SAT-based Sudoku Solving

CSC 320 Summer 2018

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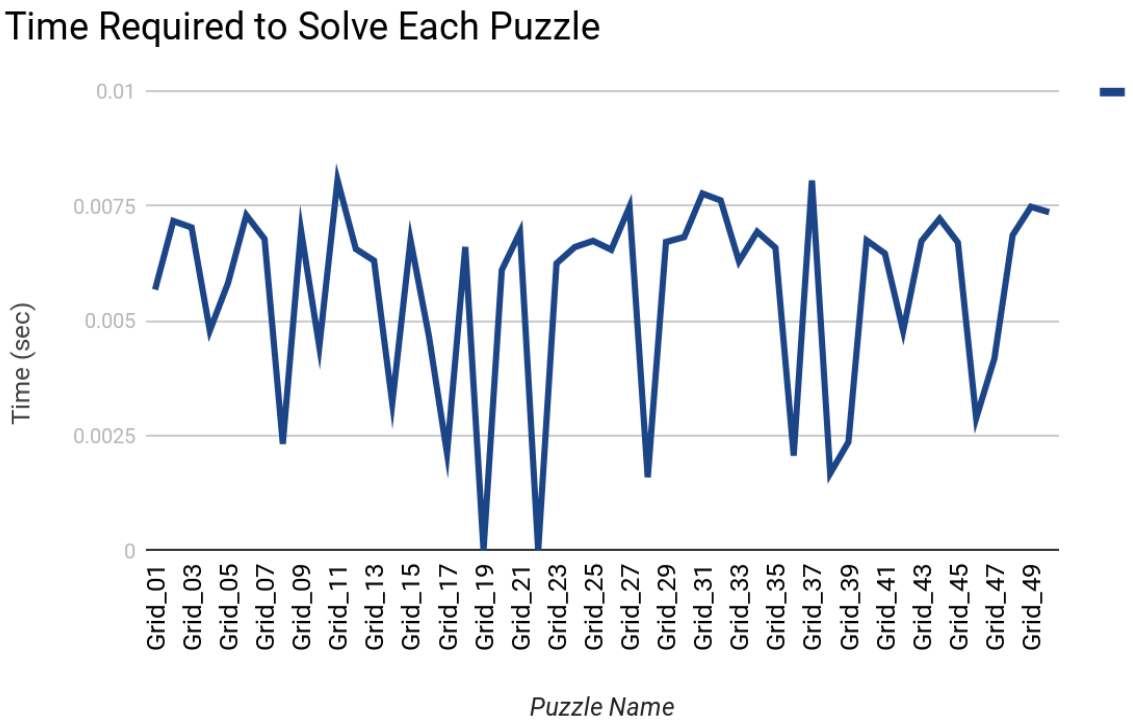
1 Project Overview

The following software project was created to explore the NP hard problem of solving sudoku puzzles, and the conversions between the various encodings and their impact on computational solving time. Two main programs were written for the project, as well as three extended tasks. The first main program used python to convert a sudoku puzzle in a specified text format, into a CNF formula suitable for the miniSAT SAT solver. The second took the output from the SAT solver and converted to a more human readable sudoku format. The extended tasks chosen were hard inputs, the use of multiple encodings for sudoku problems, and the use of other SAT solvers (for this project we used walkSAT). This report outlines the main components of both main tasks as well as the extended ones and was completed for CSC 320 at the University of Victoria. The scripts, inputs, outputs, read me, and make file referenced are all included within the containing folder.

2 Sudoku to SAT

The following table displays the time taken to solve each puzzle found at projecteuler.net/project/resources/p096 sudoku.txt.



Puzzle Name	Time to Solve (Sec)
Grid_01	0.005682
Grid_02	0.007173
Grid_03	0.007033
Grid_04	0.004792
Grid_05	0.005828
Grid_06	0.0073
Grid_07	0.006783
Grid_08	0.002326
Grid_09	0.006963
Grid_10	0.004443
Grid_11	0.008062
Grid_12	0.006566
Grid_13	0.006312
Grid_14	0.003213
Grid_15	0.006758
Grid_16	0.004687
Grid_17	0.002127
Grid_18	0.00661
Grid_19	0
Grid_20	0.006105
Grid_21	0.006931
Grid_22	0
Grid_23	0.006251
Grid_24	0.006606
Grid_25	0.006741
Grid_26	0.00655
Grid_27	0.007483
Grid_28	0.001601
Grid_29	0.006717

Grid_30	0.006825
Grid_31	0.00777
Grid_32	0.007621
Grid_33	0.006297
Grid_34	0.00694
Grid_35	0.006591
Grid_36	0.002071
Grid_37	0.008056
Grid_38	0.001686
Grid_39	0.002369
Grid_40	0.006751
Grid_41	0.006467
Grid_42	0.004782
Grid_43	0.006736
Grid_44	0.007224
Grid_45	0.006706
Grid_46	0.002884
Grid_47	0.004185
Grid_48	0.006865
Grid_49	0.007483
Grid_50	0.007365
Sum	**0.281317**
Average	**0.005626**

3 SAT to Sudoku

The following text contains the solved puzzles from projecteuler.net/project/resources/p096 sudoku.txt:

Grid 1
4 8 3 9 2 1 6 5 7
9 6 7 3 4 5 8 2 1
2 5 1 8 7 6 4 9 3
5 4 8 1 3 2 9 7 6
7 2 9 5 6 4 1 3 8
1 3 6 7 9 8 2 4 5
3 7 2 6 8 9 5 1 4
8 1 4 2 5 3 7 6 9
6 9 5 4 1 7 3 8 2

Grid 2
2 4 5 9 8 1 3 7 6
1 6 9 2 7 3 5 8 4
8 3 7 5 6 4 2 1 9
9 7 6 1 2 5 4 3 8
5 1 3 4 9 8 6 2 7
4 8 2 7 3 6 9 5 1
3 9 1 6 5 7 8 4 2
7 2 8 3 4 9 1 6 5
6 5 4 8 1 2 7 9 3

Grid 3
4 6 2 8 3 1 9 5 7
7 9 5 4 2 6 1 8 3
3 8 1 7 9 5 4 2 6
1 7 3 9 8 4 2 6 5
6 5 9 3 1 2 7 4 8
2 4 8 5 6 7 3 1 9
9 2 6 1 7 8 5 3 4
8 3 4 2 5 9 6 7 1
5 1 7 6 4 3 8 9 2

Grid 4
1 3 7 2 5 6 8 4 9
9 2 8 3 1 4 5 6 7
4 6 5 8 9 7 3 1 2
6 7 3 5 4 2 9 8 1
8 1 9 6 7 3 2 5 4
5 4 2 1 8 9 7 3 6
2 5 6 7 3 1 4 9 8
3 9 1 4 2 8 6 7 5
7 8 4 9 6 5 1 2 3

Grid 5
5 2 3 8 1 6 7 4 9
7 8 4 5 9 3 1 2 6
6 9 1 4 7 2 8 3 5
2 3 9 1 4 5 6 8 7
4 5 7 2 6 8 9 1 3
1 6 8 9 3 7 2 5 4
3 4 2 7 8 9 5 6 1
9 1 5 6 2 4 3 7 8
8 7 6 3 5 1 4 9 2

Grid 6
1 7 6 9 2 3 5 8 4
5 2 4 8 1 7 6 3 9
8 9 3 6 5 4 2 7 1
9 5 7 3 4 8 1 6 2
6 3 8 1 9 2 4 5 7
4 1 2 7 6 5 3 9 8
2 6 5 4 8 9 7 1 3
7 8 1 2 3 6 9 4 5
3 4 9 5 7 1 8 2 6

Grid 7
1 4 3 9 8 6 2 5 7
6 7 9 4 2 5 3 8 1
2 8 5 7 3 1 6 9 4
9 6 2 3 5 4 1 7 8
3 5 7 6 1 8 9 4 2
4 1 8 2 7 9 5 6 3
8 2 1 5 6 7 4 3 9
7 9 6 1 4 3 8 2 5
5 3 4 8 9 2 7 1 6

Grid 8
4 8 7 1 5 6 9 3 2
3 6 2 4 9 8 7 5 1
9 1 5 3 7 2 8 6 4
8 4 6 5 1 9 2 7 3
5 9 3 7 2 4 1 8 6
2 7 1 8 6 3 5 4 9
1 2 4 6 8 5 3 9 7
7 3 8 9 4 1 6 2 5
6 5 9 2 3 7 4 1 8

Grid 9
8 1 4 9 7 6 5 3 2
6 5 9 1 2 3 4 7 8
7 3 2 8 5 4 1 6 9
9 4 8 2 6 5 3 1 7
2 7 5 3 4 1 8 9 6
1 6 3 7 9 8 2 4 5
3 9 1 6 8 2 7 5 4
5 8 7 4 3 9 6 2 1
4 2 6 5 1 7 9 8 3

Grid 10
7 6 1 9 2 8 4 5 3
9 2 5 7 4 3 1 6 8
4 3 8 6 1 5 9 2 7
3 5 7 4 6 1 2 8 9
8 9 4 3 7 2 6 1 5
2 1 6 5 8 9 3 7 4
6 8 9 1 5 4 7 3 2
1 4 2 8 3 7 5 9 6
5 7 3 2 9 6 8 4 1

Grid 11
9 7 6 1 2 5 4 3 8
1 5 8 4 3 6 9 2 7
4 2 3 8 7 9 1 5 6
2 3 4 7 6 1 8 9 5
8 6 7 9 5 2 3 1 4
5 1 9 3 8 4 7 6 2
7 8 2 5 1 3 6 4 9
3 9 5 6 4 7 2 8 1
6 4 1 2 9 8 5 7 3

Grid 12
9 6 2 3 4 1 7 5 8
1 4 8 9 7 5 6 2 3
5 7 3 2 6 8 1 4 9
3 2 1 6 9 4 8 7 5
4 8 7 5 1 2 9 3 6
6 9 5 8 3 7 4 1 2
8 3 4 7 2 6 5 9 1
2 1 6 4 5 9 3 8 7
7 5 9 1 8 3 2 6 4

Grid 13
3 9 7 6 8 1 5 2 4
6 4 5 2 7 9 8 1 3
2 1 8 5 3 4 9 7 6
8 2 3 9 5 6 7 4 1
1 6 9 7 4 2 3 5 8
7 5 4 3 1 8 6 9 2
4 7 2 8 9 3 1 6 5
5 3 1 4 6 7 2 8 9
9 8 6 1 2 5 4 3 7

Grid 14
6 3 9 2 1 8 4 5 7
4 7 1 5 3 9 2 6 8
8 2 5 6 7 4 1 3 9
5 6 4 8 2 3 7 9 1
7 9 3 4 5 1 8 2 6
2 1 8 7 9 6 3 4 5
3 5 2 9 8 7 6 1 4
1 8 6 3 4 5 9 7 2
9 4 7 1 6 2 5 8 3

Grid 15
6 9 7 1 2 8 3 4 5
4 2 8 6 3 5 1 9 7
3 1 5 4 7 9 6 8 2
5 3 1 2 4 6 9 7 8
2 8 6 3 9 7 4 5 1
9 7 4 5 8 1 2 6 3
1 4 9 8 5 2 7 3 6
7 5 2 9 6 3 8 1 4
8 6 3 7 1 4 5 2 9

Grid 16
3 6 1 7 2 5 9 4 8
5 8 7 9 6 4 2 1 3
4 9 2 8 3 1 6 5 7
6 3 8 2 5 9 4 7 1
1 7 4 6 8 3 5 9 2
2 5 9 1 4 7 8 3 6
7 4 6 3 9 2 1 8 5
9 2 3 5 1 8 7 6 4
8 1 5 4 7 6 3 2 9

Grid 17
3 5 9 8 6 7 1 2 4
6 4 8 3 1 2 5 9 7
7 1 2 5 4 9 8 3 6
8 7 6 9 2 4 3 5 1
5 2 4 7 3 1 9 6 8
1 9 3 6 8 5 4 7 2
9 3 1 4 7 6 2 8 5
4 6 5 2 9 8 7 1 3
2 8 7 1 5 3 6 4 9

Grid 18
7 8 6 9 4 5 3 1 2
2 1 9 8 6 3 4 5 7
5 3 4 2 7 1 8 6 9
1 6 5 4 8 2 9 7 3
3 2 7 6 1 9 5 4 8
4 9 8 5 3 7 1 2 6
9 5 1 7 2 8 6 3 4
8 4 2 3 5 6 7 9 1
6 7 3 1 9 4 2 8 5

Grid 19
7 4 3 5 1 2 9 8 6
5 8 9 3 4 6 2 1 7
1 2 6 9 8 7 3 4 5
9 3 4 2 5 1 7 6 8
6 7 1 4 9 8 5 3 2
8 5 2 7 6 3 4 9 1
3 9 8 6 7 5 1 2 4
4 1 7 8 2 9 6 5 3
2 6 5 1 3 4 8 7 9

Grid 20
7 8 2 6 1 4 3 5 9
4 3 9 8 2 5 1 7 6
6 5 1 9 3 7 4 2 8

2 9 3 4 7 1 8 6 5
5 6 8 3 9 2 7 1 4
1 4 7 5 6 8 2 9 3
3 2 6 7 4 9 5 8 1
9 7 5 1 8 3 6 4 2
8 1 4 2 5 6 9 3 7

Grid 21
4 2 8 5 3 1 7 9 6
3 6 5 9 4 7 1 8 2
9 7 1 2 6 8 4 3 5
2 1 4 8 9 6 5 7 3
6 9 7 4 5 3 2 1 8
5 8 3 1 7 2 9 6 4
8 4 9 6 1 5 3 2 7
7 5 2 3 8 9 6 4 1
1 3 6 7 2 4 8 5 9

Grid 22
4 2 5 7 8 1 9 3 6
1 7 8 3 6 9 5 2 4
3 6 9 5 2 4 1 8 7
8 9 4 1 5 7 3 6 2
6 5 2 8 4 3 7 9 1
7 1 3 6 9 2 8 4 5
9 8 7 2 1 6 4 5 3
5 3 6 4 7 8 2 1 9
2 4 1 9 3 5 6 7 8

Grid 23
3 4 8 2 6 7 9 5 1
5 7 1 9 4 3 6 2 8
2 6 9 1 8 5 3 7 4
6 9 7 3 5 1 4 8 2
1 2 3 8 7 4 5 9 6
8 5 4 6 2 9 1 3 7
4 1 5 7 9 8 2 6 3
9 8 2 4 3 6 7 1 5
7 3 6 5 1 2 8 4 9

Grid 24
1 2 4 9 8 6 7 3 5
8 6 7 4 3 5 9 1 2
3 9 5 7 1 2 6 8 4
4 7 8 3 5 9 2 6 1
2 5 9 8 6 1 3 4 7
6 3 1 2 7 4 5 9 8
7 1 2 6 9 8 4 5 3
9 8 3 5 4 7 1 2 6
5 4 6 1 2 3 8 7 9

Grid 25
3 6 1 5 2 4 7 8 9
7 8 9 3 6 1 4 2 5
5 2 4 8 7 9 3 6 1
8 9 3 1 5 7 6 4 2
4 1 2 6 8 3 5 9 7
6 5 7 9 4 2 1 3 8
1 4 8 7 9 6 2 5 3
2 3 5 4 1 8 9 7 6
9 7 6 2 3 5 8 1 4

Grid 26
5 8 1 4 7 9 2 6 3
3 2 9 1 5 6 8 4 7
6 4 7 3 2 8 1 5 9
9 5 6 7 3 1 4 2 8
2 3 8 9 6 4 5 7 1
7 1 4 5 8 2 9 3 6
1 7 2 6 9 5 3 8 4
8 9 3 2 4 7 6 1 5
4 6 5 8 1 3 7 9 2

Grid 27
3 8 7 2 5 6 4 1 9
4 6 9 7 8 1 3 2 5
5 1 2 4 3 9 8 6 7
1 2 3 5 4 8 9 7 6
7 5 8 9 6 3 2 4 1
6 9 4 1 2 7 5 8 3
8 3 5 6 7 4 1 9 2
2 7 1 8 9 5 6 3 4
9 4 6 3 1 2 7 5 8

Grid 28
3 4 5 8 7 1 2 6 9
2 7 9 6 5 3 1 8 4
8 6 1 4 2 9 5 3 7
1 9 7 3 4 6 8 5 2
4 5 2 7 1 8 3 9 6
6 8 3 5 9 2 7 4 1
7 3 8 2 6 4 9 1 5
5 1 6 9 3 7 4 2 8
9 2 4 1 8 5 6 7 3

Grid 29
2 3 5 7 6 1 4 8 9
4 1 9 3 2 8 5 7 6
8 6 7 5 4 9 2 1 3
7 4 6 1 3 5 9 2 8
5 2 1 8 9 6 7 3 4
9 8 3 4 7 2 6 5 1
3 9 4 2 8 7 1 6 5
6 5 2 9 1 3 8 4 7
1 7 8 6 5 4 3 9 2

Grid 30
2 9 8 1 7 5 6 4 3
6 5 7 3 9 4 1 2 8
1 3 4 2 8 6 5 7 9
8 2 1 6 4 9 7 3 5
5 7 3 8 2 1 4 9 6
4 6 9 7 5 3 2 8 1
3 1 2 4 6 8 9 5 7

7 8 5 9 1 2 3 6 4
9 4 6 5 3 7 8 1 2

Grid 31
7 6 1 5 4 3 2 8 9
8 3 2 7 9 1 6 4 5
5 4 9 6 2 8 1 3 7
3 7 4 2 1 5 9 6 8
1 2 8 9 3 6 5 7 4
6 9 5 4 8 7 3 2 1
4 1 7 3 6 9 8 5 2
9 5 3 8 7 2 4 1 6
2 8 6 1 5 4 7 9 3

Grid 32
1 3 2 6 4 9 7 8 5
7 5 8 2 1 3 6 4 9
9 6 4 7 8 5 1 2 3
5 4 3 8 9 7 2 1 6
2 7 6 5 3 1 8 9 4
8 9 1 4 2 6 5 3 7
6 1 9 3 7 8 4 5 2
3 2 7 1 5 4 9 6 8
4 8 5 9 6 2 3 7 1

Grid 33
6 9 8 1 7 3 5 4 2
3 5 4 6 2 8 1 7 9
1 7 2 5 4 9 3 6 8
5 3 1 8 9 7 4 2 6
9 4 6 3 1 2 8 5 7
8 2 7 4 5 6 9 1 3
7 6 5 9 3 1 2 8 4
2 1 3 7 8 4 6 9 5
4 8 9 2 6 5 7 3 1

Grid 34
8 5 2 7 1 6 9 4 3
1 9 7 8 4 3 6 5 2
4 6 3 9 2 5 1 8 7
2 7 8 6 3 4 5 9 1
6 4 5 1 7 9 3 2 8
9 3 1 5 8 2 4 7 6
7 8 6 4 9 1 2 3 5
3 1 4 2 5 8 7 6 9
5 2 9 3 6 7 8 1 4

Grid 35
4 5 3 2 1 8 7 9 6
6 2 9 7 5 3 4 8 1
1 7 8 4 9 6 5 3 2
7 9 6 5 8 2 3 1 4
3 1 4 9 6 7 8 2 5
2 8 5 1 3 4 6 7 9
5 4 2 8 7 9 1 6 3
9 3 7 6 4 1 2 5 8
8 6 1 3 2 5 9 4 7

Grid 36
5 1 6 2 8 9 3 4 7
8 4 9 1 7 3 2 5 6
7 3 2 4 6 5 9 1 8
6 9 8 3 1 7 5 2 4
3 2 7 9 5 4 8 6 1
1 5 4 8 2 6 7 3 9
9 6 1 7 3 2 4 8 5
2 7 5 6 4 8 1 9 3
4 8 3 5 9 1 6 7 2

Grid 37
9 4 5 6 8 1 7 2 3
7 8 1 2 3 4 9 6 5
3 2 6 7 5 9 1 8 4
2 6 9 1 7 5 3 4 8
1 3 8 9 4 2 5 7 6
5 7 4 8 6 3 2 1 9
4 5 7 3 2 6 8 9 1
6 1 2 5 9 8 4 3 7
8 9 3 4 1 7 6 5 2

Grid 38
3 6 5 9 4 2 8 7 1
1 2 8 7 5 6 4 9 3
9 7 4 8 1 3 5 6 2
8 1 9 4 3 5 6 2 7
5 3 7 2 6 8 1 4 9
6 4 2 1 7 9 3 5 8
2 9 6 3 8 4 7 1 5
7 5 3 6 9 1 2 8 4
4 8 1 5 2 7 9 3 6

Grid 39
1 3 4 5 8 7 2 9 6
2 7 8 1 6 9 3 5 4
6 9 5 2 3 4 8 1 7
3 5 9 8 1 6 4 7 2
8 2 1 4 7 3 5 6 9
7 4 6 9 2 5 1 8 3
9 1 7 3 4 8 6 2 5
4 6 2 7 5 1 9 3 8
5 8 3 6 9 2 7 4 1

Grid 40
1 9 3 6 7 2 4 8 5
4 6 2 3 5 8 9 7 1
7 8 5 9 1 4 6 2 3
5 3 8 2 9 6 7 1 4
6 7 4 1 3 5 2 9 8
2 1 9 4 8 7 3 5 6
8 2 6 7 4 1 5 3 9
9 4 1 5 2 3 8 6 7
3 5 7 8 6 9 1 4 2

Grid 41

8 1 4 9 7 6 5 3 2
6 5 9 1 2 3 4 7 8
7 3 2 8 5 4 1 6 9
9 4 8 2 6 5 3 1 7
2 7 5 3 4 1 8 9 6
1 6 3 7 9 8 2 4 5
3 9 1 6 8 2 7 5 4
5 8 7 4 3 9 6 2 1
4 2 6 5 1 7 9 8 3

Grid 42
3 8 4 5 6 7 9 2 1
1 2 6 4 3 9 7 8 5
7 5 9 8 2 1 3 4 6
5 6 3 7 9 8 2 1 4
8 4 7 3 1 2 6 5 9
9 1 2 6 4 5 8 7 3
2 3 1 9 7 4 5 6 8
4 9 5 2 8 6 1 3 7
6 7 8 1 5 3 4 9 2

Grid 43
4 6 9 1 5 8 3 7 2
7 1 2 4 6 3 8 5 9
5 3 8 2 9 7 6 4 1
9 2 7 6 3 4 5 1 8
3 8 5 7 1 9 4 2 6
1 4 6 5 8 2 7 9 3
6 5 3 9 4 1 2 8 7
2 9 4 8 7 6 1 3 5
8 7 1 3 2 5 9 6 4

Grid 44
3 1 6 5 4 9 2 7 8
9 8 7 3 2 1 6 4 5
4 5 2 6 7 8 9 3 1
5 9 4 2 3 6 8 1 7
2 3 8 4 1 7 5 6 9
6 7 1 9 8 5 3 2 4
8 4 5 1 6 2 7 9 3
1 2 9 7 5 3 4 8 6
7 6 3 8 9 4 1 5 2

Grid 45
5 8 6 1 2 7 9 4 3
7 2 3 4 6 9 8 5 1
4 9 1 8 5 3 2 6 7
1 3 5 9 7 4 6 2 8
2 7 9 6 1 8 5 3 4
6 4 8 5 3 2 1 7 9
9 1 7 2 4 6 3 8 5
3 5 2 7 8 1 4 9 6
8 6 4 3 9 5 7 1 2

Grid 46
9 5 4 2 1 3 6 8 7
6 1 7 5 4 8 9 2 3
8 3 2 7 9 6 5 4 1
7 6 3 8 5 1 2 9 4
1 2 8 9 7 4 3 6 5
5 4 9 3 6 2 1 7 8
2 8 1 6 3 7 4 5 9
4 7 5 1 2 9 8 3 6
3 9 6 4 8 5 7 1 2

Grid 47
1 5 9 7 4 3 8 6 2
2 7 6 5 8 9 4 3 1
3 4 8 6 1 2 7 5 9
6 2 4 9 7 8 3 1 5
9 1 7 2 3 5 6 8 4
5 8 3 1 6 4 2 9 7
4 3 5 8 2 1 9 7 6
8 6 1 4 9 7 5 2 3
7 9 2 3 5 6 1 4 8

Grid 48
8 6 1 3 5 7 2 9 4
5 9 7 4 8 2 3 6 1
4 3 2 6 1 9 7 8 5
9 1 6 2 7 5 8 4 3
3 5 8 9 6 4 1 2 7
2 7 4 1 3 8 9 5 6
7 8 9 5 4 1 6 3 2
1 4 3 8 2 6 5 7 9
6 2 5 7 9 3 4 1 8

Grid 49
2 9 4 8 6 3 5 1 7
7 1 5 4 2 9 6 3 8
8 6 3 7 5 1 4 9 2
1 5 2 9 4 7 8 6 3
4 7 9 3 8 6 2 5 1
6 3 8 5 1 2 9 7 4
9 8 6 1 3 4 7 2 5
5 2 1 6 7 8 3 4 9
3 4 7 2 9 5 1 8 6

Grid 50
3 5 1 2 8 6 4 9 7
4 9 2 1 5 7 6 3 8
7 8 6 9 3 4 5 1 2
2 7 5 4 6 9 1 8 3
9 3 8 5 2 1 7 6 4
6 1 4 8 7 3 2 5 9
8 2 9 6 4 5 3 7 1
1 6 3 7 9 2 8 4 5
5 4 7 3 1 8 9 2 6

4 Extended Tasks

1 Hard Inputs

For the first extended task of reading in hard inputs of the form shown below (from http://magictour.free.fr/top95) , a file called sat2sudHI.py was created took the given hard input, converted it to minimal encoding generated the CNF formula suited as input to the miniSAT. The runtime for these puzzles are shown in the following table.

```
4.....8.5.3..........7......2.....6.....8.4......1.......6.3.7.5..2.....1.4......
52...6.........7.13...........4..8..6......5...........418.........3..2...87.....
6.....8.3.4.7.................5.4.7.3..2.....1.6.......2.....5.....8.6......1....
48.3.............71.2.......7.5....6....2..8.............1.76...3.....4......5....
....14....3....2...7..........9...3.6.1.............8.2.....1.4....5.6.....7.8...
```

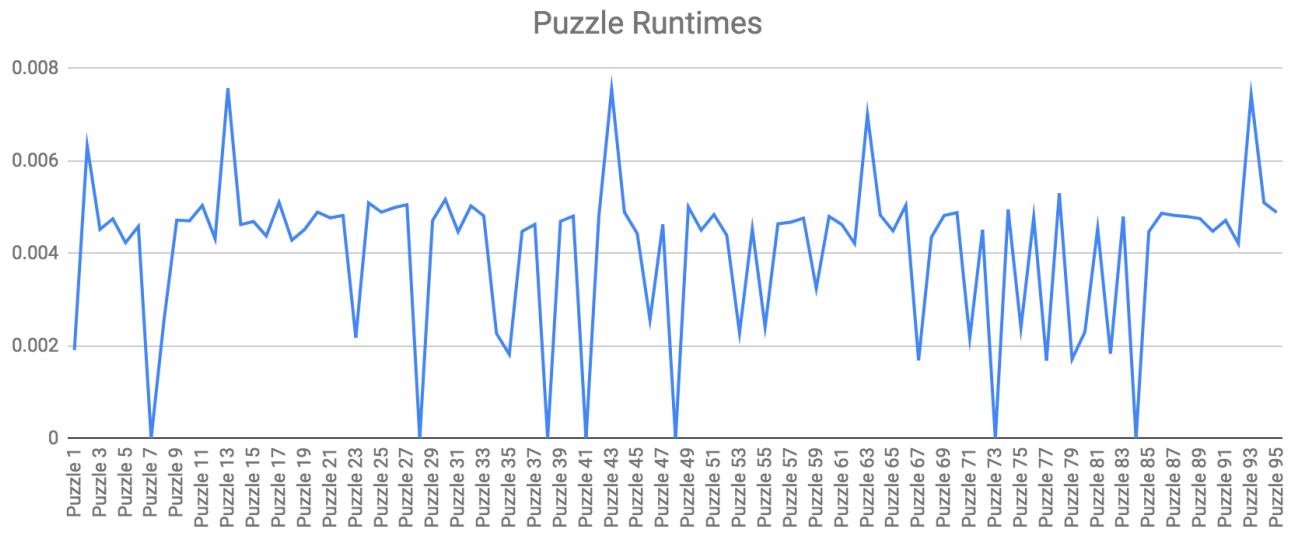
Hard Inputs Format

Puzzle Name	Time to Solve (Sec)
Puzzle 1	0.001907
Puzzle 2	0.006328
Puzzle 3	0.00452
Puzzle 4	0.00475
Puzzle 5	0.004232
Puzzle 6	0.004584
Puzzle 7	0
Puzzle 8	0.002541
Puzzle 9	0.00472
Puzzle 10	0.004705
Puzzle 11	0.005036
Puzzle 12	0.004318
Puzzle 13	0.007569
Puzzle 14	0.004622
Puzzle 15	0.00469

Puzzle 16	0.004378
Puzzle 17	0.005104
Puzzle 18	0.004286
Puzzle 19	0.004518
Puzzle 20	0.004893
Puzzle 21	0.00477
Puzzle 22	0.004821
Puzzle 23	0.002174
Puzzle 24	0.005092
Puzzle 25	0.004892
Puzzle 26	0.004989
Puzzle 27	0.005054
Puzzle 28	0
Puzzle 29	0.004709
Puzzle 30	0.005166
Puzzle 31	0.004468
Puzzle 32	0.005027
Puzzle 33	0.004813
Puzzle 34	0.002265
Puzzle 35	0.001816
Puzzle 36	0.004477
Puzzle 37	0.004627
Puzzle 38	0
Puzzle 39	0.004695
Puzzle 40	0.004807
Puzzle 41	0
Puzzle 42	0.004794
Puzzle 43	0.00755

Puzzle 44	0.004891
Puzzle 45	0.004431
Puzzle 46	0.002562
Puzzle 47	0.004626
Puzzle 48	0
Puzzle 49	0.005004
Puzzle 50	0.004502
Puzzle 51	0.004839
Puzzle 52	0.004392
Puzzle 53	0.002281
Puzzle 54	0.004529
Puzzle 55	0.002412
Puzzle 56	0.004641
Puzzle 57	0.004675
Puzzle 58	0.004763
Puzzle 59	0.003244
Puzzle 60	0.004801
Puzzle 61	0.004624
Puzzle 62	0.004215
Puzzle 63	0.007005
Puzzle 64	0.00483
Puzzle 65	0.004486
Puzzle 66	0.005039
Puzzle 67	0.001685
Puzzle 68	0.004352
Puzzle 69	0.004821
Puzzle 70	0.004881
Puzzle 71	0.002172

Puzzle 72	0.00451
Puzzle 73	0
Puzzle 74	0.004948
Puzzle 75	0.002389
Puzzle 76	0.00478
Puzzle 77	0.001682
Puzzle 78	0.005303
Puzzle 79	0.001711
Puzzle 80	0.002298
Puzzle 81	0.004539
Puzzle 82	0.001833
Puzzle 83	0.004791
Puzzle 84	0
Puzzle 85	0.004471
Puzzle 86	0.004867
Puzzle 87	0.004822
Puzzle 88	0.004797
Puzzle 89	0.004752
Puzzle 90	0.004479
Puzzle 91	0.004713
Puzzle 92	0.004213
Puzzle 93	0.007431
Puzzle 94	0.005098
Puzzle 95	0.004888
Average	0.00407078



Hard Input Puzzle Run Times

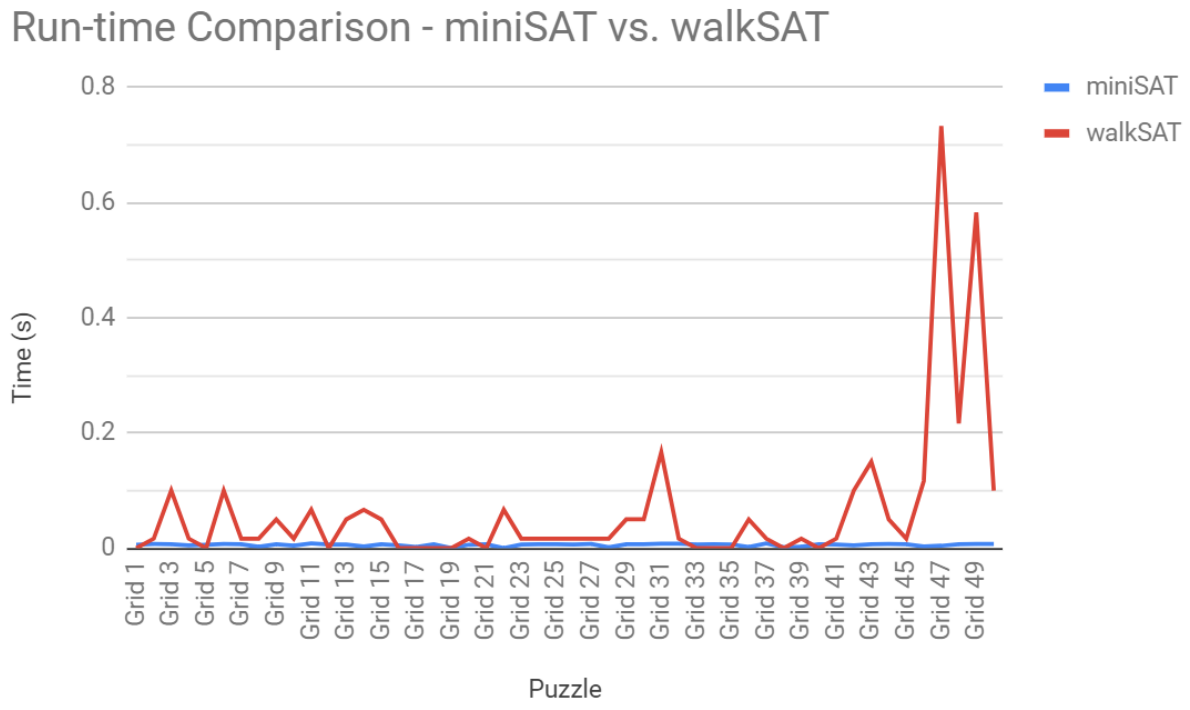
2 Multiple Encodings

Dependent on how the input of the Sudoku puzzles were encoded, the computational time needed varies with the size of the input. In the case of multiple encodings, we modified the *sud2sat.py* script to accept a wide variety of text file sudoku encodings. The additional parsing slows down the computation, but the added functionality makes it more versatile to different inputs. Below is a list of the accepted encodings for *sud2sat2.py:*

- Separated by '.'
- Separated by '|'
- Separated by '+'
- Separated by '-'
- Separated by ' '

3 Use of other SAT solvers - walkSAT

WalkSAT is another SAT solver. Walksat attempts to find a satisfying model of a generalized cnf formula just as miniSAT does. WalkSAT proved to be much slower than the given miniSAT solver. Using the command "./walksat -numsol 1", walkSAT will stop after finding the first satisfiable solution but is capable of finding many. MiniSAT out performed walkSAT with an average runtime of 0.005626 as compared to walksSAT's average runtime of 0.0640000.



Runtime Comparion - miniSAT vs. walkSAT		
Puzzle	miniSAT	walkSAT
Grid 1	0.005682	0.000000
Grid 2	0.007173	0.016667
Grid 3	0.007033	0.100000
Grid 4	0.004792	0.016667
Grid 5	0.005828	0.000000
Grid 6	0.007300	0.100000
Grid 7	0.006783	0.016667

Grid 8	0.002326	0.016667
Grid 9	0.006963	0.050000
Grid 10	0.004443	0.016667
Grid 11	0.008062	0.066667
Grid 12	0.006566	0.000000
Grid 13	0.006312	0.050000
Grid 14	0.003213	0.066667
Grid 15	0.006758	0.050000
Grid 16	0.004687	0.000000
Grid 17	0.002127	0.000000
Grid 18	0.006610	0.000000
Grid 19	0.000000	0.000000
Grid 20	0.006105	0.016667
Grid 21	0.006931	0.000000
Grid 22	0.000000	0.066667
Grid 23	0.006251	0.016667
Grid 24	0.006606	0.016667
Grid 25	0.006741	0.016667
Grid 26	0.006550	0.016667
Grid 27	0.007483	0.016667
Grid 28	0.001601	0.016667
Grid 29	0.006717	0.050000
Grid 30	0.006825	0.050000
Grid 31	0.007770	0.166667
Grid 32	0.007621	0.016667
Grid 33	0.006297	0.000000
Grid 34	0.006940	0.000000
Grid 35	0.006591	0.000000
Grid 36	0.002071	0.050000
Grid 37	0.008056	0.016667

Grid 38	0.001686	0.000000
Grid 39	0.002369	0.016667
Grid 40	0.006751	0.000000
Grid 41	0.006467	0.016667
Grid 42	0.004782	0.100000
Grid 43	0.006736	0.150000
Grid 44	0.007224	0.050000
Grid 45	0.006706	0.016667
Grid 46	0.002884	0.116667
Grid 47	0.004185	0.733333
Grid 48	0.006865	0.216667
Grid 49	0.007483	0.583333
Grid 50	0.007365	0.100000
Sum	0.281317	3.200007
Average	0.005626	0.064000