Import all necessary Packages

In [1]:

```
import random
from IPython.display import clear_output
import time
from scipy import array, newaxis
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.pyplot import figure
from scipy.interpolate import interp2d
```

Initiate the character map, specify the tile class and house class.

In [2]:

```
character_map = {0:"□",1:"□",2:"□",'W':"□", 'bot':"□"}

class tile():
  def __init__(self, position, cleanliness=0, wall = False, bot = False):
    #Capture the directions to the left, right, bottom and top as per Von Neumann neighbourhoods.
    #Capture the cleanliness, positions and also markers for visits and if the bot is on the cell
    self.position = position
    self.cleanliness = cleanliness
    self.right = (position[0],position[1]+1)
    self.left = (position[0],position[1]-1)
    self.bottom = (position[0]+1,position[1])
    self.top = (position[0]-1,position[1])
    self.bot = False
    self.visit = 0


class house_c(tile):
  def __init__(self, obstacles = 5, dimensions = (15,15), mess = "Very Dirty"):
    self.dimensions = dimensions
    self.house = house = [[0]*dimensions[1] for row in range(dimensions[0])]
    self.walls = 3
    self.obstacles = obstacles
    self.mess = mess

  def add_walls(self):
    #To keep things simple, we just add walls on horizontal walls with at most half the room
length
    half_length = self.dimensions[1]//2
    #generate 3 random walls that dont coincide with the house walls so betweeen dimension-1, non
inclusive
    wall_rows = random.sample(range(2, self.dimensions[1]-1),min(self.obstacles, half_length))
    for row in wall_rows:
      #Spawn a wall of randomlength between 1 and half_length. We limit walls to a minimum 2
length
      wall_length = random.randint(2, half_length)
      #Starting position for the wall. It must be before the midroom so any wall fits
      start_pos = random.randint(0, self.dimensions[1]//2)
      for tile in range(start_pos, start_pos+wall_length):
        self.house[row][tile].wall = True
        self.house[row][tile].cleanliness = "W"
    return None


  #This function spawns a house. By defaultm the house cleanliness is dirty in case the option sel
ected is wrong.
  #We populate the tiles with a cleanliness leve as specified by the use.
  def spawn_house(self):
    clean = 2
    for row in range(self.dimensions[1]):
      for cell in range(self.dimensions[0]):
        #Make the house messy
        if self.mess == "Very Dirty":
          pass
        elif self.mess == "Random":
          clean = random.randint(0,2)
        elif self.mess == "Slightly Clean":
          clean = 1
        elif self.mess == "Clean":
          clean = 0
        self.house[cell][row] = tile(position = (cell, row), cleanliness = clean)
    self.add_walls()
    return self.house

  #A string method to output the house as per the character map.
  def __str__(self):
    full = []
    for row in self.house:
      cur_row = []
      for tile in row:
        if not tile.bot:
          cur_row.append(character_map[tile.cleanliness])
        else:
          cur_row.append(character_map["bot"])
      full.append("".join(cur_row))
    print("########## WELCOME TO MY HOUSE! ###########")
    print(f"It is {self.mess}")
    print("And be careful, the walls have ears, literally.\n")
    return "\n".join(full)
```

This is an initialization of the roomba class. It needs to know the house it is serving. Some utility functions are included to help when programming the bot.

In [3]:

```
class roomba():
  #Initiate the roomba bot.
  #Markers for the strategies like random bounce and wall walking are specified.
  def __init__(self, house, wall_walking = True, random_bounce = True, start = (0,0), delay =1,mini
mum_visits = True):
    self.wall_walking = wall_walking
    self.random_bounce = random_bounce
    self.start = start
    self.house = house
    self.movement = {"Right":(0,1), "Left":(0, -1), "Top":(-1, 0), "Bottom":(1, 0), "Current":(0,0)
    self.direction = None
    self.delay = delay
    self.minimum_visits = minimum_visits
    self.count_steps = 0
  """
  -This utility function determines the level of cleanliness of the house.
  -A roomba user can determine this then program the roomba to run tiil it feels it
  -has collected as much dirt to leave the room in a cleanliness proportion specified.
  """
  def check_clean(self):
    dirt = 0
    for row in self.house.house:
      for tile in row:
        if tile.cleanliness !="W":
          try:
            dirt+=int(tile.cleanliness)
          except:
            pass
    return dirt
  """
  -This utility function gets the roomba position and tells it where it can go.
  -Depending on activated strategies, it can favor wall crawling or random bouncing or both.
  -The situations are discussed in tha paper/
  """
  def possible_directions(self, bot_position):
    feasible = {"Current":bot_position}
    neighbor_clean = {"Current":self.house.house[bot_position[0]][bot_position[1]].cleanliness}
    direction = None
    #There are only 4 possible directions
    direction_keys = list(self.movement.keys())

    for direction in direction_keys:
      next_row = bot_position[0]+self.movement[direction][0]
      next_col = bot_position[1]+self.movement[direction][1]
      """
      -If the tiles are outside the house span, we will skip them
      -Nonetheless, these are our wall markers so we might want to keep track of the wally
neighbors so as to follow them
      """
      if next_row <0 or next_col <0 or  next_row >=self.house.dimensions[0] or next_col>=self.house
.dimensions[1]:
        continue

      else:
        """
        -If the tiles are withn the span are walls, we will skip them, otherwise we can move to th
em
        -We move at random whether the floor is clean or not but focus will force us to sty if a t
ile is too dirty
        """
        next_tile_cleanliness = self.house.house[next_row][next_col].cleanliness

        if next_tile_cleanliness is not "W":
          feasible[direction] = (next_row, next_col)
          neighbor_clean[direction] = self.house.house[next_row][next_col].cleanliness

    #For efficiency, if there are any neighbors dirty, we will not visit clean neighbors again thu
s prioritizing dirty spots
    if sum(list(neighbor_clean.values()))>0:
      #Random bounce tells the system to jump to a random dirty cell if any. Otherwise move in a r
andom direction
      if self.random_bounce:
        for direction in list(feasible.keys()):
          if neighbor_clean[direction] == 0:
            del feasible[direction]

      #Atop the clean elimination, if wall following is enabled, we will favor the wall direction
if no dirty tile is seen.
      priority = []
      """
      -Under the same constraint, if wall walkingis enabled, we basicallt prioritize the
directions
      -That walk the wall in the feasible set and eliminate the others.
      -Affinity for dirty preceeds the wall walk either way so if we encounter a dirty cell not on
the wall
      -and a cleaner one ahead, we will stop the wall walk. This is if
      """
      if self.wall_walking:
        if len(feasible)>1:
          for direction in list(feasible.keys()):
            next_row = bot_position[0]+self.movement[direction][0]
            next_col = bot_position[1]+self.movement[direction][1]
            if direction =="Top" or direction == "Bottom":
              if bot_position[1]+1>=self.house.dimensions[1] or bot_position[1]-1<0 or
self.house.house[bot_position[0]][bot_position[1]+1].cleanliness == 'W' or self.house.house[bot_pos
ition[0]][bot_position[1]-1].cleanliness == 'W':
                priority.append(direction)

            elif direction == "Right" or direction == "Left":
              if bot_position[0]+1>=self.house.dimensions[0] or  bot_position[0]-1<0 or self.house.
ouse[bot_position[0]+1][bot_position[1]].cleanliness=="W" or self.house.house[bot_position[0]-1][bo
t_position[1]].cleanliness=="W":
                priority.append(direction)

      """
      -A check to ensure we limit our options to sensible ones.
      -The bot behaves randomly when in a clean room since the sum of neighbors cleanlines is 0
      -This means they have no dirtiness.
      """
      if len(priority)<len(feasible) and len(priority)>0:
        for direction in list(feasible.keys()):
          if direction in priority:
            continue
          else:
            del feasible[direction]
    return (feasible, neighbor_clean)

  #A utility function to produce a heatmap.
  def heatmap(self):
      x_list = [x for x in range(self.house.dimensions[1])]
      y_list = [y for y in range(self.house.dimensions[0])]
      z_list = []
      for ys in y_list:
        for xs in x_list:
          z_list.append(house1.house[xs][ys].visit)


      f = interp2d(x_list,y_list,z_list,kind="linear")

      x_coords = np.arange(min(x_list),max(x_list)+1)
      y_coords = np.arange(min(y_list),max(y_list)+1)
      Z = f(x_coords,y_coords)
      figure(num=None, figsize=(10, 10), dpi=80, facecolor='w', edgecolor='k')
      fig = plt.imshow(Z,
                 extent=[min(x_list),max(x_list),min(y_list),max(y_list)],
                 origin="lower")

      fig.axes.set_autoscale_on(False)
      plt.scatter(x_list,y_list,400,facecolors='none')
      plt.gca().invert_yaxis()
      plt.show()

  """
  This function initiates the movement.
  -Parameters such as focus tell us if we stick to a dirty cell untill it is clean.
  -Clean level is the goal state of how clean we want our house. This gives the bot
  -an idea of how much cleaning it will have done till it stops.
  -Blink is for when we want an animated version of the bot in action.
  -Out_steps is the steps moved before we show the state currently we are in.
  -Have a high out_step for big houses to limit the output.
  """
  def initiate_traversal(self, focus,fin, clean_level, blink =True, heatmap = True, out_steps=20):
    #Check how clean the house is
    dirt = self.check_clean()
    original = dirt
    target_clean = dirt*clean_level
    count_steps = 0
    #Run till we feel we have collected enough dirt to make the room clean to desired levels.
    while target_clean<dirt:
      proportion_cleaned = dirt/original
      #Get the current bot tile as is
      bot_tile = self.house.house[self.start[0]][self.start[1]]
      #Put the bot in starting tile
      self.house.house[self.start[0]][self.start[1]].bot = True
      self.house.house[self.start[0]][self.start[1]].visit +=1
      next_data = self.possible_directions(bot_tile.position)
      possible_directions = next_data[0]

      """
      -Minimum visits is my proposed third setting.This tells the bot to favor visiting cells it
      -Has not visited yet. It especially helps prevent sticking too much in a clean patch.
      -If the bot stays in a place for too long, it eventually favors moving away as it detects th
is.
      """
      if self.minimum_visits:
        min_vals = list(possible_directions.values())[0]
        min_vis = self.house.house[min_vals[0]][min_vals[1]].visit
        for direc in list(possible_directions.keys()):
          cur_vis = self.house.house[possible_directions[direc][0]][possible_directions[direc][1]].
visit
          if cur_vis<=min_vis:
            direction = direc
            min_vis = cur_vis
      else:
        #Otherwise, we will move in a random direction
        direction = random.choice(list(possible_directions.keys()))
      if focus:
        #Focus is for when we want to clean any dirty patch to completion
        if self.house.house[self.start[0]][self.start[1]].cleanliness >0:
          direction = "Current"
          self.house.house[self.start[0]][self.start[1]].visit +=2

      else:
        del possible_directions["Current"]
        #Clean bot tile then move bot in direction specified
        self.house.house[self.start[0]][self.start[1]].cleanliness = max((int(bot_tile.cleanliness)-1
),0)
        #Blink check
        if blink:
          clear_output()

        #Output checks
        if count_steps%out_steps == 0 or proportion_cleaned==0:
          if fin:
              print(f"Proportion Remaining = {proportion_cleaned}")
              print(f"Possible directions: {possible_directions}")
              print(self.house)

        #Heatmap checks
        if heatmap and count_steps%out_steps == 0 or proportion_cleaned==0:
          self.heatmap()
          print(f"\nNext step direction: {direction}")
        self.house.house[self.start[0]][self.start[1]].bot = False
        self.start = (self.start[0]+self.movement[direction][0], self.start[1]+self.movement[directio
n][1])
        #A delay that facilitates the blink system
        if blink and count_steps%out_steps == 0 or proportion_cleaned==0:
          time.sleep(self.delay)
        dirt =  self.check_clean()
        count_steps+=1
      self.count_steps = count_steps




    #Our parent function that initiates the cleaning and tells us the final state.
    def clean(self,clean_level, focus,blink =True, heatmap = True, out_steps=20, fin = True):
        self.initiate_traversal(focus = focus, clean_level = clean_level, blink =blink, heatmap = hea
tmap,  out_steps=out_steps, fin=fin)
        if fin:
            print("FINAL STATE OF THE HOUSE")
            print(f"Moves made: {self.count_steps}")
            print(self.house)
            self.heatmap()
        return self.count_steps
```

Test Individual Strategies performance

In [4]:

```
random_bounce = []
wall_walk = []
minimum_visit = []
#Each house will have Its own instance since this is modified during cleaning.
copy1 =  house_c(obstacles = 1, mess = "Random", dimensions  =(10, 10))
copy2 =  house_c(obstacles = 1, mess = "Random", dimensions  =(10, 10))
copy3 =  house_c(obstacles = 1, mess = "Random", dimensions  =(10, 10))

for i in range(1000):
    #Spawn a house
    copy1.spawn_house()
    copy2.spawn_house()
    copy3.spawn_house()

    #Initiate the roombas
    roombaRB = roomba(house = copy1, delay = 1, start = (0,0),wall_walking =False,
                 random_bounce = True, minimum_visits = True)
    roombaWW = roomba(house = copy2, delay = 1, start = (0,0),wall_walking =True,
                 random_bounce = False, minimum_visits = False)
    roombaMV = roomba(house = copy3, delay = 1, start = (0,0),wall_walking =False,
                 random_bounce = False, minimum_visits = True)

    #And lets dance!!!
    rb = roombaRB.clean(clean_level=0, focus =True, blink =False, heatmap = False, out_steps=100000
00, fin=False)
    ww = roombaWW.clean(clean_level=0, focus =True, blink =False, heatmap = False, out_steps=100000
00, fin=False)
```

```
    mv = roombaMV.clean(clean_level=0, focus =True, blink =False, heatmap = False, out_steps=100000
00, fin=False)

    random_bounce.append(rb)
    wall_walk.append(ww)
    minimum_visit.append(mv)
```

In [6]:

```
import numpy as np, scipy.stats as stats
import seaborn as sns

def mean_confidence_interval(data, confidence=0.95):
    data = np.array(data)
    return stats.norm.interval(confidence, loc=np.mean(data), scale=np.std(data))

confints_rb = mean_confidence_interval(np.array(random_bounce))
confints_ww = mean_confidence_interval(wall_walk)
confints_mv = mean_confidence_interval(minimum_visit)

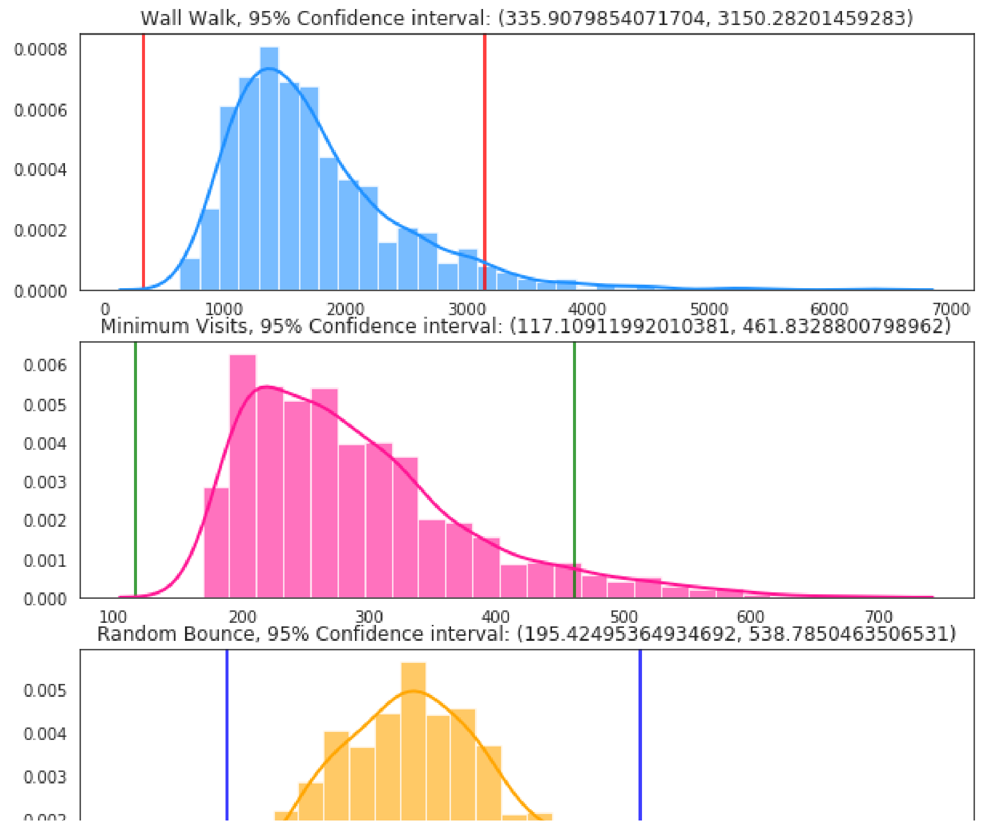
sns.set_style("white")

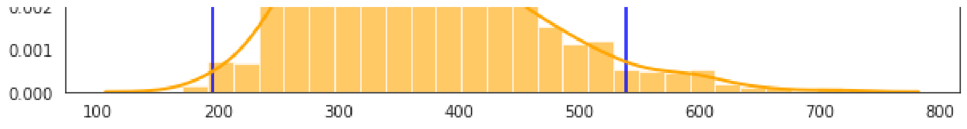
kwargs = dict(hist_kws={'alpha':.6}, kde_kws={'linewidth':2})

fig = plt.figure()
fig.set_size_inches(10, 10)
ax1 = fig.add_subplot(311)
ax1.axvline(x=confints_ww[0], color = "r")
ax1.axvline(x=confints_ww[1], color = "r")
sns.distplot(wall_walk, color="dodgerblue", label="Wall Walk", **kwargs)
ax1.set_title(f"Wall Walk, 95% Confidence interval: {(confints_ww[0], confints_ww[1])}")
ax2 = fig.add_subplot(312)
ax2.axvline(x=confints_mv[0], color = "g")
ax2.axvline(x=confints_mv[1], color = "g")
sns.distplot(minimum_visit, color="deeppink", label="Minimum Visits", **kwargs)
ax2.set_title(f"Minimum Visits, 95% Confidence interval: {(confints_mv[0], confints_mv[1])}")

ax3 = fig.add_subplot(313)
ax3.axvline(x=confints_rb[0], color = "b")
ax3.axvline(x=confints_rb[1], color = "b")
sns.distplot(random_bounce, color="orange", label="Random Bounce", **kwargs)
ax3.set_title(f"Random Bounce, 95% Confidence interval: {(confints_rb[0], confints_rb[1])}")

plt.show()
```





For our original simulations, these are the histograms

In [7]:

```
rb = []
ww_rb = []
mv_rb_ww = []

for i in range(1000):
    #Spawn a house
    copy1.spawn_house()
    copy2.spawn_house()
    copy3.spawn_house()

    #Initiate the roombas
    roombaRB = roomba(house = copy1, delay = 1, start = (0,0),wall_walking =False,
                random_bounce = True, minimum_visits = False)
    roombaWWRB = roomba(house = copy2, delay = 1, start = (0,0),wall_walking =True,
                random_bounce = True, minimum_visits = False)
    roombaMVRBWW = roomba(house = copy3, delay = 1, start = (0,0),wall_walking =True,
                random_bounce = True, minimum_visits = True)

    #And lets dance!!!
    rbi = roombaRB.clean(clean_level=0, focus =True, blink =False, heatmap = False, out_steps=10000
000, fin=False)
    ww_rbi = roombaWWRB.clean(clean_level=0, focus =True, blink =False, heatmap = False, out_steps=
10000000, fin=False)
    mv_rb_wwi = roombaMVRBWW.clean(clean_level=0, focus =True, blink =False, heatmap = False, out_s
teps=10000000, fin=False)

    rb.append(rbi)
    ww_rb.append(ww_rbi)
    mv_rb_ww.append(mv_rb_wwi)
```

In [8]:

```
confints_rb = mean_confidence_interval(np.array(rb))
confints_ww = mean_confidence_interval(ww_rb)
confints_mv = mean_confidence_interval(mv_rb_ww)

sns.set_style("white")

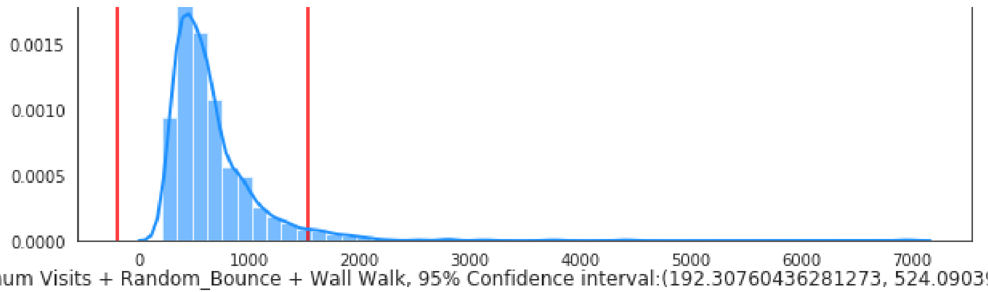
kwargs = dict(hist_kws={'alpha':.6}, kde_kws={'linewidth':2})

fig = plt.figure()
fig.set_size_inches(10, 10)
ax1 = fig.add_subplot(311)
ax1.axvline(x=confints_ww[0], color = "r")
ax1.axvline(x=confints_ww[1], color = "r")
sns.distplot(ww_rb, color="dodgerblue", label="Wall Walk", **kwargs)
ax1.set_title(f"Wall Walk + Random Bounce, 95% Confidence interval: {(confints_ww[0],
confints_ww[1])}")
ax2 = fig.add_subplot(312)
ax2.axvline(x=confints_mv[0], color = "g")
ax2.axvline(x=confints_mv[1], color = "g")
sns.distplot(mv_rb_ww, color="deeppink", label="Minimum Visits", **kwargs)
ax2.set_title(f"Minimum Visits + Random_Bounce + Wall Walk, 95% Confidence interval:
{(confints_mv[0], confints_mv[1])}")

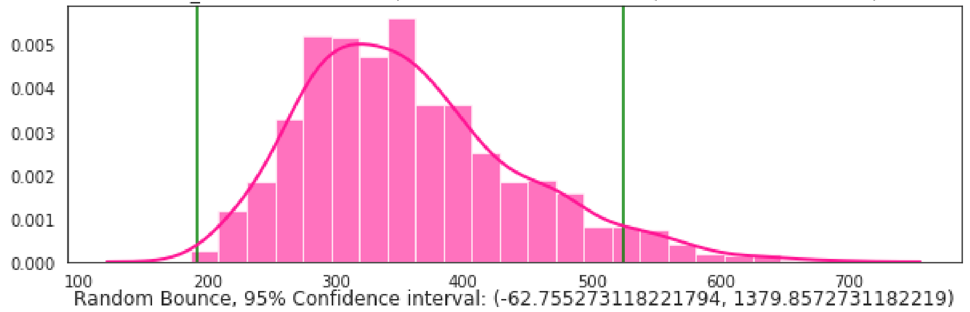
ax3 = fig.add_subplot(313)
ax3.axvline(x=confints_rb[0], color = "b")
ax3.axvline(x=confints_rb[1], color = "b")
sns.distplot(rb, color="orange", label="Random Bounce", **kwargs)
ax3.set_title(f"Random Bounce, 95% Confidence interval: {(confints_rb[0], confints_rb[1])}")

plt.show()
```

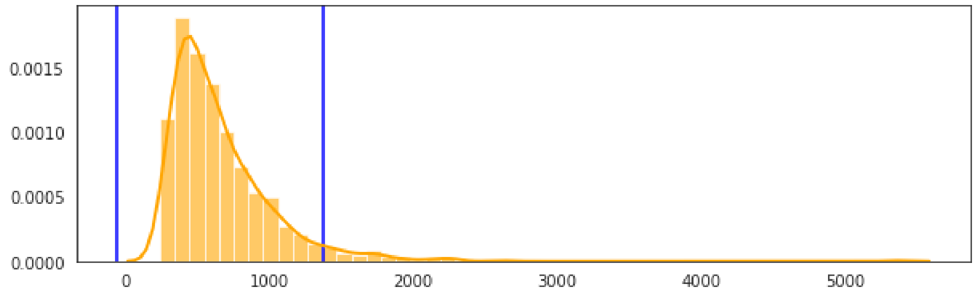
Wall Walk + Random Bounce, 95% Confidence interval: (-197.71400715706523, 1529.7180071570651)



Minimum Visits + Random_Bounce + Wall Walk, 95% Confidence interval:(192.30760436281273, 524.0903956371873)



Random Bounce, 95% Confidence interval: (-62.755273118221794, 1379.8572731182219)



Demonstrations.

1. No minimized visits, no wall walking, just random bounce

In [ ]:

```
house1 = house_c(obstacles = 5, mess = "Random", dimensions  =(10, 10))
house1.spawn_house()


roomba1 = roomba(house = house1, delay = 1, start = (0,0),wall_walking =False,
                 random_bounce = True, minimum_visits = False)
roomba1.clean(clean_level=0, focus =True, blink =True, heatmap = True, out_steps=1)
```

```
Proportion Remaining = 0.011764705882352941
Possible directions: {'Current': (1, 9)}
########## WELCOME TO MY HOUSE! ###########
It is Random
And be careful, the walls have ears, literally.

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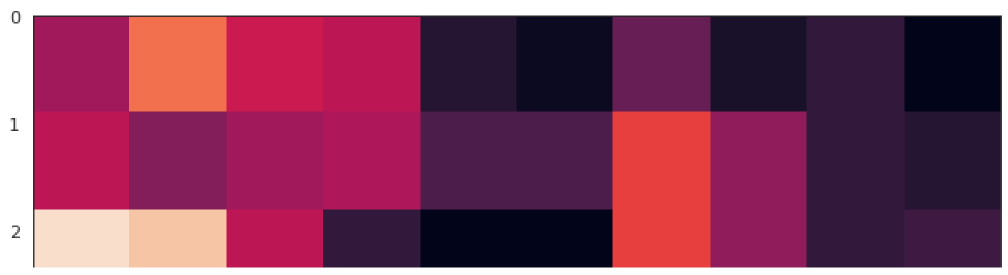

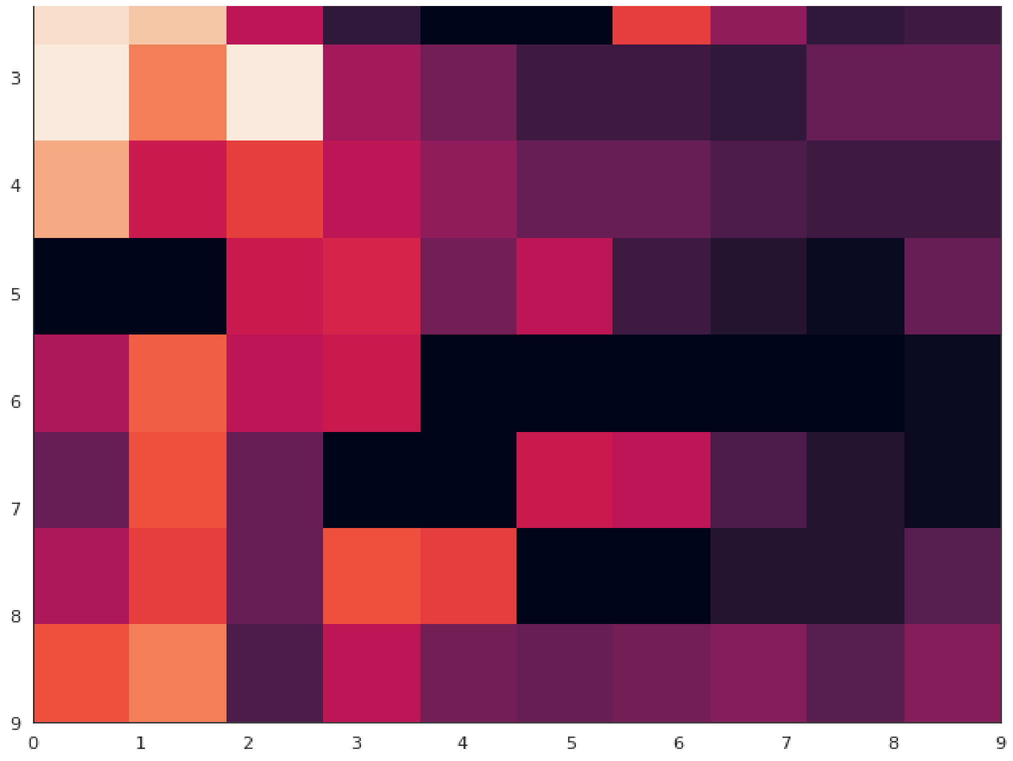

```
Next step direction: Current
FINAL STATE OF THE HOUSE
Moves made: 778
########## WELCOME TO MY HOUSE! ###########
It is Random
And be careful, the walls have ears, literally.

□□□□□□□□□□□
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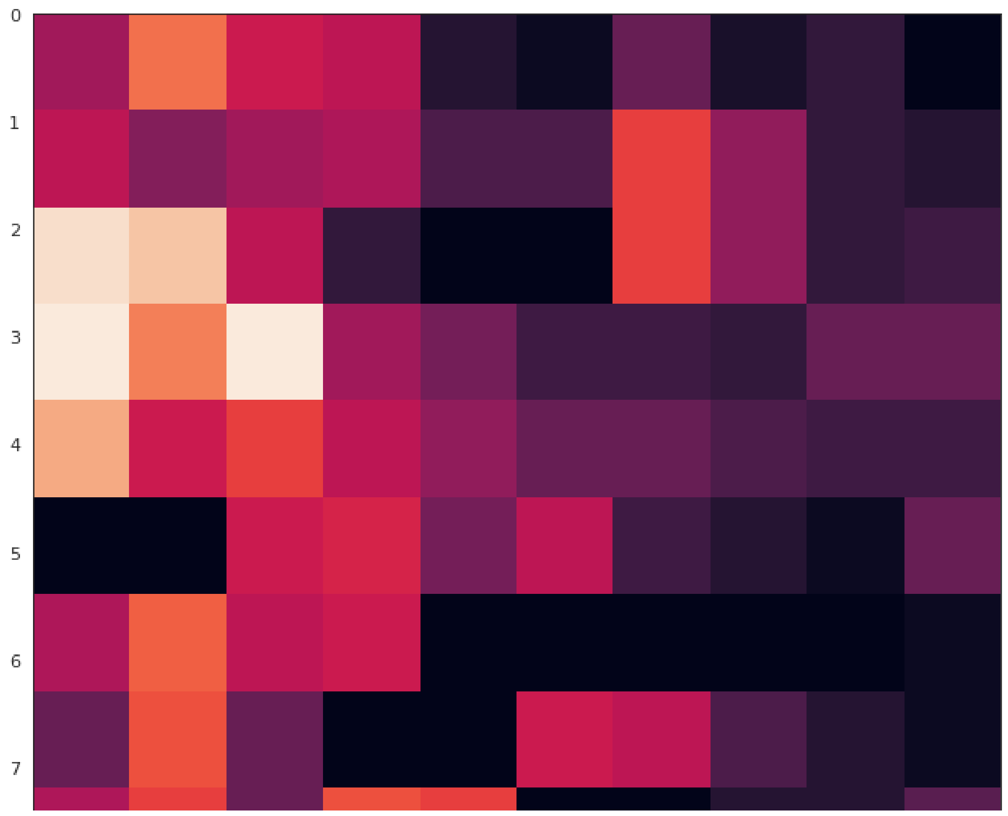
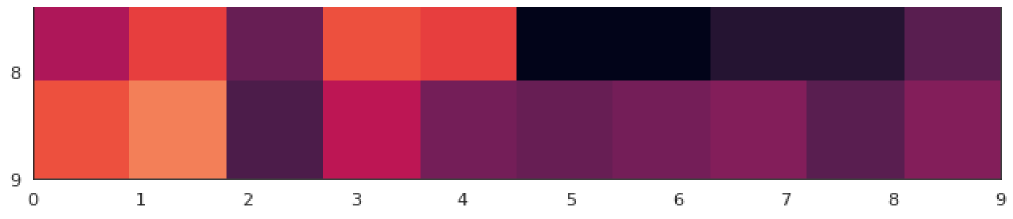
```





Out[ ]:

```
778
```

In [ ]:

```python
house1 = house_c(obstacles = 5, mess = "Random", dimensions  =(10, 10))
house1.spawn_house()


roomba1 = roomba(house = house1, delay = 1, start = (0,0),wall_walking =True,
                 random_bounce = True, minimum_visits = False)
roomba1.clean(clean_level=0, focus =True, blink =True, heatmap = True, out_steps=1)
```

```
Proportion Remaining = 0.011627906976744186
Possible directions: {'Current': (9, 9)}
########## WELCOME TO MY HOUSE! ###########
It is Random
And be careful, the walls have ears, literally.

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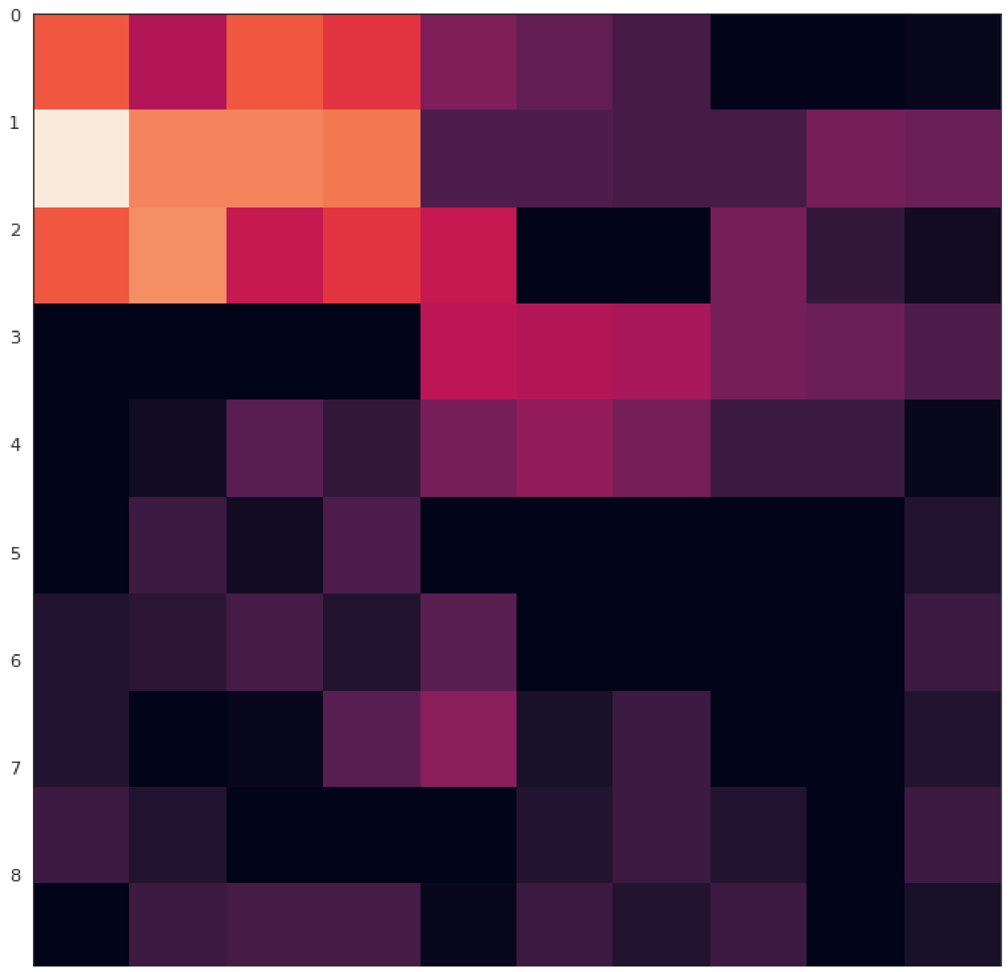

```
Next step direction: Current
FINAL STATE OF THE HOUSE
Moves made: 656
########## WELCOME TO MY HOUSE! ###########
It is Random
And be careful, the walls have ears, literally.

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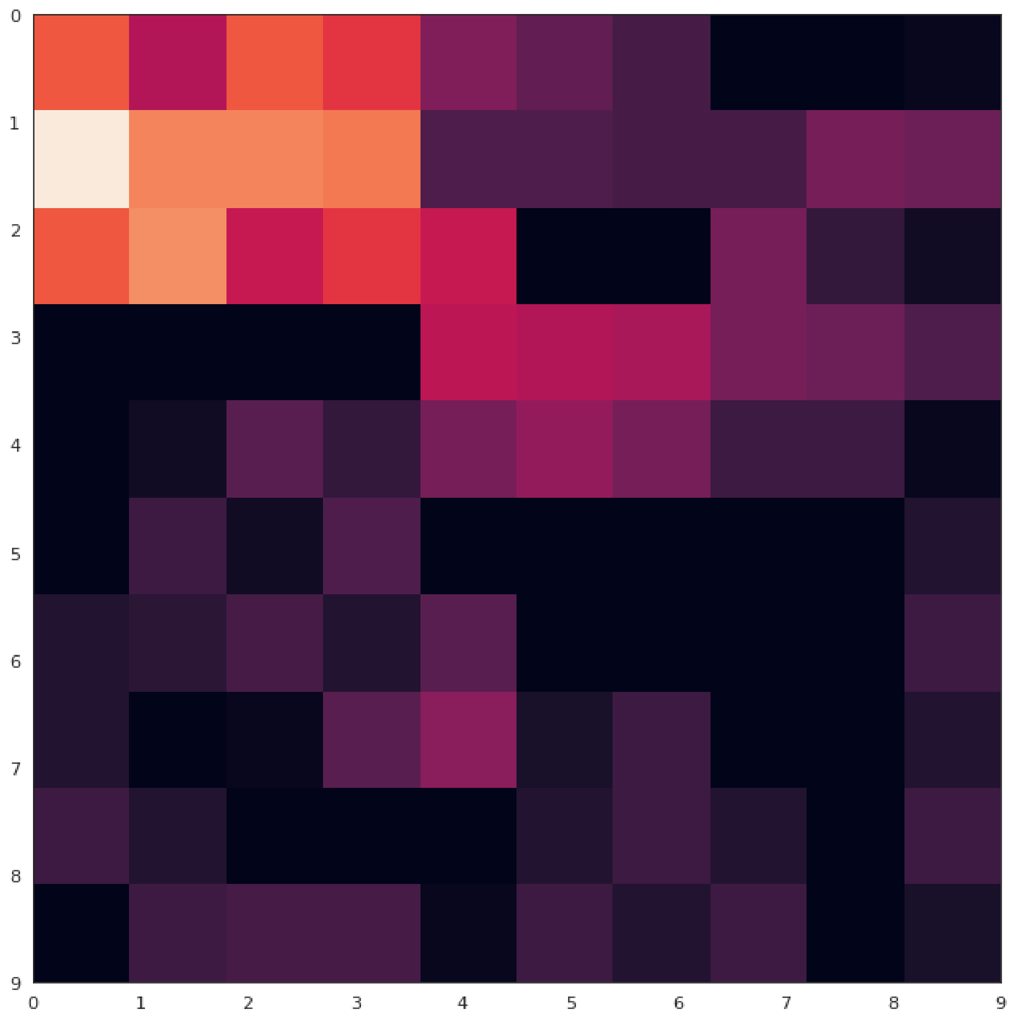

Out[ ]:

```
656
```

In [ ]:

```python
house1 = house_c(obstacles = 5, mess = "Random", dimensions  =(10, 10))
house1.spawn_house()


roomba1 = roomba(house = house1, delay = 1, start = (0,0),wall_walking =True,
                 random_bounce = True, minimum_visits = True)
roomba1.clean(clean_level=0, focus =True, blink =True, heatmap = True, out_steps=1)
```

```
Proportion Remaining = 0.05555555555555555
Possible directions: {'Current': (4, 5), 'Right': (4, 6), 'Top': (3, 5), 'Bottom': (5, 5)}
```

```
########## WELCOME TO MY HOUSE! ###########
It is Random
And be careful, the walls have ears, literally.

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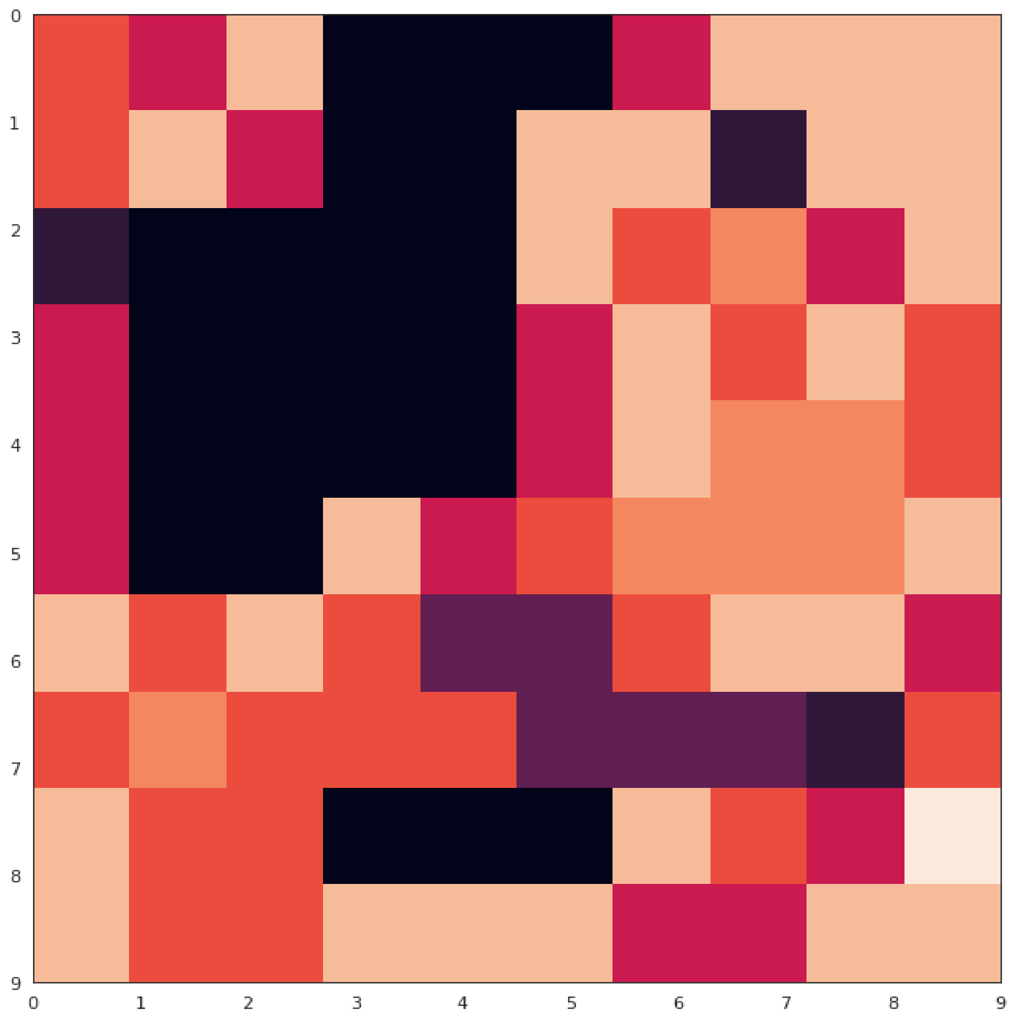

```
Next step direction: Top
```

For coverage

Only Random Bounce

In [11]:

```
house1 = house_c(obstacles = 20, mess = "Random", dimensions  =(50, 50))
house1.spawn_house()


roomba1 = roomba(house = house1, delay = 1, start = (0,0),wall_walking =False,
                 random_bounce = True, minimum_visits = False)
roomba1.clean(clean_level=0, focus =True, blink =False, heatmap = True, out_steps=1000000000)
```

```
Proportion Remaining = 1.0
Possible directions: {'Right': (0, 1), 'Bottom': (1, 0)}
########## WELCOME TO MY HOUSE! ###########
It is Random
```

And be careful, the walls have ears, literally.

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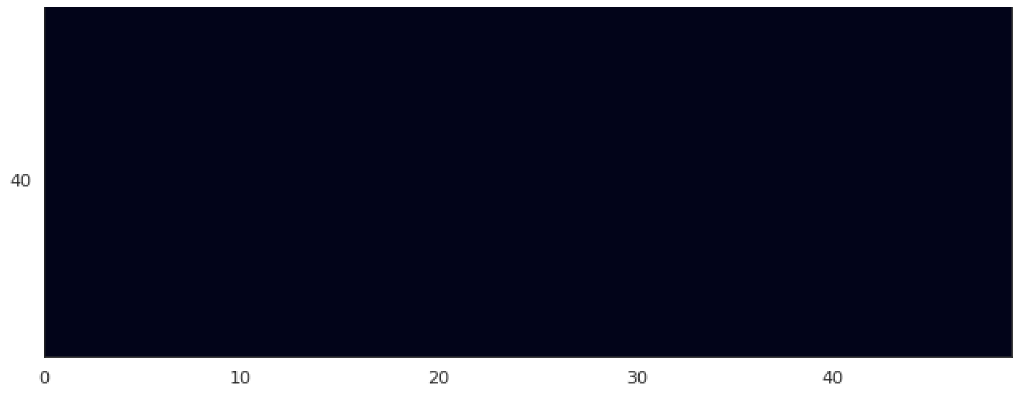

```
Next step direction: Right
FINAL STATE OF THE HOUSE
Moves made: 185140
########## WELCOME TO MY HOUSE! ###########
It is Random
And be careful, the walls have ears, literally.

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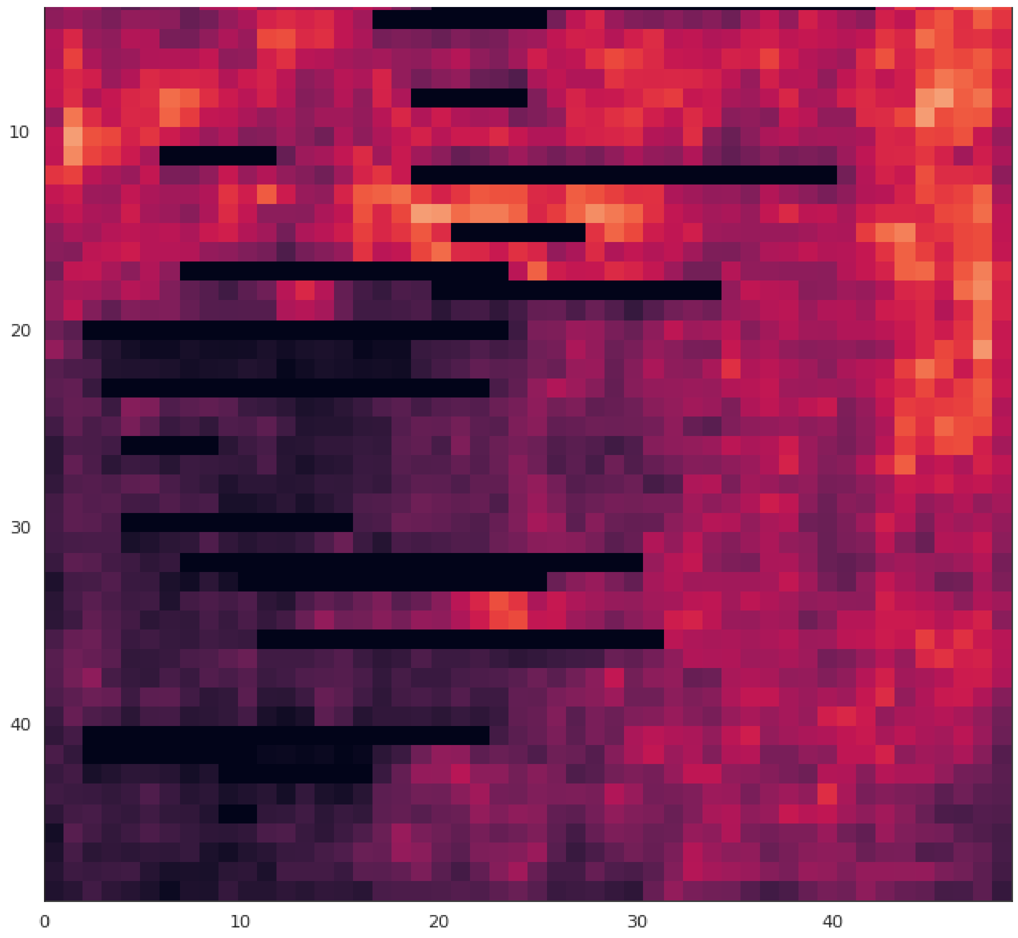

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Out[11]:
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Random Bounce +Wall Walk

```
In [10]:
```

```python
house1 = house_c(obstacles = 20, mess = "Random", dimensions  =(50, 50))
house1.spawn_house()


roomba1 = roomba(house = house1, delay = 1, start = (0,0),wall_walking =True,
                 random_bounce = True, minimum_visits = False)
roomba1.clean(clean_level=0, focus =True, blink =False, heatmap = True, out_steps=10000000)
```

```
Proportion Remaining = 1.0
Possible directions: {'Right': (0, 1), 'Bottom': (1, 0)}
########## WELCOME TO MY HOUSE! ###########
It is Random
And be careful, the walls have ears, literally.

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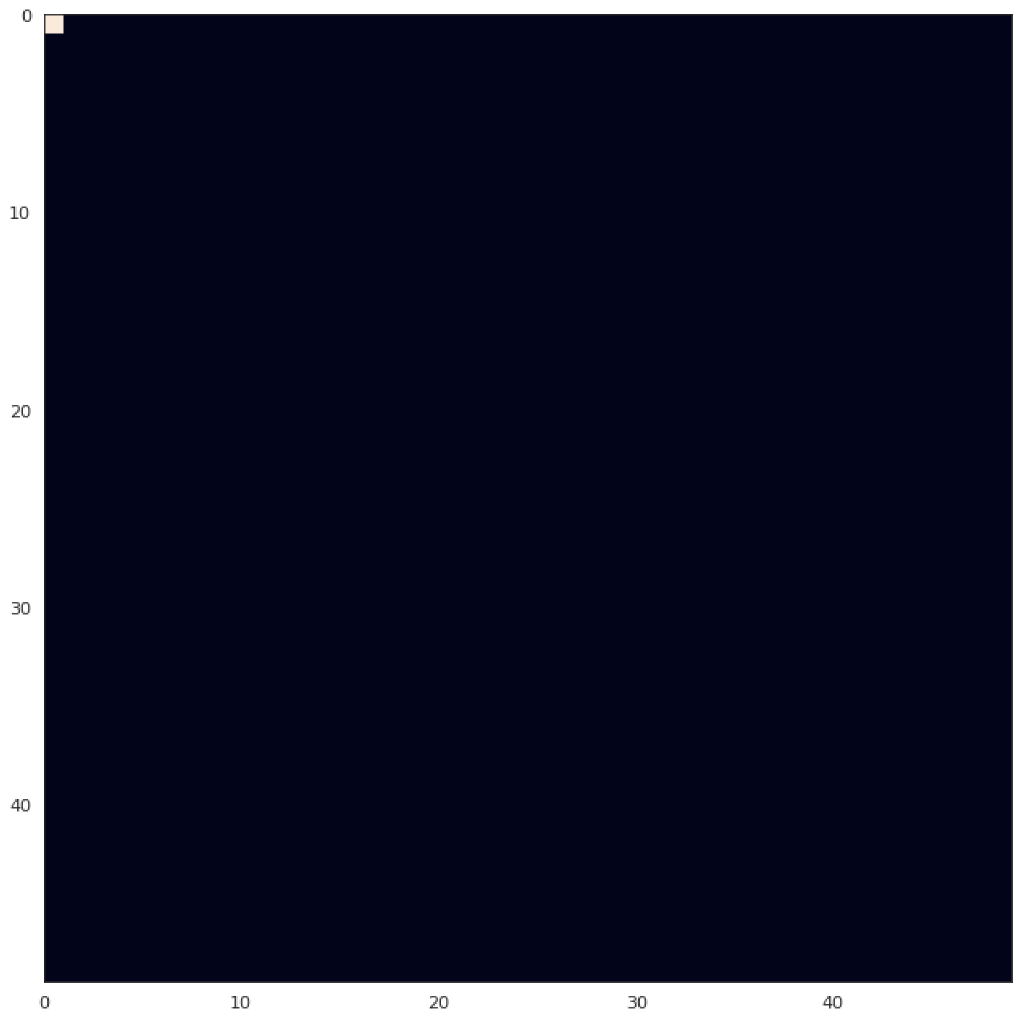

```
Next step direction: Current
FINAL STATE OF THE HOUSE
Moves made: 79157
########## WELCOME TO MY HOUSE! ###########
It is Random
```

And be careful, the walls have ears, literally.

```
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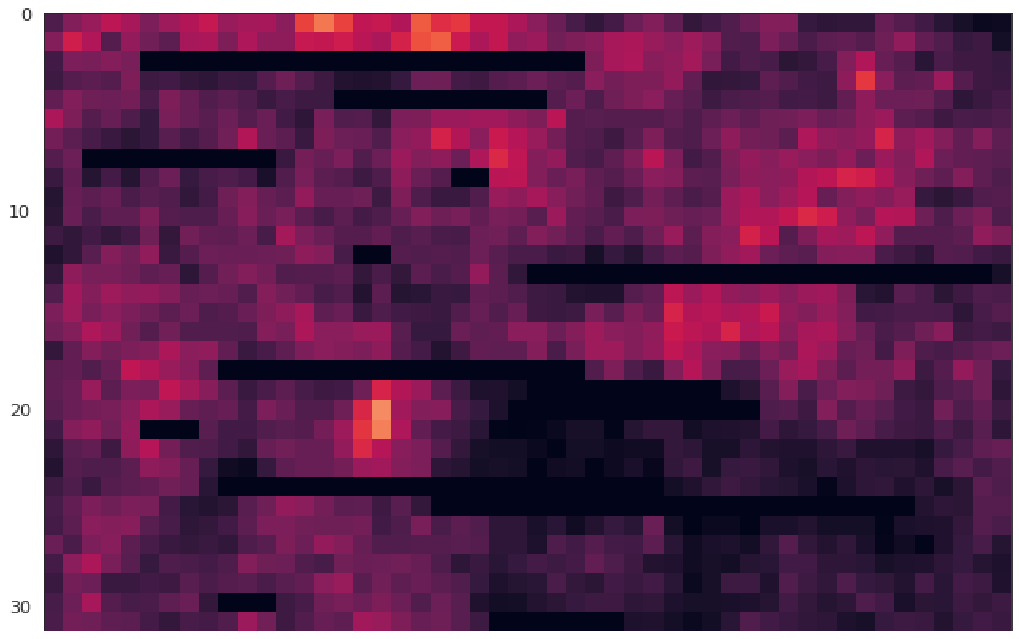

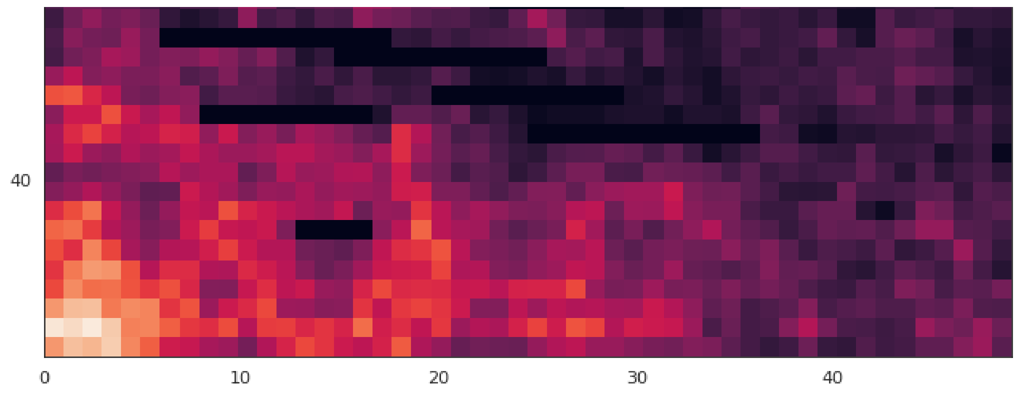

```
Out[10]:
```

```
79157
```

Random Bounce +Wall Walk + Minimum Visits

```
In [12]:
```

```python
house1 = house_c(obstacles = 20, mess = "Random", dimensions  =(50, 50))
house1.spawn_house()


roomba1 = roomba(house = house1, delay = 1, start = (0,0),wall_walking =True,
               random_bounce = True, minimum_visits = True)
roomba1.clean(clean_level=0, focus =True, blink =False, heatmap = True, out_steps=10000000)
```

```
Proportion Remaining = 1.0
Possible directions: {'Right': (0, 1)}
########## WELCOME TO MY HOUSE! ###########
It is Random
And be careful, the walls have ears, literally.

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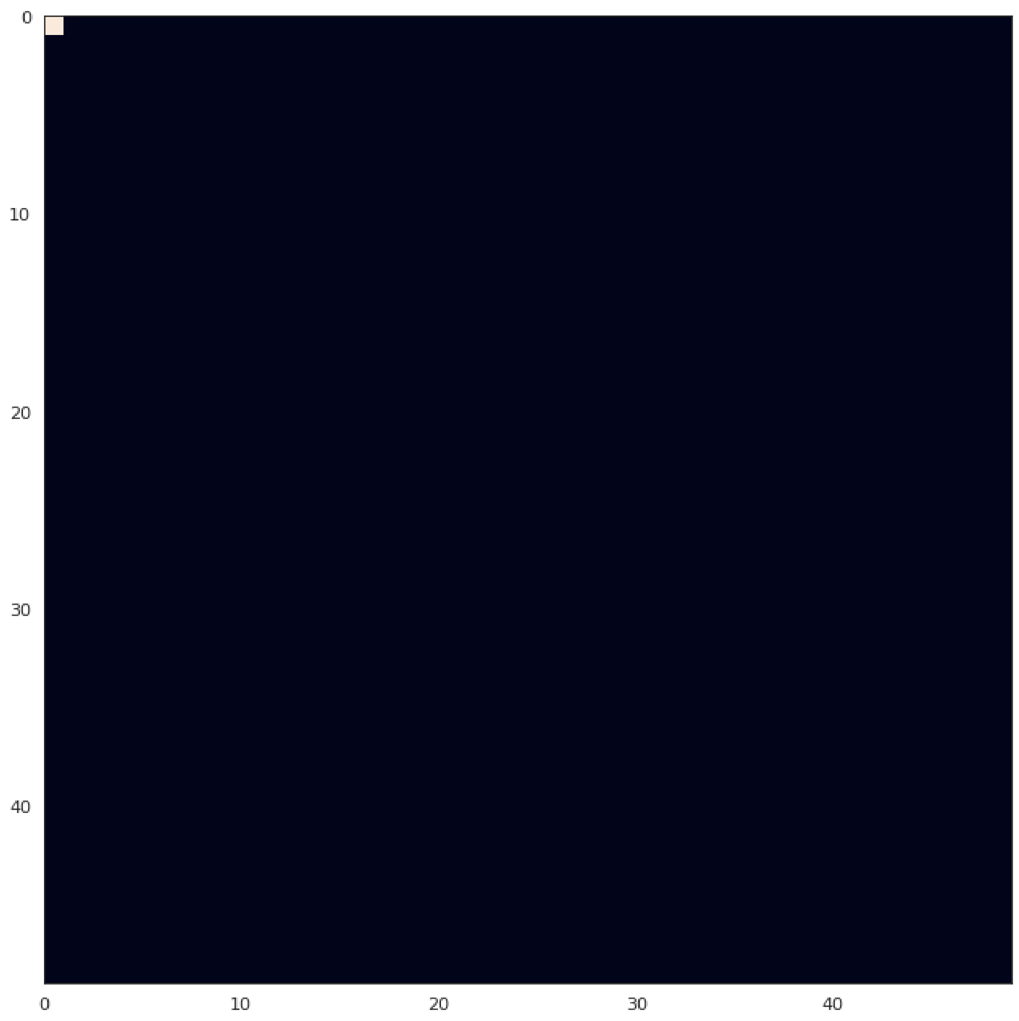

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Next step direction: Right
FINAL STATE OF THE HOUSE
Moves made: 26943
########## WELCOME TO MY HOUSE! ###########
It is Random
And be careful, the walls have ears, literally.

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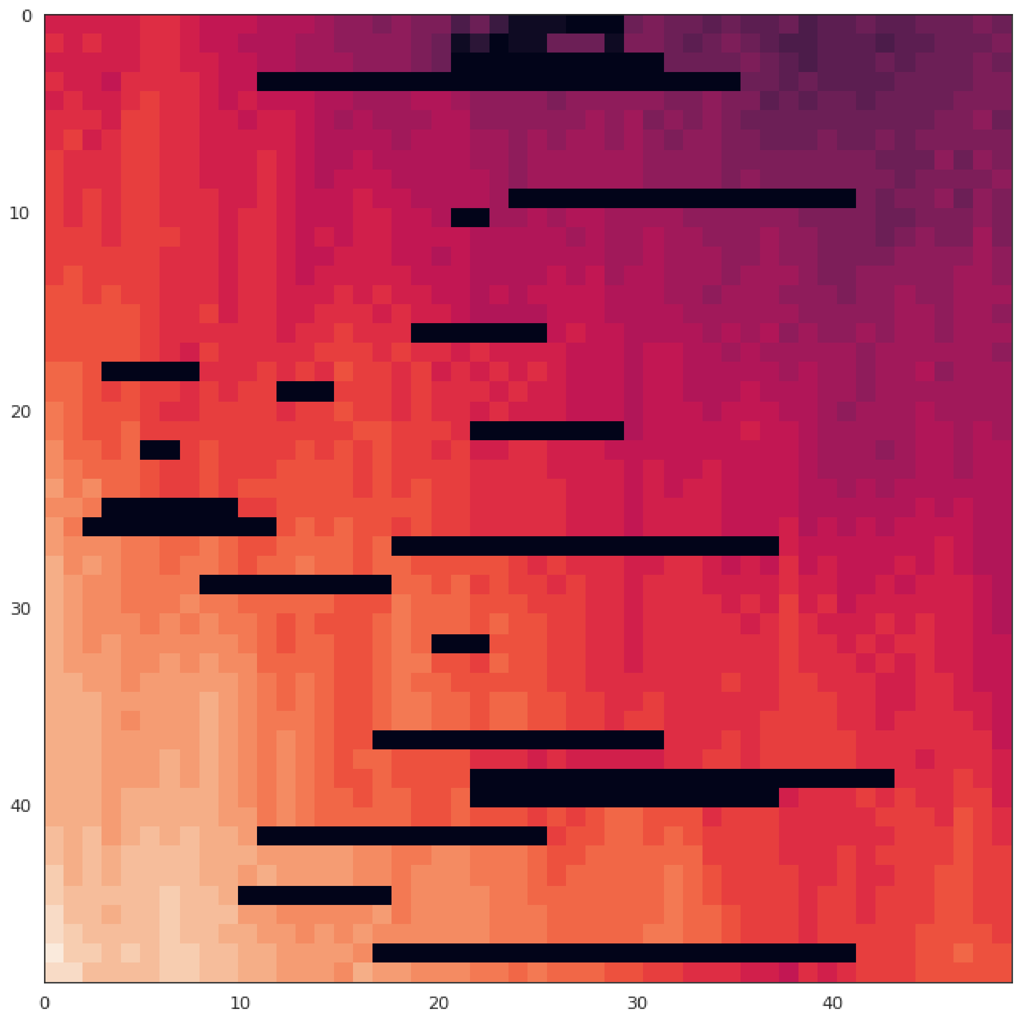

Out[12]:

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