Project Report
SAT-based Sudoku Solving

CSC320 | Bruce Kapron | Summer 2018 | UVic

Project Group Member

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1. Orientation:

1.1. Objective: the goal of this group work is to solve incomplete sudoku puzzles in SAT-based method. The basic task will apply the minimal-SAT solver.

1.2. Environment:

1.2.1. The optimal operating system is Ubuntu 18.04, with minisat package installation required. And the grader will evaluate project on Ubuntu 18.04.

1.2.2. The sudoku puzzles should be input under a format similar to either of the sample tests given by professor Bruce. (“p096_sudoku.txt” for basic tasks or “top95.txt” for extended tasks). And the undecided spaces in each puzzle will be filled with either “.”, “?”, “*” or “0”.

2. How to execute the program

Since the project will be submitted as a zip file, so we should decompress the file first.

In a nutshell, executing `python/python3 run_timer.py .txt file` will initiate both `sud2sat.py` and `sat2sud.py` and generate outputs and time statistics. For example,

“Executed command when solving p096_sudoku.txt”

The more detailed information about the execution is given in README.md.

3. Basic tasks: solutions and statistics

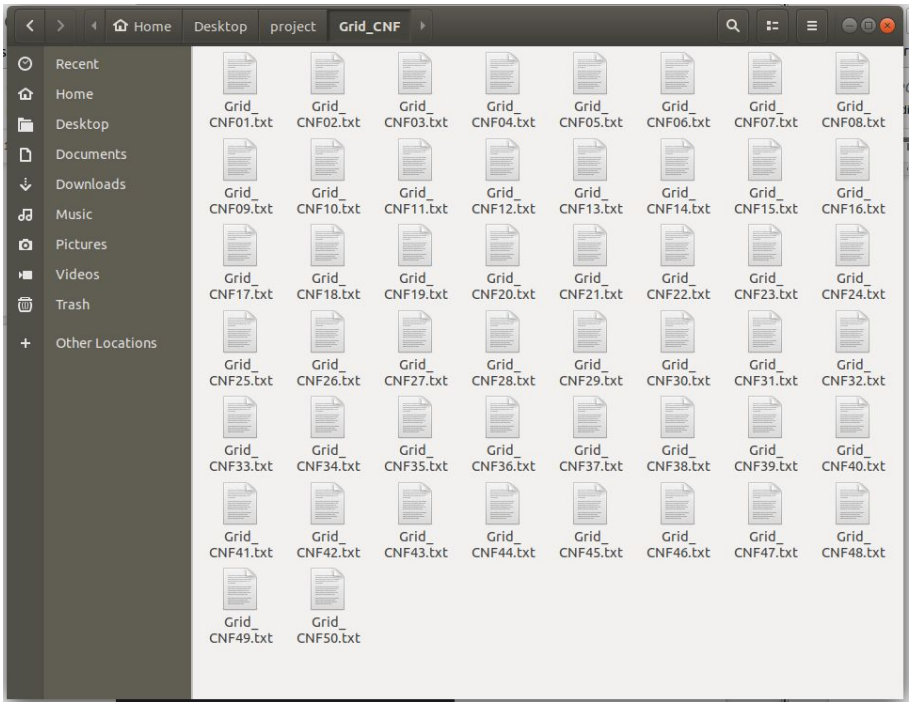
After the execution of `run_timer.py`, the program `sud2sat.py` and `sat2sud.py` will start in order.

WIth the choice of input puzzle (`p096_sudoku.py`/ `top95.txt`/ `4x4grid.txt`), `sud2sat.py` will generate a pair of output folders accordingly (`Grid_CNF`&`miniSAT_encoded`/`Grid_CNF_encoded`&`miniSAT_hard_encoded`/`Grid_CNF4x4`&`miniSAT_encoded4x4`).

We will consider the first case only in the basic.

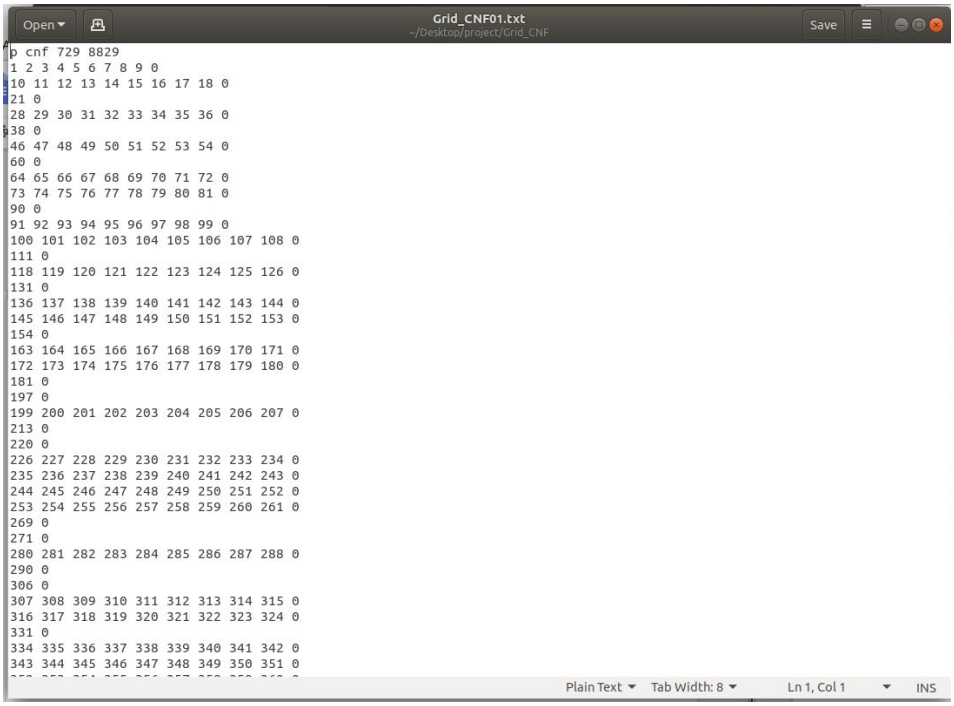
Part 1. Initiation of `sud2sat.py` with `p096_sudoku.txt`:

1.1 Output folder `Grid_CNF` contains the converted miniSAT-suitable, CNF-form file for each puzzle in `p096_sudoku.txt`. For example,



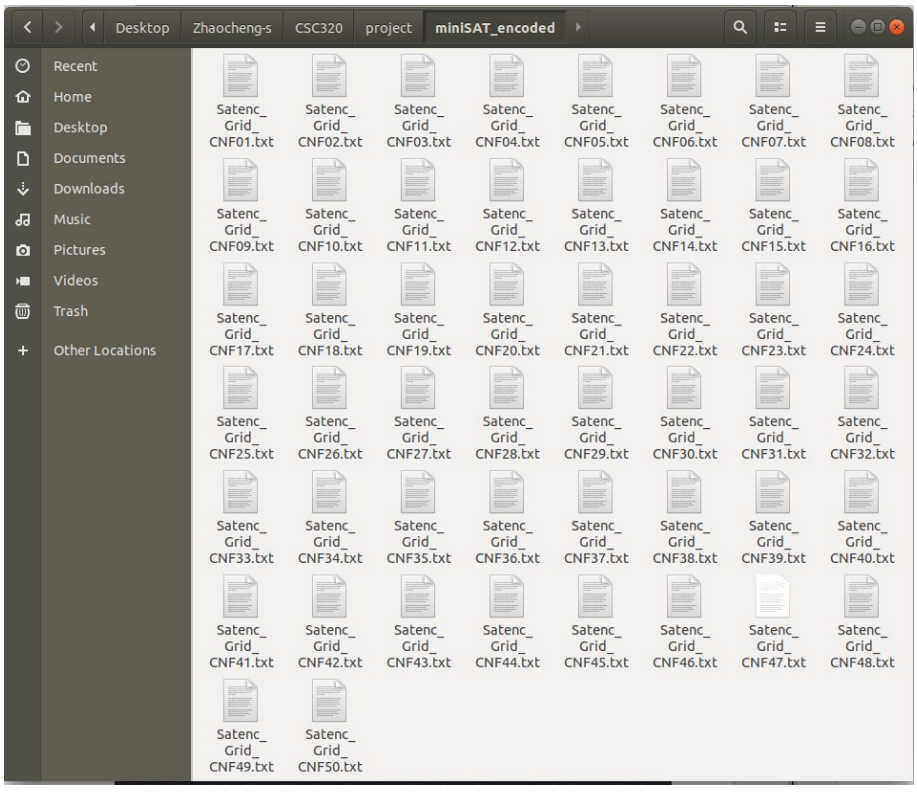
`Grid_CNF`: Folder contents overview

And each file is formatted (partially) as: (example below):



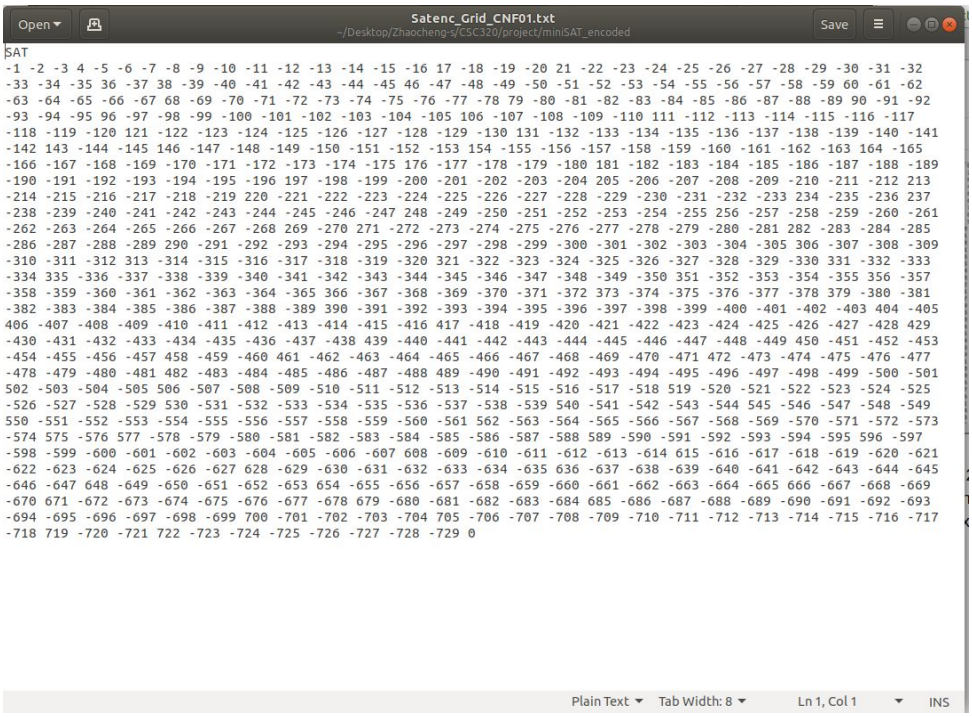
‘Partial converted file content’

1.2 Output folder `miniSAT_encoded` contains the miniSAT encoded file for each CNF-form input from `Grid_CNF`. For example,



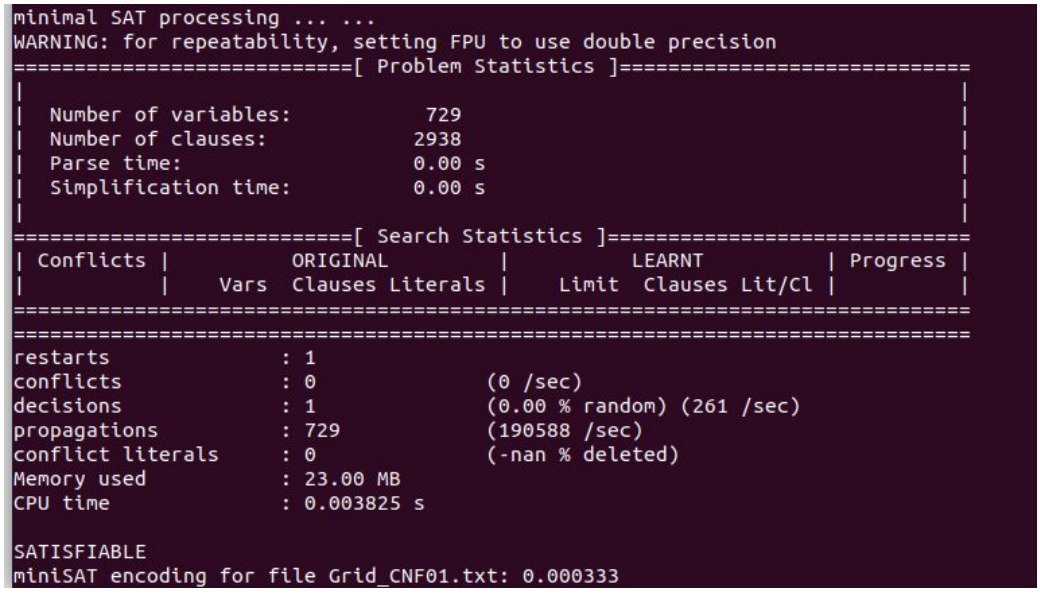
`miniSAT_encoded`: Folder contents overview

And each file is formatted as, (example below)



‘miniSAT-encoded file content’

And minisat problem statistics is partially shown as (picture below), and the full set of problem statistics generated by miniSAT is in the folder `basic_screenshot`



‘minisat problem statistics for each puzzle’

The time statistics for according process is shown below:

1. Time of converting each puzzle into CNF-form file (01-50):

```
lmo@lmo-ubuntu:~/Desktop/Zhaocheng-s/CSC320/project$ python run_timer.py p096_sudoku.txt

=========================sud2sat Statistics===================

Folder exists. Overwrite
Time CNF-ing file Grid_CNF01.txt: 0.010316
Time CNF-ing file Grid_CNF02.txt: 0.009554
Time CNF-ing file Grid_CNF03.txt: 0.009985
Time CNF-ing file Grid_CNF04.txt: 0.010257
Time CNF-ing file Grid_CNF05.txt: 0.010016
Time CNF-ing file Grid_CNF06.txt: 0.009904
Time CNF-ing file Grid_CNF07.txt: 0.009588
Time CNF-ing file Grid_CNF08.txt: 0.009978
Time CNF-ing file Grid_CNF09.txt: 0.009816
Time CNF-ing file Grid_CNF10.txt: 0.009768
Time CNF-ing file Grid_CNF11.txt: 0.010040
Time CNF-ing file Grid_CNF12.txt: 0.009525
Time CNF-ing file Grid_CNF13.txt: 0.009993
Time CNF-ing file Grid_CNF14.txt: 0.009570
Time CNF-ing file Grid_CNF15.txt: 0.009890
Time CNF-ing file Grid_CNF16.txt: 0.010018
Time CNF-ing file Grid_CNF17.txt: 0.009500
Time CNF-ing file Grid_CNF18.txt: 0.010166
Time CNF-ing file Grid_CNF19.txt: 0.009586
Time CNF-ing file Grid_CNF20.txt: 0.010122
Time CNF-ing file Grid_CNF21.txt: 0.009881
Time CNF-ing file Grid_CNF22.txt: 0.009505
Time CNF-ing file Grid_CNF23.txt: 0.010204
Time CNF-ing file Grid_CNF24.txt: 0.009646
Time CNF-ing file Grid_CNF25.txt: 0.009726
Time CNF-ing file Grid_CNF26.txt: 0.009751
Time CNF-ing file Grid_CNF27.txt: 0.009790
Time CNF-ing file Grid_CNF28.txt: 0.009853
Time CNF-ing file Grid_CNF29.txt: 0.010884
Time CNF-ing file Grid_CNF30.txt: 0.010224
Time CNF-ing file Grid_CNF31.txt: 0.009691
Time CNF-ing file Grid_CNF32.txt: 0.009836
Time CNF-ing file Grid_CNF33.txt: 0.010031
Time CNF-ing file Grid_CNF34.txt: 0.009766
Time CNF-ing file Grid_CNF35.txt: 0.009549
Time CNF-ing file Grid_CNF36.txt: 0.009956
Time CNF-ing file Grid_CNF37.txt: 0.009550
Time CNF-ing file Grid_CNF38.txt: 0.010110
```

‘Converting time for puzzle 01-50’

```
Total time of converting puzzles into CNF-form files: 0.492956
number of puzzles: 50
Average time of making each puzzles into CNF-form: 0.009859
```

'The total time / number of puzzles / average time for CNF conversion'

2. Time for each minisat encoding will be shown with minisat problem statistics screenshots. And

```
miniSAT encoding for file Grid_CNF50.txt: 0.000215
Total time of encoding CNF-form by miniSAT: 0.012139
number of puzzles: 50
Average time of encoding each CNF-form by miniSAT: 0.000243
```

'minisat encoding total time / number of puzzles / average time'

3. Total time for making each puzzle input a minisat-encoded form:

```
Total time of making puzzle input 1 into miniSAT encoded form: 0.010649
Total time of making puzzle input 2 into miniSAT encoded form: 0.009832
Total time of making puzzle input 3 into miniSAT encoded form: 0.010169
Total time of making puzzle input 4 into miniSAT encoded form: 0.010456
Total time of making puzzle input 5 into miniSAT encoded form: 0.010233
Total time of making puzzle input 6 into miniSAT encoded form: 0.010151
Total time of making puzzle input 7 into miniSAT encoded form: 0.009832
Total time of making puzzle input 8 into miniSAT encoded form: 0.010191
Total time of making puzzle input 9 into miniSAT encoded form: 0.010071
Total time of making puzzle input 10 into miniSAT encoded form: 0.009979
Total time of making puzzle input 11 into miniSAT encoded form: 0.010303
Total time of making puzzle input 12 into miniSAT encoded form: 0.009803
Total time of making puzzle input 13 into miniSAT encoded form: 0.010257
Total time of making puzzle input 14 into miniSAT encoded form: 0.009830
Total time of making puzzle input 15 into miniSAT encoded form: 0.010204
Total time of making puzzle input 16 into miniSAT encoded form: 0.010265
Total time of making puzzle input 17 into miniSAT encoded form: 0.009763
Total time of making puzzle input 18 into miniSAT encoded form: 0.010452
Total time of making puzzle input 19 into miniSAT encoded form: 0.009816
Total time of making puzzle input 20 into miniSAT encoded form: 0.010391
Total time of making puzzle input 21 into miniSAT encoded form: 0.010119
Total time of making puzzle input 22 into miniSAT encoded form: 0.009705
Total time of making puzzle input 23 into miniSAT encoded form: 0.010427
Total time of making puzzle input 24 into miniSAT encoded form: 0.009847
Total time of making puzzle input 25 into miniSAT encoded form: 0.010015
Total time of making puzzle input 26 into miniSAT encoded form: 0.009987
Total time of making puzzle input 27 into miniSAT encoded form: 0.010033
Total time of making puzzle input 28 into miniSAT encoded form: 0.010038
Total time of making puzzle input 29 into miniSAT encoded form: 0.011128
Total time of making puzzle input 30 into miniSAT encoded form: 0.010529
Total time of making puzzle input 31 into miniSAT encoded form: 0.009922
Total time of making puzzle input 32 into miniSAT encoded form: 0.010077
Total time of making puzzle input 33 into miniSAT encoded form: 0.010251
Total time of making puzzle input 34 into miniSAT encoded form: 0.010000
Total time of making puzzle input 35 into miniSAT encoded form: 0.009789
Total time of making puzzle input 36 into miniSAT encoded form: 0.010170
Total time of making puzzle input 37 into miniSAT encoded form: 0.009774
Total time of making puzzle input 38 into miniSAT encoded form: 0.010336
Total time of making puzzle input 39 into miniSAT encoded form: 0.009991
Total time of making puzzle input 40 into miniSAT encoded form: 0.009736
Total time of making puzzle input 41 into miniSAT encoded form: 0.010374
Total time of making puzzle input 42 into miniSAT encoded form: 0.010016
```

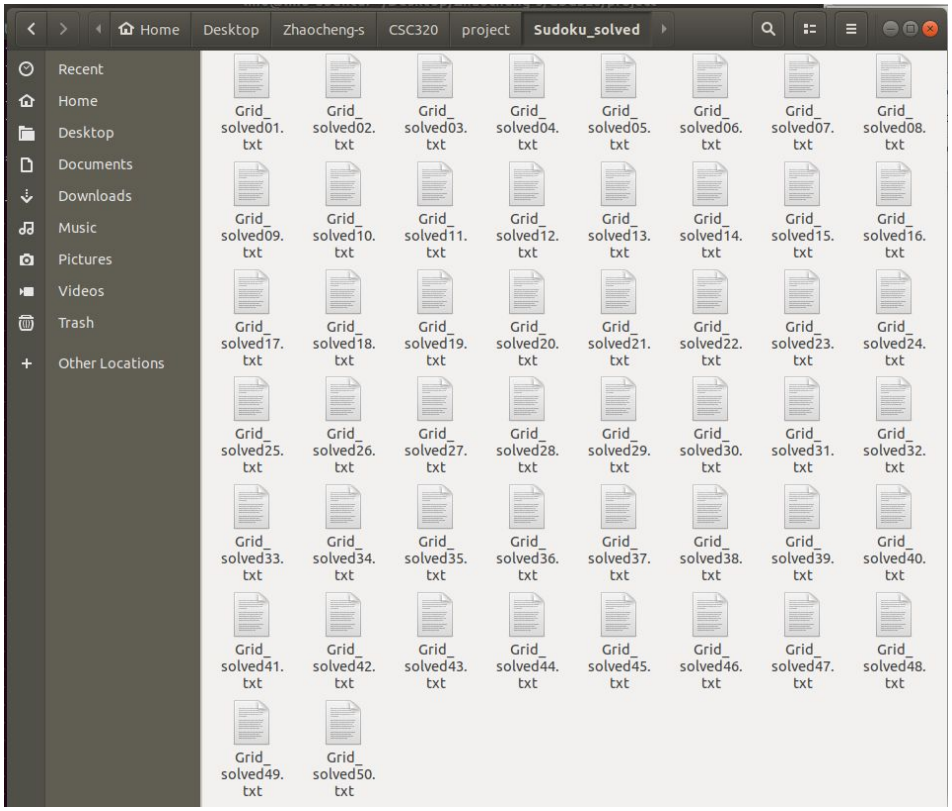
'minisat encoded time part-A'

```
Total time of making puzzle input 44 into miniSAT encoded form: 0.009981
Total time of making puzzle input 45 into miniSAT encoded form: 0.010307
Total time of making puzzle input 46 into miniSAT encoded form: 0.009975
Total time of making puzzle input 47 into miniSAT encoded form: 0.009859
Total time of making puzzle input 48 into miniSAT encoded form: 0.010388
Total time of making puzzle input 49 into miniSAT encoded form: 0.009810
Total time of making puzzle input 50 into miniSAT encoded form: 0.009986
```

'minisat encoded time part-B'

Part 2. Initiation of `sat2sud.py` with folder `miniSAT_encoded`:

Output folder `Sudoku_solved` contains the solutions for all input puzzles. For example,



'Sudoku_solved`: Folder contents overview

The time statistics for this process are:

1. Time for each minisat-encoded file into solution:

```
=========================sat2sud Statistics==================

miniSAT_encoded
Warming: Folder exists. And We will Use This One
Time of converting encoded puzzle Grid_solved01.txt into solution: 0.000531
Time of converting encoded puzzle Grid_solved02.txt into solution: 0.000463
Time of converting encoded puzzle Grid_solved03.txt into solution: 0.000449
Time of converting encoded puzzle Grid_solved04.txt into solution: 0.000461
Time of converting encoded puzzle Grid_solved05.txt into solution: 0.000467
Time of converting encoded puzzle Grid_solved06.txt into solution: 0.000465
Time of converting encoded puzzle Grid_solved07.txt into solution: 0.000456
Time of converting encoded puzzle Grid_solved08.txt into solution: 0.000467
Time of converting encoded puzzle Grid_solved09.txt into solution: 0.000467
Time of converting encoded puzzle Grid_solved10.txt into solution: 0.000466
Time of converting encoded puzzle Grid_solved11.txt into solution: 0.000466
Time of converting encoded puzzle Grid_solved12.txt into solution: 0.000465
Time of converting encoded puzzle Grid_solved13.txt into solution: 0.000461
Time of converting encoded puzzle Grid_solved14.txt into solution: 0.000509
Time of converting encoded puzzle Grid_solved15.txt into solution: 0.000449
Time of converting encoded puzzle Grid_solved16.txt into solution: 0.000440
Time of converting encoded puzzle Grid_solved17.txt into solution: 0.000442
Time of converting encoded puzzle Grid_solved18.txt into solution: 0.000440
Time of converting encoded puzzle Grid_solved19.txt into solution: 0.000439
Time of converting encoded puzzle Grid_solved20.txt into solution: 0.000440
Time of converting encoded puzzle Grid_solved21.txt into solution: 0.000495
Time of converting encoded puzzle Grid_solved22.txt into solution: 0.000491
Time of converting encoded puzzle Grid_solved23.txt into solution: 0.000457
Time of converting encoded puzzle Grid_solved24.txt into solution: 0.000414
Time of converting encoded puzzle Grid_solved25.txt into solution: 0.000413
Time of converting encoded puzzle Grid_solved26.txt into solution: 0.000413
Time of converting encoded puzzle Grid_solved27.txt into solution: 0.000413
Time of converting encoded puzzle Grid_solved28.txt into solution: 0.000444
Time of converting encoded puzzle Grid_solved29.txt into solution: 0.000417
Time of converting encoded puzzle Grid_solved30.txt into solution: 0.000417
Time of converting encoded puzzle Grid_solved31.txt into solution: 0.000416
Time of converting encoded puzzle Grid_solved32.txt into solution: 0.000467
Time of converting encoded puzzle Grid_solved33.txt into solution: 0.000430
Time of converting encoded puzzle Grid_solved34.txt into solution: 0.000454
Time of converting encoded puzzle Grid_solved35.txt into solution: 0.000447
Time of converting encoded puzzle Grid_solved36.txt into solution: 0.000432
Time of converting encoded puzzle Grid_solved37.txt into solution: 0.000440
Time of converting encoded puzzle Grid_solved38.txt into solution: 0.000432
Time of converting encoded puzzle Grid_solved39.txt into solution: 0.000417
Time of converting encoded puzzle Grid_solved40.txt into solution: 0.000417
```

‘Time for each minisat-encoded file to get solution part-A’

```
Time of converting encoded puzzle Grid_solved40.txt into solution: 0.000417
Time of converting encoded puzzle Grid_solved41.txt into solution: 0.000463
Time of converting encoded puzzle Grid_solved42.txt into solution: 0.000414
Time of converting encoded puzzle Grid_solved43.txt into solution: 0.000412
Time of converting encoded puzzle Grid_solved44.txt into solution: 0.000412
Time of converting encoded puzzle Grid_solved45.txt into solution: 0.000415
Time of converting encoded puzzle Grid_solved46.txt into solution: 0.000418
Time of converting encoded puzzle Grid_solved47.txt into solution: 0.000418
Time of converting encoded puzzle Grid_solved48.txt into solution: 0.000420
Time of converting encoded puzzle Grid_solved49.txt into solution: 0.000413
Time of converting encoded puzzle Grid_solved50.txt into solution: 0.000495
The total time of converting encoded puzzles into solutions 0.022249
```

‘Time for each minisat-encoded file to get solution part-A’

```
The total time of converting encoded puzzles into solutions 0.022249
The number of puzzle processed: 50
The average time for each puzzle: 0.000445
```

‘total time / number of puzzles / average time’

Part 3. Summary:

1. For both subprocesses, the total time consumed from puzzle inputs to getting solutions:

```
==========================Summary============================

THE TOTAL TIME OF SOLVIG PUZZLE 1 : 0.011180
THE TOTAL TIME OF SOLVIG PUZZLE 2 : 0.010295
THE TOTAL TIME OF SOLVIG PUZZLE 3 : 0.010618
THE TOTAL TIME OF SOLVIG PUZZLE 4 : 0.010917
THE TOTAL TIME OF SOLVIG PUZZLE 5 : 0.010700
THE TOTAL TIME OF SOLVIG PUZZLE 6 : 0.010616
THE TOTAL TIME OF SOLVIG PUZZLE 7 : 0.010288
THE TOTAL TIME OF SOLVIG PUZZLE 8 : 0.010658
THE TOTAL TIME OF SOLVIG PUZZLE 9 : 0.010538
THE TOTAL TIME OF SOLVIG PUZZLE 10 : 0.010445
THE TOTAL TIME OF SOLVIG PUZZLE 11 : 0.010769
THE TOTAL TIME OF SOLVIG PUZZLE 12 : 0.010268
THE TOTAL TIME OF SOLVIG PUZZLE 13 : 0.010718
THE TOTAL TIME OF SOLVIG PUZZLE 14 : 0.010339
THE TOTAL TIME OF SOLVIG PUZZLE 15 : 0.010653
THE TOTAL TIME OF SOLVIG PUZZLE 16 : 0.010705
THE TOTAL TIME OF SOLVIG PUZZLE 17 : 0.010205
THE TOTAL TIME OF SOLVIG PUZZLE 18 : 0.010892
THE TOTAL TIME OF SOLVIG PUZZLE 19 : 0.010255
THE TOTAL TIME OF SOLVIG PUZZLE 20 : 0.010831
THE TOTAL TIME OF SOLVIG PUZZLE 21 : 0.010614
THE TOTAL TIME OF SOLVIG PUZZLE 22 : 0.010196
THE TOTAL TIME OF SOLVIG PUZZLE 23 : 0.010884
THE TOTAL TIME OF SOLVIG PUZZLE 24 : 0.010261
THE TOTAL TIME OF SOLVIG PUZZLE 25 : 0.010428
THE TOTAL TIME OF SOLVIG PUZZLE 26 : 0.010400
THE TOTAL TIME OF SOLVIG PUZZLE 27 : 0.010446
THE TOTAL TIME OF SOLVIG PUZZLE 28 : 0.010482
THE TOTAL TIME OF SOLVIG PUZZLE 29 : 0.011545
THE TOTAL TIME OF SOLVIG PUZZLE 30 : 0.010946
THE TOTAL TIME OF SOLVIG PUZZLE 31 : 0.010338
THE TOTAL TIME OF SOLVIG PUZZLE 32 : 0.010544
THE TOTAL TIME OF SOLVIG PUZZLE 33 : 0.010681
THE TOTAL TIME OF SOLVIG PUZZLE 34 : 0.010454
THE TOTAL TIME OF SOLVIG PUZZLE 35 : 0.010236
THE TOTAL TIME OF SOLVIG PUZZLE 36 : 0.010602
THE TOTAL TIME OF SOLVIG PUZZLE 37 : 0.010214
THE TOTAL TIME OF SOLVIG PUZZLE 38 : 0.010768
THE TOTAL TIME OF SOLVIG PUZZLE 39 : 0.010408
```

‘Total time used for run_timer in each basic puzzle part-A’

```
THE TOTAL TIME OF SOLVIG PUZZLE 39 : 0.010408
THE TOTAL TIME OF SOLVIG PUZZLE 40 : 0.010153
THE TOTAL TIME OF SOLVIG PUZZLE 41 : 0.010837
THE TOTAL TIME OF SOLVIG PUZZLE 42 : 0.010430
THE TOTAL TIME OF SOLVIG PUZZLE 43 : 0.010290
THE TOTAL TIME OF SOLVIG PUZZLE 44 : 0.010393
THE TOTAL TIME OF SOLVIG PUZZLE 45 : 0.010722
THE TOTAL TIME OF SOLVIG PUZZLE 46 : 0.010393
THE TOTAL TIME OF SOLVIG PUZZLE 47 : 0.010277
THE TOTAL TIME OF SOLVIG PUZZLE 48 : 0.010808
THE TOTAL TIME OF SOLVIG PUZZLE 49 : 0.010223
THE TOTAL TIME OF SOLVIG PUZZLE 50 : 0.010481
```

‘Total time used for run_timer in each basic puzzle part-A’

```
THE TOTAL TIME OF SOLVING ALL PUZZLE:0.527344
the number of puzzles: 50
The average time of solving each puzzle: 0.010547
```

‘Total time for all puzzle / number of puzzles / average time for each puzzle’

And all 50 solutions are shown below:

Grid 1 solved	Grid 2 solved	Grid 3 solved	Grid 4 solved	Grid 5 solved
483921657	245981376	462831957	137256849	523816749
967345821	169273584	795426183	928314567	784593126
251876493	837564219	381795426	465897312	691472835
548132976	976125438	173984265	673542981	239145687
729564138	513498627	659312748	819673254	457268913
136798245	482736951	248567319	542189736	168937254
372689514	391657842	926178534	256731498	342789561
814253769	728349165	834259671	391428675	915624378
695417382	654812793	517643892	784965123	876351492

'Solutions for puzzle 1-5'

The remaining solutions will be shown in Appendix

3. Extended tasks: solutions and statistics:

3.1. Extended task #1 & #2: Extended encoding to solve puzzles in ' top95.txt`; alternative to minimal encoding.

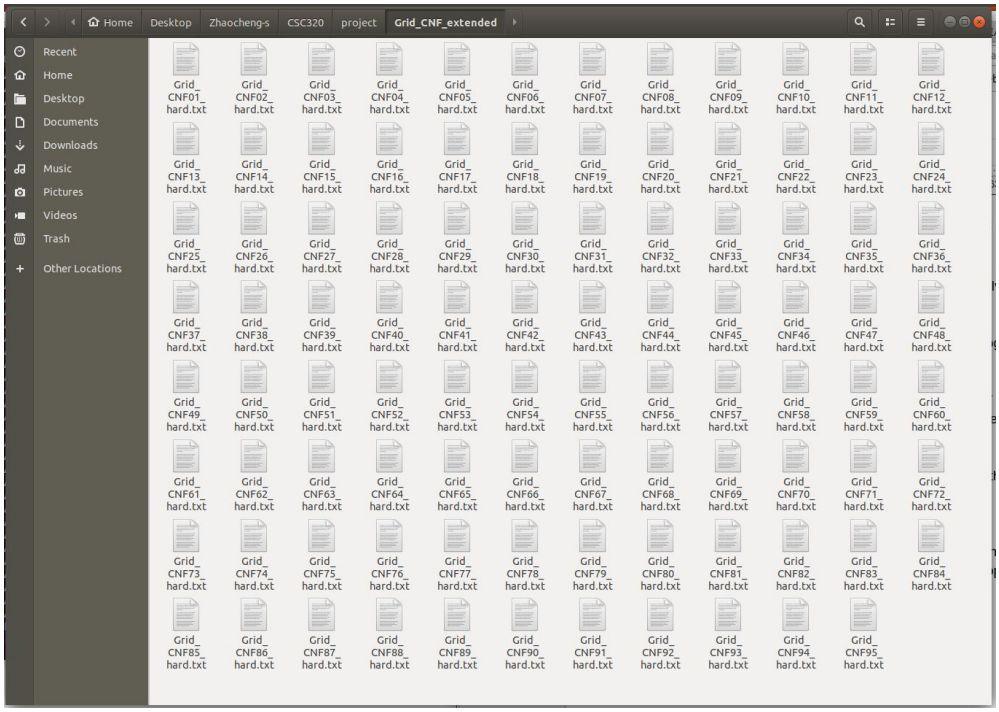
Similarly, after the execution of `run_timer.py`, the program `sud2sat .py` and `sat2sud.py` will start in order.

In this case, with the choice of input puzzle `top95.txt` here, `sud2sat .py` will generate a pair of output folders `Grid_CNF_encoded`&`mini SAT_hard_encoded`.

Notice: For those outputs which are highly similar to the basic tasks, there no need to attach any more detailed photos.

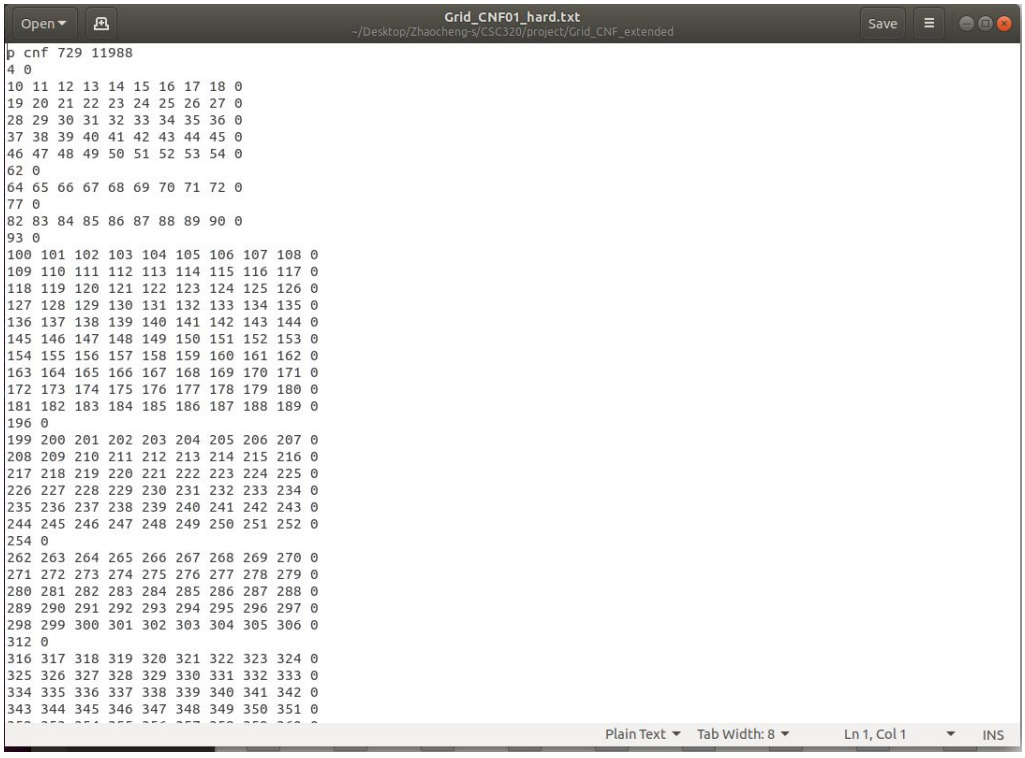
Part 1. Initiation of `sud2sat.py` with `top95.txt`:

1.1 Output folder `Grid_CNF_extended` contains the converted mi niSAT-suitable, CNF-form file for each puzzle in `top95.txt`.



‘Grid_CNF_extended`: Folder contents overview

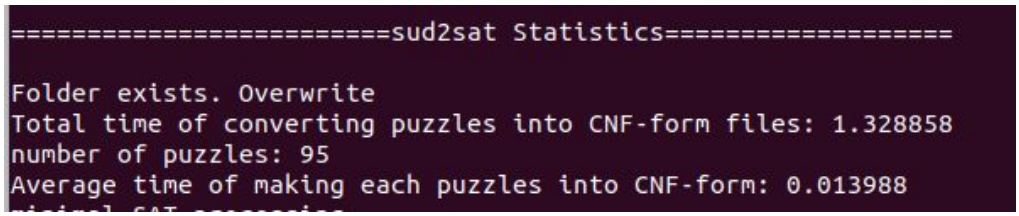
And each file is formatted (partially), (example below):



‘miniSAT-encoded file content’

The time statistics for according process is shown below, I will describe more simple:

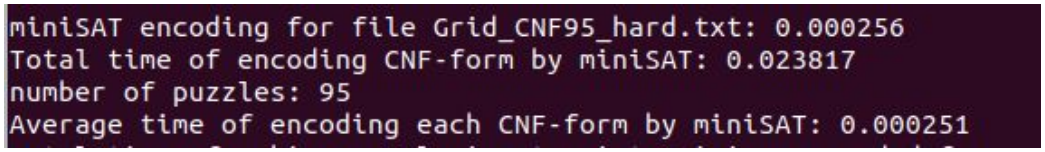
1. Time statistics of converting puzzles into CNF-form file (01-50):



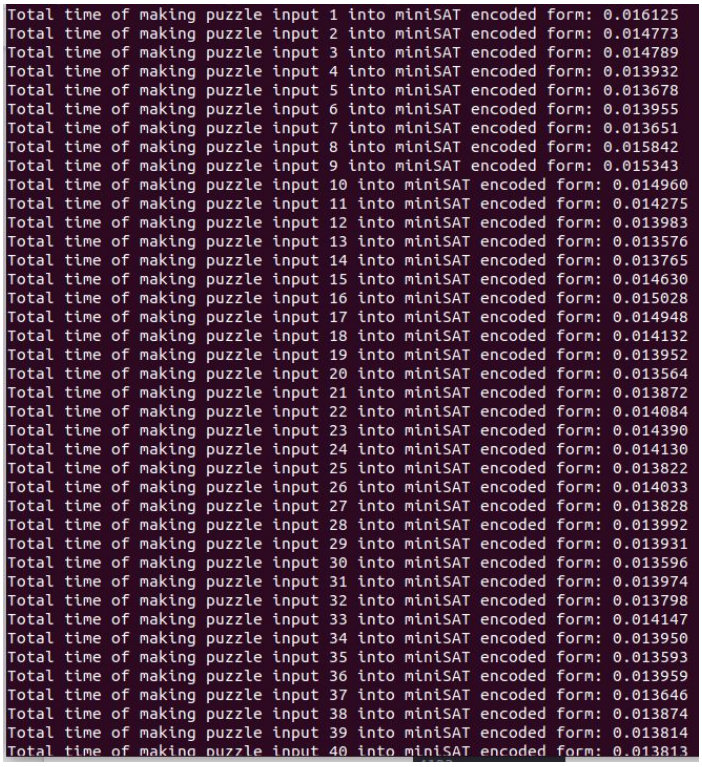
'Total time for all puzzles / number of puzzles / average time for each'

2. GIven the fact that the minisat problem statistics for `top95.txt` are too much, and the formatting is similar to the basic tasks, I will not save them.

3. Time statistics of minisat encoding CNF-form input:



'Total time for all puzzles / number of puzzles / average time for each'



'total time of making each puzzle into minisat-encoded file part-A'

```
Total time of making puzzle input 40 into miniSAT encoded form: 0.013813
Total time of making puzzle input 41 into miniSAT encoded form: 0.014225
Total time of making puzzle input 42 into miniSAT encoded form: 0.014076
Total time of making puzzle input 43 into miniSAT encoded form: 0.014044
Total time of making puzzle input 44 into miniSAT encoded form: 0.013638
Total time of making puzzle input 45 into miniSAT encoded form: 0.013901
Total time of making puzzle input 46 into miniSAT encoded form: 0.013898
Total time of making puzzle input 47 into miniSAT encoded form: 0.013561
Total time of making puzzle input 48 into miniSAT encoded form: 0.014210
Total time of making puzzle input 49 into miniSAT encoded form: 0.014965
Total time of making puzzle input 50 into miniSAT encoded form: 0.014167
Total time of making puzzle input 51 into miniSAT encoded form: 0.013955
Total time of making puzzle input 52 into miniSAT encoded form: 0.013599
Total time of making puzzle input 53 into miniSAT encoded form: 0.013890
Total time of making puzzle input 54 into miniSAT encoded form: 0.014009
Total time of making puzzle input 55 into miniSAT encoded form: 0.015417
Total time of making puzzle input 56 into miniSAT encoded form: 0.014635
Total time of making puzzle input 57 into miniSAT encoded form: 0.015039
Total time of making puzzle input 58 into miniSAT encoded form: 0.014912
Total time of making puzzle input 59 into miniSAT encoded form: 0.014765
Total time of making puzzle input 60 into miniSAT encoded form: 0.014704
Total time of making puzzle input 61 into miniSAT encoded form: 0.014587
Total time of making puzzle input 62 into miniSAT encoded form: 0.014653
Total time of making puzzle input 63 into miniSAT encoded form: 0.014541
Total time of making puzzle input 64 into miniSAT encoded form: 0.014972
Total time of making puzzle input 65 into miniSAT encoded form: 0.014986
Total time of making puzzle input 66 into miniSAT encoded form: 0.014807
Total time of making puzzle input 67 into miniSAT encoded form: 0.015225
Total time of making puzzle input 68 into miniSAT encoded form: 0.014855
Total time of making puzzle input 69 into miniSAT encoded form: 0.014684
Total time of making puzzle input 70 into miniSAT encoded form: 0.014869
Total time of making puzzle input 71 into miniSAT encoded form: 0.014542
Total time of making puzzle input 72 into miniSAT encoded form: 0.014824
Total time of making puzzle input 73 into miniSAT encoded form: 0.015104
Total time of making puzzle input 74 into miniSAT encoded form: 0.014424
Total time of making puzzle input 75 into miniSAT encoded form: 0.014533
Total time of making puzzle input 76 into miniSAT encoded form: 0.014348
Total time of making puzzle input 77 into miniSAT encoded form: 0.014106
Total time of making puzzle input 78 into miniSAT encoded form: 0.013595
Total time of making puzzle input 79 into miniSAT encoded form: 0.013983
Total time of making puzzle input 80 into miniSAT encoded form: 0.013751
```

‘total time of making each puzzle into minisat-encoded file part-B’

```
Total time of making puzzle input 80 into miniSAT encoded form: 0.013751
Total time of making puzzle input 81 into miniSAT encoded form: 0.014070
Total time of making puzzle input 82 into miniSAT encoded form: 0.013818
Total time of making puzzle input 83 into miniSAT encoded form: 0.013567
Total time of making puzzle input 84 into miniSAT encoded form: 0.014194
Total time of making puzzle input 85 into miniSAT encoded form: 0.014328
Total time of making puzzle input 86 into miniSAT encoded form: 0.014071
Total time of making puzzle input 87 into miniSAT encoded form: 0.013920
Total time of making puzzle input 88 into miniSAT encoded form: 0.013625
Total time of making puzzle input 89 into miniSAT encoded form: 0.013881
Total time of making puzzle input 90 into miniSAT encoded form: 0.013782
Total time of making puzzle input 91 into miniSAT encoded form: 0.013984
Total time of making puzzle input 92 into miniSAT encoded form: 0.013679
Total time of making puzzle input 93 into miniSAT encoded form: 0.014080
Total time of making puzzle input 94 into miniSAT encoded form: 0.013861
Total time of making puzzle input 95 into miniSAT encoded form: 0.013669
```

‘total time of making each puzzle into minisat-encoded file part-C’

Part 2. Initiation of `sat2sud.py` with folder `miniSAT_hard_encoded`:

Output folder `Sudoku_hard_solved` contains the solutions for all input puzzles.

The time statistics for according process is shown below, I will describe more simple:

1. Time statistics of converting minisat-encoded files into solutions:

```
The total time of converting encoded puzzles into solutions 0.043841
The number of puzzle processed: 95
The average time for each puzzle: 0.000461
```

‘total time of getting solution from minisat-encoded file / number of puzzles / average time for each puzzle’

2. Summary:

2.1. Time statistics for both subprocesses in order to get solutions.

```
THE TOTAL TIME OF SOLVING ALL PUZZLE:1.396516
the number of puzzles: 95
The average time of solving each puzzle: 0.014700
```

‘total time for both sud2sat.py and sat2sud.py processes’

2.2. Solutions for `top95.txt` will be shown in appendix

Grid 1 solved	Grid 2 solved	Grid 3 solved	Grid 4 solved	Grid 5 solved
417369825	527316489	617459823	487312695	962314857
632158947	896542731	248736915	593684271	134587269
958724316	314987562	539128467	126597384	578296413
825437169	172453896	982564371	735849162	847962531
791586432	689271354	374291586	914265837	651873942
346912758	453698217	156873294	268731549	329145786
289643571	941825673	823647159	851476923	285639174
573291684	765134928	791385642	379128456	793451628
164875293	238769145	465912738	642953718	416728395

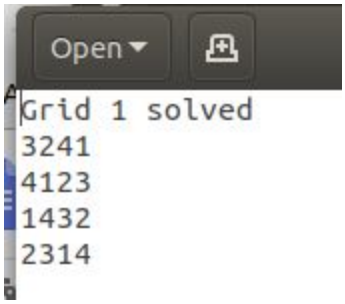
‘Solution of puzzle 01-05 in `top95.txt`

2.3. There is no additional program for the extended tasks, you can all work on `run_timer.py`. `sud2sat.py` and `sat2sud.py` are also designed to the extended encoding.

3.2. Extended task #3: Exploring nxn puzzles:

`run_timer.py`, `sud2sat.py` and `sat2sud.py` are designed to handle puzzles of any length, with the premise of required formatting. In order to test such flexibility. We create a `4x4grid.txt` file to contain a 4 by 4 sudoku puzzle to solve.

After going through the same procedures as precious two text inputs, the solution is:



‘4x4 puzzle solution’

5. Appendix:

A. Full solutions of `p096.sudoku.txt`:

Grid 1 solved 483921657 967345821 251876493 548132976 729564138 136798245 372689514 814253769 695417382	Grid 2 solved 245981376 169273584 837564219 976125438 513498627 482736951 391657842 728349165 654812793	Grid 3 solved 462831957 795426183 381795426 173984265 659312748 248567319 926178534 834259671 517643892	Grid 4 solved 137256849 928314567 465897312 673542981 819673254 542189736 256731498 391428675 784965123	Grid 5 solved 523816749 784593126 691472835 239145687 457268913 168937254 342789561 915624378 876351492
Grid 6 solved 176923584 524817639 893654271 957348162 638192457 412765398 265489713 781236945 349571826	Grid 7 solved 143986257 679425381 285731694 962354178 357618942 418279563 821567439 796143825 534892716	Grid 8 solved 487156932 362498751 915372864 846519273 593724186 271863549 124685397 738941625 659237418	Grid 9 solved 814976532 659123478 732854169 948265317 275341896 163798245 391682754 587439621 426517983	Grid 10 solved 761928453 925743168 438615927 357461289 894372615 216589374 689154732 142837596 573296841
Grid 11 solved 976125438 158436927 423879156 234761895 867952314 519384762 782513649 395647281 641298573	Grid 12 solved 962341758 148975623 573268149 321694875 487512936 695837412 834726591 216459387 759183264	Grid 13 solved 397681524 645279813 218534976 823956741 169742358 754318692 472893165 531467289 986125437	Grid 14 solved 639218457 471539268 825674139 564823791 793451826 218796345 352987614 186345972 947162583	Grid 15 solved 697128345 428635197 315479682 531246978 286397451 974581263 149852736 752963814 863714529

Grid 16 solved	Grid 17 solved	Grid 18 solved	Grid 19 solved	Grid 20 solved
361725948	359867124	786945312	743512986	782614359
587964213	648312597	219863457	589346217	439825176
492831657	712549836	534271869	126987345	651937428
638259471	876924351	165482973	934251768	293471865
174683592	524731968	327619548	671498532	568392714
259147836	193685472	498537126	852763491	147568293
746392185	931476285	951728634	398675124	326749581
923518764	465298713	842356791	417829653	975183642
815476329	287153649	673194285	265134879	814256937
Grid 21 solved	Grid 22 solved	Grid 23 solved	Grid 24 solved	Grid 25 solved
428531796	425781936	348267951	124986735	361524789
365947182	178369524	571943628	867435912	789361425
971268435	369524187	269185374	395712684	524879361
214896573	894157362	697351482	478359261	893157642
697453218	652843791	123874596	259861347	412683597
583172964	713692845	854629137	631274598	657942138
849615327	987216453	415798263	712698453	148796253
752389641	536478219	982436715	983547126	235418976
136724859	241935678	736512849	546123879	976235814

Grid 26 solved	Grid 27 solved	Grid 28 solved	Grid 29 solved	Grid 30 solved
581479263	387256419	345871269	235761489	298175643
329156847	469781325	279653184	419328576	657394128
647328159	512439867	861429537	867549213	134286579
956731428	123548976	197346852	746135928	821649735
238964571	758963241	452718396	521896734	573821496
714582936	694127583	683592741	983472651	469753281
172695384	835674192	738264915	394287165	312468957
893247615	271895634	516937428	652913847	785912364
465813792	946312758	924185673	178654392	946537812

Grid 31 solved	Grid 32 solved	Grid 33 solved	Grid 34 solved	Grid 35 solved
761543289	132649785	698173542	852716943	453218796
832791645	758213649	354628179	197843652	629753481
549628137	964785123	172549368	463925187	178496532
374215968	543897216	531897426	278634591	796582314
128936574	276531894	946312857	645179328	314967825
695487321	891426537	827456913	931582476	285134679
417369852	619378452	765931284	786491235	542879163
953872416	327154968	213784695	314258769	937641258
286154793	485962371	489265731	529367814	861325947

Grid 36 solved	Grid 37 solved	Grid 38 solved	Grid 39 solved	Grid 40 solved
516289347	945681723	365942871	134587296	193672485
849173256	781234965	128756493	278169354	462358971
732465918	326759184	974813562	695234817	785914623
698317524	269175348	819435627	359816472	538296714
327954861	138942576	537268149	821473569	674135298
154826739	574863219	642179358	746925183	219487356
961732485	457326891	296384715	917348625	826741539
275648193	612598437	753691284	462751938	941523867
483591672	893417652	481527936	583692741	357869142

Grid 41 solved	Grid 42 solved	Grid 43 solved	Grid 44 solved	Grid 45 solved
814976532	384567921	469158372	316549278	586127943
659123478	126439785	712463859	987321645	723469851
732854169	759821346	538297641	452678931	491853267
948265317	563798214	927634518	594236817	135974628
275341896	847312659	385719426	238417569	279618534
163798245	912645873	146582793	671985324	648532179
391682754	231974568	653941287	845162793	917246385
587439621	495286137	294876135	129753486	352781496
426517983	678153492	871325964	763894152	864395712

Grid 46 solved	Grid 47 solved	Grid 48 solved	Grid 49 solved	Grid 50 solved
954213687	159743862	861357294	294863517	351286497
617548923	276589431	597482361	715429638	492157638
832796541	348612759	432619785	863751492	786934512
763851294	624978315	916275843	152947863	275469183
128974365	917235684	358964127	479386251	938521764
549362178	583164297	274138956	638512974	614873259
281637459	435821976	789541632	986134725	829645371
475129836	861497523	143826579	521678349	163792845

396485712	792356148	625793418	347295186	547318926

B. Full solutions of ‘top95.txt’:

Grid 1 solved	Grid 2 solved	Grid 3 solved	Grid 4 solved	Grid 5 solved
417369825	527316489	617459823	487312695	962314857
632158947	896542731	248736915	593684271	134587269
958724316	314987562	539128467	126597384	578296413
825437169	172453896	982564371	735849162	847962531
791586432	689271354	374291586	914265837	651873942
346912758	453698217	156873294	268731549	329145786
289643571	941825673	823647159	851476923	285639174
573291684	765134928	791385642	379128456	793451628
164875293	238769145	465912738	642953718	416728395
Grid 6 solved	Grid 7 solved	Grid 8 solved	Grid 9 solved	Grid 10 solved
416837529	682154379	652481937	682153479	792351648
982465371	951763842	834679152	951764832	543786129
735129468	374892165	971325864	374892165	681429537
571298643	437528916	467812593	437528916	157648293
293746185	816937254	315794628	816947253	924137865
864351297	295416738	298563471	295316748	836295471
647913852	568271493	186937245	568271394	368572914
359682714	729345681	523146789	729435681	419863752
128574936	143689527	749258316	143689527	275914386
Grid 11 solved	Grid 12 solved	Grid 13 solved	Grid 14 solved	Grid 15 solved
614382579	863521794	135426987	356871294	129576348
953764812	127496853	846957321	972643851	376428519
827591436	954387621	927381465	841952736	584391627
742635198	645839172	213748659	213465987	293815764
168279354	739142568	598163742	794318625	417263895
395418627	281765439	674295813	685297413	865749132
286157943	498653217	351674298	128736549	958632471
579843261	512974386	482539176	569184372	731984256
431926785	376218945	769812534	437529168	642157983

Grid 16 solved	Grid 17 solved	Grid 18 solved	Grid 19 solved	Grid 20 solved
615382479	718435692	458276931	123759486	518476239
943765812	963278541	623891475	874261593	427359618
827491536	254961378	197534286	965384721	963821574
752634198	547612839	371452698	216543978	795248361
168279354	192387456	269783154	357896142	832617945
394518627	386549127	845169327	498127365	146935827
286157943	675893214	712948563	532478619	379564182
579843261	421756983	986315742	641932857	651782493
431926785	839124765	534627819	789615234	284193756
Grid 21 solved	Grid 22 solved	Grid 23 solved	Grid 24 solved	Grid 25 solved
498716523	132479658	417369825	925371486	123456789
257839461	847563291	638125947	163498725	649837251
136425987	956281347	952748316	874562391	857291634
971382654	413725869	825437169	542689137	274518963
684157392	528196473	791856432	618753942	398672415
523694718	769348125	346912758	739124658	561943827
765241839	271854936	284693571	487915263	416725398
319578246	394617582	573281694	351246879	985364172
842963175	685932714	169574283	296837514	732189546

Grid 26 solved	Grid 27 solved	Grid 28 solved	Grid 29 solved	Grid 30 solved
475691328	349526871	618342579	947582361	254379861
961832745	521897643	943765182	863471952	761248593
823754196	876413529	527891436	152639784	893516742
259143687	718369254	752634891	624813579	326791458
347586219	465281397	861279354	738295416	915824376
618927534	932745186	394518627	519764823	487653219
534269871	654178932	286157943	285946137	538167924
796318452	187932465	179483265	396157248	142985637
182475963	293654718	435926718	471328695	679432185
Grid 31 solved	Grid 32 solved	Grid 33 solved	Grid 34 solved	Grid 35 solved
385621497	836521947	427593186	781942365	748392165
179584326	142379586	315862479	324576918	369514728
426739518	975648321	968174325	659831724	125876943
762395841	364892715	659328714	815723496	932147856
534812769	259167438	731649852	936154872	687235419
891476253	781435269	284751963	247698153	514689372
917253684	598214673	593287641	578369241	853461297
243168975	413756892	842916537	162487539	476923581
658947132	627983154	176435298	493215687	291758634

Grid 36 solved	Grid 37 solved	Grid 38 solved	Grid 39 solved	Grid 40 solved
417369528	124597368	137926485	249865173	351846729
839125746	369428517	964587231	531974268	287319645
652748319	587361924	825341967	867132495	694725183
925837461	293815746	241895673	423786519	168534972
741956832	416273895	673412598	986251347	725198364
386412957	875946132	589673142	715349826	943267518
294683175	958632471	758164329	692518734	516483297
573291684	631784259	396258714	354627981	832971456
168574293	742159683	412739856	178493652	479652831
Grid 41 solved	Grid 42 solved	Grid 43 solved	Grid 44 solved	Grid 45 solved
748591326	723469851	947628351	132467895	143587962
195623847	651238794	863751492	957381246	852496731
263487519	894715632	125349678	864529731	976321584
421936758	375691428	734895126	429673158	214675398
356874291	912874365	589162734	578912364	635819427
987152634	486523917	612473985	613854972	789243615
832749165	248356179	478236519	385296417	321764859
679215483	137982546	256917843	241735689	468952173
514368972	569147283	391584267	796148523	597138246
Grid 46 solved	Grid 47 solved	Grid 48 solved	Grid 49 solved	Grid 50 solved
783465219	219675843	126739845	273681495	654312879
421973658	865439721	847625391	891754263	913876452
965281734	743281596	935481762	546392178	827495136
347128596	936512487	213864579	169537824	742638591
198546327	157348962	654973218	485269731	165729384
652397481	428967135	798512436	327148956	398541627
216854973	382754619	361248957	734916582	286157943
534719862	671893254	489157623	958423617	471983265
879632145	594126378	572396184	612875349	539264718

Grid 51 solved	Grid 52 solved	Grid 53 solved	Grid 54 solved	Grid 55 solved
152738946	174589362	126478593	964815237	476529183
864291375	953261784	837592461	258637149	895173624
973645281	862347951	945361278	317924658	321864795
216357498	219673845	412937856	872159364	517398246
348912567	387415296	569184732	495263781	289645371
597486123	546928173	783256914	631478925	634712958
421863759	628194537	251649387	783596412	752431869
639574812	495732618	374815629	529341876	168957432
785129634	731856429	698723145	146782593	943286517

Grid 56 solved	Grid 57 solved	Grid 58 solved	Grid 59 solved	Grid 60 solved
538127946	124597863	872459631	947326581	215876943
624839751	937648215	154683972	852491673	678394215
719645382	856231749	963721485	136587942	349125876
965314827	513786492	216834759	284735169	587432169
381762594	482913657	549217368	693812457	463981752
247598163	769425138	738596124	715649238	192657384
493281675	698374521	481362597	579168324	826743591
856473219	341852976	627945813	328954716	734519628
172956438	275169384	395178246	461273895	951268437
Grid 61 solved	Grid 62 solved	Grid 63 solved	Grid 64 solved	Grid 65 solved
124397856	125976348	283741596	957638421	127365489
835641297	369428517	615239748	146729385	853491276
967825341	784351926	974865321	832541679	964278351
241538769	253817694	397126854	419352768	231756894
583769412	416293875	861453972	628417953	548932617
679412538	897645132	452978613	375986142	679184523
312974685	978532461	528394167	791265834	312547968
498256173	631784259	736512489	583174296	485619732
756183924	542169783	149687235	264893517	796823145
Grid 66 solved	Grid 67 solved	Grid 68 solved	Grid 69 solved	Grid 70 solved
345671298	265389471	842359167	538219746	863751294
987253146	874251693	573186942	962874531	957432681
621984573	193647852	619274538	174356298	124689573
264795831	327894165	127865394	283497615	532976148
573816429	946125387	435791286	741568329	619843725
198432657	518763249	968423715	695123874	748125936
836529714	631578924	781942653	329645187	386217459
712348965	452916738	354617829	857931462	295364817
459167382	789432516	296538471	416782953	471598362

Grid 71 solved	Grid 72 solved	Grid 73 solved	Grid 74 solved	Grid 75 solved
986324157	945671283	724369851	126437958	152946837
124759368	136482597	651248793	895621473	963587421
537861429	827593461	893715642	374985126	847231695
413285976	614837952	375691428	457193862	574863912
695173284	798125346	912874365	983246517	289415763
278946513	253964178	486523917	612578394	631729548
342617895	362759814	238456179	269314785	796152384
869532741	581246739	147982536	548769231	415398276
751498632	479318625	569137284	731852649	328674159

Grid 76 solved	Grid 77 solved	Grid 78 solved	Grid 79 solved	Grid 80 solved
269314785	152678943	496573128	253479861	963741258
548769231	864391752	381924675	761238594	152398674
731852649	973245681	275861943	894516732	874265391
126437958	215763894	153789462	326791458	345872169
895621473	497582136	962435781	915824376	218956743
374985126	638914527	847216539	487653219	697134825
457193862	321856479	714352896	548167923	721489536
983246517	549127368	529648317	132985647	589623417
612578394	786439215	638197254	679342185	436517982
Grid 81 solved	Grid 82 solved	Grid 83 solved	Grid 84 solved	Grid 85 solved
152398647	946731582	932475861	618459723	957261384
973641285	157248639	617928534	342867519	846537921
864572931	832659471	845613279	579123468	123489567
598714362	719423865	568741392	296534187	734926815
247936158	584976123	429836715	784291635	295814736
316285794	623815947	173259648	153786294	618375492
725463819	461397258	356192487	927648351	572198643
431829576	398562714	294387156	861375942	481653279
689157423	275184396	781564923	435912876	369742158
Grid 86 solved	Grid 87 solved	Grid 88 solved	Grid 89 solved	Grid 90 solved
132749685	746513892	956327841	935748621	143258679
857361924	132869754	127486395	876231594	872964153
964285371	598742316	834951267	124695783	695137482
216457839	367925481	548739612	512469378	986541327
348692157	925481673	271864539	643872915	451372968
579813246	481637925	369215478	789153462	237896514
421536798	679154238	793548126	267514839	719623845
683974512	254378169	415692783	491386257	564789231
795128463	813296547	682173954	358927146	328415796
Grid 91 solved	Grid 92 solved	Grid 93 solved	Grid 94 solved	Grid 95 solved
937658241	924361758	856491372	659412378	354186927
864291735	156478293	143572698	238679451	298743615
125734986	837592641	927368451	741385296	167952483
583419627	613247985	278645139	865723149	481527369
649372518	749185326	514923786	427891635	932614578
712586493	582936174	639817245	913546782	576398241
471963852	498623517	361789524	396157824	729865134
396825174	371859462	485236917	574268913	845231796
258147369	265714839	792154863	182934567	613479852