5.1 Syntax-Directed Definitions

A *syntax-directed definition* (SDD) is a context-free grammar together with attributes and rules. Attributes are associated with grammar symbols and rules are associated with productions. If X is a symbol and a is one of its attributes, then we write $X.a$ to denote the value of a at a particular parse-tree node labeled X. If we implement the nodes of the parse tree by records or objects, then the attributes of X can be implemented by data fields in the records that represent the nodes for X. Attributes may be of any kind: numbers, types, table references, or strings, for instance. The strings may even be long sequences of code, say code in the intermediate language used by a compiler.

5.1.1 Inherited and Synthesized Attributes

We shall deal with two kinds of attributes for nonterminals:

1. A *synthesized attribute* for a nonterminal A at a parse-tree node N is defined by a semantic rule associated with the production at N. Note that the production must have A as its head. A synthesized attribute at node N is defined only in terms of attribute values at the children of N and at N itself.

2. An *inherited attribute* for a nonterminal B at a parse-tree node N is defined by a semantic rule associated with the production at the parent of N. Note that the production must have B as a symbol in its body. An inherited attribute at node N is defined only in terms of attribute values at N's parent, N itself, and N's siblings.

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

Figure 5.1: Syntax-directed definition of a simple desk calculator

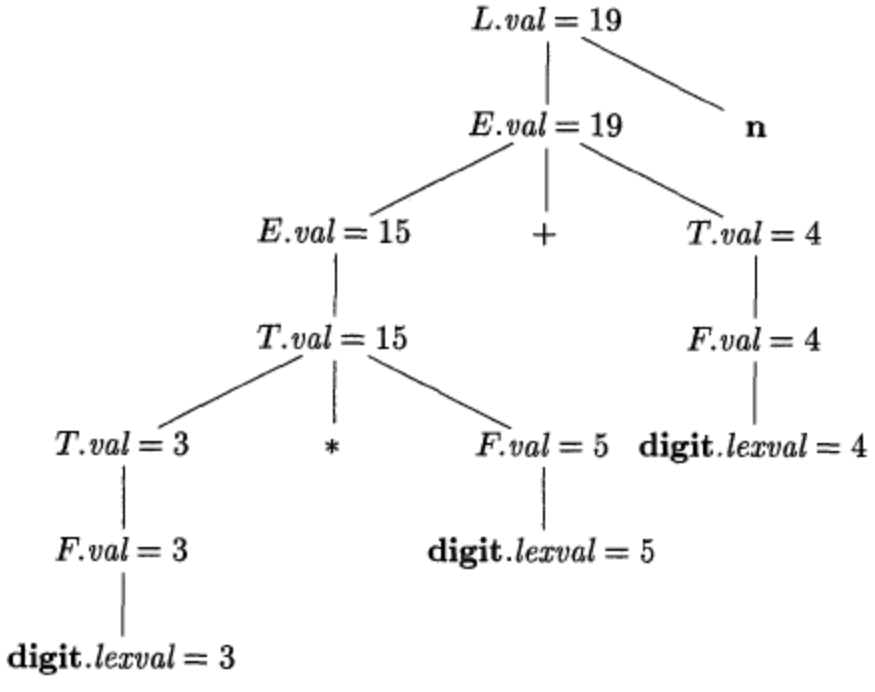

Figure 5.3: Annotated parse tree for $3 * 5 + 4$ **n**

Example 5.3: The SDD in Fig. 5.4 computes terms like $3 * 5$ and $3 * 5 * 7$. The top-down parse of input $3 * 5$ begins with the production $T \rightarrow F\,T'$. Here, F generates the digit 3, but the operator $*$ is generated by T'. Thus, the left operand 3 appears in a different subtree of the parse tree from $*$. An inherited attribute will therefore be used to pass the operand to the operator.

The grammar in this example is an excerpt from a non-left-recursive version of the familiar expression grammar; we used such a grammar as a running example to illustrate top-down parsing in Section 4.4.

	PRODUCTION	SEMANTIC RULES
1)	$T \rightarrow F\,T'$	$T'.inh = F.val$ $T.val = T'.syn$
2)	$T' \rightarrow * F\,T'_1$	$T'_1.inh = T'.inh \times F.val$ $T'.syn = T'_1.syn$
3)	$T' \rightarrow \epsilon$	$T'.syn = T'.inh$
4)	$F \rightarrow$ **digit**	$F.val =$ **digit**$.lexval$

Figure 5.4: An SDD based on a grammar suitable for top-down parsing

Each of the nonterminals T and F has a synthesized attribute *val*; the terminal **digit** has a synthesized attribute *lexval*. The nonterminal T' has two attributes: an inherited attribute *inh* and a synthesized attribute *syn*.

The semantic rules are based on the idea that the left operand of the operator $*$ is inherited. More precisely, the head T' of the production $T' \rightarrow * \; F \; T'_1$ inherits the left operand of $*$ in the production body. Given a term $x * y * z$, the root of the subtree for $* y * z$ inherits x. Then, the root of the subtree for $* z$ inherits the value of $x * y$, and so on, if there are more factors in the term. Once all the factors have been accumulated, the result is passed back up the tree using synthesized attributes.

To see how the semantic rules are used, consider the annotated parse tree for $3 * 5$ in Fig. 5.5. The leftmost leaf in the parse tree, labeled **digit**, has attribute value $lexval = 3$, where the 3 is supplied by the lexical analyzer. Its parent is for production 4, $F \rightarrow$ **digit**. The only semantic rule associated with this production defines $F.val =$ **digit**.$lexval$, which equals 3.

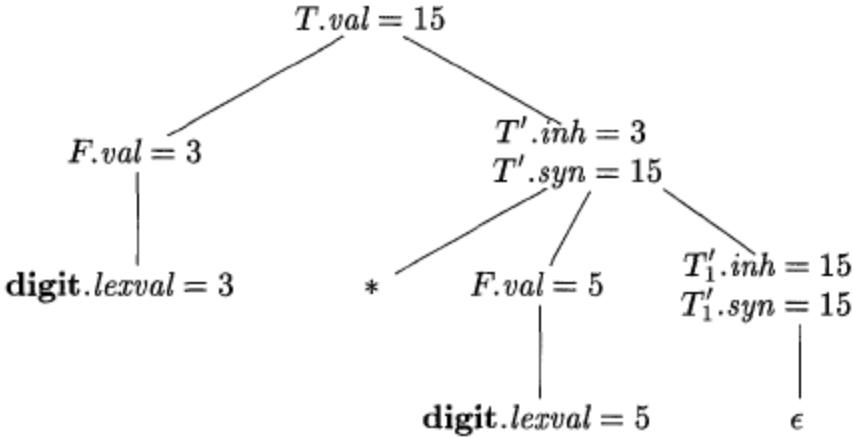

Figure 5.5: Annotated parse tree for $3 * 5$

At the second child of the root, the inherited attribute $T'.inh$ is defined by the semantic rule $T'.inh = F.val$ associated with production 1. Thus, the left operand, 3, for the $*$ operator is passed from left to right across the children of the root.

The production at the node for T' is $T' \rightarrow *FT'_1$. (We retain the subscript 1 in the annotated parse tree to distinguish between the two nodes for T'.) The inherited attribute $T'_1.inh$ is defined by the semantic rule $T'_1.inh = T'.inh \times F.val$ associated with production 2.

With $T'.inh = 3$ and $F.val = 5$, we get $T'_1.inh = 15$. At the lower node for T'_1, the production is $T' \rightarrow \epsilon$. The semantic rule $T'.syn = T'.inh$ defines $T'_1.syn = 15$. The *syn* attributes at the nodes for T' pass the value 15 up the tree to the node for T, where $T.val = 15$. $\square$

5.2.1 Dependency Graphs

A *dependency graph* depicts the flow of information among the attribute instances in a particular parse tree; an edge from one attribute instance to another means that the value of the first is needed to compute the second. Edges express constraints implied by the semantic rules. In more detail:

- For each parse-tree node, say a node labeled by grammar symbol X, the dependency graph has a node for each attribute associated with X.

- Suppose that a semantic rule associated with a production p defines the value of synthesized attribute $A.b$ in terms of the value of $X.c$ (the rule may define $A.b$ in terms of other attributes in addition to $X.c$). Then, the dependency graph has an edge from $X.c$ to $A.b$. More precisely, at every node N labeled A where production p is applied, create an edge to attribute b at N, from the attribute c at the child of N corresponding to this instance of the symbol X in the body of the production.[2]

- Suppose that a semantic rule associated with a production p defines the value of inherited attribute $B.c$ in terms of the value of $X.a$. Then, the dependency graph has an edge from $X.a$ to $B.c$. For each node N labeled B that corresponds to an occurrence of this B in the body of production p, create an edge to attribute c at N from the attribute a at the node M

that corresponds to this occurrence of X. Note that M could be either the parent or a sibling of N.

Example 5.4: Consider the following production and rule:

PRODUCTION	SEMANTIC RULE
$E \rightarrow E_1 \ + \ T$	$E.val = E_1.val + T.val$

At every node N labeled E, with children corresponding to the body of this production, the synthesized attribute *val* at N is computed using the values of *val* at the two children, labeled E and T. Thus, a portion of the dependency graph for every parse tree in which this production is used looks like Fig. 5.6. As a convention, we shall show the parse tree edges as dotted lines, while the edges of the dependency graph are solid. □

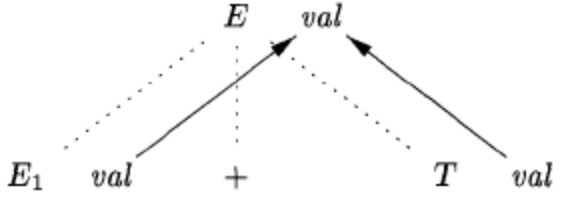

Figure 5.6: $E.val$ is synthesized from $E_1.val$ and $E_2.val$

Example 5.5: An example of a complete dependency graph appears in Fig. 5.7. The nodes of the dependency graph, represented by the numbers 1 through 9, correspond to the attributes in the annotated parse tree in Fig. 5.5.

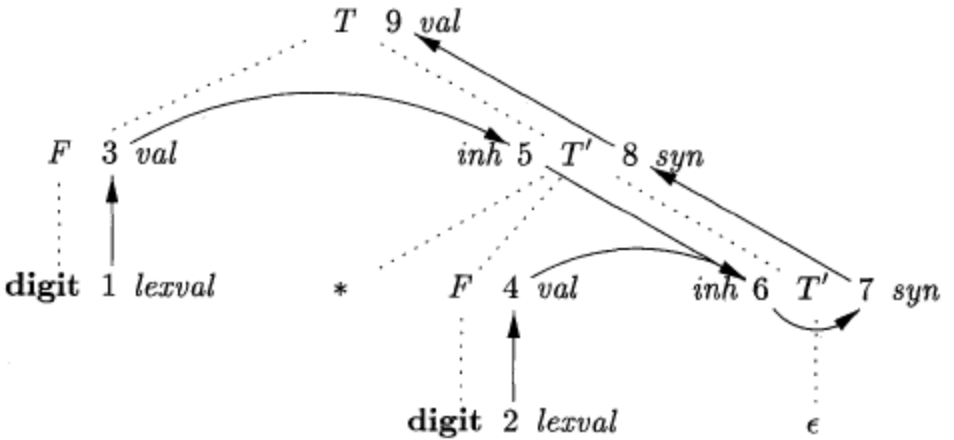

Figure 5.7: Dependency graph for the annotated parse tree of Fig. 5.5

Nodes 1 and 2 represent the attribute *lexval* associated with the two leaves labeled **digit**. Nodes 3 and 4 represent the attribute *val* associated with the two nodes labeled F. The edges to node 3 from 1 and to node 4 from 2 result

from the semantic rule that defines $F.val$ in terms of **digit**.*lexval*. In fact, $F.val$ equals **digit**.*lexval*, but the edge represents dependence, not equality.

Nodes 5 and 6 represent the inherited attribute $T'.inh$ associated with each of the occurrences of nonterminal T'. The edge to 5 from 3 is due to the rule $T'.inh = F.val$, which defines $T'.inh$ at the right child of the root from $F.val$ at the left child. We see edges to 6 from node 5 for $T'.inh$ and from node 4 for $F.val$, because these values are multiplied to evaluate the attribute inh at node 6.

Nodes 7 and 8 represent the synthesized attribute syn associated with the occurrences of T'. The edge to node 7 from 6 is due to the semantic rule $T'.syn = T'.inh$ associated with production 3 in Fig. 5.4. The edge to node 8 from 7 is due to a semantic rule associated with production 2.

Finally, node 9 represents the attribute $T.val$. The edge to 9 from 8 is due to the semantic rule, $T.val = T'.syn$, associated with production 1. □

Example 1)

Consider the following grammar:

$T \rightarrow FT'$

$T' \rightarrow +FT'$

$T' \rightarrow \epsilon$

$F \rightarrow 1 | 2 | 3 | \cdots | 9$

i) Construct SDD for the grammar

ii) Using SDD, draw annotated parse tree for input "2+3+4"

Solution:

PRODUCTIONS	SDD
$T \rightarrow FT'$	$T'.inh = F.val$ $T.val = T'.syn$
$T' \rightarrow +FT_1'$	$T_1'.inh = T'.inh + F.val$ $T'.syn = T_1'.syn$
$T' \rightarrow \epsilon$	$T'.syn = T'.inh$
$F \rightarrow 1$	$F.val = 1$
$F \rightarrow 2$	$F.val = 2$
$F \rightarrow 3$	$F.val = 3$
⋮	⋮
$F \rightarrow 9$	$F.val = 9$

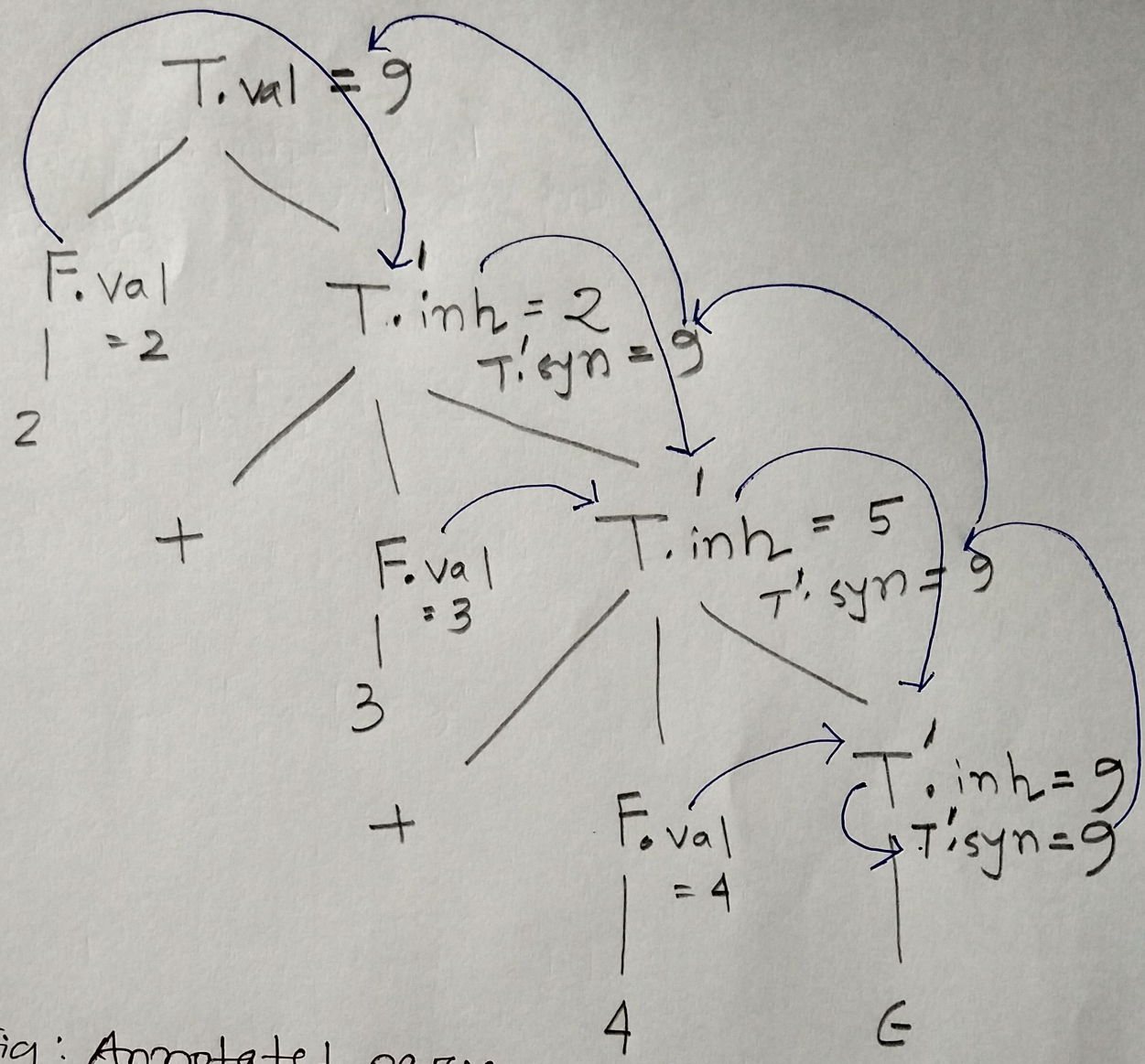

Fig: Annotated parse tree for input 2+3+4