	shift	shift	shift	shift		

Error Recovery in OPP

Phrase-Level Recovery

	+	–	*	/	^	id	(	)	$
+	reduce	reduce	shift	shift	shift	shift	shift	reduce	reduce
–	reduce	reduce	shift	shift	shift	shift	shift	reduce	reduce
*	reduce	reduce	reduce	reduce	shift	shift	shift	reduce	reduce
/	reduce	reduce	reduce	reduce	shift	shift	shift	reduce	reduce
^	reduce	reduce	reduce	reduce	shift	shift	shift	reduce	reduce
id	reduce	reduce	reduce	reduce	reduce	error1	error1	reduce	reduce
(	shift	shift	shift	shift	shift	shift	shift	shift	error2
)	reduce	reduce	reduce	reduce	reduce	error1	error1	reduce	reduce
$	shift	shift	shift	shift	shift	shift	shift	error3	accept

Handling Overloading Operators

- Overloading unary and binary operators
  - **id – id * id**
  - **id * – id**
- Distinguish or resolve overloading by the scanner
  - Remember the previous processed token.

4. What Have We Discarded?

- Automatically table construction
  - Construct an operator-precedence relation table from an unambiguous grammar of expressions.
  - Trade-off: cost vs. cost
    - Writing an unambiguous grammar
    - Constructing an precedence relation table

Saving Table Space

- Precedence functions
  - Pack an $n \times n$ matrix into a $2 \times n$ matrix.
  - Save some space to store the parsing table.
  - But something is missing.
    - Each pair of operators must have a relation.

	+	–	*	/	^	id	(	)	$
f	2	2	4	4	4	6	0	6	0
g	1	1	3	3	5	5	5	0	0

5. Does OPP Disappear?

- OPP has disappeared from many modern compiler textbooks, e.g.
  - DBv2 (while DBv1 concerned with OPP)
  - Tiger book
  - The Art of Compiler Design
  - etc.

Reasons for Ignoring OPP

- Some reasons are:

数据结构已经有使用

  - OPP only handles very simple languages.
  - OPP isn't very good at discovering when a string isn't in the language.
  - Operator precedences have been incorporated into LR parsers, so writing an LR parser for expressions with many precedence levels isn't very hard.
  - Space isn't nearly as much an issue as it used to be.
  - OPP is often taught in introductory Data Structures courses.

可能是只有表达式是使用OPP

But OPP Still Works

- Even in commercial applications, specially combination of OPP and recursive parsing
  - Some Sun **javac** compiler
    - Recursive parser parses expressions coarsely.
    - OPP parses the binary operators correctly.
  - Some open source Verilog simulator
    - OPP parses Verilog expressions as a separate section of a hand coded recursive descent parser.
    - Verilog expressions are complex and language is irregular and non context-free.
  - The early Symantec's THINK C compiler
  - The original C compiler at Bell Labs (reported)

Exercise 6.1

- Consider the grammar

$$S \rightarrow (L) \mid a$$

$$L \rightarrow L, S \mid S$$

- We have the following operator-precedence relations for the grammar.
  - Show the detailed process of the parsing of the sentence **(a, (a, a))**, follow the style in the previous slides.

	a	(	)	,	$
a			≻	≻	≻
(	≺	≺	≡	≺	
)			≻	≻	≻
,	≺	≺	≻	≻	
$	≺	≺			

Further Reading

- Dragon Book, 2nd Edition (DBv2)
  - Comprehensive Reading:
    - Section 4.5 for the abstract model for shift-reduce parsing.
- Dragon Book, 1nd Edition (DBv1)
  - Comprehensive Reading:
    - Section 4.6 for the OPP details.
  - Skip Reading:
    - Section 4.6 on precedence functions.

Enjoy the Course!