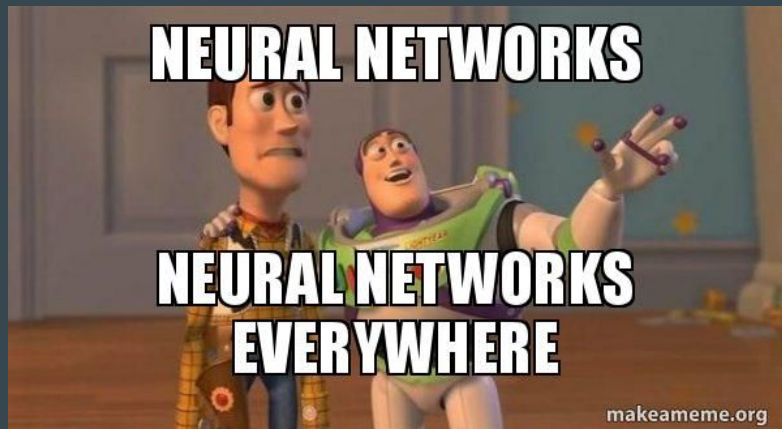# Solving Sudoku with Artificial Neural Network

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CSCE 478 - Spring 2019
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Problem

- <u>Fact</u>: Solving Sudoku is fun.
- Sudoku has been used as a benchmark for Artificial Intelligent algorithms.
- Currently, some can even be solved using Consistency algorithms only without doing any search.
- Artificial Neural Network has recently become very powerful.
- Neural Network with Python is simpler with powerful packages.

Image from https://makeameme.org

Dataset

- 1 million Sudoku puzzles from Kaggle https://www.kaggle.com/bryanpark/sudoku
  - Generated using Sudoku Generation Code from https://www.ocf.berkeley.edu/~arel/sudoku/main.html.
- Preprocess:

Read file as string	Split into integer	Reshape	One-hot encoding

| "53467891267219534819834256786976142342685379171392485696153728428741963534528617 9" | 5, 3, 4, 6, 7, 8, 9, 1, 2, 6, 7, 2, 1, 9, 5, 3, 4, 8, 1, 9, 8, 3, 4, 2, 5, 6, 7, 8, 6, 9, 7, 6, 1, 4, 2, 3, 4, 2, 6, ... | | |

Models

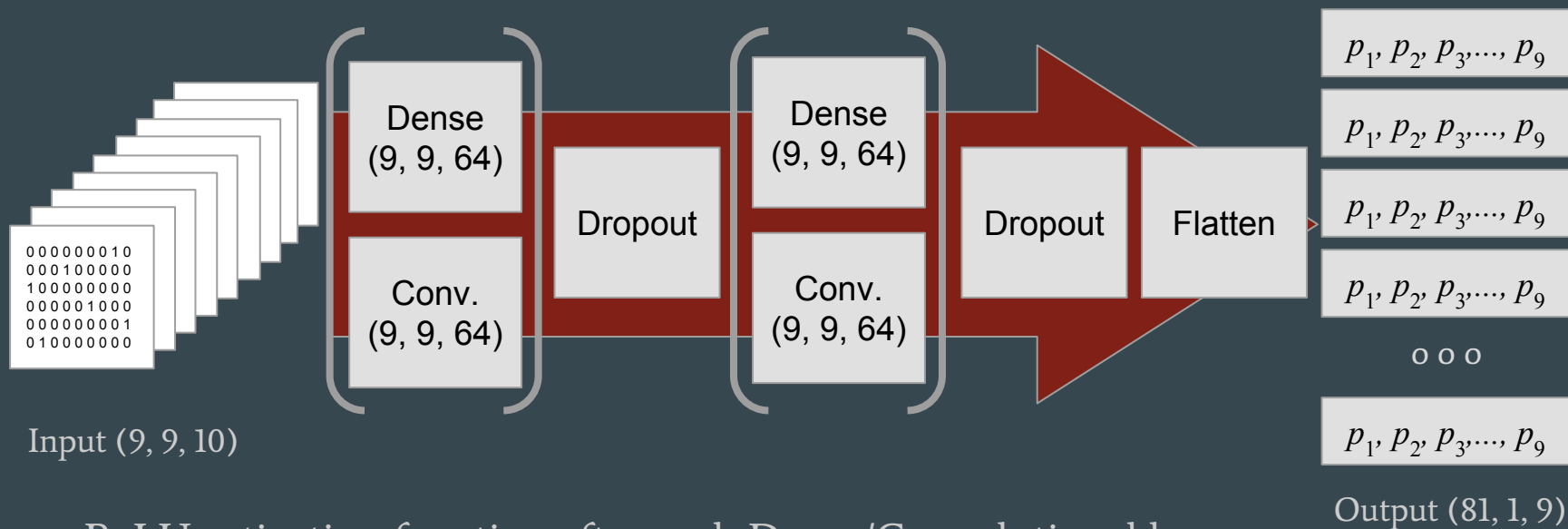Input (9, 9, 10)

Output (81, 1, 9)

- ReLU activation function after each Dense/Convolutional layer.
- Softmax activation function after the last layers.
- Loss function: categorical cross-entropy

Training and Results

- Training:
  - 50,000 puzzles: 32,000 for training, 8,000 for validating, and 10,000 for temporarily testing
  - Inspired from https://www.kaggle.com/dithyrambe/neural-nets-as-sudoku-solvers:
    - Gradually increase #blanks and #epochs in training set
    - Using the same validation set vs. gradually increase #blanks in validation set

- Results
  - Iterative predict: feed the puzzle through the models, predict the highest probability cell, and repeat
  - Dense model with increasing #blanks has the best accuracy on validation set.
  - Accuracy on 10,000 temporary test set and 950,000

    hold-out set is **~96.5%.**
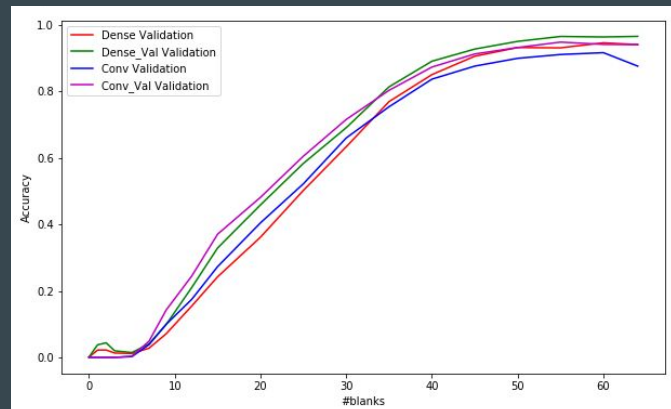
But life is not that easy...

- Additional testing data:
  - 50,000 puzzles with 17 clues[1] from UNL ConsystLab
    - Highest accuracy among all models is **0.05%**.
  - 472 puzzles from UNL Sudoku http://sudoku.unl.edu/SudokuSet/SudokuSetV5/
    - Highest accuracy among all models is **4.66%**.
    - Solvable puzzles are among the easiest ones.
- Problems:
  - Sudoku solver in C by Bill Dupree at
    https://github.com/attractivechaos/plb/blob/master/sudoku/incoming/sudoku_solver.c
    - Puzzle difficulties ranging from Trivial to Easy
  - More blanks != more difficult
  - Random deleting does not guarantee unique solution.

ARE YOU TELLING ME...

THERE'S NOT ENOUGH DATA?

memegenerator.net

[1] McGuire, G., Tugemann, B., & Civario, G. (2014). There is no 16-Clue Sudoku https://arxiv.org/pdf/1201.0749.pdf

Image from https://memegenerator.net