LatinSquareSolver Documentation

Release 1.0

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Looking to get started right away? Check out the *Instillation* and *Running* pages.

CHAPTER 1

Latin Squares Explained

A Latin Square is a $N\times N$ matrix where each row, and each column contains the numbers $\left\{ 1,2,\dots,n\right\}$. We then add in K holes to the square that must be filled in so that each row and column contain the numbers $\left\{ 1,2,\dots,n\right\}$. An example Latin Square with $N=5,\text{ and }K=16$ is:

$$\begin{array}{ccccc} \square & 2 & \square & \square & 4\\ 3 & \square & 1 & \square & \square\\ \square & 4 & \square & \square & 1\\ 2 & \square & \square & \square & 3\\ \square & \square & 2 & 1 & \square \end{array}$$

And the solution would be:

$$\begin{array}{ccccc} 1 & 2 & 5 & 3 & 4\\ 3 & 5 & 1 & 4 & 2\\ 5 & 4 & 3 & 2 & 1\\ 2 & 1 & 4 & 5 & 3\\ 4 & 3 & 2 & 1 & 5 \end{array}$$

CHAPTER 2

How The Solver Works

The initial solution to this problem would be to use depth first search to iterate through all the possible values for each hole. Unfortunately the complexity of this problem will cause depth first search to take an infeasible amount of time for even small problems like the one shown above. Since brute force depth first search is out of the question we need to come up with clever methods to help it out and this is done with two main methods, forward checking, and arc consistency. When we are filling in values to the Latin Square we have to make two decisions per branch, which hole to fill, and what value to put into the hole. We use forward checking to make sure that we select the hole, and value for that hole that has the highest probability of being correct. Arc Consistency is used to keep track of what the valid values would be for each hole, and to update this list of values as we fill in the square.

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CHAPTER 4

Contents:

4.1 Instillation

4.1.1 Using Pip

```
pip install LatinSquareSolver
```

4.1.2 Directly From Source

```
git clone https://github.com/nicholasRutherford/LatinSquareSolver.git
```

Building Documentation

If you want to build the documentation you'll need some extra packages:

```
pip install sphinx sphinx-rtd-theme Pygments
```

Then it can be built with:

```
sphinx-build -a -b html docs/source/ docs/build/
```

4.2 Running

4.2.1 Loading a square:

If you have a square to solve already, you can simply load it into the solver. The format for the square is as follows:

1. Each row of text is a row of the square.
2. Each element is an integer, separated by a space.
3. Holes are denoted as non-intger, non-space characters. ie `*` or _.

For example if we had the following in a file `square.txt`:

```
0 1 2 3 4
1 2 3 4 _
2 3 4 0 1
3 * 0 1 2
4 0 1 2 3
```

Then we can run:

```
from LatinSquareSolver.solver import Solver

rawFile = open("square.txt", "r")
square = rawFile.read()
rawFile.close()

solv = Solver()
solv.loadSquare(square)
solv.solveSquare()
print solv
```

Which will give us:

```
Original Square:
0 1 2 3 4
1 2 3 4 *
2 3 4 0 1
3 * 0 1 2
4 0 1 2 3

Solved Square:
0 1 2 3 4
1 2 3 4 0'
2 3 4 0 1
3 4'0 1 2
4 0 1 2 3
```

4.2.2 Generating a square:

We can also generate random squares as well by using the `randSquare(n, k)` function. It requires to parameters:

- \(N\) - The side length of the square.
- \(K\) - The number of holes to add to the square.

Note: The squares generated will be solvable, but the solution is not guaranteed to be unique.

```
from LatinSquareSolver.solver import Solver

solv = Solver()
solv.randSquare(10, 25) # 10 x 10 square with 25 holes
solv.solveSquare()
print solv
```

Which will give us:

```
Original Square:
3 * * * 7 * * * * 2
8 9 6 5 2 * 3 4 1 7
6 * 4 3 0 8 1 * 9 5
2 3 * 9 6 * * 8 * 1
```

```
0 1 * 7 4 2 5 6 3 *
4 5 2 1 * 6 9 0 7 3
* 8 5 4 1 9 2 3 * 6
1 2 * * 5 3 6 7 * 0
9 0 7 6 3 1 4 * 2 8
5 6 3 2 9 7 0 1 * *

Solved Square:
3 4'1'0'7 5'8'9'6'2
8 9 6 5 2 0'3 4 1 7
6 7'4 3 0 8 1 2'9 5
2 3 0'9 6 4'7'8 5'1
0 1 8'7 4 2 5 6 3 9'
4 5 2 1 8'6 9 0 7 3
7'8 5 4 1 9 2 3 0'6
1 2 9'8'5 3 6 7 4'0
9 0 7 6 3 1 4 5'2 8
5 6 3 2 9 7 0 1 8'4'
```

4.3 Object Classes

4.3.1 Solver

Solves a latin square.

class `LatinSquareSolver.solver.`**`Solver`**

`__str__`()

Pretty output

`loadSquare`(*rawString*)

Load a latin square from a string

Parameters **rawStr** (*str*) – The latin square as string

Notes

The elements must be intgers seperated by spaces. The holes are denoted as non-integer, non-space elements, such as '*', or '_'. For example:

```
0 1 2 3 4
1 2 3 4 _
2 3 4 0 1
3 4 0 1 2
4 0 1 2 3
```

`randSquare`(*n*, *k*, *seed=None*, *randomise=True*)

Initialize a random latin square.

Parameters

- **n** (*int*) – The side length of the square
- **k** (*int*) – The number of holes in the grid
- **seed** (*int*) – The seed for the random number generator

- **randomize** (*bool*) – Whether to randomize the grid, or leave with the basic grid layout

Notes

The Latin Square generated will be solveable, though the solution is not guarteed to be unique. If randomize is not selected the square will remain in the basic state where each row is one offset from the previous. Ie for N = 5:

```
0 1 2 3 4
1 2 3 4 0
2 3 4 0 1
3 4 0 1 2
4 0 1 2 3
```

solveSquare()
Solve the loaded latin square.

4.3.2 LatinSquare

Represents a Latin Square and includes methods needed to search for a solution

class LatinSquareSolver.latinSquare.**Hole**(*n*)
Represent a square in a Latin square that needs to be filled in, aka a hole in the square.

Notes

Keeps track of the location of the hole, the possible values that the hole can take, and whether the value has been set.

class LatinSquareSolver.latinSquare.**LatinSquare**

__str__()
Pretty output. Hole values are postfixed with '.

Returns The pretty output.

Return type str

addHoles()
Randomly initializes the holes in the grid.

Notes

This randomly adds K holes to the graph. The result will be a solvable Latin square, but there may be more then one solution to it.

checkHoleOptions()
Removes possible options from each hole based on the non-hole values.

isSolved()
Determine is the current square is correctly solved

Returns True if it is correctly solved.

Return type bool

Notes

Determines if the square is correct by making sure that each row and column contains all of the elements from 0 to n. This method will fail quicker than counting the values for each row and column and making sure there are no duplicates.

isValid()

Whether a partially filled in Latin square has valid hole values

Returns True if everything is valid so far, False otherwise

Return type bool

loadSquare(*rawStr*)

Load a latin square from a string

Parameters **rawStr** (*str*) – The latin square as string

Raises `RuntimeError` – Invalid Square Given

Notes

The elements must be intgers seperated by spaces. The holes are denoted as non-integer, non-space elements, such as '*', or '_'. For example:

```
0 1 2 3 4
1 2 3 4 _
2 3 4 0 1
3 * 0 1 2
4 0 1 2 3
```

nextStates()

Generate all the squares corresponding to the options of the hole with the least number of options.

Returns List of squares corresponding to selecting one of the possible values of the hole h, where h has the smallest number of possible values out of all the holes.

Return type [latinSquare]

Notes

The list of squares is calculated lazily, where the value is not calculated until it is actually used. This cuts down on the number of expensive deepcopy calls needed.

randSquare(*n*, *k*, *seed=1337*, *randomise=True*)

Initialize a random latin square.

Parameters

- **n** (*int*) – The side length of the square
- **k** (*int*) – The number of holes in the grid
- **seed** (*int*) – The seed for the random number generator
- **randomize** (*bool*) – Whether to randomize the grid, or leave with the basic grid layout

Raises `RuntimeError` – if K > N.

Notes

If randomize is not selected the square will remain in the basic state where each row is one offset from the previous. Ie for N = 5:

```
0 1 2 3 4
1 2 3 4 0
2 3 4 0 1
3 4 0 1 2
4 0 1 2 3
```

randomise()

Takes a correct Latin square and randomizes the entries.

Notes

The randomization is done by performing an in place randomization of the rows, and then of the columns. As long as the Latin square was valid before, it will be valid afterwards.

strHoles()

Pretty output. Holes are marked with an *.

Returns The pretty output.

Return type str

updateHoleOptions(*h*)

Removes possible options from each hole based on the values of the given hole.

Parameters **h** (*Hole*) – The hole to check all the other holes against

validCols()

Determines whether the columns are valid.

Returns True if the columns are valid, False otherwise.

Return type bool

Notes

Determines validity by making sure no value is repeated twice in each column. This is more expensive than the method used in isSolved, but necessary since there could be holes in the grid.

validHoles()

Determine if the values for the holes is valid.

Returns If the holes have valid values will return True

Return type bool

Notes

Determines validity by checking that each non-set hole has at least one option for it’s value.

validRows()

Determines whether the rows are valid.

Returns True if the rows are valid

Return type bool

Notes

Determines validity by making sure no value is repeated twice in each row. This is more expensive than the method used in isSolved, but necessary since there could be holes in the grid.

4.4 More Information

4.4.1 Implementation Details

In order to test our implementation we randomly generate Latin Squares to use. We do this by creating a naive Latin Square where we start off with all the elements in order, and then shift each row below over by one, like so:

$$\begin{array}{ccccc} 1 & 2 & 3 & 4 & 5\\ 2 & 3 & 4 & 5 & 1\\ 3 & 4 & 5 & 1 & 2\\ 4 & 5 & 1 & 2 & 3\\ 5 & 1 & 2 & 3 & 4 \end{array}$$

Once we have this naive square we randomize the columns, and then randomize the rows. Once we have our random square we randomly remove \(K\) holes from it. This will result in a solvable Latin Square, though the solution is not guaranteed to be unique. For the purposes of this problem the non-uniqueness does not affect anything.

To help speed up the solve time we used both forward checking and arc consistency. For arc consistency we keep a list of possible values for each hole. When the grid is initialized we go through each hole and update the possible values it can take. After this point any time we assign a value to a hole we go through any hole in the same column or row and update their remaining possibilities.

We use forward checking to pick the best hole to evaluate by picking the hole that has the least number of possible options. Normally you would want to pick the best possible value from the list of possible values for each hole, but we have no more information to go on so we simply pick the lowest possible option and check it. Once we've selected a value we check and make sure that the grid is still solvable by making sure that all remaining holes have at least one possible option, and no row or column has double elements. If we find that we selected a value that results in an invalid grid we will stop the search and backtrack until we have a valid grid again.

One last python specific optimization is that we use a generator to list all the children of a search node. Previously we were creating all the nodes, which involve an expensive copy operation, even if we never looked at the other nodes. By using a generator the nodes are only created when they are actually looked at, which requires significantly less computation.

4.4.2 How Well It Works

To test how well our implementation works we ran two tests. For the first we solved grids with \(N=K\), which can be seen in figure 1. For each value of \(N\) we generated 10 random grids and plotted the mean time to solve, and the standard deviation among the solve times. For the second test we plotted the average solve time for a 10x10 grid with an increasing number of holes. For each data point we ran the solver on 50 random grids and plotted the mean solve time. The second test can be seen in figure 2.

From the results above we can see that the solver does produce results in reasonable time. For a \(100\times 100\) grid with 100 holes it took on average 3 seconds to find the solution. It also shows a clear experiential trend that we would expect to see with a problem like this. Looking at figure 2 we see that the solver runs into significant trouble once the grid is 50-75% empty, which is the expected result of a Latin Square solver so this is not a cause for concern.

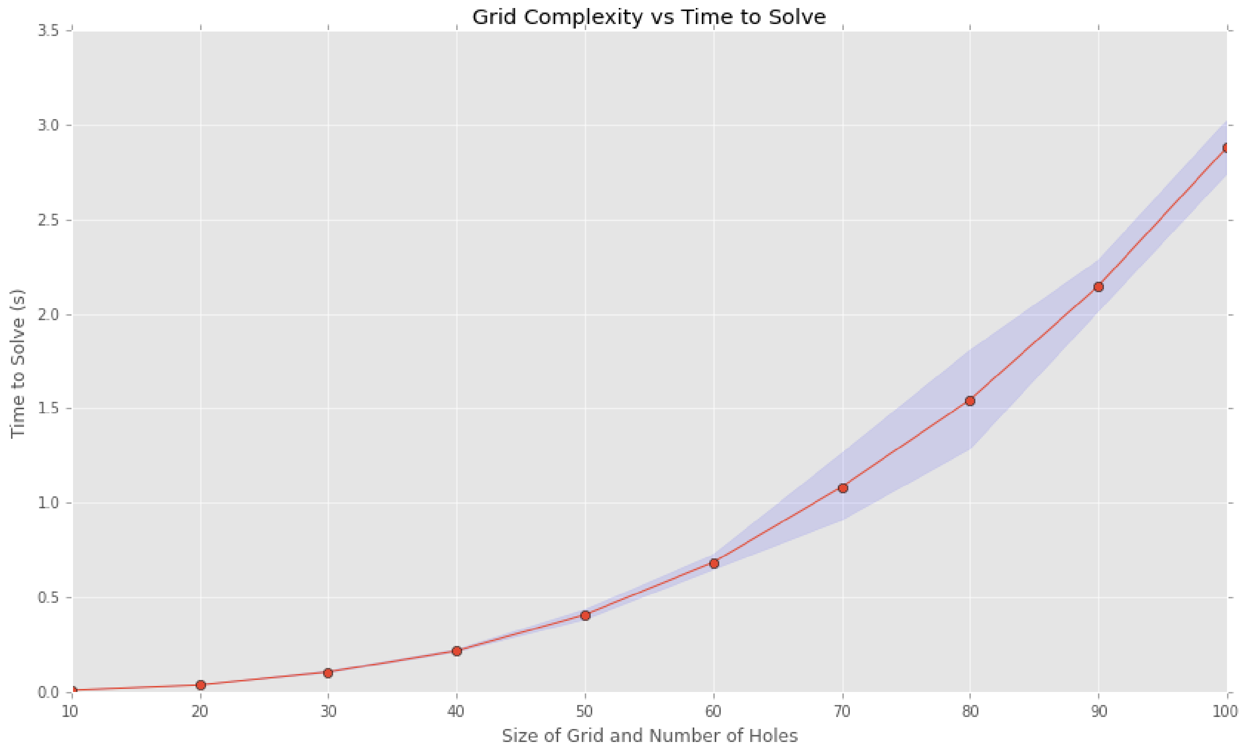

Figure 4.1: Figure 1: Time to solve for different sizes.

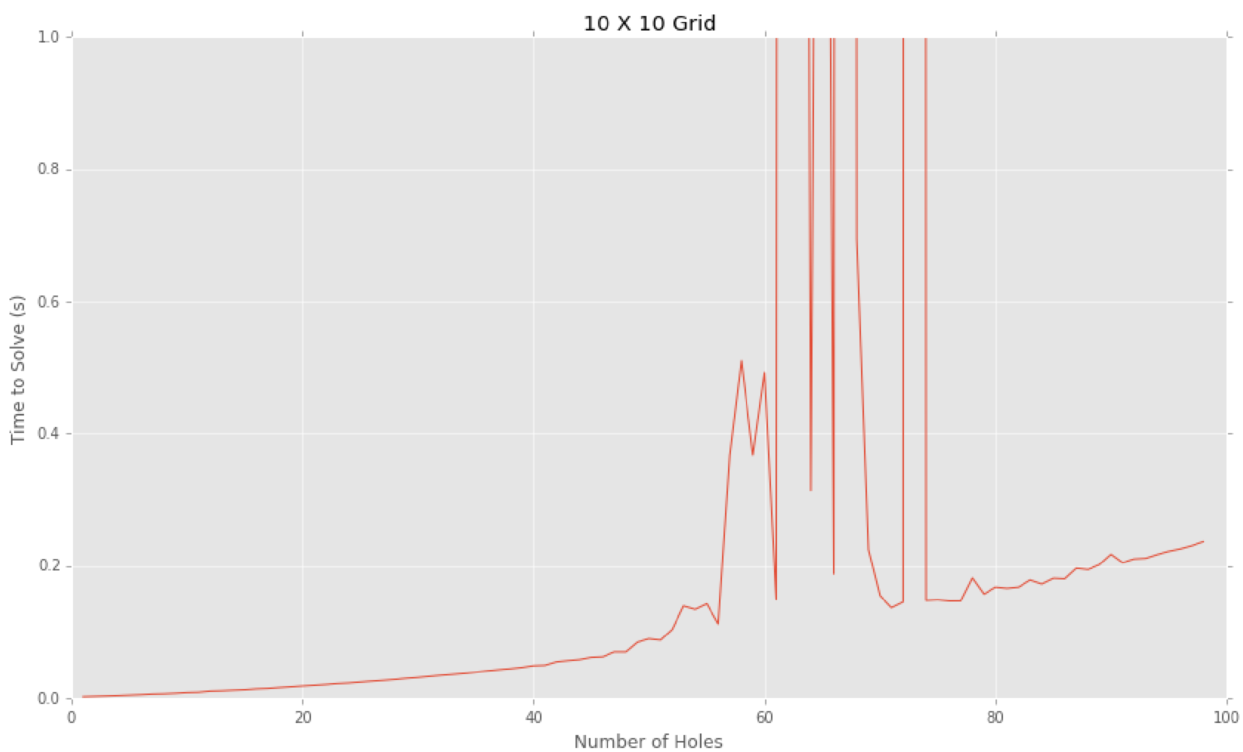

Figure 4.2: Figure 2: Solve time for increasing number of holes.

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```
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