An Investigation into Machine Learning and Neural Networks through the Simulation of Human Survival

Computer Science NEA

Name: Matthew Brabham
Candidate Number:
Centre Name: Barton Peveril College
Centre Number: 58231

1. Contents

2. Analysis

1. Statement of Investigation
   I plan to investigate Machine Learning by developing a survival simulation environment in which an Agent will be controlled by a Machine Learning algorithm. The survival simulation will present multiple challenges towards the agent in order to provide a complex problem for it to solve. The key question I aim to answer with this investigation is:

   Can you train a Machine Learning algorithm to survive in a pseudo random, open-world environment?

   I find this question to be quite interesting because there is multiple layers of complexity to it, with several different problems to solve. Answering the question will require me to dive headfirst into Machine Learning picking things up as fast as possible.

2. Background
3. Expert
4. Initial Research

5. Prototype

Before starting my Prototype I had to decide upon a short list of objectives I wanted to complete/investigate as part of it. These boiled down to a few things:

(a) Terrain Generation

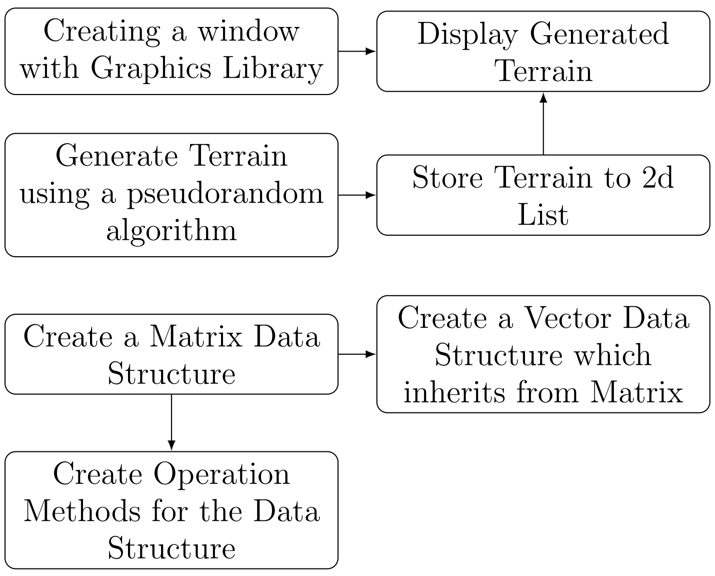
(b) Displaying the Generated Terrain using a Grahics Library

(c) Matrix and Vector implementation

For my Prototype, I first created a GitHub Repository, available here:

https://github.com/TheTacBanana/CompSciNEAPrototype

I had created a hierarchy of importance for development in my head, visualized using this flow diagram:


Creating a window with Graphics Library
Display Generated Terrain
Generate Terrain using a pseudorandom algorithm
Store Terrain to 2d List
Create a Matrix Data Structure
Create a Vector Data Structure which inherits from Matrix
Create Operation Methods for the Data Structure

I decided to use Python for developing my Prototype, this seemed like a good fit due to me having lots of experience with the language. Python is a Dynamically Typed and Interpretted language which makes it versatile for protyping and fast, iterative development.

Terrain Generation and Displaying

Starting from the begining of my hierarchy I installed Pygame using *pip* and started creating a window. This was a relatively simple task only taking a few lines:

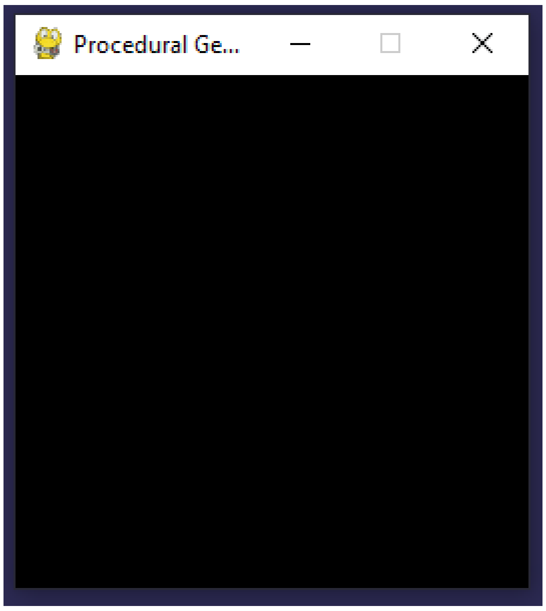
```
import pygame

simSize = 128
gridSize = 2

window = pygame.display.set_mode((simSize*gridSize, simSize*gridSize))
pygame.display.set_caption("Procedural Generation")

running = True
while running == True:
  for event in pygame.event.get():
    if event.type == pygame.QUIT:
      running = False
```

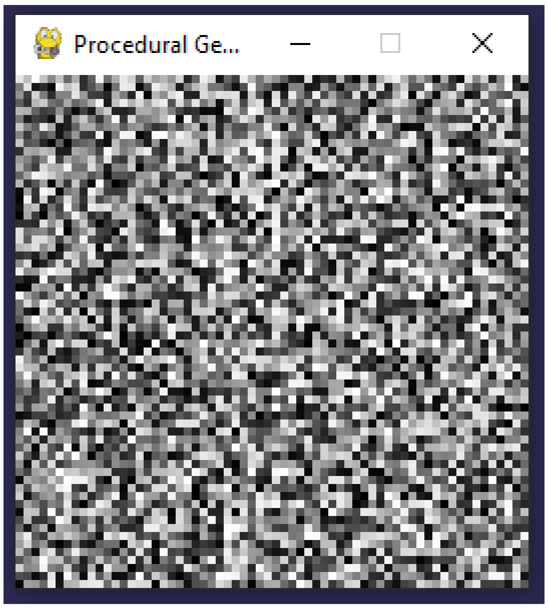
This creates a window like this:



Following the hierarchy I then added noise generation by generating random numbers and assigning them to a 2d List. Shown here:

```
def GenerateMap(self, seed):
    random.seed(seed)
    for y in range(0, self.arraySize):
        for x in range(0, self.arraySize):
            self.heightArray[x][y] = round(random.random(),2)
```

After creating some code to draw squares based upon the random value, I ended up with this random array of Black-White squares:



This was a good start, but didnt really look like terrain yet. As part of my research I came across simple algorithms to turn random noise into usable 2d terrain. I decided to implement these algorithms. They are relatively short and didnt take too much time to implement. I've named the two algorithms UpDownNeutralGen and Average.

UpDownNeutralGen Method

The UpDownNeutralGen method takes a tile, and considers every tile around it. It sums the tile which are greater than, less than, or within a certain range of the tile height. And then pulls the selected tile in the direction which has the highest precedence. As an example, here are some randomly generated values:

0.71	0.19	0.3
0.46	0.26	0.82
0.63	0.35	0.05

If we count the surrounding values into corresponding Higher, Lower and Neutral we get:

Higher	Lower	Neutral
4	1	3

This leads us to calculating the *pullValue*, respectively for each case:

$$Up- > pullValue = upTiles * 0.09$$
$$Down- > pullValue = upTiles * -0.08$$
$$Neutral- > pullValue = 0$$

$$Value[x][y] += pullValue$$

We then add the pullValue to the original square value, leaving us with the updated value. The code for this shown under the Prototype Code Header.

Average Method

The Average method takes a tile and considers every tile around it, this time instead of looking at the differences, it creates an average from the 8 surrounding tiles. It then sets the selected tile to this average value. As an example, here are some randomly generated values:

0.83	0.93	0.64
0.07	0.38	0.21
0.33	0.94	0.95

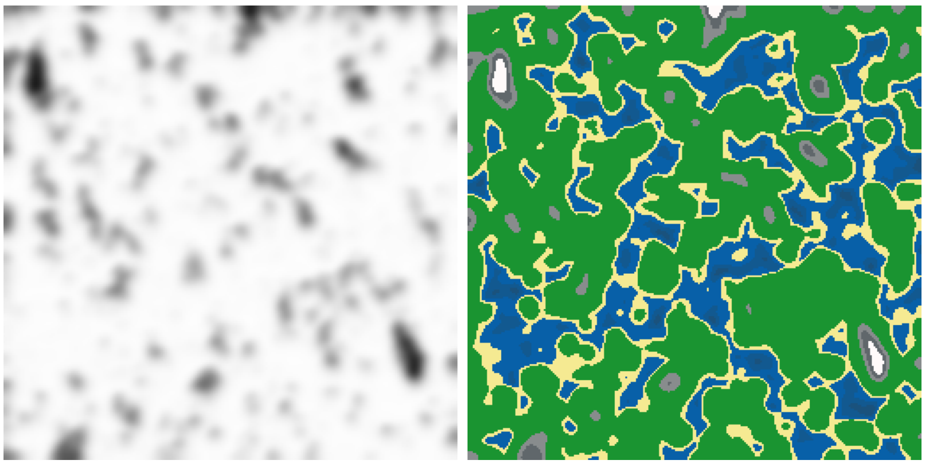
Summing these and dividing by the total grants us the average:

$$\frac{0.83 + 0.93 + 0.64 + 0.07 + 0.38 + 0.21 + 0.95 + 0.33 + 0.94}{9} = 0.586$$
$$Value[x][y] = 0.586$$

The code for this shown under the Prototype Code Header.

Finished Terrain Generation

Overall I am happy with the Terrain generation, though I feel as if it could be improved to look more realistic. The difference between the original random noise and the Colour Mapped Terrain looks so much better.



Matrix Data Structure

As part of my Matrix Class I made a list of operations which would be key to a Matrix Class, along with being useful for Machine Learning. A Matrix is an abstract data type, commonly used in Maths, but has practical uses in the world of Computer Science. It holds a 2d array of values such as:

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} \begin{pmatrix} a & b & c \\ d & e & f \\ g & h & i \end{pmatrix} \begin{pmatrix} a \\ b \\ c \end{pmatrix} \begin{pmatrix} a & b & c & d \\ e & f & g & h \end{pmatrix}$$

The values in a Matrix can be manipulated using common operations such as $+ - *$ as long as the orders of the 2 Matrices match up. Along with other, non-standard operations which have other purposes.

As part of my Matrix Class, I implemented the following operators:

(a) Addition/Subtraction
Implementing Addition didnt take too long, I utilised a nested for loop to iterate over every value in both Matrices. Adding the two values together into a temporary Matrix which the method then returned.

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} + \begin{pmatrix} e & f \\ g & h \end{pmatrix} = \begin{pmatrix} a+e & b+f \\ c+g & d+h \end{pmatrix}$$

(b) Multiplication
Multiplication of Matrices is slightly more complicated, it is of $O(n^3)$ complexity, utilising a triple nested for loop. It multiplies the row of a $M1$, by the column in $M2$. Summing the calculation into the element in the new Matrix $M3$.

$$\begin{pmatrix} a & b \\ c & d \end{pmatrix} * \begin{pmatrix} e & f \\ g & h \end{pmatrix} = \begin{pmatrix} a*e+b*g & a*f+b*h \\ c*e+d*g & c*f+d*h \end{pmatrix}$$

There is also Scalar Multiplication which multiples each value of a Matrix by the Scalar.

$$k * \begin{pmatrix} a & b \\ c & d \end{pmatrix} = \begin{pmatrix} ka & kb \\ kc & kd \end{pmatrix}$$

(c) Determinant
Calculating the Determinant of an NxN Matrix is a recursive algorithm. With the base case being the Determinant of a 2x2 Matrix. When calculating the Determinant of a 3x3 Matrix you create a Matrix of Cofactors, and multiply each value by the corresponding value in the Sin Matrix (*Formed from repeating 1's and -1's*). Summing the values from a singular Row or Column will then give you the Determinant. For a 4x4 you simply calculate the Determinant of the corresponding 3x3's to get the Cofactors.

$$\begin{vmatrix} a & b \\ c & d \end{vmatrix} = a*d - b*c$$

$$\begin{vmatrix} a & b & c \\ d & e & f \\ g & h & i \end{vmatrix} = a * \begin{vmatrix} e & f \\ h & i \end{vmatrix} - b * \begin{vmatrix} d & f \\ g & i \end{vmatrix} + c * \begin{vmatrix} d & e \\ g & h \end{vmatrix}$$

(d) Dot Product
The Dot Product occurs between two vectors, and can be used to calculate the angle between them. Its a relatively simple operation only taking a few lines of code.

$$\begin{pmatrix} a \\ b \\ c \end{pmatrix} . \begin{pmatrix} d \\ e \\ f \end{pmatrix} = a*d+b*e+c*f$$

All code is available under the Prototype Code Header.

Prototype Evaluation

Overall I am happy with my prototype, though I feel like some parts need to be improved. I did meet my objectives for my prototype but there were improvements which can me made when I create my Technical Solution. Namely the Terrain Generation along with the Matrix class. I feel that Perlin noise would be a better alternative to the two algorithms I used. In theory it should produce better results, and also provice more marks for complexity. My Matrix class could be rewritten to be more efficient, along with using operator overloading, which I didnt know Python could do at the time. I also feel like having vector inherit from matrix is relatively pointless, there is no need for it when I could just use 1 wide Matrices.

6. Objectives

Taking into account my Prototype and Interview, I have formed a list of objectives I feel to be most appropriate for my Investigation. If all completed they will form a complete solution which will answer my Investigations question. Below is the list of objectives split into 6 key sections:

(a) User Input
   i. Read Parameters from a Json formatted file
   ii. Check Parameters fall within a certain range to prevent errors
   iii. Give user option to load Neural Network Training progress

(b) Simulation
   i. Utilise Perlin Noise to generate a 2d List of terrain heights
   ii. Store Terrain Heights in a Tile Data Type
   iii. Utilise Threading to generate Terrain Faster
   iv. Display terrain to a pygame window
   v. Map ranges of terrain heights to specific colour bands
   vi. Utilise Poisson Disc Sampling to generate objects for the Agent to interact with
   vii. Implement enemies which use basic pathfinding to traverse towards the player
   viii. Generate multiple enemies upon starting the simulation
   ix. Allow the enemies to attack the Agent

(c) Agent
   i. Implement Movement options for the Agent
   ii. Implement the ability to pick up the generated Objects
   iii. Implement the ability to attack the generated enemies
   iv. Create methods to sample the terrain around the Agent
   v. Create methods to convert the sampled Tiles into a grayscale input vector for a neural network
   vi. Create reward methods to reward the agent given the terrain samples and action

(d) Matrix Class
   i. Implement a Dynamic Matrix Class with appropriate Operations such as:
      A. Multiplication
      B. Addition
      C. Subtraction

        D. Transpose
        E. Sum
        F. Select Row/Column
    ii. Create appropriate errors to throw when utilising methods the incorrect way

(e) Deep Q Learning
    i. Dynamically create a Dual Neural Network model based upon loaded parameters
    ii. Implement an Abstract Class for Activation Functions
    iii. Implement Activation Functions inheriting from the Abstract Class such as:
        A. ReLu
        B. Sigmoid
        C. SoftMax
    iv. Create methods to Forward Propagate the neural network
    v. Create methods to calculate the loss of the network using the Bellman Equation
    vi. Create methods to Back Propagate calculated error through the neural network
    vii. Create methods to update weights and biases within the network to converge on a well trained network
    viii. Utilise the outlined Matrix class to perform the mathematical operations in the specified methods
    ix. Implement Load and Save Methods to save progress in training
    x. Implement a Double Ended Queue/Deque Data Type
    xi. Implement Experience Replay utilising the Deque Data Type to increase training accuracy

(f) Data Logger
    i. Be able to create a Data Logger class to log data points across training
    ii. Be able to create a Data Structure for the Data Logger
    iii. Allow multiple types specified types for a single parameter
    iv. When adding a new Data Point the Logger will check it to make sure it matches the given Data Structure
    v. Implement a Heap Data Type
    vi. Implement a Heap sort using the Heap Data Type
    vii. Be able to sort by a parameter in the Data Structure
    viii. Be able to select a single parameter from the data points
    ix. Implement Load and Save Functions to save progress during training

3. Design

4. Testing

As part of testing my NEA, I identified the key areas of my project which needed testing. My testing targets these areas from different angles to ensure they work correctly. These areas are:

1. User Input
   (a) Parameter Loading
   (b) Neural Network Loading
2. Matrix Implementation
   (a) Constructor Cases
   (b) Matrix Operations
   (c) Thrown Exceptions
3. Deep Q Learning Algorithm
   (a) Forward Propagation
   (b) Loss Function
   (c) Back Propagation
   (d) Double Ended Queue Data Type
4. Data Logger
   (a) Data Structure Matching
   (b) Heap Data Structure
   (c) Heap Sort Implementation
5. Simulation
   (a) Generation of 2d Terrain
   (b) Continuity of Generation

Below is the included NEA Testing video for testing evidence

https://thisisalink.com/youtotallybelieveme/

1.1 User Input

Test No.	Test Name	Input Data	Expected Output	Pass / Fail	Time Stamp
1	Loading Parameters File	”Default.json” file which contains the loadable values	Loads parameters into the Parameters Dictionary variable	Pass	00:00
2	Test Parameters within range	-	-	-	-
3	Loading of Network Weights	-	-	-	-
4	-	-	-	-	-
5	-	-	-	-	-

6. Prototype Code

Below is the code I created while developing my Prototype.
The 3 Scripts listed in order are:

1. main.py
2. worldClass.py
3. mathLib.py

---

1. main.py

```
#Imports
import pygame, random, json, os, time
from datetime import datetime
import worldClass, agentClass, mathLib

#Variables
simSize = 64
gridSize = 4
simSeed = 420

#World Functions
def DrawWorld():
    if world.grayscale == False:
    for y in range(0, simSize):
        for x in range(0, simSize):
        colour = world.colourArray[x][y]
        pygame.draw.rect(window, (colour), ((x * gridSize), (y * gridSize), gridS
    else:
    for y in range(0, simSize):
        for x in range(0, simSize):
        value = world.heightArray[x][y]
        pygame.draw.rect(window, (255 * value, 255 * value, 255 * value), ((x *


#World Gen Functions
def RandomWorld():
    SetWorld(random.randint(0, 10000))
def SetWorld(seed):
    world.GenMap(seed)
    DrawWorld()

#Setup
window = pygame.display.set_mode((simSize * gridSize, simSize * gridSize))
pygame.display.set_caption(”Procedural␣Generation”)

world = worldClass.WorldMap(simSize)
RandomWorld()
```

```
#Main loop
running = True
while running == True:
    for event in pygame.event.get():
    if event.type == pygame.QUIT:
        running = False
    elif event.type == pygame.KEYDOWN:
        if event.key == pygame.K_RETURN:
        RandomWorld()
        elif event.key == pygame.K_F2:
        pygame.image.save(window,"DevelopmentScreenshots\\screenshot{}.png".forma

    pygame.display.update()
```

2. worldClass.py

```
import random, json

class WorldMap():
    def __init__(self, size):
        self.arraySize = size
        self.heightArray = [[-1 for i in range(size)] for j in range(size)]
        self.colourArray = [[(0, 0, 0) for i in range(size)] for j in range(size
        self.typeArray = [[-1 for i in range(size)] for j in range(size)]

        self.inverted = False
        self.grayscale = False
        self.upNeutralDown = 0
        self.averaging = 0
        self.params = []
        self.thresholds = []
        self.LoadParameters("DefaultParameters.json")

    def LoadParameters(self, fname):
        file = open("Presets\\{}".format(fname), "r")
        self.params = json.loads(file.read())
        file.close()

        for key in self.params:
            if key == "Inverted":
                if self.params[key] == 1:
                    self.inverted = True
            elif key == "UpNeutralDown":
                self.upNeutralDown = self.params[key]
            elif key == "Averaging":
                self.averaging = self.params[key]
            elif key == "Grayscale":
                if self.params[key] == 1:
                    self.grayscale = True
        else:
            self.thresholds.append((float(key),(self.params[key][0], self.par

def ConvertTypes(self):
    for y in range(0, self.arraySize):
        for x in range(0, self.arraySize):
            for i in range(len(self.thresholds)):
                value = self.heightArray[x][y]
                if self.inverted:
                    value = 1 - value
                if value <= self.thresholds[i][0]:
                    #print(thresholds[i][0])
                    self.colourArray[x][y] = self.thresholds[i][1]
                    self.typeArray[x][y] = i
                    break


def GenMap(self, seed):
    random.seed(seed)
    for y in range(0, self.arraySize):
        for x in range(0, self.arraySize):
            self.heightArray[x][y] = round(random.random(),2)

    for i in range(self.upNeutralDown):
        self.UpNeutralDownGen()
        #print("UNDGen")
    for i in range(self.averaging):
        self.AverageGen()
        #print("averaging")

    self.ConvertTypes()

def UpNeutralDownGen(self):
    dupMap = self.heightArray
    for y in range(0, self.arraySize):
        for x in range(0, self.arraySize):
            up = 0
            down = 0
            neutral = 0
            pointArr = []

            if x != 0 and y != 0:
                pointArr.append(self.heightArray[x - 1][y - 1])
            if x != 0 and y != self.arraySize - 1:
                pointArr.append(self.heightArray[x - 1][y + 1])
            if x != self.arraySize - 1 and y != self.arraySize - 1:
                pointArr.append(self.heightArray[x + 1][y + 1])
            if x != self.arraySize - 1 and y != 0:
                pointArr.append(self.heightArray[x + 1][y - 1])
            if x != 0:
                pointArr.append(self.heightArray[x - 1][y])
            if y != 0:
                pointArr.append(self.heightArray[x][y - 1])
            if x != self.arraySize - 1:
                pointArr.append(self.heightArray[x + 1][y])
            if y != self.arraySize - 1:
                pointArr.append(self.heightArray[x][y + 1])

            for i in range(len(pointArr)):
                if pointArr[i] >= self.heightArray[x][y] + 0.1:
                    up += 1
                elif pointArr[i] <= self.heightArray[x][y] - 0.1:
                    down += 1
                else:
                    neutral += 1

            if (up > down) and (up > neutral): # Up
                value = 0.09 * up
            elif (down > up) and (down > neutral): # Down
                value = -0.08 * down
            else: # Neutral
                value = 0

            dupMap[x][y] += value
            dupMap[x][y] = self.Clamp(dupMap[x][y], 0, 1)

    self.heightArray = dupMap

def AverageGen(self):
    dupMap = self.heightArray
    for y in range(0, self.arraySize):
        for x in range(0, self.arraySize):
            total = 0
            count = 0
            if x != 0 and y != 0:
                total += self.heightArray[x - 1][y - 1]
                count += 1
            if x != 0 and y != self.arraySize - 1:
                total += self.heightArray[x - 1][y + 1]
                count += 1
            if x != self.arraySize - 1 and y != self.arraySize - 1:
                total += self.heightArray[x + 1][y + 1]
                count += 1
            if x != self.arraySize - 1 and y != 0:
                total += self.heightArray[x + 1][y - 1]
                count += 1
            if x != 0:
                total += self.heightArray[x - 1][y]
                count += 1
            if y != 0:
                total += self.heightArray[x][y - 1]
                count += 1
            if x != self.arraySize - 1:
                total += self.heightArray[x + 1][y]
                count += 1
            if y != self.arraySize - 1:
                total += self.heightArray[x][y + 1]
                count += 1

            dupMap[x][y] = total / count
    self.heightArray = dupMap

def Clamp(self, val, low, high):
    return low if val < low else high if val > high else val
```

3. mathLib.py

```
import math, random
class Matrix():
    def __init__ (self, Values, cols = 0, identity = False):
        if type(Values) == list: # Predefined Values
            self.matrixArr = Values

        elif identity == True: # Identity Matrix
            if Values != cols:
                raise Exception("Cant create Identity Matrix of different orders'
            else:
                self.matrixArr = [[0 for i in range(cols)] for j in range(Values)
                for y in range(0, Values):
                    self.matrixArr[y][y] = 1

        elif Values > 0 and cols > 0: # Blank Matrix of size x by y
            self.matrixArr = [[0 for i in range(cols)] for j in range(Values)]

        else: # Error Creating Matrix
            raise Exception("Error Creating Matrix")

    def Val(self):
        return self.matrixArr

    def Dimensions(self):
        return [len(self.matrixArr), len(self.matrixArr[0])] # Rows - Columns

    def ScalarMultiply(self, multiplier):
        for y in range(0, len(self.matrixArr)):
            for x in range(0, len(self.matrixArr[0])):
                self.matrixArr[y][x] = self.matrixArr[y][x] * multiplier
```

```
def SubMatrixList(self, rowList, colList):
    newMat = Matrix(self.Dimensions()[0] - len(rowList),self.Dimensions()[1]
    xoffset = 0
    yoffset = 0
    yRowList = []

    for y in range(0, self.Dimensions()[0]):
        for x in range(0, self.Dimensions()[1]):
            if x in colList and y in rowList:
                xoffset += 1
                yoffset += 1
                continue
            elif x in colList:
                xoffset += 1
                continue
            elif y in rowList and y not in yRowList:
                yoffset += 1
                yRowList.append(y)
                continue
            else:
                newMat.matrixArr[y - yoffset][x - xoffset] = self.matrixArr[y
        xoffset = 0
    return newMat


def SubMatrixRange(self, y1, y2, x1, x2):
    subMat = Matrix(y2 - y1 + 1, x2 - x1 + 1)
    for y in range(y1, y2 + 1):
        for x in range(x1, x2 + 1):
            subMat.matrixArr[y][x] = self.matrixArr[y][x]
    return subMat

def RandomVal(self):
    self.matrixArr = [[random.randint(1, 100) for i in range(self.Dimensions

def ConvertToVector(self):
    return Vector(self.matrixArr)

@staticmethod
def Determinant(m):
    dims = m.Dimensions()
    if dims[1] <= 2:
        det = (m.matrixArr[0][0] * m.matrixArr[1][1]) - (m.matrixArr[0][1] *
        return (det)
    elif dims[1] != 2:
        det = 0
        subtract = False
        tempMat = m.SubMatrixList([0],[])
        for i in range(0, dims[1]):
            subMat = None
            subMat = m.SubMatrixList([0],[i])
            if subtract == False:
                det += m.matrixArr[0][i] * Matrix.Determinant(subMat)
                subtract = True
            elif subtract == True:
                det -= m.matrixArr[0][i] * Matrix.Determinant(subMat)
                subtract = False
        return det

def det(m):
    top_length = len(m[0])
    height = top_length - 1
    submats = []

    for i in range(0, top_length):
        submat = [[] for i in range(height)]
        for j in range(0, top_length):
            if i != j:
                for k in range(height):
                    submat[k].append(m[k+1][j])
        submats.append(submat)
    return submats

# Static Methods
@staticmethod
def MatrixAddSubtract(m1, m2, subtract = False): # Dont know how else i woul
    m1Dims = m1.Dimensions()
    m2Dims = m2.Dimensions()
    if m1Dims[0] != m2Dims[0]:
        raise Exception("Matrices␣Row␣Order␣does␣not␣match")
    elif m1Dims[1] != m2Dims[1]:
        raise Exception("Matrices␣Column␣Order␣does␣not␣match")
    elif type(m1) != type():
        raise Exception("Types␣do␣not␣match,␣Convert␣Vector␣to␣Matrix␣or␣vice
    else:
        newMat = Matrix(m1Dims[0], m1Dims[1])
        for y in range(0, m1Dims[0]):
            for x in range(0, m1Dims[1]):
                if subtract:
                    newMat.matrixArr[y][x] = m1.Val()[y][x] - m2.Val()[y][x]
                else:
                    newMat.matrixArr[y][x] = m1.Val()[y][x] + m2.Val()[y][x]
        return newMat

@staticmethod
def MatrixMultiply(m1, m2): # Not that efficient, needs optimisation
    m1Dims = m1.Dimensions()
    m2Dims = m2.Dimensions()
```

```
        if m1Dims[1] != m2Dims[0]:
            raise Exception("Matrices Multiplication Error")
        else:
            if(type(m2) == Vector):
                newMat = Matrix(m1Dims[0], m2Dims[1])
            else:
                newMat = Matrix(m1Dims[0], m2Dims[1])
            for row in range(0, m1Dims[1]):
                subRow = m1.Val()[row][0:m1Dims[1]]
                for col in range(0, m2Dims[1]):
                    subCol = []
                    for i in range(0, m1Dims[0]):
                        print(i)
                        subCol.append(m2.Val()[i][col])
                    total = 0
                    for x in range(0, len(subRow)):
                        total += subRow[x] * subCol[x]
                    newMat.matrixArr[row][col] = total
            return newMat

class Vector(Matrix):
    def __init__(self, val):
        if type(val) == list:
            if len(val[0]) != 1:
                raise Exception("Invalid Vector, use Matrix Instead")
            else:
                self.matrixArr = val
        else:
            self.matrixArr = [[0 for i in range(1)] for j in range(val)]

    def ConvertToMatrix(self):
        return Matrix(self.matrixArr)

    @staticmethod
    def DotProduct(v1,v2):
        if type(v1) != Vector or type(v2) != Vector:
            raise Exception("Wront Types:{},{} passed into Dot Product".format(ty
        else:
            total = 0
            for i in range(v1.Dimensions()[0]):
                total += v1.Val()[i][0] * v2.Val()[i][0]
            return total
```

7. Technical Solution