

Syntax-Directed Translation

Technique used to build semantic information for large structures, based on its syntax.

In a compiler, *Syntax-Directed Translation* is used for

- Constructing Abstract Syntax Tree
- Type checking
- Intermediate code generation

The Essence of Syntax-Directed Translation

The semantics (*i.e.*, *meaning*) of the various constructs in the language is viewed as attributes of the corresponding grammar symbols.

Example:

sequence of characters 495

→ *grammar symbol* TOK_INT

→ *meaning* $\equiv$ *integer 495*

→ *is an attribute of* TOK_INT (*yylval.int_val*).

Attributes are associated with **Terminal** as well as **Nonterminal** symbols.

An Example of Syntax-Directed Translation

E	$\longrightarrow$	$E * E$
E	$\longrightarrow$	$E + E$
E	$\longrightarrow$	id

E	$\longrightarrow$	$E_1 * E_2$	$\{E.val := E_1.val * E_2.val\}$
E	$\longrightarrow$	$E_1 + E_2$	$\{E.val := E_1.val + E_2.val\}$
E	$\longrightarrow$	int	$\{E.val := \text{int}.val\}$

Another Example of Syntax-Directed Translation

$Decl$	$\longrightarrow$	$Type\ VarList$
$Type$	$\longrightarrow$	integer
$Type$	$\longrightarrow$	float
$VarList$	$\longrightarrow$	$\text{id} , VarList$
$VarList$	$\longrightarrow$	id

$Decl$	$\longrightarrow$	$Type\ VarList$	$\{VarList.type := Type.type\}$
$Type$	$\longrightarrow$	integer	$\{Type.type := \text{int}\}$
$Type$	$\longrightarrow$	float	$\{Type.type := \text{float}\}$
$VarList$	$\longrightarrow$	$\text{id} , VarList_1$	$\{VarList_1.type := VarList.type;$ $\quad \text{id}.type := VarList.type\}$
$VarList$	$\longrightarrow$	id	$\{\text{id}.type := VarList.type\}$

Attributes

- **Synthesized:** Attribute of LHS symbol of a grammar rule, whose value depends on attributes of RHS symbols of the grammar rule.
 - Value flows from child to parent in the parse tree.
 - Example: *val* in Expression grammar
- **Inherited:** Attribute of an RHS symbol of a grammar rule, whose value depends on attributes of the LHS symbol and the other RHS symbols of the grammar rule.
 - Value flows into a node in the parse tree from parents and/or siblings.
 - Example: *type* of *VarList* in declaration grammar

Syntax-Directed Definition

Actions associated with each production in a grammar.

For a production $A \rightarrow X Y$, actions may be of the form:

- $A.attr := f(X.attr', Y.attr'')$ for synthesized attributes
- $Y.attr := f(A.attr', X.attr'')$ for inherited attributes

If the function f does not have side effects, syntax directed definitions is also called as **attribute grammars**.

Attributes and Definitions

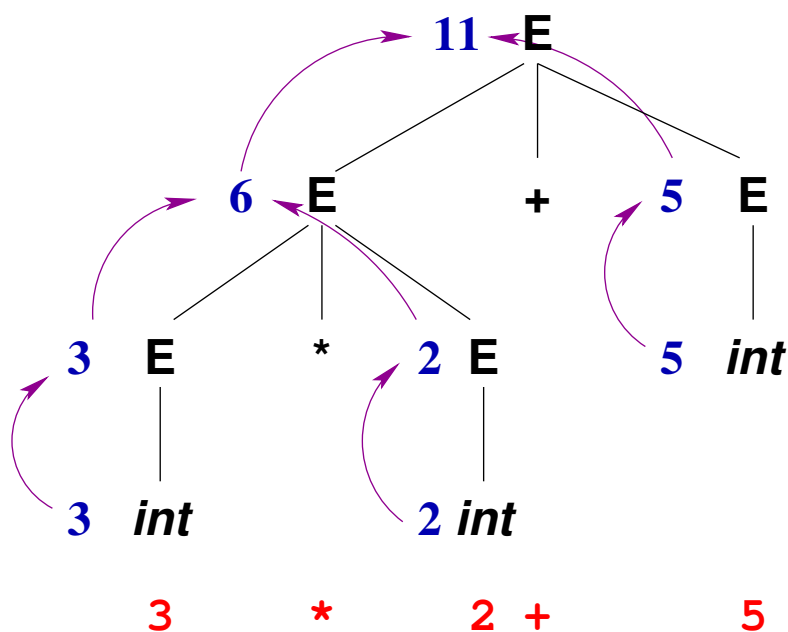
- **S-Attributed Definitions:** Where all attributes are synthesized.
- **L-Attributed Definitions:** Where all inherited attributes are such that their values depend only on
 - inherited attributes of the parent, and
 - attributes of left siblings

Synthesized Attributes: An Example

E	$\longrightarrow$	$E * E$
E	$\longrightarrow$	$E + E$
E	$\longrightarrow$	<code>int</code>

E	$\longrightarrow$	$E_1 * E_2$	$\{E.val := E_1.val * E_2.val\}$
E	$\longrightarrow$	$E_1 + E_2$	$\{E.val := E_1.val + E_2.val\}$
E	$\longrightarrow$	<code>int</code>	$\{E.val := \text{int}.val\}$

Information Flow for “Expression” Example

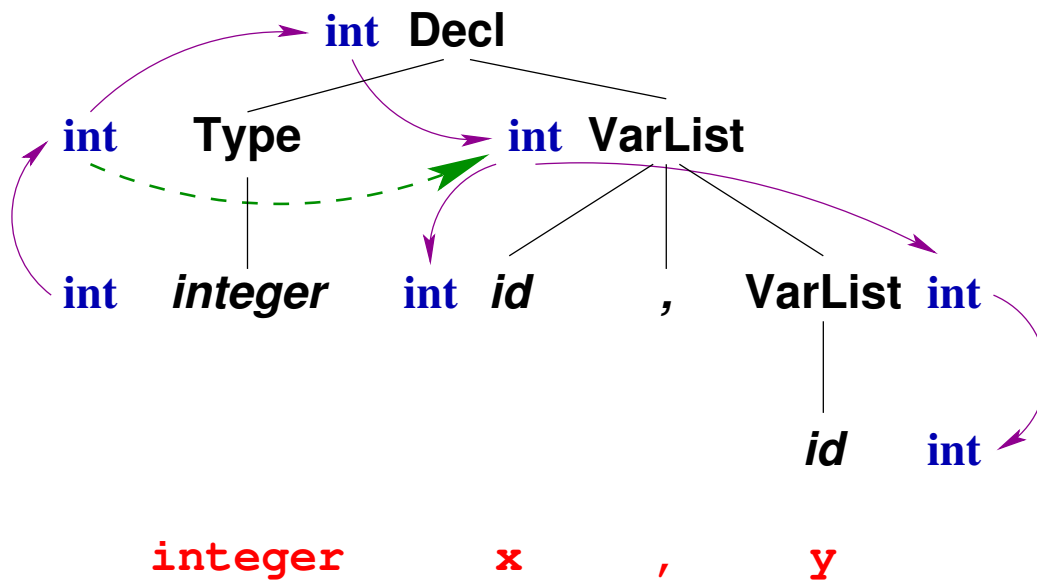


Another Example of Syntax-Directed Translation

<i>Decl</i>	$\longrightarrow$	<i>Type</i> <i>VarList</i>
<i>Type</i>	$\longrightarrow$	<i>integer</i>
<i>Type</i>	$\longrightarrow$	<i>float</i>
<i>VarList</i>	$\longrightarrow$	<i>id</i> , <i>VarList</i>
<i>VarList</i>	$\longrightarrow$	<i>id</i>

<i>Decl</i>	$\longrightarrow$	<i>Type</i> <i>VarList</i>	{ <i>VarList.type</i> := <i>Type.type</i> }
<i>Type</i>	$\longrightarrow$	<i>integer</i>	{ <i>Type.type</i> := <i>int</i> }
<i>Type</i>	$\longrightarrow$	<i>float</i>	{ <i>Type.type</i> := <i>float</i> }
<i>VarList</i>	$\longrightarrow$	<i>id</i> , <i>VarList</i> ₁	{ <i>VarList</i> ₁ . <i>type</i> := <i>VarList.type</i> ; <i>id.type</i> := <i>VarList.type</i> }
<i>VarList</i>	$\longrightarrow$	<i>id</i>	{ <i>id.type</i> := <i>VarList.type</i> }

Information Flow for “Type” Example



Syntax-Directed Definitions with yacc/Bison

$E \longrightarrow E_1 * E_2$	$\{E.val := E_1.val * E_2.val\}$
$E \longrightarrow E_1 + E_2$	$\{E.val := E_1.val + E_2.val\}$
$E \longrightarrow \text{int}$	$\{E.val := \text{int}.val\}$

$E : E \text{ MULT } E$	$\{\$.val = \$1.val * \$3.val\}$
$E : E \text{ PLUS } E$	$\{\$.val = \$1.val + \$3.val\}$
$E : \text{INT}$	$\{\$.val = \$1.val\}$

Synthesized Attributes and Bottom-up Parsing

Keep track of attributes of symbols while parsing.

- **Shift-reduce parsing:** Keep a stack of attributes corresponding to stack of symbols.

Compute attributes of LHS symbol while performing reduction (*i.e.*, while pushing the symbol on symbol stack)

Synthesized Attributes & Shift-reduce parsing

$\begin{array}{l} E \longrightarrow E + E \\ E \longrightarrow E * E \\ E \longrightarrow \text{int} \end{array}$		
STACK	INPUT STREAM	ATTRIBUTES
\$	3 * 2 + 5 \$	\$
\$ int	* 2 + 5 \$	\$ 3
\$ E	* 2 + 5 \$	\$ 3
\$ E *	2 + 5 \$	\$ 3 $\perp$
\$ E * int	+ 5 \$	\$ 3 $\perp$ 2
\$ E	+ 5 \$	\$ 6
\$ E +	5 \$	\$ 6 $\perp$
\$ E + int	\$	\$ 6 $\perp$ 5
\$ E + E	\$	\$ \$ 6 $\perp$ 5
\$ E	\$	\$ 11

Inherited Attributes

Ss	$\longrightarrow$	$S ; Ss$
Ss	$\longrightarrow$	ϵ
B	$\longrightarrow$	$\{ Ss \}$
S	$\longrightarrow$	B
S	$\longrightarrow$	other

Ss	$\longrightarrow$	$S ; Ss_1$	$\{ S.block = Ss.block;$ $Ss_1.block = Ss.block; \}$
Ss	$\longrightarrow$	ϵ	
B	$\longrightarrow$	$\{ Ss \}$	$\{ Ss.block = child(B.block); \}$
S	$\longrightarrow$	B	$\{ B.block = S.block; \}$
S	$\longrightarrow$	other	$\{ \text{other}.block = S.block; \}$

Top-down Parsing

```
parse_Ss() {  
  /* production 1 */  
  parse_S();  
  parse_Ss();  
  return;  
  
  /* production 2 */  
  return;  
}  
parse_B() {  
  consume(OPEN_BRACE);  
  parse_Ss();  
  consume(CLOSE_BRACE);  
}
```

Inherited Attributes and Top-down Parsing

```
parse_Ss(block) {  
    /* production 1 */  
    parse_S(block);  
    parse_Ss(block);  
    return;  
  
    /* production 2 */  
    return;  
}  
parse_B(block) {  
    consume(OPEN_BRACE);  
    parse_Ss(child(block));  
    consume(CLOSE_BRACE);  
}
```

Attributes and Top-down Parsing

- **Inherited**: analogous to function arguments
- **Synthesized**: analogous to return values

L-attributed definitions mean that argument to a parsing function is

- argument of the calling function, or
- return value/argument of a previously called function

Attributes and Bottom-up Parsing

- **Synthesized:** stored along with symbols on stack
- **Inherited:** ???

Inherited Attributes and Bottom-up Parsing

Inherited attributes depend on the *context* in which a symbol is used. For inherited attributes, we cannot assign a value to a node's attributes unless the parent's attributes are known.

When building parse trees bottom-up, parent of a node is not known when the node is created!

Solution:

- *Ensure that all attributes are inherited only from left siblings.*
- *Use “global” variables to capture inherited values,*
- *and introduce “marker” nonterminals to manipulate the global variables.*

Inherited Attributes & Bottom-up parsing

Ss	$\longrightarrow$	$S ; Ss$
Ss	$\longrightarrow$	ϵ
B	$\longrightarrow$	$\{ Ss \}$
S	$\longrightarrow$	B
S	$\longrightarrow$	other

$$\begin{array}{lll} B & \longrightarrow & \{ M_1 \ Ss \ M_2 \} \\ M_1 & \longrightarrow & \epsilon \quad \quad \quad \{ \textit{current_block}++;\} \\ M_2 & \longrightarrow & \epsilon \quad \quad \quad \{ \textit{current_block}--;\} \end{array}$$

M_1 and M_2 are marker non-terminals.