Part IX.
Syntax Directed Translation and Intermediate Code

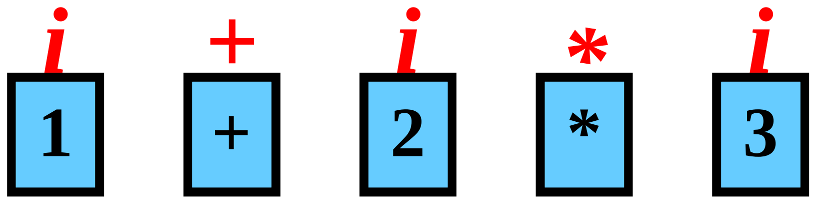
Syntax-Directed Translation

Gist: *Semantic actions* are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.

Example:

Rule:	**Semantic Action:**
$E_i \rightarrow E_j + E_k$	`{ Ei.a := Ej.a + Ek.a}`
$E_i \rightarrow E_j * E_k$	`{ Ei.a := Ej.a * Ek.a}`
$E_i \rightarrow (E_j)$	`{ Ei.a := Ej.a }`
$E_i \rightarrow i$	`{ Ei.a := i.val }`

Rule: **Action:**



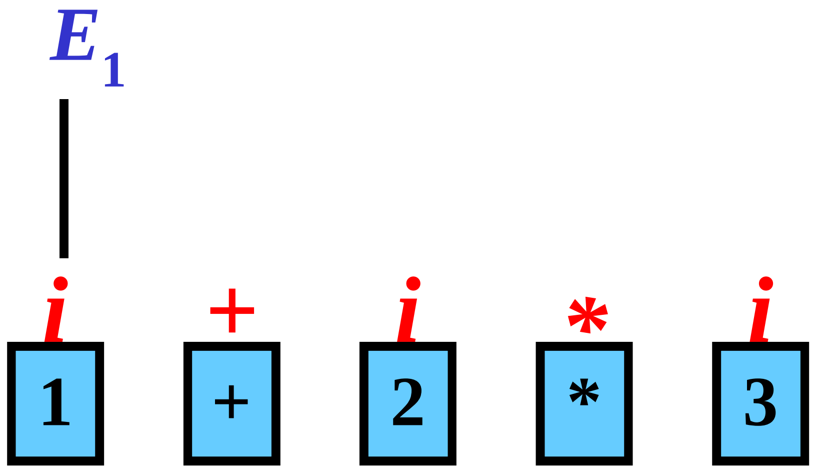
Syntax-Directed Translation

Gist: *Semantic actions* are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.

Example:

Rule:	**Semantic Action:**
$E_i \to E_j + E_k$	`{ E`$_i$`.a := E`$_j$`.a + E`$_k$`.a}`
$E_i \to E_j * E_k$	`{ E`$_i$`.a := E`$_j$`.a * E`$_k$`.a}`
$E_i \to (E_j)$	`{ E`$_i$`.a := E`$_j$`.a }`
$E_i \to i$	`{ E`$_i$`.a := i.val }`

Rule:	**Action:**
$E_1 \to i$	

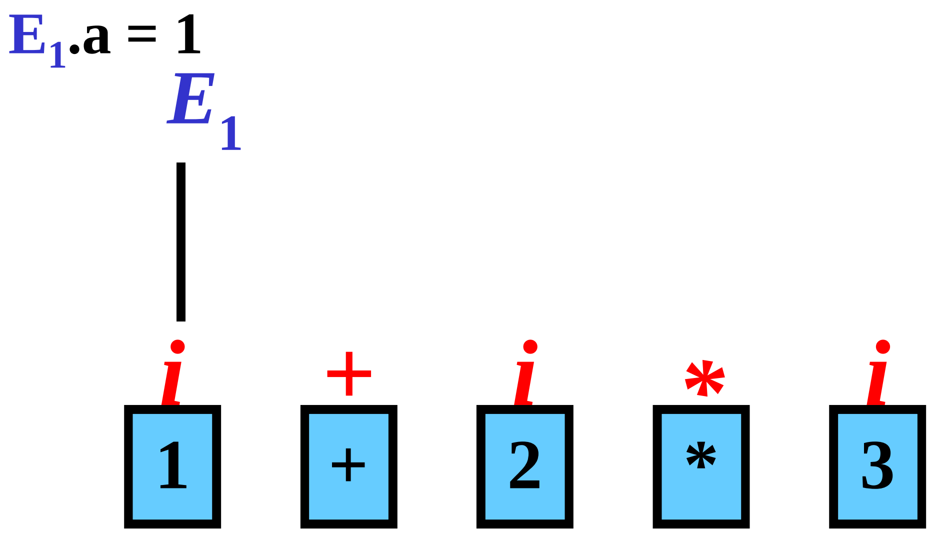


Syntax-Directed Translation

Gist: *Semantic actions* are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.

Example:

Rule:	Semantic Action:
$E_i \rightarrow E_j + E_k$	{ E$_i$.a := E$_j$.a + E$_k$.a}
$E_i \rightarrow E_j * E_k$	{ E$_i$.a := E$_j$.a * E$_k$.a}
$E_i \rightarrow (E_j)$	{ E$_i$.a := E$_j$.a }
$E_i \rightarrow i$	{ E$_i$.a := i.val }



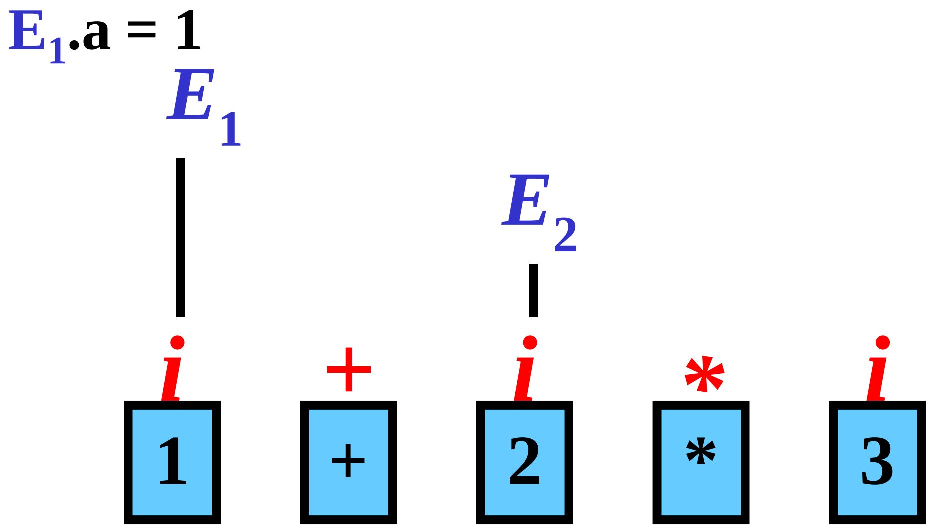
Rule:	Action:
$E_1 \rightarrow i$	E$_1$.a:= i.val

Syntax-Directed Translation

Gist: *Semantic actions* are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.

Example:

Rule:	Semantic Action:
$E_i \rightarrow E_j + E_k$	`{ Ei.a := Ej.a + Ek.a}`
$E_i \rightarrow E_j * E_k$	`{ Ei.a := Ej.a * Ek.a}`
$E_i \rightarrow (E_j)$	`{ Ei.a := Ej.a }`
$E_i \rightarrow i$	`{ Ei.a := i.val }`



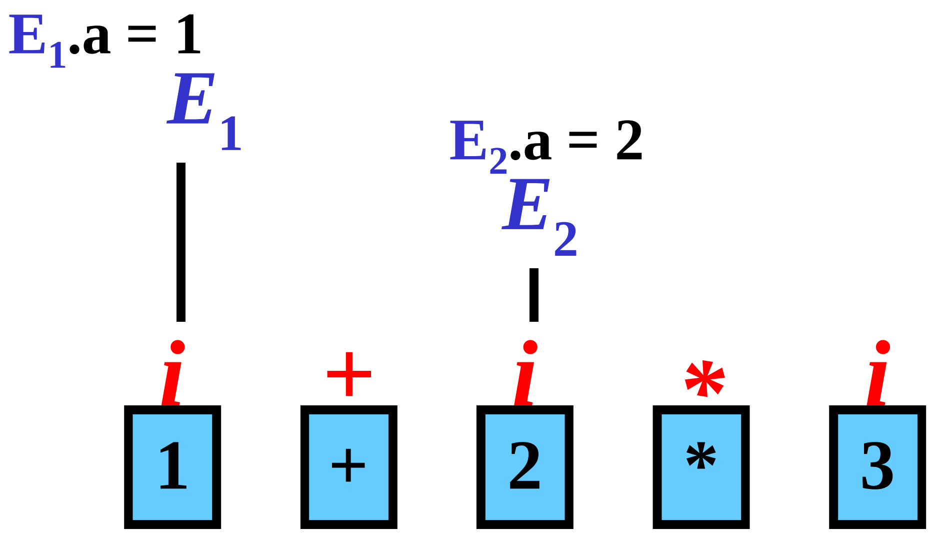
Rule:	Action:
$E_1 \rightarrow i$	`E1.a:= i.val`
$E_2 \rightarrow i$	

Syntax-Directed Translation

Gist: *Semantic actions* are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.

Example:

Rule:	Semantic Action:
$E_i \rightarrow E_j + E_k$	`{ Ei.a := Ej.a + Ek.a}`
$E_i \rightarrow E_j * E_k$	`{ Ei.a := Ej.a * Ek.a}`
$E_i \rightarrow (E_j)$	`{ Ei.a := Ej.a }`
$E_i \rightarrow i$	`{ Ei.a := i.val }`



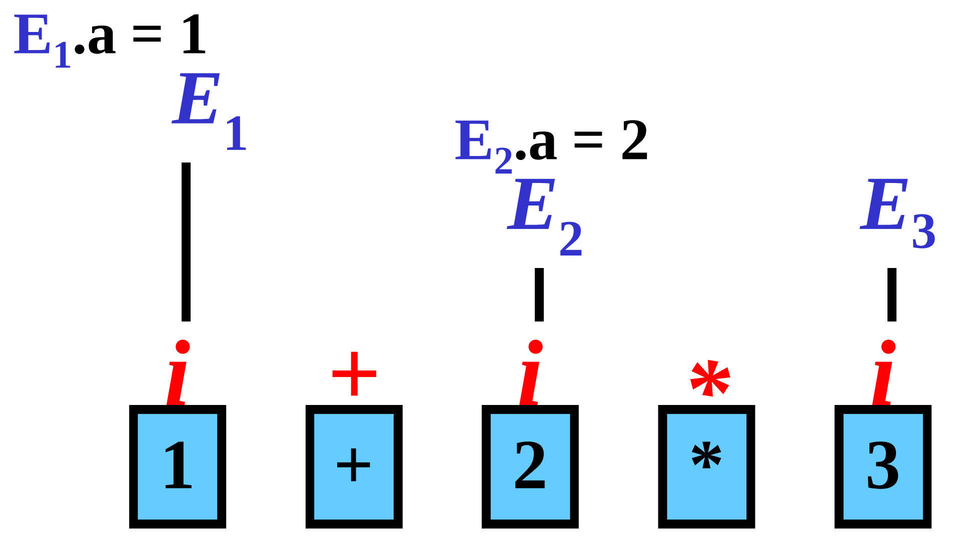
Rule:	Action:
$E_1 \rightarrow i$	`E1.a:= i.val`
$E_2 \rightarrow i$	`E2.a:= i.val`

Syntax-Directed Translation

Gist: ***Semantic actions*** **are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.**

Example:

Rule:	Semantic Action:
$E_i \rightarrow E_j + E_k$	`{` E_i`.a := `E_j`.a + `E_k`.a}`
$E_i \rightarrow E_j * E_k$	`{` E_i`.a := `E_j`.a * `E_k`.a}`
$E_i \rightarrow (E_j)$	`{` E_i`.a := `E_j`.a }`
$E_i \rightarrow i$	`{` E_i`.a := i.val }`



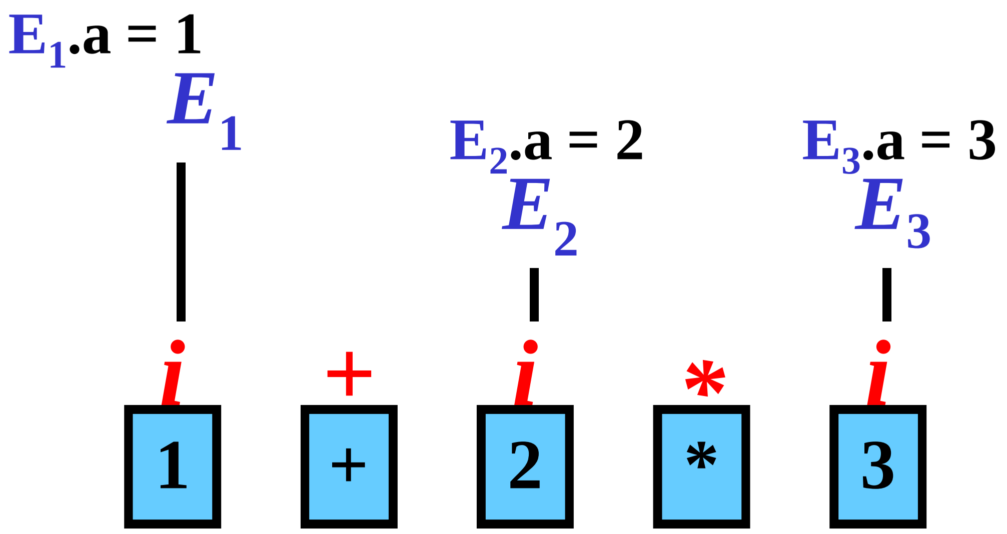
Rule:	Action:
$E_1 \rightarrow i$	E_1`.a:= i.val`
$E_2 \rightarrow i$	E_2`.a:= i.val`
$E_3 \rightarrow i$	

Syntax-Directed Translation

Gist: *Semantic actions* are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.

Example:

Rule:	**Semantic Action:**
$E_i \rightarrow E_j + E_k$	`{ Ei.a := Ej.a + Ek.a}`
$E_i \rightarrow E_j * E_k$	`{ Ei.a := Ej.a * Ek.a}`
$E_i \rightarrow (E_j)$	`{ Ei.a := Ej.a }`
$E_i \rightarrow i$	`{ Ei.a := i.val }`



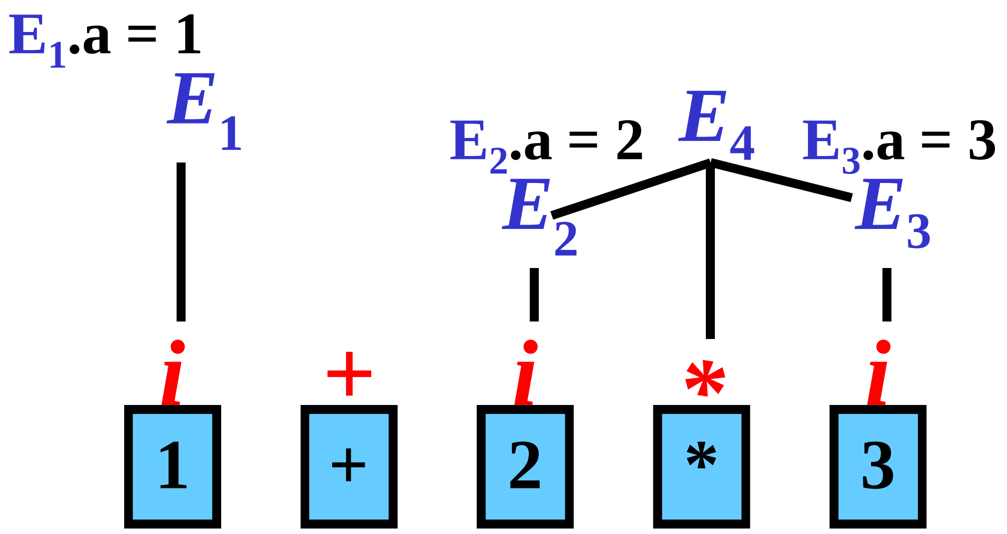
Rule:	**Action:**
$E_1 \rightarrow i$	`E1.a:= i.val`
$E_2 \rightarrow i$	`E2.a:= i.val`
$E_3 \rightarrow i$	`E3.a:= i.val`

Syntax-Directed Translation

Gist: *Semantic actions* are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.

Example:

Rule:	Semantic Action:
$E_i \rightarrow E_j + E_k$	`{ E`$_i$`.a := E`$_j$`.a + E`$_k$`.a}`
$E_i \rightarrow E_j * E_k$	`{ E`$_i$`.a := E`$_j$`.a * E`$_k$`.a}`
$E_i \rightarrow (E_j)$	`{ E`$_i$`.a := E`$_j$`.a }`
$E_i \rightarrow i$	`{ E`$_i$`.a := i.val }`



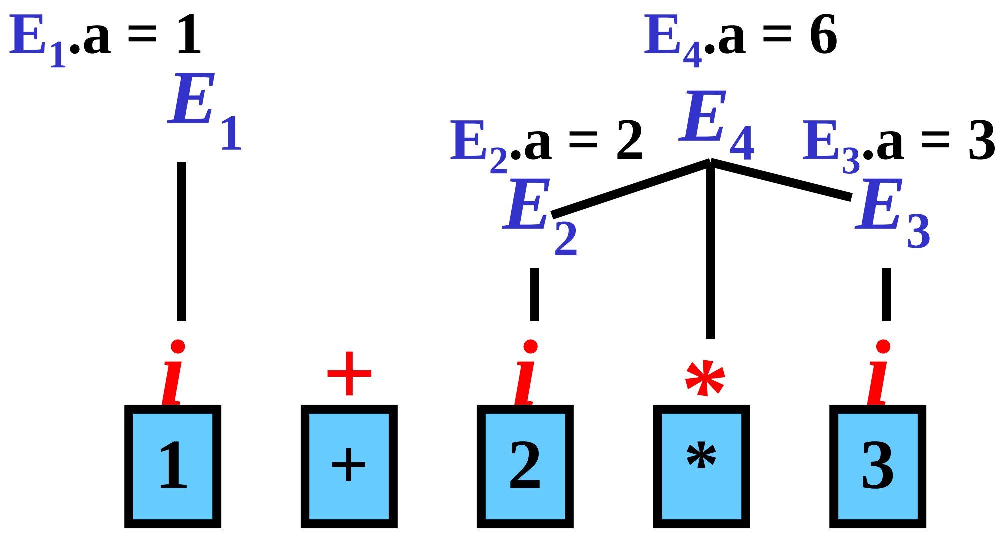
Rule:	Action:
$E_1 \rightarrow i$	`E`$_1$`.a:= i.val`
$E_2 \rightarrow i$	`E`$_2$`.a:= i.val`
$E_3 \rightarrow i$	`E`$_3$`.a:= i.val`
$E_4 \rightarrow E_2 * E_3$	

Syntax-Directed Translation

Gist: *Semantic actions* are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.

Example:

Rule:	Semantic Action:
$E_i \rightarrow E_j + E_k$	{ E_i.a := E_j.a + E_k.a}
$E_i \rightarrow E_j * E_k$	{ E_i.a := E_j.a * E_k.a}
$E_i \rightarrow (E_j)$	{ E_i.a := E_j.a }
$E_i \rightarrow i$	{ E_i.a := i.val }



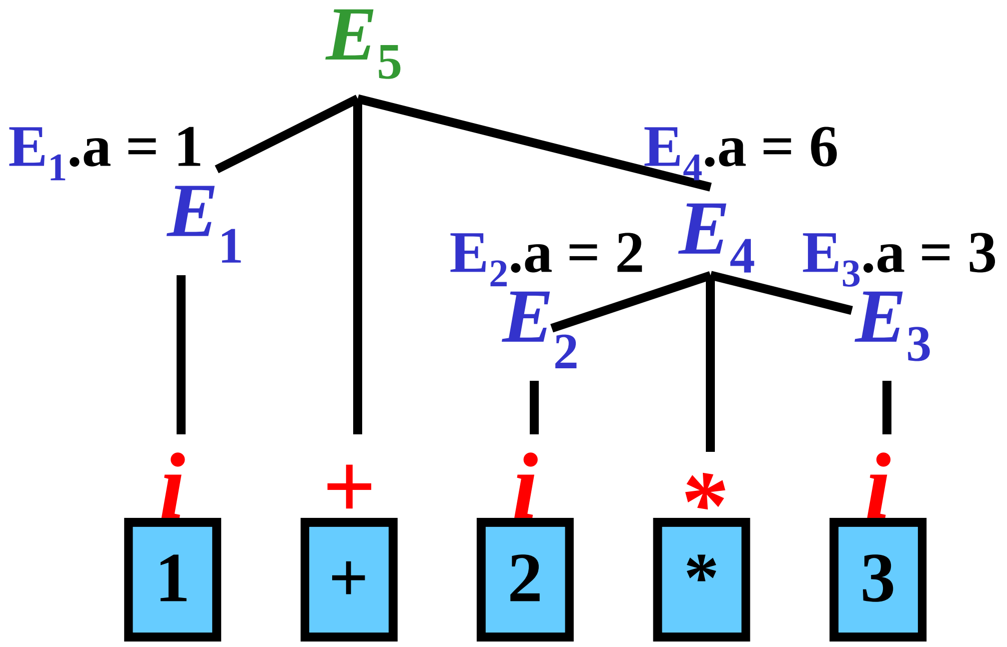
Rule:	Action:
$E_1 \rightarrow i$	E_1.a:= i.val
$E_2 \rightarrow i$	E_2.a:= i.val
$E_3 \rightarrow i$	E_3.a:= i.val
$E_4 \rightarrow E_2 * E_3$	E_4.a:= E_2.a*E_3.a

Syntax-Directed Translation

Gist: *Semantic actions* are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.

Example:

Rule:	Semantic Action:
$E_i \to E_j + E_k$	`{ Ei.a := Ej.a + Ek.a}`
$E_i \to E_j * E_k$	`{ Ei.a := Ej.a * Ek.a}`
$E_i \to (E_j)$	`{ Ei.a := Ej.a }`
$E_i \to i$	`{ Ei.a := i.val }`



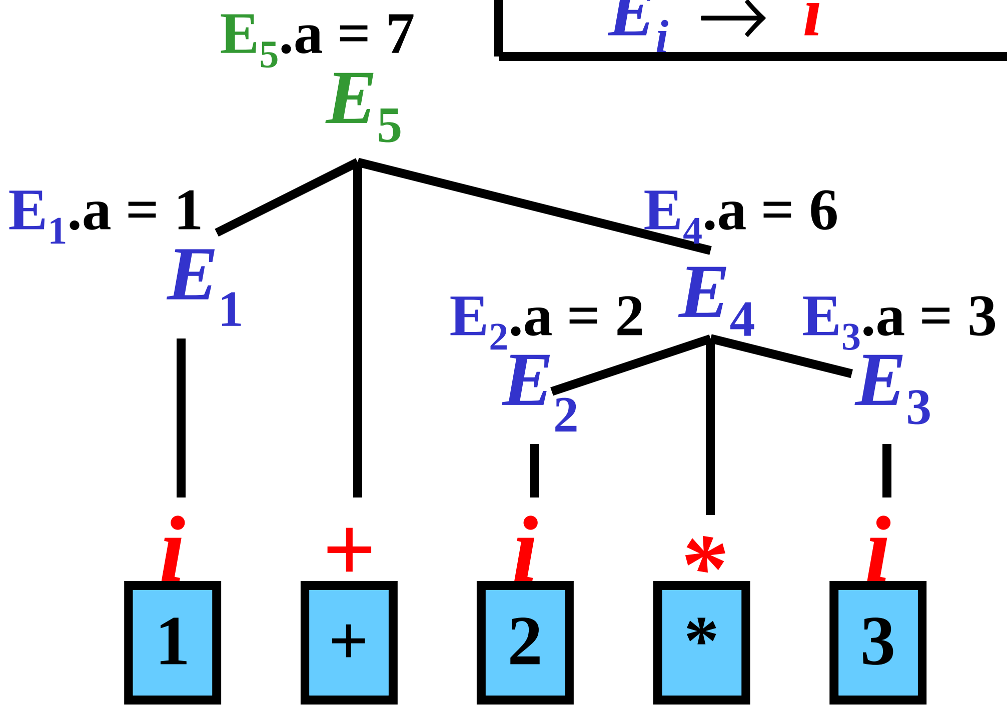
Rule:	Action:
$E_1 \to i$	E_1`.a:= i.val`
$E_2 \to i$	E_2`.a:= i.val`
$E_3 \to i$	E_3`.a:= i.val`
$E_4 \to E_2 * E_3$	E_4`.a:= `E_2`.a*`E_3`.a`
$E_5 \to E_1 + E_4$	

Syntax-Directed Translation

Gist: *Semantic actions* are attached to gramatical rules. Most importantly, these actions make intermediate code generation and type checking.

Example:

Rule:	Semantic Action:
$E_i \rightarrow E_j + E_k$	`{ Ei.a := Ej.a + Ek.a}`
$E_i \rightarrow E_j * E_k$	`{ Ei.a := Ej.a * Ek.a}`
$E_i \rightarrow (E_j)$	`{ Ei.a := Ej.a }`
$E_i \rightarrow i$	`{ Ei.a := i.val }`



Rule:	Action:
$E_1 \rightarrow i$	E_1.a:= i.val
$E_2 \rightarrow i$	E_2.a:= i.val
$E_3 \rightarrow i$	E_3.a:= i.val
$E_4 \rightarrow E_2 * E_3$	E_4.a:= E_2.a*E_3.a
$E_5 \rightarrow E_1 + E_4$	E_5.a:= E_1.a+E_4.a

Intermediate Code: Three–Address Code

• Instruction in **three–address code** (**3AC**) has the form:

(o, ☛a, ☛b, ☛r)

- **o** – operator (+, –, *, …)
- **a** – operand 1 (☛*a* = address of *a*)
- **b** – operand 2 (☛*b* = address of *b*)
- **r** – result (☛*r* = address of *r*)

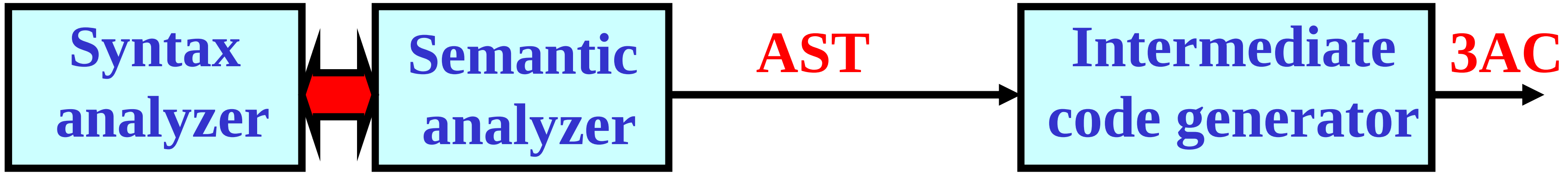
Examples:

```
(:=  ,   a,   ,  c )  ...  c := a
(+   ,   a, b,  c )  ...  c := a + b
(not ,   a,   ,  b )  ...  b := not(a)
(goto,     ,  , L1)  ...  goto L1
(goto,   a,   , L1)  ...  if a = true then goto L1
(lab , L1,   ,    )  ...  label L1:
```

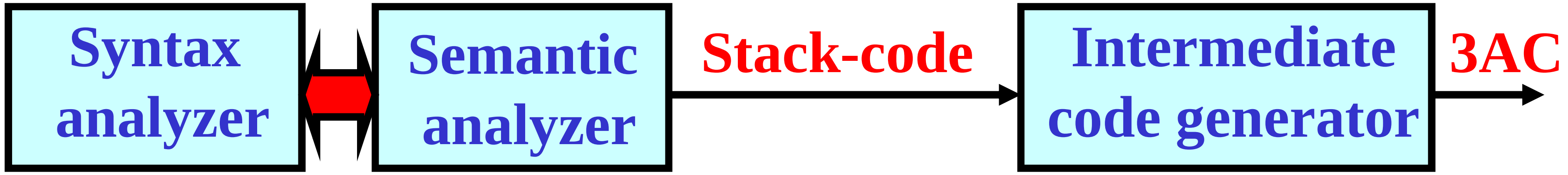
Syntax-Directed Generation of 3AC

Basic approaches:

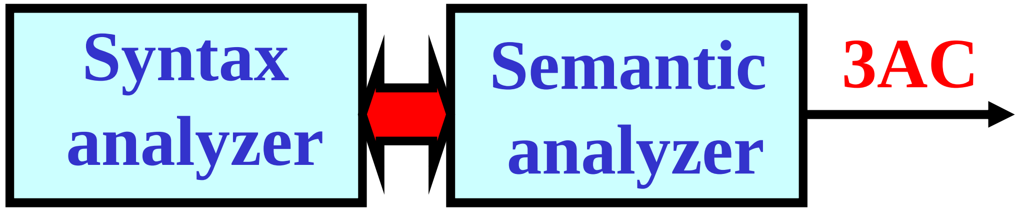
1) Parser directs the creation of an ***abstract-syntax tree* (AST)** , which is then converted to **3AC**.



2) Parser directs the creation of a ***postfix notation* (PN)** , which is then converted to **3AC**.

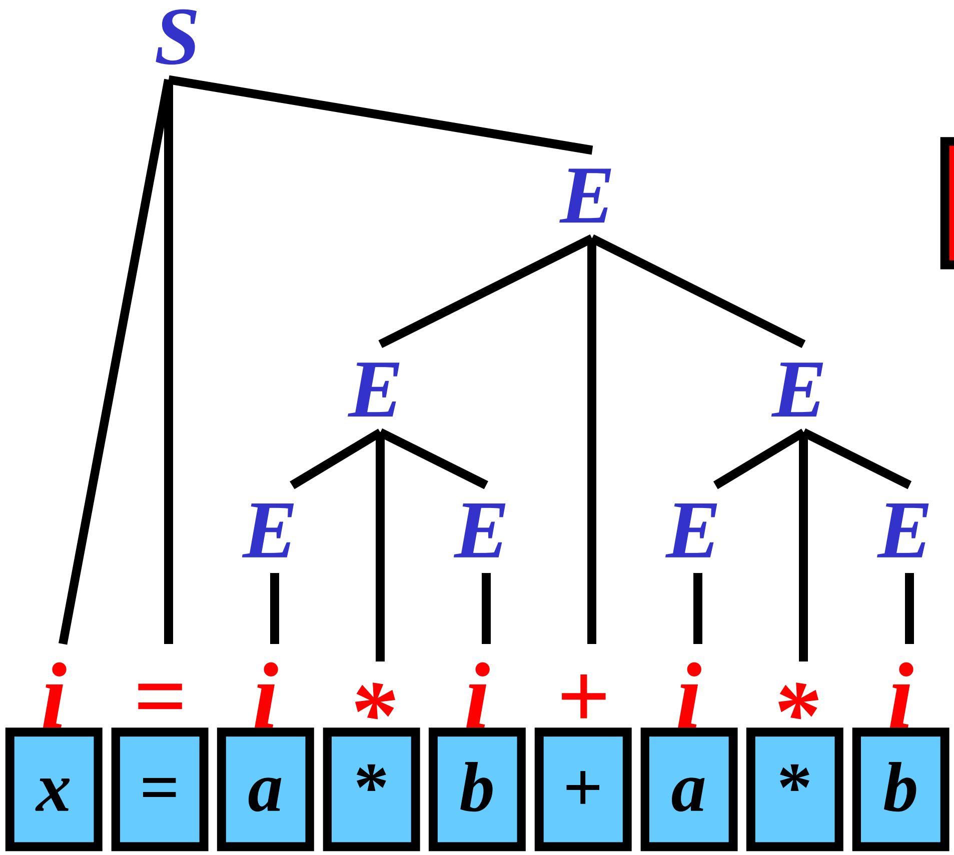


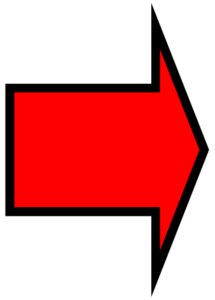
3) A parser directs the creation of **3AC.**



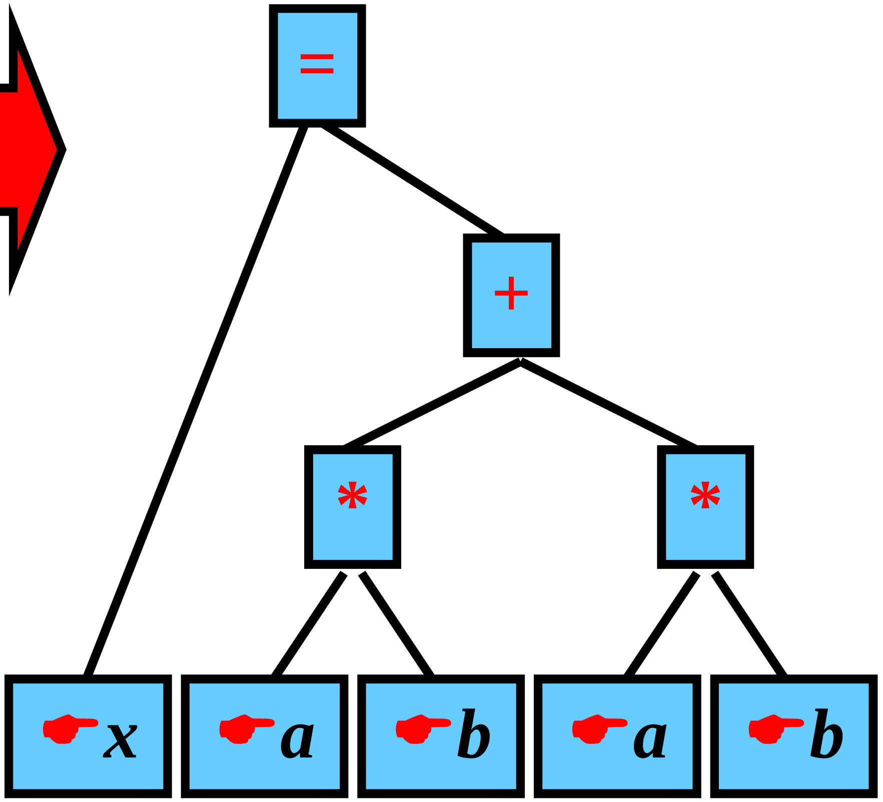
From a Parse Tree (PT) to an AST: Example

- **PT for**
  ***x = a*b + a*b*:**





- **AST for**
  ***x = a*b + a*b*:**



Generation of AST

Gist: A parser simulates the construction of PT and, simultaneously, calls some semantic actions to create AST.

Example:

Rule:	Semantic Action:
$S \rightarrow i := E_k$	{ $S.a$:= MakeTree('=', $i.a$, $E_k.a$) }
$E_i \rightarrow E_j + E_k$	{ $E_i.a$:= MakeTree('+', $E_j.a$, $E_k.a$) }
$E_i \rightarrow E_j * E_k$	{ $E_i.a$:= MakeTree('*', $E_j.a$, $E_k.a$) }
$E_i \rightarrow (E_j)$	{ $E_i.a$:= $E_j.a$ }
$E_i \rightarrow i$	{ $E_i.a$:= MakeLeaf($i.a$) }

Notes:

- **MakeTree(*o*, *a*, *b*)** creates a new node ***o***, attaches sons ***a*** (left) and ***b***, and returns a pointer to node ***o***
- **MakeLeaf(*i.a*)** creates a new node ***i.a*** (***i.a*** is a symbol-table address) and returns a pointer to this new node

AST Generation: Example 1/2

Pushdown	Input	Rule	Semantic action
$\$$	$i = (i + i) * i\$$		
$\$i$	$= (i + i) * i\$$		
$\$i =$	$(i + i) * i\$$		
$\$i = ($	$i + i) * i\$$		
$\$i = (i$	$+ \mathrm{i}) * i\$$	$E_1 \rightarrow i$	$E_1.a$:= MakeLeaf($i.a$)
$\$i = (E_1$	$+ i) * i\$$		
$\$i = (E_1 +$	$i) * i\$$		
$\$i = (E_1 + i$	$) * i\$$	$E_2 \rightarrow i$	$E_2.a$:= MakeLeaf($i.a$)
$\$i = (E_1 + E_2$	$) * i\$$	$E_3 \rightarrow E_1 + E_2$	$E_3.a$:=MakeTree(‘+’, $E_1.a$, $E_2.a$)
$\$i = (E_3$	$) * i\$$		
$\$i = (E_3)$	$* i\$$	$E_4 \rightarrow (E_3)$	$E_4.a := E_3.a$
$\$i = E_4$	$* i\$$		
$\$i = E_4 *$	$i\$$		
$\$i = E_4 * i$	$\$$	$E_5 \rightarrow i$	$E_5.a$:= MakeLeaf($i.a$)
$\$i = E_4 * E_5$	$\$$	$E_6 \rightarrow E_4 * E_5$	$E_6.a$:=MakeTree(‘*’, $E_4.a$, $E_5.a$)
$\$i = E_6$	$\$$	$S \rightarrow i = E_6$	$S.a$:= MakeTree(‘=’, i.a, $E_6.a$)
$\$S$	$\$$		

$$\underbrace{\hspace{12cm}}_{\textbf{Bottom-Up parsing}} \underbrace{\hspace{8cm}}_{\textbf{Semantic actions}}$$

AST Generation: Example 2/2

Rule:	Semantic Action:

<u>Simulated</u> Parse tree:

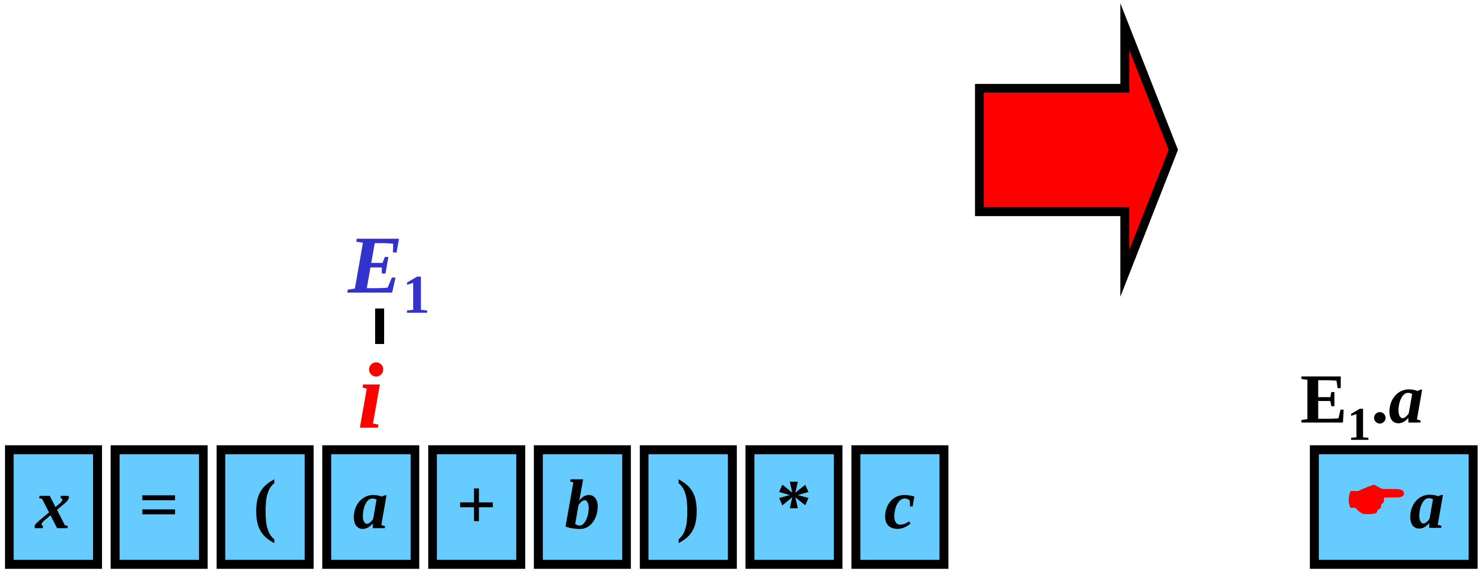
Abstract syntax tree:

x	=	(	*a*	+	*b*	)	*	*c*

AST Generation: Example 2/2

Rule:	Semantic Action:
$E_1 \to i$	$E_1.a$:= MakeLeaf($i.a$)

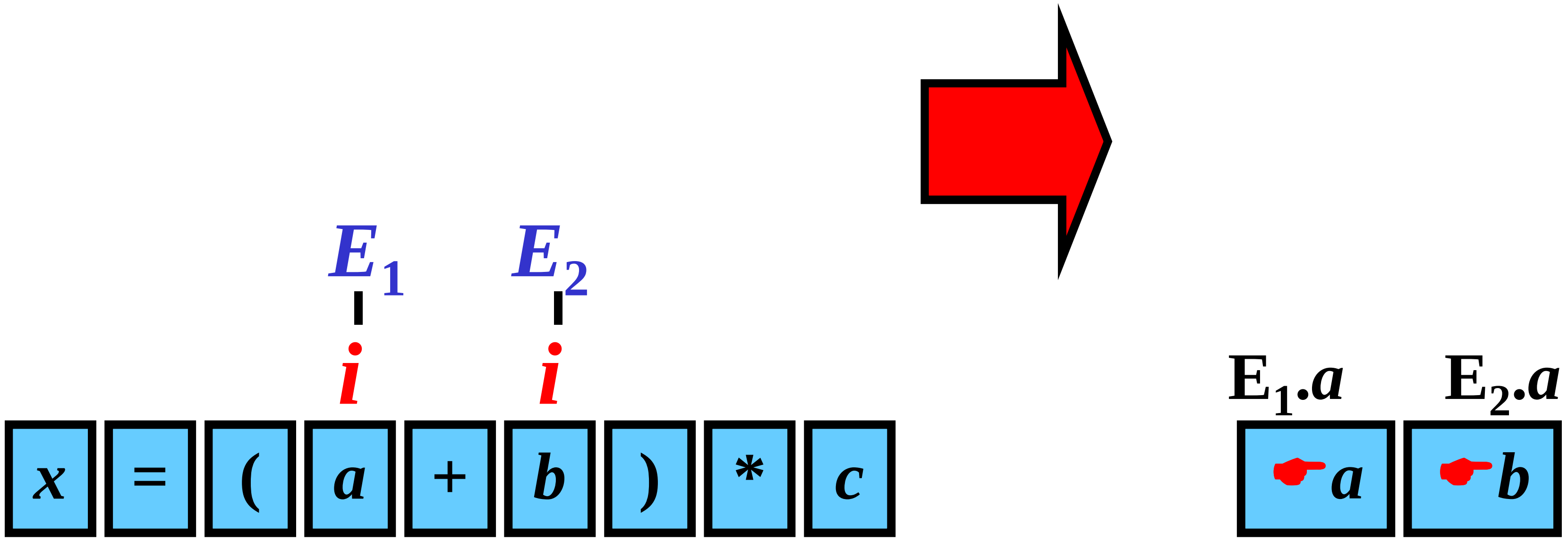
Simulated Parse tree: **Abstract syntax tree:**



AST Generation: Example 2/2

Rule:	Semantic Action:
$E_1 \rightarrow i$	$E_1.a$:= MakeLeaf($i.a$)
$E_2 \rightarrow i$	$E_2.a$:= MakeLeaf($i.a$)

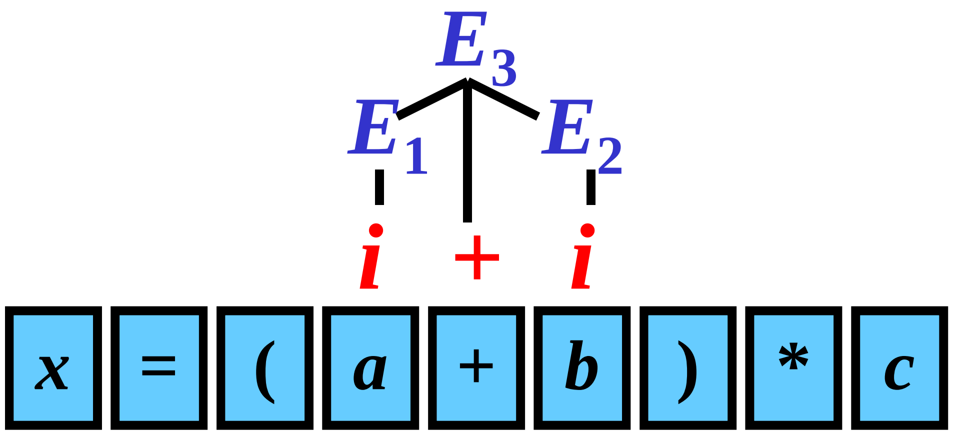
Simulated Parse tree: **Abstract syntax tree:**

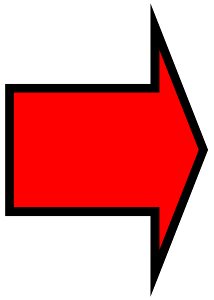


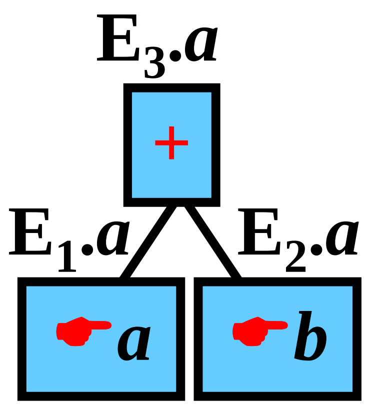
AST Generation: Example 2/2

Rule:	Semantic Action:
$E_1 \to i$	$E_1.a$:= MakeLeaf($i.a$)
$E_2 \to i$	$E_2.a$:= MakeLeaf($i.a$)
$E_3 \to E_1 + E_2$	$E_3.a$:= MakeTree('+', $E_1.a$, $E_2.a$)

Simulated Parse tree: **Abstract syntax tree:**





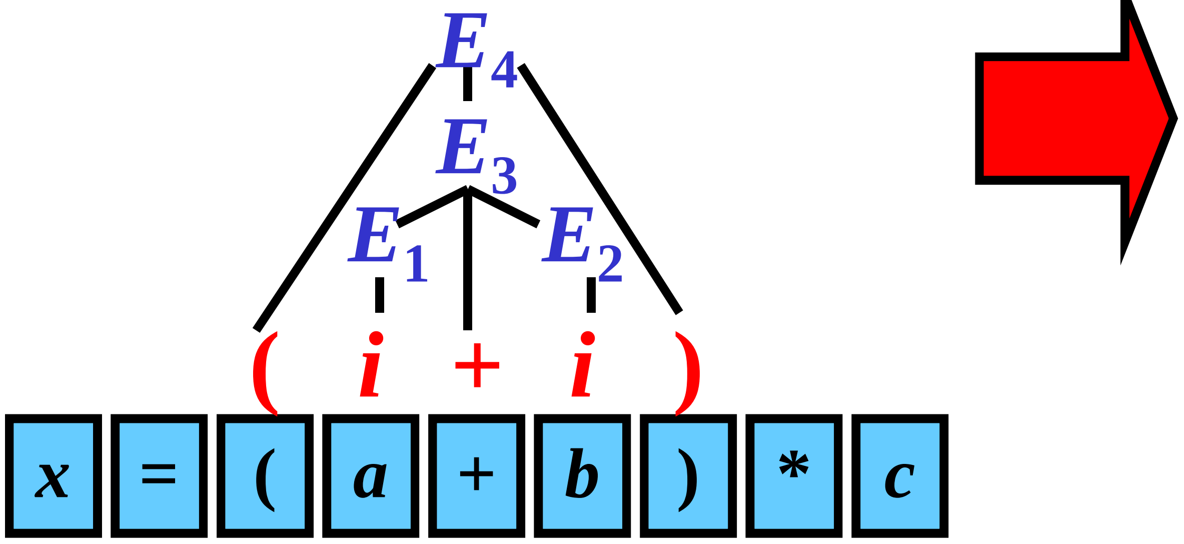


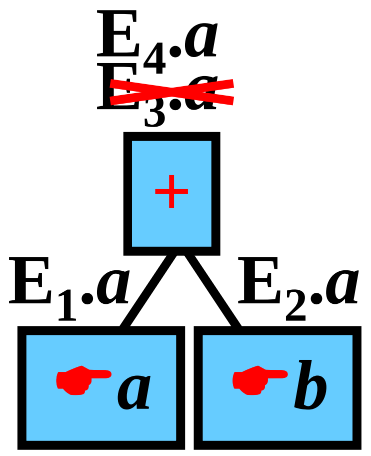
AST Generation: Example 2/2

Rule:	Semantic Action:
$E_1 \rightarrow i$	$E_1.a$:= MakeLeaf($i.a$)
$E_2 \rightarrow i$	$E_2.a$:= MakeLeaf($i.a$)
$E_3 \rightarrow E_1 + E_2$	$E_3.a$:= MakeTree('+', $E_1.a$, $E_2.a$)
$E_4 \rightarrow (E_3)$	$E_4.a$:= $E_3.a$

Simulated Parse tree:

Abstract syntax tree:

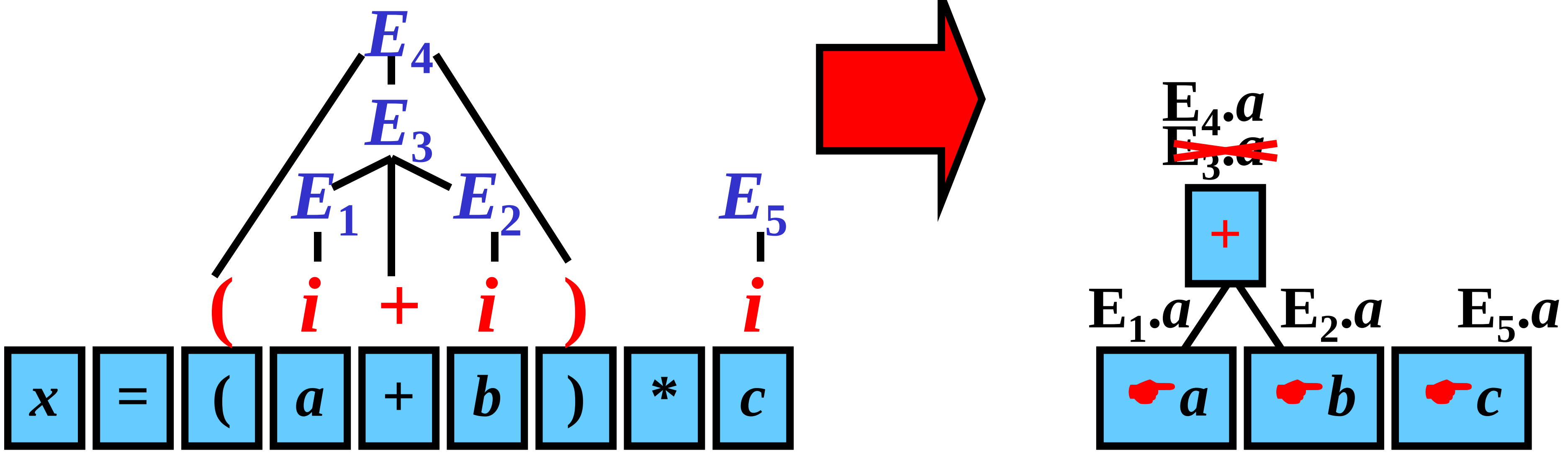




AST Generation: Example 2/2

Rule:	Semantic Action:
$E_1 \rightarrow i$	$E_1.a$:= MakeLeaf($i.a$)
$E_2 \rightarrow i$	$E_2.a$:= MakeLeaf($i.a$)
$E_3 \rightarrow E_1+E_2$	$E_3.a$:= MakeTree('+', $E_1.a, E_2.a$)
$E_4 \rightarrow (E_3)$	$E_4.a$:= $E_3.a$
$E_5 \rightarrow i$	$E_5.a$:= MakeLeaf($i.a$)

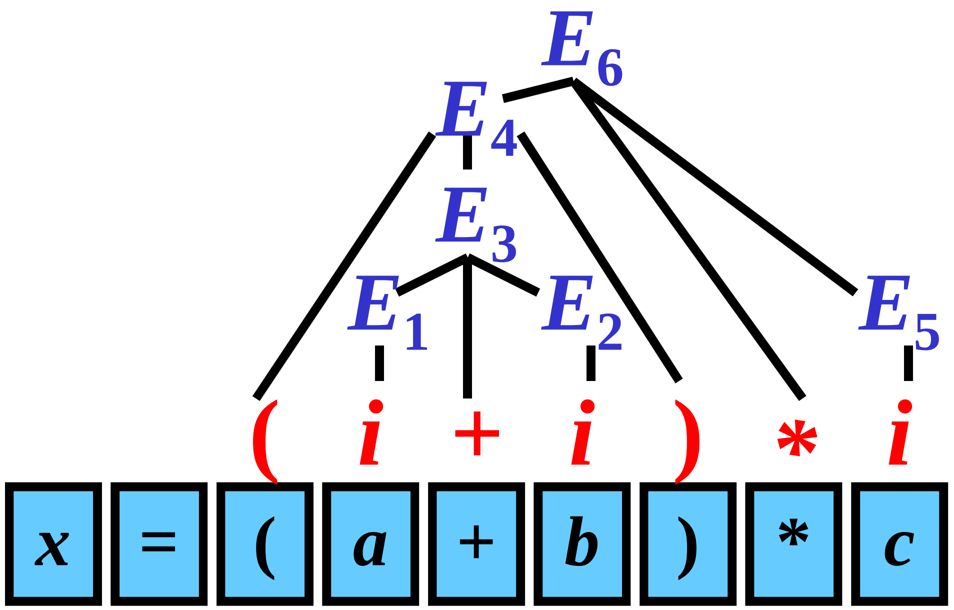
Simulated Parse tree: **Abstract syntax tree:**



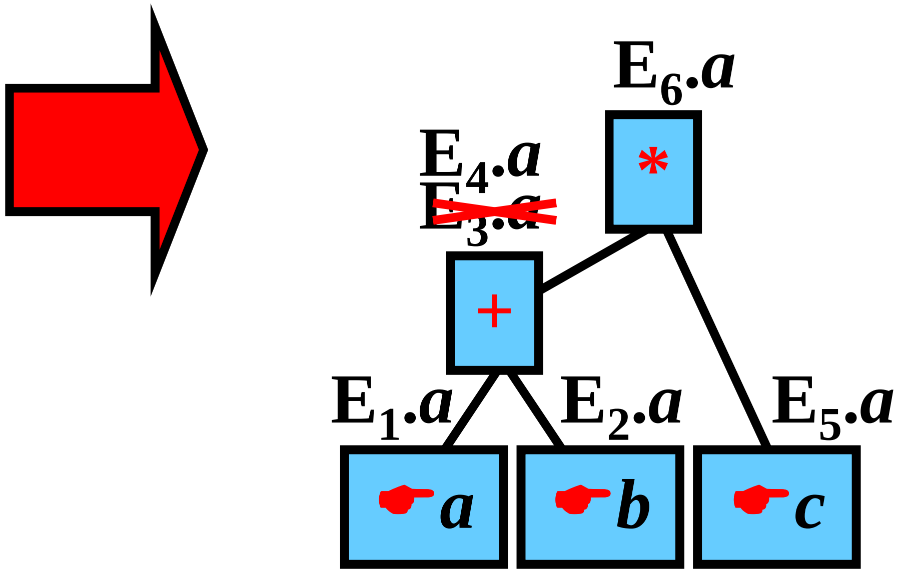
AST Generation: Example 2/2

Rule:	Semantic Action:
$E_1 \rightarrow i$	$E_1.a$:= MakeLeaf($i.a$)
$E_2 \rightarrow i$	$E_2.a$:= MakeLeaf($i.a$)
$E_3 \rightarrow E_1 + E_2$	$E_3.a$:= MakeTree('+', $E_1.a, E_2.a$)
$E_4 \rightarrow (E_3)$	$E_4.a$:= $E_3.a$
$E_5 \rightarrow i$	$E_5.a$:= MakeLeaf($i.a$)
$E_6 \rightarrow E_4 * E_5$	$E_6.a$:= MakeTree('*', $E_4.a, E_5.a$)

Simulated Parse tree:



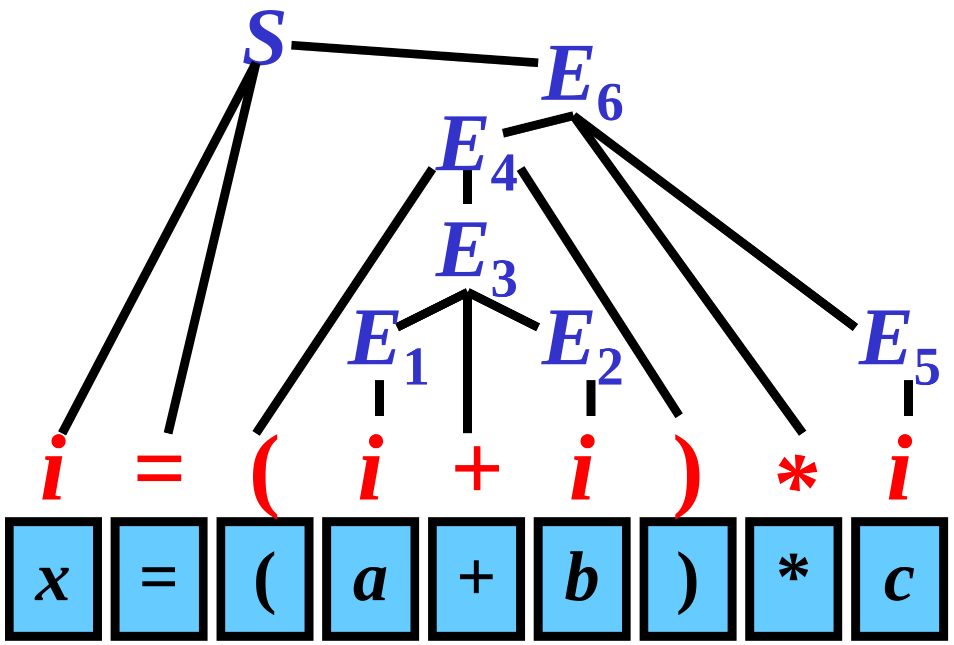
Abstract syntax tree:



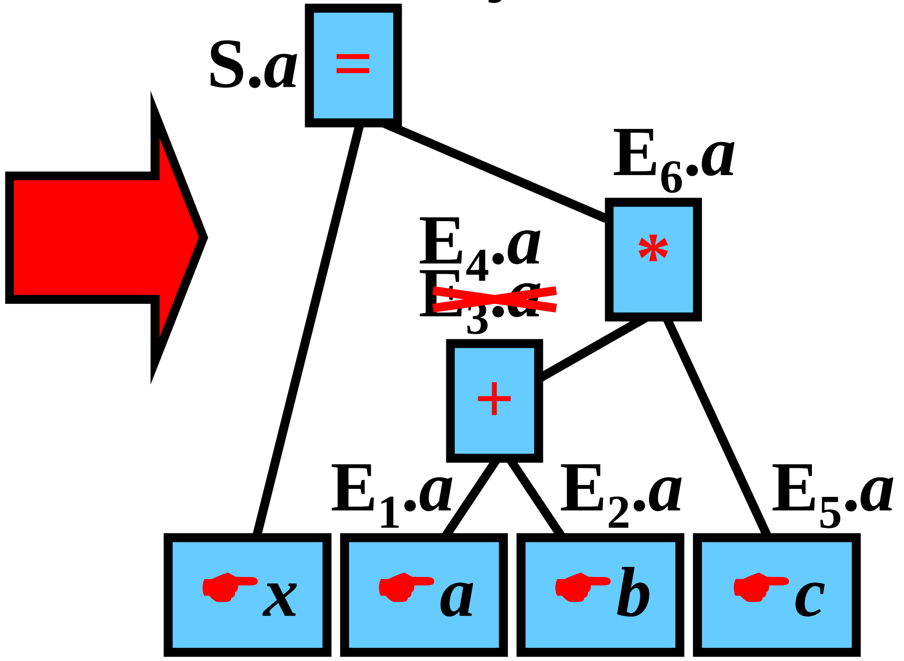
AST Generation: Example 2/2

Rule:	Semantic Action:
$E_1 \to i$	$E_1.a$:= MakeLeaf($i.a$)
$E_2 \to i$	$E_2.a$:= MakeLeaf($i.a$)
$E_3 \to E_1 + E_2$	$E_3.a$:= MakeTree('+', $E_1.a$, $E_2.a$)
$E_4 \to (E_3)$	$E_4.a$:= $E_3.a$
$E_5 \to i$	$E_5.a$:= MakeLeaf($i.a$)
$E_6 \to E_4 * E_5$	$E_6.a$:= MakeTree('*', $E_4.a$, $E_5.a$)
$S \to i = E_6$	$S.a$:= MakeTree('=', $i.a$, $E_6.a$)

Simulated Parse tree:

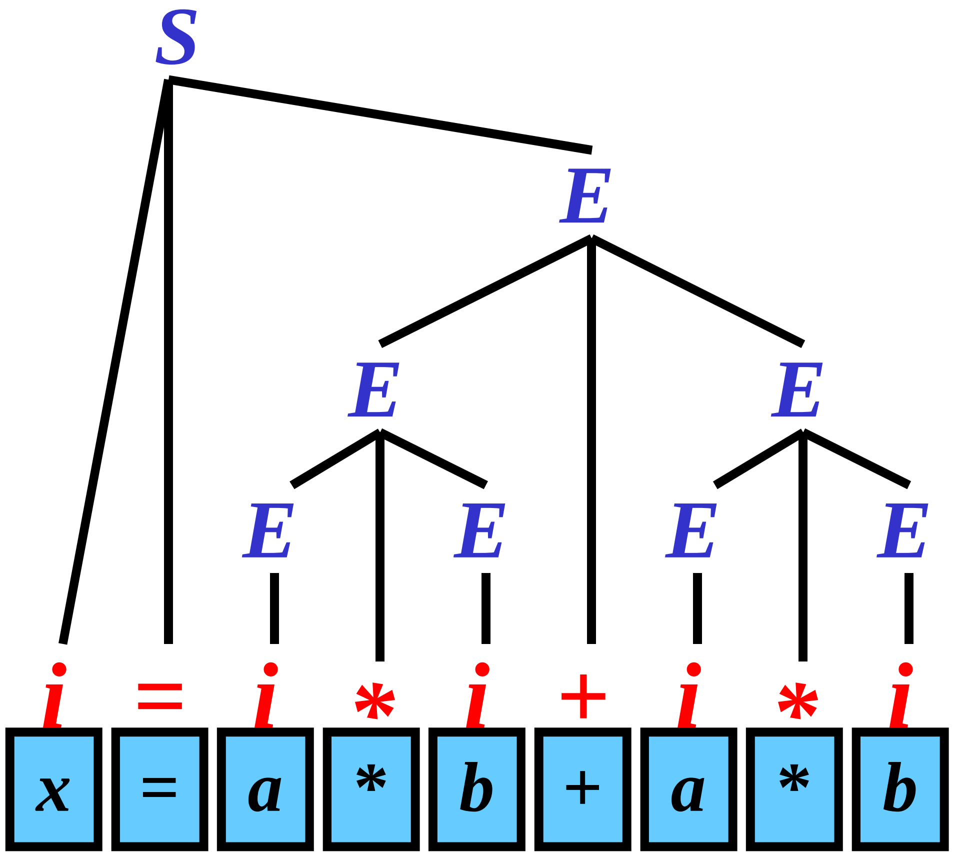


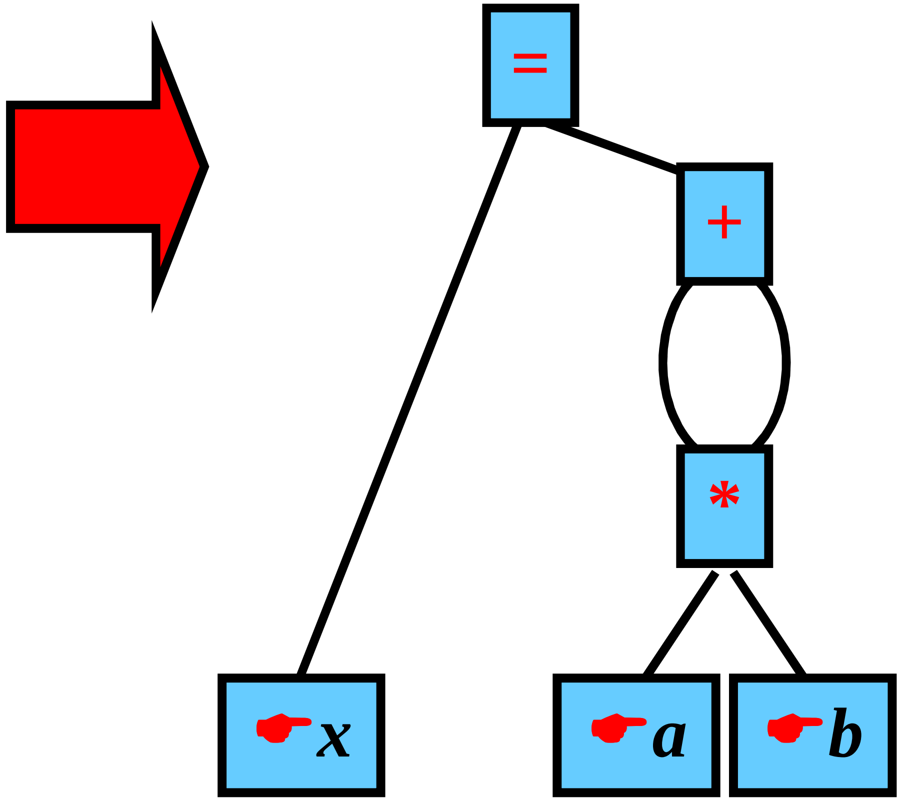
Abstract syntax tree:



Direct Acyclic Graph(DAG): Example

- **Parse tree for** ***x = a*b + a*b*:**
- **DAG for** ***x = a*b + a*b*:**





Note: DAG has no redundant nodes.

Postfix Notation

Gist: Every operator occurs behind its operands.

Example:

Infix notation	**Postfix notation**
$a + b$	$a\ b\ +$
$a = b$	$a\ b\ =$
if C **then** S_1 **else** S_2	$C\ S_1\ S_2$ **if-then-else**

Note: Postfix notation is achievable by the postorder traversal of AST.

Infix to Postfix Directed by a BU Parser

Gist: Semantic actions produce the postfix version of the tokenized source program.

Example:

Rule:	Semantic Action:
1: $E \rightarrow E+E$	{*generate*('+')}
2: $E \rightarrow E*E$	{*generate*('*')}
3: $E \rightarrow (E)$	{ - }
4: $E \rightarrow i$	{*generate*(*i.a*) }

Input: | *a* | + | *b* | * | *c* |

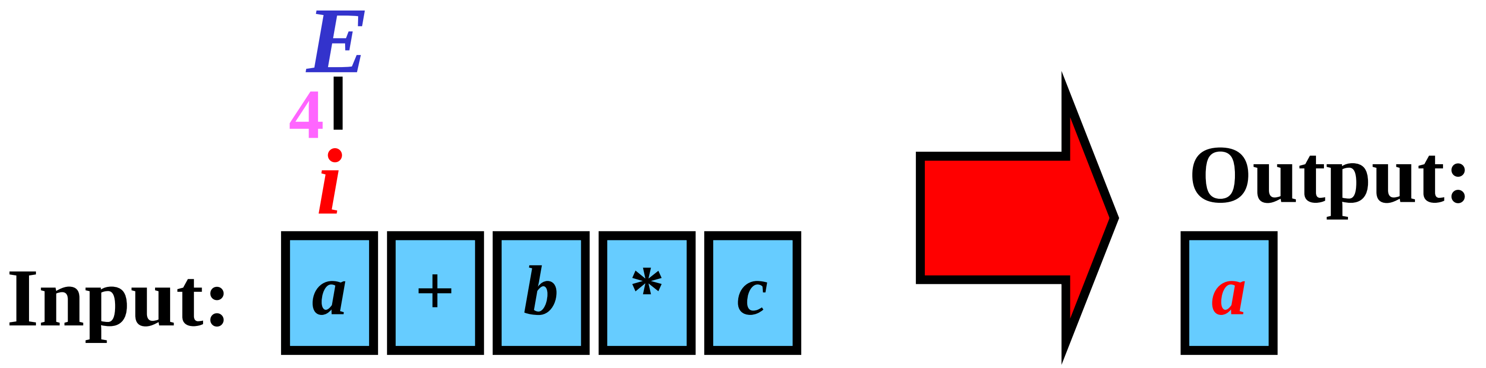
Output:

Infix to Postfix Directed by a BU Parser

Gist: Semantic actions produce the postfix version of the tokenized source program.

Example:

Rule:	**Semantic Action:**
1: $E \rightarrow E+E$	{*generate*('+')}
2: $E \rightarrow E*E$	{*generate*('*')}
3: $E \rightarrow (E)$	{ - }
4: $E \rightarrow i$	{*generate*(*i.a*) }

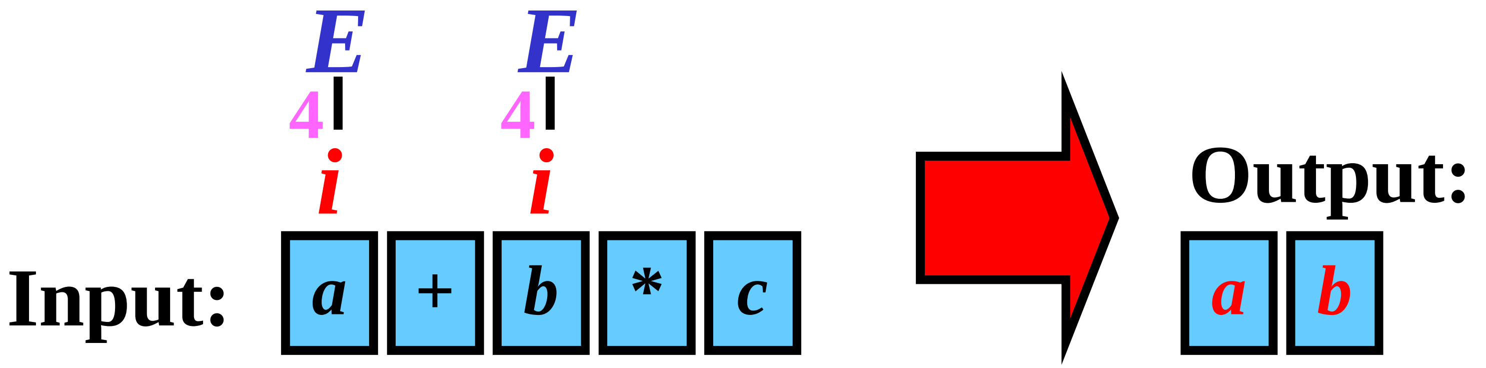


Infix to Postfix Directed by a BU Parser

Gist: Semantic actions produce the postfix version of the tokenized source program.

Example:

Rule:	**Semantic Action:**
1: $E \rightarrow E+E$	{*generate*(‘+’)}
2: $E \rightarrow E*E$	{*generate*(‘*’)}
3: $E \rightarrow (E)$	{ - }
4: $E \rightarrow i$	{*generate*($i.a$) }

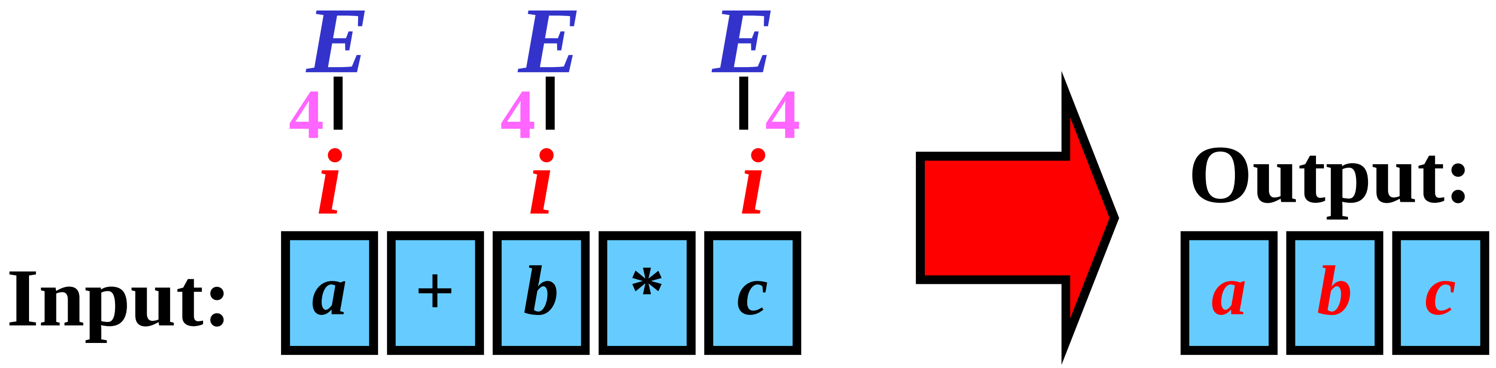


Infix to Postfix Directed by a BU Parser

Gist: Semantic actions produce the postfix version of the tokenized source program.

Example:

Rule:	Semantic Action:
1: $E \rightarrow E+E$	{*generate*('+')}
2: $E \rightarrow E*E$	{*generate*('*')}
3: $E \rightarrow (E)$	{ - }
4: $E \rightarrow i$	{*generate*(*i.a*) }

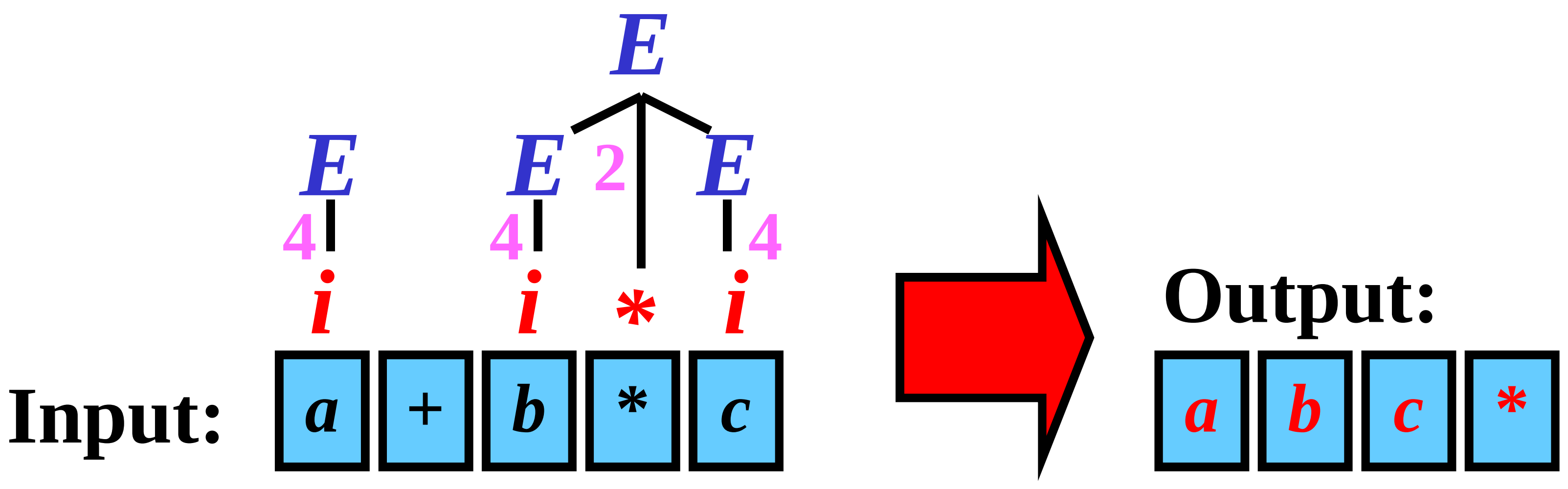


Infix to Postfix Directed by a BU Parser

Gist: Semantic actions produce the postfix version of the tokenized source program.

Example:

Rule:	Semantic Action:
1: $E \rightarrow E+E$	{*generate*('+')}
2: $E \rightarrow E*E$	{*generate*('*')}
3: $E \rightarrow (E)$	{ - }
4: $E \rightarrow i$	{*generate*(*i.a*) }

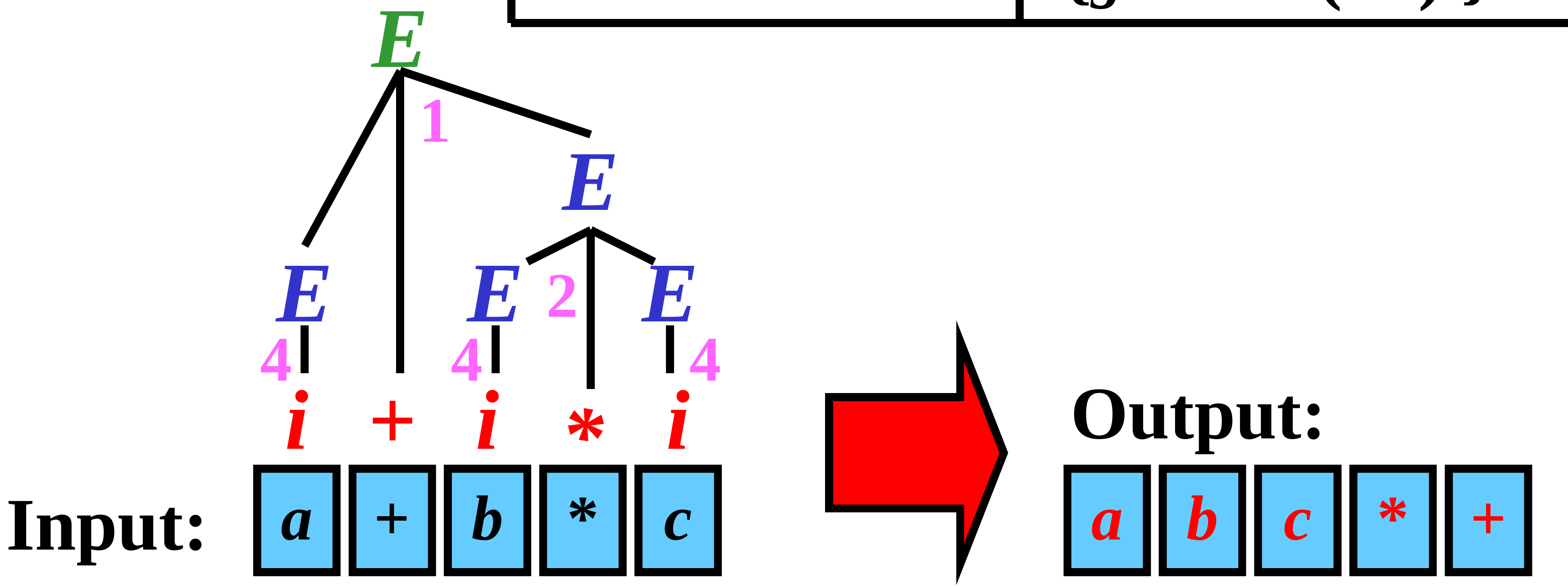


Infix to Postfix Directed by a BU Parser

Gist: Semantic actions produce the postfix version of the tokenized source program.

Example:

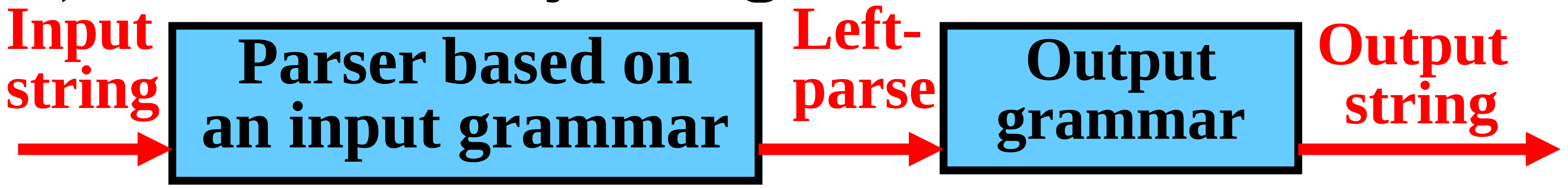
Rule:	**Semantic Action:**
1: $E \rightarrow E+E$	{*generate*('+')}
2: $E \rightarrow E*E$	{*generate*('*')}
3: $E \rightarrow (E)$	{ - }
4: $E \rightarrow i$	{*generate*(*i.a*) }



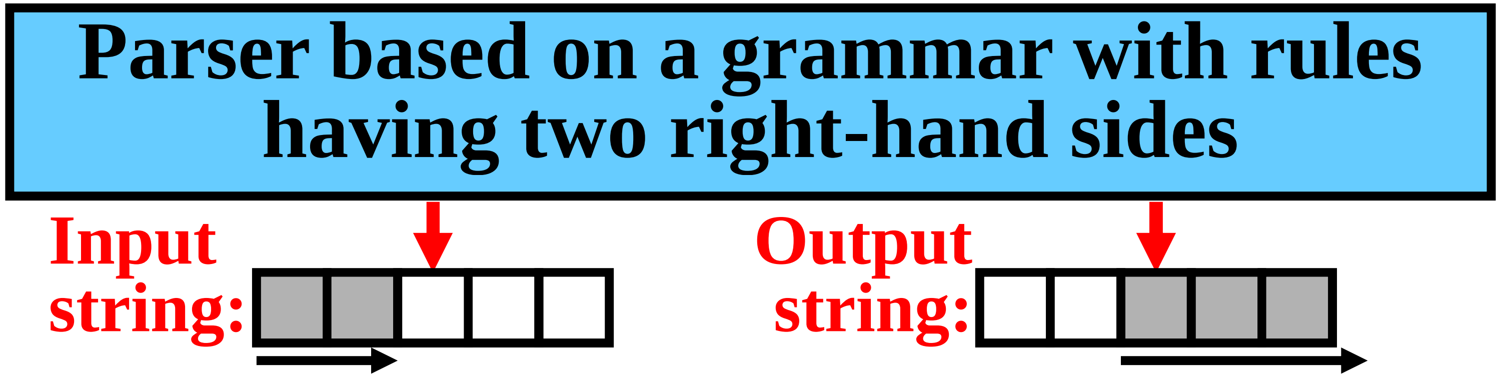
Translation Grammars

Gist: Translation grammars translate input strings to output strings

1) Translation by two grammars:



2) Translation by a single grammar


Parser based on a grammar with rules having two right-hand sides
Input string:
Output string:

Note: During the parse of an input string, a simultaneous generation f an output string occurs

Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	Rules of G_2
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$

E E

Left parse:

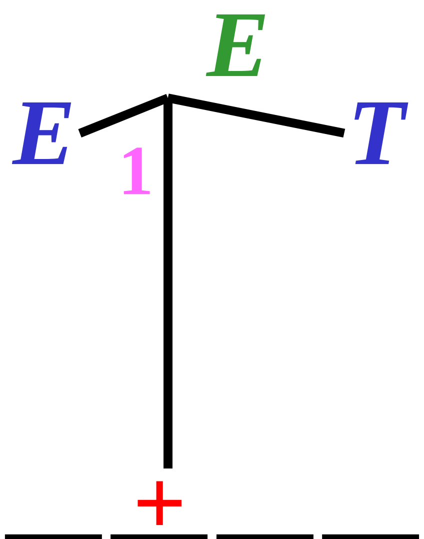
Input: $\boxed{a}\boxed{+}\boxed{b}\boxed{*}\boxed{c}$

Output:

Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	Rules of G_2
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Left parse:
1

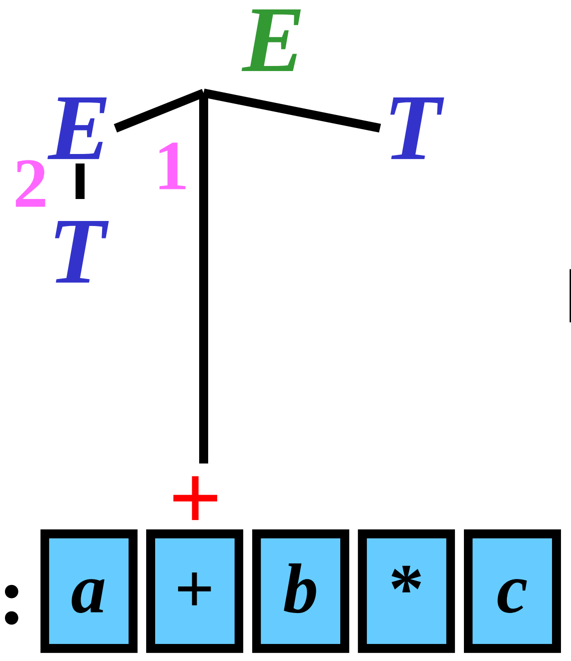
Input: | *a* | + | *b* | * | *c* |

Output:

Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	**Rules of G_2**
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Left parse:
12

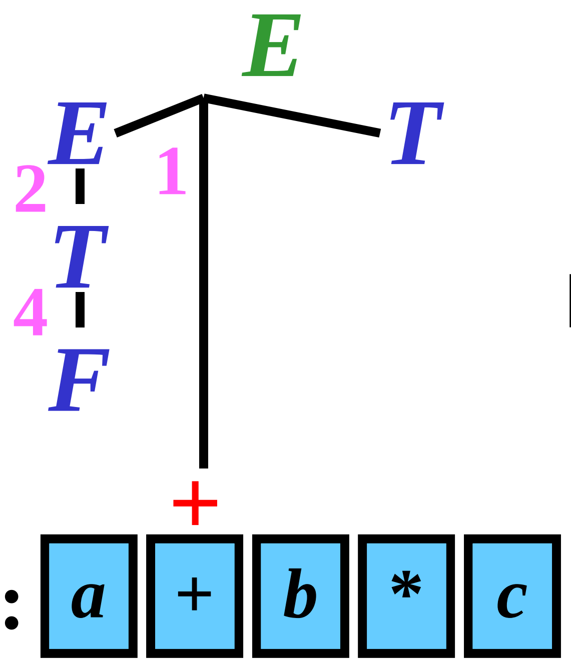
E

Output:

Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	Rules of G_2
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



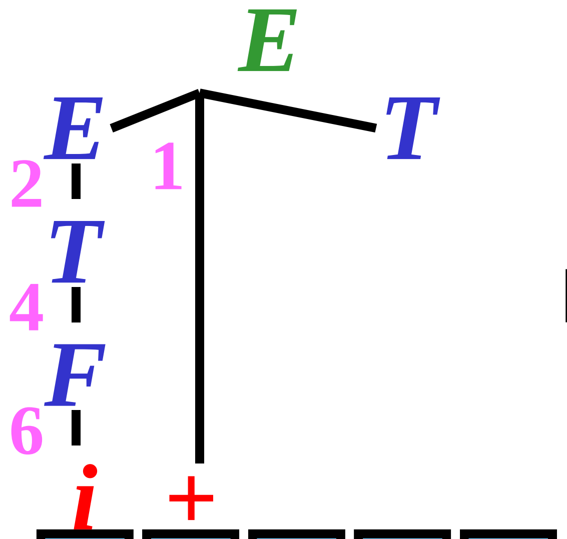
Left parse:
124

Output:

Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	**Rules of G_2**
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Left parse:
1246

Input: a | + | b | * | c

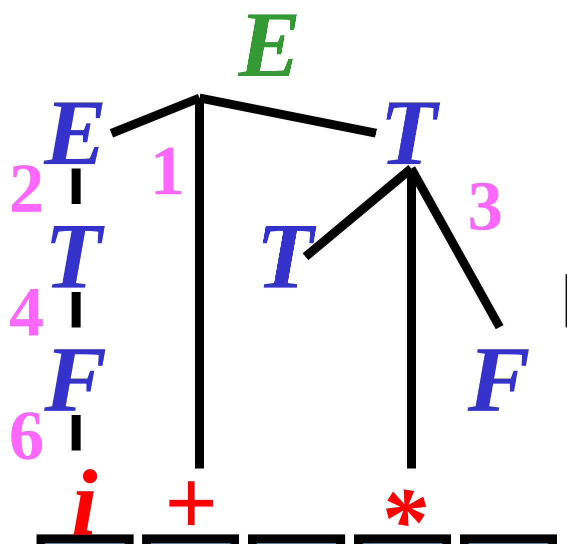
Output:

E

Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	Rules of G_2
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Left parse:
12463

E

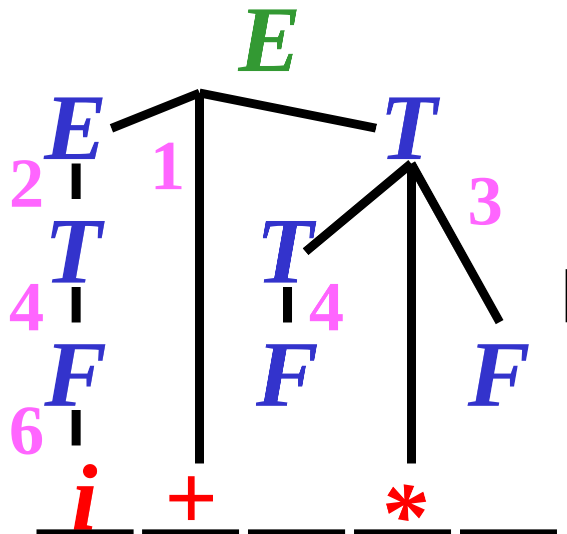
Input: $\boxed{a}\ \boxed{+}\ \boxed{b}\ \boxed{*}\ \boxed{c}$

Output:

Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	**Rules of G_2**
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Left parse:
124634

E

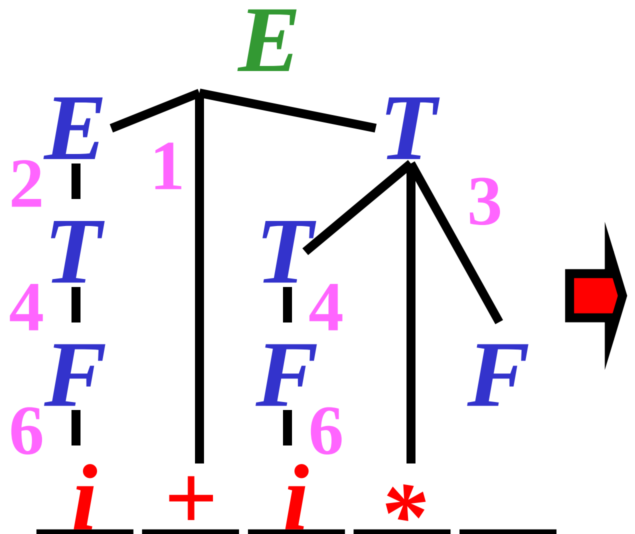
Input: *a* + *b* * *c*

Output:

Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	Rules of G_2
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Left parse:
1246346

E

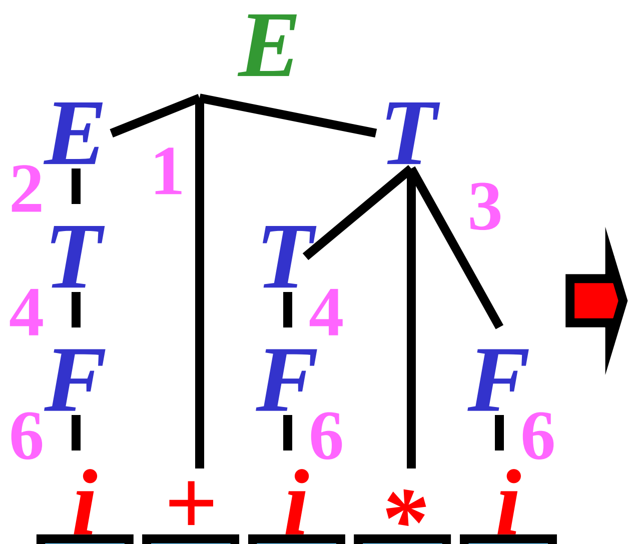
Input: a + b * c

Output:

Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	**Rules of G_2**
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Left parse:
12463466

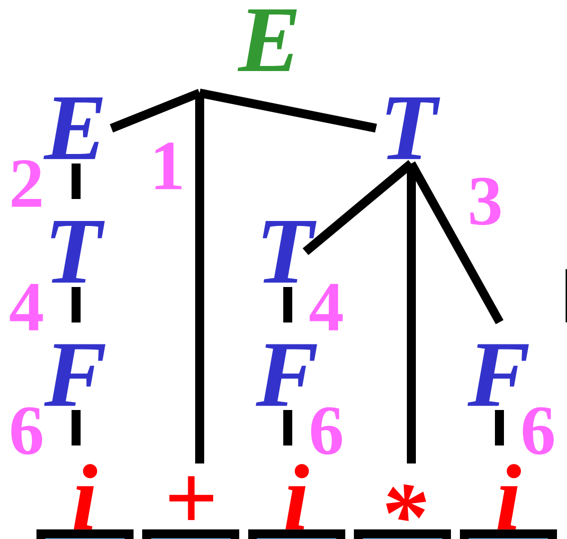
Input: a + b * c

Output:

Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	Rules of G_2
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Left parse:
12463466

E

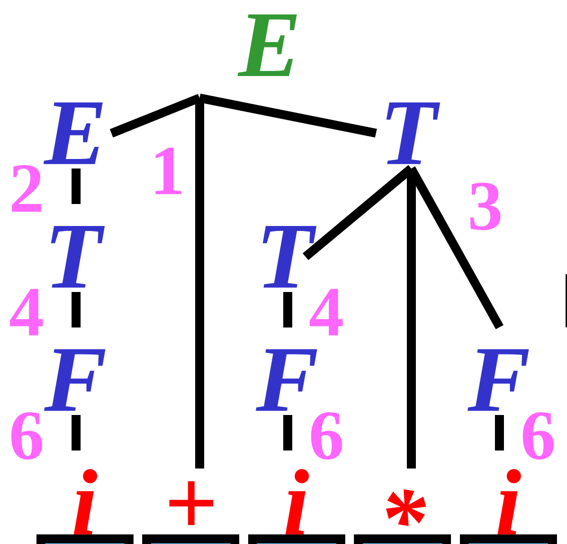
Input: a + b * c

Output:

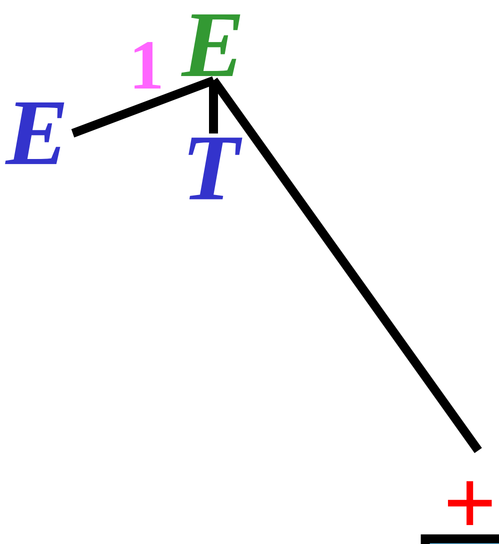
Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	Rules of G_2
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Left parse:
12463466



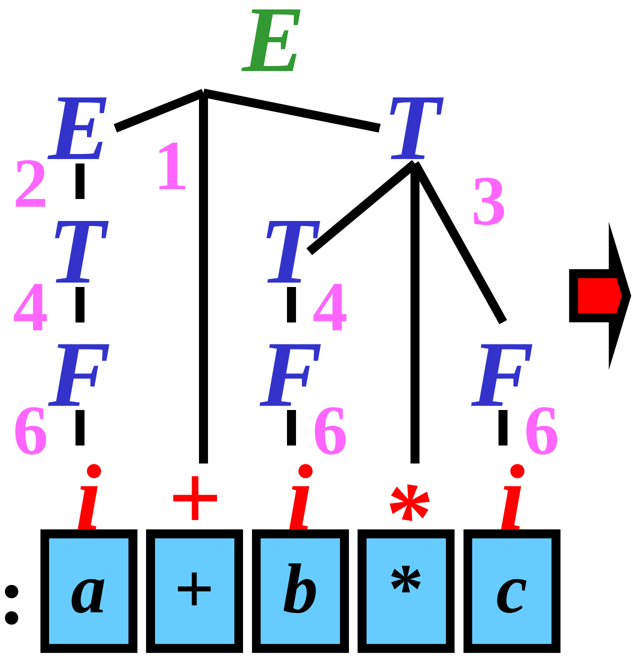
Input: $\boxed{a}\boxed{+}\boxed{b}\boxed{*}\boxed{c}$

Output: $\boxed{+}$

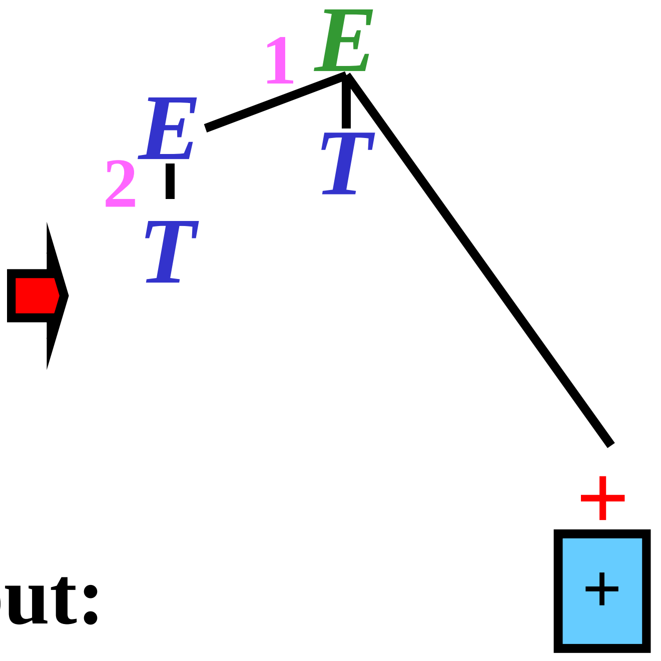
Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	**Rules of G_2**
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



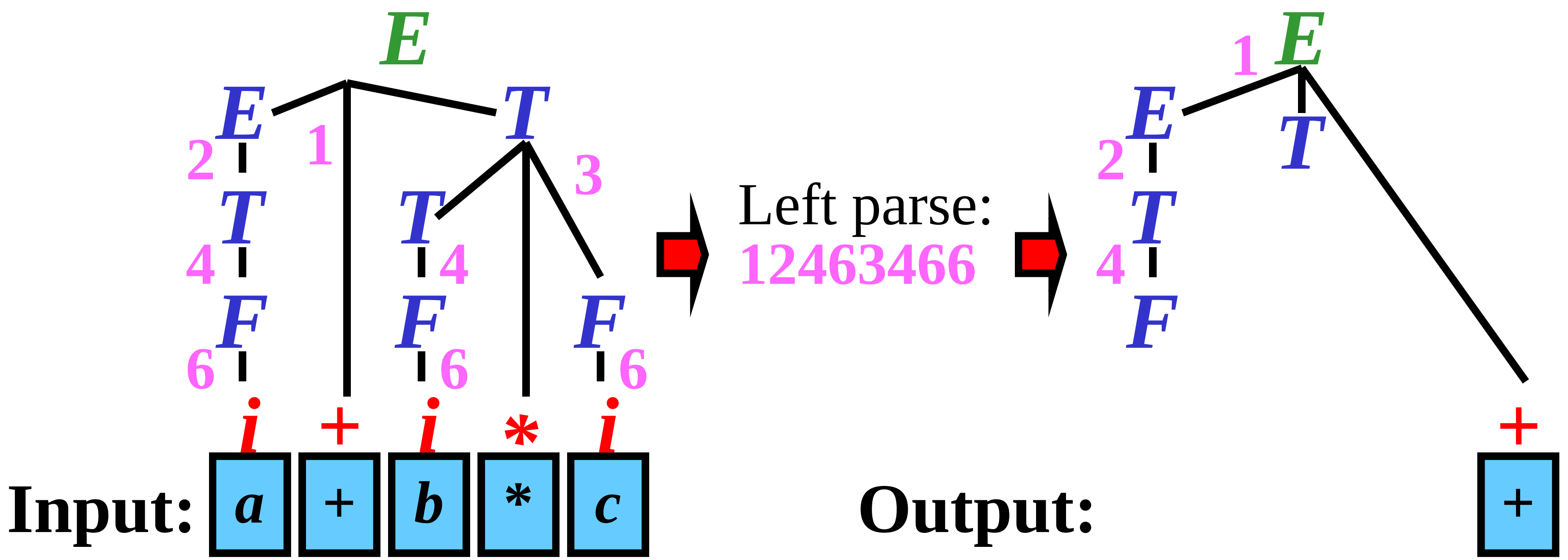
Left parse:
12463466



Two-Grammar Translation

Infix to postfix translation:

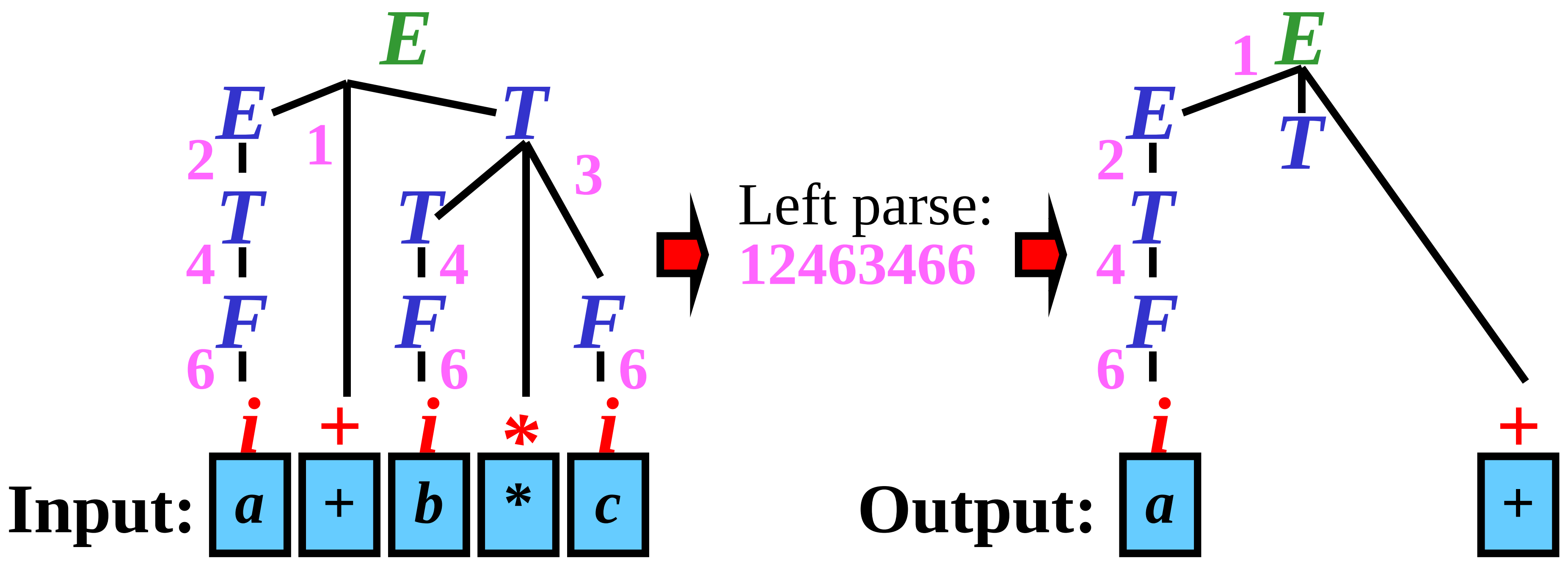
Rules of G_1	Rules of G_2
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Two-Grammar Translation

Infix to postfix translation:

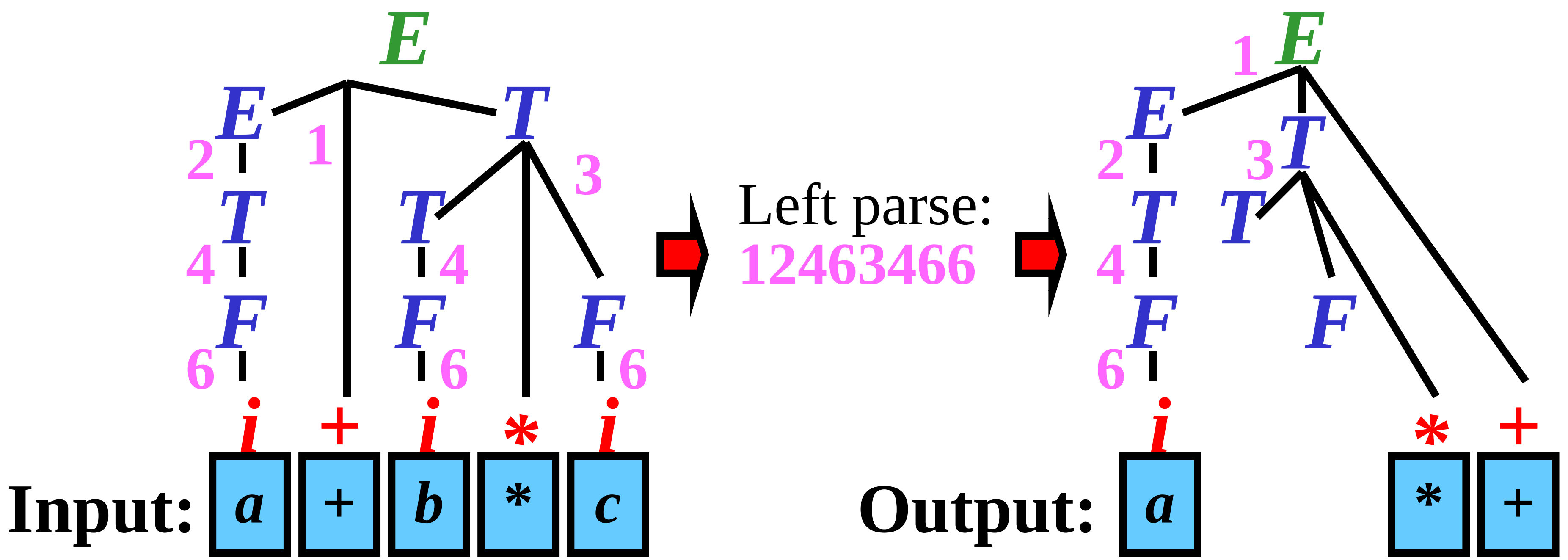
Rules of G_1	**Rules of G_2**
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Two-Grammar Translation

Infix to postfix translation:

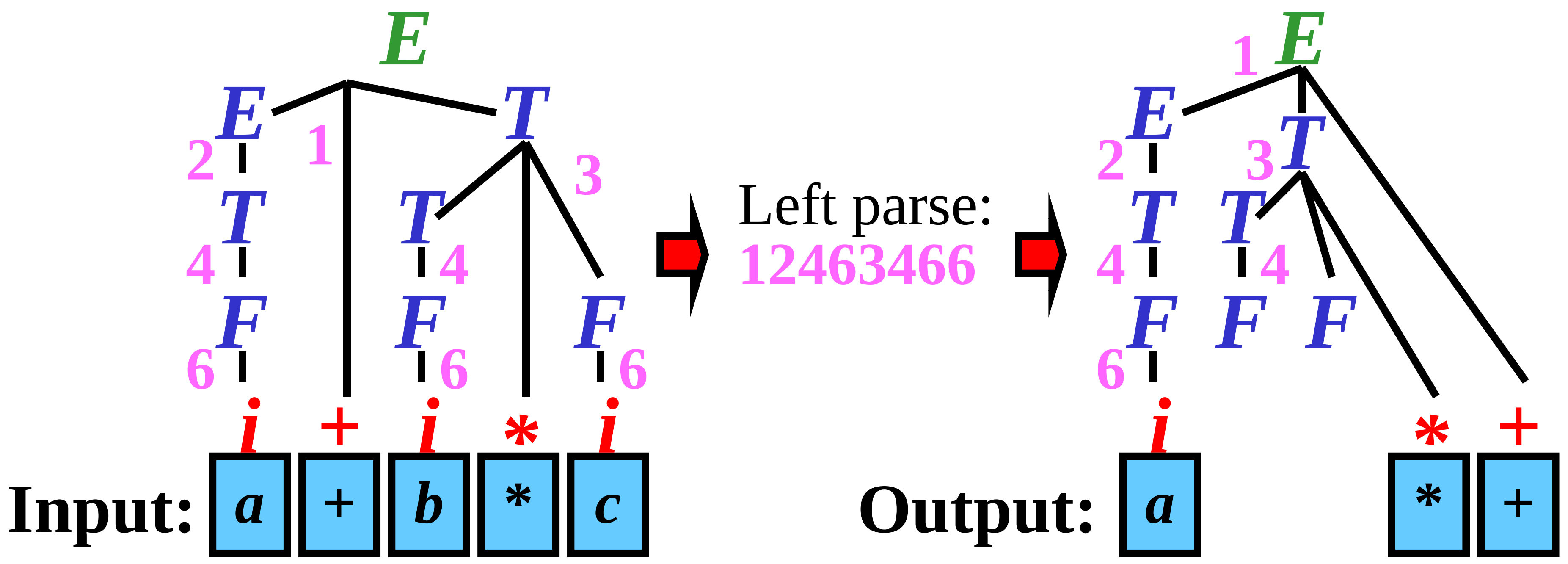
Rules of G_1	Rules of G_2
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	**Rules of G_2**
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$

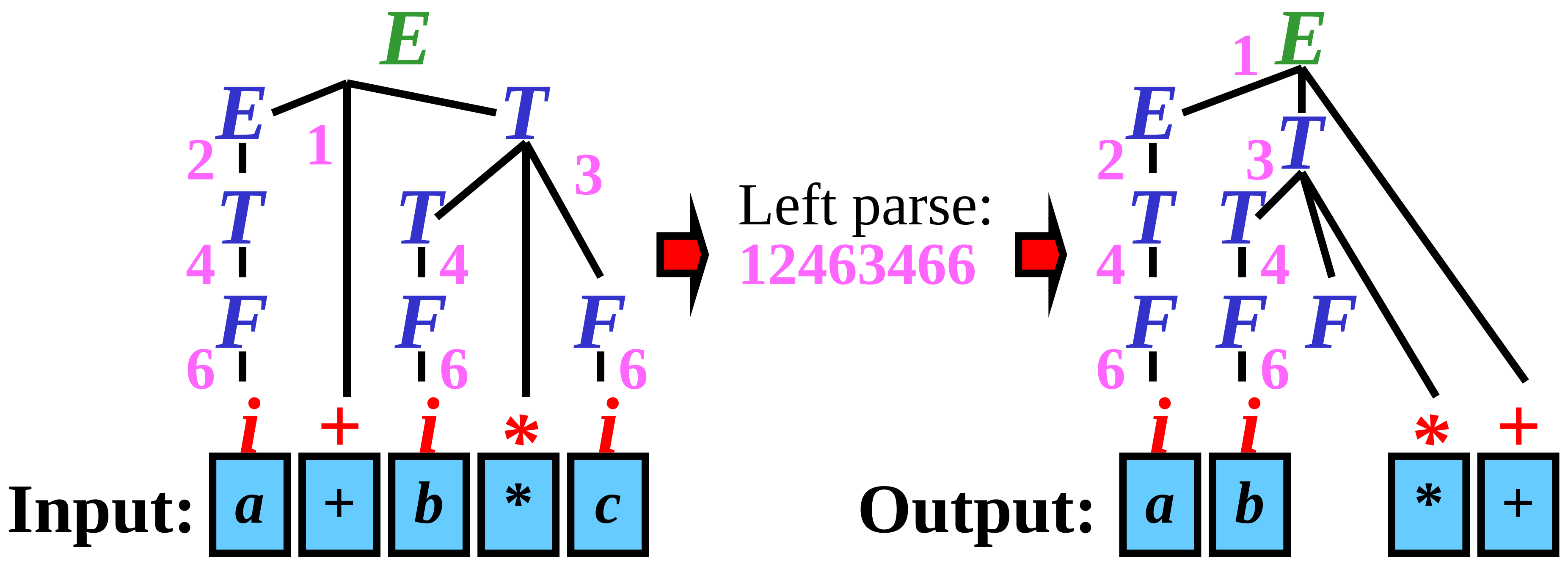


Left parse:
12463466

Two-Grammar Translation

Infix to postfix translation:

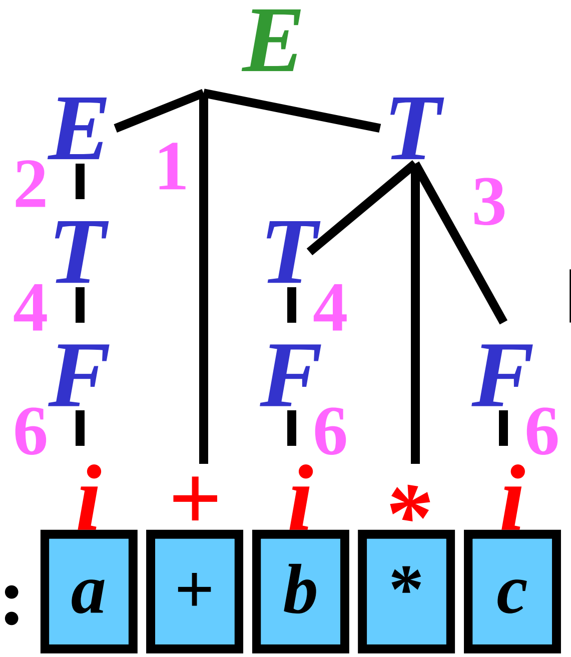
Rules of G_1	**Rules of G_2**
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



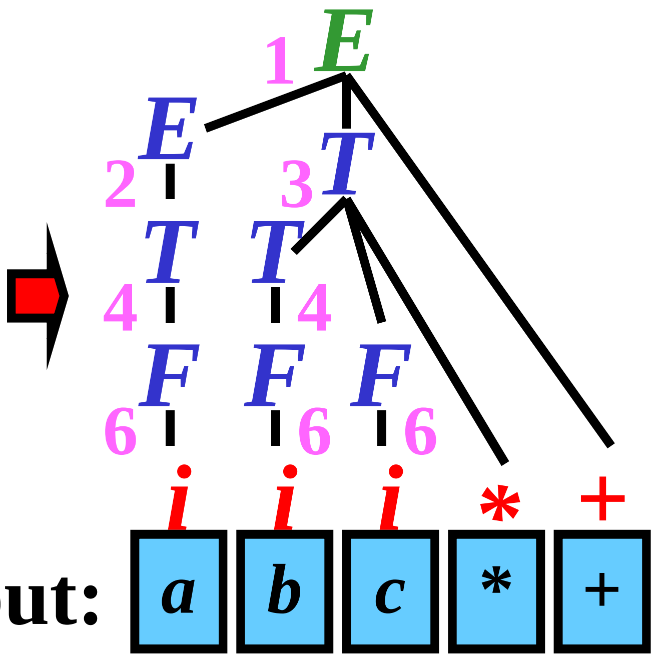
Two-Grammar Translation

Infix to postfix translation:

Rules of G_1	**Rules of G_2**
1: $E \rightarrow E+T$	1: $E \rightarrow ET+$
2: $E \rightarrow T$	2: $E \rightarrow T$
3: $T \rightarrow T*F$	3: $T \rightarrow TF*$
4: $T \rightarrow F$	4: $T \rightarrow F$
5: $F \rightarrow (E)$	5: $F \rightarrow E$
6: $F \rightarrow i$	6: $F \rightarrow i$



Left parse:
12463466

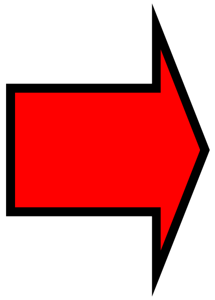


One-Grammar Translation

Infix to postfix translation:

Rule	Tran. Element
1: $E \to E+T$	$ET+$
2: $E \to T$	T
3: $T \to T*F$	$TF*$
4: $T \to F$	F
5: $F \to (E)$	E
6: $F \to i$	i

E E

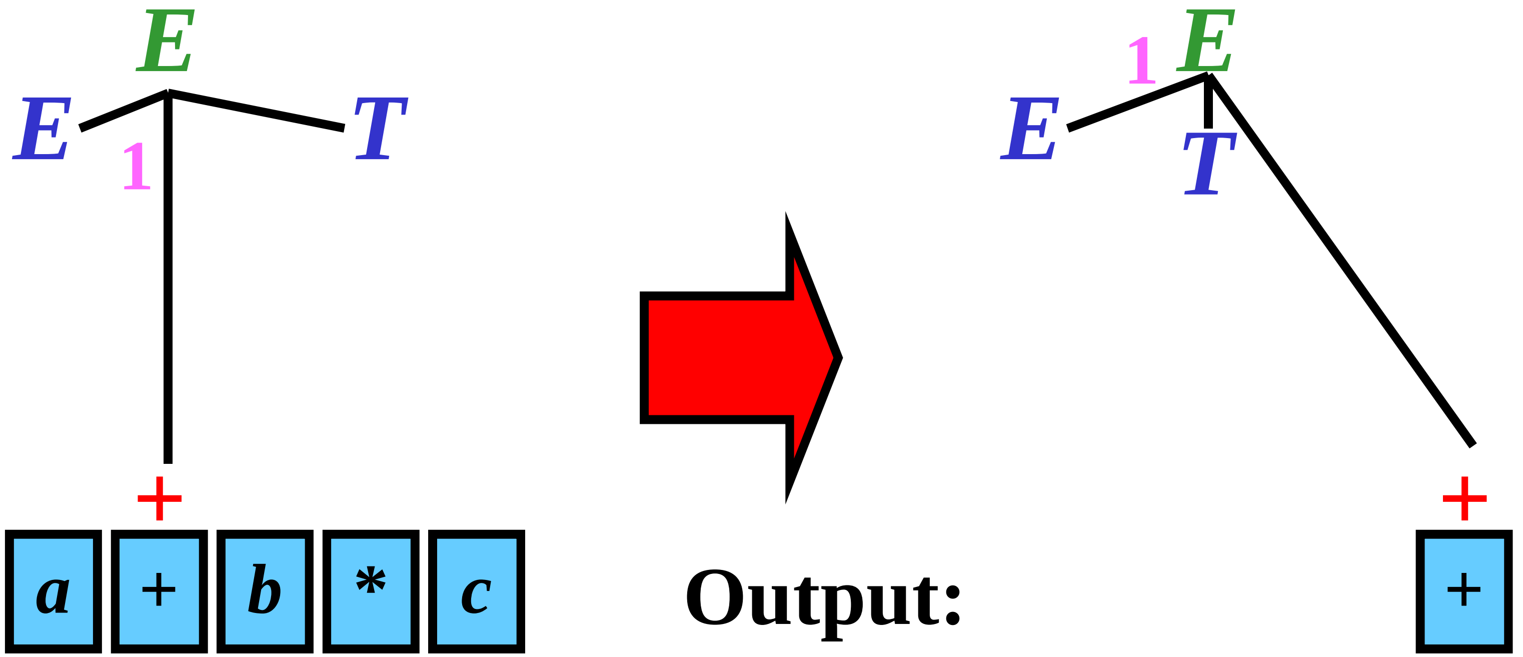


Input: a $+$ b $*$ c **Output:**

One-Grammar Translation

Infix to postfix translation:

Rule	Tran. Element
1: $E \rightarrow E+T$	$ET+$
2: $E \rightarrow T$	T
3: $T \rightarrow T*F$	$TF*$
4: $T \rightarrow F$	F
5: $F \rightarrow (E)$	E
6: $F \rightarrow i$	i

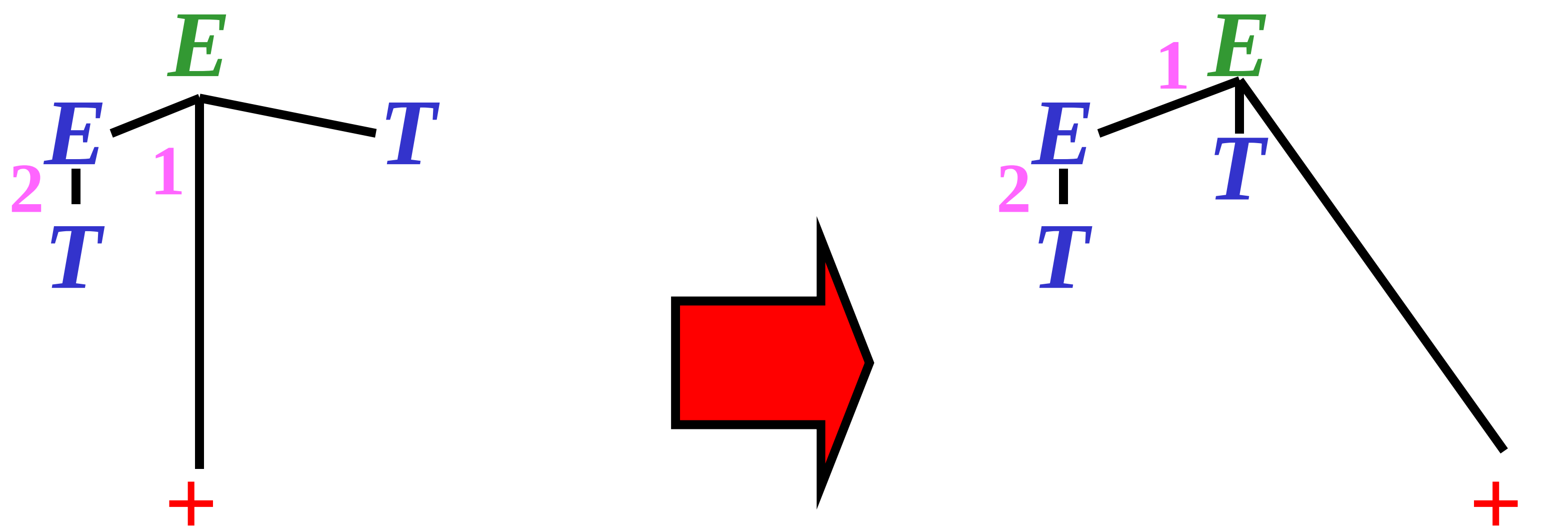


Input: **Output:**

One-Grammar Translation

Infix to postfix translation:

Rule	Tran. Element
1: $E \rightarrow E+T$	$ET+$
2: $E \rightarrow T$	T
3: $T \rightarrow T*F$	$TF*$
4: $T \rightarrow F$	F
5: $F \rightarrow (E)$	E
6: $F \rightarrow i$	i

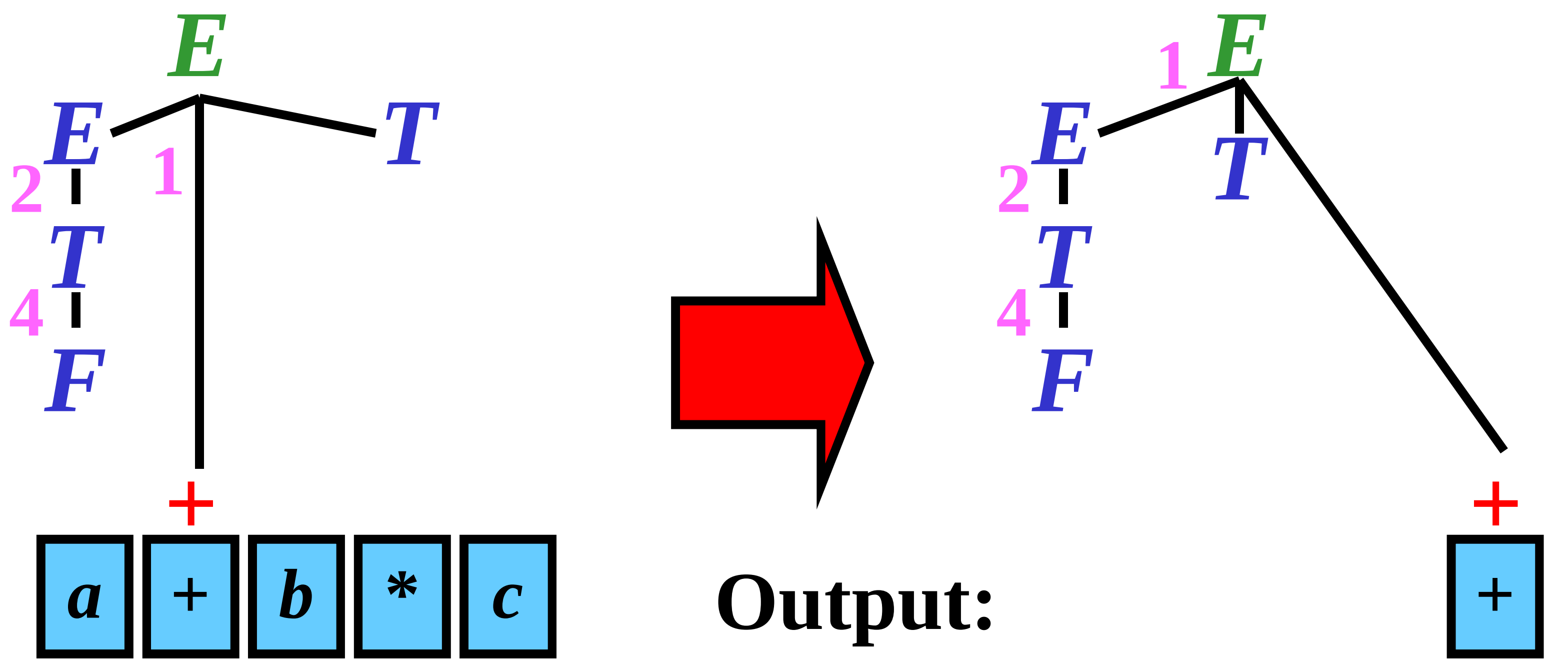


Input: $\boxed{a}\boxed{+}\boxed{b}\boxed{*}\boxed{c}$ **Output:** $\boxed{+}$

One-Grammar Translation

Infix to postfix translation:

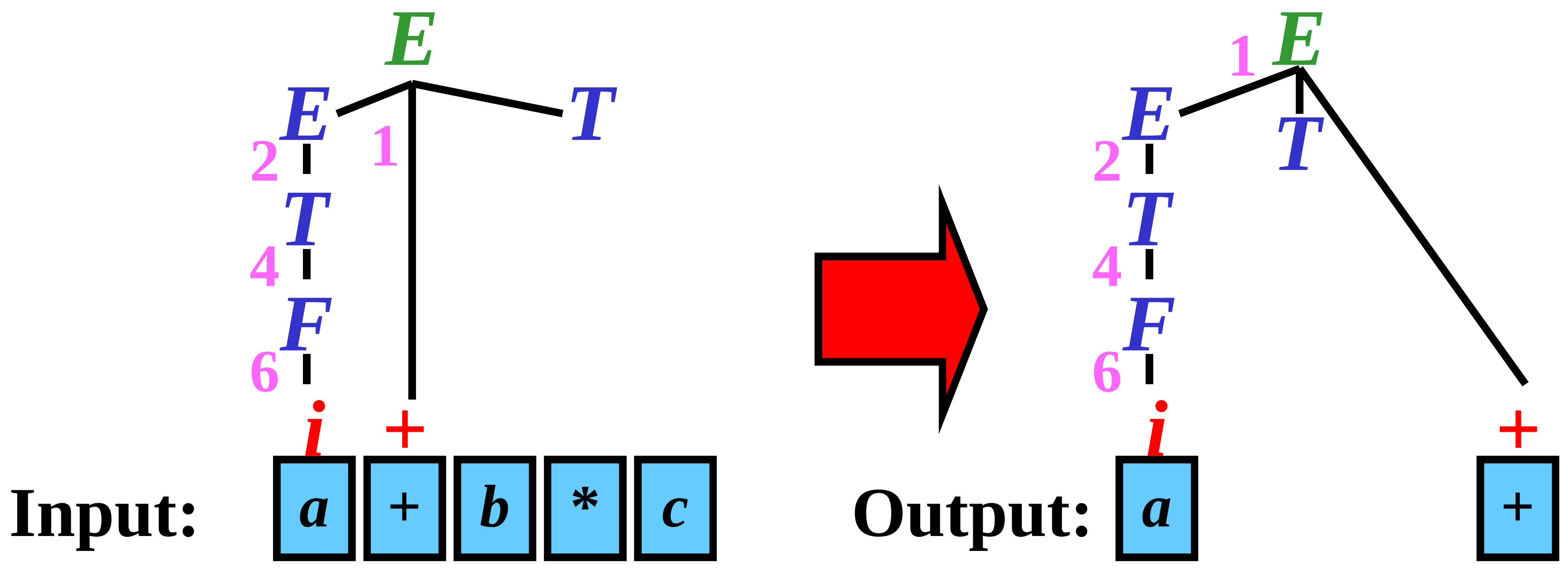
Rule	Tran. Element
1: $E \rightarrow E+T$	$ET+$
2: $E \rightarrow T$	T
3: $T \rightarrow T*F$	$TF*$
4: $T \rightarrow F$	F
5: $F \rightarrow (E)$	E
6: $F \rightarrow i$	i



One-Grammar Translation

Infix to postfix translation:

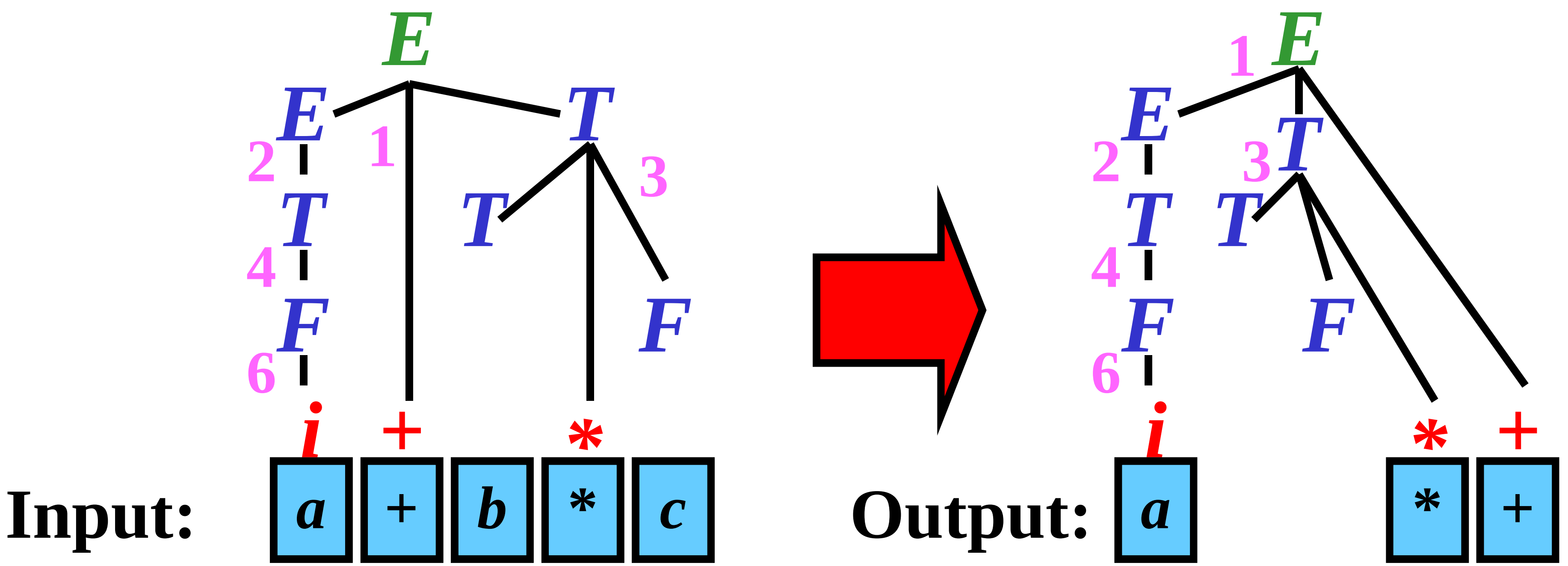
Rule	Tran. Element
1: $E \to E+T$	$ET+$
2: $E \to T$	T
3: $T \to T*F$	$TF*$
4: $T \to F$	F
5: $F \to (E)$	E
6: $F \to i$	i



One-Grammar Translation

Infix to postfix translation:

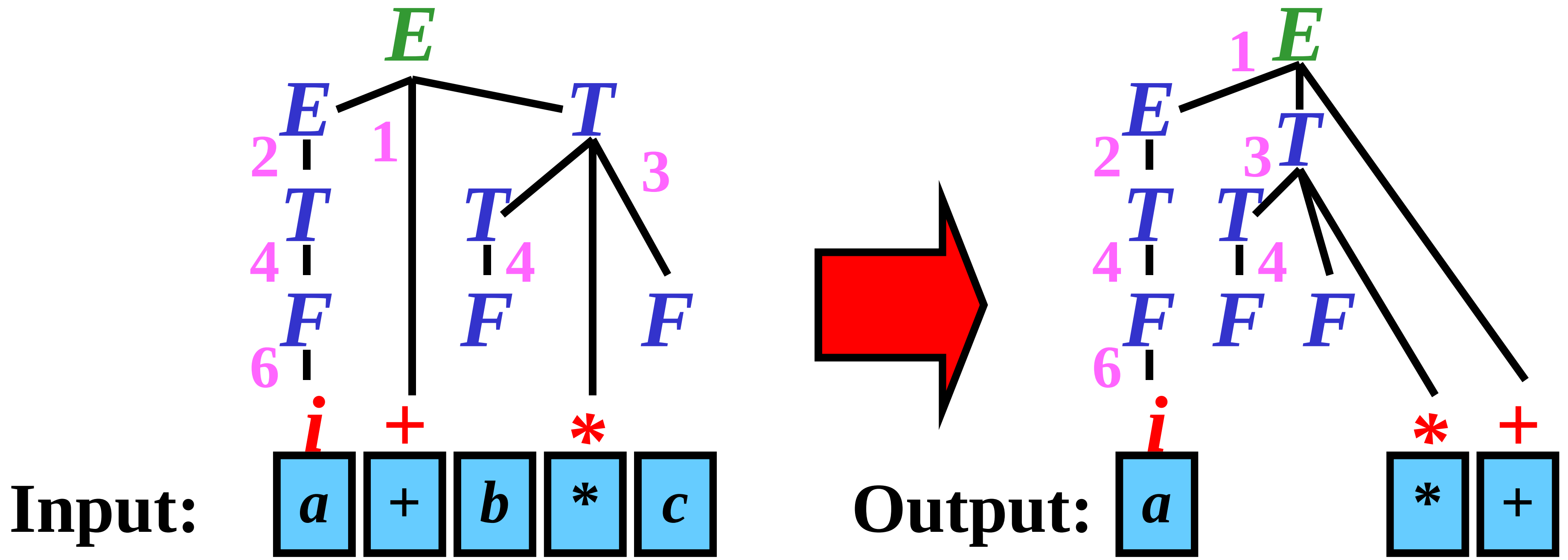
Rule	**Tran. Element**
1: $E \to E+T$	$ET+$
2: $E \to T$	T
3: $T \to T*F$	$TF*$
4: $T \to F$	F
5: $F \to (E)$	E
6: $F \to i$	i



One-Grammar Translation

Infix to postfix translation:

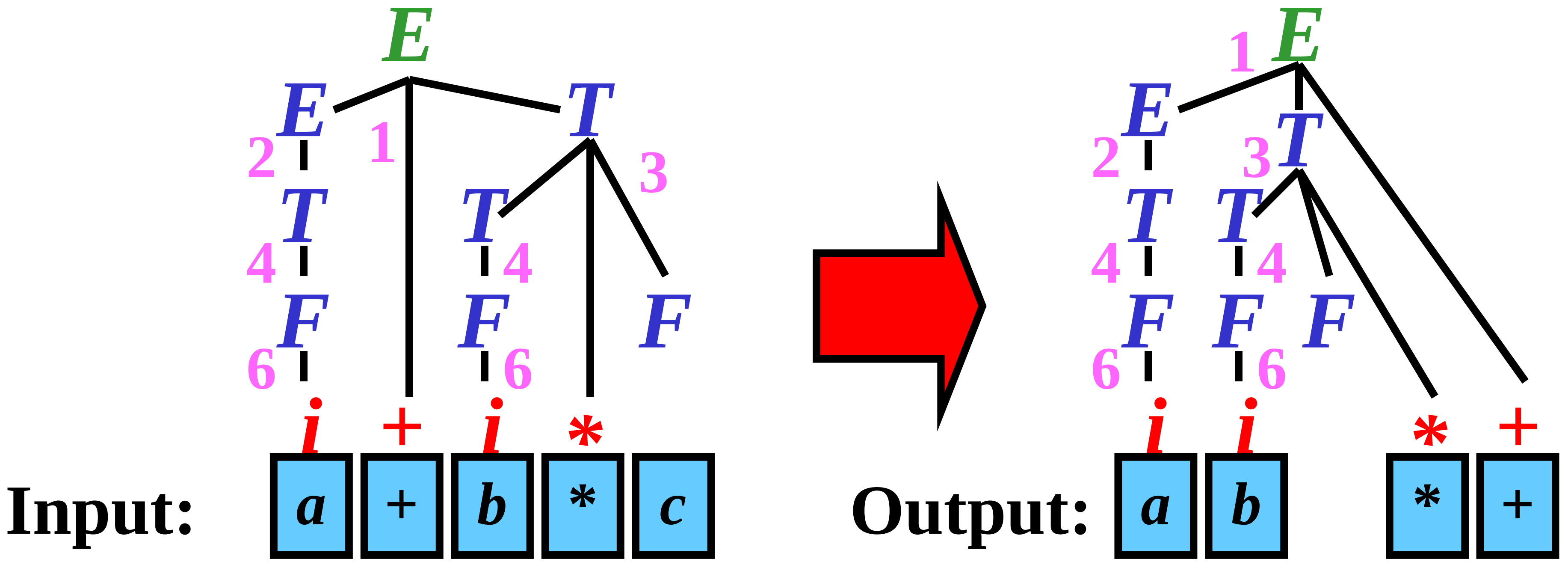
Rule	Tran. Element
1: $E \rightarrow E+T$	$ET+$
2: $E \rightarrow T$	T
3: $T \rightarrow T*F$	$TF*$
4: $T \rightarrow F$	F
5: $F \rightarrow (E)$	E
6: $F \rightarrow i$	i



One-Grammar Translation

Infix to postfix translation:

Rule	**Tran. Element**
1: $E \rightarrow E+T$	$ET+$
2: $E \rightarrow T$	T
3: $T \rightarrow T*F$	$TF*$
4: $T \rightarrow F$	F
5: $F \rightarrow (E)$	E
6: $F \rightarrow i$	i



One-Grammar Translation

Infix to postfix translation:

Rule	Tran. Element
1: $E \rightarrow E+T$	$ET+$
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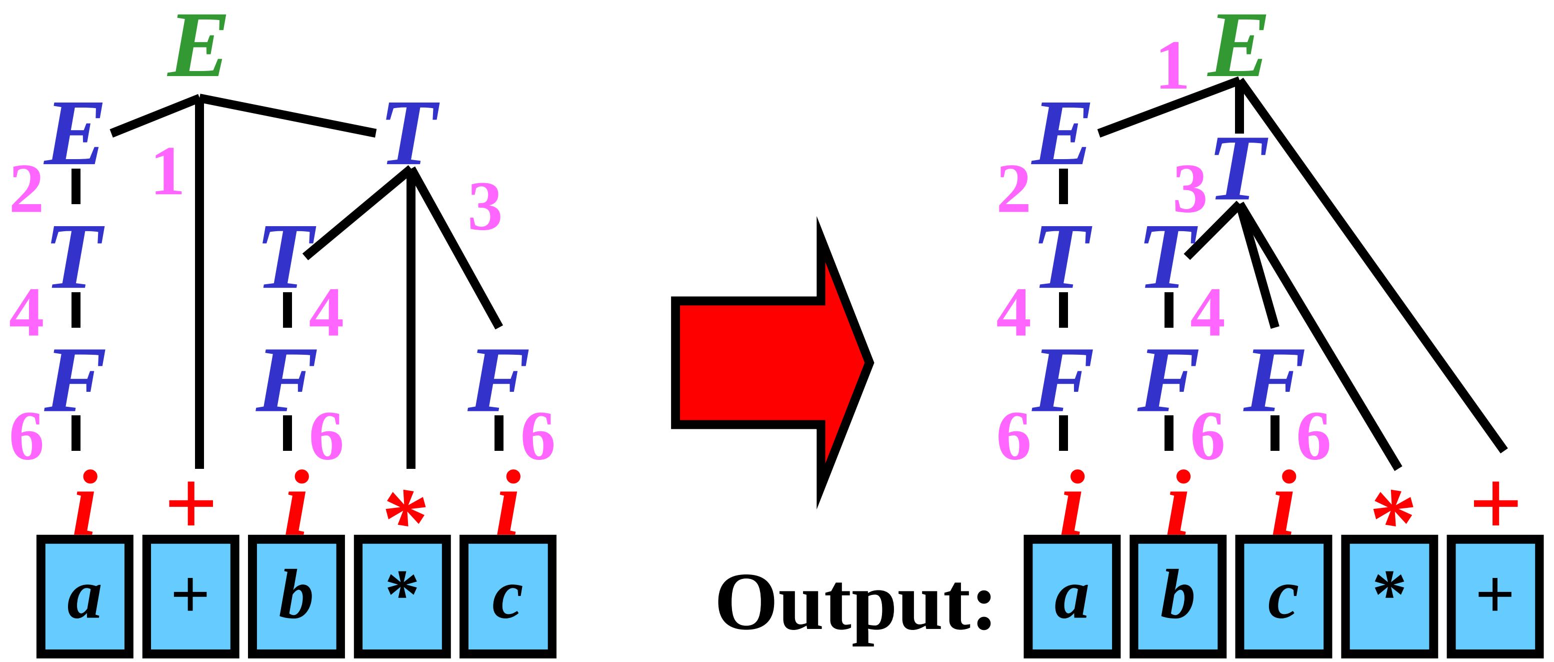
6: $F \rightarrow i$	i



Direct Generation of 3AC

Gist: BU parser directs the generation of 3AC directly.

Example:

Rule:	Semantic Action:
1: $S \rightarrow i = E_k$	{ generate(‘=’, E_k.loc, , i.loc)}
2: $E_i \rightarrow E_j + E_k$	{ generate(‘+’, E_j.loc, E_k.loc, E_i.loc)}
3: $E_i \rightarrow E_j * E_k$	{ generate(‘*’, E_j.loc, E_k.loc, E_i.loc)}
4: $E_i \rightarrow (E_j)$	{ generate(‘=’, E_j.loc, , E_i.loc)}
5: $E_i \rightarrow i$	{ generate(‘=’, i.loc, , E_i.loc)}

Output:

Input: $\boxed{x}\ \boxed{=}\ \boxed{a}\ \boxed{+}\ \boxed{b}\ \boxed{*}\ \boxed{c}$

Direct Generation of 3AC

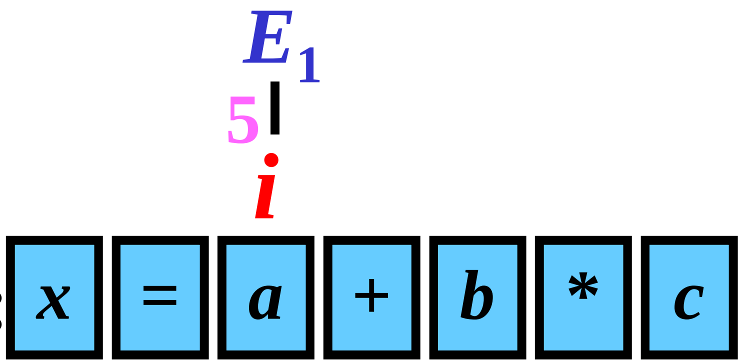
Gist: BU parser directs the generation of 3AC directly.

Example:

Rule:	Semantic Action:
1: $S \rightarrow i = E_k$	{ generate('=', E_k.*loc*, , i.*loc*)}
2: $E_i \rightarrow E_j + E_k$	{ generate('+', E_j.*loc*, E_k.*loc*, E_i.*loc*)}
3: $E_i \rightarrow E_j * E_k$	{ generate('*', E_j.*loc*, E_k.*loc*, E_i.*loc*)}
4: $E_i \rightarrow (E_j)$	{ generate('=', E_j.*loc*, , E_i.*loc*)}
5: $E_i \rightarrow i$	{ generate('=', i.*loc*, , E_i.*loc*)}

Output:

('=', ☛*a*, , E_1.*loc*)

Input:


Direct Generation of 3AC

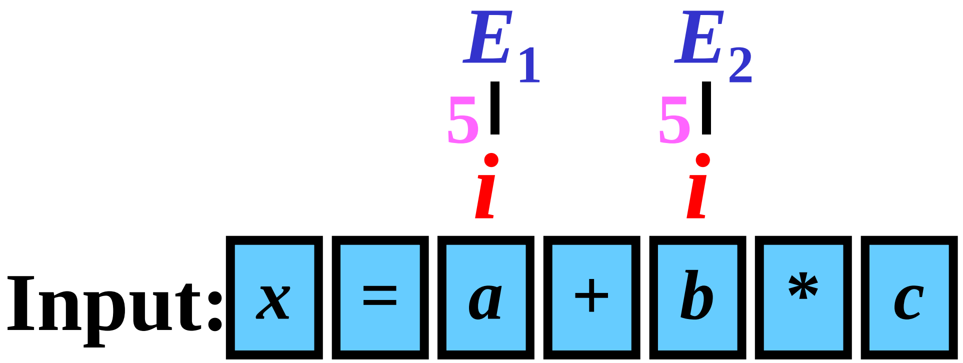
Gist: BU parser directs the generation of 3AC directly.

Example:

Rule:	Semantic Action:
1: $S \rightarrow i = E_k$	{ generate('=', E_k.*loc*, , *i.loc*)}
2: $E_i \rightarrow E_j + E_k$	{ generate('+', E_j.*loc*, E_k.*loc*, E_i.*loc*)}
3: $E_i \rightarrow E_j * E_k$	{ generate('*', E_j.*loc*, E_k.*loc*, E_i.*loc*)}
4: $E_i \rightarrow (E_j)$	{ generate('=', E_j.*loc*, , E_i.*loc*)}
5: $E_i \rightarrow i$	{ generate('=', *i.loc*, , E_i.*loc*)}

Output:

('=', ☛*a*, , E_1.*loc*)
('=', ☛*b*, , E_2.*loc*)

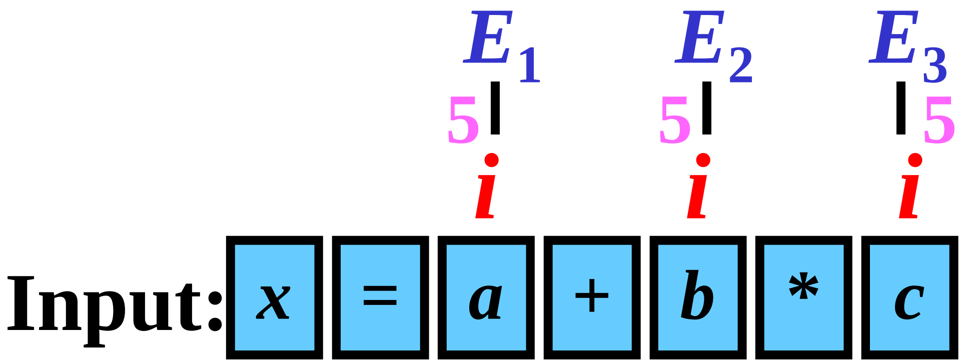


Direct Generation of 3AC

Gist: BU parser directs the generation of 3AC directly.

Example:

Rule:	Semantic Action:
1: $S \rightarrow i = E_k$	{ generate('=', E_k.*loc*, , i.*loc*)}
2: $E_i \rightarrow E_j + E_k$	{ generate('+', E_j.*loc*, E_k.*loc*, E_i.*loc*)}
3: $E_i \rightarrow E_j * E_k$	{ generate('*', E_j.*loc*, E_k.*loc*, E_i.*loc*)}
4: $E_i \rightarrow (E_j)$	{ generate('=', E_j.*loc*, , E_i.*loc*)}
5: $E_i \rightarrow i$	{ generate('=', i.*loc*, , E_i.*loc*)}



Output:

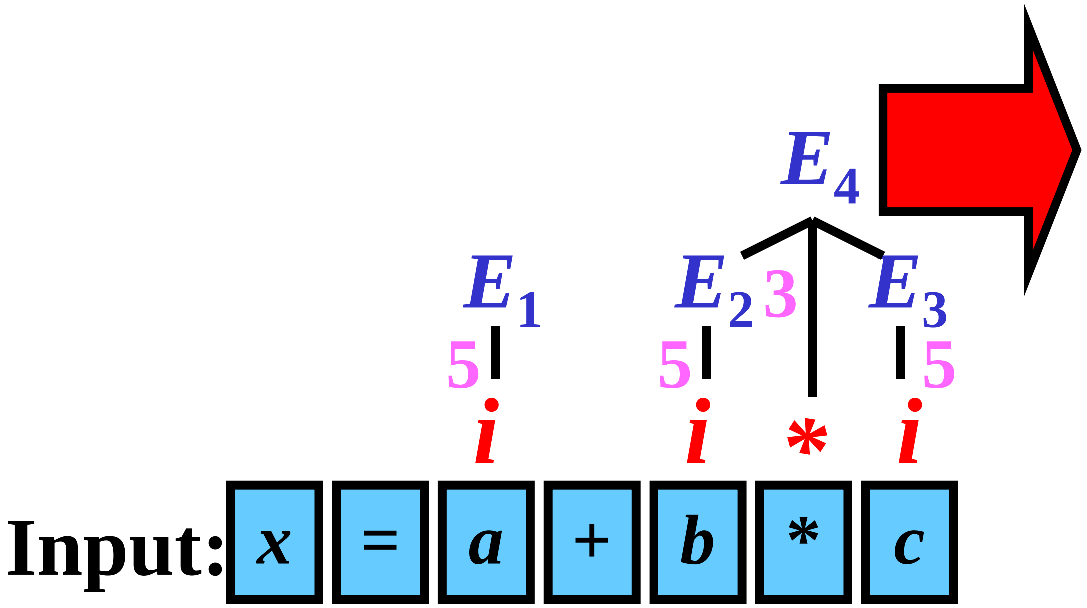
('=', ☛*a*, , E_1.*loc*)
('=', ☛*b*, , E_2.*loc*)
('=', ☛*c*, , E_3.*loc*)

Direct Generation of 3AC

Gist: BU parser directs the generation of 3AC directly.

Example:

Rule:	**Semantic Action:**
1: $S \rightarrow i = E_k$	{ generate('=', $E_k.loc$, , $i.loc$)}
2: $E_i \rightarrow E_j + E_k$	{ generate('+', $E_j.loc$, $E_k.loc$, $E_i.loc$)}
3: $E_i \rightarrow E_j * E_k$	{ generate('*', $E_j.loc$, $E_k.loc$, $E_i.loc$)}
4: $E_i \rightarrow (E_j)$	{ generate('=', $E_j.loc$, , $E_i.loc$)}
5: $E_i \rightarrow i$	{ generate('=', $i.loc$, , $E_i.loc$)}



Output:

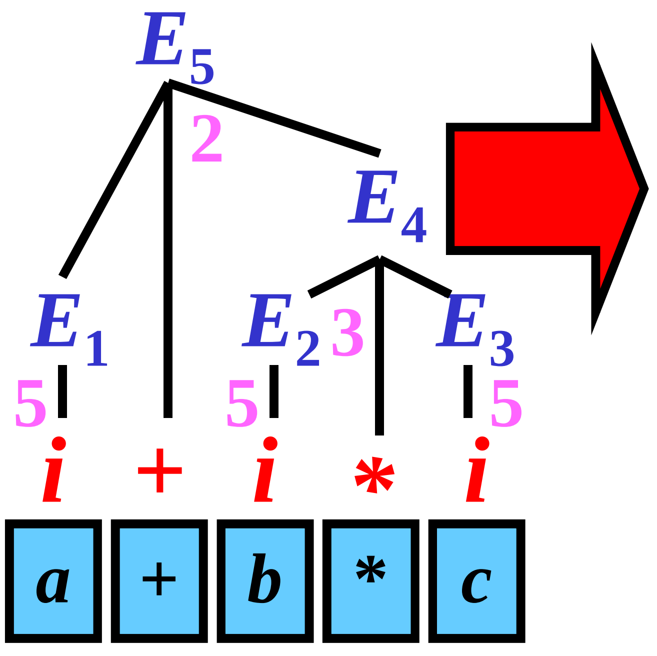
('=', ☛a, , $E_1.loc$)
('=', ☛b, , $E_2.loc$)
('=', ☛c, , $E_3.loc$)
('*', $E_2.loc$,$E_3.loc$,$E_4.loc$)

Direct Generation of 3AC

Gist: BU parser directs the generation of 3AC directly.

Example:

Rule:	**Semantic Action:**
1: $S \rightarrow i = E_k$	**{ generate(‘=’,** E_k.*loc*, , *i.loc*)}
2: $E_i \rightarrow E_j + E_k$	**{ generate(‘+’,** E_j.*loc*, E_k.*loc*, E_i.*loc*)}
3: $E_i \rightarrow E_j * E_k$	**{ generate(‘*’,** E_j.*loc*, E_k.*loc*, E_i.*loc*)}
4: $E_i \rightarrow (E_j)$	**{ generate(‘=’,** E_j.*loc*, , E_i.*loc*)}
5: $E_i \rightarrow i$	**{ generate(‘=’,** *i.loc*, , E_i.*loc*)}



Output:

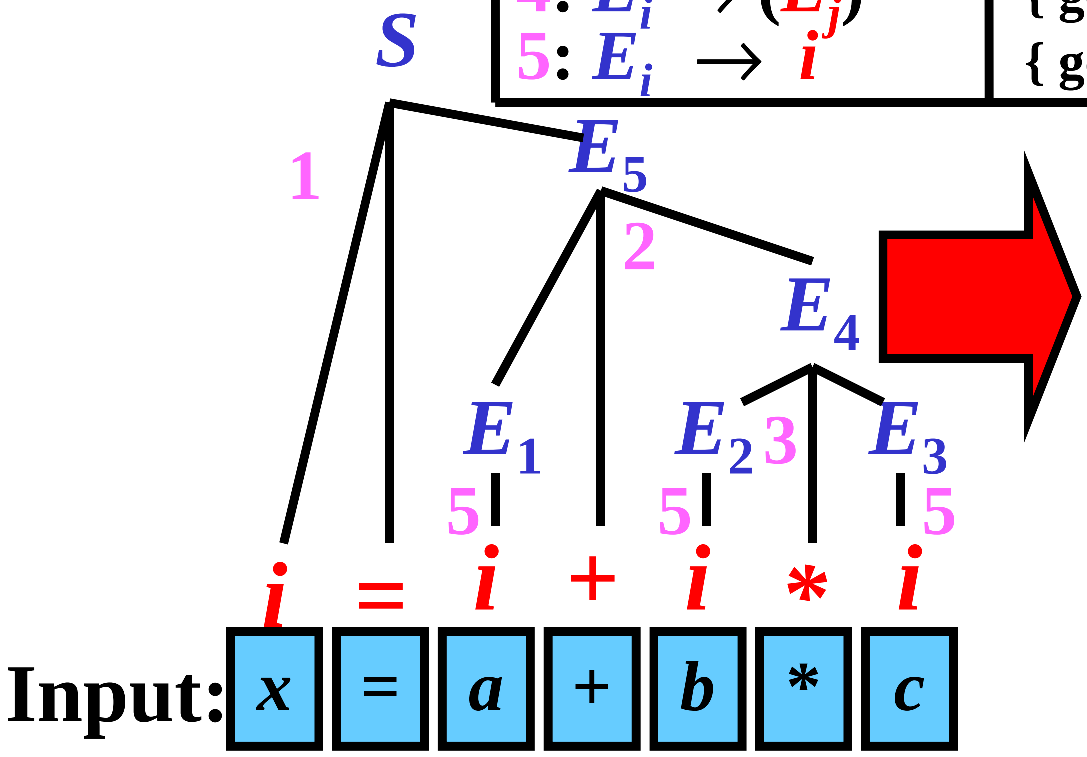
(‘=’, ☛*a*, , E_1.*loc*)
(‘=’, ☛*b*, , E_2.*loc*)
(‘=’, ☛*c*, , E_3.*loc*)
(‘*’, E_2.*loc*,E_3.*loc*,E_4.*loc*)
(‘+’, E_1.*loc*,E_4.*loc*,E_5.*loc*)

Direct Generation of 3AC

Gist: BU parser directs the generation of 3AC directly.

Example:

Rule:	Semantic Action:
1: $S \rightarrow i = E_k$	{ generate('=', E_k.loc, , i.loc)}
2: $E_i \rightarrow E_j + E_k$	{ generate('+', E_j.loc, E_k.loc, E_i.loc)}
3: $E_i \rightarrow E_j * E_k$	{ generate('*', E_j.loc, E_k.loc, E_i.loc)}
4: $E_i \rightarrow (E_j)$	{ generate('=', E_j.loc, , E_i.loc)}
5: $E_i \rightarrow i$	{ generate('=', i.loc, , E_i.loc)}

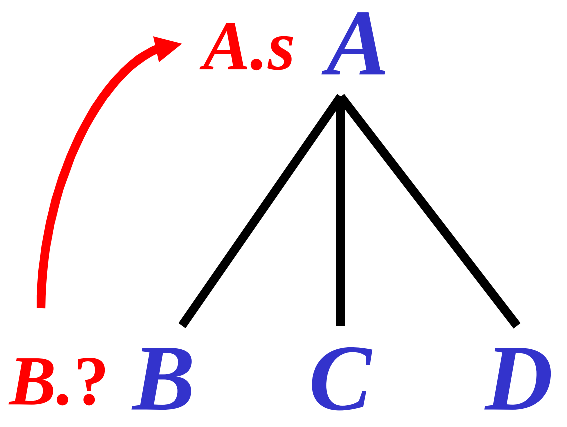


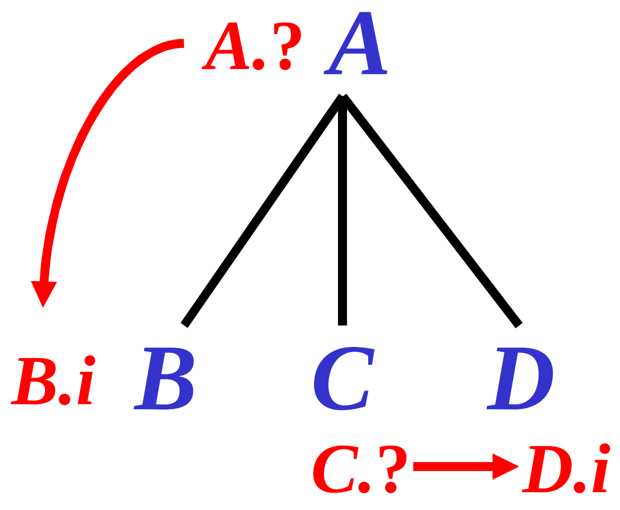
Output:

('=', ☛a, , E_1.loc)
('=', ☛b, , E_2.loc)
('=', ☛c, , E_3.loc)
('*', E_2.loc, E_3.loc, E_4.loc)
('+', E_1.loc, E_4.loc, E_5.loc)
('=', E_5.loc, , ☛x)

Top-Down Translation: Introduction

- **LL-grammar with attributes**
- **Two pushdown:**
  - **parser pushdown × semantic pushdown**
- **Two type of attributes:**
  - **synthesized:** (from children to parent) | **iherited:** (from parent to children or between siblings)



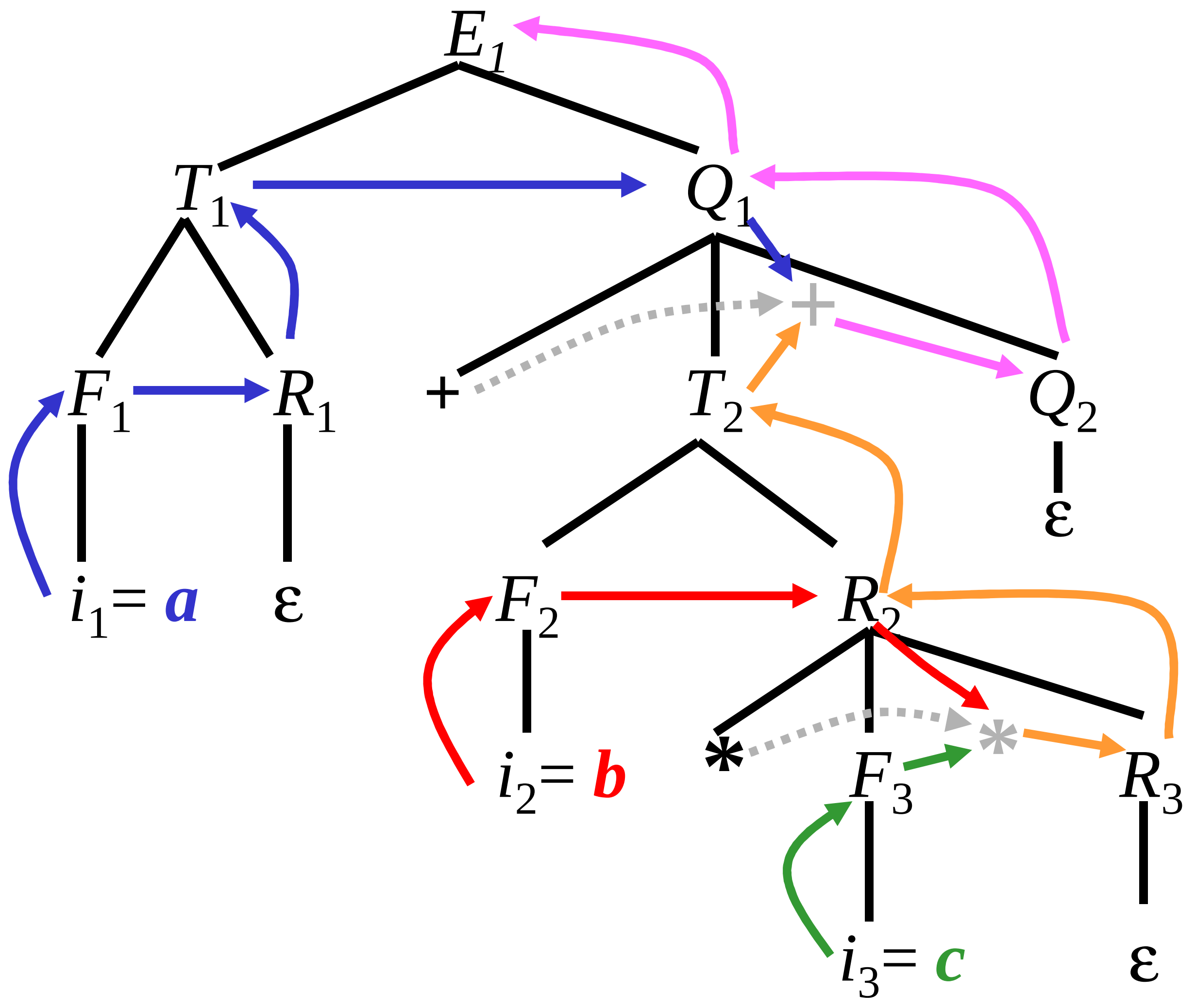


Top-Down Translation: Expressions

Grammar:

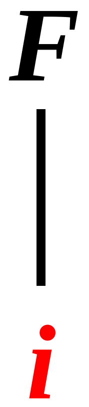
$E \rightarrow TQ$
$Q \rightarrow +TQ$
$Q \rightarrow \varepsilon$
$T \rightarrow FR$
$R \rightarrow *FR$
$R \rightarrow \varepsilon$
$F \rightarrow (E)$
$F \rightarrow i$

Parse tree for *a* + *b* * *c*:



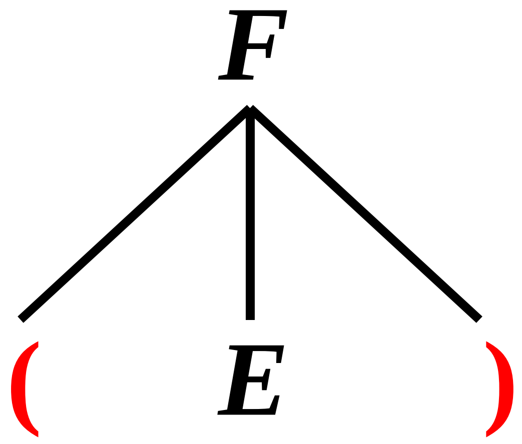
Expressions: Variable & Parentheses

Variable:



$F \rightarrow i$

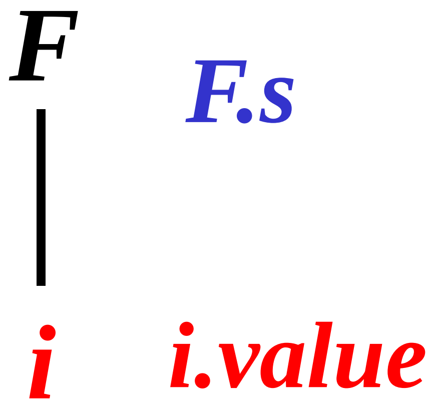
Parentheses:



$E \rightarrow (F \qquad)$

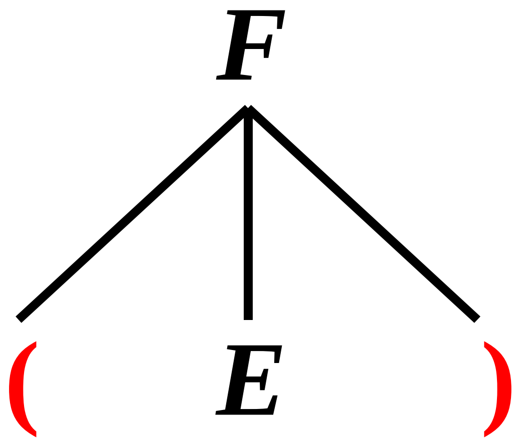
Expressions: Variable & Parentheses

Variable:



$F \rightarrow i$

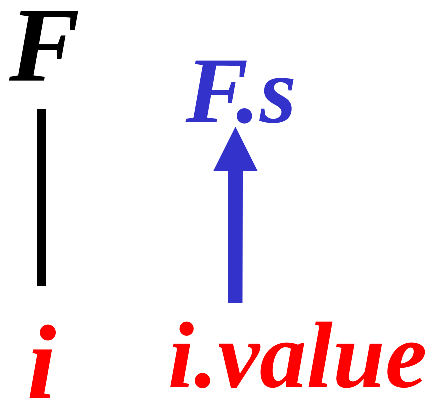
Parentheses:



$E \rightarrow (F \qquad)$

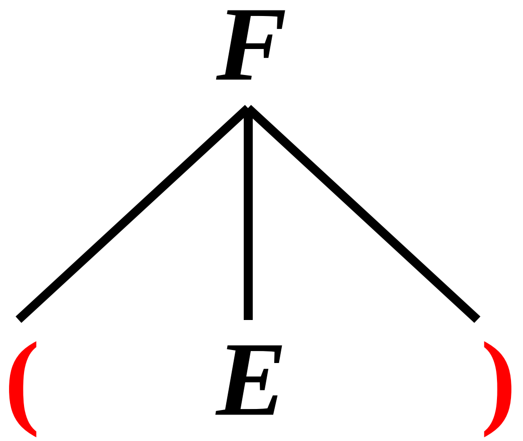
Expressions: Variable & Parentheses

Variable:



$$\boxed{F \rightarrow i \ \{F.s := i.value\}}$$

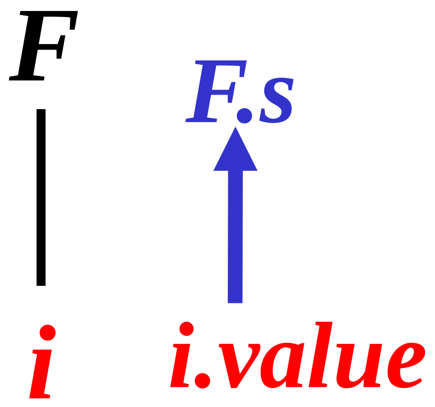
Parentheses:



$E \rightarrow (F \qquad)$

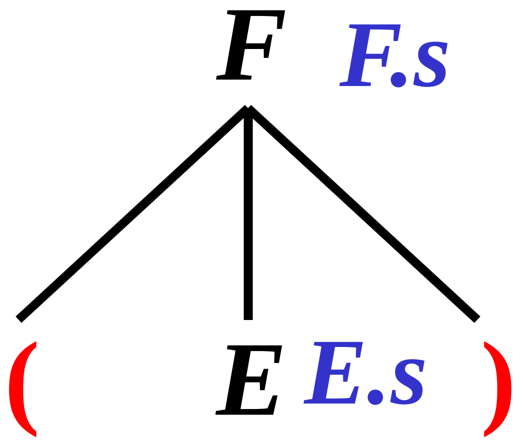
Expressions: Variable & Parentheses

Variable:



$\boxed{F \rightarrow i \ \{F.s := i.value\}}$

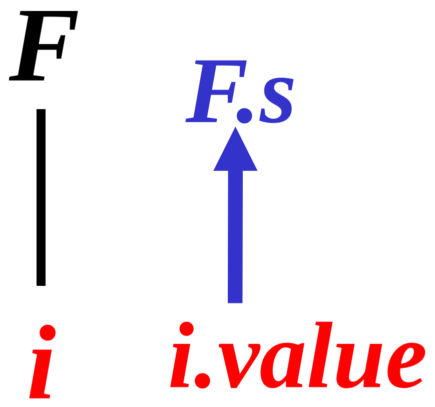
Parentheses:



$E \rightarrow (F \qquad\qquad\qquad)$

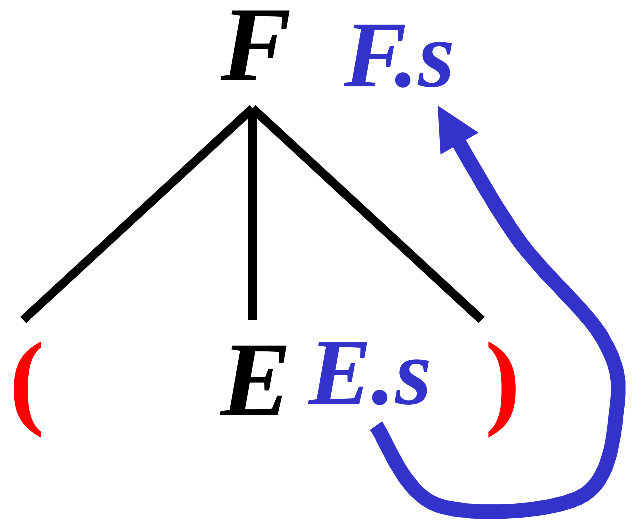
Expressions: Variable & Parentheses

Variable:



$F \rightarrow i \; \{F.s := i.value\}$

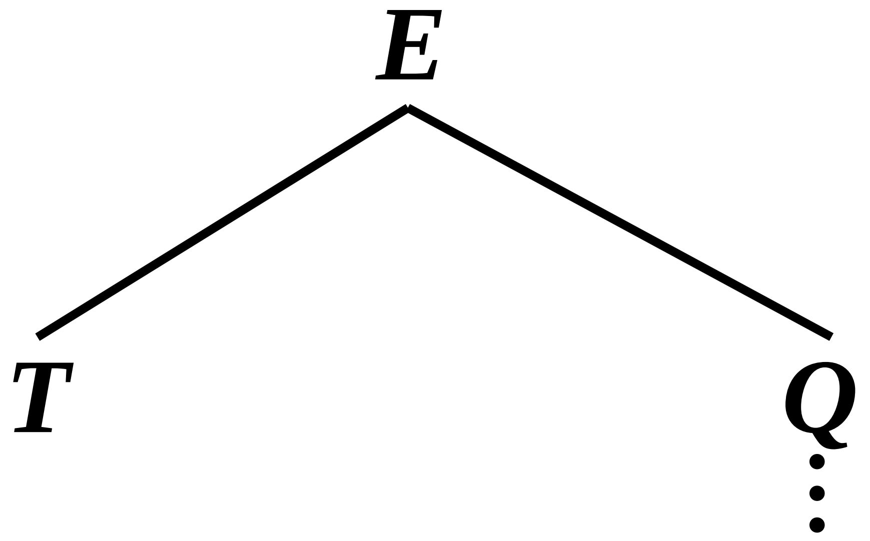
Parentheses:



$E \rightarrow (F \; \{F.s := E.s\} \;)$

Expressions: Addition 1/4

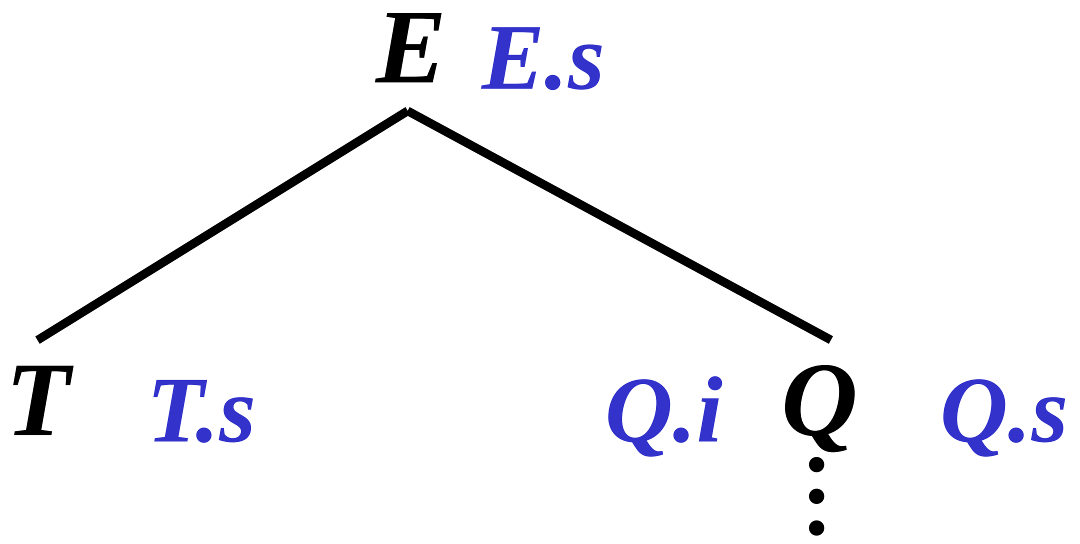
I.



$$E \rightarrow T \qquad\qquad\qquad\qquad Q$$

Expressions: Addition 1/4

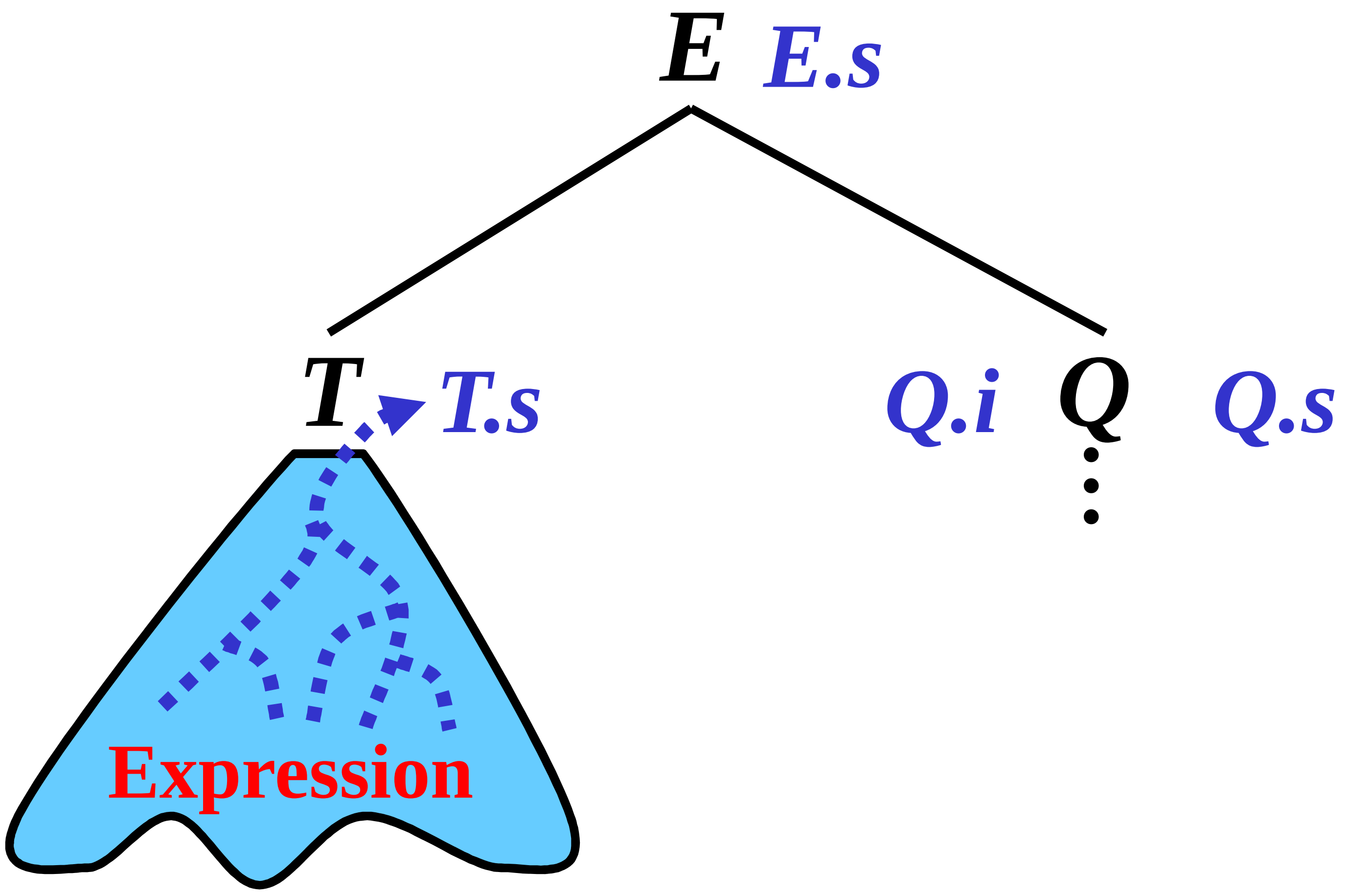
I.



$\boldsymbol{E} \rightarrow \boldsymbol{T} \qquad\qquad\qquad\qquad \boldsymbol{Q}$

Expressions: Addition 1/4

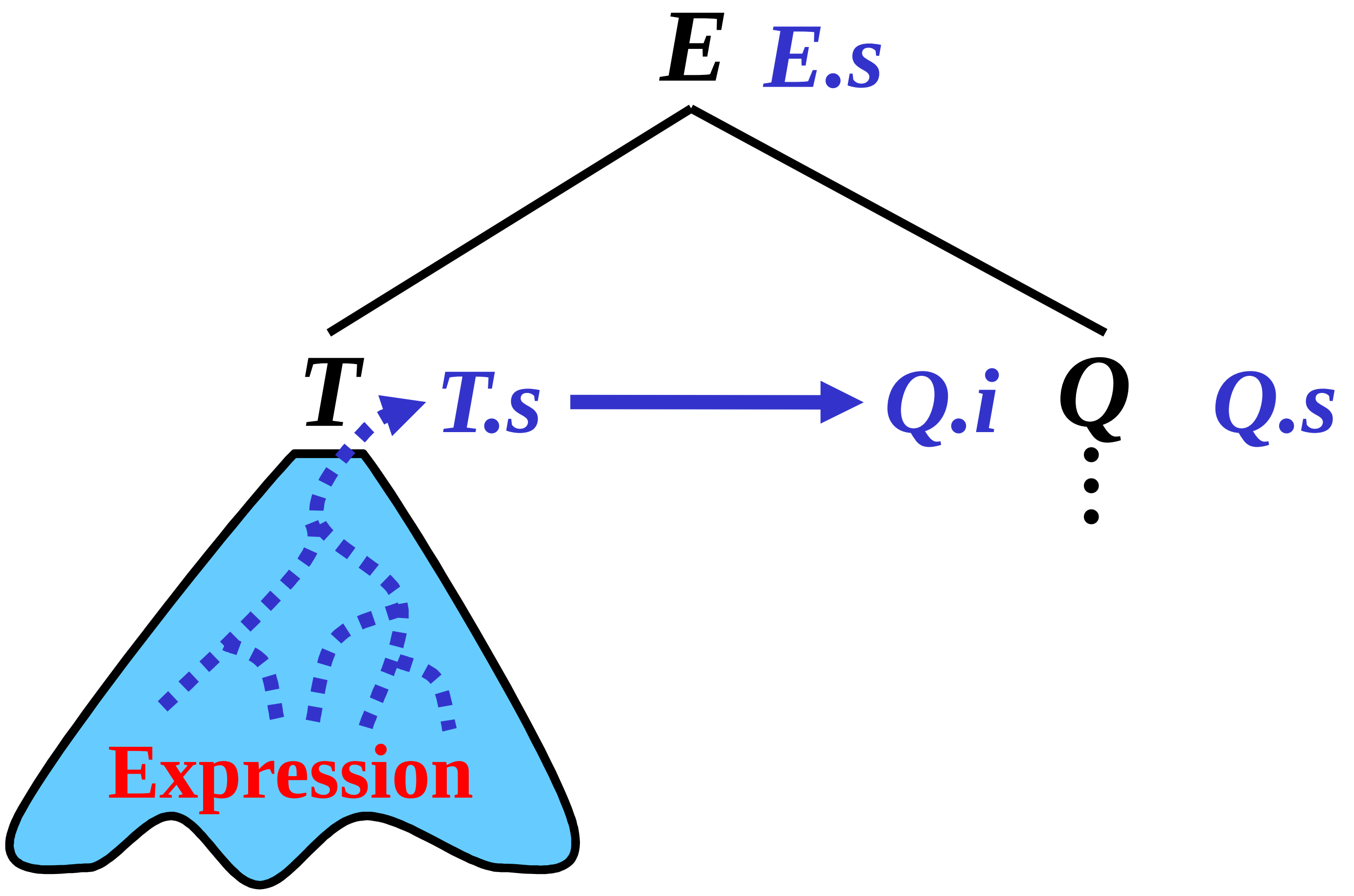
I.



$E \rightarrow T$ Q

Expressions: Addition 1/4

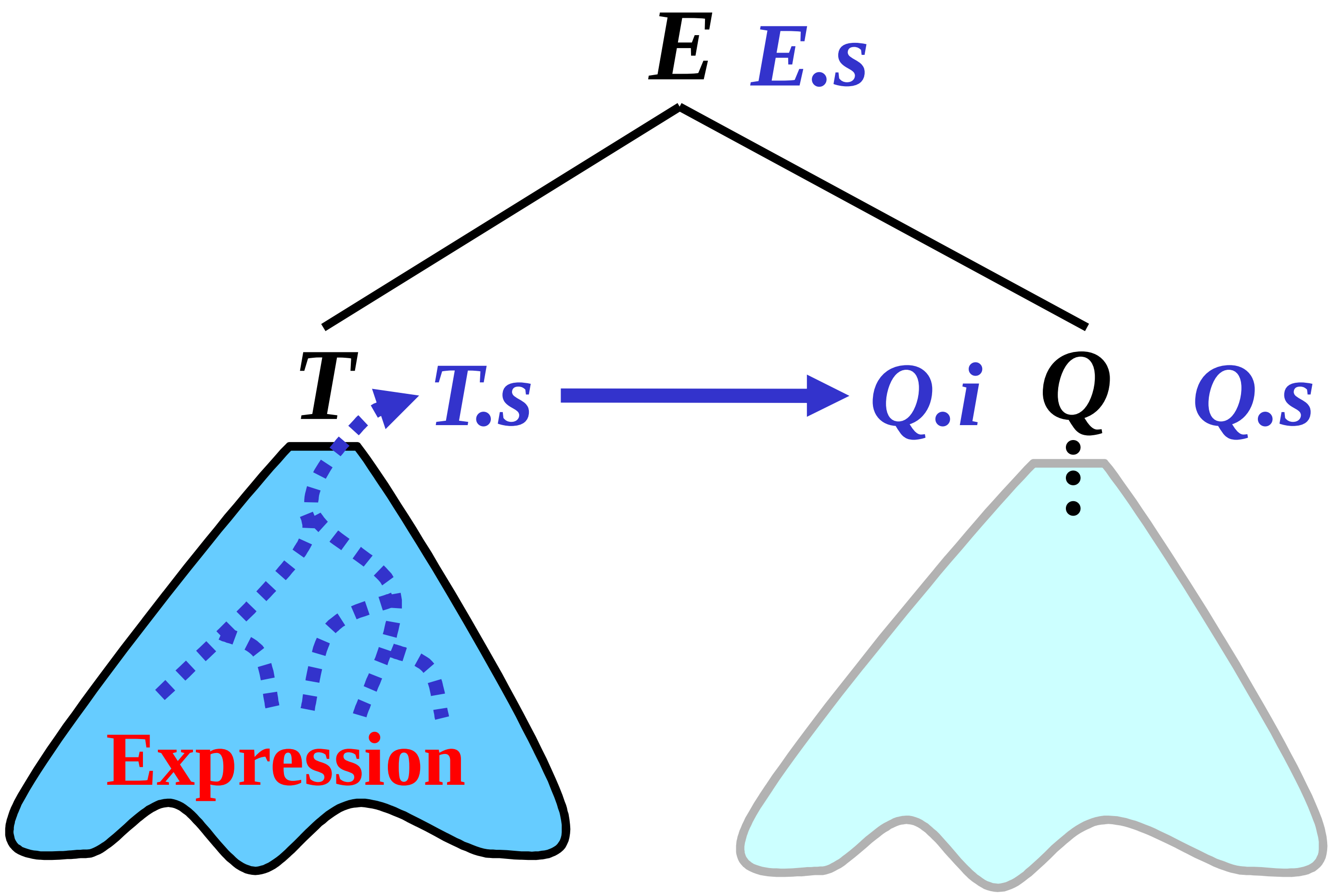
I.



$E \to T$ { $Q.i := T.s$ } Q

Expressions: Addition 1/4

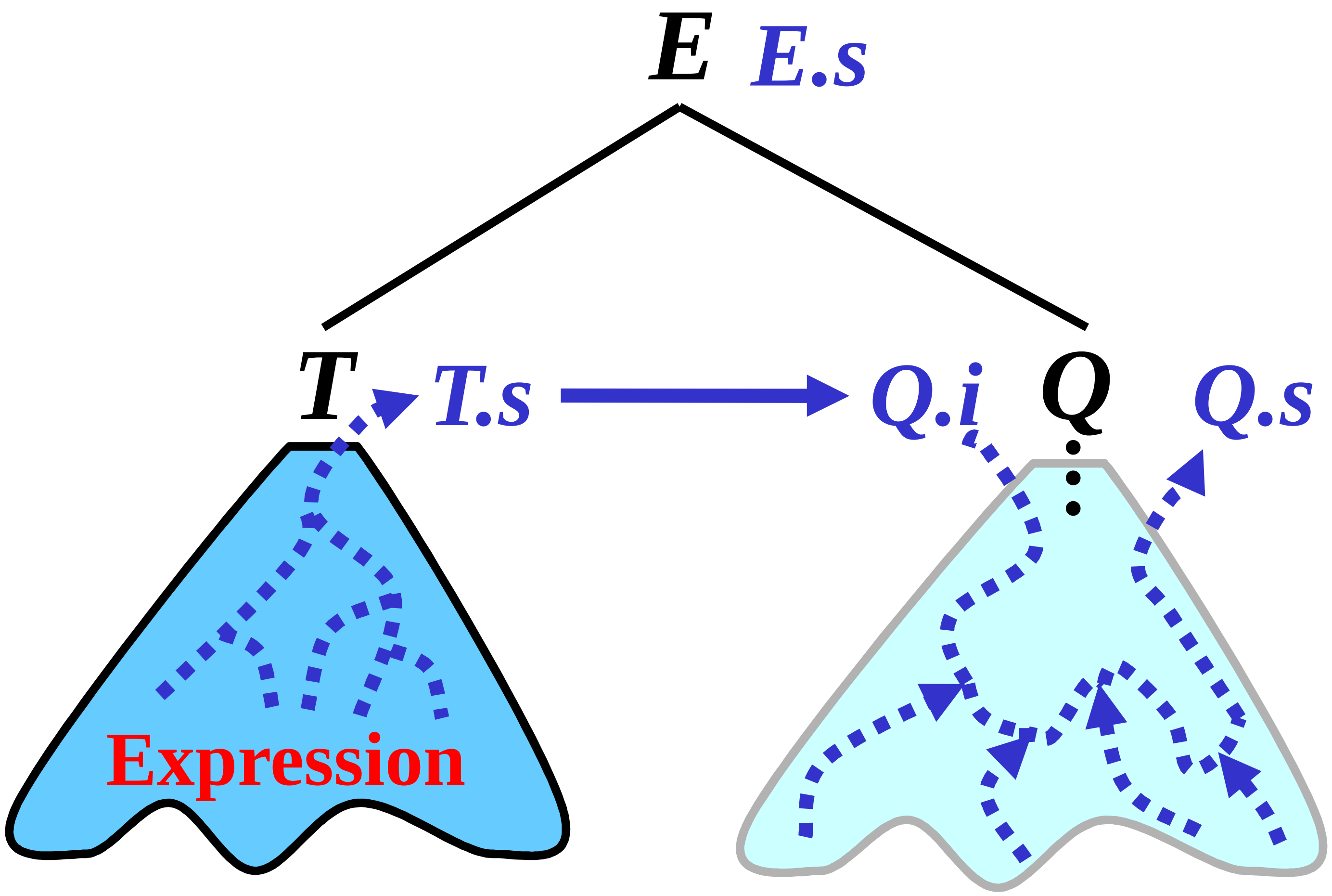
I.



$E \rightarrow T \; \{\, Q.i := T.s \,\} \; Q$

Expressions: Addition 1/4

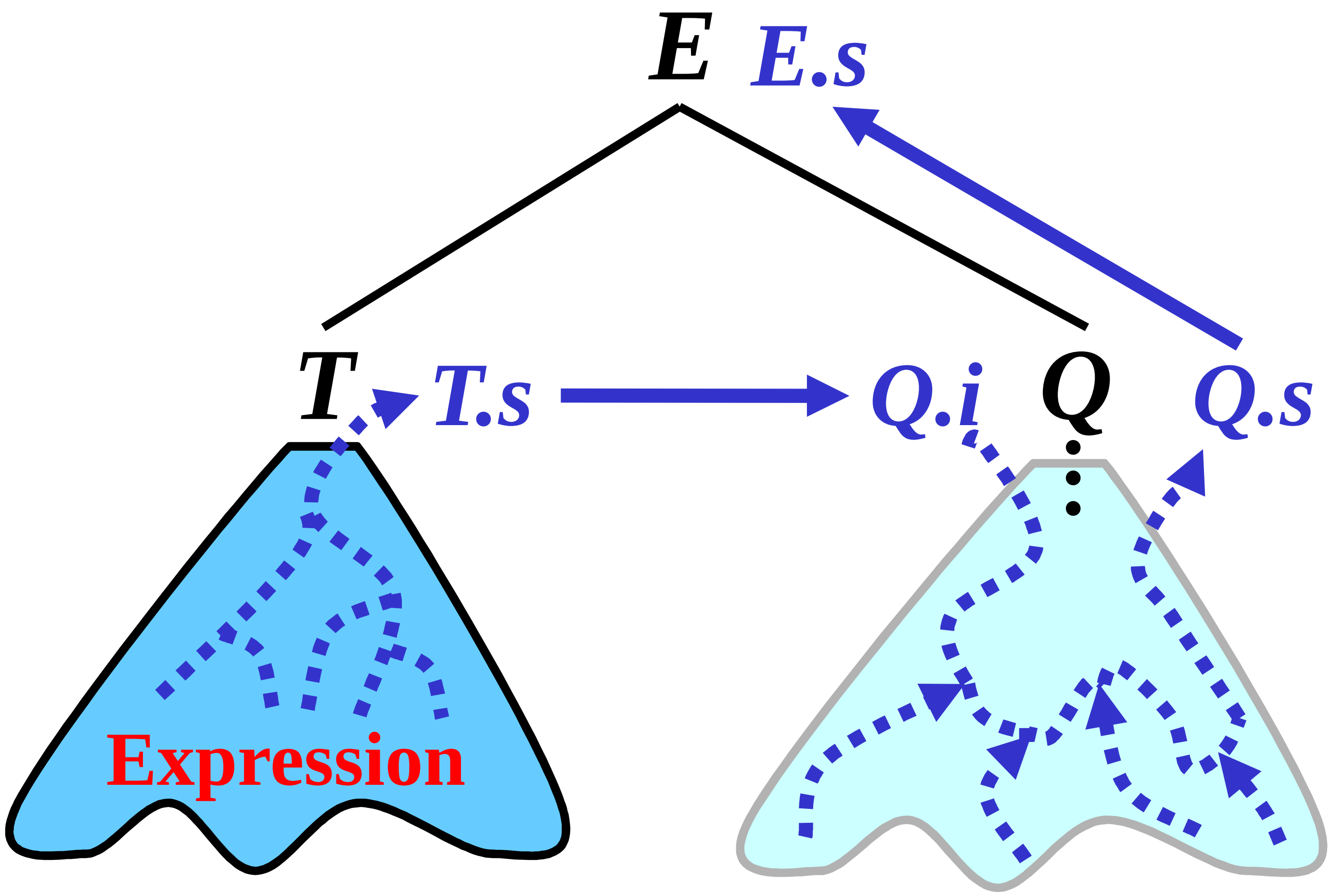
I.



$E \rightarrow T \;\{\; Q.i := T.s \;\}\; Q$

Expressions: Addition 1/4

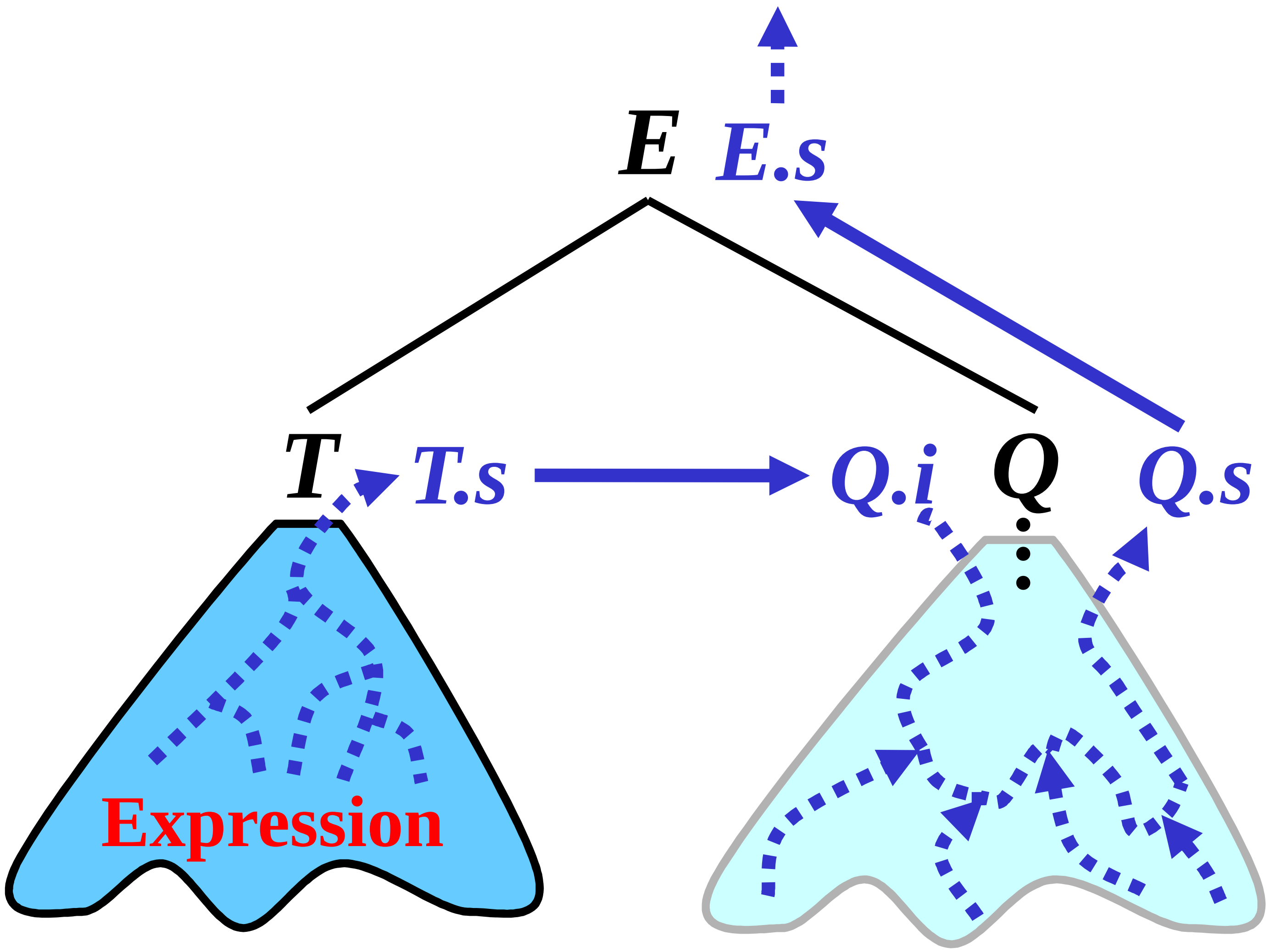
I.



$E \rightarrow T \; \{ \; Q.i := T.s \; \} \;\; Q \; \{ \; E.s := Q.s \; \}$

Expressions: Addition 1/4

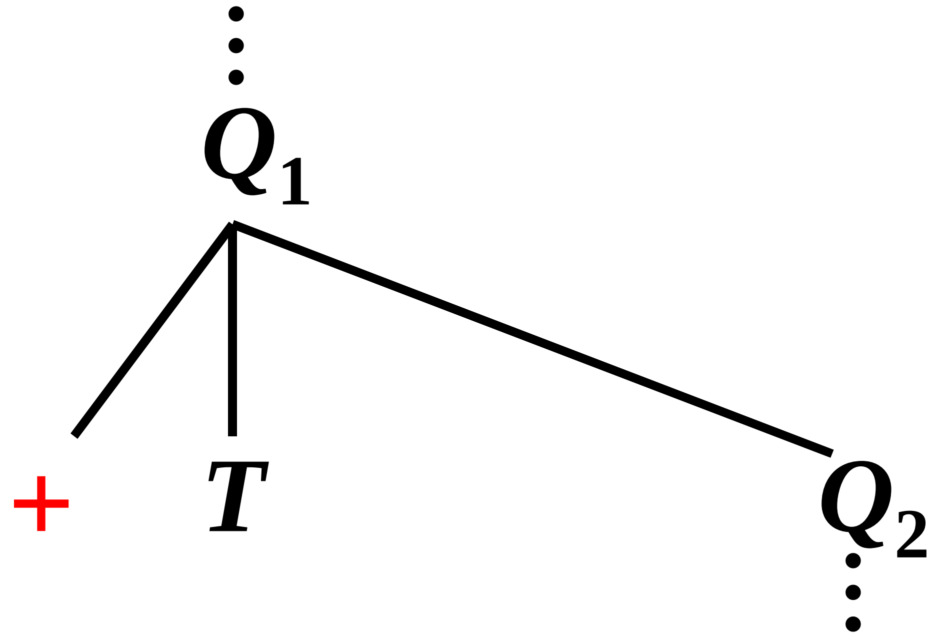
I.



$E \rightarrow T \; \{ \; Q.i := T.s \; \} \;\; Q \; \{ \; E.s := Q.s \; \}$

Expressions: Addition 2/4

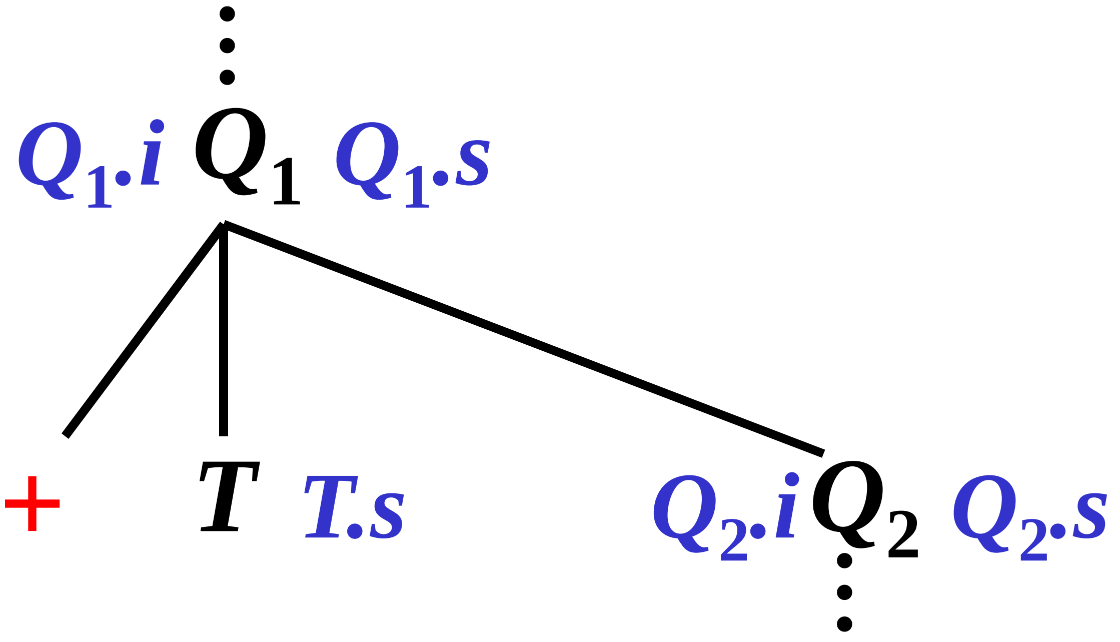
II.



$Q_1 \rightarrow +T$ $\qquad\qquad\qquad\qquad$ Q_2

Expressions: Addition 2/4

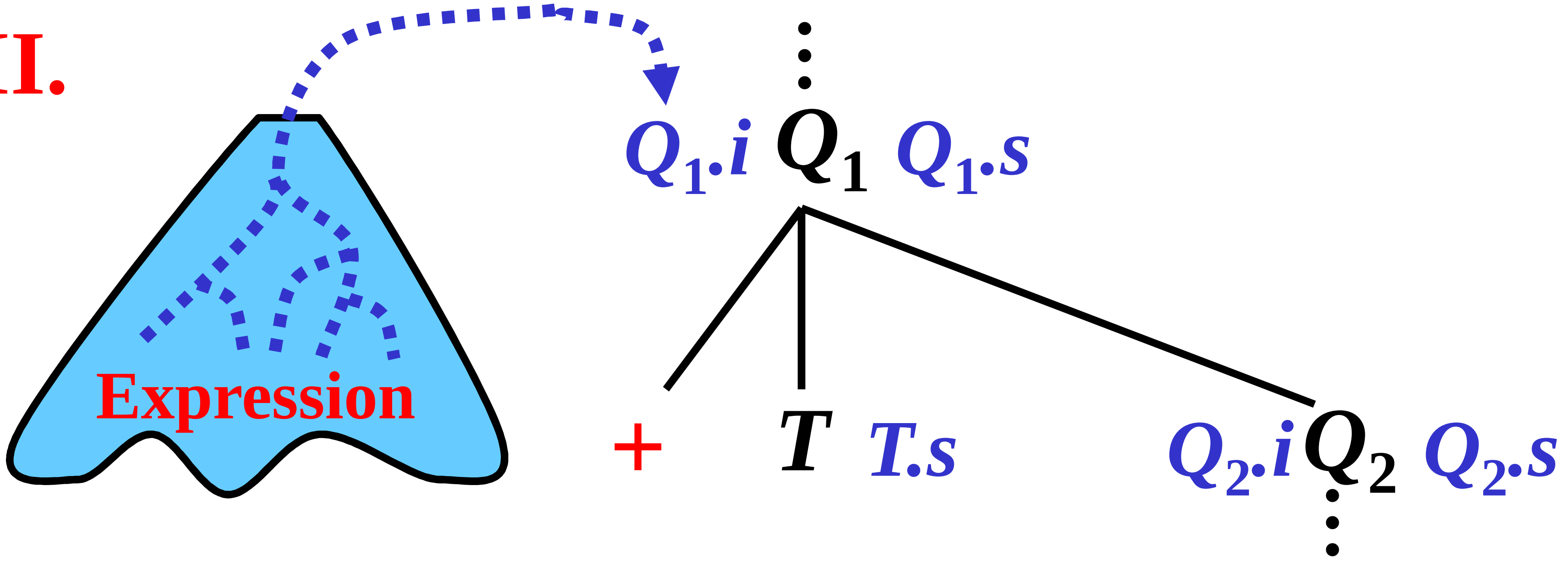
II.



$Q_1 \rightarrow +T$ $\qquad\qquad$ Q_2

Expressions: Addition 2/4

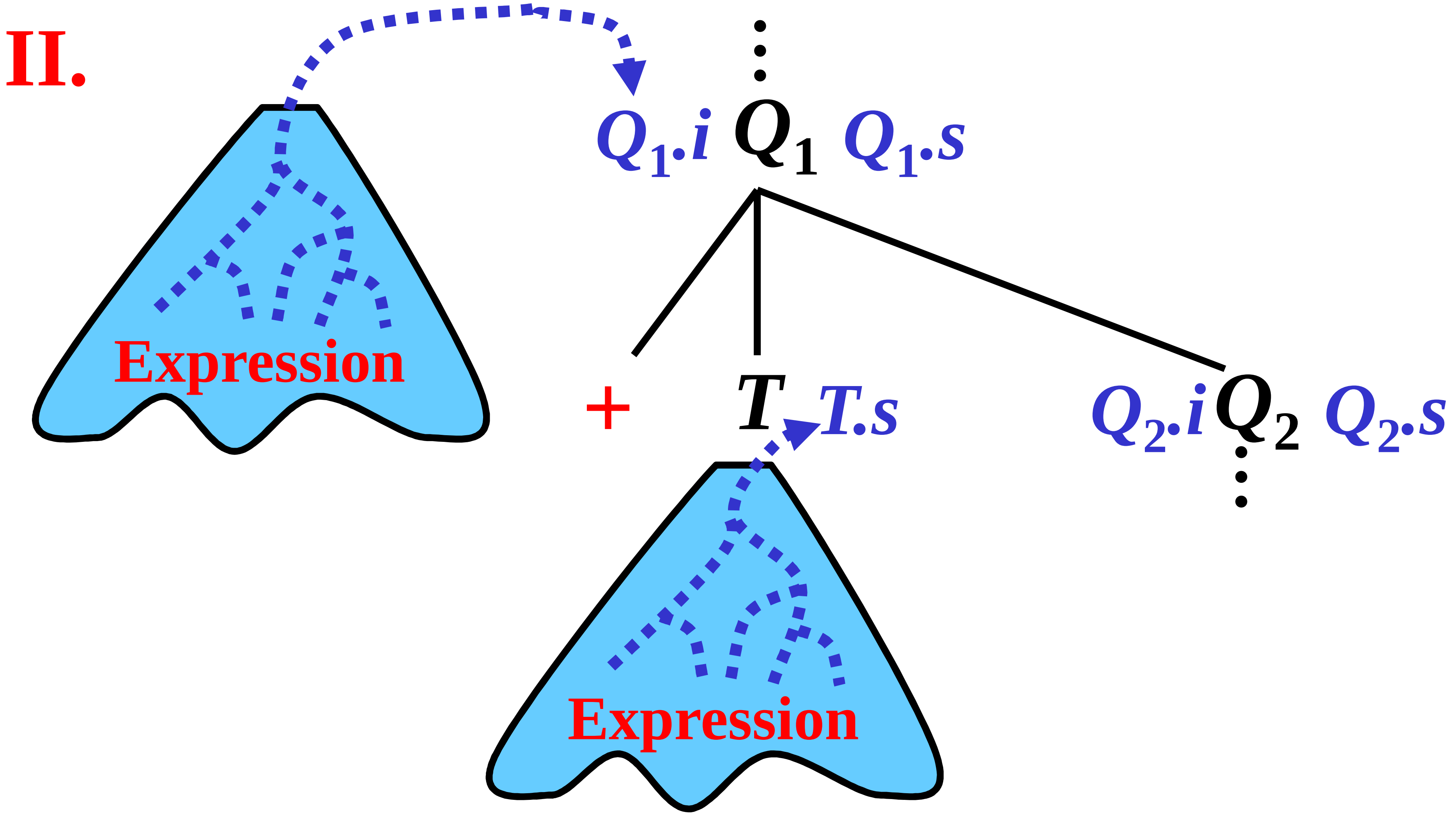
II.



$Q_1 \rightarrow +T$ $\qquad\qquad\qquad\qquad$ Q_2

Expressions: Addition 2/4

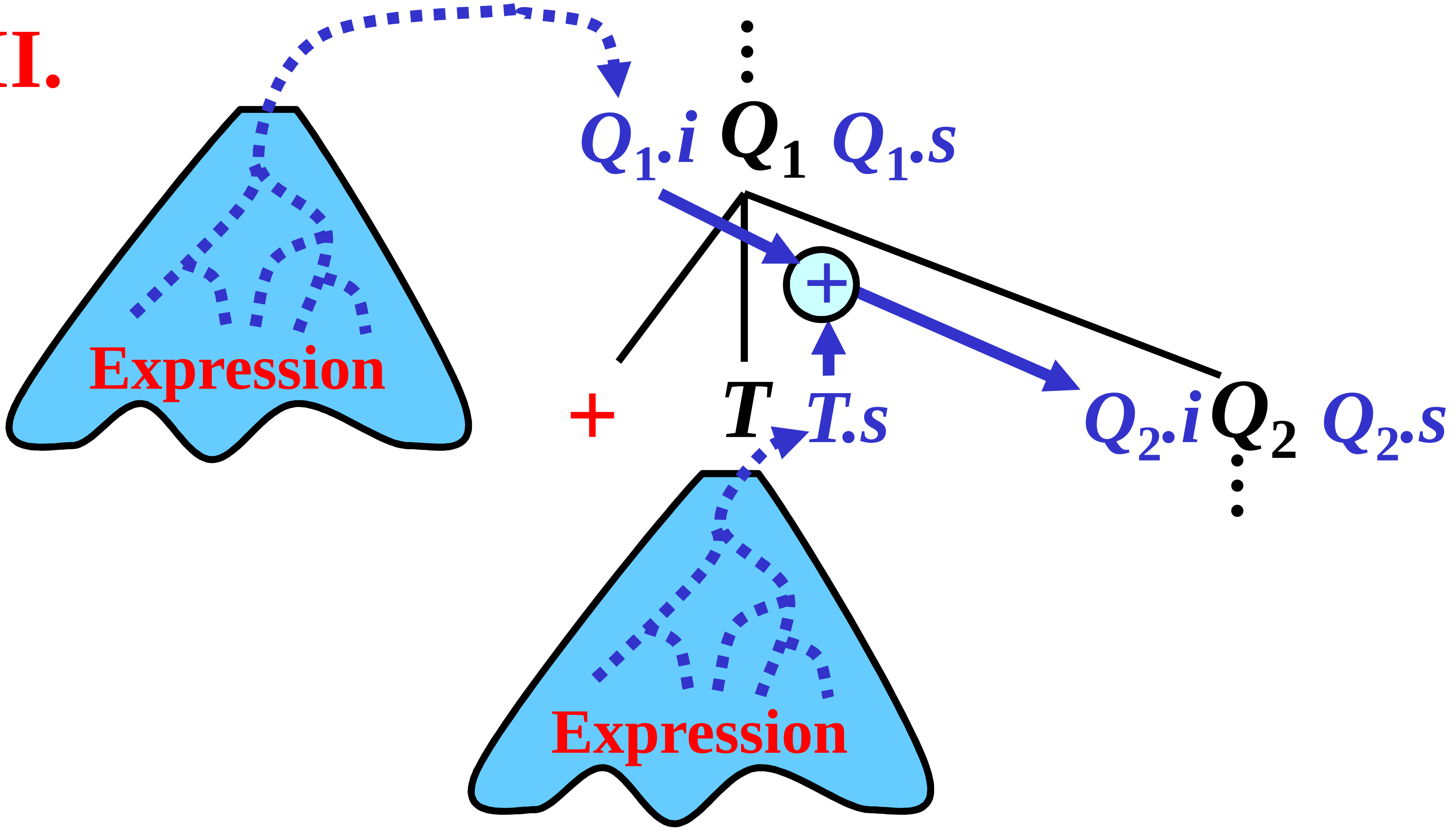
II.



$Q_1 \rightarrow +T$ Q_2

Expressions: Addition 2/4

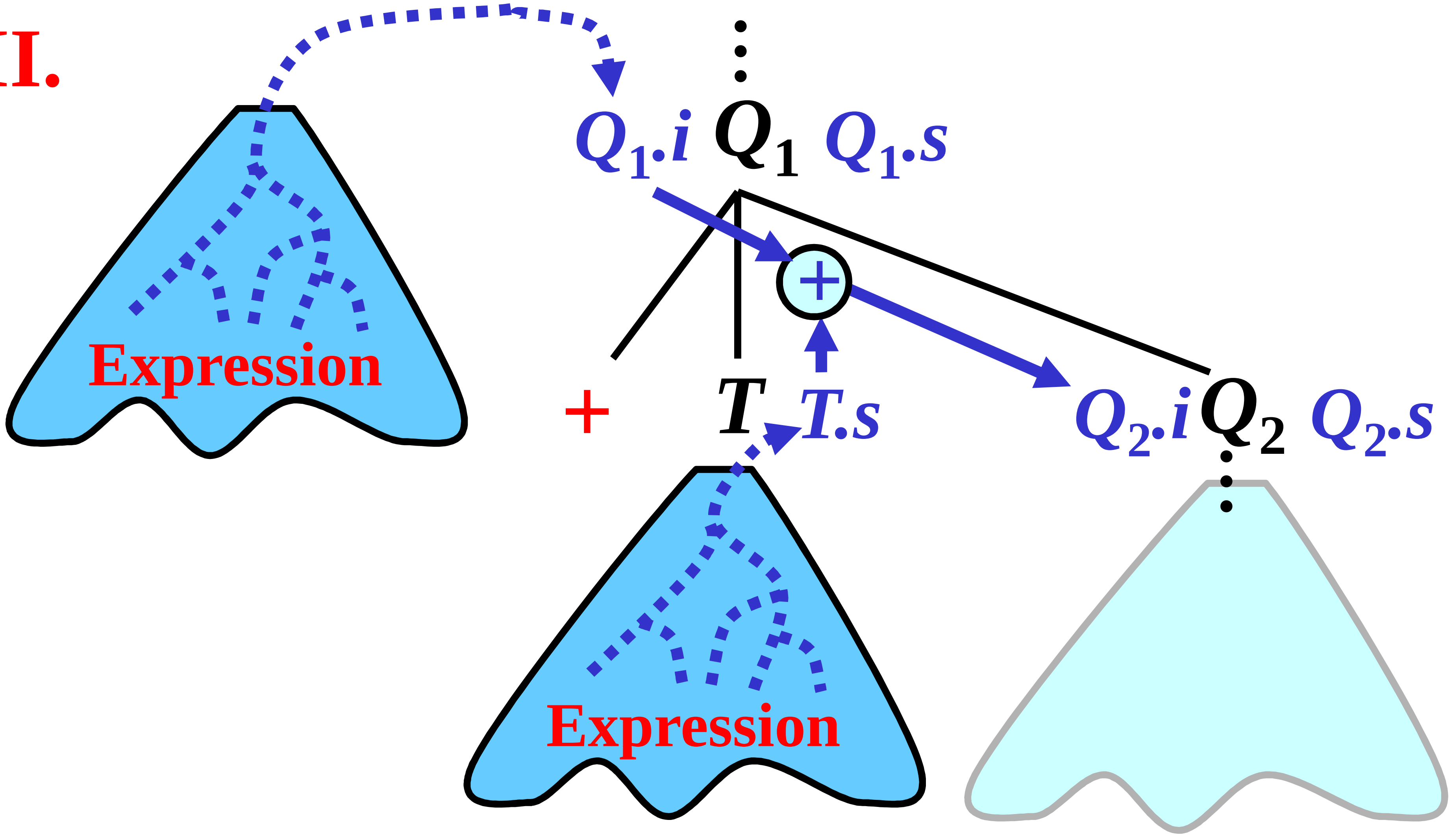
II.



$Q_1 \rightarrow +T \{ Q_2.i := Q_1.i + T.s \}\ Q_2$

Expressions: Addition 2/4

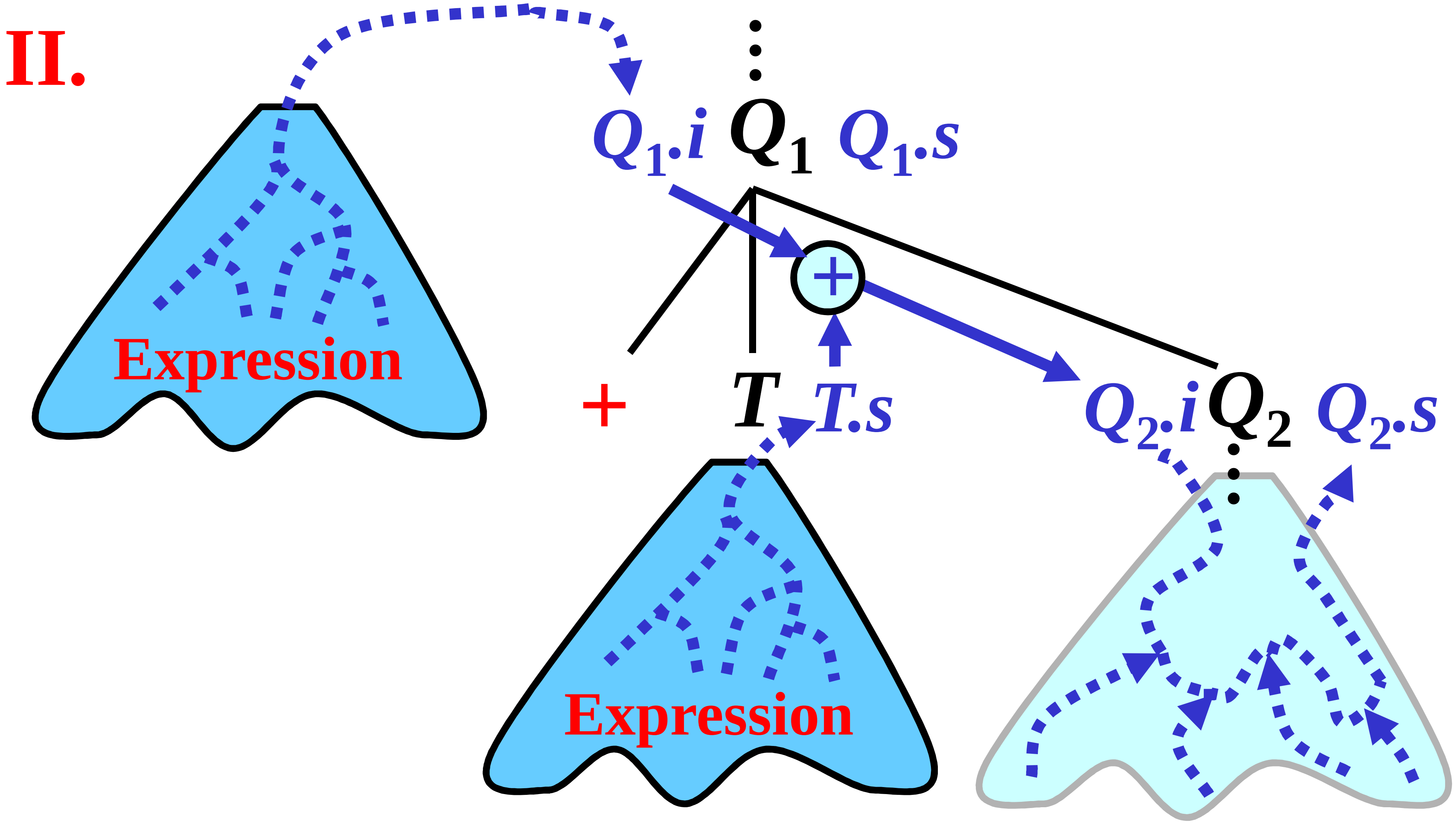
II.



$Q_1 \rightarrow +T \{\ Q_2.i := Q_1.i + T.s\ \}\ Q_2$

Expressions: Addition 2/4

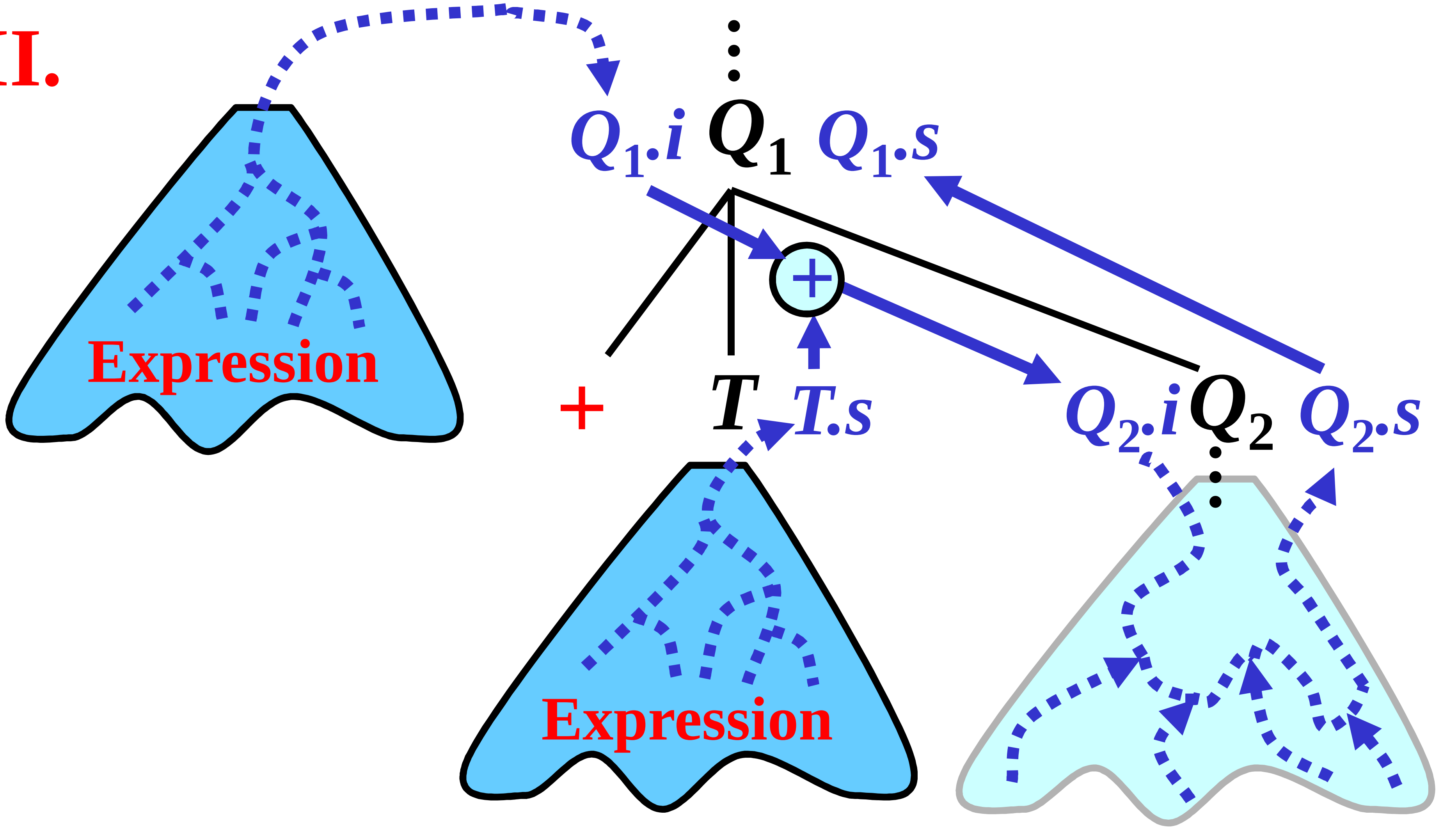
II.



$Q_1 \rightarrow +T \{ Q_2.i := Q_1.i + T.s \} Q_2$

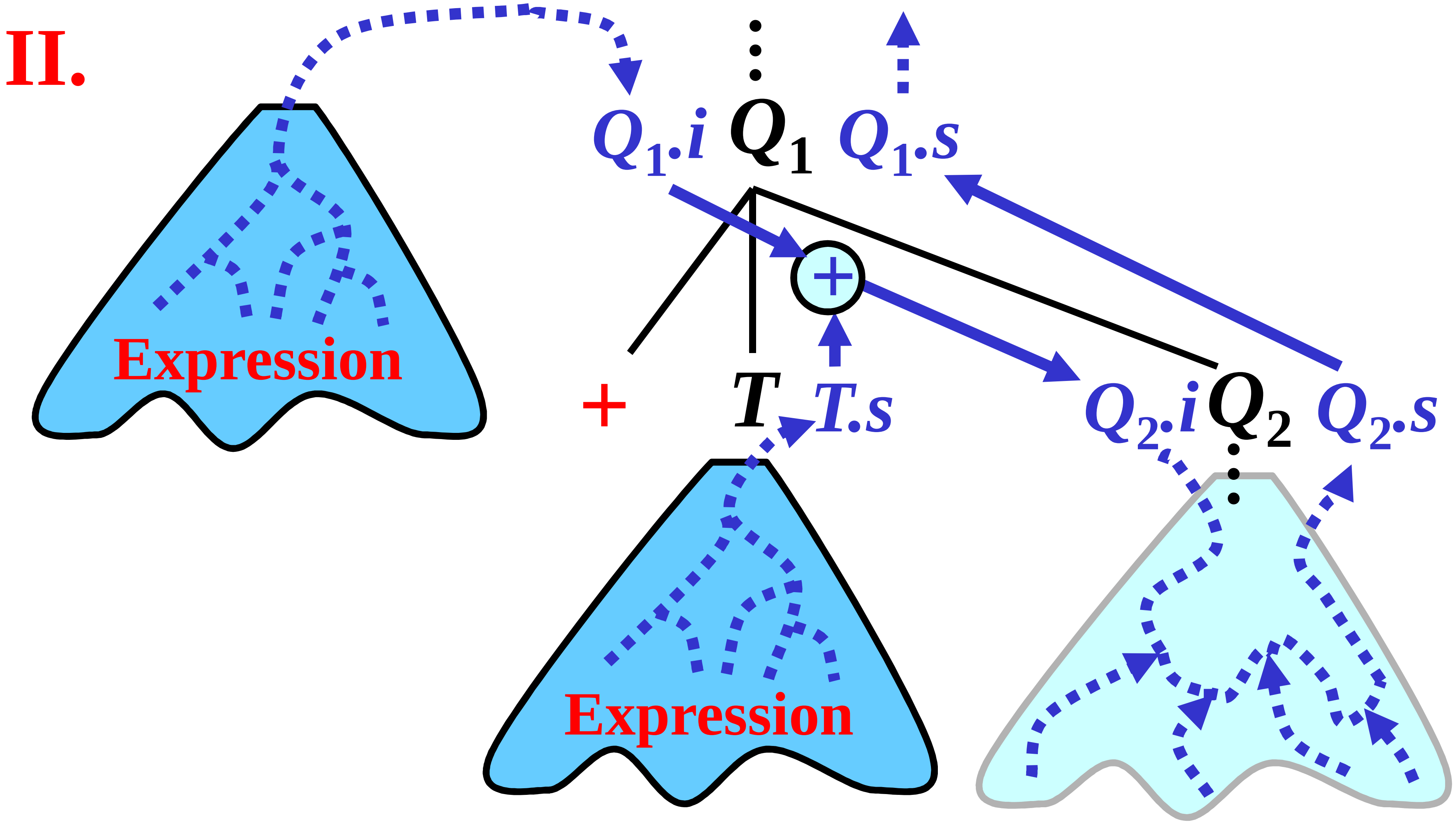
Expressions: Addition 2/4

II.



$$Q_1 \rightarrow +T \{\ Q_2.i := Q_1.i + T.s\ \}\ Q_2 \{ Q_1.s := Q_2.s\ \}$$

Expressions: Addition 2/4



$Q_1 \rightarrow +T\ \{\ Q_2.i := Q_1.i + T.s\ \}\ Q_2 \{Q_1.s := Q_2.s\ \}$

Expressions: Addition 3/4

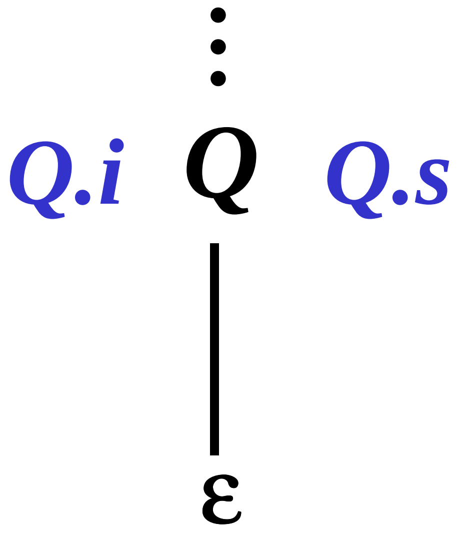
III.

$$\begin{tikzcd}
\vdots \arrow[d, phantom] \\
\boldsymbol{Q} \arrow[d, dash] \\
\varepsilon
\end{tikzcd}$$

$$\boldsymbol{Q} \to \varepsilon$$

Expressions: Addition 3/4

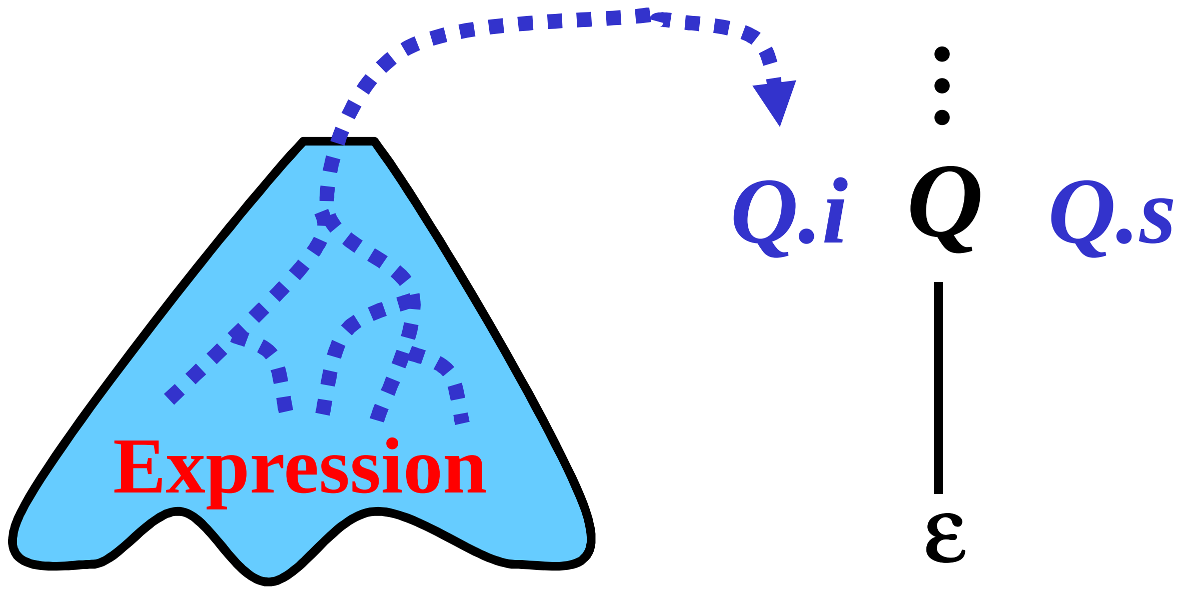
III.



$$Q \rightarrow \varepsilon$$

Expressions: Addition 3/4

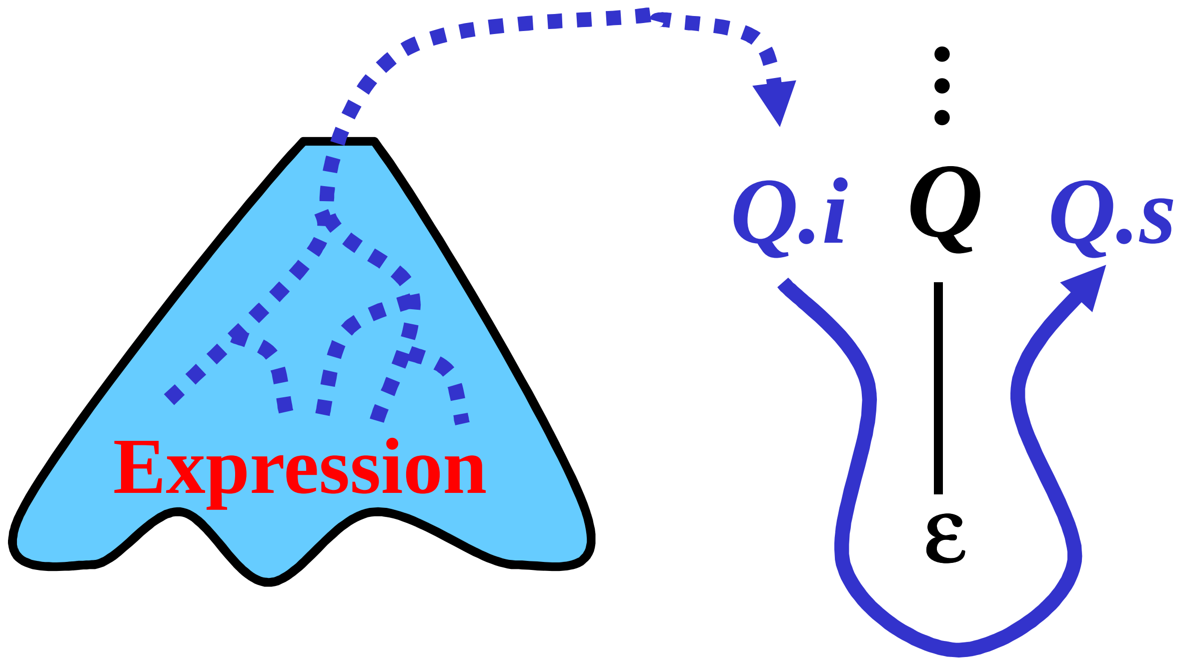
III.



$$Q \rightarrow \varepsilon$$

Expressions: Addition 3/4

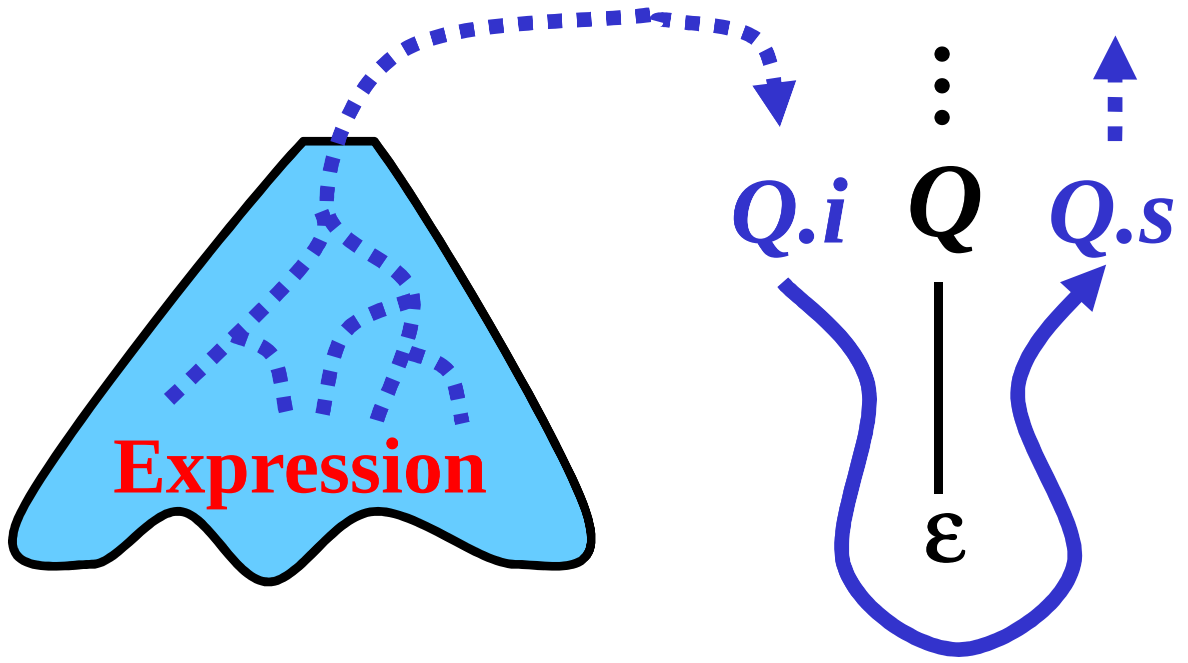
III.



$Q \rightarrow \varepsilon \quad \{Q.s := Q.i\}$

Expressions: Addition 3/4

III.



$Q \rightarrow \varepsilon \quad \{Q.s := Q.i\}$

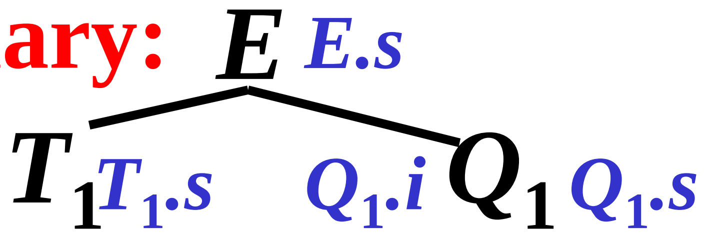
Expressions: Addition 4/4

Summary:

$$\begin{tikzcd} & \boldsymbol{E} \arrow[dl, no head] \arrow[dr, no head] & \\ \boldsymbol{T}_1 & & \boldsymbol{Q}_1 \end{tikzcd}$$

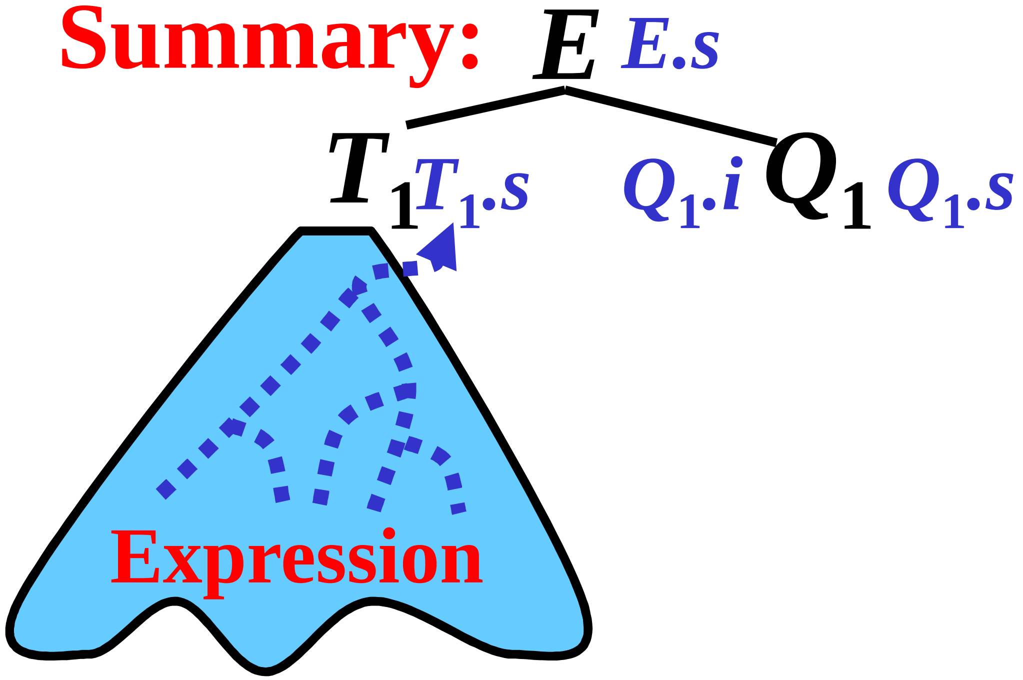
Expressions: Addition 4/4

Summary:



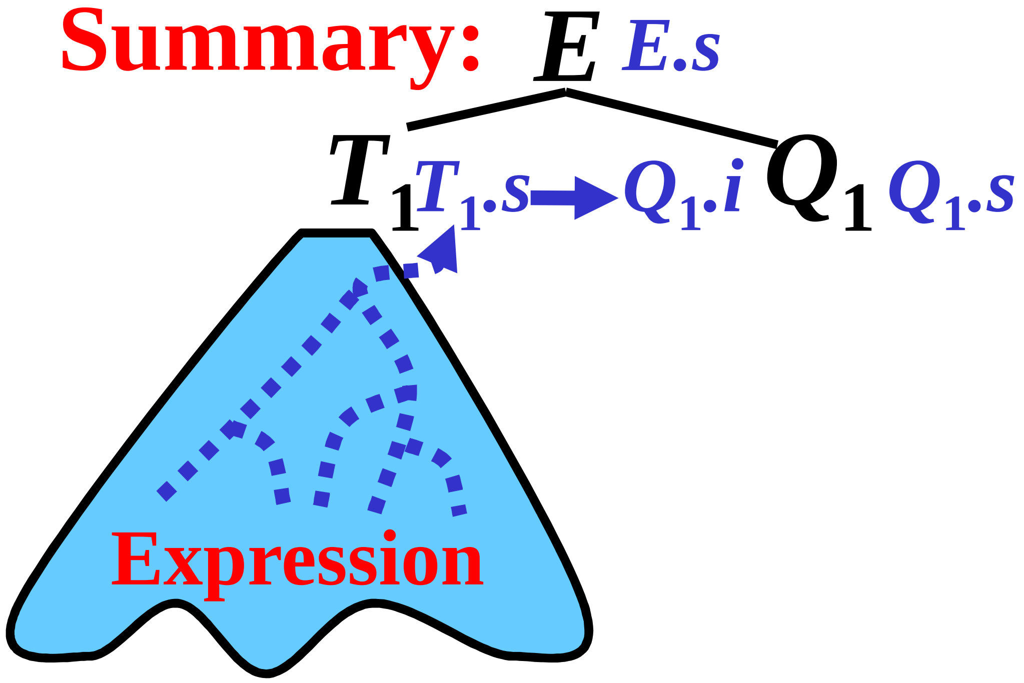
Expressions: Addition 4/4

Summary:



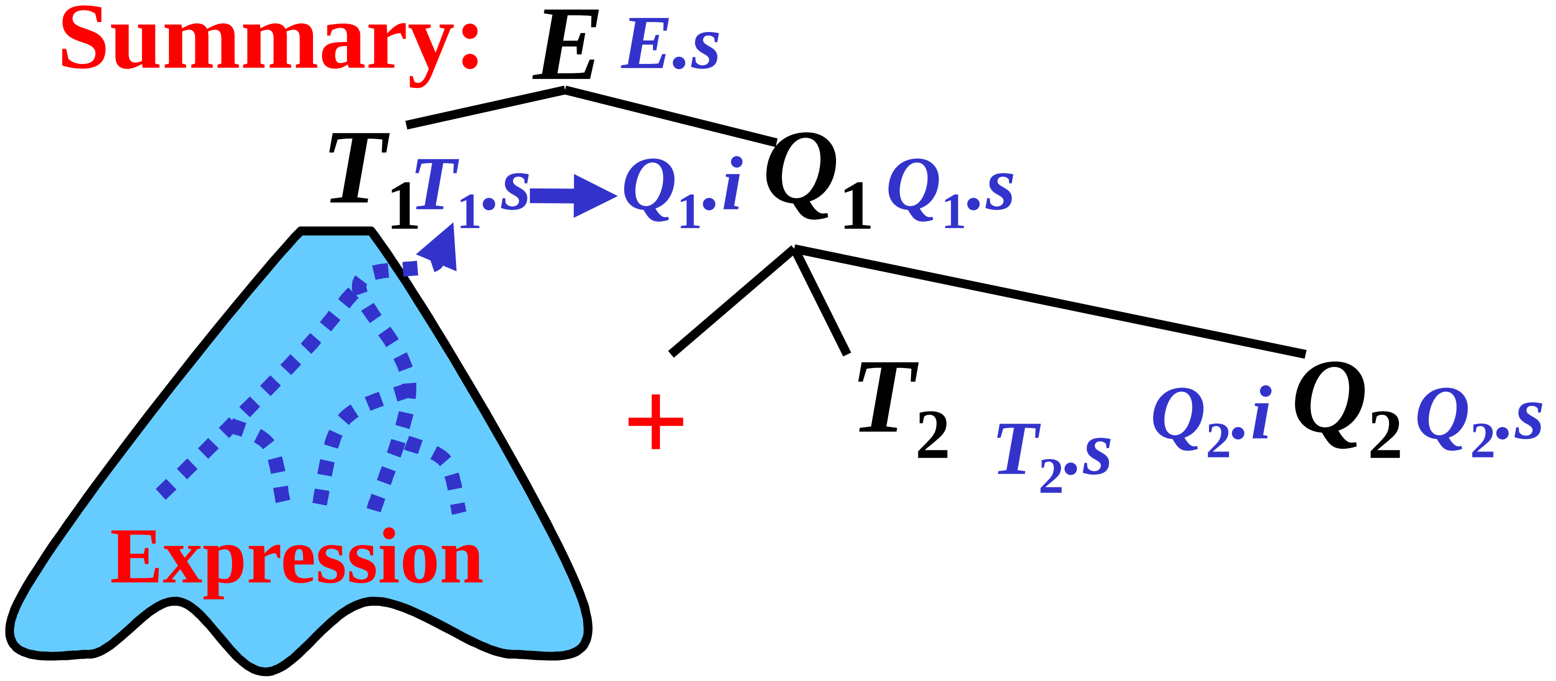
Expressions: Addition 4/4

Summary:



Expressions: Addition 4/4

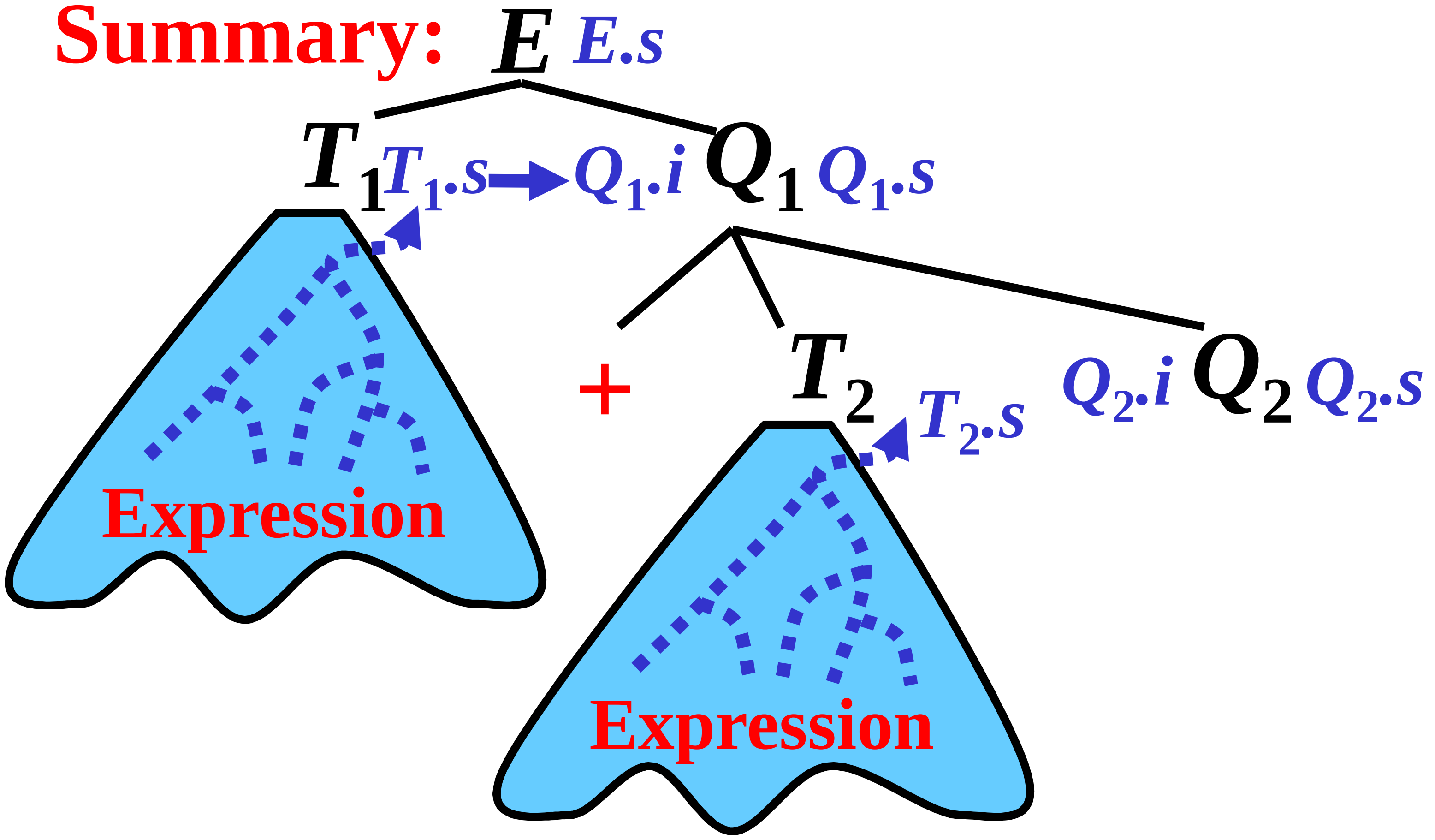
Summary:



E $E.s$
T_1 $T_1.s$ $Q_1.i$ Q_1 $Q_1.s$
$+$
T_2 $T_2.s$ $Q_2.i$ Q_2 $Q_2.s$
Expression

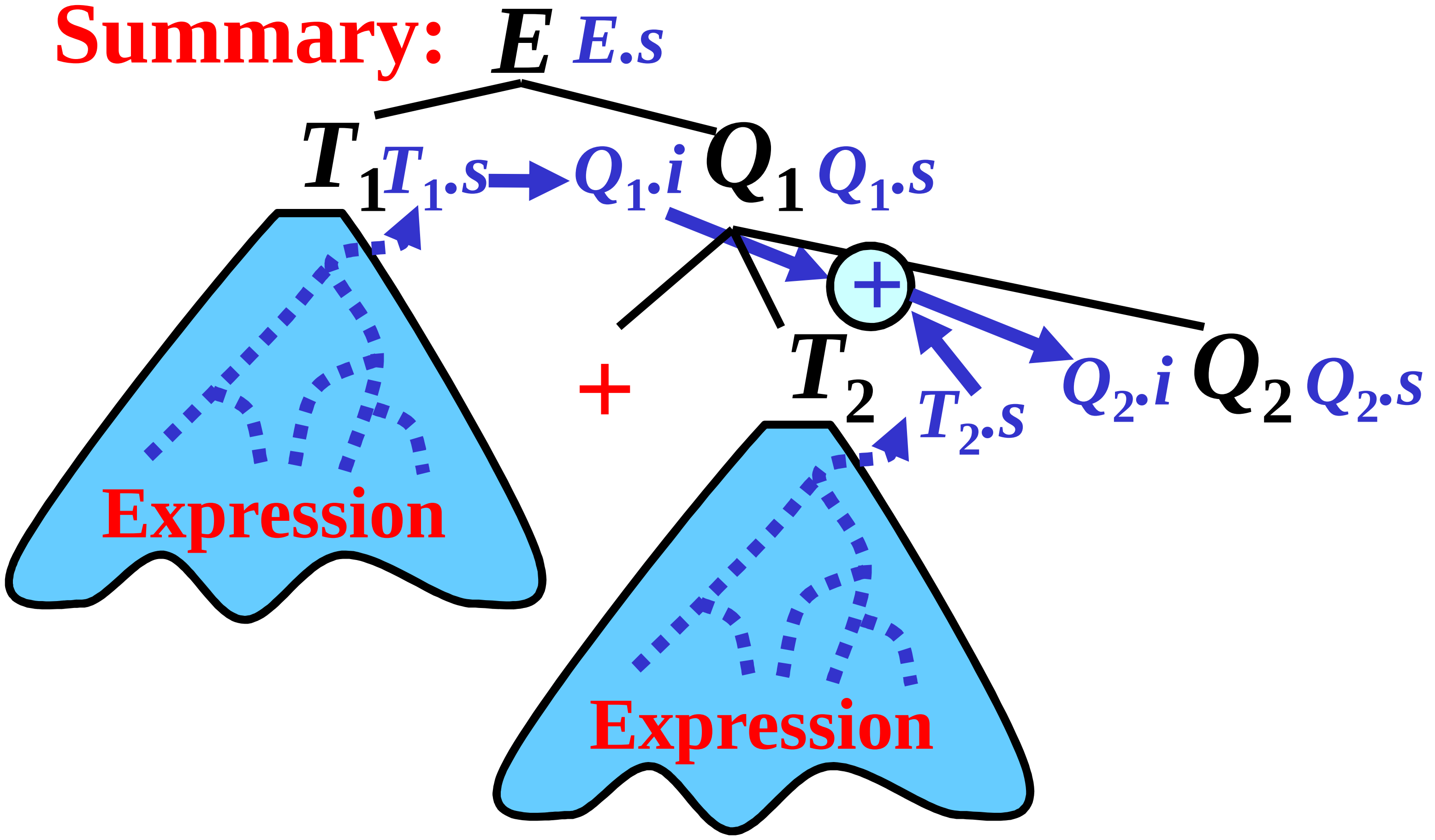
Expressions: Addition 4/4

Summary:


E $E.s$
T_1 $T_1.s$ $Q_1.i$ Q_1 $Q_1.s$
+
T_2 $T_2.s$ $Q_2.i$ Q_2 $Q_2.s$
Expression
Expression

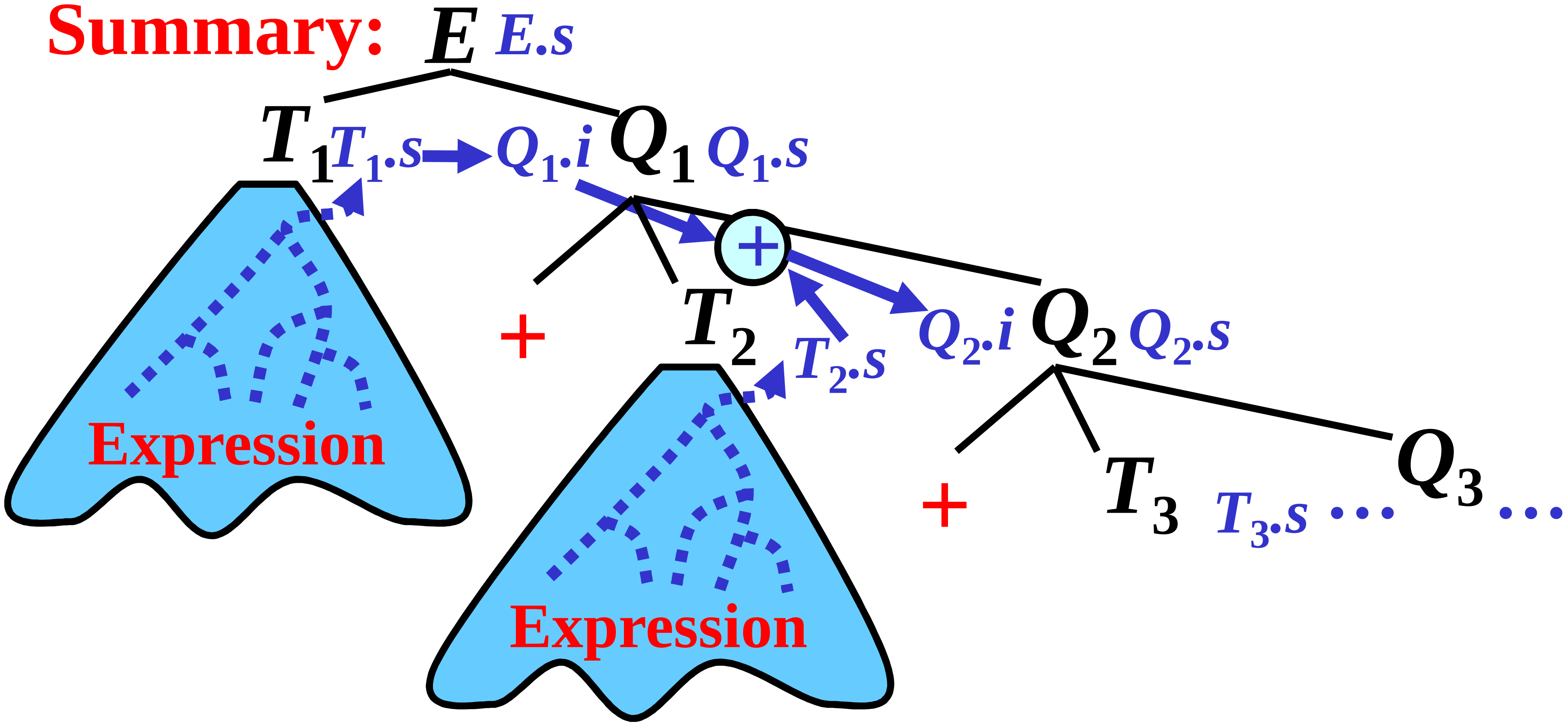
Expressions: Addition 4/4

Summary:

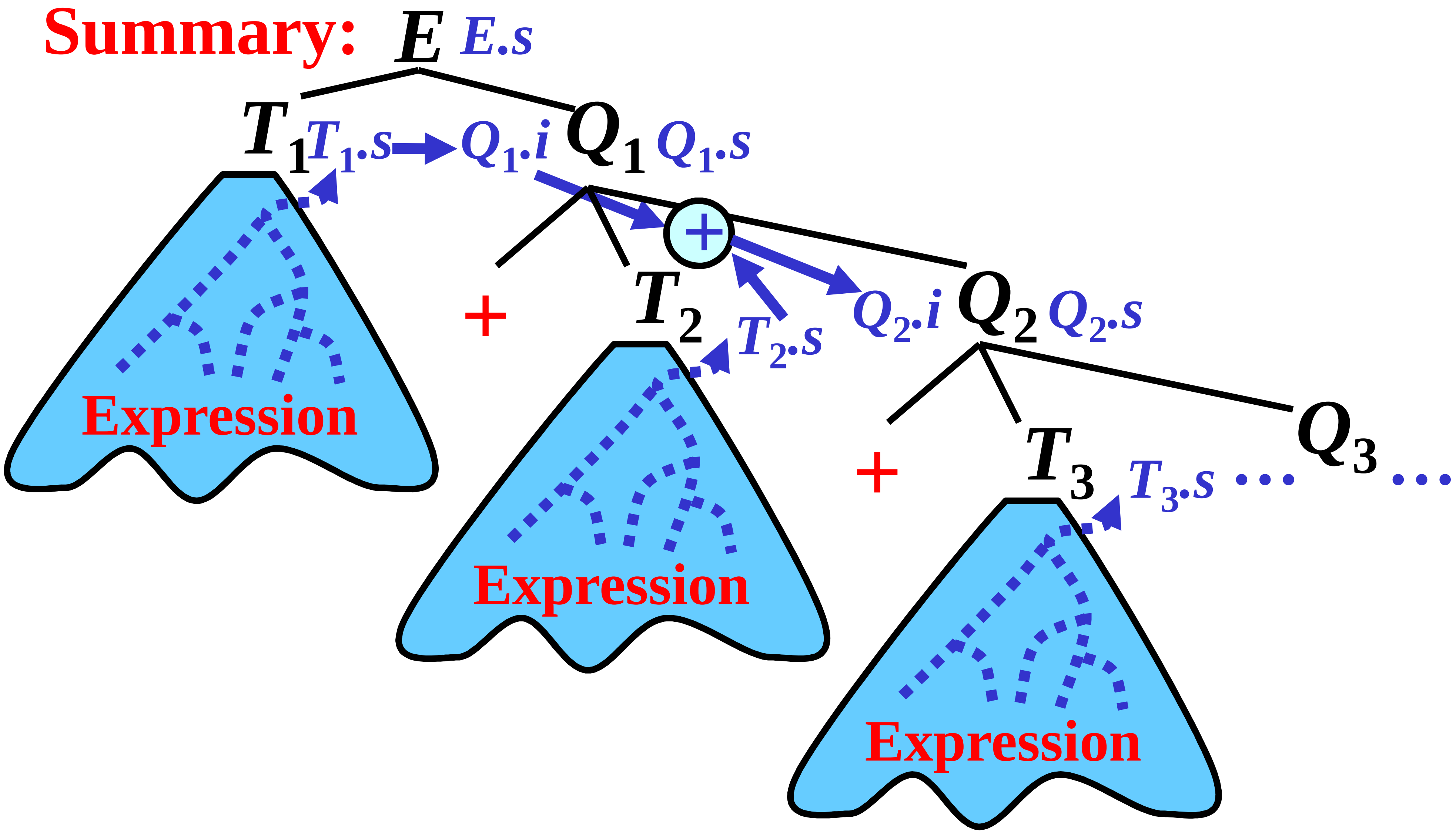


Expressions: Addition 4/4

Summary:

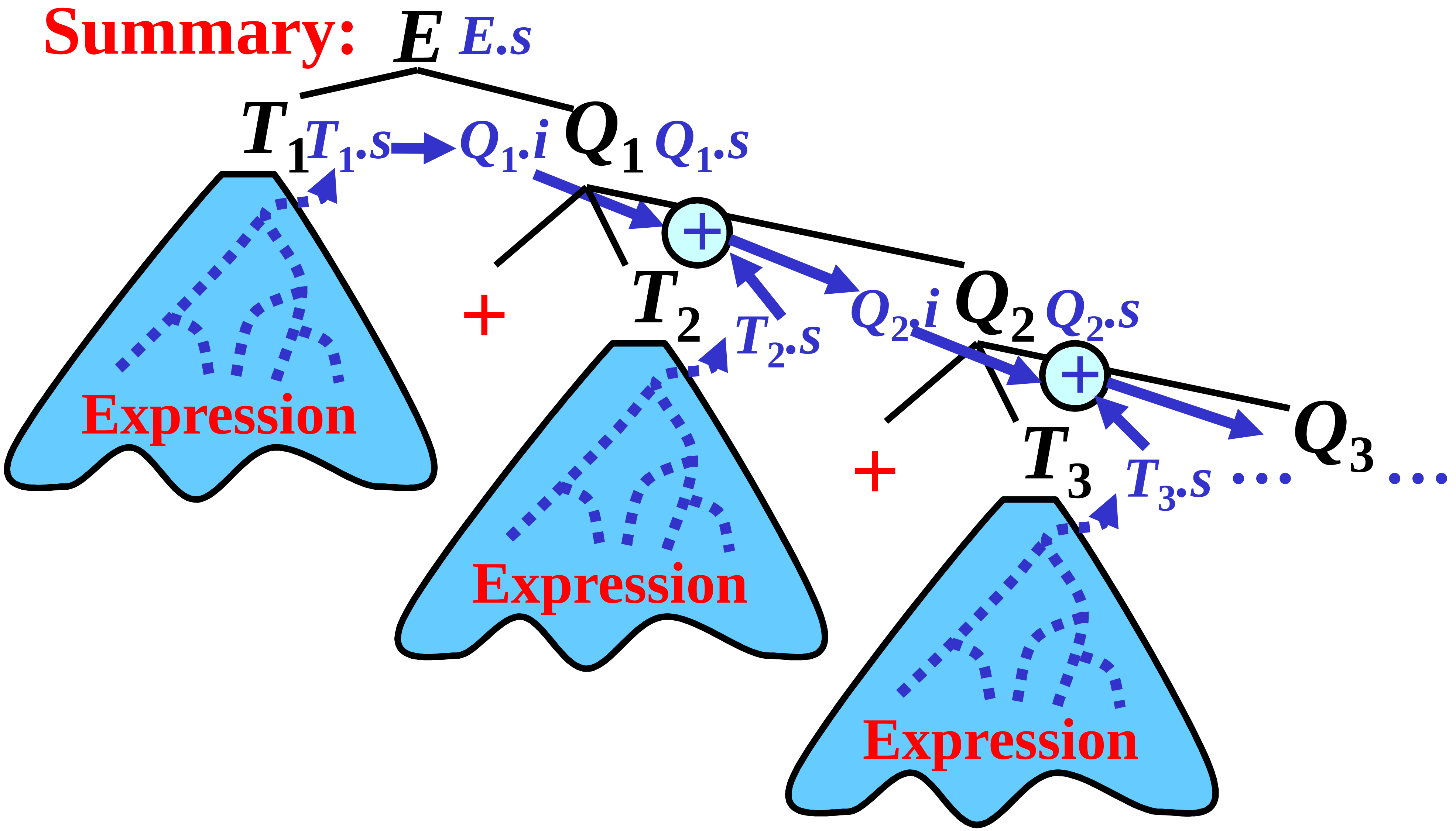


Expressions: Addition 4/4



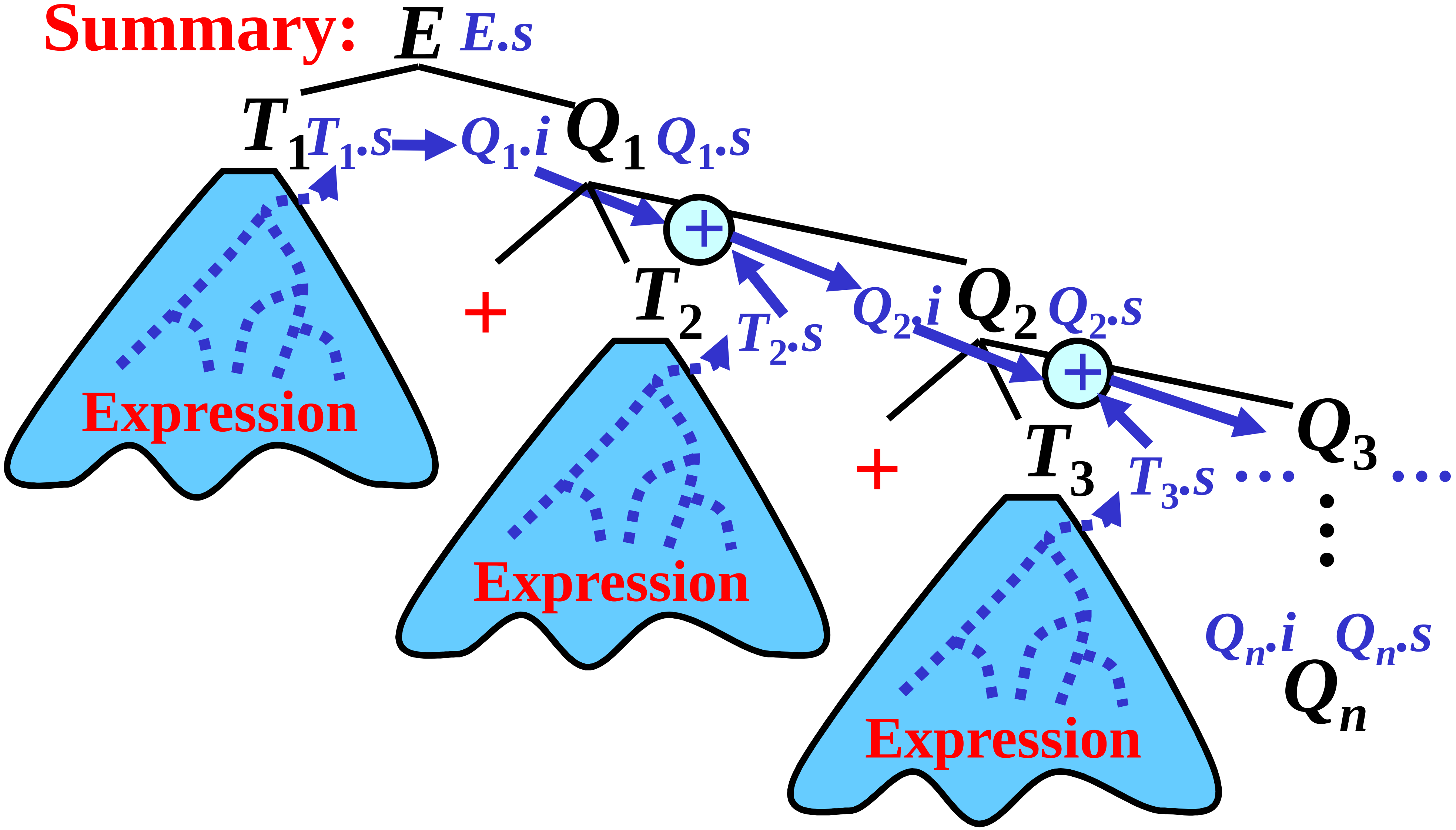
Expressions: Addition 4/4

Summary:



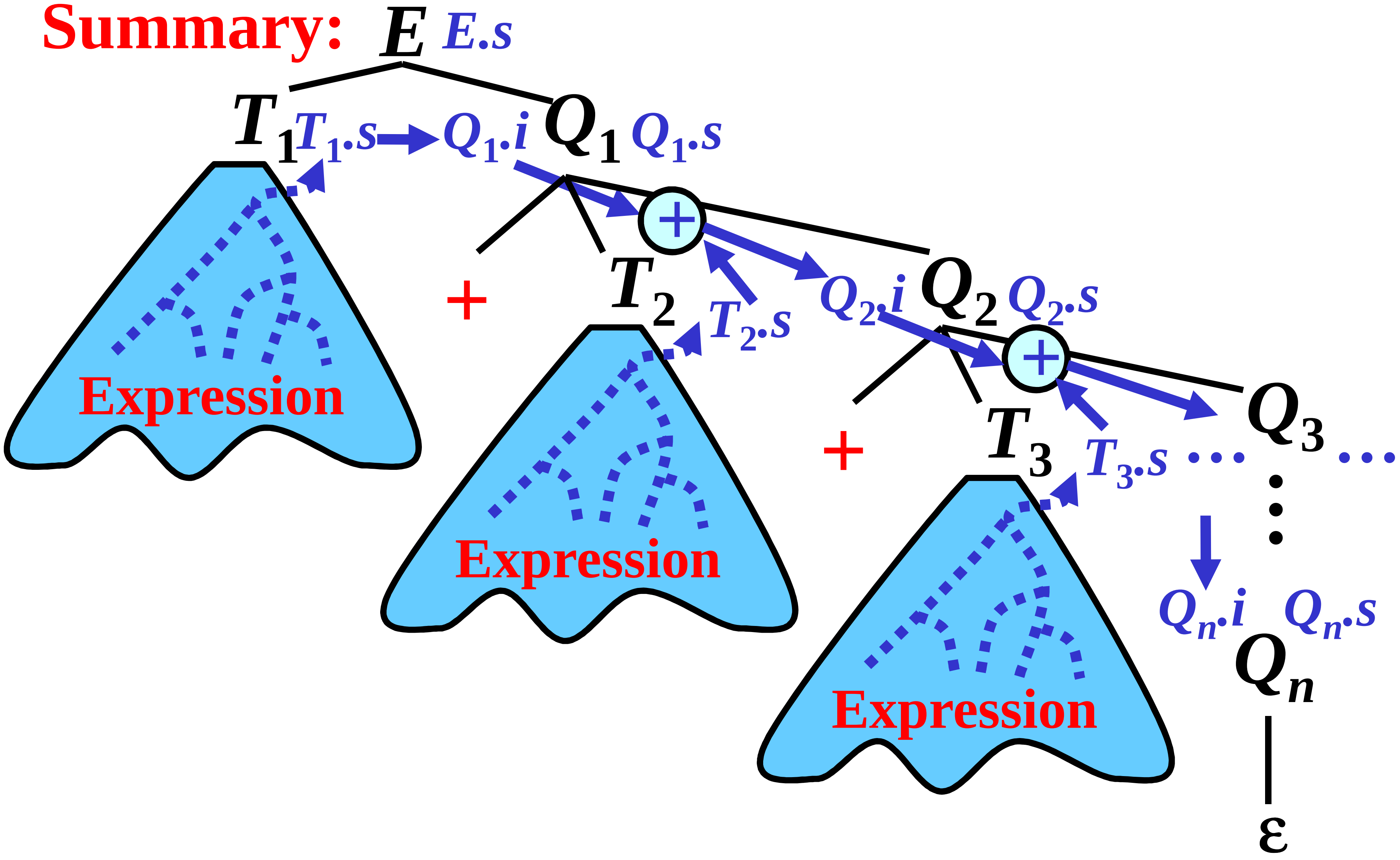
Expressions: Addition 4/4

Summary:



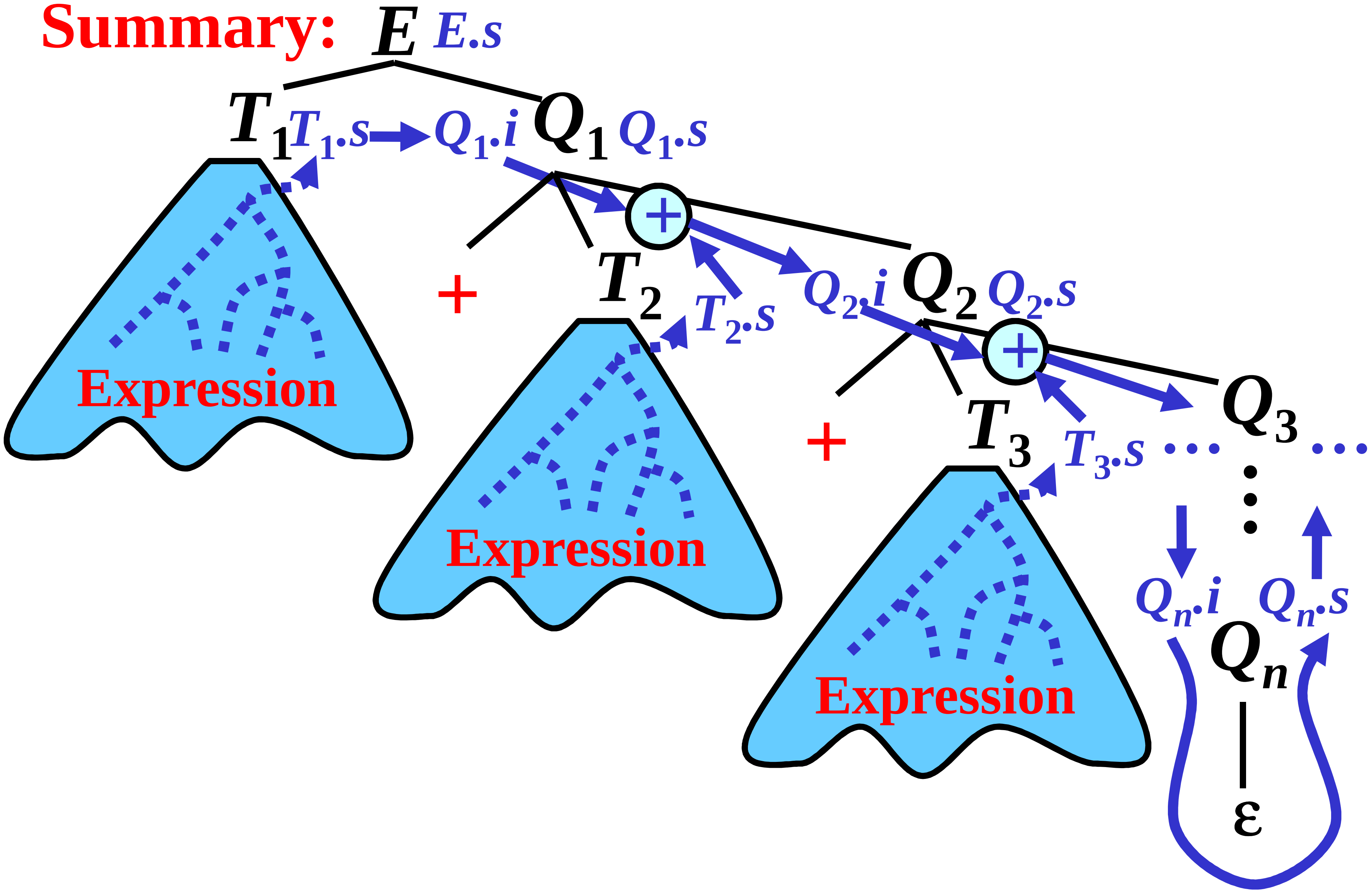
Expressions: Addition 4/4

Summary:



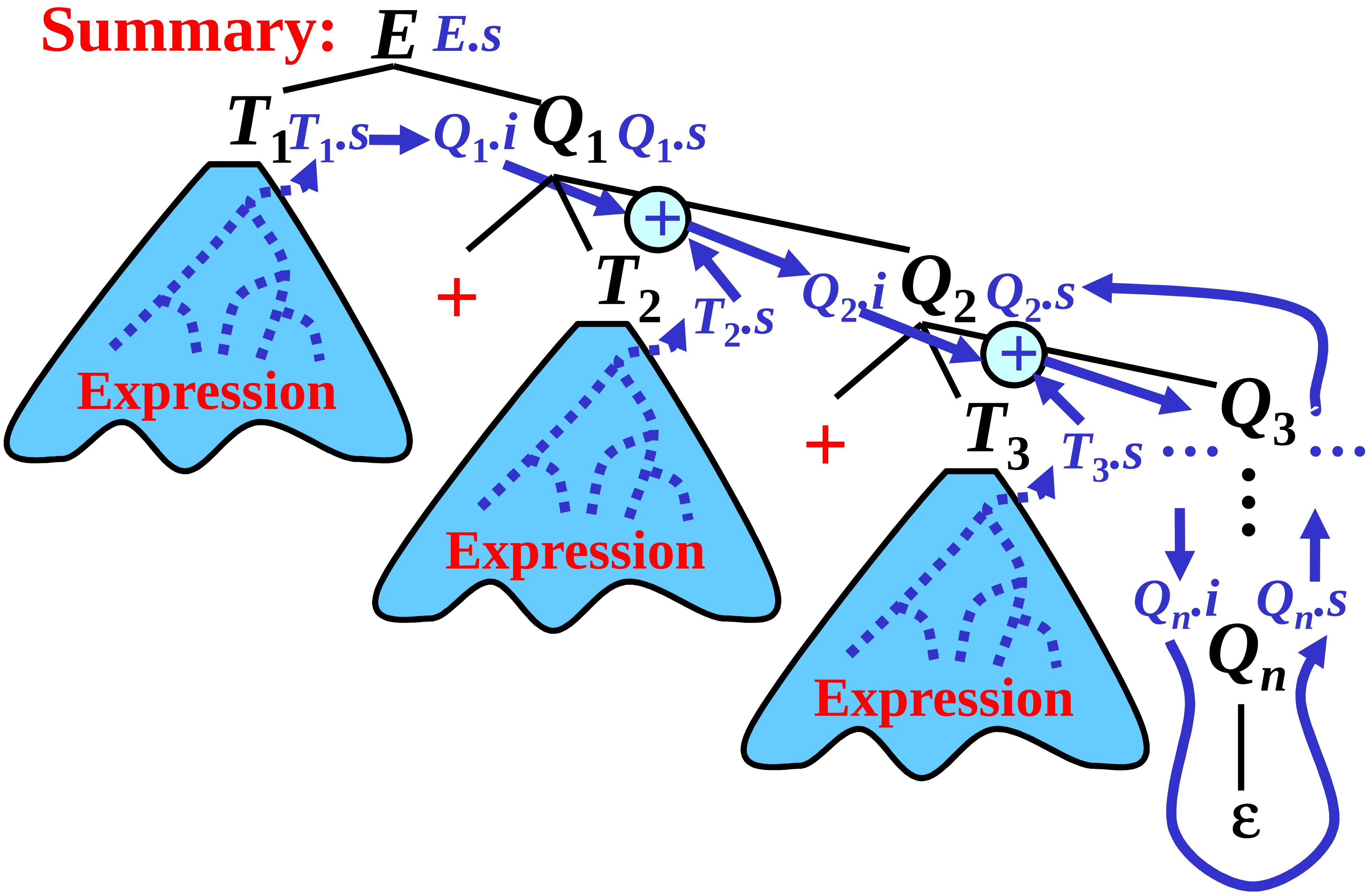
Expressions: Addition 4/4

Summary:



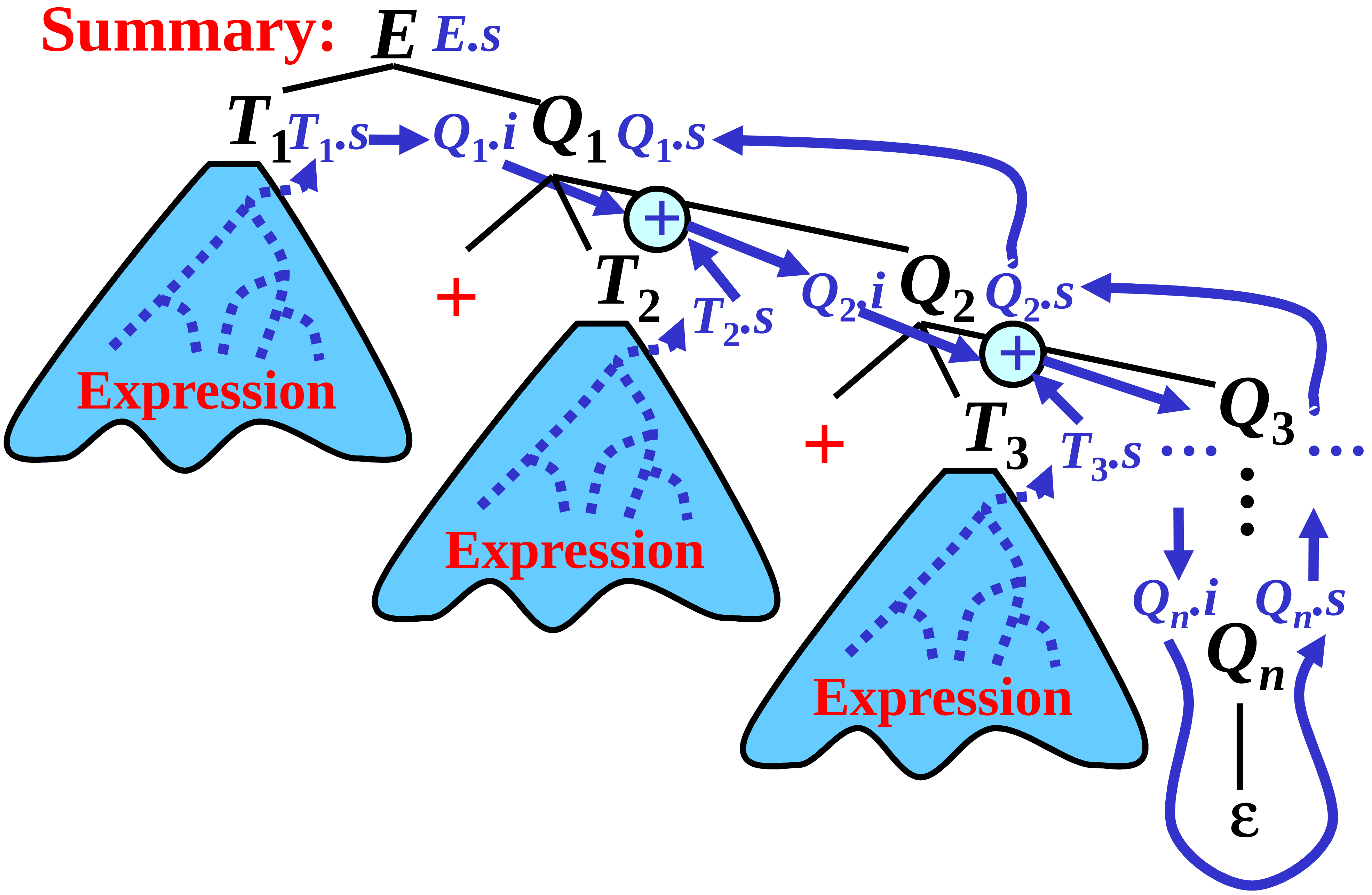
Expressions: Addition 4/4

Summary:



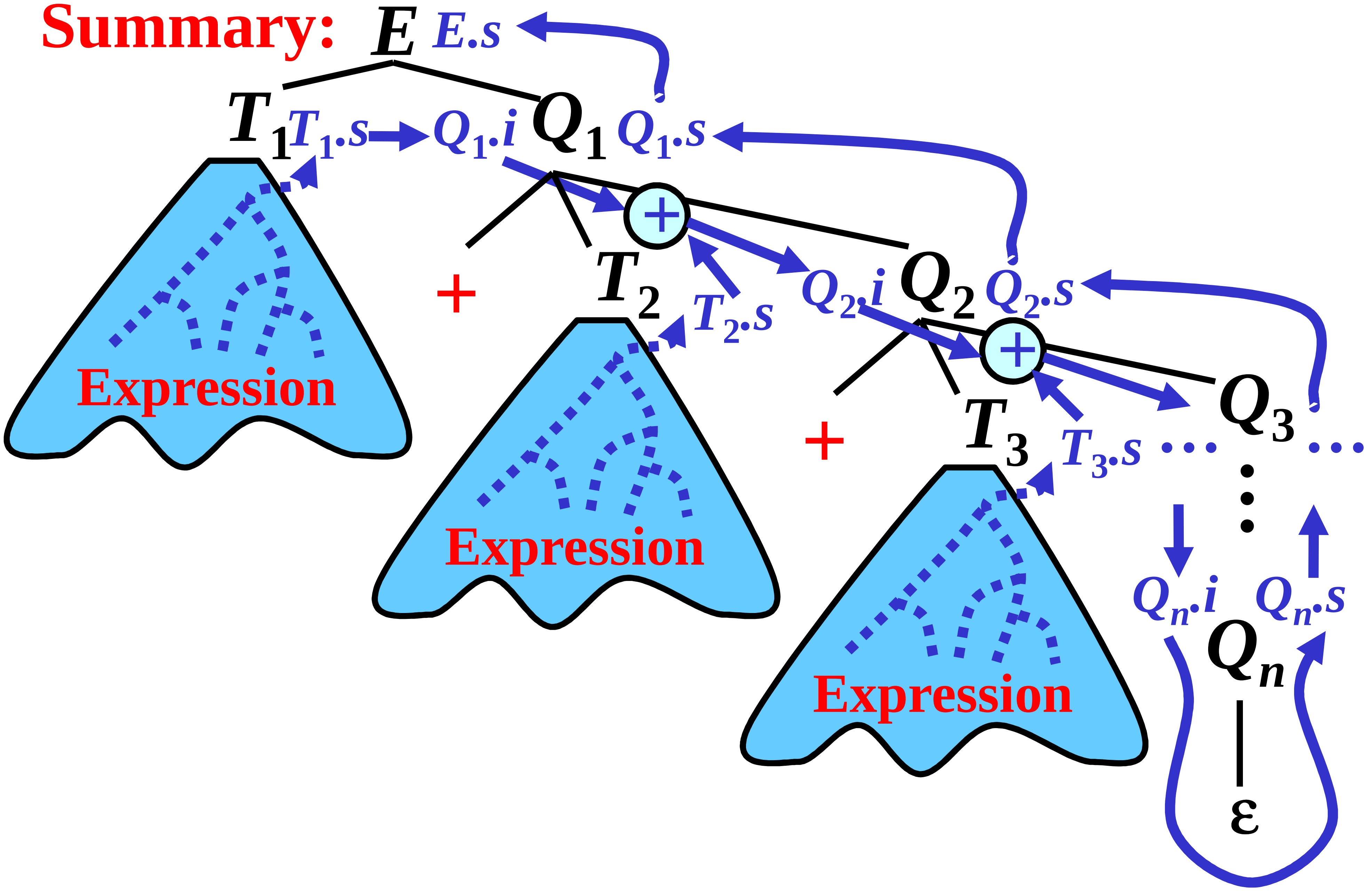
Expressions: Addition 4/4

Summary:



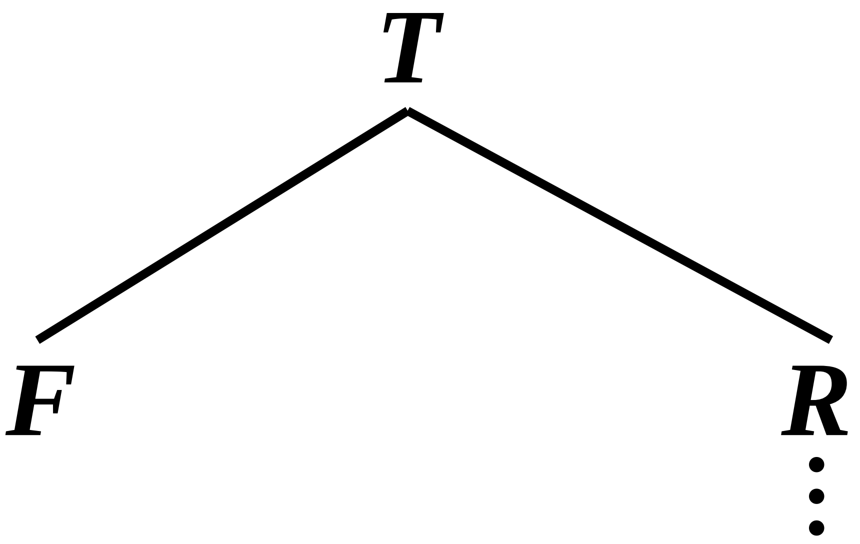
Expressions: Addition 4/4

Summary:



Expressions: Multiplication 1/4

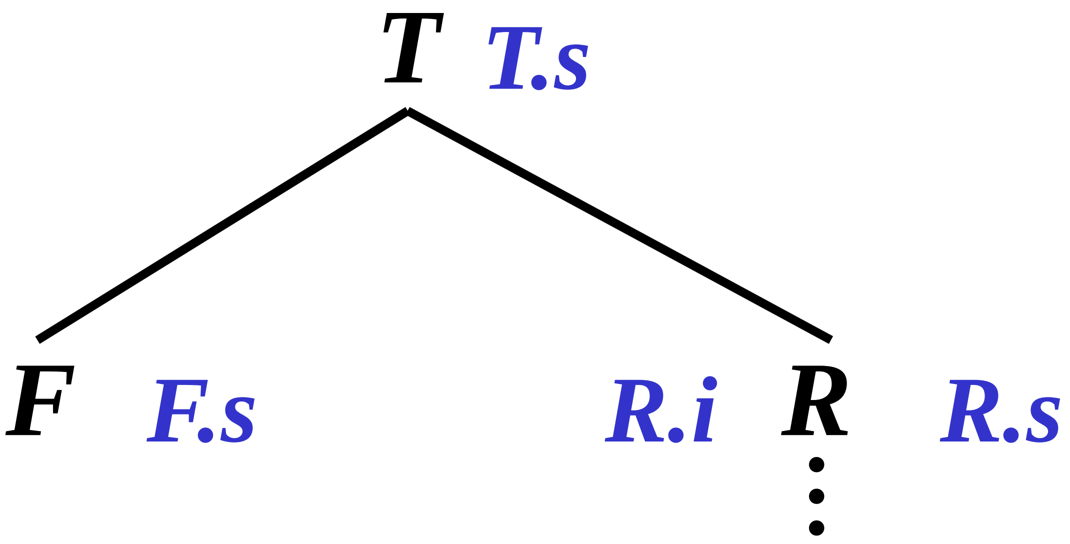
I.



$\boldsymbol{T} \rightarrow \boldsymbol{F}$ $\boldsymbol{R}$

Expressions: Multiplication 1/4

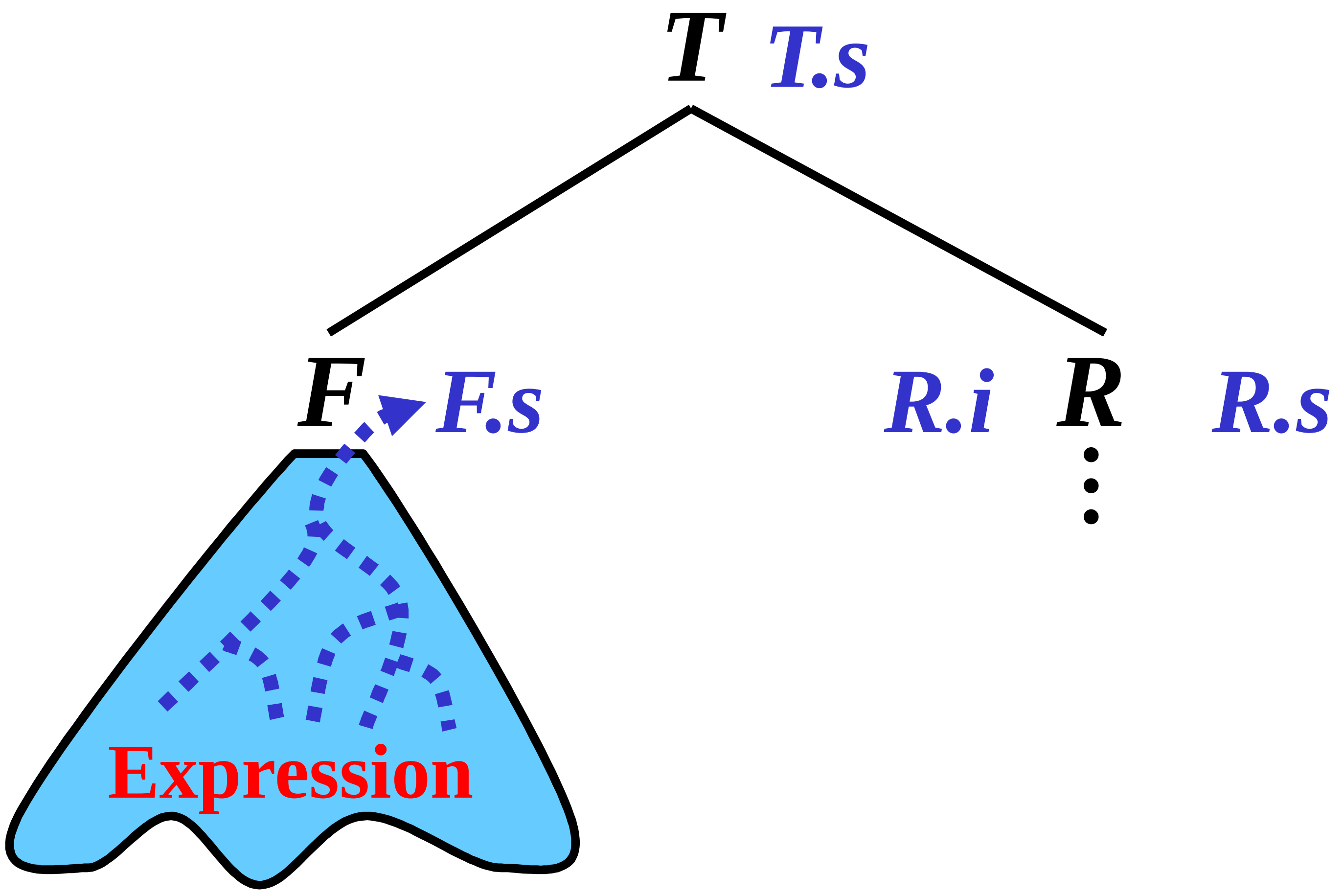
I.



$\boldsymbol{T \to F \qquad\qquad\qquad R}$

Expressions: Multiplication 1/4

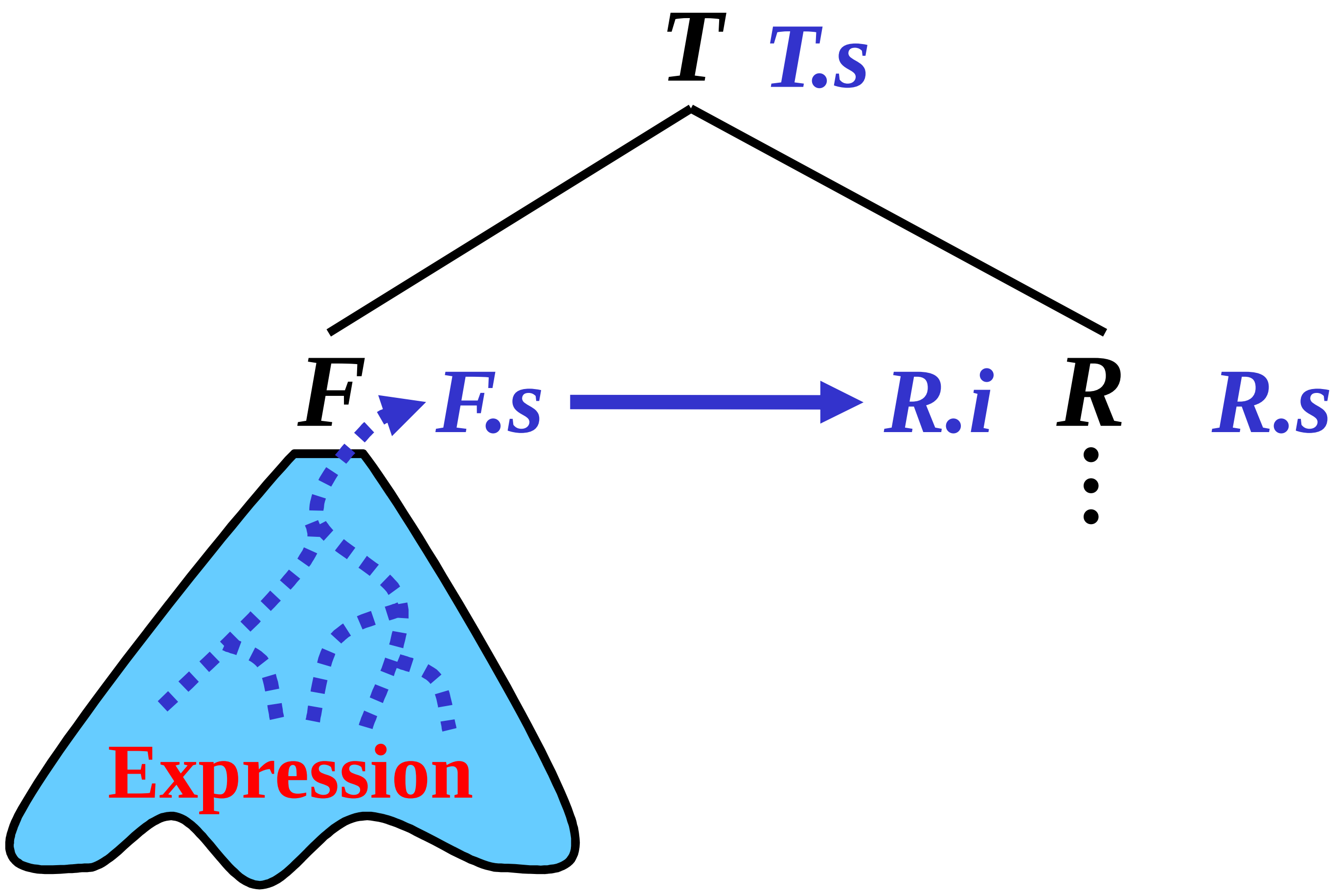
I.



$T \rightarrow F$ *R*

Expressions: Multiplication 1/4

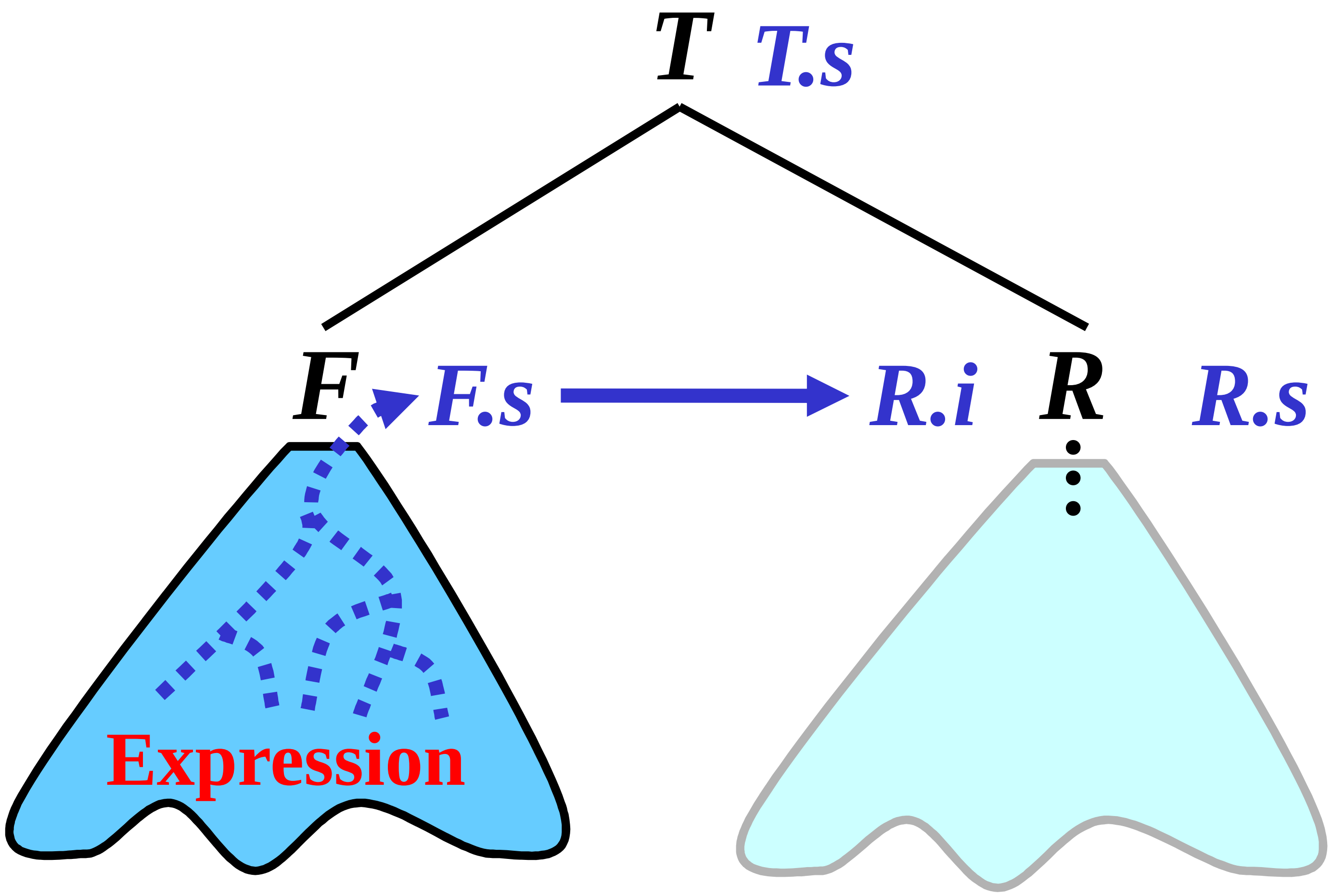
I.



$T \rightarrow F$ { $R.i := F.s$ } R

Expressions: Multiplication 1/4

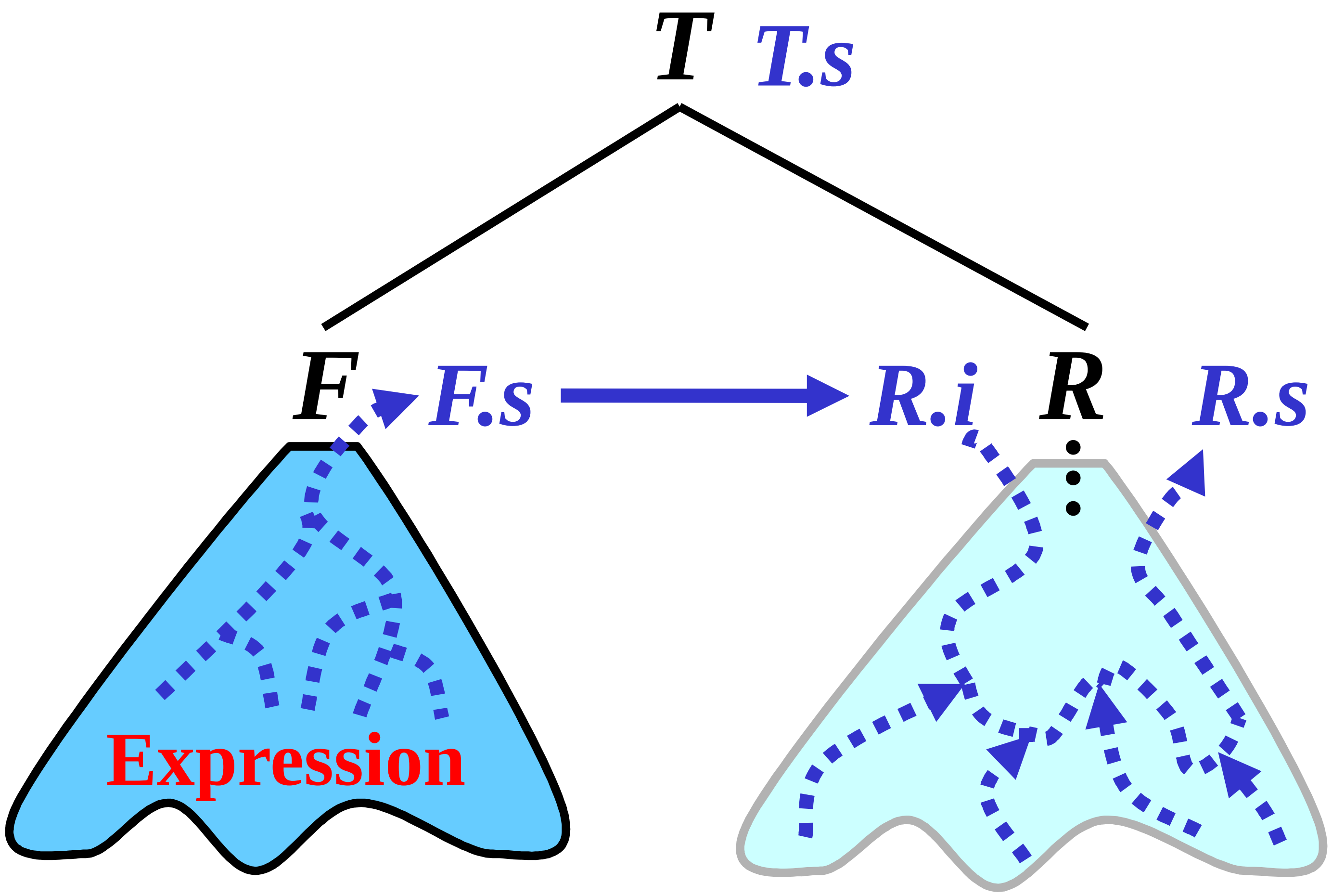
I.



$T \rightarrow F$ { $R.i := F.s$ } R

Expressions: Multiplication 1/4

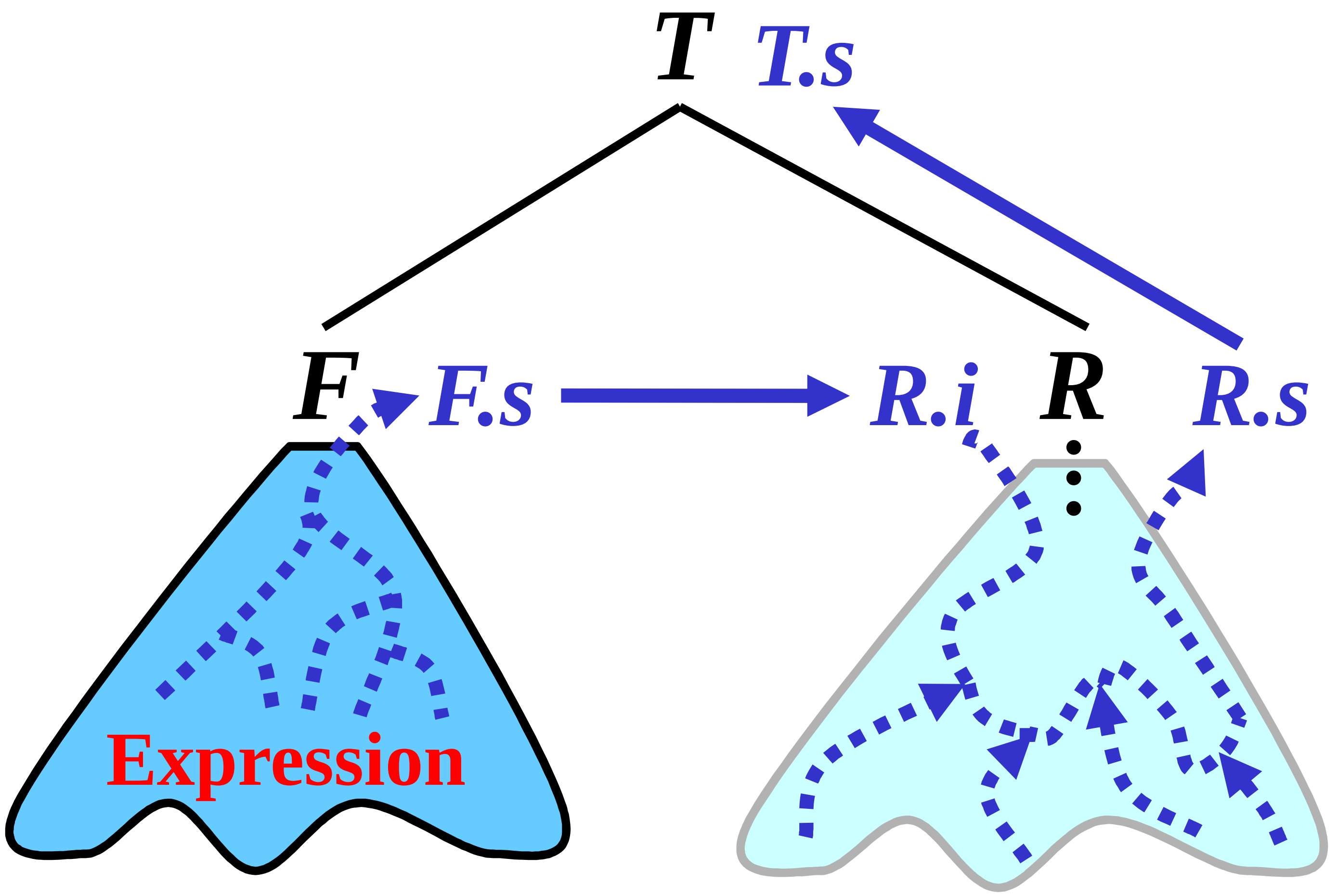
I.



$T \rightarrow F$ { $R.i := F.s$ } R

Expressions: Multiplication 1/4

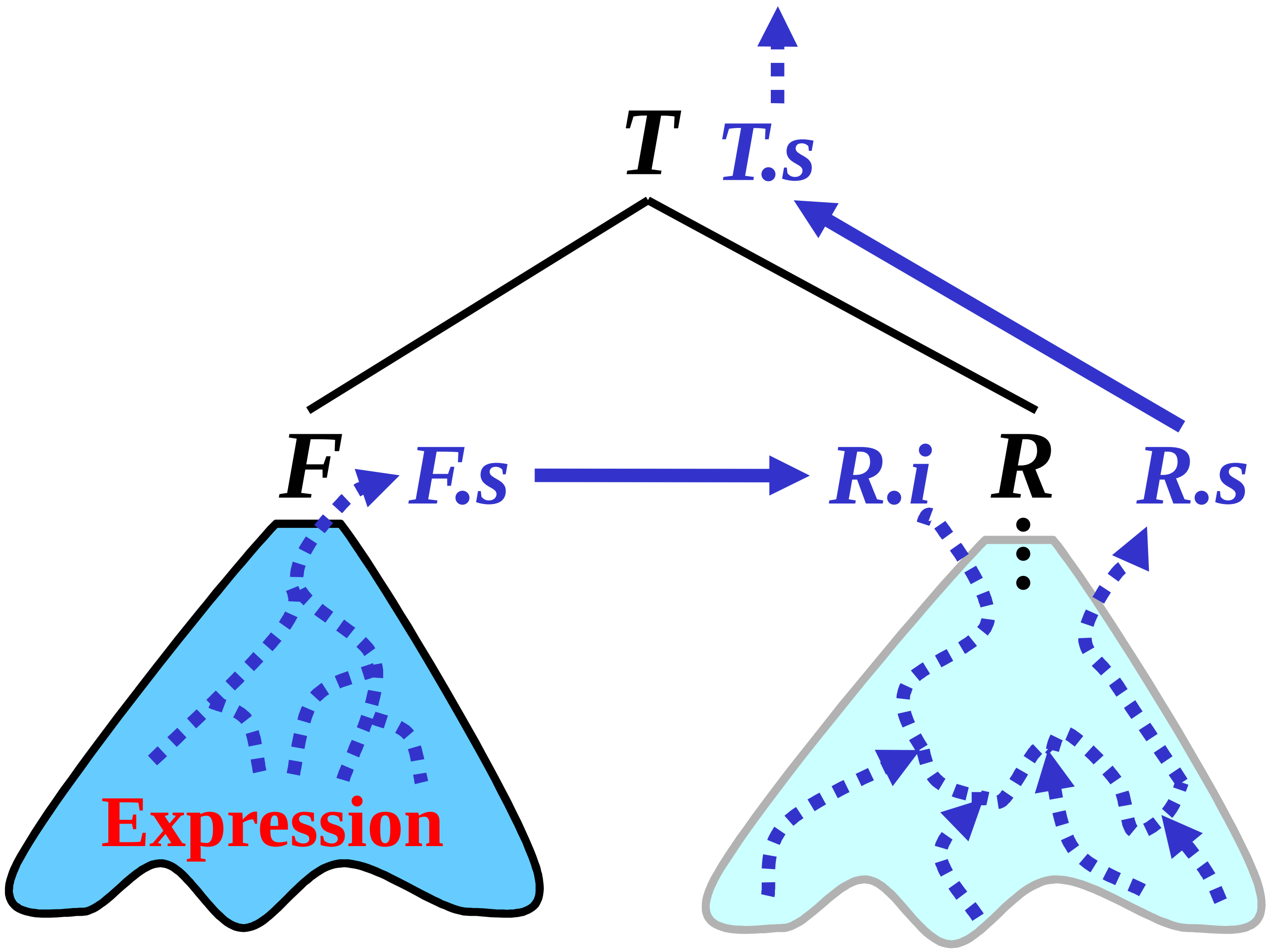
I.



$T \to F$ { $R.i := F.s$ } R { $T.s := R.s$ }

Expressions: Multiplication 1/4

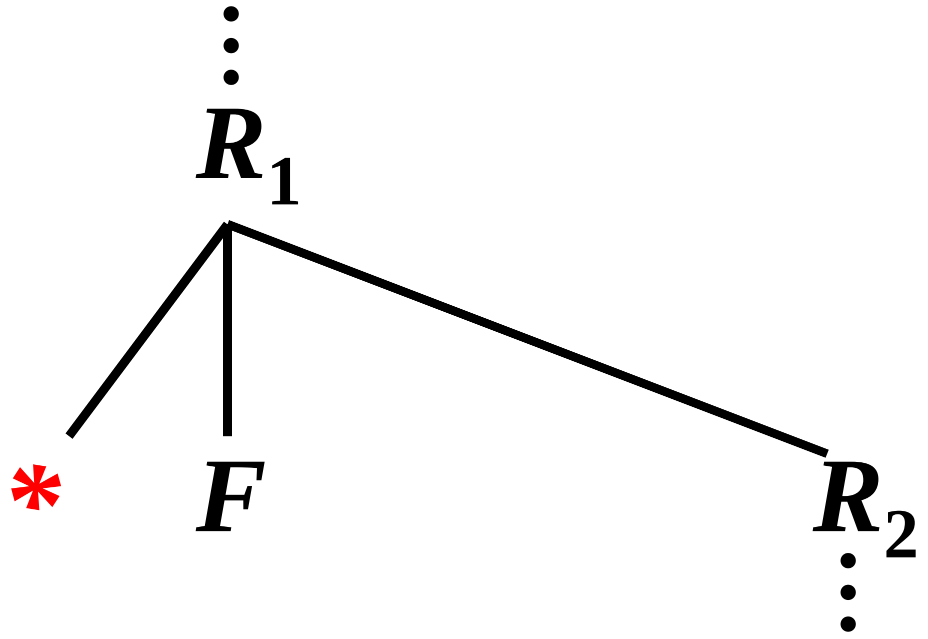
I.



$T \to F$ { $R.i := F.s$ } R { $T.s := R.s$ }

Expressions: Multiplication 2/4

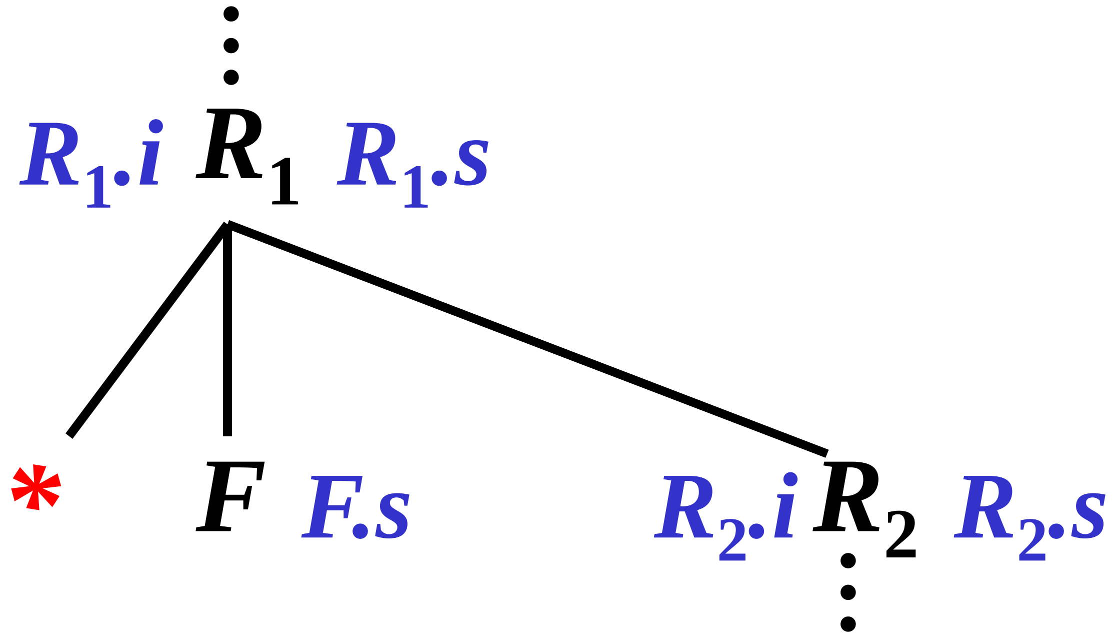
II.



$R_1 \to *F$ Q_2

Expressions: Multiplication 2/4

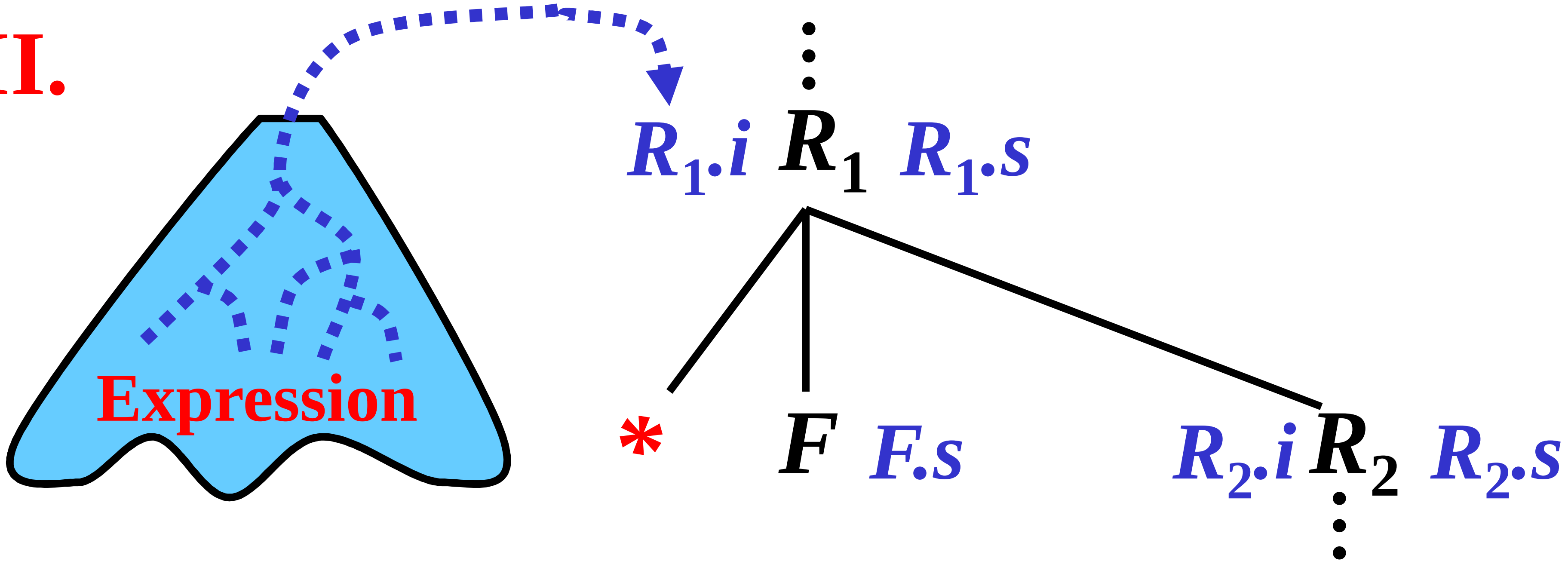
II.



$R_1 \rightarrow *F$ Q_2

Expressions: Multiplication 2/4

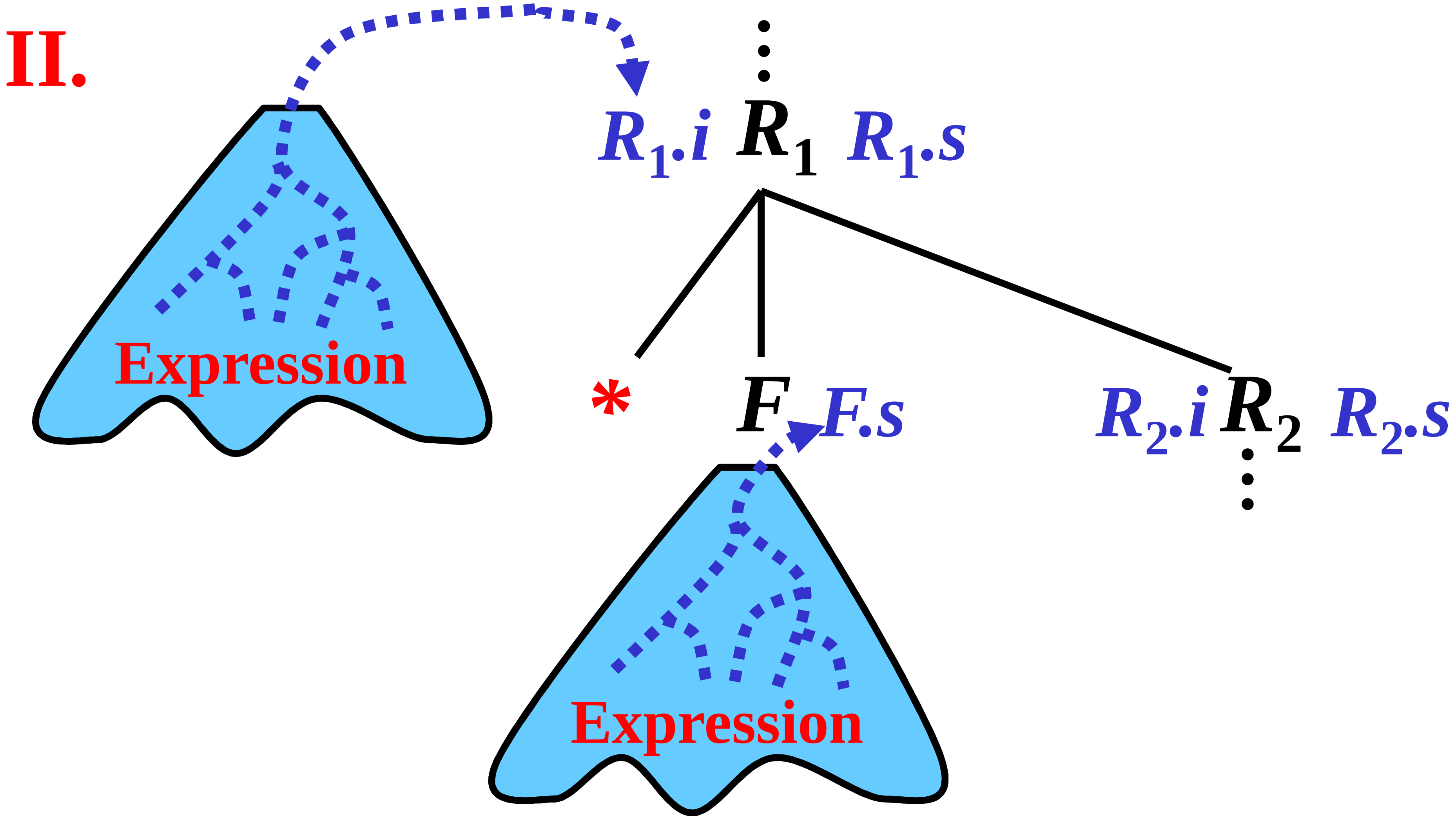
II.



$R_1 \rightarrow *F$

Q_2

Expressions: Multiplication 2/4

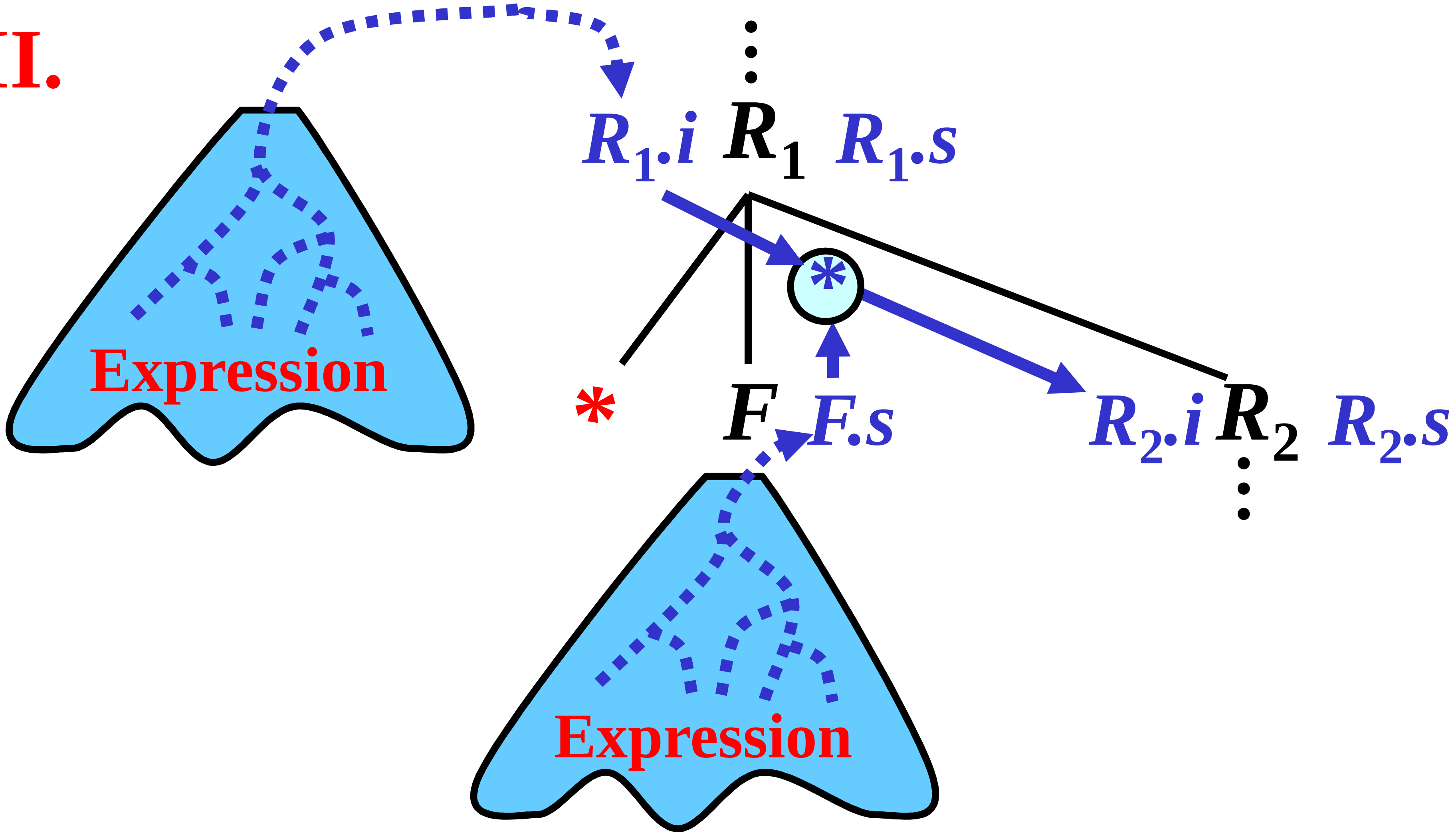


$R_1 \rightarrow *F$

Q_2

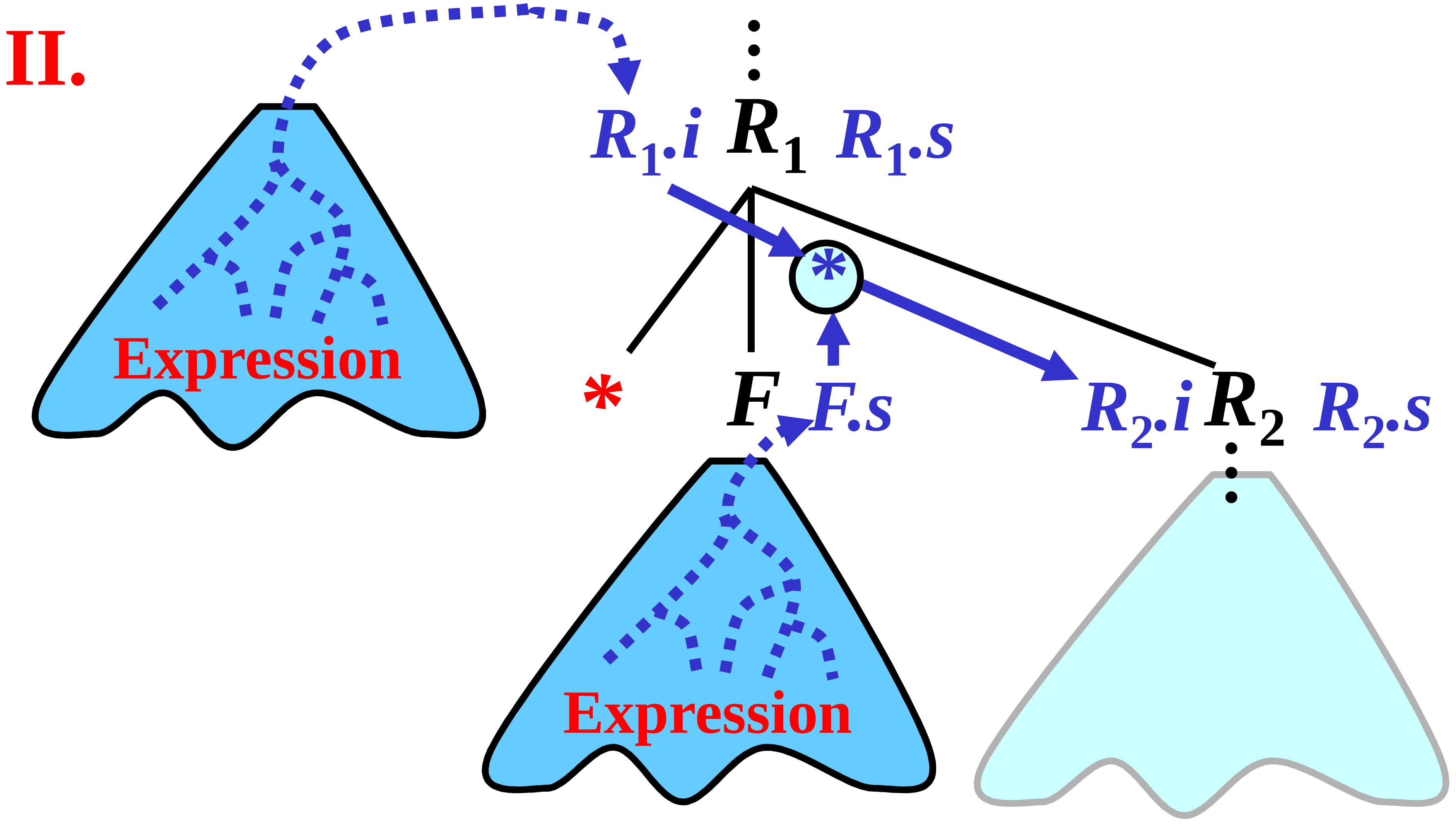
Expressions: Multiplication 2/4

II.



$R_1 \rightarrow *F$ { $R_2.i := R_1.i * F.s$ } Q_2

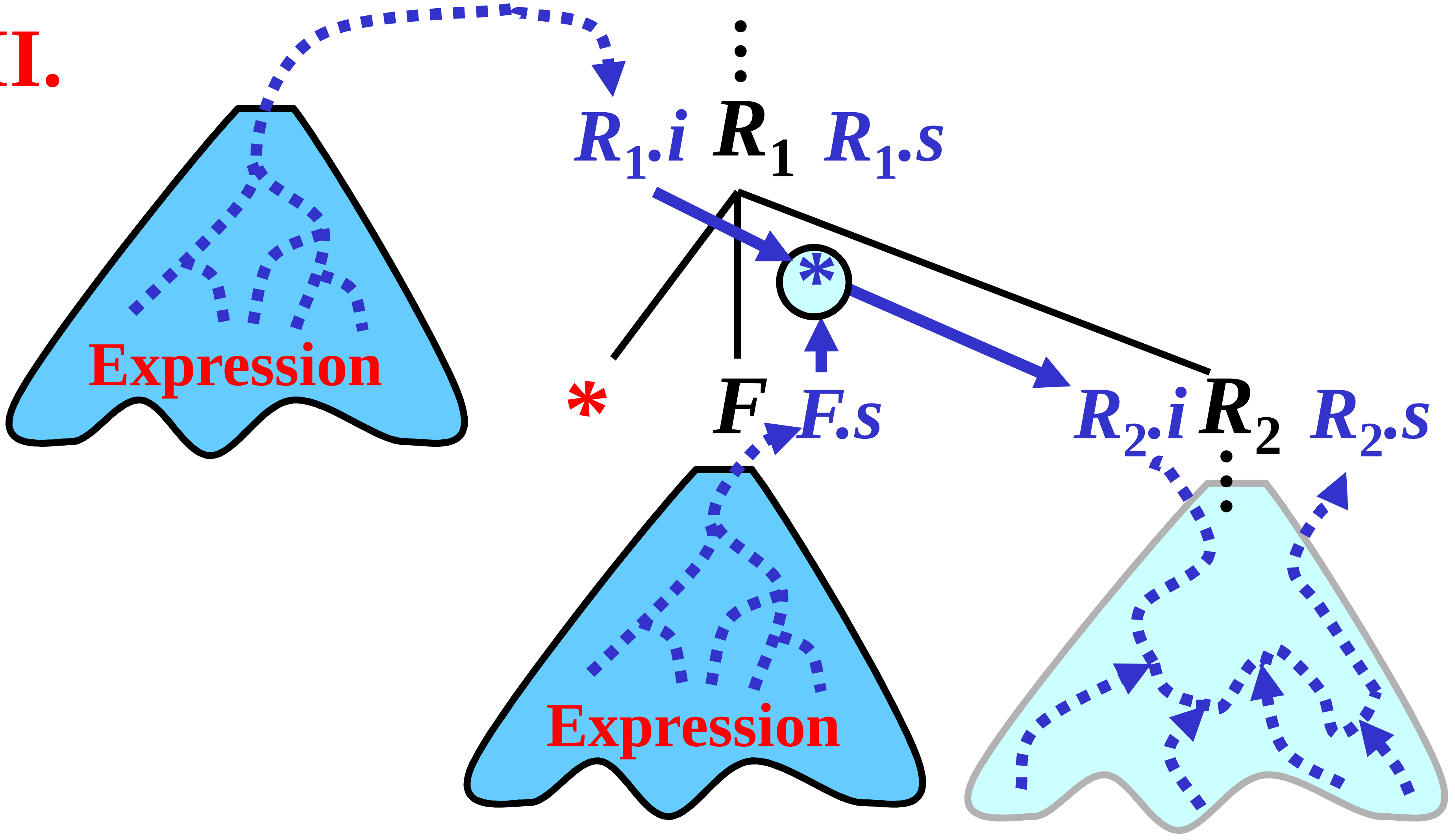
Expressions: Multiplication 2/4



$R_1 \rightarrow *F \; \{ \; R_2.i := R_1.i * F.s \; \} \; Q_2$

Expressions: Multiplication 2/4

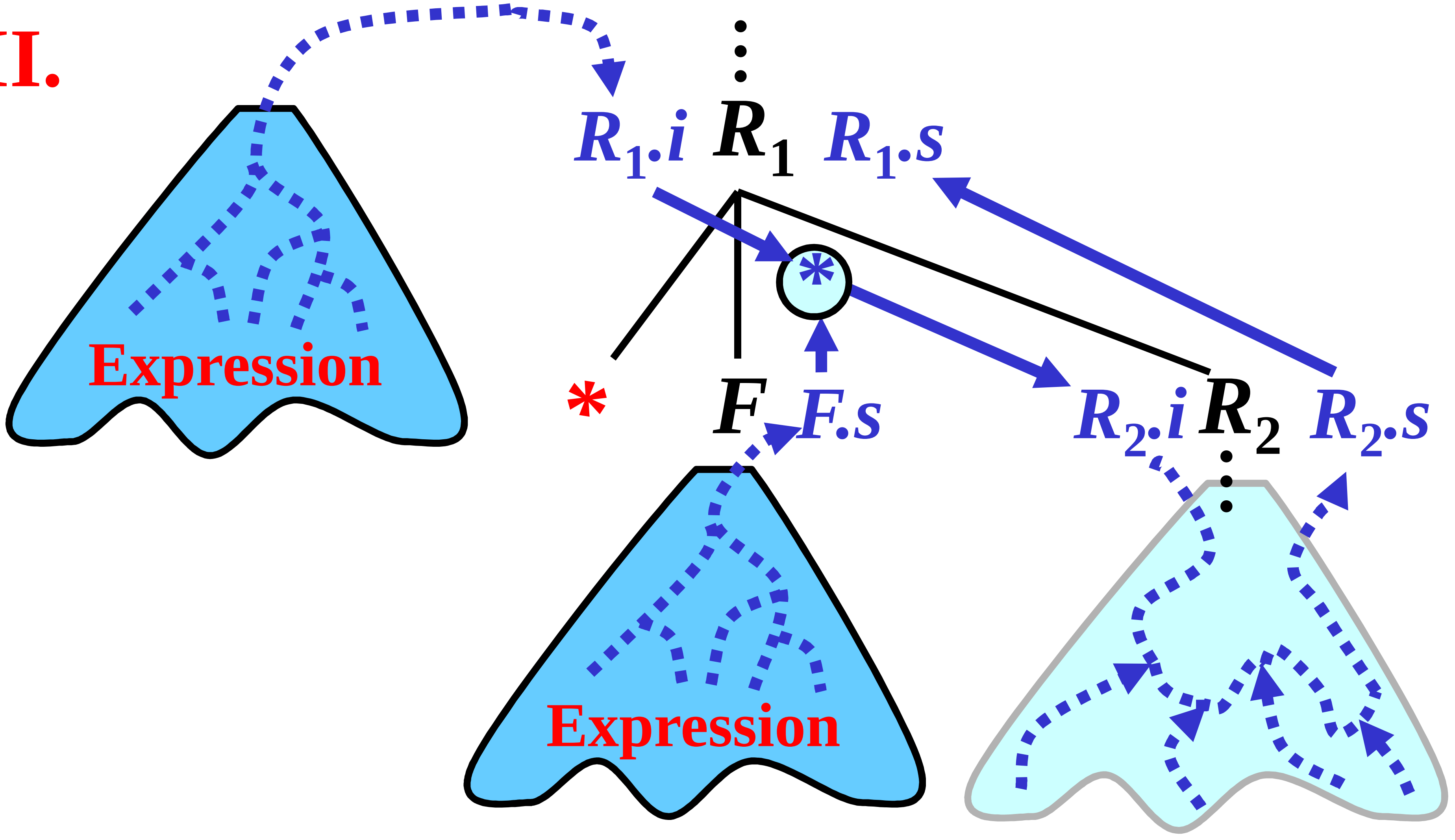
II.



$R_1 \rightarrow *F \; \{ \; R_2.i := R_1.i * F.s \; \} \; Q_2$

Expressions: Multiplication 2/4

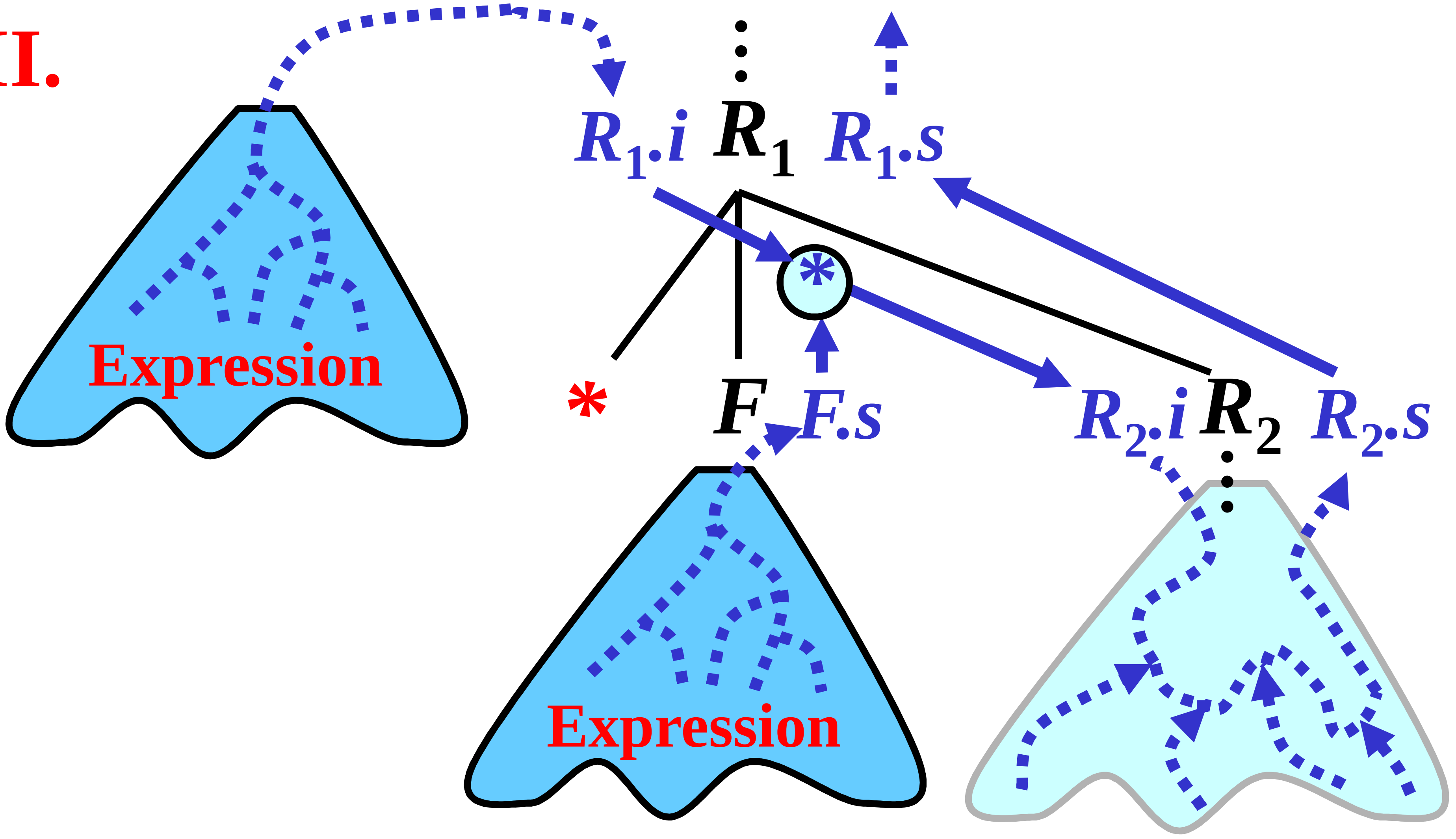
II.



$R_1 \rightarrow *F \; \{ R_2.i := R_1.i * F.s \} \; Q_2 \{ R_1.s := R_2.s \}$

Expressions: Multiplication 2/4

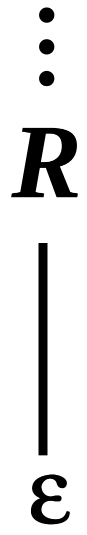
II.



$R_1 \rightarrow *F \;\{\, R_2.i := R_1.i * F.s \,\}\; Q_2 \{\, R_1.s := R_2.s \,\}$

Expressions: Multiplication 3/4

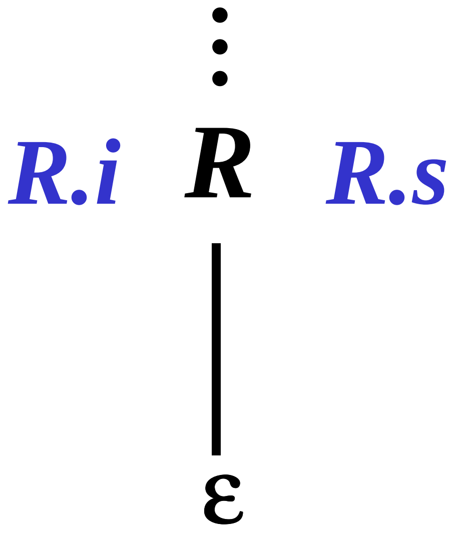
III.



$$\boldsymbol{R} \to \varepsilon$$

Expressions: Multiplication 3/4

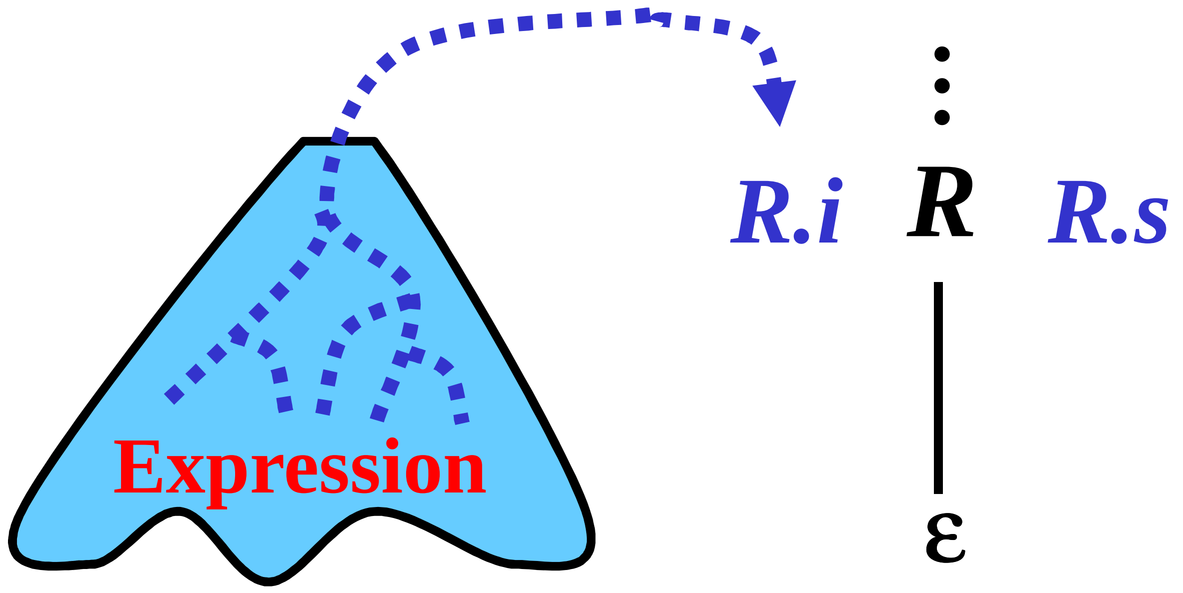
III.



$$R \rightarrow \varepsilon$$

Expressions: Multiplication 3/4

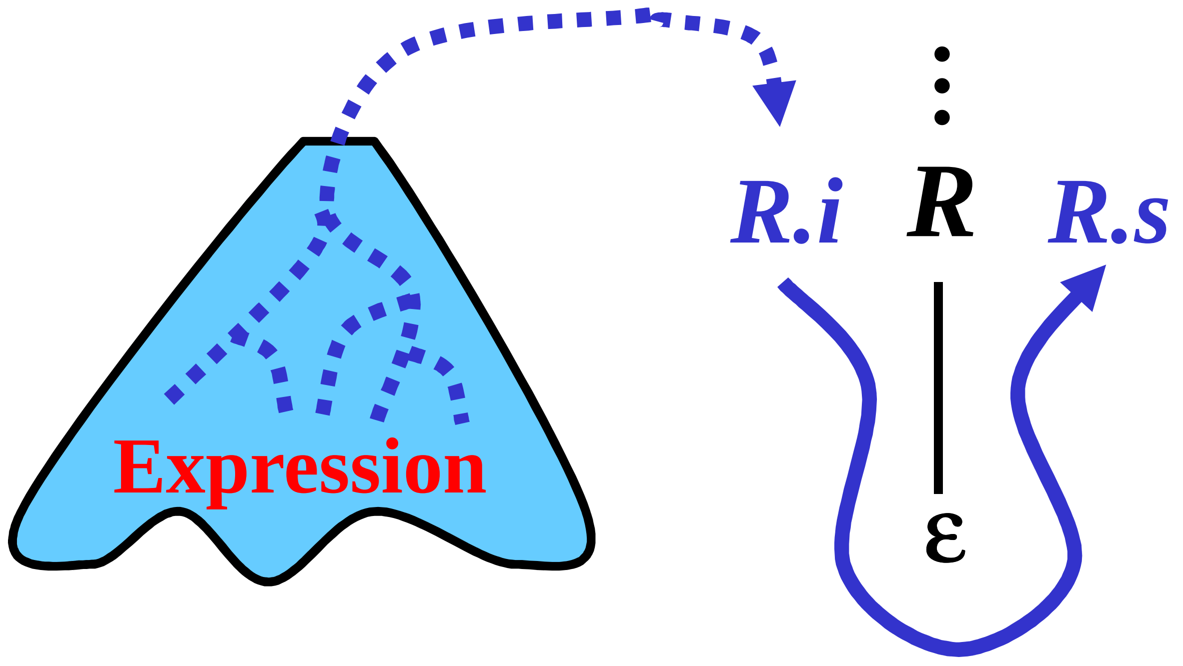
III.



$$\boldsymbol{R} \rightarrow \varepsilon$$

Expressions: Multiplication 3/4

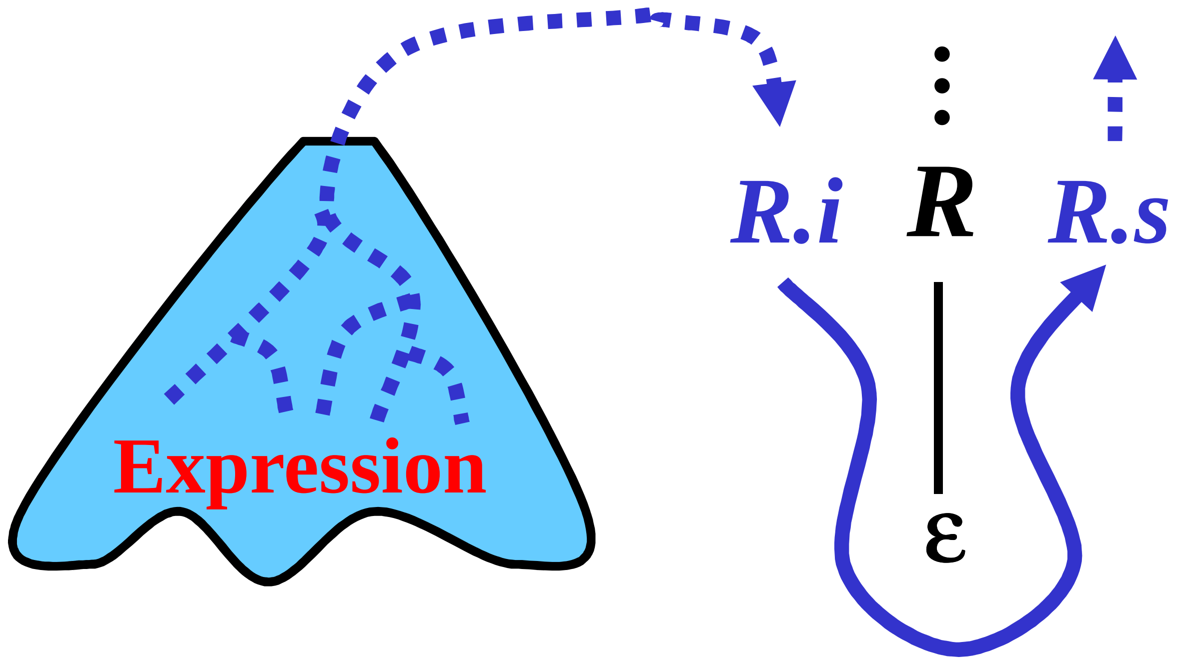
III.



$R \rightarrow \varepsilon \quad \{R.s := R.i\}$

Expressions: Multiplication 3/4

III.



$R \rightarrow \varepsilon \quad \{R.s := R.i\}$

Expressions: Multiplication 4/4

Summary:

$$\begin{tikzcd} & \boldsymbol{T} \arrow[dl, no head] \arrow[dr, no head] & \\ \boldsymbol{F}_1 & & \boldsymbol{R}_1 \end{tikzcd}$$

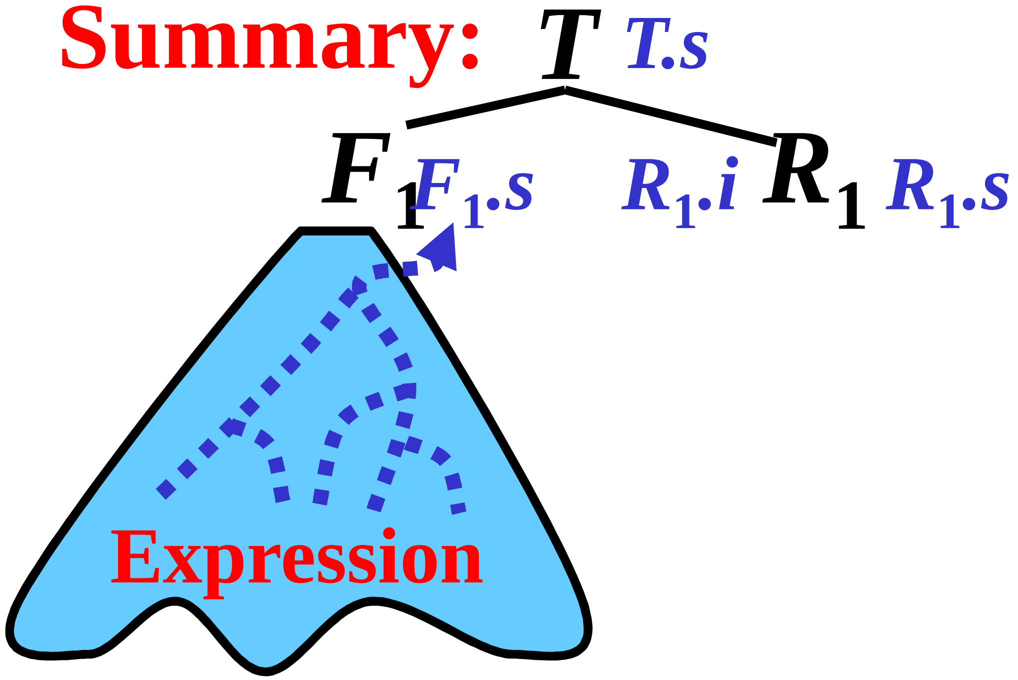
Expressions: Multiplication 4/4

Summary:

$$\begin{tikzcd} & T \quad T.s \arrow[dl, no head] \arrow[dr, no head] & \\ F_1 \; F_1.s & & R_1.i \; R_1 \; R_1.s \end{tikzcd}$$

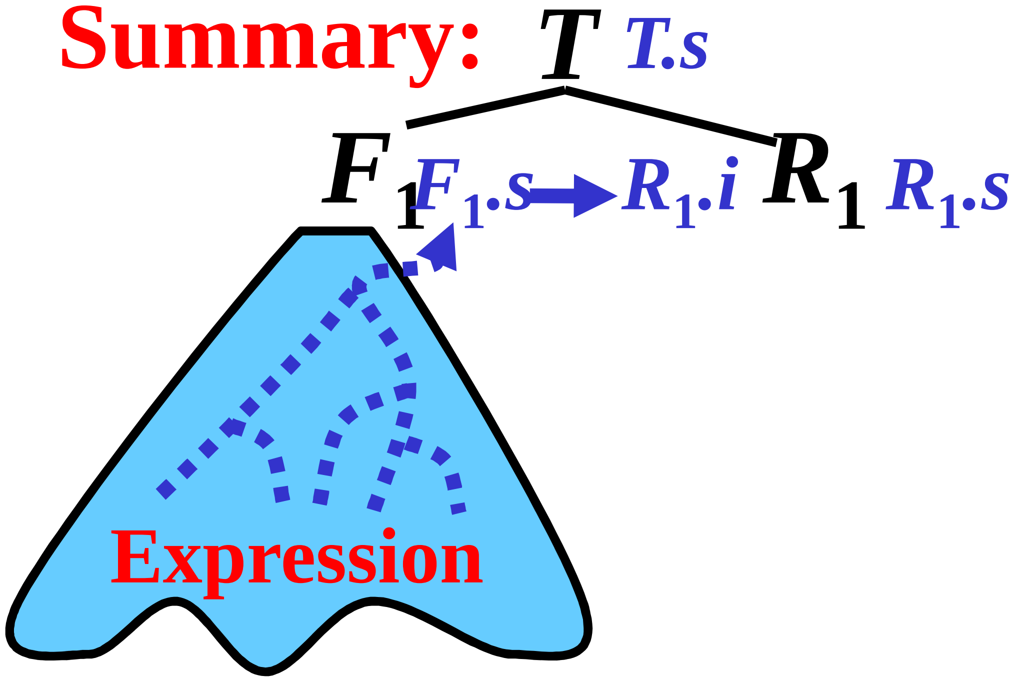
Expressions: Multiplication 4/4

Summary:



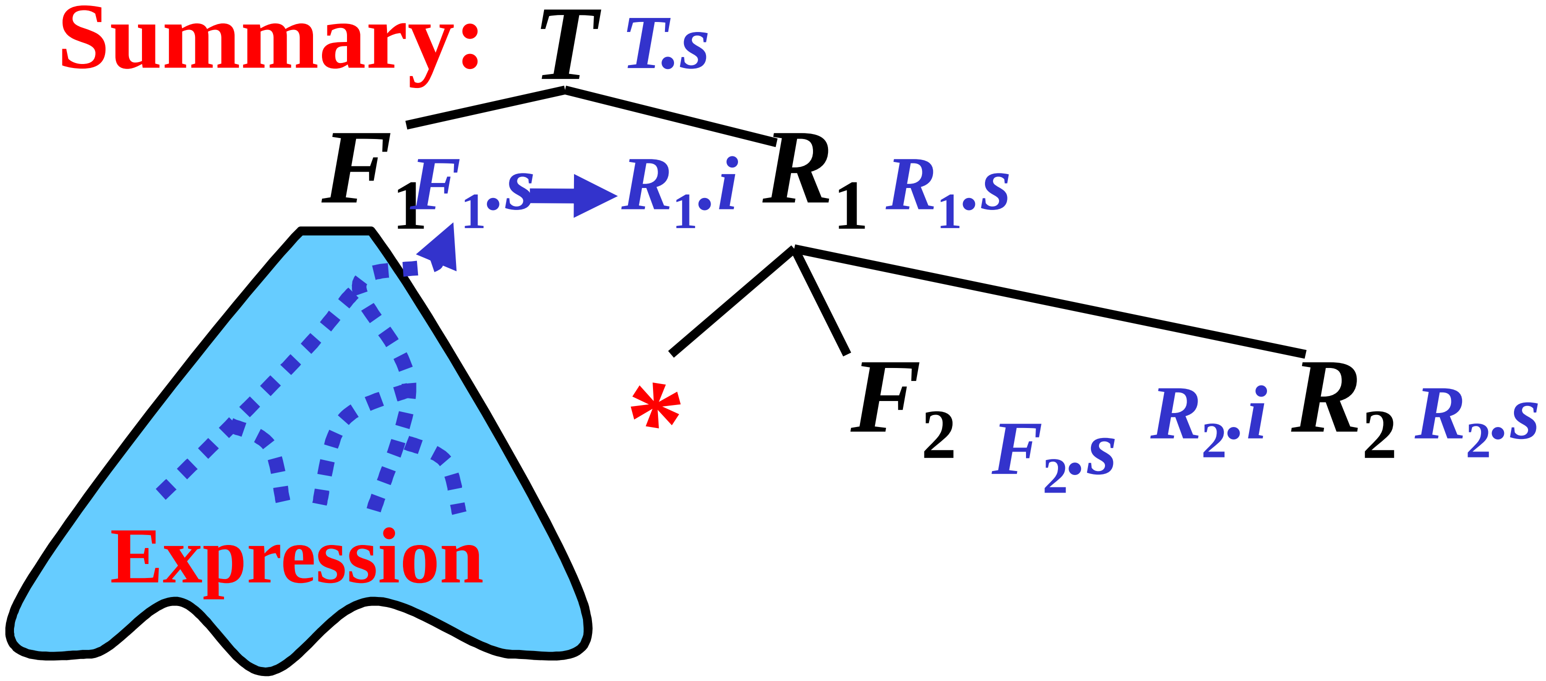
Expressions: Multiplication 4/4

Summary:



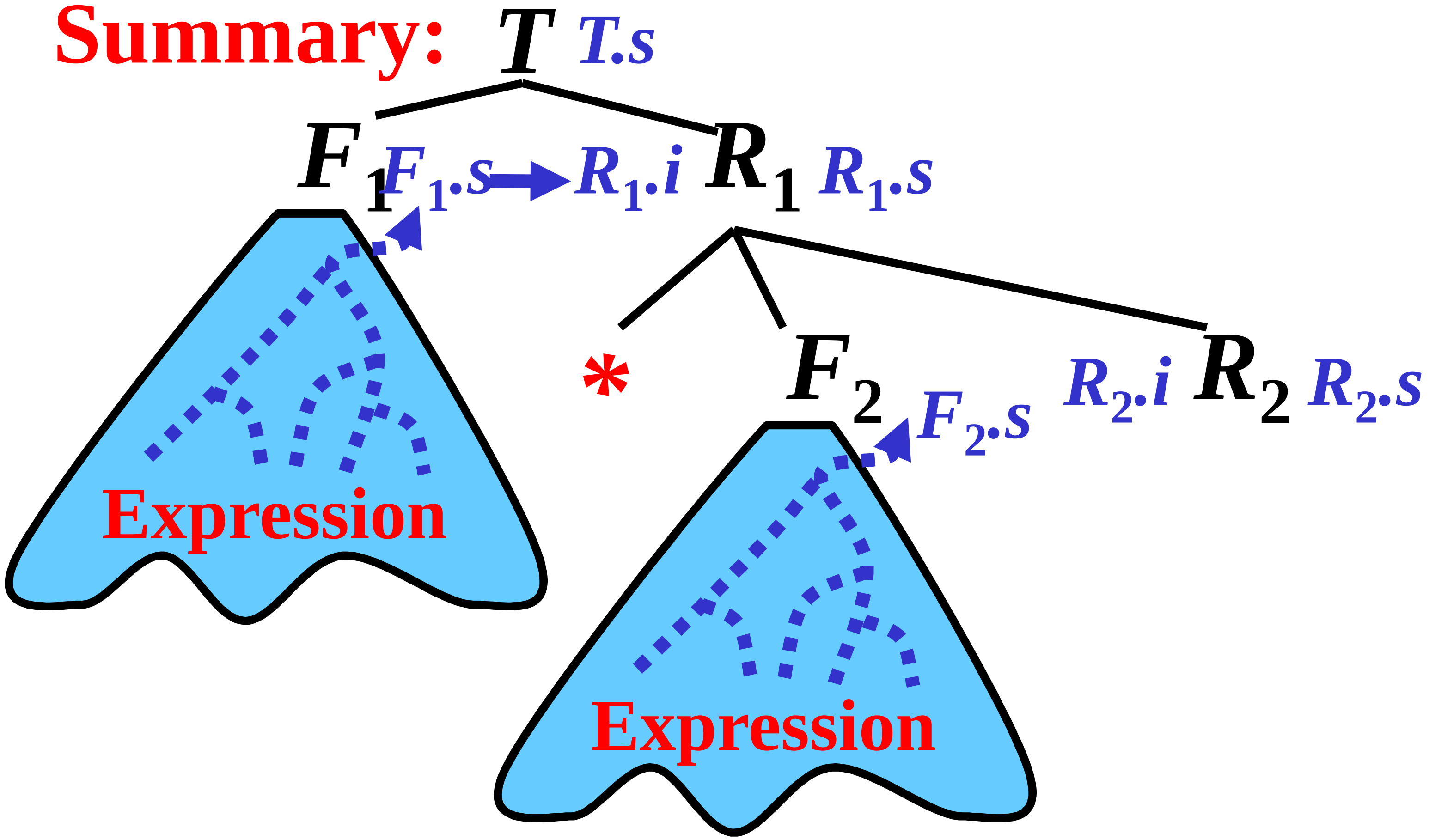
Expressions: Multiplication 4/4

Summary:



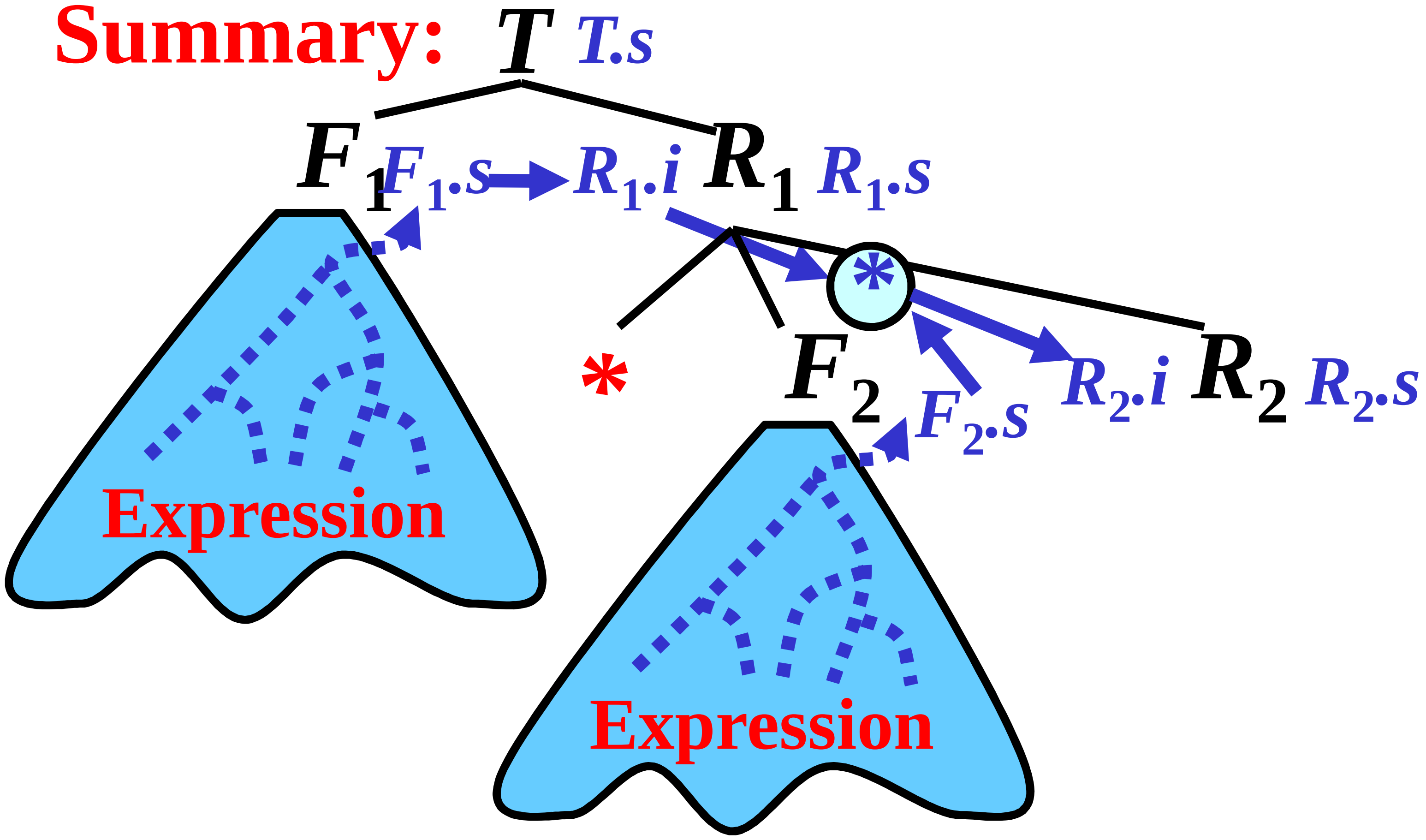
Expressions: Multiplication 4/4

Summary:



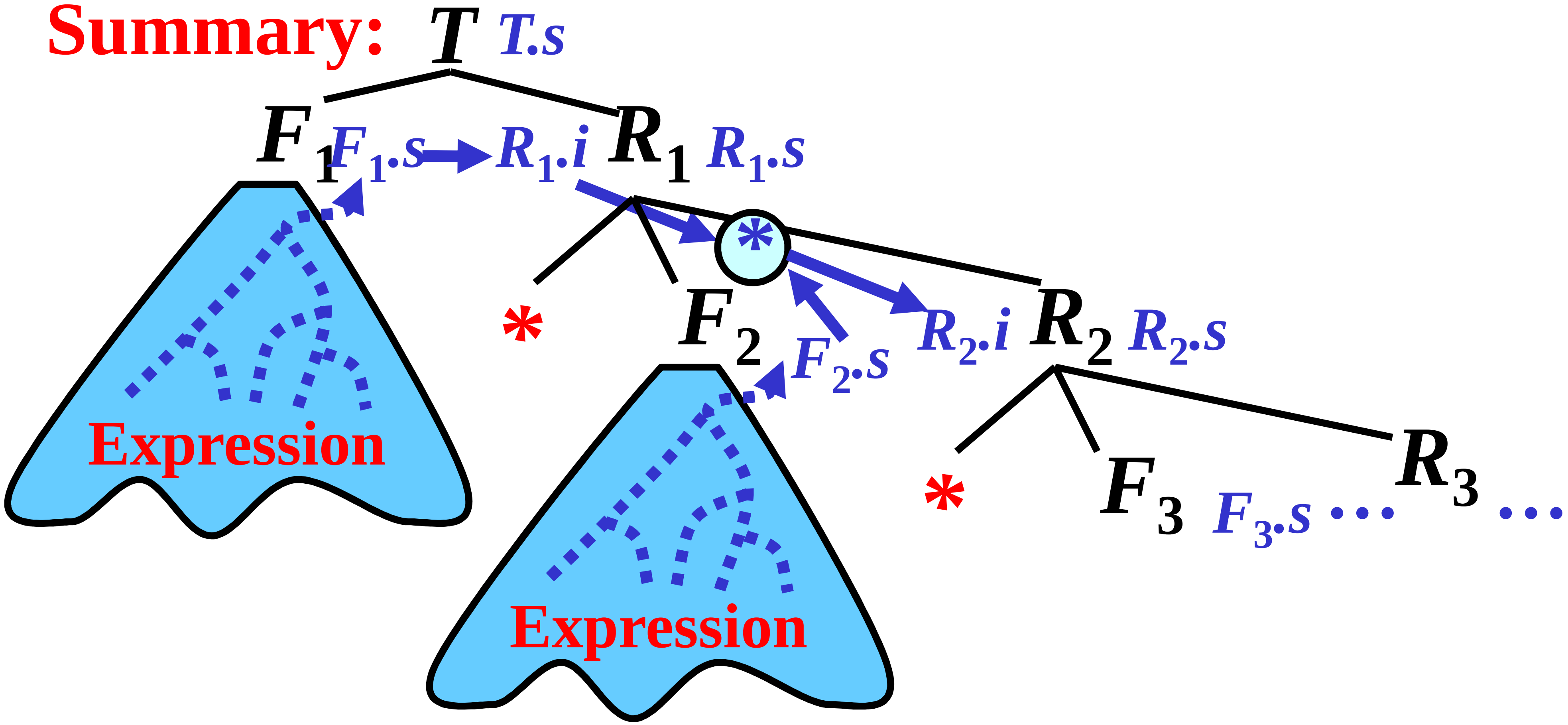
Expressions: Multiplication 4/4

Summary:



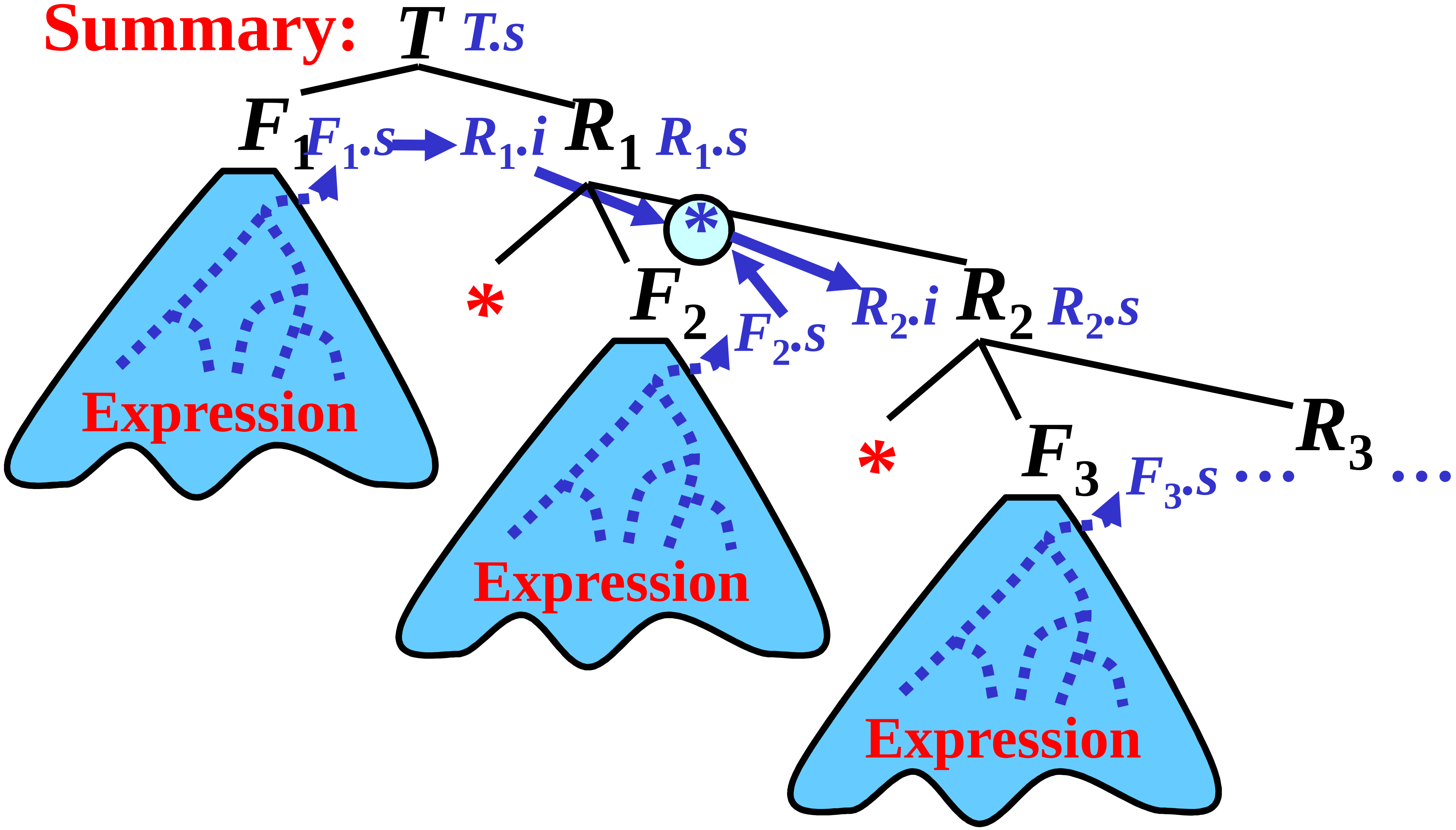
Expressions: Multiplication 4/4

Summary:



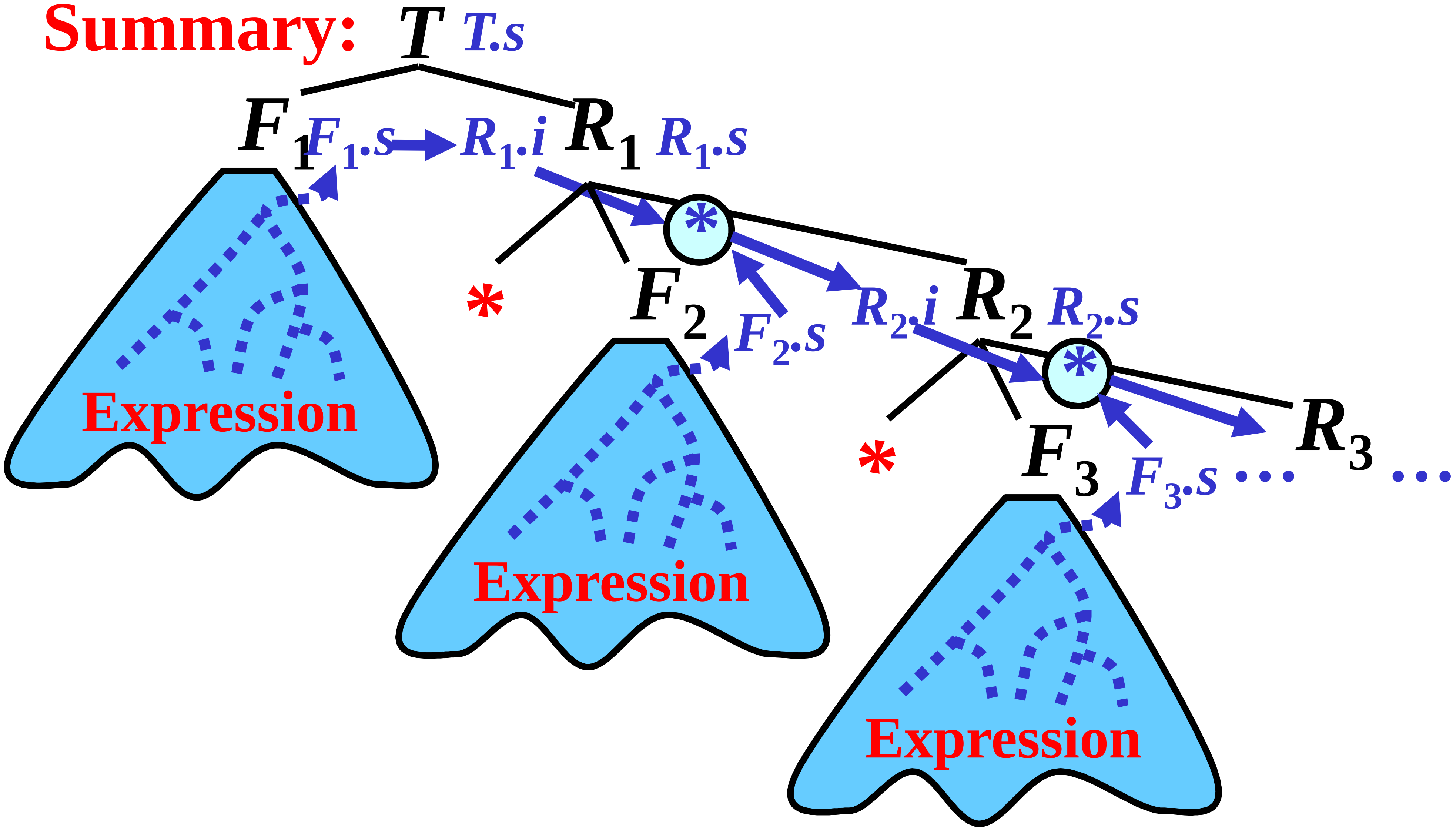
Expressions: Multiplication 4/4

Summary:



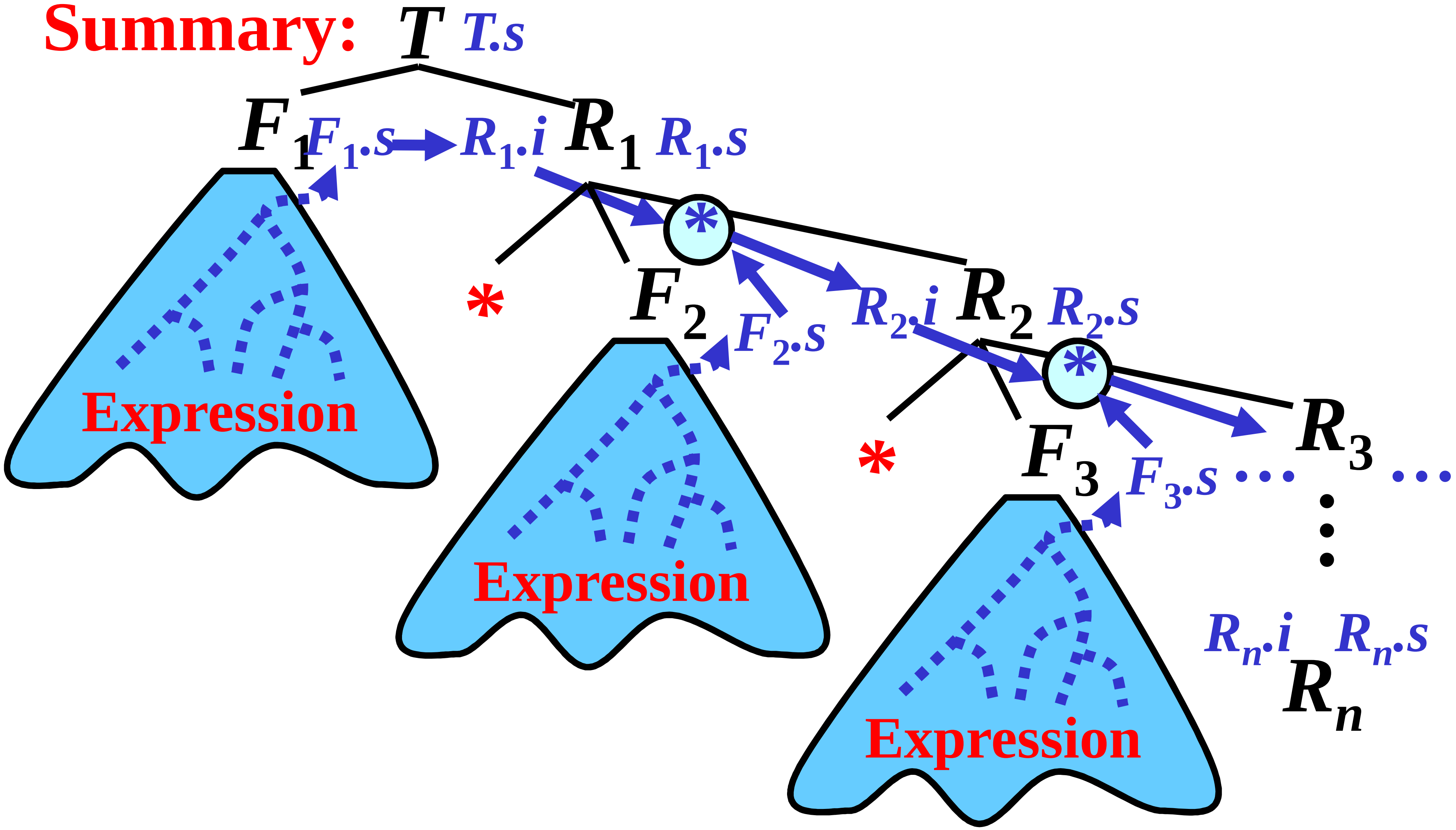
Expressions: Multiplication 4/4

Summary:



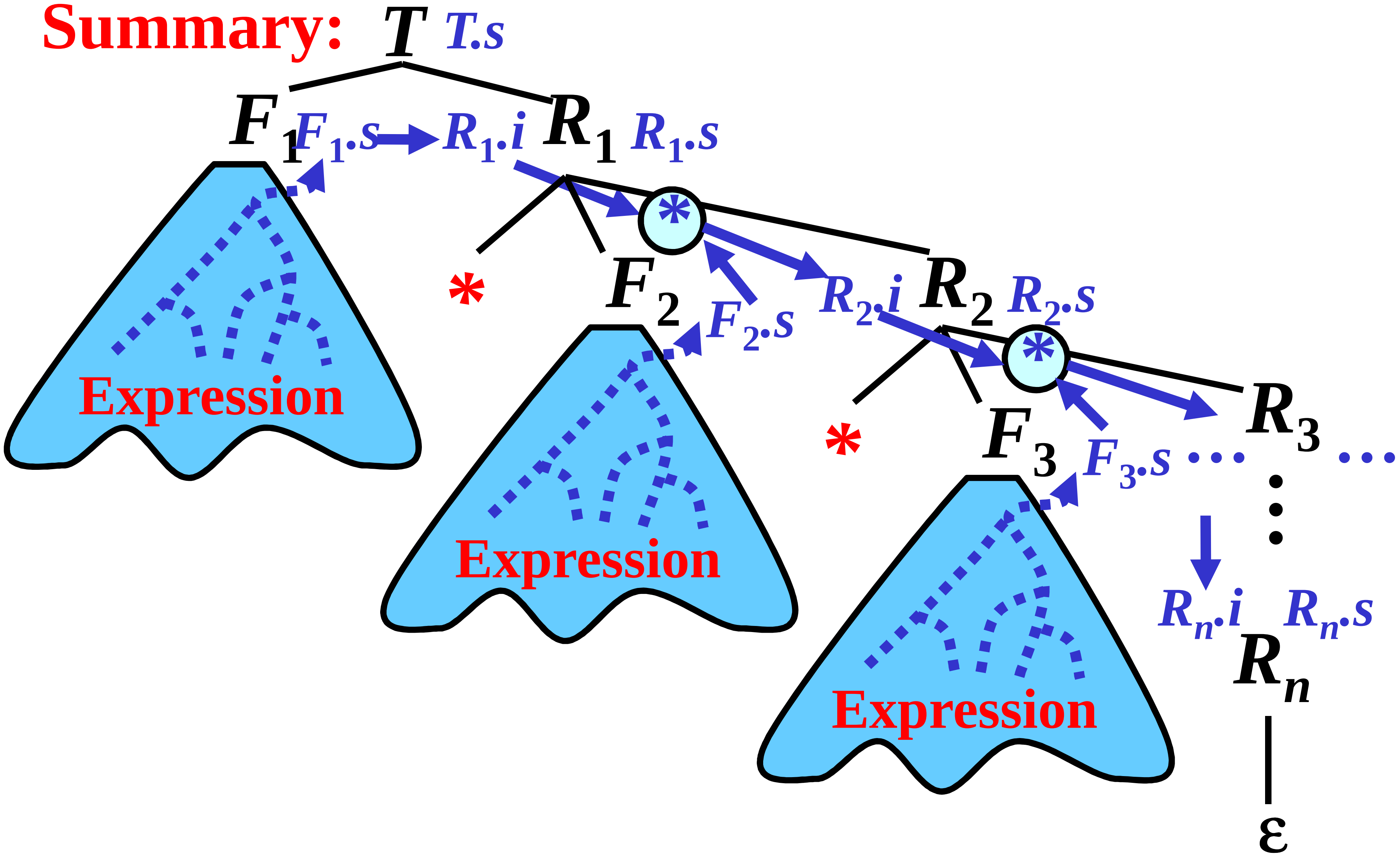
Expressions: Multiplication 4/4

Summary:



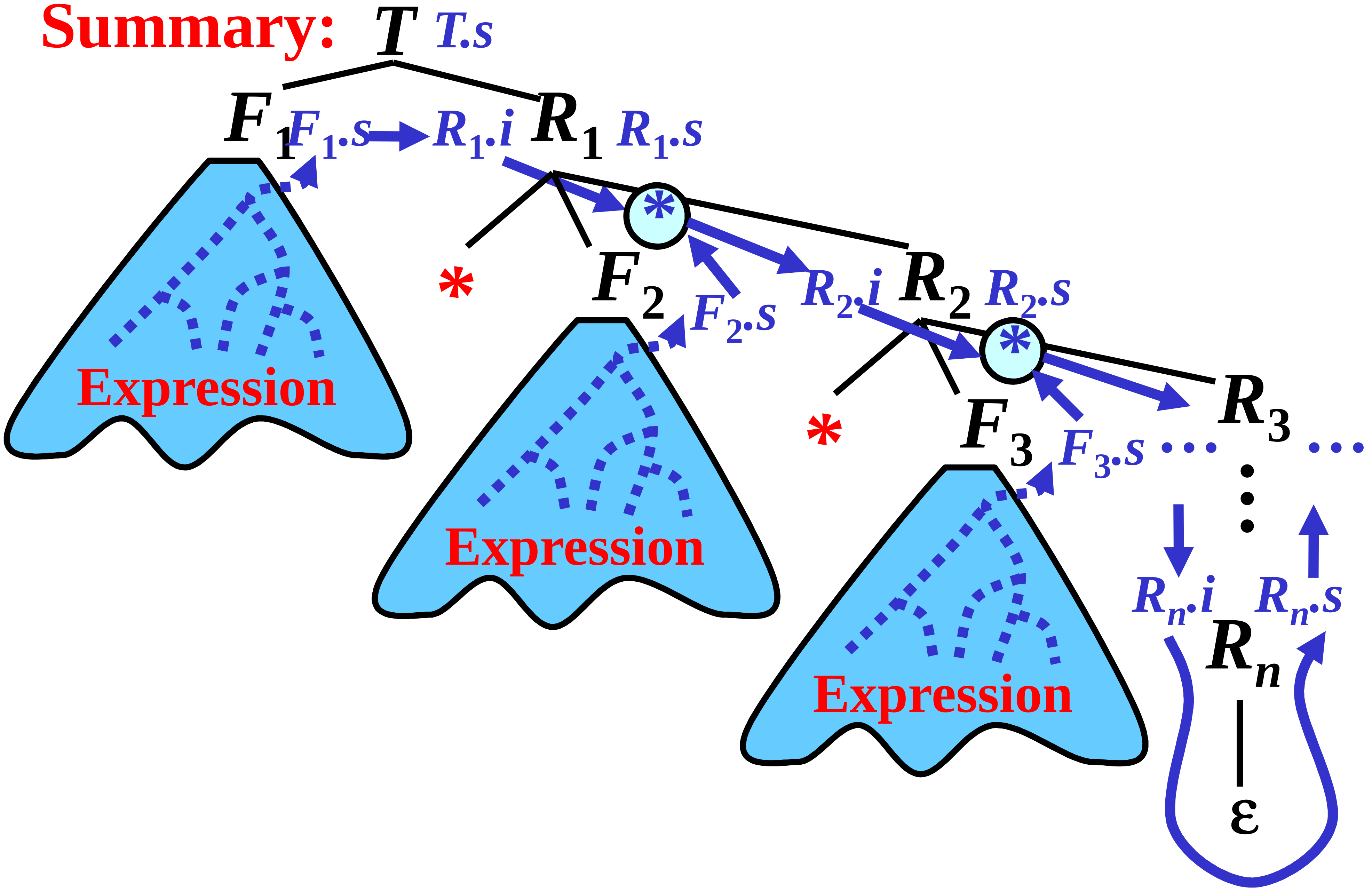
Expressions: Multiplication 4/4

Summary:



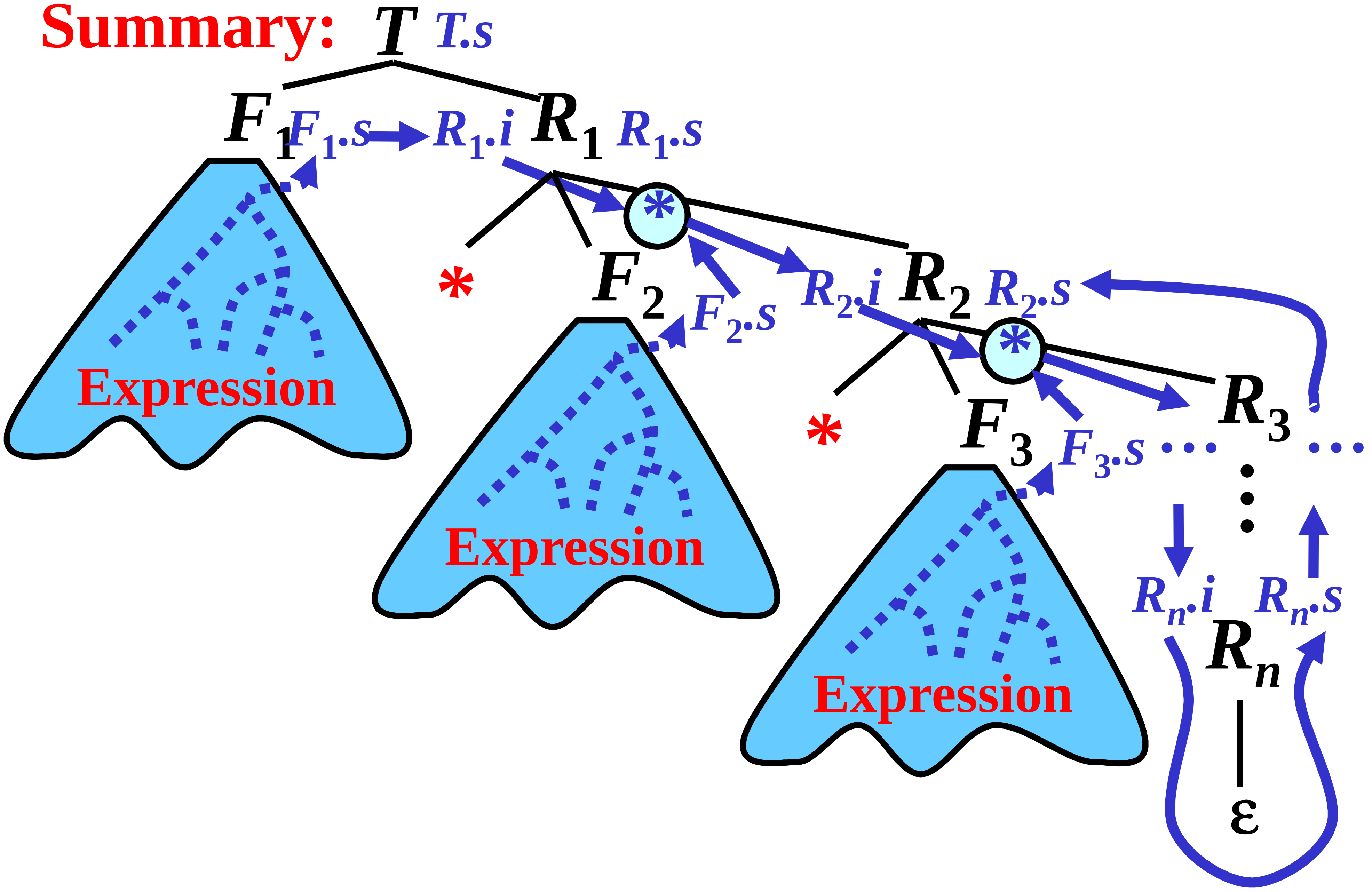
Expressions: Multiplication 4/4

Summary:



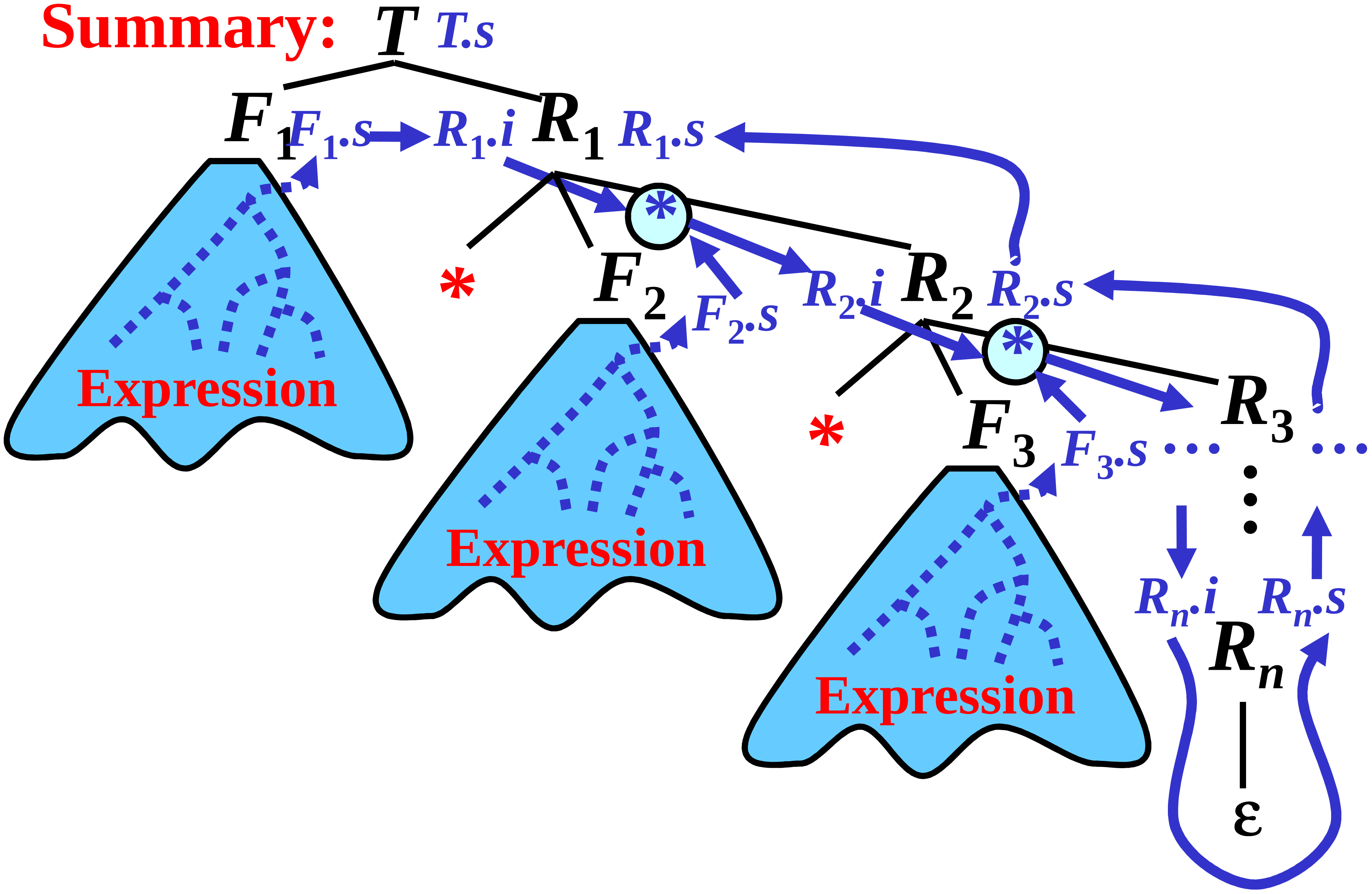
Expressions: Multiplication 4/4

Summary:



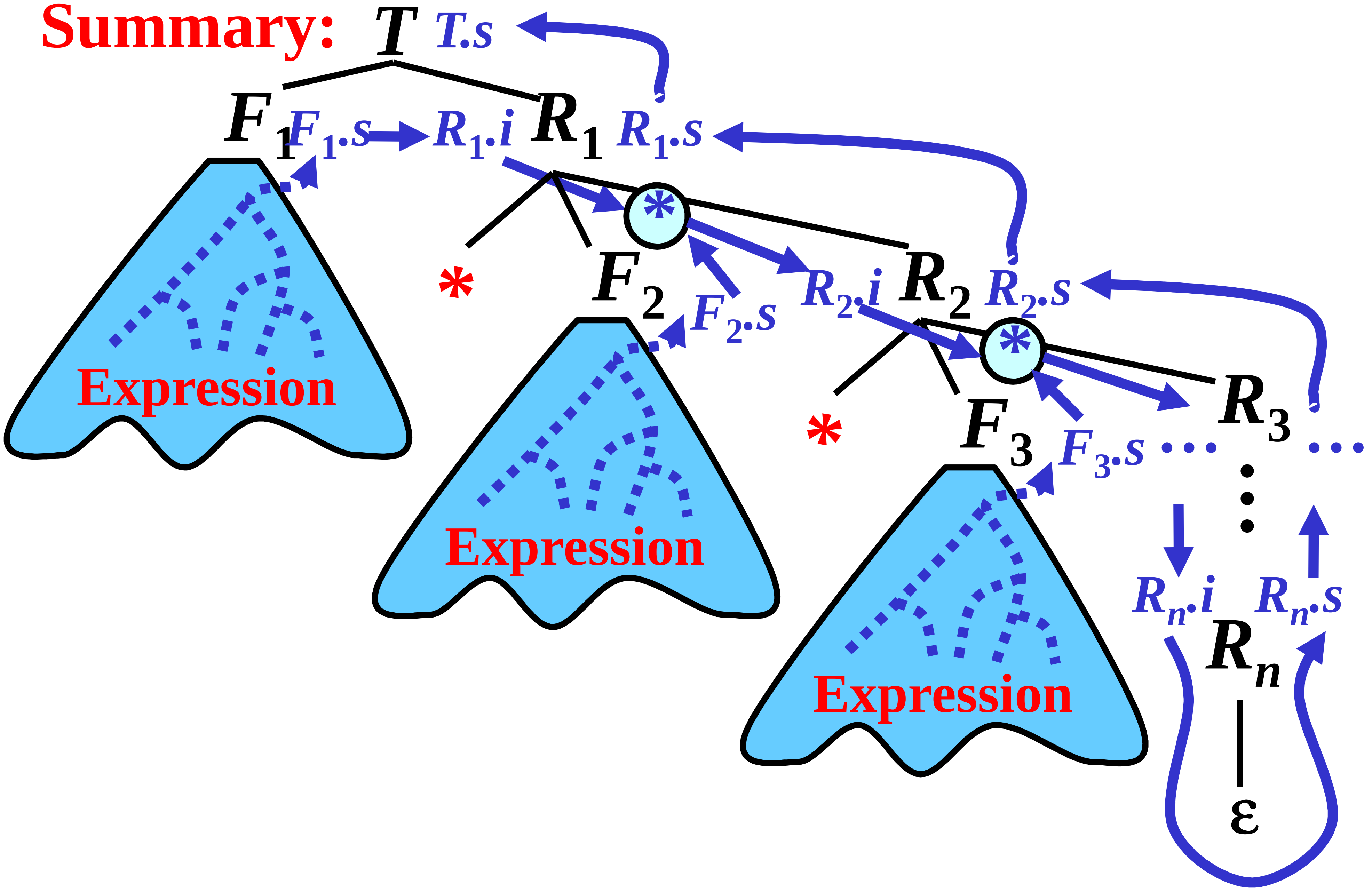
Expressions: Multiplication 4/4

Summary:



Expressions: Multiplication 4/4

Summary:



Grammar for Expressions: Summary

1. $E \rightarrow T$ $\{Q.i := T.s\}$ Q $\{E.s := Q.s\}$
2. $Q_1 \rightarrow +T$ $\{Q_2.i := Q_1.i + T.s\}$ Q_2 $\{Q_1.s := Q_2.s\}$
3. $Q \rightarrow \varepsilon$ $\{Q.s := Q.i\}$
4. $T \rightarrow F$ $\{R.i := F.s\}$ R $\{T.s := R.s\}$
5. $R_1 \rightarrow *F$ $\{R_2.i := R_1.i * F.s\}$ R_2 $\{R_1.s := R_2.s\}$
6. $R \rightarrow \varepsilon$ $\{R.s := R.i\}$
7. $F \rightarrow (E$ $\{F.s := E.s\}$ $)$
8. $F \rightarrow i$ $\{F.s := i.value\}$

Evaluation of Expressions: Example 1/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $i_1 + i_2\ \$$

Rule: $E \rightarrow T_1\ \{Q_1.i := T_1.s\}\ Q_1\ \{E.s := Q_1.s\}$

Parser pushdown:

E
$\$$

Semantic pushdown:

Illustration:

Evaluation of Expressions: Example 2/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $i_1 + i_2\ \$$

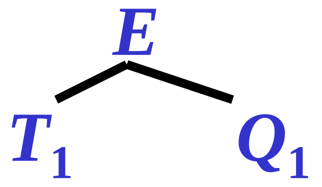
Rule: $T_1 \rightarrow F_1\ \{R_1.i := F_1.s\}\ R_1\ \{T_1.s := R_1.s\}$

Parser pushdown:

T_1
$\{Q_1.i := T_1.s\}$
Q_1
$\{E.s := Q_1.s\}$
$\$$

Semantic pushdown:

Illustration:



10 | + | 20

Evaluation of Expressions: Example 3/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $i_1 + i_2$ \$

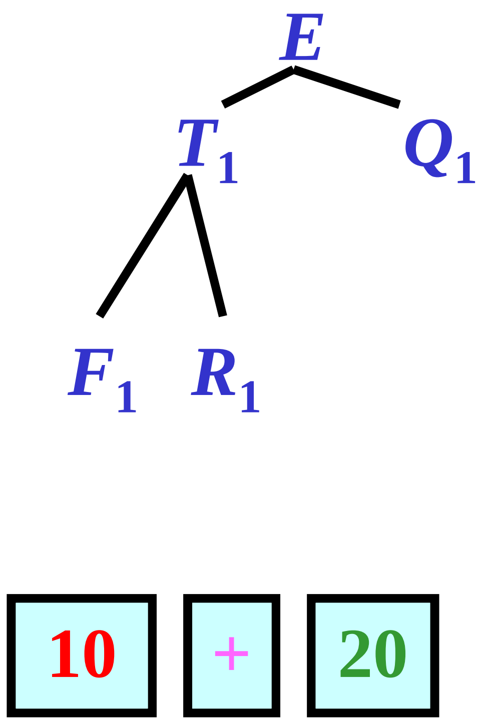
Rule: $F_1 \rightarrow i_1$ $\{F_1.s := i.value\}$

Parser pushdown:

F_1
$\{R_1.i := F_1.s\}$
R_1
$\{T_1.s := R_1.s\}$
$\{Q_1.i := T_1.s\}$
Q_1
$\{E.s := Q_1.s\}$
\$

Semantic pushdown:

Illustration:



Evaluation of Expressions: Example 4/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $i_1 + i_2$ $

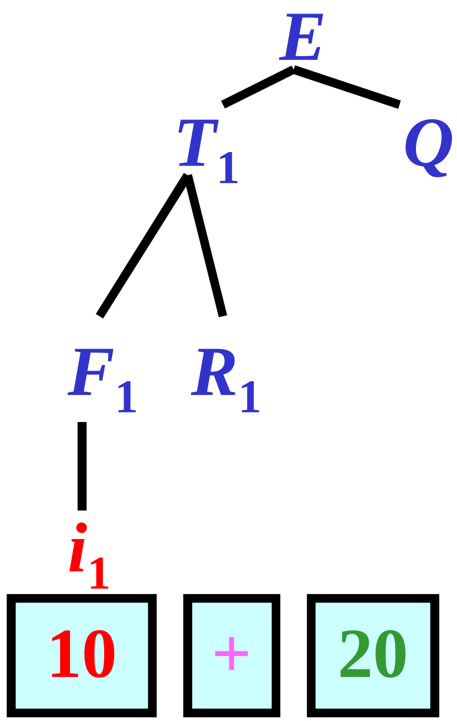
Rule:

Parser pushdown:

i_1
$\{F_1.s := i.value\}$
$\{R_1.i := F_1.s\}$
R_1
$\{T_1.s := R_1.s\}$
$\{Q_1.i := T_1.s\}$
Q_1
$\{E.s := Q_1.s\}$
$

Semantic pushdown:

Illustration:



Evaluation of Expressions: Example 5/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $+\ i_2\ \$$

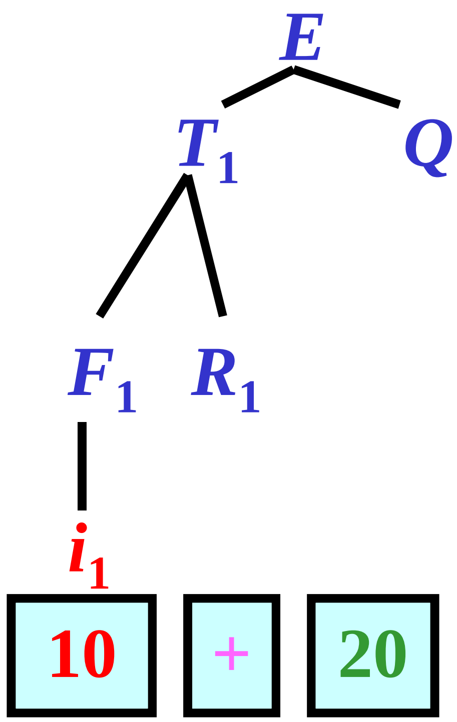
Rule:

Parser pushdown:

$\{F_1.s := i.value\}$
$\{R_1.i := F_1.s\}$
R_1
$\{T_1.s := R_1.s\}$
$\{Q_1.i := T_1.s\}$
Q_1
$\{E.s := Q_1.s\}$
$\$$

Semantic pushdown:

Illustration:



Evaluation of Expressions: Example 6/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $+ \ i_2 \ \$$

Rule:

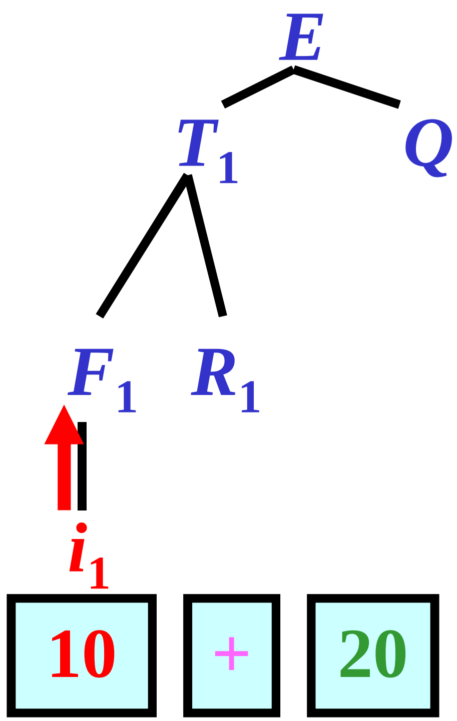
Parser pushdown:

$\{R_1.i := F_1.s\}$
R_1
$\{T_1.s := R_1.s\}$
$\{Q_1.i := T_1.s\}$
Q_1
$\{E.s := Q_1.s\}$
$\$$

Semantic pushdown:

$F_1.s = 10$

Illustration:



Evaluation of Expressions: Example 6/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $+\ i_2\ \$$

Rule: $R_1 \to \varepsilon\ \{R_1.s := R_1.i\}$

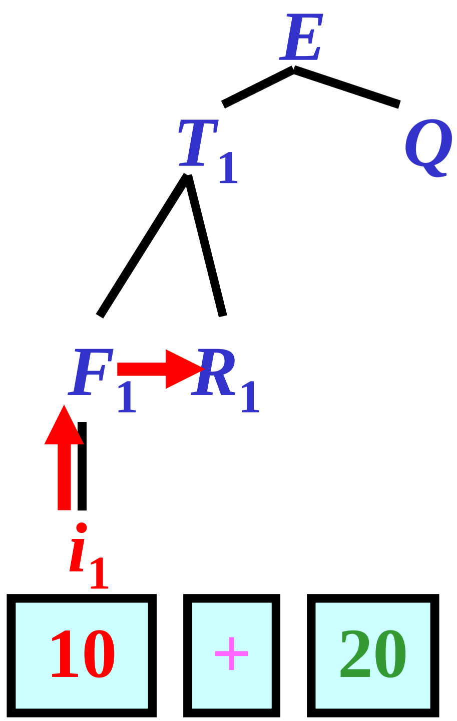
Parser pushdown:

R_1
$\{T_1.s := R_1.s\}$
$\{Q_1.i := T_1.s\}$
Q_1
$\{E.s := Q_1.s\}$
$\$$

Semantic pushdown:

$R_1.i = 10$

Illustration:



Evaluation of Expressions: Example 7/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $+\ i_2\ \$$

Rule:

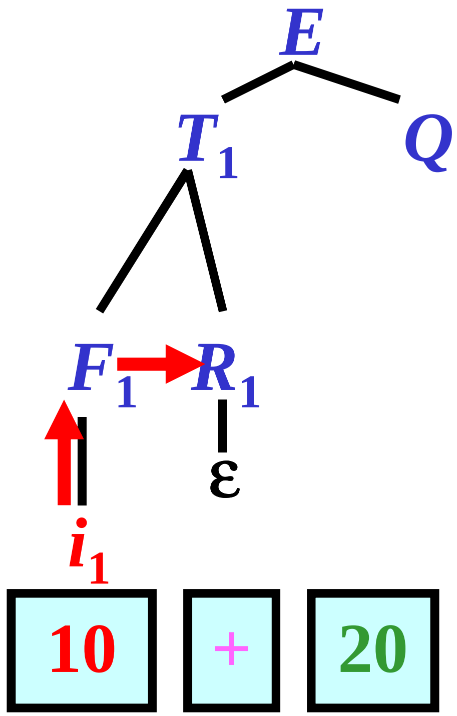
Parser pushdown:

$\{R_1.s := R_1.i\}$
$\{T_1.s := R_1.s\}$
$\{Q_1.i := T_1.s\}$
Q_1
$\{E.s := Q_1.s\}$
$\$$

Semantic pushdown:

$R_1.i = 10$

Illustration:



Evaluation of Expressions: Example 7/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $+ \; i_2 \; \$$

Rule:

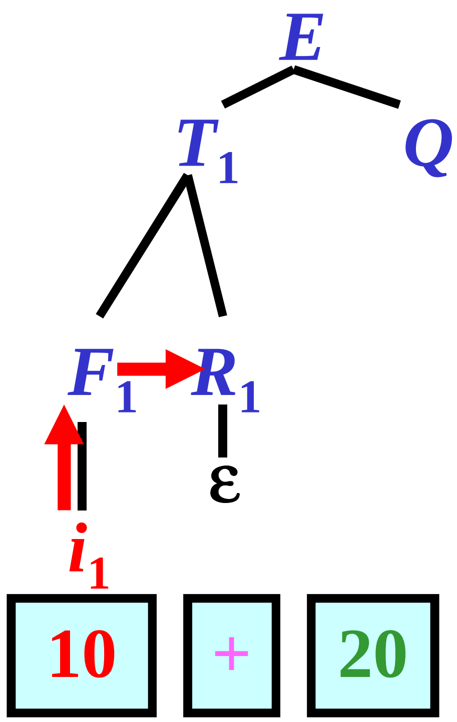
Parser pushdown:

$\{T_1.s := R_1.s\}$
$\{Q_1.i := T_1.s\}$
Q_1
$\{E.s := Q_1.s\}$
$\$$

Semantic pushdown:

$R_1.s = 10$

Illustration:



Evaluation of Expressions: Example 7/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $+\ i_2\ \$$

Rule:

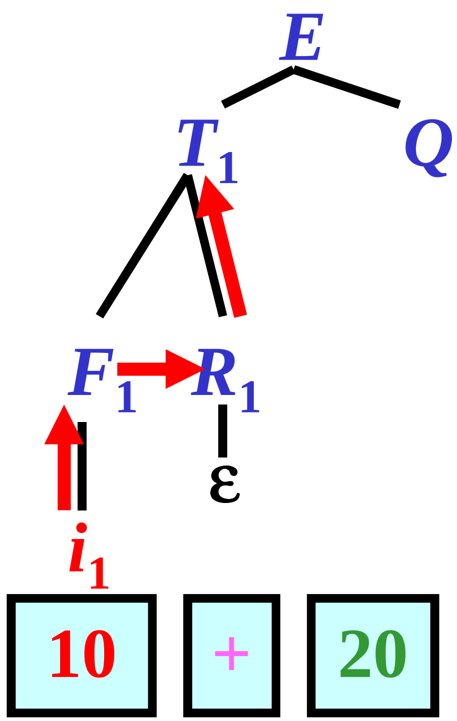
Parser pushdown:

$\{Q_1.i := T_1.s\}$
Q_1
$\{E.s := Q_1.s\}$
$\$$

Semantic pushdown:

$T_1.s = 10$

Illustration:



Evaluation of Expressions: Example 7/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $+ \; i_2 \; \$$

Rule: $Q_1 \rightarrow +T_2 \; \{Q_2.i := Q_1.i + T_2.s\} \; Q_2 \; \{Q_1.s := Q_2.s\}$

Parser pushdown:

Q_1

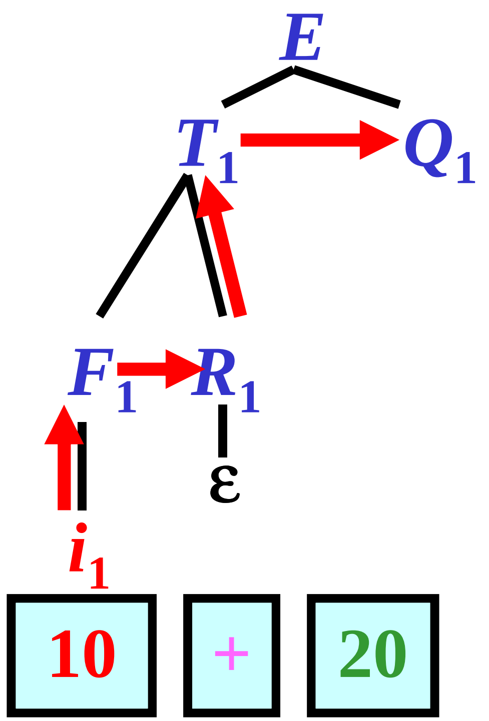
$\{E.s := Q_1.s\}$

$\$$

Semantic pushdown:

$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 8/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $+ \ i_2 \ \$$

Rule:

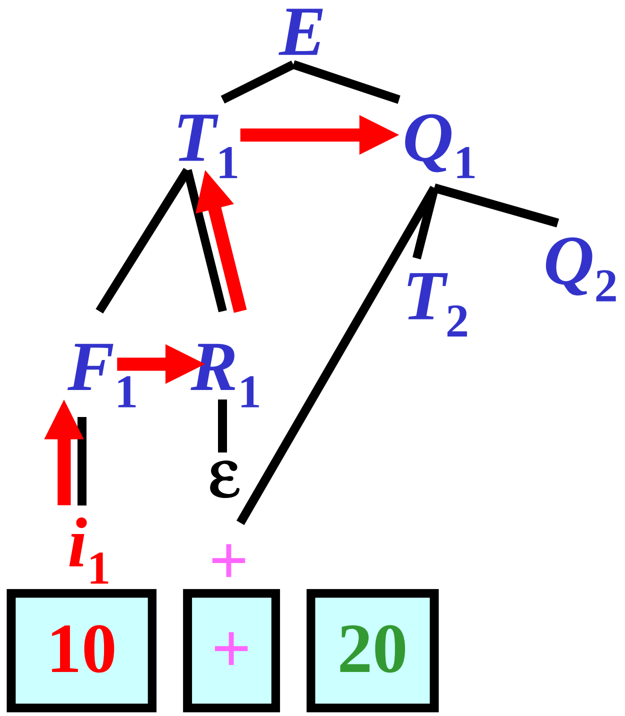
Parser pushdown:

$+$
T_2
$\{Q_2.i := Q_1.i + T_2.s\}$
Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$\$$

Semantic pushdown:

$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 9/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: i_2 \$

Rule: $T_2 \rightarrow F_2$ $\{R_2.i := F_2.s\}$ R_2 $\{T_2.s := R_2.s\}$

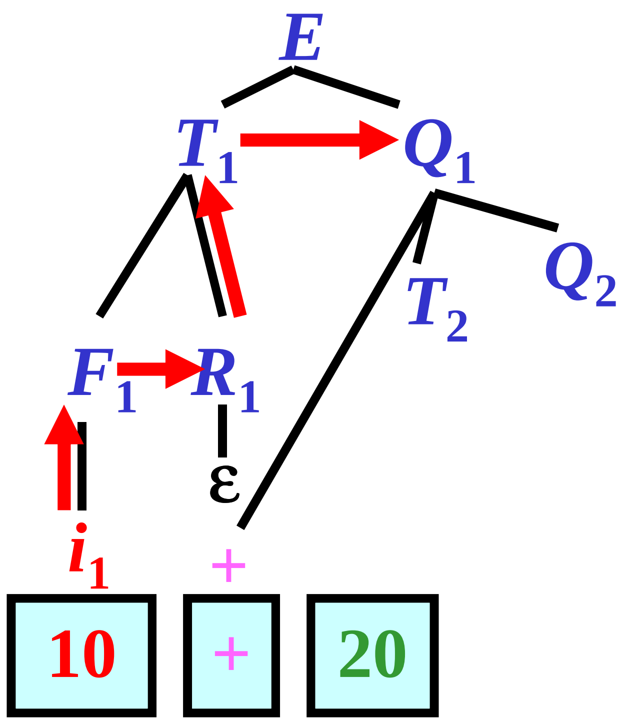
Parser pushdown:

T_2
$\{Q_2.i := Q_1.i + T_2.s\}$
Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
\$

Semantic pushdown:

$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 10/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: i_2 $

Rule: $F_2 \rightarrow i_2$ $\{F_2.s := i.value\}$

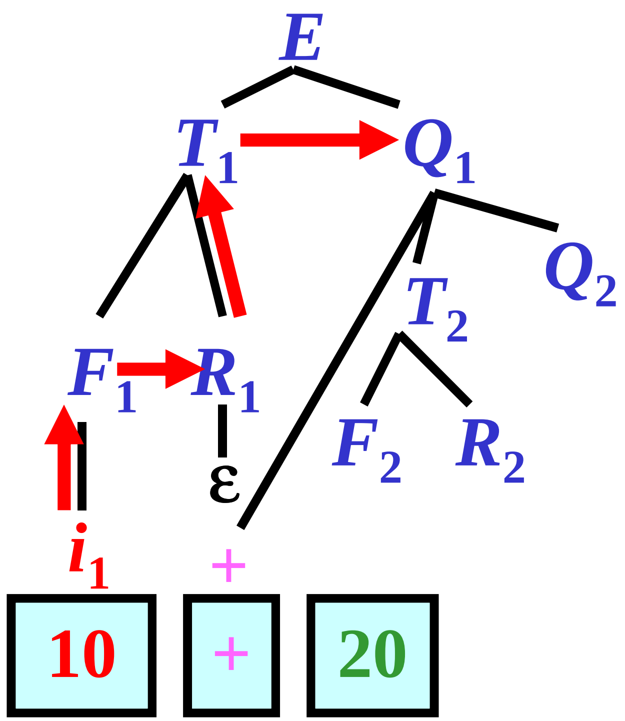
Parser pushdown:

F_2
$\{R_2.i := F_2.s\}$
R_2
$\{T_2.s := R_2.s\}$
$\{Q_2.i := Q_1.i + T_2.s\}$
Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$

Semantic pushdown:

$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 11/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: i_2 \$

Rule:

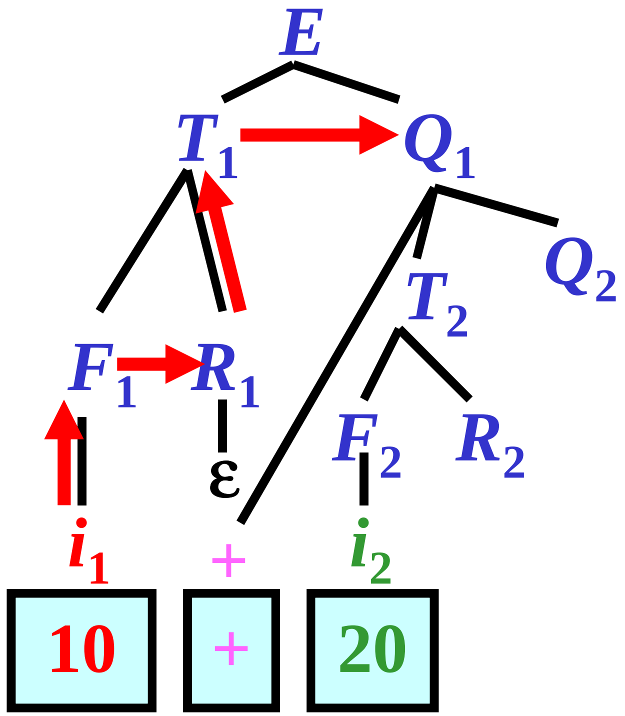
Parser pushdown:

i_2
$\{F_2.s := i.value\}$
$\{R_2.i := F_2.s\}$
R_2
$\{T_2.s := R_2.s\}$
$\{Q_2.i := Q_1.i + T_2.s\}$
Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
\$

Semantic pushdown:

$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 12/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $

Rule:

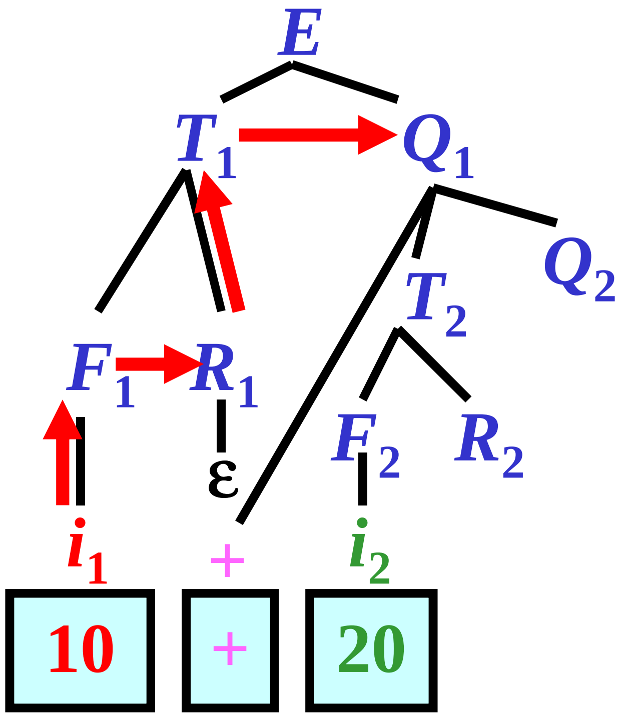
Parser pushdown:

$\{F_2.s := i.value\}$
$\{R_2.i := F_2.s\}$
R_2
$\{T_2.s := R_2.s\}$
$\{Q_2.i := Q_1.i + T_2.s\}$
Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$

Semantic pushdown:

$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 13/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $

Rule:

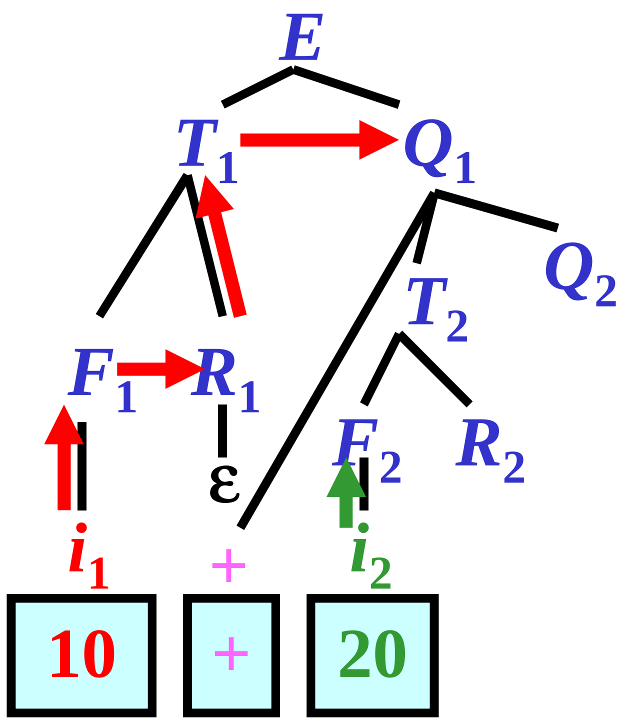
Parser pushdown:

$\{R_2.i := F_2.s\}$
R_2
$\{T_2.s := R_2.s\}$
$\{Q_2.i := Q_1.i + T_2.s\}$
Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$

Semantic pushdown:

$F_2.s = 20$
$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 13/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $\$$

Rule: $R_2 \rightarrow \varepsilon \; \{R_2.s := R_2.i\}$

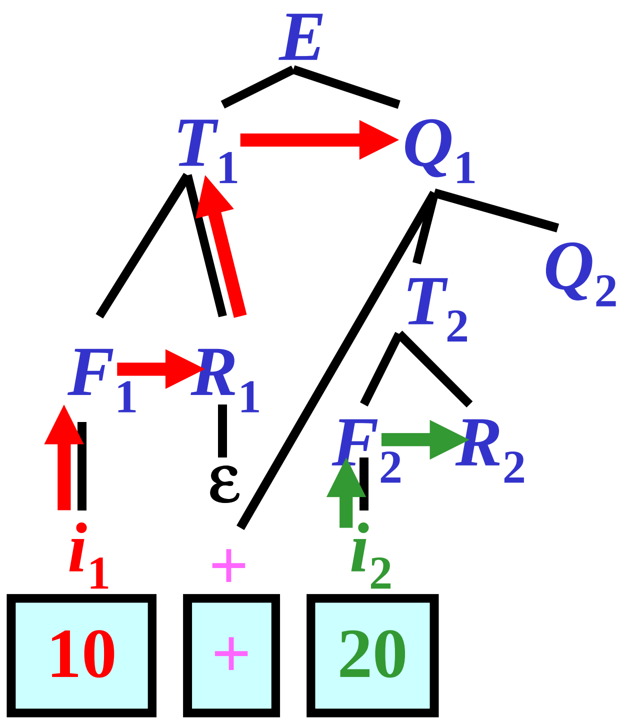
Parser pushdown:

R_2
$\{T_2.s := R_2.s\}$
$\{Q_2.i := Q_1.i + T_2.s\}$
Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$\$$

Semantic pushdown:

$R_2.i = 20$
$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 14/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $

Rule:

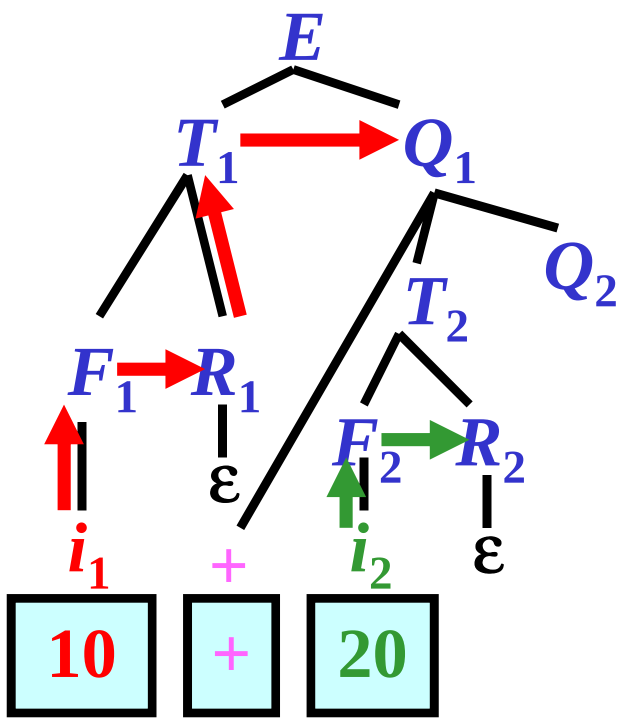
Parser pushdown:

$\{R_2.s := R_2.i\}$
$\{T_2.s := R_2.s\}$
$\{Q_2.i := Q_1.i + T_2.s\}$
Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$

Semantic pushdown:

$R_2.i = 20$
$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 14/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $

Rule:

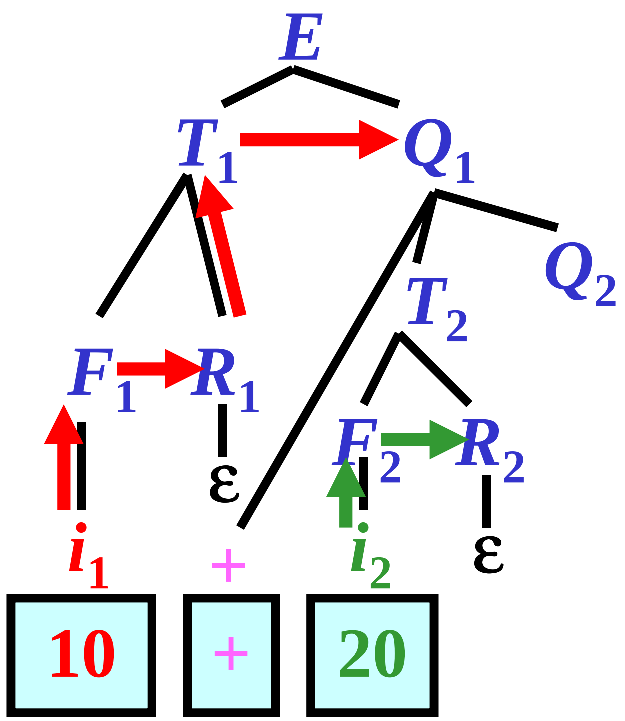
Parser pushdown:

$\{T_2.s := R_2.s\}$
$\{Q_2.i := Q_1.i + T_2.s\}$
Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$

Semantic pushdown:

$R_2.s = 20$
$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 14/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $

Rule:

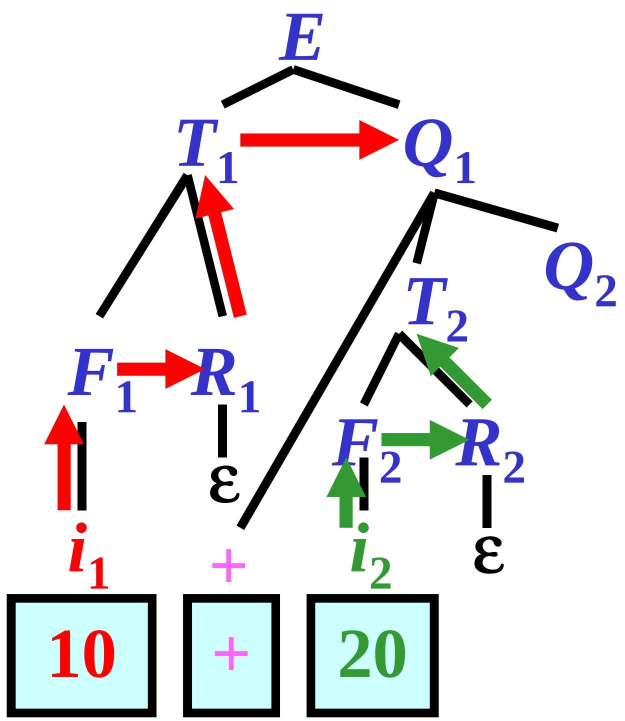
Parser pushdown:

$\{Q_2.i := Q_1.i + T_2.s\}$
Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$

Semantic pushdown:

$T_2.s = 20$
$Q_1.i = 10$

Illustration:



Evaluation of Expressions: Example 15/16

Example for $a + b$, where $a.value = 10$, $b.value = 20$

Input: $

Rule: $Q_2 \to \varepsilon$ $\{Q_2.s := Q_2.i\}$

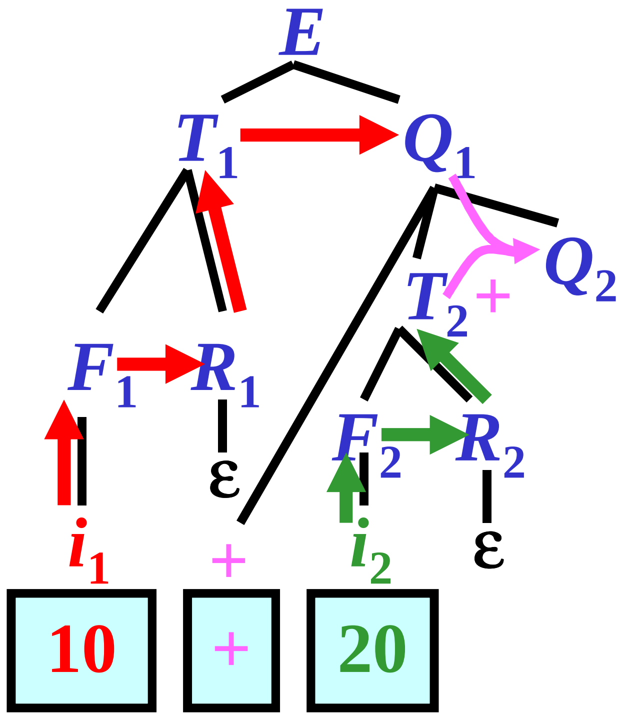
Parser pushdown:

Q_2
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$

Semantic pushdown:

$Q_2.i = 30$

Illustration:



Evaluation of Expressions: Example 16/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $

Rule:

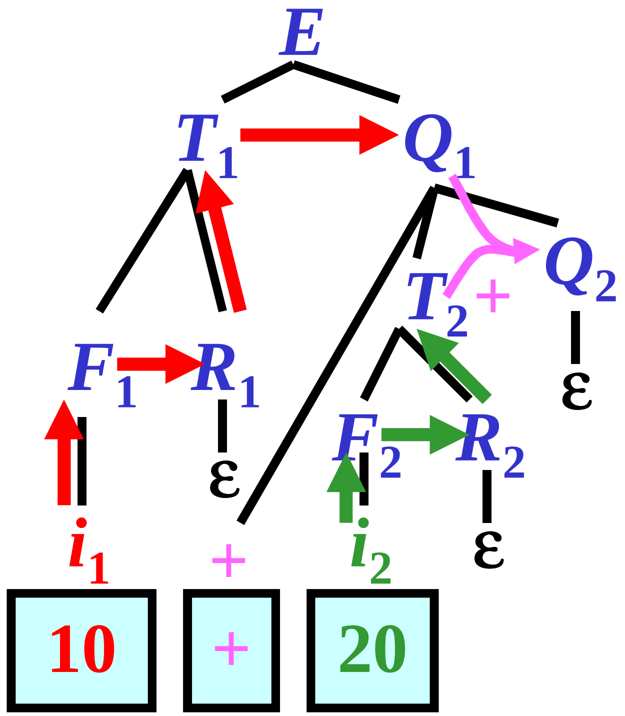
Parser pushdown:

$\{Q_2.s := Q_2.i\}$
$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$

Semantic pushdown:

$Q_2.i$ = 30

Illustration:



Evaluation of Expressions: Example 16/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $

Rule:

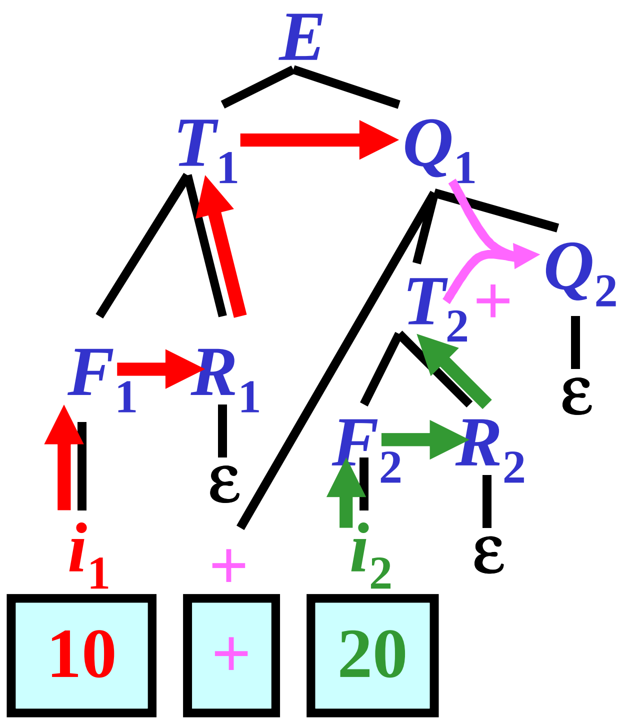
Parser pushdown:

$\{Q_1.s := Q_2.s\}$
$\{E.s := Q_1.s\}$
$

Semantic pushdown:

$Q_2.s = 30$

Illustration:



Evaluation of Expressions: Example 16/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $

Rule:

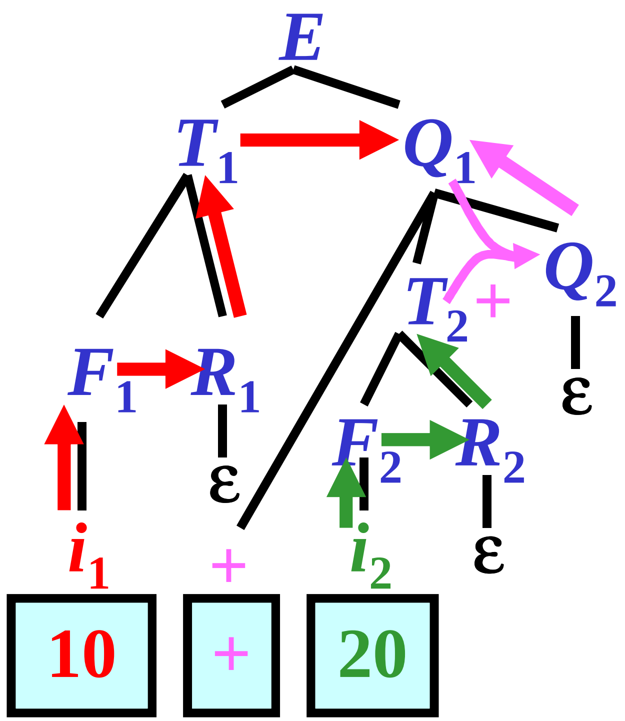
Parser pushdown:

{$E.s := Q_1.s$}
$

Semantic pushdown:

$Q_1.s = 30$

Illustration:



Evaluation of Expressions: Example 16/16

Example for *a* + *b*, where *a.value* = 10, *b.value* = 20

Input: $

Rule:

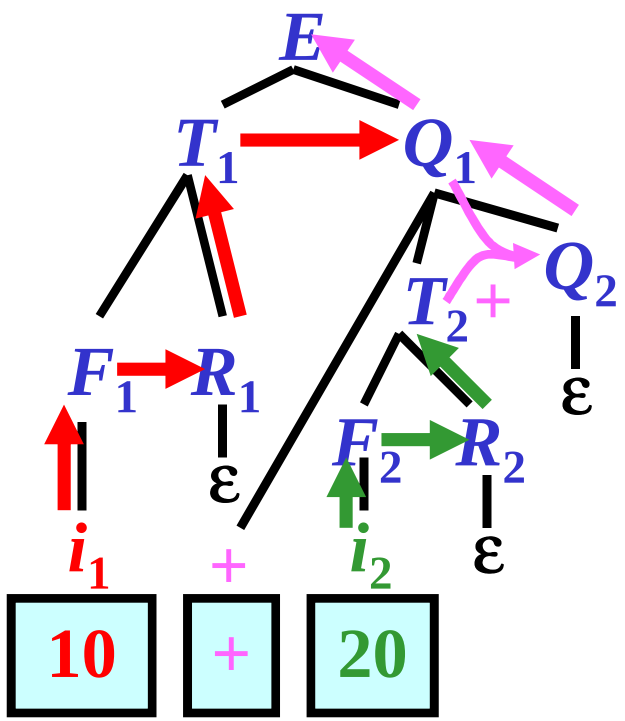
Parser pushdown:

$

Semantic pushdown:

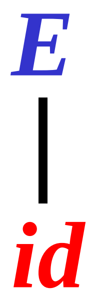
$E.s = 30$

Illustration:



Semantic Analysis: Type Checking

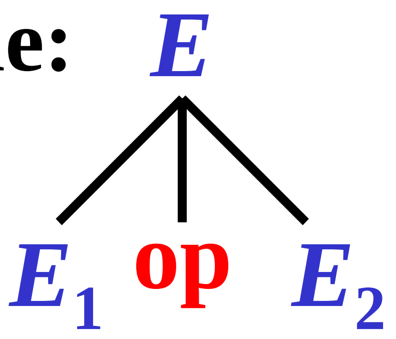
1) **Rule:**



Action:

E.type := id.type

2) **Rule:**



Operation op is defined over types:

t_1 **op** $t_2 \rightarrow t_3$

Action:

```
if ($E_1$.type = $t_1$ or
$E_1$.type is convertable to $t_1$)
and
($E_2$.type = $t_2$ or
$E_2$.type is convertable to $t_2$)
then
$E$.type := $t_3$
else
Semantic Error.
```

Type Checking: Example 1/3

- **Make a type-checking for a grammar:**
- $G_{expr1} = (N, T, P, E)$, where $N = \{E, F, T\}$, $T = \{i, +, *, (,)\}$,
  $P = \{ E \rightarrow E+T, E \rightarrow T, T \rightarrow T*F, T \rightarrow F, F \rightarrow (E), F \rightarrow i \}$
- **Operators *, + are defined as:**
  - **int * int → int**
  - **int + int → int**
  - **real * real → real**
  - **real + real → real**

Possible Conversion:
- **From int to real**

Rule: $F \rightarrow i$	$\{F.type := i.type;$ generate$(:=, i.loc, , F.loc)$ $\}$
Rule: $F_i \rightarrow (E_j)$	$\{F_i.type := E_j.type\}$
Rule: $T_i \rightarrow F_j$	$\{T_i.type := F_j.type\}$
Rule: $E_i \rightarrow T_j$	$\{E_i.type := T_j.type\}$

Type Checking: Example 2/3

```
Rule: $E_i \rightarrow E_j + T_k$ { if $E_j$.type = $T_k$.type then begin
                                          $E_i$.type := $E_j$.type
                                          generate(+, $E_j$.loc, $T_k$.loc, $E_i$.loc)
                                      end
                                      else begin
                                          generate(new.loc, h, ,  )
                                          if $E_j$.type = int then begin
                                              generate(int-to-real, $E_j$.loc , , h)
                                              generate(+, h, $T_k$.loc, $E_i$.loc)
                                          end
                                          else begin
                                              generate(int-to-real, $T_k$.loc , , h)
                                              generate(+, $E_j$.loc, h, $E_i$.loc)
                                          end
                                          $E_i$.type := real
                                       end
                                     }
```

Type Checking: Example 3/3

```
Rule: $T_i \rightarrow T_j * F_k$ {  if $T_j$.type = $F_k$.type then begin
                                          $T_i$.type := $T_j$.type
                                          generate(*, $T_j$.loc, $F_k$.loc, $T_i$.loc)
                                      end
                                      else begin
                                          generate(new.loc, h, ,  )
                                          if $T_j$.type = int then begin
                                              generate(int-to-real, $T_j$.loc , , h)
                                              generate(*, h, $F_k$.loc, $T_i$.loc)
                                          end
                                          else begin
                                              generate(int-to-real, $F_k$.loc , , h)
                                              generate(*, $T_j$.loc, h, $T_i$.loc)
                                          end
                                          $T_i$.type := real
                                       end
                                     }
```

Short Evaluation (Jumping Code)

Idea:

- ***a*** **=** ***true*** **implies** ***a*** **or (… ? …) =** ***true***
- ***a*** **=** ***false*** **implies** ***a*** **and (… ? …) =** ***false***

Note: (… ? …) is not evaluated.

---

1) (*a* and *b*) = *p*:

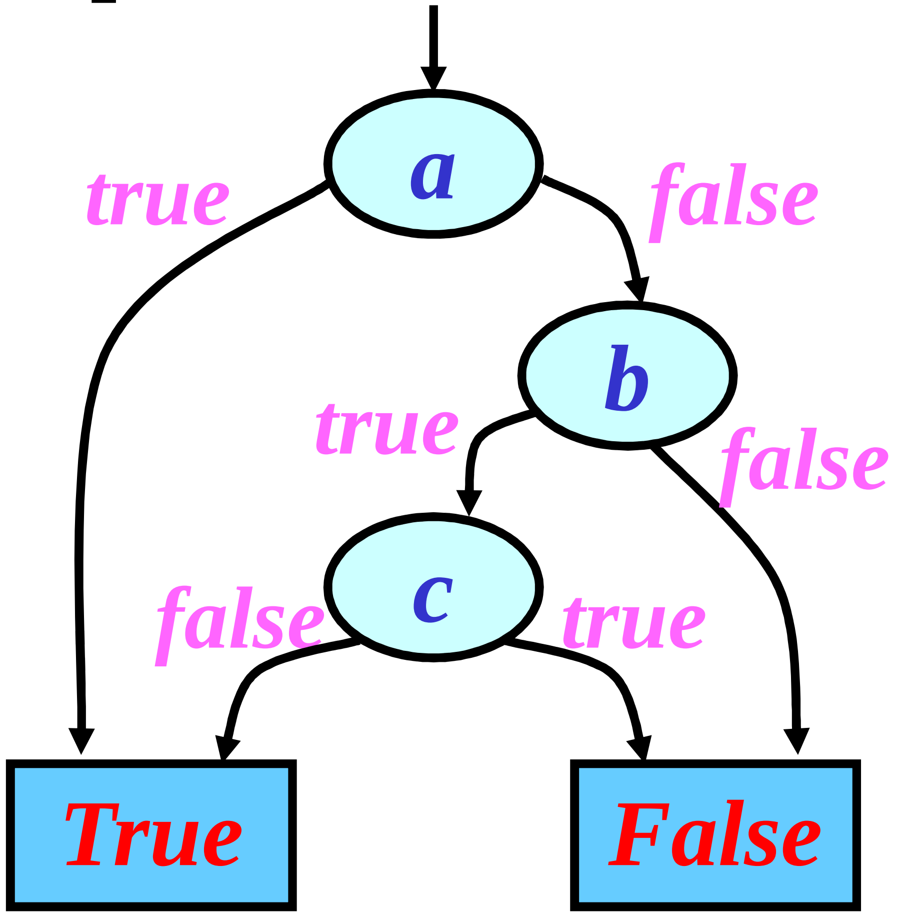
```
    if  a = false     then  p = false
                      else  p = b
```

2) (*a* or *b*) = *p*:

```
    if  a = true      then  p = true
                      else  p = b
```

Short Evaluation: Graphic Representation

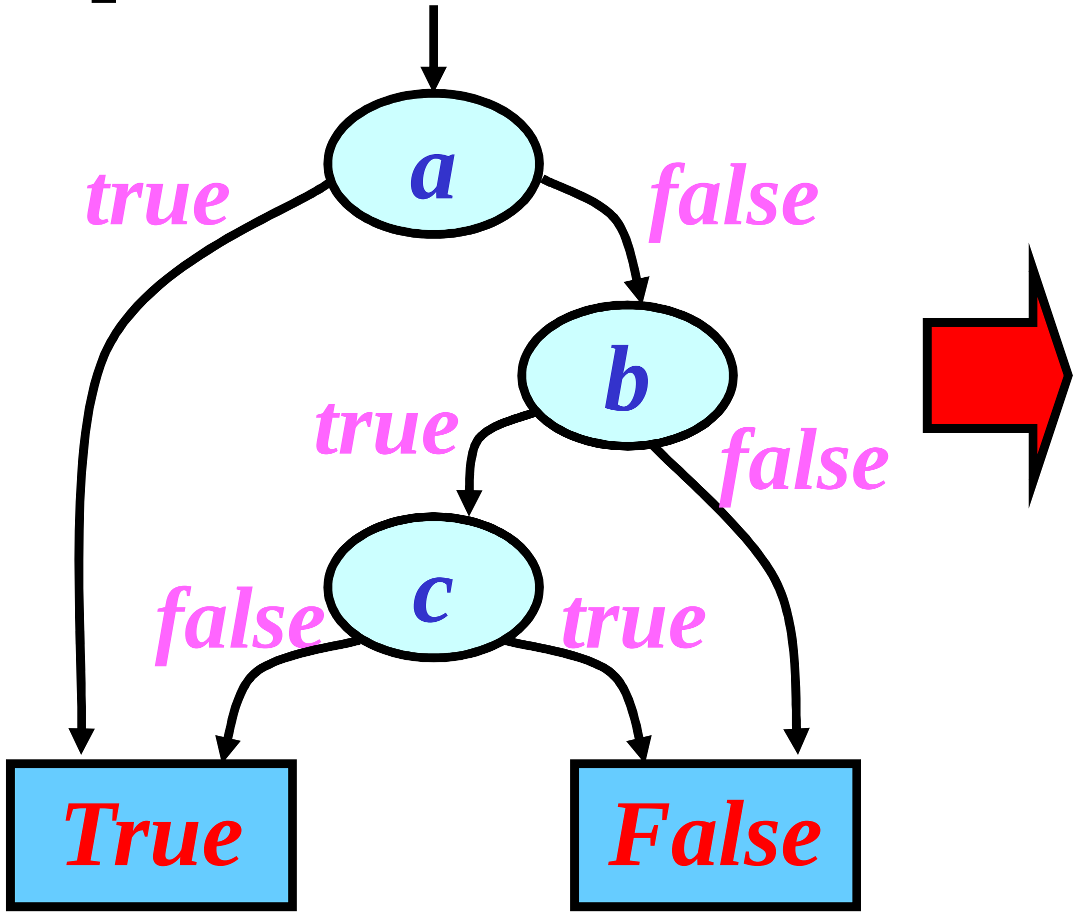
Example: ***a*** **or (*b* and (not *c*)):**



• Simulation of this graphic representation by 3AC jumps

Short Evaluation: Graphic Representation

Example: ***a*** **or (*b* and (not *c*)):**



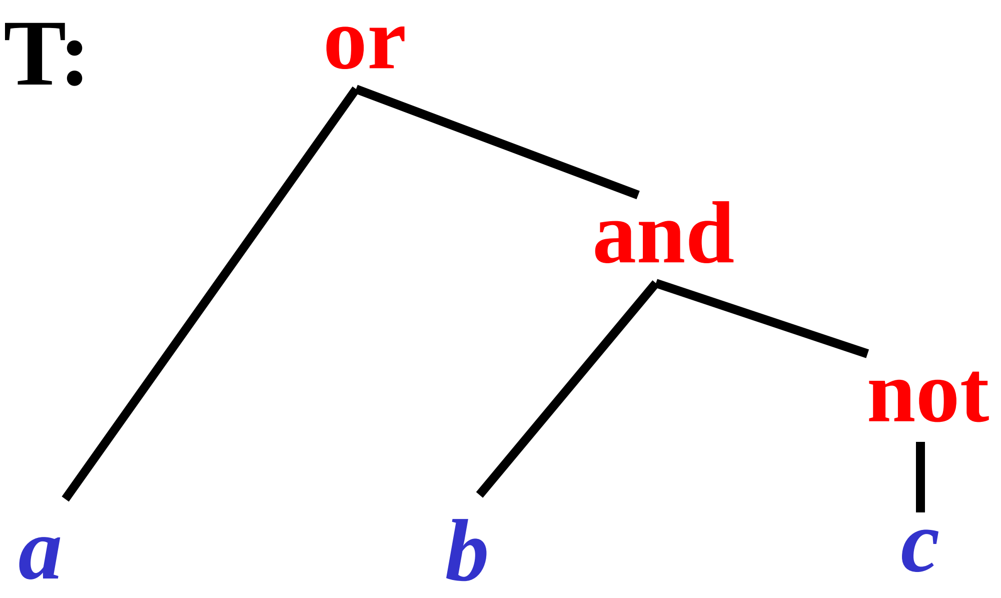
```
if a goto True
goto X
X:
if b goto Y
goto False
Y:
if c goto False
goto True
True: …
False: …
```

• Simulation of this graphic representation by 3AC jumps

Short Evaluation Using AST: Introduction

Example: ***a*** **or (*b* and (not *c*)):**

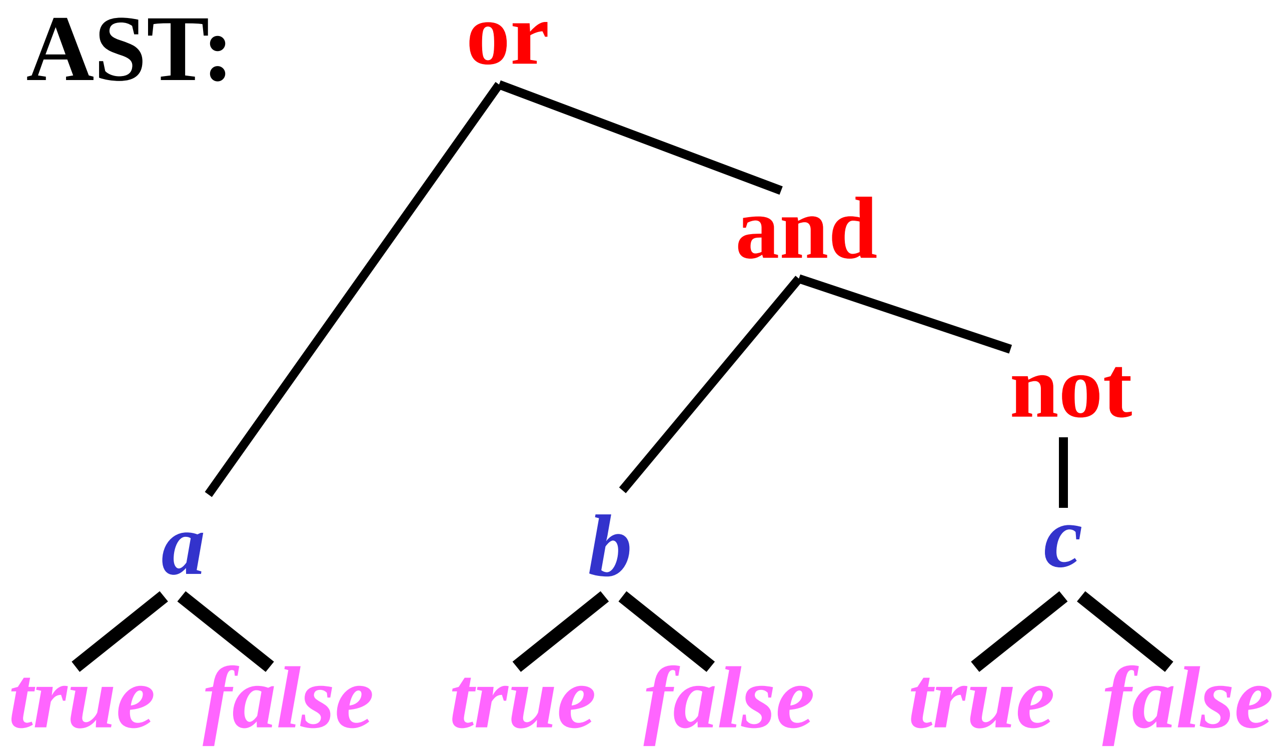
AST:



Short Evaluation Using AST: Introduction

Example: ***a*** **or (*b* and (not *c*)):**

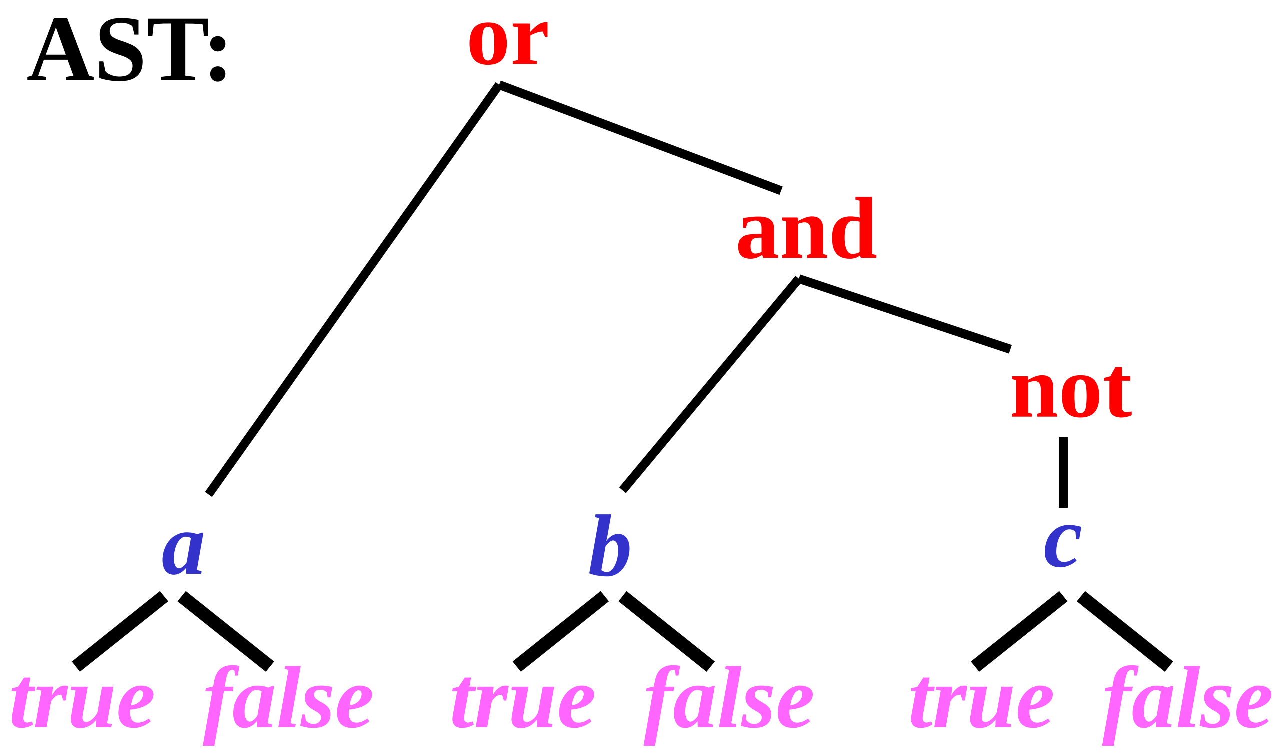
AST:



Short Evaluation Using AST: Introduction

Example: ***a*** **or (*b* and (not *c*)):**

AST:



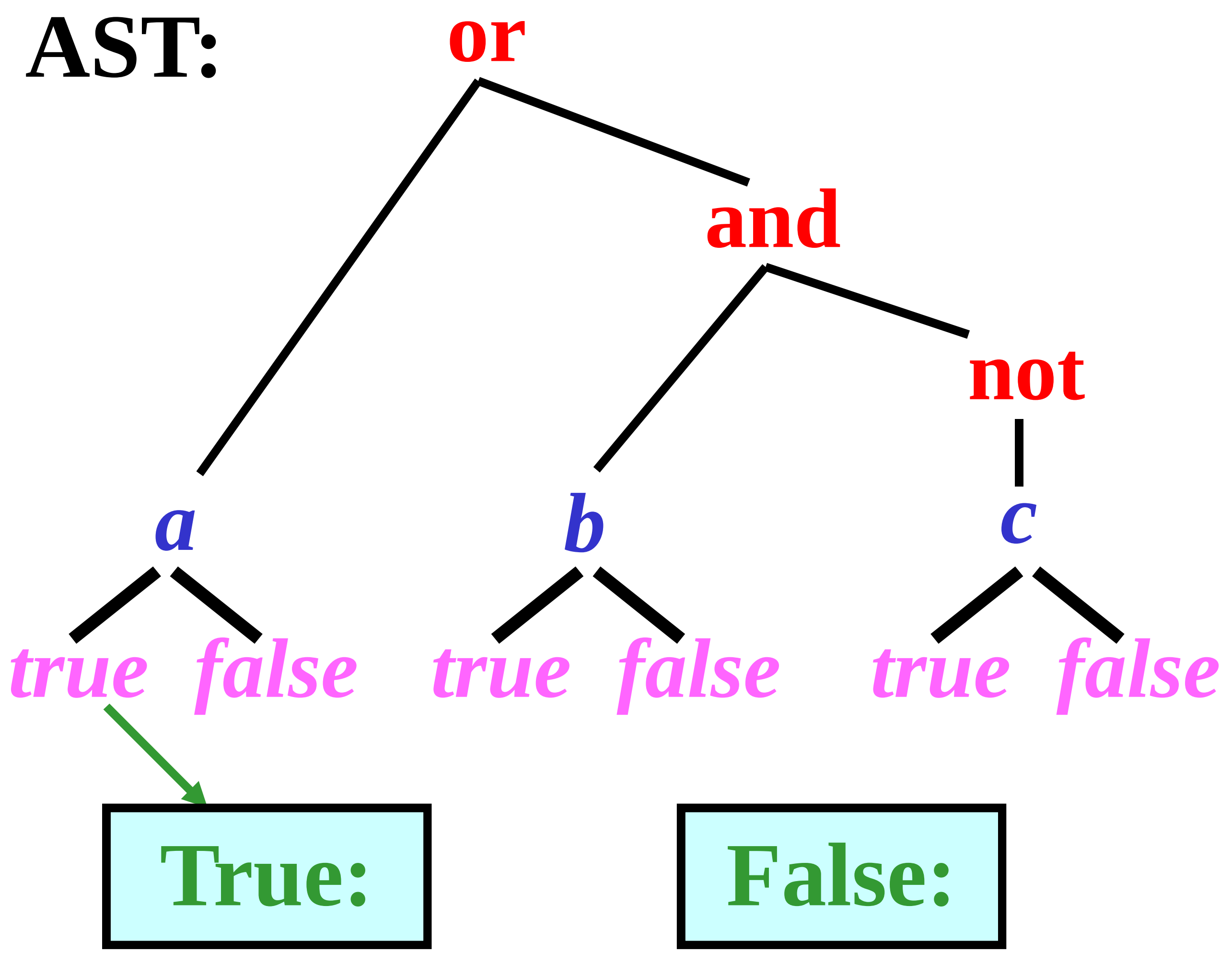
True:

False:

Short Evaluation Using AST: Introduction

Example: ***a*** **or (*b* and (not *c*)):**

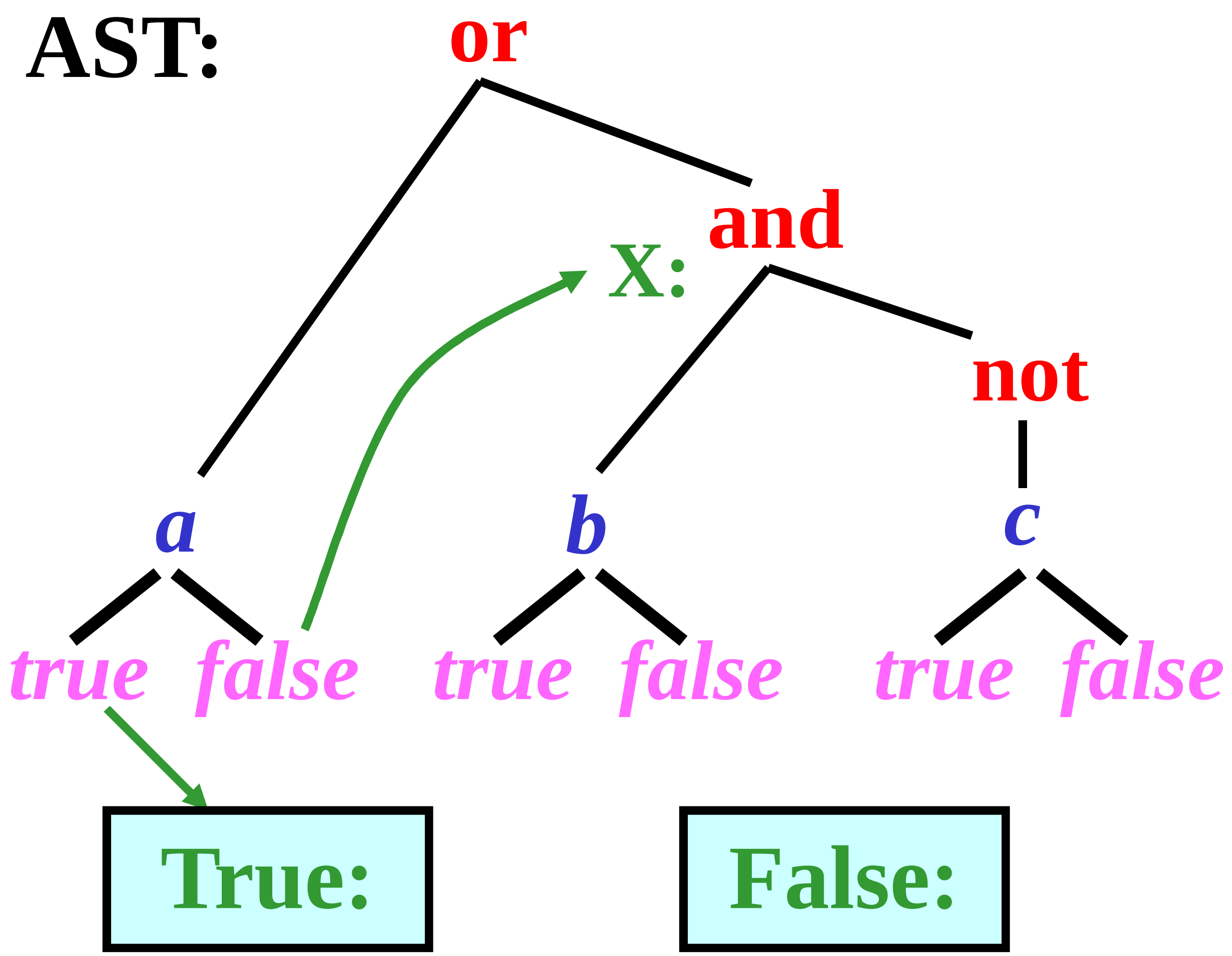
AST:



Short Evaluation Using AST: Introduction

Example: ***a*** **or (*b* and (not *c*)):**

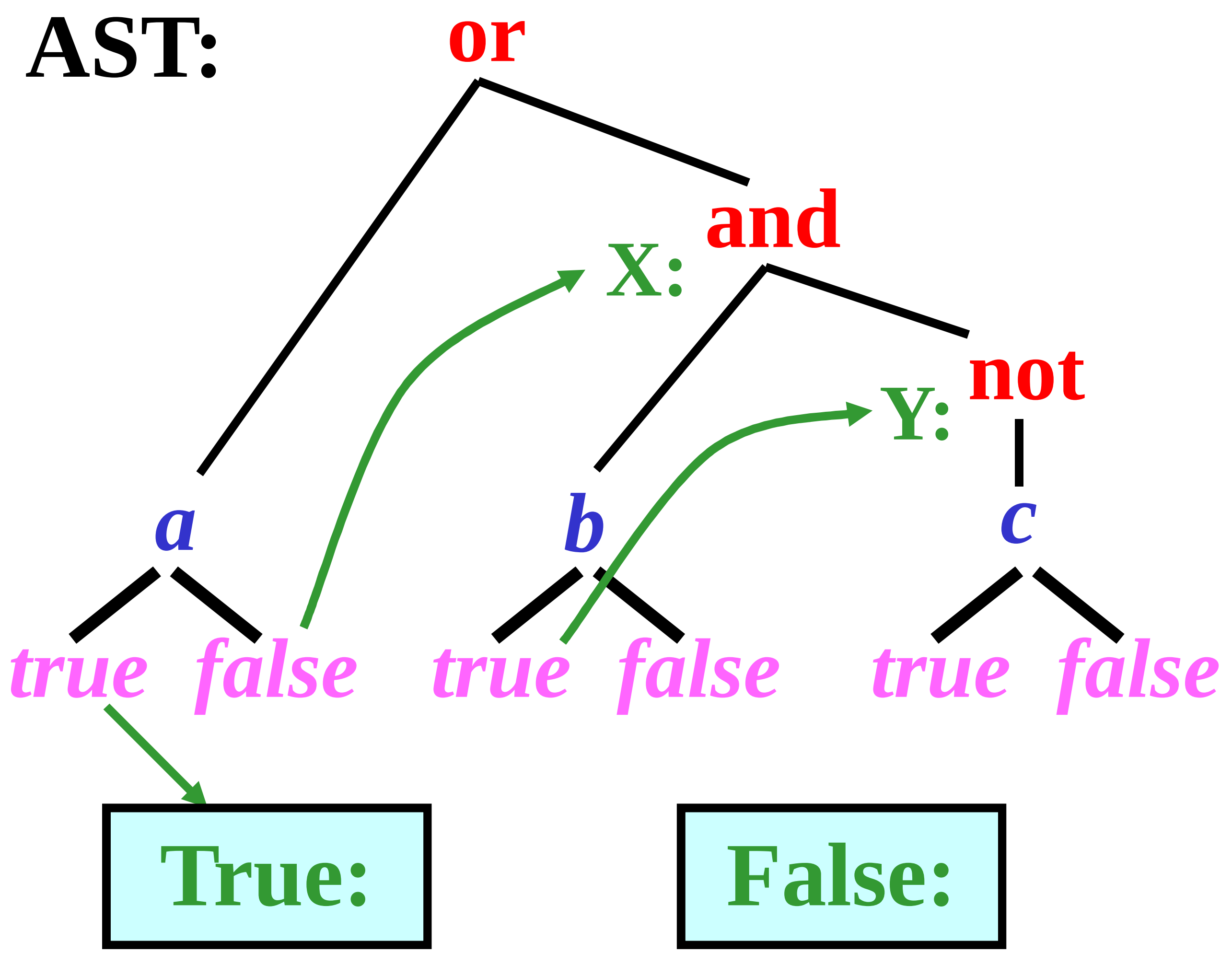
AST:



Short Evaluation Using AST: Introduction

Example: ***a*** **or (*b* and (not *c*)):**

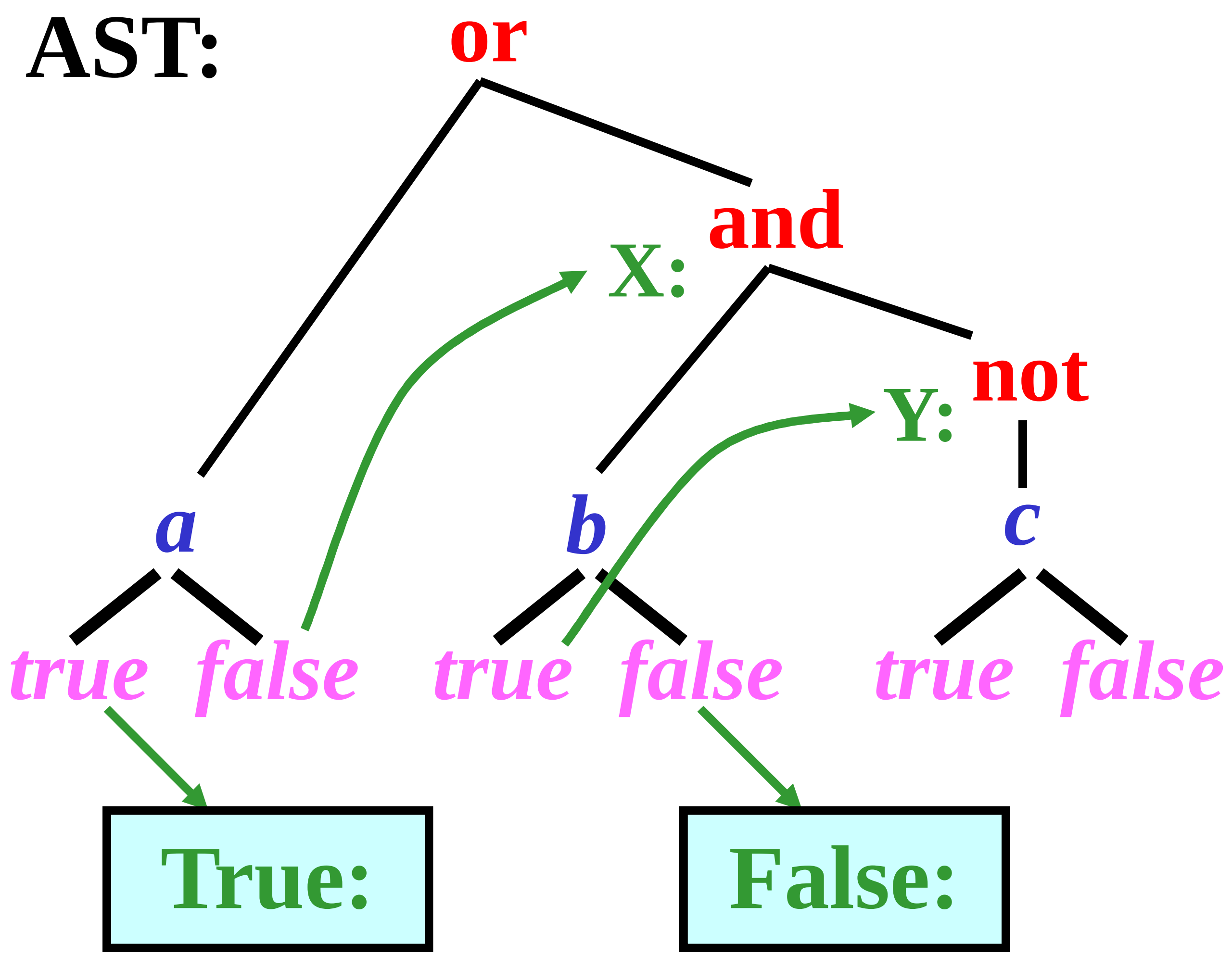
AST:



Short Evaluation Using AST: Introduction

Example: ***a*** **or (*b* and (not *c*)):**

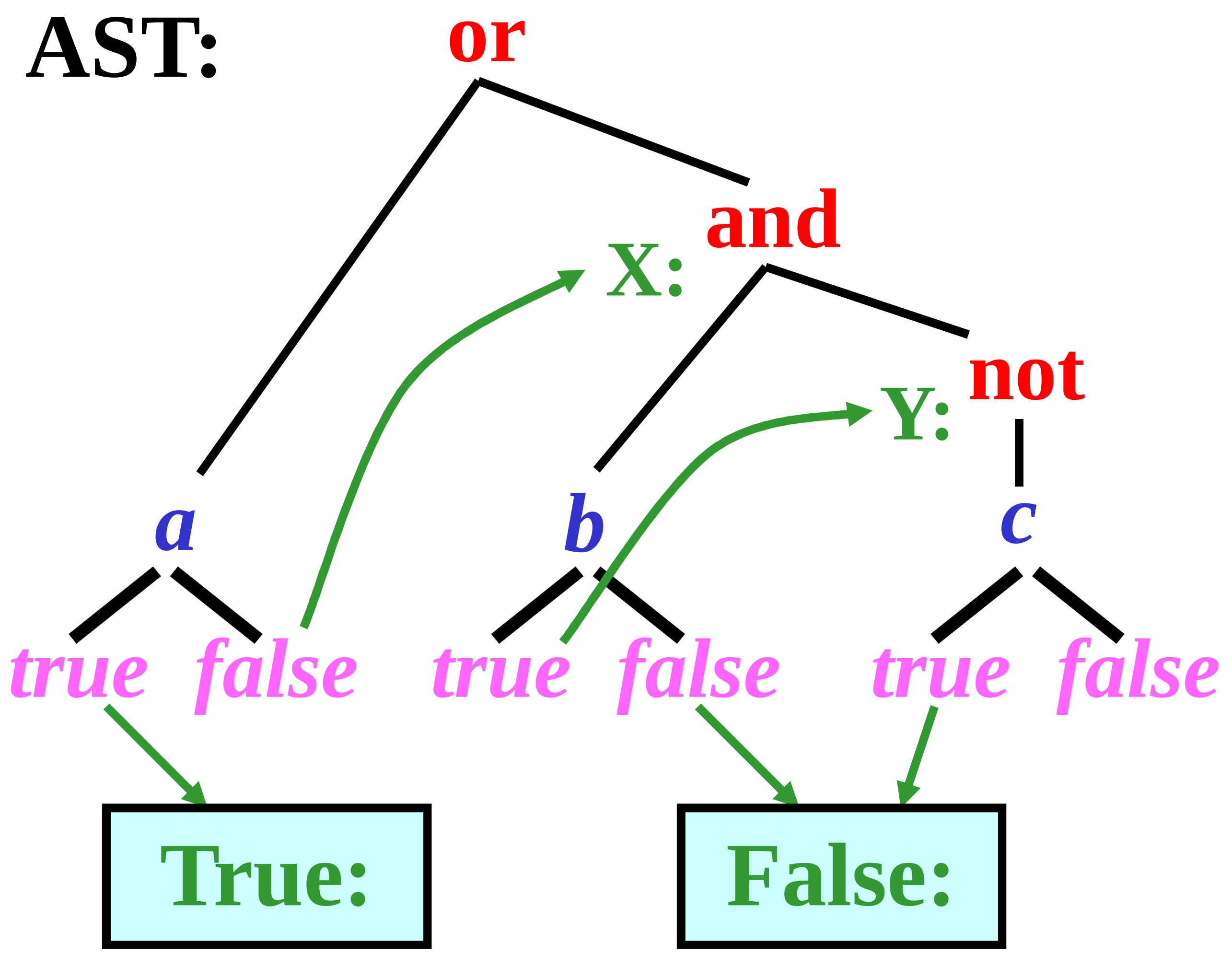
AST:



Short Evaluation Using AST: Introduction

Example: ***a*** **or (*b* and (not *c*)):**

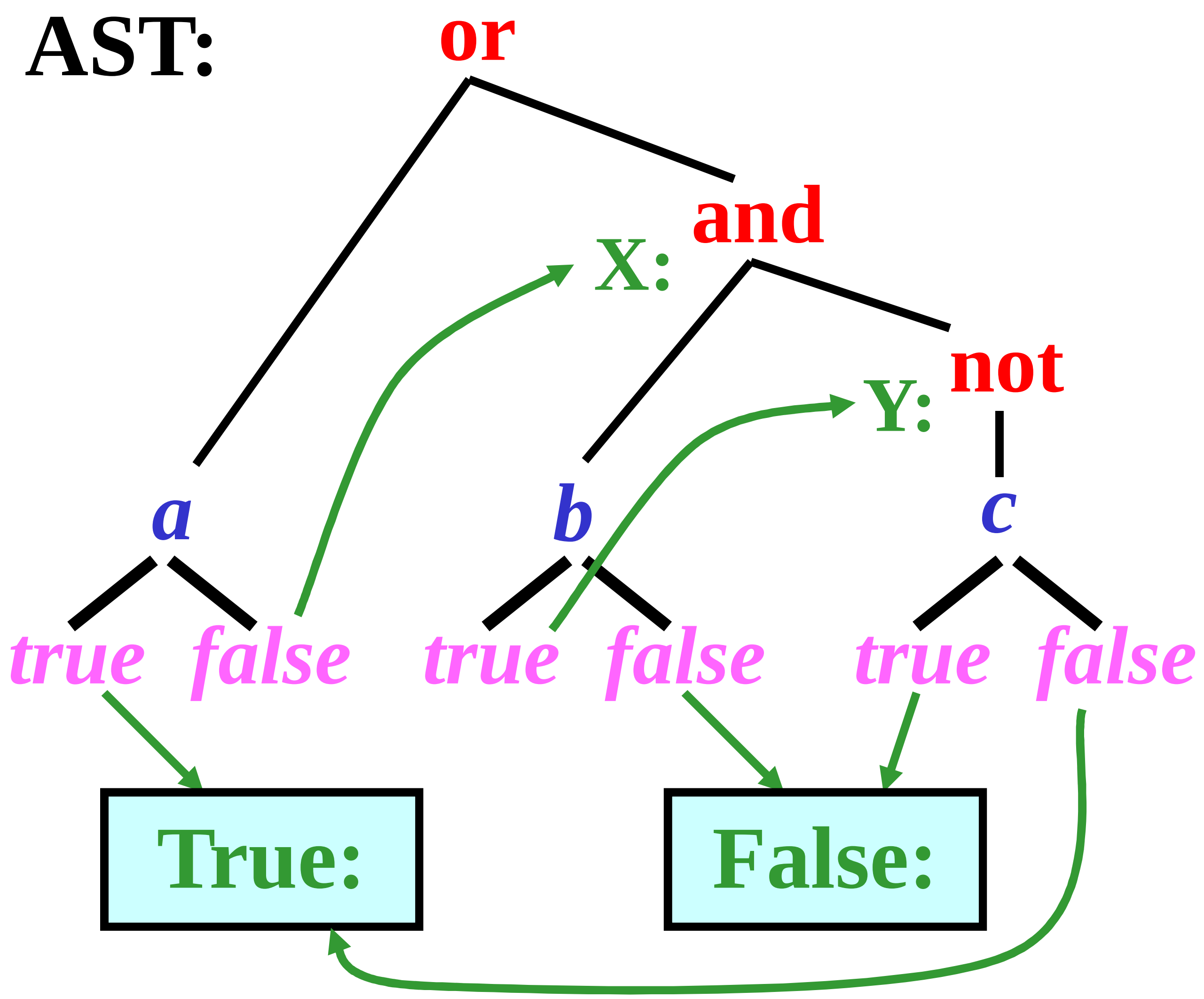
AST:



Short Evaluation Using AST: Introduction

Example: ***a*** **or (*b* and (not *c*)):**

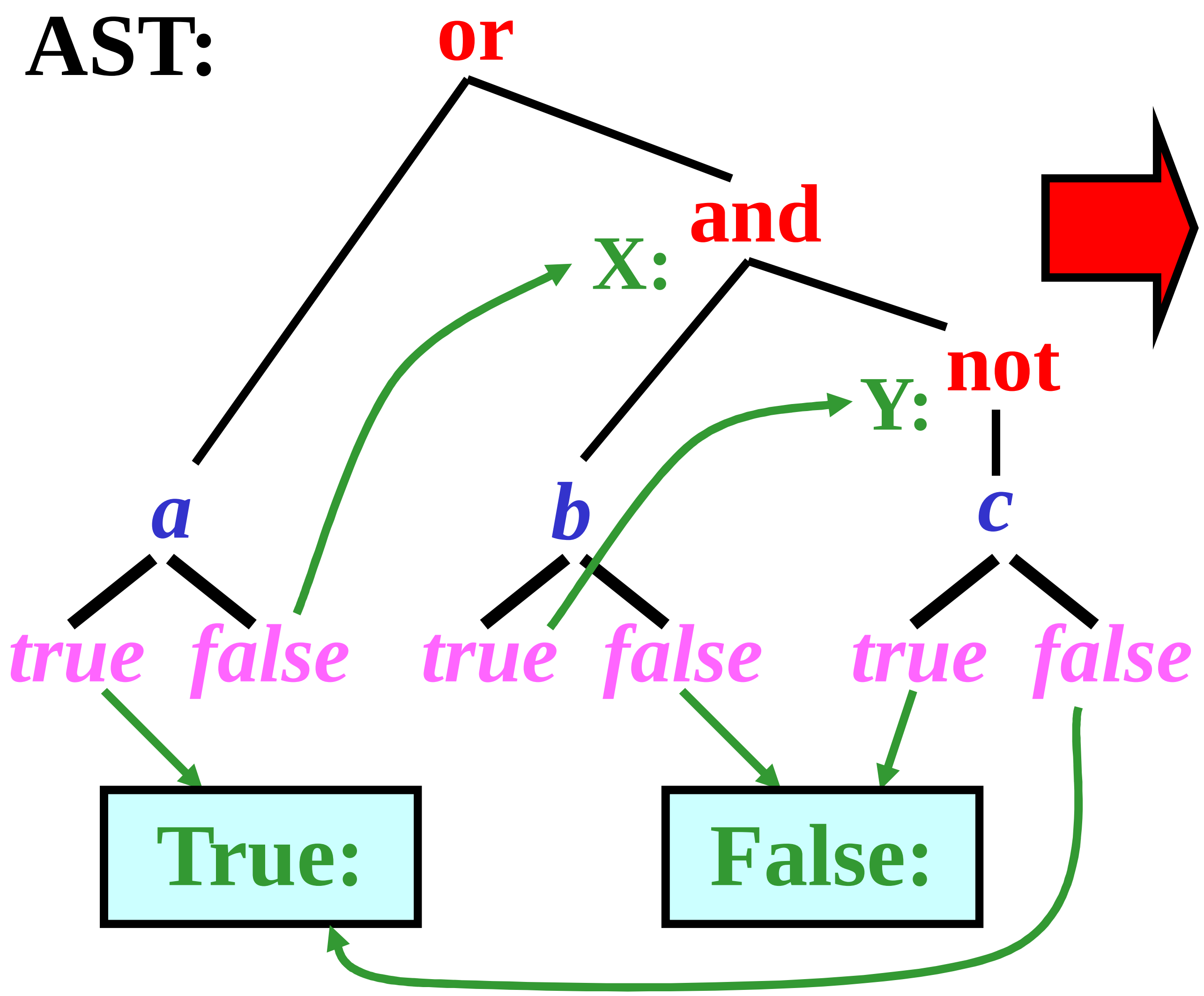
AST:



Short Evaluation Using AST: Introduction

Example: ***a*** **or (*b* and (not *c*)):**

AST:



if *a* goto True
goto X

X:
if *b* goto Y
goto False

Y:
if *c* goto False
goto True

True: …

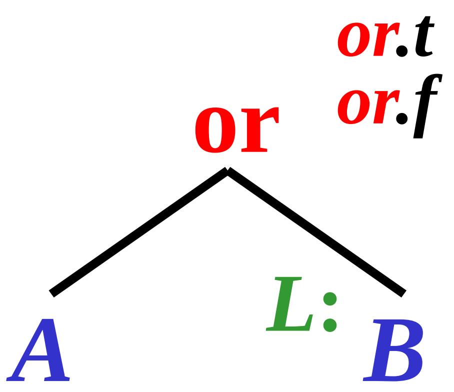
False: …

Short Evaluation Using AST: Implementation

- Every AST node, ***X***, has assigned two attributes ***X.t***, ***X.f***

Elementary ASTs:

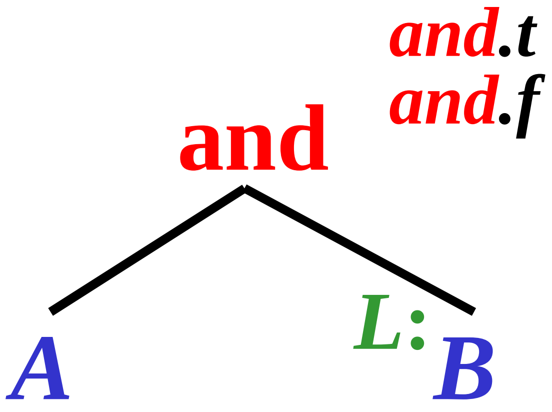
1)



A.t := ***or.t*** ***B.t*** := ***or.t***
A.f := ***L*** ***B.f*** := ***or.f***

- **Note:** ***L*** = a new label

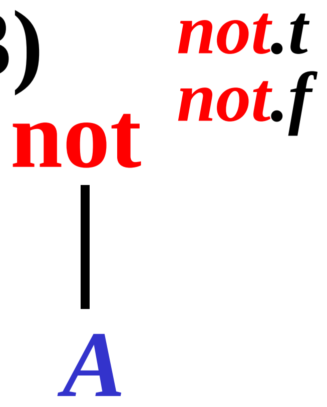
2)



A.t := ***L*** ***B.t*** := ***and.t***
A.f := ***and.f*** ***B.f*** := ***and.f***

- **Note:** ***L*** = a new label

3)



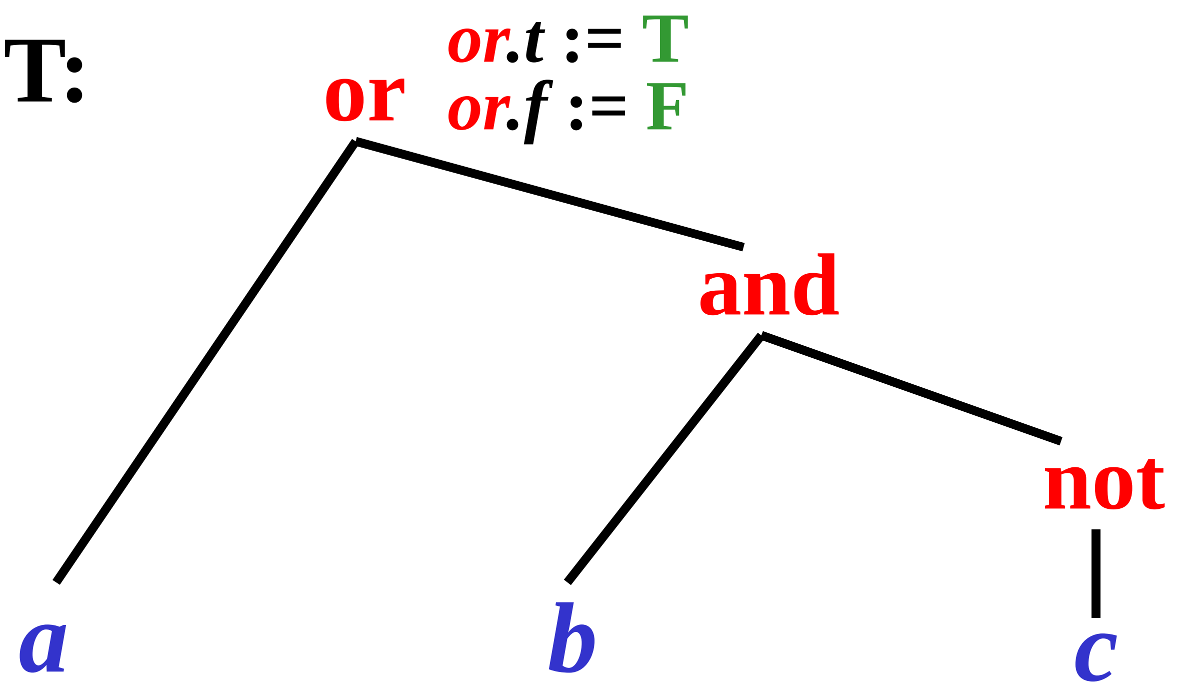
A.t := ***not.f***
A.f := ***not.t***

- **Initialization:** Let ***R*** is the root of AST, then:
  R.t := **True**, ***R.f*** := **False** (**True** & **False** are labels)
- **Propagation:** Attributes are propagated from root to leaves in AST using rules **1)**, **2)** and **3)**.

Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

AST:



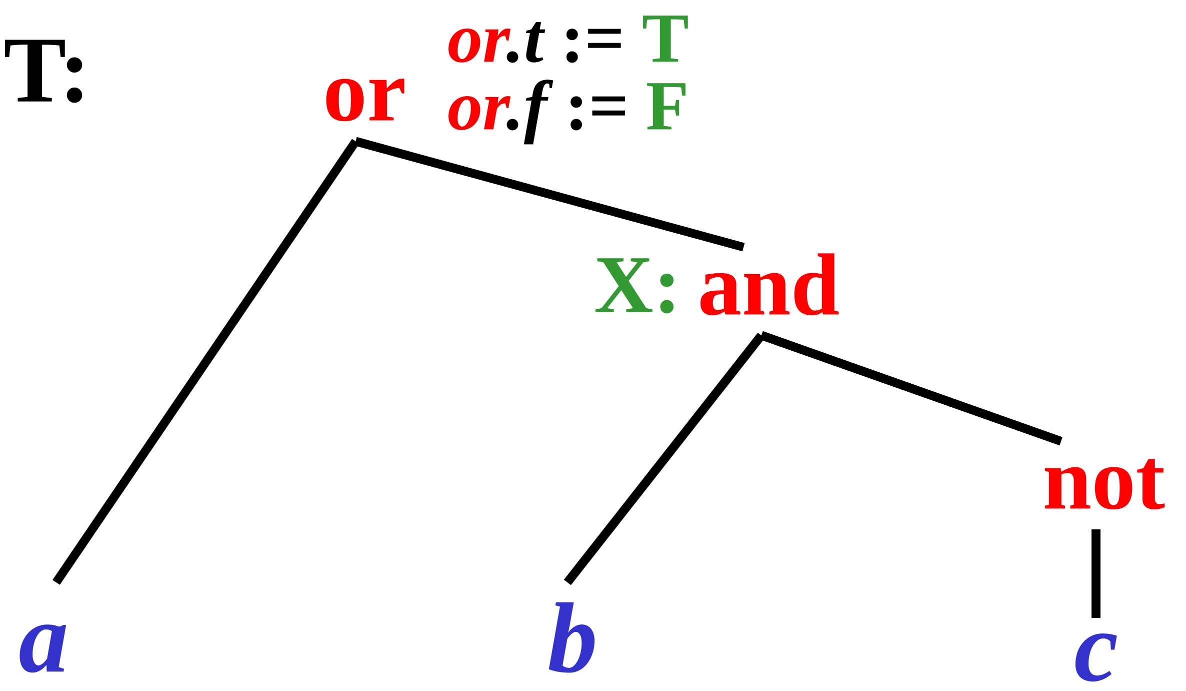
Note:

- T = *True*
- F = *False*

Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

AST:



Note:

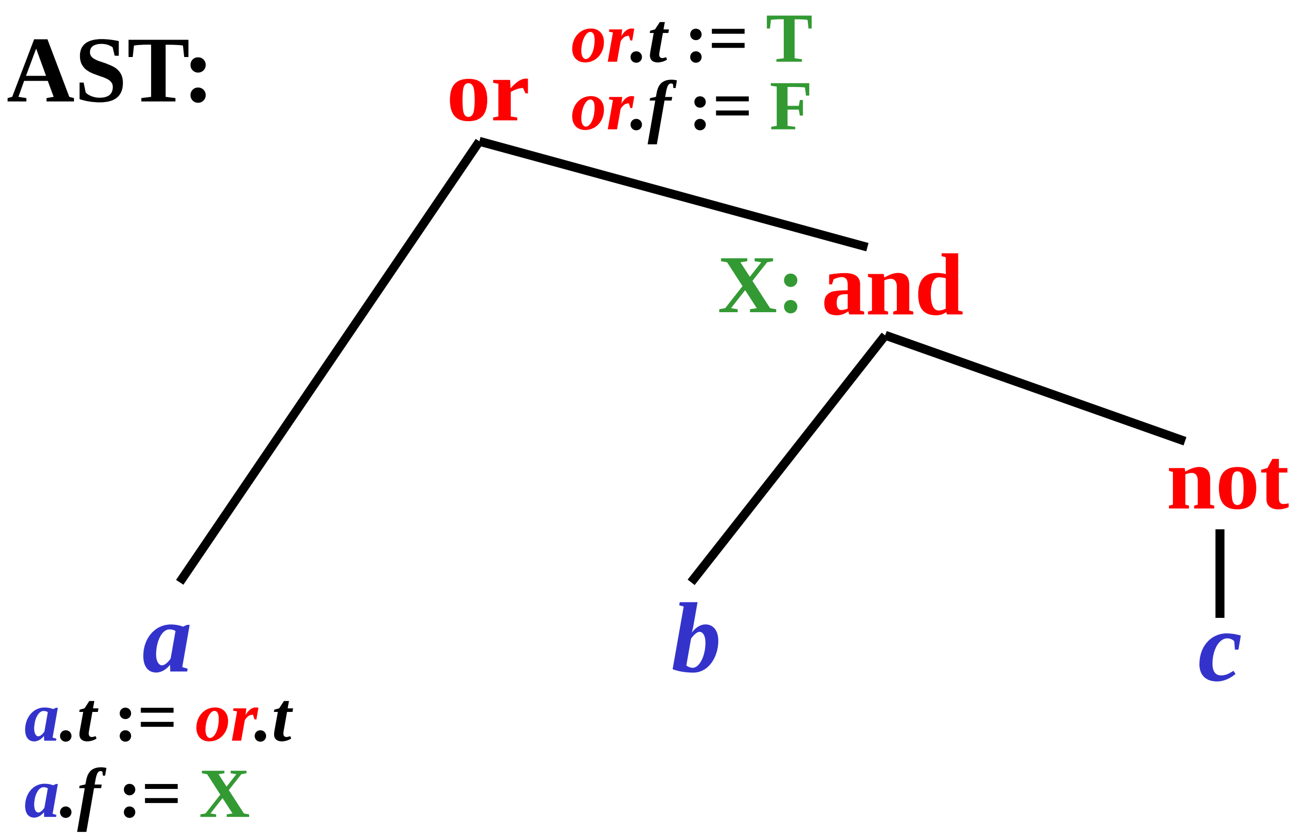
- T = *True*
- F = *False*

Short Evaluation Using AST: Example

Example: ***a*** **or (*****b*** **and (not *****c*****)):**

Note:
- **T** = ***True***
- **F** = ***False***

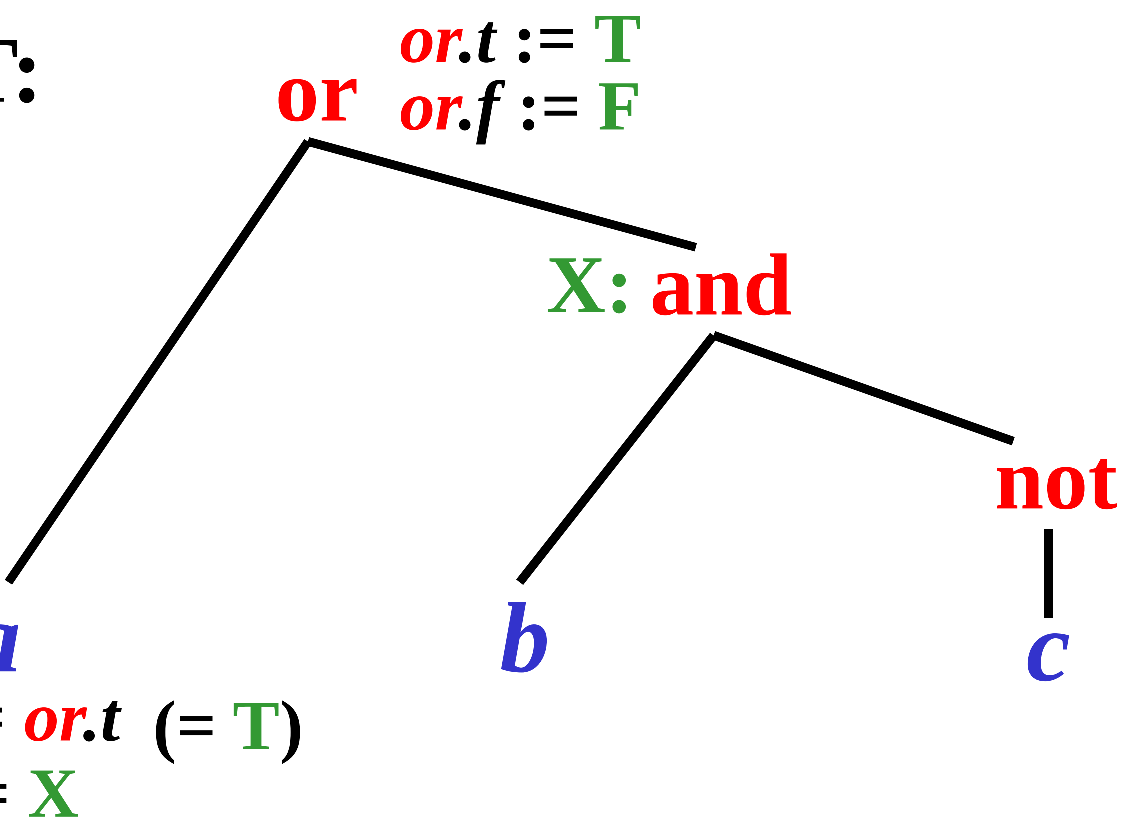
AST:



Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

AST:



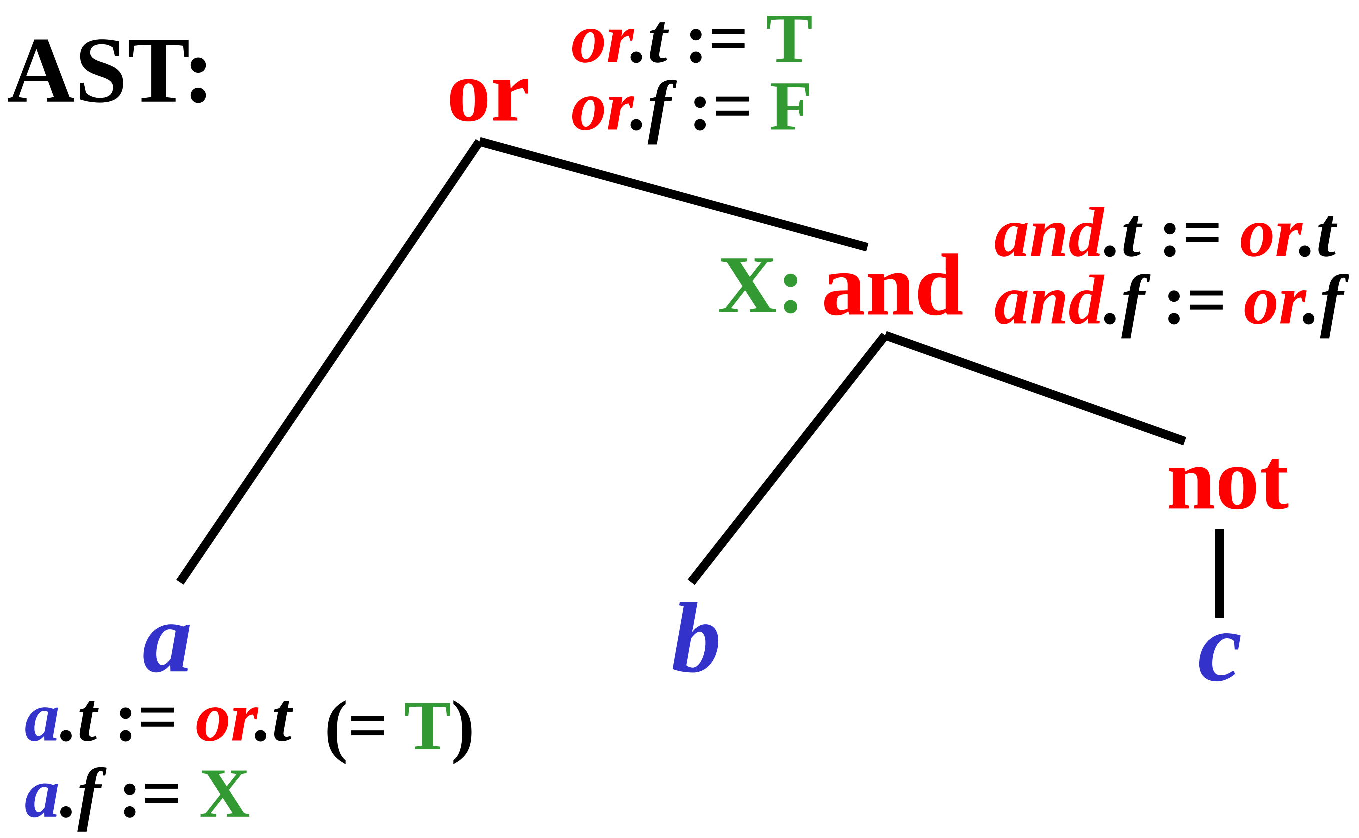
Note:

- T = *True*
- F = *False*

Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

AST:



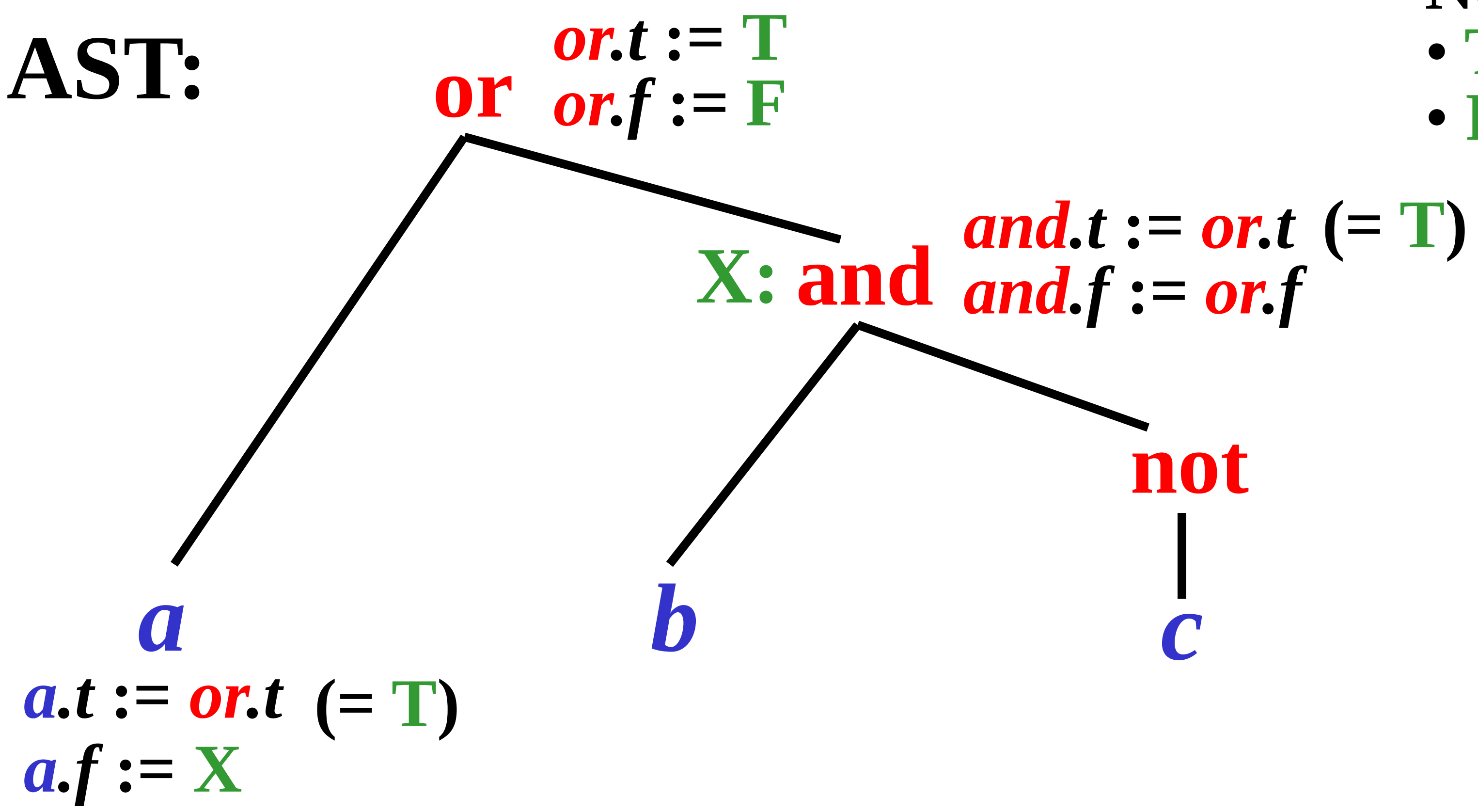
Note:
- **T = *True***
- **F = *False***

Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

AST:

Note:
- **T = *True***
- **F = *False***

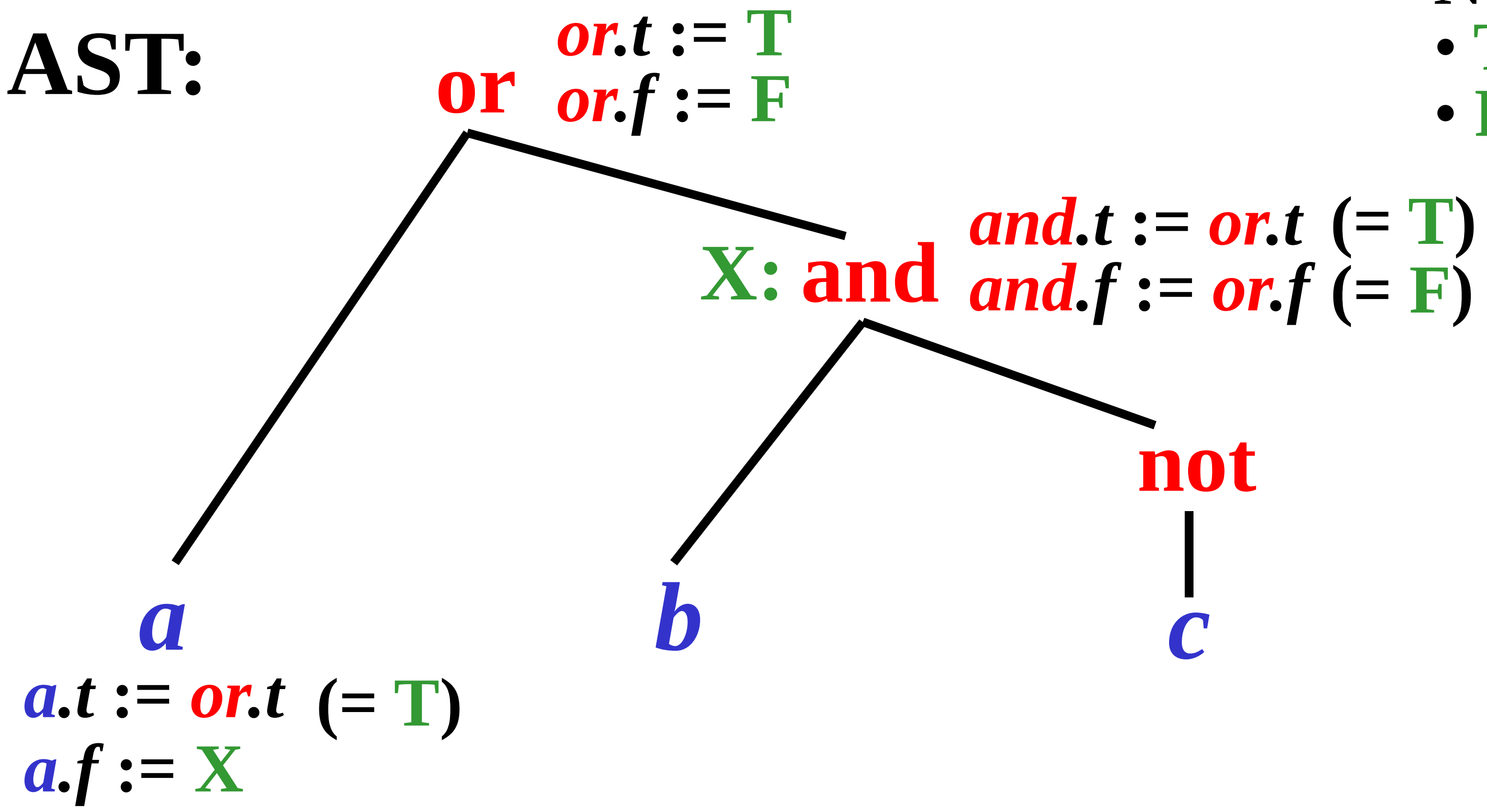


Short Evaluation Using AST: Example

Example: ***a* or (*b* and (not *c*)):**

Note:
- **T** = ***True***
- **F** = ***False***

AST:

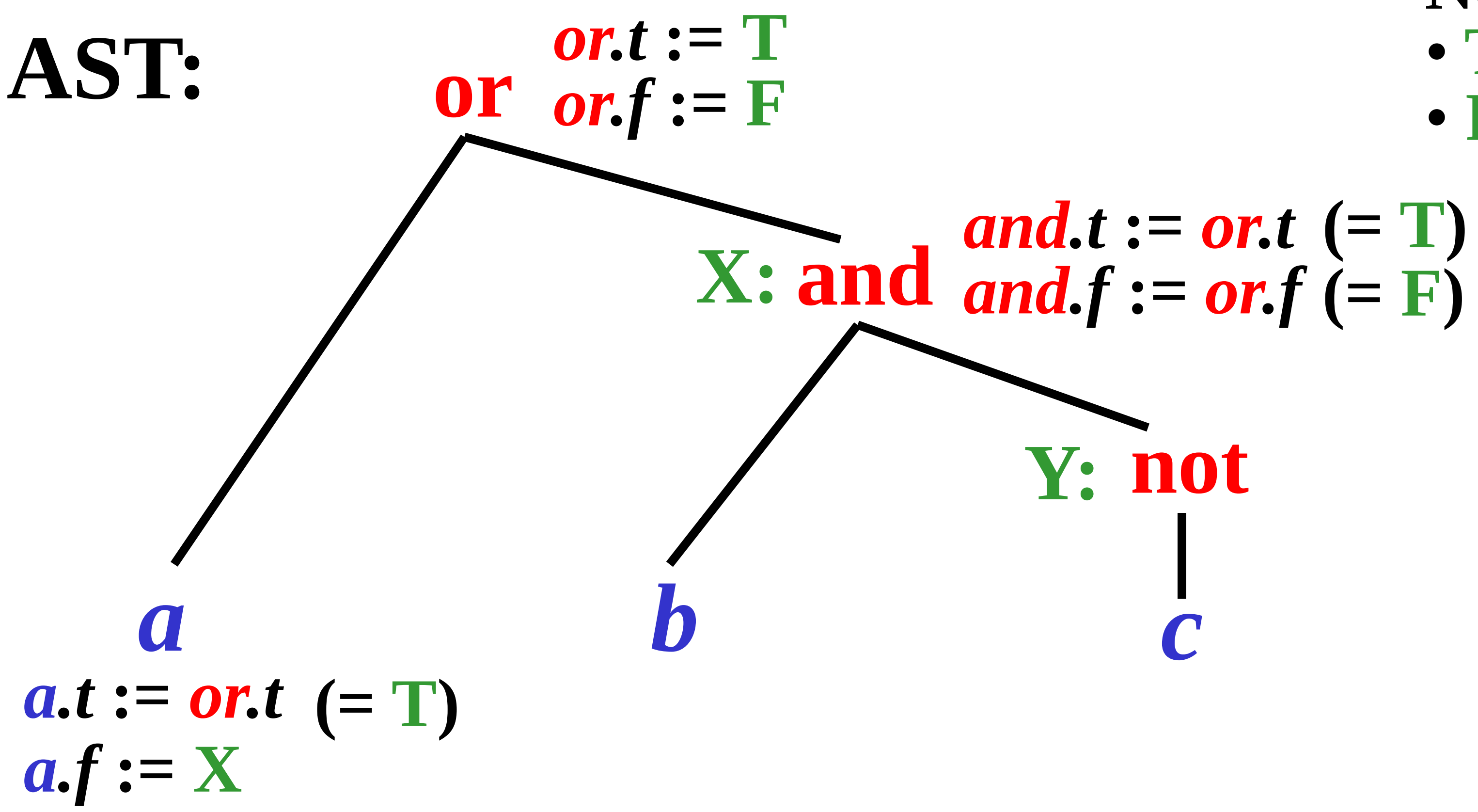


Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

AST:

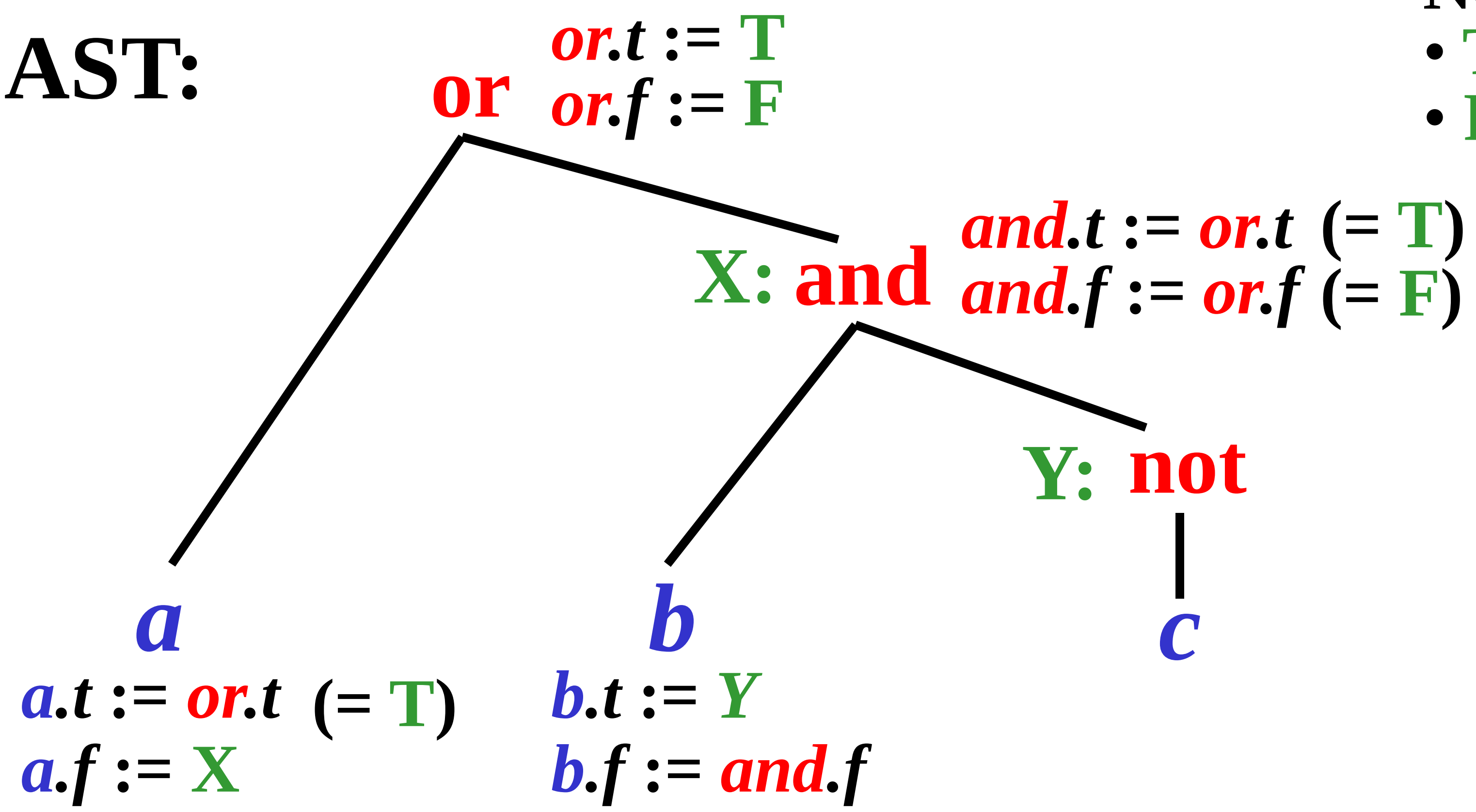
Note:
- T = *True*
- F = *False*



Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

AST:



Note:

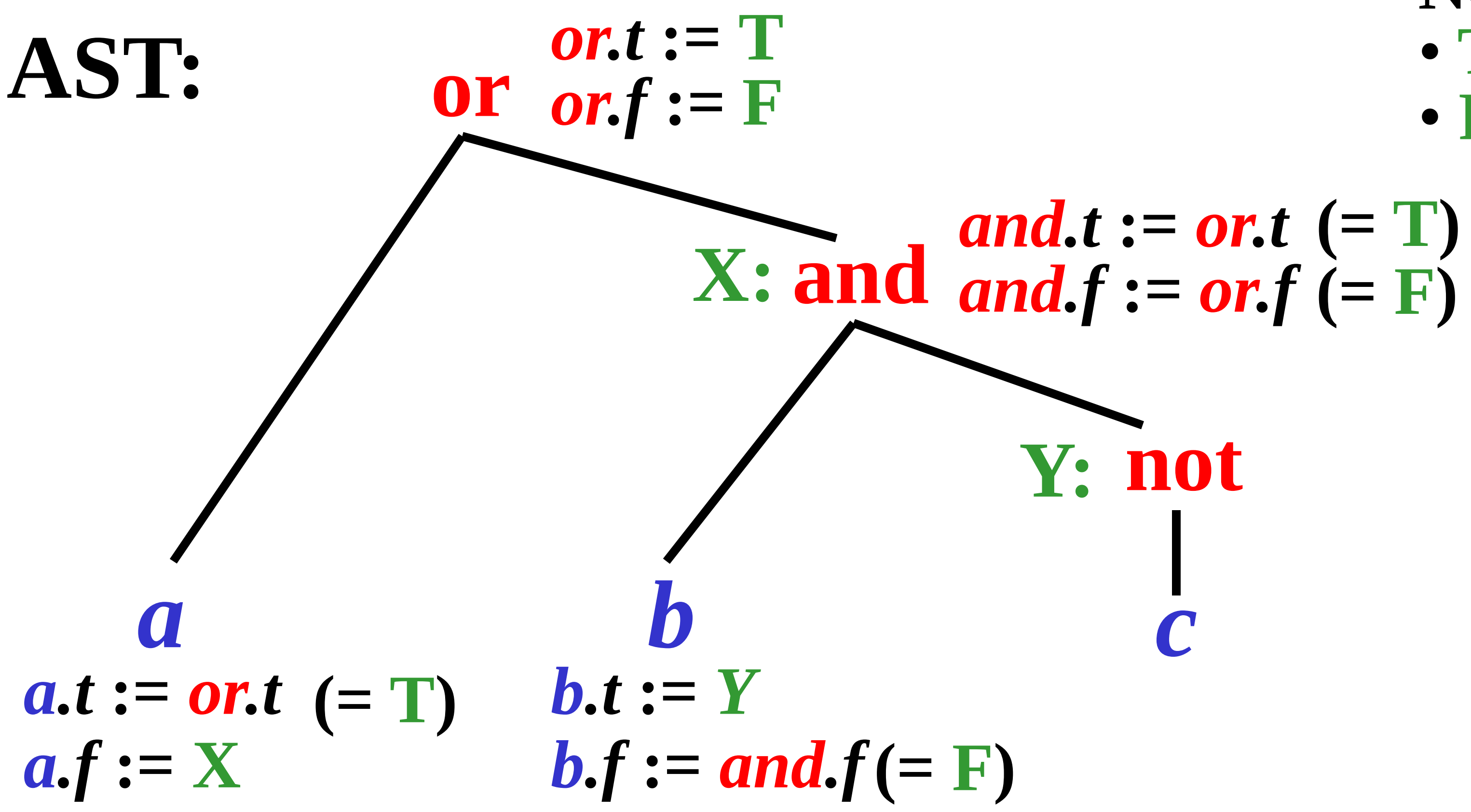
- T = *True*
- F = *False*

Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

Note:
- **T = *True***
- **F = *False***

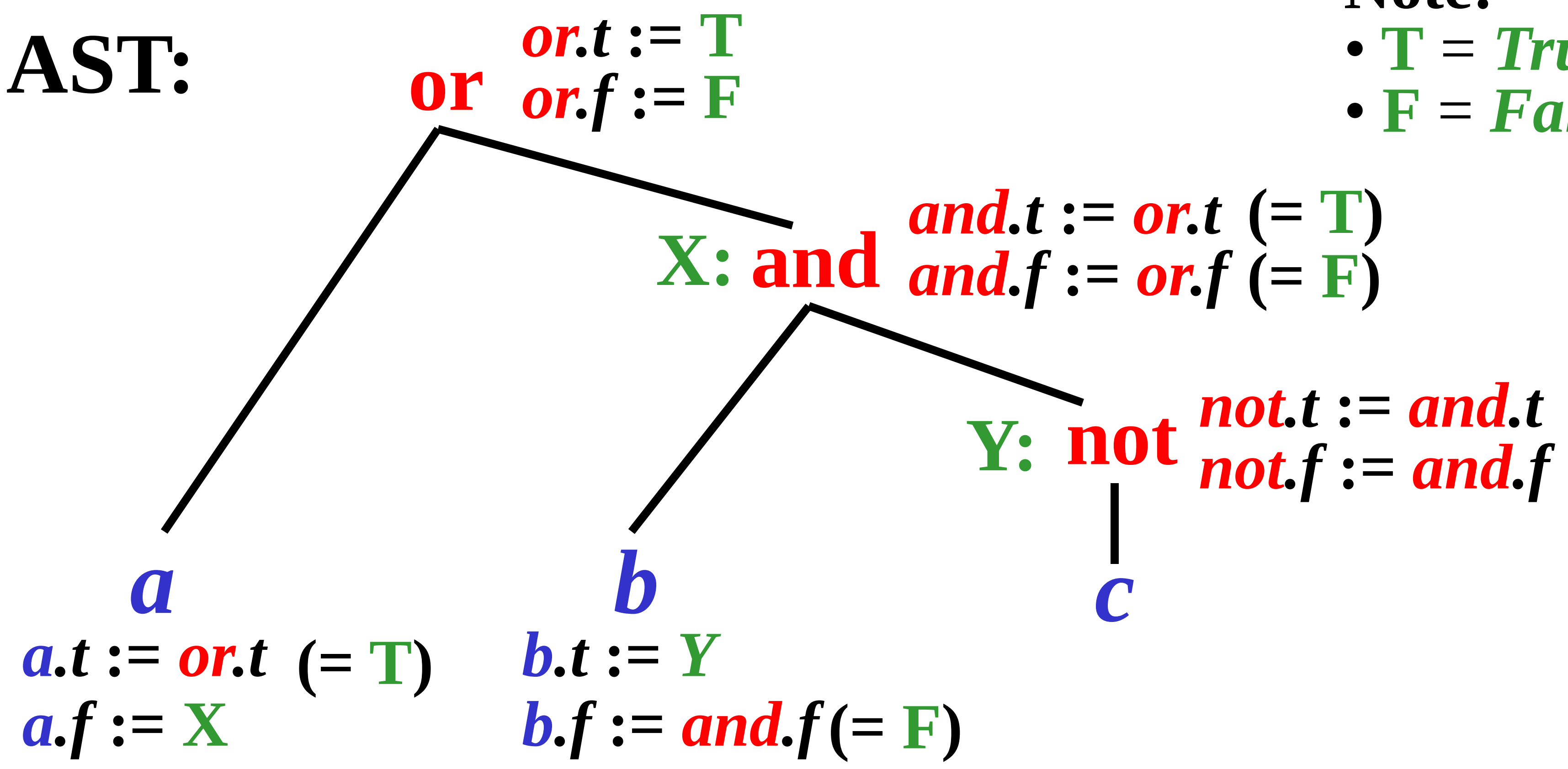
AST:



Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

AST:



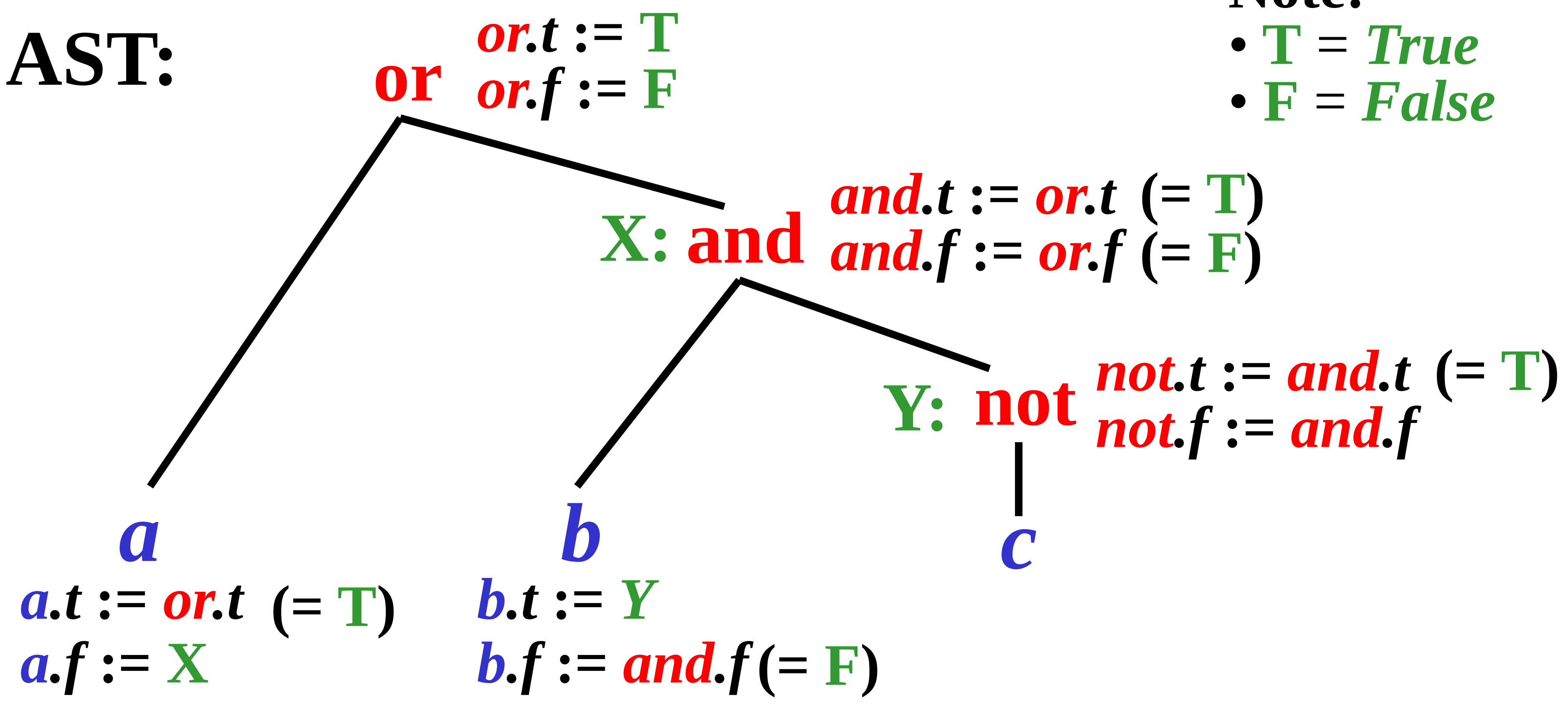
Note:
- T = *True*
- F = *False*

Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

Note:
- **T = *True***
- **F = *False***

AST:



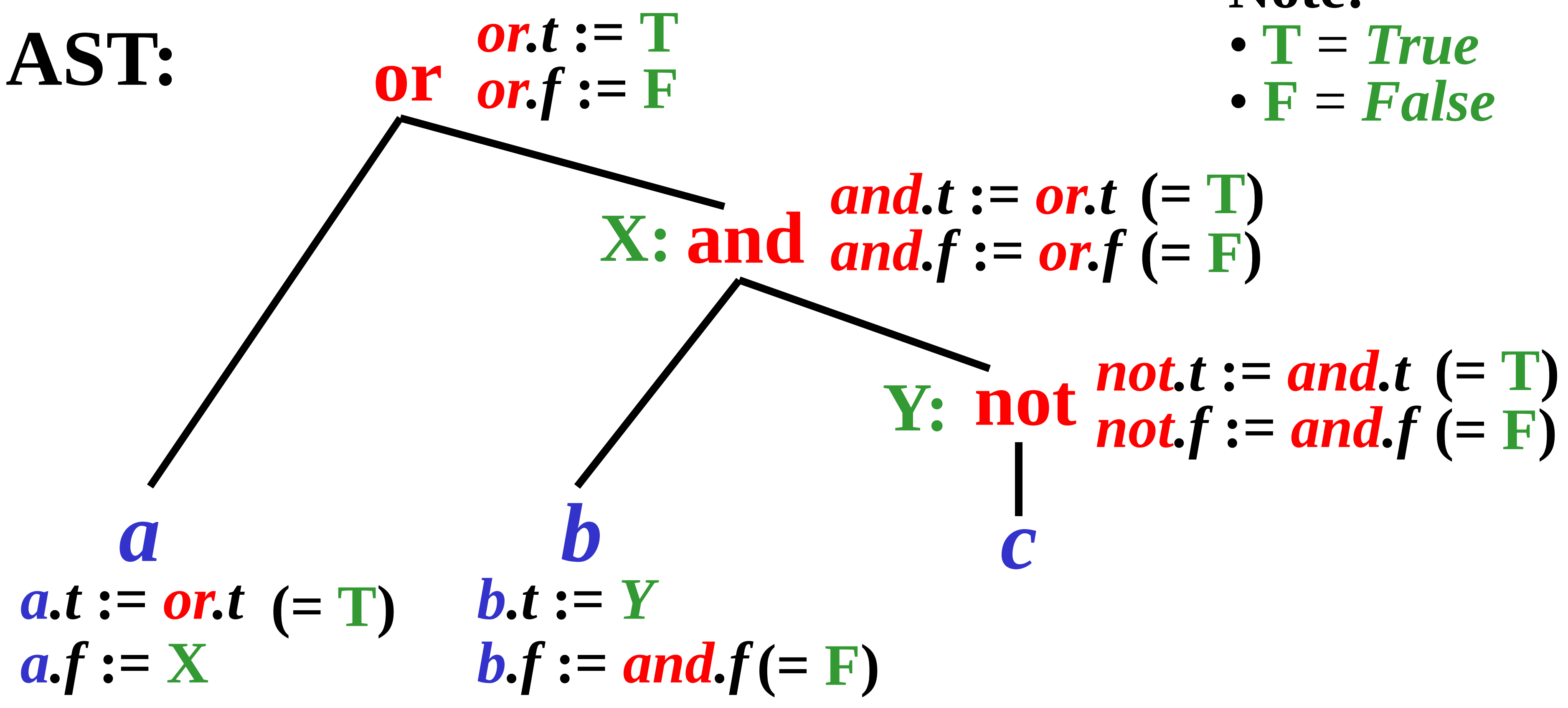
or
or.*t* := T
or.*f* := F
X: and
and.*t* := *or*.*t* (= T)
and.*f* := *or*.*f* (= F)
Y: not
not.*t* := *and*.*t* (= T)
not.*f* := *and*.*f*
a
a.*t* := *or*.*t* (= T)
a.*f* := X
b
b.*t* := Y
b.*f* := *and*.*f* (= F)
c

Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

AST:

Note:
- **T =** ***True***
- **F =** ***False***

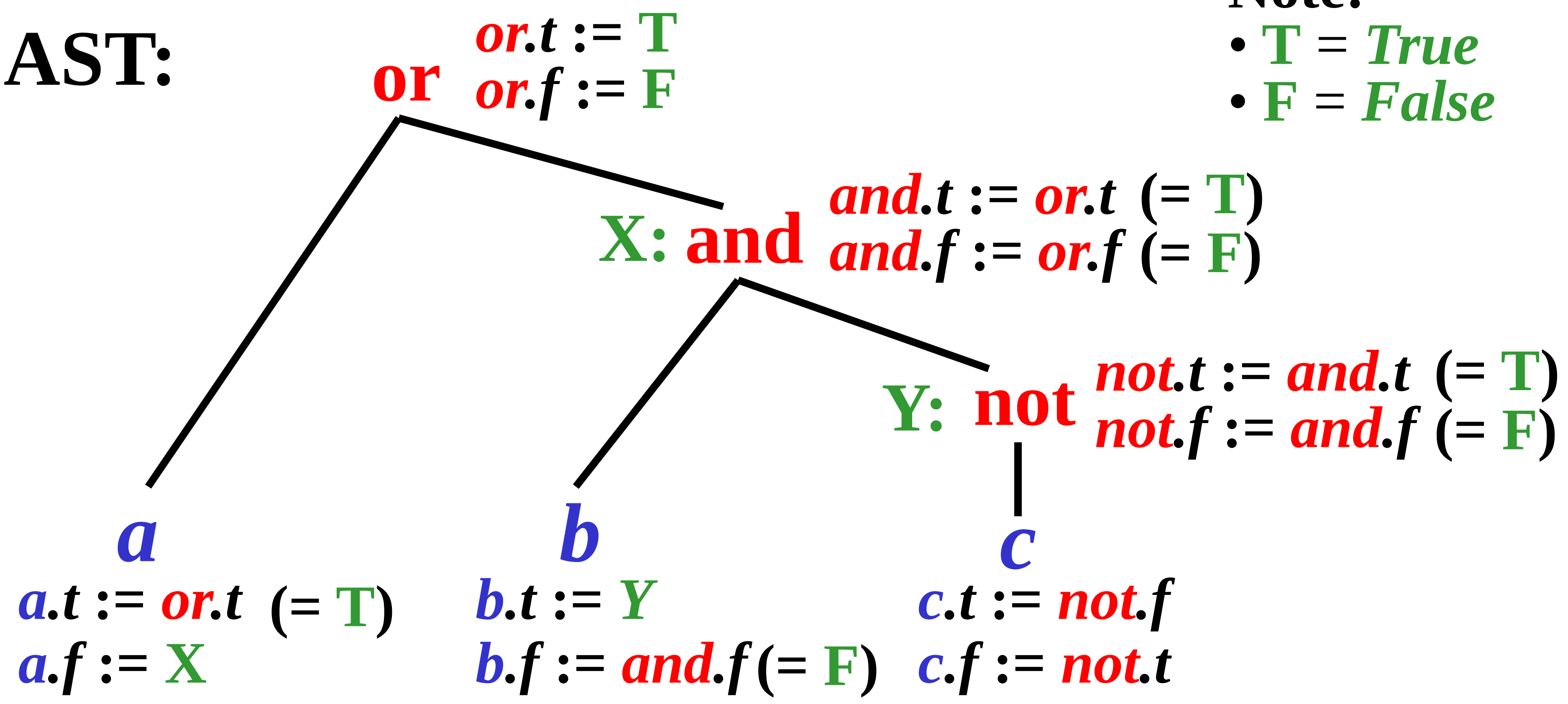


Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

Note:
- **T = *True***
- **F = *False***

AST:



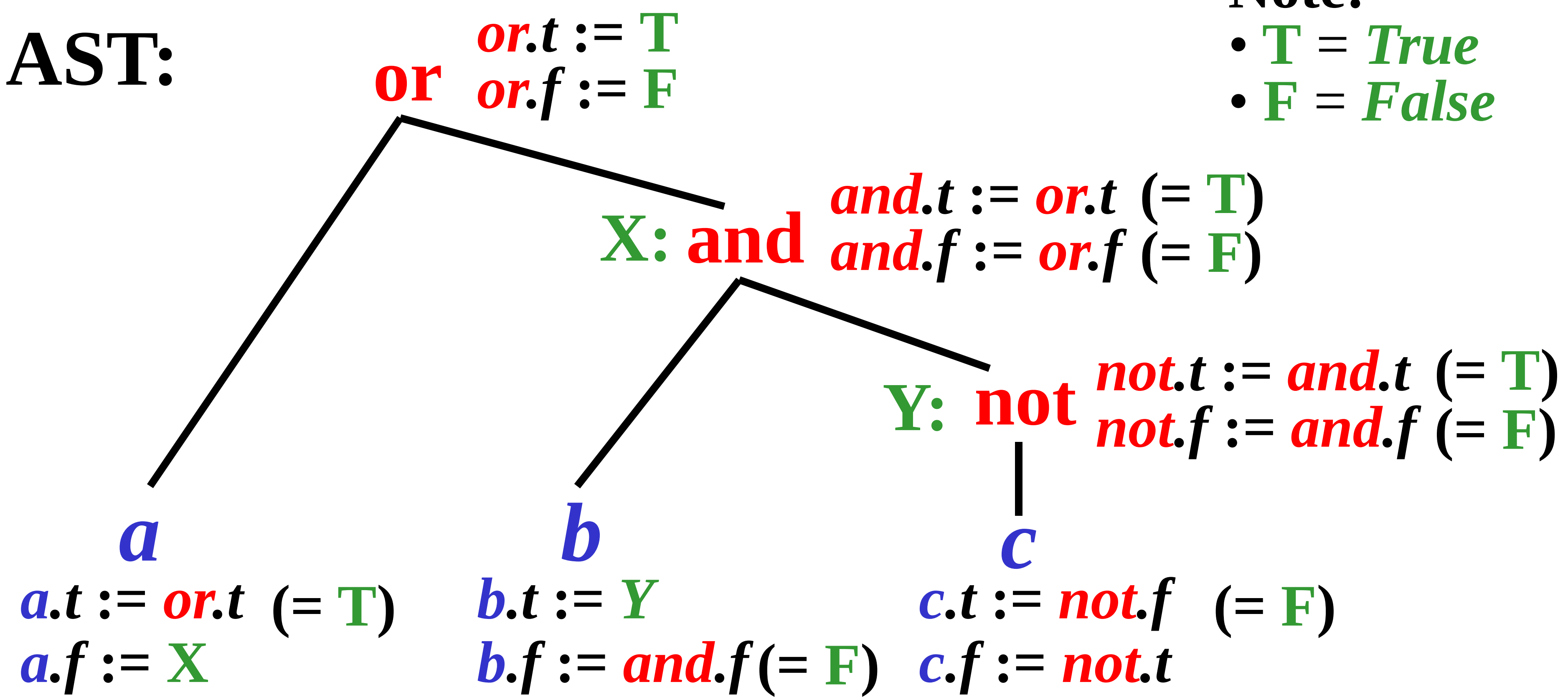
or
or.*t* := T
or.*f* := F
X: and
and.*t* := *or*.*t* (= T)
and.*f* := *or*.*f* (= F)
Y: not
not.*t* := *and*.*t* (= T)
not.*f* := *and*.*f* (= F)
a
a.*t* := *or*.*t* (= T)
a.*f* := X
b
b.*t* := *Y*
b.*f* := *and*.*f* (= F)
c
c.*t* := *not*.*f*
c.*f* := *not*.*t*

Short Evaluation Using AST: Example

Example: ***a* or (*b* and (not *c*)):**

Note:
- **T** = ***True***
- **F** = ***False***

AST:

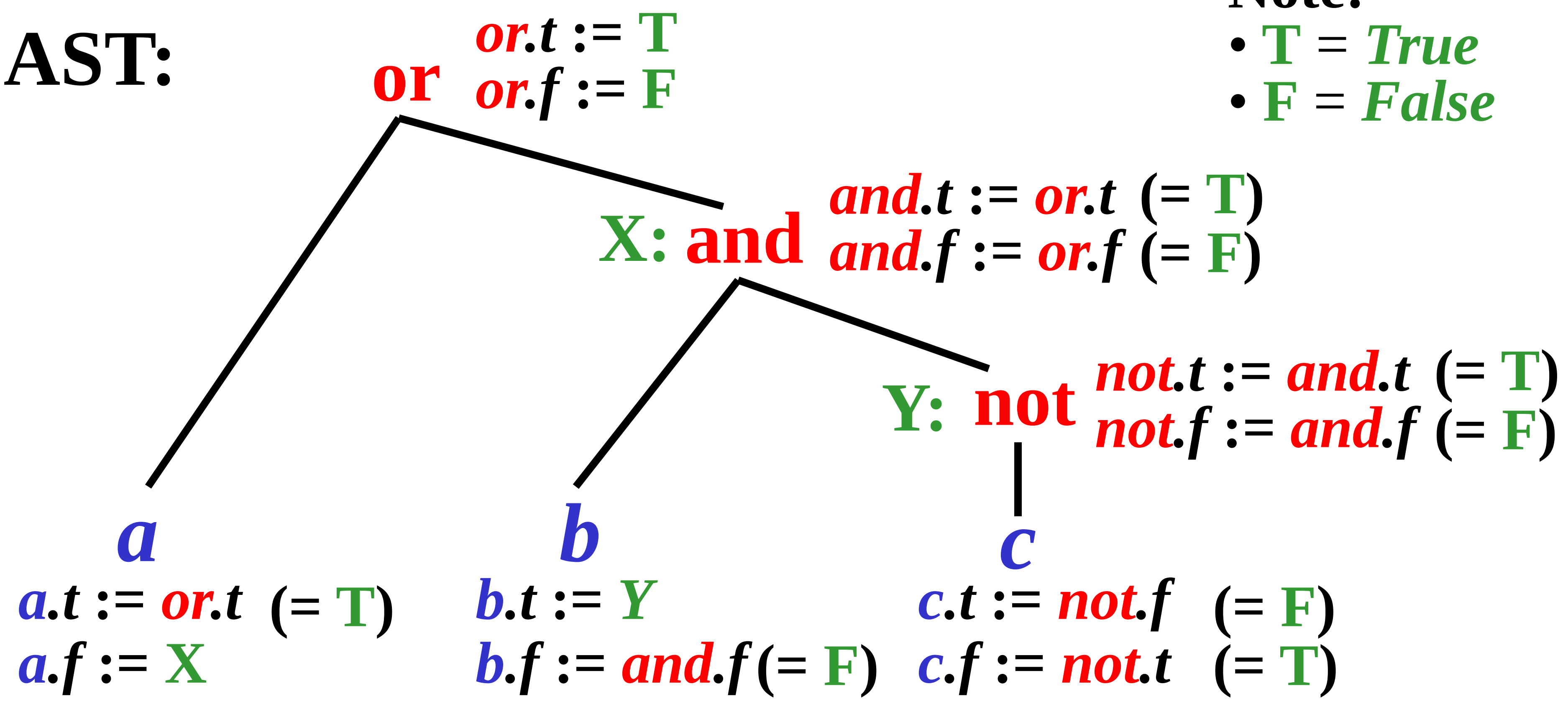


Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

Note:
- **T** = ***True***
- **F** = ***False***

AST:

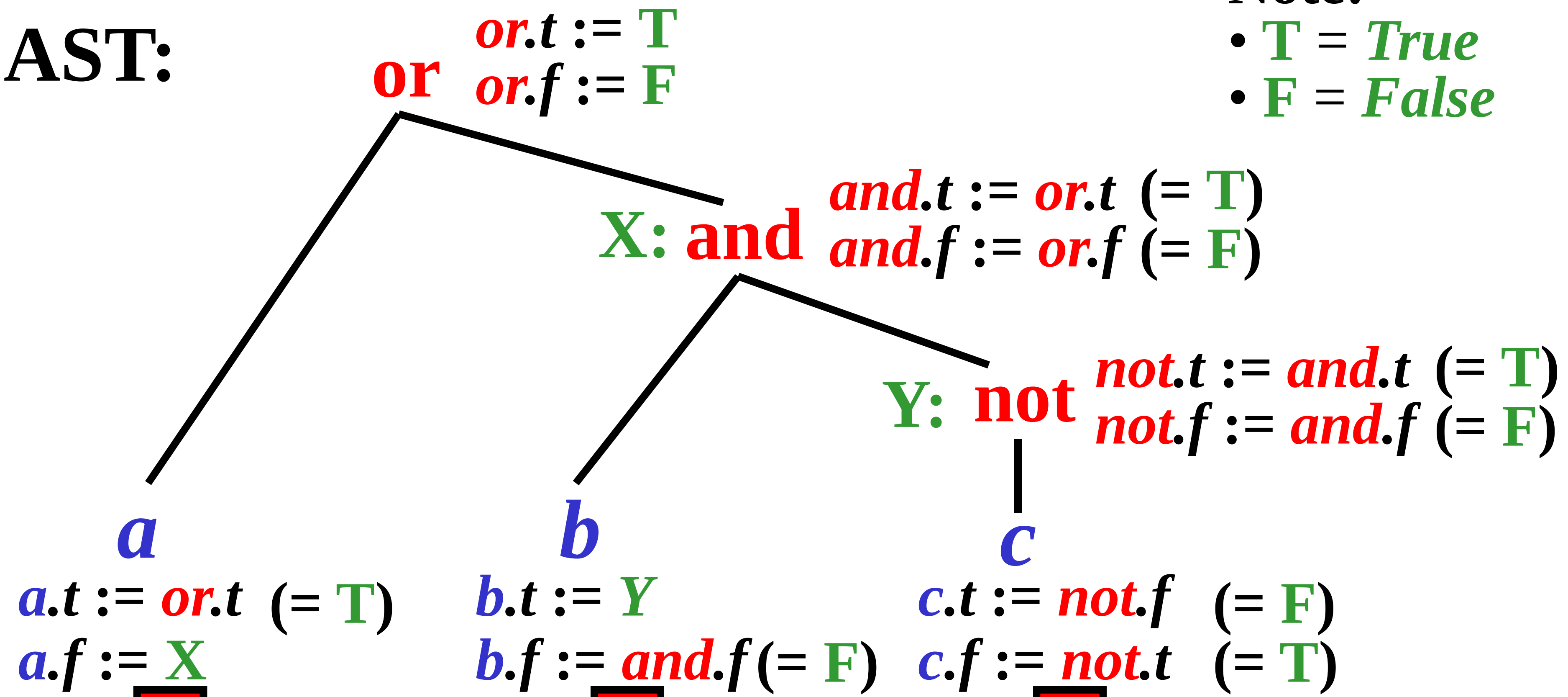

or
or.*t* := T
or.*f* := F
X: and
and.*t* := *or*.*t* (= T)
and.*f* := *or*.*f* (= F)
Y: not
not.*t* := *and*.*t* (= T)
not.*f* := *and*.*f* (= F)
a
a.*t* := *or*.*t* (= T)
a.*f* := X
b
b.*t* := *Y*
b.*f* := *and*.*f* (= F)
c
c.*t* := *not*.*f* (= F)
c.*f* := *not*.*t* (= T)

Short Evaluation Using AST: Example

Example: ***a*** **or (*b* and (not *c*)):**

Note:
- T = *True*
- F = *False*

AST:



```
if a goto T        X:                 Y:                 T: …
goto X             if b goto Y        if c goto F
                   goto F             goto T             F: …
```

Short Evaluation: Direct Code Generation 1/5

- **Grammar for boolean expressions:**

Rules:

$$\begin{tikzcd}[column sep=small] & E\ \textcircled{1.} \arrow[dl, dash] \arrow[d, dash] \arrow[dr, dash] & \\ E & \textbf{or} & E \end{tikzcd} \quad \begin{tikzcd}[column sep=small] & E\ \textcircled{2.} \arrow[dl, dash] \arrow[d, dash] \arrow[dr, dash] & \\ E & \textbf{and} & E \end{tikzcd} \quad \begin{tikzcd}[column sep=small] & E\ \textcircled{3.} \arrow[dl, dash] \arrow[dr, dash] & \\ \textbf{not} & & E \end{tikzcd} \quad \begin{tikzcd}[column sep=small] & E\ \textcircled{4.} \arrow[dl, dash] \arrow[d, dash] \arrow[dr, dash] & \\ (& E &) \end{tikzcd} \quad \begin{tikzcd} E\ \textcircled{5.} \arrow[d, dash] \\ \textbf{id} \end{tikzcd}$$

Note: Ambiguity!

- **Modification of grammar:**

1) Replace rules $\textcircled{1.}$ & $\textcircled{2.}$ with:

$$\begin{tikzcd}[column sep=small] & E \arrow[dl, dash] \arrow[d, dash] \arrow[dr, dash] \arrow[drr, dash] & & \\ E & \textbf{or} & M & E \end{tikzcd} \quad \begin{tikzcd}[column sep=small] & E \arrow[dl, dash] \arrow[d, dash] \arrow[dr, dash] \arrow[drr, dash] & & \\ E & \textbf{and} & M & E \end{tikzcd} \quad \begin{tikzcd} M \arrow[d, dash] \\ \varepsilon \end{tikzcd}$$

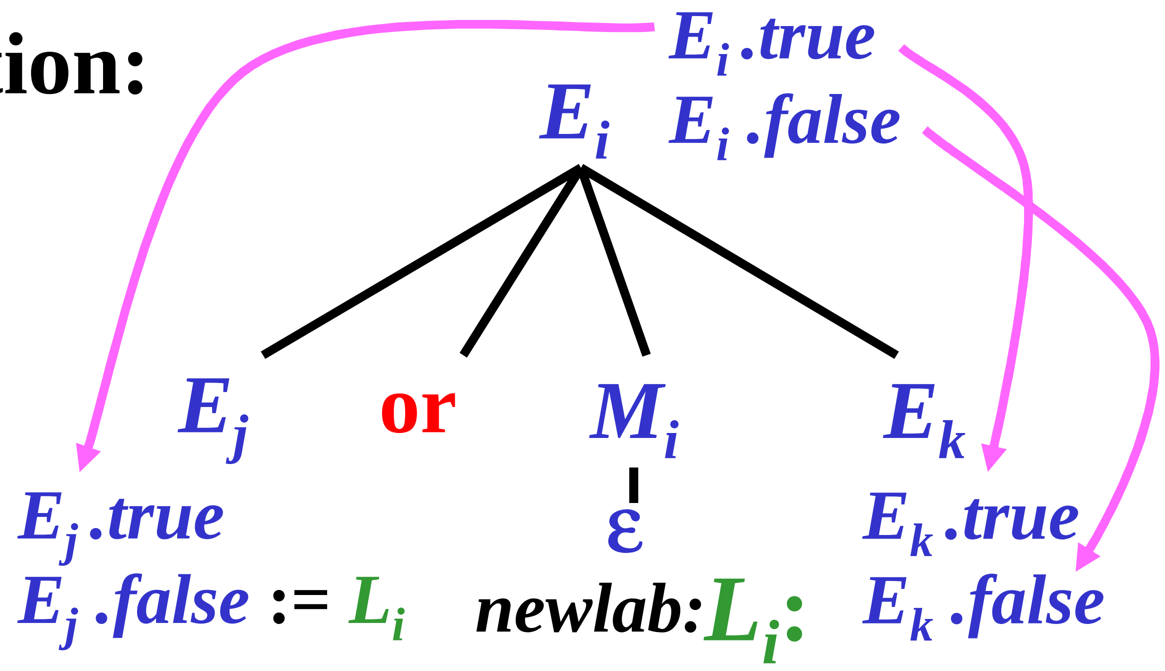
2) Assign to each rule the following semantic action

Short Evaluation: Direct Code Generation 2/5

$\boldsymbol{M_i} \rightarrow \varepsilon$ {generate "$\boldsymbol{M_i . lab}$:"} // Generation of a new label

$\boldsymbol{E_i} \rightarrow \boldsymbol{E_j}$ **or** $\boldsymbol{M_i}\ \boldsymbol{E_k}$ {$\boldsymbol{M_i}.lab := GenerateNewLab$;
$\boldsymbol{E_j}.true := \boldsymbol{E_i}.true$; $\boldsymbol{E_j}.false := \boldsymbol{M_i}.lab$
$\boldsymbol{E_k}.true := \boldsymbol{E_i}.true$; $\boldsymbol{E_k}.false := \boldsymbol{E_i}.false$ }

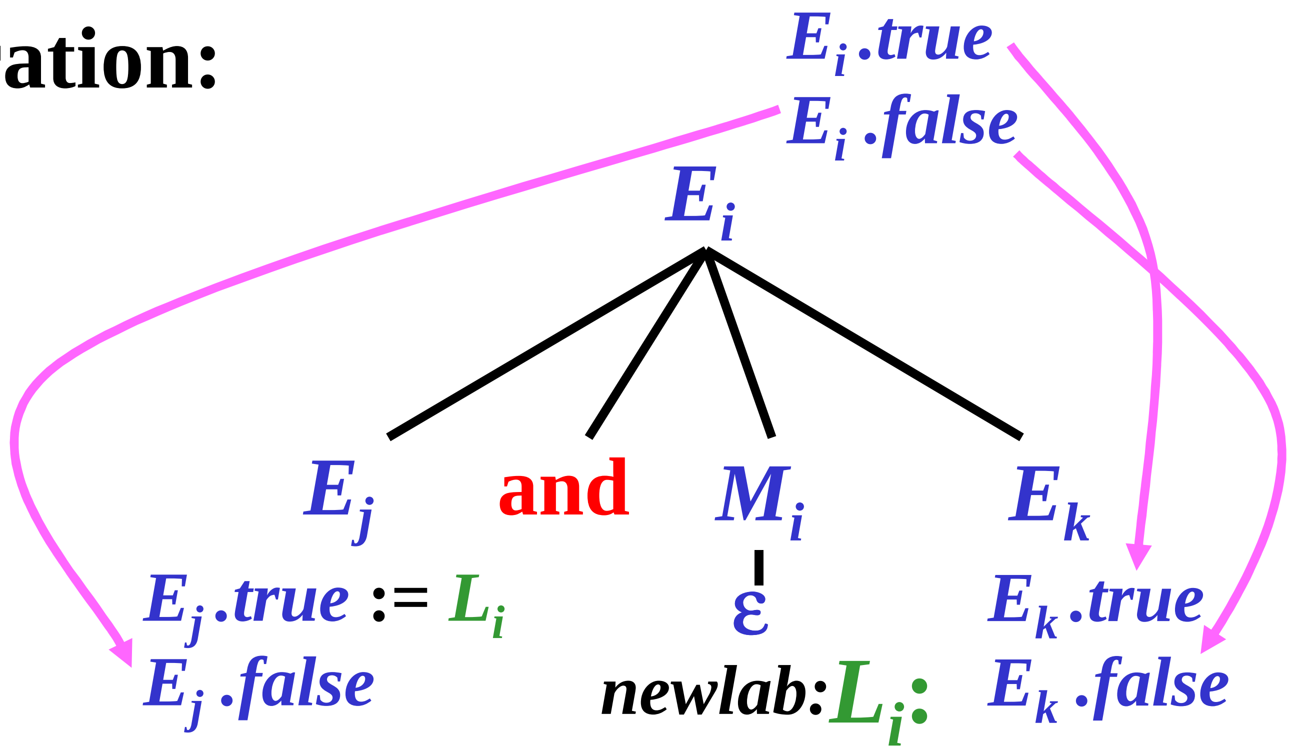
Illustration:



Short Evaluation: Direct Code Generation 3/5

$\boldsymbol{E_i} \rightarrow \boldsymbol{E_j}$ **and** $\boldsymbol{M_i}\ \boldsymbol{E_k}$ $\{\boldsymbol{M_i}.lab := GenerateNewLab;$
$\boldsymbol{E_j}.true := \boldsymbol{M_i}.lab;\ \boldsymbol{E_j}.false := \boldsymbol{E_i}.false$
$\boldsymbol{E_k}.true := \boldsymbol{E_i}.true;\ \boldsymbol{E_k}.false := \boldsymbol{E_i}.false\ \}$

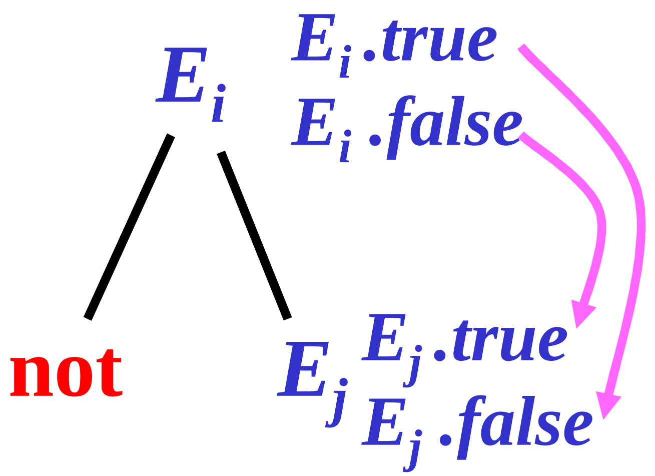
Illustration:



Short Evaluation: Direct Code Generation 4/5

$E_i \rightarrow$ **not** E_j { $E_j.true$:= $E_i.false$;
$E_j.false$:= $E_i.true$ }

Illustration:

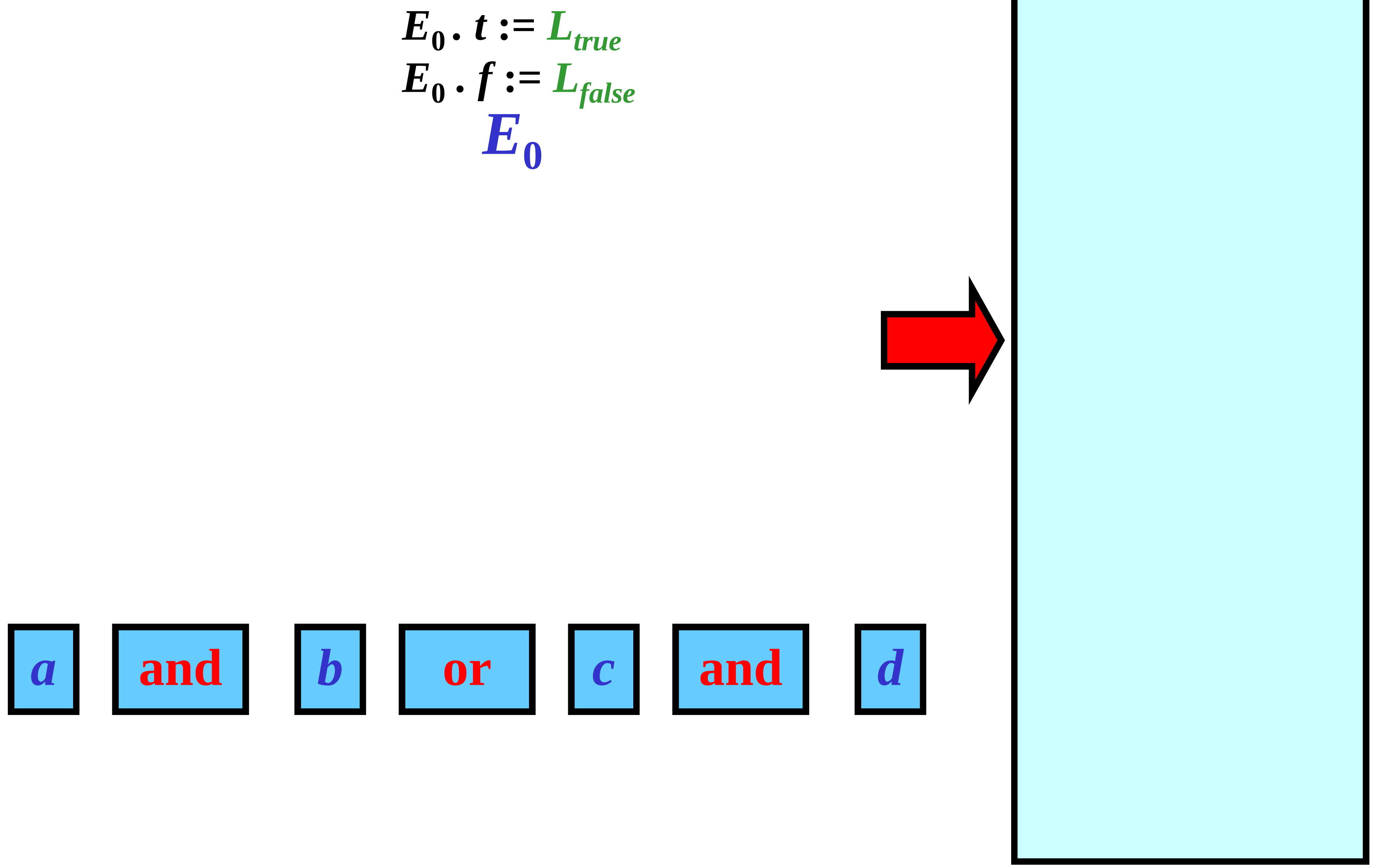


$E_i \rightarrow (E_j)$ {$E_j.true$:= $E_i.true$;
$E_j.false$:= $E_i.false$ }

$E_i \rightarrow id_j$ { generate "**if** $id_j.val$ **goto** $E_i.true$";
generate "**goto** $E_i.false$" }

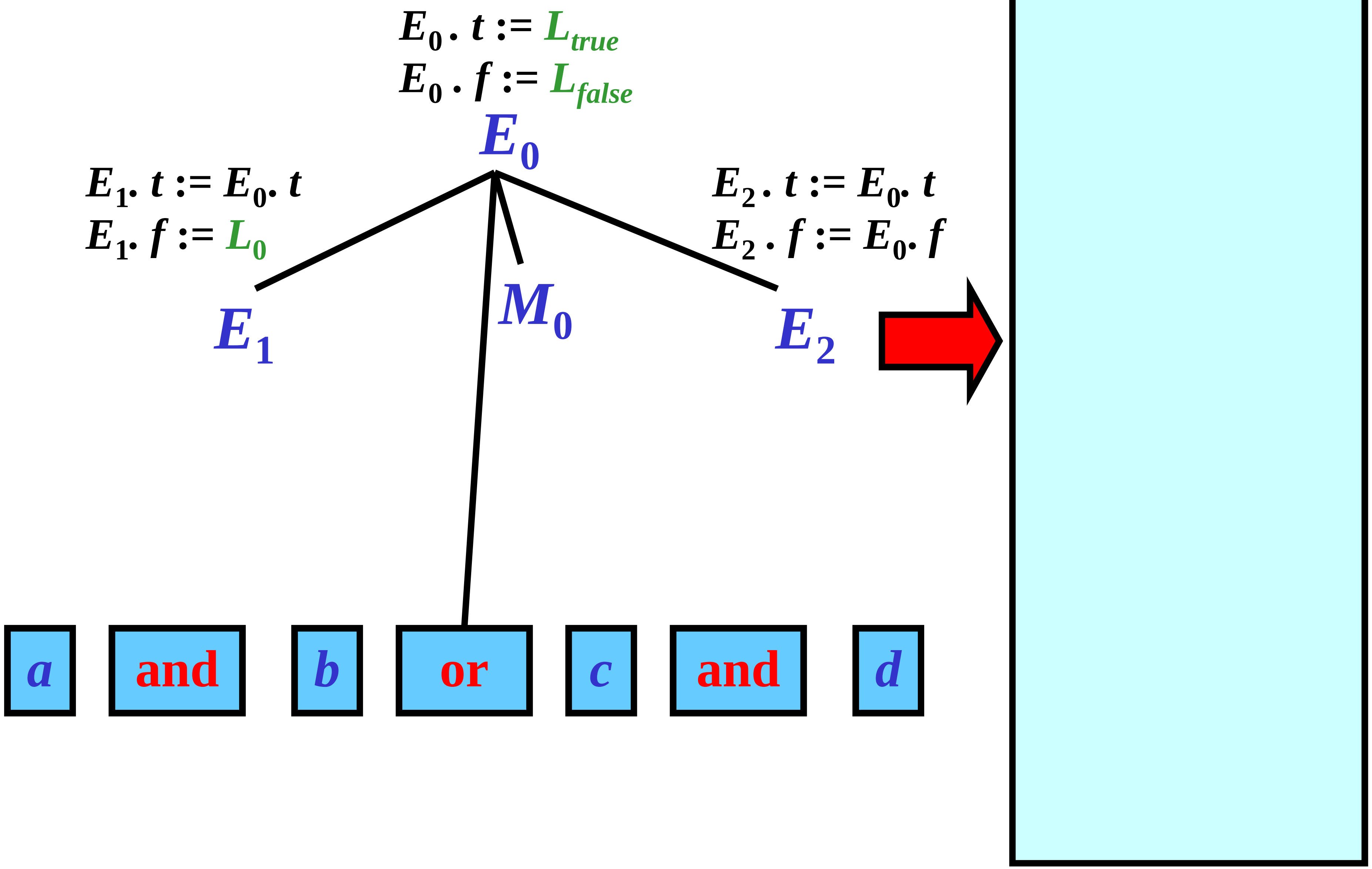
Short Evaluation: Direct Code Generation 5/5

Example: ***a* and *b* or *c* and *d*:**



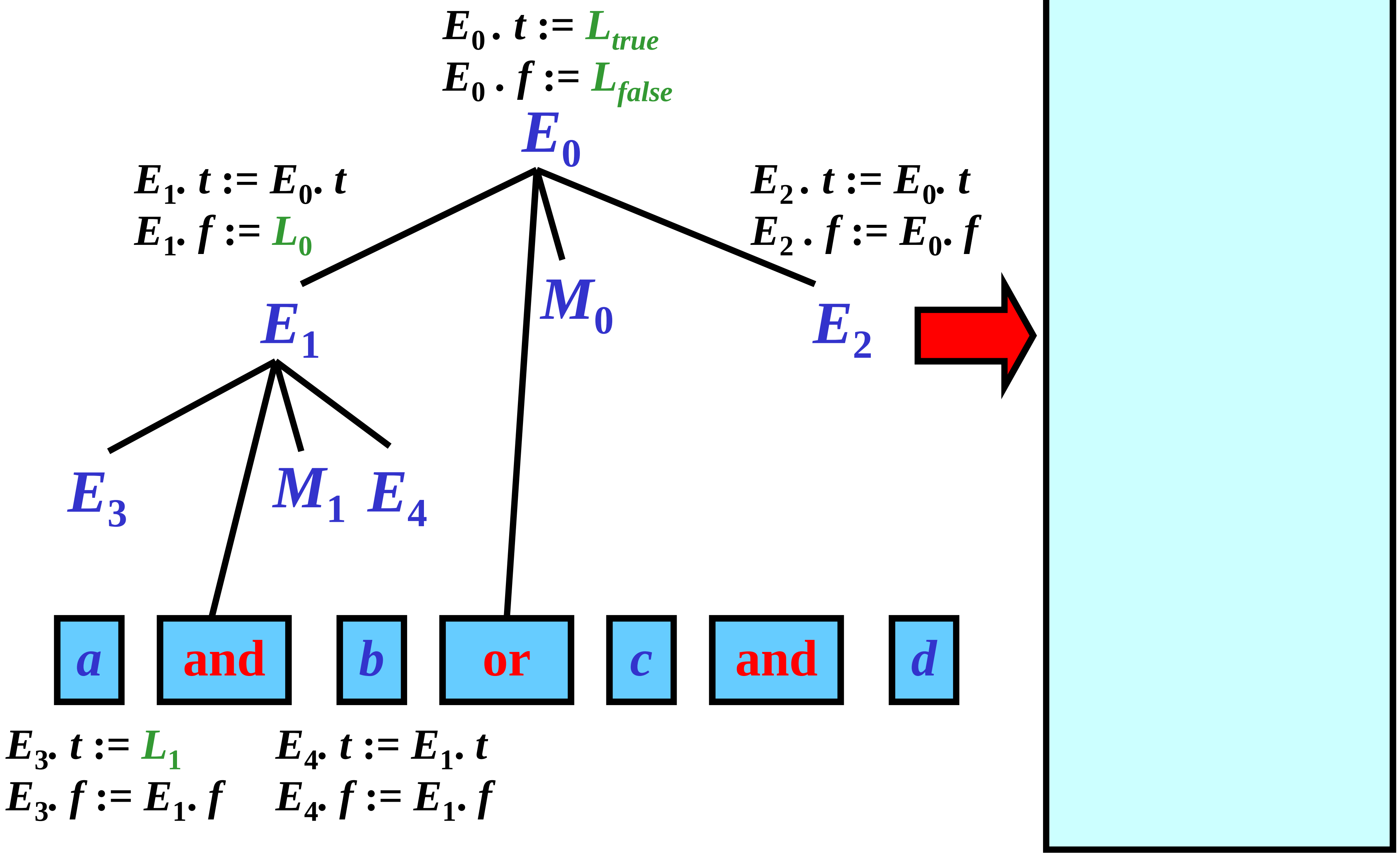
Short Evaluation: Direct Code Generation 5/5

Example: *a* and *b* or *c* and *d*:



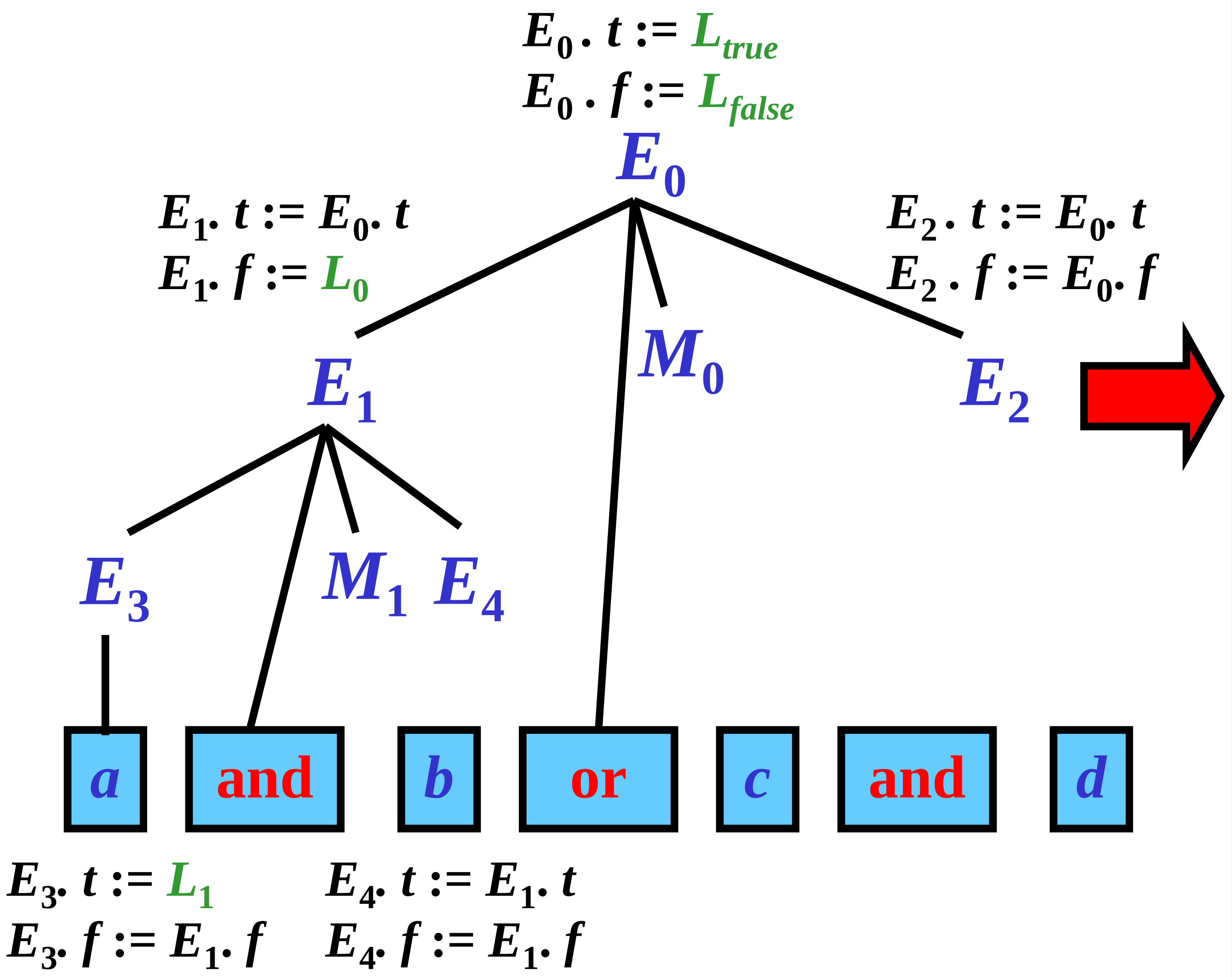
Short Evaluation: Direct Code Generation 5/5

Example: *a* and *b* or *c* and *d*:



Short Evaluation: Direct Code Generation 5/5

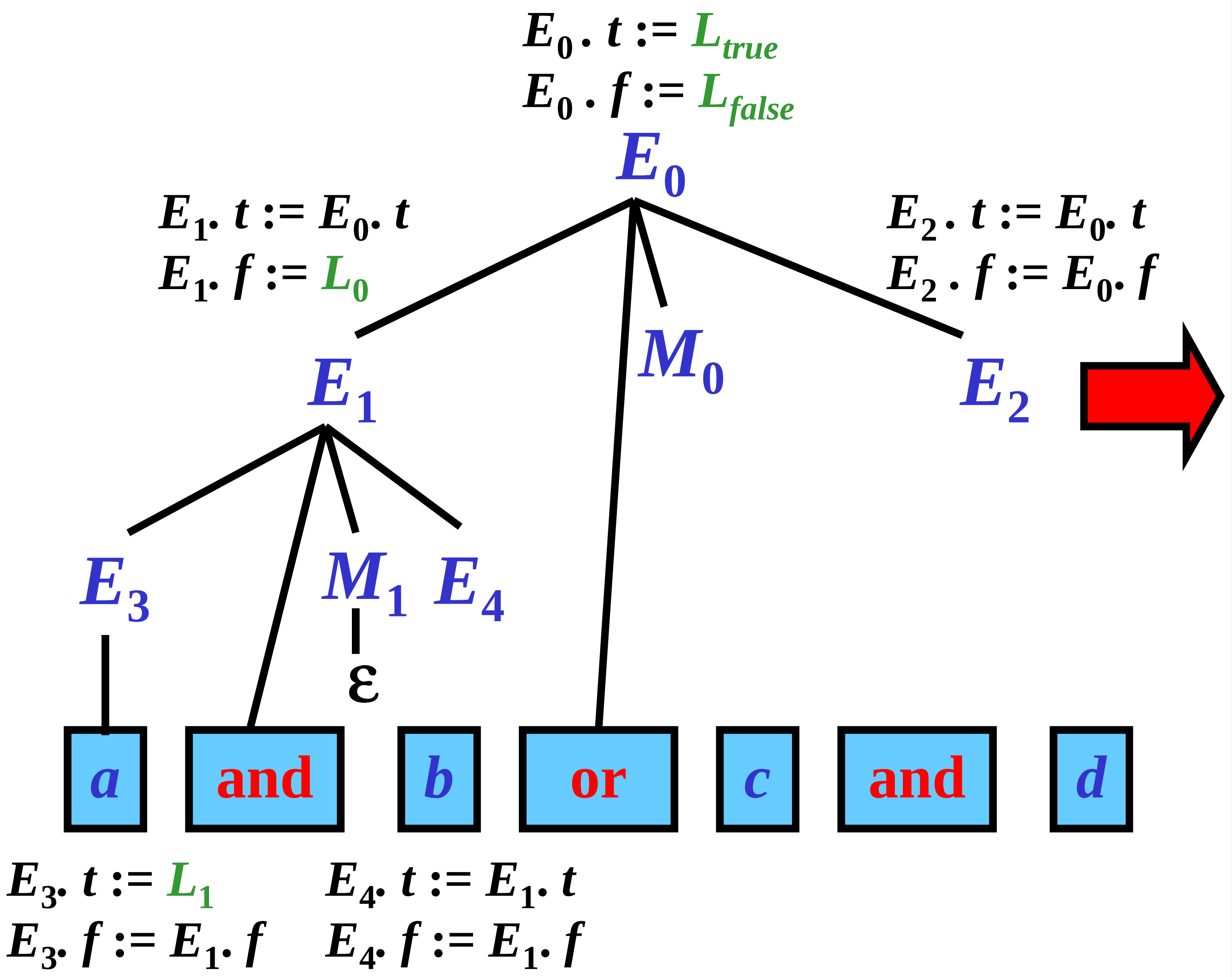
Example: ***a* and *b* or *c* and *d*:**



if ***a*** *goto* $\boldsymbol{L_1}$
goto $\boldsymbol{L_0}$

Short Evaluation: Direct Code Generation 5/5

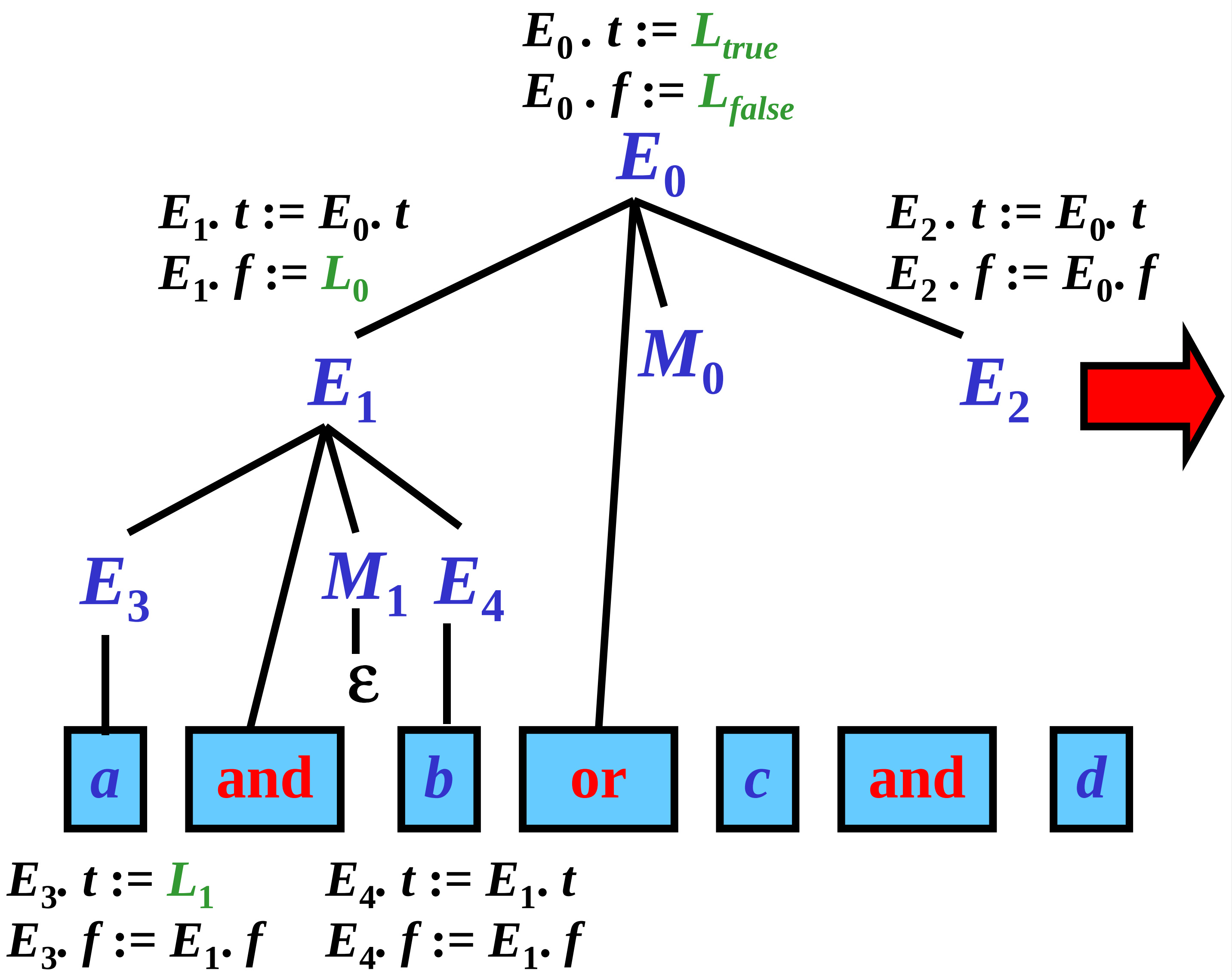
Example: *a* and *b* or *c* and *d*:



if ***a*** *goto* L_1
goto L_0
L_1:

Short Evaluation: Direct Code Generation 5/5

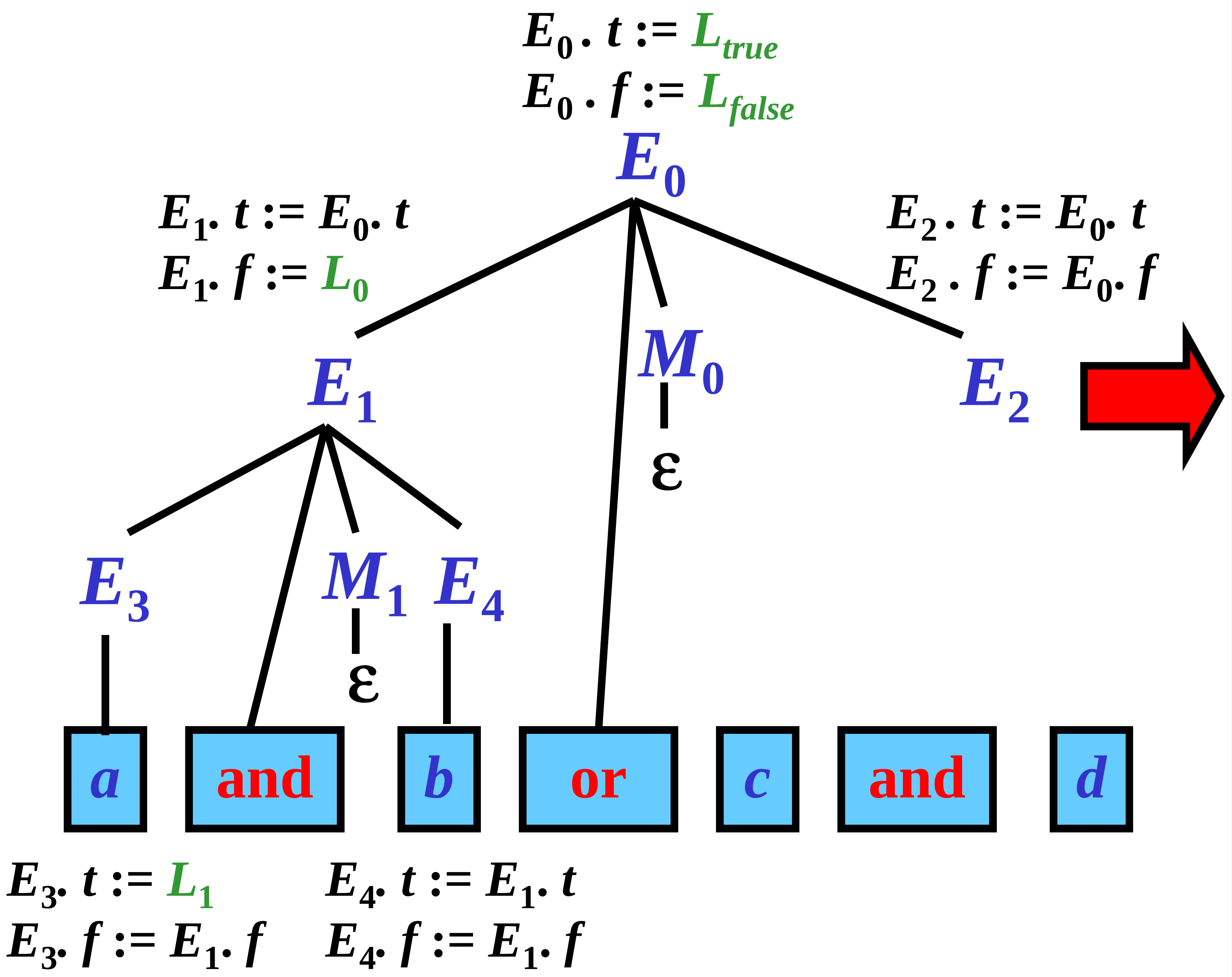
Example: ***a* and *b* or *c* and *d*:**



if ***a*** *goto* L_1
goto L_0
L_1:
if ***b*** *goto* L_{true}
goto L_0

Short Evaluation: Direct Code Generation 5/5

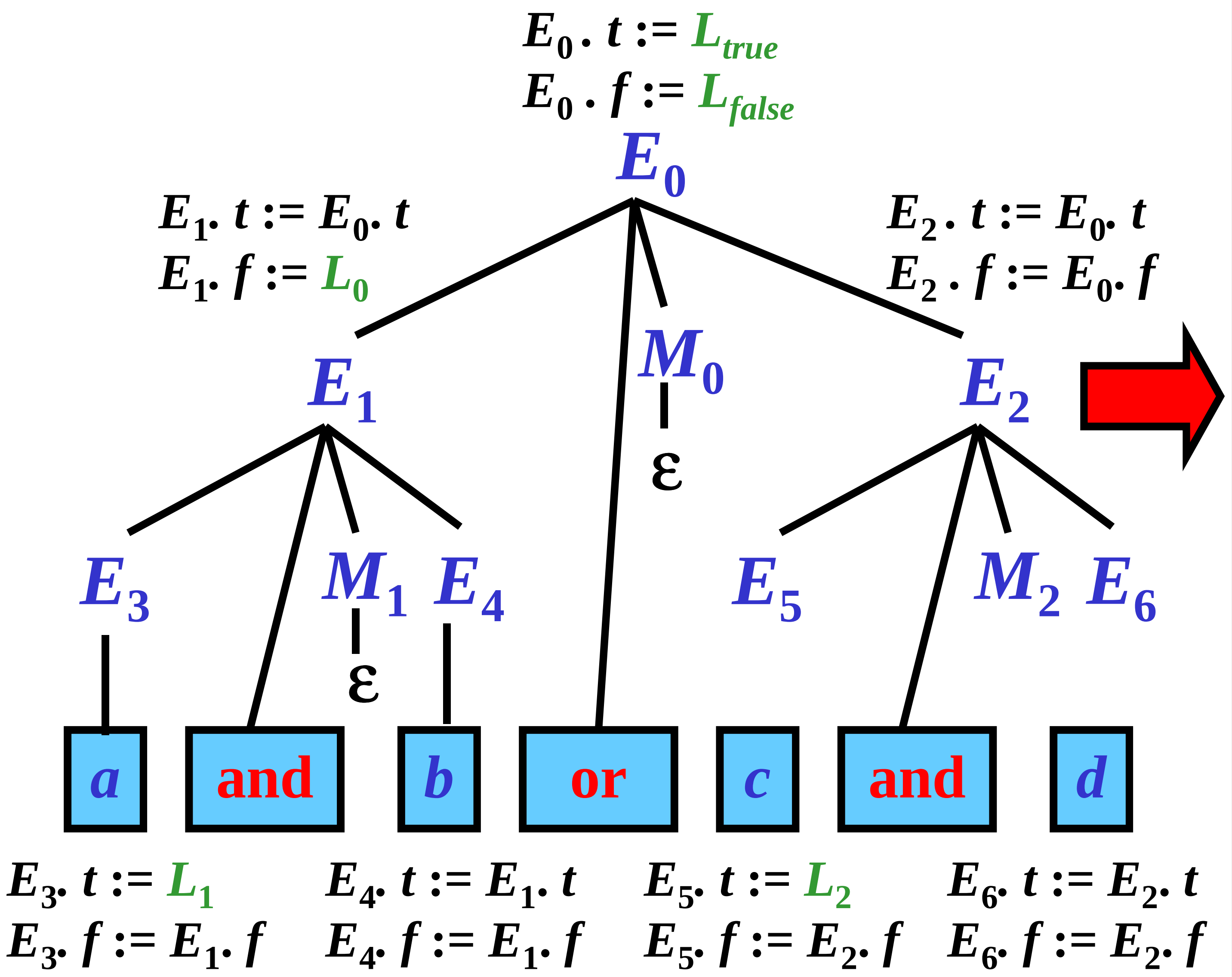
Example: *a* and *b* or *c* and *d*:



if ***a*** *goto* L_1
goto L_0
L_1:
if ***b*** *goto* L_{true}
goto L_0
L_0:

Short Evaluation: Direct Code Generation 5/5

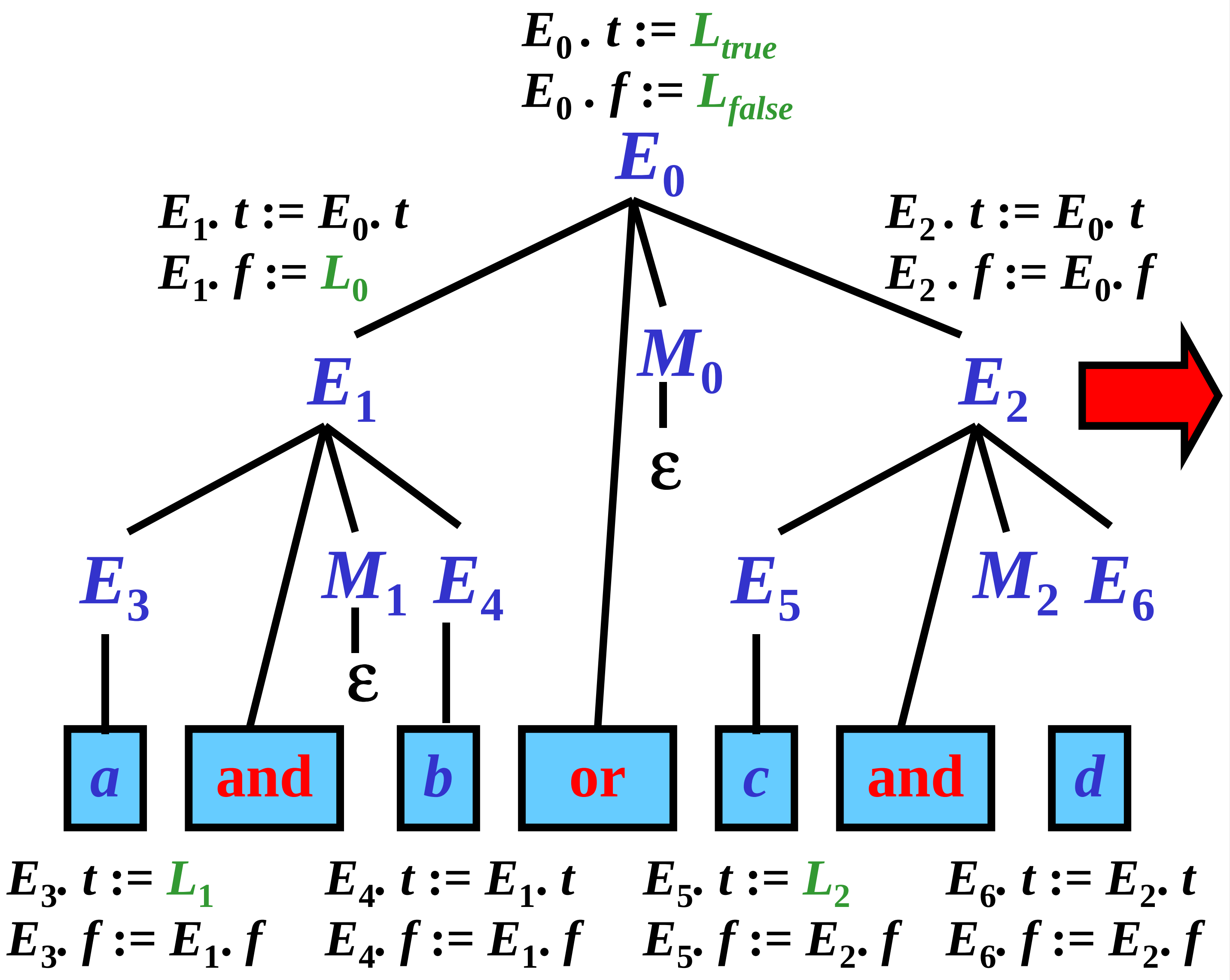
Example: *a* and *b* or *c* and *d*:



if ***a*** *goto* L_1
goto L_0
L_1:
if ***b*** *goto* L_{true}
goto L_0
L_0:

Short Evaluation: Direct Code Generation 5/5

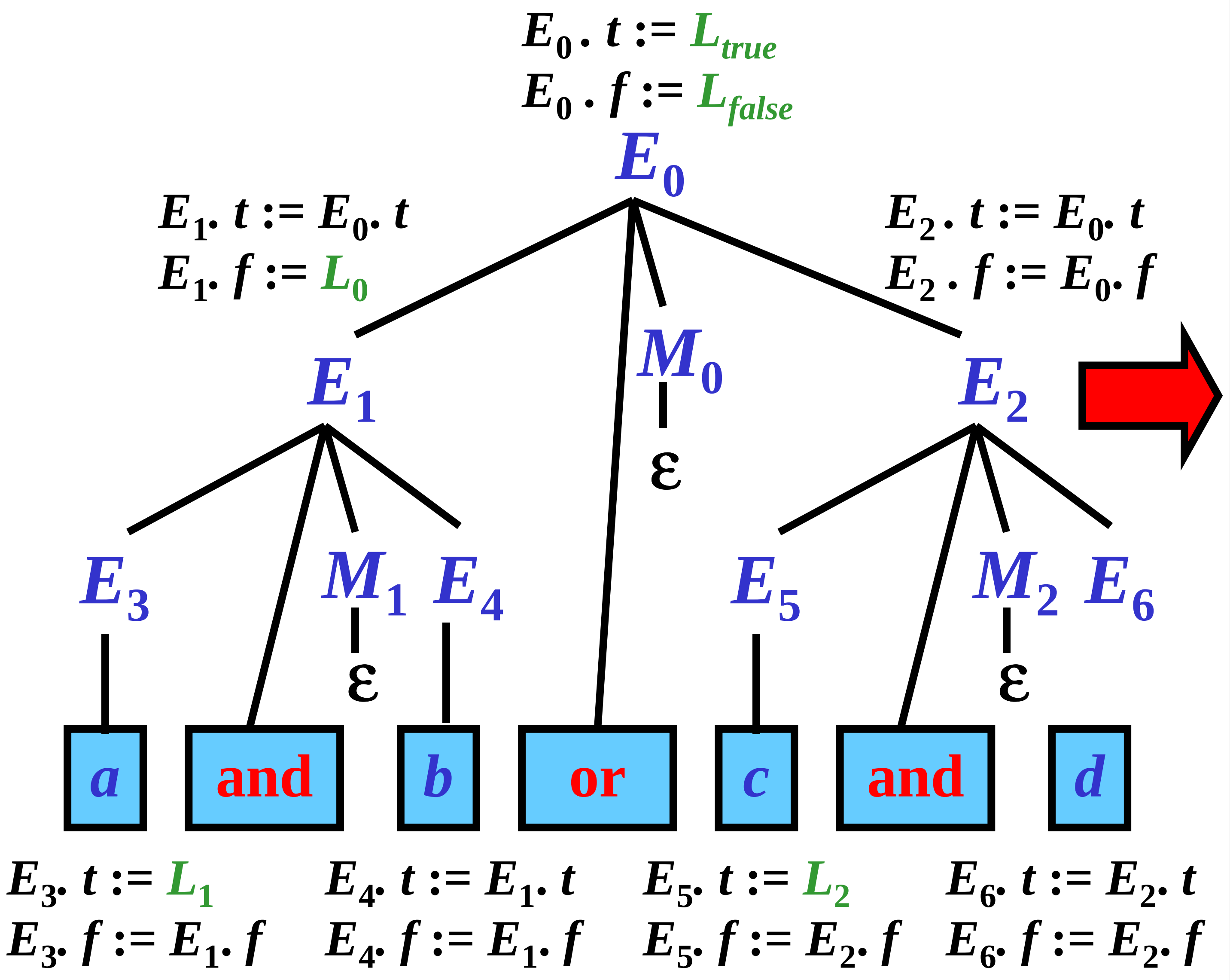
Example: ***a*** **and** ***b*** **or** ***c*** **and** ***d*****:**



if ***a*** *goto* L_1
goto L_0
L_1:
if ***b*** *goto* L_{true}
goto L_0
L_0:
if ***c*** *goto* L_2
goto L_{false}

Short Evaluation: Direct Code Generation 5/5

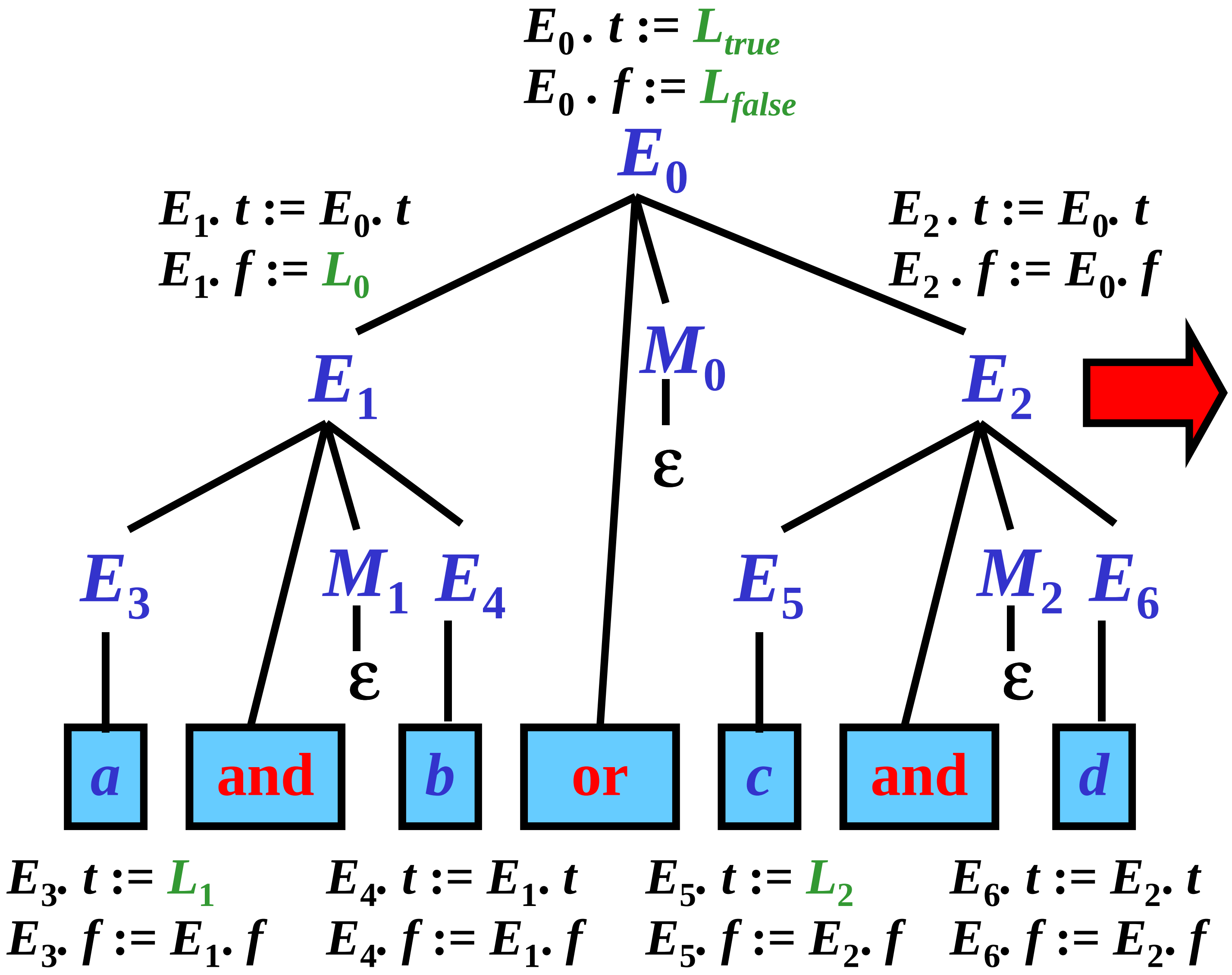
Example: *a* and *b* or *c* and *d*:



if ***a*** *goto* L_1
goto L_0
L_1:
if ***b*** *goto* L_{true}
goto L_0
L_0:
if ***c*** *goto* L_2
goto L_{false}
L_2:

Short Evaluation: Direct Code Generation 5/5

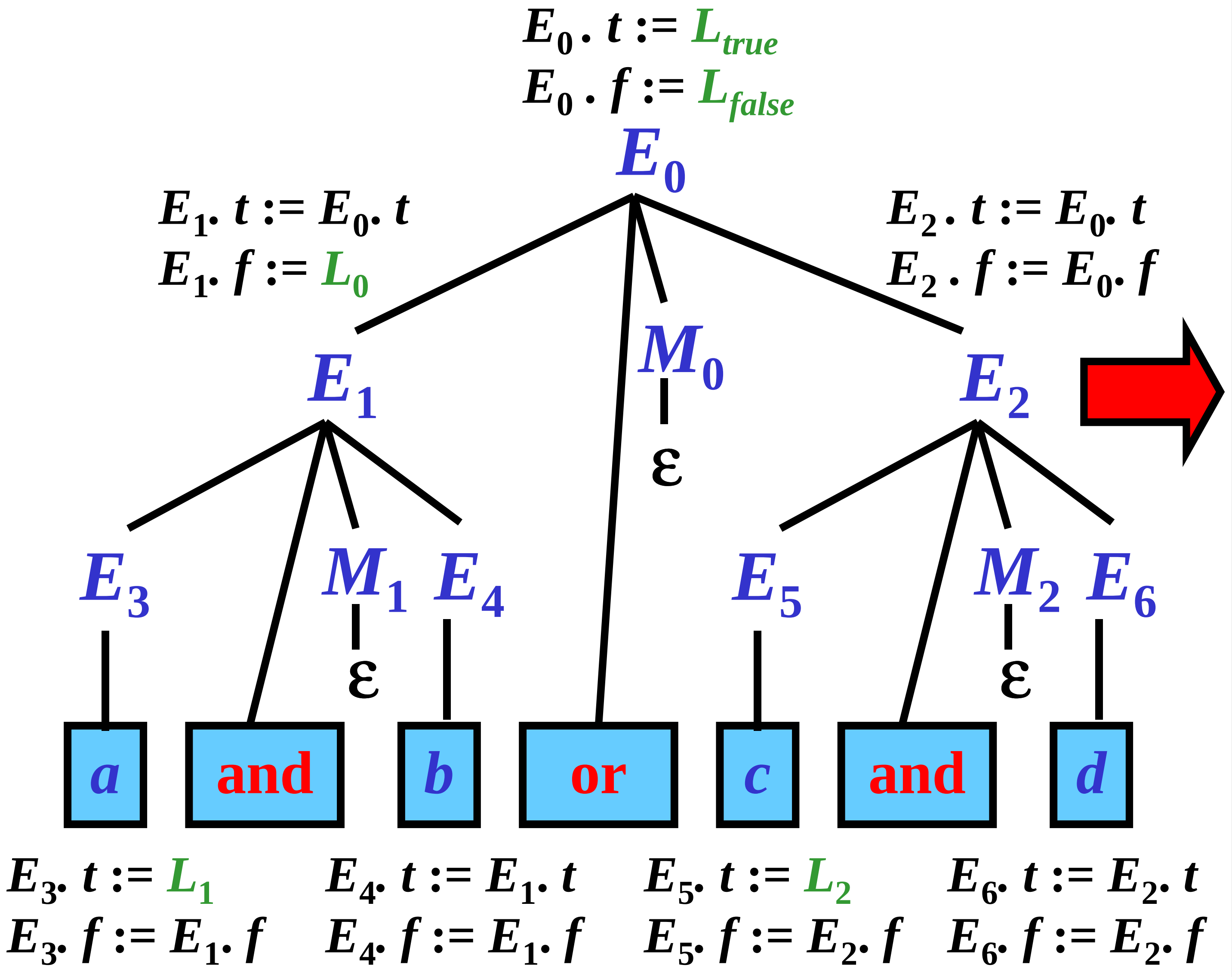
Example: ***a*** **and** ***b*** **or** ***c*** **and** ***d*****:**



if ***a*** *goto* L_1
goto L_0
L_1:
if ***b*** *goto* L_{true}
goto L_0
L_0:
if ***c*** *goto* L_2
goto L_{false}
L_2:
if ***d*** *goto* L_{true}
goto L_{false}

Short Evaluation: Direct Code Generation 5/5

Example: *a* and *b* or *c* and *d*:

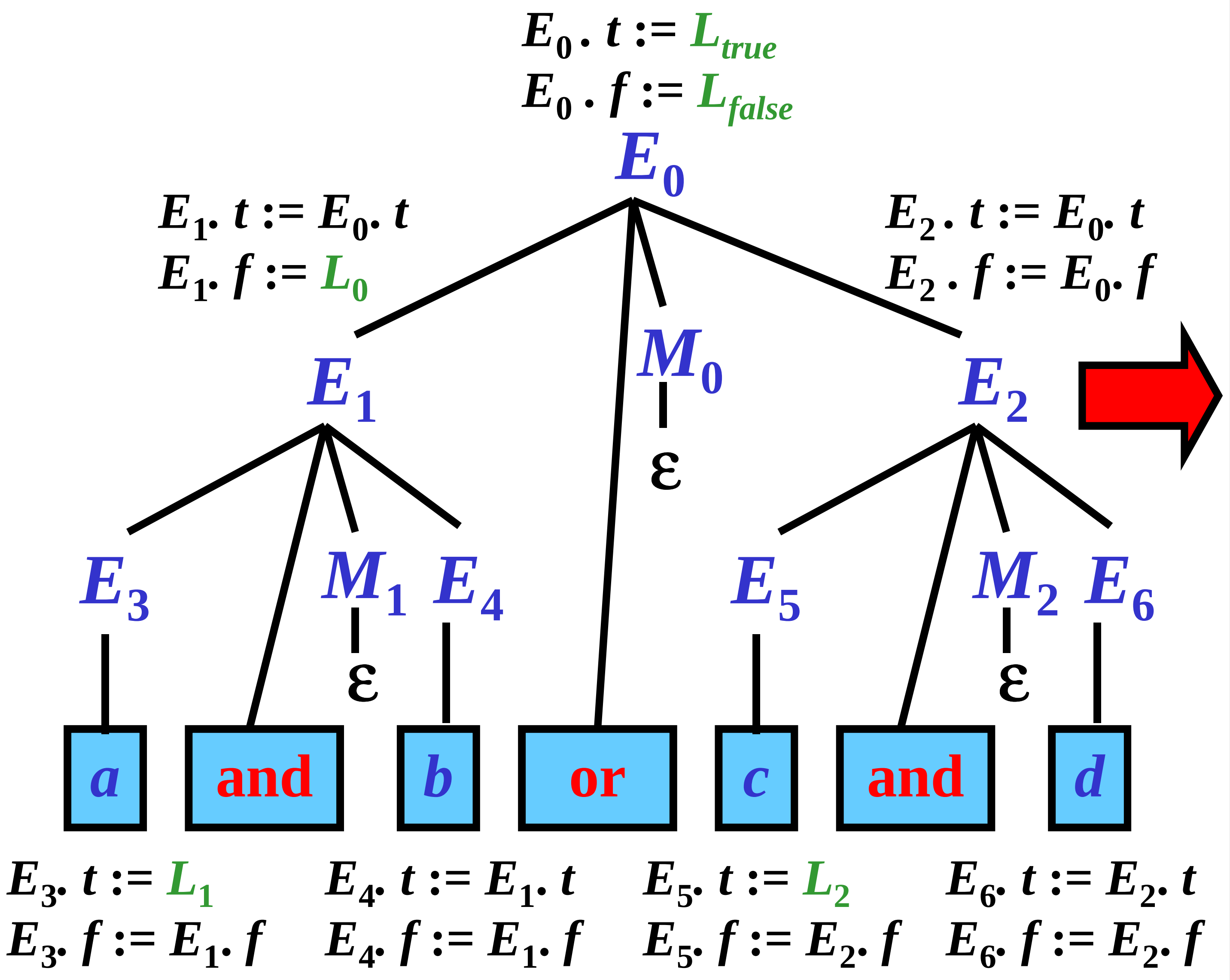


if ***a*** *goto* L_1
goto L_0
L_1:
if ***b*** *goto* L_{true}
goto L_0
L_0:
if ***c*** *goto* L_2
goto L_{false}
L_2:
if ***d*** *goto* L_{true}
goto L_{false}

L_{true}: …

Short Evaluation: Direct Code Generation 5/5

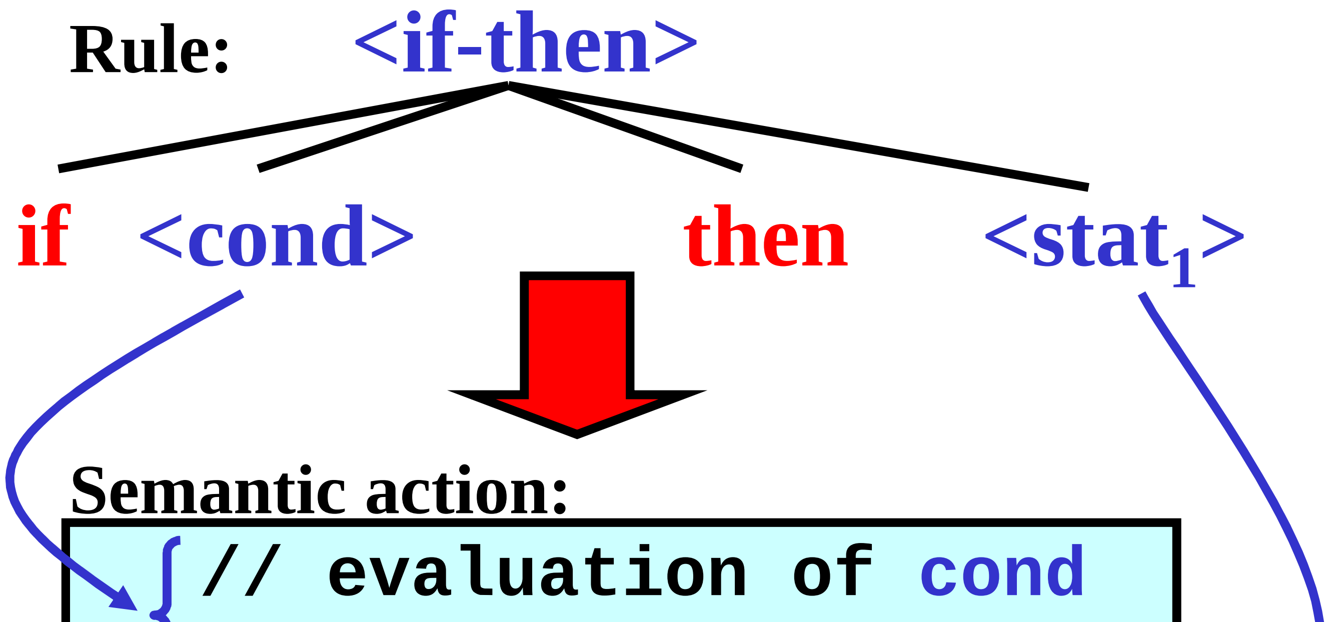
Example: *a* and *b* or *c* and *d*:



```
if a goto $L_1$
goto $L_0$
$L_1$:
if b goto $L_{true}$
goto $L_0$
$L_0$:
if c goto $L_2$
goto $L_{false}$
$L_2$:
if d goto $L_{true}$
goto $L_{false}$

$L_{true}$: …
$L_{false}$: …
```

Branching: If-Then



Semantic action:

```
// evaluation of cond
// to c.val
(not , c.val, , c.val)
(goto, c.val, , L1   )
 // code of stat1
(lab , L1   , ,      )
```

Branching: If-Then-Else

Rule: **<if-then-else>**

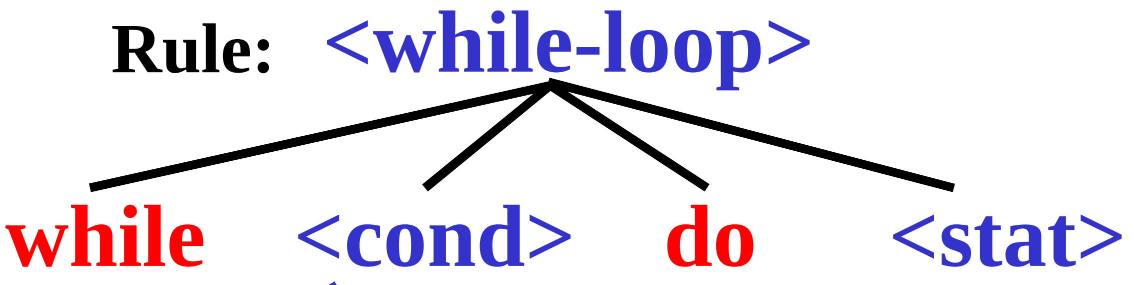
if <cond> then <stat$_1$> else <stat$_2$>

Semantic action:

```
// evaluation of cond
// to c.val
(not , c.val, , c.val)
(goto, c.val, , L1   )
 // code of stat1
(goto,       , , L2   )
(lab , L1    , ,      )
 // code of stat2
(lab , L2    , ,      )
```

While Loop

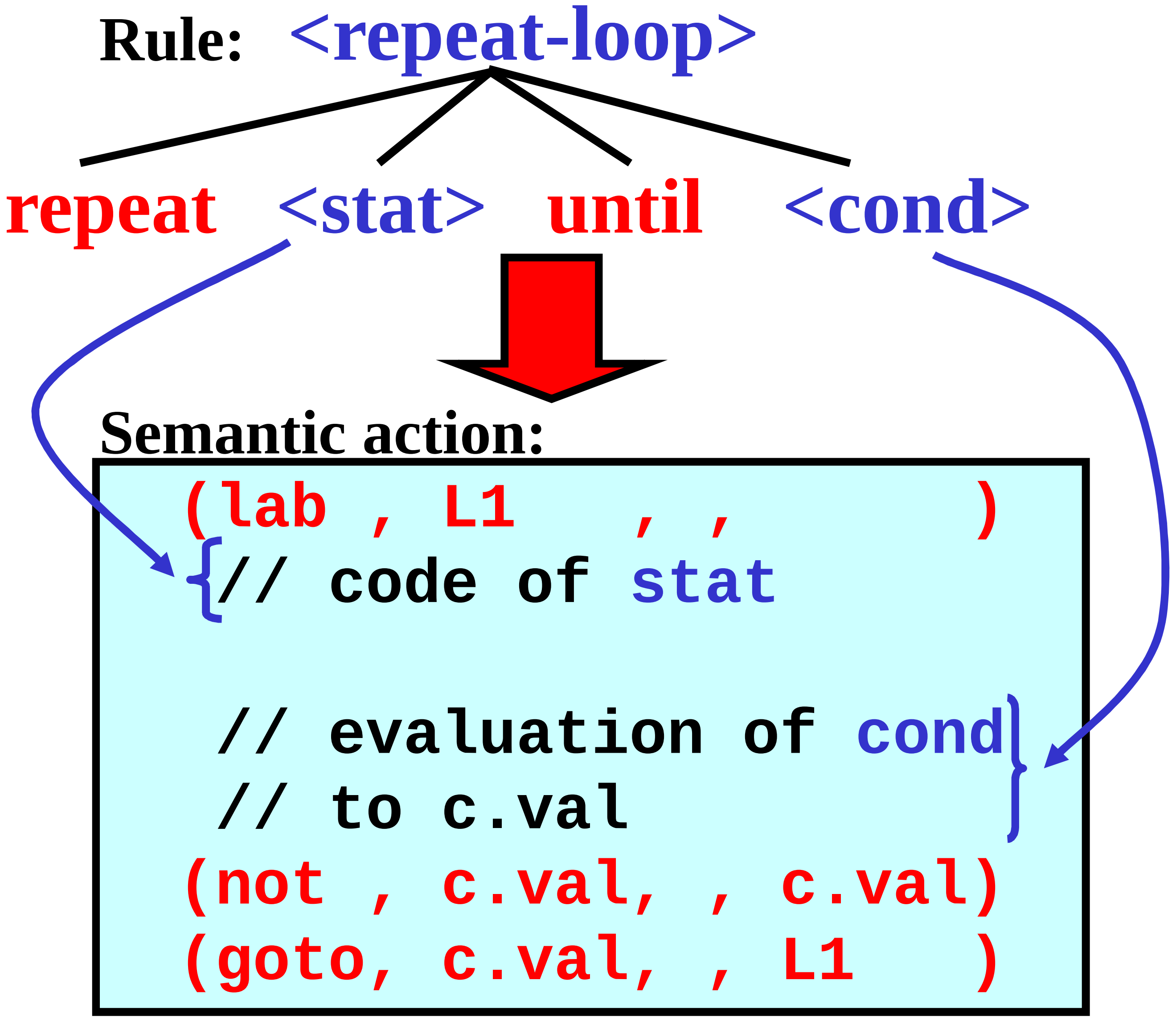
Rule:



Semantic action:

```
(lab , L1    , ,       )
// evaluation of cond
// to c.val
(not , c.val, , c.val)
(goto, c.val, , L2    )
 // code of stat
(goto,        , , L1    )
(lab ,  L2    , ,       )
```

Repeat Loop



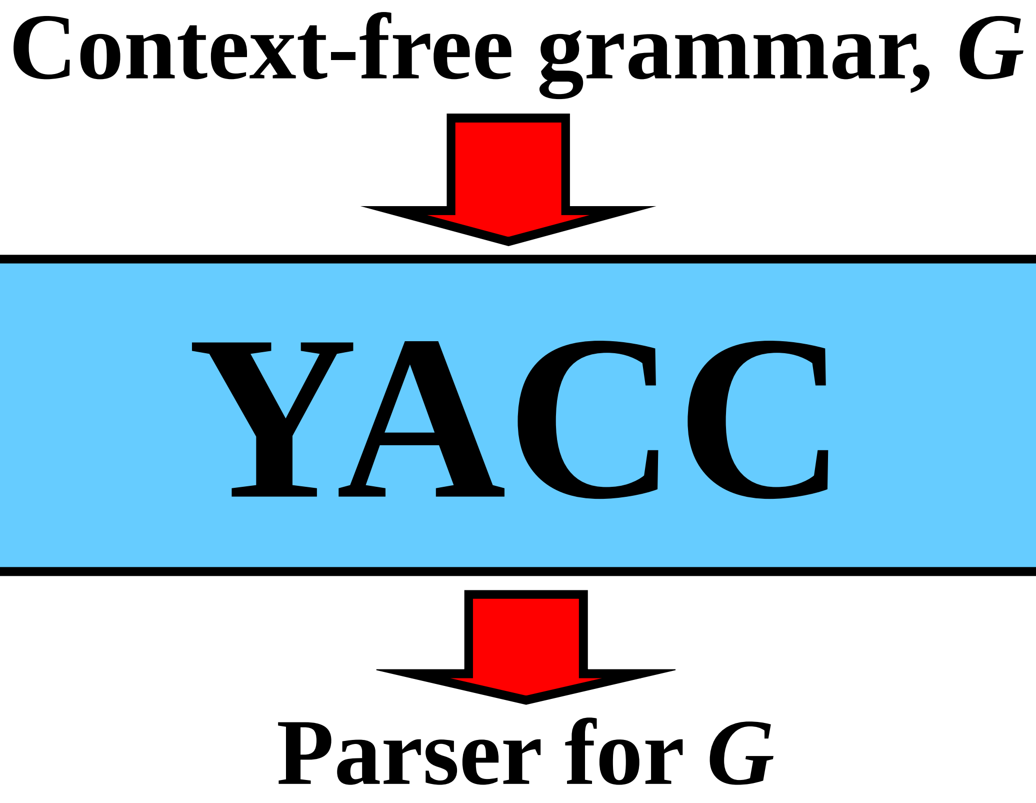
```
(lab , L1    , ,        )
// code of stat

// evaluation of cond
// to c.val
(not , c.val, , c.val)
(goto, c.val, , L1    )
```

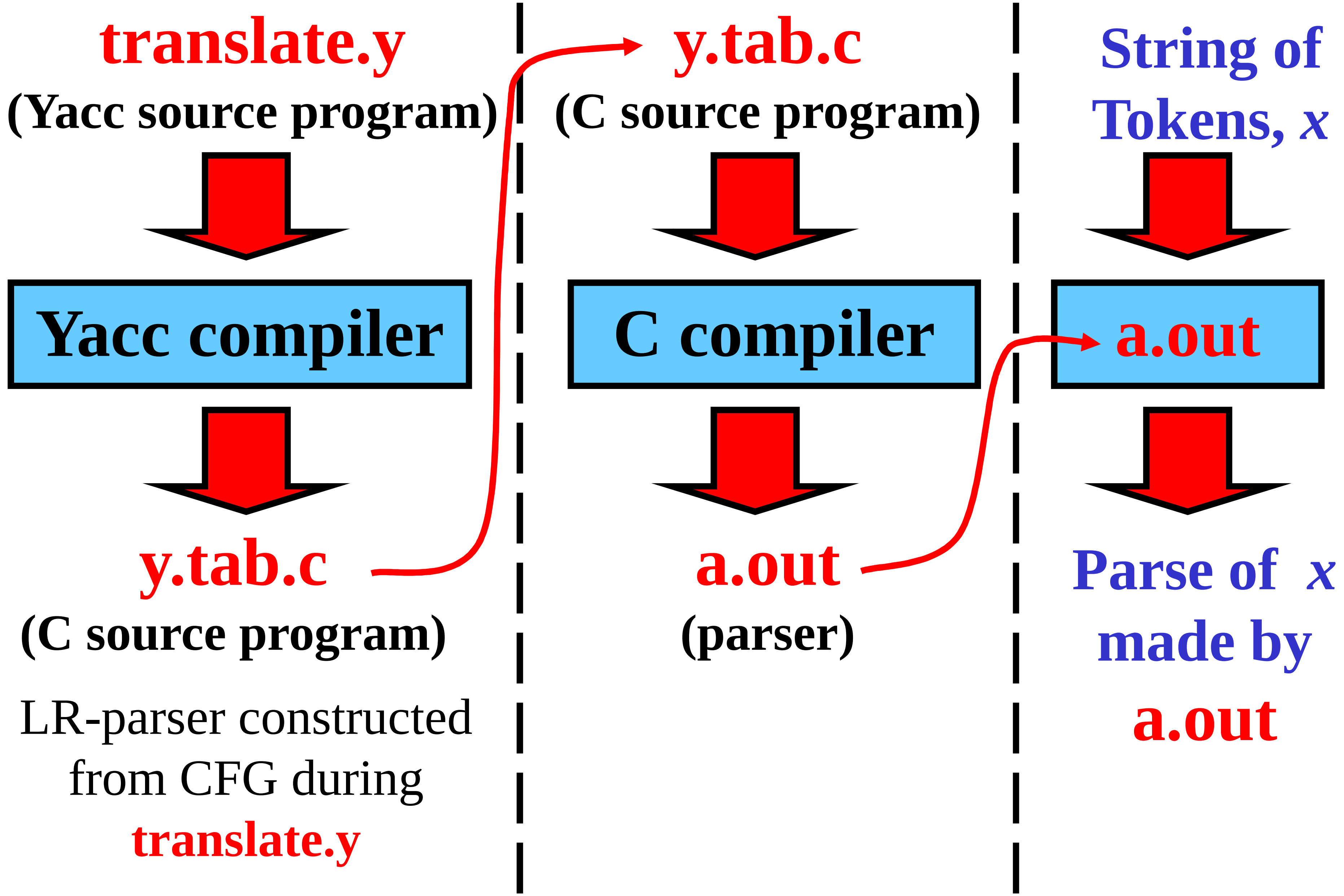
Yacc: Basic Idea

- Automatic construction of **parser** from **CFG**
- Yacc compiler × Yacc language
- *Yacc* from *Y*et *a*nother *c*ompiler *c*ompiler

Ilustrace:



Yacc: Phases of Compilation



LR-parser constructed from CFG during **translate.y**

Structure of Yacc Source Program

/* Section I: Declaration */

$d_1, d_2, \dots, d_i$

%% /* End of Section I*/

/* Section II: Translation rules */

$r_1, r_2, \dots, r_j$

%% /* End of Section II*/

/* Section III: Auxiliary procedures*/

$p_1, p_2, \dots, p_k$

Description of Grammar in Yacc

- **Nonterminals:** names (= strings)
- **Example:** `prog`, `stat`, `expr`, …

- **Terminals:** Characters in quotes or declared tokens
- **Example:** `'+'`, `'*'`, `'('`, `')'`, `ID`, `INTEGER`

- **Rules:** Set of *A*-rules $\{ A \rightarrow x_1, A \rightarrow x_2, \ldots A \rightarrow x_n \}$

  is written as

```
A : x1
  | x2
  …
  | xn
```

- **Example:**

```
expr : expr '+' expr
     | ID
```

- **Start Nonterminal:** A left side of the first rule.

Section I: Declaration

1) Declaration of tokens

```
%token TYPE_OF_TOKEN
```

2) Specification of asociativity & precedence in an ambigous grammar.

The same precedence $\longrightarrow$

Higher precedence

%left op_{i1}, op_{i2}, … ,op_{im}

%left op_{j1}, op_{j2}, … ,op_{jm}

…

$\underbrace{\texttt{\%right}}$ op_{k1}, op_{k2}, … ,op_{kp}

Associativity of the following operators

Example:

```
%token INTEGER
%token ID
%left '+'
%left '*'
```

Section II: Translation Rules

• Translation rules are in the form:

```
Rule    Semantic_Action
```

• `Semantic_Action` is a program routine that specifies what to do if `Rule` is used.

Special symbols for a rule, *r*:

$$ = attribute of *r*'s left-hand side

$*i* = attribute of the *i*-th symbols on *r*'s right-hand side

Example:

```
expr : expr '+' expr {$$ = $1 + $3}
     | expr '*' expr {$$ = $1 * $3}
     | '(' expr ')'  {$$ = $2}
     | INTEGER
     | ID
```

Section III: Auxiliary Procedures

- Auxiliary procedures used by translation rules

Note: If the Yacc-parser do not cooperate with a scanner (e.g. Lex), then there is **yylex()** implemented in this section.

Example:

```
int yylex() {
        /* Get the next token */
        &yylval = attribute;
        return TYPE_OF_TOKEN;
}
```

Complete Source Program in Yacc

```
%token INTEGER
%token ID
%left ‘+’
%left ‘*’

%%

expr : expr ‘+’ expr {$$ = $1 + $3}
     | expr ‘*’ expr {$$ = $1 * $3}
     | ‘(’ expr ‘)’  {$$ = $2}
     | INTEGER
     | ID

%%

int yylex () { … }
```