# ProgrammingAssignment1

January 27, 2024

# 1 0. Imports

[ ]:
```
import math
import numpy as np
import matplotlib as mpl
import matplotlib.pyplot as plt
from random import random, randint
from queue import PriorityQueue
from copy import deepcopy
from time import time
#from google.colab import drive
#drive.mount('/content/gdrive')
```

## 1.1 0.1 Accessibility

[ ]:
```
colorVisionDeficiencyMode = False
```

# 2 1. Helper Classes

## 2.1 1.1 Perlin Noise

[ ]:
```
# Perline noise code courtesy of tgroid on SO
def perlin(x,y,seed=0):
    # permutation table
    np.random.seed(seed)
    p = np.arange(256,dtype=int)
    np.random.shuffle(p)
    p = np.stack([p,p]).flatten()
    # coordinates of the top-left
    xi = x.astype(int)
    yi = y.astype(int)
    # internal coordinates
    xf = x - xi
    yf = y - yi
    # fade factors
    u = fade(xf)
```

```
    v = fade(yf)
    # noise components
    n00 = gradient(p[p[xi]+yi],xf,yf)
    n01 = gradient(p[p[xi]+yi+1],xf,yf-1)
    n11 = gradient(p[p[xi+1]+yi+1],xf-1,yf-1)
    n10 = gradient(p[p[xi+1]+yi],xf-1,yf)
    # combine noises
    x1 = lerp(n00,n10,u)
    x2 = lerp(n01,n11,u)
    return lerp(x1,x2,v)

def lerp(a,b,x):
    "linear interpolation"
    return a + x * (b-a)

def fade(t):
    "6t^5 - 15t^4 + 10t^3"
    return 6 * t**5 - 15 * t**4 + 10 * t**3

def gradient(h,x,y):
    "grad converts h to the right gradient vector and return the dot product␣
 ↪with (x,y)"
    vectors = np.array([[0,1],[0,-1],[1,0],[-1,0]])
    g = vectors[h%4]
    return g[:,:,0] * x + g[:,:,1] * y

if __name__ == 'main':
    lin = np.linspace(0,5,100,endpoint=False)
    x,y = np.meshgrid(lin,lin)

    plt.imshow(perlin(x,y,seed=5),origin='upper')
    plt.show()
```

## 2.2 1.2 Point

[ ]:
```
class Point():

        def __init__(self, posx, posy):
                self.x = posx
                self.y = posy
                self.comparator = math.inf

        def __lt__(self, other):
                return self.comparator < other.comparator

        def __gt__(self, other):
                return self.comparator > other.comparator
```

```
    def __eq__(self, other):
        return self.x == other.x and self.y == other.y
```

## 2.3 1.3 Map

[ ]:
```
def scale(X):
    X = ((X+1)/2 * 255).astype(int)
    return X

class Map():

    def __init__(self, length, width, cost_function='exp',seed=None,
                 filename=None, start=None, goal=None):

        self.seed = seed
        if self.seed == None:
            # Randomly assign seed from 0 to 10k if not provided
            self.seed = randint(0,10000)
        self.length = length
        self.width = width
        self.generateTerrain(filename)
        self.explored = []
        self.explored_lookup = {}
        for i in range(self.width):
            for j in range(self.length):
                self.explored_lookup[str(i)+','+str(j)] = False
        if start == None:
            self.start = Point(int(self.width*0.5),int(self.
↪length*0.5))
        else:
            self.start = Point(start[0], start[1])
        if goal == None:
            self.goal = Point(int((self.width-1)*0.9),int((self.
↪length-1)*0.9))
        else:
            self.goal = Point(goal[0], goal[1])
        if cost_function == 'exp':
            self.cost_function = lambda h0, h1: math.pow(math.
↪e,h1-h0)
        elif cost_function == 'div':
            self.cost_function = lambda h0, h1: h0/(h1+1)
        self.cmap = mpl.colors.ListedColormap(['white', 'red'])
        if colorVisionDeficiencyMode:
            self.cmap = mpl.colors.ListedColormap(['white',␣
↪'magenta'])
```

```
        '''generateTerrain: modifes self.map to either be the specified file, or
        randomly generated from perlin noise.
        input:
        filename - str, string of the npy file to generate the map
        seed - int, integer for reproducibility of a particular map
        octaves - int parameter for perlin noise
        output:
        None, self.map modified'''
        def generateTerrain(self, filename=None):
                if filename is None:
                        linx = np.linspace(0,5,self.width,endpoint=False)
                        liny = np.linspace(0,5,self.length,endpoint=False)
                        x,y = np.meshgrid(linx,liny)
                        self.map = scale(perlin(x, y, seed=self.seed))

                else:
                        self.map = np.load(filename)
                        self.width = self.map.shape[0]
                        self.length = self.map.shape[1]

        def interpolate(self, a0, a1, w):
                if (0.0 > w):
                        return a0
                if (1.0 < w):
                        return a1
                return (a1 - a0) * ((w * (w * 6.0 - 15.0) + 10.0) * w ** 3) + a0

        def calculatePathCost(self, path):
                prev = path[0]
                if self.start != prev:
                        print('Path does not start at start. Path starts at␣
↪point: ' , str(prev.x),
                                ',', str(prev.y))
                        return math.inf
                cost = 0
                for item in path[1:]:
                        if self.isAdjacent(prev, item):
                                cost += self.getCost(prev, item)
                                prev = item
                        else:
                                print('Path does not connect at points: ',␣
↪str(prev.x), ',', str(prev.y),
                                        ' and ', str(item.x), ',', str(item.y))
                                return math.inf
                if prev != self.goal:
```

```
                        print('Path does not end at goal. Path ends at point: '␣
↪, str(prev.x),
                                ',', str(prev.y))
                        return math.inf
                return cost

        def validTile(self, x, y):
                return x >= 0 and y >= 0 and x < self.width and y < self.length

        '''def validTile(self, p1):
                return self.validTile(p1.x, p1.y)'''

        def getTile(self, x, y):
                return self.map[x][y]

        '''def getTile(self, p1):
                return self.getTile(p1.x, p1.y)'''

        def getCost(self, p1, p2):
                h0 = self.getTile(p1.x, p1.y)
                h1 = self.getTile(p2.x, p2.y)
                return self.cost_function(h0, h1)

        def isAdjacent(self, p1, p2):
                return (abs(p1.x - p2.x) == 1 or abs(p1.y - p2.y)) == 1 and␣
↪(abs(p1.x - p2.x) < 2 and abs(p1.y - p2.y) < 2)

        def getNeighbors(self, p1):
                neighbors = []
                for i in [-1, 0, 1]:
                        for j in [-1, 0, 1]:
                                if i == 0 and j == 0:
                                        continue
                                possible_point = Point(p1.x + i, p1.y + j)
                                if self.validTile(possible_point.x,␣
↪possible_point.y):
                                        neighbors.append(possible_point)
                                        if not self.
↪explored_lookup[str(possible_point.x)+','+str(possible_point.y)]:
                                                self.
↪explored_lookup[str(possible_point.x)+','+str(possible_point.y)] = True
                                                self.explored.
↪append(possible_point)
                return neighbors

        def getStartPoint(self):
```

```python
            return self.start

    def getEndPoint(self):
            return self.goal

    def getHeight(self):
            return np.amax(self.map)

    '''Creates a 2D image of the path taken and nodes exploroed, prints
    pathcost and number of nodes explored'''
    def createImage(self, path):
            img = self.map
            path_img = np.zeros_like(self.map)
            explored_img = np.zeros_like(self.map)
            for item in self.explored:
                    explored_img[item.x, item.y] = 1
            path_img_x = [item.x for item in path]
            path_img_y = [item.y for item in path]
            print('Path cost:', self.calculatePathCost(path))
            print('Nodes explored: ', len(self.explored) + len(path))
            plt.imshow(img, cmap='gray')
            plt.imshow(explored_img, cmap=self.cmap, alpha=0.3)
            plt.plot(path_img_y, path_img_x, color='blue', linewidth=1)
            plt.show()

    '''Set the start and goal point on the 2D map, each point is a pair of␣
↪integers'''
    def setStartGoal(self, start, goal):
            self.start = Point(np.clip(start[0], 0, self.length-1), np.
↪clip(start[1], 0, self.width-1))
            self.goal = Point(np.clip(goal[0], 0, self.length-1), np.
↪clip(goal[1], 0, self.width-1))
```

# 3 2. AI Modules

You'll write your code here!

## 3.1 2.1 AI Module & Dijkstras

[ ]:
```python
'''AIModule Interface
createPath(map map_) -> list<points>: Adds points to a path'''
class AIModule:

    def createPath(self, map_):
            raise NotImplementedError
```

```
'''
A sample AI that takes a very suboptimal path.
This is a sample AI that moves as far horizontally as necessary to reach
the target, then as far vertically as necessary to reach the target.
It is intended primarily as a demonstration of the various pieces of the
program.
'''
class StupidAI(AIModule):

        def createPath(self, map_):
                path = []
                explored = []
                # Get starting point
                path.append(map_.start)
                current_point = deepcopy(map_.start)

                # Keep moving horizontally until we match the target
                while(current_point.x != map_.goal.x):
                        # If we are left of goal, move right
                        if current_point.x < map_.goal.x:
                                current_point.x += 1
                        # If we are right of goal, move left
                        else:
                                current_point.x -= 1
                        path.append(deepcopy(current_point))

                # Keep moving vertically until we match the target
                while(current_point.y != map_.goal.y):
                        # If we are left of goal, move right
                        if current_point.y < map_.goal.y:
                                current_point.y += 1
                        # If we are right of goal, move left
                        else:
                                current_point.y -= 1
                        path.append(deepcopy(current_point))

                # We're done!
                return path

class Dijkstras(AIModule):

        def createPath(self, map_):
                q = PriorityQueue()
                ''' Maintain three dictionaries to keep track of cost ("x,y" ->␣
↪cost per
                node), previous (node -> parent). This keeps track of paths,␣
↪and explored
```

```
                which helps us run faster by ignoring nodes already visited'''
                cost = {}
                prev = {}
                explored = {}
                # Dictionary initialization
                for i in range(map_.width):
                        for j in range(map_.length):
                                cost[(i,j)] = math.inf
                                prev[(i,j)] = None
                                explored[(i,j)] = False
                current_point = deepcopy(map_.start)
                current_point.comparator = 0
                cost[(current_point.x, current_point.y)] = 0
                # Add start node to the queue
                q.put(current_point)
                # Search loop
                while q.qsize() > 0:
                        # Get new point from PQ
                        v = q.get()
                        if explored[(v.x,v.y)]:
                                continue
                        explored[(v.x,v.y)] = True
                        # Check if popping off goal
                        if v == map_.getEndPoint():
                                break
                        # Evaluate neighbors
                        neighbors = map_.getNeighbors(v)
                        for neighbor in neighbors:
                                alt = map_.getCost(v, neighbor) + cost[(v.x,v.
↪y)]

                                if alt < cost[(neighbor.x,neighbor.y)]:
                                        cost[(neighbor.x,neighbor.y)] = alt
                                        neighbor.comparator = alt
                                        prev[(neighbor.x,neighbor.y)] = v
                                q.put(neighbor)
                # Find and return path
                path = []
                while v != map_.getStartPoint():
                        path.append(v)
                        v = prev[(v.x,v.y)]
                path.append(map_.getStartPoint())
                path.reverse()
                return path
```

### 3.2 2.2 AIExp and AIMSH

Here, specifically

Heuristic for Exponential Cost Function $cost(h_0, h_1) = e^{(h_1 - h_0)} - 1$ We know that the true cost of the path includes multiple nodes with height differences. The heuristic only considers the direct height difference between the goal and the current node. It subtracts 1 to never overestimate the actual cost, and when the goal is reached, the cost is zero. Thus, this heuristic is admissible.

Heuristic for Divisional Cost Function $cost(h_0, h_1) = \frac{1}{|h_1 - h_0| + 1}$ We know that the true cost between any 2 nodes with a height difference is at least 1. The heuristic will always provide a value that is less than or equal to 1. Thus, the heuristic never overestimates the cost and is admissible.

[ ]:
```
class AStar(AIModule):
    def heuristic(self, map_, node):
        raise NotImplementedError

    def createPath(self, map_):
        q = PriorityQueue()
        ''' Maintain three dictionaries to keep track of cost ("x,y" -> cost per
        node), previous (node -> parent). This keeps track of paths, and␣
↪explored
        which helps us run faster by ignoring nodes already visited'''
        cost, prev, explored = {}, {}, {}

        for i in range(map_.width):
            for j in range(map_.length):
                cost[(i,j)], prev[(i,j)], explored[(i,j)] = math.inf, None,␣
↪False

        current_point = deepcopy(map_.start)
        current_point.comparator = 0
        cost[(current_point.x, current_point.y)] = 0

        # Add start node to the queue
        q.put(current_point)

        # Search loop
        while q.qsize() > 0:
            # Get new point from PQ
            v = q.get()
            if explored[(v.x,v.y)]:
               continue

            explored[(v.x,v.y)] = True

            # Check if popping off goal
            if v == map_.getEndPoint():
               break

            # Evaluate neighbors
            neighbors = map_.getNeighbors(v)
```

```
            for neighbor in neighbors:
                alt = map_.getCost(v, neighbor) + cost[(v.x,v.y)]
                if alt < cost[(neighbor.x,neighbor.y)]:
                    cost[(neighbor.x,neighbor.y)] = alt
                    neighbor.comparator = alt + self.heuristic(map_, neighbor)
                    prev[(neighbor.x,neighbor.y)] = v
                q.put(neighbor)

        # Find and return path
        path = []
        while v != map_.getStartPoint():
            path.append(v)
            v = prev[(v.x,v.y)]

        path.append(map_.getStartPoint())
        path.reverse()
        return path

class AStarExp(AStar):

    def heuristic(self, map_, node):
        h_goal = map_.getTile(map_.goal.x, map_.goal.y)
        h_n = map_.getTile(node.x, node.y)
        delta_h = h_goal - h_n

        dx = abs(map_.goal.x - node.x)
        dy = abs(map_.goal.y - node.y)
        # chebyshev distance
        delta_d = max(dx, dy)

        heuristic = math.exp(h_goal - h_n) - 1

        # uphill
        if delta_h > 0:
            heuristic = delta_d + (delta_h * .98)
        # downhill
        elif delta_h < 0:
            heuristic = delta_d - (delta_h * 1.02)
        # flat
        elif delta_h == 0:
            heuristic = delta_d

        # heuristic cannot be negative
        if heuristic < 0:
            raise ValueError('heuristic is negative')

        return heuristic * .2
```

```python
class AStarDiv(AStar):

    def heuristic(self, map_, node):
        h_goal = map_.getTile(map_.goal.x, map_.goal.y)
        h_n = map_.getTile(node.x, node.y)

        heuristic = 1 / (abs(h_goal - h_n) + 1)

        # heuristic cannot be negative
        if heuristic < 0:
            raise ValueError('heuristic is negative')

        return heuristic

class AStarMSH(AStar):

    def heuristic(self, map_, node):
        h_goal = map_.getTile(map_.goal.x, map_.goal.y)
        h_n = map_.getTile(node.x, node.y)
        delta_h = h_goal - h_n

        dx = abs(map_.goal.x - node.x)
        dy = abs(map_.goal.y - node.y)
        # chebyshev distance
        delta_d = max(dx, dy)

        heuristic = math.exp(h_goal - h_n) - 1

        # uphill
        if delta_h > 0:
            heuristic = delta_d + (delta_h * .98)
        # downhill
        elif delta_h < 0:
            heuristic = delta_d - (delta_h * 1.02)
        # flat
        elif delta_h == 0:
            heuristic = delta_d

        # heuristic cannot be negative
        if heuristic < 0:
            raise ValueError('heuristic is negative')

        return heuristic * .2

    def createPath(self, map_):
        q = PriorityQueue()
```

```python
        cost, prev, explored = {}, {}, {}
        weight = 1.1  # weight for the weighted A*

        for i in range(map_.width):
            for j in range(map_.length):
                cost[(i,j)], prev[(i,j)], explored[(i,j)] = math.inf, None, False

        current_point = deepcopy(map_.start)
        current_point.comparator = 0
        cost[(current_point.x, current_point.y)] = 0
        q.put(current_point)

        while q.qsize() > 0:
            v = q.get()
            if explored[(v.x,v.y)]:
                continue

            explored[(v.x,v.y)] = True

            if v == map_.getEndPoint():
                break

            neighbors = map_.getNeighbors(v)
            for neighbor in neighbors:
                alt = map_.getCost(v, neighbor) + cost[(v.x,v.y)]
                if alt < cost[(neighbor.x,neighbor.y)]:
                    cost[(neighbor.x,neighbor.y)] = alt
                    heuristic = self.heuristic(map_, neighbor)
                    # dynamic weighting
                    # decrease weight as it gets closer to the goal
                    # dynamic_weight = lambda: (alt + (2 * weight - 1) * heuristic) / weight if alt < heuristic else (alt + heuristic) / weight
                    # increase weight as it gets closer to the goal
                    dynamic_weight = lambda: alt + heuristic if alt < heuristic else (alt + (1.5 * weight - 1) * heuristic) / weight
                    neighbor.comparator = alt + (heuristic * dynamic_weight())
                    prev[(neighbor.x,neighbor.y)] = v
                q.put(neighbor)

        path = []
        while v != map_.getStartPoint():
            path.append(v)
            v = prev[(v.x,v.y)]

        path.append(map_.getStartPoint())
        path.reverse()
```

```
        return path
```

# 4 3. Run

## 4.1 3.1 Setup

w(int): Width of map

l(int): Length of map

start(array-like): Start position

goal(array-like): Goal position

seed(int): Seed for random generation

AI(AIModule): AI agent to use. Use any of the following: AStarExp, AStarDiv, AStarMSH, Djikstras

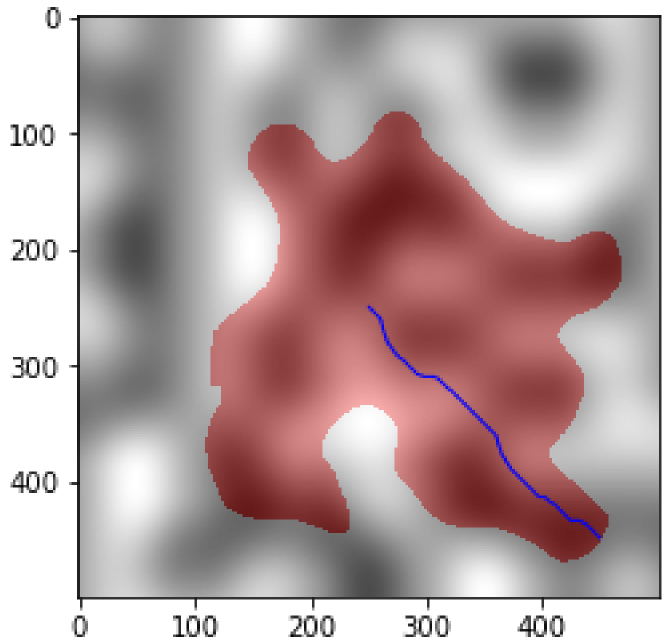
filename(string): Filepath for .npy file to be used for map

[ ]:
```
w = 500
l = 500
start = None
goal = None
seed = 0
cost_function = 'exp'
#cost_function = 'div'
AI = AStarExp()
filename = None
```

## 4.2 3.2 Run

[ ]:
```
m = Map(w,l, seed=seed, cost_function = cost_function, filename=filename,
        start=start, goal=goal)
t1 = time()
path = AI.createPath(m)
t2 = time()
print('Time (s): ', t2-t1)
m.createImage(path)
```

```
Time (s):  7.475179672241211
Path cost: 241.55253710831192
Nodes explored:  87576
```




# 5 4. Tests

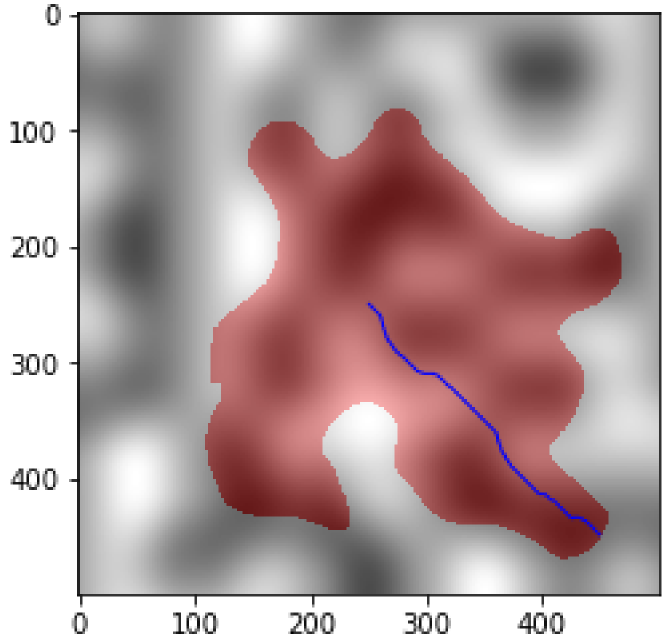
## 5.1 4.1 AStarExp

[ ]:
```
cost_function = 'exp'
```

[ ]:
```
w = 500
l = 500
start = None
goal = None
seed = 0
# Change to AStarExp() after implemented
AI = AStarExp()
filename = None

m = Map(w,l, seed=seed, cost_function = cost_function, filename=filename,
        start=start, goal=goal)
t1 = time()
path = AI.createPath(m)
t2 = time()
print('Time (s): ', t2-t1)
m.createImage(path)
```

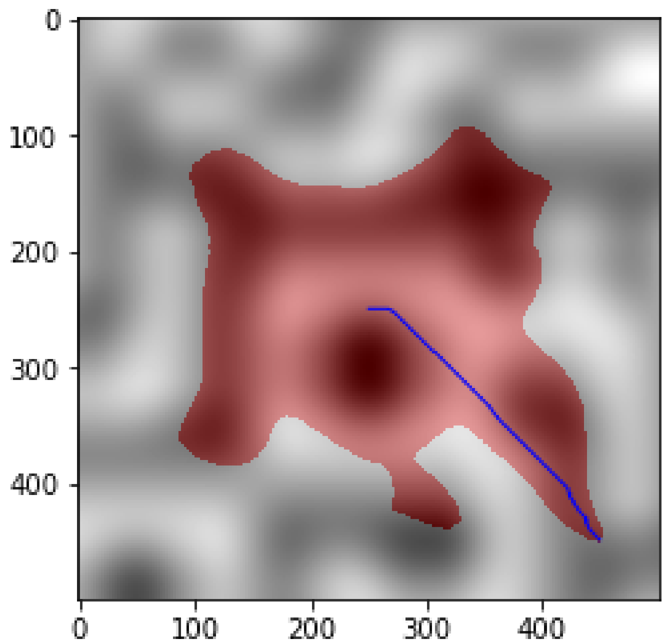
```
Time (s):  7.973608016967773
Path cost: 241.55253710831192
```

```
Nodes explored:  87576
```



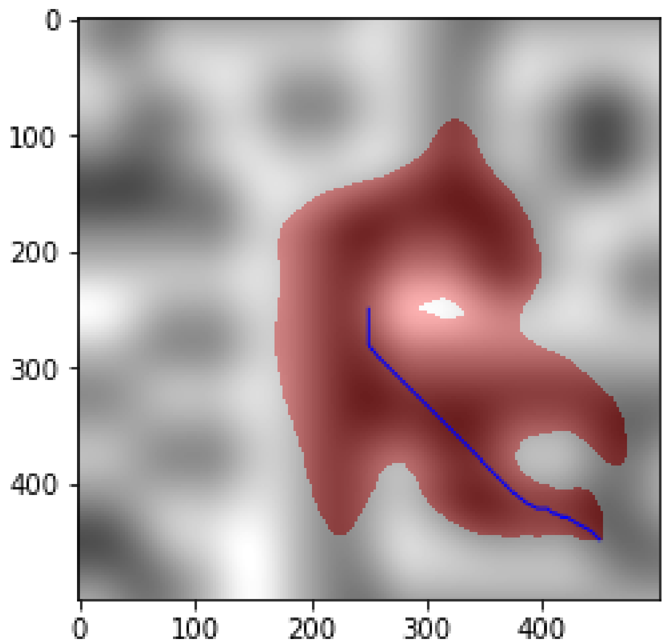

```
[ ]: seed = 1

     m = Map(w,l, seed=seed, filename=filename, start=start, goal=goal)
     t1 = time()
     path = AI.createPath(m)
     t2 = time()
     print('Time (s): ', t2-t1)
     m.createImage(path)
```

```
Time (s):  7.191416025161743
Path cost: 238.5060683830129
Nodes explored:  79604
```



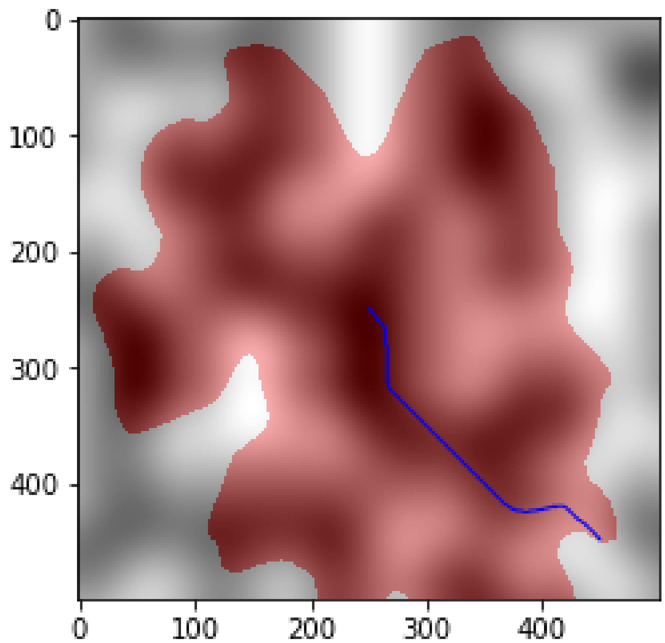

[ ]:
```
seed = 2

m = Map(w,l, seed=seed, filename=filename, start=start, goal=goal)
t1 = time()
path = AI.createPath(m)
t2 = time()
print('Time (s): ', t2-t1)
m.createImage(path)
```

```
Time (s):  5.870873928070068
Path cost: 236.667690049357
Nodes explored:  68511
```



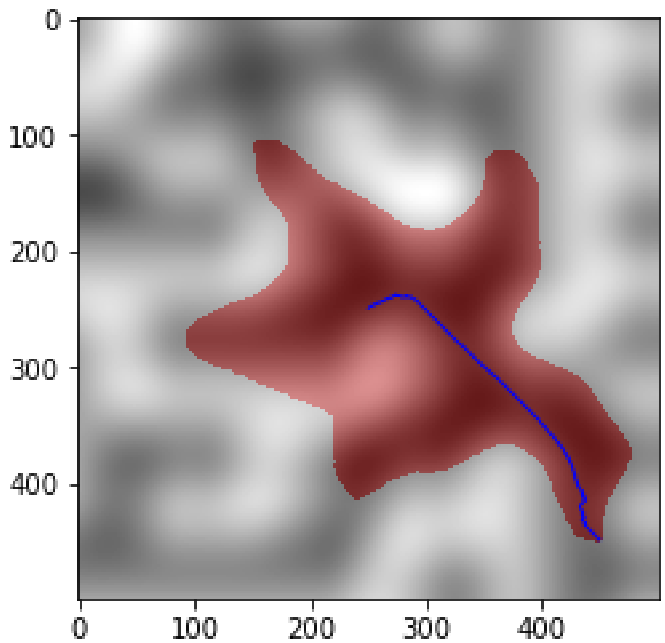

[ ]:
```
seed = 3

m = Map(w,l, seed=seed, filename=filename, start=start, goal=goal)
t1 = time()
path = AI.createPath(m)
t2 = time()
print('Time (s): ', t2-t1)
m.createImage(path)
```

```
Time (s):  13.061457395553589
Path cost: 422.01798243905006
Nodes explored:  151506
```




```
[ ]: seed = 4

     m = Map(w,l, seed=seed, filename=filename, start=start, goal=goal)
     t1 = time()
     path = AI.createPath(m)
     t2 = time()
     print('Time (s): ', t2-t1)
     m.createImage(path)
```

```
Time (s):  5.11358380317688
Path cost: 254.34464507852198
Nodes explored:  63366
```

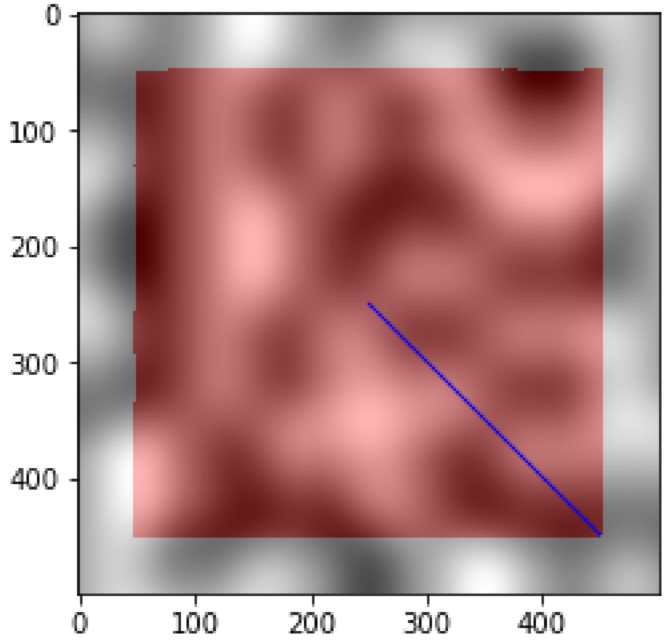



## 5.2 4.1 AStarDiv

[ ]:
```
cost_function = 'div'
```

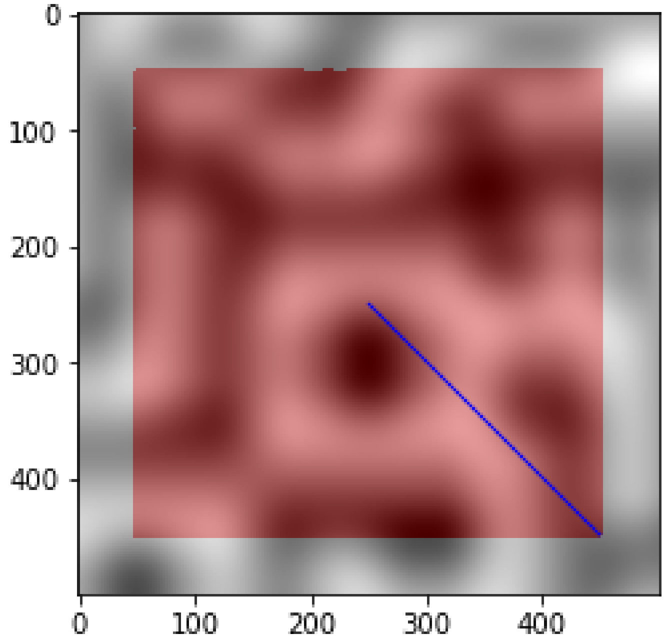
[ ]:
```
w = 500
l = 500
start = None
goal = None
seed = 0
# Change to AStarDiv() after implemented
AI = AStarDiv()
filename = None

m = Map(w,l, seed=seed, cost_function = cost_function, filename=filename,
        start=start, goal=goal)
t1 = time()
path = AI.createPath(m)
t2 = time()
print('Time (s): ', t2-t1)
m.createImage(path)
```

```
Time (s):  11.879684448242188
Path cost: 197.67690128917357
Nodes explored:  162023
```



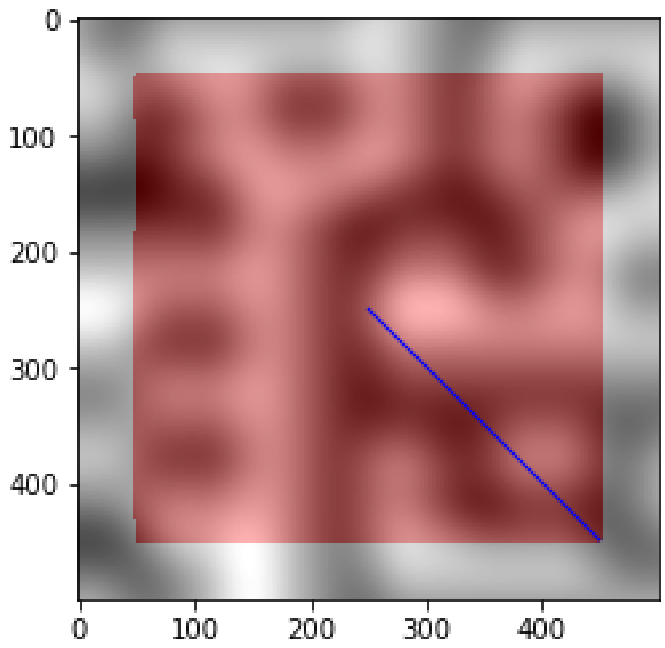

[ ]:
```
seed = 1

m = Map(w,l, seed=seed, cost_function = cost_function, filename=filename,
        start=start, goal=goal)
t1 = time()
path = AI.createPath(m)
t2 = time()
print('Time (s): ', t2-t1)
m.createImage(path)
```

```
Time (s):  11.10111379623413
Path cost: 197.71721595331226
Nodes explored:  162536
```



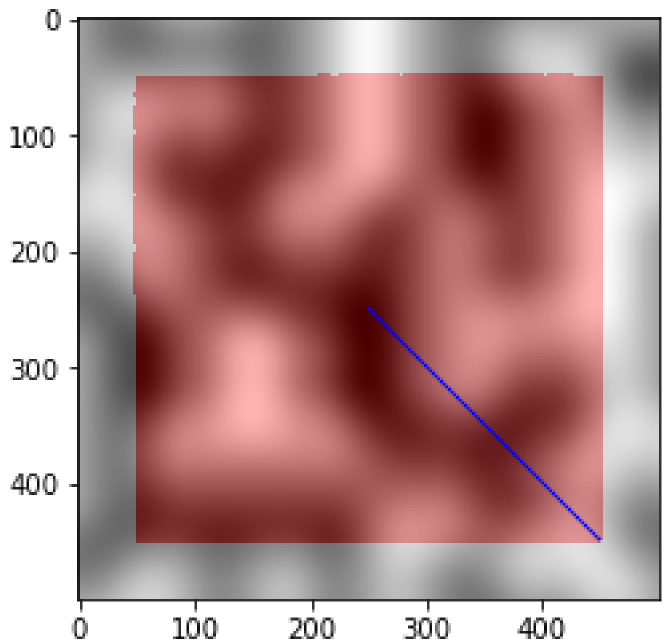

```
[ ]: seed = 2

     m = Map(w,l, seed=seed, cost_function = cost_function, filename=filename,
             start=start, goal=goal)
     t1 = time()
     path = AI.createPath(m)
     t2 = time()
     print('Time (s): ', t2-t1)
     m.createImage(path)
```

```
Time (s):  11.698748111724854
Path cost: 197.58110211547168
Nodes explored:  162288
```



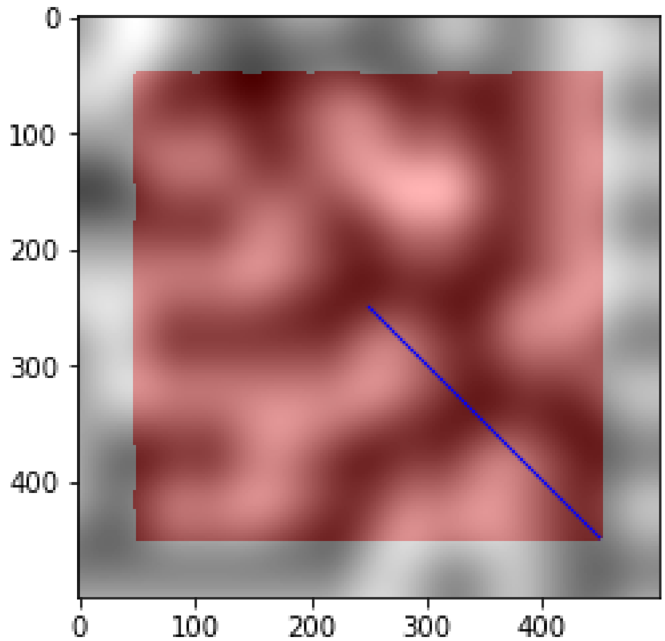

[ ]:
```
seed = 3

m = Map(w,l, seed=seed, cost_function = cost_function, filename=filename,
        start=start, goal=goal)
t1 = time()
path = AI.createPath(m)
t2 = time()
print('Time (s): ', t2-t1)
m.createImage(path)
```

```
Time (s):  11.317492723464966
Path cost: 196.29556836229682
Nodes explored:  161896
```




[ ]:
```
seed = 4

m = Map(w,l, seed=seed, cost_function = cost_function, filename=filename,
        start=start, goal=goal)
t1 = time()
path = AI.createPath(m)
t2 = time()
print('Time (s): ', t2-t1)
m.createImage(path)
```

```
Time (s):  11.312933921813965
Path cost: 197.24829713437708
Nodes explored:  162268
```

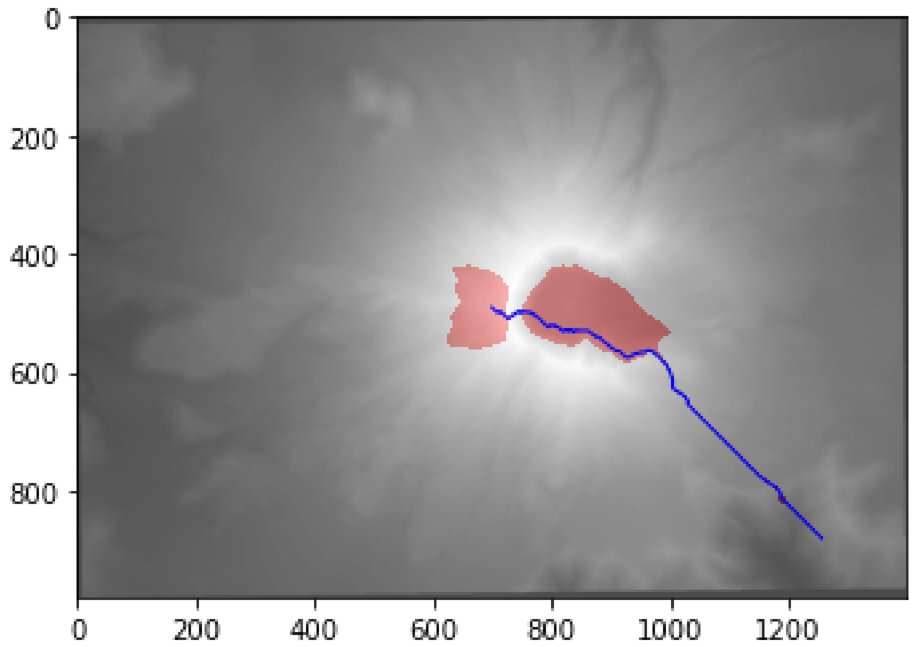



### 5.3 4.2 MSH

Weighted A* uses a weighted heuristic and multiplies it by a constant factor. This encourages the algorithm to explore paths closer to the goal, even if they are not the cheapest ones. Weighted A* significantly reduces the time to find a solution compared to A*, especially in large or complex search spaces. However, the path found may not be optimal.

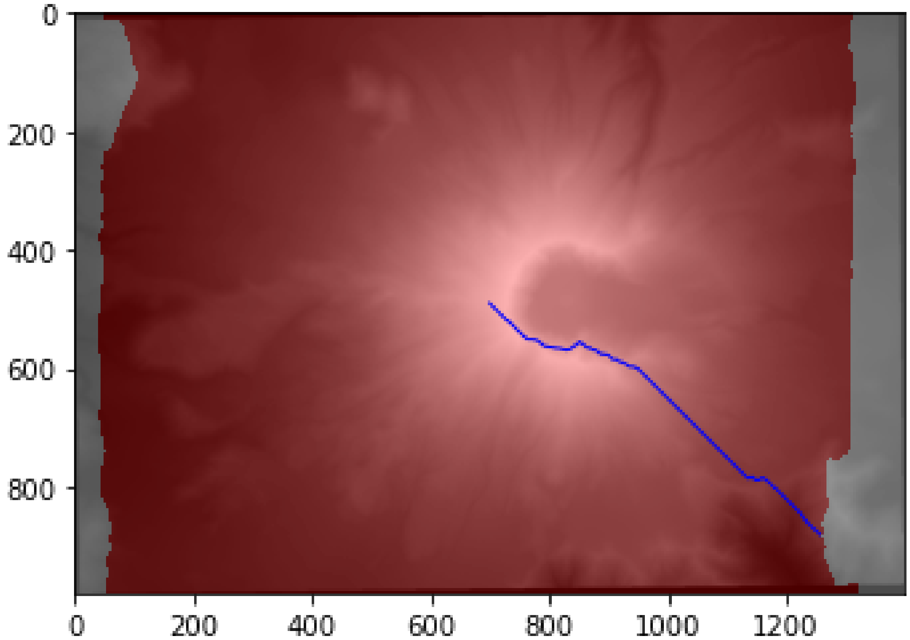
[ ]:
```
w = 500
l = 500
start = None
goal = None
seed = 0
# Change to AStarMSH() after implemented
AI = AStarMSH()
# AI = Dijkstras()
# Change to the filepath on your drive
filename = r'C:\Users\russe\Desktop\Code\ECS170-Artificial_Intelligence\msh.npy'

m = Map(w,l, seed=seed, filename=filename, start=start, goal=goal)
t1 = time()
path = AI.createPath(m)
t2 = time()
print('Time (s): ', t2-t1)
m.createImage(path)
```

```
Time (s):  4.508168935775757
Path cost: 587.933672548331
Nodes explored:  39048
```




```
[ ]: AI = Dijkstras()
m = Map(w,l, seed=seed, filename=filename, start=start, goal=goal)
t1 = time()
path = AI.createPath(m)
t2 = time()
print('Time (s): ', t2-t1)
m.createImage(path)
```

```
Time (s):  84.78116345405579
Path cost: 515.2967010603603
Nodes explored:  1218683
```


0
200
400
600
800
0
200
400
600
800
1000
1200