Unit-4
Semantic Analysis:
Syntax Directed Translation

- **Syntax Directed Translations**

- Syntax Directed Definitions

- Implementing Syntax Directed Definitions

  – Dependency Graphs

  – S-Attributed Definitions

  – L-Attributed Definitions

- Translation Schemes

Semantic Analysis

- **Semantic Analysis** computes additional information related to the meaning of the program once the syntactic structure is known.

- In typed languages as C, semantic analysis involves adding information to the symbol table and performing type checking.

- The information to be computed is beyond the capabilities of standard parsing techniques, therefore it is not regarded as syntax.

- As for Lexical and Syntax analysis, also for Semantic Analysis we need both a *Representation Formalism* and an *Implementation Mechanism*.

Syntax Directed Translation: Intro

- The **Principle of Syntax Directed Translation** states that the meaning of an input sentence is related to its syntactic structure, i.e., to its Parse-Tree.

- By **Syntax Directed Translations** we indicate those formalisms for specifying translations for programming language constructs guided by context-free grammars.

  - We associate **Attributes** to the grammar symbols representing the language constructs.

  - Values for attributes are computed by **Semantic Rules** associated with grammar productions.

Syntax Directed Translation: Intro (Cont.)

- Evaluation of Semantic Rules may:

  - Generate Code;

  - Insert information into the Symbol Table;

  - Perform Semantic Check;

  - Issue error messages;

  - etc.

- There are two notations for attaching semantic rules:

  1. **Syntax Directed Definitions.** High-level specification hiding many implementation details (also called **Attribute Grammars**).

  2. **Translation Schemes.** More implementation oriented: Indicate the order in which semantic rules are to be evaluated.

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Syntax Directed Definitions

- **Syntax Directed Definitions** are a generalization of context-free grammars in which:

  1. Grammar symbols have an associated set of **Attributes**;

  2. Productions are associated with **Semantic Rules** for computing the values of attributes.

- Such formalism generates **Annotated Parse-Trees** where each node of the tree is a record with a field for each attribute (e.g., $X.a$ indicates the attribute a of the grammar symbol X).

Syntax Directed Definitions (Cont.)

- The value of an attribute of a grammar symbol at a given parse-tree node is defined by a semantic rule associated with the production used at that node.

- We distinguish between two kinds of attributes:

  1. **Synthesized Attributes.** They are computed from the values of the attributes of the children nodes.

  2. **Inherited Attributes.** They are computed from the values of the attributes of both the siblings and the parent nodes.

Form of Syntax Directed Definitions

- Each production, $A \to \alpha$, is associated with a set of semantic rules:

  $b := f(c_1, c_2, \ldots, c_k)$, where f is a function and either

  1. b is a **synthesized** attribute of A, and $c_1, c_2, \ldots, c_k$ are attributes of the grammar symbols of the production, or

  2. b is an **inherited** attribute of a grammar symbol in α, and $c_1, c_2, \ldots, c_k$ are attributes of grammar symbols in α or attributes of A.

- **Note.** Terminal symbols are assumed to have synthesized attributes supplied by the lexical analyzer.

- Procedure calls (e.g. *print* in the next slide) define values of *Dummy* synthesized attributes of the non terminal on the left-hand side of the production.

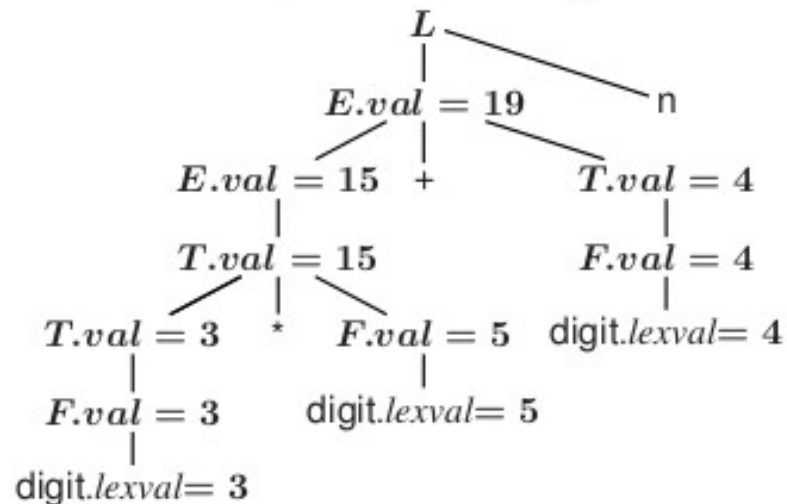# Syntax Directed Definitions: An Example

- **Example.** Let us consider the Grammar for arithmetic expressions. The Syntax Directed Definition associates to each non terminal a synthesized attribute called *val*.

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

S-Attributed Definitions

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

- **Evaluation Order.** Semantic rules in a S-Attributed Definition can be evaluated by a bottom-up, or PostOrder, traversal of the parse-tree.

- **Example.** The above arithmetic grammar is an example of an S-Attributed Definition. The annotated parse-tree for the input 3*5+4n is:

$$L$$

$$E.val = 19 \qquad \text{n}$$

$$E.val = 15 \quad + \qquad T.val = 4$$

$$T.val = 15 \qquad F.val = 4$$

$$T.val = 3 \quad * \quad F.val = 5 \quad digit.lexval = 4$$

$$F.val = 3 \qquad digit.lexval = 5$$

$$digit.lexval = 3$$

Inherited Attributes

- **Inherited Attributes** are useful for expressing the dependence of a construct on the context in which it appears.

- It is always possible to rewrite a syntax directed definition to use only synthesized attributes, but it is often more natural to use both synthesized and inherited attributes.

- **Evaluation Order.** Inherited attributes cannot be evaluated by a simple PreOrder traversal of the parse-tree:

  - Unlike synthesized attributes, the order in which the inherited attributes of the children are computed is important!!! Indeed:

    * Inherited attributes of the children can depend from both left and right siblings!
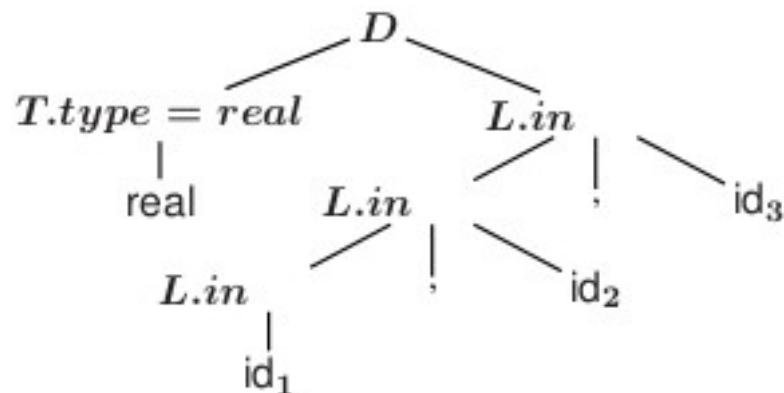
Inherited Attributes: An Example

- **Example.** Let us consider the syntax directed definition with both inherited and synthesized attributes for the grammar for "type declarations":

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

- The non terminal T has a synthesized attribute, *type*, determined by the keyword in the declaration.

- The production $D \rightarrow TL$ is associated with the semantic rule $L.in := T.type$ which set the *inherited* attribute $L.in$.

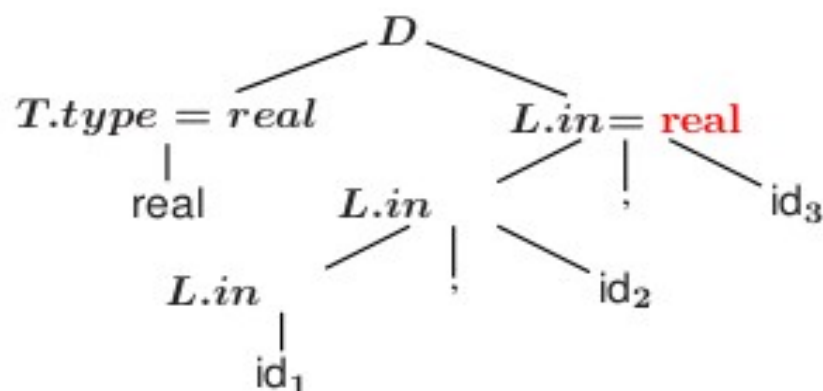- Note: The production $L \rightarrow L_1, \text{id}$ distinguishes the two occurrences of L.

- Synthesized attributes can be evaluated by a PostOrder traversal.

- Inherited attributes that *do not depend from right children* can be evaluated by a classical PreOrder traversal.

- The annotated parse-tree for the input real id_1, id_2, id_3 is:

$$D$$

$$T.type = real \qquad L.in$$

$$real \qquad L.in \qquad , \qquad id_3$$

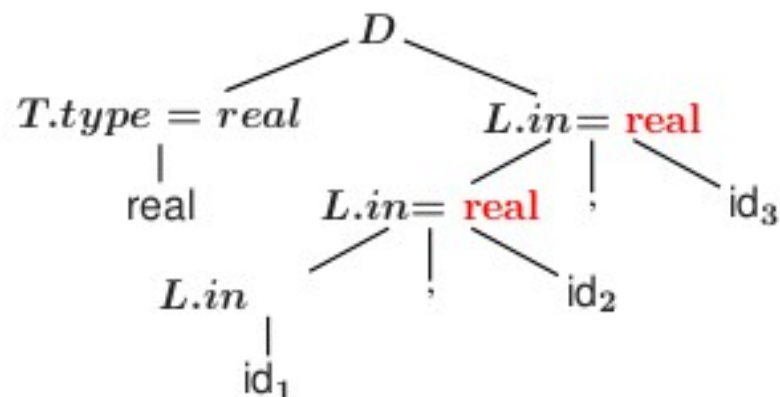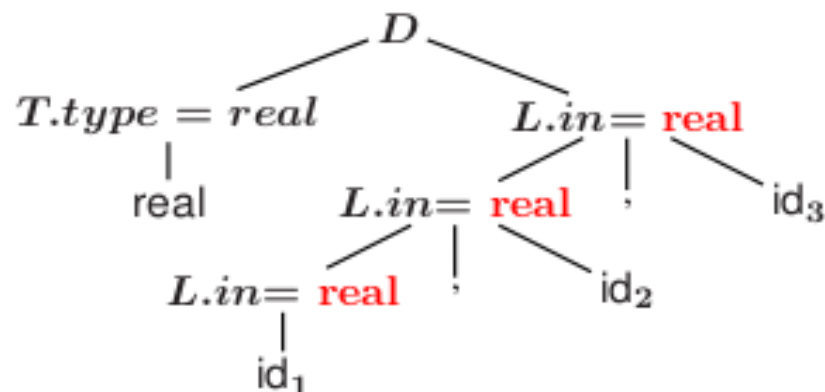$$L.in \qquad , \qquad id_2$$

$$id_1$$

Inherited Attributes: An Example (Cont.)

- Synthesized attributes can be evaluated by a PostOrder traversal.

- Inherited attributes that *do not depend from right children* can be evaluated by a classical PreOrder traversal.

- The annotated parse-tree for the input real id_1, id_2, id_3 is:

- Synthesized attributes can be evaluated by a PostOrder traversal.

- Inherited attributes that *do not depend from right children* can be evaluated by a classical PreOrder traversal.

- The annotated parse-tree for the input real id_1, id_2, id_3 is:

$$D$$

$$T.type = real \qquad L.in = real$$

$$real \qquad L.in = real \qquad , \qquad id_3$$

$$L.in \qquad , \qquad id_2$$

$$id_1$$

Inherited Attributes: An Example (Cont.)

- Synthesized attributes can be evaluated by a PostOrder traversal.

- Inherited attributes that *do not depend from right children* can be evaluated by a classical PreOrder traversal.

- The annotated parse-tree for the input real id_1, id_2, id_3 is:

- $L.in$ is then inherited top-down the tree by the other L-nodes.

- At each L-node the procedure *addtype* inserts into the symbol table the type of the identifier.

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- Syntax Directed Definitions

- **Implementing Syntax Directed Definitions**

  - **Dependency Graphs**

  - S-Attributed Definitions

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Dependency Graphs

- Implementing a Syntax Directed Definition consists primarily in finding an order for the evaluation of attributes

  - Each attribute value must be available when a computation is performed.

- **Dependency Graphs** are the most general technique used to evaluate syntax directed definitions with both synthesized and inherited attributes.

- A Dependency Graph shows the interdependencies among the attributes of the various nodes of a parse-tree.

  - There is a node for each attribute;

  - If attribute b depends on an attribute c there is a link from the node for c to the node for b ($b \leftarrow c$).

- **Dependency Rule:** If an attribute b depends from an attribute c, then we need to fire the semantic rule for c first and then the semantic rule for b.

Evaluation Order

- The evaluation order of semantic rules depends from a *Topological Sort* derived from the dependency graph.

- **Topological Sort:** Any ordering $m_1, m_2, \ldots, m_k$ such that if $m_i \rightarrow m_j$ is a link in the dependency graph then $m_i < m_j$.

- Any topological sort of a dependency graph gives a valid order to evaluate the semantic rules.

Evaluation of S-Attributed Definitions

- **Example.** Consider the S-attributed definitions for the arithmetic expressions. To evaluate attributes the parser executes the following code

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

- The variable $ntop$ is set to the *new top of the stack*. After a reduction is done *top* is set to *ntop*: When a reduction $A \rightarrow \alpha$ is done with $|\alpha| = r$, then $ntop = top - r + 1$.

- During a shift action both the token and its value are pushed into the stack.

L-Attributed Definitions

- **L-Attributed Definitions** contain both synthesized and inherited attributes but do not need to build a dependency graph to evaluate them.

- **Definition.** A syntax directed definition is *L-Attributed* if each *inherited attribute* of X_j in a production $A \rightarrow X_1 \ldots X_j \ldots X_n$, depends only on:

  1. The attributes of the symbols to the **left** (this is what L in *L-Attributed* stands for) of X_j, i.e., $X_1 X_2 \ldots X_{j-1}$, and

  2. The *inherited* attributes of A.

- **Theorem.** Inherited attributes in L-Attributed Definitions can be computed by a PreOrder traversal of the parse-tree.

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- **Translation Schemes**

Translation Schemes

- **Translation Schemes** are more implementation oriented than syntax directed definitions since they **indicate the order** in which semantic rules and attributes are to be evaluated.

- **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.**

- Yacc uses Translation Schemes.

Translation Schemes (Cont.)

- Translation Schemes deal with both synthesized and inherited attributes.

- Semantic Actions are treated as terminal symbols: Annotated parse-trees contain semantic actions as children of the node standing for the corresponding production.

- Translation Schemes are useful to evaluate L-Attributed definitions at parsing time (even if they are a general mechanism).

    - **An L-Attributed Syntax-Directed Definition can be turned into a Translation Scheme.**

Translation Schemes: An Example

- Consider the Translation Scheme for the L-Attributed Definition for "type declarations":

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

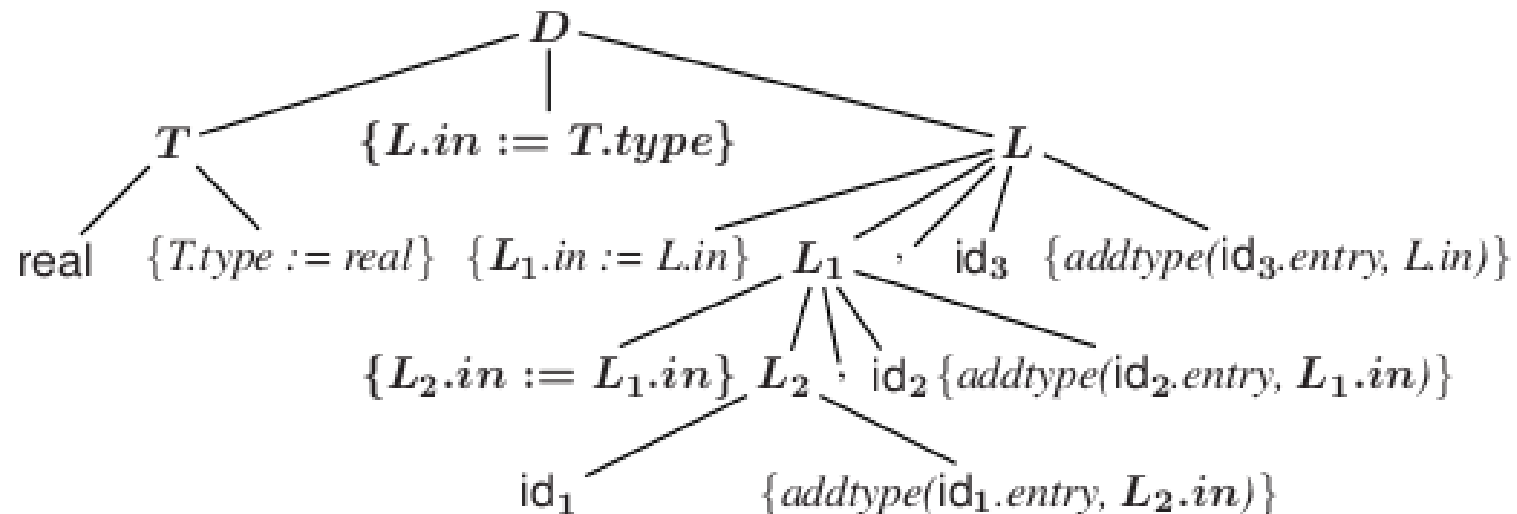$$T \rightarrow \quad \text{int} \ \{T.type := integer\}$$

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

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

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

Translation Schemes: An Example (Cont.)

- **Example (Cont).** The parse-tree with semantic actions for the input
  real id_1, id_2, id_3 is:

- **Traversing the Parse-Tree in depth-first order (PostOrder) we can evaluate the attributes.**