MineSweeper Solver

March 15, 2019

1 Training a Convolutional Neural Network to solve minesweeper

1.1 Description

I wanted to learn a bit of tensorflow, and also to solve the minesweeper problem. At first, (a year ago), I thought to use basic machine learning, but didn't succeed because I barely knew how to do anything. The idea was to train a network, that gets a partially open board and tries to predict where the mines are on the board. We then use this network to look at the game-board and find the square with the least likelihood of being a mine. We then open it and predict once more on the updated game-board, and so on. ## Code

In [2]:
```
#%% Importing libraries
import tensorflow as tf
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.image as mpimg
import os
```

In [3]:
```
#%% Create board
def createBoard(boardSize, mineNum):
  """
    Creates a board given the size of the board (a square), and the number of
    mines. It places the mines randomaly, then runs over all squares and
    whenever there is a mine, it adds 1 to all 8 neighbours.
  """
  # put the mines in random places
  A = np.zeros([boardSize, boardSize])
  for ii in range(mineNum): # randomly allocate mine
    randX = np.random.randint(0, boardSize - 1)
    randY = np.random.randint(0, boardSize - 1)
    while A[randX, randY] == 9: # while the place already has a mine
      randX = np.random.randint(0, boardSize - 1)
      randY = np.random.randint(0, boardSize - 1)
    A[randX, randY] = 9
  B = np.zeros([boardSize, boardSize])
  midY = boardSize / 2 #-(1-size)/2
  midX = midY
```

```
        # the following creates the numbers around the board
        for y1 in range(boardSize):
          for x1 in range(boardSize):
            if A[y1, x1]==9:
              for e in [-1, 0,  1]:
                for f in [-1, 0, 1]:
                  if e*e + f*f != 0 and abs(y1 + e - midY) <= midY and \
                  abs(x1 + f - midX) <= midX:
                    if A[y1 + e, x1 + f] != 9:
                      B[y1 + e, x1 + f] = B[y1 + e, x1 + f] + 1
        board = A + B
        return board
```

In [4]:
```
#%% Draw board
def drawBoard(boardMat, imgPath):
  """
    Receives the matrix description of the board, and the path to the images
    of the numbers and mine and flag, and creates the board.
  """
  # load images
  currImg = mpimg.imread(imgPath + '\\' + str(0) + '.png')
  imshp = currImg.shape[:2] # relays on the fact that all images are the same size
  boardImg = np.zeros([boardMat.shape[0] * imshp[0], boardMat.shape[1] * imshp[1], 3])
  for ii in range(boardMat.shape[0]):
    for jj in range(boardMat.shape[1]):
      boardImg[ii*imshp[0]:(ii+1)*imshp[0], jj*imshp[1]:(jj+1)*imshp[1], :] = \
           mpimg.imread(imgPath + '\\' + str(int(boardMat[ii, jj])) + '.png')
  plt.figure(figsize=(8, 8))
  plt.imshow(boardImg)
  return boardImg
```

In [5]:
```
#%% Create partial board for training, and testing
def createPartialBoards(N, boardSize, mineNum): # N is the number of boards
  """ We'll get a random number of open squares for each board, create N boards,
      and then get a partial solution and the binary solution"""
  boardGT  = [] # list of boards
  openRand = np.random.randint(boardSize*boardSize, size = N) # random number of open
  openRand = openRand.tolist()
  trainBrd = [] # list of the partial boards for training
  boardSol = [] # list of the solutions for the training boards
  for ii in range(N):
    # create board
    currBoard = createBoard(boardSize, mineNum)
    boardGT.append(currBoard)
    # create partial board
    currRand = np.random.randint(boardSize, size = [openRand[ii], 2]) # the location o
    currRand = currRand.tolist()
    currPrtl = 10 * np.ones([boardSize, boardSize])
```

```
      for jj in range(openRand[ii]):
        currPrtl[currRand[jj][0], currRand[jj][1]] = currBoard[currRand[jj][0], currRand
      trainBrd.append(currPrtl)
      # create solution
      currSol  = (currBoard == 9)
      boardSol.append(currSol)
    boardGT  = np.array(boardGT)
    boardGT  = boardGT[:,:,:,np.newaxis]
    trainBrd = np.array(trainBrd)
    trainBrd = trainBrd[:,:,:,np.newaxis]
    boardSol = np.array(boardSol)
    boardSol = boardSol[:,:,:,np.newaxis]
    return boardGT, trainBrd, boardSol
```

In [6]:
```
#%% Create network
def createCNN(boardSize):
  CNet = tf.keras.Sequential()
  CNet.add(tf.keras.layers.Conv2D(32, 3, activation = 'relu',
           input_shape = (boardSize, boardSize, 1), name = 'conv1'))
  CNet.add(tf.keras.layers.Conv2D(64, 3, activation = 'relu', name = 'conv2')) # use_b
  CNet.add(tf.keras.layers.Conv2D(128, 3, activation = 'relu', name = 'conv3'))
  CNet.add(tf.keras.layers.Conv2DTranspose(128, 3, activation = 'relu', name = 'deconv1
  CNet.add(tf.keras.layers.Conv2DTranspose(128, 3, activation = 'relu', name = 'deconv2
  CNet.add(tf.keras.layers.Conv2DTranspose(64, 3, activation = 'relu', name = 'deconv3
  #CNet.add(tf.keras.layers.Dense(32, name = 'dense1'))
  CNet.add(tf.keras.layers.Dense(1, name = 'dense1'))
  # compile
  CNet.compile(optimizer = tf.train.AdamOptimizer(0.001), loss = 'mse', metrics = ['acc
  print('CNet.summary():')
  CNet.summary()
  return CNet
```

In [7]:
```
#%% Show prediction output
def showPrediction(currGT, currBrd, currSol, currOut, thresh, imgPath):
  GTImg  = drawBoard(currGT, imgPath)
  BrdImg = drawBoard(currBrd, imgPath)
  SolImg = drawBoard(9*currSol, imgPath)
  # Out is between 0 and 1, so we'll use a threshold, and then multiply by 9:
  outMat = 9*(currOut > thresh)
  OutImg = drawBoard(outMat, imgPath)
  plt.figure(figsize=(15,15))
  plt.subplot(221)
  plt.imshow(GTImg)
  plt.title('Ground Truth')
  plt.subplot(222)
  plt.imshow(BrdImg)
  plt.title('Training board')
  plt.subplot(223)
```

```
    plt.imshow(SolImg)
    plt.title('Real solution')
    plt.subplot(224)
    plt.imshow(OutImg)
    plt.title('Auto solution')
```

In [8]:
```
#%% open zeros neighbors opens all the neighbors of some index, given that its
# value is 0.
def openZerosNeighbors(gameBoard, GTBoard, ind, cntr):
  midY = gameBoard.shape[1] / 2 #-(1-size)/2
  midX = midY
  Y = gameBoard.shape[1]
  X = gameBoard.shape[1]
  for e in [-1, 0,  1]:
    for f in [-1, 0, 1]:
      newInd =[0, ind[1] + e, ind[2] + f, 0]
      # print(newInd)
      if e*e + f*f > 0 and newInd[1] >= 0 and newInd[1] < Y and newInd[2] >= 0 and newI
      #if e*e + f*f > 0 and abs(newInd[1] - midY) <= midY and abs(newInd[2] - midX) <=
        if gameBoard[newInd[0], newInd[1], newInd[2], newInd[3]] == 10:
          gameBoard[newInd[0], newInd[1], newInd[2], newInd[3]] = GTBoard[newInd[1], ne
          cntr += 1
          if gameBoard[newInd[0], newInd[1], newInd[2], newInd[3]] == 0: # we landed o
            gameBoard, cntr = openZerosNeighbors(gameBoard, GTBoard, newInd, cntr)
  return gameBoard, cntr
```

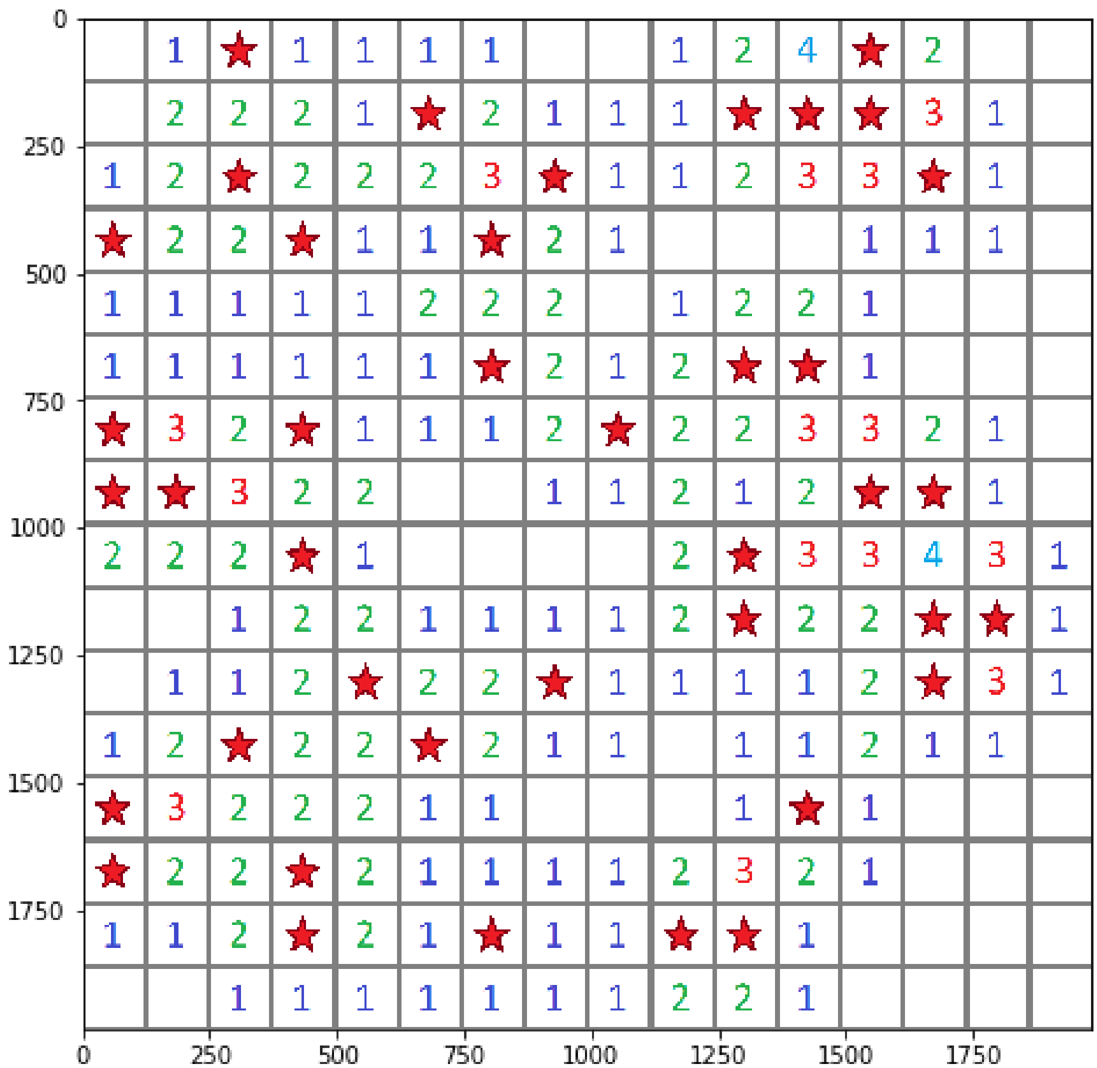
In [9]:
```
#%% Play games and check if you win or lose, and return the number of steps until you
def playGame(boardSize, mineNum, CNet, imgPath, showOutcome, open0, expFlag):
  # showOutcome is a boolian for whther to print and show or not
  GTBoard = createBoard(boardSize, mineNum)
  # We also need the changing board:
  gameBoard = 10 * np.ones([1, boardSize, boardSize, 1])
  # And now we need a while loop that predicts the board and opens the least
  # probable square (closest to nil):
  done = 0
  cntr = 0 # counter of the number of steps
  while done == 0:
    cntr = cntr + 1
    if expFlag:
      predBoard = CNet.predict(np.log10(gameBoard + 0.1))
    else:
      predBoard = CNet.predict(gameBoard)
    # We need to force the machine to pick squares he hasn't picked yet, so we subtrac
    ind = np.unravel_index(np.argmin(predBoard - gameBoard, axis=None), predBoard.shape
    gameBoard[ind] = GTBoard[ind[1:3]]
    if GTBoard[ind[1:3]] == 9: # landed on a mine
      done = 1
      if showOutcome:
```

```
            print('You LOST :(')
        if cntr == boardSize**2 - mineNum:
          done = 1
          if showOutcome:
            print('You WON :)')
        if open0 and gameBoard[ind] == 0: # open0 - open neighbors of 0, and we landed on
          gameBoard, cntr = openZerosNeighbors(gameBoard, GTBoard, ind, cntr)
      # Show the outcome
      if showOutcome:
        GTImg   = drawBoard(GTBoard, imgPath)
        gameImg = drawBoard(np.squeeze(gameBoard), imgPath)
        plt.figure(figsize=(16, 16))
        plt.subplot(211)
        plt.imshow(GTImg)
        plt.title('Ground Truth')
        plt.subplot(212)
        plt.imshow(gameImg)
        plt.title('Game Board')
        print(cntr)
      return cntr
```

In [10]:
```
#%% test the program:
def testCNet(testN, showOutcome, open0, boardSize, mineNum, imgPath, expFlag):
  maxCnt = boardSize**2 - mineNum # the number of steps needed to win
  stepCnt = np.zeros(testN)
  for ii in range(testN):
    stepCnt[ii] = playGame(boardSize, mineNum, CNet, imgPath, showOutcome, open0, expF

  # show the histogram:
  plt.figure(figsize=(10,10))
  gamehist = plt.hist(stepCnt, maxCnt)
  winRate  = np.sum(stepCnt == maxCnt) / (testN - np.sum(stepCnt == 1)) # success rat
  print(winRate)
  return 0
```

In [12]:
```
#%% Main:
# create a board as an example, and then show it:
  # We'll try intermediate, which is 16x16 with 40 mines
boardSize = 16
mineNum = 40
board = createBoard(boardSize, mineNum)
imgPath = '.\\MineSweeper' # the path where the images of the
boardImg = drawBoard(board, imgPath) # draw the board in an understandable manner
```




```
In [13]: #%% create data:
         # We want partial boards in all the different stages, and their solutions - a
         # binary board with 1's for mines and 0's for all else.
         # Lets assume we have N boards:
         N = 400000
         expFlag = 1
         # Now we want to create the boards:
         boardDat, trainBrd, boardSol = createPartialBoards(N, boardSize, mineNum)
         if expFlag:
           boardDat = np.log10(boardDat + 0.1)
           trainBrd = np.log10(trainBrd + 0.1)
         # split into training and validation
         splitInt = int(0.9 * N)
         validDat = trainBrd[splitInt:]
```

```
validSol = boardSol[splitInt:]
trainDat = trainBrd[:splitInt]
trainSol = boardSol[:splitInt]
```

In [14]:
```
#%% Create Network
# Saving network
checkpoint_path = ".\\checkpoint9\\cp.ckpt"
checkpoint_dir = os.path.dirname(checkpoint_path)
cp_callback = tf.keras.callbacks.ModelCheckpoint(checkpoint_path,
                                                 save_weights_only=True,
                                                 verbose=1)
# create the network
CNet = createCNN(boardSize)
# Now we want to train the network:
CNet.fit(trainDat, trainSol, epochs = 10, batch_size = 128,
         validation_data = (validDat, validSol), callbacks = [cp_callback])
```

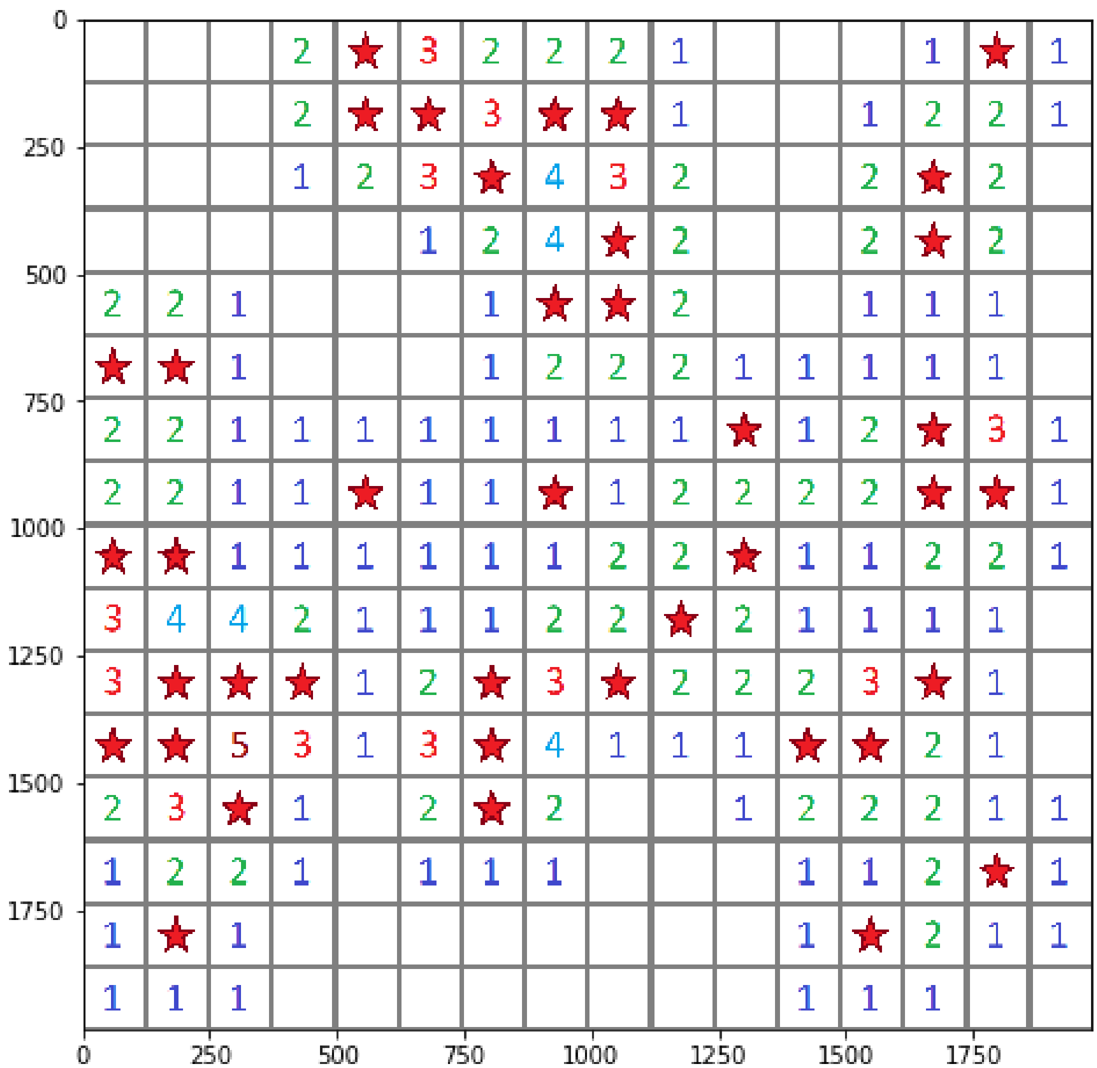
```
WARNING:tensorflow:From C:\Anaconda\envs\tf-cpu\lib\site-packages\tensorflow\python\ops\resour
Instructions for updating:
Colocations handled automatically by placer.
WARNING:tensorflow:From C:\Anaconda\envs\tf-cpu\lib\site-packages\tensorflow\python\keras\utils
Instructions for updating:
Use tf.cast instead.
CNet.summary():
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv1 (Conv2D)               (None, 14, 14, 32)        320
_________________________________________________________________
conv2 (Conv2D)               (None, 12, 12, 64)        18496
_________________________________________________________________
conv3 (Conv2D)               (None, 10, 10, 128)       73856
_________________________________________________________________
deconv1 (Conv2DTranspose)    (None, 12, 12, 128)       147584
_________________________________________________________________
deconv2 (Conv2DTranspose)    (None, 14, 14, 128)       147584
_________________________________________________________________
deconv3 (Conv2DTranspose)    (None, 16, 16, 64)        73792
_________________________________________________________________
dense1 (Dense)               (None, 16, 16, 1)         65
=================================================================
Total params: 461,697
Trainable params: 461,697
Non-trainable params: 0
_________________________________________________________________
Train on 360000 samples, validate on 40000 samples
WARNING:tensorflow:From C:\Anaconda\envs\tf-cpu\lib\site-packages\tensorflow\python\ops\math_op
Instructions for updating:
```

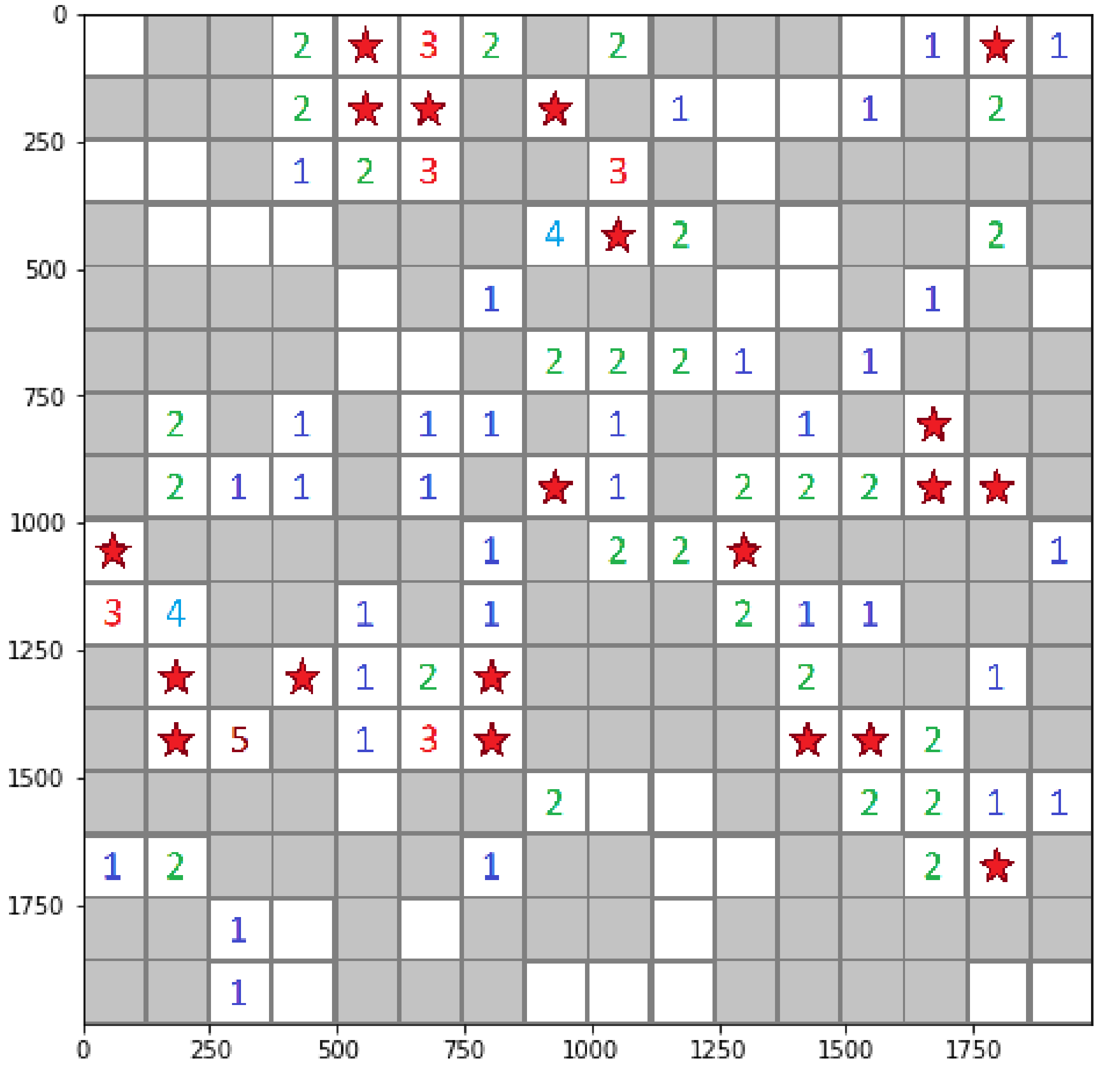
```
Use tf.cast instead.
Epoch 1/10
359936/360000 [============================>.] - ETA: 0s - loss: 0.0630 - acc: 0.9140
Epoch 00001: saving model to .\checkpoint9\cp.ckpt
WARNING:tensorflow:From C:\Anaconda\envs\tf-cpu\lib\site-packages\tensorflow\python\keras\engin
Instructions for updating:
Use tf.train.CheckpointManager to manage checkpoints rather than manually editing the Checkpoin
360000/360000 [==============================] - 1740s 5ms/sample - loss: 0.0630 - acc: 0.9140
Epoch 2/10
359936/360000 [============================>.] - ETA: 0s - loss: 0.0490 - acc: 0.9339
Epoch 00002: saving model to .\checkpoint9\cp.ckpt
360000/360000 [==============================] - 1637s 5ms/sample - loss: 0.0490 - acc: 0.9339
Epoch 3/10
359936/360000 [============================>.] - ETA: 0s - loss: 0.0459 - acc: 0.9384
Epoch 00003: saving model to .\checkpoint9\cp.ckpt
360000/360000 [==============================] - 1639s 5ms/sample - loss: 0.0459 - acc: 0.9384
Epoch 4/10
359936/360000 [============================>.] - ETA: 0s - loss: 0.0445 - acc: 0.9402
Epoch 00004: saving model to .\checkpoint9\cp.ckpt
360000/360000 [==============================] - 1642s 5ms/sample - loss: 0.0445 - acc: 0.9402
Epoch 5/10
359936/360000 [============================>.] - ETA: 0s - loss: 0.0437 - acc: 0.9413
Epoch 00005: saving model to .\checkpoint9\cp.ckpt
360000/360000 [==============================] - 1638s 5ms/sample - loss: 0.0437 - acc: 0.9413
Epoch 6/10
359936/360000 [============================>.] - ETA: 0s - loss: 0.0431 - acc: 0.9420
Epoch 00006: saving model to .\checkpoint9\cp.ckpt
360000/360000 [==============================] - 1637s 5ms/sample - loss: 0.0431 - acc: 0.9420
Epoch 7/10
359936/360000 [============================>.] - ETA: 0s - loss: 0.0427 - acc: 0.9425
Epoch 00007: saving model to .\checkpoint9\cp.ckpt
360000/360000 [==============================] - 1636s 5ms/sample - loss: 0.0427 - acc: 0.9425
Epoch 8/10
359936/360000 [============================>.] - ETA: 0s - loss: 0.0424 - acc: 0.9429
Epoch 00008: saving model to .\checkpoint9\cp.ckpt
360000/360000 [==============================] - 1639s 5ms/sample - loss: 0.0424 - acc: 0.9429
Epoch 9/10
359936/360000 [============================>.] - ETA: 0s - loss: 0.0422 - acc: 0.9432
Epoch 00009: saving model to .\checkpoint9\cp.ckpt
360000/360000 [==============================] - 1637s 5ms/sample - loss: 0.0422 - acc: 0.9432
Epoch 10/10
359936/360000 [============================>.] - ETA: 0s - loss: 0.0420 - acc: 0.9434
Epoch 00010: saving model to .\checkpoint9\cp.ckpt
360000/360000 [==============================] - 1675s 5ms/sample - loss: 0.0420 - acc: 0.9434
```

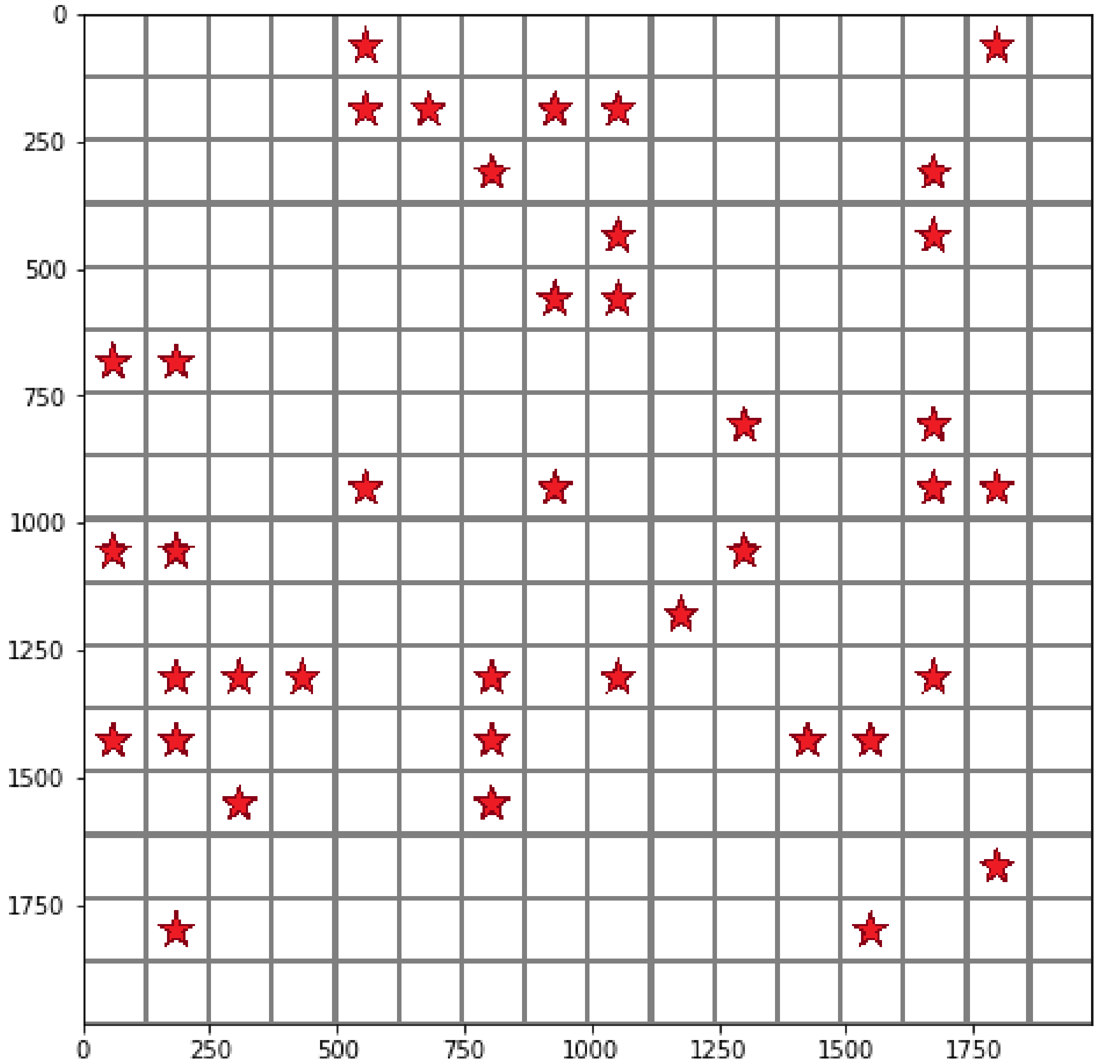
Out[14]: <tensorflow.python.keras.callbacks.History at 0x119cda694a8>

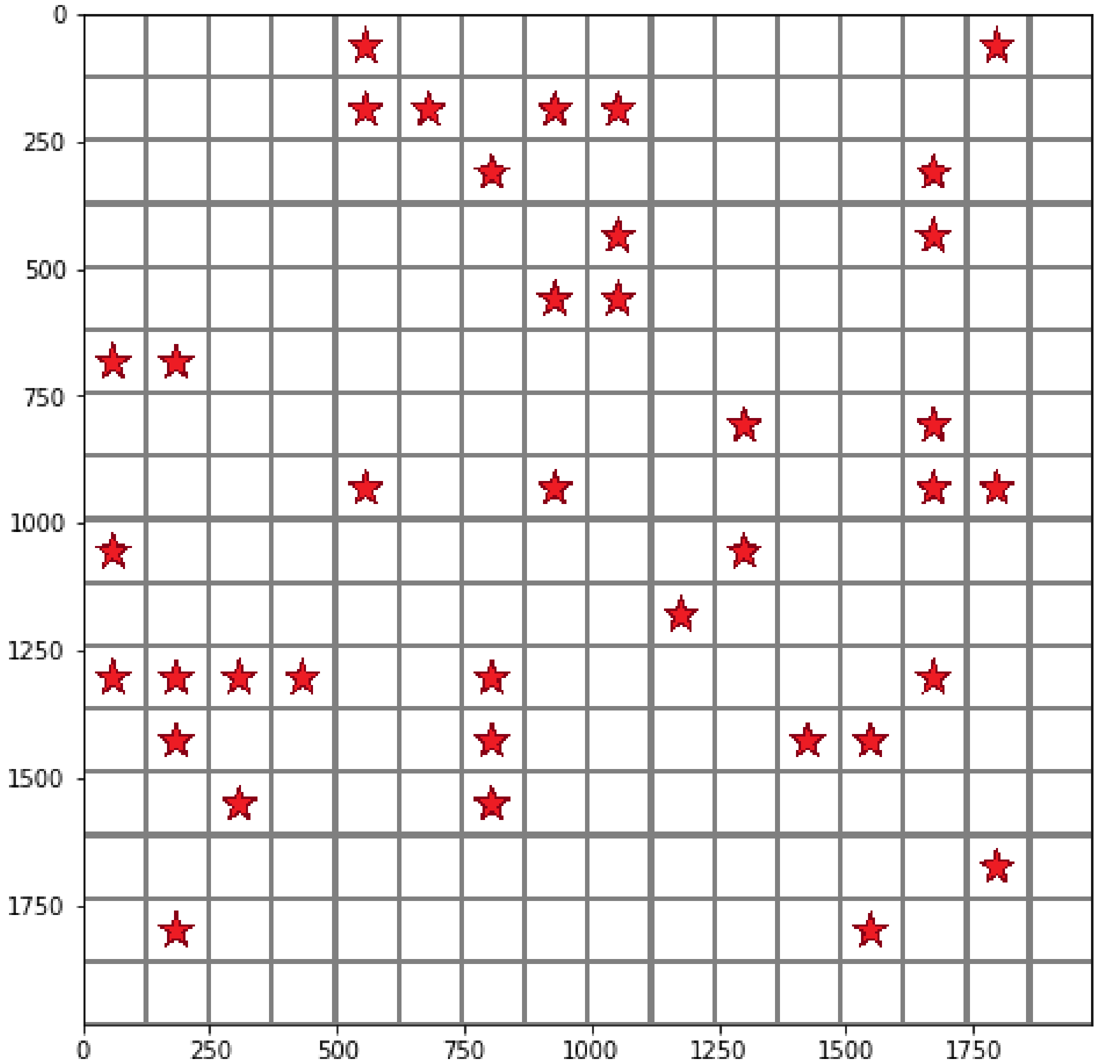
```
In [15]: #%% Test:
```

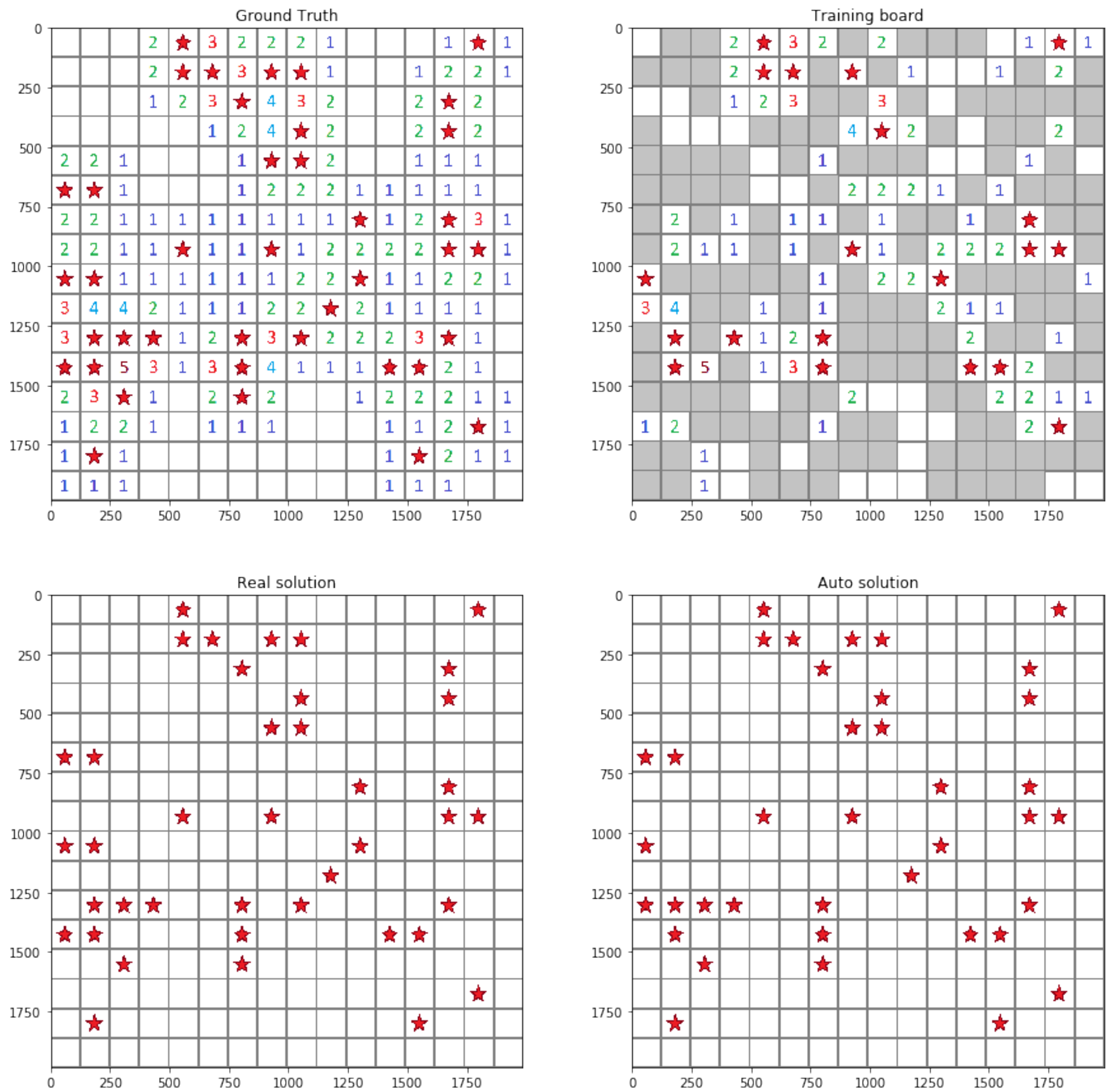
```
# create another board, and look at the solution
threshold = 0.5 # threshold above which we think we have a mine
#create a board:
testGT, testBrd, testSol = createPartialBoards(1, boardSize, mineNum)
testOut = CNet.predict(np.log10(testBrd+0.1))
ii = 0;
currGT  = np.squeeze(testGT [ii,:,:])
currBrd = np.squeeze(testBrd[ii,:,:])
currSol = np.squeeze(testSol[ii,:,:])
currOut = np.squeeze(testOut[ii,:,:])
showPrediction(currGT, currBrd, currSol, currOut, threshold, imgPath)
```




0
250
500
750
1000
1250
1500
1750

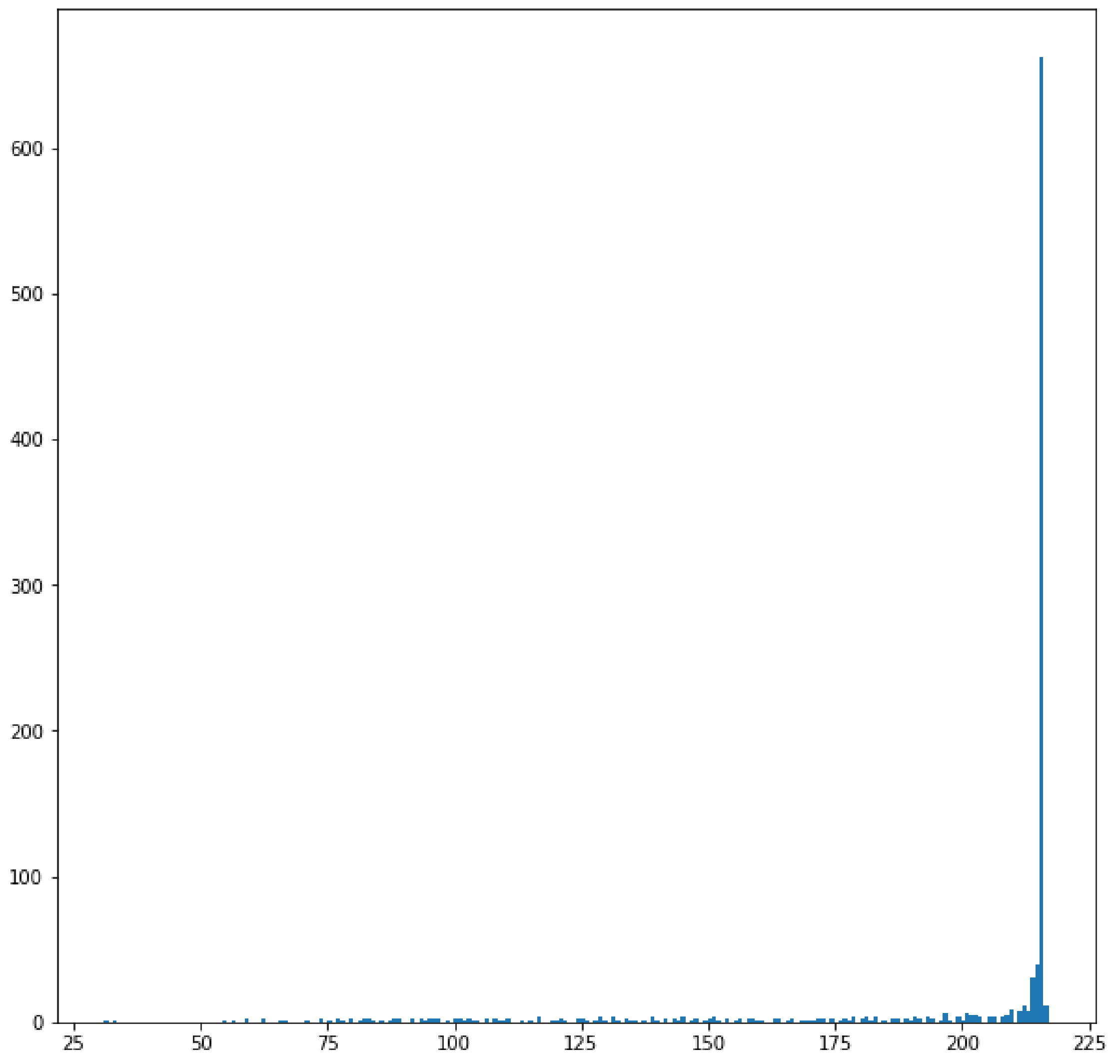

0
250
500
750
1000
1250
1500
1750
0
250
500
750
1000
1250
1500
1750


0
250
500
750
1000
1250
1500
1750
0
250
500
750
1000
1250
1500
1750




```
In [16]: #%% Now we want a system that gets a board, and plays it.
         # We'll make a game board, and then use it to
         testN = 1000 # number of games to test
         showOutcome = 0
         open0 = 1
         test = testCNet(testN, showOutcome, open0, boardSize, mineNum, imgPath, expFlag)
```

```
0.662
```



1.2 I tried various networks: