# 中间代码生成

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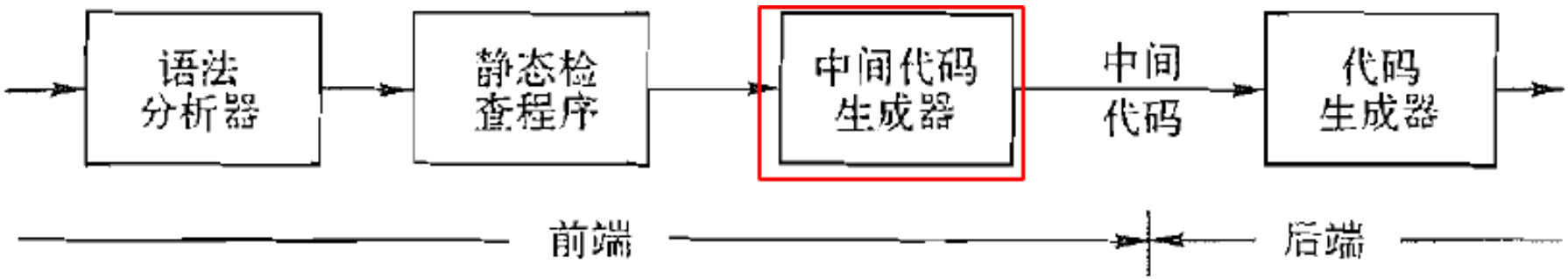
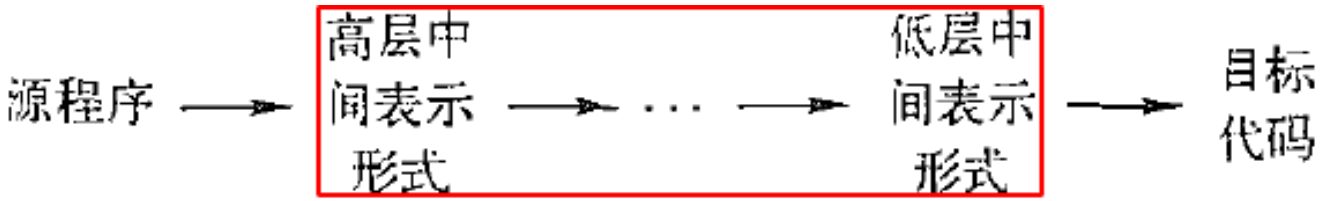
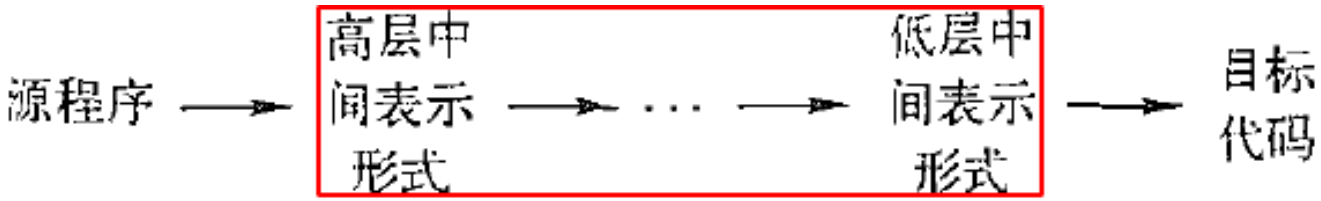

语法
分析器
静态检
查程序
中间代码
生成器
中间
代码
代码
生成器
前端
后端

# Intermediate Representation (IR)



# 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)

## Intermediate Representation (IR)

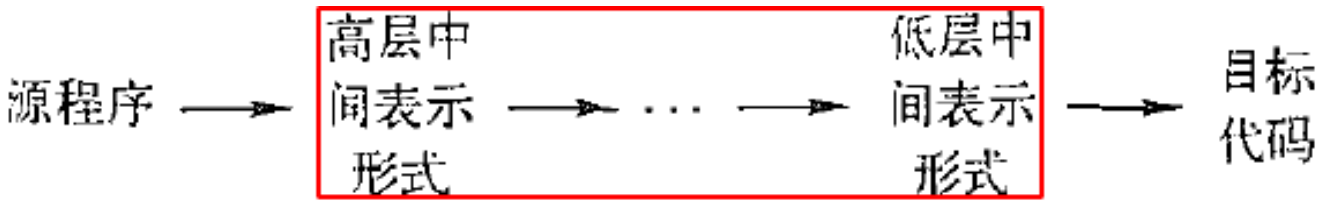
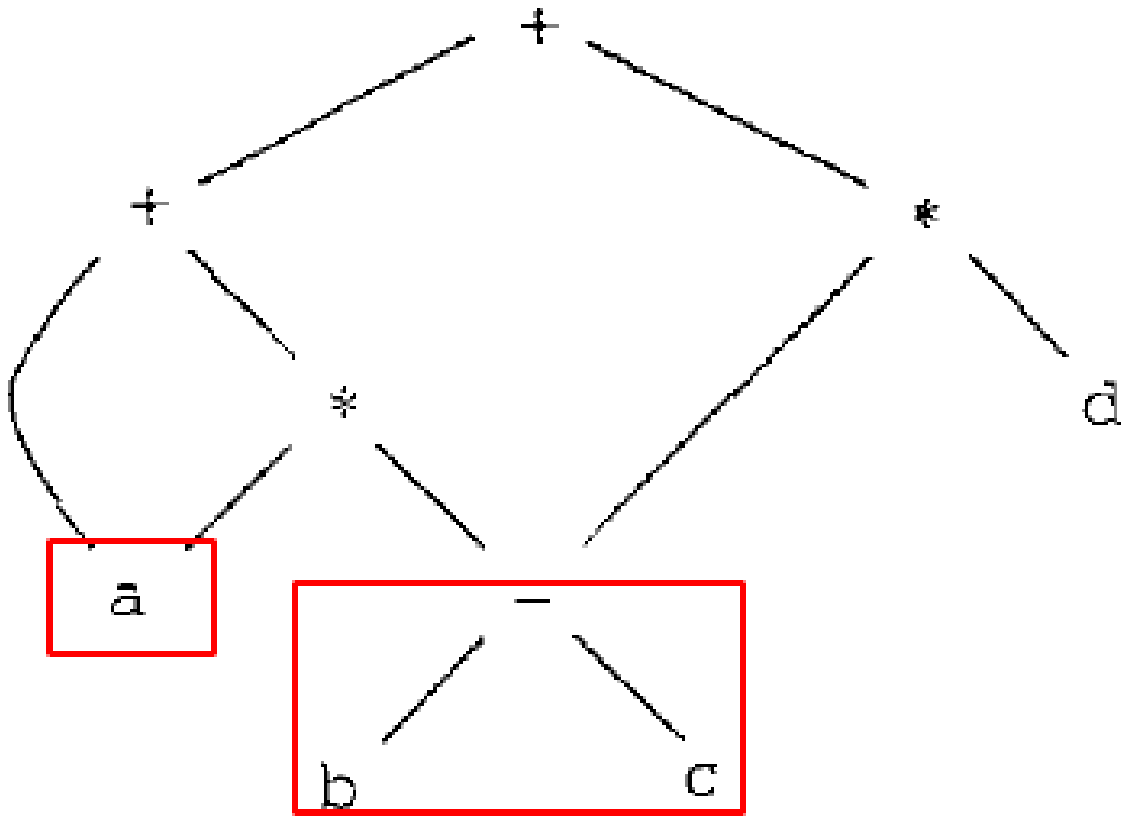



图 (抽象语法树)、**三地址代码**、C 语言

# 表达式的有向无环图




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

| 产生式 | | 语义规则 |
|---|---|---|
| 1) | $E \to E_1 + T$ | $E.node =$ **new** $Node('+', E_1.node, T.node)$ |
| 2) | $E \to E_1 - T$ | $E.node =$ **new** $Node('-', E_1.node, T.node)$ |
| 3) | $E \to T$ | $E.node = T.node$ |
| | $T \to T_1 * F$ | $T.node =$ **new** $Node('*', T_1.node, F.node)$ |
| 4) | $T \to (\ E\ )$ | $T.node = E.node$ |
| 5) | $T \to$ **id** | $T.node =$ **new** $Leaf(\mathbf{id}, \mathbf{id}.entry)$ |
| 6) | $T \to$ **num** | $T.node =$ **new** $Leaf(\mathbf{num}, \mathbf{num}.val)$ |

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| 1) | $E \to E_1 + T$ | $E.node =$ **new** $Node('+', E_1.node, T.node)$ |
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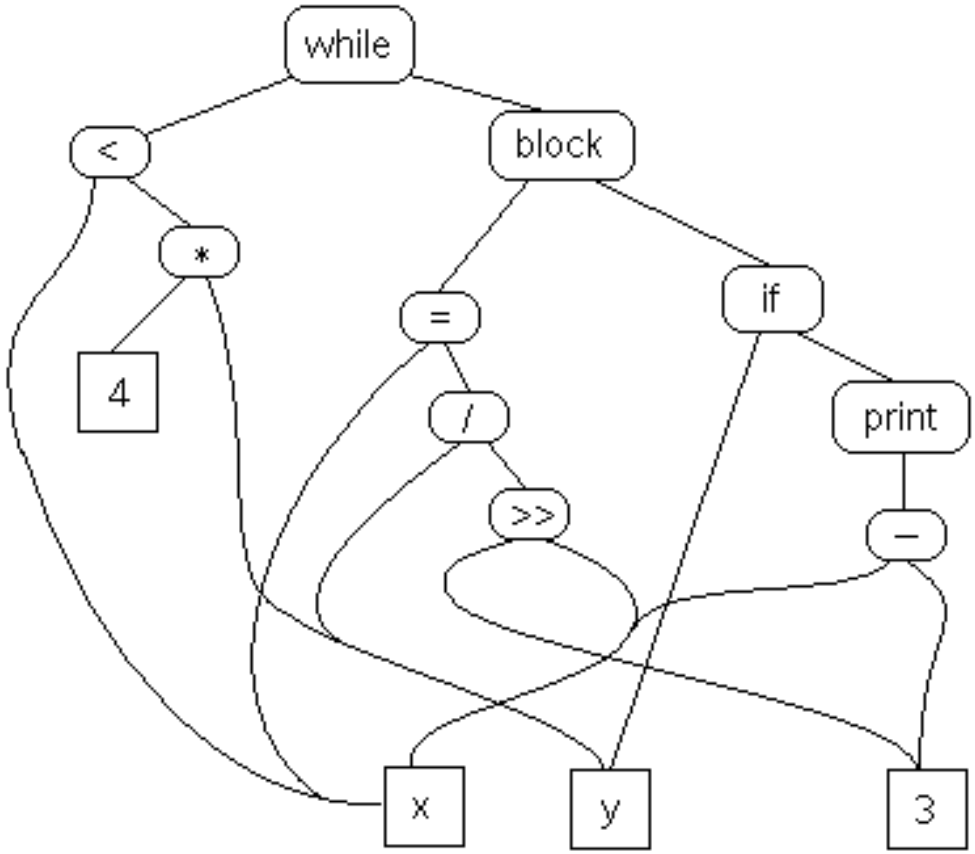
| 6) | $T \to$ **num** | $T.node =$ **new** $Leaf(\mathbf{num}, \mathbf{num}.val)$ |

在创建节点之前，先判断是否已存在 (哈希表)

```
while (x < 4 * y) {
    x = y / 3 >> x;
    if (y) print x - 3;
}
```



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

每个 **TAC** 指令**最多**包含三个操作数。

$$x = y \ \mathbf{op} \ z \tag{1}$$

$$x = \mathbf{op} \ y \tag{2}$$

$$x = y \tag{3}$$

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$$x = y \ \mathbf{op} \ z \tag{1}$$
$$x = \mathbf{op} \ y \tag{2}$$
$$x = y \tag{3}$$

$$\mathbf{goto} \ L \tag{4}$$
$$\mathbf{if} \ x \ \mathbf{goto} \ L \tag{5}$$
$$\mathbf{if \ False} \ x \ \mathbf{goto} \ L \tag{6}$$
$$\mathbf{if} \ x \ \mathbf{relop} \ y \ \mathbf{goto} \ L \tag{7}$$

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

每个 **TAC** 指令**最多**包含三个操作数。

$$\textbf{param}\ x \tag{8}$$
$$\textbf{call}\ p, n \tag{9}$$
$$y = \textbf{call}\ p, n \tag{10}$$
$$\textbf{return}\ y \tag{11}$$

```
param x_1
param x_2
...
param x_n
call p, n
```

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

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

每个 **TAC** 指令**最多**包含三个操作数。

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

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

**距离位置 $y$ 处 $i$ 个内存单元**

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

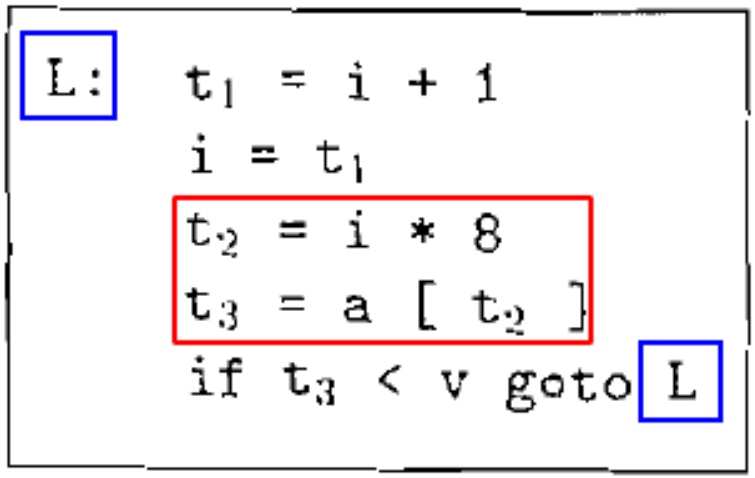
每个 **TAC** 指令**最多**包含三个操作数。

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

**距离位置 $y$ 处 $i$ 个内存单元**

$$x = \&y \tag{14}$$
$$x = *y \tag{15}$$
$$*x = y \tag{16}$$

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



```
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```

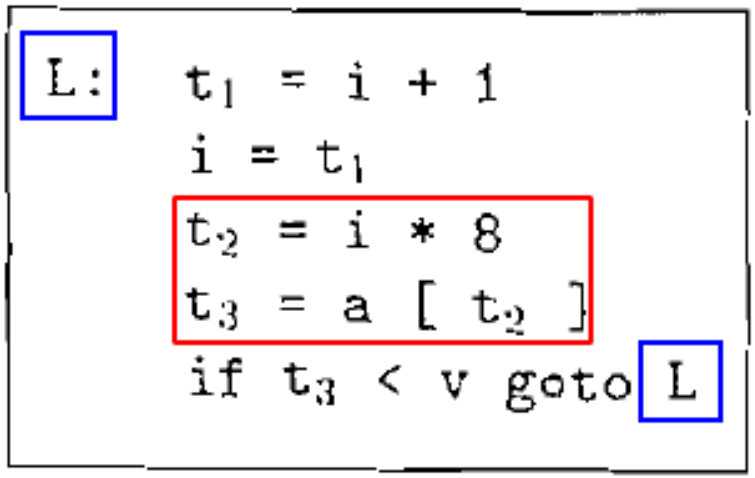


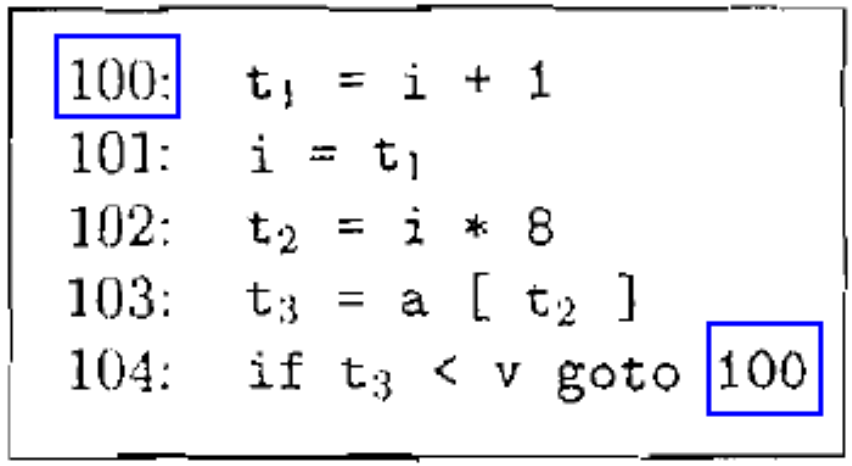

# 三地址代码的四元式表示

**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 |
| | | ... | | |

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

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

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

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

$$x = \&y$$

$$x = *y$$

$$*x = y$$

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

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

$$x = \&y \qquad =\& \quad y \quad x$$

$$x = *y \qquad =* \quad y \quad x$$

$$*x = y \qquad *= \quad y \quad x$$

# 表达式的中间代码翻译

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

符号表条目

**综合属性 $E.code$ 与 $E.addr$**

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

符号表条目

$$a = b + -c$$

```
t1 = minus c
t2 = b + t1
a = t2
```

# 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** $E.addr$

## 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

声明：$\text{int } a[2][3]$

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**

# 数组引用的中间代码翻译

int $a[2][3]$

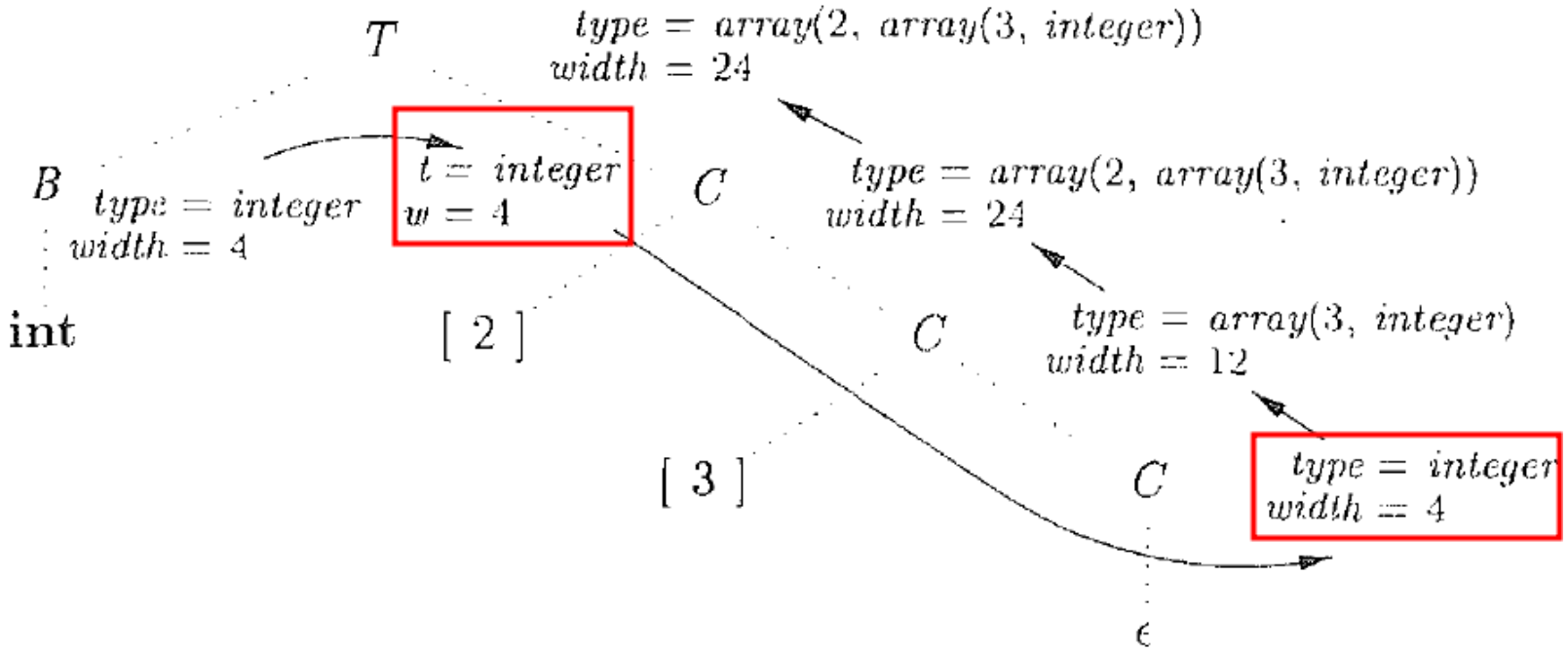



图 6-16　数组类型的语法制导翻译

## 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

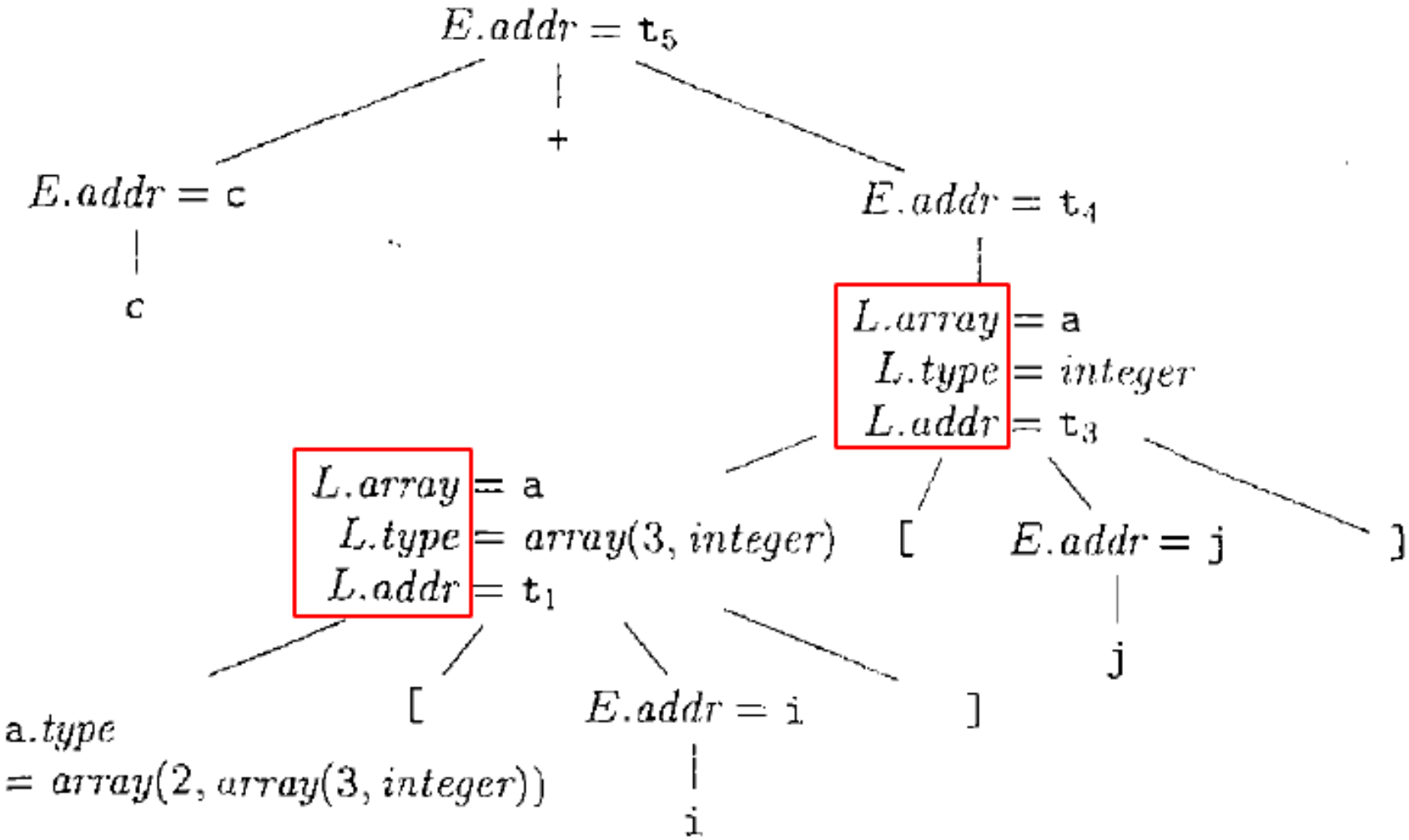
$$
\begin{aligned}
L \rightarrow\ & \mathbf{id}\ [\ E\ ] \quad \{\ L.array = top.get(\mathbf{id}.lexeme); \\
& \quad L.type = L.array.type.elem; \\
& \quad L.addr = \mathbf{new}\ Temp\,(); \\
& \quad gen(L.addr\ '='\ E.addr\ '*'\ L.type.width);\ \} \\
\mid\ & L_1\ [\ E\ ] \quad \{\ L.array = L_1.array;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

## 综合属性 $L.type$：(当前) 元素类型

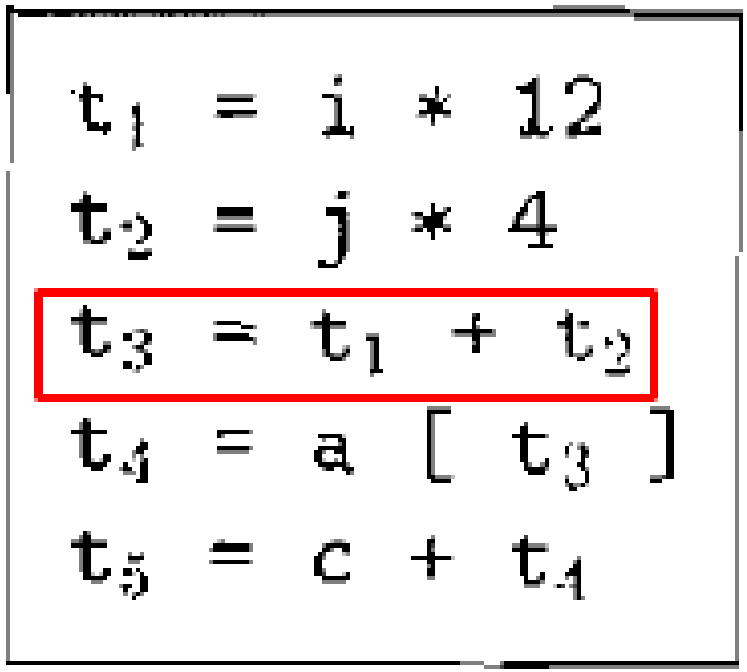
$$
\begin{aligned}
L \rightarrow\ & \mathbf{id}\ [\ E\ ] \quad \{\ L.array = top.get(\mathbf{id}.lexeme);\\
& \quad L.type = L.array.type.elem;\\
& \quad L.addr = \mathbf{new}\ Temp\,();\\
& \quad gen(L.addr\ '='\ E.addr\ '*'\ L.type.width);\ \}\\
\\
|\ \ & L_1\ [\ E\ ] \quad \{\ L.array = L_1.array;\\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

## 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

int $a[2][3]$




int $a[2][3]$

## 控制流语句与布尔表达式的中间代码翻译

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

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

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

# 控制流语句与布尔表达式的中间代码翻译

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

**继承属性 $S.next$ : $S$ 的下一条指令**

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

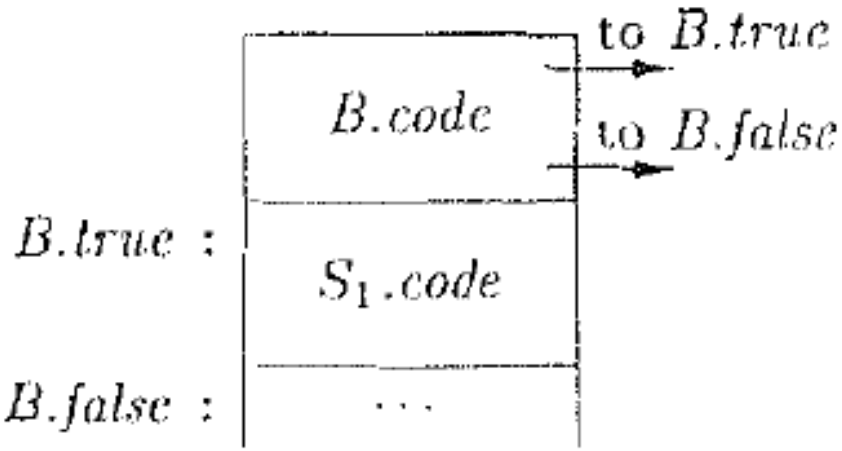
**$S.next$ 为语句 $S$ 指明了 “跳出” $S$ 的目标**

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

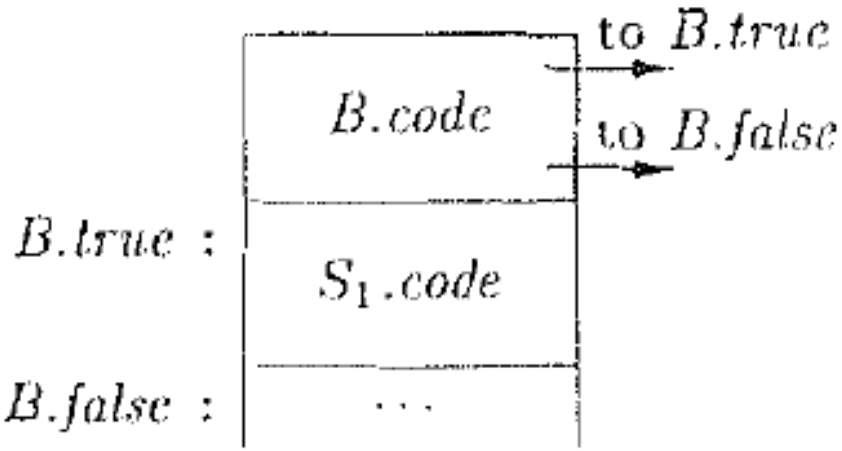
代表了表达式的翻译, 包括数组引用

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

| | |
|---|---|
| $S \rightarrow \textbf{if}\ (\ B\ )\ S_1$ | $B.true = newlabel()$<br>$B.false = S_1.next = S.next$<br>$S.code = B.code \mid\mid label(B.true) \mid\mid S_1.code$ |



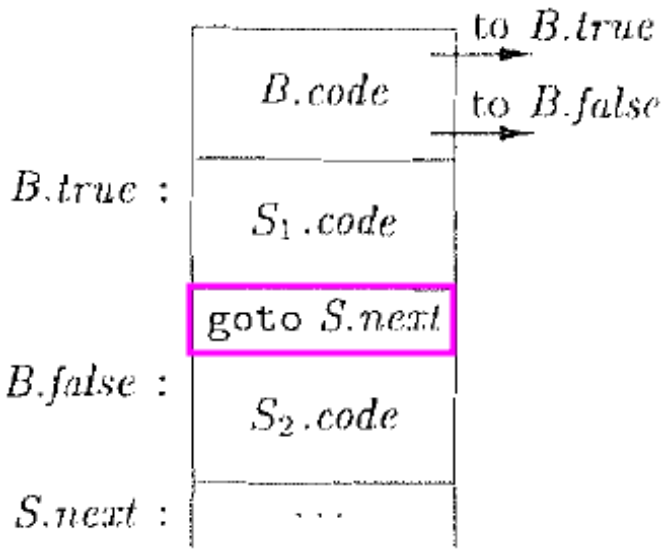
| $S \rightarrow \textbf{if}\ (\ B\ )\ S_1$ | $B.true = newlabel()$<br>$B.false = S_1.next = S.next$<br>$S.code = B.code \mid\mid label(B.true) \mid\mid S_1.code$ |
|---|---|



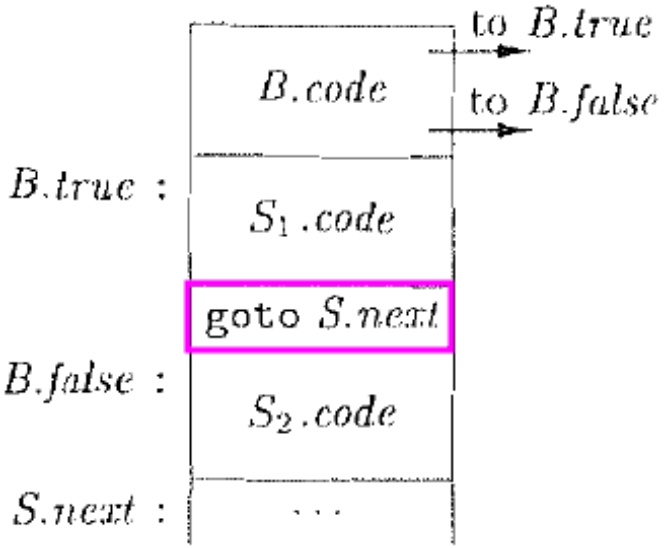

```
if (true)
  if (false) assign
```

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

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



| $S \rightarrow$ **if** ( $B$ ) $S_1$ **else** $S_2$ | $B.true = newlabel()$<br>$B.false = newlabel()$<br>$S_1.next = S_2.next = S.next$<br>$S.code = B.code$<br>$\|\| label(B.true) \|\| S_1.code$<br>$\|\| gen('\texttt{goto}'\ S.next)$<br>$\|\| label(B.false) \|\| S_2.code$ |
|---|---|



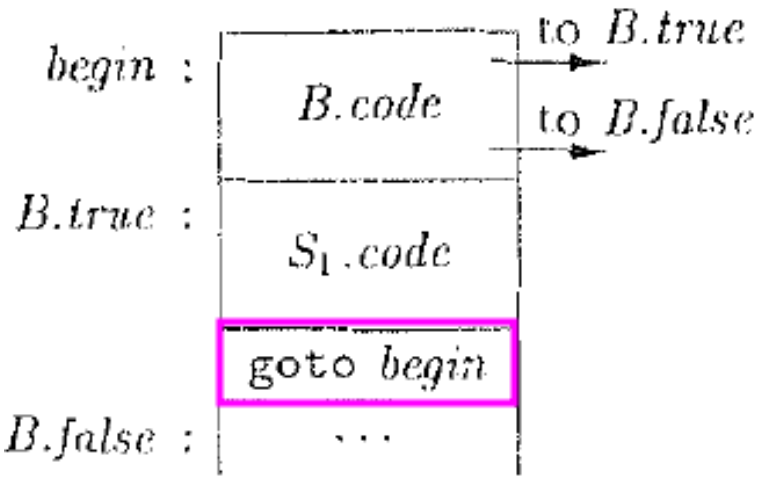

```
if (true)
  if (true) assign else assign
else
  assign
```

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

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

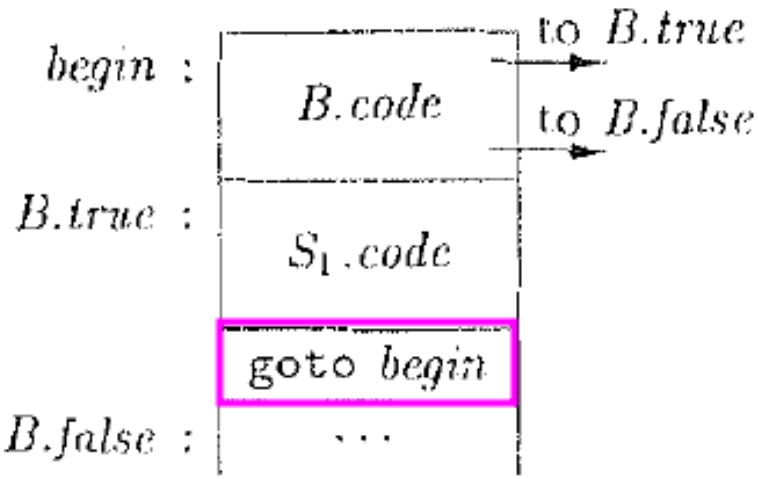
$S \rightarrow$ **while** ( $B$ ) $S_1$

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



$S \rightarrow$ **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
```

$$S \rightarrow S_1\ S_2$$

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

$$
\begin{array}{lll}
S \rightarrow S_1\ S_2 & \boxed{S_1.next} = newlabel() \\
& \boxed{S_2.next} = S.next \\
& S.code = S_1.code \mid\mid label(S_1.next) \mid\mid S_2.code
\end{array}
$$

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

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

# 布尔表达式的中间代码翻译

| 产生式 | 语义规则 |
| --- | --- |
| $B \rightarrow B_1 \mid\mid B_2$ | $B_1.true = B.true$<br>$B_1.false = newlabel()$<br>$B_2.true = B.true$<br>$B_2.false = B.false$<br>$B.code = B_1.code \mid\mid label(B_1.false) \mid\mid B_2.code$ |
| $B \rightarrow B_1 \;\&\&\; B_2$ | $B_1.true = newlabel()$<br>$B_1.false = B.false$<br>$B_2.true = B.true$<br>$B_2.false = B.false$<br>$B.code = B_1.code \mid\mid label(B_1.true) \mid\mid B_2.code$ |
| $B \rightarrow ! B_1$ | $B_1.true = B.false$<br>$B_1.false = B.true$<br>$B.code = B_1.code$ |
| $B \rightarrow E_1$ **rel** $E_2$ | $B.code = E_1.code \mid\mid E_2.code$<br>$\mid\mid gen('\texttt{if}'\ E_1.addr\ \textbf{rel}.op\ E_2.addr\ '\texttt{goto}'\ B.true)$<br>$\mid\mid gen('\texttt{goto}'\ B.false)$ |
| $B \rightarrow$ **true** | $B.code = gen('\texttt{goto}'\ B.true)$ |
| $B \rightarrow$ **false** | $B.code = gen('\texttt{goto}'\ B.false)$ |

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

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

if (true) assign

| | | |
|---|---|---|
| $S \rightarrow \textbf{if}\ (\ B\ )\ S_1$ | | $B.true = newlabel()$<br>$B.false = S_1.next = S.next$<br>$S.code = B.code \mid\mid label(B.true) \mid\mid S_1.code$ |

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

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

# 短路求值

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

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

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

```
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

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

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

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

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

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

```
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**

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

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

布尔表达式的作用: **布尔值** *vs.* **控制流跳转**

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

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

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

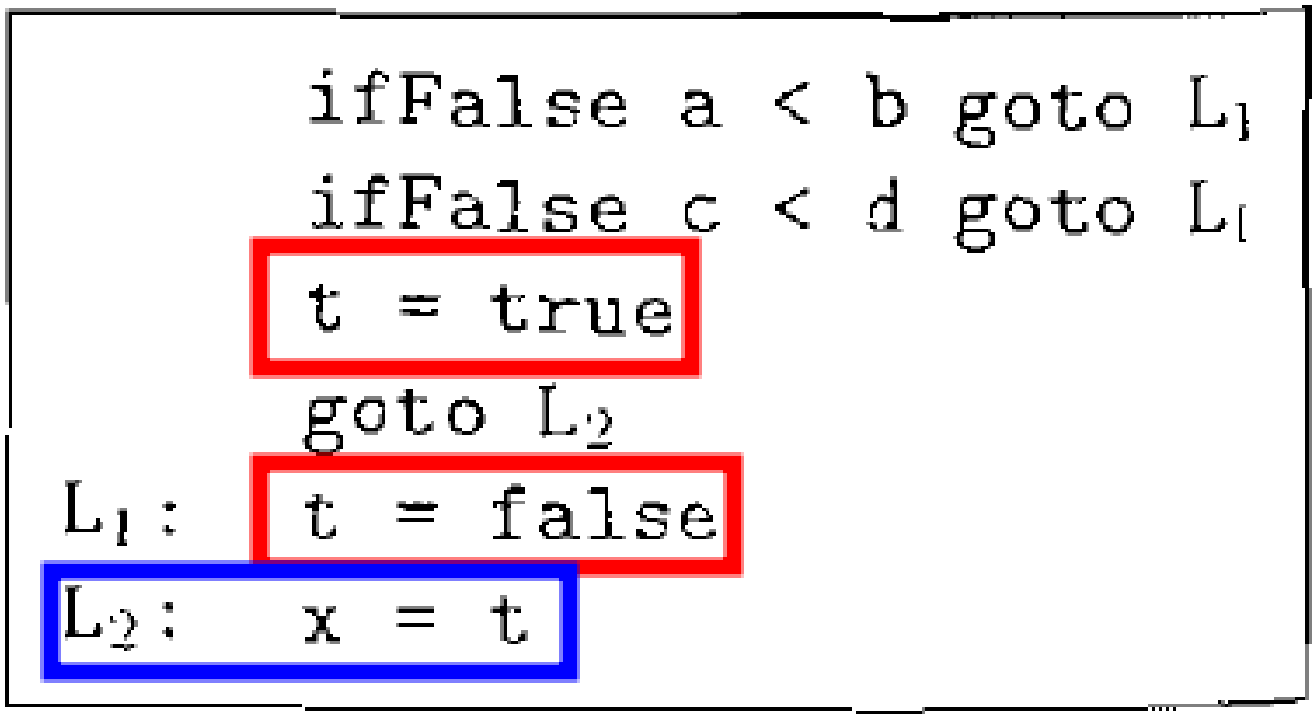
| 产生式 | 语义规则 |
| --- | --- |
| $S \rightarrow \mathbf{id} = E\ ;$ | $S.code = E.code \mid\mid gen(top.get(\mathbf{id}.lexeme)\ '='\ E.addr)$ |
| $E \rightarrow E_1 + E_2$ | $E.addr = \mathbf{new}\ Temp()$<br>$E.code = E_1.code \mid\mid E_2.code \mid\mid gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr)$ |
|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

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

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

**$B$ 还不知道 $S.next$ 的指令地址，如何跳转？**

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

**$B$ 还不知道 $S.next$ 的指令地址，如何跳转？**

再扫描一遍中间代码，将标号替换成指令 (相对) 地址

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

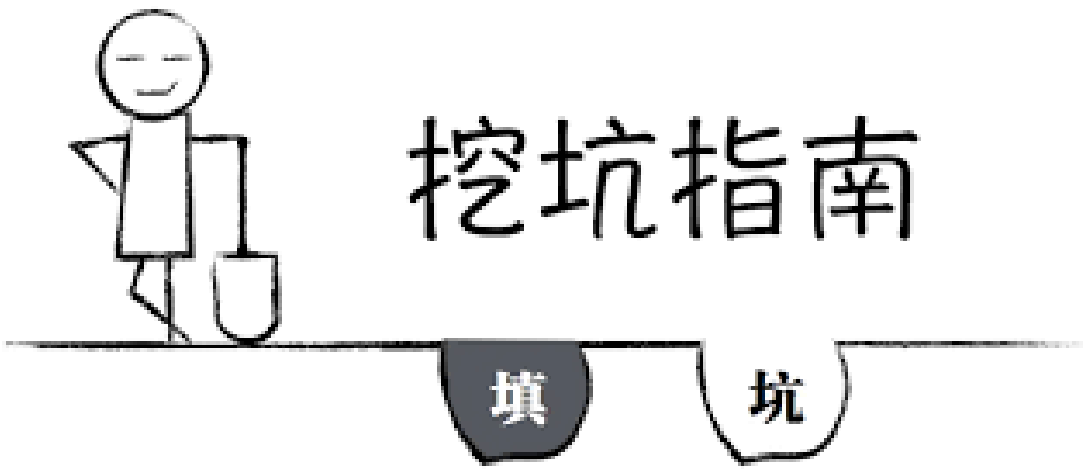
**$B$ 还不知道 $S.next$ 的指令地址，如何跳转？**

再扫描一遍中间代码，将标号替换成指令 (相对) 地址

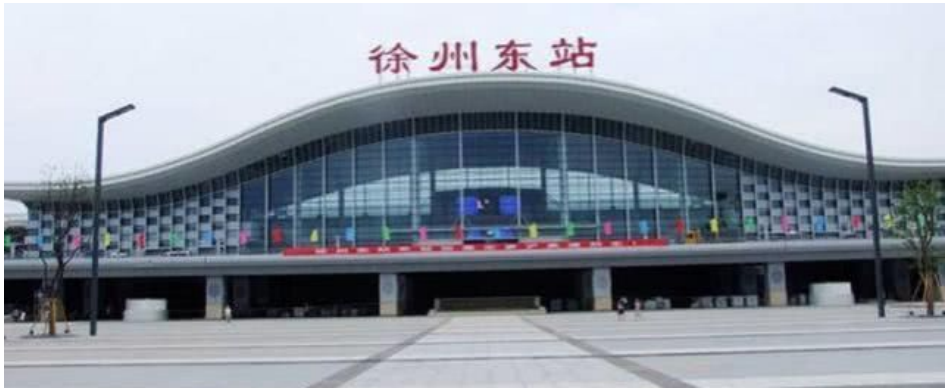
**可否在生成中间代码的时候就填入指令地址？**

# 回填 (Backpatching) 技术

# 回填 (Backpatching) 技术




**子节点挖坑、祖先节点填坑**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# 针对布尔表达式的回填技术

| | | |
|---|---|---|
| 1) | $B \rightarrow B_1 \ \| \ M \ B_2$ | { $backpatch(B_1.falselist, M.instr)$; $B.truelist = merge(B_1.truelist, B_2.truelist)$; $B.falselist = B_2.falselist$; } |
| 2) | $B \rightarrow B_1 \ \&\& \ M \ B_2$ | { $backpatch(B_1.truelist, M.instr)$; $B.truelist = B_2.truelist$; $B.falselist = merge(B_1.falselist, B_2.falselist)$; } |
| 3) | $B \rightarrow \ ! \ B_1$ | { $B.truelist = B_1.falselist$; $B.falselist = B_1.truelist$; } |
| 4) | $B \rightarrow ( \ B_1 \ )$ | { $B.truelist = B_1.truelist$; $B.falselist = B_1.falselist$; } |
| 5) | $B \rightarrow E_1 \ \mathbf{rel} \ E_2$ | { $B.truelist = makelist(nextinstr)$; $B.falselist = makelist(nextinstr + 1)$; $gen('\texttt{if}' \ E_1.addr \ \mathbf{rel}.op \ E_2.addr \ '\texttt{goto}\ \_')$; $gen('\texttt{goto}\ \_')$; } |
| 6) | $B \rightarrow \mathbf{true}$ | { $B.truelist = makelist(nextinstr)$; $gen('\texttt{goto}\ \_')$; } |
| 7) | $B \rightarrow \mathbf{false}$ | { $B.falselist = makelist(nextinstr)$; $gen('\texttt{goto}\ \_')$; } |
| 8) | $M \rightarrow \epsilon$ | { $M.instr = nextinstr$; } |

综合属性 $B.truelist$ 保存 需要跳转到 $B.true$ 的指令地址

6) $B \rightarrow \textbf{true}$ { $B.truelist = makelist(nextinstr)$; $gen('\texttt{goto}\ \_')$; }

7) $B \rightarrow \textbf{false}$ { $B.falselist = makelist(nextinstr)$; $gen('\texttt{goto}\ \_')$; }

综合属性 $B.falselist$ 保存 需要跳转到 $B.false$ 的指令地址

**综合属性 $B.truelist$ 保存 需要跳转到 $B.true$ 的指令地址**

6) $B \rightarrow$ **true** { $B.truelist = makelist(nextinstr)$; $gen('\texttt{goto}\ \_')$; }

7) $B \rightarrow$ **false** { $B.falselist = makelist(nextinstr)$; $gen('\texttt{goto}\ \_')$; }

**综合属性 $B.falselist$ 保存 需要跳转到 $B.false$ 的指令地址**

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

5) $B \rightarrow E_1 \ \mathbf{rel} \ E_2$ { $B.truelist = makelist(nextinstr)$;
$B.falselist = makelist(nextinstr + 1)$;
$gen('\texttt{if}' \ E_1.addr \ \mathbf{rel}.op \ E_2.addr \ '\texttt{goto}\ \_')$;
$gen('\texttt{goto}\ \_')$; }

| | |
|---|---|
| $B \rightarrow E_1 \ \mathbf{rel} \ E_2$ | $B.code = E_1.code \ \|\| \ E_2.code$ $\|\| \ gen('\texttt{if}' \ E_1.addr \ \mathbf{rel}.op \ E_2.addr \ '\texttt{goto}' \ B.true)$ $\|\| \ gen('\texttt{goto}' \ B.false)$ |

3) $B \rightarrow\ !\ B_1$ { $B.truelist = B_1.falselist;$ $B.falselist = B_1.truelist;$ }

4) $B \rightarrow (\ B_1\ )$ { $B.truelist = B_1.truelist;$ $B.falselist = B_1.falselist;$ }

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

2) $B \rightarrow B_1 \;\&\&\; M \; B_2$ { $backpatch(B_1.truelist, M.instr)$;
$B.truelist = B_2.truelist$;
$B.falselist = merge(B_1.falselist, B_2.falselist)$; }

8) $M \rightarrow \epsilon$ { $M.instr = nextinstr$; }

$B \rightarrow B_1 \;\&\&\; B_2$

$B_1.true = newlabel()$
$B_1.false = B.false$
$B_2.true = B.true$
$B_2.false = B.false$
$B.code = B_1.code \;||\; label(B_1.true) \;||\; B_2.code$

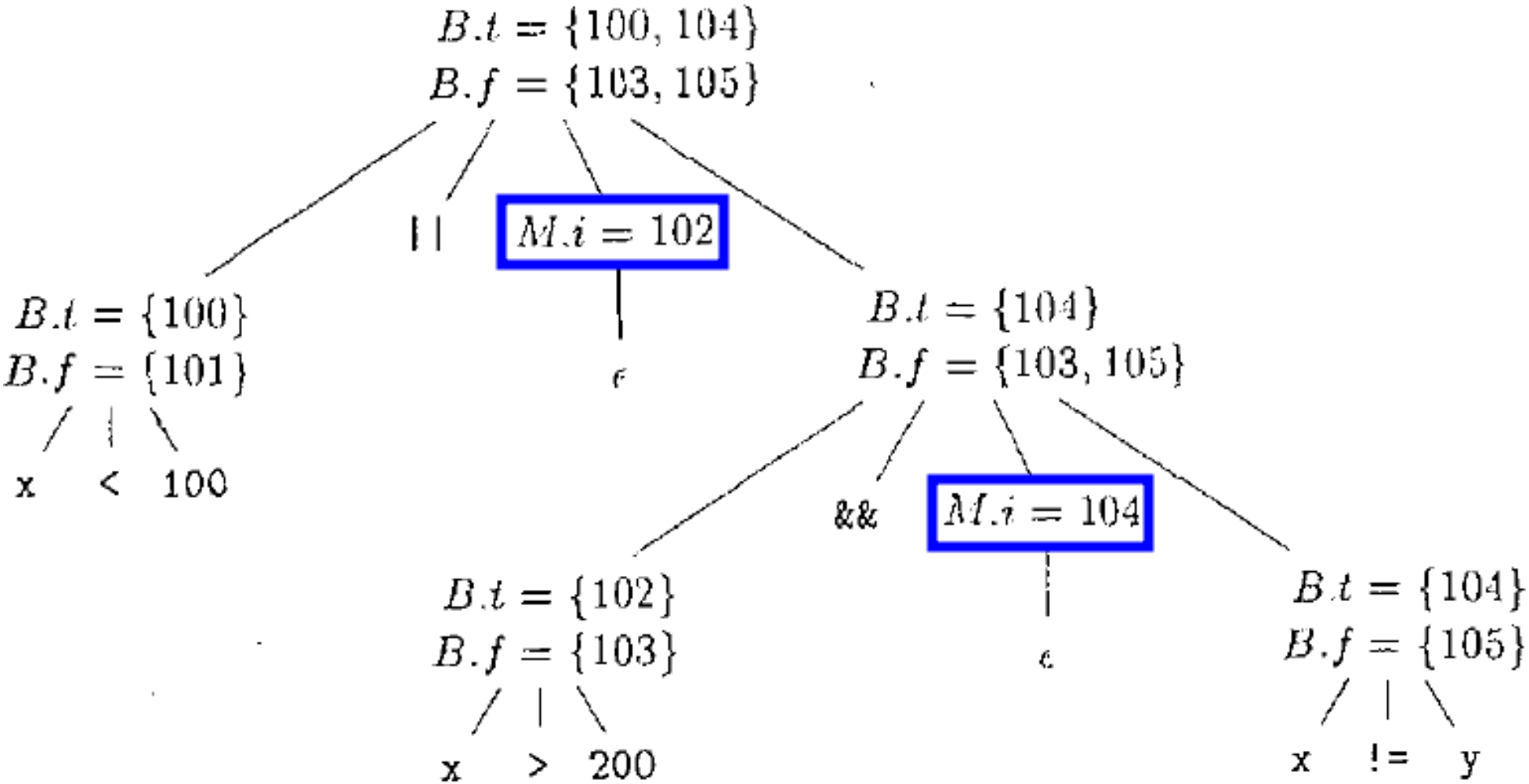
1) $B \rightarrow B_1 \;||\; M \; B_2$ { $backpatch(B_1.falselist, M.instr)$;
$B.truelist = merge(B_1.truelist, B_2.truelist)$;
$B.falselist = B_2.falselist$; }

8) $M \rightarrow \epsilon$ { $M.instr = nextinstr$; }

$B \rightarrow B_1 \;||\; B_2$

$B_1.true = B.true$
$B_1.false = newlabel()$
$B_2.true = B.true$
$B_2.false = B.false$
$B.code = B_1.code \;||\; label(B_1.false) \;||\; B_2.code$

# x < 100 || x > 200 && x != y


B.t = {100, 104}
B.f = {103, 105}
||
M.i = 102
ε
B.t = {100}
B.f = {101}
x < 100
B.t = {104}
B.f = {103, 105}
&&
M.i = 104
ε
B.t = {102}
B.f = {103}
x > 200
B.t = {104}
B.f = {105}
x != y

```
100:   if x < 100 goto _
101:   goto _
102:   if x > 200 goto 104
103:   goto _
104:   if x != y goto _
105:   goto _
```

a) 将 104 回填到指令 102 中之后

```
100:   if x < 100 goto _
101:   goto 102
102:   if x > 200 goto 104
103:   goto _
104:   if x != y goto _
105:   goto _
```

b) 将 102 回填到指令 101 中之后

$$S \rightarrow \textbf{if}\,(\,B\,)\,S \mid \textbf{if}\,(\,B\,)\,S\,\textbf{else}\,S \mid \textbf{while}\,(\,B\,)\,S \mid \{\,L\,\} \mid A\;;$$
$$L \rightarrow L\,S \mid S$$

1) $S \rightarrow \text{if}\,(\,B\,)\,M\,S_1$ { *backpatch*$(B.truelist,\ M.instr)$;
$S.nextlist = merge(B.falselist,\ S_1.nextlist)$; }

6) $M \rightarrow \epsilon$ { $M.instr = nextinstr$; }

1) $S \rightarrow \textbf{if}\ (\ B\ )\ M\ S_1\ \{\ backpatch(B.truelist,\ M.instr);$
$S.nextlist = merge(B.falselist,\ S_1.nextlist);\ \}$

6) $M \rightarrow \epsilon \qquad \{\ M.instr = nextinstr;\ \}$

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

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

$S \rightarrow$ **if** ( $B$ ) $M_1$ $S_1$ $N$ **else** $M_2$ $S_2$

{ $backpatch(B.truelist,\ M_1.instr)$;
$backpatch(B.falselist,\ M_2.instr)$;
$temp = merge(S_1.nextlist,\ N.nextlist)$;
$S.nextlist = merge(temp,\ S_2.nextlist)$; }

6) $M \rightarrow \epsilon$ { $M.instr = nextinstr$; }

7) $N \rightarrow \epsilon$ { $N.nextlist = makelist(nextinstr)$;
$gen('\texttt{goto}\ \_')$; }

$$S \rightarrow \textbf{if}\ (\ B\ )\ M_1\ S_1\ N\ \textbf{else}\ M_2\ S_2$$
$$\{\ backpatch(B.truelist,\ M_1.instr);$$
$$backpatch(B.falselist,\ M_2.instr);$$
$$temp\ =\ merge(S_1.nextlist,\ N.nextlist);$$
$$S.nextlist\ =\ merge(temp,\ S_2.nextlist);\ \}$$

6) $M \rightarrow \epsilon$ $\{\ M.instr\ =\ nextinstr;\ \}$

7) $N \rightarrow \epsilon$ $\{\ N.nextlist\ =\ makelist(nextinstr);$
$gen('\texttt{goto}\ \_');\ \}$

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

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

3) $S \rightarrow$ **while** $M_1$ ( $B$ ) $M_2$ $S_1$

{ *backpatch*( $S_1.nextlist$, $M_1.instr$);
*backpatch*( $B.truelist$, $M_2.instr$);
$S.nextlist = B.falselist$;
*gen*('goto' $M_1.instr$); }

6) $M \rightarrow \epsilon$ { $M.instr = nextinstr$; }

3) $S \rightarrow$ **while** $M_1$ ( $B$ ) $M_2$ $S_1$

{ $backpatch(S_1.nextlist,\ M_1.instr)$;
$backpatch(B.truelist,\ M_2.instr)$;
$S.nextlist = B.falselist$;
$gen('\texttt{goto}'\ M_1.instr)$; }

6) $M \rightarrow \epsilon$ { $M.instr = nextinstr$; }

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

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

4) $S \rightarrow \{\ L\ \}$ $\{\ S.nextlist = L.nextlist;\ \}$

5) $S \rightarrow A\ ;$ $\{\ S.nextlist = \mathbf{null};\ \}$

6) $M \rightarrow \epsilon$ $\{\ M.instr = nextinstr;\ \}$

8) $L \rightarrow L_1\ M\ S$ $\{\ backpatch(L_1.nextlist,\ M.instr);$
$L.nextlist = S.nextlist;\ \}$

9) $L \rightarrow S$ $\{\ L.nextlist = S.nextlist;\ \}$

```
switch ( E ) {
        case l_1: S_1
        case l_2: S_2
                  ...
        case l_{n-1}: S_{n-1}
        default: S_n
}
```

非 $C$ 语言语义 (`break`)

```
switch ( E ) {
        case V_1: S_1
        case V_2: S_2
                  ...
        case V_{n-1}: S_{n-1}
        default: S_n
}
```

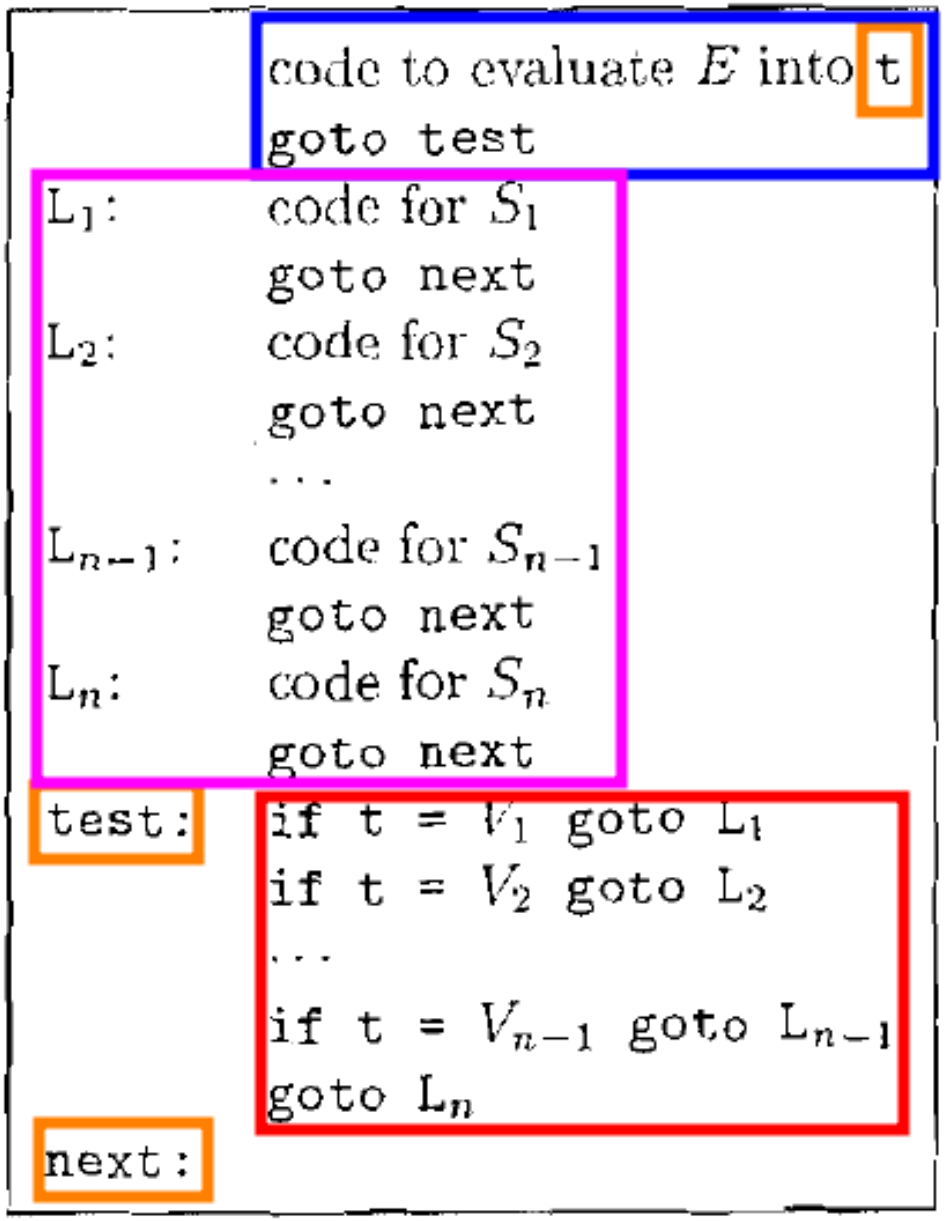
非 $C$ 语言语义 (break)

```
        code to evaluate E into t
        goto test
L_1:    code for S_1
        goto next
L_2:    code for S_2
        goto next
        ...
L_{n-1}: code for S_{n-1}
        goto next
L_n:    code for S_n
        goto next
test:   if t = V_1 goto L_1
        if t = V_2 goto L_2
        ...
        if t = V_{n-1} goto L_{n-1}
        goto L_n
next:
```

```
switch ( E ) {
    case V_1 : S_1
    case V_2 : S_2
             ...
    case V_{n-1} : S_{n-1}
    default : S_n
}
```

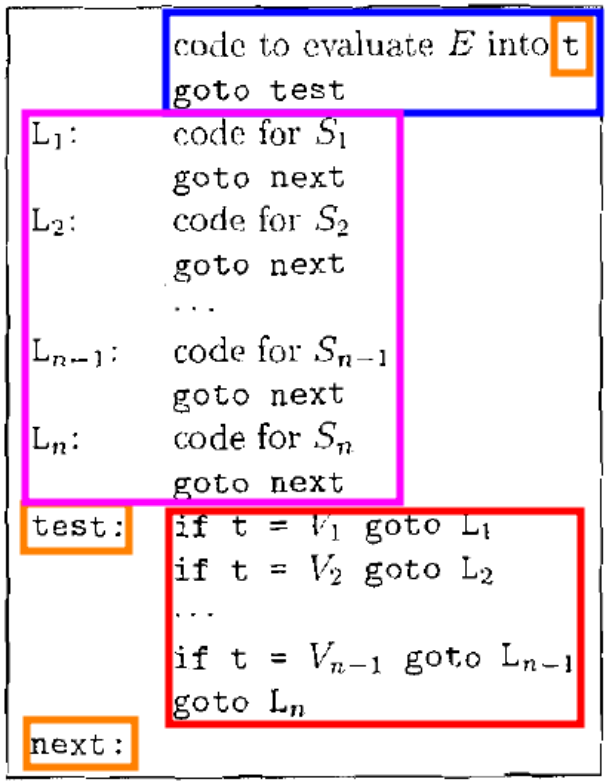
$V_i : L_i$ 队列

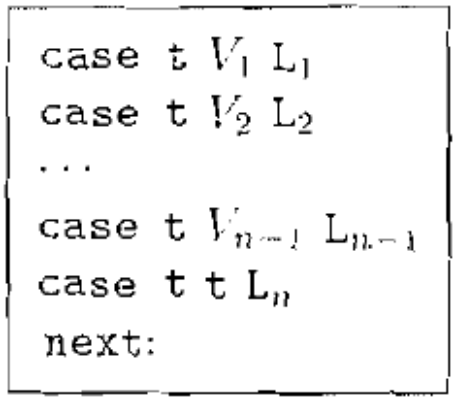
```
        code to evaluate E into t
        goto test
L_1 :   code for S_1
        goto next
L_2 :   code for S_2
        goto next
        ...
L_{n-1} : code for S_{n-1}
        goto next
L_n :   code for S_n
        goto next
test :  if t = V_1 goto L_1
        if t = V_2 goto L_2
        ...
        if t = V_{n-1} goto L_{n-1}
        goto L_n
next :
```




```
case t V1 L1
case t V2 L2
...
case t Vn-1 Ln-1
case t t Ln
next:
```

case 三地址代码


code to evaluate $E$ into t
goto test
$L_1$: code for $S_1$
goto next
$L_2$: code for $S_2$
goto next
...
$L_{n-1}$: code for $S_{n-1}$
goto next
$L_n$: code for $S_n$
goto next
test: if t = $V_1$ goto $L_1$
if t = $V_2$ goto $L_2$
...
if t = $V_{n-1}$ goto $L_{n-1}$
goto $L_n$
next:


case t $V_1$ $L_1$
case t $V_2$ $L_2$
...
case t $V_{n-1}$ $L_{n-1}$
case t t $L_n$
next:

```
        code to evaluate E into t
        goto test
L1:     code for S1
        goto next
L2:     code for S2
        goto next
        ...
Ln-1:   code for Sn-1
        goto next
Ln:     code for Sn
        goto next
test:   if t = V1 goto L1
        if t = V2 goto L2
        ...
        if t = Vn-1 goto Ln-1
        goto Ln
next:
```

```
case t V1 L1
case t V2 L2
...
case t Vn-1 Ln-1
case t t Ln
next:
```



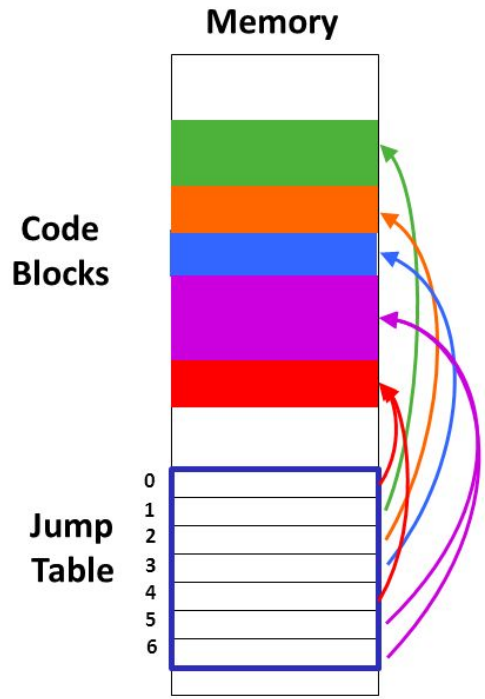
## Jump Table Structure

C code:

```
switch(x) {
  case 1: <some code>
          break;
  case 2: <some code>
  case 3: <some code>
          break;
  case 5:
  case 6: <some code>
          break;
  default: <some code>
}
```

We can use the jump table when x <= 6:

```
if (x <= 6)
  target = JTab[x];
  goto *target;
else
  goto default;
```






Jump Table 优化

# 函数/过程的中间代码翻译

```
n = f(a[i])
```

```
1)   t1 = i * 4
2)   t2 = a [ t1 ]
3)   param t2
4)   t3 = call f, 1
5)   n = t3
```

## 新增文法以支持函数定义与调用

$$
\begin{array}{lcl}
D & \rightarrow & \textbf{define}\ T\ \textbf{id}\ (\ F\ )\ \{\ S\ \} \\
F & \rightarrow & \epsilon \mid T\ \textbf{id}\ ,\ F \\
S & \rightarrow & \textbf{return}\ E\ ; \\
E & \rightarrow & \textbf{id}\ (\ A\ ) \\
A & \rightarrow & \epsilon \mid E\ ,\ A
\end{array}
$$

# 函数定义

$$
\begin{array}{lcl}
D & \rightarrow & \textbf{define}\ T\ \textbf{id}\ (\ F\ )\ \{\ S\ \} \\
F & \rightarrow & \epsilon \mid T\ \textbf{id}\ ,\ F \\
S & \rightarrow & \textbf{return}\ E\ ;
\end{array}
$$

函数名 id 放入当前符号表，建立新的符号表，处理形参 $F$ 与函数体 $S$

# 函数调用

$$E \rightarrow \boxed{\text{id} \ ( \ A \ )}$$

$$A \rightarrow \epsilon \mid E \ , \ A$$

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

# 函数调用

S::= CALL id(Elist) { S.code := Elist.code
A
|| gencode("CALL", id.place, Elist.number) }

Elist::= $Elist_1$ , E { Elist.code := E.code || $Elist_1$ .code
逆序
|| gencode("PARAM", E.place);
Elist.number := $Elist_1$ .number + 1 }

Elist::= E { Elist.code := E.code || gencode("PARAM", E.place);
Elist.number := 1 }

C 语言并未规定参数计算的顺序

# 函数调用

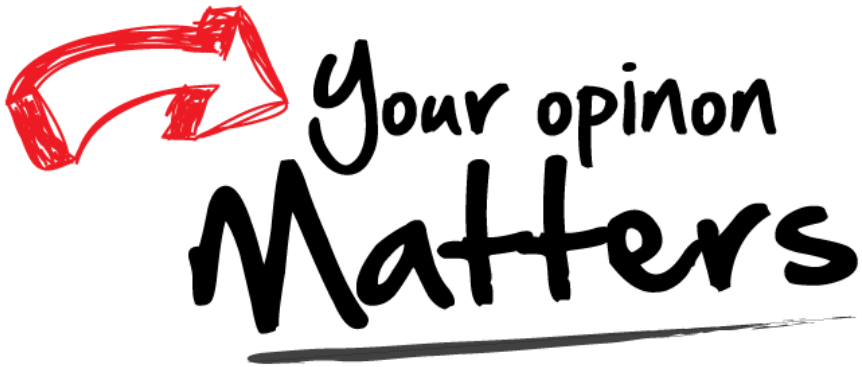
```
S::= CALL id(Elist)A
      { Count := 0; S.code := Elist.code;
        while NOT EmptyQ(q) do
        begin
           t := HeadQ(q);
           S.code := S.code || gencode("PARAM",t);
           DelQ(q); Count := Count + 1
        end;
        S.code := S.code || gencode("CALL",id.place,Coun
      }
```

逆序

```
Elist::= Elist1,E { Elist.code := E.code || Elist1.code;
                    EnterQ(E.place,q)}
Elist::= E        { Elist.code := E.code; CreateQ(q);
                    EnterQ(E.place,q)}
```

集中生成 **param** 指令, 代码更紧凑


Thank
You!

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