SDD, Attribute Grammar and SDT

Translation

- So far we have talked about parsing[a] of a language. But our main goal is translation.
- Semantic actions to translate the source language program to a target language program often go hand-in-hand with parsing. It is called syntax-directed translation.

[a] Even the parsing cannot be completed without some analysis beyond the context-free structure.

Translation

- To perform semantic actions along with parsing actions (e.g. reduction), we associate computation with the production rules. Computed information is propagated as attributes of non-terminals.
- An alternative is to be built the parse tree explicitly, and perform semantic actions by traversing the tree.

Example

Consider the following production rule of the classic expression grammar: $E \rightarrow E_1 + T$[a].

We consider three different translations:

- implementation of a simple calculator,
- conversion of an infix expression to a postfix expression,
- general purpose code generation.

[a] We have used subscript to differentiate between two instances of E.

Example: Calculator

- We have already seen that the only attribute of E and T required for this translation are values expressions corresponding to the sub-trees of E and T.
- Let us call the attribute to be val.
- The semantic action associated with the given production rule is,
  $E \rightarrow E_1 + T \ \{E{\cdot}\text{val} = E_1{\cdot}\text{val} + T{\cdot}\text{val}\}$[a].

[a] In `bison` this gets translated to `$$ = $1 + $3`.

Note

- The action may take place when $E_1 + T$ is reduced to E. The computed value is saved as the attribute of E.
- Alternatively, it may take place during the postorder traversal of the syntax tree.
- There is no other side-effect of the semantic action.

Note

- But if we want to keep a provision to store a value as a named object (variable), we need a symbol table where the variables names and their values are stored.
- In that case the semantic action of $ES \rightarrow id := E$ will changes the state of the symbol-table data structure (side effect) by entering the $E \cdot \text{val}$ corresponding to $id.\text{name}$.

Example: Infix to Postfix Conversion

- Here the problem is to convert an infix arithmetic expression to an equivalent postfix expression.
- Both the input and output are strings of characters.
- Let the attribute associated to each non-terminal be exp of type char *. The semantic action is the following.

Example: Infix to Postfix

$E \rightarrow E_1 + T$

```
{
  E.exp=(char*)malloc(strlen(E1.exp)+
                      strlen(T.exp)+4);
  strcpy(E.exp, E1.exp); strcat(E.exp, " ");
  strcat(E.exp, T.exp);
  strcat(E.exp, " + ");
  free(E1.exp); free(T.exp);
}
```

Again there is no side-effect

Example: Code Generation

- The main difference of translation for code generation with two previous translations is that there is no data value corresponding to E_1 and T available at compilation time.
- Both E_1 and T corresponds to two sequences of translated codes that will compute values of expressions corresponding to E_1 and T when they are executed.

Example: Code Generation

- The translation for to the rule $E \rightarrow E_1 + T$ generates code so that the computed values of E_1 and T are added to generate and store the value of expression for E.
- The computed values of the expressions E_1 and T are stored in compiler defined temporary locations.

Example: Code Generation

- Compiler creates temporary variables[a] where the intermediate values of sub-expressions are stored. These variable names are also entered in the symbol table.
- The main attribute of a non-terminal like E or T is the index of the symbol table corresponding to its temporary variable name.

[a] They are also called virtual registers.

Example: Code Generation

The code corresponding to $E \rightarrow E_1 + T$ may look like,

```
{
 E.loc = newLoc();
 codeGen(assignPlus, E.loc, E1.loc, T.loc);
}
```

where assignPlus means `E.loc = E1.loc + T.loc`.

Note

- This action has side-effects, it makes an entry of the new location in the symbol table. And the generated code is added in a data structure.
- As an alternative E and T may store their code sequences as their attributes.

Associating Information

- Information is associated to syntactic categories by attaching attributes to the corresponding non-terminals.
- Computation of these attributes are associated with the production rules.
- Initial attribute values are supplied by the scanner.

Definition

- A syntax-directed definition is a context-free grammar where attributes are associated with the grammar symbols. Rules for computing the attributes are associated with the production rules. There should not be any circularity in the definition.
- These are called attribute grammars when the definition does not have any side-effect.

Definition

- A syntax-directed translation is an executable specification of SDD. Fragments of programs are associated to different points in the production rules.
- The order of execution of the code is important in this case.

Example

$$A \rightarrow \{\text{Action}_1\}\ B\ \{\text{Action}_2\}\ C\ \{\text{Action}_3\}$$

$\underline{\text{Action}_1}$: takes place before parsing of the input corresponding to the non-terminal B.
$\underline{\text{Action}_2}$: takes place after consuming the input for B, but before consuming the input for C.
$\underline{\text{Action}_3}$: takes place at the time of reduction of BC to A or after consuming the input corresponding to BC.

Note

- Embedded action may create some problem in a parser generator like Bison.
- Bison replaces the embedded action in a production rule by an ε-production and associates the embedded action with the new rule.

Note

- But this may change the nature of the grammar. As an example, the grammar $S \rightarrow A \mid B$, $A \rightarrow aba, B \rightarrow abb$ is LALR.
- An embedded action is introduced as shown, $S \rightarrow A \mid B$, $A \rightarrow a$ {action} $ba, B \rightarrow abb$.

Note

- Bison modifies the grammar to
  $S \rightarrow A|B, A \rightarrow aMba, B \rightarrow abb,$
  $M \rightarrow \varepsilon$ {action} .
- The modified grammar is no longer LALR.

Attribute Computation: a General Approach

- Construct the parse tree. Compute the attributes of the non-terminals following the data-flow in attribute dependence graph. But construction of complete parse tree is costly.
- There are restricted SDDs that do not require explicit construction of parse tree. They are S-attributed and L-attributed definitions.

A Simple Example

Consider the following grammar of signed binary numerals. We wish to translate it to decimal number.

$$
\begin{aligned}
0: &\quad S' \rightarrow N\$ \\
1: &\quad N \rightarrow S\ L \\
2: &\quad S \rightarrow + \\
3: &\quad S \rightarrow - \\
4: &\quad L \rightarrow L\ B \\
5: &\quad L \rightarrow B \\
6: &\quad B \rightarrow 0 \\
7: &\quad B \rightarrow 1
\end{aligned}
$$

Note

- We first construct the $LR(0)$ automaton of the grammar and find that the grammar is SLR.
- We associate attributes to the non-terminals.
- We also associate SDDs to the production rules.

$LR(0)$ Automaton

q_0 :	$S' \to \bullet N\$ \quad N \to \bullet SL \quad S \to \bullet +$ $S \to \bullet -$
q_1 :	$S' \to N \bullet \$$
q_2 :	$N \to S \bullet L \quad L \to \bullet LB \quad L \to \bullet B$ $B \to \bullet 0 \quad B \to \bullet 1$
q_3 :	$S \to + \bullet$
q_4 :	$S \to - \bullet$
q_5 :	$N \to SL \bullet \quad L \to L \bullet B \quad B \to \bullet 0$ $B \to \bullet 1$

$LR(0)$ Automaton

q_6 :	$L \rightarrow B\bullet$
q_7 :	$B \rightarrow 0\bullet$
q_8 :	$B \rightarrow 1\bullet$
q_9 :	$L \rightarrow LB\bullet$

SLR Parsing Table

S	*Action*					*Goto*			
	$+$	$-$	0	1	\$	N	S	L	B
0	s_3	s_4				1	2		
1					Acc				
2			s_7	s_8				5	6
3			r_6	r_6					
4			r_7	r_7					
5			s_7	s_8	r_1				9

SLR Parsing Table

S	*Action*					*Goto*			
	$+$	$-$	0	1	\$	N	S	L	B
6			r_5	r_5	r_5				
7			r_6	r_6	r_6				
8			r_7	r_7	r_7				

Attributes of Non-Terminals

Following are the attributes of different non-terminals:

Non-terminal	Attribute	Type
N	val	`int`
S	sign	`char`
L	val	`int`
B	val	`int`

SDD

0 :	S'	$\rightarrow$	N	print N.val
1 :	N	$\rightarrow$	SL	`if (S.sign == '-') N.val= - L.val;`
				`else N.val = L.val;`
2 :	S	$\rightarrow$	$+$	`S.sign = '+';`
3 :	S	$\rightarrow$	$-$	`S.sign = '-';`
4 :	L	$\rightarrow$	L_1B	`L.val = 2*L1.val+B.val;`
5 :	L	$\rightarrow$	B	`L.val = B.val;`
6 :	B	$\rightarrow$	0	`B.val = 0;`
7 :	B	$\rightarrow$	1	`B.val = 1;`

Example: Parsing & Value Stack

Type	Stack →	Input→	Action/Value
Parsing	$0	+101$	shift
Value	$		
Parsing	$03	101$	reduce
Value	$+		
Parsing	$02	101$	shift
Value	$S		S.sign='+'
Parsing	$028	01$	reduce
Value	$S1		

Example: Parsing & Value Stack

Type	Stack →	Input→	Action/Value
Parsing	$026	01$	reduce
Value	$SB		B.val = 1
Parsing	$025	01$	shift
Value	$SL		L.val = B.val
Parsing	$0257	1$	reduce
Value	$SL0		
Parsing	$0259	1$	reduce
Value	$SLB		B.val = 0

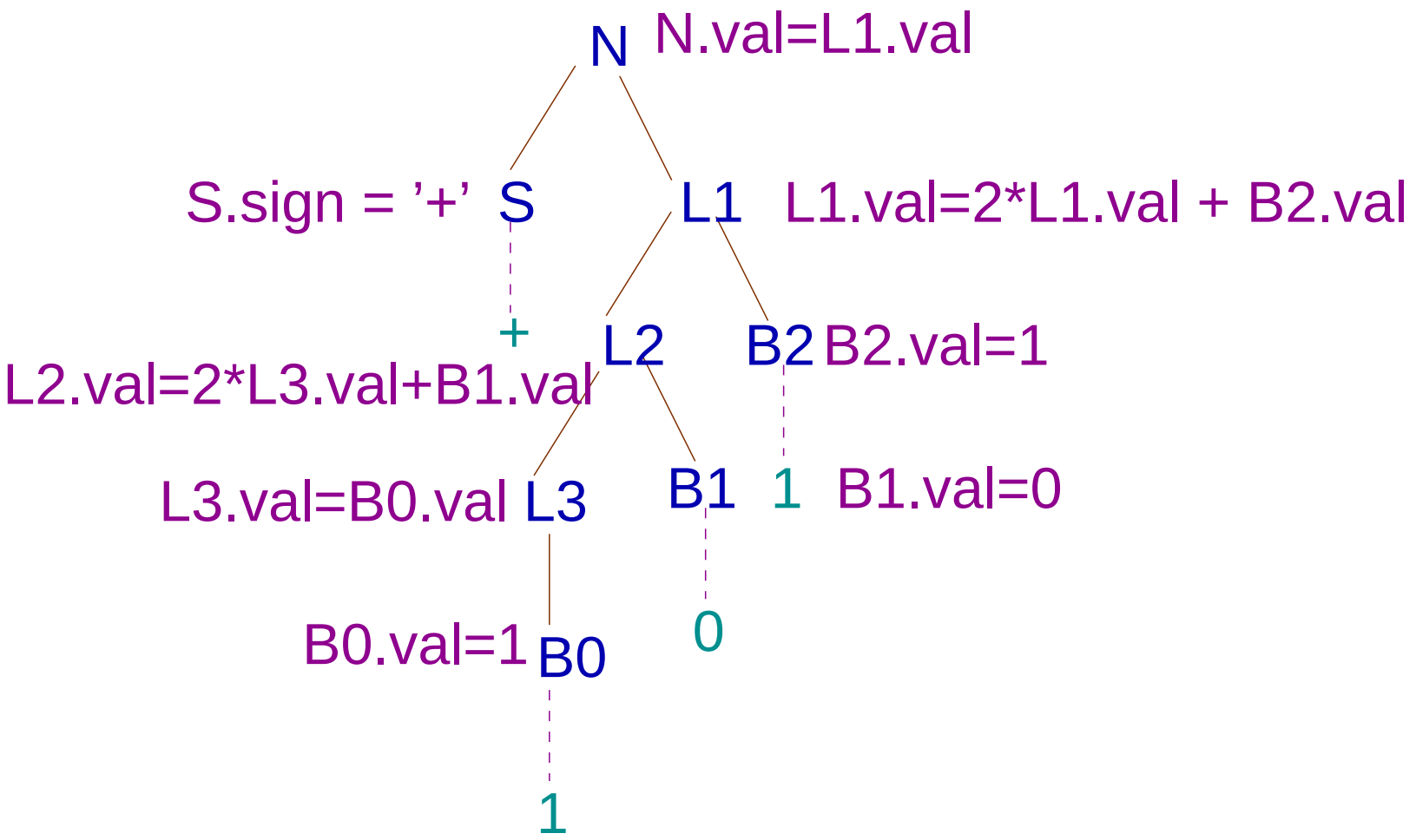
Example: Parsing & Value Stack

Type	Stack →	Input→	Action/Value
Parsing	$025	1$	shift
Value	$SL		L.val = 2*L1.val + B.val
Parsing	$0258	$	reduce
Value	$SL1		
Parsing	$0259	$	reduce
Value	$SLB		B.val=1
Parsing	$025	$	reduce
Value	$SL		L.val = 2*L1.val + B.val

Example: Parsing & Value Stack

Type	Stack →	Input→	Action/Value
Parsing	`$01`	`$`	Accept
Value	`$N`		`N.val = +L.val`

Decorated Parse Tree



Synthesized Attribute

- In this example the value of an attribute of a non-terminal is either coming from the scanner[a] or it is computed from the attributes of its children.
- This type of attribute is known as a synthesized attribute.

[a] Attribute of a terminal comes from the scanner.

S-Attributed

- An attributed grammar is called *S*-attributed if every attribute is synthesized.
- Attributes in such a grammar can be easily computed during a bottom-up parsing.

Another Set of Attributes

Non-terminal	Attribute	Type
N	val	`int`
S	sign	`char`
L	val, pos	`int, int`
B	val, pos	`int, int`

SDD

0 :	S'	$\rightarrow$	N	print N.val
1 :	N	$\rightarrow$	SL	L.pos = 0
				if (S.sign == '-') N.val= - L.val;
				else N.val = L.val;
2 :	S	$\rightarrow$	$+$	S.sign = '+';
3 :	S	$\rightarrow$	$-$	S.sign = '-';
4 :	L	$\rightarrow$	L_1B	L_1.pos = L.pos+1;
				B.pos = L.pos;
				L.val = L_1.val+B.val;

SDD

$5: \quad L \rightarrow B$ `B.pos = L.pos;`

`L.val = B.val;`

$6: \quad B \rightarrow 0$ `B.val = 0;`

$7: \quad B \rightarrow 1$ `B.val =` $2^{\texttt{B.pos}}$`;`

Exercise

Draw the parse tree for -101 and show the flow of information.

Note

- Attributes of a non-terminal depends on the nature of translation. But it may also depend on the nature of the grammar.
- Following is a grammar of integers in 2's complement numerals. It is to be translated to a signed decimal numeral.

Exercise

$$1: \quad N \rightarrow L$$

$$2: \quad L \rightarrow L\ B$$

$$3: \quad L \rightarrow B$$

$$4: \quad B \rightarrow 0$$

$$5: \quad B \rightarrow 1$$

Associate appropriate attributes to the non-terminals and give rules of semantic actions. Write bison specification for the grammar.

Example

Consider a right-recursive grammar of signed binary strings:

$$
\begin{aligned}
0: &\quad S' \rightarrow N \\
1: &\quad N \rightarrow S\ L \\
2: &\quad S \rightarrow + \\
3: &\quad S \rightarrow - \\
4: &\quad L \rightarrow B\ L \\
5: &\quad L \rightarrow B \\
6: &\quad B \rightarrow 0 \\
7: &\quad B \rightarrow 1
\end{aligned}
$$

Attributes of Non-Terminals

We need a new attribute of L to remember the bit position:

Non-terminal	Attribute	Type
N	val	`int`
S	sign	`char`
L	val	`int`
	pos	`int`
B	val	`int`

Action for Rules

$0:$	S'	$\rightarrow$	N	print N.val
$1:$	N	$\rightarrow$	SL	`if (S.sign == '-') N.val=- L.val;`
				`else N.val = L.val;`
$2:$	S	$\rightarrow$	$+$	`S.sign = '+';`
$3:$	S	$\rightarrow$	$-$	`S.sign = '-';`
$4:$	L	$\rightarrow$	BL_1	`if(B.val)`
				`  L.val=pow(2,L1.pos)+L1.val;`
				`else L.val=L1.val;`
				`L.pos=L1.pos+1;`

Actions for Production Rules

$5: \quad L \rightarrow B$ `L.val = B.val; L.pos = 1`

$6: \quad B \rightarrow 0$ `B.val = 0;`

$7: \quad B \rightarrow 1$ `B.val = 1;`

Example

Consider the following grammar for variable declaration:

$$1: \quad D \rightarrow T\ L\ ;$$

$$2: \quad T \rightarrow \texttt{int}$$

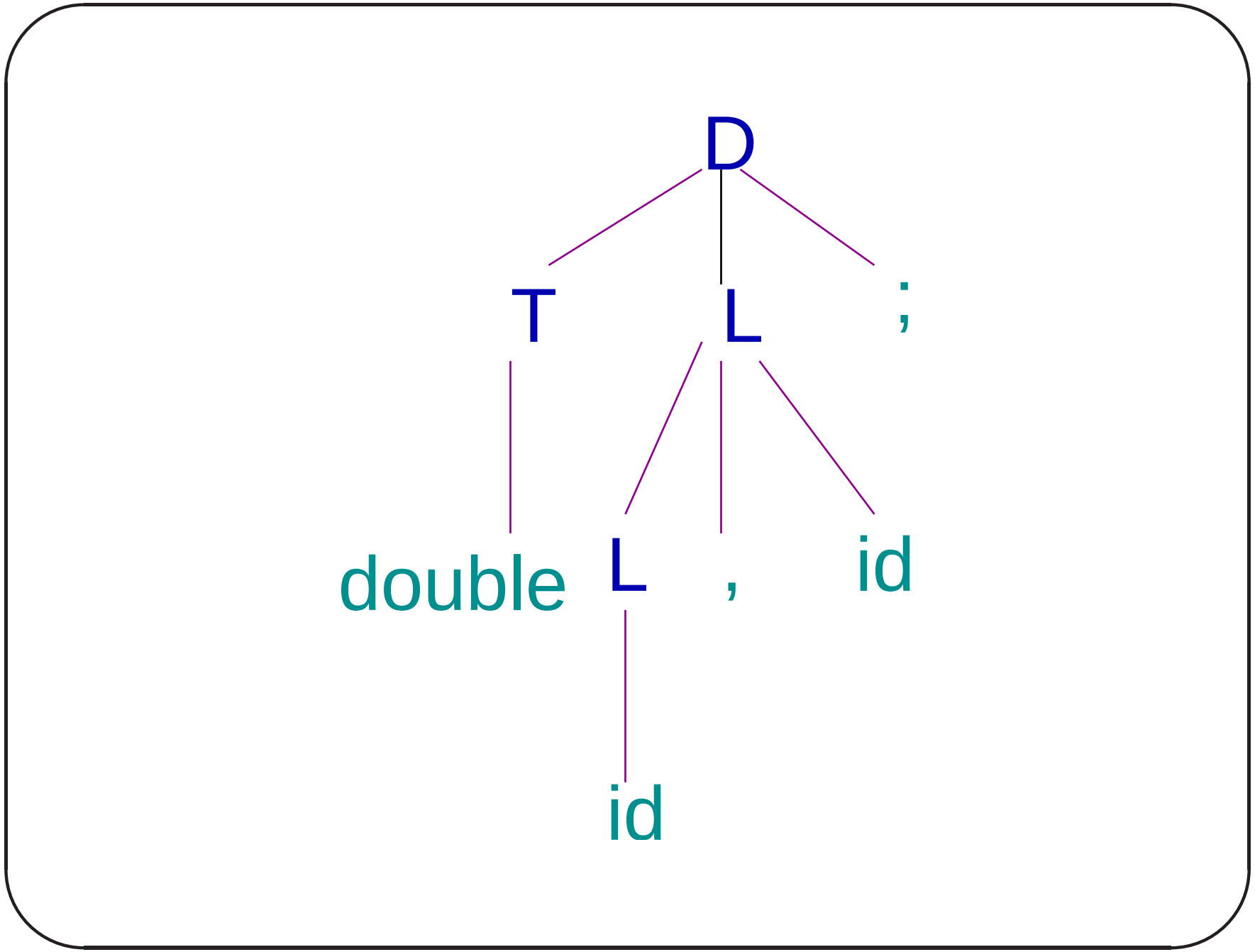
$$3: \quad T \rightarrow \texttt{double}$$

$$4: \quad L \rightarrow L\ ,\ \texttt{id}$$

$$5: \quad L \rightarrow \texttt{id}$$

Parse Tree

The parse tree for the string `double id, id;` is as follows:


D
T
L
;
double
L
,
id
id

Note

When an `id` is reduced to the non-terminal L, it is inserted in the symbol table along with its type information[a]. The type information is not available from any subtree rooted at L. It has to be inherited from T via the root D.

[a]The type information is important for space allocation, representation, operations, correctness and other purposes.

SDDefinition

1 :	D	$\rightarrow$	TL;	L.type = T.type
2 :	T	$\rightarrow$	int	T.type = INT
3 :	T	$\rightarrow$	double	T.type = DOUBLE
4 :	L	$\rightarrow$	L_1, id	L1.type = L.type
				addSym(id.name, L.type)
5 :	L	$\rightarrow$	id	addSym(id.name, L.type)

Inherited Attribute

- Let B be a non-terminal of a parse tree node.
- An inherited attribute $B.i$ is defined in terms of the attributes of the parent and sibling nodes of B.
- In the previous example the non-terminal L gets the attribute from T as an inherited attribute.

Synthesized Attribute

- The synthesized attribute $B.s$ of a non-terminal B is defined by the attributes of its children.
- The attribute of a leaf-node comes from the scanner.

S-Attributed Definitions

An SDD is S-attributed if every attribute is synthesized. This may be called an S-attributed grammar.

This definition can be implemented in a LR-parser during a reduction as the traversal on the parse-tree is postorder.

L-Attributed Definitions

An SDD is called L-attributed ('L' for left) if each attribute is either synthesized, or inherited with the following restrictions.
Let $A \rightarrow \alpha_1 \alpha_2 \cdots \alpha_n$ be a production rule, and α_k has an inherited attribute 'a'.

L-Attributed Definition

The value of $\alpha_k.a$ is computed using

- the inherited attribute of A (parent),
- the inherited or synthesized attributes of $\alpha_1, \alpha_2, \cdots, \alpha_{k-1}$ (symbols to the left of α_k),
- attributes of α_k, provided no dependency cycle[a] is formed.

[a] $A \rightarrow B \ \{ A.s = B.i; B.i = A.s + k \}$.

Rules

The type definition mentioned earlier is L-attributed.

1 :	D	$\rightarrow$	TL;	L.type = T.type
2 :	T	$\rightarrow$	int	T.type = INT
3 :	T	$\rightarrow$	double	T.type = DOUBLE
4 :	L	$\rightarrow$	L_1, id	L1.type = L.type
				addSym(id.name, L.type)
5 :	L	$\rightarrow$	id	addSym(id.name, L.type)

Note

The question is how to propagate the type information in a parser generated by `bison`
The non-terminal T gets the value of synthesized type attribute when a T-production rule is reduced.
But that cannot be propagated as an attribute of the non-terminal L directly as this non-terminal is not present in the stack.

Solution I

An ad hoc solution is to use a global variable to hold the type value.

T	$\rightarrow$	`int`	`type = INT`
T	$\rightarrow$	`double`	`type = DOUBLE`
L	$\rightarrow$	L_1, `id`	`addSym(id.name, type)`
L	$\rightarrow$	`id`	`addSym(id.name, type)`

Solution II

We introduce a different attribute of L, a list of symbol table entries corresponding to different identifiers, and initialize their types at the end.

1 :	$D \rightarrow TL;$		`initType(L.list, T.type)`
2 :	$T \rightarrow$	`int`	`T.type = INT`
3 :	$T \rightarrow$	`double`	`T.type = DOUBLE`
4 :	$L \rightarrow L_1,$	`id`	`L.list = L_1.list +`
			`mklist(addSym(id.name))`
5 :	$L \rightarrow$	`id`	`L.list =`
			`mklist(addSym(id.name))`

Read '+' as append in the list.

Solution III

We can device another solution from the value stack. For that we consider the states of $LR(0)$ automaton of the grammar.

$LR(0)$ Automaton

q_0 :	$S \to \bullet D \quad D \to \bullet T\,L; \quad T \to \bullet\texttt{int}$ $T \to \bullet\texttt{double}$
q_1 :	$S \to D\bullet$
q_2 :	$D \to T \bullet L \quad L \to \bullet L, \texttt{id} \quad L \to \bullet\texttt{id}$
q_3 :	$T \to \texttt{int}\bullet$
q_4 :	$S \to \texttt{double}\bullet$
q_5 :	$D \to T\,L\bullet; \quad L \to L\bullet, \texttt{id}$
q_6 :	$L \to \texttt{id}\bullet$

$LR(0)$ Automaton

q_7 :	$L \rightarrow L, \bullet \texttt{id}$
q_8 :	$L \rightarrow L, \texttt{id} \bullet$
q_9 :	$D \rightarrow TL; \bullet$

Example: Parsing & Value Stack

Type	Stack →	Input→	Action/Value
Par	`$0`	`int id, id;$`	shift
Val	`$`		
Par	`$03`	`id, id;$`	reduce
Val	`$int`		
Par	`$02`	`id, id;$`	shift
Val	`$T`		`T.type=INT`
Par	`$026`	`, id;$`	reduce
Val	`$T id`		

Example: Parsing & Value Stack

Type	Stack →	Input→	Action/Value
Par	$025	, id;$	reduce
Val	$T L		addSym(id.name,L.type)

How does L gets the type information. Note that in bison $L \equiv \$\$$ and `id` $\equiv \$1$. But the type information is available in T in the stack, below the handle.

Type	Stack →	Input→	Action/Value
Par	$0257	id;$	shift
Val	$T L ,		

Example: Parsing & Value Stack

Type	Stack →	Input→	Action/Value
Par	$02578	;$	reduce
Val	$T L , id		
Par	$025	;$	
Val	$T L		addSym(id.name,L.type)

Again the type information is available just below the handle.

Note

In Bison the attribute below the handle can be accessed. In this case the non-terminal T corresponds to `$0` and its type attribute is `$0.type`.

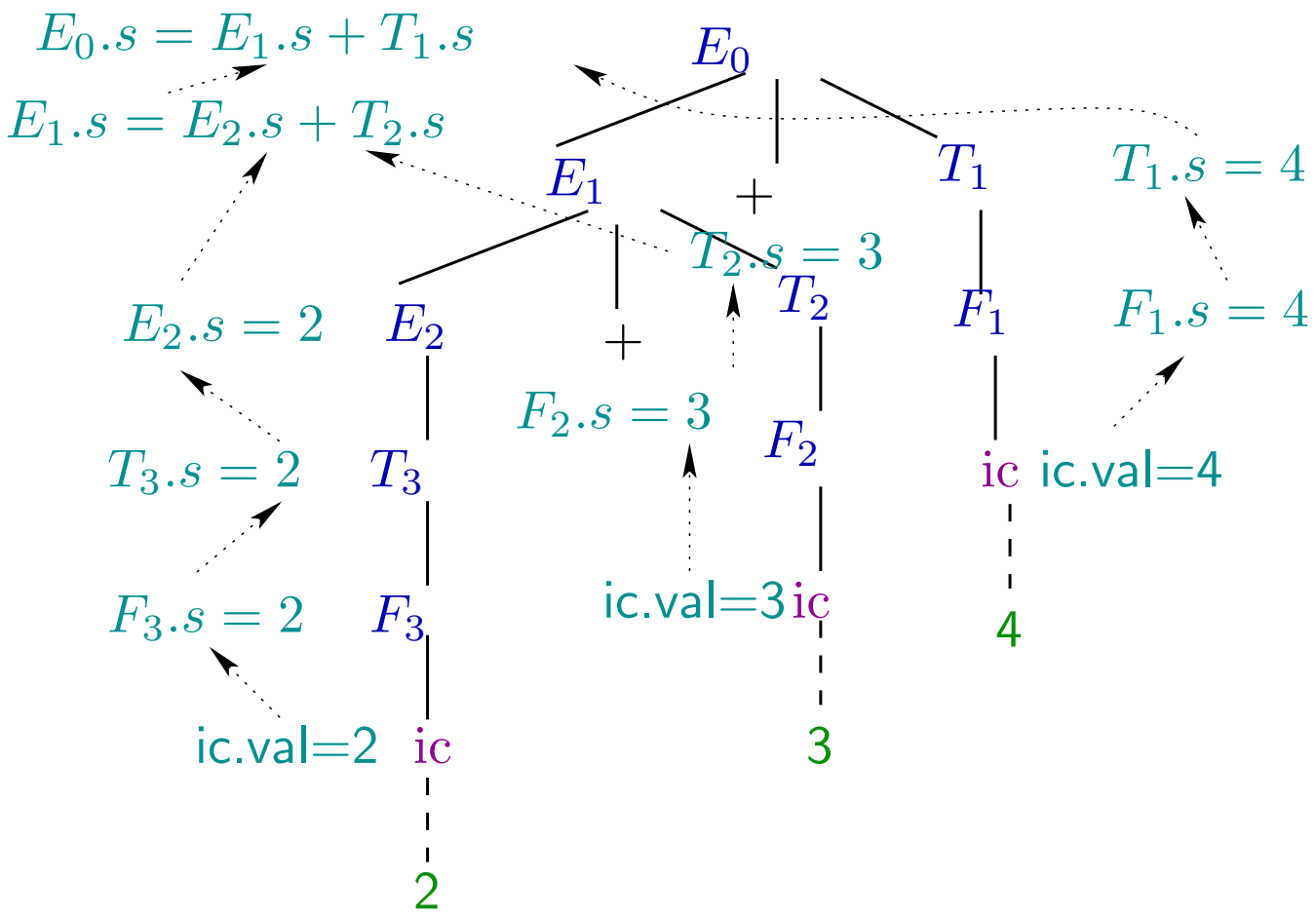
Note

- Often a natural grammar is transformed to make it suitable for parsing.
- But the new parse tree no longer match with the abstract syntax tree of the language.
- As an example the left-recursion is removed from the grammar for $LL(1)$ parsing.
- The original S-attributed grammar gets modified after this transformation.

S-Attributed Expression Grammar

S	$\rightarrow$	$E\$$	{ print E.val }
E	$\rightarrow$	$E_1 + T$	{ E.val = E1.val + T.val}
E	$\rightarrow$	T	{ E.val = T.val}
T	$\rightarrow$	$T_1 * F$	{ T.val = T1.val * F.val}
T	$\rightarrow$	F	{ T.val = F.val}
F	$\rightarrow$	(F)	{ F.val = E.val}
F	$\rightarrow$	ic	{ F.val = ic.val}

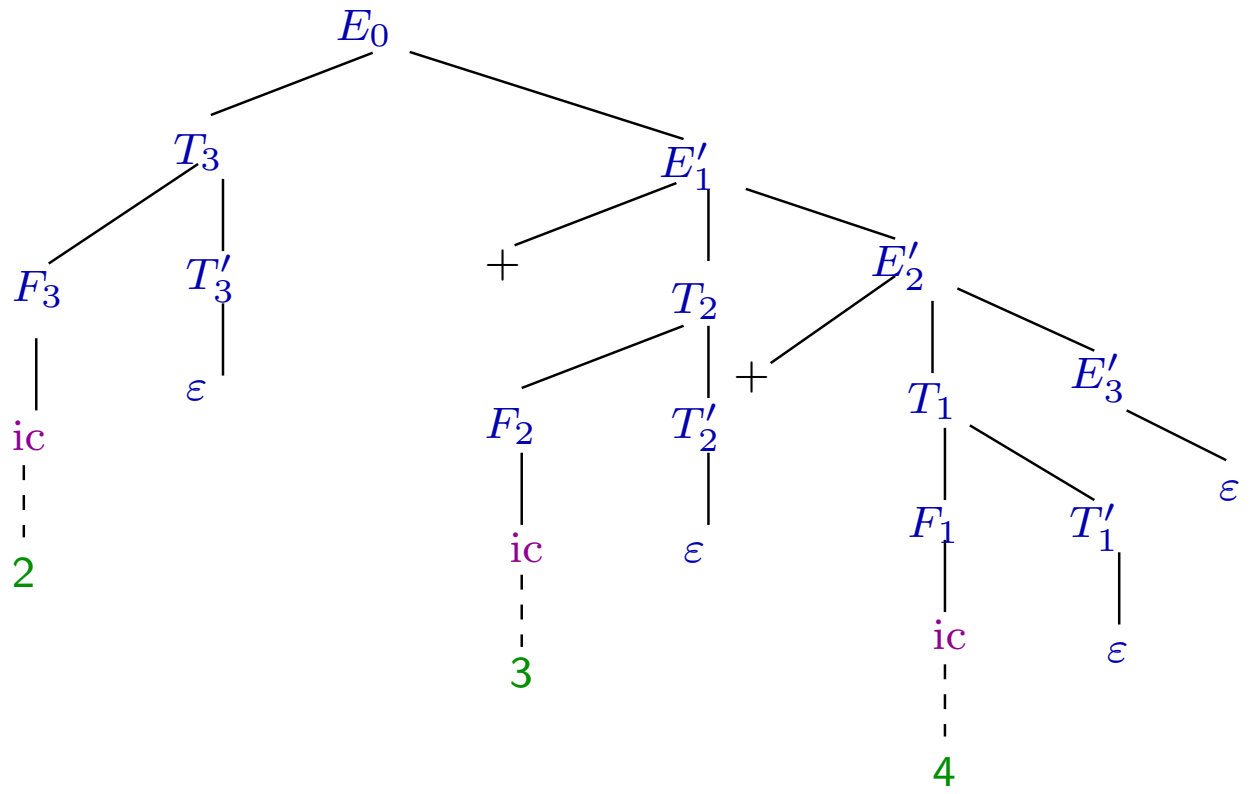
Decorated Parse Tree of $2 + 3 + 4$



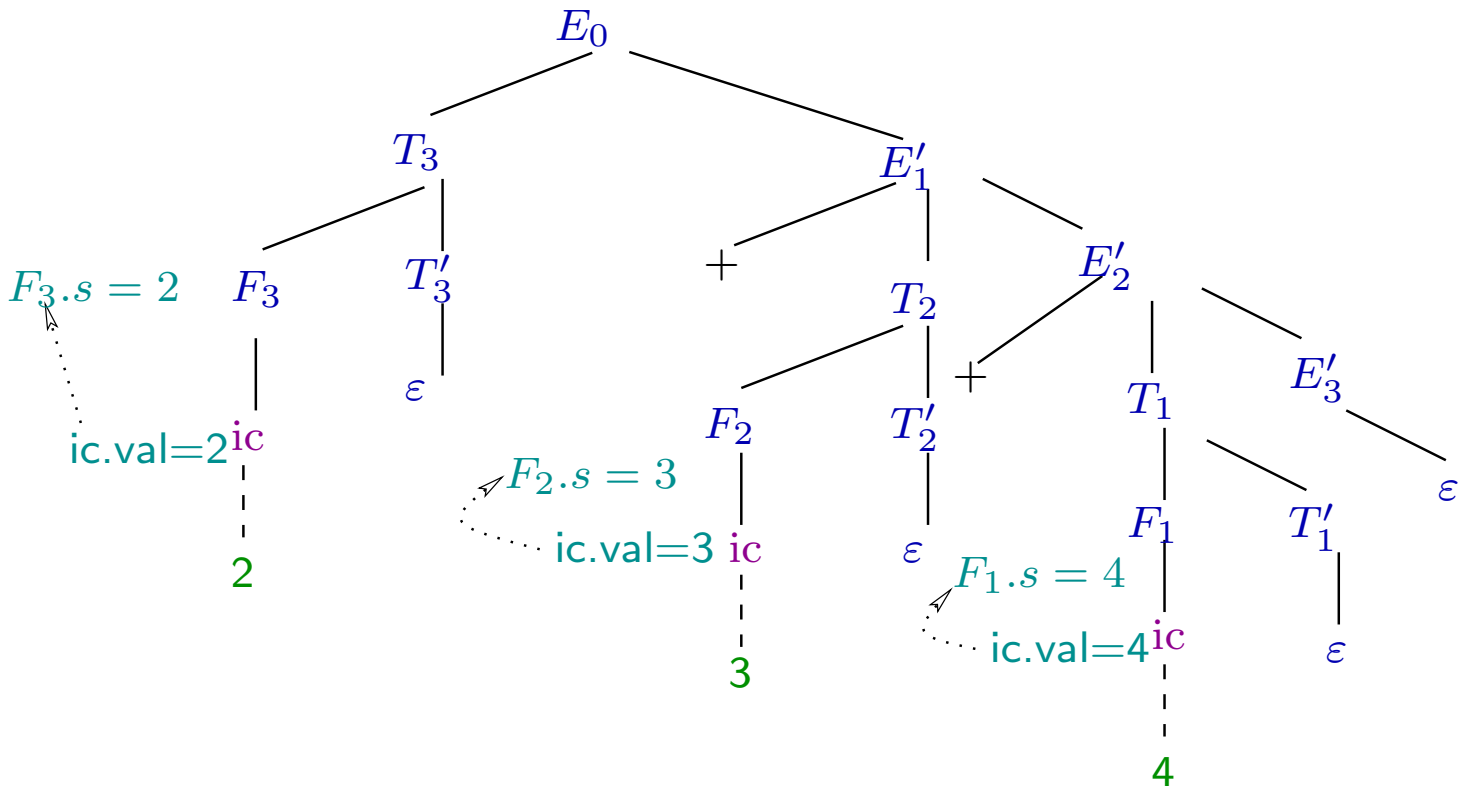
Equivalent $LL(1)$ Grammar

$$
\begin{aligned}
S &\rightarrow E\$ \\
E &\rightarrow TE' \\
E' &\rightarrow +TE' \\
E' &\rightarrow \varepsilon \\
T &\rightarrow FT' \\
T' &\rightarrow *FT' \\
T' &\rightarrow \varepsilon \\
F &\rightarrow (E) \\
F &\rightarrow \texttt{ic}
\end{aligned}
$$

Parse Tree of $LL(1)$ Grammar



Partially Decorated Parse Tree of $LL(1)$ Grammar



Note

- Two arguments of '+' are in different subtrees. It is necessary to pass the value of $T_3.s$ to the subtree of E'_1.
- It is also necessary for left-associativity of '+', to propagate the computed value down the tree say from E'_1 to E'_2.
- We achieve this by inherited attributes $E'.i$ and $T'.i$ of the non-terminals E' and T'.

Note

But it is also necessary to propagate the computed value towards the root. This is done through the synthesized attributes of E' and T' i.e. $E'.s, T'.s$.

L-Attributed $LL(1)$ Expression Grammar

$$E \rightarrow T \{ \texttt{E'.ival = T.sval} \} E'$$
$$\{ \texttt{E.sval = E'.sval} \}$$
$$E' \rightarrow +T \{ \texttt{E1'.ival = E'.ival + T.sval} \} E'_1$$
$$\{ \texttt{E'.sval = E1'.sval} \}$$
$$E' \rightarrow \varepsilon \{ \texttt{E'.sval = E'.ival} \}$$

L-Attributed $LL(1)$ Expression Grammar

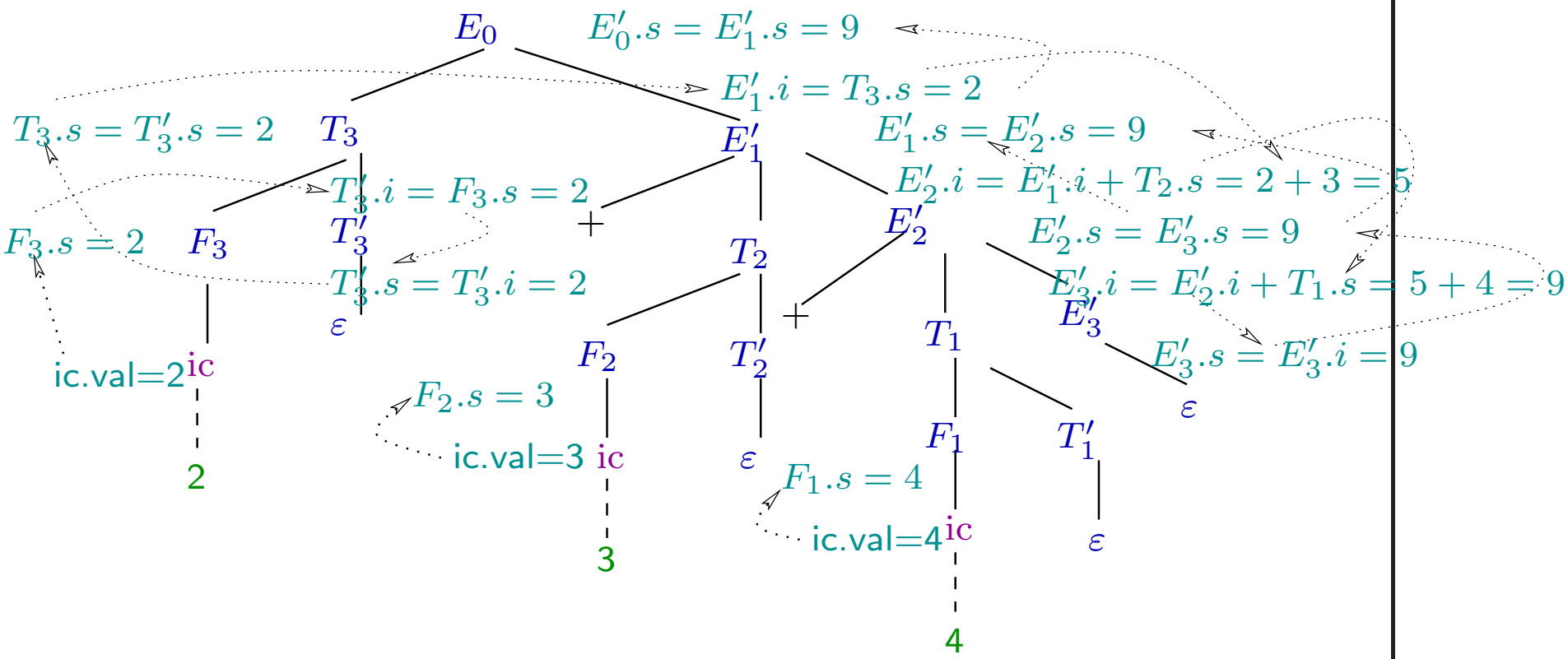
$$T \rightarrow F \{ \texttt{T'.ival = F.sval} \} T'$$
$$\{ \texttt{T.sval = T'.sval} \}$$
$$T' \rightarrow *F \{ \texttt{T1'.ival = T'.ival * F.sval} \} T'_1$$
$$\{ \texttt{T'.sval = T1'.sval} \}$$
$$T' \rightarrow \varepsilon \{ \texttt{T'.sval = T'.ival} \}$$

L-Attributed $LL(1)$ Expression Grammar

$$F \rightarrow (E) \{ \texttt{F.sval = E.sval} \}$$

$$F \rightarrow ic \{ \texttt{F.sval = ic.val} \}$$

Decorated Parse Tree of $LL(1)$ Grammar



Another Example

L-attributed grammars come naturally with flow-control statements. Following is an example with `if-then-else` statement.

$$\text{IS} \rightarrow \texttt{if}\ \text{BE}\ \texttt{then}\ S_1\ \texttt{else}\ S_2.$$

Attributes of Statement

- Every statement has a natural synthesized attribute, S.code, holding the code corresponding to S.
- Also a statement S has a continuation, the next instruction to be executed after execution of S. This may be handled as a jump target (label). But this label is an inherited attribute of S, S.next, propagated in the subtree of S.

Attributes of Boolean Expression

- The boolean expression also has a synthesized attribute BE.code.
- But it has two inherited attributes, BE.true, a jump target (label) where the control is transferred if the boolean expression is evaluated to true. This is the beginning of S_1.
  Similarly there is BE.false, a label at the beginning of S_2.

SDD for `if-then-else`

IS $\rightarrow$	`if` BE	l1=newLabel(), l2=newLabel()
	`then` S_1	BE.true = l1, BE.false=l2
	`else` S_2.	S_1.next = S_2.next = IS.next
		IS.code = BE.code + l1':' +
		S_1.code + l2':' + S_2.code

L-Attributed SDT for `if-then-else`

$$
\begin{aligned}
\text{IS} \rightarrow\ & \texttt{if} && \{\text{l1=newLabel(),l2=newLabel()} \\
& && \text{BE.true} = \text{l1},\ \text{BE.false=l2}\} \\
& \texttt{BE} && \{\text{S}_1\text{.next} = \text{IS.next}\ \} \\
& \texttt{then}\ S_1 && \{\text{S}_2\text{.next} = \text{IS.next}\ \} \\
& \texttt{else}\ S_2. && \\
& && \{\text{IS.code} = \text{BE.code} + \text{l1':'} + \\
& && \text{S}_1\text{.code} + \text{l2':'} + \text{S}_2\text{.code}\}
\end{aligned}
$$

Note

Afterward we shall see how this is managed in an actual implementation using back-patching.

SDD for Boolean Expression `and`

$BE \rightarrow BE_1$ `and` BE_2	BE_1.true=l=newLabel()
	BE_1.false = BE.false
	BE_2.true = BE.true
	BE_2.false = BE.false
	BE.code = BE_1.code +
	l':' + BE_2.code

L-Attributed SDT for Boolean Expression `and`

$BE \rightarrow$ { BE_1.true=l=newLabel()

BE_1.false = BE.false }

BE_1 `and`

{ BE_2.true = BE.true

BE_2.false = BE.false }

BE_2

{ BE.code = BE_1.code +

l':' + BE_2.code }