Sudoku Solver

11.06.2018

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Sudoku Primer

Project Description

What is Sudoku?

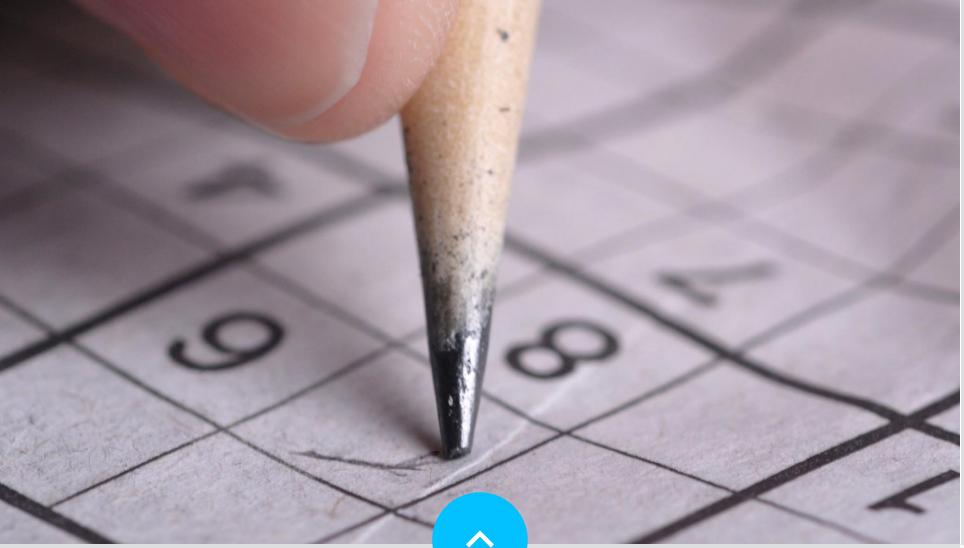
Fill 9x9 Grid with 81 × 1-9

Why FPGA?

Parallelism

Techniques?

Candidate Line, Naked and Hidden Groups

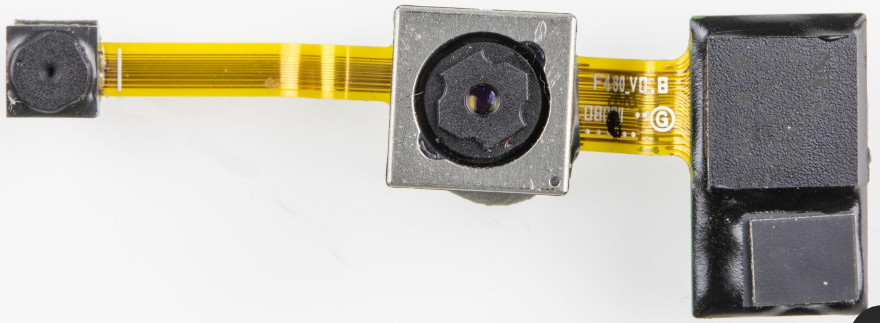


Human Techniques

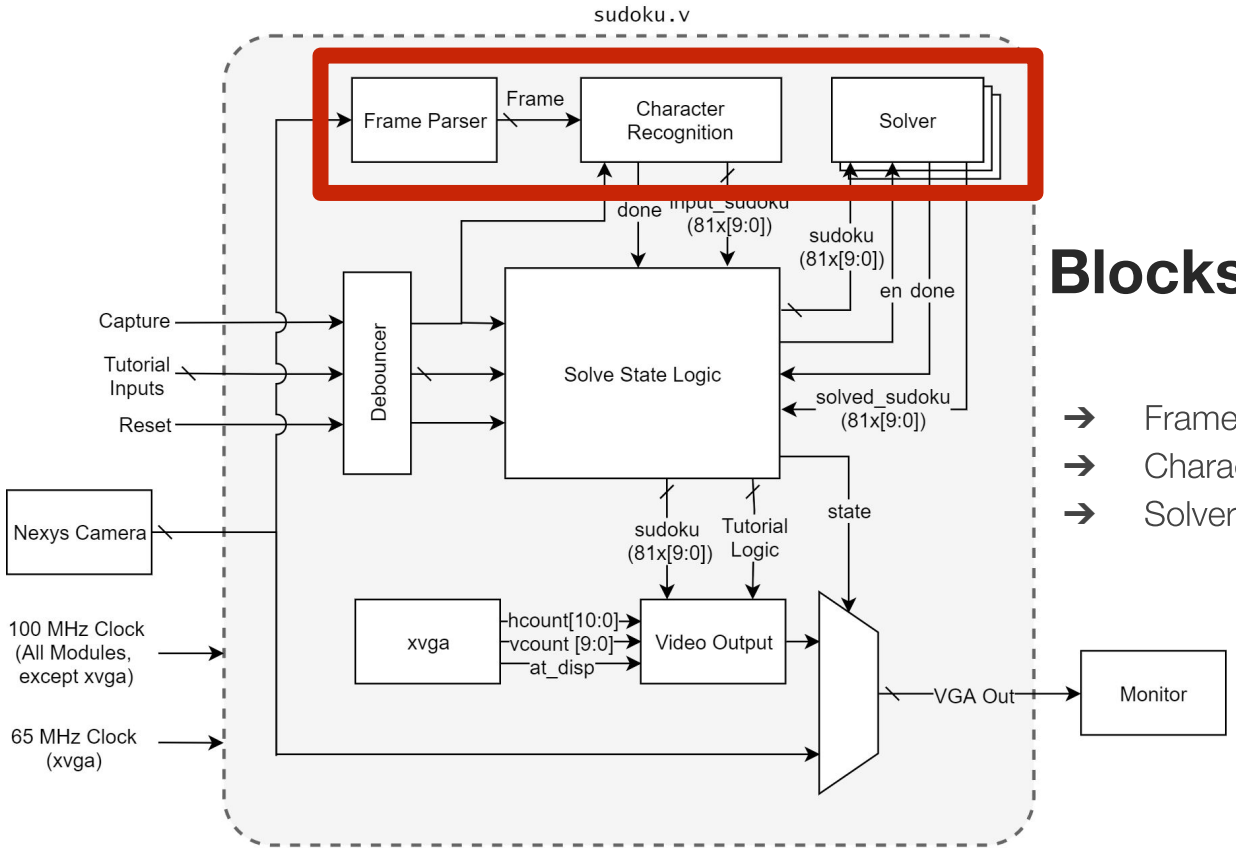
- ➔ Single position and single candidate
- ➔ Candidate line
- ➔ Hidden group
- ➔ Many more… (but only we have 8 minutes)

Goals

- ➔ Solve Sudoku using human techniques
- ➔ Read Sudoku using a camera
- ➔ Stretch Goal: include a tutorial mode which displays the steps for any solve



Block Diagram



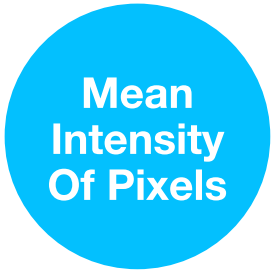
Blocks of Interest

- ➔ Frame Parser
- ➔ Character Recognition
- ➔ Solver

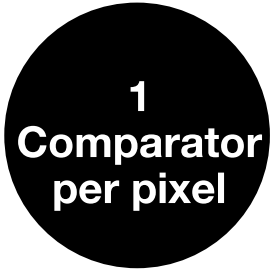
Frame Parsing

Reducing the number of gates for Character Recognition

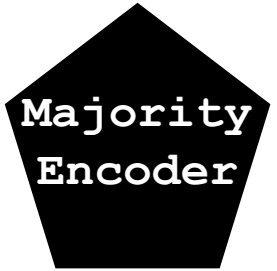
Calculate Threshold



Convert to Black and White



Resize



Character Recognition

Template Matching

Store flattened B/W values of #s

ROM size: 9× pixels/char (bits)

Compare with processed frames

9 XOR operations/cycle
9 result registers

Select

Comparison operation using LUTs

Solving a Sudoku

Keywords

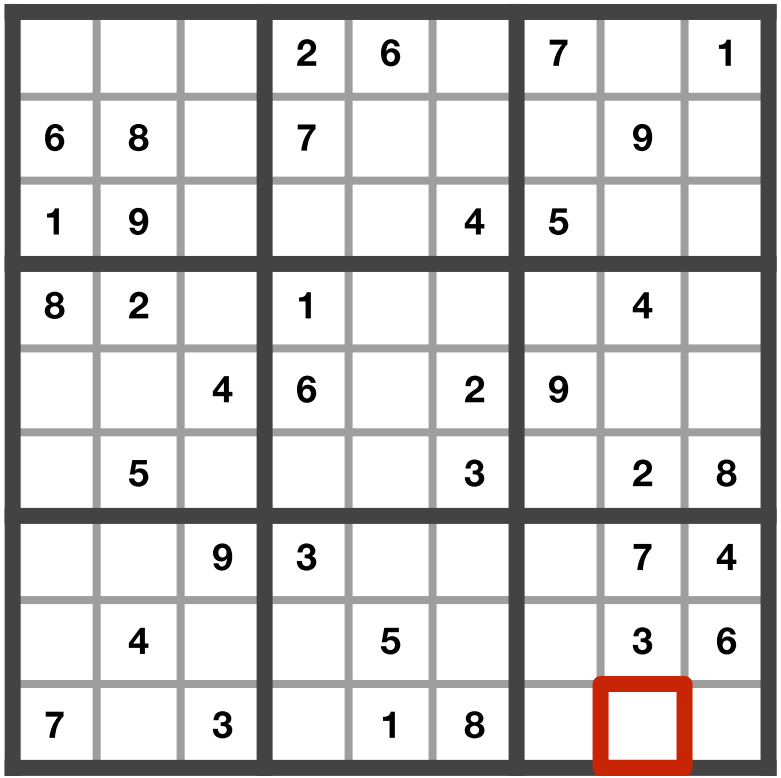
			2	6		7		1
6	8		7				9	
1	9				4	5		
8	2		1				4	
		4	6		2	9		
	5				3		2	8
		9	3				7	4
	4			5			3	6
7		3		1	8			

Squares

Rows

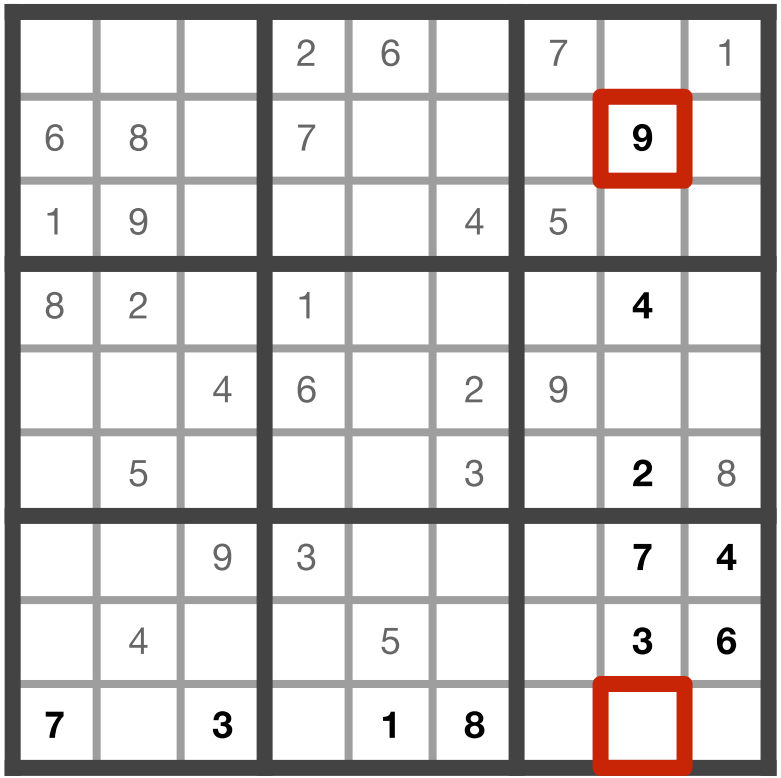
Columns

Single Candidate/Position



What can go here?

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



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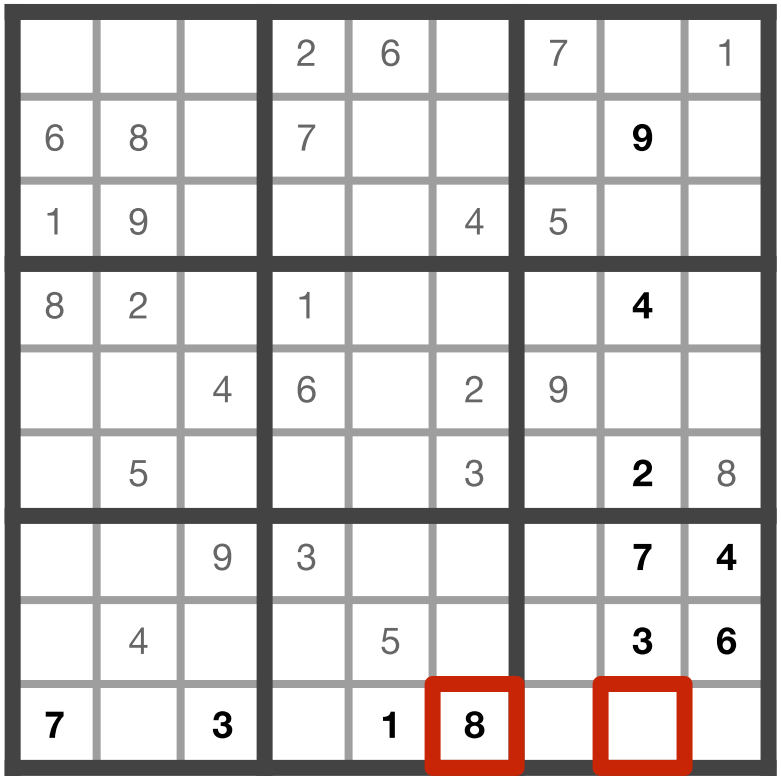

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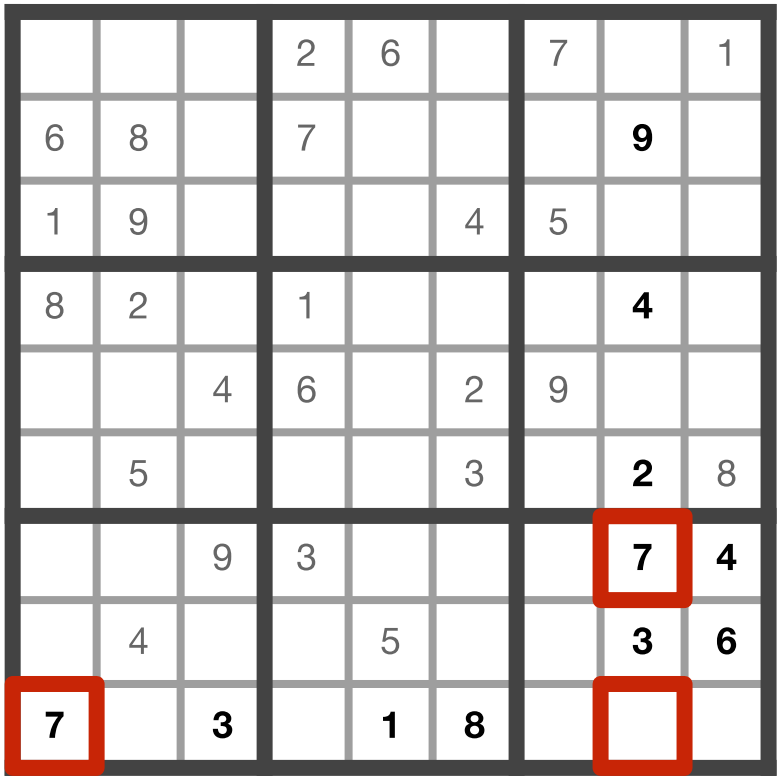

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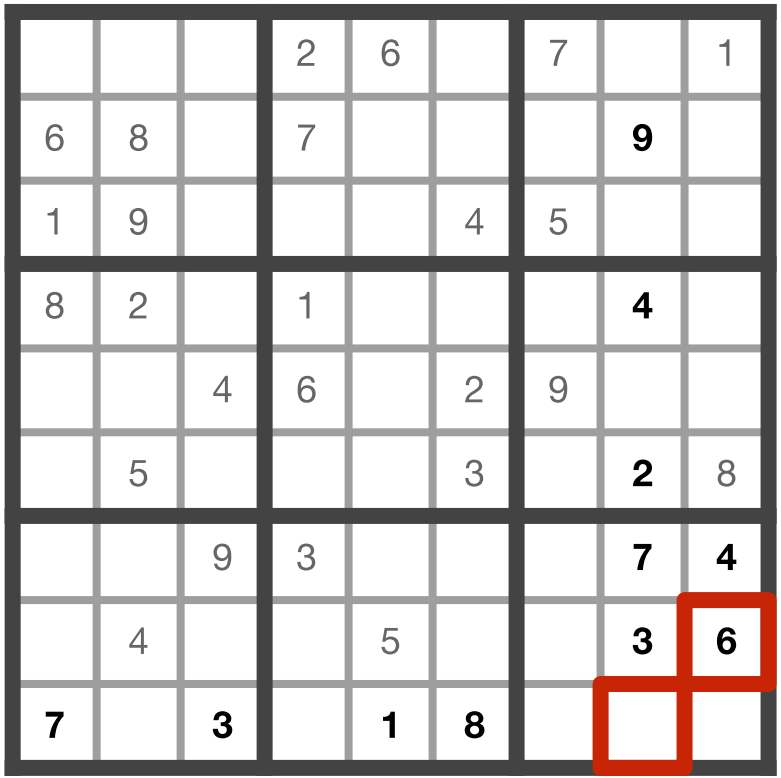

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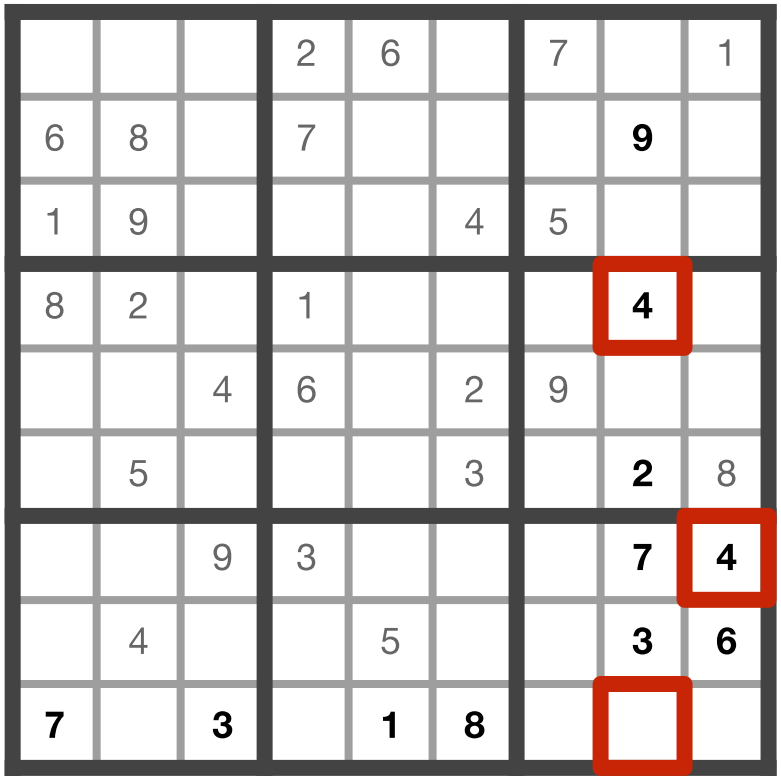

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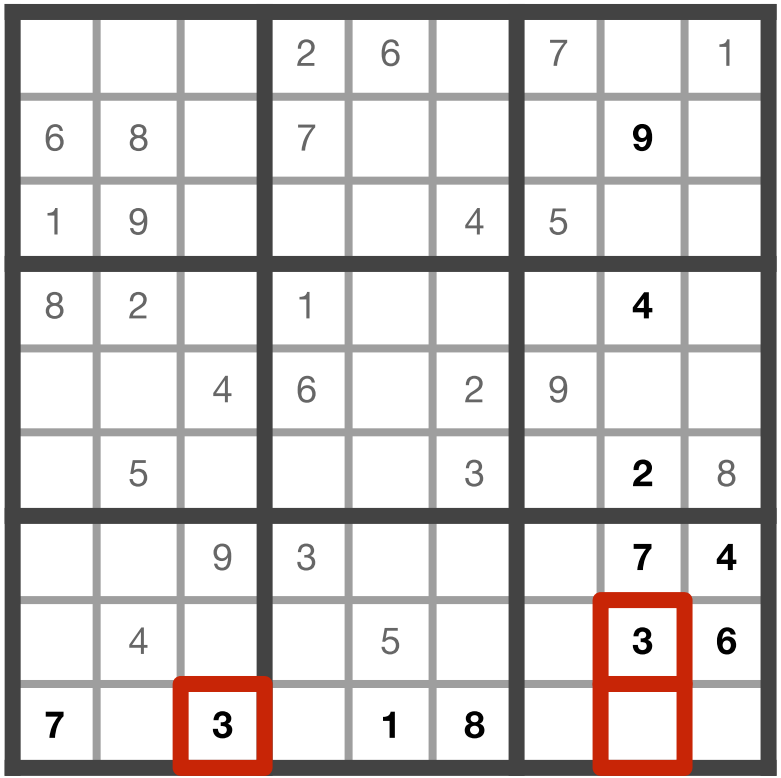
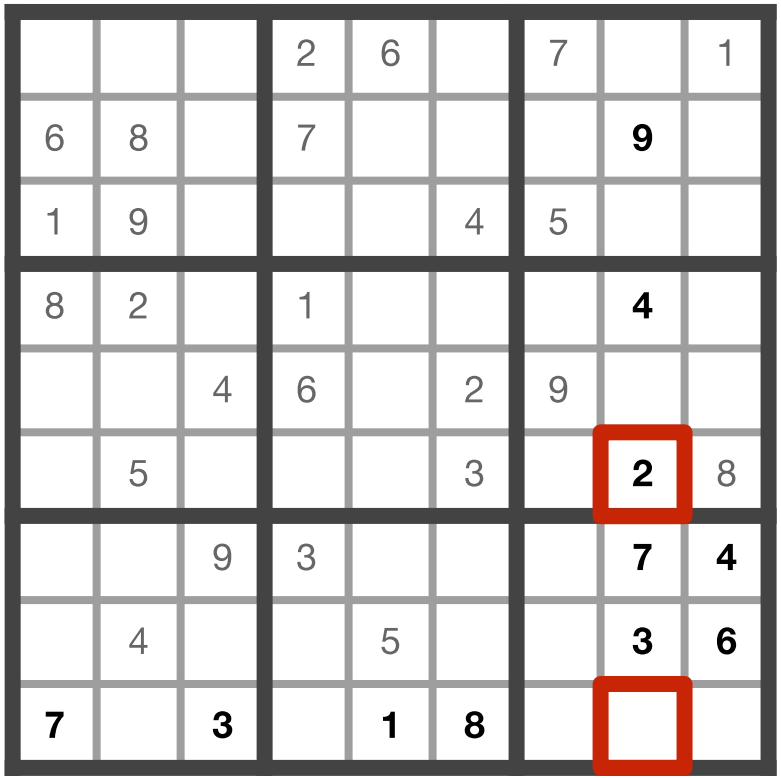


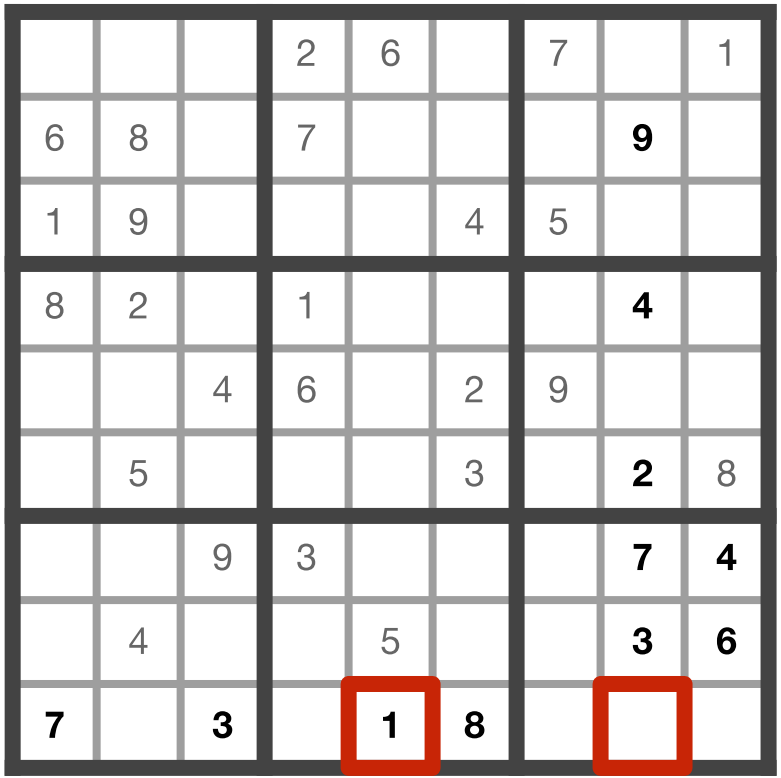
What can go here?

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



What can go here?

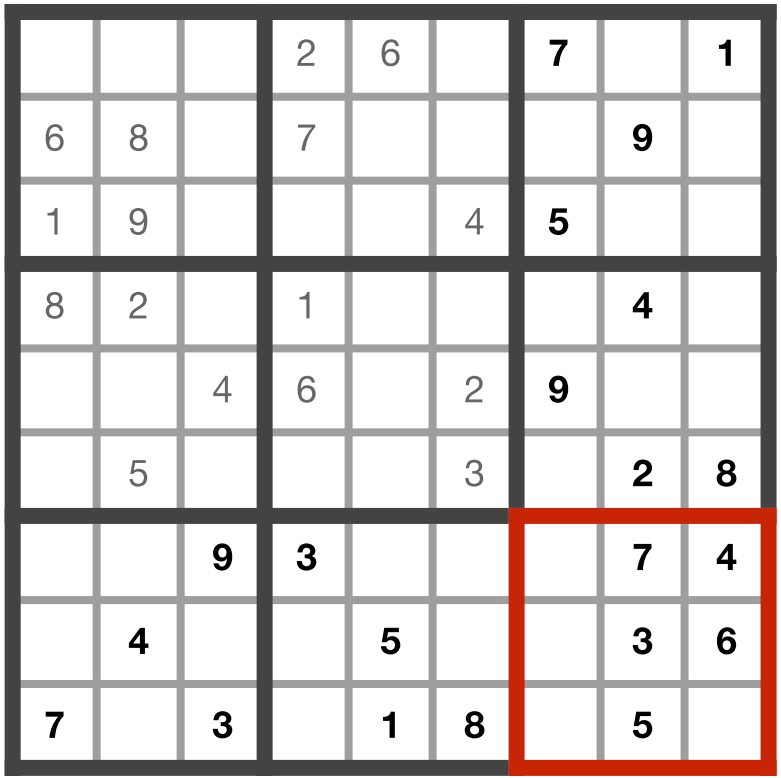
1,2,3,4,5,6,7,8,9



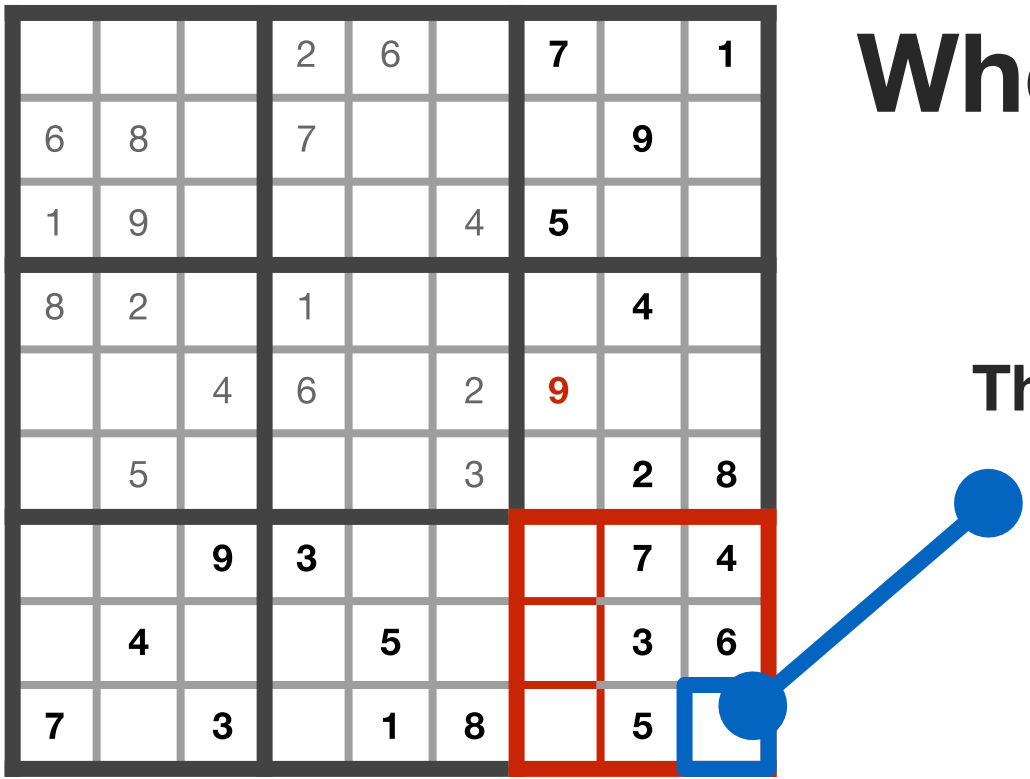
What can go here?

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

5 is the Single Candidate



Where can 9 go?



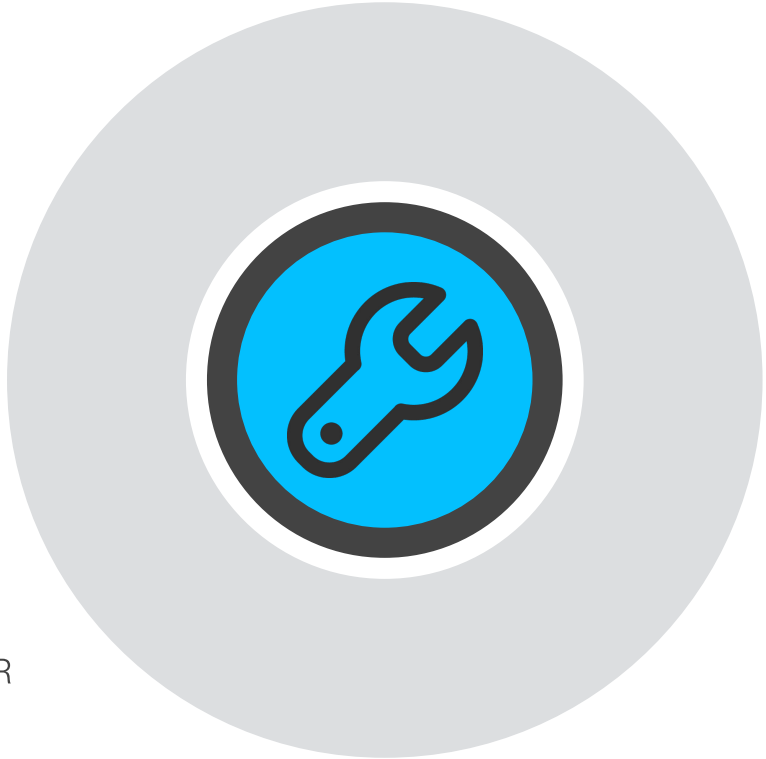
Where can 9 go?

This is the Single Position

How can a bunch of gates do Sudoku?

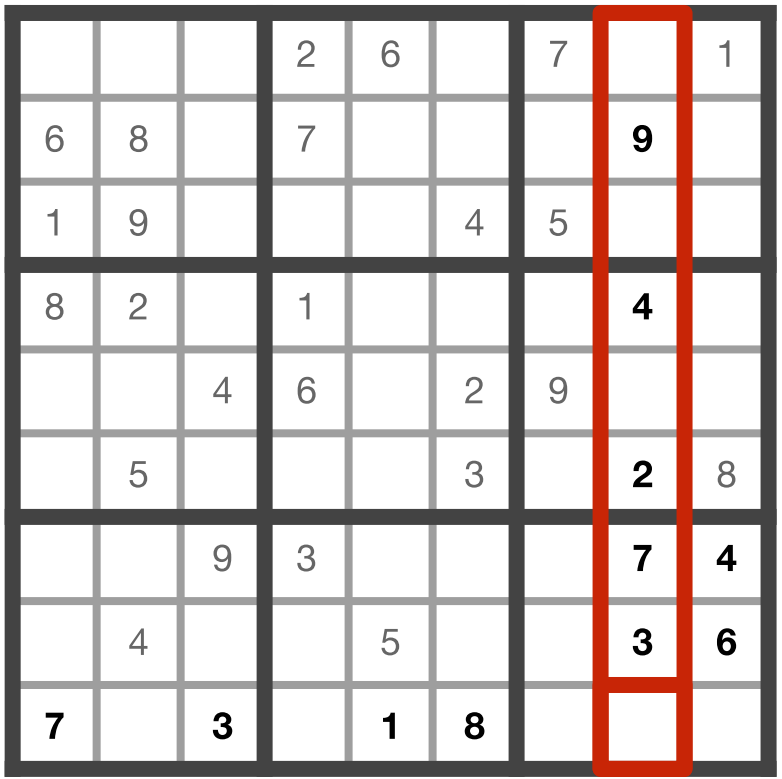
One-hot Representation

- ➔ Simplifies logic significantly
- ➔ Empty Cells = 0
- ➔ Determining single candidates is a simple AND operation with masks of possible values
- ➔ Determining single positions is a NOR and AND operation between masks



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

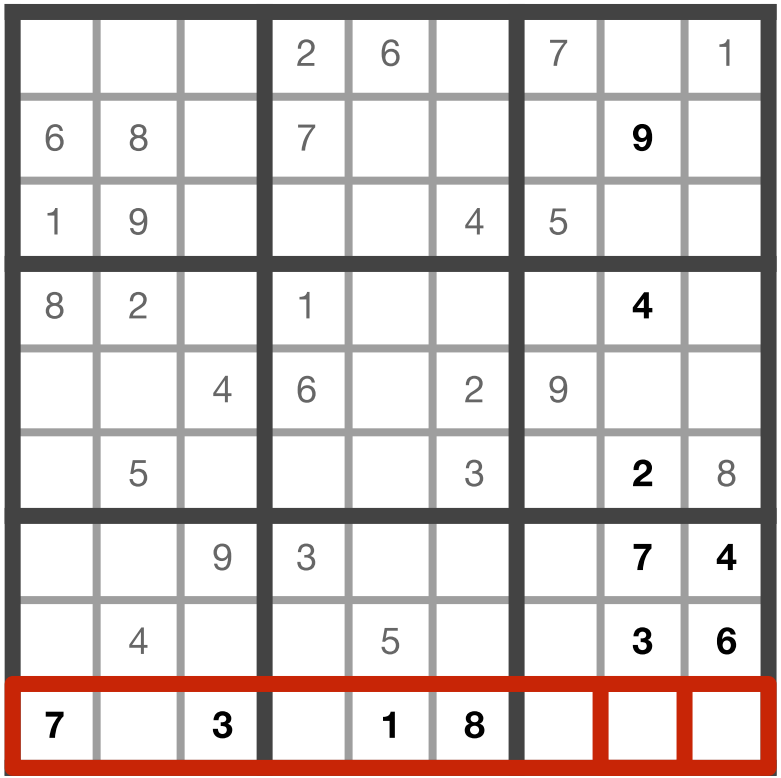
What can go here?



What can go here?

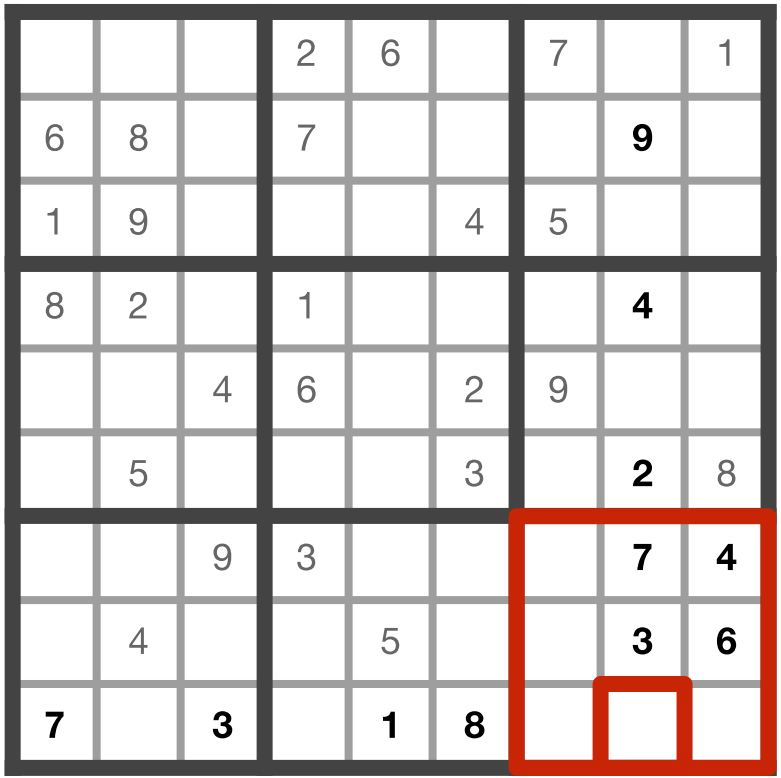
```
    987654321
9= 100000000
4= 000001000
2= 000000010
7= 001000000
3= 000000100
|= 101001110
~= 010110001
```

8,6,5 or 1



What can go here?

```
    987654321
7=  001000000
3=  000000100
1=  000000001
8=  010000000
|=  011000101
~=  100111010   not 1 and not 8
 &  010110001
=   000110000
```



What can go here?

```
    987654321
7=  001000000
4=  000001000
3=  000000100
6=  000100000
|=  001101100
~=  110010011
 &  000110000
```

Must be a 5

Hidden Group Setup

- ➔ Suppose we have **N** numbers which can **only** be placed in **N** positions
- ➔ Then **all N positions must contain one of the N numbers**.

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

What can't go here?

The empty cells contain the possible values:

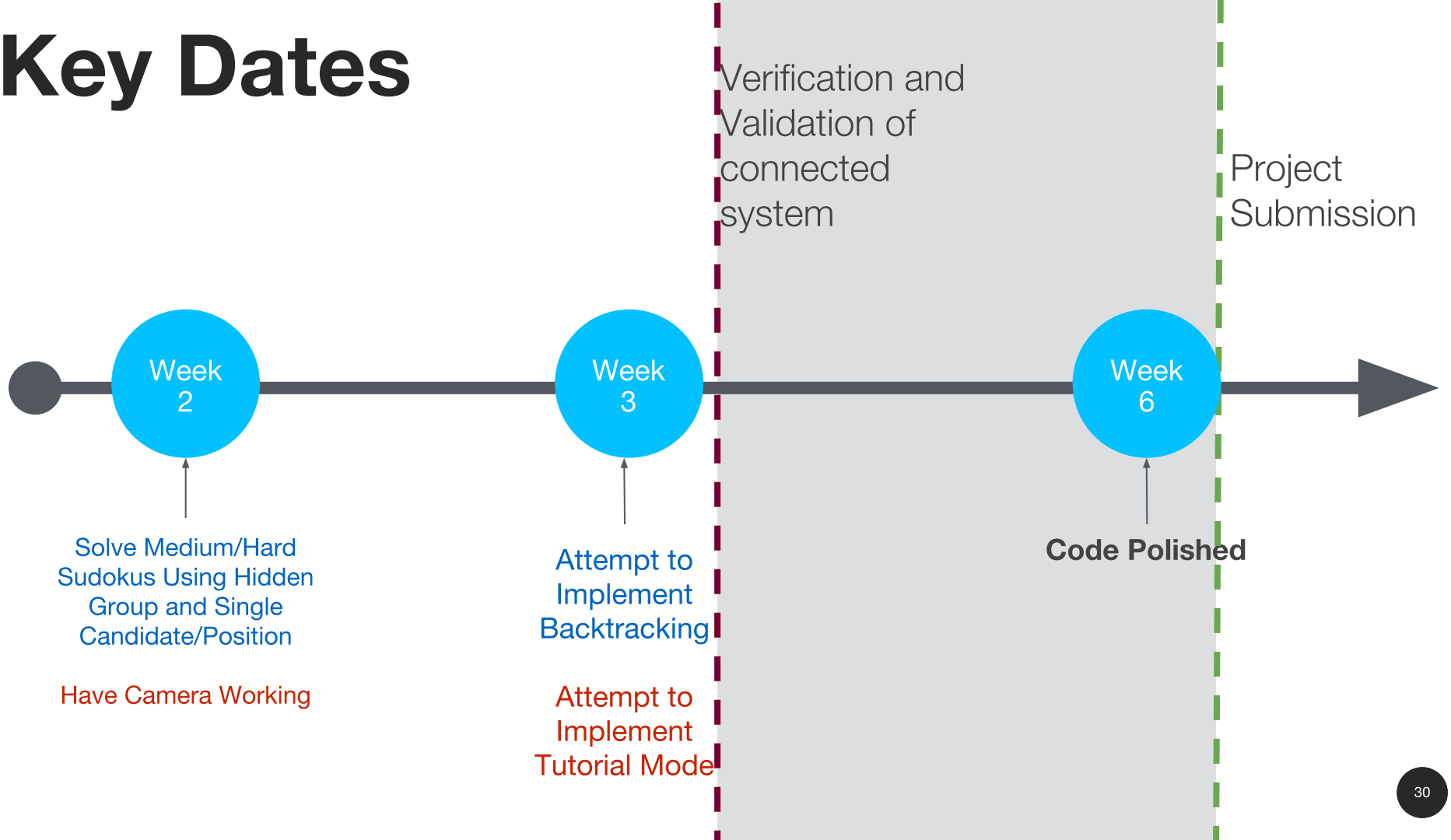
{4,9}
{4,6}
{2,4}
{1,3}
{2,6}
{1,2,3} -> {1,3}

We have only 2 places where 1 and 3 can go, so it is impossible for 2 to be in the last cell

The digital algorithm very cool! The Q&A is coming up *wink* *wink*

Project Timeline

Key Dates


Verification and Validation of connected system
Project Submission
Week 2
Week 3
Week 6
Solve Medium/Hard Sudokus Using Hidden Group and Single Candidate/Position
Have Camera Working
Attempt to Implement Backtracking
Attempt to Implement Tutorial Mode
Code Polished

Thank you for your attention

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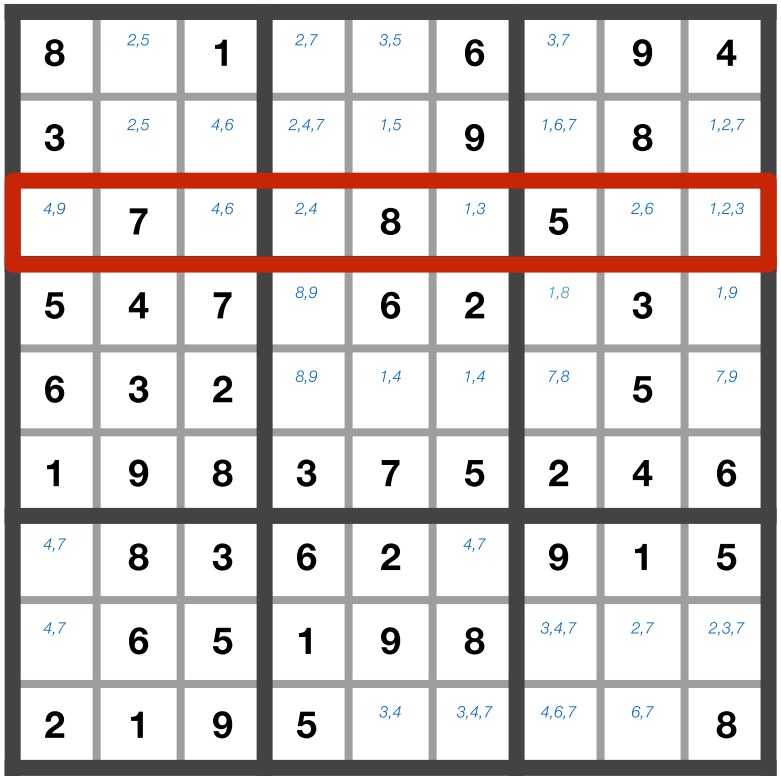


What can't go here?

The empty cells contain the possible values: 987654321

{4,9} = 100001000

{4,6} = 000101000

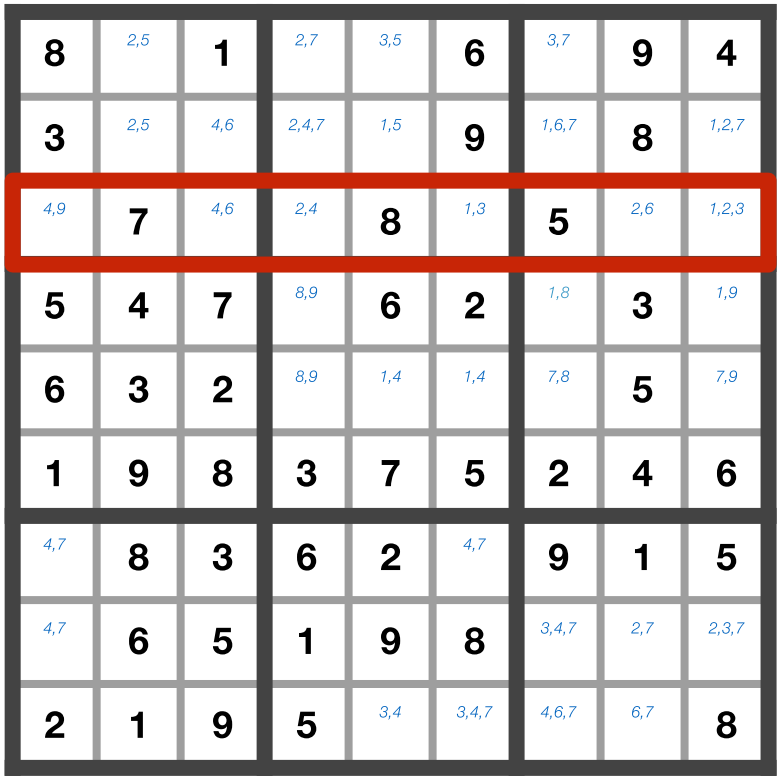
{2,4} = 000001010

{1,3} = 000000101

{2,6} = 000100010

{1,2,3} = 000000111

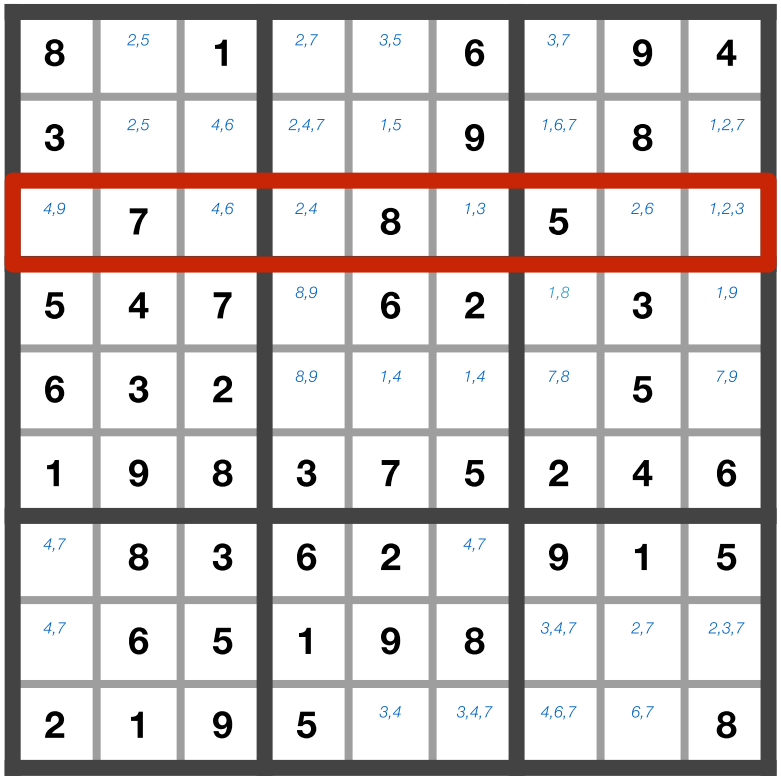
In this algorithm we iterate over each set



What can't go here?

Steps*

- ➔ Add up the number of 1s of the mask we are working on (let's call the number of 1s ***X*** and the mask we are working on ***Y***).
- ➔ AND mask ***Y*** with every other possibilities mask (this includes the ones that are solved, though **these always give 0**). Let us call the results of the AND operations ***A***.
- ➔ If the number of 0s in ***A*** are equal to (`9-X`) then a **hidden group** is detected
- ➔ If the number of masks in ***A*** with (# of 1s = ***X***) is equal to (`X-1`) a **naked group** exists between the ***Y*** and the masks in these positions.
- ➔ For every mask in the **hidden group**, replace it with the mask stored in ***A***. For every mask outside the **naked group** replace the mask with (`mask & ~Y`).



What can't go here?

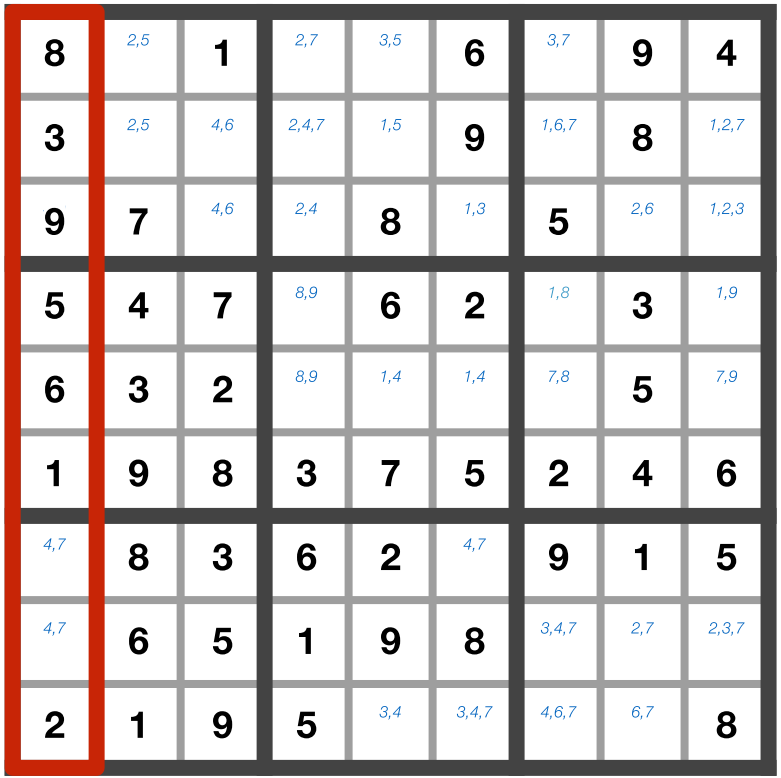
The empty cells contain the possible values:

```
                987654321   A:987654321
{4,9}   =       100001000   ->000000000
{4,6}   =       000101000   ->000000000
{2,4}   =       000001010   ->000000000
{1,3}   =       000000101   = Y
{2,6}   =       000100010   ->000000000
{1,2,3} =       000000111   ->000000101
X = 2,
Number of masks = 0 in A = 4 + 3
Number of masks with   2×1s = 1
```

*This method works for all hidden pairs and the vast majority of other worthwhile group sizes

Naked Group Setup

- ➔ Suppose we have **N** numbers which are the **only** possible values for **N** positions
- ➔ Then **all N positions must contain one of the N numbers. No other position in the row/column/square can contain the N numbers.**



What can't go here?

The empty cells contain the possible values:

```
987654321 A: 987654321
{4,9} =    100001000 -> 000001000
{4,7} =    001001000 =  Y
{4,7} =    001001000 -> 001001000
X = 2,~Y =110110111
Number of masks = 0 in A = 0 + 6
Number of masks with   2×1s = 1
```

The 3rd cell must be a 9