Scanner

Selected Fun Problems of the ACM Programming Contest SS25

04.06.2025

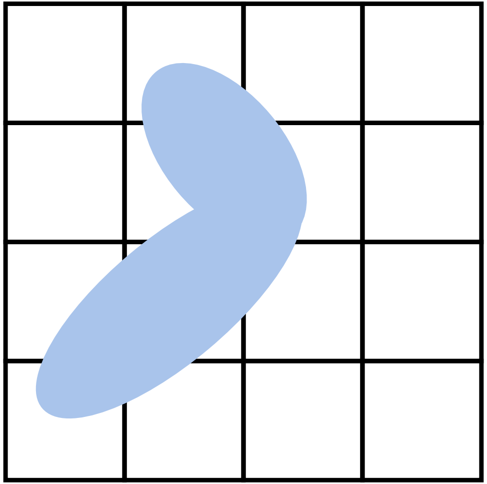
David Knöpp

About questions

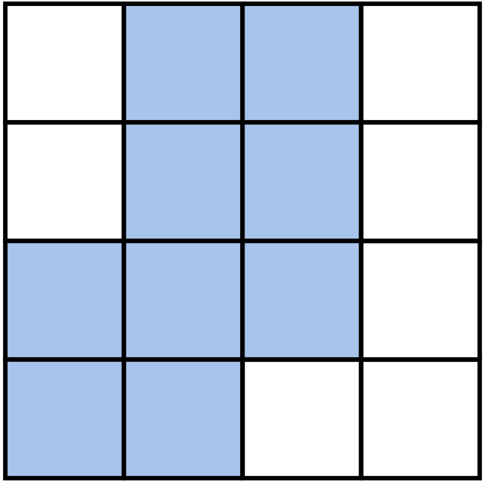
- Please ask questions if you do not understand an important aspect
- Otherwise, please save your questions for the discussion after the presentation

1 Problem Definition

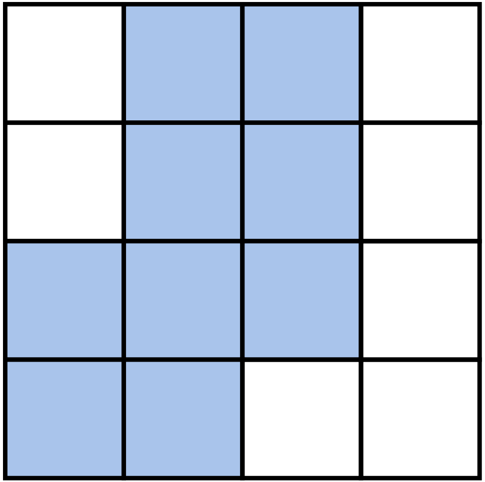
Result Matrix



Result Matrix



Result Matrix

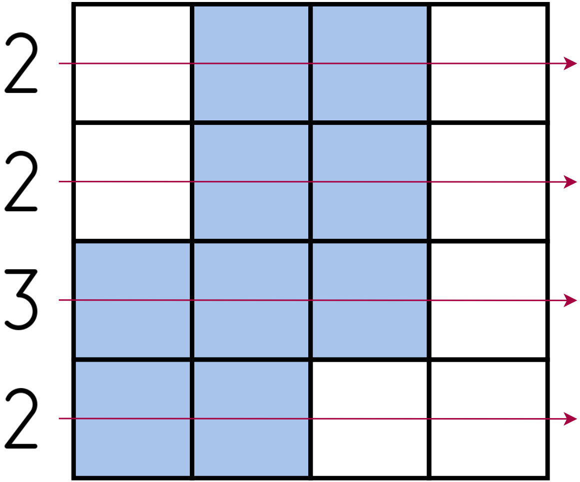


```
. # # .
. # # .
# # # .
# # . .
```

This is our actual output.

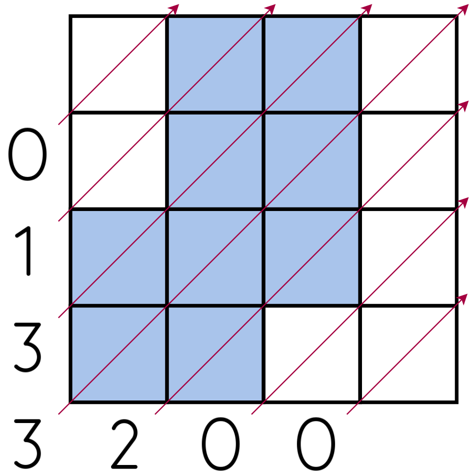
But what is our input?

Getting the input



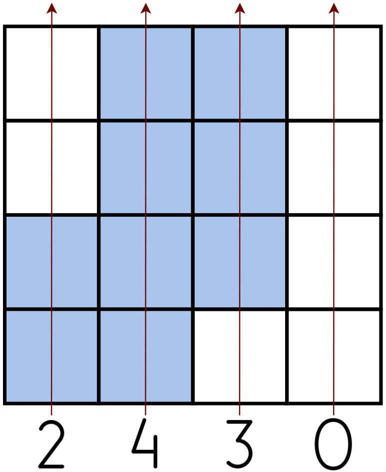
2 2 3 2

Getting the input



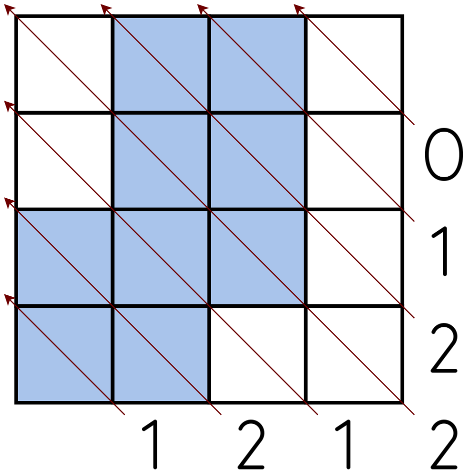

```
2 2 3 2
0 1 3 3 2 0 0
```

Getting the input




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

Getting the input

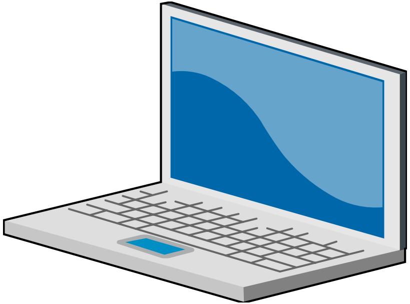



```
2 2 3 2
0 1 3 3 2 0 0
2 4 3 0
1 2 1 2 2 1 0
```

Getting the input


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

Live Demo

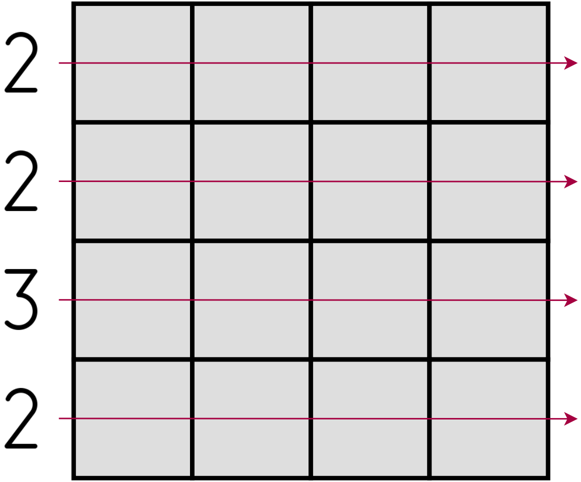


2 Solution

Tools

- Python
  - Personal experience
- Numpy
  - Convenient and efficient matrix operations
  - Personal experience

Example

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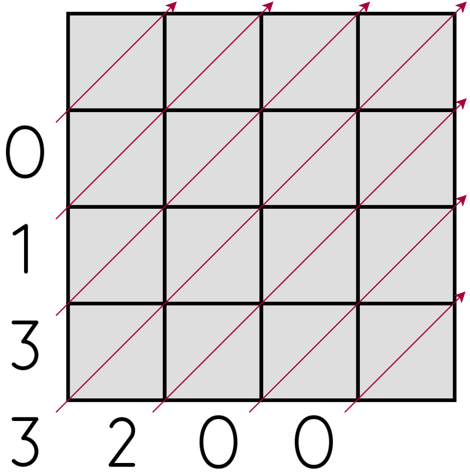

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1 2 1 2 2 1 0

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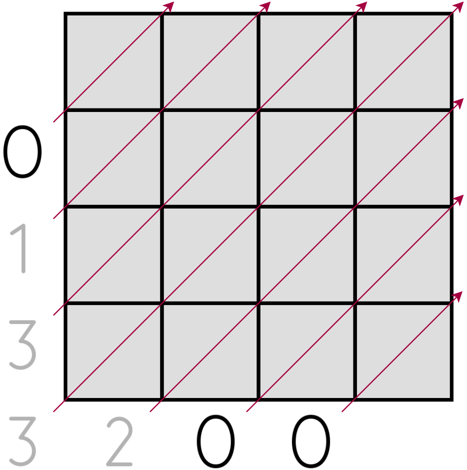


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```

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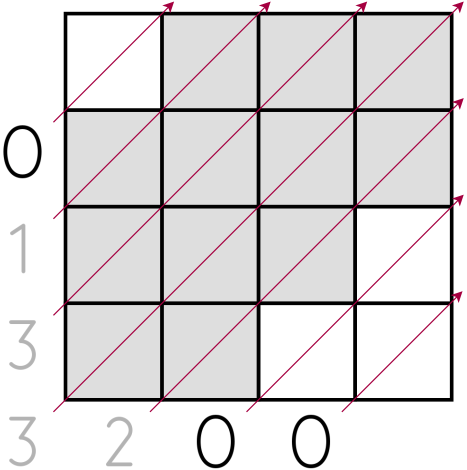

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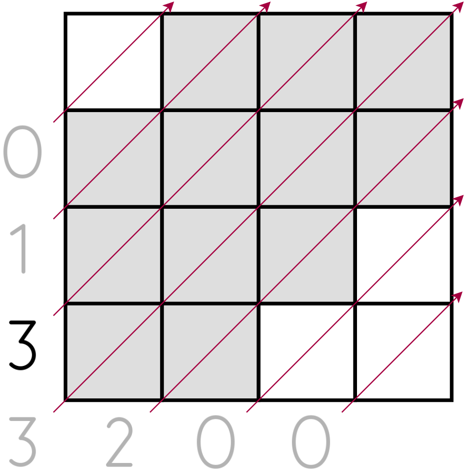

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1 2 1 2 2 1 0

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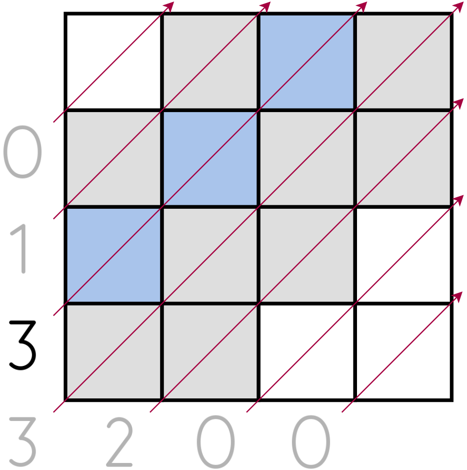


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1
2 2 3 2
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1 2 1 2 2 1 0
```

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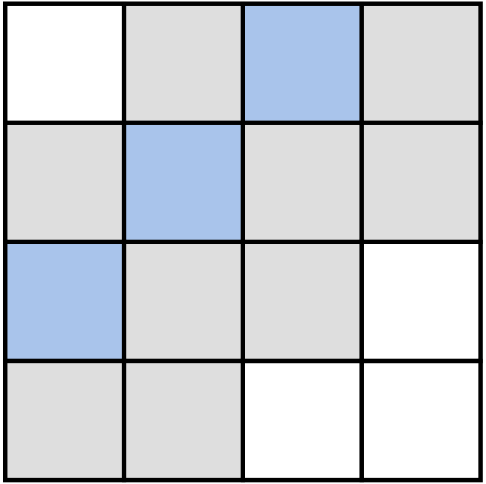

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2 2 3 2
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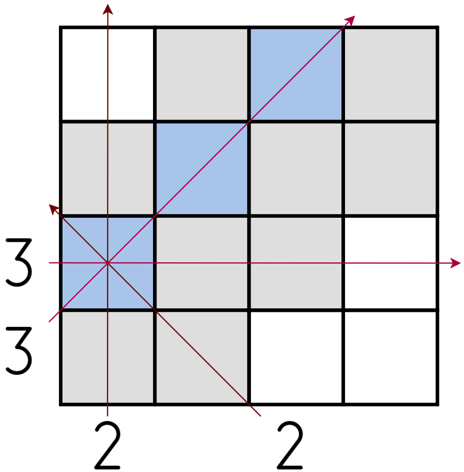
```

Example



1

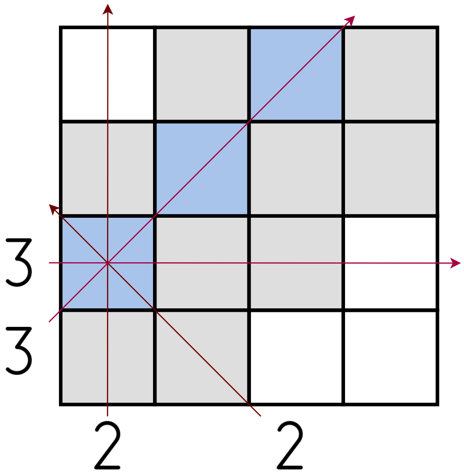
2 2 3 2

0 1 3 3 2 0 0

2 4 3 0

1 2 1 2 2 1 0

Example

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```
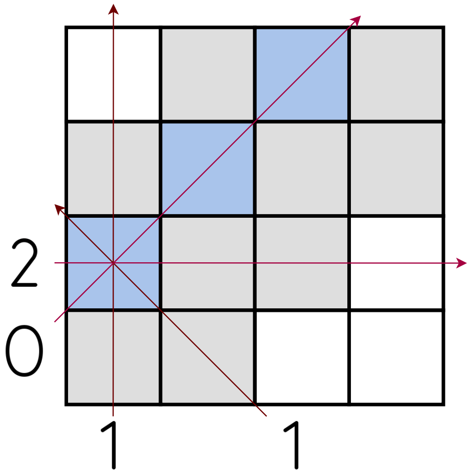

Example



1

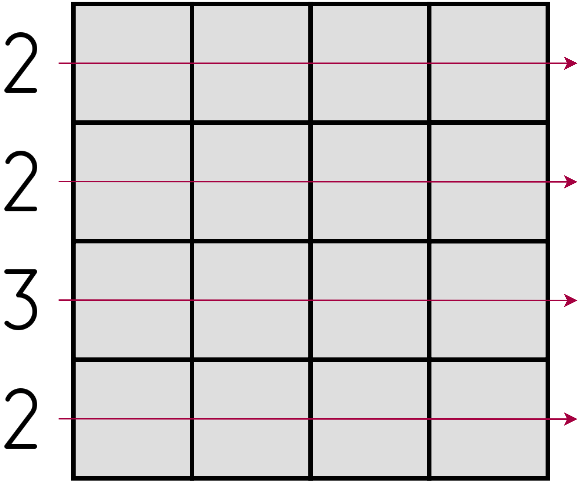
1 1 2 2

0 1 0 3 2 0 0

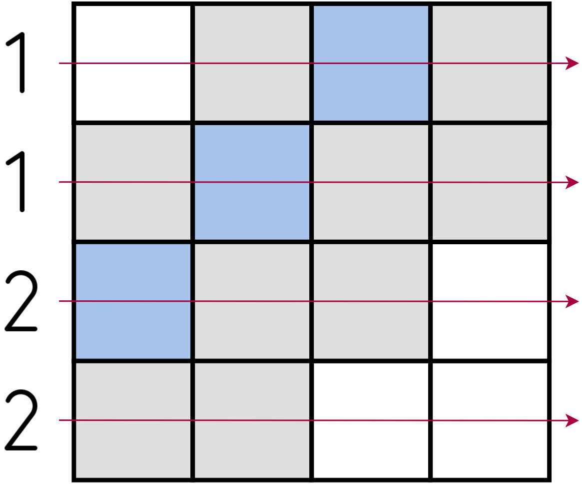
1 3 2 0

1 1 1 1 2 0 0

Example

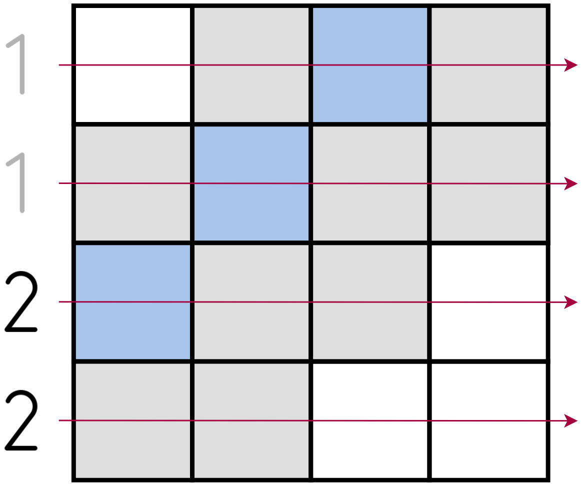


Example




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

Example



1

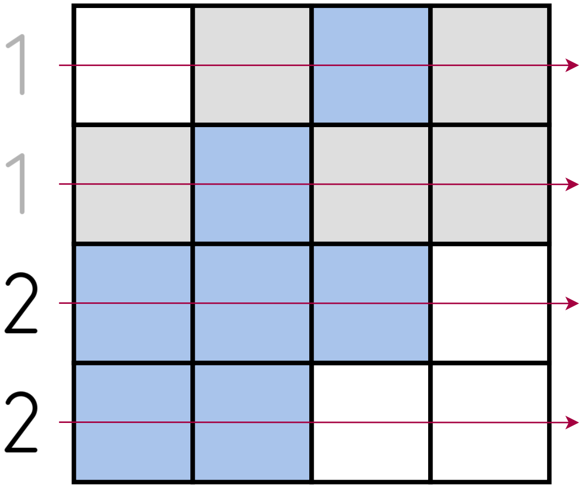
1 1 2 2

0 1 0 3 2 0 0

1 3 2 0

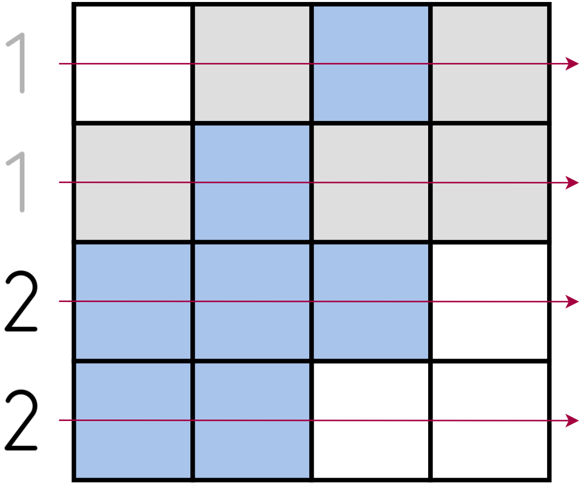
1 1 1 1 2 0 0

Example




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

Example



1

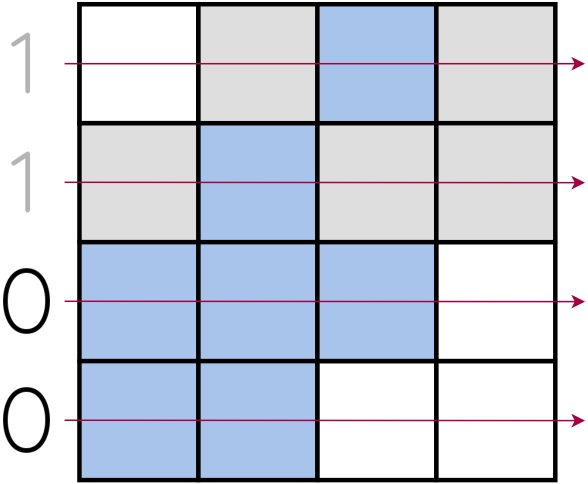
1 1 2 2

0 1 0 3 2 0 0

1 3 2 0

1 1 1 1 2 0 0

Example



1

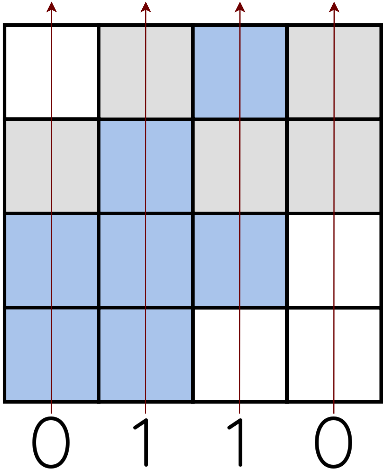
1 1 0 0

0 1 0 1 0 0 0

0 1 1 0

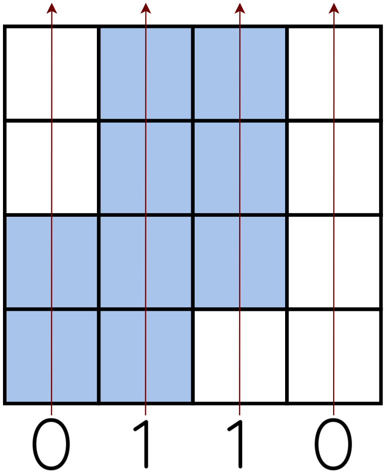
0 0 0 0 2 0 0

Example



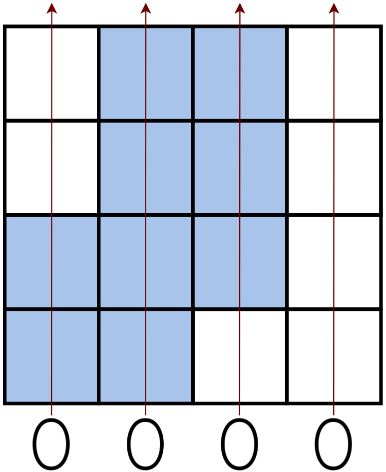

```
1
1 1 0 0
0 1 0 1 0 0 0
0 1 1 0
0 0 0 0 2 0 0
```

Example




```
1
1 1 0 0
0 1 0 1 0 0 0
0 1 1 0
0 0 0 0 2 0 0
```

Example



1

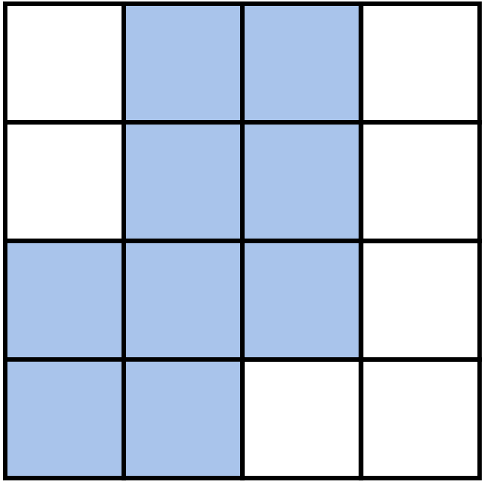
0 0 0 0

0 0 0 0 0 0 0

0 0 0 0

0 0 0 0 0 0 0

Example



```
1
0 0 0 0
0 0 0 0 0 0 0
0 0 0 0
0 0 0 0 0 0 0
```

Fill known cells


```
def compare_and_fill(sensor_data_point, arr):
        # number of unassigned elements
        n_of_unassigned = n_of_unassigned(arr)

        # Declare all unassigned as empty
        if sensor_data_point == 0:
            for cell in arr:
                if cell == UNASSIGNED:
                    cell = EMPTY

        # Declare all unassigned as full
        elif sensor_data_point == n_of_unassigned:
            for cell in arr:
                if cell == UNASSIGNED:
                    cell = FULL
                    update_sensor_data(cell.x, cell.y)
```

Main Loop


```
while(not is_done()):
            diag_lr = get_diagonal_lr(matrix)
            diag_rl = get_diagonal_rl(matrix)

            # Horizontals
            for i in range(height):
                compare_and_fill(sensor_data_horizontal[i], matrix[i,:])
            # LR-Diags
            for i in range(height + width - 1):
                compare_and_fill(sensor_data_diagonal_lr[i], diag_lr[i])
            # Verticals
            for i in range(width):
                compare_and_fill(sensor_data_vertical[i], matrix[:,i])
            # RL-Diags
            for i in range(height + width - 1):
                compare_and_fill(sensor_data_diagonal_rl[i], diag_rl[i])
```

Are we done?

- Does `compare_and_fill` always find a solution?
- What if there is no solution?
- What if there are multiple solutions?

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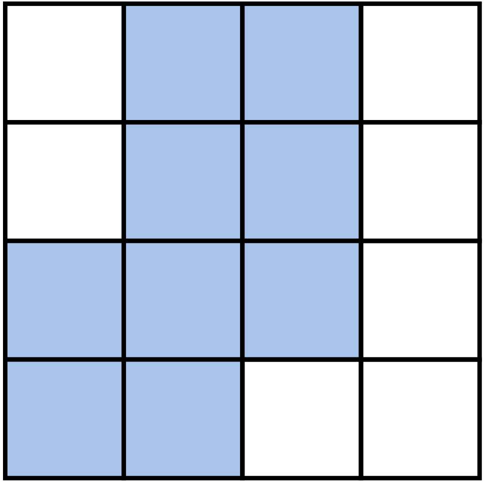
Let’s first answer a different question:

- How do we know whether we found a solution?

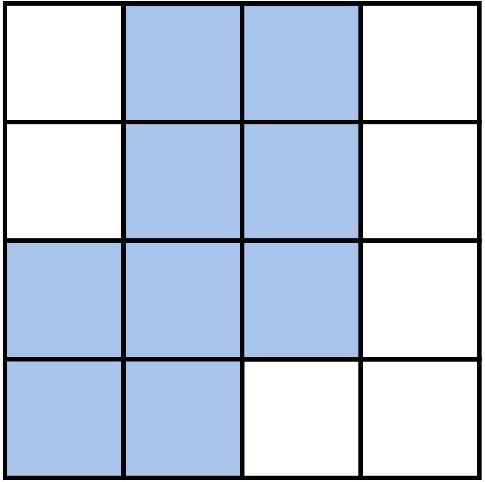
How do we know whether we found a solution?



```
1
0 0 0 0
0 0 0 0 0 0 0
0 0 0 0
0 0 0 0 0 0 0
```

All input_datas-entries are zero

Invalid state



```
1
0 0 0 0
0 0 0 0 0 0 0
0 1 0 0
0 0 0 0 0 0 0
```

Every cell is assigned, but there is one input_data-entry left!

$\Rightarrow$ contradiction

Termination Condition

1. Check whether all `input_data` is zero

```
def is_data_used(sensor_data):
        return not np.any(sensor_data != 0)
```

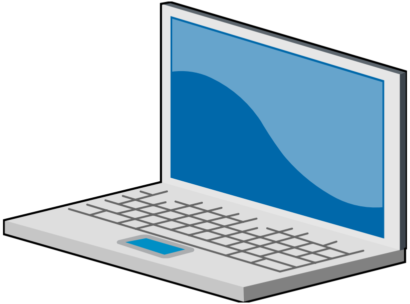
2. Check whether all cells are assigned

```
def is_all_assigned(matrix):
        return not np.any(matrix.cell == UNASSIGNED)
```

3. Check whether we are done

```
def is_done():
        return is_data_used(sensor_data) or is_all_assigned(matrix)
```

Demo: No Solution



Multiple solutions

- We assign `EMPTY` or `FULL` **only if** we know a state for certain
- $\Rightarrow$ with `compare_and_fill`, we can only detect **single** solutions
- If multiple solutions exist for a given input $\Rightarrow$ get stuck

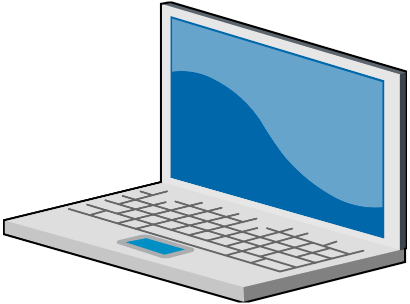
Multiple Solutions: Local Search


```python
# value is either FULL or EMPTY
def search_in_branch(idx, value, matrix, sensor_data):
        # save old data
        old_matrix = matrix.copy()
        old_sensor_data = sensor_data.copy()

        # assign variable
        matrix[idx] = value
        if value == FULL:
            update_sensor_data(idx[1], idx[0])
        fill_loop()

        # re-assign old data
        matrix = old_matrix
        sensor_data = old_sensor_data
```

Multiple Solutions: Local Search


```
# ... inside fill_loop()
if not has_change_occured:
            # indices of unassigned fields
            indices_of_unassigned = np.argwhere(matrix.cell == UNASSIGNED)

            for idx in indices_of_unassigned:
                # recursive calls
                for assignment in [EMPTY, FULL]:
                    search_in_branch(idx, value, matrix, sensor_data)
                    if solutions_found > 1:
                        # the solution is ambiguous -> leave loop
                        return
```

Demo: Local Search



Conclusion

Does the algorithm always find a solution?

Answer: If it exists: Yes! But…

- … we can get stuck $\Rightarrow$ perform local search

What if there is no solution?

Answer: Data will be contradictory

What if there are multiple solutions?

Answer: We get stuck $\Rightarrow$ perform local search

3 Discussion

Time Complexity

- Take a matrix of dimension $(n \times m)$
- Worst case: Local search from the beginning
- Worst case time complexity: $\mathcal{O}(2^{n \cdot m})$

Time Complexity: Using matrix property

- Problem Definition: **Body** Scanner
- ⇒ Matrix property: Most `FULL` cells are neighbored

```
. . . . . . . . . . . . . . .
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. . . . . . . . . # # # . . .
. . . . . . . . . . # . . . .
```
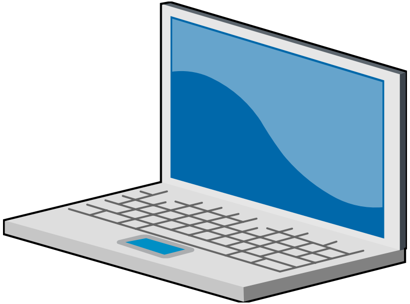

- `compare_and_fill` uses this property.
- Reduces search-space significantly.

Demo: Chunk Inputs



Algorithm Justification

Experiment:

1. Generate 10000 inputs of dimension (10×15)
2. Run `scanner.py`: Abort after $t_{\text{max}} = 0.01s$
3. Measure number of timeouts

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Results:

matrix type	timeout-rate
random	99.69%
chunk	1.47%

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Results:

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random	99.69%
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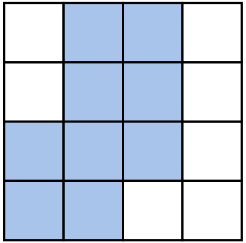
$\Rightarrow$ Most inputs can be solved in sub-exponential time!

Summary

Input:

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

Output:



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