Compiler
--- Intermediate Code Generation

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Role I

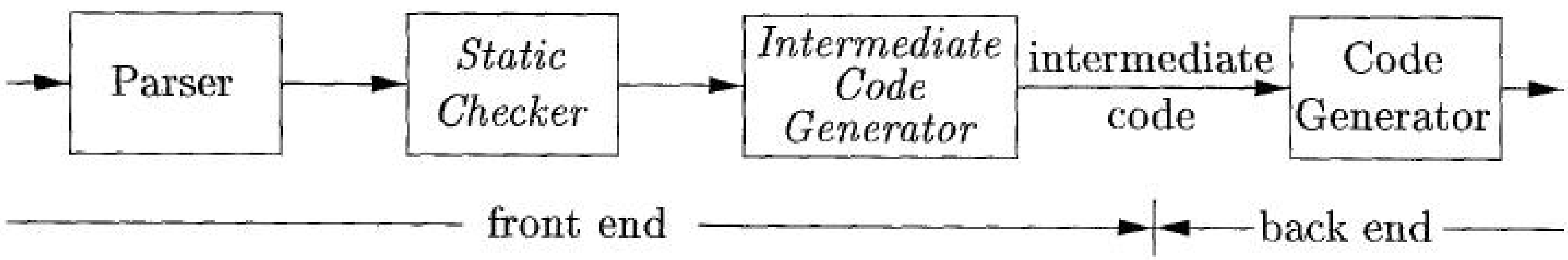
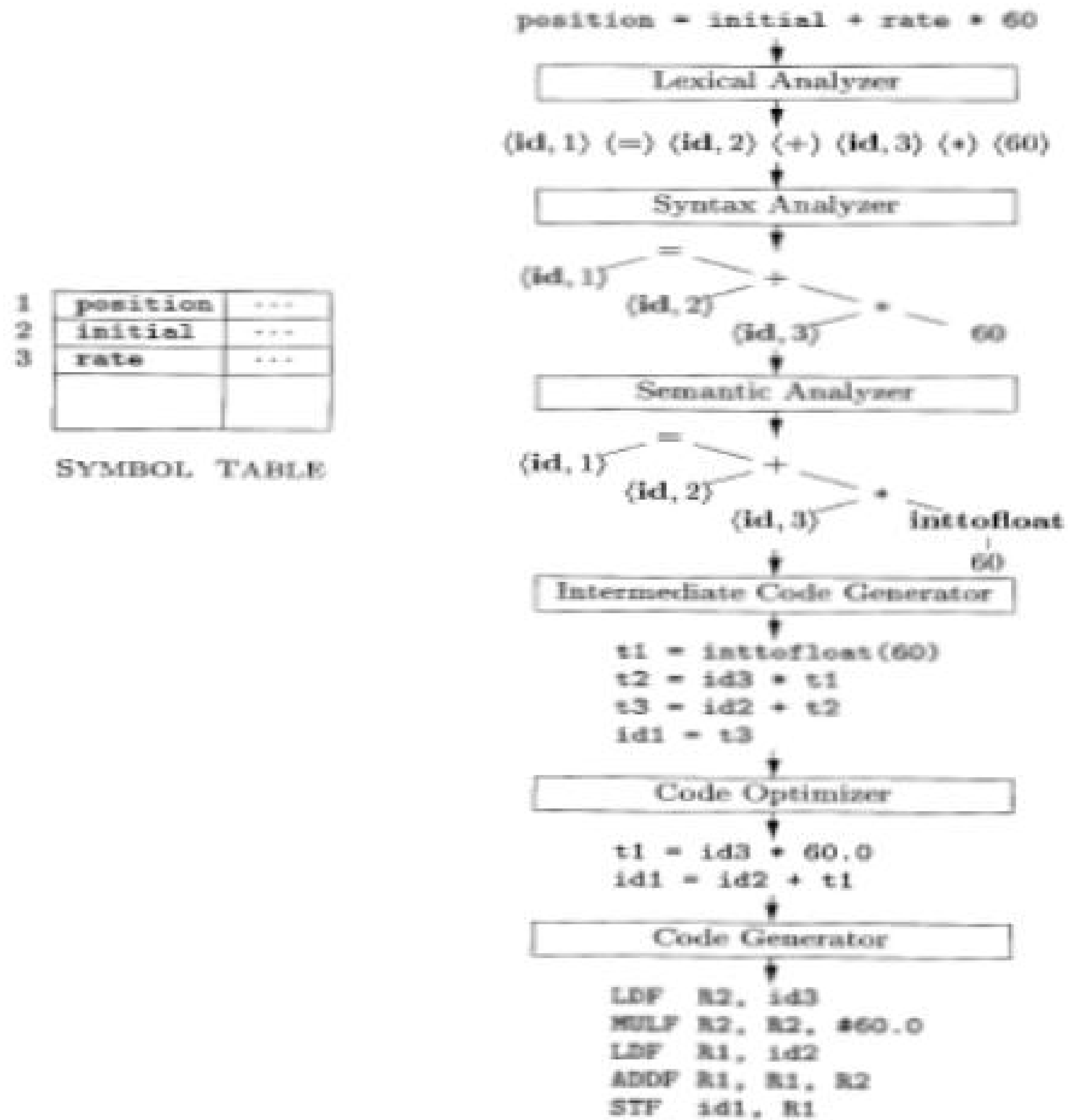


Figure 6.1: Logical structure of a compiler front end

Role II


position = initial + rate * 60
Lexical Analyzer
⟨id, 1⟩ ⟨=⟩ ⟨id, 2⟩ ⟨+⟩ ⟨id, 3⟩ ⟨*⟩ ⟨60⟩
Syntax Analyzer
Semantic Analyzer
inttofloat
Intermediate Code Generator
t1 = inttofloat(60)
t2 = id3 * t1
t3 = id2 + t2
id1 = t3
Code Optimizer
t1 = id3 * 60.0
id1 = id2 + t1
Code Generator
LDF R2, id3
MULF R2, R2, #60.0
LDF R1, id2
ADDF R1, R1, R2
STF id1, R1
1 position
2 initial
3 rate
SYMBOL TABLE

Why Use Intermediate code

- Facilitate Portability
- Facilitate Opertimization
  - $E \rightarrow E1 * Digit$ has E.val=E1.val $\times$ Digit.val

    Digit.type=E1.type

    E.code=E1.code '$*$' Digit.code

How to implement

- Utilize semantics rule to evaluate the "code" attribute
  - $E \rightarrow E1 * Digit$ has $E.val = E1.val \times Digit.val$

    $Digit.type = E1.type$

    $E.code = E1.code$ '$*$' $Digit.code$

Example

PRODUCTION	SEMANTIC RULES
$S \rightarrow \textbf{id} = E\ ;$	$S.code = E.code \ \|\|$ $gen(top.get(\textbf{id}.lexeme)\ '='\ E.addr)$
$E \rightarrow E_1 + E_2$	$E.addr = \textbf{new}\ Temp\,()$ $E.code = E_1.code \ \|\|\ E_2.code \ \|\|$ $gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr)$
$\mid\ - E_1$	$E.addr = \textbf{new}\ Temp\,()$ $E.code = E_1.code \ \|\|$ $gen(E.addr\ '='\ '\textbf{minus}'\ E_1.addr)$
$\mid\ (\ E_1\ )$	$E.addr = E_1.addr$ $E.code = E_1.code$
$\mid\ \textbf{id}$	$E.addr = top.get(\textbf{id}.lexeme)$ $E.code = ''$

Figure 6.19: Three-address code for expressions

Example 6.11: The syntax-directed definition in Fig. 6.19 translates the assignment statement `a = b + - c ;` into the three-address code sequence

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

Intermediate Representation: Three address code

1. Assignment instructions of the form $x = y \ op \ z$, where *op* is a binary arithmetic or logical operation, and x, y, and z are addresses.

2. Assignments of the form $x = op \ y$, where *op* is a unary operation. Essential unary operations include unary minus, logical negation, shift operators, and conversion operators that, for example, convert an integer to a floating-point number.

3. *Copy instructions* of the form $x = y$, where x is assigned the value of y.

4. An unconditional jump `goto` L. The three-address instruction with label L is the next to be executed.

5. Conditional jumps of the form `if` x `goto` L and `ifFalse` x `goto` L. These instructions execute the instruction with label L next if x is true and false, respectively. Otherwise, the following three-address instruction in sequence is executed next, as usual.

6. Conditional jumps such as `if` x *relop* y `goto` L, which apply a relational operator (<, ==, >=, etc.) to x and y, and execute the instruction with label L next if x stands in relation *relop* to y. If not, the three-address instruction following `if` x *relop* y `goto` L is executed next, in sequence.

7. Procedure calls and returns are implemented using the following instructions: `param` x for parameters; `call` p, n and y = `call` p, n for procedure and function calls, respectively; and `return` y, where y, representing a returned value, is optional. Their typical use is as the sequence of three-address instructions

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

8. Indexed copy instructions of the form $x = y[i]$ and $x[i] = y$. The instruction $x = y[i]$ sets x to the value in the location i memory units beyond location y. The instruction $x[i] = y$ sets the contents of the location i units beyond x to the value of y.

9. Address and pointer assignments of the form $x = \&y$, $x = *y$, and $*x = y$. The instruction $x = \&y$ sets the r-value of x to be the location (l-value) of y.[2] Presumably y is a name, perhaps a temporary, that denotes an expression with an l-value such as `A[i][j]`, and x is a pointer name or temporary. In the instruction $x = *y$, presumably y is a pointer or a temporary whose r-value is a location. The r-value of x is made equal to the contents of that location. Finally, $*x = y$ sets the r-value of the object pointed to by x to the r-value of y.

Example 6.5: Consider the statement

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

array of elements that each take 8 units of space.

L: t_1 = i + 1	100: t_1 = i + 1
i = t_1	101: i = t_1
t_2 = i * 8	102: t_2 = i * 8
t_3 = a [t_2]	103: t_3 = a [t_2]
if t_3 < v goto L	104: if t_3 < v goto 100
(a) Symbolic labels.	(b) Position numbers.

Two ways of assigning labels to three-address statements

Data Structure of Three Address Code I

□Quadruples

A *quadruple* (or just "*quad*") has four fields, which we call *op*, arg_1, arg_2, and *result*. The *op* field contains an internal code for the operator. For instance, the three-address instruction $x = y + z$ is represented by placing + in *op*, y in arg_1, z in arg_2, and x in *result*. The following are some exceptions to this rule:

1. Instructions with unary operators like x = `minus` y or $x = y$ do not use arg_2. Note that for a copy statement like $x = y$, *op* is =, while for most other operations, the assignment operator is implied.

2. Operators like `param` use neither arg_2 nor *result*.

3. Conditional and unconditional jumps put the target label in *result*.

Data Structure of Three Address Code I

- Example

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

(a) Three-address code

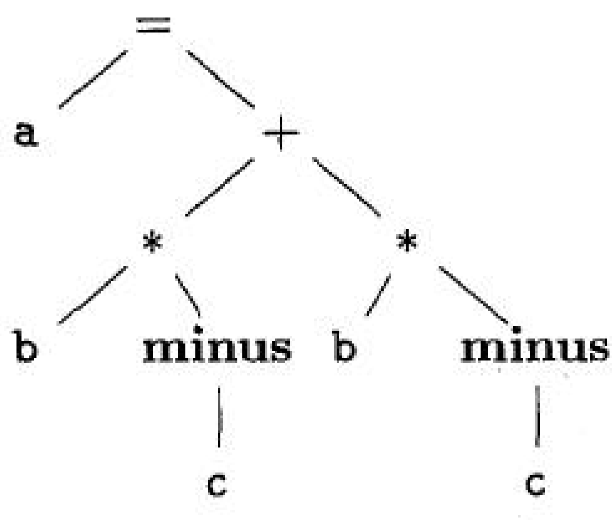
	op	*arg*$_1$	*arg*$_2$	*result*
0	minus	c		t_1
1	*	b	t_1	t_2
2	minus	c		t_3
3	*	b	t_3	t_4
4	+	t_2	t_4	t_5
5	=	t_5		a
		...		

(b) Quadruples

Figure 6.10: Three-address code and its quadruple representation

Data Structure of Three Address Code II

- Triples



(a) Syntax tree

	op	arg_1	arg_2
0	minus	c	
1	*	b	(0)
2	minus	c	
3	*	b	(2)
4	+	(1)	(3)
5	=	a	(4)
		...	

(b) Triples

Figure 6.11: Representations of $a + a * (b - c) + (b - c) * d$

Data Structure of Three Address Code III

- Indirect Triples

	instruction
35	(0)
36	(1)
37	(2)
38	(3)
39	(4)
40	(5)
	...

	op	arg_1	arg_2
0	minus	c	
1	*	b	(0)
2	minus	c	
3	*	b	(2)
4	+	(1)	(3)
5	=	a	(4)
		...	

Figure 6.12: Indirect triples representation of three-address code

Data Structure of Three Address Code I

- Example

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

(a) Three-address code

	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
		...		

(b) Quadruples

Figure 6.10: Three-address code and its quadruple representation

Translation of common statements I

- Expression

PRODUCTION	SEMANTIC RULES
$S \rightarrow \textbf{id} = E\ ;$	$S.code = E.code \;\|\|$ $gen(top.get(\textbf{id}.lexeme)\ '='\ E.addr)$
$E \rightarrow E_1 + E_2$	$E.addr = \textbf{new}\ Temp\,()$ $E.code = E_1.code \;\|\|\; E_2.code \;\|\|$ $gen(E.addr\ '='\ E_1.addr\ '+'\ E_2.addr)$
$\quad \mid\ - E_1$	$E.addr = \textbf{new}\ Temp\,()$ $E.code = E_1.code \;\|\|$ $gen(E.addr\ '='\ '\textbf{minus}'\ E_1.addr)$
$\quad \mid\ (\ E_1\ )$	$E.addr = E_1.addr$ $E.code = E_1.code$
$\quad \mid\ \textbf{id}$	$E.addr = top.get(\textbf{id}.lexeme)$ $E.code = ''$

Figure 6.19: Three-address code for expressions

Translation of common statements I

Example

Example 6.11: The syntax-directed definition in Fig. 6.19 translates the assignment statement `a = b + - c;` into the three-address code sequence

$$
\begin{aligned}
&\mathtt{t}_1 = \mathtt{minus}\ \mathtt{c} \\
&\mathtt{t}_2 = \mathtt{b} + \mathtt{t}_1 \\
&\mathtt{a} = \mathtt{t}_2
\end{aligned}
$$

Translation of common statements II

- Array

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

Array starts from [0][0]

Figure 6.22: Semantic actions for array references

Translation of common statements II

Example

Example 6.12: Let `a` denote a 2×3 array of integers, and let `c`, `i`, and `j` all denote integers. Then, the type of `a` is $array(2, array(3, integer))$. Its width w is 24, assuming that the width of an integer is 4. The type of `a[i]` is $array(3, integer)$, of width $w_1 = 12$. The type of `a[i][j]` is *integer*.

a [0...1, 0...2]

Translation of common statements II

Example (Cont.)

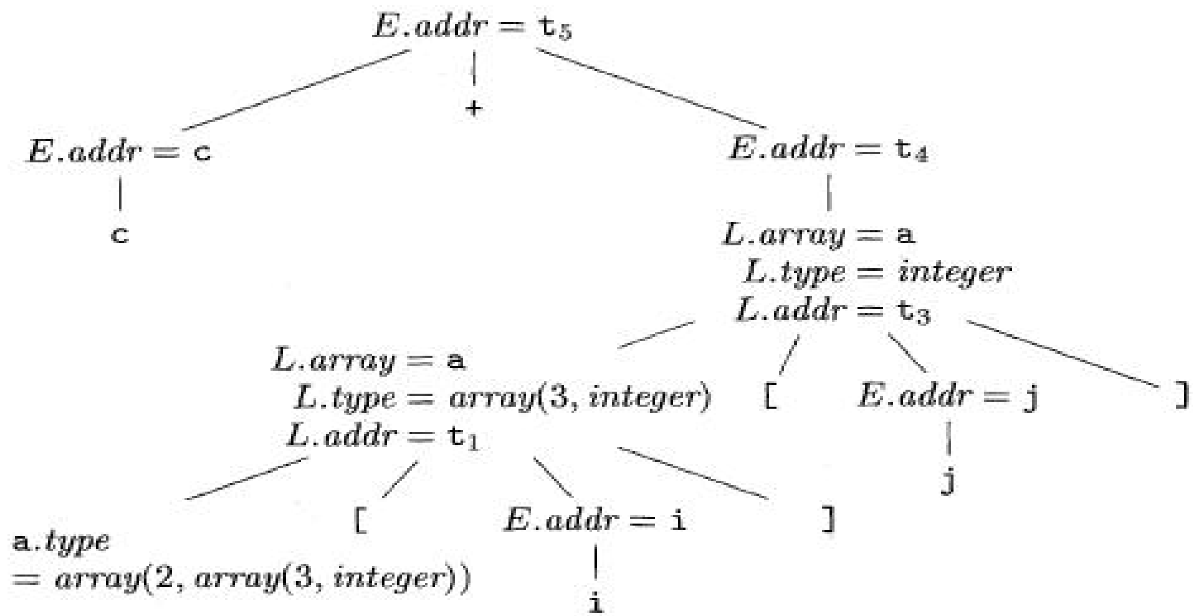


Figure 6.23: Annotated parse tree for c+a[i][j]

$$
\begin{aligned}
t_1 &= i * 12 \\
t_2 &= j * 4 \\
t_3 &= t_1 + t_2 \\
t_4 &= a [t_3] \\
t_5 &= c + t_4
\end{aligned}
$$

Figure 6.24: Three-address code for expression c+a[i][j]

Translation of common statements III

- Flow-of-Control statements

$$
\begin{array}{lcl}
S & \rightarrow & \textbf{if} \; (\; B \;) \; S_1 \\
S & \rightarrow & \textbf{if} \; (\; B \;) \; S_1 \; \textbf{else} \; S_2 \\
S & \rightarrow & \textbf{while} \; (\; B \;) \; S_1
\end{array}
$$

$$
B \rightarrow B \; || \; B \; \mid \; B \; \&\& \; B \; \mid \; ! \, B \; \mid \; (\; B \;) \; \mid \; E \; \textbf{rel} \; E \; \mid \; \textbf{true} \; \mid \; \textbf{false}
$$

Translation of common statements III

- Coding Approaches

Two ways:

1)**Short Circuit(Jumping) codes**, where .code is managed as inherited attribute.

2)**Backpatching codes**, where .code is managed as synthesized attribute.

Translation of common statements III

□Short Circuit Encoding I

① For Boolean Expression

In *short-circuit* (or *jumping*) code, the boolean operators &&, ||, and ! translate into jumps. The operators themselves do not appear in the code; instead, the value of a boolean expression is represented by a position in the code sequence.

Translation of common statements III

- Short Circuit Encoding I

① For Boolean Expression Example

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

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

ifFalse is allowed

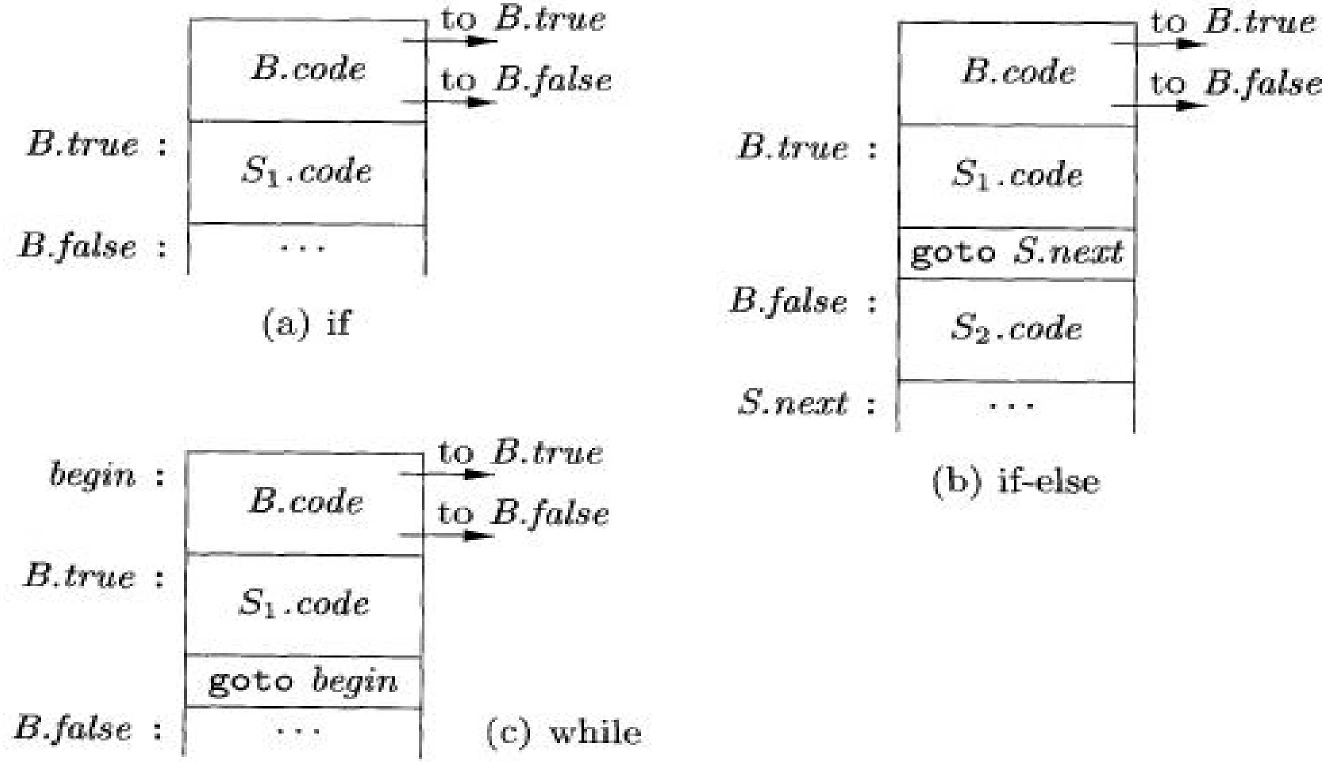
```
        if x < 100 goto L2
        goto L3
L3:     if x > 200 goto L4
        goto L1
L4:     if x != y goto L2
        goto L1
L2:     x = 0
L1:
```

ifFalse is not allowed

Translation of common statements III

□Short Circuit Encoding II

② For Flow Control



(a) if

(b) if-else

(c) while

Translation of common statements III

□Short Circuit Encoding II

② For Flow Control example

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

	if x < 100 goto L_2
	goto L_3
L_3:	if x > 200 goto L_4
	goto L_1
L_4:	if x != y goto L_2
	goto L_1
L_2:	x = 0
L_1:	ifFalse is not allowed

Translation of common statements III

- Short Circuit Encoding III

③ Semantics Rules

PRODUCTION	SEMANTIC RULES
$P \rightarrow S$	$S.next = newlabel()$ $P.code = S.code \mathbin{\Vert} label(S.next)$
$S \rightarrow \mathbf{assign}$	$S.code = \mathbf{assign}.code$
$S \rightarrow \mathbf{if}\ (\ B\ )\ S_1$	$B.true = newlabel()$ $B.false = S_1.next = S.next$ $S.code = B.code \mathbin{\Vert} label(B.true) \mathbin{\Vert} S_1.code$
$S \rightarrow \mathbf{if}\ (\ B\ )\ S_1\ \mathbf{else}\ S_2$	$B.true = newlabel()$ $B.false = newlabel()$ $S_1.next = S_2.next = S.next$ $S.code = B.code$ $\mathbin{\Vert} label(B.true) \mathbin{\Vert} S_1.code$ $\mathbin{\Vert} gen(\text{'goto'}\ S.next)$ $\mathbin{\Vert} label(B.false) \mathbin{\Vert} S_2.code$
$S \rightarrow \mathbf{while}\ (\ B\ )\ S_1$	$begin = newlabel()$ $B.true = newlabel()$ $B.false = S.next$ $S_1.next = begin$ $S.code = label(begin) \mathbin{\Vert} B.code$ $\mathbin{\Vert} label(B.true) \mathbin{\Vert} S_1.code$ $\mathbin{\Vert} gen(\text{'goto'}\ begin)$
$S \rightarrow S_1\ S_2$	$S_1.next = newlabel()$ $S_2.next = S.next$ $S.code = S_1.code \mathbin{\Vert} label(S_1.next) \mathbin{\Vert} S_2.code$

PRODUCTION	SEMANTIC RULES
$B \rightarrow B_1 \;\|\|\; B_2$	$B_1.true = B.true$ $B_1.false = newlabel()$ $B_2.true = B.true$ $B_2.false = B.false$ $B.code = B_1.code \;\|\|\; label(B_1.false) \;\|\|\; B_2.code$
$B \rightarrow B_1 \;\&\&\; B_2$	$B_1.true = newlabel()$ $B_1.false = B.false$ $B_2.true = B.true$ $B_2.false = B.false$ $B.code = B_1.code \;\|\|\; label(B_1.true) \;\|\|\; B_2.code$
$B \rightarrow \; ! \; B_1$	$B_1.true = B.false$ $B_1.false = B.true$ $B.code = B_1.code$
$B \rightarrow E_1 \; \mathbf{rel} \; E_2$	$B.code = E_1.code \;\|\|\; E_2.code$ $\quad \|\| \; gen('\texttt{if}' \; E_1.addr \; \mathbf{rel}.op \; E_2.addr \; '\texttt{goto}' \; B.true)$ $\quad \|\| \; gen('\texttt{goto}' \; B.false)$
$B \rightarrow \mathbf{true}$	$B.code = gen('\texttt{goto}' \; B.true)$
$B \rightarrow \mathbf{false}$	$B.code = gen('\texttt{goto}' \; B.false)$

Case Analysis

```
i=1;
tag=0;
while (tag==0 && i<=10) do
{
  j=1;
 while (tag==0 && j<=10) do
   if (a[i,j]==x) tag=1;
   else j=j+1;
 if (tag==0) i=i+1
}
```

Jumping codes.
a starts from a[1][1] and one element of it occupies one unit.

```
i=1
tag=0
L1:  if (tag==0) goto L2
     goto L3
L2:  if (i<=10) goto L4
     goto L3
L4:  j=1
L5:  if (tag==0) goto L6
     goto L7
L6:  if (j<=10) goto L8
     goto L7
```

```
L8: t1=addrA-11
     t2=i*10
     t3=t2+j
     t4=t1[t3]
     if (t4==x) goto L9
     goto L10
L9: tag=1
     goto L11
L10: t5=j+1
     j=t5
L11: goto L5
```

```
L7: if (tag==0) goto L12
     goto L13
L12: t6=i+1
     i=t6
L13: goto L1
L3:
```

Jumping codes

A starts from a[1][1]

Backpatching &Using Quadruples

(1) (=,1,_,i)

(2) (=,0,_,tag)

(3) (j==,tag,0,(5))

(4) (j,_,_,~~0~~(28))

(5) (j<=,i,10,(7))

(6) (j,_,_,~~4~~(28))

(7) (=,1,_,j)

(8) (j==,tag,0,(10))

(9) (j,_,_,~~0~~(23))

(10) (j<=,j,10,(12))

(11) (j,_,_,~~9~~(23))

(12) (-,addrA,11,t1)

(13) (*,i,10,t2)

(14) (+,t2,j,t3)

(15) (=[],t1[t3],_,t4)

(16) (j==,t4,x,(18))

(17) (j,_,_,(20))

(18) (=,1,_,tag)

(19) (j,_,_,(22))

(20) (+,j,1,t5)

(21) (=,t5,_,j)

(22) (j,_,_,(8))

(23) (j==,tag,0,(25))

(24) (j,_,_,(27))

(25) (+,i,1,t6)

(26) (=,t6,_,i)

(27) (j,_,_,(3))

(28)

Appendix Backpatching

1.Why and what is backpatching?

- When generating code for boolean expressions and flow-of-control statements , we may not know the labels that control must go to.
- We can get around this problem by generating a series of branching statement with the targets of the jumps temporarily left unspecified.
- Each such statement will be put on a list of goto statements whose labels will be filled in when the proper label can be determined.
- This subsequent filling in of labels is called backpatching

2.Functions to manipulate lists of labels related to backpatching

- Makelist(i)
  - Creates a new list containing only i, an index into the array of quadruples; makelist returns a pointer to the list it has made.
- Merge(p1,p2)
  - Concatenates the lists pointed to by p1 and p2, and returns a pointer to the concatenated list.
- Backpatch(p,i)
  - Inserts i as the target label for each of the statements on the list pointed to by p.

3.Boolean expression

1)Modify the grammar

$E \rightarrow E^A E \mid E^0 E \mid \text{not } E \mid (E) \mid i \mid E_a \text{ rop } E_a$

$E^A \rightarrow E \text{ and}$

$E^0 \rightarrow E \text{ or}$

2)Semantic Rules

(1) $E \rightarrow i$ {E•TC=NXQ; E•FC=NXQ+1;
GEN(jnz,ENTRY(i),_,0);
GEN(j,_,_,0)}

3.Boolean expression

2)Semantic Rules

(2) $E \rightarrow E_a \text{ rop } E_a$

$\{E \bullet TC=NXQ;\ \ E \bullet FC=NXQ+1;$

$GEN(jrop, E_a^{(1)} \bullet PLACE, E_a^{(2)} \bullet PLACE,0);$

$GEN(j,\_,\_,0)\}$

(3) $E \rightarrow (E^{(1)})$

$\{E \bullet TC= E^{(1)} \bullet TC; E \bullet FC= E^{(1)} \bullet FC\}$

(4) $E \rightarrow \text{not } E^{(1)}$

$\{E \bullet TC= E^{(1)} \bullet FC; E \bullet FC= E^{(1)} \bullet TC\}$

3.Boolean expression

2)Semantic Rules

(5)$E^A \to E^{(1)}$ and {BACKPATCH($E^{(1)} \bullet$TC,NXQ);

$E^A \bullet FC = E^{(1)} \bullet FC$;}

(6) $E \to E^A E^{(2)}$

{$E \bullet TC = E^{(2)} \bullet TC$;

$E \bullet FC = MERG(E^A \bullet FC, E^{(2)} \bullet FC$}

3.Boolean expression

2)Semantic Rules

(7)$E^{0} \rightarrow E^{(1)}$ or

$\{BACKPATCH(E^{(1)} \bullet FC, NXQ);$

$E^{0} \bullet TC = E^{(1)} \bullet TC;\}$

(8) $E \rightarrow E^{0} E^{(2)}$

$\{E \bullet FC = E^{(2)} \bullet FC;$

$E \bullet TC = MERG(E^{0} \bullet TC, E^{(2)} \bullet TC\}$

Translate A and B or not C

INPUT	SYM	TC	FC	quadruple
A and B or not C#	#	-	-	
and B or not C#	#i	--	--	
and B or not C#	#E	-1	-2	1.(jnz,a,-,(3))
B or not C#	#E and	-1-	-2-	2.(j,-,-(5))
B or not C#	# E^{A}	--	-2	
or not C#	# E^{A}i	---	-2-	

INPUT	SYM	TC	FC	quadruple
or not C	# $E^A E$	— — 3	— 2 4	3.(jnz,B,—,0)
#or not C#	#E	—3	—4	4.(j,—,—(5))
or not C#	#E or	—3—	—4—	
not C#	# E^0	—3	— —	
C#	# E^0 not	—3—	— — —	
#	# E^0 not i	—3—	— — — —	
#	# E^0 notE	═3—5	— — —6	5.(jnz,C,—,0)
#	# E^0 E	—3 6	— —5	6.(j,—,—,3)
#	#E	—6	—5	
success				

4.Flow of control statements

1) modify the grammar

$S \rightarrow$ if E then $S^{(1)}$ else $S^{(2)}$ ➔

$C \rightarrow$ if E then

$T \rightarrow C\ S^{(1)}$ else

$S \rightarrow T\ S^{(2)}$

$S \rightarrow$ if E then $S^{(1)}$ ➔

$C \rightarrow$ if E then

$S \rightarrow C\ S^{(1)}$

4.Flow of control statements

2) Semantic Rules

$C \rightarrow$ if E then {BACKPATCH(E•TC,NXQ);
C•CHAIN=E•FC;}

$T \rightarrow C\ S^{(1)}$ else {q=NXQ; GEN(j,—,—0);
BACKPATCH(C•CHAIN,NXQ);
T •CHAIN=MERG($S^{(1)}$•CHAIN,q)}

$S \rightarrow T\ S^{(2)}$ {S•CHAIN=MERG(T•CHAIN,$S^{(2)}$•CHAIN)}

$S \rightarrow C\ S^{(1)}$ {S•CHAIN=MERG(C•CHAIN,$S^{(1)}$•CHAIN)}

e.g.

If a then

  if b then

    A:=2

  else A:=3

Else if c then

  A=4

Else a=5

(1) (jnz,a,_,0)

(2) (j,_,_,0)

If a then

if b then

A:=2

else A:=3

Else if c then

A=4

Else a=5

(1)(jnz,a,_,(3))
(2)(j,_,_,0)
(3)(jnz,b,_,0)
(4)(j,_,_,0)

Ca•CHAIN->2

If a then

if b then

A:=2

else A:=3

Else if c then

A=4

Else a=5

(1)(jnz,a,_,(3))

(2)(j,_,_,0)

(3)(jnz,b,_,(5))

(4)(j,_,_,0)

(5)(:=,2,_,A)

Ca•CHAIN->2

Cb•CHAIN->4

If a then

if b then

A:=2

else A:=3

Else if c then

A=4

Else a=5

(1)(jnz,a,_,(3))

(2)(j,_,_,0)

(3)(jnz,b,_,(5))

(4)(j,_,_,(7))

(5)(:=,2,_,A)

(6)(j,_,_,0)

Ca•CHAIN->2

Cb•CHAIN->6

Answer

(1)(jnz,a,_,(3))

(2)(j,_,_,(9))

(3)(jnz,b,_,(5))

(4)(j,_,_,(7))

(5)(:=,2,_,A)

(6)(j,_,_,0)

(7)(:=,3,_,A)

(8)(j,_,_,6)

(9)(jnz,c,_,(11))

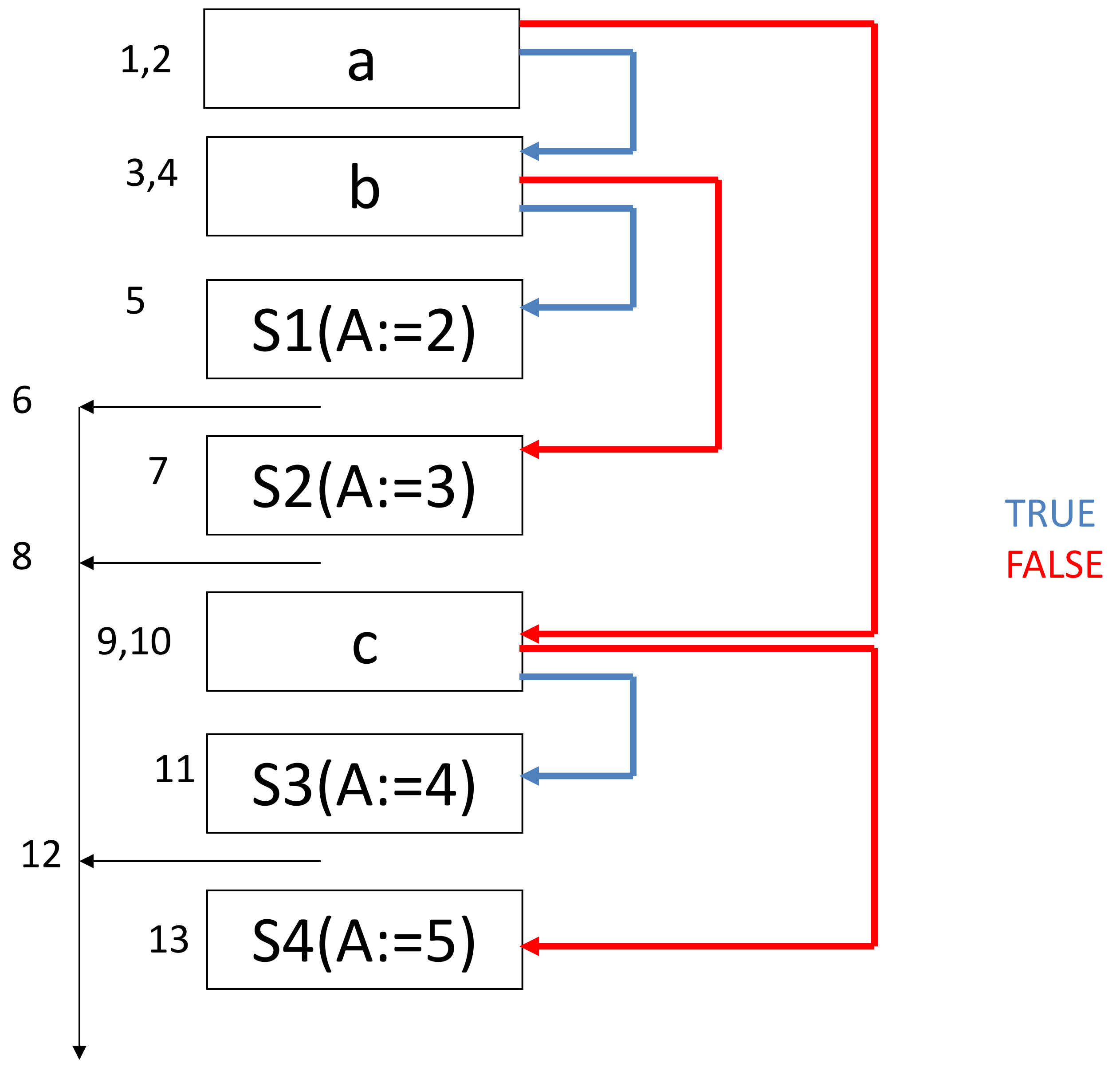
(10)(j,_,_,(13))

(11)(:=,4,_,A)

(12)(j,_,_,8)

(13)(:=,5,_,A)

S•CHAIN->6->8->12



1,2
a
3,4
b
5
S1(A:=2)
6
7
S2(A:=3)
8
9,10
c
11
S3(A:=4)
12
13
S4(A:=5)
TRUE
FALSE

4.Flow of control statements

3) While statement

$S \rightarrow$ while E do $S^{(1)}$ ➔

$W \rightarrow$ while

$W^d \rightarrow W$ E do

$S \rightarrow W^d S^{(1)}$

4.flow of control statements

3) While statement

$W \rightarrow$ while {W•QUAD=NXQ}

$W^d \rightarrow W$ E do {BACKPATCH(E•TC,NXQ);

W^d•CHAIN=E•FC;

W^d•QUAD=W•QUAD;}

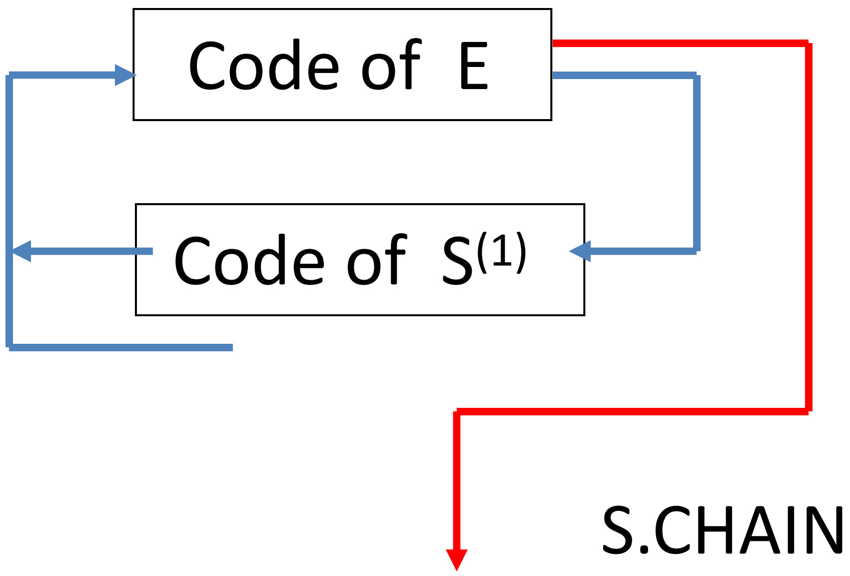
$S \rightarrow W^d\, S^{(1)}$ {BACKPATCH($S^{(1)}$•CHAIN, W^d•QUAD);

GEN(j,_,_, W^d •QUAD);

S • CHAIN= W^d•CHAIN}

4.flow of control statements

3) While statement



e.g.

While (A<B) do

if (C<D) then

X:=Y+Z;

→ (100) (j<,A,B,0)

(101)(j,_,_,0)

e.g.

While (A<B) do

  if (C<D) then

   X:=Y+Z;

➔: (100) (j<,A,B,(102))

(101)(j,_,_,0)

(102)(j<,C,D,0)

(103)(j,_,_,(100))

e.g.

While (A<B) do

  if (C<D) then

   X:=Y+Z;

➔ :   (100) (j<,A,B,(102))

(101)(j,_,_,0)

(102)(j<,C,D,(104))

(103)(j,_,_,(100))

(104)(+,Y,Z,T_1)

(105)(:=, T_1,_,X)

e.g.

```
While (A<B) do
  if (C<D)  then
   X:=Y+Z;
```

→ :

(100) (j<,A,B,(102))

(101)(j,_,_,(107))

(102)(j<,C,D,(104))

(103)(j,_,_,(100))

(104)(+,Y,Z,T_1)

(105)(:=, T_1,_,X)

(106)(j,_,_,(100))