中间代码生成
(2. 回填技术)

魏恒峰

hfwei@nju.edu.cn

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

B 还不知道 $S.next$ 的指令地址，如何跳转？

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

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

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

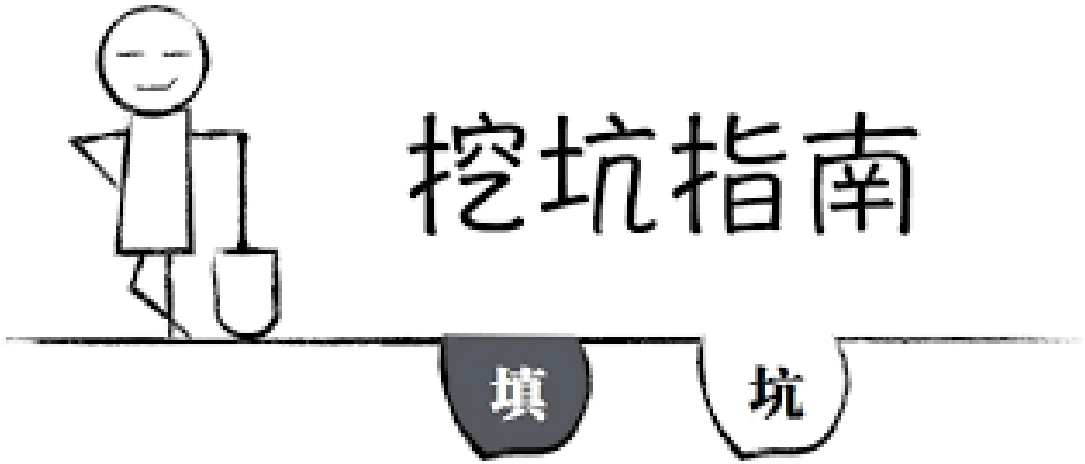
$S \rightarrow \textbf{if}\ (\ B\ )\ S_1$	$B.true = newlabel()$ $B.false = S_1.next = S.next$ $S.code = B.code \mid\mid label(B.true) \mid\mid S_1.code$

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

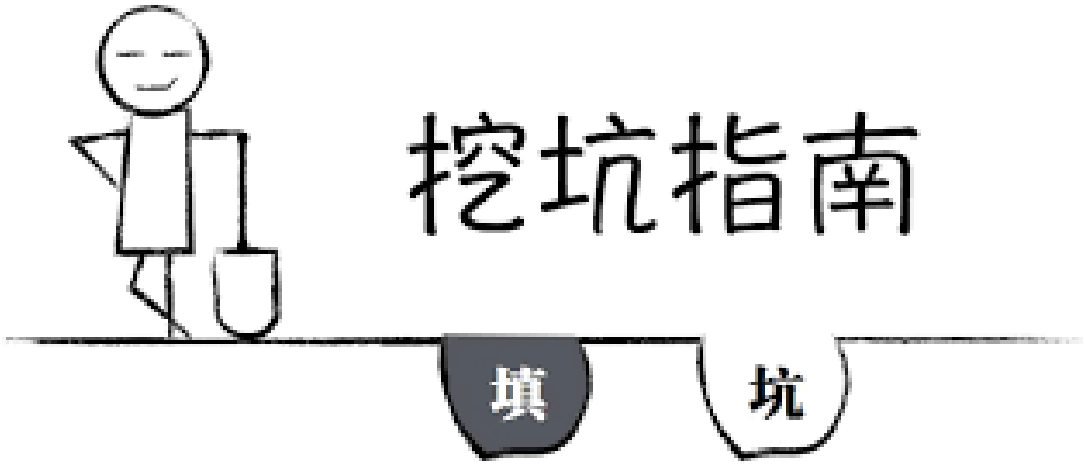
可否在生成中间代码的时候就填入指令地址？

回填 (Backpatching) 技术



子节点挖坑、祖先节点填坑

回填 (Backpatching) 技术

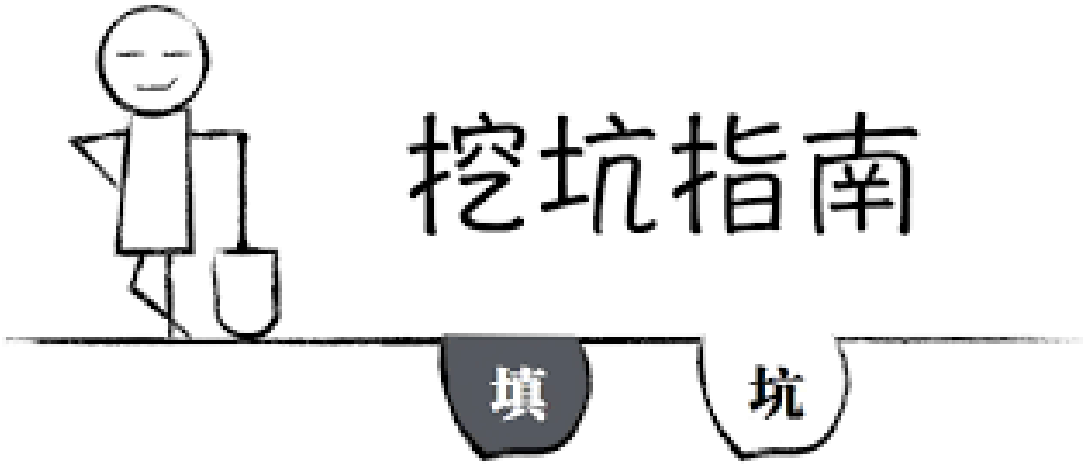


子节点挖坑、祖先节点填坑

子节点暂时不指定跳转指令的目标

待祖先节点能够确定正确的目标地址时回头填充

回填 (Backpatching) 技术



子节点挖坑、祖先节点填坑

子节点暂时不指定跳转指令的目标

待祖先节点能够确定正确的目标地址时回头填充

父节点通过**综合属性**收集子节点中具有相同目标的跳转指令

在自底向上的分析过程中

为左部非终结符 B 计算综合属性 B.truelist 与 B.falselist

为左部非终结符 S/L 计算综合属性 S/L.nextlist

并为已能确定目标地址的跳转指令进行回填 (考虑每个综合属性)

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

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

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

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

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

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

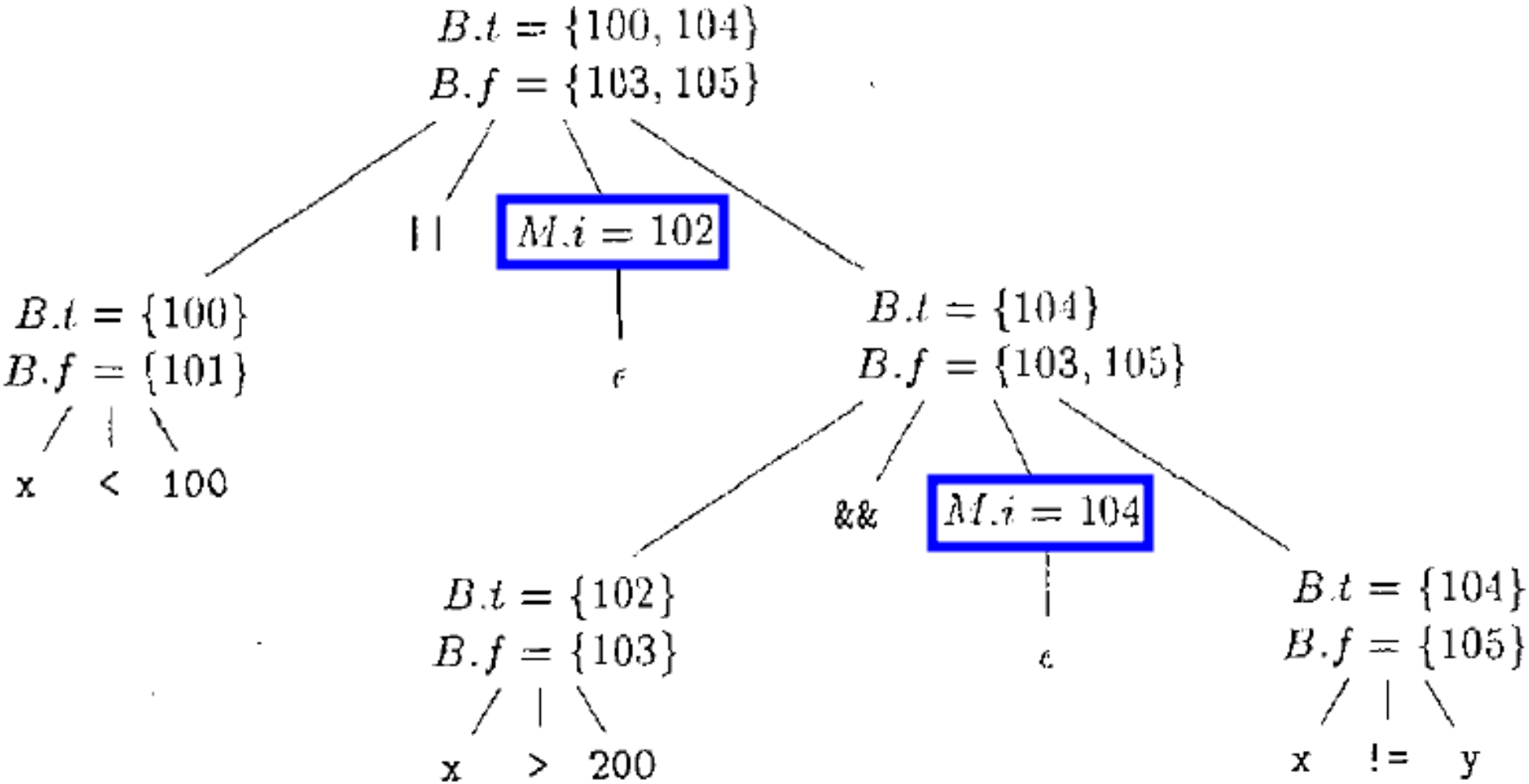
1) $B \rightarrow B_1 \;||\; M \; B_2$ { $backpatch(B_1.falselist, M.instr)$;
$B.truelist = merge(B_1.truelist, B_2.truelist)$;
$B.falselist = B_2.falselist$; }

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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('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*('goto' *begin*)

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

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

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

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

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

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

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

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

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

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

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

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

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

只有 (3) 与 (7) 生成了新的代码, 控制流语句的主要目的是“控制”流。

```
1: procedure AreYouOK(score)
2:     if score ≥ 60 then
3:         while true do
4:             print "Happy New Year"
5:     else
6:         print "Sad"
```

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

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

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

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

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

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

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

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

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

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

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

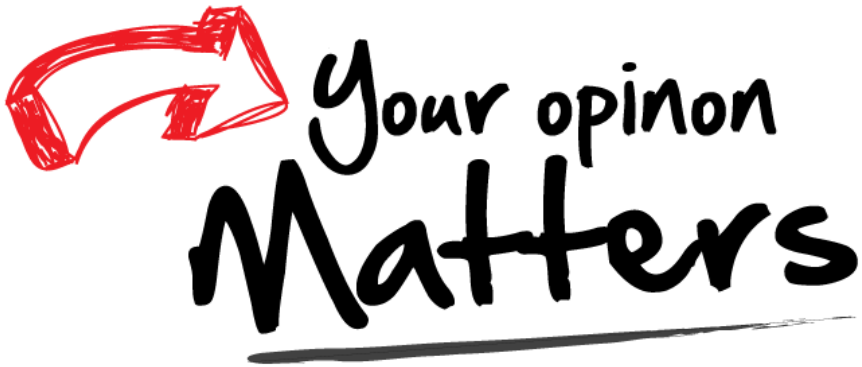
{ $backpatch(S_1.nextlist,\ M_1.instr)$;
$backpatch(B.truelist,\ M_2.instr)$;
$S.nextlist\ =\ B.falselist$;
$gen('\texttt{goto}'\ M_1.instr)$; }

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

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

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


Thank
You!



Office 926

hfwei@nju.edu.cn