Syntax-Directed Translation

ASU Textbook Chapter 5

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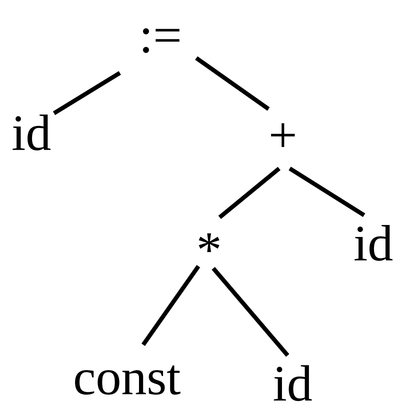
What is syntax-directed translation?

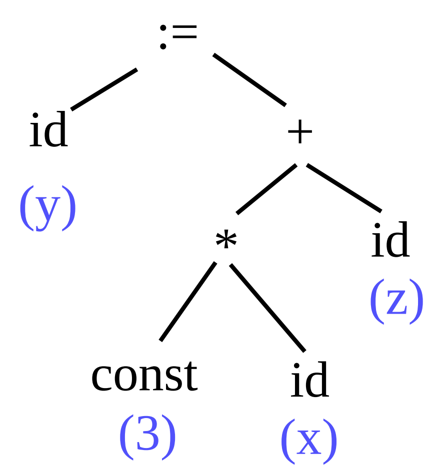
- **Definition:**
  - **The compilation process is driven by the syntax.**
  - **The semantic routines perform interpretation based on the syntax structure.**
  - **Attaching attributes to the grammar symbols.**
  - **Values for attributes are computed by semantic rules associated with the grammar productions.**

Example: Syntax-directed translation

- **Example in a parse tree:**
  - **Annotate the parse tree by attaching semantic attributes to the nodes of the parse tree.**
  - **Generate code by visiting nodes in the parse tree in a given order.**
  - **Input:** $y := 3 * x + z$



parse tree



annotated parse tree

Syntax-directed definitions (1/2)

- **Each grammar symbol is associated with a set of attributes.**
  - **Synthesized attribute : values computed from its children or associated with the meaning of the tokens.**
  - **Inherited attribute : values computed from parent and/or siblings.**
- **Format for writing syntax-directed definitions.**

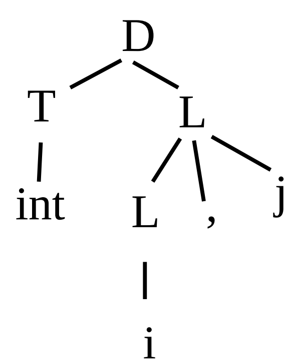
Production	Semantic rules
$L \rightarrow E$	$\text{print}(E.val)$
$E \rightarrow E_1 + T$	$E.val := E_1.val + T.val$
$E \rightarrow T$	$E.val := T.val$
$T \rightarrow T_1 * F$	$T.val := T_1.val * F.val$
$T \rightarrow F$	$T.val := F.val$
$F \rightarrow (E)$	$F.val := E.val$
$F \rightarrow digit$	$F.val := digit.lexval$

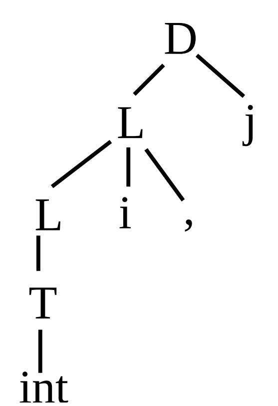
  - ▷ ***$E.val$ is one of the attributes of E.***
  - ▷ ***To avoid confusion, recursively defined nonterminals are numbered on the LHS.***

Syntax-directed definitions (2/2)

- **It is always possible to rewrite syntax-directed definitions using only synthesized attributes, but the one with inherited attributes is easier to understand.**
  - **Use inherited attributes to keep track of the type of a list of variable declarations.**
    - ▷ $int\ i, j$
  - **Reconstruct the tree:**
    - ▷ $D \rightarrow TL$
    - ▷ $T \rightarrow int \mid char$
    - ▷ $L \rightarrow L, id \mid id$

    - ▷ $D \rightarrow L\ id$
    - ▷ $L \rightarrow L\ id, \mid T$
    - ▷ $T \rightarrow int \mid char$

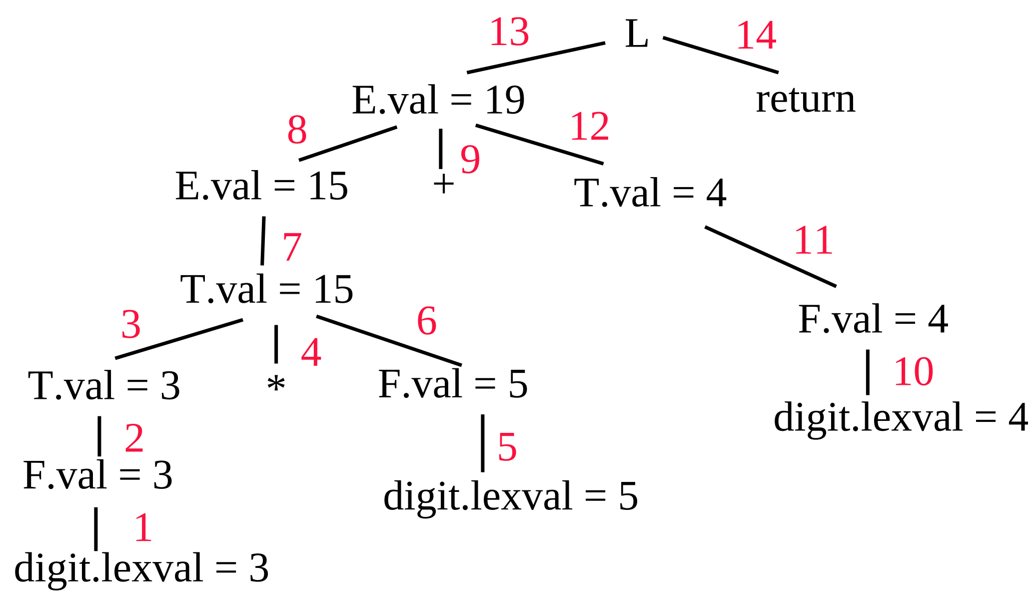




Attribute grammars (1/2)

- **Attribute grammar: a grammar with syntax-directed definitions such that functions used cannot have side effects.**
  - **Side effect: change values of others not related to the return values of functions themselves.**
- **S-attributed definition: a syntax-directed definition that uses synthesized attributed only.**
  - **A parse tree can be represented using a directed graph.**
  - **A post-order traverse of the parse tree can properly evaluate grammars with S-attributed definitions.**
  - **Bottom-up evaluation.**

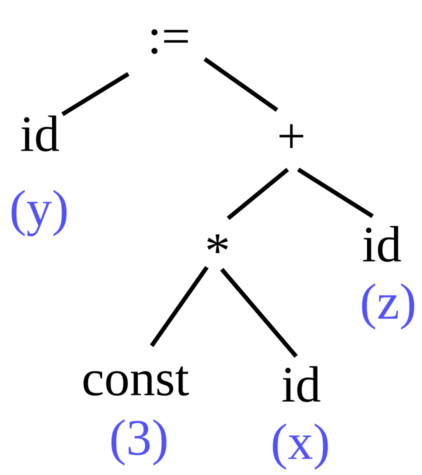
Attribute grammars (2/2)

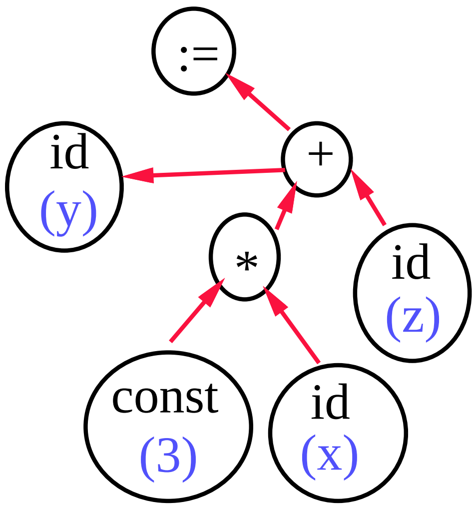


- **Example of an S-attributed definition: $3 * 5 + 4$ return**
- **L-attributed definition :**
  - **Each attribute in each semantic rule for the production $A \to X_1 \cdots X_n$ is either a synthesized attribute or an inherited attribute X_j depends only on the inherited attribute of A and/or the attributes of $X_1, \ldots, X_{j-1}$.**
  - **Independent of the evaluation order.**
  - **Every S-attributed definition is an L-attributed definition.**

Order of evaluation

- **Order of evaluating attributes is important.**
- **General rule for ordering:**
  - **Dependency graph** :
    - ▷ ***If attribute b needs attributes a and c, then a and c must be evaluated before b.***
    - ▷ ***Represented as a directed graph without cycles.***
    - ▷ ***Topologically order nodes in the dependency graph as $n_1, n_2, \ldots, n_k$ such that there is no path from n_i to n_j with $i > j$.***





Orders for L-attributed definitions

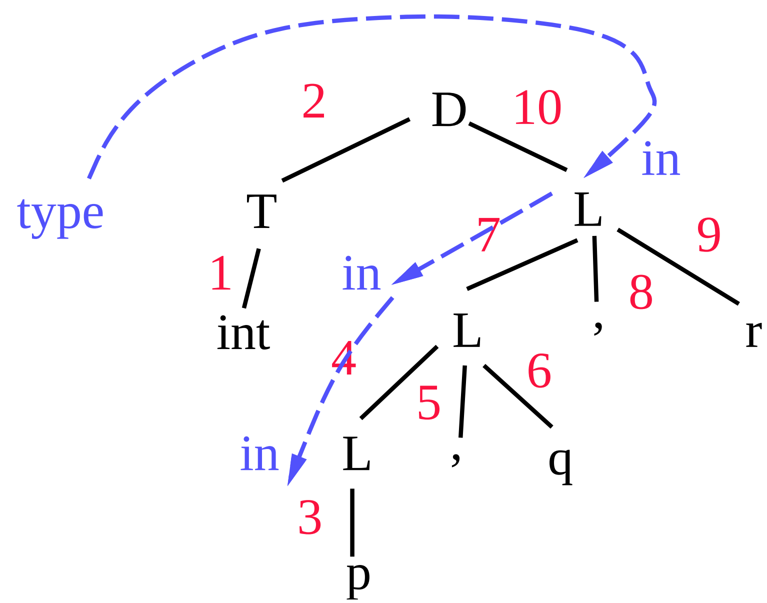
- **For grammars with L-attributed definitions, special evaluation algorithms must be designed.**
- **Bottom-up evaluation of L-attributed grammars.**
  - **Can handle all $LL(1)$ grammars and most $LR(1)$ grammars.**
  - **All translation actions are taken at the right end of the production.**
- **Key observation: when a bottom-up parser reduces by the production $A \rightarrow XY$, by removing X and Y from the top of the stack and replacing them by A, $X.s$ (the synthesized attribute of X) is on the top of the stack and thus can be used to compute $Y.in$ (the inherited attribute of Y).**

Example for L-attributed definitions

- $D \rightarrow T\ \{L.in := T.type\}\ L$
- $T \rightarrow int\ \{T.type := integer\}$
- $T \rightarrow real\ \{T.type := real\}$
- $L \rightarrow\ \{L_1.in := L.in\}\ L_1, id\ \{addtype(id.entry, L.in)\}$
- $L \rightarrow id\ \{addtype(id.entry, L.in)\}$

Parsing and dependency graph:

input	stack	production used
int p, q, r		
p, q, r	**int**	
p, q, r	T	$T \rightarrow int$
$, q, r$	$T\ p$	
$, q, r$	$T\ L$	$L \rightarrow id$
q, r	$T\ L$,	
$, r$	$T\ L\ , q$	
$, r$	$T\ L$	$L \rightarrow L, id$
r	$T\ L\ ,$	
	$T\ L\ , r$	
	$T\ L$	$L \rightarrow L, id$
	D	$D \rightarrow TL$

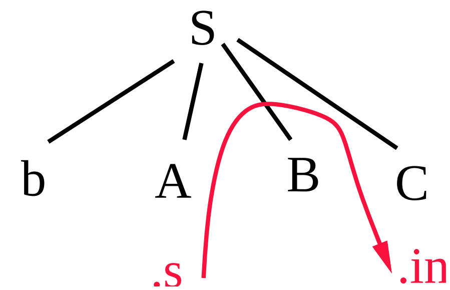


Implementation

- **Information contained in the stack can be used by replacing special markers to mark the production we are currently in.**

  - **Example 1:**

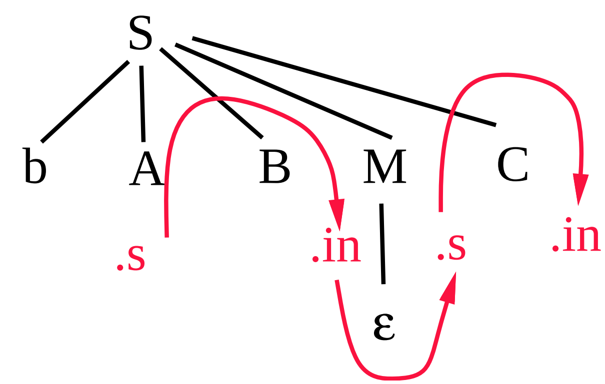
production	semantic rules
$S \rightarrow aAC$	$C.in := A.s$
$S \rightarrow bABC$	$C.in := A.s$
$C \rightarrow c$	$C.s := \cdots$
$\cdots$	$\cdots$



Same rule for the first two productions. It is difficult to tell which one and to find the position of A in the stack in each case.

  - **Example 2:**

production	semantic rules
$S \rightarrow aAC$	$C.in := A.s$
$S \rightarrow bABMC$	$M.in := A.s;$
	$C.in := M.s$
$C \rightarrow c$	$C.s := \cdots$
$M \rightarrow \epsilon$	$M.s := M.in$
$\cdots$	$\cdots$



A is always one place below in the stack.

- **Markers can also be used to perform error checking and other intermediate semantic actions.**

Limitation

- **Limitation of syntax-directed definitions: Without using global data to create side effects, some of the semantic actions cannot be performed.**
- **Example:**
  - **Checking whether a variable is defined before its usage.**
  - **Checking the type and storage address of a variable.**
  - **Checking whether a variable is used or not.**
- **Need to use a symbol table: global data to show side effects of semantic actions.**
- **YACC can be used to implement syntax-directed translations.**
- **Common approach:**
  - **A program with too many global variables is difficult to understand and maintain.**
  - **Restrict the usage of global variables to essential items and use them as objects.**
    - ▷ ***Symbol table.***
    - ▷ ***Labels for GOTO's.***
    - ▷ ***Forwarded declarations.***
  - **Use syntax-directed definitions as much as you can.**