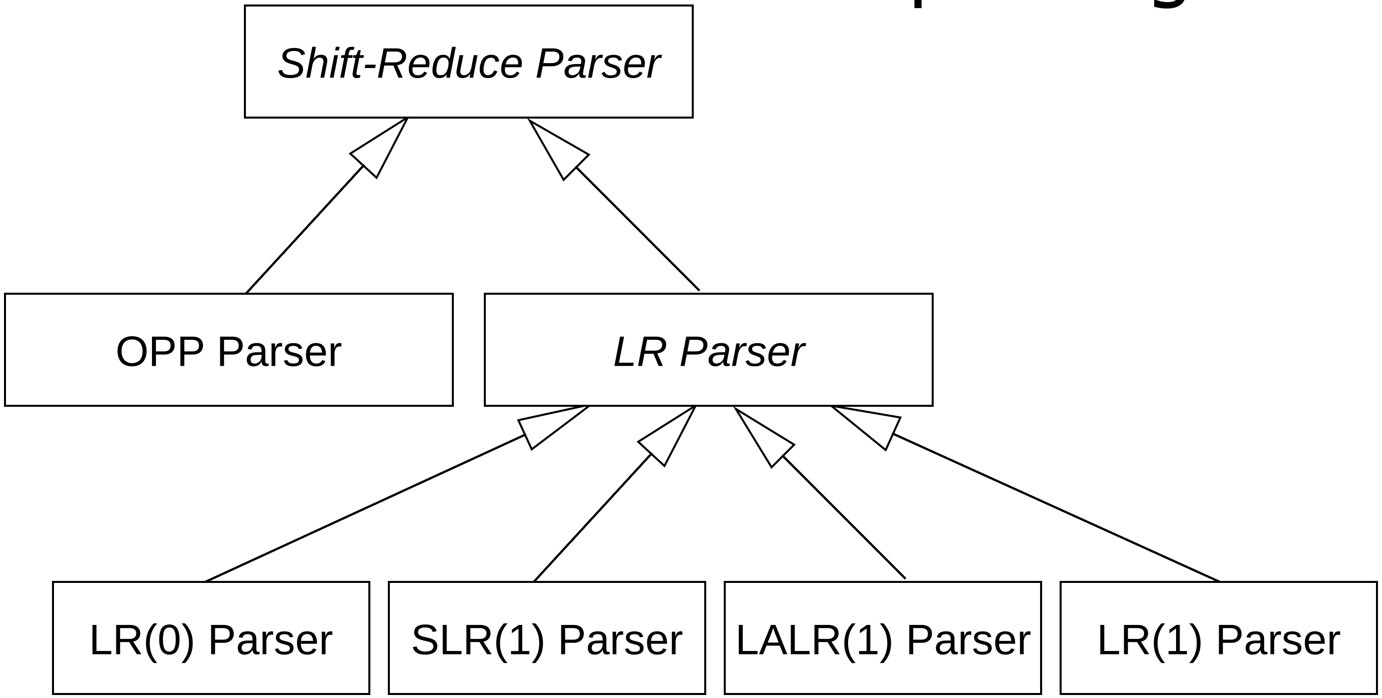
Principles of Compiler Construction

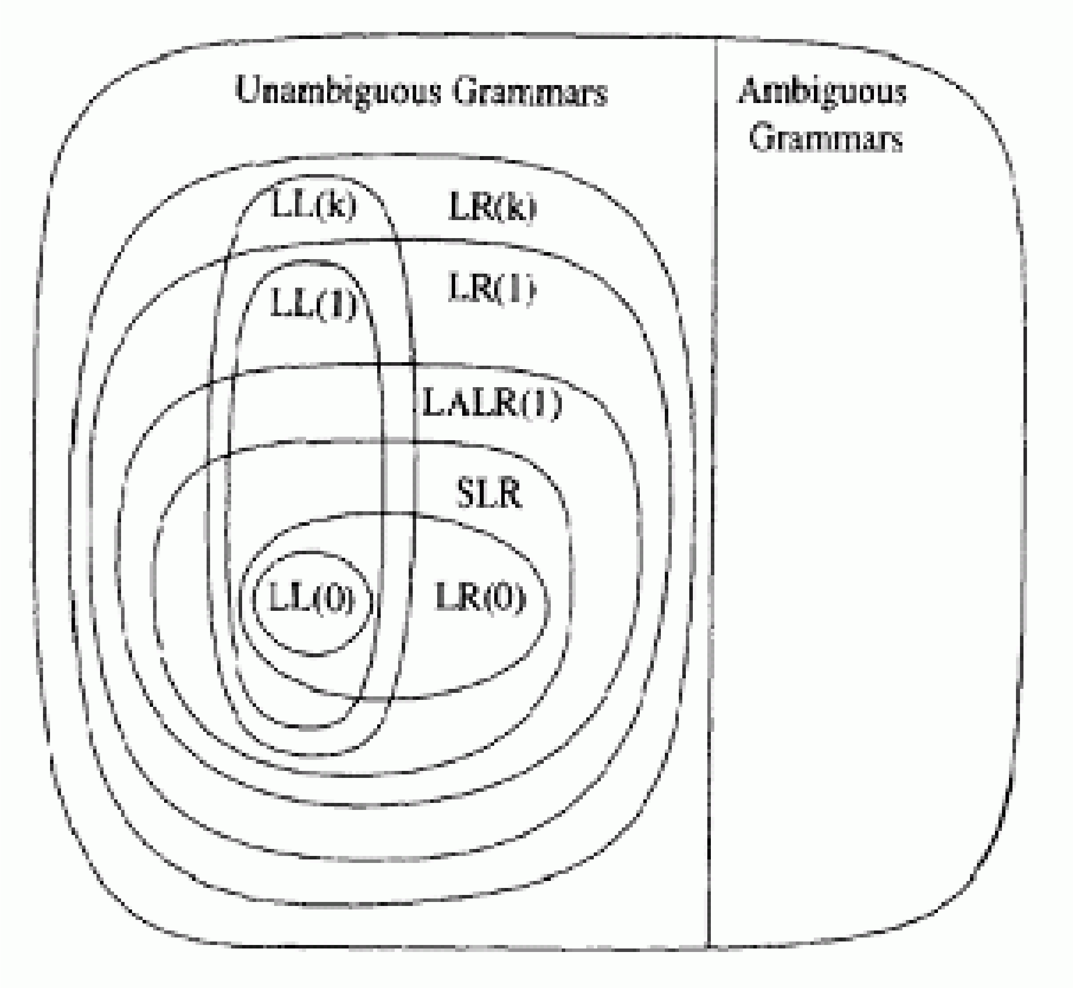
Lecturer: CHANG HUIYOU

Review

- Implementations of the abstract model for shift-reduce parsing



Conclusions:
Context-Free Grammar Classification

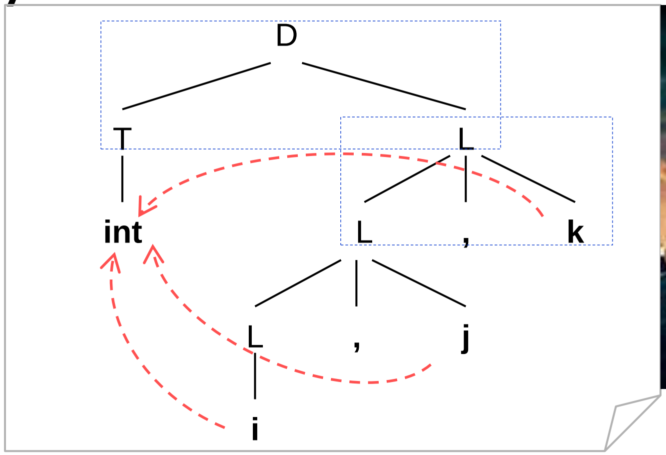


Lecture . Syntax-Directed Translation

1. Introduction
2. Syntax-Directed Definition: Examples
3. Evaluation Order and Dependency Graphs
4. S-Attributed Definitions
5. L-Attributed Definitions and Translation Schemes
6. L-Attributed Definitions in Predictive Parsing
7. L-Attributed Definitions in LR Parsing

1. Introduction

- What is syntax-directed translation ?
  - E.g. denotational semantics
    - Every component has its denotation.
    - The denotation of a composite component depends only on the denotations of its sub-components.
- Why syntax-directed ?



Applications of Syntax-Directed Translation

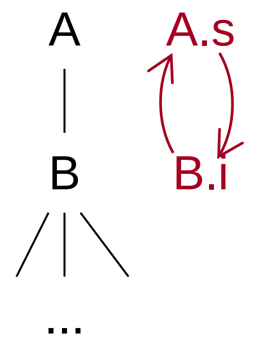
- Two compiling phases are covered
  - Semantic analysis
  - Intermediate code generation
- Our learning steps
  1. The general concepts and framework of syntax-directed translation
  2. Application of these concepts and framework to semantic analysis and intermediate code generation.

Basic Ideas

- Associate grammar symbols with attributes
  - Based on specific applications.
  - The **data** to be manipulated.
- Associate productions with semantic rules
  - Also named semantic actions.
  - The **operations** that manipulate the attributes.

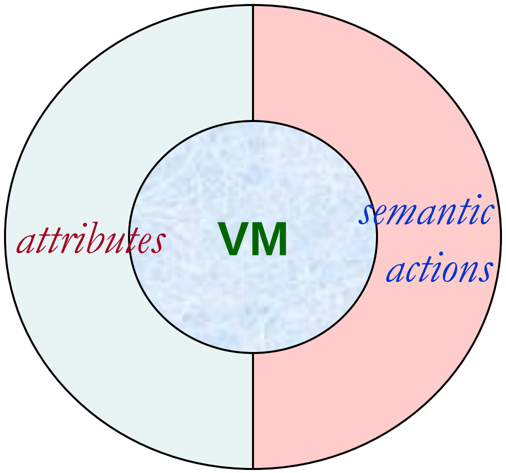
$A \rightarrow B$

$A.s = B.i; \ \ B.i = A.s + 1$



More Insights: A Virtual Machine

- Syntax-directed translation can be explained as a virtual machine
  - What to do: semantic actions.
  - How to do: evaluation order, i.e. the order in which the actions are performed.



Challenges

- Efficiency of the decision of semantic actions execution order
  - The best way is to execute the semantic actions while parsing.
  - I.e. the evaluation order of actions is the same as the order of parsing output.
  - Trade-off: capability vs. efficiency

Concepts

- Syntax-directed definition
  - Translation Scheme
- Annotated parse tree
  - Annotated parse tree with actions
- Synthesized Attribute
- Inherited Attribute

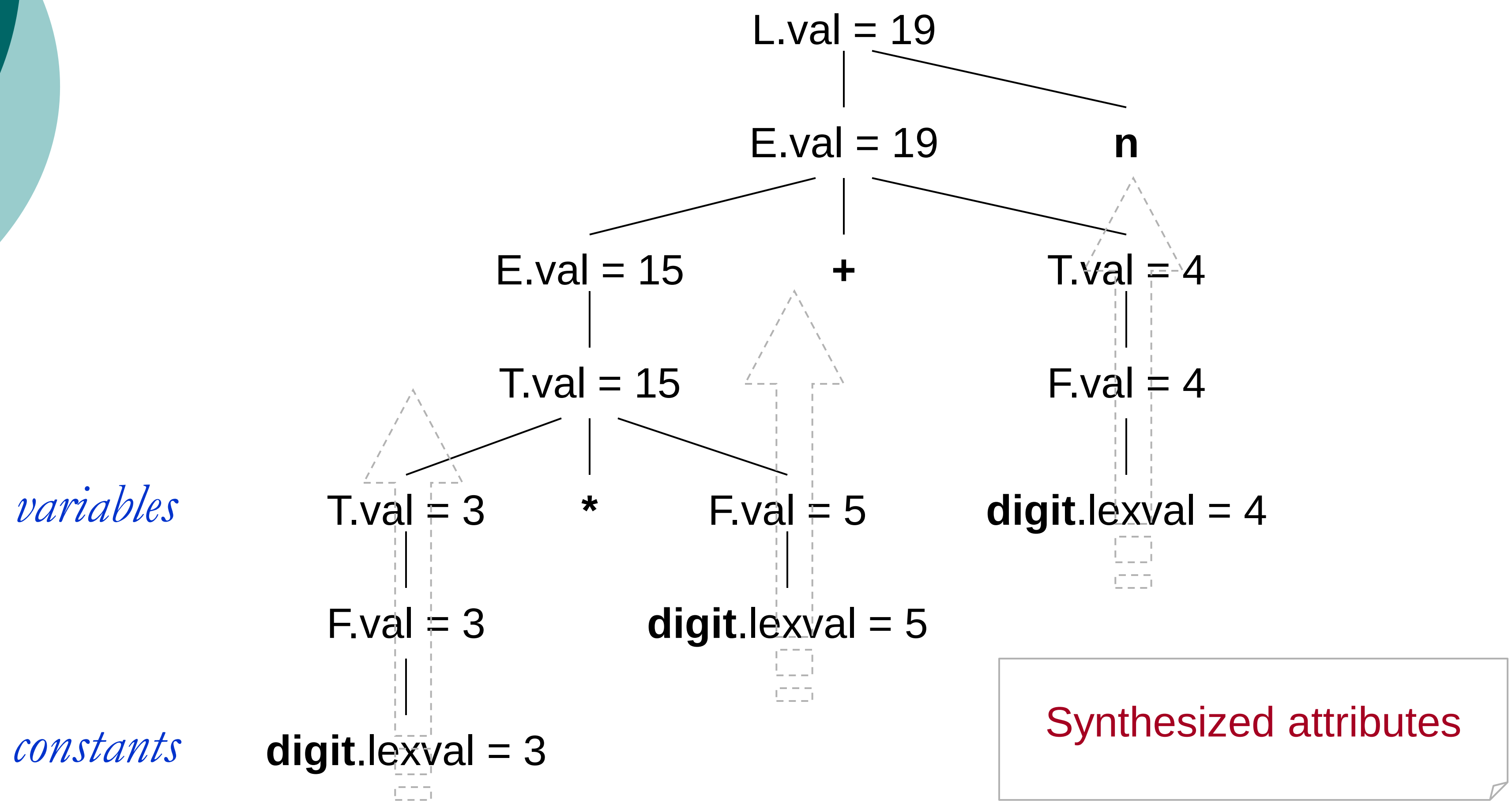
Syntax-Directed Definition

	Productions	Semantic Rules
1	L $\rightarrow$ E **n**	L.val = E.val print(L.val)
2	E $\rightarrow$ E_1 **+** T	E.val = E_1.val + T.val
3	E $\rightarrow$ T	E.val = T.val
4	T_1 $\rightarrow$ T_2 ***** F	T_1.val = T_2.val * F.val
5	T $\rightarrow$ F	T.val = F.val
6	F $\rightarrow$ **(** E **)**	F.val = E.val
7	F $\rightarrow$ **digit**	F.val = **digit**.lexval

Side-effects

Different
subfix style

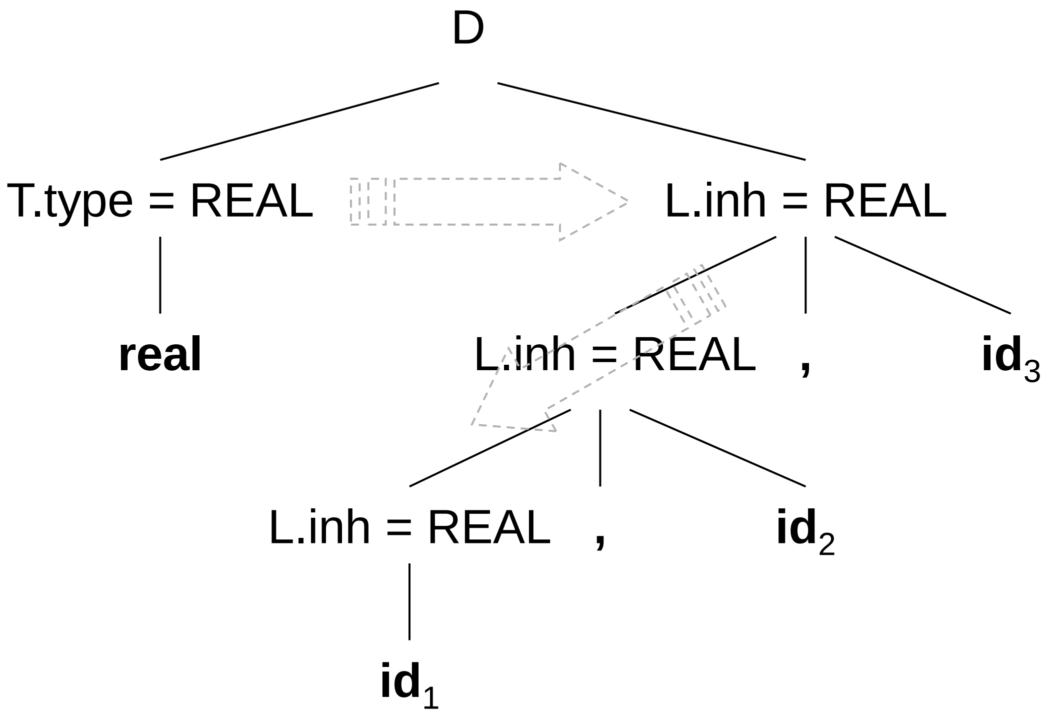
Annotated Parse Tree



Inherited Attribute

No.	Productions	Semantic Rules
1	D $\rightarrow$ T L	L.inh = T.type
2	T $\rightarrow$ **int**	T.type = INTEGER
3	T $\rightarrow$ **real**	T.type = REAL
4	L $\rightarrow$ L_1 **, id**	L_1.inh = L.inh addType(**id**.entry, L.inh)
5	L $\rightarrow$ **id**	addType(**id**.entry, L.inh)

Annotated Parse Tree



2. Syntax-Directed Definition: Examples

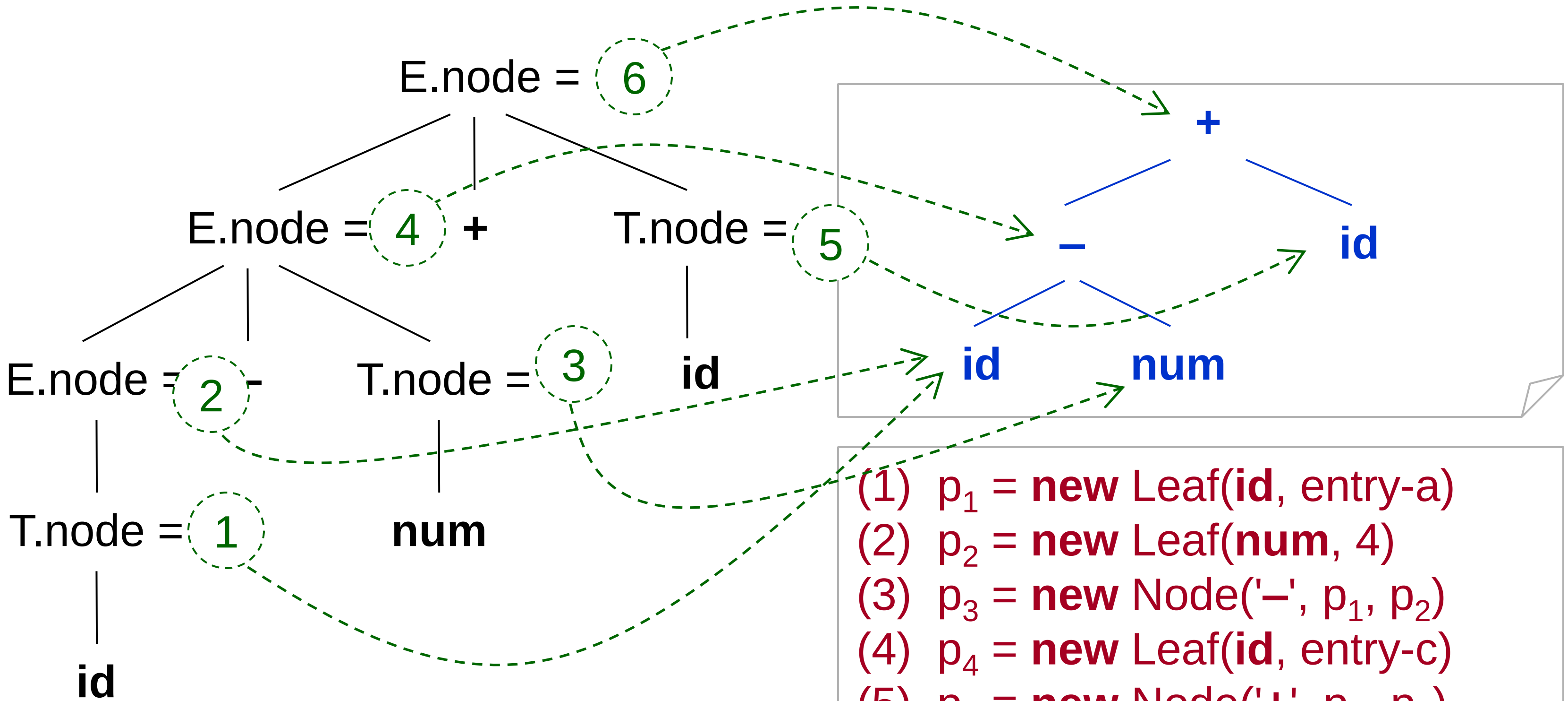
- Construction of Syntax Trees
- Construction of DAG
- Type Structure of Arrays

Syntax Trees

No.	Productions	Semantic Rules
1	$E \rightarrow E_1$ **+** T	E.node = **new** Node('+', E_1.node, T.node)
2	$E \rightarrow E_1$ **−** T	E.node = **new** Node('−', E_1.node, T.node)
3	$E \rightarrow T$	E.node = T.node
4	$T \rightarrow$ **(** E **)**	T.node = E.node
5	$T \rightarrow$ **id**	T.node = **new** Leaf(**id**, **id**.entry)
6	$T \rightarrow$ **num**	T.node = **new** Leaf(**num**, **num**.val)

Syntax Trees (cont')

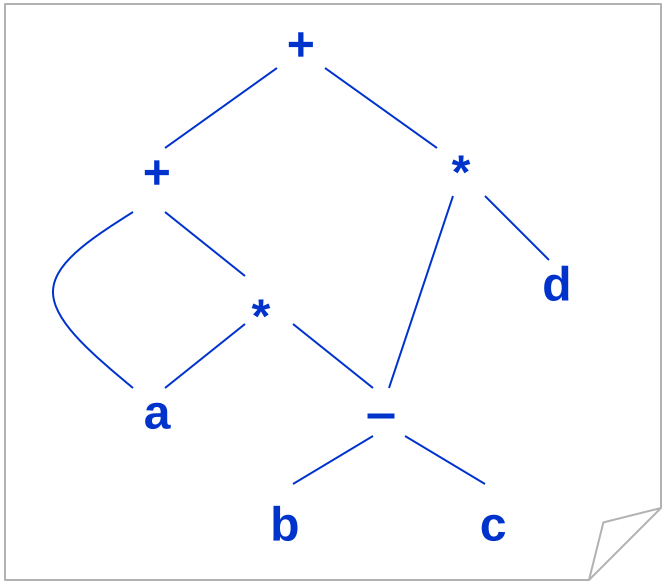
- Syntax tree for **a – 4 + c**



(1) p_1 = **new** Leaf(**id**, entry-a)
(2) p_2 = **new** Leaf(**num**, 4)
(3) p_3 = **new** Node('**–**', p_1, p_2)
(4) p_4 = **new** Leaf(**id**, entry-c)
(5) p_5 = **new** Node('**+**', p_3, p_4)

DAG

- DAG: Directed Acyclic Graph
  - **a + a * (b – c) + (b – c) * d**



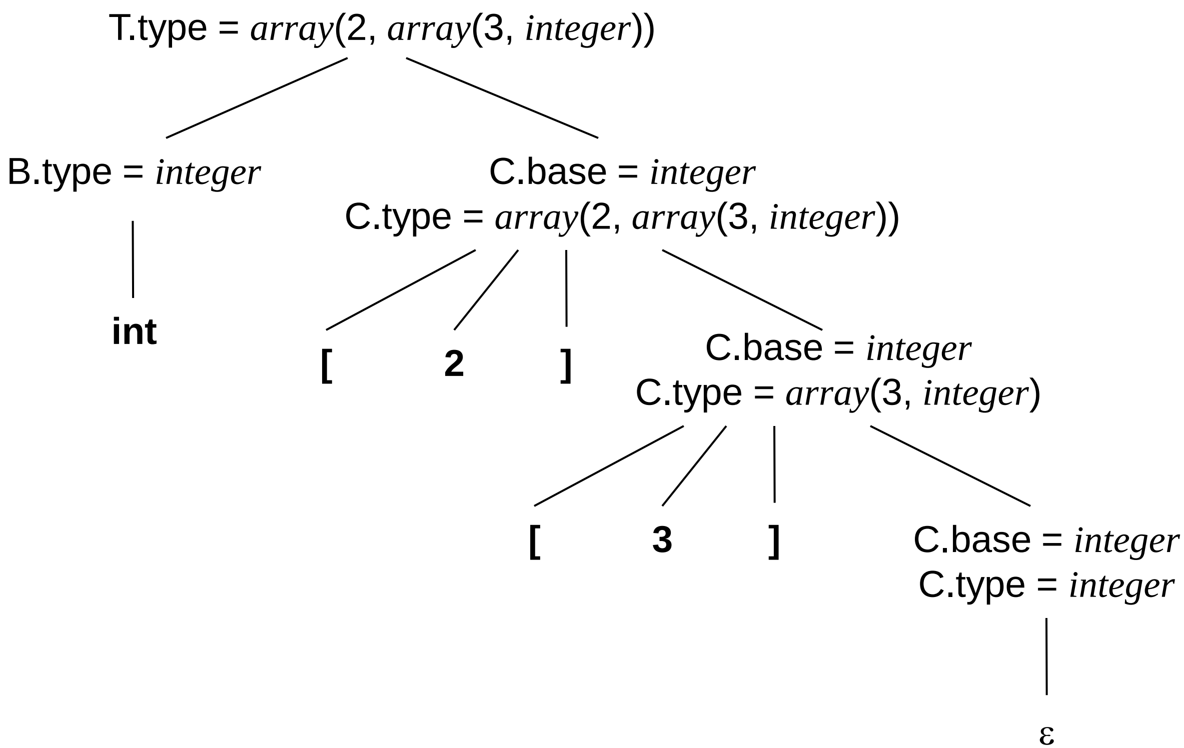
(1) p_1 = **new** Leaf(**id**, entry-a)
(2) p_2 = **new** Leaf(**id**, entry-a)
(3) p_3 = **new** Leaf(**id**, entry-b)
(4) p_4 = **new** Leaf(**id**, entry-c)
(5) p_5 = **new** Node('**–**', p_3, p_4)
(6) p_6 = **new** Node('*****', p_2, p_5)
(7) p_7 = **new** Node('**+**', p_1, p_6)
(8) p_8 = **new** Leaf(**id**, entry-b)
(9) p_9 = **new** Leaf(**id**, entry-c)
(10) p_{10} = **new** Node('**–**', p_8, p_9)
(11) p_{11} = **new** Leaf(**id**, entry-d)
(12) p_{12} = **new** Node('*****', p_{10}, p_{11})
(13) p_{13} = **new** Node('**+**', p_7, p_{12})

Type Structures

No.	Productions	Semantic Rules
1	T $\rightarrow$ B C	T.type = C.type C.base = B.type
2	B $\rightarrow$ **int**	B.type = *int*
3	B $\rightarrow$ **float**	B.type = *float*
4	C $\rightarrow$ **[num]** C_1	C.type = *array*(**num**.val, C_1.type) C_1.base = C.base
5	C $\rightarrow$ ε	C.type = C.base

Type Structures (cont')

- Type structure for **int[2][3]**



3. Evaluation Order and Dependency Graphs

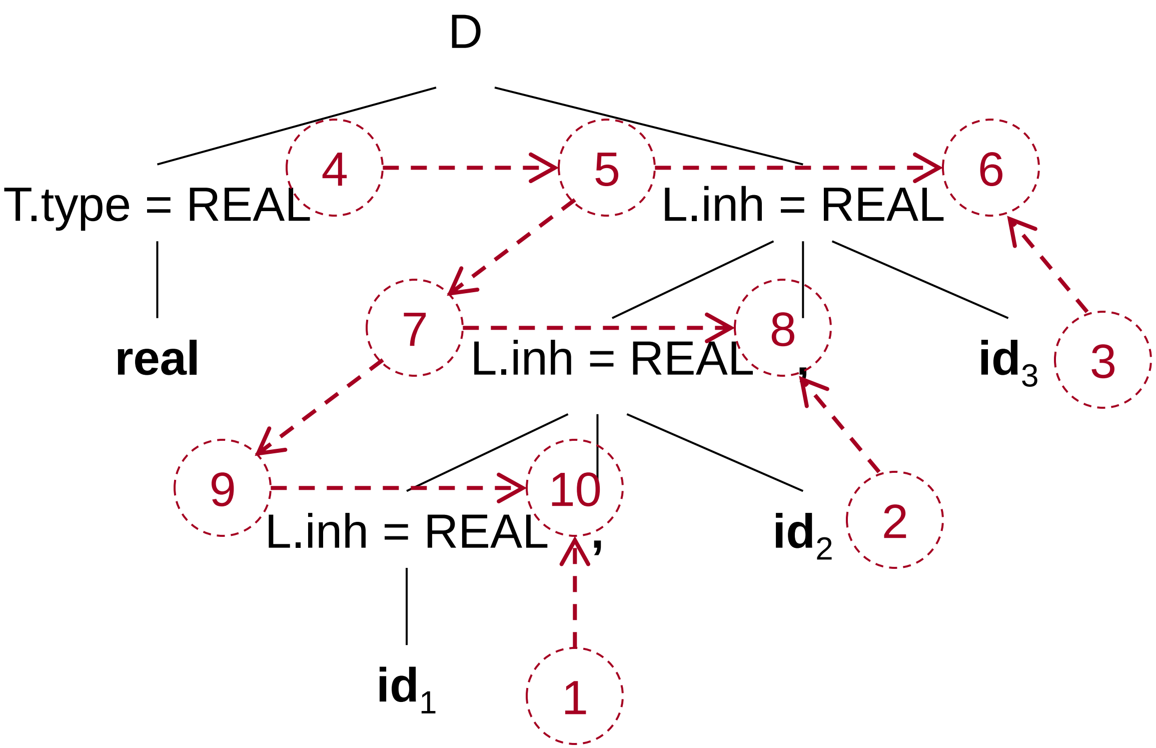
- A general framework of working steps:
  - Introduce attributes to grammar symbols.
  - Define semantic rules for each production.
  - Draw the **dependency graph** based on the parse tree.
  - Determine the **evaluation order** by topological sorting of the dependency graph.
  - Execute the semantic rules according to the evaluation order.

Work with **explicit** parse tree

Pros and Cons

- Pros
  - A general and powerful approach.
  - Can be used to demonstrate the principles of evaluation order of syntax-directed definitions.
- Cons
  - Explicit parse tree.
  - Low efficiency and impractical.

Dependency Graph: An Example



6, 8, 10 are dummy attributes

addType(id.entry, L.inh)

Evaluation Order

- Topological sorting
  - Specification: dependency graph
  - Implementation: evaluation order
- Mapping a specification to an implementation
  - 1 : 1 -- without any cycles in the graph
  - 1 : n -- without any cycles in the graph
  - 1 : 0 -- with cycles in the graph

Implicit Parse Trees

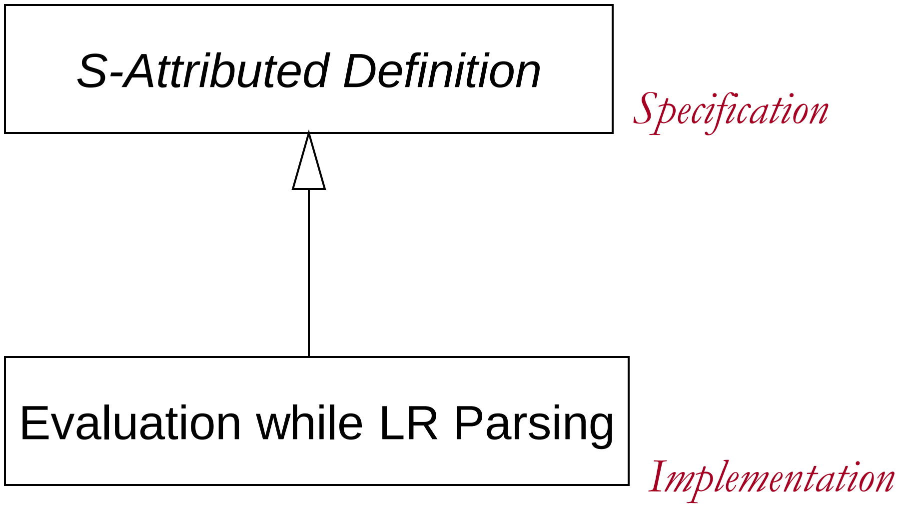
- S-attributed definitions
  - Every attribute is synthesized.
  - Guarantee an evaluation order that is the same order of the output of LR parsing.
- L-attributed definitions
  - Every attribute is synthesized, or only inherited from parent or left siblings (not from right siblings).
  - Guarantee an evaluation order that is the same order of recursive descent predictive parsing.

4. S-Attributed Definitions

- A syntax-directed definition with only synthesized attributes
- Evaluation order for S-attributed definitions
  - Upwards, and only upwards
  - The same order as LR parsing !

Specification vs. Implementation

- Evaluate S-attributed definitions while bottom-up parsing



The Previous Calculator Example

No.	Productions	Semantic Rules
1	L $\rightarrow$ E **n**	L.val = E.val print(L.val)
2	E $\rightarrow$ E_1 **+** T	E.val = E_1.val + T.val
3	E $\rightarrow$ T	E.val = T.val
4	T_1 $\rightarrow$ T_2 ***** F	T_1.val = T_2.val + F.val
5	T $\rightarrow$ F	T.val = F.val
6	F $\rightarrow$ **(** E **)**	F.val = E.val
7	F $\rightarrow$ **digit**	F.val = **digit**.lexval

Associate attributes of grammar symbols with positions in the parsing stack.

Implementation in LR Parsing

No.	Productions	Code	Notes
1	L $\to$ E **n**	stack[ntop].val = stack[top – 1].val; print(stack[ntop].val);	
2	E $\to$ E_1 **+** T	stack[ntop].val = stack[top – 2].val + stack[top].val;	stack[top – 1].val = '**+**'
3	E $\to$ T		
4	T_1 $\to$ T_2 ***** F	stack[ntop].val = stack[top – 2].val * stack[top].val;	stack[top – 1].val = '*****'
5	T $\to$ F		
6	F $\to$ **(** E **)**	stack[ntop].val = stack[top – 1].val;	stack[top].val = '**)**' stack[top – 2].val = '**(**'
7	F $\to$ **digit**		

Setup an attribute stack with the same height as parsing (state) stack:

ntop = top – | right-side | + 1

Evaluation While LR Parsing

Step	States (Illustrative)	Attributes	Input	Code	Output
1	$	$	**3 * 5 + 4 n $**		
2	$ 3	$ 3	*** 5 + 4 n $**	--	F $\rightarrow$ **digit**
3	$ F	$ 3	*** 5 + 4 n $**	--	T $\rightarrow$ F
4	$ T	$ 3	*** 5 + 4 n $**		
5	$ T *	$ 3 *	**5 + 4 n $**		
6	$ T * 5	$ 3 * 5	**+ 4 n $**	--	F $\rightarrow$ **digit**
7	$ T * F	$ 3 * 5	**+ 4 n $**	3 * 5	T $\rightarrow$ T ***** F
8	$ T	$ 15	**+ 4 n $**	--	E $\rightarrow$ T
9	$ E	$ 15	**+ 4 n $**		
10	$ E +	$ 15 +	**4 n $**		
11	$ E + 4	$ 15 + 4	**n $**	--	F $\rightarrow$ **digit**
12	$ E + F	$ 15 + 4	**n $**	--	T $\rightarrow$ F
13	$ E + T	$ 15 + 4	**n $**	15 * 4	E $\rightarrow$ E **+** T
14	$ E	$ 19	**n $**		
15	$ E **n**	$ 19 **n**	**$**	print(19)	L $\rightarrow$ E **n**
16	$ L	$ 19	**$**	accept	

5. L-Attributed Definitions and Translation Schemes

- A syntax-directed definition is L-attributed if each inherited attribute depends only on attributes of its **left** siblings or **inherited** attributes of its parent.
  - Synthesized attributes are supported.
  - Can NOT depend on any synthesized attributes of its parent ! (Why ?)

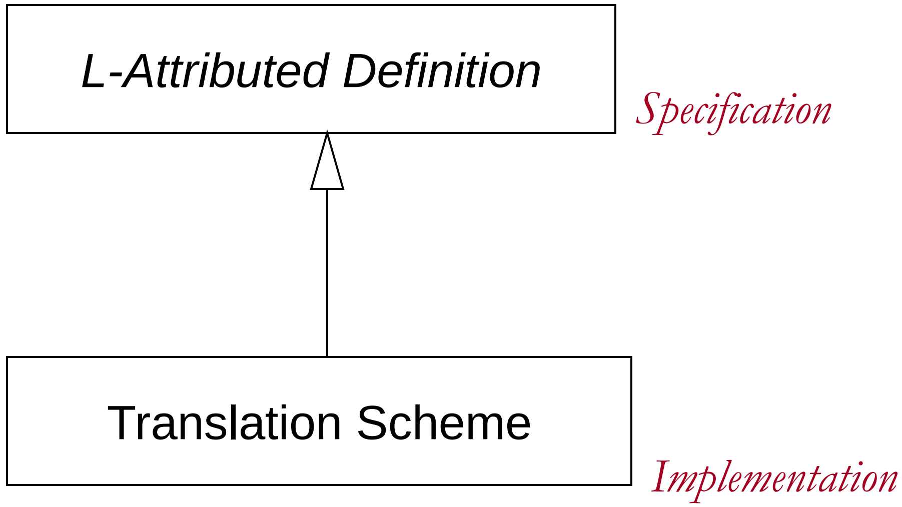
Depth-First Evaluation Order

- The evaluation order of an L-attributed definition
  - The same as depth-first visiting of the parse tree.
  - Also the same order as top-down parsing.

```
void dfvisit(n: Node) {
    for (each child m of n, from left to right) {
        evaluate inherited attributes of m;
        dfvisit(m)
    }
    evaluate synthesized attributes of n
}
```

Translation Schemes

- Translation scheme vs. L-attributed definition
  - **Explicit** evaluation order in a translation scheme.
  - Perform semantic actions in a left-to-right depth-first order.



Translation Scheme: Example 1

- **Postfix translation scheme** for an L-attributed definition:

$L \rightarrow E\ \mathbf{n}$	{ print(E.val); }
$E \rightarrow E_1\ \mathbf{+}\ T$	{ $E.val = E_1.val + T.val$; }
$E \rightarrow T$	{ $E.val = T.val$; }
$T \rightarrow T_1\ \mathbf{*}\ F$	{ $T.val = T_1.val + F.val$; }
$T \rightarrow F$	{ $T.val = F.val$; }
$F \rightarrow \mathbf{(}\ E\ \mathbf{)}$	{ $F.val = E.val$; }
$F \rightarrow \mathbf{digit}$	{ F.val = **digit**.lexval; }

Translation Scheme: Example 2

- Translation scheme for LR parsing:

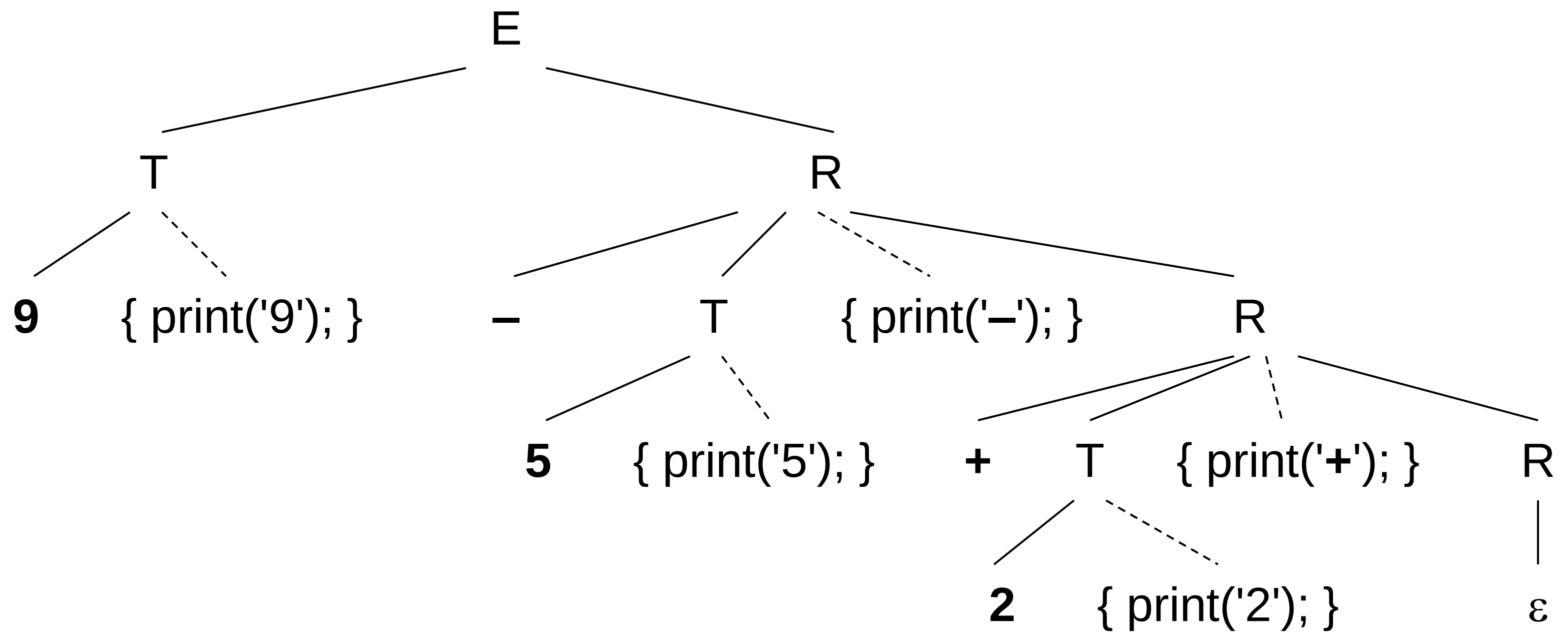
$L \rightarrow E$ **n**	{ print(stack[top – 1].val); top = top – 1; }
$E \rightarrow E_1$ **+** T	{ stack[top – 2].val = stack[top – 2].val + stack[top].val; top = top – 2; }
$E \rightarrow T$	
$T \rightarrow T_1$ ***** F	{ stack[top – 2].val = stack[top – 2].val * stack[top].val; top = top – 2; }
$T \rightarrow F$	
$F \rightarrow$ **(** E **)**	{ stack[top – 2].val = stack[top – 1].val; top = top – 2; }
$F \rightarrow$ **digit**	

Translation Scheme: Example 3

- Translation scheme for transformation from infix to postfix expressions:
  - Actions inside productions.

E	$\rightarrow$	T R	
R	$\rightarrow$	**addop** T	{ print(**addop**.lexeme); }
		R_1	
R	$\rightarrow$	ε	
T	$\rightarrow$	**num**	{ print(**num**.val); }

Translation Scheme: Example 3 (cont')



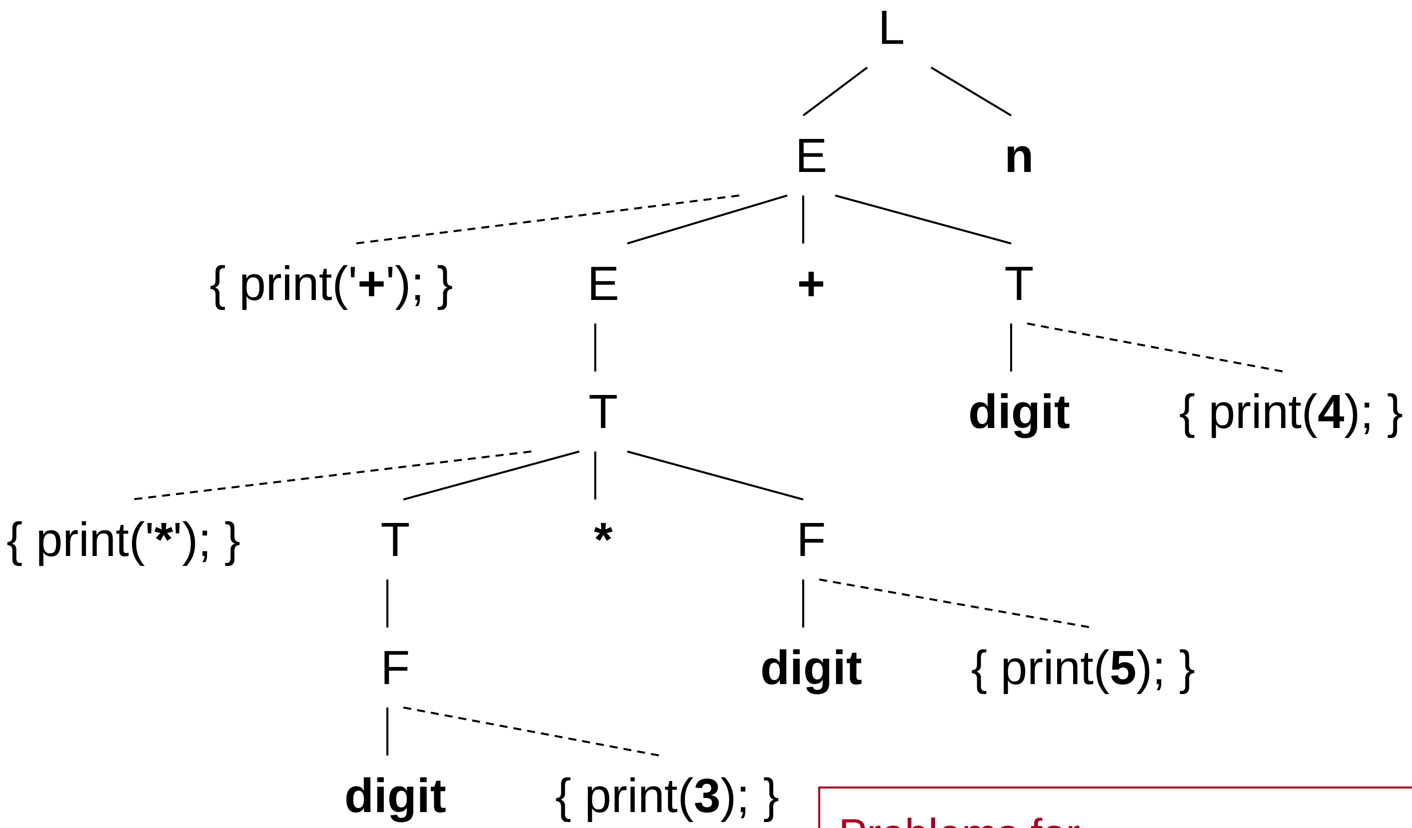
Parse Tree with Actions

Translation Scheme: Example 4

- Problematic translation scheme for prefix expressions:
  - In both top-down and bottom-up parsing.

L	$\rightarrow$	E **n**	
E	$\rightarrow$		{ print('+'); }
		E_1 **+** T	
E	$\rightarrow$	T	
T	$\rightarrow$		{ print('*'); }
		T_1 * F	
T	$\rightarrow$	F	
F	$\rightarrow$	**(** E **)**	
F	$\rightarrow$	**digit**	{ print(**digit**.lexval); }

Translation Scheme: Example 4 (cont')



Problems for
top-down parsing: left-recursion
bottom-up parsing: embedded actions

From L-Attributed Definitions to Translation Schemes

- Three transformation rules
  1. Inherited attributes of A must be calculated before A.
  2. An action must not refer to a synthesized attribute of a symbol to the right of the action.
  3. A synthesized attribute must be computed after all attributes it references have been computed.

Does not satisfy the requirements:

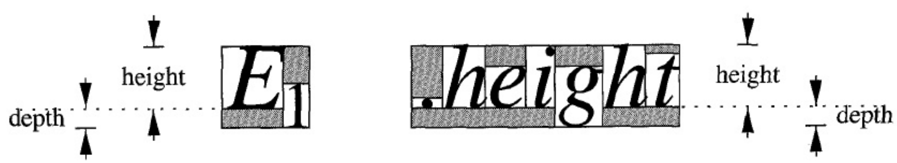
S	$\rightarrow$	A_1 A_2	{ A_1.in = 1; A_2.in = 2; }
A	$\rightarrow$	**a**	{ print(A.in); }

Typesetting Boxes: **EQN** and **TeX**

No.	Productions	Semantic Actions
1	$S \rightarrow B$	$B.ps = 10$
2	$B \rightarrow B_1\ B_2$	$B_1.ps = B.ps$ $B_2.ps = B.ps$ $B.ht = \max(B_1.ht, B_2.ht)$ $B.dp = \max(B_1.dp, B_2.dp)$
3	$B \rightarrow B_1$ **sub** B_2	$B_1.ps = B.ps$ $B_2.ps = B.ps \times 70\%$ $B.ht = \max(B_1.ht, B_2.ht - B.ps \times 25\%)$ $B.dp = \max(B_1.dp, B_2.dp + B.ps \times 25\%)$
4	$B \rightarrow$ **(** B_1 **)**	$B_1.ps = B.ps$ $B.ht = B_1.ht$ $B.dp = B_1.dp$
5	$B \rightarrow$ **text**	$B.ht = getHight(B.ps,$ **text**$.lexval)$ $B.dp = getDepth(B.ps,$ **text**$.lexval)$

ps = point size
ht = height
dp = depth

Higher precedence,
right associativity



From L-Attributed Definition to Translation Scheme

S	$\rightarrow$		{ B.ps = 10; }
		B	
B	$\rightarrow$		{ B_1.ps = B.ps; }
		B_1	{ B_2.ps = B.ps; }
		B_2	{ B.ht = max(B_1.ht, B_2.ht);
			B.dp = max(B_1.dp, B_2.dp); }
B	$\rightarrow$		{ B_1.ps = B.ps; }
		B_1 **sub**	{ B_2.ps = B.ps $\times$ 70%; }
		B_2	{ B.ht = max(B_1.ht, B_2.ht – B.ps $\times$ 25%);
			B.dp = max(B_1.dp, B_2.dp + B.ps $\times$ 25%); }
B	$\rightarrow$	**(**	{ B_1.ps = B.ps; }
		B_1 **)**	{ B.ht = B_1.ht;
			B.dp = B_1.dp; }
B	$\rightarrow$	**text**	{ B.ht = getHight(B.ps, **text**.lexval);
			B.dp = getDepth(B.ps, **text**.lexval); }

6. L-Attributed Definitions in Predictive Parsing

May have
left-recursions

- Development steps
  - Write a possibly LL(1) grammar for syntax rules.
  - Define an L-attributed definition by appending semantic rules.
  - Transform the L-attributed definition to a translation scheme.
  - Eliminate **left-recursion** in the translation scheme.
  - Write a recursive descent predictive parser (translator).

Eliminating Left-Recursion: A Simple Example

- A motivating example: a simple case
  - Trick: treating actions as terminals if they do not calculate any attributes.

$$
\begin{aligned}
E &\rightarrow E_1 + T \; \{\, \text{print('+');} \,\} \\
E &\rightarrow T
\end{aligned}
$$

$$
\begin{aligned}
E &\rightarrow T\, R \\
R &\rightarrow + T \; \{\, \text{print('+');} \,\} \; R \\
R &\rightarrow \varepsilon
\end{aligned}
$$

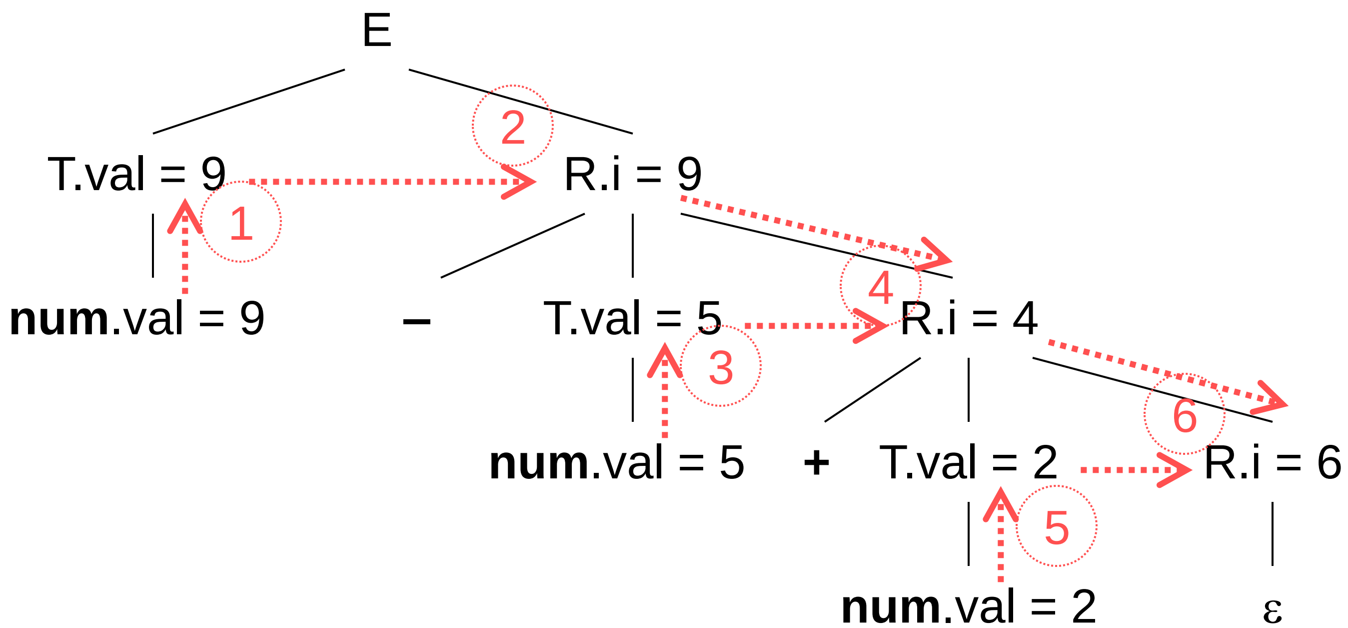
Eliminating Left-Recursion: More Examples

- A more complex case

E	$\rightarrow$	E_1 **+** T	{ E.val = E_1.val + T.val; }
E	$\rightarrow$	E_1 **–** T	{ E.val = E_1.val – T.val; }
E	$\rightarrow$	T	{ E.val = T.val; }
T	$\rightarrow$	**(** E **)**	{ T.val = E.val; }
T	$\rightarrow$	**num**	{ T.val = **num**.val; }

E	$\rightarrow$	T	{ R.i = T.val; }
		R	{ E.val = R.s; }
R	$\rightarrow$	**+** T	{ R_1.i = R.i + T.val; }
		R_1	{ R.s = R_1.s; }
R	$\rightarrow$	**–** T	{ R_1.i = R.i – T.val; }
		R_1	{ R.s = R_1.s; }
R	$\rightarrow$	ε	{ R.s = R.i; }
T	$\rightarrow$	**(** E **)**	{ T.val = E.val; }
T	$\rightarrow$	**num**	{ T.val = **num**.val; }

Eliminating Left-Recursion: More Examples (cont')



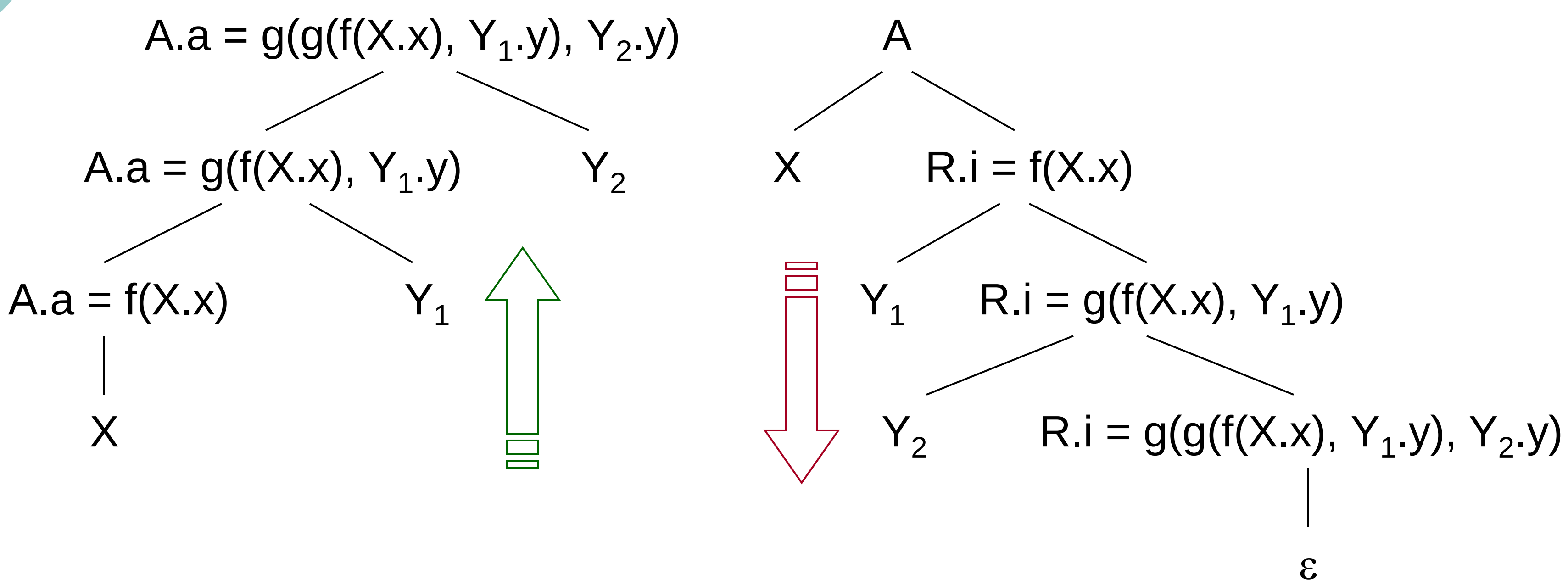
Evaluation Order of Input Expression **9 – 5 + 2**

Eliminating Left-Recursion

- General rules
  - Only available for S-attributed definitions (postfix translation schemes).

$$A \rightarrow A_1\ Y\ \{\ A.a = g(A_1.a,\ Y.y);\ \}$$
$$A \rightarrow X\ \{\ A.a = f(X.x);\ \}$$

$$A \rightarrow X\ \{\ R.i = f(X.x);\ \}\ R\ \{\ A.a = R.s;\ \}$$
$$R \rightarrow Y\ \{\ R_1.i = g(R.i,\ Y.y);\ \}\ R_1\ \{\ R.s = R_1.s;\ \}$$
$$R \rightarrow \varepsilon\ \{\ R.s = R.i;\ \}$$



Writing a Predictive Parser

- Review: writing a recursive descent predictive parser (only for parsing)
  - Each grammar symbol corresponds to a (recursive) subprogram.
  - The start symbol corresponds to the main entry subprogram.
  - In each subprogram, branching actions with regard to the lookahead.

Writing a Predictive Parser: An Example

- For parsing only

R	$\rightarrow$	**addop** T	{ R_1.i = mknode(**addop**.lexeme, R.i, T.nptr); }
		R_1	{ R.s = R_1.s; }
R	$\rightarrow$	ε	{ R.s = R.i; }

```
void R() {
    if (lookahead == addop) {
        match(addop);
        T();
        R()
    } else {
        // do nothing
    }
}
```

Writing a Predictive Translator

- Writing a translator with semantic actions
  - Each inherited attribute corresponds to a formal parameter.
  - All synthesized attributes correspond to the return value
    - Multiple synthesized attributes may be merged in a single record.
  - Each attribute of the child nodes corresponds to a local variable.
  - Process the right side of the production
    - Terminals: match()
    - Nonterminals: procedure call
    - Actions: direct execution (copy)

From a Parser to a Translator

R	$\rightarrow$	**addop** T	{ R_1.i = mknode(**addop**.lexeme, R.i, T.nptr); }
		R_1	{ R.s = R_1.s; }
R	$\rightarrow$	ε	{ R.s = R.i; }

```
SyntaxTreeNode R(SyntaxTreeNode i) {
    SyntaxTreeNode s;  // synthesized attributes
    SyntaxTreeNode t_nptr, r1_i, r1_s;  // for children
    char addopLexeme;  // temporary

    if (lookahead == addop) {
        addopLexeme = lookahead.lexval;
        match(addop);
        t_nptr = T();
        r1_i = mknode(addopLexeme, i, t_nptr);
        r1_s = R(r1_i);
        s = r1_s;
    } else {
        s = i;
    }
    return s;
}
```

7. L-Attributed Definitions in LR Parsing

- S-attributed definitions are easy to be evaluated by LR parsing.
  - See section 4 in these slides.
- What are the challenges for evaluating L-attributed definitions in LR parsing ?
  1. Not all actions are on the right-most of a production body (postfix translation scheme).
  2. Inherited attributes are not stored in the parsing stack.

Make Use of Tricks

- Using **markers** to move all embedded actions to the right-most of a production body.
- **Tracing** inherited attributes in the parsing stack.
  1. The simplest case: locating inherited attributes which are calculated by **copy rules**.
  2. Introduce **markers** to help to locate inherited attributes in the stack.
  3. Also make use of new **markers** to locate inherited attributes which are not calculated by copy rules.

Move Embedded Actions to Right-Most

- A marker is an ε-production that acts as a place-holder.

E	→	T R
R	→	**+** T { print('+'); } R
	|	**–** T { print('–'); } R
	|	ε
T	→	**num** { print(**num**.val); }

E	→	T R	
R	→	**+** T M R	
	|	**–** T N R	
	|	ε	
T	→	**num**	{ print(**num**.val); }
M	→	ε	{ print('+'); }
N	→	ε	{ print('–'); }

Trace a Copied Inherited Attribute

- Calculations of inherited attributes are the biggest source of embedded actions.

D	$\rightarrow$	T	{ L.inh = T.type; }
		L	
T	$\rightarrow$	**int**	{ T.type = INTEGER; }
T	$\rightarrow$	**real**	{ T.type = REAL; }
L	$\rightarrow$		{ L_1.inh = L.inh; }
		L_1 **, id**	{ addType(**id**.entry, L.inh); }
L	$\rightarrow$	**id**	{ addType(**id**.entry, L.inh); }

Trace a Rewriting Inherited Attribute (cont')

D	$\rightarrow$	T L	{ L.inh = T.type; }
T	$\rightarrow$	**int**	{ T.type = INTEGER; }
T	$\rightarrow$	**real**	{ T.type = REAL; }
L	$\rightarrow$		{ L_1.inh = L.inh; }
		L_1 **, id**	{ addType(**id**.entry, L.inh); }
L	$\rightarrow$	**id**	{ addType(**id**.entry, L.inh); }

Productions	Code
D $\rightarrow$ T L	
T $\rightarrow$ **int**	stack[ntop].val = INTEGER;
T $\rightarrow$ **real**	stack[ntop].val = REAL;
L $\rightarrow$ L_1 **, id**	addType(stack[top].val, stack[top – 3].val);
L $\rightarrow$ **id**	addType(stack[top].val, stack[top – 1].val);

Predict Positions of Inherited Attributes

- Introduce new markers

S	$\rightarrow$	**a** A	{ C.i = A.s; }
		C	
S	$\rightarrow$	**b** A B	{ C.i = A.s; }
		C	
C	$\rightarrow$	**c**	{ C.s = g(C.i); }

S	$\rightarrow$	**a** A	{ C.i = A.s; }
		C	
S	$\rightarrow$	**b** A B	{ M.i = A.s; }
		M	{ C.i = M.s; }
		C	
C	$\rightarrow$	**c**	{ C.s = g(C.i); }
M	$\rightarrow$	ε	{ M.s = M.i; }

Store Calculated Inherited Attributes

- Also make use of new markers

S	$\rightarrow$	**a** A	{ C.i = f(A.s); }
		C	
C	$\rightarrow$	**c**	{ C.s = g(C.i); }

S	$\rightarrow$	**a** A	{ M.i = A.s; }
		M	{ C.i = M.s; }
		C	
C	$\rightarrow$	**c**	{ C.s = g(C.i); }
M	$\rightarrow$	ε	{ M.s = f(M.i); }

A Practical Example

Productions	Semantic Actions
S → K B	B.ps = K.s
K → ε	K.s = 10
B → B_1 L B_2	B_1.ps = B.ps L.i = B.ps B_2.ps = L.s B.ht = max(B_1.ht, B_2.ht) B.dp = max(B_1.dp, B_2.dp)
L → ε	L.s = L.i
B → B_1 **sub** M B_2	B_1.ps = B.ps M.i = B.ps B_2.ps = M.s B.ht = max(B_1.ht, B_2.ht – B.ps × 25%) B.dp = max(B_1.dp, B_2.dp + B.ps × 25%)
M → ε	M.s = M.i × 70%
B → **(** N B_1 **)**	B_1.ps = B.ps N.i = B.ps B.ht = B_1.ht B.dp = B_1.dp
N → ε	N.s = N.i
B → **text**	B.ht = getHight(B.ps, **text**.lexval) B.dp = getDepth(B.ps, **text**.lexval)

Anytime when B is reduced, **B.ps** is immediately under B

A Practical Example (cont')

Productions	Code
S → K B	
K → ε	stack[ntop].ps = 10;
B → B_1 L B_2	stack[ntop].ht = max(stack[top – 2].ht, stack[top].ht); stack[ntop].dp = max(stack[top – 2].dp, stack[top].dp);
L → ε	stack[ntop].ps = stack[top – 1].ps;
B → B_1 **sub** M B_2	stack[ntop].ht = max(stack[top – 3].ht, stack[top].ht – stack[top – 4].ps × 25%); stack[ntop].dp = max(stack[top – 3].dp, stack[top].dp + stack[top – 4].ps × 25%);
M → ε	stack[ntop].ps = stack[top – 2].ps × 70%
B → **(** N B_1 **)**	stack[ntop].ht = stack[top – 1].ht stack[ntop].dp = stack[top – 1].dp
N → ε	stack[ntop].ps = stack[top – 1].ps;
B → **text**	stack[ntop].ht = getHight(stack[top – 1].ps, stack[top].lexval); stack[ntop].dp = getDepth(stack[top – 1].ps, stack[top].lexval);

ps is treated as a synthesized attribute

Remove all calculations for inherited attributes

Exercise 8.1

- Given the translation scheme for the EQN language (see pp.41 in this lecture), calculate the height and depth of the input: **text sub text sub text**.
  - Suppose that for each **text**,
    - getHeight(ps, **text**.lexval) = 8 * ps
    - getDepth(ps, **text**.lexval) = 0

Enjoy the Course!