**CONTENTS**

**ACKNOWLEDGMENTS i**

**ABSTRACT ii**

**CONTENTS iii**

**LIST OF FIGURES vii**

**LIST OF TABLES ix**

**LIST OF EQUATIONS x**

**NOMENCLATURE xi**

**CHAPTER 1 INTRODUCTION**

1.1 Problem Statement and Motivations 1

1.2 Objective of the Thesis 2

1.3 Organization of the Thesis 3

**CHAPTER 2 THEORETICAL BACKGROUND**

2.1 Problem Solving in AI 4

2.2 General Problem Solving 4

2.3 Problem Definitions 5

2.3.1 Problem Space 5

2.3.2 Problem Solving Methods 5

2.3.3 State 6

2.3.4 State Change 6

2.3.5 State Space 6

2.3.6 Problem Solution 7

2.3.7 Searching for Solutions 7

2.4 Constraint Satisfaction Problems 7

2.4.1 Standard Search Problem 8

2.4.2 General Characteristics of 9

CSP’s Search Space

2.4.3 Reduction Techniques of CSP 10

2.4.4 Characteristics of 11

Individual CSPs

2.5 N-Queens Problem 14

2.6 Applications Related with N-Queens Problem 14

2.7 Modeling N-Queens Problem as CSP 15

2.8 Caution with modelling N-Queens problem 16

2.9 Map Coloring Problem 16

2.9.1 Modelling as CSP 17

2.10 Sudoku Problem 17

2.10.1 Modeling as CSP 18

2.11 Langford Pairing Problem 18

2.11.1 Modeling as CSP 19

2.12 Magic Square Problem 19

2.12.1 Modelling as CSP 20

2.13 Wedding Seating Arrangement CSP 20

2.14 Reminder System CSP 20

2.15 Summary 21

**CHAPTER 3 CSPs SOLVING TECHNIQUES**

3.1 Generate-and-Test Algorithm 22

3.2 Backtracking Algorithm 22

3.2.1 Improvement of backtracking 25

3.2.2 BT with N-Queens Problem 26

3.3 Forward Checking Algorithm 27

3.3.1 FC with N-Queens 30

3.4 Arc Consistency Technique 31

3.4.1 AC3-FC with N-Queens 33

3.5 MAC Algorithm 34

3.5.1 MAC with N-Queens 36

3.6 Variable Ordering Heuristic 37

3.6.1 FC-MRV with N-Queens 39

3.7 Value Ordering Heuristic 40

3.7.1 FC-LCV with N-Queens 42

3.8 Backjumping Algorithm 43

3.8.1 CBJ with N-Queens 46

3.9 Summary 46

**CHAPTER 4 IMPLEMENTATION AND RESULTS**

4.1 System Architecture 47

4.2 Solving N-Queens Problem 48

4.2.1 Detail Description of Simulator 49

4.3 Experimental Results and Analysis 49

4.3.1 Performance Evaluation Criteria 51

4.3.2 The N-Queens Problem 52

4.3.3 First Solution of N-Queens Problem 52

4.3.3.1 Analysis of Respective Algorithms 53

4.3.3.2 Comparison of No. of Backtracking 55 Counts and Nodes Visited

4.3.4 Time vs Value of N in N-Queen Graph 57

4.3.5 Results of All Solutions 59

4.3.6 Results of First Solution with UI 62

4.4 Discussion 63

4.4.1 AC-3 algorithm 63

4.4.2 MAC-3 algorithm 63

4.4.3 BJ algorithm 64

4.4.4 Trade-off between 64

propagation and search

4.4.5 Board size 65

4.4.6 Heuristics 66

4.4.7 Complexity of CSPs 67

4.5 Summary 69

**CHAPTER 5 CONCLUSION, LIMITATIONS AND FURTHER EXTENSION**

5.1 Conclusion 70

5.2 Limitations 70

5.3 Future Work 71

**REFERENCES**

**APPENDIX A**

**APPENDIX B**

**APPENDIX C**

**LIST OF FIGURES**

**FIGURES** **PAGE**

Figure 2.1 CSP is a type of Search Problem 8

Figure 2.2 A solution to the four queen problem 16

Figure 2.3 (a) Map of Australia before Coloring 17

Figure 2.3 (b) Map of Australia after Coloring 17

Figure 2.4 (a) Sudoku before Solved 18

Figure 2.4 (b) Sudoku after Solved 18

Figure 2.5 A Langford pairing for n=4 19

Figure 2.6 L(2,4), with black=1, red=2, blue=3 and 19

yellow=4

Figure 2.7 A graphical representation of Magic Square 20

with size=3

Figure 3.1 A pictorial illustration of Backtracking processes 23

Figure 3.2 A pictorial illustration of thrashing 24

Figure 3.3 Backtracking Algorithm 25

Figure 3.4 Illustrative view to visualize Backtrack 26

Algorithm for 4-Queens Problem

Figure 3.5 Forward Checking Algorithm process 28

Figure 3.6 Forward Checking Algorithm 29

Figure 3.7 Illustrative view to visualize Forward Checking 30

Algorithm for 4-Queens Problem

Figure 3.8 AC-3 Algorithm 32

Figure 3.9 AC3-FC with N-Queens 33

Figure 3.10 MAC implementation processes 34

Figure 3.11 MAC-3 Algorithm 35

Figure 3.12 Illustrative view to visualize MAC 36

Algorithm for 4-Queens Problem

Figure 3.13 FC-MRV Algorithm 38

Figure 3.14 Illustrative view to visualize FC-MRV 39

Algorithm for 4-Queens Problem

Figure 3.15 FC-LCV Algorithm 41

Figure 3.16 A pictorial illustration of Backjumping process 44

Figure 4.1 System Architecture 47

Figure 4.2 N-Queens CSP Simulator 48

Figure 4.3 CPU Time for 23 Queens Problem 52

Figure 4.4 Comparison of BT vs BJ 57

Figure 4.5 (a)Time vs Value of N in N-Queen Graph for 58

normal algorithm

Figure 4.5 (b)Time vs Value of N in N-Queen Graph for 58

outperforming algorithm

Figure 4.6 Cost of problem reduction vs cost of backtracking 65

Figure 4.7 Tackle NP-complete problems through 68

polynomial pre-processing

**LIST OF TABLES**

**TABLES PAGE**

Table 4.1 Hardware Environment 50

Table 4.2 Software Environment 50

Table 4.3 Results for N-Queens(when N=23) 52

Table 4.4 Results for N-Queens(According to 53

the size of N that is even)

Table 4.5 Results for N-Queens(According to the 53

Size of N that is odd)

Table 4.6 Results for N-Queens with backtracking counts 55

Table 4.7 Results for N-Queens with number of nodes 55

visited

Table 4.8 Results for N-Queens with number of nodes 55

assigned

Table 4.9 N-Queens with backtracking Count 56

(According to the size of N)

Table 4.10 N-Queens with nodes assigned 56

(According to the size of N)

Table 4.11 BT algorithm for all solutions of N 59

Table 4.12 FC algorithm for all solutions of N 60

Table 4.13 MAC algorithm for all solutions of N 60

Table 4.14 FC with MRV algorithm for all solutions of N 61

Table 4.15 FC with LCV algorithm for all solutions of N 61

Table 4.16 AC-3 with FC algorithm for all solutions of N 62

Table 4.17 N-Queens Problem with UI for one solution 62