中间代码生成
(2. 回填技术)

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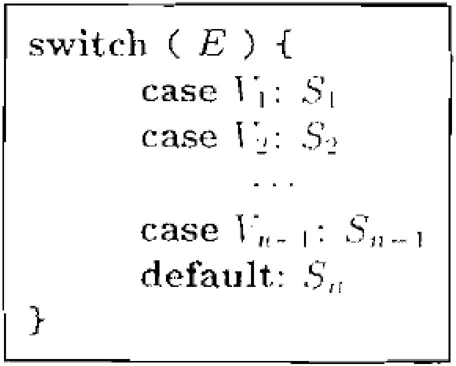
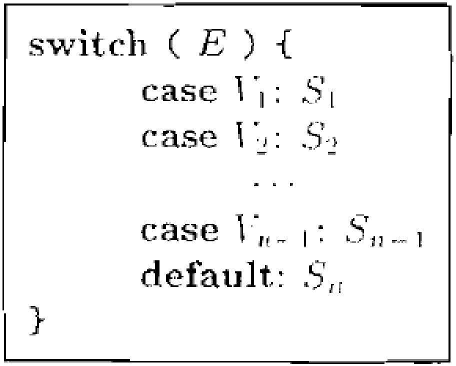
2021 年 12 月 21 日



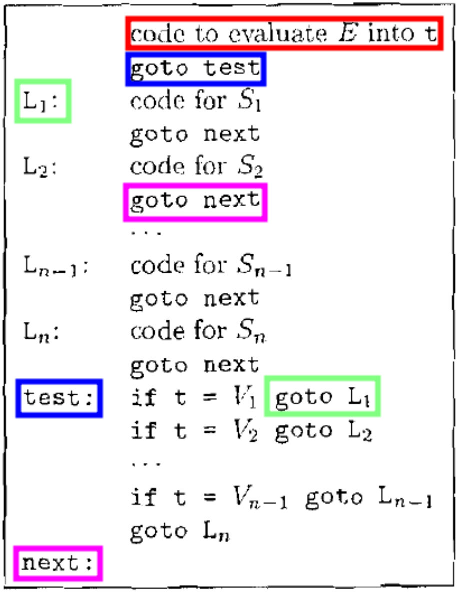
```
switch ( $E$ ) {
        case $V_1$: $S_1$
        case $V_2$: $S_2$
              ...
        case $V_{n-1}$: $S_{n-1}$
        default: $S_n$
}
```

非 C 语言语义 (`break`)

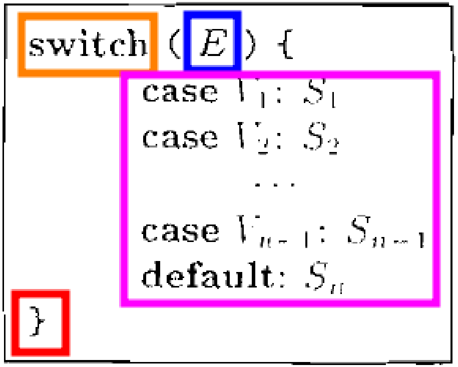


```
switch ( $E$ ) {
        case $V_1$: $S_1$
        case $V_2$: $S_2$
            ...
        case $V_{n-1}$: $S_{n-1}$
        default: $S_n$
}
```

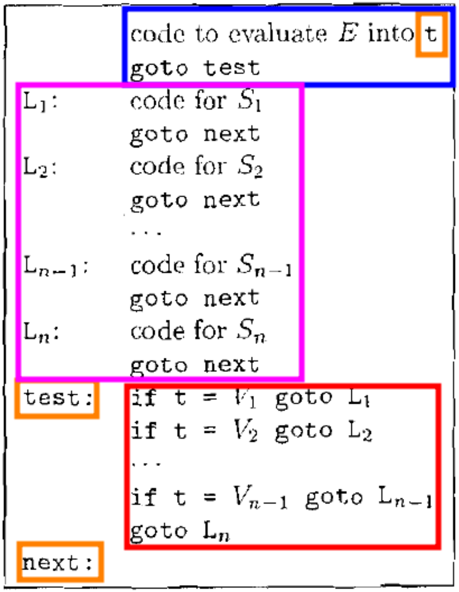
非 C 语言语义 (break)



```
            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:
```

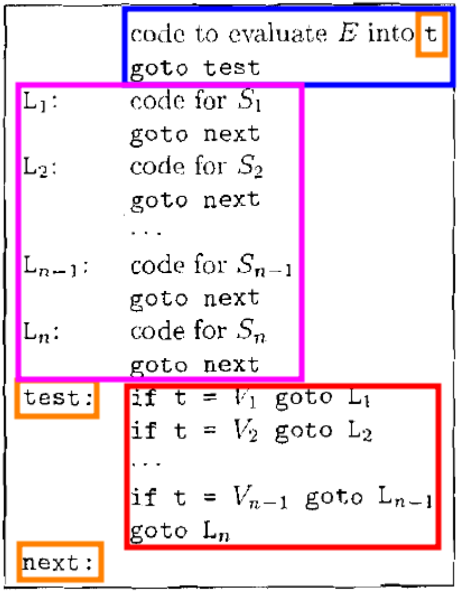


```
switch ( E ) {
        case V1: S1
        case V2: S2
            ...
        case Vn-1: Sn-1
        default: Sn
}
```

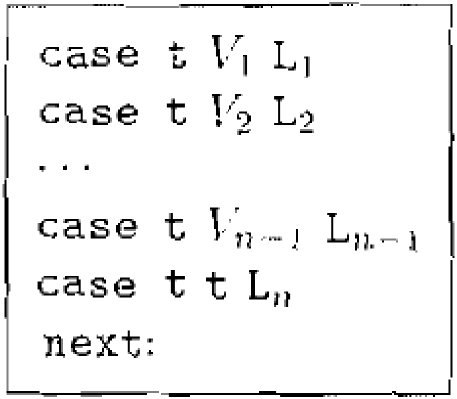


```
              code to evaluate E into t
              goto test
L1:           code for S1
              goto next
L2:           code for S2
              goto next
              ...
Ln-1:         code for Sn-1
              goto next
Ln:           code for Sn
              goto next
test:       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

$V_i : L_i$ 队列

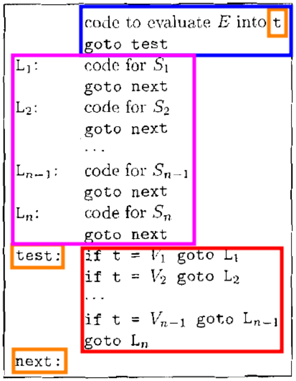


```
                code to evaluate $E$ into t
                goto test
$L_1$:          code for $S_1$
                goto next
$L_2$:          code for $S_2$
                goto next
                ...
$L_{n-1}$:      code for $S_{n-1}$
                goto next
$L_n$:          code for $S_n$
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

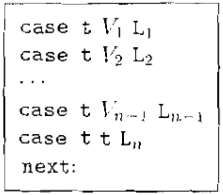


```
case t $V_1$ $L_1$
case t $V_2$ $L_2$
...
case t $V_{n-1}$ $L_{n-1}$
case t t $L_n$
next:
```

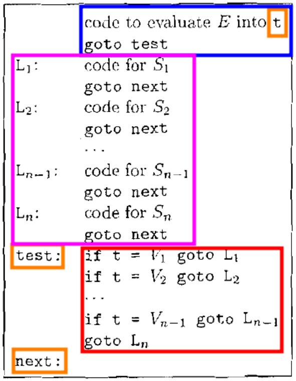
case 三地址代码



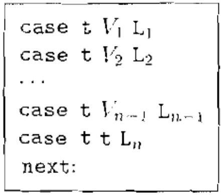
```
         code to evaluate $E$ into t
         goto test
L_1:     code for $S_1$
         goto next
L_2:     code for $S_2$
         goto next
         ...
L_{n-1}: code for $S_{n-1}$
         goto next
L_n:     code for $S_n$
         goto next
test:    if t = $V_1$ goto $L_1$
         if t = $V_2$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



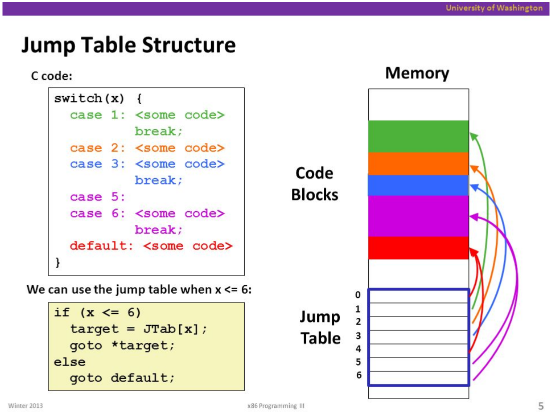
```
case t $V_1$ $L_1$
case t $V_2$ $L_2$
...
case t $V_{n-1}$ $L_{n-1}$
case t t $L_n$
next:
```



```
          code to evaluate $E$ into t
          goto test
L₁:       code for $S_1$
          goto next
L₂:       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 L₁
          if t = $V_2$ goto L₂
          ...
          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:
```



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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;
```

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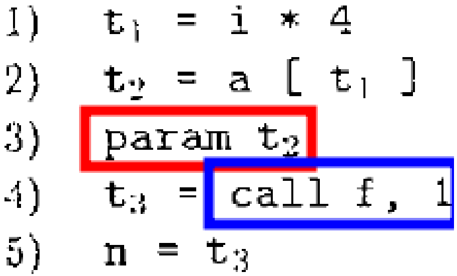
Jump Table 优化

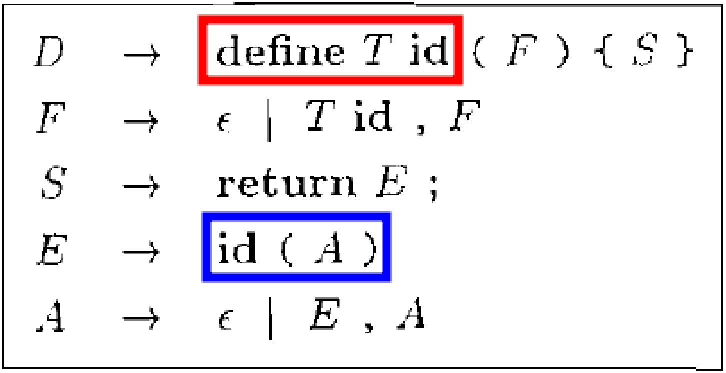
函数/过程的中间代码翻译

```
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



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

函数定义

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

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

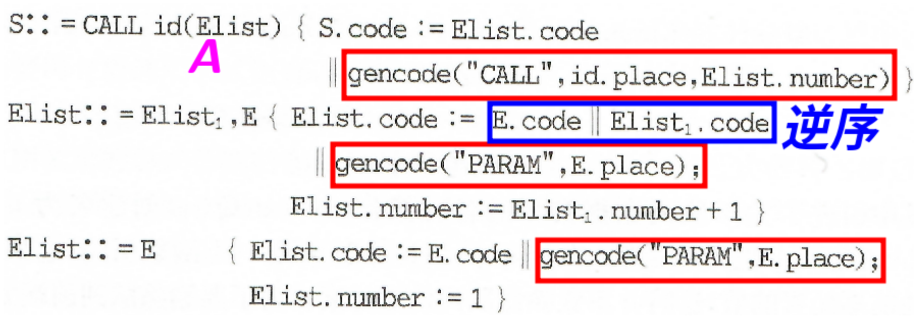
函数调用

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

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

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

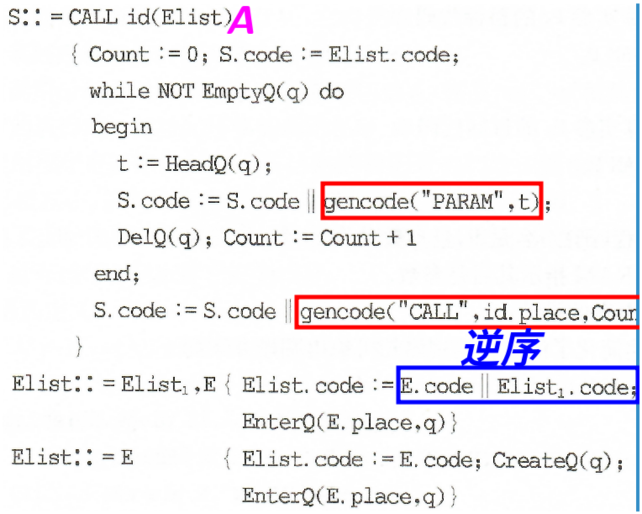
函数调用



```
S::=CALL id(Elist) { S.code := Elist.code
                        || gencode("CALL",id.place,Elist.number) }
Elist::=Elist₁,E { Elist.code := E.code || Elist₁.code
                        || gencode("PARAM",E.place);
                     Elist.number := Elist₁.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

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

B 还不知道 $S.next$ 的指令地址，如何跳转？

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

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

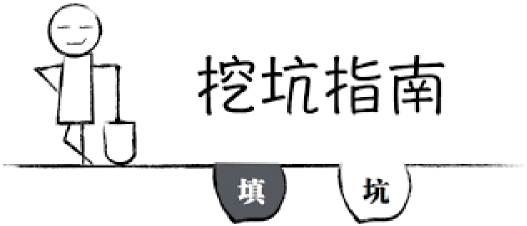
$$S \to \textbf{if} (B) S_1 \quad \left| \begin{array}{l} \boxed{B.true} = newlabel() \\ \boxed{B.false = S_1.next = S.next} \\ S.code = B.code \,||\, label(B.true) \,||\, S_1.code \end{array} \right.$$

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

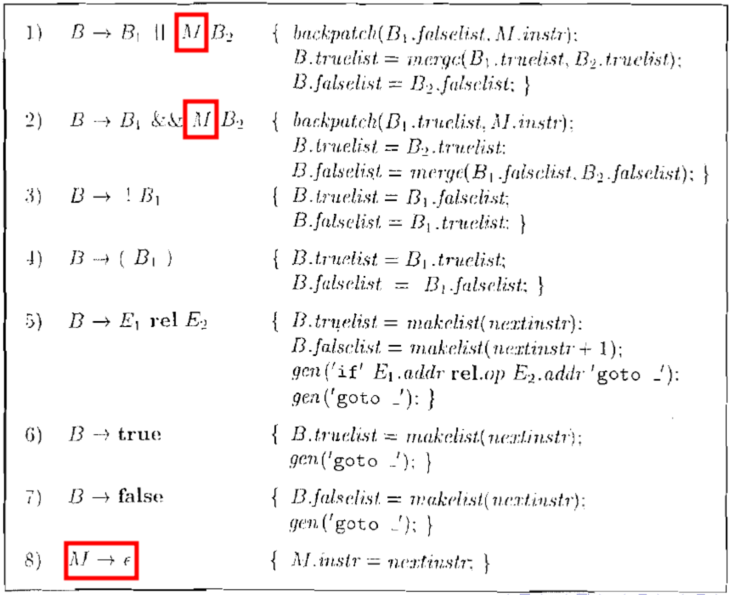
可否在生成中间代码的时候就填入指令地址?

回填 (Backpatching) 技术



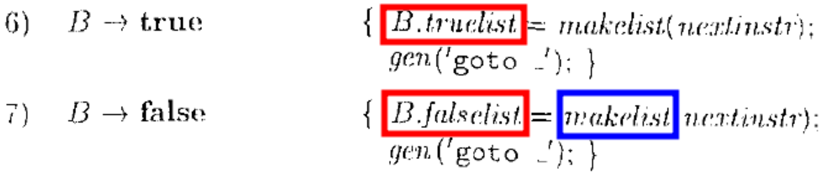
子节点挖坑、祖先节点填坑

针对布尔表达式的回填技术



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

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

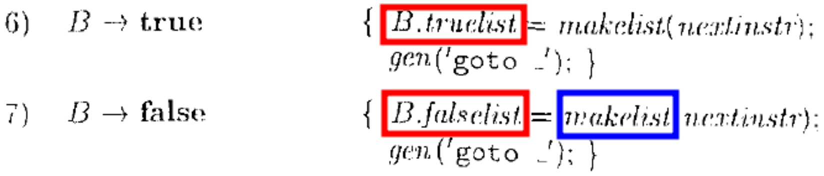


6) $B \to$ **true** $\{$ $\boxed{B.truelist} = makelist(nextinstr);$
`gen('goto _'); }`

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

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

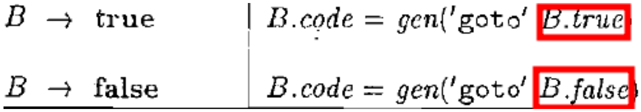
综合属性 $B.truelist$ 保存 需要跳转到 $B.true$ 的指令地址



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

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

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



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

5) $B \rightarrow E_1$ **rel** E_2 $\{$ $\boxed{B.truelist}$ $= makelist(nextinstr);$

$\boxed{B.falselist}$ $= makelist(nextinstr + 1);$

$gen($`'if'` $E_1.addr$ **rel**$.op$ $E_2.addr$ `'goto _'`$);$

$gen($`'goto _'`$);$ $\}$

$$
\begin{array}{lll|l}
B & \rightarrow & E_1 \ \mathbf{rel} \ E_2 & B.code = E_1.code \ || \ E_2.code \\
 & & & \quad || \ gen(\texttt{'if'} \ E_1.addr \ \mathbf{rel}.op \ E_2.addr \ \texttt{'goto'} \ \boxed{B.true}) \\
 & & & \quad || \ gen(\texttt{'goto'} \ \boxed{B.false})
\end{array}
$$

$$3)\quad B \to\ !\ B_1 \qquad \left\{ \boxed{\begin{array}{l} B.truelist \\ B.falselist \end{array}} \begin{array}{l} = B_1.falselist; \\ = B_1.truelist; \end{array} \right\}$$

$$4)\quad B \to (\ B_1\ ) \qquad \left\{ \boxed{\begin{array}{l} B.truelist \\ B.falselist \end{array}} \begin{array}{l} = B_1.truelist; \\ = B_1.falselist; \end{array} \right\}$$

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

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

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

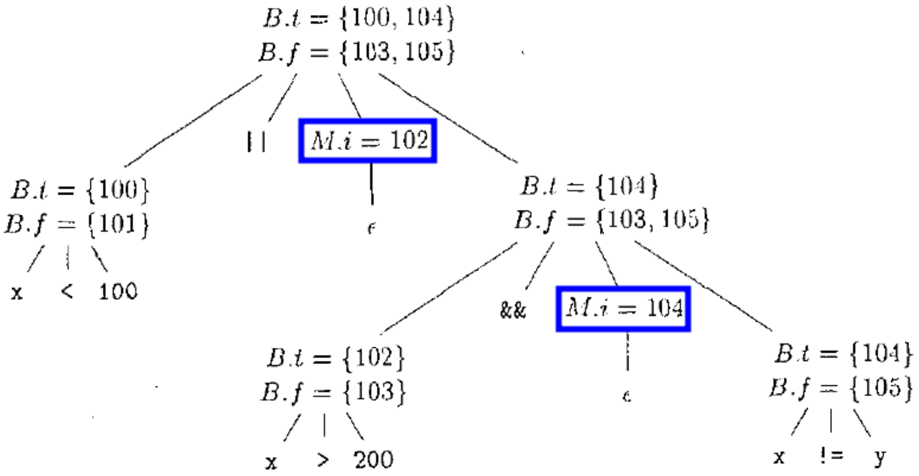
$$
B \to B_1 \;\&\&\; B_2 \quad
\begin{array}{|l}
\boxed{B_1.true = newlabel()} \\
\boxed{B_1.false} = B.false \\
B_2.true = B.true \\
\boxed{B_2.false} = B.false \\
B.code = B_1.code \;||\; label(B_1.true) \;||\; B_2.code
\end{array}
$$

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

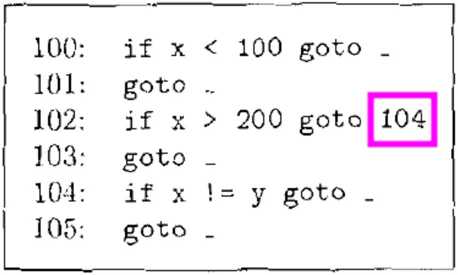
8) $\boxed{M \rightarrow \epsilon}$ $\{\ M.instr = nextinstr;\ \}$

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

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

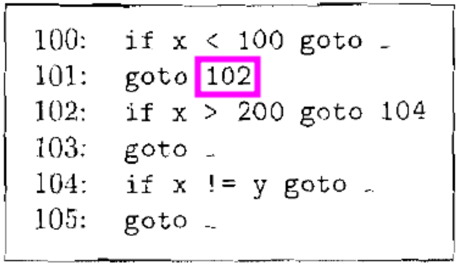


$B.t = \{100, 104\}$
$B.f = \{103, 105\}$
$B.t = \{100\}$
$B.f = \{101\}$
x < 100
||
$\boxed{M.i = 102}$
ϵ
$B.t = \{104\}$
$B.f = \{103, 105\}$
$B.t = \{102\}$
$B.f = \{103\}$
x > 200
&&
$\boxed{M.i = 104}$
ϵ
$B.t = \{104\}$
$B.f = \{105\}$
x != y



```
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

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

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

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

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

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

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

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

$$S \rightarrow \textbf{if}\,(\,B\,)\,M_1\,S_1\,N\ \textbf{else}\ M_2\,S_2$$

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

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

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

$$S \rightarrow \textbf{if}\,(\,B\,)\,M_1\,S_1\,N\ \textbf{else}\ M_2\,S_2$$

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

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

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

$$S \rightarrow \textbf{if}\,(\,B\,)\,S_1\ \textbf{else}\ S_2 \quad \left|\ \begin{aligned}
& B.\mathit{true} = \mathit{newlabel}()\\
& B.\mathit{false} = \mathit{newlabel}()\\
& \boxed{S_1.\mathit{next} = S_2.\mathit{next} = S.\mathit{next}}\\
& S.\mathit{code} = B.\mathit{code}\\
& \qquad\qquad \|\ \mathit{label}(B.\mathit{true})\ \|\ S_1.\mathit{code}\\
& \qquad\qquad \|\ \boxed{\mathit{gen}(\texttt{'goto'}\ S.\mathit{next})}\\
& \qquad\qquad \|\ \mathit{label}(B.\mathit{false})\ \|\ S_2.\mathit{code}
\end{aligned}\right.$$

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

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

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

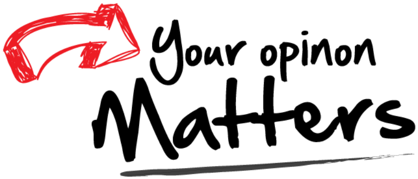
$$
\begin{aligned}
3)\quad S \rightarrow\ & \textbf{while}\ M_1\ (\ B\ )\ M_2\ S_1 \\
& \{\ \boxed{backpatch}(S_1.nextlist,\ M_1.instr); \\
& \quad \boxed{backpatch}(B.truelist,\ M_2.instr); \\
& \quad \boxed{S.nextlist} = B.falselist; \\
& \quad gen(\text{'goto'}\ M_1.instr);\ \}
\end{aligned}
$$

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

$$
S \rightarrow \textbf{while}\ (\ B\ )\ S_1 \quad
\left|\
\begin{aligned}
& begin = newlabel() \\
& B.true = newlabel() \\
& B.false = S.next \\
& \boxed{S_1.next} = begin \\
& S.code = label(begin)\ \|\ B.code \\
& \qquad\qquad \|\ label(B.true)\ \|\ S_1.code \\
& \qquad\qquad \|\ \boxed{gen(\text{'goto'}\ begin)}
\end{aligned}
\right.
$$

4)	$S \rightarrow \{ L \}$	$\{ S.nextlist = L.nextlist; \}$
5)	$S \rightarrow A ;$	$\{ \boxed{S.nextlist = \textbf{null};} \}$
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)	$L \rightarrow S$	$\{ L.nextlist = S.nextlist; \}$

Thank
You!



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