Syntax Directed Translation for LR Parsers

CMPT 379: Compilers
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Syntax directed Translation

- Models for translation from parse trees into intermediate code
- Representation of translations
  - Attribute Grammars (semantic actions for CFGs)
  - Tree Matching Code Generators
  - Tree Parsing Code Generators

Attribute Grammars

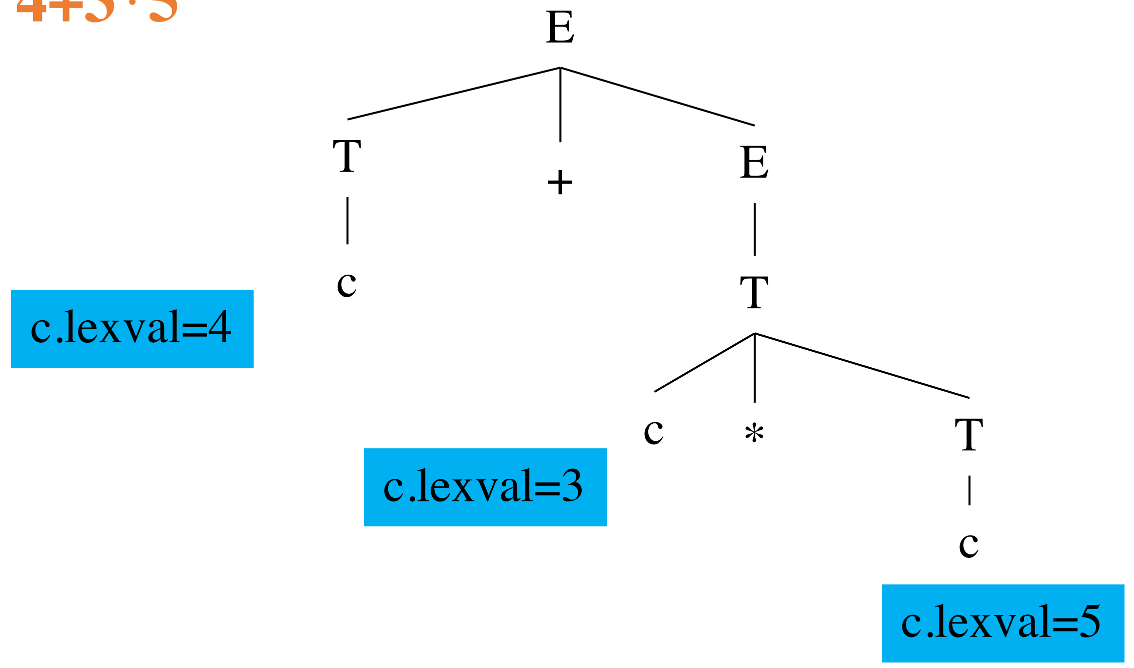
- Syntax-directed translation uses a grammar to produce code (or any other “semantics”)
- We are generalizing context-free grammars
- Each grammar symbol is associated with an attribute
- An attribute can be anything: a string, a number, a tree, any kind of record or object

Attribute Grammars

- A CFG can be viewed as a function that relates strings to derivations (aka parse trees)
- Similarly, an attribute grammar is a way of relating strings with attributes (or “meanings”)
- Attribute grammars are a method to *decorate* or *annotate* the parse tree with the desired output attributes

Expr concrete syntax tree

Input: **4+3*5**



$E \rightarrow T + E$

$E \rightarrow T$

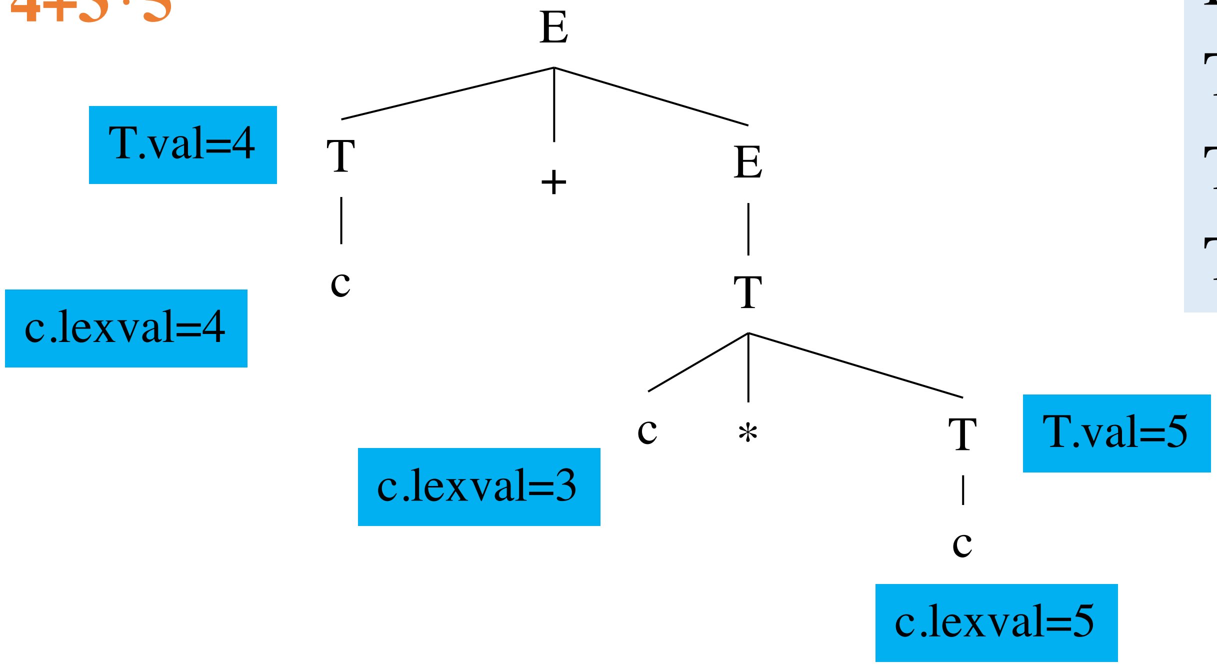
$T \rightarrow c$

$T \rightarrow c * T$

$T \rightarrow (E)$

Expr concrete syntax tree

Input: **4+3*5**



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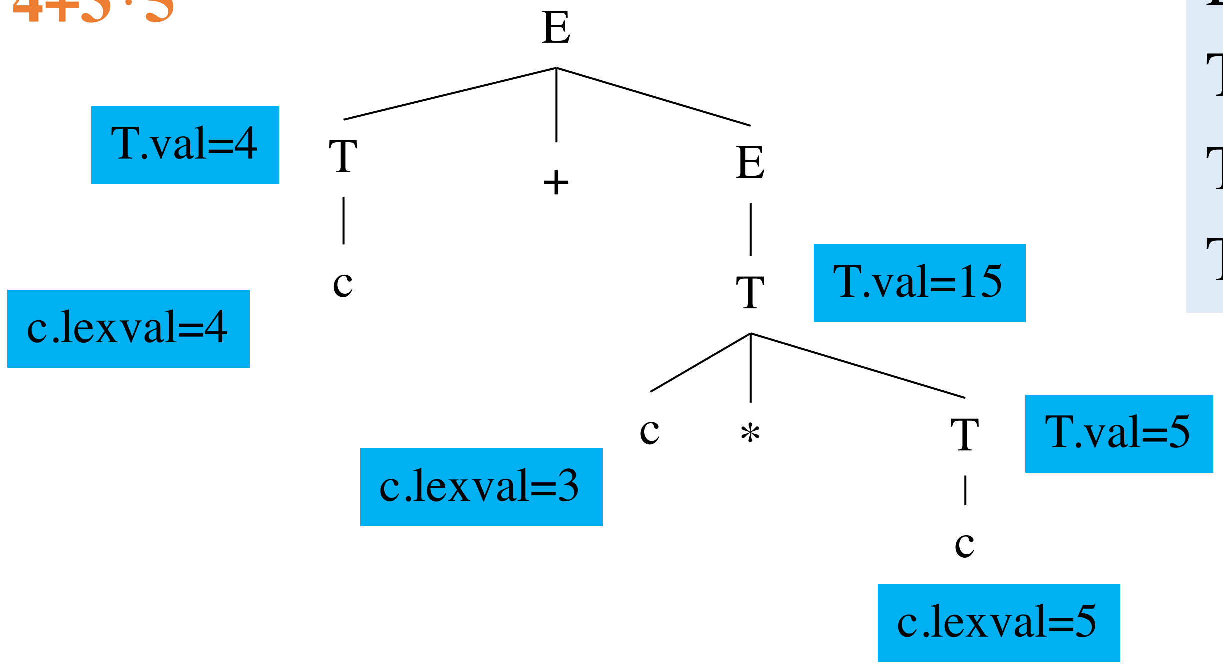

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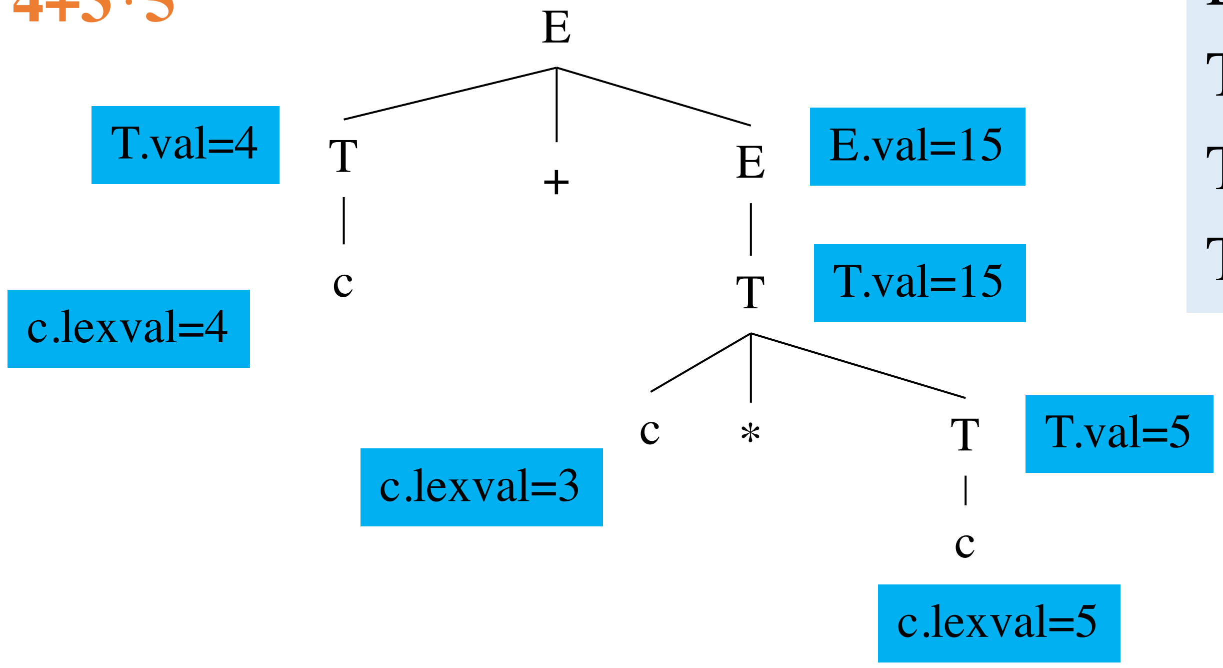

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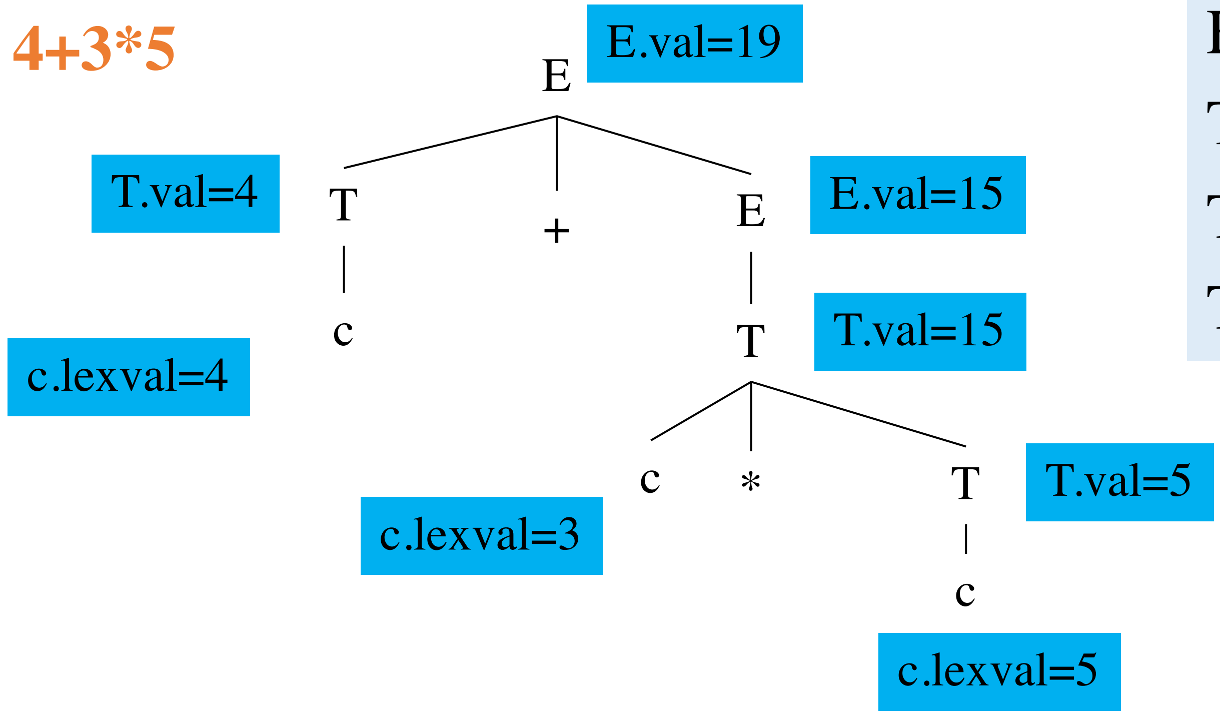
Expr concrete syntax tree

Input: 4+3*5



$E \rightarrow T + E$

$E \rightarrow T$

$T \rightarrow c$

$T \rightarrow c * T$

$T \rightarrow (E)$

Syntax directed definition

T → **c**

{ $$.val = $1.lexval; }

T → **c** ***** T

{ $$.val = $1.lexval * $3.val ; }

E → T

{ $$.val = $1.val; }

E → T **+** E

{ $$.val = $1.val + $3.val; }

T → **(** E **)**

{ $$.val = $2.val; }

Flow of Attributes in *Expr*

- Consider the flow of the attributes in the *E* syntax-directed defn
  - The lhs attribute is computed using the rhs attributes
- Purely bottom-up:
  - compute attribute values of all children (rhs) in the parse tree
  - And then use them to compute the attribute value of the parent (lhs)

Synthesized Attributes

- **Synthesized attributes** are attributes that are computed purely bottom-up
- A grammar with semantic actions (or syntax-directed definition) can choose to use *only* synthesized attributes
- Such a grammar plus semantic actions is called an **S-attributed definition**

Inherited Attributes

- Synthesized attributes may not be sufficient for all cases that might arise for semantic checking and code generation

- Consider the (sub)grammar:

  Var-decl $\rightarrow$ Type IdList **;**

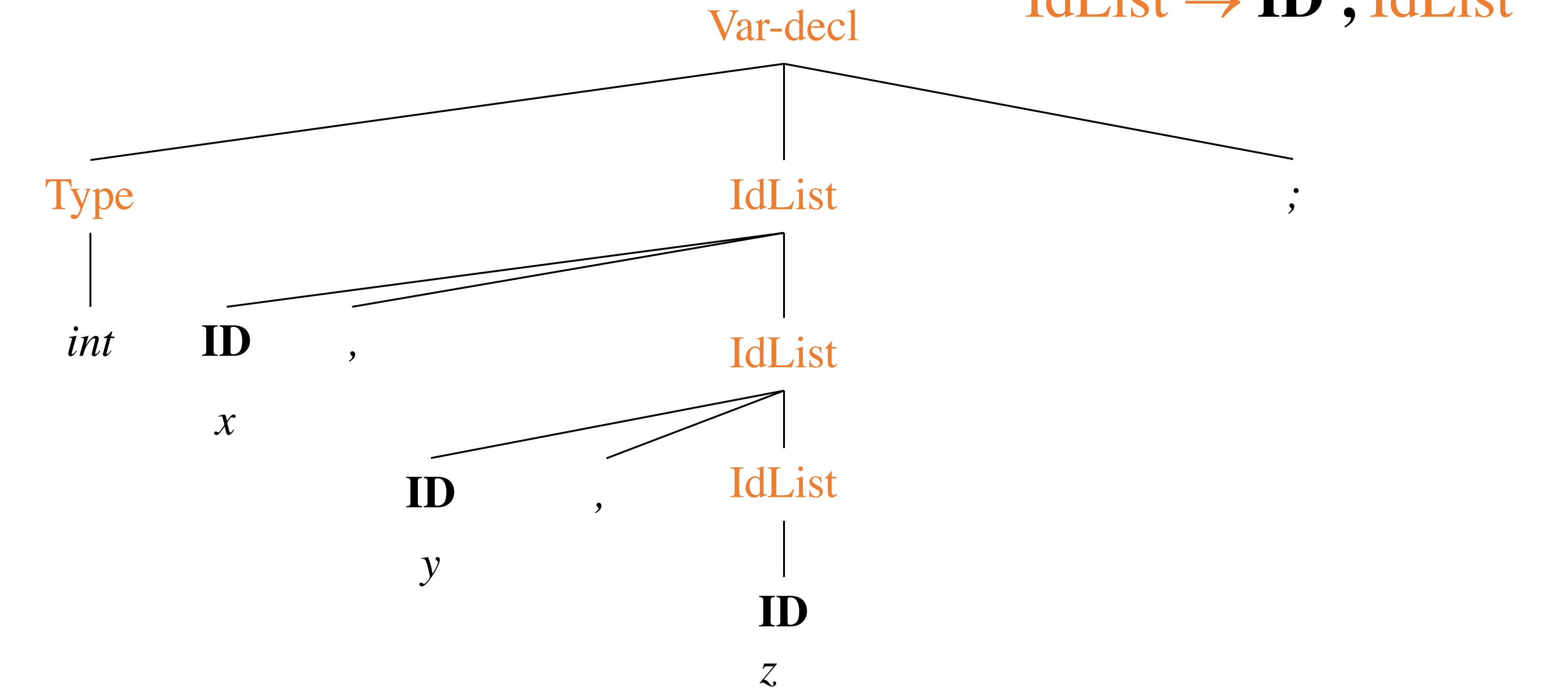
  Type $\rightarrow$ ***int*** | ***bool***

  IdList $\rightarrow$ **ID**

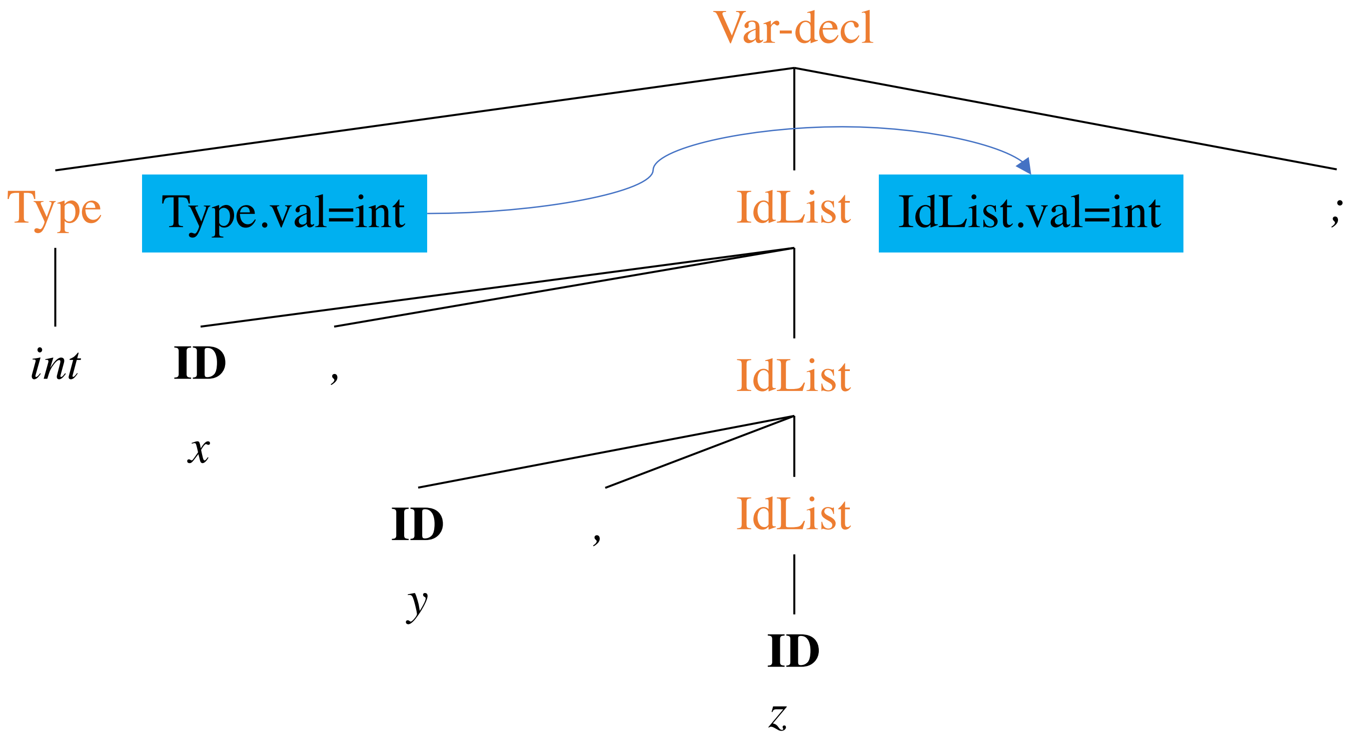
  IdList $\rightarrow$ **ID ,** IdList

Var-decl → Type IdList
Type → ***int*** | ***bool***
IdList → **ID**
IdList → **ID ,** IdList

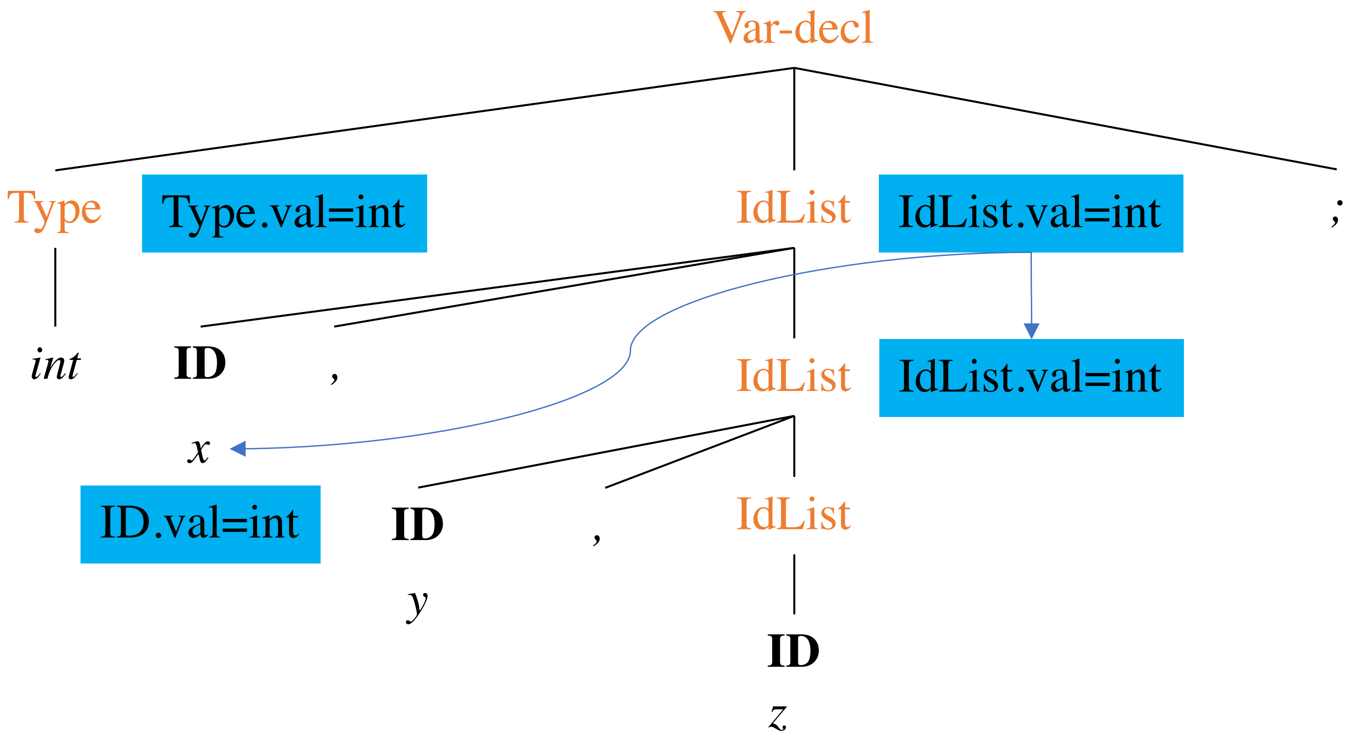
Example input: *int x, y, z ;*



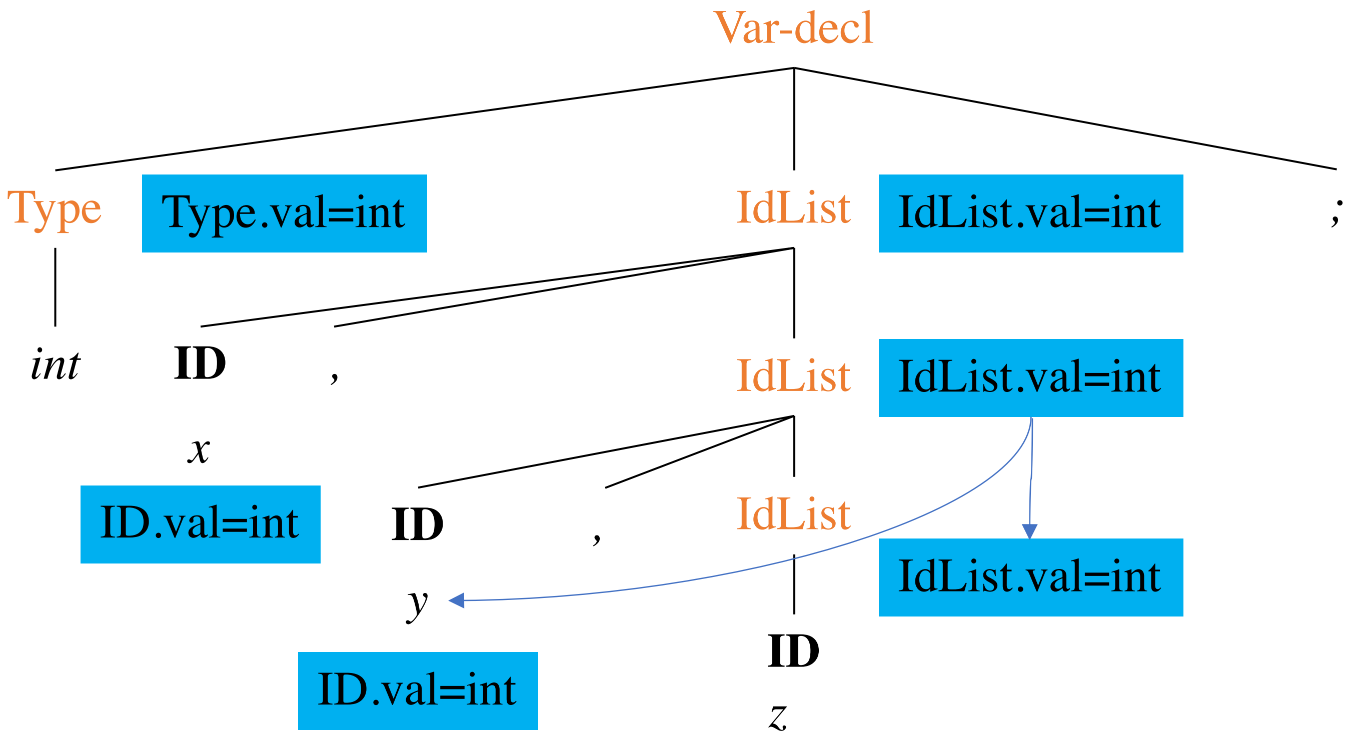
Example input: *int x, y, z ;*



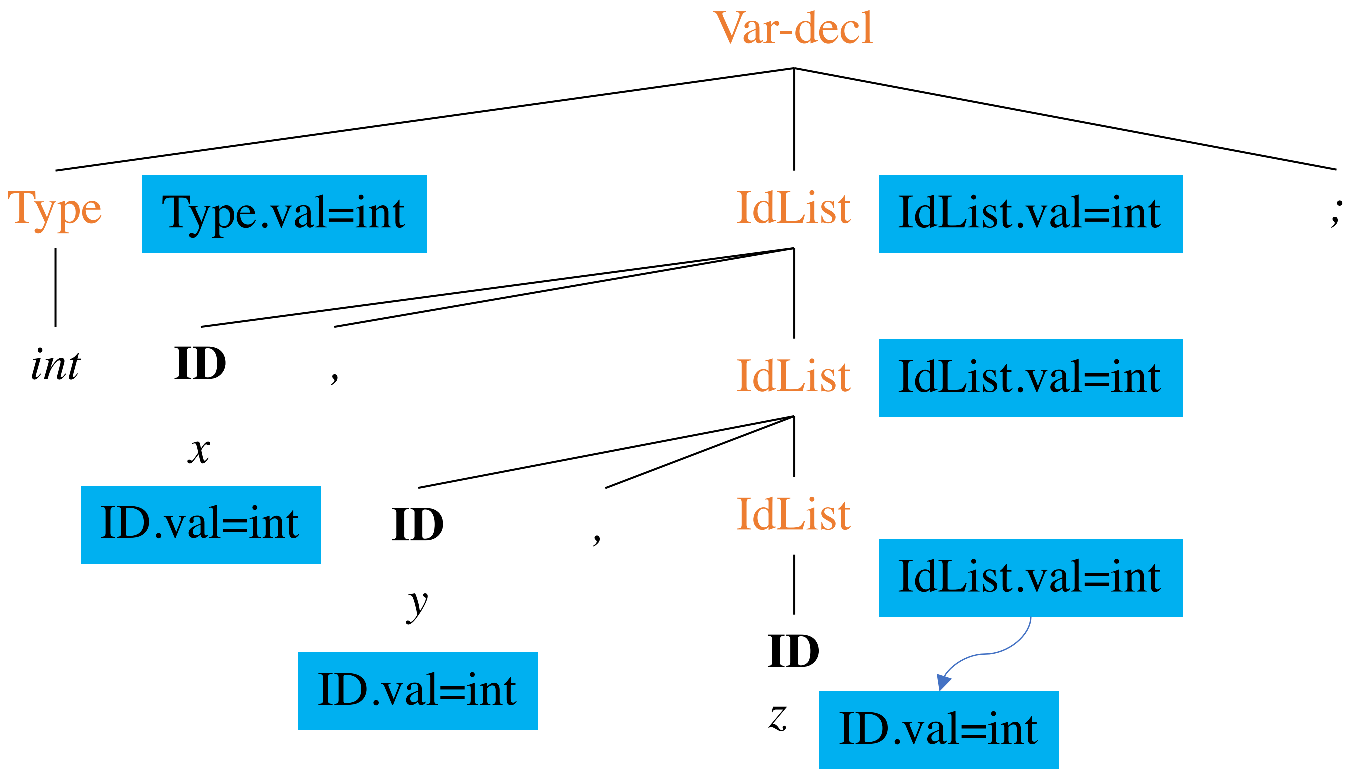
Example input: *int x, y, z ;*



Example input: *int x, y, z ;*



Example input: *int x, y, z ;*



Flow of Attributes in *Var-decl*

- How do the attributes flow in the *Var-decl* grammar?
- **ID** takes its attribute value from its parent node
- *IdList* takes its attribute from its left sibling *Type*
- or *IdList* takes its attribute from its parent *IdList*

Syntax-directed definition

Var-decl $\rightarrow$ Type IdList **;**

{$2.in = $1.val; }

Type $\rightarrow$ **int**

{ $$.val = int; }

| **bool**

{ $$.val = bool; }

IdList $\rightarrow$ **ID**

{ $1.val = $0.in; }

IdList $\rightarrow$ **ID ,** IdList

{ $1.val = $0.in; $3.in = $0.in; }

Top-down (inheriting from the left-hand side) uses $0
Bottom-up (sending a value to the left-hand-side) uses $$

Inherited Attributes

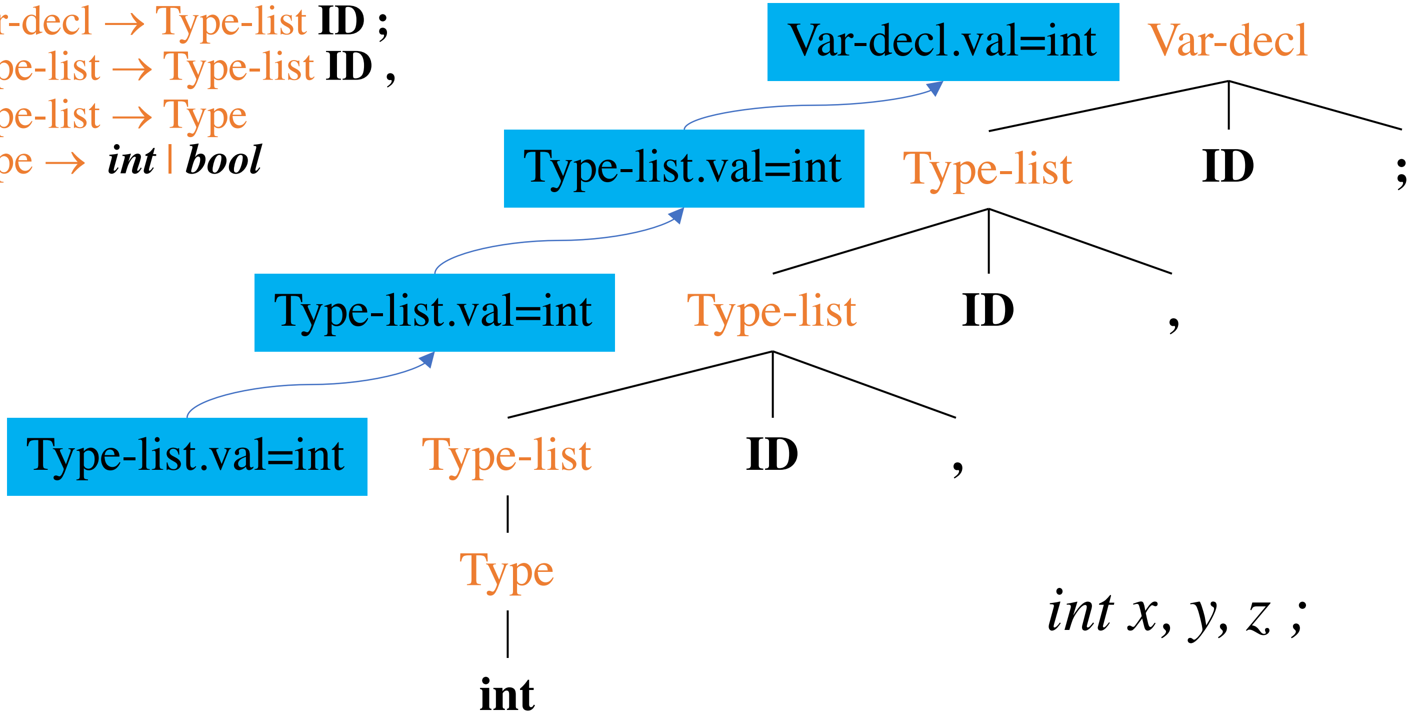
- **Inherited attributes** are attributes that are computed at a node based on attributes from siblings or the parent
- Typically we combine synthesized attributes and inherited attributes
- Q: It is possible to convert the grammar into a form that *only* uses synthesized attributes?

Var-decl → Type-list **ID ;**
Type-list → Type-list **ID ,**
Type-list → Type
Type → ***int*** | ***bool***

int x, y, z ;

Removing Inherited Attributes

Var-decl → Type-list **ID ;**
Type-list → Type-list **ID ,**
Type-list → Type
Type → ***int*** | ***bool***



int x, y, z ;

Removing inherited attributes

Var-decl → Type-List **ID ;**

{ $$.val = $1.val; }

Type-list → Type-list **ID ,**

{ $$.val = $1.val; }

Type-list → Type

{ $$.val = $1.val; }

Type → **int**

{ $$.val = int; }

| **bool**

{ $$.val = bool; }

Direction of inherited attributes

- Consider the syntax directed defns:

  $A \rightarrow L\ M$

  { $1.in = $0.in; $2.in = $1.val; $$.val = $2.val; }

  $A \rightarrow Q\ R$

  { $2.in = $0.in; $1.in = $2.val; $$.val = $1.val; }

- Problematic definition: $1.in = $2.val
- Incompatible with incremental processing (left to right parsing)

L-attributed Definitions

- A syntax-directed definition is **L-attributed** if for each production $A \rightarrow X_1..X_{j-1}X_j..X_n$, for each $j=1 \ldots n$, each inherited attribute of X_j depends on:
  - The attributes of $X_1 \ldots X_{j-1}$
  - The inherited attributes of A
- These two conditions ensure left to right and depth first parse tree construction
- Every S-attributed definition is L-attributed

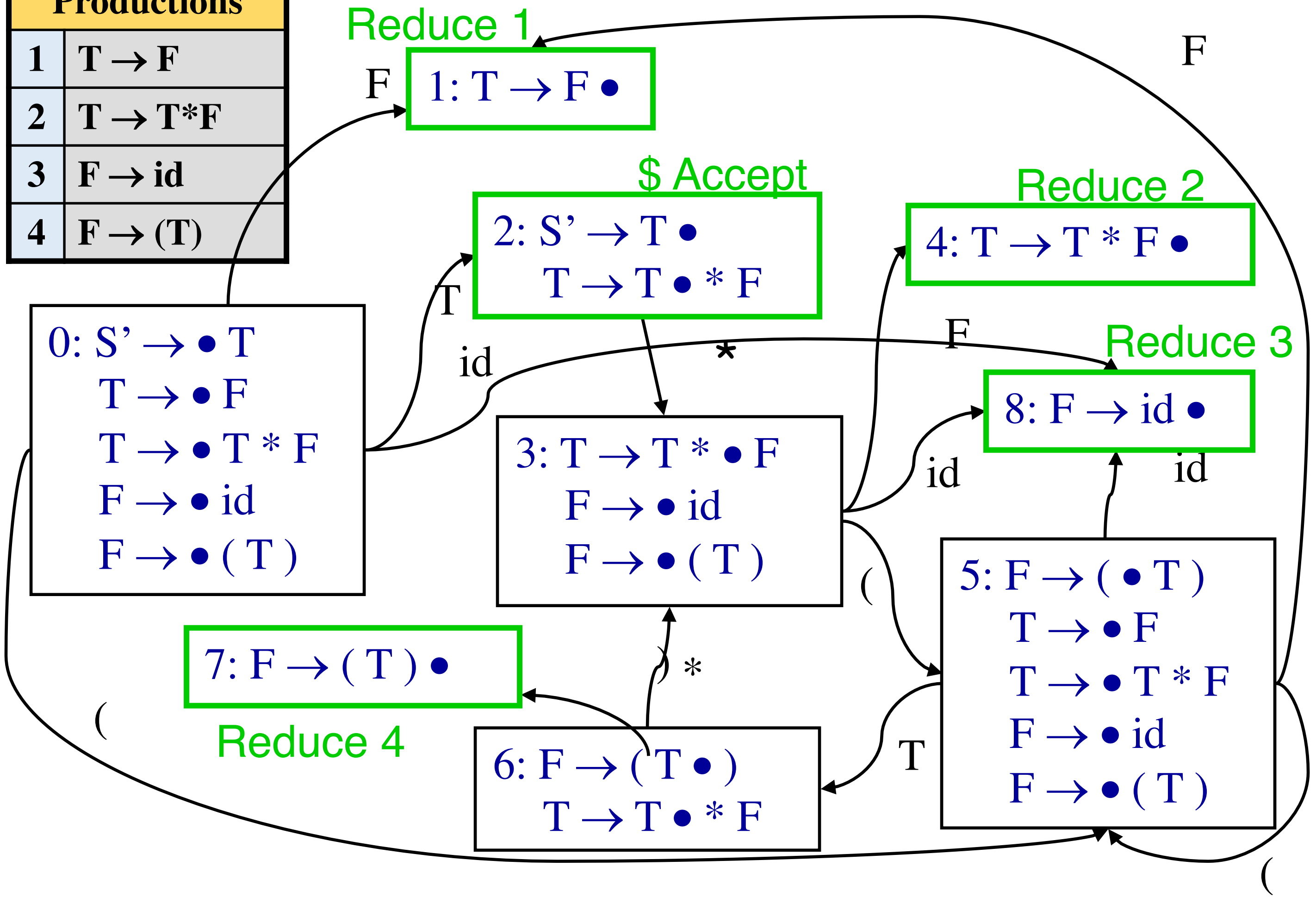
LR parsing and inherited attributes

- LR parsing is inherently left to right
- Attributes can be stored on the stack used by the shift-reduce parsing
- For synthesized attributes: when a reduce action is invoked, store the value on the stack based on value popped from stack
- For inherited attributes: transmit the attribute value when executing the **goto** function

Example: Synthesized Attributes

```
T → F    { $$.val = $1.val; }
T → T * F
  { $$.val = $1.val * $3.val; }
F → id
  { val := id.lookup();
     if (val) { $$.val = $1.val; }
     else { error; }
  }
F → ( T )   { $$.val = $2.val; }
```

Productions	
1	T → F
2	T → T*F
3	F → id
4	F → (T)



Trace “($id_{val=3}$)*$id_{val=2}$”

Stack	Input	Action	Attribute Stack
0	**(id) * id $**	**Shift 5**	
0 5	**id) * id $**	**Shift 8**	**a.Push(id.val==3);**

0 5 8	**) * id $**	**Reduce 3 F→id,**
		pop 8, goto [5,F]=1
			{ $$.val = $1.val }
			a.Push(a.Pop==3);

0 5 1	**) * id $**	**Reduce 1 T→ F,**
		pop 1, goto [5,T]=6
			{ $$.val = $1.val }
			a.Push(a.Pop==3);

0 5 6	**) * id $**	**Shift 7**	
0 5 6 7	*** id $**	**Reduce 4 F→ (T),** **pop 7 6 5, goto [0,F]=1**	{ $$.val = $2.val } **3 pops; a.Push(3)**

Trace “(id$_{val=3}$)*id$_{val=2}$”

Stack	Input	Action	Attribute Stack

0 1	*** id $**	**Reduce 1 T→F,**
		pop 1, goto [0,T]=2
			{ $$.val = $1.val }
			a.Push(a.Pop==3)

0 2	*** id $**	**Shift 3**	**a.Push(*)**
0 2 3	**id $**	**Shift 8**	**a.Push(id.val==2)**
0 2 3 8	**$**	**Reduce 3 F→id,** **pop 8, goto [3,F]=4**	**a.Push(a.Pop==2)**
0 2 3 4	**$**	**Reduce 2 T→T * F** **pop 4 3 2, goto [0,T]=2**	{ $$.val = $1.val * $3.val; } **3 pops; a.Push(3*2==6)**
0 2	**$**	**Accept**	**return(6)**

Practice question

$S \rightarrow L \,.\, L$

$S \rightarrow L$

$L \rightarrow L \,.\, B$

$L \rightarrow B$

$B \rightarrow 0$

$B \rightarrow 1$

This grammar generates binary floating-point numbers, e.g. 101.101

Q: Write down an attribute grammar (syntax directed translation) that converts the input binary into decimal.

e.g. 101.101 = $5\frac{5}{8}$ = 5.625

integer part: $1\times 2^2 + 0\times 2^1 + 1\times 2^0 = 5$

fractional part: $1\times \frac{1}{2^1} + 0\times \frac{1}{2^2} + 1\times \frac{1}{2^3} = \frac{5}{8}$

Practice question

$$
\begin{array}{lll}
E & \rightarrow & E \text{ ‘+’ } T \\
 & \mid & T \\
T & \rightarrow & T \text{ ‘*’ } F \\
 & \mid & F \\
F & \rightarrow & \texttt{exp} \text{ ‘(’ } E \text{ ‘)} \\
 & \mid & \texttt{ln} \text{ ‘(’ } E \text{ ‘)’} \\
 & \mid & \text{‘-’ } F \\
 & \mid & \text{‘}\mathbf{x}\text{’} \\
 & \mid & \mathsf{c}
\end{array}
$$

c stands for any integer constant

Provide a L-attributed syntax directed definition that computes the derivative of an input expression. Explain each attribute used in your attribute grammar.

D[input string]	output string = derivative(input string)
$D[c]$	0
$D[x]$	1
$D[x+c]$	1
$D[E_1 + E_2]$	$D[E_1] + D[E_2]$
$D[-E]$	$-D[E]$
$D[c * E]$	$c * D[E]$
$D[E_1 * E_2]$	$E_1 * D[E_2] + E_2 * D[E_1]$
$D[exp(x)]$	$exp(x)$
$D[ln(x)]$	$1/x$

$D[f(E)]$	$D[E] * f'(E)$, f' is the derivative of f
	if $f(E)$ is $exp(E)$, $f'(E)$ is $exp(E)$
	if $f(E)$ is $ln(E)$, $f'(E)$ is $1/E$

Extra Slides

Example: Inherited Attributes

E $\rightarrow$ T R

    { $2.in = $1.val; $$.val = $2.val; }

R $\rightarrow$ + T R

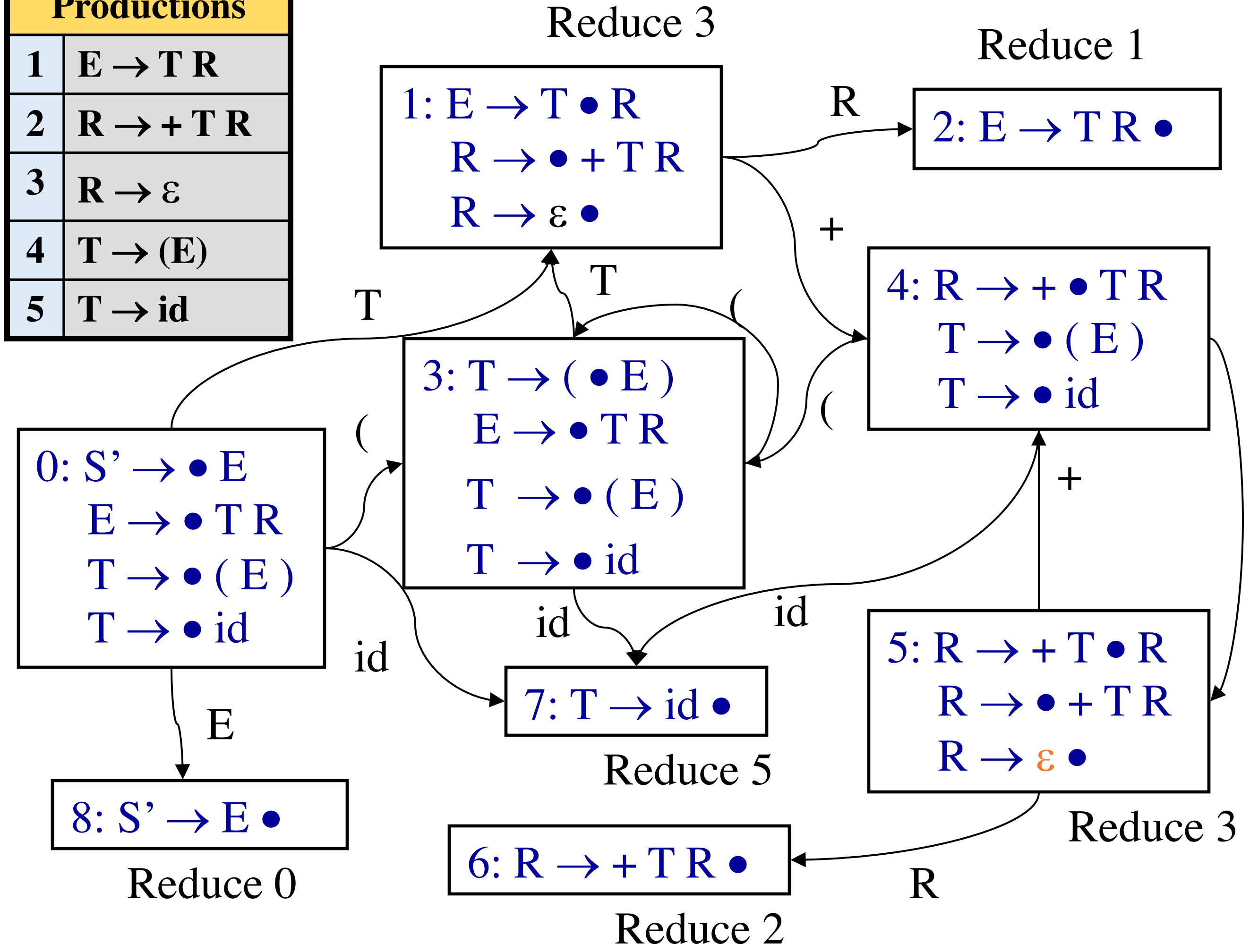
    { $3.in = $0.in + $2.val; $$.val = $3.val; }

R $\rightarrow$ ε { $$.val = $0.in; }

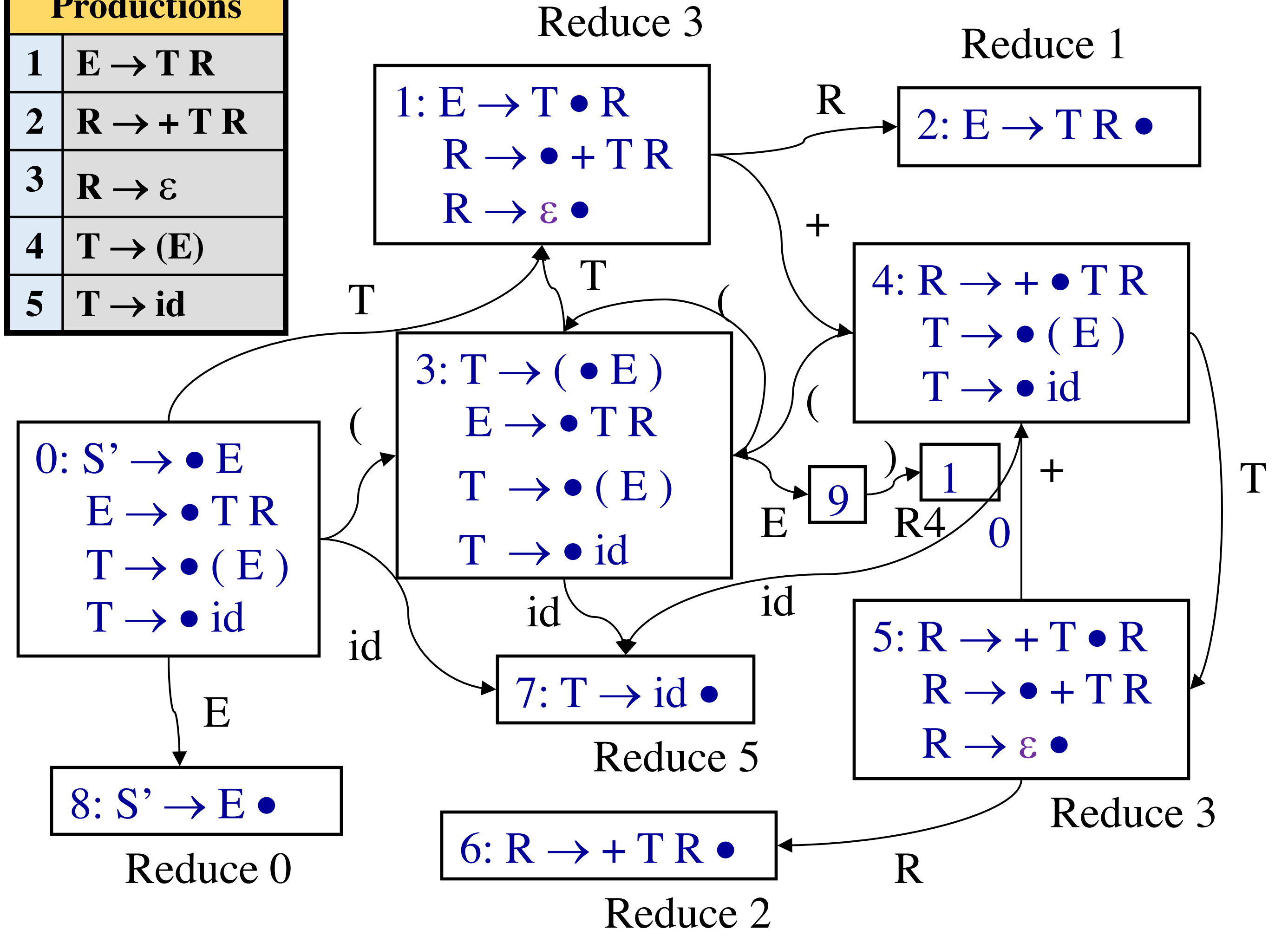
T $\rightarrow$ (E) { $$.val = $1.val; }

T $\rightarrow$ **id** { $$.val = **id**.lookup; }

Productions	
1	E → T R
2	R → + T R
3	R → ε
4	T → (E)
5	T → id



Productions	
1	E → T R
2	R → + T R
3	R → ε
4	T → (E)
5	T → id



	Productions
1	**E → T R** { $2.in = $1.val; $$.val = $2.val; }
2	**R → + T R** { $3.in = $0.in + $2.val; $$.val = $3.val; }
3	**R →** ε { $$.val = $0.in; }
4	**T → (E)** { $$.val = $1.val; }
5	**T → id** { $$.val = **id**.lookup; }

			Attributes
0 7	**+ id $**	**Reduce 5 T→id**	**{ $$.val = id.lookup }**
		pop 7, goto [0,T]=1	**{ pop; attr.Push(3)**
0 1	**+ id $**	**Shift 4**	**$2.in = $1.val**
0 1 4	**id $**	**Shift 7**	**$2.in := (1).attr }**
0 1 4 7	**$**	**Reduce 5 T→id**	**{ $$.val = id.lookup }**
		pop 7, goto [4,T]=5	**{ pop; attr.Push(2); }**
0 1 4 5	**$**	**Reduce 3 R→ ε**	**{ $3.in = $0.in+$1.val**
			(5).attr := (1).attr+2
		goto [5,R]=6	**$$.val = $0.in**
			$$.val = (5).attr = 5 }

Trace “$\text{id}_{\text{val=3}}$+$\text{id}_{\text{val=2}}$”

Stack	Input	Action	Attributes
0	**id + id $**	**Shift 7**	
0 7	**+ id $**	**Reduce 5 T→id**	**{ $$.val = id.lookup }**
		pop 7, goto [0,T]=1	**{ pop; attr.Push(3)**
0 1	**+ id $**	**Shift 4**	**$2.in = $1.val**
0 1 4	**id $**	**Shift 7**	**$2.in := (1).attr }**
0 1 4 7	**$**	**Reduce 5 T→id**	**{ $$.val = id.lookup }**
		pop 7, goto [4,T]=5	**{ pop; attr.Push(2); }**
0 1 4 5	**$**	**Reduce 3 R→ ε**	**{ $3.in = $0.in+$1.val**
			(5).attr := (1).attr+2
		goto [5,R]=6	**$$.val = $0.in**
			$$.val = (5).attr = 5 }

Trace "$\text{id}_{\text{val=3}}$+$\text{id}_{\text{val=2}}$"

Stack	Input	Action	Attributes
0 1 4 5 6	**\$**	**Reduce 2 R$\rightarrow$ + T R** **Pop 4 5 6, goto [1,R]=2**	**{ \$\$.val = \$3.val** **pop; attr.Push(5); }**
0 1 2	**\$**	**Reduce 1 E$\rightarrow$ T R** **Pop 1 2, goto [0,E]=8**	**{ \$\$.val = \$3.val** **pop; attr.Push(5); }**
0 8	**\$**	**Accept**	**{ \$\$.val = 5** **attr.top = 5; }**

LR parsing with inherited attributes

Bottom-Up/rightmost	
ccbca ⇐ Acbca	A→c
⇐ AcbB	B→ca
line 3 ⇐ AB	B→cbB
⇐ S	S→AB

Parse stack at line 3:
[‘x’] A [‘x’] c b B

$1.in = ‘x’

$2.in = $1.val

A → c { $$.val = $0.in }

Consider:

S→AB
{ $1.in = ‘x’;
  $2.in = $1.val }
B→cbB
{ $$.val = $0.in + ‘y’; }

Parse stack at line 4:
[‘x’] A B

[‘xy’]