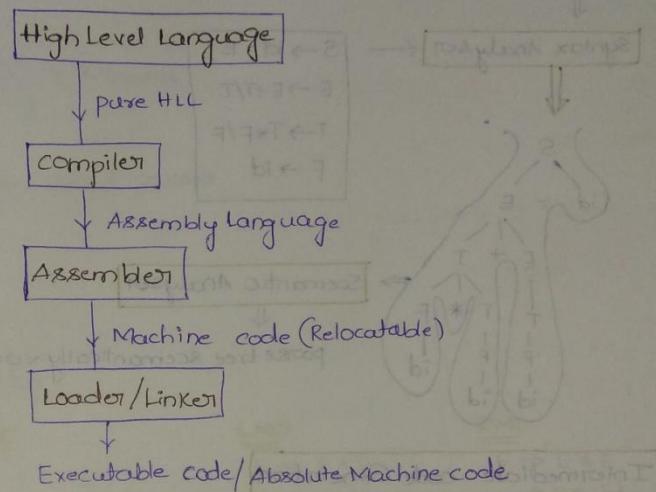


## COMPILER DESIGN

(1)

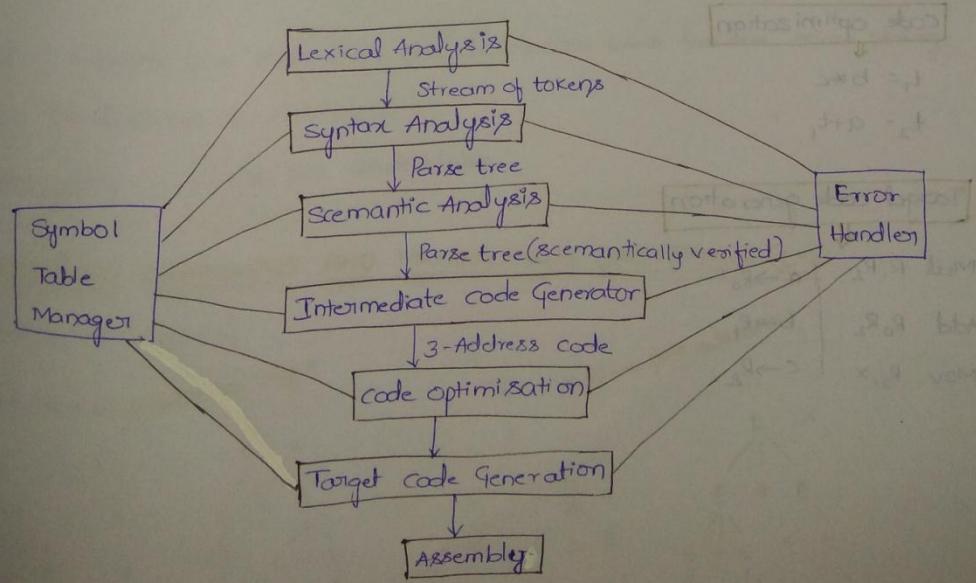
### INTRODUCTION AND VARIOUS PHASES OF COMPILER (L-1)

⇒ The main aim of the compiler is to convert a High Level Language to Low level language.



⇒ Removing #includes by including a specific file is called "File Inclusion".

⇒ "Assembler" is dependent on the platform [Hardware + OS].



## COMPILE TIME DESIGN

(2)

INT

$\Rightarrow T$

$\Rightarrow P$

$\Rightarrow P$

$\Rightarrow S$

Gram

$E \rightarrow$

$\Rightarrow ($

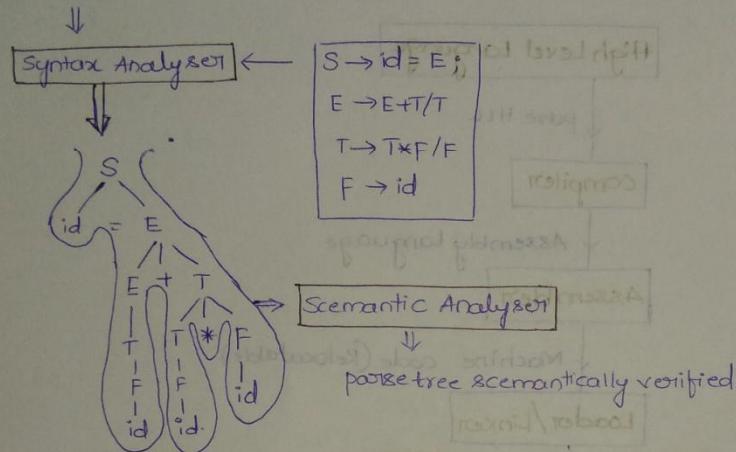
LM

$E \rightarrow$

### INTRODUCTION AND PHASES OF COMPILES

0)  $x = a + b * c$

$\downarrow$   
 Lexical Analyzer  $\Rightarrow$  The Lexical Analyzer identifies the "identifiers", "tokens" using some Regular expressions called patterns  $l(id)^*$   
 $id = id + id * id$



### Intermediate code Generation

$t_1 = b * c$

$t_2 = a + t_1$

$x = t_2$

### Code Optimization

$t_1 = b * c$

$t_2 = a + t_1$

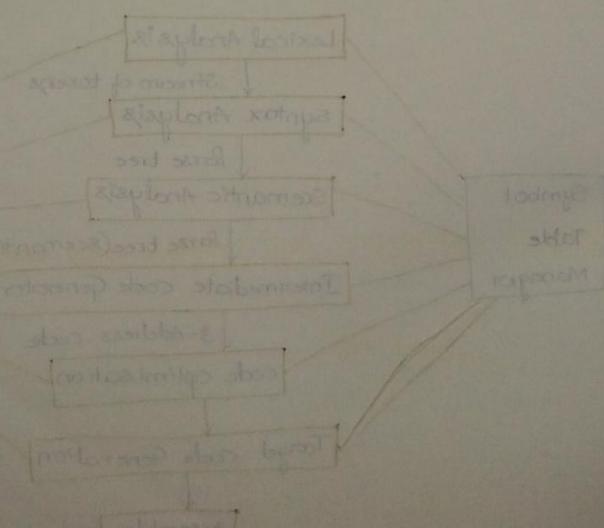
### Target code generation

Mul R<sub>1</sub>, R<sub>2</sub>

Add R<sub>0</sub>, R<sub>2</sub>

Mov R<sub>2</sub>, X

$$\left| \begin{array}{l} a \rightarrow R_0 \\ b \rightarrow R_1 \\ c \rightarrow R_2 \end{array} \right.$$



## INTRODUCTION TO LEXICAL ANALYSER (L-2)

(2)

(3)

⇒ This is the only phase that reads the Input character by character

INTROD

"tokens" is  
attempts 1(1+1)\*

⇒ int max(x,y)

int x,y;

/\* find max of x and y \*/

{

return (x>y?x:y);

}

95 Tokens are present

int = 1 token

max = 1 token

return = 1 token

⇒ printf("%d\n", x);

1 Token  
1 2 3 4 5 6 7 8 ⇒ 8 Tokens

⇒ Syntax Analyzer is also called parser

Grammar:

$E \rightarrow E+E / E * E / id$

⇒ [id + id \* id] = Given string

LNP

$E \rightarrow E+E$

→ id + E \* E

→ id + id \* E

→ id + id \* id

RMD

$E \rightarrow E+E$

→ E + E \* E

→ E + E \* id

→ E + id \* id

LMD

$E \rightarrow E * E$

→ E + E \* E

→ id + E \* E

→ id + id \* E

RMD

$E \rightarrow E * E$

→ E \* id

→ E + E \* id

→ E + id \* id

→ id + id \* id

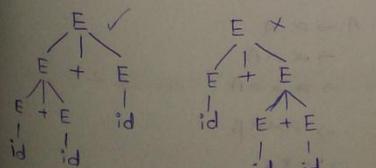
⇒ If a Grammar has more than one derivation trees for the same string  
then the Grammar is Ambiguous

⇒ Ambiguity problems are undecidable

## AMBIGUOUS GRAMMARS AND MAKING THEM UNAMBIGUOUS (L-3)

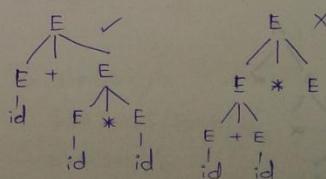
$E \rightarrow E+E / E * E / id$

id + id + id ⇒ Associativity ×



Leftmost plus should be evaluated first.

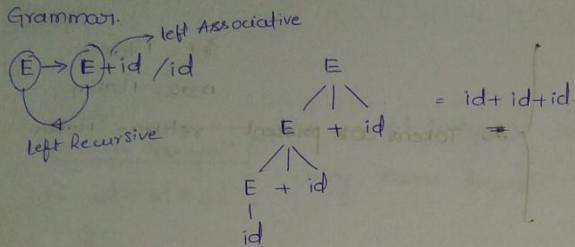
id + id \* id ⇒ precedence (X)



Highest precedence one should be evaluated first (\* should be evaluated first)

### (S-3) REDUCTION TO LEFT-ASSOCIATIVE

To avoid the above Ambiguity we have to restrict the growth of the Grammar.



$\Rightarrow$  The Grammar is said to be left recursive if the left most symbol in the RHS = LHS

$\Rightarrow$  In order to overcome the associativity we need to define the Grammar to be left recursive

$$\Rightarrow E \rightarrow E + T / T \\ T \rightarrow T * F / F \\ F \rightarrow id$$

$$\Rightarrow 21312 = 2^{3^2} = (2)^{2^3} = 2^9$$

$$\Rightarrow A \rightarrow \$B/B \quad \$\# @ = \text{Left associative}$$

$$B \rightarrow B \# C/C$$

$$C \rightarrow C @ D/D$$

$$D \rightarrow d$$

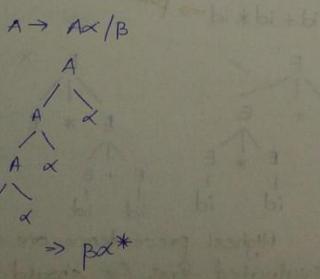
$$\$ > \# > @$$

$$\$ < \# < @$$

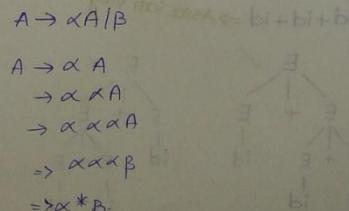
### LEFT RECURSION ELIMINATION AND LEFT FACTORING OF GRAMMARS. (L-4)

#### Recursion

##### Left Recursion



##### Right Recursion



$$\Rightarrow Bx^* (A \rightarrow$$

$$A \rightarrow PA^1 \\ A^1 \rightarrow \alpha A^1 / \epsilon$$

$$) E \rightarrow E + T / T \\ A \quad A \alpha / \beta$$

$$\Rightarrow A \rightarrow B_1 A^1 / B_2 \\ A^1 \rightarrow \alpha_1 A^1 / \alpha_2$$

### 3) Grammars

#### G

##### Ambiguous

##### Left Recursion

##### Deterministic

$$① S \rightarrow iE^*$$

$$E \rightarrow b$$

$\Rightarrow$  The el

of Ar

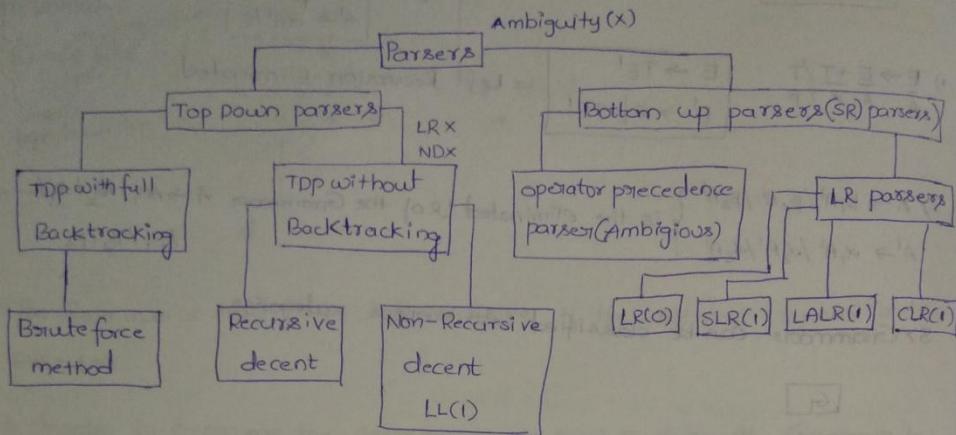
$$② S \rightarrow \alpha S$$

$$③ S \rightarrow bS$$



## PARSERS

→ parsers are nothing but Syntax Analyzers. (L-5)

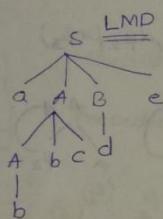


$S \rightarrow aABe$

$A \rightarrow Abc/b$

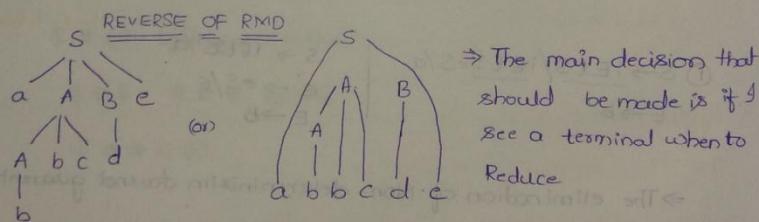
$B \rightarrow d$

$w = abbade$



The main thing that we must assure is

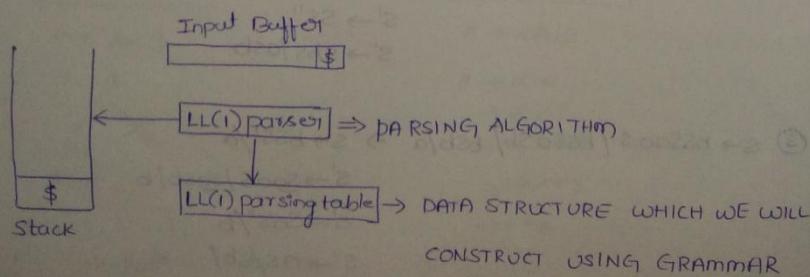
at every point when we have more than two productions to be chosen "which one to choose"



→ The main decision that should be made is if I see a terminal when to Reduce

### LL(1) PARSER / NON RECURSIVE DECENT PARSER

Left to Right, Left most Derivation, (1) = No. of look aheads



Now, Before  
functions

FIRST():

$S \rightarrow aABC$

$A \rightarrow b$

$B \rightarrow c$

$C \rightarrow d$

$D \rightarrow e$

$S \rightarrow ABCD$

$A \rightarrow b$

$B \rightarrow c$

$C \rightarrow d$

$D \rightarrow e$

FOLLOW():

⇒ what is

derivation

⇒ follow o

$S \rightarrow ABCD$

$A \rightarrow b/c$

$B \rightarrow c/d$

$C \rightarrow d$

$D \rightarrow e$

⇒ Now, If n

Variable

Now, Before Constructing the LL(1) parsing table we should Know two functions they are FIRST AND FOLLOW

FIRST():

$$S \rightarrow aABCD$$

$$A \rightarrow b$$

$$B \rightarrow c$$

$$C \rightarrow d$$

$$D \rightarrow e$$

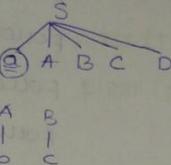
$$S \rightarrow ABCD$$

$$A \rightarrow b$$

$$B \rightarrow c$$

$$C \rightarrow d$$

$$D \rightarrow e$$



$$\text{FIRST}(S) = a$$

$$\text{FIRST}(c) = d$$

$$\text{FIRST}(A) = b$$

$$\text{FIRST}(D) = e$$

$$\text{FIRST}(B) = c$$

$$S \rightarrow ABCD$$

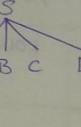
$$A \rightarrow b$$

$$B \rightarrow c$$

$$C \rightarrow d$$

$$D \rightarrow e$$

$$\text{FIRST}(S) = b$$



$$S \rightarrow ABCD$$

$$A \rightarrow b/e$$

$$B \rightarrow c \text{ (small 'c')}$$

$$C \rightarrow d$$

$$D \rightarrow e$$

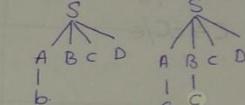
$$\text{FIRST}(S) = \{b, c\}$$

$$A \rightarrow b/e$$

$$B \rightarrow c \text{ (small 'c')}$$

$$C \rightarrow d$$

$$D \rightarrow e$$



FOLLOW():

⇒ what is the terminal which could follow a variable in the process of derivation.

⇒ Follow of start symbol always contain '\$'

$$S \rightarrow ABCD$$

$$A \rightarrow b/e$$

$$B \rightarrow c/e$$

$$C \rightarrow d$$

$$D \rightarrow e$$

$$\text{FOLLOW}(S) = \{\$\}$$

$$\text{FOLLOW}(A) = \text{FIRST}(B, C, D) = \{c, d, e\}$$

$$\text{FOLLOW}(B) = \text{FIRST}(C, D) = \{d\}$$

$$\text{FOLLOW}(C) = \text{FIRST}(D) = \{e\}$$

FOLLOW NEVER CONTAIN  
"EPSILON"

⇒ Now, If nothing is following a variable i.e. If nothing is at the RHS of a variable then the follow of that variable is the follow of LHS

$$\therefore \text{FOLLOW}(D) = \text{FOLLOW}(S) = \{\$\}$$

SAMPLES ON HOW TO FIND FIRST AND FOLLOW IN LL(1) PARSER (L-E)

1>  $S \rightarrow ABCDE$

$A \rightarrow a/\epsilon$

$B \rightarrow b/\epsilon$

$C \rightarrow c$

$D \rightarrow d/\epsilon$

$E \rightarrow e/\epsilon$

FIRST(S) = {a, b, c}

FIRST(A) = {a,  $\epsilon$ }

FIRST(B) = {b,  $\epsilon$ }

FIRST(C) = {c}

FIRST(D) = {d,  $\epsilon$ }

FIRST(E) = {e,  $\epsilon$ }

FOLLOW(S) = { $\$, \epsilon$ }

FOLLOW(A) = {b, c}

FOLLOW(B) = {c}

FOLLOW(C) = {d, e,  $\$$ }

FOLLOW(D) = {e,  $\$$ }

FOLLOW(E) = { $\$$ }

(8)

2>  $S \rightarrow Bb/cd$

$B \rightarrow aB/\epsilon$

$C \rightarrow cC/\epsilon$

FIRST(S) = {a, b, c, d}

FIRST(B) = {a,  $\epsilon$ }

FIRST(C) = {c,  $\epsilon$ }

FOLLOW(S) = { $\$$ }

FOLLOW(B) = {b}

FOLLOW(C) = {d}

NOW THE

	id
E	$E \rightarrow TE$

E'	

T	$T \rightarrow FT$

T'	

F	$F \rightarrow$

3>  $E \rightarrow TE'$

$E' \rightarrow +TE'/\epsilon$

$T \rightarrow FT$

$T' \rightarrow *FT'/\epsilon$

$F \rightarrow id/(E)$

FIRST(E) = {id, c}

FIRST(E') = {+,  $\epsilon$ }

FIRST(T) = {id, c}

FIRST(T') = {\*},  $\epsilon$

FIRST(F) = {id, c}

FOLLOW(E) = { $\$, ,$ }

FOLLOW(E') = { $\$, ,$ }

FOLLOW(T) = {+,  $\$, ,$ }

FOLLOW(T') = {+,  $\$, ,$ }

FOLLOW(F) = {\*}, {+,  $\$, ,$ }

4>  $S \rightarrow ACB/\epsilon BB/Ba$

$A \rightarrow da/Bc$

$B \rightarrow g/\epsilon$

$c \rightarrow h/\epsilon$

FIRST(S) = { $\epsilon$ , d, g, h, b, a}

FIRST(A) = {d, g, b,  $\epsilon$ }

FIRST(B) = {g,  $\epsilon$ }

FIRST(C) = {h,  $\epsilon$ }

FOLLOW(S) = { $\$$ }

FOLLOW(A) = {h, g,  $\$$ }

FOLLOW(B) = { $\$, a, hg$ }

FOLLOW(C) = {g,  $\$, bb$ }

S	s

2>  $S \rightarrow (S)$ ,

Now,  $w =$

5>  $S \rightarrow aABb$

$A \rightarrow C/\epsilon$

$B \rightarrow d/\epsilon$

FIRST(S) = {a}

FIRST(A) = {c,  $\epsilon$ }

FIRST(B) = {d,  $\epsilon$ }

FOLLOW(S) = { $\$$ }

FOLLOW(A) = {d, b}

FOLLOW(B) = {b}

6>  $S \rightarrow abdh$

$B \rightarrow CC$

$C \rightarrow BC/\epsilon$

$D \rightarrow EF$

$E \rightarrow g/\epsilon$

$F \rightarrow f/\epsilon$

FIRST(S) = {a}

FIRST(B) = {c}

FIRST(C) = {b,  $\epsilon$ }

FIRST(D) = {g, b,  $\epsilon$ }

FIRST(E) = {g,  $\epsilon$ }

FIRST(F) = {f,  $\epsilon$ }

FOLLOW(S) = { $\$$ }

FOLLOW(B) = {g, t, ht}

FOLLOW(C) = {g, t, ht}

FOLLOW(D) = {ht}

FOLLOW(E) = {f, ht}

FOLLOW(F) = {ht}

## CONSTRUCTION OF LL(1) PARSING TABLE (L-7)

(8)

$$E \rightarrow TE'$$

$$\text{FIRST}(E) = \{\text{id}, C\}$$

$$\text{FOLLOW}(E) = \{\$\}$$

$$E' \rightarrow +TE'/\epsilon$$

$$\text{FIRST}(E') = \{+, \epsilon\}$$

$$\text{FOLLOW}(E') = \{\$\}$$

$$T \rightarrow FT'$$

$$\text{FIRST}(T) = \{\text{id}, C\}$$

$$\text{FOLLOW}(T) = \{+, \$, )\}$$

$$T' \rightarrow *FT'/\epsilon$$

$$\text{FIRST}(T') = \{*, \epsilon\}$$

$$\text{FOLLOW}(T') = \{+, \$, )\}$$

$$F \rightarrow \text{id}/(E)$$

$$\text{FIRST}(F) = \{\text{id}, C\}$$

$$\text{FOLLOW}(F) = \{*, +, \$, )\}$$

NOW THE LL(1) PARSING TABLE LOOKS LIKE

	id	+	*	(	)	\$
E	$E \rightarrow TE'$			$E \rightarrow TE'$		
E'		$E' \rightarrow +TE'$			$E' \rightarrow \epsilon$	$E' \rightarrow \epsilon$
T	$T \rightarrow FT'$			$T \rightarrow FT'$		
T'		$T' \rightarrow \epsilon$	$T' \rightarrow *FT'$		$T \rightarrow \epsilon$	$T' \rightarrow \epsilon$
F	$F \rightarrow \text{id}$			$F \rightarrow (E)$		

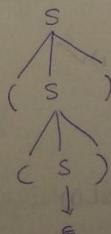
$$\Rightarrow S \rightarrow (S)/\epsilon$$

All Grammars are not feasible  
for LL(1) parsing.

S	(	)	\$
$s \rightarrow (s)$			$s \rightarrow \epsilon$

$$\text{Now, } w = ((\$)$$

$\$ | S | S | ( | ) | \$ | \$$



ANY GRAMMAR WHICH  
IS LEFT RECURSIVE/NO  
CANNOT BE USED FOR  
LL(1) PARSING

\* Non-deterministic

## CHECK WHETHER THE GRAMMARS ARE LL(1) OR NOT

$$1) S \rightarrow aSbS / bSaS / \epsilon$$

$\{a\} \{b\} \{a, b, \$\} \Rightarrow \text{Not LL}(1)$

↳ which means the production must be placed under 'S' row and 'a' column.

↳ Since the  $S \rightarrow \epsilon$  production should be placed under the follow(s) which are  $\{a, b\}$ , we have already placed production in 'S' row and 'a' column which means a single CELL has more than one entry, so the grammar is not LL(1) X

$$2) S \rightarrow aABb \Rightarrow \{a\} \xrightarrow{A \rightarrow C} \{C\} \xrightarrow{A \rightarrow E} \{E\}$$

$A \rightarrow C / \epsilon \Rightarrow \{C\}$  and follow(A) =  $\{d, b\}$

$B \rightarrow d / \epsilon \Rightarrow \{d\}$  and  $\{b\} \Rightarrow \text{IS LL}(1) \checkmark$

↳ Conflict

$$3) S \rightarrow A/a \quad \{a\} \cap \{a\} = \text{Not LL}(1) \times$$

$A \rightarrow a \quad \{a\}'$

$$4) S \rightarrow AB/\epsilon \quad \{a\} \{ \$ \} \Rightarrow \text{NO } x^n$$

$B \rightarrow bC/\epsilon \quad \{b\} \{ \$ \} \Rightarrow \text{NO } x^n$

$C \rightarrow cS/\epsilon \quad \{c\} \{ \$ \} \Rightarrow \text{NO } x^n$

$$5) S \rightarrow AB$$

$$\begin{aligned} A \rightarrow a/\epsilon &\Rightarrow \{a\} \{b, \$\} \Rightarrow \text{NO } x^n \\ B \rightarrow b/\epsilon &\Rightarrow \{b\} \{ \$ \} \Rightarrow \text{NO } x^n \end{aligned} \quad \left. \begin{array}{l} \text{LL}(1) \checkmark \\ \text{LL}(1) \checkmark \end{array} \right\}$$

$$6) S \rightarrow ASA/\epsilon \Rightarrow \{a\} \{c, \$\} \Rightarrow \text{NO } x^n$$

$$A \rightarrow C/\epsilon \Rightarrow \{c\} \{ \$ \} \Rightarrow x^n \text{ is there} \quad \left. \begin{array}{l} \text{X} \end{array} \right\}$$

$$7) S \rightarrow A$$

$$\begin{aligned} A \rightarrow Bb/cd &\Rightarrow \{a, b\} \{c, d\} \\ B \rightarrow aB/\epsilon &\Rightarrow \{a\} \{b\} \\ C \rightarrow cc/\epsilon &\Rightarrow \{c\} \{d\} \end{aligned} \quad \left. \begin{array}{l} \text{LL}(1) \checkmark \\ \text{LL}(1) \checkmark \end{array} \right\}$$

$$8) S \rightarrow aAa/\epsilon \quad \{a\} \{ \$, a\} \quad \text{X Not LL}(1)$$

$$A \rightarrow abS/\epsilon$$

$$\begin{aligned} ⑨ S \rightarrow iEtSS'/a &\quad \{i\} \{a\} \\ S' \rightarrow es/\epsilon &\quad \{e\} \{ \$ \} \\ E \rightarrow b & \end{aligned} \quad \left. \begin{array}{l} \text{Not LL}(1) \times \\ \text{Not LL}(1) \times \end{array} \right\}$$

## RECURSIVE

$$E \rightarrow iE'$$

$$E' \rightarrow +iE'/\epsilon$$

⇒ The position

we are going

$$E()$$

{

1 if ( $i =$   
2 {

m

} 3 E'

} 4  
 $i = \text{getchar}()$

↳ J

(dibuat)

main()

{

1) E()

2) if ( $i =$

3) printf()

}

## OPERATOR

### OPERATOR

A Gramma

operator G

⇒ NO Two

⇒ NO eps

⇒ This po

## RECURSIVE DECENT PARSER (L-8)

$$E \rightarrow i E'$$

$$E' \rightarrow +i E'/e$$

The parser is called Recursive Decent parser because for every variable we are going to write Recursive functions.

E()

{

1) if ( $l == 'i'$ )

2 {

    match('i');

3) E();

}

l = getchar();

E'()

{

1) if ( $l == '+'$ )

2) match('+');

3) match('1');

4) E'();

5) else { return;

}

}

match (char t)

if ( $l == t$ )

l = getchar();

else

printf("error");

main()

{

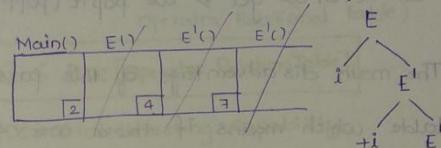
1) E()

2) if ( $l == '$'$ )

3) printf(" parsing success");

}

{(i+e)s} is generated from above grammar



⇒ This parser uses Recursion stack for parsing.  
⇒ Here l = look ahead

## OPERATOR GRAMMAR AND OPERATOR PRECEDENCE PARSER (L-9)

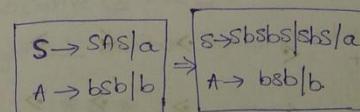
### OPERATOR GRAMMAR

A Grammar that is used to define the mathematical operations is called Operator Grammar (with some Restrictions).

⇒ NO Two variables must be Adjacent

⇒ NO epsilon productions

$$E \rightarrow E+E/E*E/id \quad (\checkmark)$$



Not operator precedence      Operator precedence  
Grammar.

$$\left. \begin{array}{l} E \rightarrow EAE/id \\ A \rightarrow +/* \end{array} \right\} \text{Not Operator Grammar}$$

⇒ This parser parses the Ambiguous grammars by creating operator Relation

Table

The operator Relational table looks like

	id	+	*	\$
id	-	>	>	>
+	<	>	<	<
*	<	>	>	>
\$	<	<	<	⊖

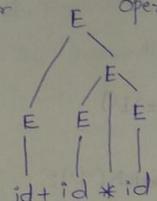
The given grammar is  
 $E \rightarrow E+E/E*E/id$

$\Rightarrow id$  will have higher precedence than any other operator  
 $\Rightarrow \$$  will have least precedence than any other operator.

$$W = id + id * id \$$$

↑↑↑↑↑↑  
root head

\$	id	+	id	*	id
----	----	---	----	---	----



$\Rightarrow$  Top of the stack will be \$.

Now The Algorithm goes like this

- 1) when the top of the stack is  $<$  than the lookahead then push it and whenever we get  $>$  we pop it (popping means actually we Reduced it)

The main disadvantage of this parser is the size of the operator Relational table which means if there are 4 operators then size of the table is  $16(4^2)$  and if there are 5 operators then there would be  $25$  entries( $5^2$ ). So Generally if there are  $m$  operators, the size of the table is  $O(n^2)$

### OPERATOR GRAMMAR AND OPERATOR PRECEDENCE PARSER

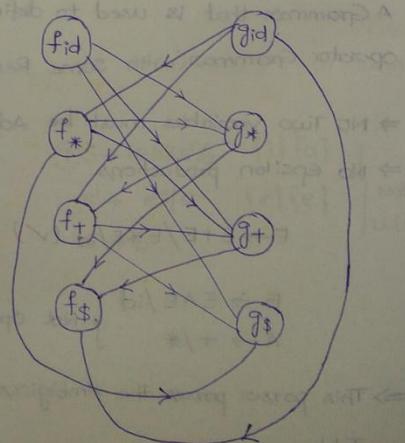
Now, To reduce the size of the table we use operator function table

	id	+	*	\$
id	-	>	>	>
+	<	>	<	>
*	<	,>	>	>
\$	<	<	<	<

Function(F)

$$\Rightarrow = F_{id} \rightarrow g_{id} (F \rightarrow G)$$

$$\Leftarrow = g_{id} \rightarrow f_{id} (G \rightarrow F)$$



Now, the L

Now, the L

Similarly fi

Now if inc

$\therefore$  The Size

$\Rightarrow$  In the -

nothing bu  
is less th

ED

2)  $P \rightarrow SR/S$

$R \rightarrow bSR$

$S \rightarrow wSb$

$w \rightarrow L*$

$L \rightarrow id$

id

\*

b

\$

Now the Longest path from  $f_{id}$  is  $f_{id} \rightarrow g_* \rightarrow f_+ \rightarrow g_+ \rightarrow f_\$$  13

Now the Longest path from  $g_{id}$  is  $g_{id} \rightarrow f_* \rightarrow g_* \rightarrow f_+ \rightarrow g_+ \rightarrow f_\$$

Similarly find the longest paths from each node the function table looks like

$f$	$+$	*	$\$$
4	2	4	0
5	1	3	0

$$f_{id} \xrightarrow{1} g_* \xrightarrow{2} f_+ \xrightarrow{3} g_+ \xrightarrow{4} f_\$ = 4$$

$$f_+ \xrightarrow{1} g_+ \xrightarrow{2} f_\$ = 2$$

Now if need to compose  $(+, +) \Rightarrow f_+ \cdot g_+$   
 $\Rightarrow \downarrow \quad \downarrow$   
 $2 \quad 1 \Rightarrow 2 > 1 \Rightarrow (+ > +)$

will be  $\$$ .

∴ The Size of the table =  $O(2^n)$   $n = \text{no. of operators.}$

⇒ In the functional table, we don't have blank entries (Blank Entries are nothing but errors) so the error detecting capability of the functional table is less than that of operator Relation table (we have blank entries in Operator Relational table).

EDC [Operator Functional Table] < EDC [Operator Relation Table]

EDC = Error Detecting Capability.

2)  $P \rightarrow SR/S$

$R \rightarrow bSR/bS$

$S \rightarrow wbs/w$

$w \rightarrow L * w/L$

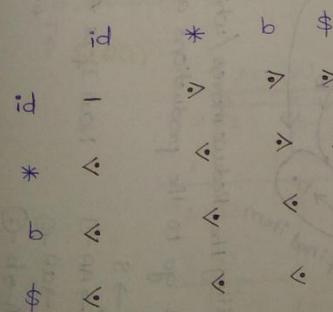
$L \rightarrow id$

$P \rightarrow SbP/SbS/S$

$S \rightarrow wbs/w$

$w \rightarrow L * w/L$

$L \rightarrow id$



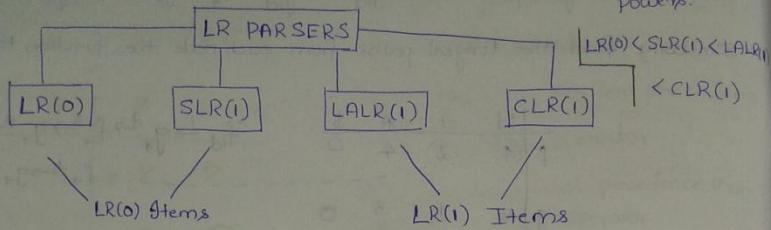
⇒ Here \* is defined as Right associative ( $w \rightarrow L * w \rightleftharpoons L * w/L$ ) so the Right side star has highest precedence

∴  $* < *$

## LR PARSING, LR(0) ITEMS AND LR(0) PARSING TABLE (L-10)

14

## LR(0) PARSING



powers.

$$S' \rightarrow S$$

$$S \rightarrow AA^{\dagger}$$

$$A \rightarrow aA/b$$

(2) (3)

Input

- 1)  $S \rightarrow AA$   
 $A \rightarrow aA/b$

In LR parsers we have CLOSURE and GOTO Operations

The Augmented Grammar is

$$S' \rightarrow S$$

$$S \rightarrow AA$$

$$A \rightarrow aA/b$$

Any production with a dot in the RHS is called an item.

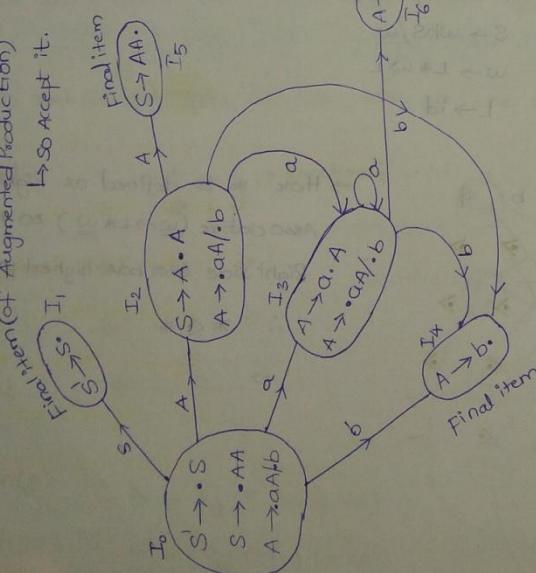
The LR(0) parsing Tree is,

$$\begin{aligned} S' &\rightarrow S \\ S &\rightarrow AA^{\dagger} \\ A &\rightarrow aA/b \end{aligned}$$

ACTION	GOTO		Accept
	S	A	
-	\$		
a	S <sub>3</sub>	S <sub>4</sub>	
b	S <sub>4</sub>	R <sub>3</sub>	
	S <sub>3</sub>	R <sub>1</sub>	R <sub>1</sub>
	S <sub>4</sub>	R <sub>2</sub>	R <sub>2</sub>

The parsing table is

### CANONICAL COLLECTION OF LR(0) ITEMS



- While writing the Reduce moves / while inspecting final items go to the productions and check

$$\begin{aligned} S' &\rightarrow S \\ S &\rightarrow AA^{\dagger} \\ A &\rightarrow aA/b \end{aligned}$$

$$\Rightarrow I_4 \xrightarrow{R_3}$$

$R_1 : S \rightarrow AA$   
 $\text{Place } R_1 \text{ in follow}$   
 $\text{follow}(S) = \{\$\}$

⇒ Always the  
 ⇒ Initially 'I'  
 at and as  
 and increment  
 ⇒ Now top of  
 which stat  
 previous  
 ⇒ Now In the  
 RHS of the  
 RHS. In thi  
 which mea  
 'x then i  
 onto the  
 it turns  
 = 6, so  
 SLR(0)

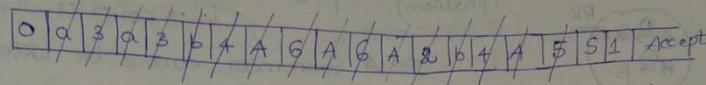
## LR(0) PARSING EXAMPLE AND SLR(1) TABLE

14

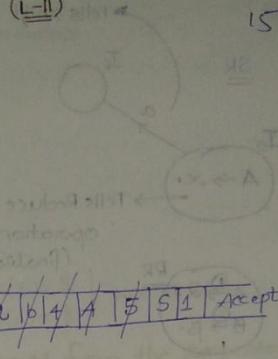
$S \rightarrow S$   
 $S \rightarrow AA^1$   
 $A \rightarrow aA/b$   
 $\text{CLRC}(1)$

$S \rightarrow S$   
 $S \rightarrow AA^1$   
 $A \rightarrow aA/b$   
 $\text{CLRC}(1)$

Let the given string be  $aabb\$$   
 $aabb \$$   
 Input pointer ↑↑↑↑↑



15



⇒ Always the top of the stack contains state (and first state will be zero)

⇒ Initially 'I\_0' on 'a' is  $s_3$  which means shift the input you are looking at and as well as the state no on to the stack  $\Rightarrow [Input=a, State=3]$   
 and increment the Input pointer [continue]

⇒ Now top of the stack is '4' and Input pointer is 'b' which means ' $R_3$ ' which states that Reduce the production no. 3, which means reduce the previous 'b'. (previous symbol).  $\hookrightarrow (A \rightarrow b)$

⇒ Now In the stack how could we make Reduce move is look the RHS of the production that must be Reduced, and find the length of RHS. In this example ' $A \rightarrow b$ ' is the production  $\Rightarrow$  length of RHS = 1 ( $\because |b|=1$ ) which means pop 2 symbols ( $1 \times 2$ ) from stack. (If the length of RHS is 'x' then pop '2x' elements from stack) and push the LHS symbol onto the stack, and see the stack for the last used state number it turns out that it is '3' and look what '3' on 'A' is generating = 6, so push '6' onto the stack. when we see reduce moves we don't increment Input pointer.

SLR(1)

	ACTION			GOTO	
	a	b	\$	A	S
0	$s_3$	$s_4$		2	1
1					
2	$s_3$	$s_4$		5	
3	$s_3$	$s_4$		6	
4	$R_3$	$R_3$	$R_3$		
5					
6	$R_2$	$R_2$	$R_2$		

$R_1: S \rightarrow AA$

Place  $R_1$  in follow(S)  
 $\text{follow}(S) = \{\$\}$

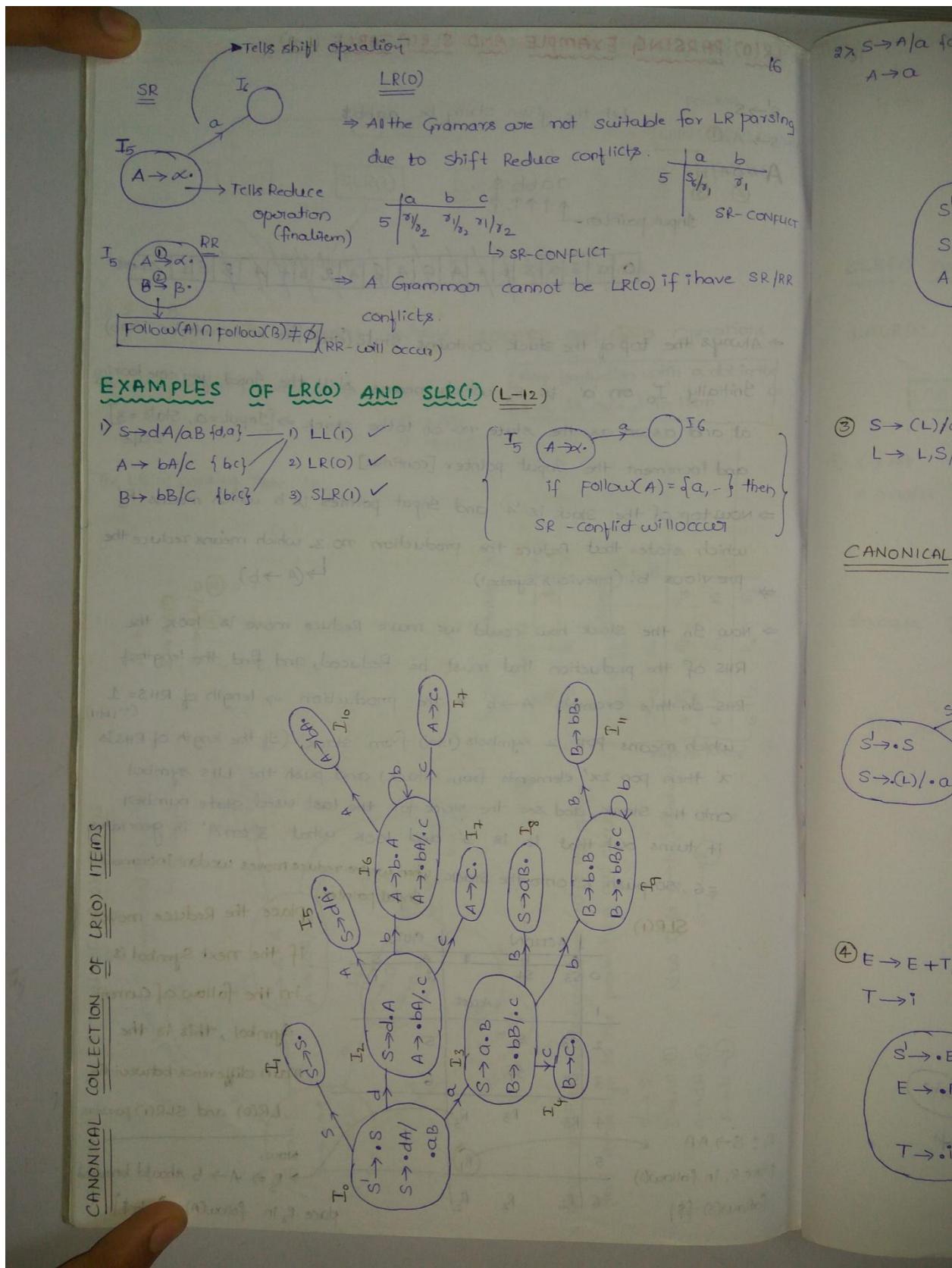
place the Reduce moves

if the next symbol is  
 in the follow of current  
 symbol, this is the  
 main difference between the

LR(0) and SLR(1) parsers

Now,

$\Rightarrow R_3 \Rightarrow A \rightarrow b$  should be derived  
 place  $R_3$  in  $\text{follow}(A) = \{a, b, \$\}$

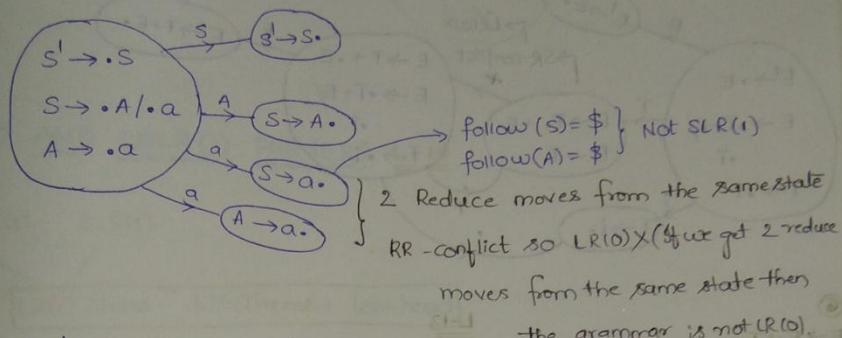


16       $\Rightarrow S \rightarrow A/a \{ a \} \{ a \}$   
 $A \rightarrow a$   
Not LL(1) X  
LR(0) X  
SLR(1) X } Ambiguous Grammar

Parsing

$\xrightarrow{a} A$   
- CONFLICT

SR/RR



③  $S \rightarrow (L)/a$

$L \rightarrow L, S/S$

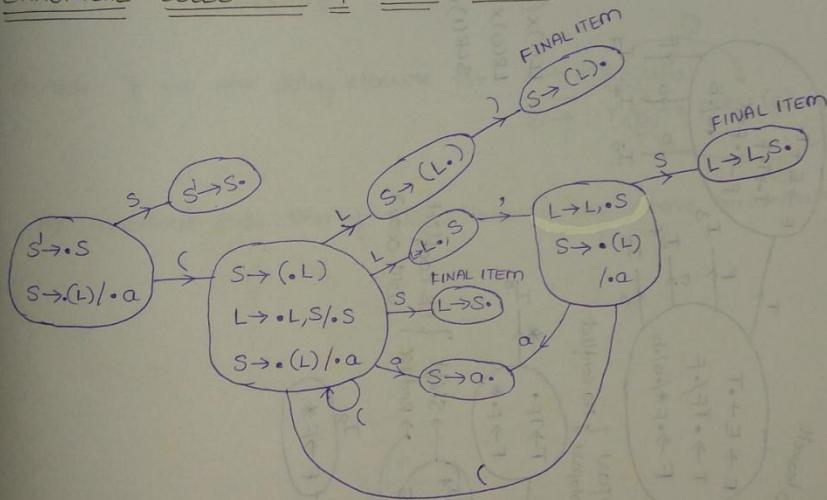
LL(1) X (Left Recursive)

LR(0) ✓

SLR(1) ✓

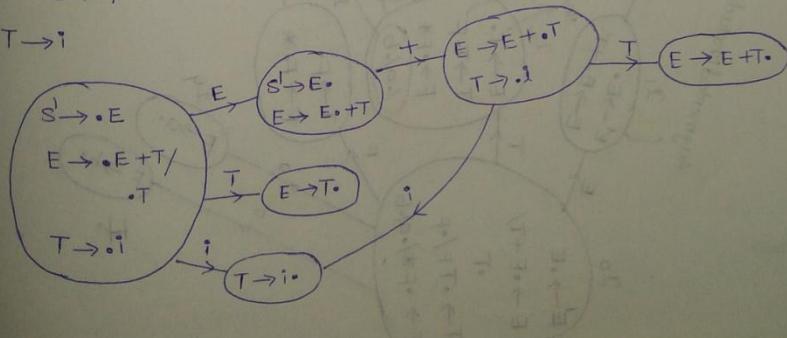
the grammar is not LR(0).

### CANONICAL COLLECTION OF LR(0) ITEMS



④  $E \rightarrow E + T / T$

$T \rightarrow i$



⑤  $E \rightarrow T + E/T$   
 $T \rightarrow i$

LL(1) X  
LR(0) X  
SLR(1) ✓

Right Associative

18

⑦  $S \rightarrow AaAb$   
 $A \rightarrow E$   
 $B \rightarrow E$

CLRC(1) AN

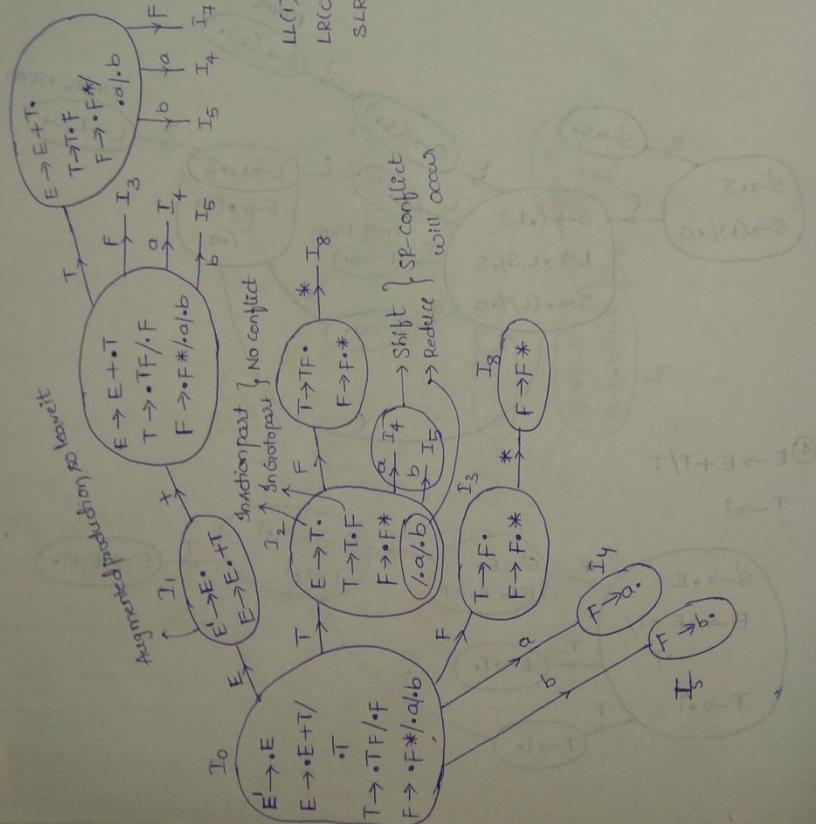
LALR(1)

LR(1)

⑥  $E \rightarrow E + T$   
 $T \rightarrow TF/$   
 $F$   
 $F \rightarrow F^*/a/b$

L-13

LL(1) X (Left Recursive)  
LR(0) X  
SLR(1) ✓



⑧  $S \rightarrow AA$   
 $A \rightarrow aA/b$

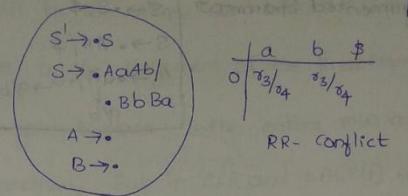
In case if

The cano

18

77  $S \rightarrow AaAb / BbBa \{a, b\}$  LL(1) ✓  
 $A \rightarrow E$   
 $B \rightarrow E$

LR(0) X  
SLR(1) X



### CLR(1) AND LALR(1) PARSERS L-14

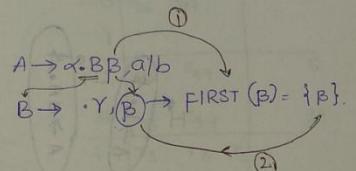
LALR(1) CLR(1)

LR(1) Items = LR(0) Items + Lookhead

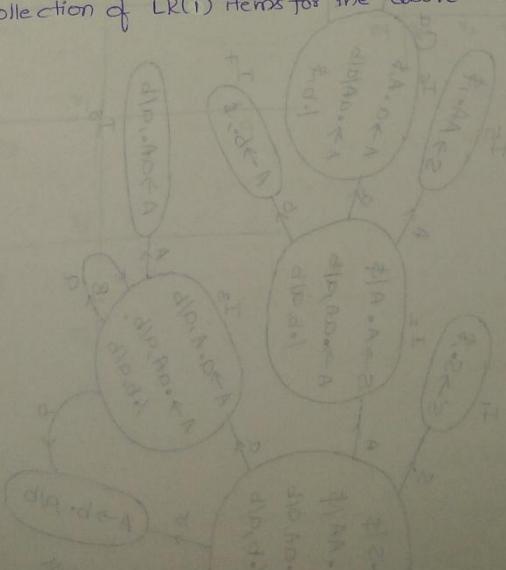
①  $S \rightarrow AA$  $A \rightarrow aA/b$  $S' \rightarrow S$  is the Augmented Grammar

$S \rightarrow \bullet AA$   
 $A \rightarrow \bullet aA / \bullet b$

In case if we are doing closure for



The canonical collection of LR(1) Items for the above Grammar is



Augmented Grammar

$$\begin{array}{l} S' \rightarrow S, \$ \\ S \rightarrow A \cdot A / \$ \\ A \rightarrow aA / b \xrightarrow{a/b} a/b \end{array}$$

→ look ahead is always \$ for Augmented production.

(20)

⇒ The Goto tables, +  
In the following  
the following  
code goes

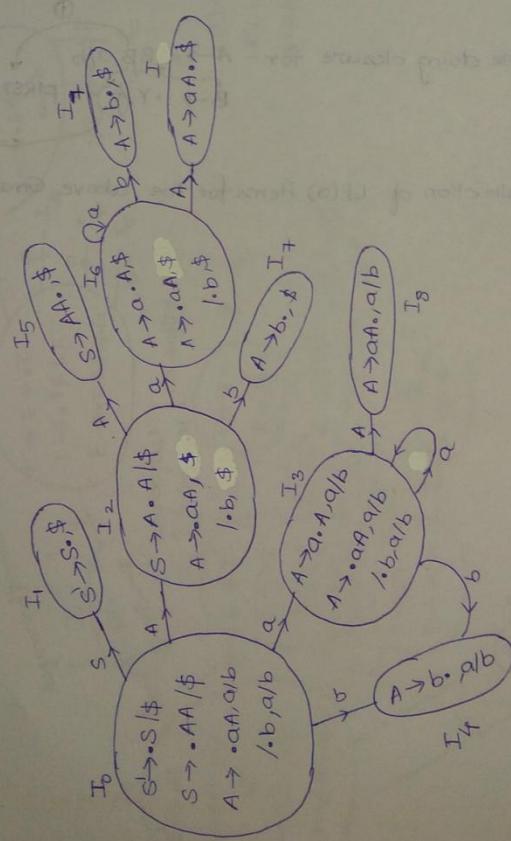
CLR(1) AND LAR(1) F-11

LAR(1) CLR(1)

Look ahead + next(0)(1) = next(1)(0)

⇒ From the  
look ahead  
⇒ Similar  
look ahead

CANONICAL COLLECTION OF LR(0) ITEMS



$I_3, I_6 =$   
 $I_4, I_7 =$   
 $I_8, I_9 =$

[No of states]

\$ for Augmented

(20)

⇒ The Goto point and shift point will be the same as LR(0) SLR(1) parsing tables, the main difference arises in the placement of the final items. In the LR(0) and SLR(1) we are going to place in the entire row and the follow of LHS (in SLR(1)) respectively. But in CLR and LALR(1) we are going to place the reduce moves only in look ahead symbols.

⇒ From the above diagram  $[I_3, I_6]$  have same LR(0) items but differ in look heads.

⇒ Similarly  $[I_4, I_7], [I_8, I_9]$  also have same LR(0) items but differ in look aheads.

CLR(1) PARSING TABLE vs LALR(1) TABLE

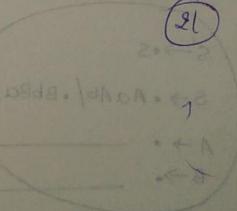
	a	b	\$	S → A		a	b	\$	S → A	
0	$s_3$	$s_4$		2		0	$s_{36}$	$s_{47}$	2	
1						1				
2	$s_6$	$s_7$		5		2	$s_{36}$	$s_{47}$	5	
3	$s_3$	$s_4$		8		36	$s_{36}$	$s_{47}$	89	
4	$\tau_3$	$\tau_3$				47	$\tau_3$	$\tau_3$	$\tau_3$	
5				$\tau_1$		5			$\tau_1$	
6	$s_6$	$s_7$		9		89	$\tau_2$	$\tau_2$	$\tau_2$	
7				$\tau_3$						
8	$\tau_2$	$\tau_2$								
9				$\tau_2$						

$$[I_3, I_6] \Rightarrow I_{36}$$

$$[I_4, I_7] \Rightarrow I_{47}$$

$$[I_8, I_9] \Rightarrow I_{89}$$

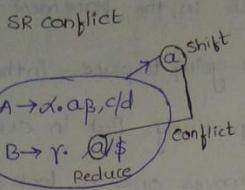
$[\text{No of states in CLR(1)}] \geq [\text{No of states in SLR(1)}] = [\text{No of states in LALR(1)}] = [\text{No of States in LR(0)}]$



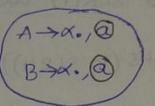
## CONFLICTS AND EXAMPLES OF CLR(1) AND LALR(1) (L-15)

20

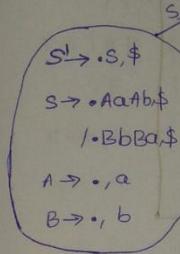
LR(0) Items



RR conflict



LR(0) Items



⇒ If the grammar is not CLR(1) then the Grammar is not LALR(1) because we reduce the size of the table but not the conflicts in LALR(1) parser

⇒ If the Grammar is CLR(1) then it may or may not be LALR(1)

i)  $S \rightarrow AaAb / BbBa$

$A \rightarrow \epsilon$

$B \rightarrow \epsilon$

LL(1) X

LR(0) X

SLR(1) X

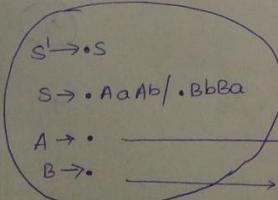
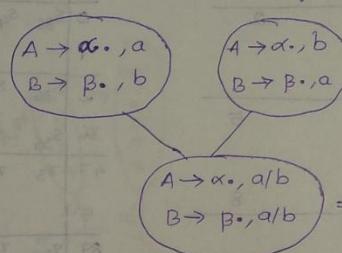
CLR(1) ✓

LALR(1) ✓

②

$S \rightarrow Aa/bAc/c$   
 $A \rightarrow d$

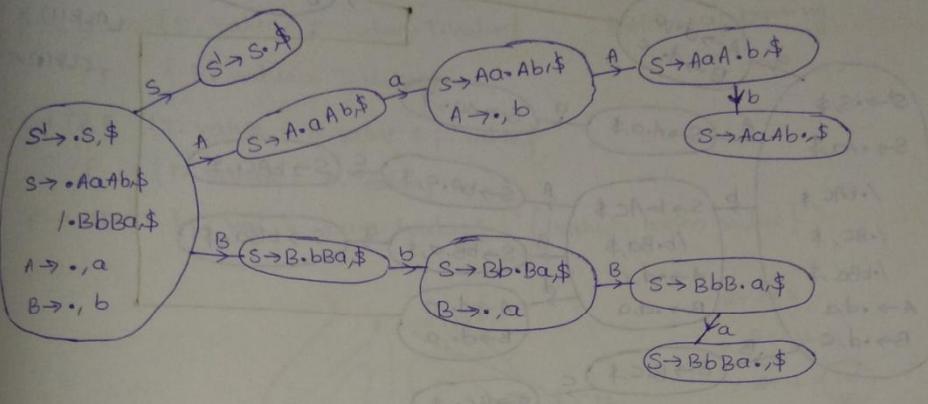
$S \rightarrow S$   
 $S \rightarrow \cdot Aa, \$$   
 $\quad / \cdot bAc, \$$   
 $\quad / \cdot dc, \$$   
 $\quad / \cdot bda, \$$   
 $A \rightarrow \cdot d, a$



placed under follow of  $A = \{a, b\}$   
placed under follow of  $B = \{a, b\}$

I = {I, I}  
F = {F, F}

NOT SLR(1)



because

parson

$S \rightarrow Aa/bAC/dc/bdA$

$$A \rightarrow d$$

LL(1) X

LR(0)

SLR(1) x

CLR(1) ✓

LHLR (1)

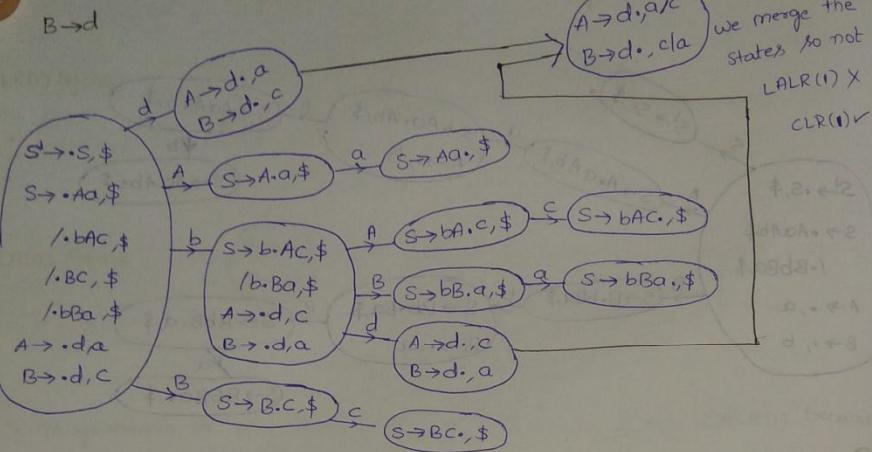
```

graph TD
    S1((S → S, S → Aa, $, /bAC, $, /dc, $, /bda, $, A → d, a))
    S2((S → d.c, $, A → d, a))
    S3((S → A.a, $, S → Aa, $))
    S4((S → b.AC, $, S → b.da, $, A → d, c))
    S5((S → bd.a, $, A → d, c))
    S6((S → bA.c, $, S → bAC, $))

    S1 -- "d" --> S2
    S1 -- "A" --> S3
    S1 -- "b" --> S4
    S2 -- "c" --> S6
    S3 -- "a" --> S5
    S4 -- "d" --> S5
    S4 -- "A" --> S6
    S5 -- "c" --> S6
  
```

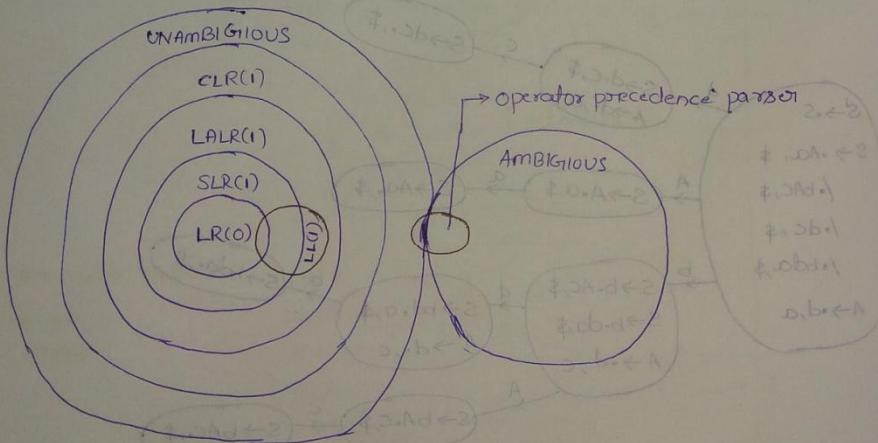
③  $S \rightarrow Aa/bAc/BC/bBa$

$A \rightarrow d$   
 $B \rightarrow d$



### COMPARISON OF THE PARSERS (L-16)

⇒ Every Grammar which is LL(1) is definitely LALR(1)



### SYNTAX DIRE

⇒ Grammar +

1)  $E \rightarrow E + T \{ E \}$   
 $/ T \{ E \}$

$T \rightarrow T * F \{ T \}$   
 $/ F \{ T \}$

$F \rightarrow \text{num} \{ F \}$

and their rules

2)  $E \rightarrow E + T \{ E \}$   
 $/ T \{ E \}$

$T \rightarrow T * F \{ T \}$   
 $/ F \{ T \}$

$F \rightarrow \text{num} \{ F \}$

+ num = soft salt

num  
2

## SYNTAX DIRECTED TRANSLATION (L-H)

(24)  
conflict arises if  
we merge the  
states so not

LALR(1) X  
CLR(1) ✓

#2. ← 2  
d10A ← 2  
d9d8 ← 1  
d1 ← 3  
d2 ← 4

⇒ Grammar + Semantic Rules = SDT

i)  $E \rightarrow E + T \{ E.\text{value} = E.\text{value} + T.\text{value} \}$

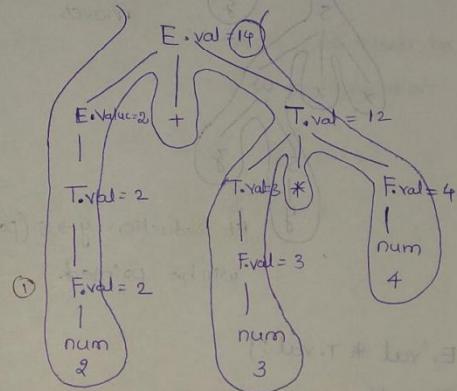
Bottom-up parsing.

/T { E.value = T.value }

T → T \* F { T.value = T.value \* F.value }

/F { T.value = F.value }

F → num { F.val = num.value } { value = lexem value }



$$\begin{aligned} 2 + 3 * 4 \\ = 2 + (3 * 4) \\ = 2 + 12 = 14 \end{aligned}$$

ii)  $E \rightarrow E + T \{ \text{printf}( "+"); \} \textcircled{1}$

/T { } \textcircled{2}

T → T \* F { printf("\*"); } \textcircled{3}

/F { } \textcircled{4}

F → num { printf(num, lval); } \textcircled{5}

⇒ This is the SDT for conversion  
of infix to postfix expression

= & final non

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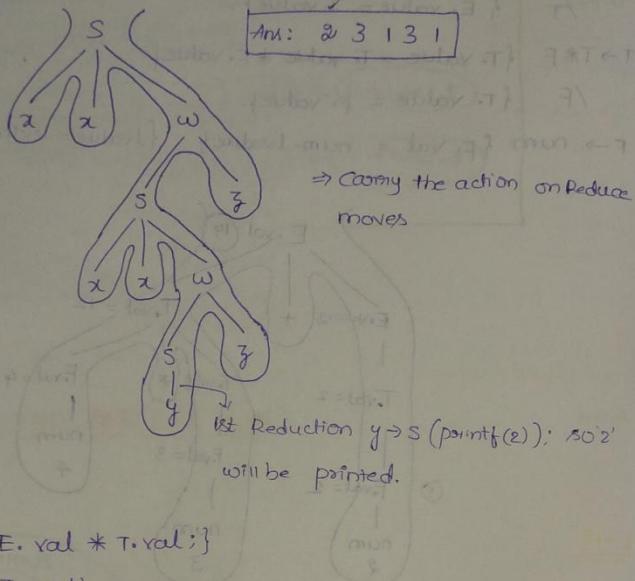
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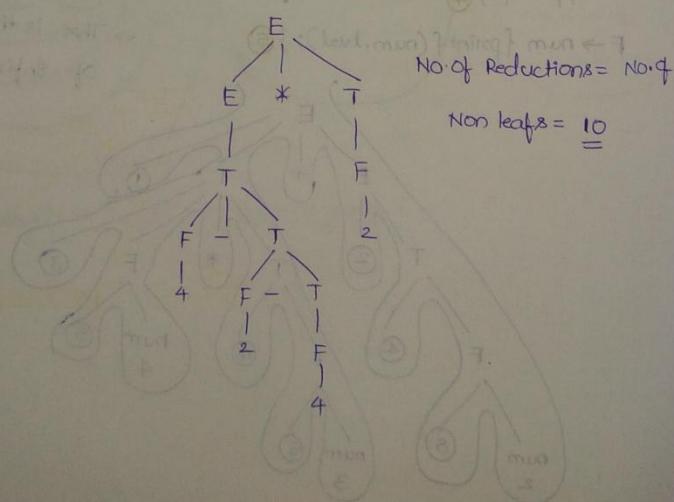
③  $S \rightarrow xxw \{ \text{printf}(1); \}$   
 $y \{ \text{printf}(2); \}$   
 $w \rightarrow S_3 \{ \text{printf}(3); \}$

String  $xxxxyz$



④  $E \rightarrow E * T \{ E.\text{val} = E.\text{val} * T.\text{val}; \}$   
 $/T \{ E.\text{val} = T.\text{val}; \}$   
 $T \rightarrow F - T \{ T.\text{val} = F.\text{val} - T.\text{val}; \}$   
 $/F \{ T.\text{val} = F.\text{val}; \}$   
 $F \rightarrow 2 \{ F.\text{val} = 2; \}$   
 $/4 \{ F.\text{val} = 4; \}$

$$W = 4 - 2 - (-4) * 2 \\ W = ((4 - (-2)) * 2) \\ = (4 - (-2)) * 2 \\ = (4 + 2) * 2 \\ = 12$$



⑤  $E \rightarrow E \# T$

/T

$T \rightarrow T \& F$

/F

$F \rightarrow \text{num}$

$$W = 2 \# 3 \& 5$$

$$= 2 * 3 + 5$$

$$= ((2 * 3) + 5)$$

$$= (6 + 30)$$

$$= \underline{\underline{40}}$$

L-18

SDT TO BUILD

②  $E \rightarrow E_1 + T \{$

/T {

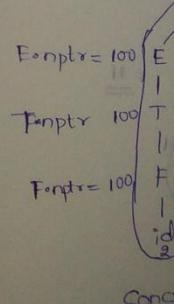
$T \rightarrow T_1 * F \{$

/F {

$F \rightarrow \text{id} \{$

{ I = true }

$$W = 2 + 3 * 4$$



⑥  $E \rightarrow E \# T \{ E.\text{val} = E.\text{val} * T.\text{val}; \}$

$/T \{ E.\text{val} = T.\text{val} \}$

$T \rightarrow T \& F \{ T.\text{val} = T.\text{val} + F.\text{val} \}$

$/F \{ T.\text{val} = F.\text{val} \}$

$F \rightarrow \text{num} \{ F.\text{val} = \text{num}.lvalue; \}$

$\text{Q} = 2 \# 3 \& 5 \# 6 \& 4$  what is the output

$$= 2 * 3 + 5 * 6 + 4$$

$$= ((2 * 3) + (5 * 6) + 4) \quad \left\{ \begin{array}{l} \text{wrong because '+' is defined at highest level} \\ (\text{Bottom level}) \text{ and must be evaluated first} \end{array} \right.$$

$$= (6 + 30 + 4)$$

$\Rightarrow 40$  and then multiplication must be evaluated.

$$\Rightarrow 2 * (3 + 5) * (6 + 4)$$

$$= 2 * (8) * (10)$$

$$= 160$$

### L-18

#### SDT TO BUILD SYNTAX TREE

⑦  $E \rightarrow E_1 + T \{ E.\text{nptr} = \text{mknode}(E_1.\text{nptr}, '+', T.\text{nptr}); \}$

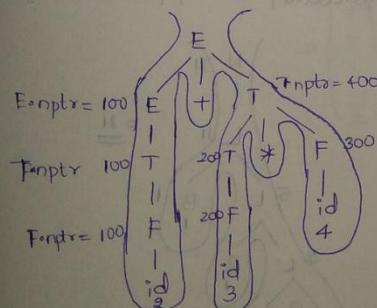
$/T \{ E.\text{nptr} = T.\text{nptr} \}$

$T \rightarrow T_1 * F \{ T.\text{nptr} = \text{mknode}(T_1.\text{nptr}, '*', F.\text{nptr}); \}$

$/F \{ T.\text{nptr} = F.\text{nptr} \}$

$F \rightarrow \text{id} \{ F.\text{nptr} = \text{mknode}(\text{null}, \text{id}.name, \text{null}); \}$

$$W = 2 + 3 * 4$$

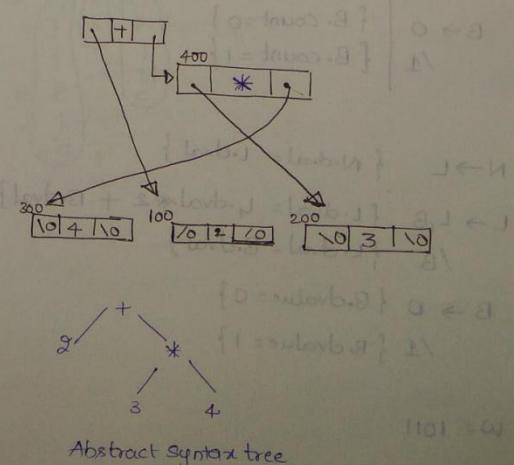


Concrete Syntax tree

Returns Address

$\text{mknode} = \text{make node}$

$\text{nptr} = \text{node pointer}$



### ⑦ SDT FOR TYPE CHECKING

$E \rightarrow E_1 + E_2 \{ \text{if } (E_1.\text{type} == E_2.\text{type}) \& \& (E_1.\text{type} = \text{int}) \text{ then } E.\text{type} = \text{int} \text{ else error} \}$

$/E_1 == E_2 \{ \text{if } (E_1.\text{type} == E_2.\text{type}) \& \& (E_1.\text{type} = \text{int}/\text{boolean}) \text{ then } E.\text{type} = \text{boolean} \text{ else error} \}$

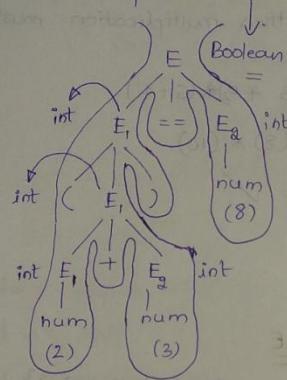
$(E_1) \{ E.\text{type} = E_1.\text{type} \}$

$/\text{num} \{ E.\text{type} = \text{int} \}$

$/\text{True} \{ E.\text{type} = \text{boolean} \}$

$/\text{False} \{ E.\text{type} = \text{boolean} \}$

$w = \{ (2+3) == 8 \} = \text{Boolean Expression}$

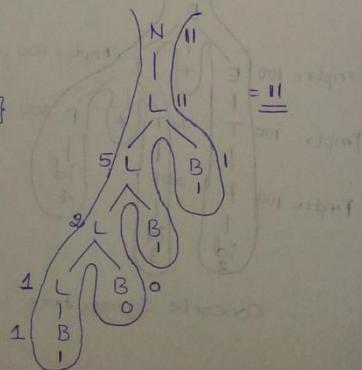


count all 1's	
$N \rightarrow L$	$\{ N.\text{count} = L.\text{count} \}$
$L \rightarrow L, B$	$\{ L.\text{count} = L_1.\text{count} + B.\text{count} \}$
$/B$	$\{ L.\text{count} = B.\text{count} \}$
$B \rightarrow O$	$\{ B.\text{count} = 0 \}$
$/1$	$\{ B.\text{count} = 1 \}$

count all 0's	
$\Rightarrow$	$\{ \text{No. of Bits} \}$
$\Rightarrow$	$\{ \text{sum} = \text{sum} \}$
$\Rightarrow$	$\{ \text{sum} = \text{sum} \}$
$\{ B.\text{count} \} = 1$	$\{ B.\text{count} = 1 \}$
$\{ B.\text{count} \} = 0$	$\{ B.\text{count} = 1 \}$

$N \rightarrow L \{ N.\text{dval} = L.\text{dval} \}$
$L \rightarrow L, B \{ L.\text{dval} = L_1.\text{dval} * 2 + B.\text{dval} \}$
$/B \{ L.\text{dval} = B.\text{dval} \}$
$B \rightarrow O \{ B.\text{dval} = 0 \}$
$/1 \{ B.\text{dval} = 1 \}$

$$w = 1011$$



### L-19 S-ATT

• (I) =  $\frac{1}{2^2} = 0.25$   
• (II) =  $\frac{3}{4} = 0.75$

①  $N \rightarrow L_1, L_2$

$L \rightarrow LB/B$

$B \rightarrow O$

/1

SDT TO GENE

⑩  $S \rightarrow id = E$

$E \rightarrow E_1 + T$

$T \rightarrow T_1 * F$

/F

$F \rightarrow id$

## L-19 S- ATTRIBUTED AND L- ATTRIBUTED DEFINITIONS

else error}

E.type = boolean,  
error}

j.value

$$\textcircled{I} \Rightarrow \frac{1}{2} = 0.5$$

$$\textcircled{II} \Rightarrow \frac{3}{4} = 0.75$$

$$N \rightarrow L_1 L_2$$

$$L \rightarrow LB/B$$

$$B \rightarrow O$$

$$/1$$

$$\{L_i.dval = L_i.dval + (L_j.dval / 2^i) L_j.count\}$$

$$\{L_i.value = L_i.dval + B_i.dval\} \{L_i.count = L_i.count + B_i.count\}$$

$$\{B_i.count = 1, B_i.value = 0\}$$

$$\{B_i.count = 1, B_i.value = 1\}$$

SIT TO GENERATE THREE ADDRESS CODE

$$S \rightarrow id = E \quad \{gen(id.name = E.place);\}$$

$$E \rightarrow E_1 + T \quad \{E.place = newTemp(); gen(E.place = E_1.place + T.place);\}$$

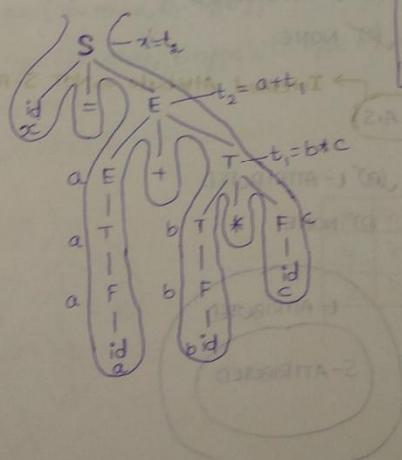
$$/T \quad \{E.place = T.place;\}$$

$$T \rightarrow T_1 * F \quad \{T.place = newTemp(); gen(T.place = T_1.place * F.place);\}$$

$$/F \quad \{T.place = F.place;\}$$

$$F \rightarrow id \quad \{F.place = id.name\}$$

$$\begin{aligned} t_1 &= b * c \\ t_2 &= a + t_1 \\ x &= t_2 \end{aligned}$$



## DIFFERENCE BETWEEN S-ATTRIBUTED AND L-ATTRIBUTED SDT

### S-ATTRIBUTED SDT

- 1) Uses only synthesized attributes
- 2) Semantic actions are placed at Right end of production  

$$A \rightarrow Bcc \{ \}$$
- 3) Attributes are evaluated during Bottom up passing

### L-ATTRIBUTED SDT

- 1) Uses Both inherited and synthesized attributes. Each inherited attribute is restricted to inherit either from parent or Left siblings only.
- 2) Semantic Actions are placed anywhere

Ex:  $A \rightarrow xyz \{ y.S = A.S, y.S = x.S, y.S = z.S \}$

### Inherited Attribute

- 1)  $A \rightarrow LM \{ L.i = f(A,i); M.i = f(L,s); A.S = f(m,s); \}$
- 2)  $A \rightarrow QR \{ R.i = f(A,i), Q.i = f(R,i); A.S = f(Q,s); \}$
- 3) Attributes are evaluated by traversing parse tree depth first left to Right

(A) S- ATTRIBUTED

(B) L- ATTRIBUTED

(C) BOTH

(D) NONE

②  $A \rightarrow BC \{ B.S = A.S \}$

a) S- ATTRIBUTED

b) L- ATTRIBUTED

c) BOTH

d) NONE



### SDT TO A

⑩  $D \rightarrow TL$

$T \rightarrow int$

/char

$L \rightarrow L_i$

/id

$\rightarrow d$

$\rightarrow i$

$\rightarrow s$

$\rightarrow r$

$\rightarrow t$

$\rightarrow n$

$\rightarrow l$

$\rightarrow o$

$\rightarrow u$

$\rightarrow m$

$\rightarrow p$

$\rightarrow h$

$\rightarrow v$

$\rightarrow f$

$\rightarrow g$

$\rightarrow b$

$\rightarrow w$

$\rightarrow x$

$\rightarrow y$

$\rightarrow z$

$\rightarrow \epsilon$

$\rightarrow \cdot$

$\rightarrow \#$

SDT TO ADD TYPE INFORMATION INTO SYMBOL TABLE

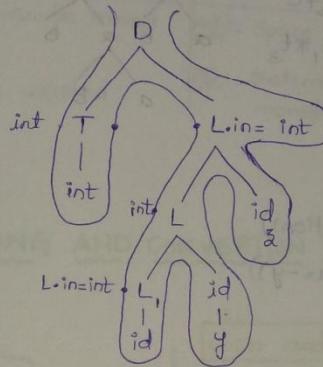
(31)

- ①  $D \rightarrow TL \{ L.in = T.type \} \Rightarrow$  Inherited Attribute  
 $T \rightarrow int \{ T.type = int; \} \Rightarrow$  Synthesized Attribute  
 $/char \{ T.type = char; \}$
- $L \rightarrow L_1 id \{ L_1.in = L.in, \text{add type}(id.name, L_1.in); \}$   
 $/id \text{ add type}(id.name, L.in) \Rightarrow$  Inherited

x	int
y	int
z	int

$\Rightarrow$  Evaluate the synthesized attribute when you last visit it.

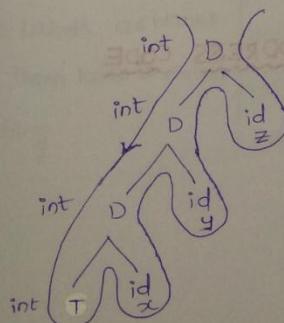
$\Rightarrow$  Evaluate the Inherited attribute when you first visit it.



S-ATTRIBUTED SDT FOR THE SAME QUESTION

- ②  $D \rightarrow D_1 id \{ \text{add-type}(id.name, D_1.type) \}$   
 $/T id \{ \text{add-type}(id.name, T.type), D_1.type = T.type \}$   
 $T \rightarrow int \{ T.type = int; \}$   
 $/char \{ T.type = char; \}$

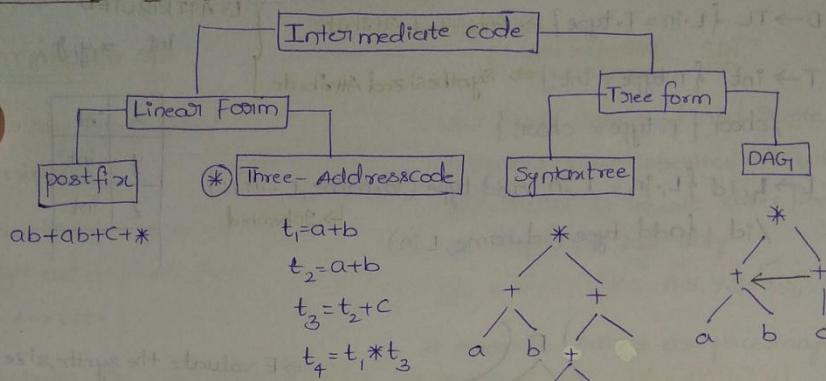
x	int
y	int
z	int



## INTERMEDIATE CODE GENERATION

### INTRODUCTION TO INTERMEDIATE CODE

Ex:  $(a+b)*(a+b+c)$



### TYPES OF 3-ADDRESS CODE

- 1)  $x = y \text{ op } z$  ( $x = a+b$  (Binary operation))
- 2)  $x = \text{op } z$  (Unary operation ( $x = -y$ ))
- 3)  $x = y$  (Assignment)
- 4) if  $x$  (rel op)  $y$  goto L (if ' $x$ ' (Relational operator)  $y$  goto L)
- 5) goto L  $\Rightarrow$  (unconditional)
- 6)  $A[i] = x$  (Array indexing)
- 7)  $x = *p \Rightarrow$  pointer
- 8)  $y = &y \Rightarrow$  Address of variable assigned to another variable

### VARIOUS REPRESENTATIONS OF 3-ADDRESS CODE

$$\Rightarrow (a+b)*(c+d)+(a+b+c)$$

$$1) t_1 = a+b$$

$$2) t_2 = -t_1$$

$$3) t_3 = c+d$$

$$4) t_4 = t_2 * t_3$$

$$5) t_5 = a+b$$

$$6) t_6 = t_5 + c$$

$$7) t_7 = t_4 + t_6$$

OPR
1) +
2) -
3) *
4) /
5) +
6) -
7) *

Adv:
Arith
Dis:

### BASIC STATEMENTS

#### Back

If (ac  
else

(i) : if

(i+1) : t

(i+2) : go

(i+3) : t

(i+4) :

Leaving

and f

Back

QUADRUPLE				TRIPLE			INDIRECT TRIPLE	
opr	op1	op2	Result	opr	op1	op2		
1) +	a	b	t <sub>1</sub>	1) +	a	b	i) (1)	
2) -	t <sub>2</sub>	NULL	t <sub>2</sub>	2) -	(1)		ii) (2)	
3) *	c	d	t <sub>3</sub>	3) +	c	d	iii) (3)	
4) *	t <sub>2</sub>	t <sub>3</sub>	t <sub>4</sub>	4) * (3)	(2)	(3)	iv) (4)	
5) +	a	b	t <sub>5</sub>	5) + a	a	b	v) (5)	
6) +	t <sub>5</sub>	c	t <sub>6</sub>	6) + (5)	c		vi) (6)	
7) +	t <sub>4</sub>	t <sub>6</sub>	t <sub>7</sub>	7) + (4)	(6)		vii) (7)	

Adv: Statements can be moved around  
 Dis: More Space wasted

Adv: Space is not wasted  
 Dis: Statements cannot be moved

Adv: Statements can be moved  
 Dis: Two Access of Memory

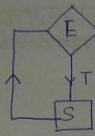
### BACK PATCHING AND CONVERSION TO 3-ADDRESS CODE

t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>
$a < b \text{ and } c < d \text{ or } e < f$		

```

    100) if (a < b) goto 103      110) goto 112
    101) t1 = 0                  111) t3 = 1
    102) goto 104
    103) t1 = 1
    104) if (c < d) goto 107
    105) t2 = 0
    106) goto 108
    107) t2 = 1
    108) if (e < f) goto 111
    109) t3 = 0
  
```

① While : E do S



L: if ( $E == 0$ ) goto L1      (P0) if ( $E$ ) goto L1

S      (P1)      goto last      (P2)

Goto L      (P3)

L1:      (P4)      L1: S      (P5)

    (P6)      (P7)      (P8)      goto L      (P9)

② while ( $a < b$ ) do

program to add sum of 1 to 100

$x = y + z$

Type

L: if  $a < b$  goto L1

goto last

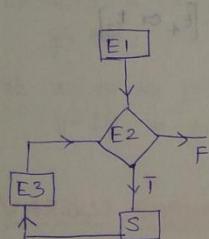
L1:  $t = y + z$

$x = t$

goto L1

last:

③ for (E1; E2; E3)



for ( $i = 0; i < 10; i++$ )

    F0:  $a = b + c$ ; f (P0)

    i = 0      o = 3 (P0)

    L: if ( $i < 10$ ) goto L1

    goto last      (P0)

    L1:  $t_1 = b + c$       (P0)

$a = t_1$       (P0)

$t = i + 1$       (P0)

$i = t$

    goto L

last:

④ switch  
f

case 1

case 2

case 3

case 4

case 5

case 6

case 7

case 8

case 9

case 10

case 11

case 12

case 13

case 14

case 15

case 16

case 17

case 18

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case 230

case 231

case 232

case 233

case 234

case 235

case 236

case 237

case 238

case 239

case 240

case 241

case 242

case 243

case 244

case 245

(34)

Switch (i+j)

```

    case (i) = a+b+c;
    break;
    case (ii) : p=q+r;
    break;
    default : x=y+z;
    break;
}

```

$t = i+j$   
goto test

L1:  $t_1 = b+c$  $a=t_1$ 

goto last

last :

L2:  $t_2 = q+r$  $p=t_2$ 

goto last

L3:  $t_3 = y+z$  $x=t_3$ 

goto last

test: if ( $t == 1$ ) goto L1if ( $t == 2$ ) goto L2

goto L3

(35)

## TWO DIMENSIONAL ARRAY TO 3-ADDRESS CODE

 $x = A[y \ z]$  $t_1 = y * 20$  $t_2 = t_1 + z$  $t_3 = t_2 * 4$  $t_4 = \text{Base Address of } A$  $x = t_4[t_3]$  $A: 10x20$  $A[4][4]$  $(y*20+z)*4$  $t_3$  $t_2$  $t_1$  $t_0$  $t_{10}$  $t_{20}$  $t_{30}$  $t_0$  $t_1$  $t_2$  $t_3$  $t_{10}$  $t_{11}$  $t_{12}$  $t_{13}$  $t_{20}$  $t_{21}$  $t_{22}$  $t_{23}$  $t_{30}$  $t_{31}$  $t_{32}$  $t_{33}$  $t_0$  $t_1$  $t_2$  $t_3$  $t_{10}$  $t_{11}$  $t_{12}$  $t_{13}$  $t_{20}$  $t_{21}$  $t_{22}$  $t_{23}$  $t_{30}$  $t_{31}$  $t_{32}$  $t_{33}$ 

↳ Base offset Addressing

(Base Address + Offset) result at based address location

Row Major order: 00 01 02 03 10 11 12 13 20 21 22 23 30 31 32 33

column major order: 00 10 20 30 01 11 21 31 02 12 22 32 03 13 23 33

↳ Base offset Addressing

(Base Address + Offset) result at based address location

Row Major order: 00 01 02 03 10 11 12 13 20 21 22 23 30 31 32 33

column major order: 00 10 20 30 01 11 21 31 02 12 22 32 03 13 23 33

↳ Base offset Addressing

(Base Address + Offset) result at based address location

Row Major order: 00 01 02 03 10 11 12 13 20 21 22 23 30 31 32 33

column major order: 00 10 20 30 01 11 21 31 02 12 22 32 03 13 23 33

↳ Base offset Addressing

(Base Address + Offset) result at based address location

Row Major order: 00 01 02 03 10 11 12 13 20 21 22 23 30 31 32 33

column major order: 00 10 20 30 01 11 21 31 02 12 22 32 03 13 23 33

↳ Base offset Addressing

(Base Address + Offset) result at based address location

Row Major order: 00 01 02 03 10 11 12 13 20 21 22 23 30 31 32 33

column major order: 00 10 20 30 01 11 21 31 02 12 22 32 03 13 23 33

↳ Base offset Addressing

(Base Address + Offset) result at based address location

## RUN ENVIRONMENT

⇒ Run time Environment means when you run the program what is the support that you need from the operating system.

### STORAGE ALLOCATION STRATEGIES

#### 1) Static

- 1) Allocation is done at compile time
- 2) Bindings don't change at Runtime
- 3) One Activation Record per procedure

#### Disadvantages

- 1) Recursion is not supported.
- 2) size of data objects must be known at compile time
- 3) Data structures cannot be created Dynamically

#### 2) Stack

whenever a new activation begins, Activation record is pushed onto the stack and whenever Activation ends, Activation record is popped off

Local variables are bound to fresh storage

#### Disadvantages

- 1) Local variables cannot be retained once activation ends

#### 3) Heaps

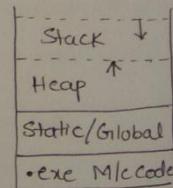
⇒ Allocation and deallocation can be in any order

⇒ Disadv: heap management is overhead

### SUMMARY

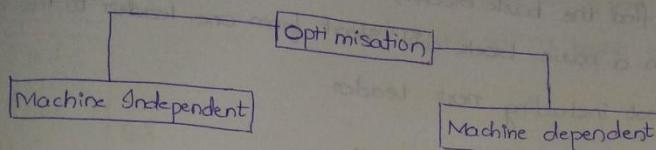
Activations can have

- 1) permanent lifetime in case of static allocation
- 2) Nested lifetime in case of stack Allocation
- 3) Arbitrary lifetime in case of Heap Allocation.



## CODE OPTIMISATION

### INTRODUCTION TO CODE OPTIMISATION



#### 1) Loop optimisations

##### (a) code motion (cont)

Frequency reduction

##### (b) Loop unrolling

##### (c) Loop Jamming

##### 2) Folding

- constant propagation

##### 3) Redundancy Elimination

##### 4) Strength Reduction

#### 1) Register Allocation

#### 2) Use of Addressing modes

#### 3) Peephole optimisation

##### (a) Redundant load/store

##### (b) Strength Reduction

##### (c) flow of control options

##### (d) use of M/C idioms

### LOOP OPTIMISATION AND BASIC BLOCKS

→ To apply optimisations, we must first detect loops

→ For detecting loops we can use control flow Analysis (CFA) using program Flow Graph (PFG)

→ To find PFG, we need to find Basic blocks

A basic block is a sequence of 3-Address statements where control enters at the beginning and leaves at the end without any jumps or halts.

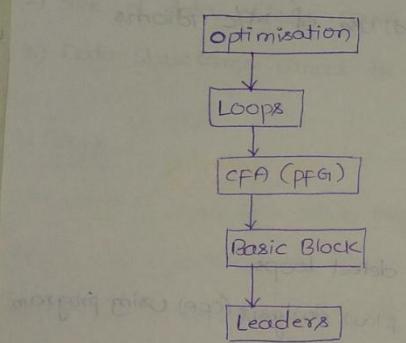
## ALGORITHM TO FIND LEADERS

### Finding the Basic Blocks

→ In order to find the basic blocks, we need to find the leaders in the program then a basic block will start from one leader to the next Leader but not including next Leader.

### Identifying Leaders in the Basic Block

- 1) Statement is a leader
- 2) Statement that is target of conditional or unconditional Statement is a Leader → if() goto [200] (or) goto [200] → leader
- 3) Statement that follows immediately a conditional or unconditional Statement is a Leader.



### Example

```

fact(x)
{
    int f=1;
    for(i=2;i<=x;i++)
        f=f*i;
    return f;
}
  
```

Now, the

- \*1)  $f = 1$
- 2)  $i = 2$
- \*3)  $t_0 (i > x)$
- \*4)  $t_1 = f$
- 5)  $t_2 = i$
- 7)  $i = t_2;$
- 8) goto (3)
- \*9) Goto co

### TYPES

Frequencies

Moving

frequencies

frequencies

code m

Ex: whi

{

A  
j  
}

t =

whi

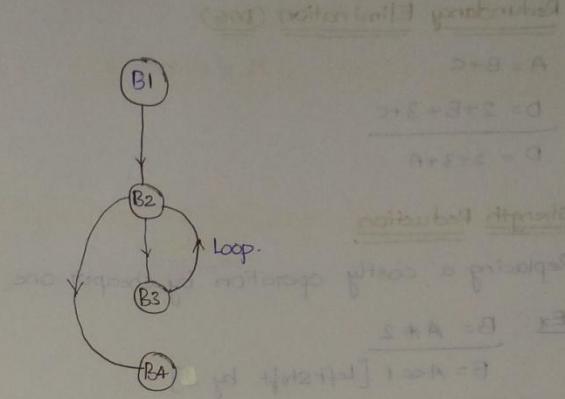
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Now, the 3-Address code for the above problem will be

```

#1) f = 1          B1
#2) i = 2          B1
#3) if (i > x) goto 9    B2
#4) t1 = f * i;
#5) t2 = i + 1;
#6) i = t2;
#7) goto (3)
#8) Goto calling program B4
  
```

⇒ Incase you have  $n$  leaders we will get  $n$  Basic Blocks  $\Rightarrow$  if you have  $m$  basic Leaders will get  $m$  basic blocks



### TYPES OF LOOP OPTIMIZATION

#### Frequency Reduction

Moving the code from high frequency region to low frequency Region is called code motion.

Ex: while ( $i < 5000$ )

```

{
    A = sin(x)/cos(x) * i;
    i++;
}
t = sinx/cosx
while (i < 5000)
    A = t * i;
  
```

#### Loop Unrolling

while ( $i < 10$ )

```

{
    x[i] = 0
    i++;
}
while ( $i < 10$ )
{
    x[i] = 0;
    i++;
}
  
```

#### Loop Jamming

combines the bodies of two loops

for( $i=0; i < 10; i++$ )

for( $j=0; j < 10; j++$ )

$x[i,j] = 0;$

for( $i=0; i < 10; i++$ )

$x[i,j] = 0;$

for( $i=0; i < 10; i++$ )

$x[i,j] = 0;$

## MACHINE INDEPENDENT optimisation

(b) Flow

### Folding:

Replacing an expression that can be computed at compile time by its value.

$$\text{Ex: } 2+3+C+B = 5+C+B$$

### Redundancy Elimination (DAG)

$$A = B+C$$

$$D = 2+B+3+C$$

$$D = 2+3+A$$

### Strength Reduction

Replacing a costly operation by cheaper one

$$\text{Ex: } B = A * 2$$

$$B = A \ll 1 \quad [\text{Left shift by 1}]$$

### Algebraic Simplification

$$A = A + 0 \quad \left. \begin{array}{l} \text{eliminate such} \\ \text{statements} \end{array} \right\}$$

$$x = x * 1 \quad \left. \begin{array}{l} \text{statements} \end{array} \right\}$$

## MACHINE DEPENDENT OPTIMISATION

### 1) Register Allocation

Local Allocation

Global Allocation

### 2) Use of Addressing modes

### 3) peephole optimization

#### a) Redundant Load and store elimination

$$x = y + z$$

- Mov y, R0
- Add z, R0
- Mov R0, x

$$\begin{array}{l|l}
a = b + c & \text{Mov } b, R0 \\
d = a + e & \text{Add } c, R0 \\
& \boxed{\begin{array}{l} \text{Mov } R0, a \\ \text{Mov } a, R0 \end{array}} X \\
& \text{Add } e, R0 \\
& \text{Mov } R0, d
\end{array}$$

$\Rightarrow$  Har

$\Rightarrow$  RR

$\Rightarrow$  SR

$\Rightarrow$  fb

at

(b) Flow control optimisation

values

Q1

Avoid jumps  
on jumps

L1: Jump L2

L2: Jump L3

L3: Jump L4

Eliminate dead

code

#define x 0

if (x)

{

↓ dead code X

d) Use of M/c idioms

i = i + 1      | MOV R0, i  
                | add R0, i  
                | mov i, R0 } increment 'i' [inc i]

⇒ Handle of the string is a substring that matches with RHS of production

⇒ RR conflicts occur in LALR(1) parser when merging of the states

⇒ SR conflicts does not occur in LALR(1) parser

⇒ If the attribute can be evaluated in Depth-first-order then the

attribute is L-attributed.