中间代码生成
(1. 表达式的翻译与控制流的翻译)

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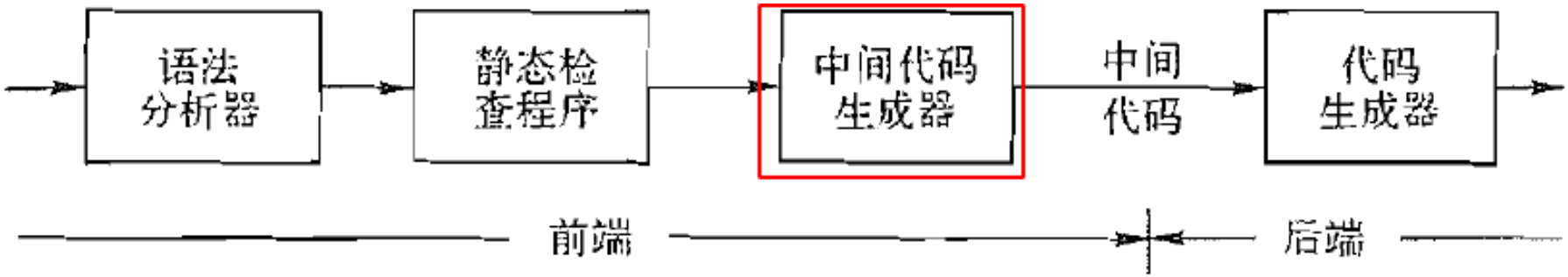
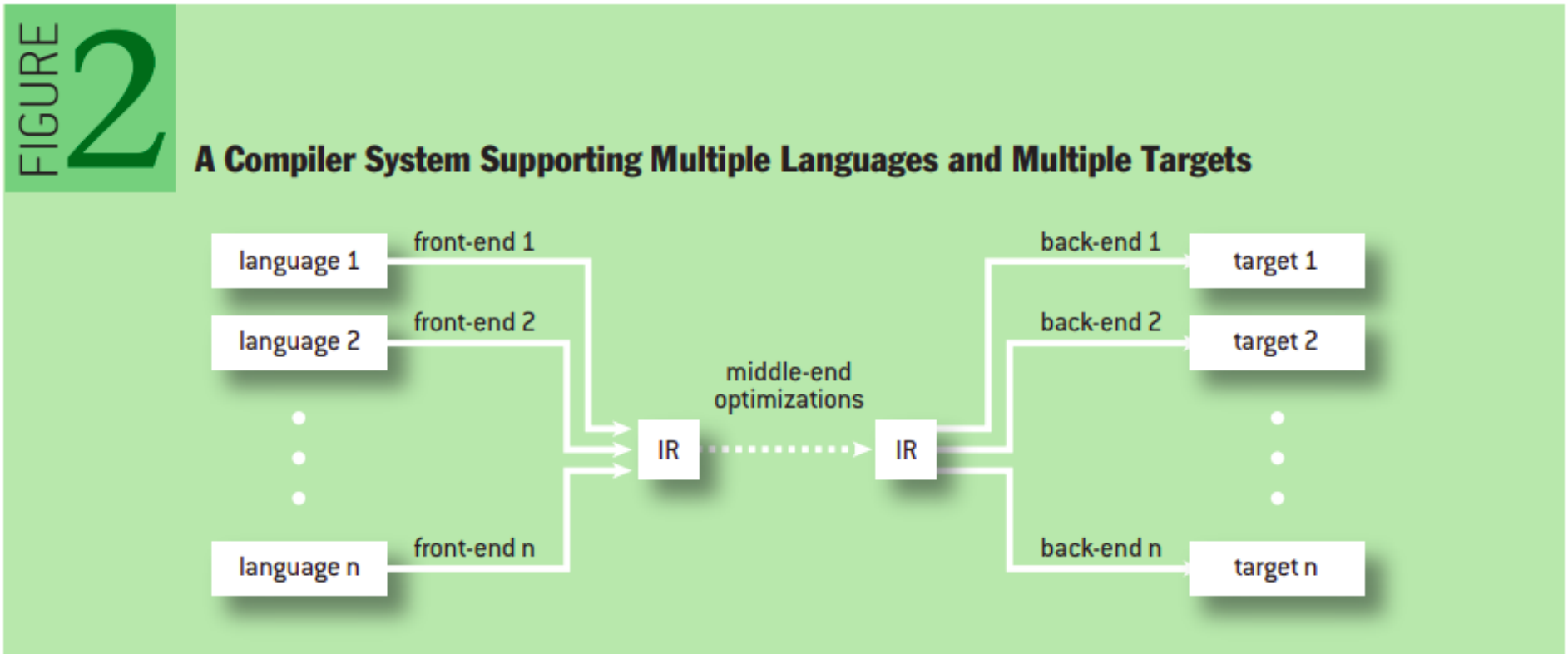
Intermediate Representation (IR)



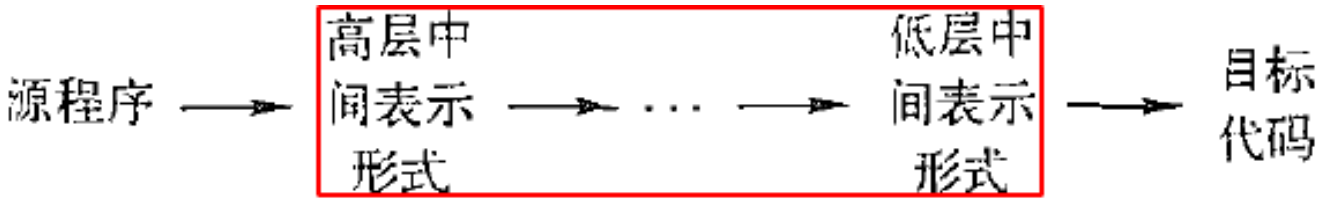


The Increasing Significance of Intermediate Representations in Compilers (Fred Chow; 2013)

LLVM 的核心就是它的 LLVM IR

(希望下一轮授课可以加入 LLVM IR 内容)

Intermediate Representation (IR)



精确: 不能丢失源程序的信息

独立: 不依赖特定的源语言与目标语言

(如, 没有复杂的寻址方式)

华为方舟编译器的 Maple IR 采用多层设计

Intermediate Representation (IR)

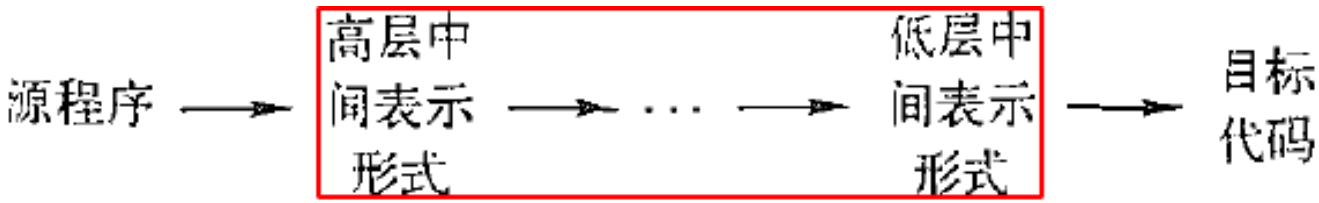


图 (抽象语法树)、**三地址代码**、C 语言

Definition (三地址代码 (Three-Address Code (TAC; 3AC)))

每个 TAC **指令**最多包含三个**地址**。

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地址: 源程序中的名字、常量、编译器生成的临时变量

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每个 TAC **指令**最多包含三个**地址**。

5 组 16 条**指令**格式 (x, y, z 为**地址**):

$$x = y \ \mathbf{op} \ z \qquad (1)$$

$$x = \mathbf{op} \ y \qquad (2)$$

$$x = y \qquad (3)$$

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$$x = y \ \mathbf{op} \ z \quad (1)$$

$$x = \mathbf{op} \ y \quad (2)$$

$$x = y \quad (3)$$

$$\mathbf{goto} \ L \quad (4)$$

$$\mathbf{if} \ x \ \mathbf{goto} \ L \quad (5)$$

$$\mathbf{if \ False} \ x \ \mathbf{goto} \ L \quad (6)$$

$$\mathbf{if} \ x \ \mathbf{relop} \ y \ \mathbf{goto} \ L \quad (7)$$

Definition (三地址代码 (Three-Address Code (TAC; 3AC)))

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5 组 16 条**指令**格式 (x, y, z 为**地址**):

$$\textbf{param}\ x \tag{8}$$

$$\textbf{call}\ p, n \tag{9}$$

$$y = \textbf{call}\ p, n \tag{10}$$

$$\textbf{return}\ y \tag{11}$$

```
param x1
param x2
...
param xn
call p, n
```

$p(x_1, x_2, \ldots, x_n)$

Definition (三地址代码 (Three-Address Code (TAC; 3AC)))

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$$x = y[i] \tag{12}$$
$$x[i] = y \tag{13}$$

距离位置 x/y 处 i 个内存单元

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$$x = y[i] \quad (12)$$

$$x[i] = y \quad (13)$$

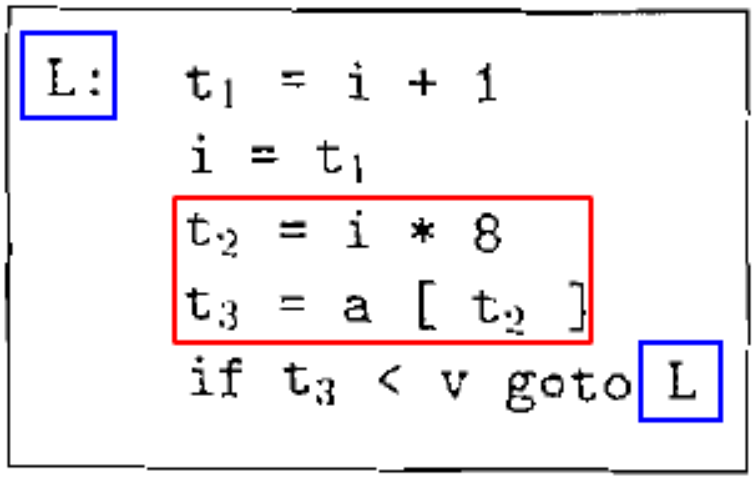
$$x = \&y \quad (14)$$

$$x = *y \quad (15)$$

$$*x = y \quad (16)$$

距离位置 x/y 处 i 个内存单元

```
do i = i + 1; while (a[i] < v);
```



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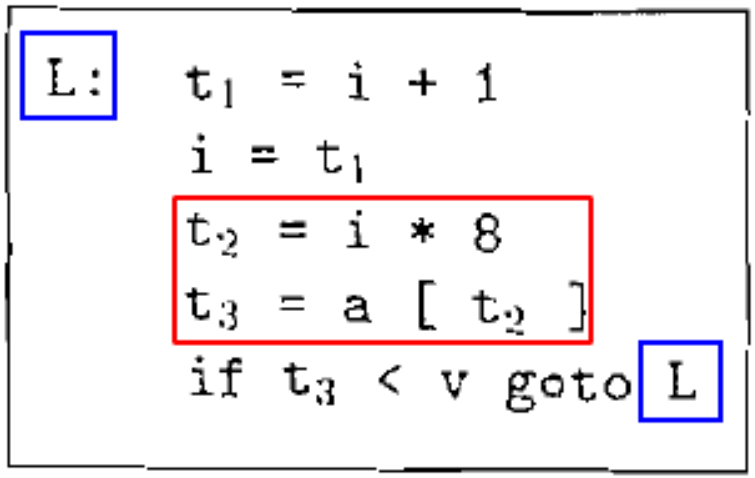

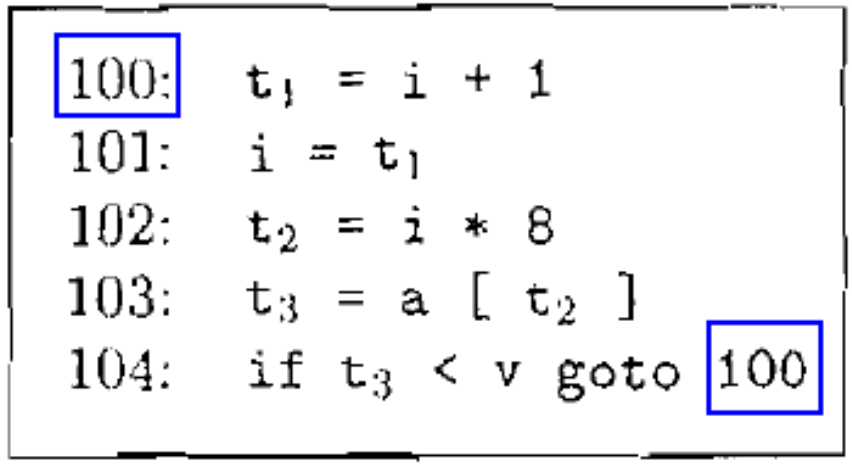

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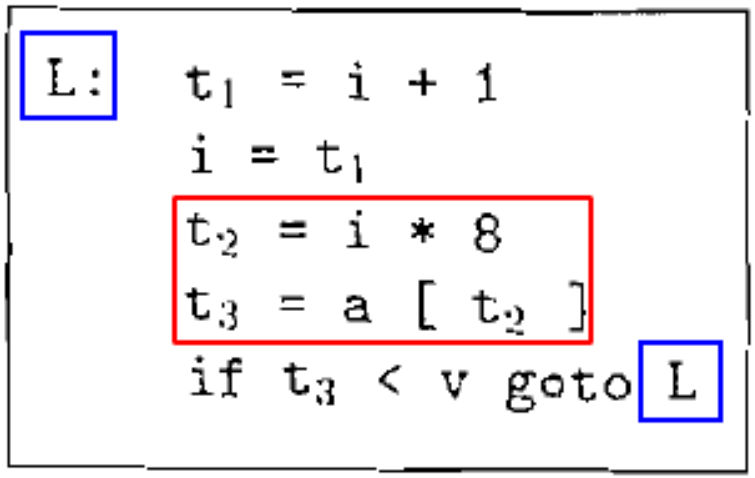

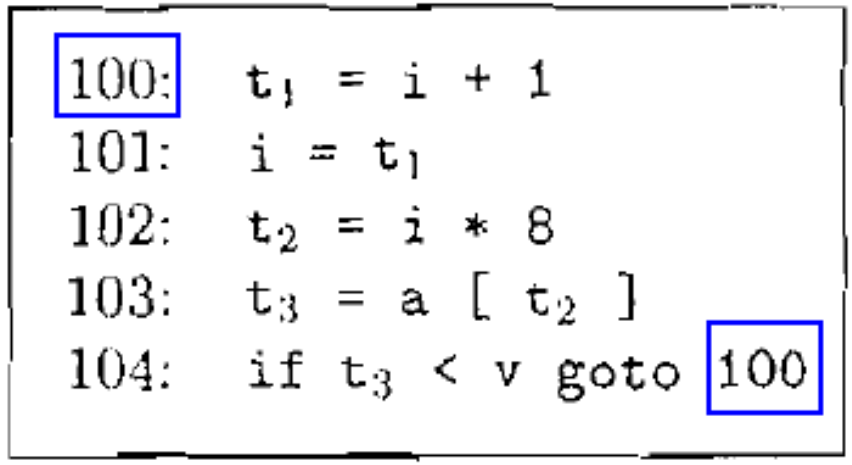

为 (某些) 控制语句生成**带有位置号**的中间代码时, 需要采用**回填技术**

三地址代码的四元式表示

Definition (四元式 (Quadruple))

一个四元式包含四个字段, 分别为 op、arg_1、arg_2 与 $result$。

三地址代码的四元式表示

Definition (四元式 (Quadruple))

一个四元式包含四个字段, 分别为 op、arg_1、arg_2 与 $result$。

$$a + a * (b - c) + (b - c) * d$$

```
t1 = minus c
t2 = b * t1
t3 = minus c
t4 = b * t3
t5 = t2 + t4
 a = t5
```

	op	arg_1	arg_2	result
0	minus	c		t_1
1	*	b	t_1	t_2
2	minus	c		t_3
3	*	b	t_3	t_4
4	+	t_2	t_4	t_5
5	=	t_5		a
		...		

$$x = y[i] \qquad =[\,] \quad y \quad i \quad x$$

$$x[i] = y \qquad [\,]= \quad i \quad y \quad x$$

$x = y[i]$	$=[\,]$	y	i	x
$x[i] = y$	$[\,]=$	i	y	x

$x = \&y$	$=\&$	y	x
$x = *y$	$=*$	y	x
$*x = y$	$*=$	y	x

表达式的中间代码翻译

产生式	语义规则
$S \rightarrow \mathbf{id} = E\ ;$	$S.code = E.code \ \|\|$ $gen(top.get(\mathbf{id}.lexeme)\ '='\ E.addr)$
$E \rightarrow E_1 + E_2$	$E.addr = \mathbf{new}\ Temp()$ $E.code = E_1.code \ \|\| \ E_2.code \ \|\|$ $gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr)$
$\mid\ - E_1$	$E.addr = \mathbf{new}\ Temp()$ $E.code = E_1.code \ \|\|$ $gen(E.addr\ '='\ '\mathbf{minus}'\ E_1.addr)$
$\mid\ (\ E_1\ )$	$E.addr = E_1.addr$ $E.code = E_1.code$
$\mid\ \mathbf{id}$	$E.addr = top.get(\mathbf{id}.lexeme)$ $E.code = ''$

符号表条目

综合属性 $E.code$ 与 $E.addr$

产生式	语义规则
$S \rightarrow \mathbf{id} = E\ ;$	$S.code = E.code \mid\mid gen(top.get(\mathbf{id}.lexeme)\ '='\ E.addr)$
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$\mid\ \mathbf{id}$	$E.addr = top.get(\mathbf{id}.lexeme)$ $E.code = ''$

符号表条目

$$t_1 = \text{minus } c$$
$$t_2 = b + t_1$$
$$a = t_2$$

$$a = b + -c$$

表达式的中间代码翻译 (增量式)

$S \rightarrow$	**id** = E ;	{ *gen*(*top.get*(**id**.*lexeme*) '=' E.*addr*); }
$E \rightarrow$	$E_1 + E_2$	{ E.*addr* = **new** *Temp*(); *gen*(E.*addr* '=' E_1.*addr* '+' E_2.*addr*); }
|	$- E_1$	{ E.*addr* = **new** *Temp*(); *gen*(E.*addr* '=' '**minus**' E_1.*addr*); }
|	(E_1)	{ E.*addr* = E_1.*addr*; }
|	**id**	{ E.*addr* = *top.get*(**id**.*lexeme*); }

综合属性 $E.addr$

假想一个全局指令缓冲区, 对 *gen* 的连续调用将生成一个指令序列

数组引用的中间代码翻译

声明：$\text{int } a[2][3]$

数组引用：$x = a[1][2];\ a[1][2] = x$

数组引用的中间代码翻译

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数组引用：$x = a[1][2];\ a[1][2] = x$

需要计算 $a[1][2]$ 的相对于**数组基地址** a 的**偏移地址**

int $a[2][3]$

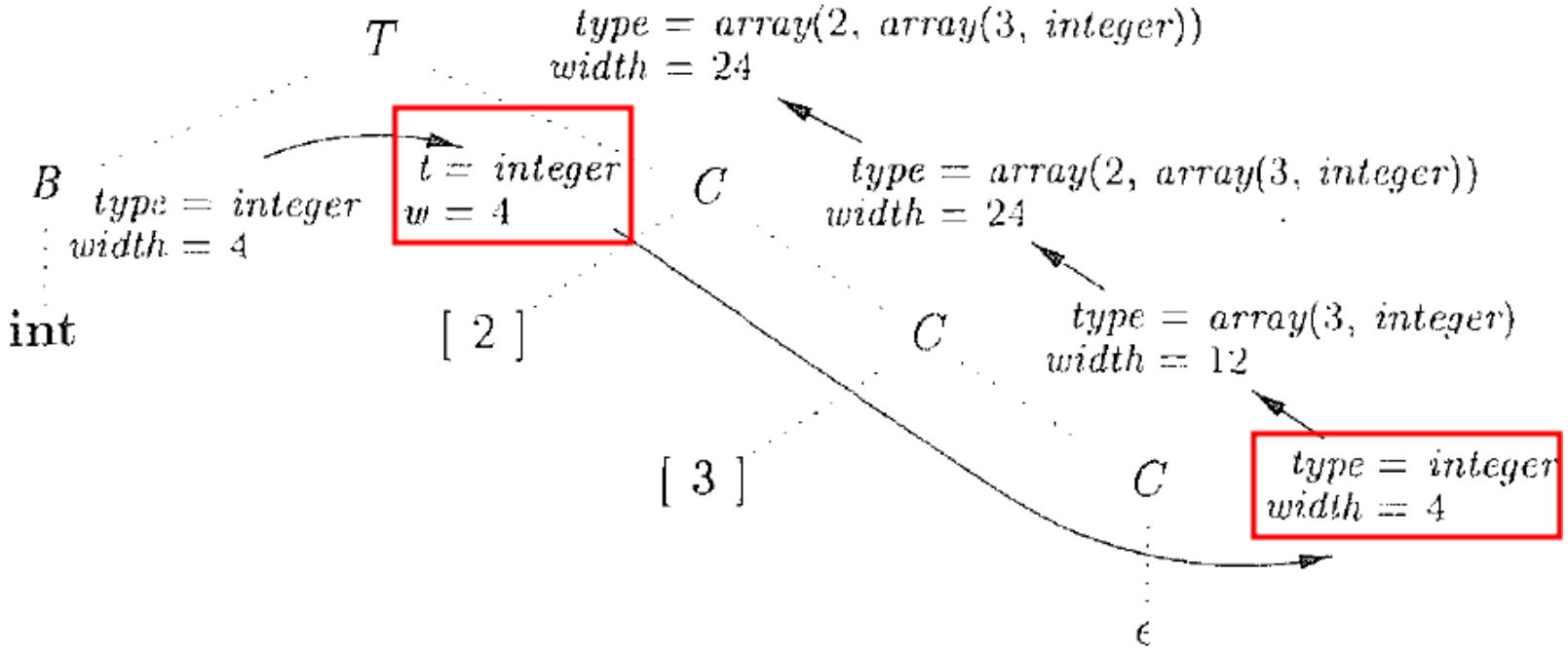


图 6-16　数组类型的语法制导翻译

数组类型声明

int $a[2][3]$

$$array(2, array(3, \text{integer}))$$

	类型	宽度
a	$array(2, array(3, \text{integer}))$	24
$a[i]$	$array(3, \text{integer})$	12
$a[i][j]$	integer	4

int $a[2][3]$

$$array(2, array(3, \text{integer}))$$

	类型	宽度
a	$array(2, array(3, \text{integer}))$	24
$a[i]$	$array(3, \text{integer})$	12
$a[i][j]$	integer	4

$$addr(a[1][2]) = base + 1 \times 12 + 2 \times 4$$

S	$\rightarrow$ **id** = E ;	{ $gen($ $top.get($**id**$.lexeme)$ $'='$ $E.addr)$; }
	| L = E ;	{ $gen(L.array.base$ $'['$ $L.addr$ $']'$ $'='$ $E.addr)$; }
E	$\rightarrow$ E_1 + E_2	{ $E.addr$ = **new** $Temp()$; $gen(E.addr$ $'='$ $E_1.addr$ $'+'$ $E_2.addr)$; }
	| **id**	{ $E.addr$ = $top.get($**id**$.lexeme)$; }
	| L	{ $E.addr$ = **new** $Temp()$; $gen(E.addr$ $'='$ $L.array.base$ $'['$ $L.addr$ $']')$; }
L	$\rightarrow$ **id** [E]	{ $L.array$ = $top.get($**id**$.lexeme)$; $L.type$ = $L.array.type.elem$; $L.addr$ = **new** $Temp()$; $gen(L.addr$ $'='$ $E.addr$ $'*'$ $L.type.width)$; }
	| L_1 [E]	{ $L.array$ = $L_1.array$; $L.type$ = $L_1.type.elem$; t = **new** $Temp()$; $L.addr$ = **new** $Temp()$; $gen(t$ $'='$ $E.addr$ $'*'$ $L.type.width)$; $gen(L.addr$ $'='$ $L_1.addr$ $'+'$ $t)$; }

int $a[2][3]$

综合属性 $L.array.base$：数组基地址（即，数组名）

$$
\begin{array}{lcll}
S & \rightarrow & \mathbf{id} = E\ ; & \{\ gen(\ top.get(\mathbf{id}.lexeme)\ '='\ E.addr);\ \} \\
 & | & L = E\ ; & \{\ gen(L.array.base\ '['\ L.addr\ ']'\ '='\ E.addr); \\
E & \rightarrow & E_1 + E_2 & \{\ E.addr = \mathbf{new}\ Temp\,();\ gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr);\ \} \\
 & | & \mathbf{id} & \{\ E.addr = top.get(\mathbf{id}.lexeme);\ \} \\
 & | & L & \{\ E.addr = \mathbf{new}\ Temp\,();\ gen(E.addr\ '='\ L.array.base\ '['\ L.addr\ ']');\ \}
\end{array}
$$

综合属性 $L.addr$：偏移地址

综合属性 $L.array$：数组名 id对应的符号表条目

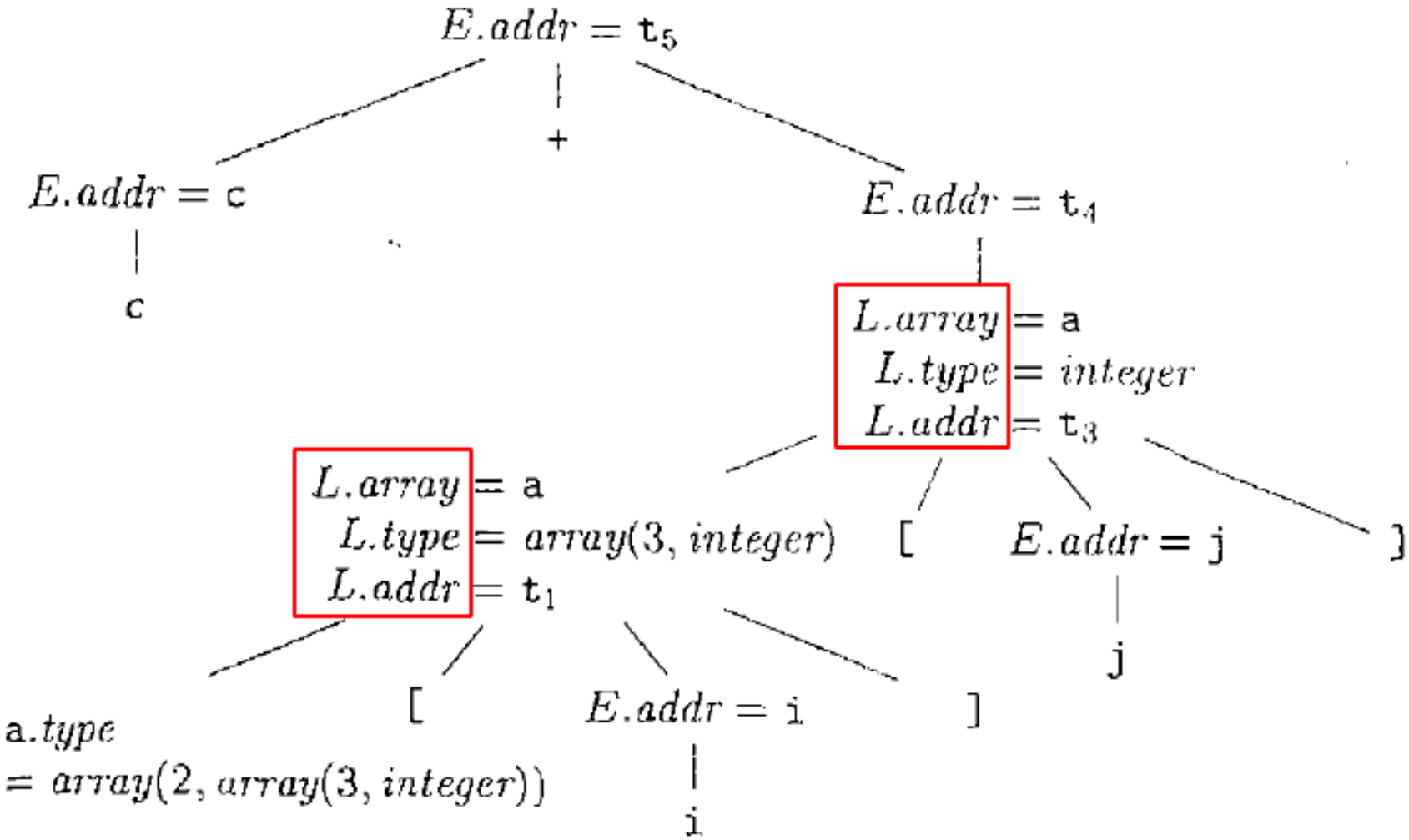
$$
\begin{aligned}
L \rightarrow\ & \mathbf{id}\ [\ E\ ] \quad \{\ L.array = top.get(\mathbf{id}.lexeme);\\
& \quad L.type = L.array.type.elem;\\
& \quad L.addr = \mathbf{new}\ Temp\,();\\
& \quad gen(L.addr\ '='\ E.addr\ '*'\ L.type.width);\ \}\\
\mid\ & L_1\ [\ E\ ] \quad \{\ L.array = L_1.array;\\
& \quad L.type = L_1.type.elem;\\
& \quad t = \mathbf{new}\ Temp\,();\\
& \quad L.addr = \mathbf{new}\ Temp\,();\\
& \quad gen(t\ '='\ E.addr\ '*'\ L.type.width);\\
& \quad gen(L.addr\ '='\ L_1.addr\ '+'\ t);\ \}
\end{aligned}
$$

综合属性 $L.type$：(当前) 元素类型

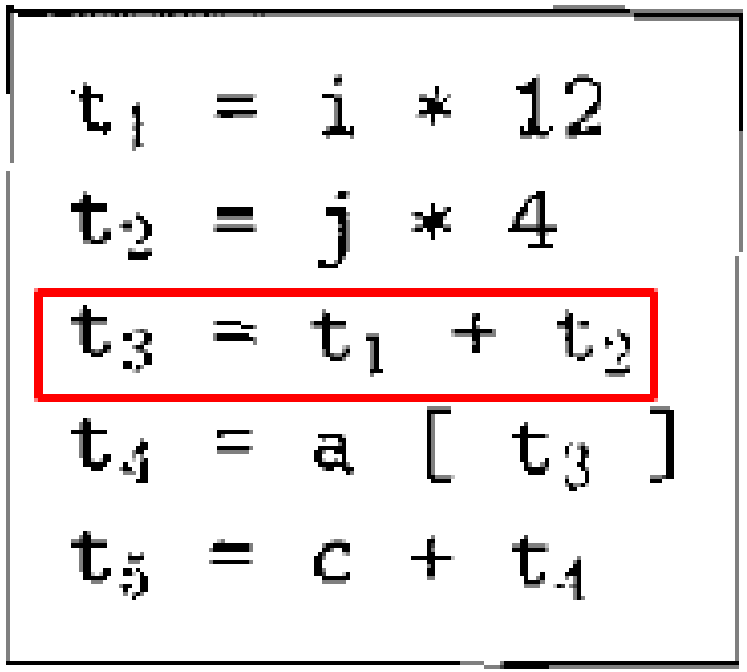
$$
\begin{aligned}
L \rightarrow\ & \mathbf{id}\ [\ E\ ] \quad \{\ L.array = top.get(\mathbf{id}.lexeme);\\
& \quad L.type = L.array.type.elem;\\
& \quad L.addr = \mathbf{new}\ Temp\,();\\
& \quad gen(L.addr\ '='\ E.addr\ '*'\ L.type.width);\ \}\\
\\
|\ \ & L_1\ [\ E\ ] \quad \{\ L.array = L_1.array;\\
& \quad L.type = L_1.type.elem;\\
& \quad t = \mathbf{new}\ Temp\,();\\
& \quad L.addr = \mathbf{new}\ Temp\,();\\
& \quad gen(t\ '='\ E.addr\ '*'\ L.type.width);\\
& \quad gen(L.addr\ '='\ L_1.addr\ '+'\ t);\ \}
\end{aligned}
$$

综合属性 $L.addr$：(当前) 偏移地址

$$
\begin{aligned}
L \rightarrow\ & \mathbf{id}\ [\ E\ ] \quad \{\ L.array = top.get(\mathbf{id}.lexeme);\\
& \quad L.type = L.array.type.elem;\\
& \quad L.addr = \mathbf{new}\ Temp\,();\\
& \quad gen(L.addr\ '='\ E.addr\ '*'\ L.type.width);\ \}\\
\mid\ & L_1\ [\ E\ ] \quad \{\ L.array = L_1.array;\\
& \quad L.type = L_1.type.elem;\\
& \quad t = \mathbf{new}\ Temp\,();\\
& \quad L.addr = \mathbf{new}\ Temp\,();\\
& \quad gen(t\ '='\ E.addr\ '*'\ L.type.width);\\
& \quad gen(L.addr\ '='\ L_1.addr\ '+'\ t);\ \}
\end{aligned}
$$


E.addr = t5
+
E.addr = c
c
E.addr = t4
L.array = a
L.type = integer
L.addr = t3
L.array = a
L.type = array(3, integer)
L.addr = t1
[
E.addr = j
]
j
a.type
= array(2, array(3, integer))
[
E.addr = i
]
i

$c + a[2][3]$



$c + a[2][3]$

控制流语句与布尔表达式的中间代码翻译

$$S \rightarrow \textbf{if}\ (B)\ S_1$$

$$S \rightarrow \textbf{if}\ (B)\ S_1\ \textbf{else}\ S_2$$

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

布尔表达式的作用：布尔值 *vs.* 控制流跳转

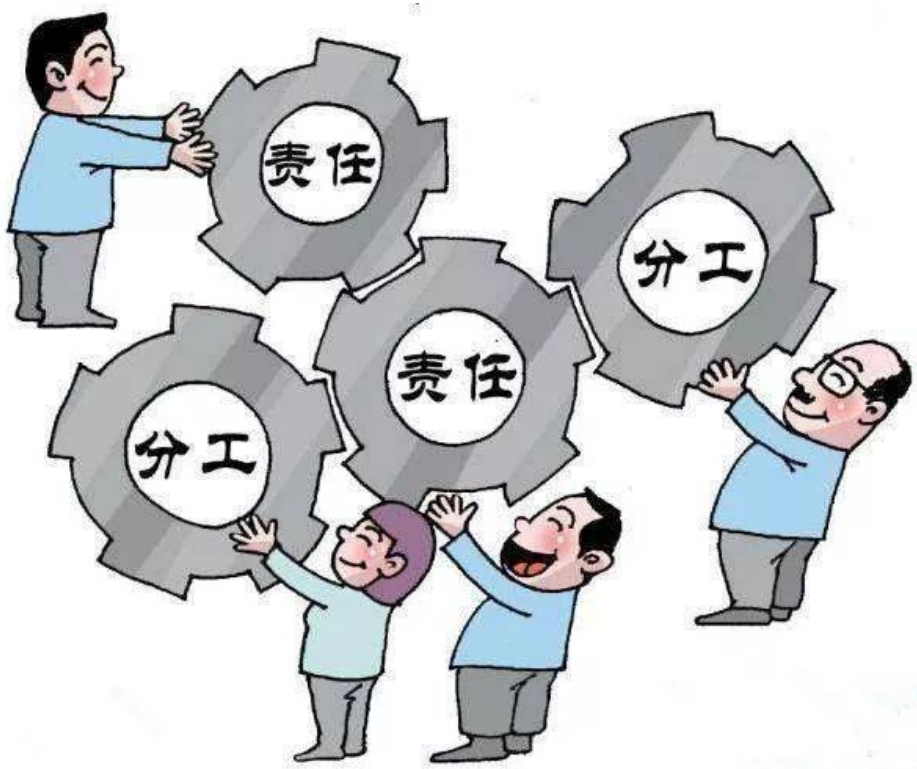
$S \rightarrow$ **id** $=E$; | **if** (E) S | **while** (E) S | $S\ S$

$E \rightarrow E \mid\mid E \mid E \&\& E \mid E$ **rel** $E \mid E + E \mid (E) \mid$ **id** | **true** | **false**

我们先关注“控制流跳转”

控制流语句与布尔表达式的中间代码翻译

分工明确　　各司其职



产生式	语义规则
$P \rightarrow S$	$S.next = newlabel()$ $P.code = S.code \mid\mid label(S.next)$
$S \rightarrow$ **assign**	$S.code =$ **assign**$.code$
$S \rightarrow$ **if** (B) S_1	$B.true = newlabel()$ $B.false = S_1.next = S.next$ $S.code = B.code \mid\mid label(B.true) \mid\mid S_1.code$
$S \rightarrow$ **if** (B) S_1 **else** S_2	$B.true = newlabel()$ $B.false = newlabel()$ $S_1.next = S_2.next = S.next$ $S.code = B.code$ $\mid\mid label(B.true) \mid\mid S_1.code$ $\mid\mid gen('\texttt{goto}'\ S.next)$ $\mid\mid label(B.false) \mid\mid S_2.code$
$S \rightarrow$ **while** (B) S_1	$begin = newlabel()$ $B.true = newlabel()$ $B.false = S.next$ $S_1.next = begin$ $S.code = label(begin) \mid\mid B.code$ $\mid\mid label(B.true) \mid\mid S_1.code$ $\mid\mid gen('\texttt{goto}'\ begin)$
$S \rightarrow S_1\ S_2$	$S_1.next = newlabel()$ $S_2.next = S.next$ $S.code = S_1.code \mid\mid label(S_1.next) \mid\mid S_2.code$

继承属性 $S.next$

$$P \rightarrow S \qquad \left| \begin{array}{lcl} S.next & = & newlabel() \\ P.code & = & S.code \,||\, label(S.next) \end{array} \right.$$

$S.next$ 为语句 S 指明了“跳出” S 的目标

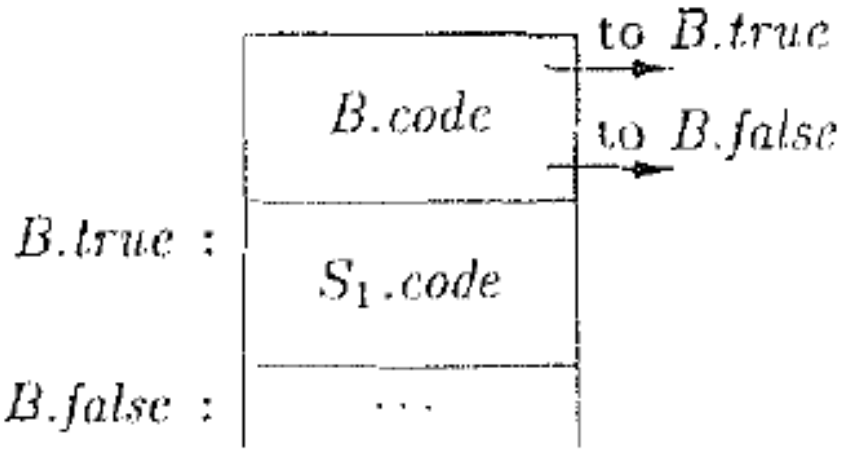
$$S \rightarrow \textbf{assign} \quad \Big| \quad S.code = \textbf{assign}.code$$

代表了表达式的翻译, 包括数组引用

$$S \rightarrow \textbf{if}\ (\ B\ )\ S_1 \quad \left| \begin{array}{l} B.true = newlabel() \\ B.false = S_1.next = S.next \\ S.code = B.code \,||\, label(B.true) \,||\, S_1.code \end{array} \right.$$

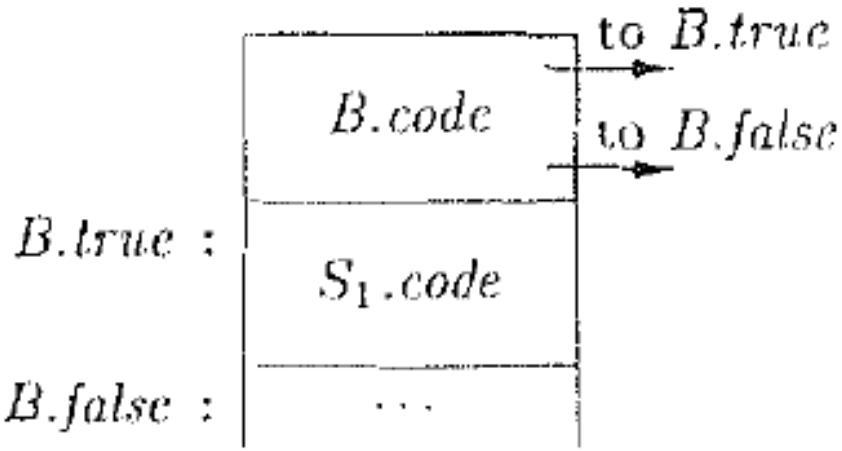
$$S \rightarrow \textbf{if}\ (\ B\ )\ S_1$$

$$\begin{array}{l} B.true = newlabel() \\ B.false = S_1.next = S.next \\ S.code = B.code \,||\, label(B.true) \,||\, S_1.code \end{array}$$



$S \rightarrow \textbf{if}\ (\ B\ )\ S_1$

$$
\begin{aligned}
B.true &= newlabel() \\
B.false &= S_1.next = S.next \\
S.code &= B.code \,||\, label(B.true) \,||\, S_1.code
\end{aligned}
$$




```
if (true)
  if (false) assign
```

$S \rightarrow \textbf{if}\ (\ B\ )\ S_1$

$B.true = newlabel()$
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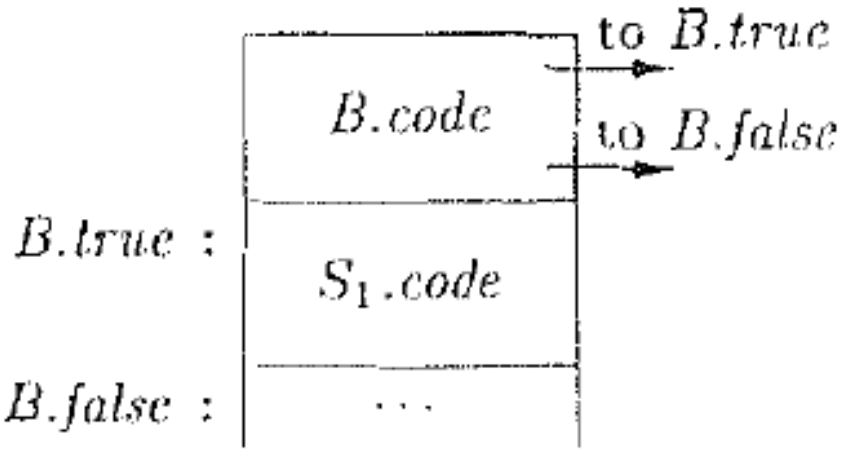


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$P \rightarrow S$

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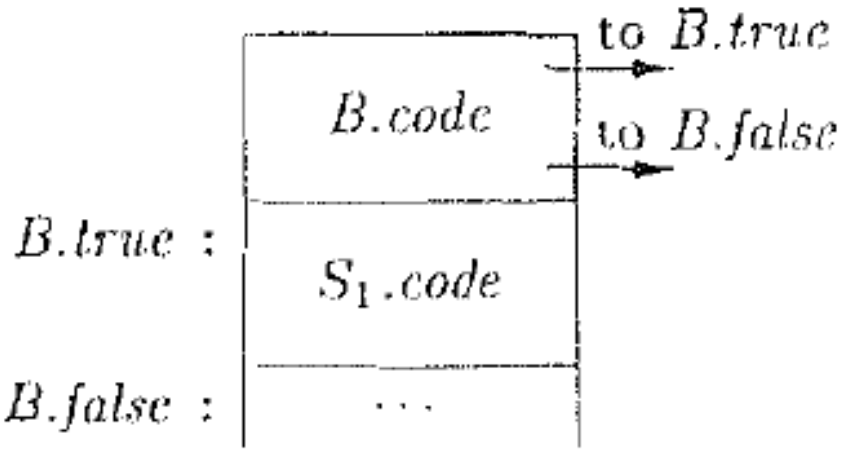
$B.false = S_1.next = S.next$
$S.code = B.code \,||\, label(B.true) \,||\, S_1.code$




```
if (true)
  if (false) assign
```

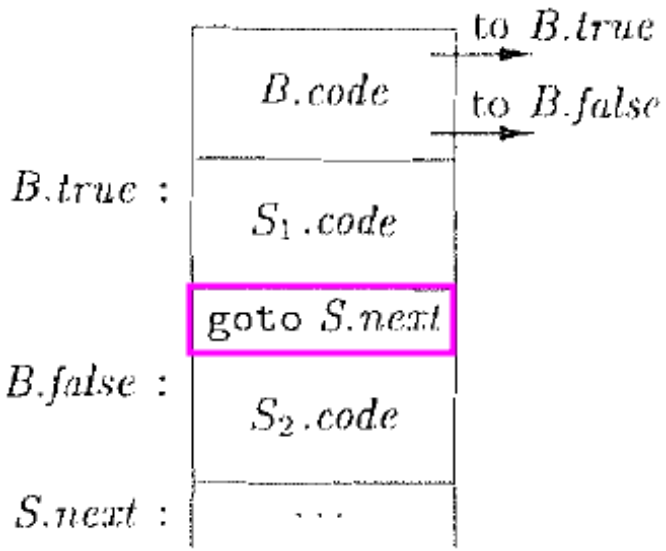
$P \rightarrow S$

$B \rightarrow \textbf{true}$ | $B.code = gen('\texttt{goto}'\ B.true)$

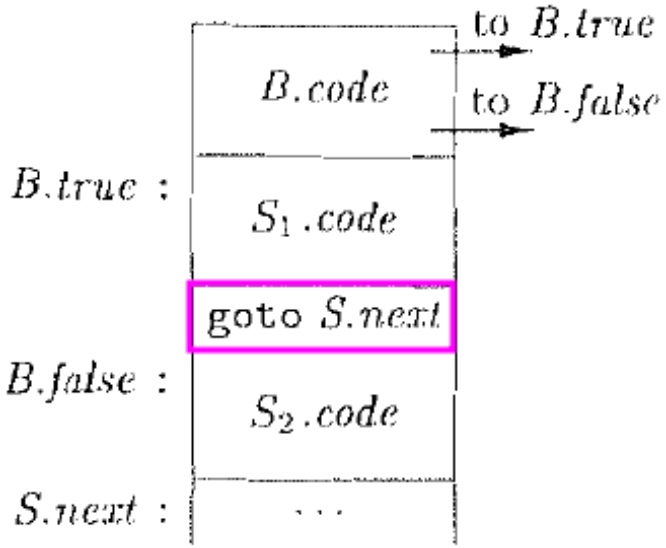
$B \rightarrow \textbf{false}$ | $B.code = gen('\texttt{goto}'\ B.false)$

$$
\begin{array}{lll}
S \rightarrow \textbf{if}\ (\ B\ )\ S_1\ \textbf{else}\ S_2 & B.true = newlabel() \\
& B.false = newlabel() \\
& S_1.next = S_2.next = S.next \\
& S.code = B.code \\
& \quad || \ label(B.true) \ || \ S_1.code \\
& \quad || \ gen(\text{'goto'}\ S.next) \\
& \quad || \ label(B.false) \ || \ S_2.code
\end{array}
$$

$S \rightarrow \textbf{if}\ (\ B\ )\ S_1\ \textbf{else}\ S_2$	$B.true = newlabel()$ $B.false = newlabel()$ $S_1.next = S_2.next = S.next$ $S.code = B.code$ $\quad \| \| label(B.true) \| \| S_1.code$ $\quad \| \| gen('\texttt{goto}'\ S.next)$ $\quad \| \| label(B.false) \| \| S_2.code$



$S \rightarrow \textbf{if}\ (\ B\ )\ S_1\ \textbf{else}\ S_2$	$B.true = newlabel()$ $B.false = newlabel()$ $S_1.next = S_2.next = S.next$ $S.code = B.code$ $\quad \| \| label(B.true) \| \| S_1.code$ $\quad \| \| gen('\texttt{goto}'\ S.next)$ $\quad \| \| label(B.false) \| \| S_2.code$



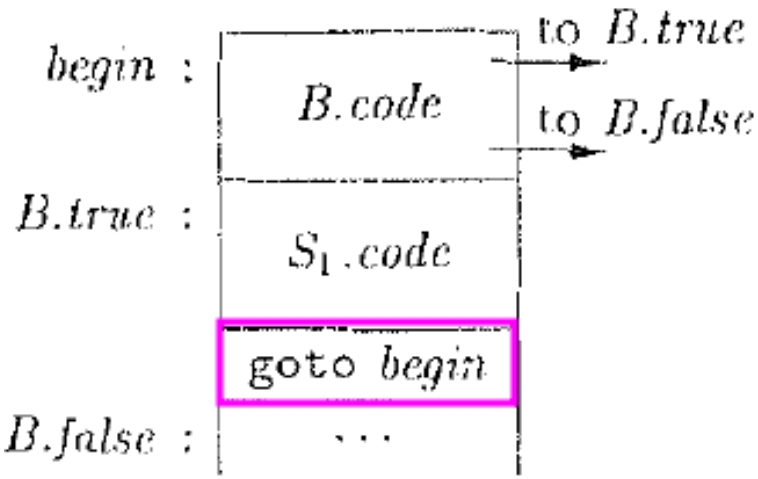

```
if (true)
  if (true) assign else assign
else
  assign
```

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

$$
\begin{aligned}
&begin = newlabel() \\
&B.true = newlabel() \\
&B.false = S.next \\
&S_1.next = begin \\
&S.code = label(begin) \,||\, B.code \\
&\qquad ||\, label(B.true) \,||\, S_1.code \\
&\qquad ||\, gen(\text{'goto'}\ begin)
\end{aligned}
$$

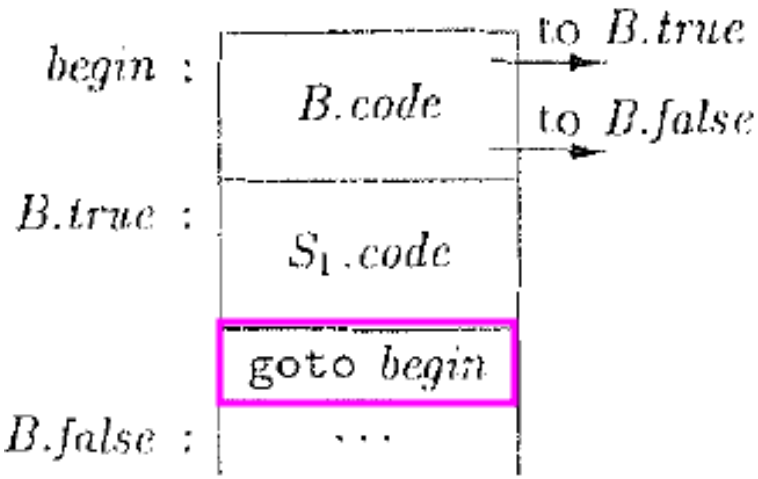
$S \rightarrow$ **while** (B) S_1

$$
\begin{aligned}
&begin = newlabel() \\
&B.true = newlabel() \\
&B.false = S.next \\
&S_1.next = begin \\
&S.code = label(begin) \,||\, B.code \\
&\qquad ||\, label(B.true) \,||\, S_1.code \\
&\qquad ||\, gen(\text{'goto'}\ begin)
\end{aligned}
$$



$S \rightarrow$ **while** (B) S_1

$begin = newlabel()$
$B.true = newlabel()$
$B.false = S.next$
$S_1.next = begin$
$S.code = label(begin) \,||\, B.code$
$\,||\, label(B.true) \,||\, S_1.code$
$\,||\, gen(\text{'goto'}\ begin)$




```
while (true)
  if (false) assign else assign
```

$$S \rightarrow S_1\ S_2$$

$$\begin{array}{|l} S_1.next = newlabel() \\ S_2.next = S.next \\ S.code = S_1.code \mid\mid label(S_1.next) \mid\mid S_2.code \end{array}$$

$$S \rightarrow S_1\ S_2$$

$$\begin{array}{|l} S_1.next = newlabel() \\ S_2.next = S.next \\ S.code = S_1.code \mid\mid label(S_1.next) \mid\mid S_2.code \end{array}$$

```
if (true) assign else assign assign
```

产生式	语义规则
$P \rightarrow S$	$S.next = newlabel()$ $P.code = S.code \mid\mid label(S.next)$
$S \rightarrow$ **assign**	$S.code =$ **assign**$.code$
$S \rightarrow$ **if** (B) S_1	$B.true = newlabel()$ $B.false = S_1.next = S.next$ $S.code = B.code \mid\mid label(B.true) \mid\mid S_1.code$
$S \rightarrow$ **if** (B) S_1 **else** S_2	$B.true = newlabel()$ $B.false = newlabel()$ $S_1.next = S_2.next = S.next$ $S.code = B.code$ $\mid\mid label(B.true) \mid\mid S_1.code$ $\mid\mid gen('\texttt{goto}'\ S.next)$ $\mid\mid label(B.false) \mid\mid S_2.code$
$S \rightarrow$ **while** (B) S_1	$begin = newlabel()$ $B.true = newlabel()$ $B.false = S.next$ $S_1.next = begin$ $S.code = label(begin) \mid\mid B.code$ $\mid\mid label(B.true) \mid\mid S_1.code$ $\mid\mid gen('\texttt{goto}'\ begin)$
$S \rightarrow S_1\ S_2$	$S_1.next = newlabel()$ $S_2.next = S.next$ $S.code = S_1.code \mid\mid label(S_1.next) \mid\mid S_2.code$

布尔表达式的中间代码翻译

产生式	语义规则
$B \rightarrow B_1 \mid\mid B_2$	$B_1.true = B.true$ $B_1.false = newlabel()$ $B_2.true = B.true$ $B_2.false = B.false$ $B.code = B_1.code \mid\mid label(B_1.false) \mid\mid B_2.code$
$B \rightarrow B_1 \;\&\&\; B_2$	$B_1.true = newlabel()$ $B_1.false = B.false$ $B_2.true = B.true$ $B_2.false = B.false$ $B.code = B_1.code \mid\mid label(B_1.true) \mid\mid B_2.code$
$B \rightarrow ! B_1$	$B_1.true = B.false$ $B_1.false = B.true$ $B.code = B_1.code$
$B \rightarrow E_1 \;\mathbf{rel}\; E_2$	$B.code = E_1.code \mid\mid E_2.code$ $\mid\mid gen('\mathtt{if}'\ E_1.addr\ \mathbf{rel}.op\ E_2.addr\ '\mathtt{goto}'\ B.true)$ $\mid\mid gen('\mathtt{goto}'\ B.false)$
$B \rightarrow \mathbf{true}$	$B.code = gen('\mathtt{goto}'\ B.true)$
$B \rightarrow \mathbf{false}$	$B.code = gen('\mathtt{goto}'\ B.false)$

B	$\rightarrow$ true	$B.code = gen('\texttt{goto}'\ B.true)$
B	$\rightarrow$ false	$B.code = gen('\texttt{goto}'\ B.false)$

$B \rightarrow$	**true**	$B.code = gen('\texttt{goto}'\ B.true)$
$B \rightarrow$	**false**	$B.code = gen('\texttt{goto}'\ B.false)$

if (true) assign

$S \rightarrow$ **if** (B) S_1	$B.true = newlabel()$	
	$B.false = S_1.next = S.next$	
	$S.code = B.code \mid\mid label(B.true) \mid\mid S_1.code$	

if (false) assign

$$B \rightarrow\ !\ B_1$$

$$\begin{cases} B_1.true = B.false \\ B_1.false = B.true \\ B.code = B_1.code \end{cases}$$

$$B \rightarrow\ !\ B_1 \quad \left| \begin{array}{l} B_1.true = B.false \\ B_1.false = B.true \\ B.code = B_1.code \end{array} \right.$$

if (!true) assign

$$S \rightarrow \textbf{if}\ (\ B\ )\ S_1 \quad \left| \begin{array}{l} B.true = newlabel() \\ B.false = S_1.next = S.next \\ S.code = B.code \,||\, label(B.true) \,||\, S_1.code \end{array} \right.$$

if (!false) assign

短路求值

$$
\begin{array}{lll}
B & \rightarrow & B_1 \mid\mid B_2 \\
\end{array}
\quad
\left|
\begin{array}{l}
B_1.true = B.true \\
B_1.false = newlabel() \\
B_2.true = B.true \\
B_2.false = B.false \\
B.code = B_1.code \mid\mid label(B_1.false) \mid\mid B_2.code
\end{array}
\right.
$$

短路求值

$$B \rightarrow B_1 \ || \ B_2 \quad \left| \begin{array}{l} B_1.true = B.true \\ B_1.false = newlabel() \\ B_2.true = B.true \\ B_2.false = B.false \\ B.code = B_1.code \ || \ label(B_1.false) \ || \ B_2.code \end{array} \right.$$

```
if (true || false) assign
```

$$S \rightarrow \textbf{if} \ (\ B \ ) \ S_1 \quad \left| \begin{array}{l} B.true = newlabel() \\ B.false = S_1.next = S.next \\ S.code = B.code \ || \ label(B.true) \ || \ S_1.code \end{array} \right.$$

```
if (false || true) assign
```

短路求值

$$
\begin{array}{lll}
B & \rightarrow & B_1 \ \&\& \ B_2 \\
\end{array}
\left|
\begin{array}{l}
B_1.true = newlabel() \\
B_1.false = B.false \\
B_2.true = B.true \\
B_2.false = B.false \\
B.code = B_1.code \ || \ label(B_1.true) \ || \ B_2.code
\end{array}
\right.
$$

短路求值

$$
\begin{array}{l|l}
B \rightarrow B_1 \;\&\&\; B_2 & B_1.true = newlabel() \\
 & B_1.false = B.false \\
 & B_2.true = B.true \\
 & B_2.false = B.false \\
 & B.code = B_1.code \;||\; label(B_1.true) \;||\; B_2.code
\end{array}
$$

```
if (true && false) assign
```

$$
\begin{array}{l|l}
S \rightarrow \textbf{if}\ (\ B\ )\ S_1 & B.true = newlabel() \\
 & B.false = S_1.next = S.next \\
 & S.code = B.code \;||\; label(B.true) \;||\; S_1.code
\end{array}
$$

```
if (false && true) assign
```

$$B \rightarrow E_1 \ \mathbf{rel} \ E_2 \quad \left| \begin{array}{l} B.code = E_1.code \ || \ E_2.code \\ \qquad || \ gen(\text{'}\mathtt{if}\text{'} \ E_1.addr \ \mathbf{rel}.op \ E_2.addr \ \text{'}\mathtt{goto}\text{'} \ B.true) \\ \qquad || \ gen(\text{'}\mathtt{goto}\text{'} \ B.false) \end{array} \right.$$

```
if (x < 100 || x > 200 && x != y) x = 0;
```

```
        if x < 100 goto L2
        goto L3
L3:     if x > 200 goto L4
        goto L1
L4:     if x != y goto L2
        goto L1
L2:     x = 0
L1:
```

布尔表达式的作用: 布尔值 *vs.* 控制流跳转

$$S \rightarrow \textbf{id} = E; \mid \textbf{if}\ (E)\ S \mid \textbf{while}\ (E)\ S \mid S\ S$$

$$E \rightarrow E \mid\mid E \mid E \&\& E \mid E\ \textbf{rel}\ E \mid E + E \mid (E) \mid \textbf{id} \mid \textbf{true} \mid \textbf{false}$$

布尔表达式的作用: 布尔值 *vs.* 控制流跳转

$S \rightarrow$ **id** $=E;$ | **if** $(E)\ S$ | **while** $(E)\ S$ | $S\ S$

$E \rightarrow E \,\|\, E \mid E \&\& E \mid E$ **rel** $E \mid E + E \mid (E) \mid$ **id** | **true** | **false**

根据 E 所处的上下文判断 E 所扮演的角色, 调用不同的代码生成函数

函数 $jump(t, f)$: 生成控制流代码

函数 $rvalue()$: 生成计算布尔值的代码, 并将结果存储在临时变量中

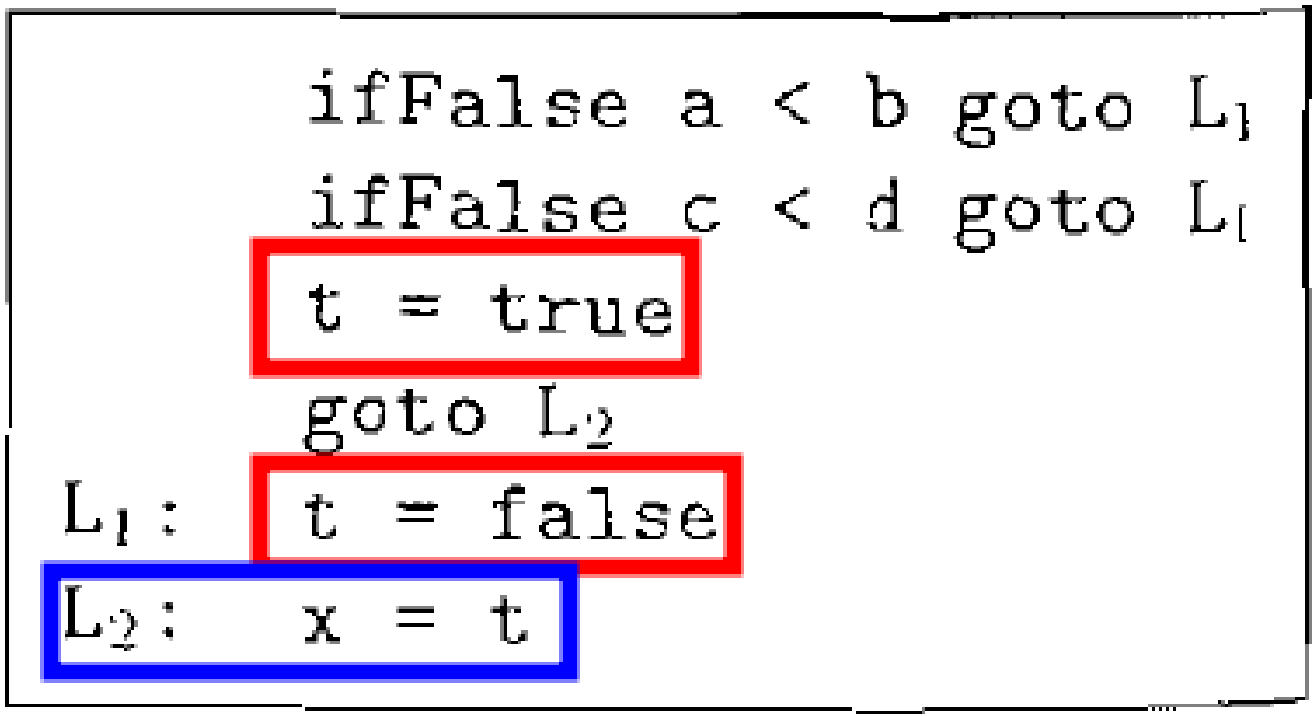
产生式	语义规则
$S \rightarrow \mathbf{id} = E\ ;$	$S.code = E.code \mid\mid gen(top.get(\mathbf{id}.lexeme)\ '='\ E.addr)$
$E \rightarrow E_1 + E_2$	$E.addr = \mathbf{new}\ Temp()$ $E.code = E_1.code \mid\mid E_2.code \mid\mid gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr)$
$\mid\ -E_1$	$E.addr = \mathbf{new}\ Temp()$ $E.code = E_1.code \mid\mid gen(E.addr\ '='\ '\mathbf{minus}'\ E_1.addr)$
$\mid\ (E_1)$	$E.addr = E_1.addr$ $E.code = E_1.code$
$\mid\ \mathbf{id}$	$E.addr = top.get(\mathbf{id}.lexeme)$ $E.code = ''$

符号表条目

$$E \rightarrow E_1 \&\& E_2$$

为 E 生成**跳转代码**, 在**真假出口处**将 **true** 或 **false** 存储到临时变量

x = a < b && c < d


ifFalse a < b goto L1
ifFalse c < d goto L1
t = true
goto L2
L1 : t = false
L2 : x = t

布尔表达式的作用：布尔值 *vs.* 控制流跳转

$$S \rightarrow \textbf{id} = E\ ; \mid \textbf{if}\ (E)\ S \mid \textbf{while}\ (E)\ S \mid S\ S$$

$$E \rightarrow E \mid\mid E \mid E \&\& E \mid E\ \textbf{rel}\ E \mid E + E \mid (E) \mid \textbf{id} \mid \textbf{true} \mid \textbf{false}$$

布尔表达式的作用：布尔值 *vs.* 控制流跳转

$$S \rightarrow \textbf{id} = E\ ; \mid \textbf{if}\ (E)\ S \mid \textbf{while}\ (E)\ S \mid S\ S$$

$$E \rightarrow E \mid\mid E \mid E \&\& E \mid E\ \textbf{rel}\ E \mid E + E \mid (E) \mid \textbf{id} \mid \textbf{true} \mid \textbf{false}$$

为什么要区分布尔表达式的这两种角色?

布尔表达式的作用：布尔值 *vs.* 控制流跳转

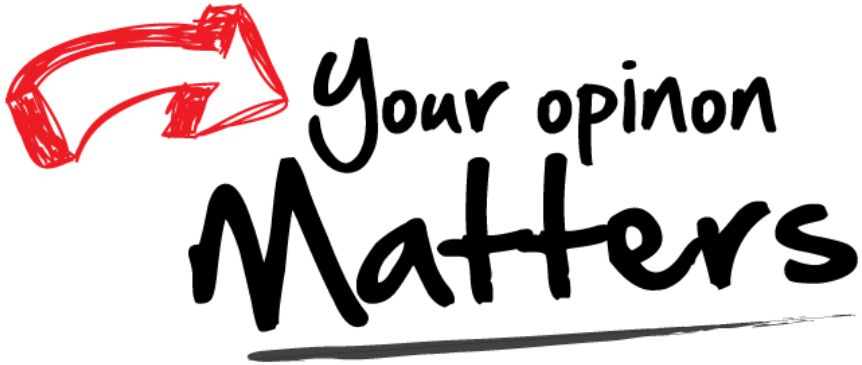
$S \rightarrow$ **id** $=E$; | **if** (E) S | **while** (E) S | $S\ S$

$E \rightarrow E \mid\mid E \mid E \&\& E \mid E$ **rel** $E \mid E + E \mid (E) \mid$ **id** | **true** | **false**

为什么要区分布尔表达式的这两种角色?

可以不区分布尔表达式的这两种角色吗?


Thank
You!



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