NEW YORK UNIVERSITY

CSCI-GA.2130-001

Compiler Construction

Lecture 8: Syntax-Directed Translation

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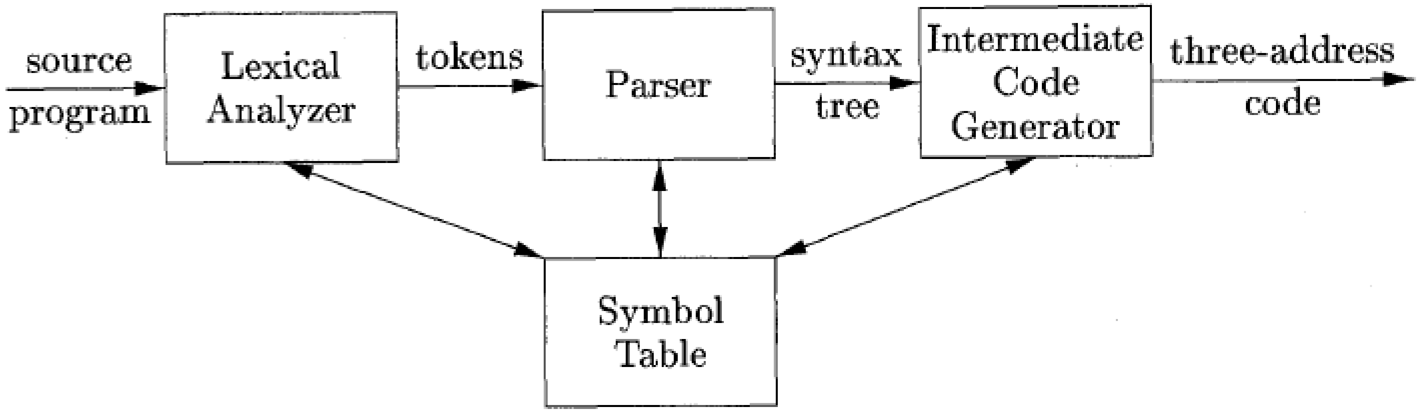
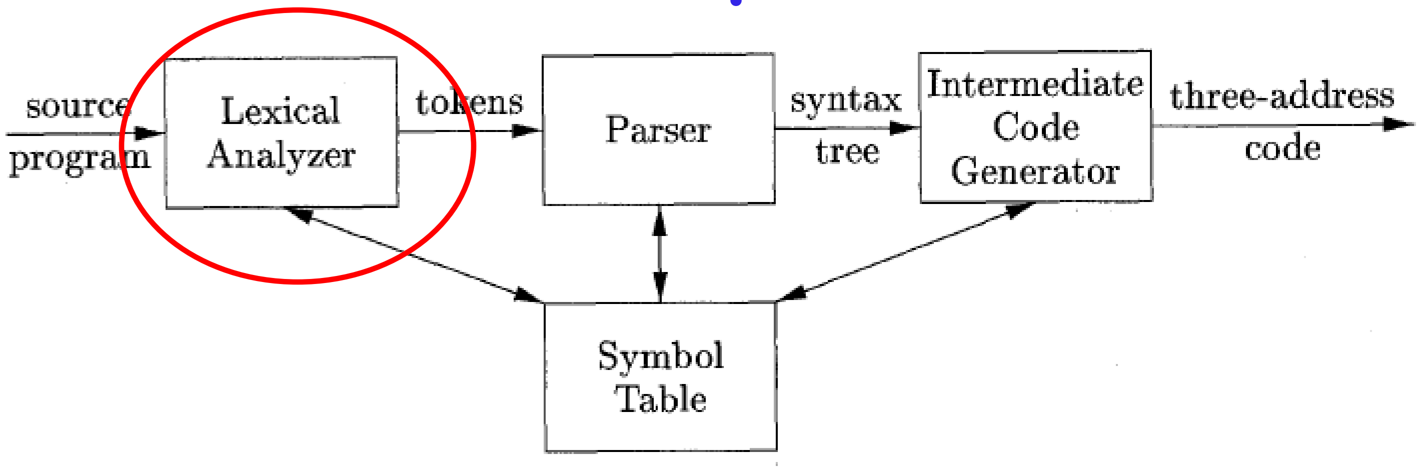
A Step-Back


source
program
Lexical
Analyzer
tokens
Parser
syntax
tree
Intermediate
Code
Generator
three-address
code
Symbol
Table

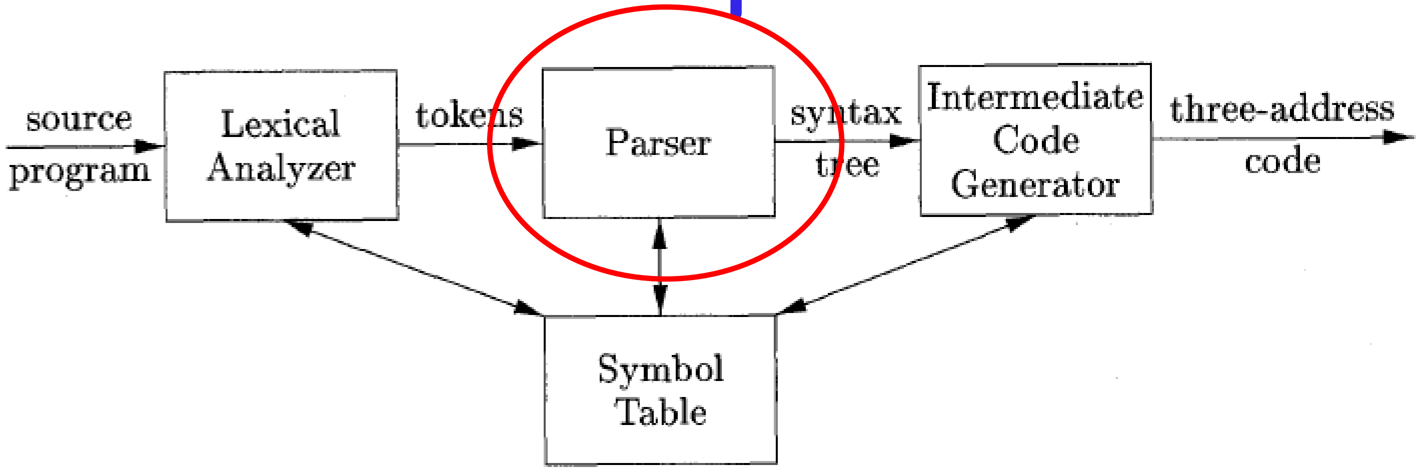
A Step-Back



Chapter 3

- Strings
- Regular expressions
- Tokens
- Transition diagrams
- Finite Automata

A Step-Back



Chapter 4

- Grammars
- Derivations
- Parse-trees
- Top-down parsing (LL)
- Bottom-up paring (LR, SLR,LALR)

Now What?

We Need Some Tools

- To help in semantic analysis
- To help in intermediate code generation
- Two such tools
  - Semantic rules (Syntax-Directed Definitions)

PRODUCTION	SEMANTIC RULE
$E \to E_1 + T$	$E.code = E_1.code \parallel T.code \parallel '+'$

  - Semantic actions (Syntax Directed Translations)

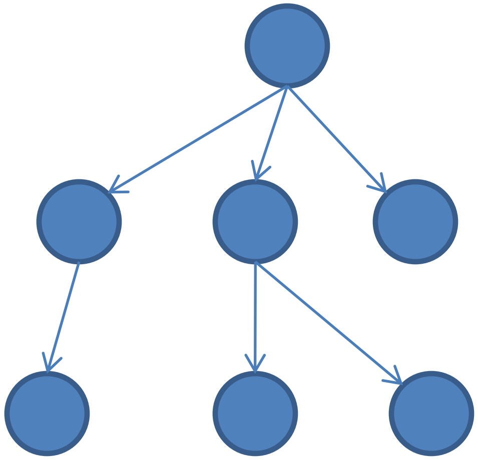
$$E \to E_1 + T \quad \{ \text{print } '+' \}$$

Syntax-Directed Definitions

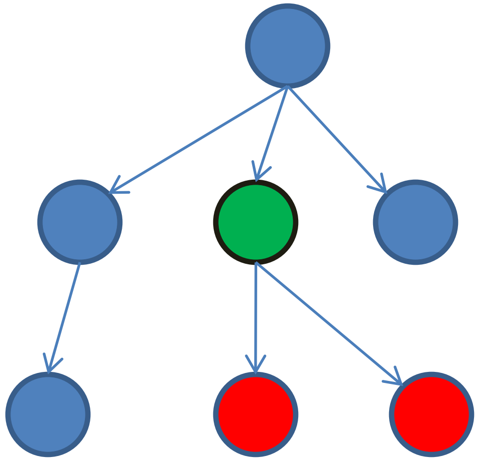
- Context-free grammar
- With attributes and rules to calculate the attributes

PRODUCTION	SEMANTIC RULE
$E \rightarrow E_1 + T$	$E.code = E_1.code \parallel T.code \parallel '+'$

Two Types of Attributes



Two Types of Attributes



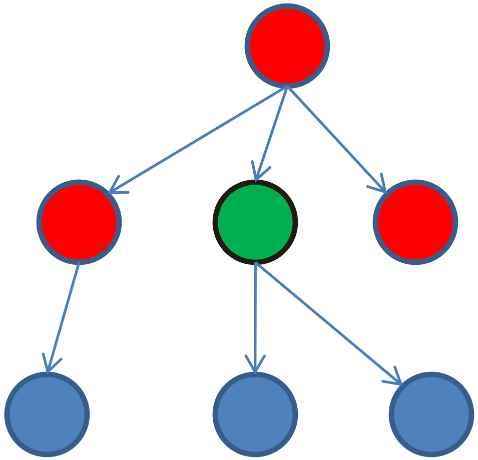
SDD involving only synthesized attributes is called ***S-attributed***

Synthesized Attributes

Attribute of the node is defined in terms of:

- Attribute values at children of the node
- Attribute value at node itself

Two Types of Attributes

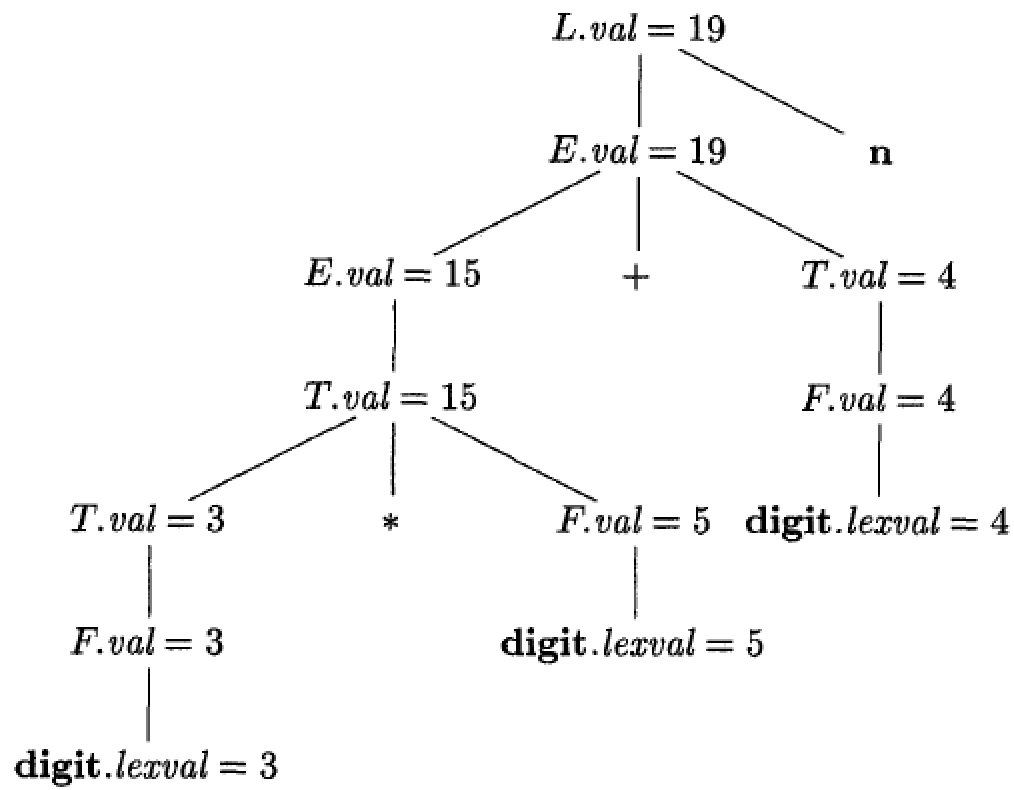


Inherited Attributes

Attribute of the node is defined in terms of:
•Attribute values at parent of the node
•Attribute values at siblings
•Attribute value at node itself

3*5+4n

	Production	Semantic Rules
1)	$L \to E\ \mathbf{n}$	$L.val = E.val$
2)	$E \to E_1\ +\ T$	$E.val = E_1.val + T.val$
3)	$E \to T$	$E.val = T.val$
4)	$T \to T_1\ *\ F$	$T.val = T_1.val \times F.val$
5)	$T \to F$	$T.val = F.val$
6)	$F \to (\ E\ )$	$F.val = E.val$
7)	$F \to \mathbf{digit}$	$F.val = \mathbf{digit}.\text{lexval}$



A parse tree showing the values of its attributes is called ***annotated parse tree***.

Example

Give the annotated parse tree of (3+4)*(5+6)n

	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)	$F \rightarrow \mathbf{digit}$	$F.val = \mathbf{digit}.\text{lexval}$

When Are Inherited Attributes Useful?

	Production
1)	$T \rightarrow F\, T'$
2)	$T' \rightarrow * \, F\, T'_1$
3)	$T' \rightarrow \epsilon$
4)	$F \rightarrow \textbf{digit}$

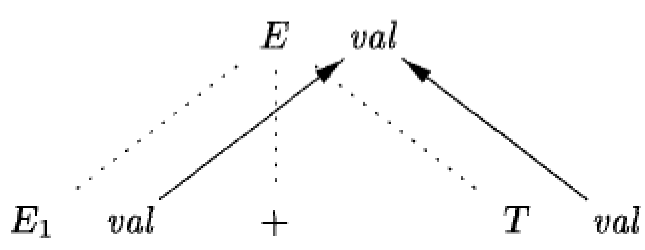
Example

	Production	Semantic Rules
1)	$D \to T\ L$	$L.inh = T.type$
2)	$T \to \textbf{int}$	$T.type = \text{integer}$
3)	$T \to \textbf{float}$	$T.type = \text{float}$
4)	$L \to L_1\ ,\ \textbf{id}$	$L_1.inh = L.inh$ $addType(\textbf{id}.entry, L.inh)$
5)	$L \to \textbf{id}$	$addType(\textbf{id}.entry, L.inh)$

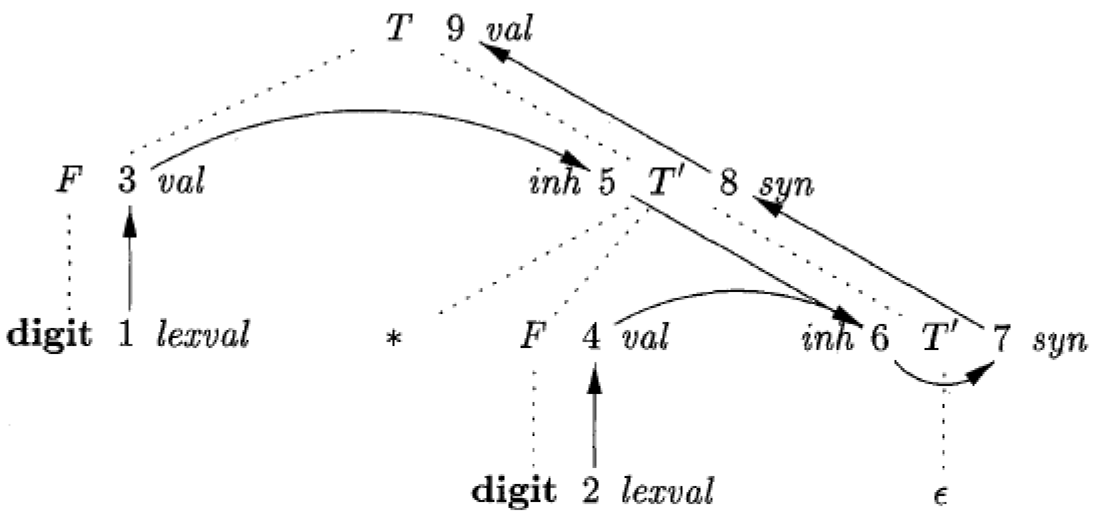
Give annotated parse-trees for:
int a, b, c

Evaluation Orders of SDDs

- Annotated parse tree shows attribute values
- Dependency graph helps us determine how those values are computed

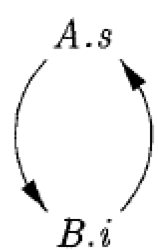


Topological Order



Cycles

- Arbitrary SDDs can have cycles.
- Cycles need to be avoided
  - Cannot proceed
  - Detecting cycles has exponential time-complexity.
- Two type of SDDs guarantee no-cycles:
  - S-attributed
  - L-attributed



PRODUCTION	SEMANTIC RULES
$A \to B$	$A.s = B.i;$ $B.i = A.s + 1$

S-Attributed Definitions

- Every attribute is synthesized
- We can evaluate its attribute in any bottom-up order of the nodes of the parse tree

(e.g. postorder traversal -> LR parser).

L-Attributed Definitions

- Dependency graph edges can only go from left to right
  - i.e. use attributes from above or from the left

Example

	Production	Semantic Rules
1)	$D \rightarrow T\ L$	$L.inh = T.type$
2)	$T \rightarrow \textbf{int}$	$T.type = \text{integer}$
3)	$T \rightarrow \textbf{float}$	$T.type = \text{float}$
4)	$L \rightarrow L_1\ ,\ \textbf{id}$	$L_1.inh = L.inh$ $addType(\textbf{id}.entry, L.inh$
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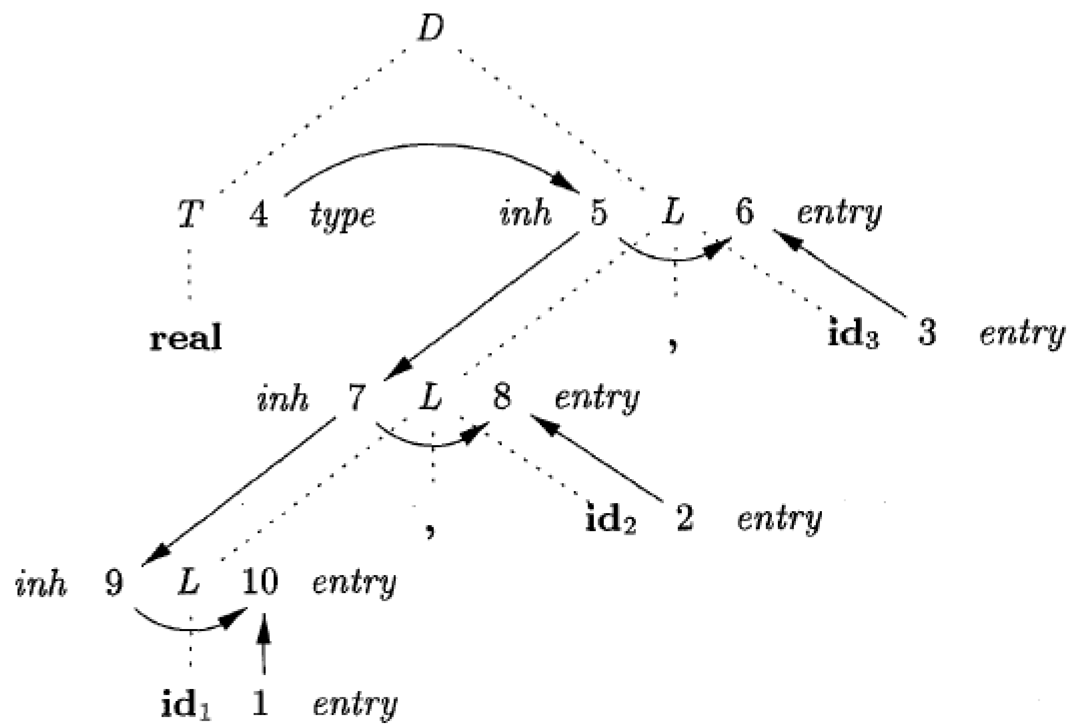

Syntax-Directed Translations

- Context-free grammar
- Can implement SDDs
- Program fragments embedded within production bodies
  - called semantic rules
  - Can appear anywhere within the production body
- Steps are usually as follows
  - Build parse tree
  - perform actions as you traverse left-to-right, depth-first (preorder)

Example

$$
\begin{array}{lcll}
L & \rightarrow & E\ \mathbf{n} & \{\ \text{print}(E.val);\ \} \\
E & \rightarrow & E_1 + T & \{\ E.val = E_1.val + T.val;\ \} \\
E & \rightarrow & T & \{\ E.val = T.val;\ \} \\
T & \rightarrow & T_1 * F & \{\ T.val = T_1.val \times F.val;\ \} \\
T & \rightarrow & F & \{\ T.val = F.val;\ \} \\
F & \rightarrow & (\ E\ ) & \{\ F.val = E.val;\ \} \\
F & \rightarrow & \mathbf{digit} & \{\ F.val = \mathbf{digit}.lexval;\ \}
\end{array}
$$

Implementing L-Attributed SDDs

- L-attributed definitions can be used in many translation applications
- Several methods of implementation
  - Build parse tree and annotate
  - Build parse tree, add actions, execute in preorder
  - Recursive descent

Recursive Descent

- Function *A* for each nonterminal *A*
- Arguments of *A* are inherited attributes of nonterminal *A*
- Return value of *A* is the collection of synthesized attributes of *A*

Example

$S \rightarrow \textbf{while} \ (\ C \ ) \ S_1$

For that rule we want to generate labels:
L1: C
L2: S1

$S \rightarrow \textbf{while} \ (\ C \ ) \ S_1$

$$
\begin{aligned}
& L1 = new(); \\
& L2 = new(); \\
& S_1.next = L1; \\
& C.false = S.next; \\
& C.true = L2; \\
& S.code = \textbf{label} \ || \ L1 \ || \ C.code \ || \ \textbf{label} \ || \ L2 \ || \ S_1.code
\end{aligned}
$$

Example

$S \rightarrow \textbf{while} (C) S_1$

For that rule we want to generate labels:
L1: C
L2: S1

```
string S(label next) {
    string Scode, Ccode; /* local variables holding code fragments */
    label L1, L2; /* the local labels */
    if ( current input == token while ) {
        advance input;
        check '(' is next on the input, and advance;
        L1 = new();
        L2 = new();
        Ccode = C(next, L2);
        check ')' is next on the input, and advance;
        Scode = S(L1);
        return("label" || L1 || Ccode || "label" || L2 || Scode);
    }
    else /* other statement types */
}
```

Example

$S \rightarrow \textbf{while} \ (\ C \ ) \ S_1$

For that rule we want to generate labels:
L1: C
L2: S1

```
string S(label next) {
        string Scode, Ccode; /* local variables holding code fragment
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        if ( current input == token while ) {
                advance input;
                check '(' is next on the input, and advance;
                L1 = new();
                L2 = new();
                Ccode = C(next, L2);
                check ')' is next on the input, and advance;
                Scode = S(L1);
                return("label" || L1 || Ccode || "label" || L2 || Scode
        }
        else /* other statement types */
}
```

```
void S(label next) {
        label L1, L2; /* the local labels */
        if ( current input == token while ) {
                advance input;
                check '(' is next on the input, and advance;
                L1 = new();
                L2 = new();
                print("label", L1);
                C(next, L2);
                check ')' is next on the input, and advance;
                print("label", L2);
                S(L1);
        }
        else /* other statement types */
}
```

Reading

- Skim: 5.3, 5.4.3, 5.4.4, 5.4.5, 5.5.3, and 5.5.4
- Read the rest