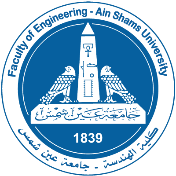
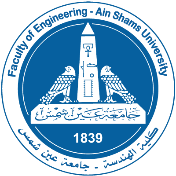
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KENEN Puzzle  
CSP Solver

Report showing analysis and program design

|  |  |
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# Introduction

In this report we demonstrate the difference in performance of running three Constraint Satisfaction solving algorithms on the Kenken game with various sizes.

We also provide program design illustration showing the interaction between the modules of the program, and the class diagram.

# Analysis Results

## Glossary

* (BT) : “Backtracking”.
* (FC) : “Forward Checking”
* (AC) : “Arc Consistency”
* (MCV) : “Most Constraining Variable” heuristic.

We ran different variations of algorithms on each board (the 3 techniques (BT, BT with FC, BT with AC), each with and without MCV heuristic)

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| # | Size | Technique | Assignments | time elapsed |
| 1 | 3 | **BT** | 13 | 0.001002 |
| 2 | 3 | **BT with MCV** | 16 | 0.002996 |
| 3 | 3 | **FC** | 8 | 0.00102 |
| 4 | 3 | **FC with MCV** | 9 | 0.001 |
| 5 | 3 | **AC** | 9 | 0.002977 |
| 6 | 3 | **AC with MCV** | 8 | 0.001 |
| 7 | 3 | **BT** | 13 | 0.001015 |
| 8 | 3 | **BT with MCV** | 13 | 0.002989 |
| 9 | 3 | **FC** | 8 | 0.000994 |
| 10 | 3 | **FC with MCV** | 8 | 0.001001 |
| 11 | 3 | **AC** | 8 | 0.002997 |
| 12 | 3 | **AC with MCV** | 8 | 0.002996 |
| 13 | 3 | **BT** | 10 | 0.001015 |
| 14 | 3 | **BT with MCV** | 10 | 0.001981 |
| 15 | 3 | **FC** | 7 | 0.001016 |
| 16 | 3 | **FC with MCV** | 7 | 0.000985 |
| 17 | 3 | **AC** | 7 | 0.002998 |
| 18 | 3 | **AC with MCV** | 7 | 0.001996 |
| 19 | 4 | **BT** | 75 | 0.01299 |
| 20 | 4 | **BT with MCV** | 36 | 0.003995 |
| 21 | 4 | **FC** | 24 | 0.007996 |
| 22 | 4 | **FC with MCV** | 15 | 0.002999 |
| 23 | 4 | **AC** | 27 | 0.023988 |
| 24 | 4 | **AC with MCV** | 14 | 0.009003 |
| 25 | 4 | **BT** | 188 | 0.032982 |
| 26 | 4 | **BT with MCV** | 188 | 0.030984 |
| 27 | 4 | **FC** | 49 | 0.016989 |
| 28 | 4 | **FC with MCV** | 49 | 0.016994 |
| 29 | 4 | **AC** | 16 | 0.006992 |
| 30 | 4 | **AC with MCV** | 16 | 0.012993 |
| 31 | 4 | **BT** | 385 | 0.065961 |
| 32 | 4 | **BT with MCV** | 191 | 0.03398 |
| 33 | 4 | **FC** | 118 | 0.030984 |
| 34 | 4 | **FC with MCV** | 58 | 0.013993 |
| 35 | 4 | **AC** | 35 | 0.015988 |
| 36 | 4 | **AC with MCV** | 15 | 0.006995 |
| 37 | 5 | **BT** | 175 | 0.042976 |
| 38 | 5 | **BT with MCV** | 174 | 0.034979 |
| 39 | 5 | **FC** | 38 | 0.012995 |
| 40 | 5 | **FC with MCV** | 37 | 0.007993 |
| 41 | 5 | **AC** | 23 | 0.026984 |
| 42 | 5 | **AC with MCV** | 22 | 0.022987 |
| 43 | 5 | **BT** | 10066 | 1.822951 |
| 44 | 5 | **BT with MCV** | 4328 | 0.759564 |
| 45 | 5 | **FC** | 597 | 0.160909 |
| 46 | 5 | **FC with MCV** | 707 | 0.172899 |
| 47 | 5 | **AC** | 32 | 0.050973 |
| 48 | 5 | **AC with MCV** | 35 | 0.046971 |
| 49 | 5 | **BT** | 4270 | 0.969445 |
| 50 | 5 | **BT with MCV** | 4139 | 0.793541 |
| 51 | 5 | **FC** | 744 | 0.154911 |
| 52 | 5 | **FC with MCV** | 202 | 0.054968 |
| 53 | 5 | **AC** | 40 | 0.043977 |
| 54 | 5 | **AC with MCV** | 43 | 0.037976 |
| 55 | 6 | **BT** | 74 | 0.011995 |
| 56 | 6 | **BT with MCV** | 64 | 0.01399 |
| 57 | 6 | **FC** | 36 | 0.010015 |
| 58 | 6 | **FC with MCV** | 26 | 0.004977 |
| 59 | 6 | **AC** | 33 | 0.076956 |
| 60 | 6 | **AC with MCV** | 23 | 0.046973 |
| 61 | 6 | **BT** | 1273 | 0.266847 |
| 62 | 6 | **BT with MCV** | 2351 | 0.487741 |
| 63 | 6 | **FC** | 220 | 0.081935 |
| 64 | 6 | **FC with MCV** | 340 | 0.094943 |
| 65 | 6 | **AC** | 39 | 0.063963 |
| 66 | 6 | **AC with MCV** | 44 | 0.080955 |
| 67 | 6 | **BT** | 403 | 0.094961 |
| 68 | 6 | **BT with MCV** | 339 | 0.086935 |
| 69 | 6 | **FC** | 104 | 0.038978 |
| 70 | 6 | **FC with MCV** | 82 | 0.023987 |
| 71 | 6 | **AC** | 38 | 0.074339 |
| 72 | 6 | **AC with MCV** | 32 | 0.053264 |
| 73 | 7 | **BT** | 604 | 0.184895 |
| 74 | 7 | **BT with MCV** | 791 | 0.21689 |
| 75 | 7 | **FC** | 149 | 0.051957 |
| 76 | 7 | **FC with MCV** | 147 | 0.062978 |
| 77 | 7 | **AC** | 45 | 0.140902 |
| 78 | 7 | **AC with MCV** | 44 | 0.119932 |
| 79 | 7 | **BT** | 278 | 0.095943 |
| 80 | 7 | **BT with MCV** | 178 | 0.058966 |
| 81 | 7 | **FC** | 57 | 0.016004 |
| 82 | 7 | **FC with MCV** | 50 | 0.015978 |
| 83 | 7 | **AC** | 45 | 0.181894 |
| 84 | 7 | **AC with MCV** | 32 | 0.118822 |
| 85 | 7 | **BT** | 7593 | 2.24771 |
| 86 | 7 | **BT with MCV** | 3604 | 1.051394 |
| 87 | 7 | **FC** | 1350 | 0.467752 |
| 88 | 7 | **FC with MCV** | 1073 | 0.48612 |
| 89 | 7 | **AC** | 46 | 0.144919 |
| 90 | 7 | **AC with MCV** | 41 | 0.140919 |
| 91 | 8 | **BT** | 9306 | 3.347078 |
| 92 | 8 | **BT with MCV** | 5921 | 2.221559 |
| 93 | 8 | **FC** | 299 | 0.186642 |
| 94 | 8 | **FC with MCV** | 666 | 0.348397 |
| 95 | 8 | **AC** | 63 | 0.346825 |
| 96 | 8 | **AC with MCV** | 87 | 0.432751 |
| 97 | 8 | **BT** | 3212 | 1.049343 |
| 98 | 8 | **BT with MCV** | 1779 | 0.621706 |
| 99 | 8 | **FC** | 226 | 0.100753 |
| 100 | 8 | **FC with MCV** | 317 | 0.154945 |
| 101 | 8 | **AC** | 63 | 0.326183 |
| 102 | 8 | **AC with MCV** | 63 | 0.360795 |
| 103 | 8 | **BT** | 1715 | 0.705614 |
| 104 | 8 | **BT with MCV** | 3283 | 1.223297 |
| 105 | 8 | **FC** | 284 | 0.164885 |
| 106 | 8 | **FC with MCV** | 300 | 0.129411 |
| 107 | 8 | **AC** | 65 | 0.357797 |
| 108 | 8 | **AC with MCV** | 50 | 0.264868 |
| 109 | 9 | **BT** | 2741 | 1.888914 |
| 110 | 9 | **BT with MCV** | 11560 | 5.849909 |
| 111 | 9 | **FC** | 391 | 0.240885 |
| 112 | 9 | **FC with MCV** | 1503 | 1.017395 |
| 113 | 9 | **AC** | 85 | 0.73366 |
| 114 | 9 | **AC with MCV** | 127 | 0.747572 |
| 115 | 9 | **BT** | 1571 | 0.678617 |
| 116 | 9 | **BT with MCV** | 11811 | 4.77325 |
| 117 | 9 | **FC** | 291 | 0.142917 |
| 118 | 9 | **FC with MCV** | 2198 | 1.261276 |
| 119 | 9 | **AC** | 76 | 0.666615 |
| 120 | 9 | **AC with MCV** | 63 | 0.510728 |
| 121 | 9 | **BT** | 88396 | 41.21631 |
| 122 | 9 | **BT with MCV** | 99338 | 48.2323 |
| 123 | 9 | **FC** | 8250 | 4.773257 |
| 124 | 9 | **FC with MCV** | 10260 | 5.436855 |
| 125 | 9 | **AC** | 76 | 0.678096 |
| 126 | 9 | **AC with MCV** | 108 | 0.780575 |

## Comment

* + Forward Checking and Arc Consistency proved to be a great improvement over the Backtracking only algorithm.
  + (Backtracking with Arc Consistency) had a significant impact on the number of assignments and time taken over the other two algorithms.
  + The Most Constraining Variable heuristic had a little impact on the performance of the algorithms, but it worth noting that this highly depends on the cage sizes of the board.

# Interaction Sequence Diagram

# Class Diagram

