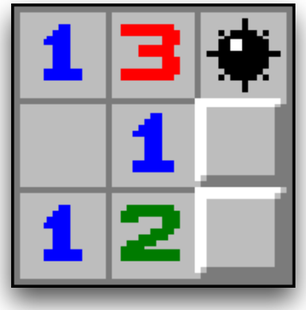


Minesweeper AI

Using Logic Inference, CSP and CNN Approaches

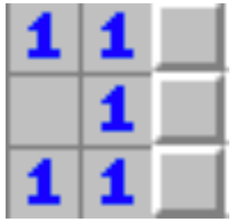
Chenyang Zhang, Chunxu Guo, Jiahao Huang, Qianyu Liu, Tianyi Zhang

Team 4

Problem Statement

Minesweeper AI

- **Two perspectives**
  - Deterministic: know where is a mine for sure—Inference
  - Non-deterministic: need to guess where is a mine—Probability
- **NP-Complete problem**
- **Goal**
  - Higher winning rate
  - Computational efficiency



Related Works

State of the Art

Related Works

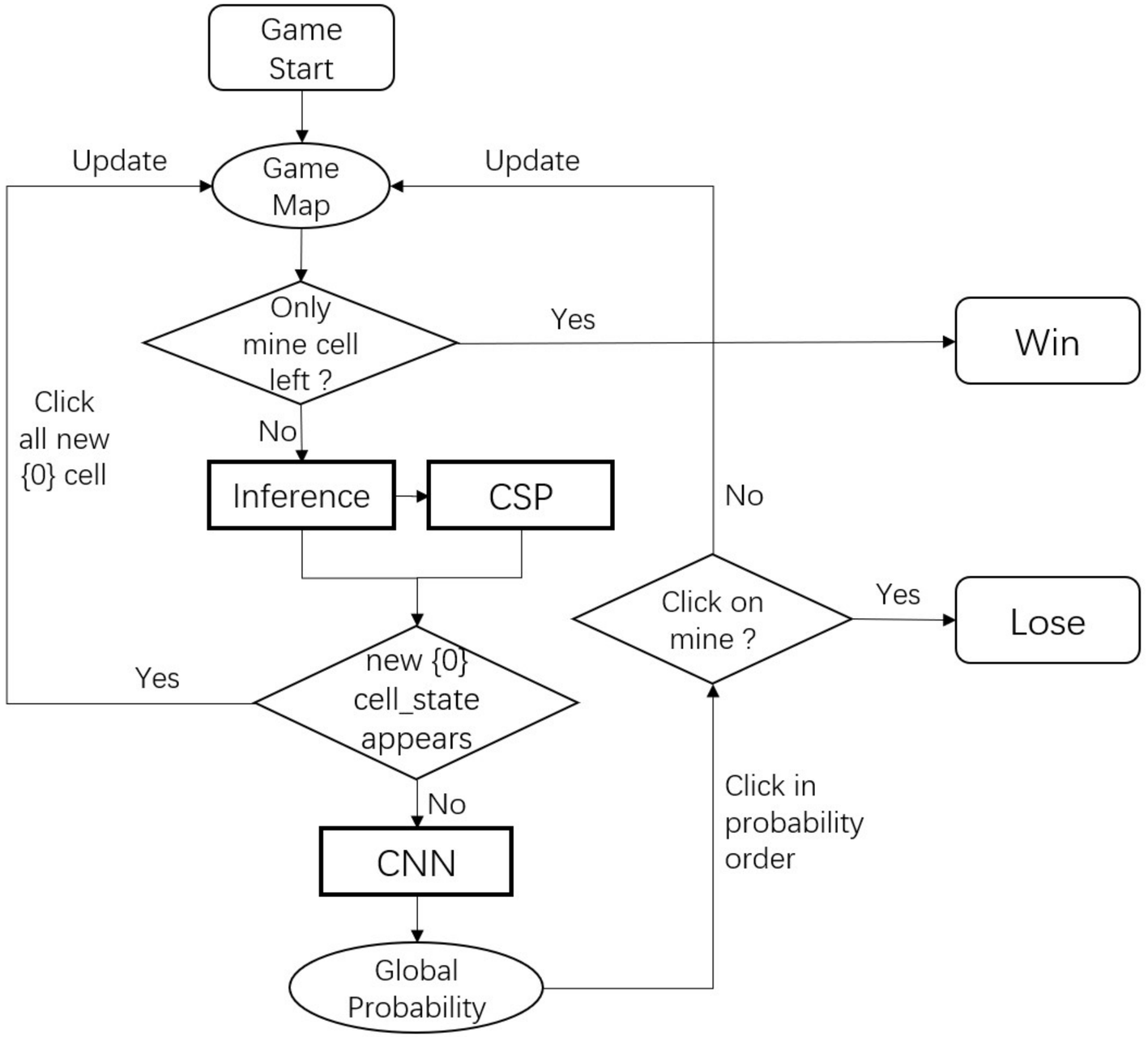
- **Logic**: SAT solver
  - Inference process is slow
- **Search**: CSP
- **RL**: Q Learning
  - Hard to define the state: too many states if use the whole map
  - Poor performance
- **Neural Network**: CNN

Approach

Pipeline

Approach

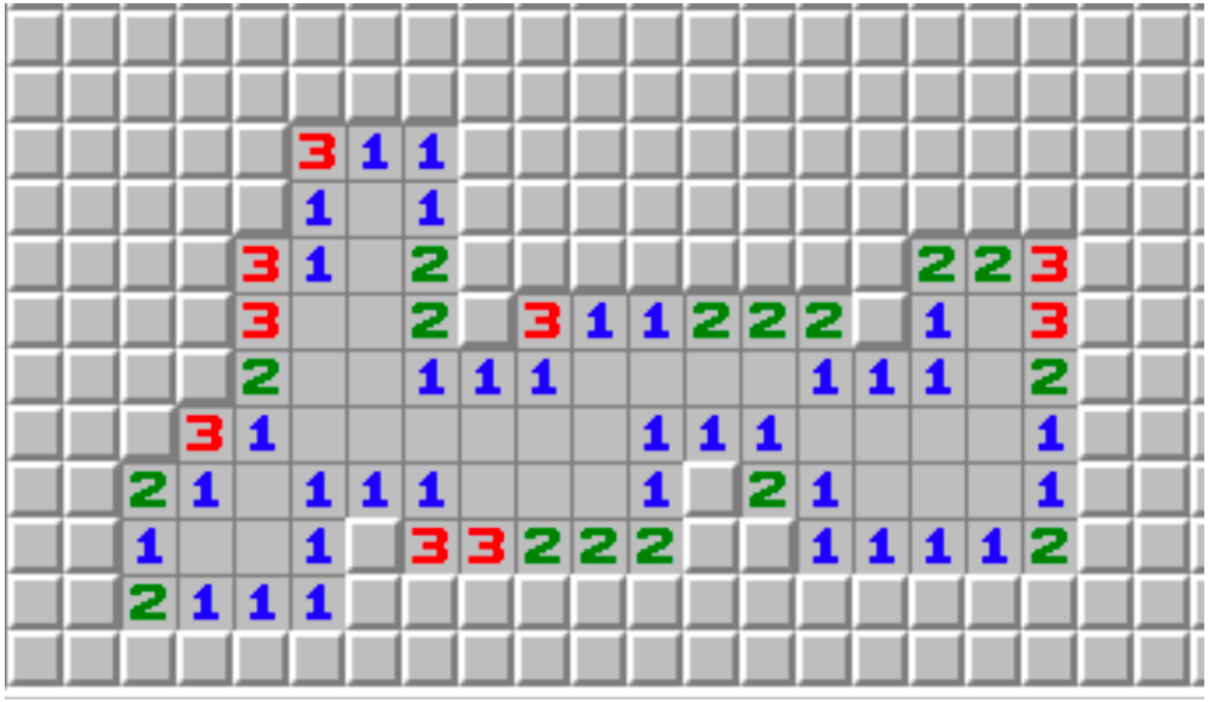
- **Logic Inference**
  - Fast & Accurate
- **CSP**
  - Complex Inference
- **CNN**
  - Global Probability



Stage 1: Logic Inference

Approach

- **Goal**: Fast and Accuracy check for deterministic case
- **Define 4 rules**
  - Flag
  - Revealing
  - Elimination
  - Confirmation



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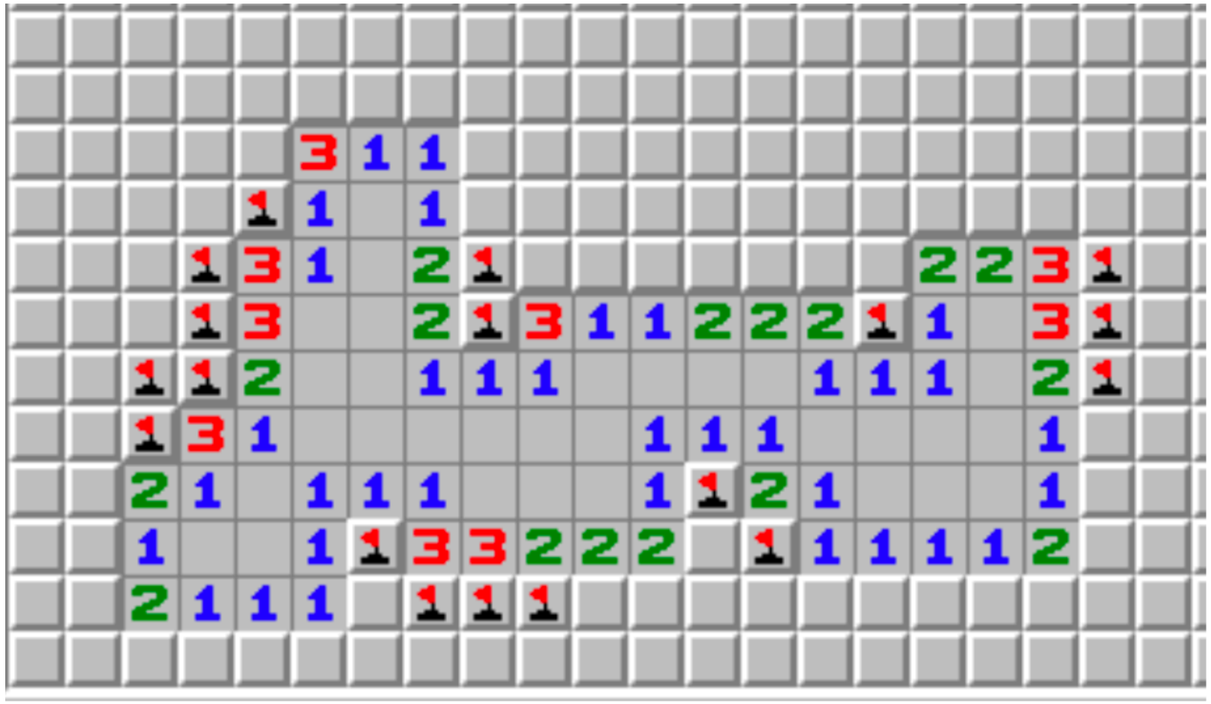


Stage 2: CSP

Approach

- **Goal**: find hidden <u>deterministic</u> cells
- **Method**:
  - Define *variables* and *constraints*
    - *variables*: for every cell, *v* = {0} (safe) or {1} (mine) or {0, 1} (both possible)
    - *constraints*: for every number, number = SUM(neighboring true values)
  - Basic solution: backtracking search
  - All variables start from state {0, 1}, and any state changes means new deterministic information

Stage 3: CNN

Approach

- **Goal**: handle non-deterministic case—Probability
- **Inspiration**:
  - 3x3 grid is of great importance in Minesweeper
  - Combining many convolutional layers with 3x3 kernels gives larger receptive field
  - We may find more global information using CNN

Stage 3: CNN

Approach

- **Net Architecture**:
  - 5 convolutional layers with 3x3 kernels
  - 3 fully connected layers
- **Training**:
  - Input: game state map, Output: mine probability map
  - Easy to train—not resource-consuming
  - Loss: only focus on the ‘edge’

Stage 3: CNN

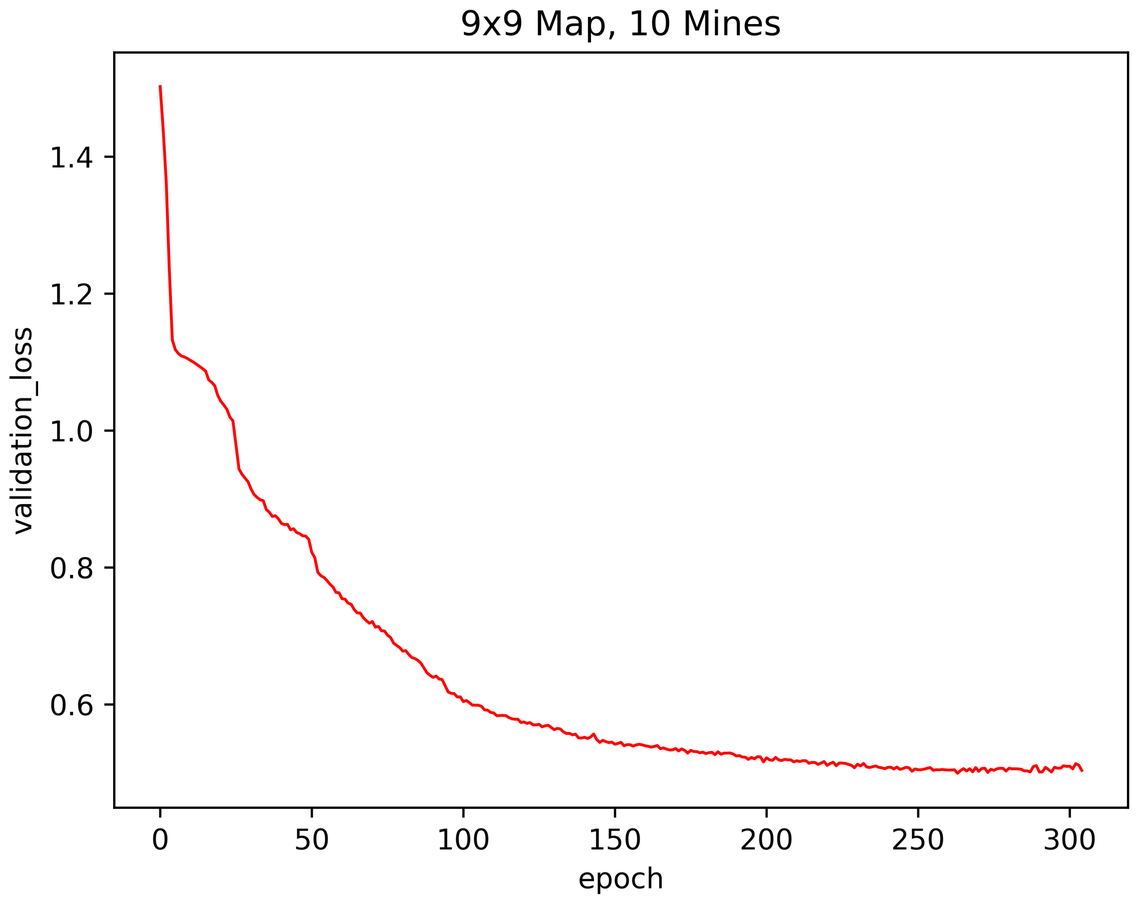
Approach

```
[-1., -1., -1., -1., -1., -1., -1., -1., -1.]
[-1., -1., -1., -1., -1., -1., -1., -1., -1.]
[-1., -1., -1., -1., -1.,  1., -1., -1., -1.]
[-1., -1.,  1., -1.,  2.,  1.,  1., -1., -1.]
[-1.,  2.,  2.,  1.,  1.,  0.,  1., -1., -1.]
[-1., -1.,  1.,  0.,  0.,  0.,  1., -1., -1.]
[ 1.,  1.,  1.,  0.,  0.,  0.,  1., -1., -1.]
[ 0.,  0.,  0.,  0.,  0.,  0.,  1.,  1., -1.]
[ 0.,  0.,  0.,  0.,  0.,  0.,  1., -1.,  1.]
```

Game State Map

```
[0., 0., 0., 0., 0., 0., 0., 0., 0.]
[0., 0., 0., 0., 1., 1., 1., 0., 0.]
[0., 1., 1., 1., 1., 0., 1., 1., 0.]
[1., 1., 0., 1., 0., 0., 0., 1., 0.]
[1., 0., 0., 0., 0., 0., 0., 1., 0.]
[1., 1., 0., 0., 0., 0., 0., 1., 0.]
[0., 0., 0., 0., 0., 0., 0., 1., 1.]
[0., 0., 0., 0., 0., 0., 0., 0., 1.]
[0., 0., 0., 0., 0., 0., 0., 1., 0.]
```

Edge Map



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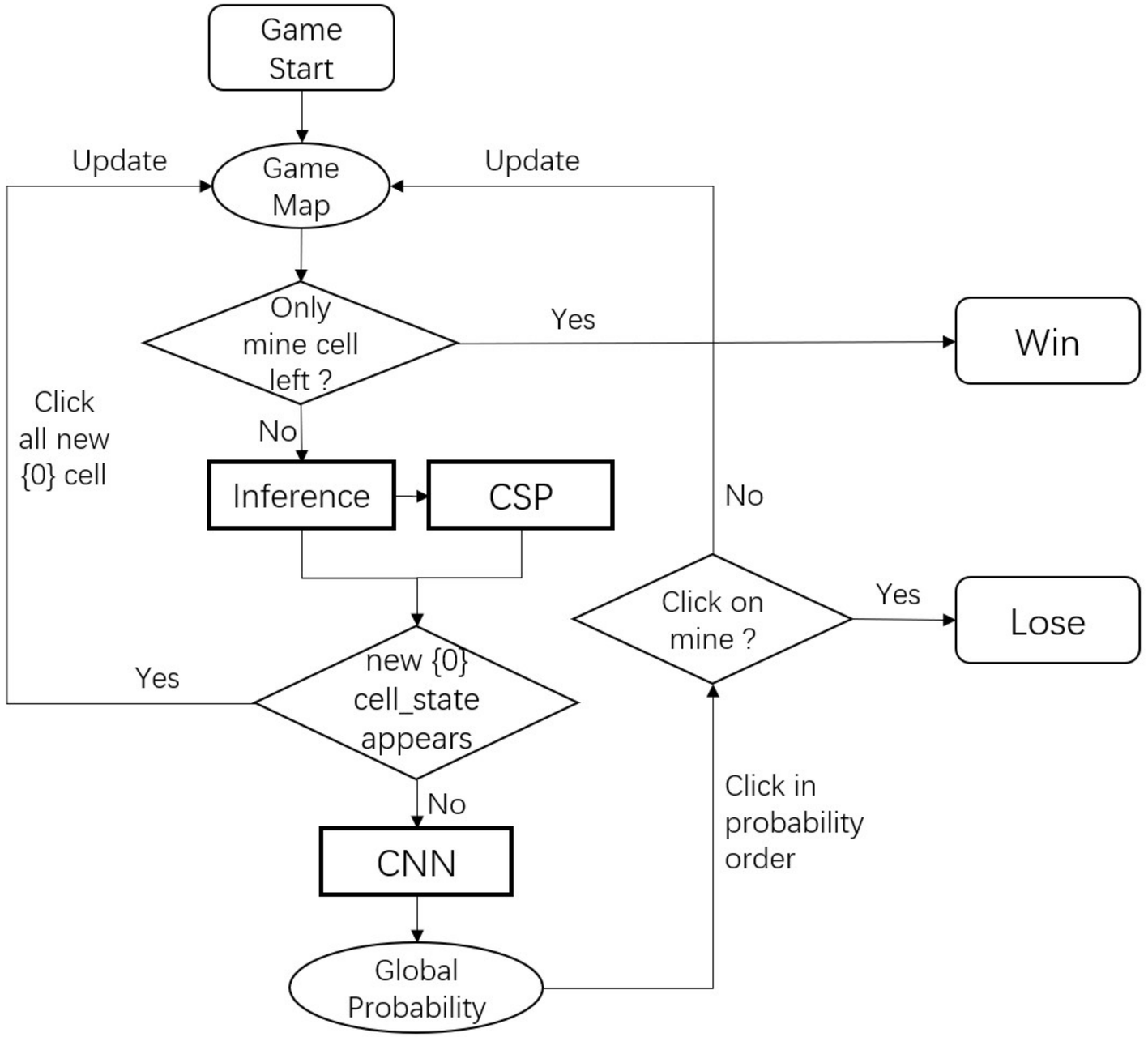

Experiments and Results

Winning Rate Improvement

Experiments and Results

Approach	9x9 Map, 10 Mines	16x16 Map, 40 Mines
Random pick	0%	0%
Logic	70.7%	31.4%
CSP	45%	1%
Net	32.8%	0%
Logic + CSP	84.5%	48.7%
CSP + Net	77%	7%
Logic + CSP + Net	95%	66.1%

Testing: Play 1000 rounds random generated game.

Conclusion

Conclusion

Minesweeper AI

- **Contribution**:
  - Combining deterministic (logic inference, CSP) and non-deterministic (CNN) models
  - Good performance & Computational efficiency
- **Future Works**:
  - Do filtering optimization (Forward Checking, Arc Consistency) with CSP
  - Expert mode (16x30, 100 mines) optimization