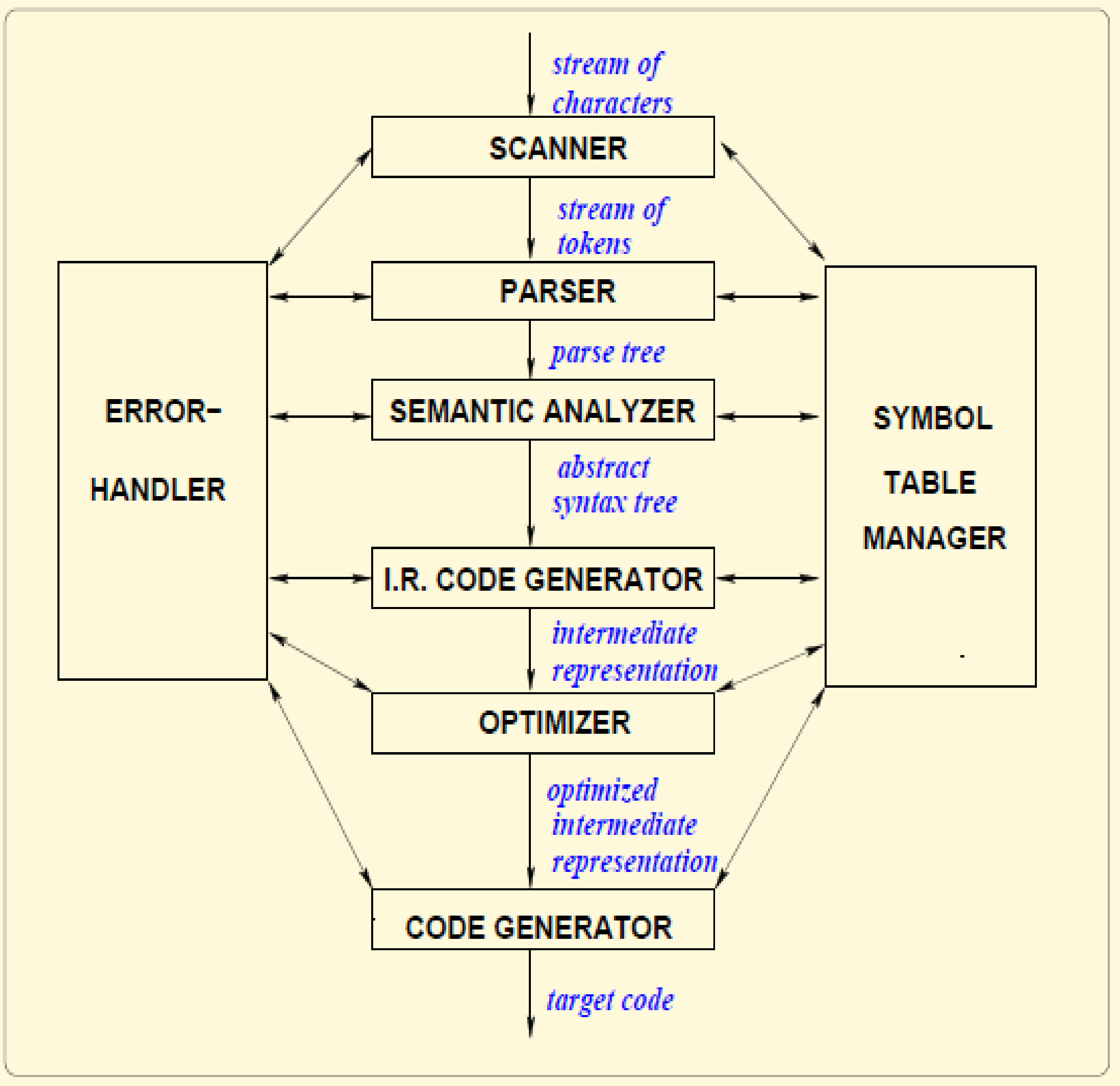
Semantic Analysis


stream of characters
SCANNER
stream of tokens
PARSER
parse tree
SEMANTIC ANALYZER
abstract syntax tree
I.R. CODE GENERATOR
intermediate representation
OPTIMIZER
optimized intermediate representation
CODE GENERATOR
target code
ERROR-HANDLER
SYMBOL TABLE MANAGER

Semantic Analysis

- There are context-sensitive aspects of a program that cannot be represented/enforced by a context-free grammar definition.
- For example
  - correspondence between formal and actual parameters
  - type consistency between declaration and use.
  - scope and visibility issues with respect to identifiers in a program.

Semantic Analysis

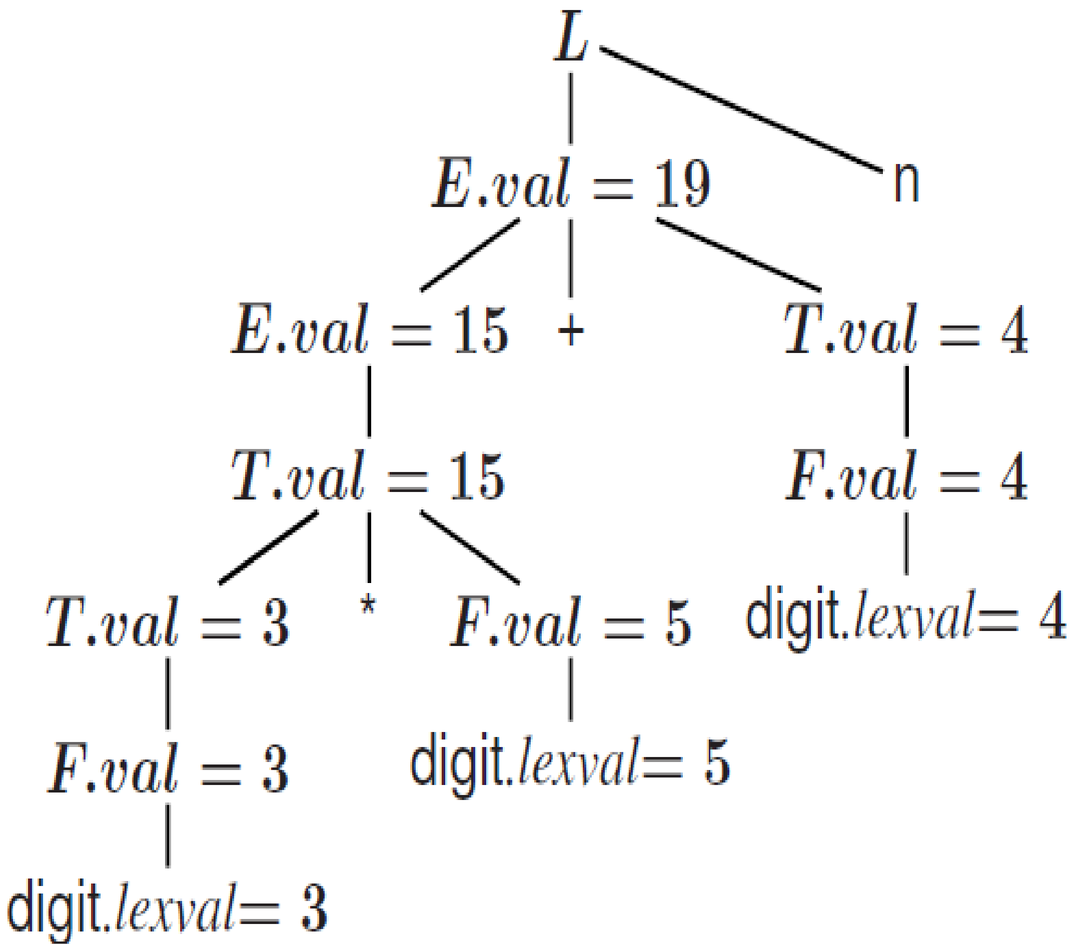
- To capture the context sensitive aspect, we need to understand
  - How to represent it (representation formalism)
  - How to implement it (implementation mechanism)
- As representation formalism we use *Syntax Directed Translations*
- Syntax Directed Translation relates an input sentence to its syntactic structure, i.e., to its Parse-Tree.
- We associate Attributes to the grammar symbols representing the language constructs.
- Values for attributes are computed by Semantic Rules associated with grammar productions.

Semantic Analysis

- Evaluation of Semantic Rules is used to:
  - Generate Code;
  - Insert information into the Symbol Table;
  - Perform Semantic Check;
  - Issue error messages; etc.
- Two notations :
  - Syntax Directed Definitions. High-level specification hiding many implementation details (also called Attribute Grammars).
  - Translation Schemes. More implementation oriented: Indicate the order in which semantic rules are to be evaluated.

Syntax Directed Definitions

- Grammar symbols associated with **attributes**
- Productions are associated with **Semantic Rules**
- Generates **Annotated Parse-Trees** where each node is a record with a field for each attribute



Syntax Directed Definitions

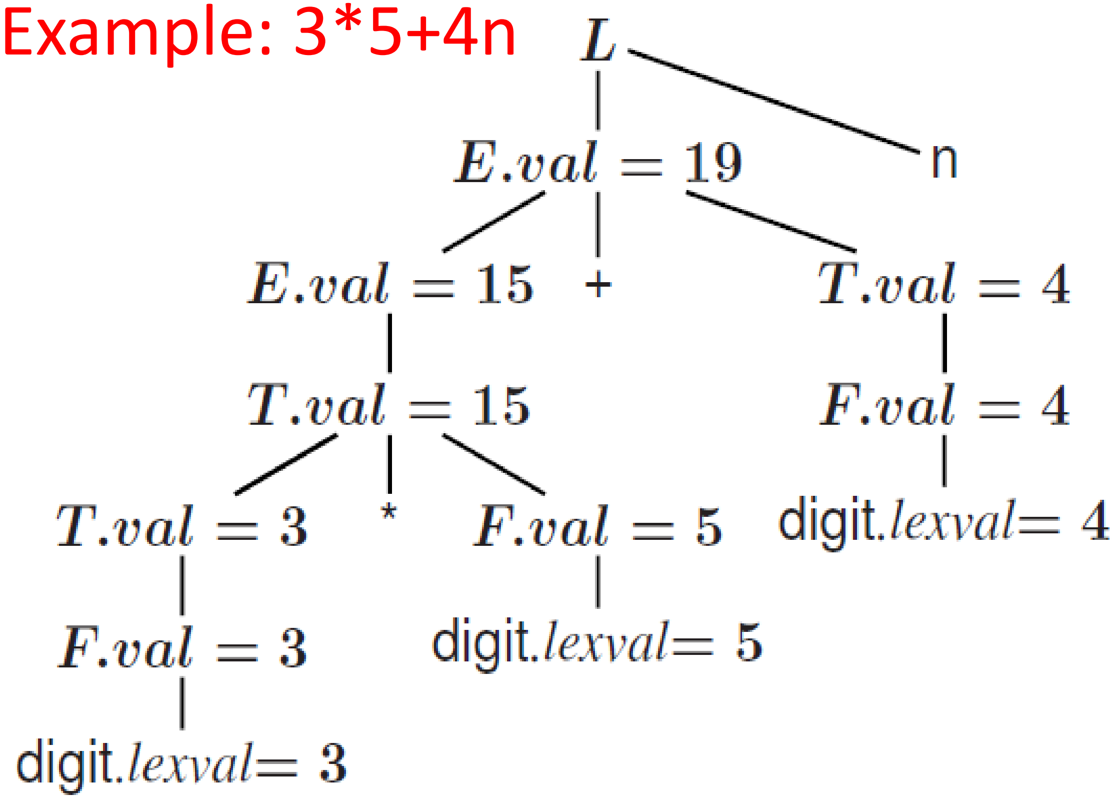
- Attributes are of two types:
- **Synthesized Attributes.** They are computed from the values of the attributes of the children nodes.
- **Inherited Attributes.** They are computed from the values of the attributes of both the siblings and the parent nodes.

S-Attributed Definitions

An **S-Attributed Definition** is a Syntax Directed Definition that uses only synthesized attributes.

PRODUCTION	SEMANTIC RULE
$L \rightarrow E\mathrm{n}$	$print(E.val)$
$E \rightarrow E_1 + T$	$E.val := E_1.val + T.val$
$E \rightarrow T$	$E.val := T.val$
$T \rightarrow T_1 * F$	$T.val := T_1.val * F.val$
$T \rightarrow F$	$T.val := F.val$
$F \rightarrow (E)$	$F.val := E.val$
$F \rightarrow \mathrm{digit}$	$F.val := \mathrm{digit}.lexval$

Example: 3*5+4n



L-Attributed Definitions

- A grammar is L-attributed if each attribute a_j at X_i of a grammar rule:

  $X_0 \text{ -> } X_1\ X_2 \ldots X_n$

1) is either a synthesized attribute, or
2) the value of a_j at X_i only depends on attribute of the symbols

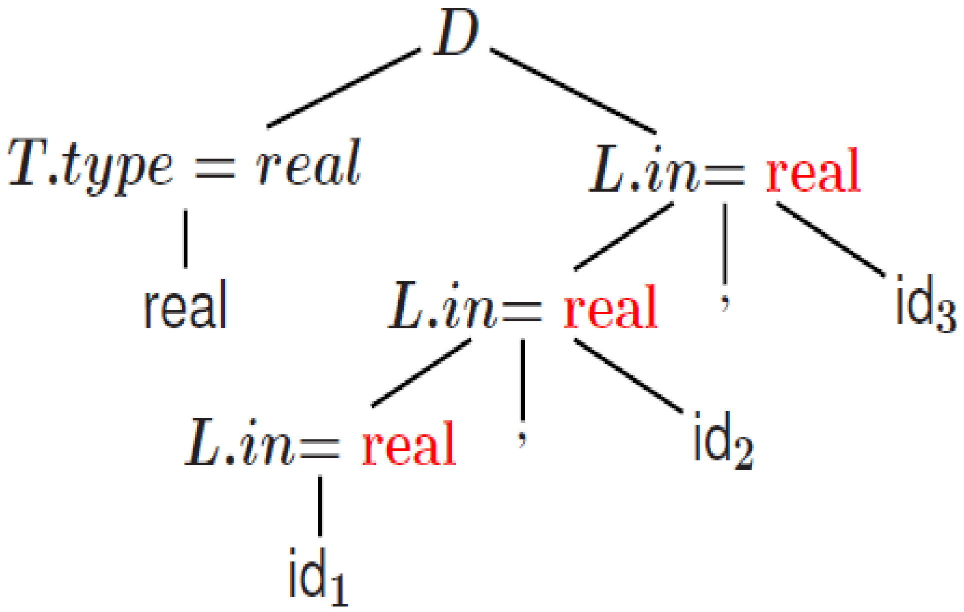
$X_0, \ldots X_{i-1}$, that occur to the left of X_i in the grammar rule, or

3) depends on the *inherited* attributes of X_0.

L-Attributed Definitions

Example: real id1, id2, id3

PRODUCTION	SEMANTIC RULE
$D \rightarrow TL$	$L.in := T.type$
$T \rightarrow$ int	$T.type :=$ *integer*
$T \rightarrow$ real	$T.type :=$ *real*
$L \rightarrow L_1$, id	$L_1.in := L.in$; *addtype*(id.*entry*, $L.in$)
$L \rightarrow$ id	*addtype*(id.*entry*, $L.in$)



Implementing Attribute Evaluation

- **Evaluation of S-Attributed Definitions**
- **Using a bottom-up parser**
- The parser keeps the values of the synthesized attributes in its stack.
- Whenever a reduction A -> α is made, the attribute for A is computed from the attributes of α which appear on the stack.

Extending a parser stack

state	*val*
Z	$Z.x$
Y	$Y.x$
X	$X.x$
$\dots$	$\dots$

PRODUCTION	CODE
$L \to E\mathsf{n}$	$print(val[top-1])$
$E \to E_1 + T$	$val[ntop] := val[top] + val[top-2]$
$E \to T$	
$T \to T_1 * F$	$val[ntop] := val[top] * val[top-2]$
$T \to F$	
$F \to (E)$	$val[ntop] := val[top-1]$
$F \to \mathsf{digit}$	

INPUT	*state*	*val*	PRODUCTION USED
3*5+4**n**	–	–	
*5+4**n**	3	3	
*5+4**n**	F	3	$F \to$ **digit**
*5+4**n**	T	3	$T \to F$
5+4**n**	T *	3 _	
+4**n**	T * 5	3 _ 5	
+4**n**	T * F	3 _ 5	$F \to$ **digit**
+4**n**	T	15	$T \to T * F$
+4**n**	E	15	$E \to T$
4**n**	E +	15 _	
n	E + 4	15 _ 4	
n	E + F	15 _ 4	$F \to$ **digit**
n	E + T	15 _ 4	$T \to F$
n	E	19	$E \to E + T$
	E **n**	19 _	
	L	19	$L \to E$ **n**

Implementing Attribute Evaluation

- **Evaluation of L-Attributed Definitions**
- Inherited attributes in L-Attributed Definitions can be computed by a PreOrder traversal of the parse-tree.
- L-Attributed Definitions can be evaluated by mixing PostOrder traversal for synthesized attributes and PreOrder traversal for inherited attributes.

Implementation using Translation Scheme

- **Definition.** A Translation Scheme is a context-free grammar in which

1. Attributes are associated with grammar symbols;
2. Semantic Actions are enclosed between braces {} and **are inserted within the right-hand side of productions.**
3. Yacc uses Translation Schemes.

Implementation using Translation Scheme

$$D \rightarrow \quad T \; \{L.in := T.type\} \; L$$

$$T \rightarrow \quad \text{int} \; \{T.type := integer\}$$

$$T \rightarrow \quad \text{real} \; \{T.type := real\}$$

$$L \rightarrow \quad \{L_1.in := L.in\} \; L_1, \text{id} \; \{addtype(\text{id}.entry, L.in)\}$$

$$L \rightarrow \quad \text{id} \; \{addtype(\text{id}.entry, L.in)\}$$