Course: Compiler Construction

Week 7: Bottom-Up Parsing

Lecturer: Martha Gichuki

Course Description

- The course begins with a coverage of basic Principles in Compiler Design with an introduction to Formal programming language translation and compiler design concepts; compilers and interpreters.
- A coverage of Language theory, Parsing Context-Free Languages (Top - down and bottom - up parsing), translation specifications and machine- independent code optimization will then follow.

Course Description …

- The main phases of compilation i.e. Lexical, Syntax and Semantic analysis will be taught.
- Code generation and Optimization, Symbol table design, Program compilation, Loading and execution will then be covered.
- Compilation techniques, Optimization, Design of a simple complete compiler. will culminate the course.

Learning outcomes Week 7: Bottom-Up Parsing

At the end of the lecture, you will be able to:

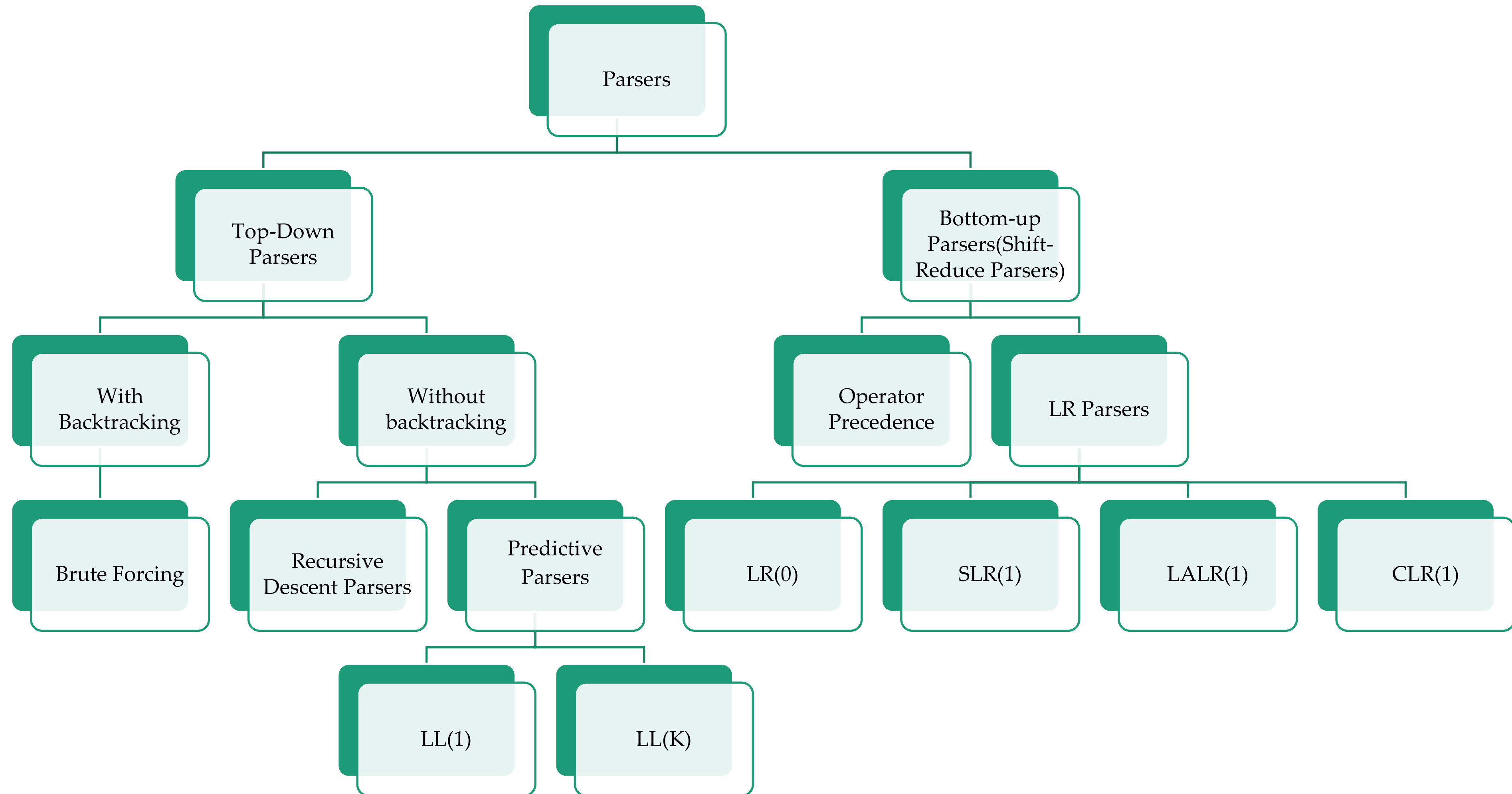
i. Define Shift Reduce Parsing, Left Right Parser
ii. Implement Shift Reduction
iii. Describe stack implementation in Bottom-up Parsing

Definition: Parsing

- ✓**Parsing** is a convenient way to see how strings are derived from the start symbol.
- ✓It is a way of analyzing a string or text into **logical syntactic components**
- ✓Tokens are divided into parts and the relations between the parts can then be described[1]

1. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 86

Classification of parsers[2]



2. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007) page 324

BOTTOM-UP PARSING

- ✓This approach is also known as **shift-reduce parsing**
- ✓It is the primary parsing method for many compilers, due to its **speed** and the **tools** which automatically generate a parser based on the grammar[3].
- ✓Generally, bottom-up parsing **starts from the leaf nodes of a tree and works in upward direction till it reaches the root node.**
- ✓This parsing strategy is based on the **reverse process to top-down parsing.**

3. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 322

Example:- Consider the grammar below:

1 $S \rightarrow aABe$

2 $A \rightarrow Abc \mid b$

3 $B \rightarrow d$

- ✓ To parse the sentence ***abbcde*** using the bottom up approach gives the following reductions:-

$\boldsymbol{abbcde}$

$\boldsymbol{aAbcde}$ by 2

$aA\boldsymbol{d}e$ by 2

$\boldsymbol{aABe}$ by 3

S by 1

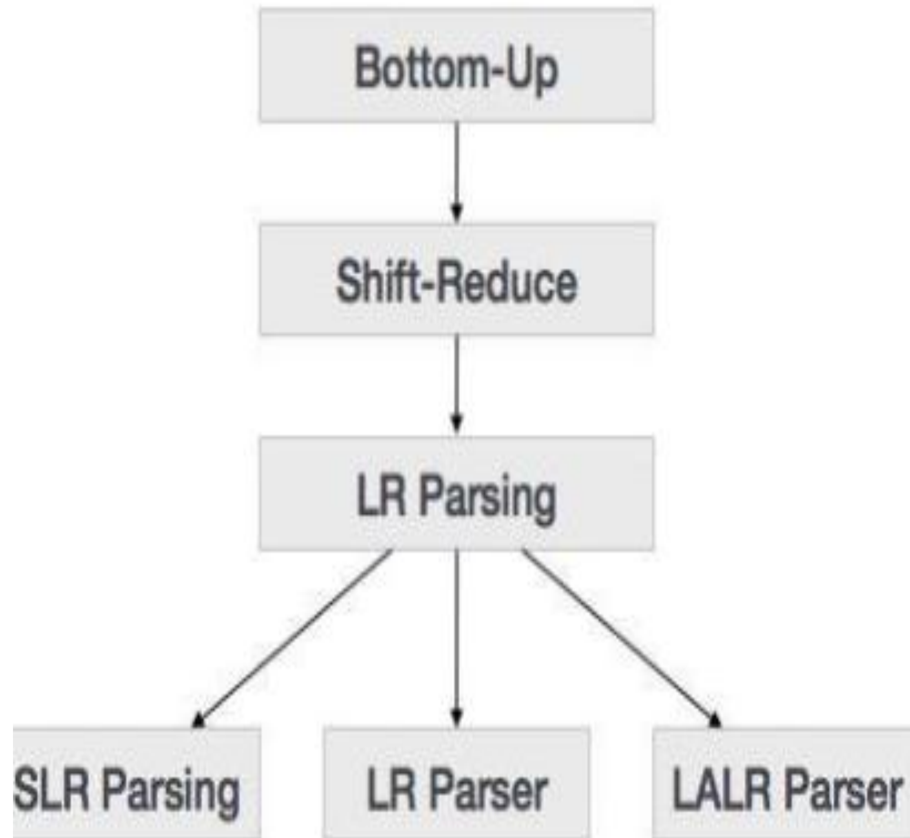
Reverse gives in right most derivation:

$S \to aABe \to aAde \to aAbcde \to abbcde$

- ✓ Here, we start from a sentence and then apply production rules in **reverse manner in order to reach the start symbol**.
- ✓ Instead of expanding successful non-terminals according to production rules, a current string or right sentential form is collapsed each time until the start non-terminal is reached to predict the legal next symbol; i.e. it can be regarded as a **series of reductions**[4].

4. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007) page 27

The figure below is a summary of the bottom-up parsers available[5]



5. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007) page 323

LR Parsing

- ✓ The LR parser is a non-recursive, shift-reduce, bottom-up parser.
- ✓ It uses a wide class of context-free grammar which makes it the most efficient syntax analysis technique.
- ✓ It is one of the best methods of syntactic recognition of programming languages[6].
- ✓ The **L stands for left to right** scan, and **R stands for right most derivation in reverse**.
- ✓ In general, we can have ***LR*(*k*) parsing with *k* symbols of LOOKAHEAD.**
- ✓ However, **LR parsing** refers to ***LR*(1)** parsing.

6. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007) page 324

Advantages of LR Parsing[7]

i) LR parsers can recognize virtually **all programming language constructs** written with CFG grammars.

ii) It is the **most general, non-backtracking** technique known.

iii) It can be implemented in a **very efficient** manner.

iv) The language it can recognize is a proper **super set of that of predictive parsers.**

v) It can recognize **syntax errors quickly**.

7. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007) page 266

Disadvantages of LR parsing[8]

- ✓ The primary drawback of LR parsers is that they **require too much work to manually create LR parsing tables**.
- ✓ However, **tools exist to generate LR parsers** from a given grammar i.e. parser generators such as Yet Another Compiler Compiler (YACC), BISON etc.

8. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007) page 267

LR Parsing Methods

- ✓There are three widely used algorithms available for constructing an LR parser:

i) **Simple LR (SLR)**

- ✓**Easy to implement but less powerful** than other parsing methods.
- ✓Generally works on **smallest class of grammar and have a few number of states, hence a very small table**[9]

9. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 325

ii) Canonical LR

- ✓This is the most general and most powerful.
- ✓However, it is **tedious and costly to implement**, i.e. for the same grammar, it has got much number of states as compared to SLR parsers.
- ✓Generally **works on complete set of LR(1) Grammar and generates a larger table and more states**[10]

10. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 325

iii) **LOOKAHEAD LR (LALR)**

- ✓A mixture of SLR and canonical LR, but it can be implemented efficiently i.e. it contains the same number of states as Simple LR parser for the same grammar.
- ✓Notice that most parser generators generate LALR parsers since they are a trade-off between power and efficiency[11].

11. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 324

Implementing Shift Reduction

- ✓ A shift-reduce parser is implemented using the following notation[12]:

An input stream, containing
a phrase to be parsed and
a stack holding a symbols

12. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 281

- ✓ The **input stream** holds terminals, the stack can hold a mixture of terminals and non-terminals, the latter generated by earlier reductions.
- ✓ The operation **shift** moves a symbol from the input to the stack while the operation **reduce** combines the sequence ending with the last terminal shifted to form a non-terminal on the stack.
- ✓ When the input is exhausted, the single start symbol should be presented assuming all reductions have been performed[13].

13. Compilers: Principles, Techniques and Tools Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 279

Example:- Consider the following grammar[14]:

$$exp \rightarrow exp + exp$$

$$exp \rightarrow exp * exp$$

$$exp \rightarrow (exp)$$

$$exp \rightarrow id$$

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Example:- Show the sequence of **shift/reduce** for the string

$id_1 + id_2 * id_3$. [15]

$exp \rightarrow exp + exp$
$exp \rightarrow exp * exp$
$exp \rightarrow (exp)$
$exp \rightarrow id$

Stack	Input	Action
$	id1+id2*id3$	shift
$id1	+id2*id3$	reduce using exp→id
$exp	+id2*id3$	shift
$exp+	id2*id3$	shift
$exp+id2	*id3$	Reduce using exp→id
$exp+exp	*id3$	shift
$exp+exp*	id3$	shift
$exp+exp*id3	$	Reduce using exp→id
$exp+exp*exp	$	Reduce using exp→exp*exp
$exp+exp	$	Reduce using exp→exp+exp
$exp	$	Accept

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Comparison between LL and LR[16]

LL	LR
Does a left-most derivation	Does a right-most derivation in reverse
Starts with the root non-terminal on the stack	Ends with the root non-terminal on the stack
Ends when the stack is empty	Starts with an empty stack
Uses the stack for designating what is still to be expected	Uses the stack for designating what is already seen
Builds the parse tree top-down	Builds the parse tree bottom -up
Continuously pops a non-terminal off the stack and pushes the corresponding right hand side	Tries to recognize a right hand side on the stack, pops it and pushes the corresponding non-terminal
Expands the non-terminals	Reduces the non-terminals
Reads the terminals when it pops one off the stack	Reads the terminals while it pushes them on the stack
Pre-order traversal of the parse tree	Post-order traversal of the parse tree

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Handles

- ✓ A handle of a right-sentential form γ is a production **A → β** and a position in γ where **β** may be found and replaced by **A** to produce the previous right sentential form in a **rightmost derivation** of γ
- ✓ This means that if **S → *rmαAw → rmαβw** then **A → β** in the position following **α** is a handle of **αβw**[17]

17. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007) page 27

Handles …

- ✓ Because γ is a **right-sentential form**, the substring to the right of a handle contains **only terminal symbols**
- ✓ This means that a handle is a string that can be reduced and also allows further reductions back to the start symbol (using a particular production at a specific spot) **[18]**.

18. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007) page 27

- ✓ Informally, a "**handle**" is a substring that **matches the body of a production,** and whose reduction represents one step along the reverse of a rightmost derivation.
- ✓ **Note:-** The string **w** to the right of the handle must only contain terminal symbols.
- ✓ For convenience, we refer to the **body β rather than A → β as a handle**[19]**.**

19. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 27

Handle-pruning

- ✓ The process to construct a bottom-up parse is called **handle-pruning** that is start with a **string of terminals w** to be parsed.
- ✓ If **w** is a sentence of the grammar at hand, then let **w = γn,** where **γn** is the **nth right-sentential form** of some; yet **unknown** rightmost derivation

$$S = \gamma 0 \rightarrow \gamma 1 \rightarrow \gamma 2 \rightarrow \ldots \rightarrow \gamma n = w$$ [20]

20. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 260

- ✓To reconstruct this derivation in **reverse order**, we **locate** the **handle βn** in **γn** and replace **βn** by the **head** of the relevant production **An → βn** to obtain the previous right-sentential form **γn-1**.
- ✓Repeat this process. i.e. locate the handle **βn-1 in γn-1** and reduce it to obtain the right- sentential form **γn-2**.
- ✓At the end of this process, if we produce a **right-sentential form** with only the **start symbol S**, then we halt and announce successful completion of parsing[21].

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Algorithm

Set **i to n** and apply the following simple algorithm

*For **i** = **n** down to 1*

1. *Find the handle* $A_i \rightarrow \beta_i$ *in* γ_i
2. *Replace* β_i *with* A_i *to generate* γ_{i-1}

✓This takes 2^n steps,

✓Where **n** is the **length of the derivation**[22]

22. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 261, 273

Stack implementation

- ✓One scheme to implement a handle-pruning, bottom-up parser is to use a **shift-reduce parser**.
- ✓Shift-reduce parsers use a **stack** and an input buffer as shown below[23]:-

23. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 262

1. Initialize stack with **$**
2. Repeat until the top of the stack is the goal symbol and the **input token** is **$**

i). find the handle if we don't have a handle on top of the stack, shift an input symbol onto the stack

ii). prune the handle if we have a handle:-

A → **β** on the stack, reduce

i). pop |**β**| symbols off the stack

ii). push **A** onto the stack[24]

24. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 262

Generally, a shift-reduce parser has four canonical actions:

1. ***shift*** - next input symbol is shifted onto the top of the stack
2. ***reduce*** - right end of handle is on top of stack;
   - ✓locate left end of handle within the stack;
   - ✓pop handle off stack and push appropriate nonterminal LHS
3. ***accept*** - terminate parsing and signal success
4. ***error*** - call an error recovery routine[25]

25. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 184

LR Parsers

✓ As with LL(1), the aim of LR parsers is to **make the choice of action** depend only on the next input symbol and the symbol on top of the stack.

✓ To achieve this, a DFA needs to be **constructed**.

✓ The DFA is used to determine the next action and it only needs to look at the **current state** (stored at the top of the stack) and the **next input symbol** (*shift action*) or **non-terminal** (*reduce action*).

✓ We represent the DFA as a table, where we cross-index a DFA state with a symbol (terminal or non-terminal) [26].

26. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 184

- ✓Generally, we need to encode the DFA in a table i.e. a shift-reduce parser’s DFA can be encoded in two tables
- ✓One row for each state

I. ***action table*** encodes what to do given the current state and the next input symbol

II. ***goto table*** encodes the transitions to take after a reduction[27]

27. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison- Wesley Pub Co, ISBN: 0201100886 (2007) page 184

Once the DFA has been encoded as a table, one of the following actions should be performed:-

Actions (1)

Given the current state and input symbol, the main possible actions are:-

- ✓ ***si*** – shift the input symbol and state ***i*** onto the stack (i.e., shift and move to **state i**)
- ✓ ***rj*** – reduce using grammar **production j**
- ✓ The production number tells us how many <symbol, state> pairs to **pop** off the stack[28]

28. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007) page 185

Actions (2)

Other possible action table entries

- ✓accept
- ✓**blank** – no transition, which means syntax error
- ✓A LR parser will **detect an error** as soon as possible on a left-to-right scan
- ✓real compiler needs to produce an **error message**, **recover,** and **continue parsing** when this happens[29]

29. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; Addison-Wesley Pub Co, ISBN: 0201100886 (2007) page 185

Content Covered in Week 7: Bottom-up Parsing

At the end of the lecture, we were able to:

i. Define Shift Reduce Parsing, Left Right Parser
ii. Implement Shift Reduction
iii. Describe stack implementation in Bottom-up Parsing

Course Text Books

1. Compilers: Principles, Techniques and Tools, Aho, Lam, Sethi, and Ullman; *Addison- Wesley Pub Co,* ISBN: 0201100886 (2007))
2. Compiler Construction: Principles and practices; Kenneth C. Louden; *Cengage Learning*; 1st edition, ISBN-10 : 0534939724 (1997)
3. Basics of Compiler Design: Torben Mogensen; *DIKU University of Copenhagen Universitetsparken 1 DK-2100 Copenhagen DENMARK* (2007)
4. Engineering a Compiler: 2nd edition; Keith D. Cooper and Linda Torczon; *Morgan Kaufmann Publishers* ISBN: 978-0-12-088478-0 (2003)
5. Compiler Design: Santanu Chattopadhyay; *PHI Learning Publishers*, ISBN 812032725X, 9788120327252 (2005)