A Brief Introduction

- **Syntax-directed translation (语法制导的翻译) is the process of language translation guided by context-free grammars**
  - Here, "language translation" is in a broad sense
    - Transforming infix expressions (中缀表达式) to postfix expressions (后缀表达式) is also viewed as "translation"
  - A language construct is typically made of smaller constructs
  - The semantics of a construct can be synthesized from its constituent constructs' semantics
    - The type of the expression `x + y` is determined by the type of `x` and `y`, and the operator `+`
  - Or inherited from other constructs (e.g., siblings in the parse tree)
    - In "`int x`", the type of `x` is determined by the type specifier to the left of `x`

由上下文无关文法指导的语言翻译过程

语言的construct是由多个小construct构成的.
①从子成分综合
②从其他成分继承

Syntax-Directed Definitions

- A ***syntax-directed definition* (语法制导定义, SDD)** is a context-free grammar together with ***attributes*** and ***rules***
  - A set of **attributes (属性)** is associated with each grammar symbol*
    - Can be anything, e.g., data type of expressions, # instructions in the generated code
  - A **semantic rule (语义规则)** is associated with a production and describes how attributes are computed

$E \to E_1 + T$ $\quad$ $E.code = E_1.code \parallel T.code \parallel \text{'+'}$

The attribute *code* represents the postfix notation of the construct

$\parallel$ is the operator for string concatenation

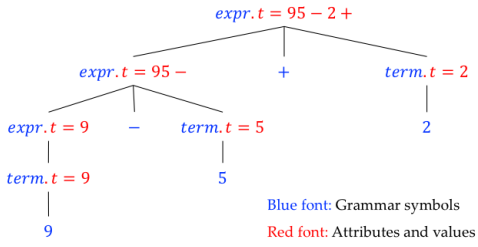
*Grammar symbols represent language constructs. Nonterminal nodes and subtrees rooted at these nodes correspond to productions.

属性即语法符号
语义规则描述了属性如何计算

Annotated Parse Tree

- An annotated parse tree for infix expression `9-5+2`
- The attribute t represents postfix notation

$expr \to expr + term$
$expr \to expr - term$
$expr \to term$
$term \to 0$
...
$term \to 9$



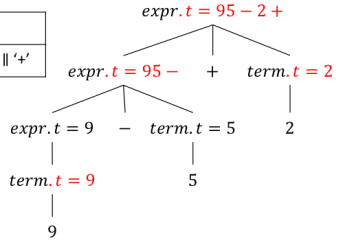
Blue font: Grammar symbols
Red font: Attributes and values

Synthesized Attributes (合成属性)

- An attribute is said to be *synthesized* if its value at a parse-tree node N is only determined from attribute values at the children of N and at N itself (defined by a semantic rule associated with the production at N)

Production	$expr \to expr_1 + term$
Rule	$expr.t = expr_1.t \parallel term.t \parallel \text{'+'}$

Production	$term \to 9$
Rule	$term.t = \text{'9'}$



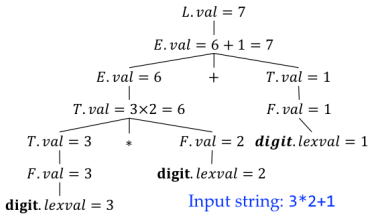
Terminals can also have synthesized attributes (lexical values), but there are no rules for computing the value of an attribute for a terminal.

合成属性的值是由其在parse-tree上的节点与其子节点的属性值决定的.

A Complete Example of SDD

- The SDD below helps compute the value of an expression L
- SDD's do not specify the evaluation order of attributes on a parse tree
  - Any order that computes an attribute a after all other attributes that a depends on is fine
  - Synthesized attributes have a nice property that they can be evaluated during a single bottom-up traversal of a parse tree (it is often unnecessary to explicitly create the tree)

	Production	Semantic Rules
1)	$L \to E$ **n**	$L.val = E.val$
2)	$E \to E_1 + T$	$E.val = E_1.val + T.val$
3)	$E \to T$	$E.val = T.val$
4)	$T \to T_1 * F$	$T.val = T_1.val \times F.val$
5)	$T \to F$	$T.val = F.val$
6)	$F \to (E)$	$F.val = E.val$
7)	$F \to$ **digit**	$F.val =$ **digit**.lexval



SDD不会指定属性的计算顺序.

Inherited Attributes (继承属性)

- ***Inherited attributes*** have their value at a parse-tree node determined from attribute values at the node itself, its parent, and its siblings in the parse tree

We already have synthesized attributes. When are inherited attributes useful???

继承属性的值由parse-tree的本节点、父节点、兄弟节点决定.

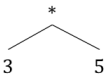
Top-Down Parse of 3*5

$T \to FT'$

$T' \to * FT'$

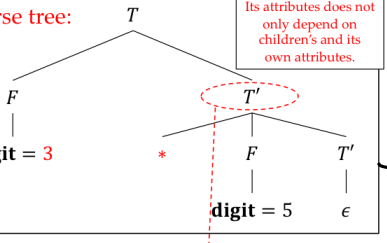
$T' \to \epsilon$

$F \to$ **digit**



Abstract syntax tree

Parse tree:



Does not represent a valid subexpression;

Its attributes does not only depend on children's and its own attributes.

For some grammars, the structure of the parse tree does not **match** the abstract syntax of the code (3 and * are in different subtrees)

Not all non-terminals in a parse tree correspond to proper language constructs, e.g., T' above.

Parse tree与abstract syntax tree不一样时. 就需要继承属性了.

→只靠这个子树无法综合. 因为*5无法计算3在另一个子树上.

SDD with Inherited Attributes

	Production	Semantic Rules
1)	$T \to F T'$	$T'.inh = F.val$ $T.val = T'.syn$
2)	$T' \to * F T'_1$	$T'_1.inh = T'.inh \times F.val$ $T'.syn = T'_1.syn$
3)	$T' \to \epsilon$	$T'.syn = T'.inh$
4)	$F \to$ **digit**	$F.val =$ **digit**.lexval

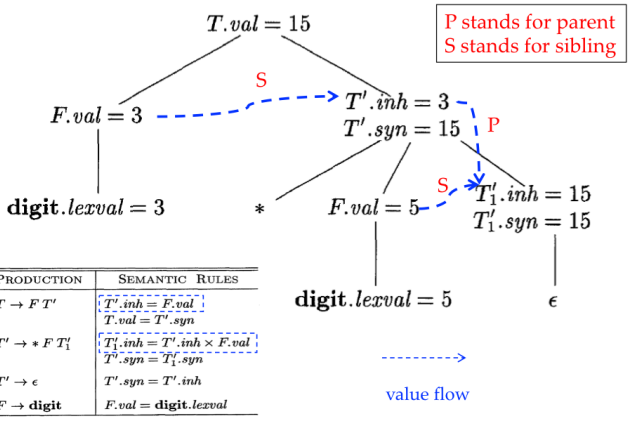
The left operand of the operator * is inherited by T' and kept for later computation when T' further gets replaced

The inherited attribute of T' is not defined by a rule associated with the production (2) or (3), whose head is T'

→应用T→FT'时，3与*5分离了，所以需要T'继承F.val.

→当所有因子都处理完毕，再向上综合

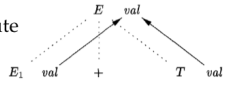
Annotated Parse Tree for 3*5



	Production	Semantic Rules
1)	$T \to F\ T'$	$T'.inh = F.val$ $T.val = T'.syn$
2)	$T' \to *\ F\ T'_1$	$T'_1.inh = T'.inh \times F.val$ $T'.syn = T'_1.syn$
3)	$T' \to \epsilon$	$T'.syn = T'.inh$
4)	$F \to$ **digit**	$F.val =$ **digit**$.lexval$

Evaluation Orders for SDD's

- Given parse tree nodes N, M_1, M_2, …, M_k, if the attribute a of N is defined as $N.a = f(M_1.a_1, M_2.a_2, \ldots, M_k.a_k)$, then in order to compute $N.a$, we must first compute $M_i.a_i$ $(1 \le i \le k)$
- *Dependency graphs* (依赖图) are a useful tool for determining evaluation orders
  - Depict the information flow among the attribute instances in a particular parse tree
  - Model the partial order among attribute instances (not every pair of elements has an order)

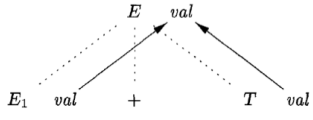


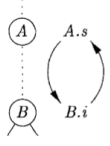
描述 parse tree 中各 attribute 的求值顺序

Dependency Graph

- An edge from one attribute instance (a_1) to another (a_2) means that the value of a_1 is needed to compute the value of a_2
- If there is any cycle in a dependency graph, we cannot find an order to compute the value of all attribute instances

Production	Semantic Rule
$E \to E_1\ +\ T$	$E.val = E_1.val + T.val$



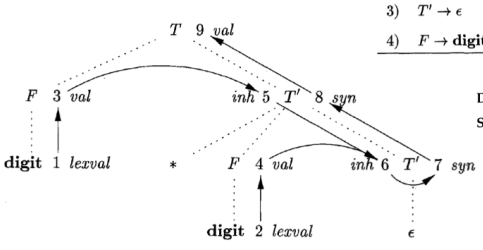


Dotted lines: parse tree edges **Solid lines:** depedency graph edges

Example: Parsing 3*2

Attribute values can be computed according to any *topological sort* (拓扑排序)* of the graph, e.g., 1, 2, 3, …, 9 in the example below

	Production	Semantic Rules
1)	$T \to F\ T'$	$T'.inh = F.val$ $T.val = T'.syn$
2)	$T' \to *\ F\ T'_1$	$T'_1.inh = T'.inh \times F.val$ $T'.syn = T'_1.syn$
3)	$T' \to \epsilon$	$T'.syn = T'.inh$
4)	$F \to$ **digit**	$F.val =$ **digit**$.lexval$



Dotted lines: parse tree edges
Solid lines: depedency graph edges

1–9: Evaluation order

* Topological sorting for a directed acyclic graph is a linear ordering of vertices such that for every directed edge $u \to v$, vertex u comes before v in the ordering. Topological sorting is not possible for graphs with cycles.

Ordering the Evaluation of Attributes

- Given an arbitrary SDD, it is hard to tell whether there exist any parse trees (annotated) whose dependency graphs have cycles (i.e., whether the SDD is computable)

给定SDD，难找出是否存在parse-tree，其依赖图有环，即SDD是否可计算

- In practice, translations can be implemented using classes of SDD's that guarantee an evaluation order*
  - ***S-attributed*** SDD's
  - ***L-attributed*** SDD's

*The dependency graphs for such SDDs are directed acyclic graphs

S-Attributed SDDs

- An SDD is *S-attributed* if every attribute is synthesized

所有属性都是合成的，即边全都从子节点指向父节点

	PRODUCTION	SEMANTIC RULES
1)	$L \to E$ **n**	$L.val = E.val$
2)	$E \to E_1 + T$	$E.val = E_1.val + T.val$
3)	$E \to T$	$E.val = T.val$
4)	$T \to T_1 * F$	$T.val = T_1.val \times F.val$
5)	$T \to F$	$T.val = F.val$
6)	$F \to (E)$	$F.val = E.val$
7)	$F \to$ **digit**	$F.val =$ **digit**.lexval

Intuitively, there cannot be cycles in the dependency graph of any parse tree, since edges always go from children nodes to parent nodes, never the other way around.

- When an SDD is S-attributed, we can evaluate its attributes in any bottom up order of the parse-tree nodes
  - e.g., postorder traversal (后序遍历) of the parse tree

后序遍历可计算 S-attributed SDD

- So, S-attributed SDDs can be easily implemented during bottom-up parsing (the parsing process corresponds to a postorder traversal)

```
postorder(N) {
    for ( each child C of N, from the left ) postorder(C);
    evaluate the attributes associated with node N;
}
```

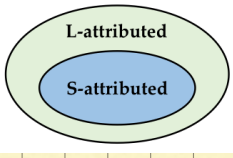
L-Attributed SDDs

- An SDD is *L-attributed* if for each production $A \to X_1 X_2 \ldots X_n$, for each $j = 1 \ldots n$, each inherited attribute of X_j depends on only:
  - the attributes of $X_1, \ldots, X_{j-1}$ (either synthesized or inherited), or
  - the inherited attributes of A
- Or each attribute is synthesized

① X_j 的继承属性只依赖于
a. $X_1 \ldots X_{j-1}$ 的合成/继承属性
b. A 的继承属性
② 所有属性都是合成的

属性只来自于上面和左边。

- Dependency-graph edges can go from left to right (on an annotated parse tree), but not right to left (hence the SDD is named "L-attributed")
- There cannot be cycles in the graph, as edges only go from left to right or from parents to children



L-Attributed SDD Example

	Production	Semantic Rules
1)	$T \to F\ T'$	$T'.inh = F.val$ $T.val = T'.syn$
2)	$T' \to *\ F\ T'_1$	$T'_1.inh = T'.inh \times F.val$ $T'.syn = T'_1.syn$
3)	$T' \to \epsilon$	$T'.syn = T'.inh$
4)	$F \to \textbf{digit}$	$F.val = \textbf{digit}.lexval$

Left sibling's attribute

- Parent's inherited attribute
- Left sibling's attribute

Synthesized attributes: val, syn, lexval. Inherited attributes: inh

Attributed Evaluation for L-Attributed SDD's

Input: A node n in a parse tree T

Output: An evaluation order for the attributes of the subtree rooted at n

procedure depth_first(n)*

Imagine the directions of the dependency graph edges, then it is easy to understand why DFS works here. Is the evaluation order a topological sort of parse tree nodes?

begin

  for every child m of n from left to right **do begin**

    evaluate the inherited attributes of m;

    depth_first(m); // here m's synthesized attributes will be evaluated

  end

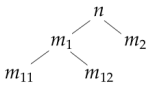
  evaluate the synthesized attributes of n;

end

*The inherited attributes of x (non-root) are computed before calling depth_first(x), as indicated by the for body

Example

Example




```
procedure depth_first(n)*
begin
    for every child m of n from left to right do begin
        evaluate the inherited attributes of m;
        depth_first(m);
    end
    evaluate the synthesized attributes of n;
end
```

1. Compute m_1's inherited attribute — depth_first(n)
2. Compute m_{11}'s inherited attribute — depth_first(m_1)
3. Compute m_{11}'s synthesized attribute — depth_first(m_{11})
4. Compute m_{12}'s inherited attribute
5. Compute m_{12}'s synthesized attribute — depth_first(m_{12})
6. Compute m_1's synthesized attribute
7. Compute m_2's inherited attribute
8. Compute m_2's synthesized attribute — depth_first(m_2)
9. Compute n's synthesized attribute

Attributed Evaluation for L-Attributed Definitions

Input: A node n in a parse tree T

Output: An evaluation order for the attributes of the subtree rooted at n

procedure depth_first(n)*

When evaluating the inherited attributes of a node, the attributes of nodes to its left have been evaluated

Guarantee

begin

  for every child m of n from left to right **do begin**

    evaluate the inherited attributes of m;

    depth_first(m); // here m's synthesized attributes will be evaluated

  end

  evaluate the synthesized attributes of n;

end

*The inherited attributes of x (non-root) are computed before calling depth_first(x), as indicated by the for body

Input: A node n in a parse tree T

Output: An evaluation order for the attributes of the subtree rooted at n

procedure depth_first(n)*

When evaluating the inherited attributes of a node (m), the inherited attributes of its parent node (n) have been evaluated

Guarantee

begin

  for every child m of n from left to right **do begin**

    evaluate the inherited attributes of m;

    depth_first(m); // here m's synthesized attributes will be evaluated

  end

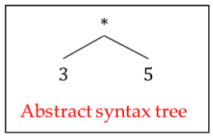
  evaluate the synthesized attributes of n;

end

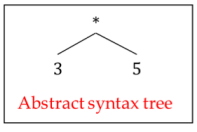
*The inherited attributes of n are computed before calling depth_first(n), as indicated by the for body

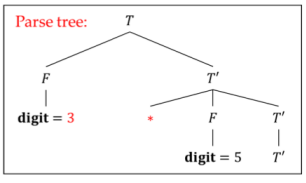
Construction of Syntax Tree

- Abstract syntax tree (or syntax tree for short) revisited:
  - Each interior node N represents a construct (corresponding to an operator)
  - The children of N represent the meaningful components of the construct represented by N (corresponding to operands)



- Syntax tree vs. parse tree
  - In a syntax tree, interior nodes represent programming constructs, while in a parse tree, interior nodes represent nonterminals*
  - A parse tree is also called a *concrete syntax tree*, and the underlying grammar is called a *concrete syntax* for the language



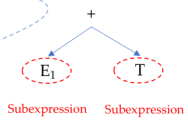


*Not all nonterminals represent programming constructs, e.g., those introduced to eliminate left recursions (T' in the earlier L-attributed SDD example)

parse tree 也叫具体语法树.

- An S-attributed SDD for building syntax trees for simple expressions
  - Each node of the syntax tree is implemented as an **object** with a field *op*, representing the label of the node, and some additional fields
    - **Leaf node:** one additional field holding the lexical value
    - **Interior node:** # additional fields = # of children

	Production	Semantic Rules
1)	$E \to E_1 + T$	$E.node =$ **new** $Node('+', E_1.node, T.node)$
2)	$E \to E_1 - T$	$E.node =$ **new** $Node('-', E_1.node, T.node)$
3)	$E \to T$	$E.node = T.node$
4)	$T \to (\ E\ )$	$T.node = E.node$
5)	$T \to$ **id**	$T.node =$ **new** $Leaf(\textbf{id}, \textbf{id}.entry)$
6)	$T \to$ **num**	$T.node =$ **new** $Leaf(\textbf{num}, \textbf{num}.val)$

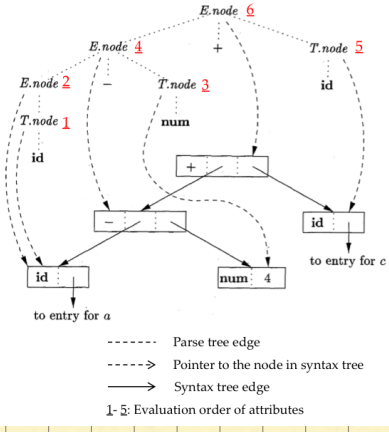


后序遍历 parse tree，依 S-attributed SDD 构建 syntax tree

Input expression: $a - 4 + c$

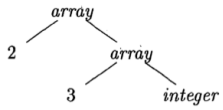
Steps (object creations only; bottom-up evaluation):

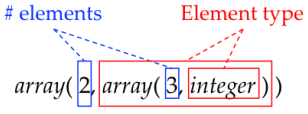
1) $p_1 =$ **new** $Leaf(\textbf{id}, entry\text{-}a)$;
2) $p_2 =$ **new** $Leaf(\textbf{num}, 4)$;
3) $p_3 =$ **new** $Node('-', p_1, p_2)$;
4) $p_4 =$ **new** $Leaf(\textbf{id}, entry\text{-}c)$;
5) $p_5 =$ **new** $Node('+', p_3, p_4)$;



Computing the Structure of a Type

`int[2][3] a = ...;` What is the type of a?





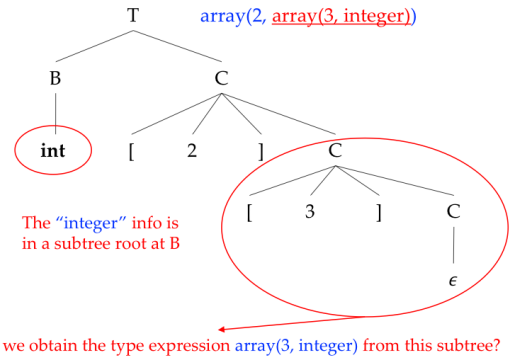
That is: array of 2 arrays of 3 integers

PRODUCTION
$T \rightarrow B\ C$
$B \rightarrow$ **int**
$B \rightarrow$ **float**
$C \rightarrow$ [**num**] C_1
$C \rightarrow \epsilon$

The grammar generates type specifiers:

- `int` } Basic types
- `float`
- `int[2]` } Array types
- `int[2][3]`
- `int[4][5][6]`
- ...

- `int[2][3]`



How can we obtain the type expression array(3, integer) from this subtree?

PRODUCTION	SEMANTIC RULES
$T \rightarrow B\ C$	$T.t = C.t$
	$C.b = B.t$
$B \rightarrow$ **int**	$B.t = integer$
$B \rightarrow$ **float**	$B.t = float$
$C \rightarrow$ [**num**] C_1	$C.t = array($**num**$.val,\ C_1.t)$
	$C_1.b = C.b$
$C \rightarrow \epsilon$	$C.t = C.b$

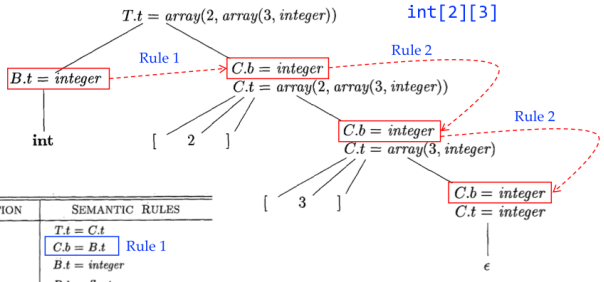
L-attributed SDD

Synthesized attribute t represents a type

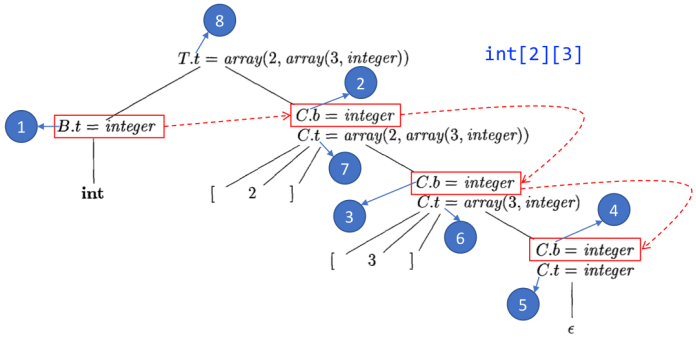
Inherited attribute b passes the basic type down the parse tree

Computing the Structure of a Type

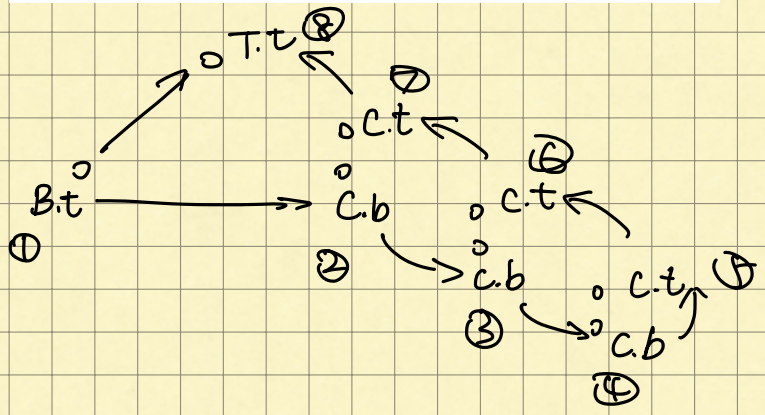
Dependency ⇢



PRODUCTION	SEMANTIC RULES
$T \rightarrow B\ C$	$T.t = C.t$
	$C.b = B.t$ Rule 1
$B \rightarrow$ **int**	$B.t = integer$
$B \rightarrow$ **float**	$B.t = float$
$C \rightarrow$ [**num**] C_1	$C.t = array($**num**$.val,\ C_1.t)$
	$C_1.b = C.b$ Rule 2
$C \rightarrow \epsilon$	$C.t = C.b$



1 ... 8 : evaluation order (according to the algorithm on #22)



Syntax-Directed Translation Schemes

- SDD's tell us what to do (high-level specifications) in the translation, but not how to do
- Syntax-directed translation schemes (SDT's, 语法制导的翻译方案) specify more details on how to do the translation
- An SDT* is a context-free grammar with semantic actions (program fragments) embedded within production bodies
  - Differ from the semantic rules in SDD's
  - Semantic actions can appear anywhere within a production body

*In this course, we are only interested in SDT's for computing L-attributed SDD's.

SDD：要做什么
SDT：要怎么做

语法动作可在产生式的任何地方

Example SDT

- The SDT below implements a simple calculator

SDT

L	$\rightarrow$	E **n**	{ print($E.val$); }
E	$\rightarrow$	$E_1 + T$	{ $E.val = E_1.val + T.val$; }
E	$\rightarrow$	T	{ $E.val = T.val$; }
T	$\rightarrow$	$T_1 * F$	{ $T.val = T_1.val \times F.val$; }
T	$\rightarrow$	F	{ $T.val = F.val$; }
F	$\rightarrow$	(E)	{ $F.val = E.val$; }
F	$\rightarrow$	**digit**	{ $F.val =$ **digit**.$lexval$; }

Semantic actions:
Real code in {}

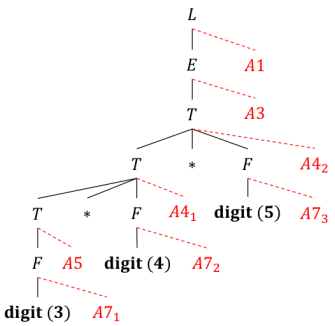
SDD

$L \rightarrow E$ **n**	$L.val = E.val$
$E \rightarrow E_1 + T$	$E.val = E_1.val + T.val$
$E \rightarrow T$	$E.val = T.val$
$T \rightarrow T_1 * F$	$T.val = T_1.val \times F.val$
$T \rightarrow F$	$T.val = F.val$
$F \rightarrow (E)$	$F.val = E.val$
$F \rightarrow$ **digit**	$F.val =$ **digit**.lexval

Semantic rules:
Mathematical definitions

- Parse and calculate 3*4*5

L	$\rightarrow$	E **n**	{ print($E.val$); } A1
E	$\rightarrow$	$E_1 + T$	{ $E.val = E_1.val + T.val$; } A2
E	$\rightarrow$	T	{ $E.val = T.val$; } A3
T	$\rightarrow$	$T_1 * F$	{ $T.val = T_1.val \times F.val$; } A4
T	$\rightarrow$	F	{ $T.val = F.val$; } A5
F	$\rightarrow$	(E)	{ $F.val = E.val$; } A6
F	$\rightarrow$	**digit**	{ $F.val =$ **digit**.$lexval$; } A7



Order of actions:
$A7_1, A5, A7_2, A4_1, A7_3, A4_2, A3, A1$

All SDT's (for computing L-attributed SDD's) can be implemented by: 1) first building the parse tree, 2) treating semantic actions as "virtual" parse-tree nodes, and 3) performing preorder traversal

SDT实现：
①建立parse tree
②将semantic action视作parse tree的节点
③前序遍历

SDT's With Actions Inside Productions

$$B \rightarrow X\{a\}Y$$

- The action a should be done after we have recognized X (if X is a terminal) or all the terminals derived from X (if X is a nonterminal)
  - If the parse is bottom-up, we perform the action a as soon as X appears on the top of the parsing stack
  - If the parse is top-down, we perform the action a before attempting to expand Y (if Y is a nonterminal) or check for Y on the input (if Y is a terminal)

SDT's Implementable During Parsing

- In practice, SDT's are often implemented during parsing, without first building a parse tree
- Not all SDT's can be implemented during parsing*
  - Even if the underlying grammar is parsable by a method (e.g., LL, LR), after introducing semantic actions, the parsing method may become inapplicable
- Determine if an SDT can be implemented during parsing
  - Introduce distinct *marker nonterminals* to replace each embedded action; each marker M has only one production $M \to \epsilon$
  - If the grammar with marker nonterminals can be parsed by a given method, then the SDT can be implemented during parsing

*Note that all SDT's for computing L-attributed SDD's can be implemented after building the parse tree, as earlier mentioned

SDT在parse过程中就已实现

不是所有的SDT都能在parse中实现

action都使用一个marker M代替.

A Problematic SDT

- This SDT translates infix expression to prefix expressions

$$
\begin{array}{lcl}
L & \to & E\ \mathbf{n} \\
E & \to & \{\ \text{print}('+');\ \}\ E_1 + T \\
E & \to & T \\
T & \to & \{\ \text{print}('*');\ \}\ T_1 * F \\
T & \to & F \\
F & \to & (\ E\ ) \\
F & \to & \mathbf{digit}\ \{\ \text{print}(\mathbf{digit}.lexval);\ \}
\end{array}
\quad \Rightarrow \quad
\begin{array}{l}
L \to E \\
E \to M_1 E + T \quad M_1 \to \epsilon \\
E \to T \\
T \to M_2 T * F \quad M_2 \to \epsilon \\
T \to F \\
F \to (E) \\
F \to \mathbf{digit}\ M_3 \quad M_3 \to \epsilon
\end{array}
$$

It is impossible to build parsing tables without conflicts using top-down or bottom-up parsing methods. This SDT cannot be implemented during parsing. It can be implemented after parsing according to earlier mentioned steps.

可生成 parse tree，则SDT就可以在parse过程中实现

Uses of SDT's

- We can use SDT's to implement two important classes of SDD's:
  - The underlying grammar is LR, and the SDD is S-attributed
  - The underlying grammar is LL, and the SDD is L-attributed

LR & S-attributed
LL & L-attributed

Postfix Translation Schemes

- If the grammar of an SDD is LR, and the SDD is S-attributed, then we can construct a *postfix SDT* (后缀SDT) to implement the SDD in bottom-up parsing
  - Semantic actions always appear at the end of productions (hence "postfix")

SDD	
$L \to E\ \mathbf{n}$	$L.val = E.val$
$E \to E_1\ +\ T$	$E.val = E_1.val + T.val$
$E \to T$	$E.val = T.val$
$T \to T_1\ *\ F$	$T.val = T_1.val \times F.val$
$T \to F$	$T.val = F.val$
$F \to (\ E\ )$	$F.val = E.val$
$F \to \mathbf{digit}$	$F.val = \mathbf{digit}.\text{lexval}$

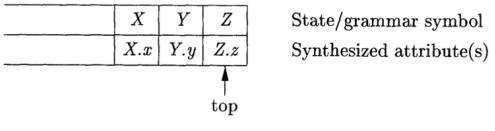
SDT		
L	$\to$ $E\ \mathbf{n}$	$\{\ \text{print}(E.val);\ \}$
E	$\to$ $E_1 + T$	$\{\ E.val = E_1.val + T.val;\ \}$
E	$\to$ T	$\{\ E.val = T.val;\ \}$
T	$\to$ $T_1 * F$	$\{\ T.val = T_1.val \times F.val;\ \}$
T	$\to$ F	$\{\ T.val = F.val;\ \}$
F	$\to$ $(\ E\ )$	$\{\ F.val = E.val;\ \}$
F	$\to$ $\mathbf{digit}$	$\{\ F.val = \mathbf{digit}.lexval;\ \}$

This is possible because in bottom-up parsing, before reducing to a production head, the grammar symbols in the production body have been visited and their synthesized attributes have been computed (both non-terminals and terminals).

若SDD的文法是LR，且SDD是S-attributed的.
则可构建后缀SDD

Parser-Stack Implementation of Postfix SDT's

- Postfix SDT's can be implemented during LR parsing by executing the actions when reductions occur
- The synthesized attributes can be placed along with the grammar symbols on the stack

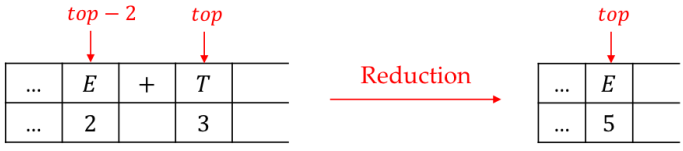


If we do reduction using $A \to XYZ$, then the attributes of A can be calculated based on the attributes of X, Y, and Z, which are already on the stack.

在归约时执行semantic action

The Calculator Example

PRODUCTION	ACTIONS
$L \to E$ **n**	{ print($stack[top-1].val$); $top = top - 1$; }
$E \to E_1 + T$	{ $stack[top-2].val = stack[top-2].val + stack[top].val$; $top = top - 2$; }
$E \to T$	
$T \to T_1 * F$	{ $stack[top-2].val = stack[top-2].val \times stack[top].val$; $top = top - 2$; }
$T \to F$	
$F \to (\ E\ )$	{ $stack[top-2].val = stack[top-1].val$; $top = top - 2$; }
$F \to$ **digit**	



SDT's for L-Attributed SDD's

- L-attributed SDD's can be implemented during top-down parsing, if the underlying grammar is LL
- The way of turning an L-attributed SDD into an SDT is to place semantic actions at appropriate positions in the concerned production $A \to X_1 X_2 \ldots X_n$
  - Embed the action that computes the inherited attributes for a nonterminal X_i immediately before X_i in the production body
  - Place the actions that compute a synthesized attribute for the production head at the end of the production body

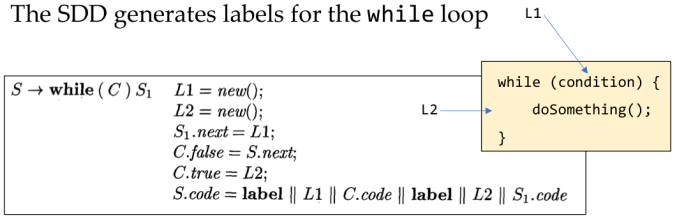
若SDD的文法是LL，且SDD是L-attributed的，则可在top-down parse中实现。

将非终结符X_i的继承属性插在其之前。

将产生式头的综合属性插在最后。

An L-Attributed SDD

- The SDD generates labels for the `while` loop



$S \to$ **while** (C) S_1	$L1 = new()$; $L2 = new()$; $S_1.next = L1$; $C.false = S.next$; $C.true = L2$; $S.code =$ **label** $\|\|\ L1\ \|\|\ C.code\ \|\|$ **label** $\|\|\ L2\ \|\|\ S_1.code$

Inherited attributes: $S.next$, $C.true$, $C.false$

Synthesized attribute: $S.code$

* There will be jump instructions with the labels as targets in $C.code$ and $S_1.code$.

Turning into an SDT

- Semantic actions:
  - a) $L1 = new()$; $L2 = new()$;
  - b) $C.false = S.next$; $C.true = L2$;
  - c) $S_1.next = L1$;
  - d) $S.code = \cdots$;
- According to the rules of action placement:
  - b) should be placed before C, c) should be placed before S_1, and d) should be placed at the end of the production body
  - a) can be placed at the very beginning; there is no constraint

$S \to$ **while** (C) S_1	{ $L1 = new()$; $L2 = new()$; $C.false = S.next$; $C.true = L2$; } { $S_1.next = L1$; } { $S.code =$ **label** $\|\|\ L1\ \|\|\ C.code\ \|\|$ **label** $\|\|\ L2\ \|\|\ S_1.code$; }

Translation During Recursive-Descent Parsing

- Many translation applications can be addressed using L-attributed SDD's. It is possible to extend a recursive-descent parser to implement L-attributed SDD's.
  - A recursive-decent parser has a function A for each nonterminal A

```
void A() {
1)      Choose an A-production, A → X1 X2 ··· Xk;
2)      for ( i = 1 to k ) {
3)          if ( Xi is a nonterminal )
4)              call procedure Xi();
5)          else if ( Xi equals the current input symbol a )
6)              advance the input to the next symbol;
7)          else /* an error has occurred */;
        }
}
```

递归下降 parser 能实现 L-attributed SDD

- Extend a recursive-descent parser to implement L-attributed SDD's as follows:
  - A recursive-decent parser has a function A for each nonterminal A
  - Use the arguments of function A to **pass** A's inherited attributes so that children nodes on the parse tree can use the attributes
  - **Return** the synthesized attributes of A when the function A completes so that parent node on the parse three can use the attributes
- With the above extension, in the body of the function A, we need to both parse and handle attributes

非终结符 A 的函数以参数接收 A 的继承属性，返回 A 的综合属性.

The While-Loop Example

The While-Loop Example

$S \rightarrow \textbf{while}\ (\ C\ )\ S_1$

Pass inherited attributes (the label of the statement after while)

Save attributes in local variables

```
string S(label next) {
    string Scode, Ccode; /* local variables holding code fragments */
    label L1, L2; /* the local labels */
    if ( current input == token while ) {
        advance input;
        check '(' is next on the input, and advance;
        L1 = new();   C.false   C.true
        L2 = new();
        Ccode = C(next, L2);
        check ')' is next on the input, and advance;
        Scode = S(L1, S1.next (the label of the condition evaluating statement));
        return("label" || L1 || Ccode || "label" || L2 || Scode);
    }
    else /* other statement types */
}
```

Pass inherited attributes when further handling other nonterminals

Compute synthesized attributes and return

We mainly put code that handles attributes here, the code is not complete.