Summary

Team #8435

In modeling a highly volatile system such as that of a serial killer's attacks, many potential issues arise. Many assumptions must be made and many variables must be ignored. In our models there was little or no mathematical representation of many lurking variables which may have undoubtedly had some effect on the killer's tendencies. Perhaps our killer's sadistic urges are influenced by barometric pressure, domestic conflict, or even the outcome of the latest football game. An attempt to include variables such as these would result in a convoluted, largely meaningless model. In an attempt to arrive at some meaningful understanding, our model uses coordinates of body dump sites as it's only form of input.

Our model implemented two schemes. The first is a simple heat mapping program. Given coordinate input data it plots the points of the body dump sites and includes a variable length radius around each. From there it takes the average of the points and outputs a center of mass (a good place to begin the search) and another variable length radius around that point. By extending this radius to encompass all (or most) prior body dump sites, one has a reasonable area for investigation.

Here our second scheme takes over. Taking the farthest North, South East, and West points on the heat map we create a box. This box is then divided up into a grid. Each grid box ij corresponds to a matrix entry in our probability matrix Pij. Pij gives the likely hood that the killer's base of operations is located in grid box ij. These probabilities are found using Rossmo's formula (described in detail later in our paper.)

These probabilities assume that the killer is located somewhere inside the of the box. If the killer is thought to be a wanderer or commuter, this model will likely only serve to throw off the investigation!

When using this model to predict future kill locations, the first heat map is likely to be the best geographical aid. Although a killer may be apprehensive about returning to the scene of a crime, he/she may also prefer killing in a familiar location- possibly near past body dump sites.

When investigating possible bases of operations for the killer it would be better to use the probability matrix or probability matrix plot. The way in which these values are found takes into account the concept of a buffer. A killer is not likely to drive an extraordinary long distance (again, familiar locations are desirable). That being said, a serial killer would likely maintain a buffer around their residence so as to deter suspicion. Our model allows for a variable sized buffer of variable importance.

Executive Summary

In modeling a highly volatile system such as that of a serial killer's attacks, many potential issues arise. Many assumptions must be made and many variables must be ignored. In our models there was little or no mathematical representation of many lurking variables which may have undoubtedly had some effect on the killer's tendencies. Perhaps our killer's sadistic urges are influenced by barometric pressure, domestic conflict, or even the outcome of the latest football game. An attempt to include variables such as these would result in a convoluted, largely meaningless model. In an attempt to arrive at some meaningful understanding, our model uses coordinates of body dump sites as it's only form of input.

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Again, it is important to note the assumptions that this model is making. Serial killers are not mentally sound individuals and to assume that they behave rationally about things like buffer strips may be also facetious. This is why we felt that a variable buffer was so important.

Making models like these is an art as well as a science. Yes, there are facts and data. Yes, there are probability distributions. Math can indeed help us catch the "bad guys." But to make realistic predictions and understand the data many assumptions must be made. Many variables must be ignored. Compromises must be made in either precision, realism, and generality. Modeling is a search for the truth among many lies. This search is the art; the model the masterpiece. The hope is that our masterpiece will help us to better see the real world- to gain a glimpse into the minds of killers and apprehend them before they strike again.

Mathematical Contest in Modeling

February 18th-22nd 2010

Team # 8435

Problem B: Criminology

In 1981 Peter Sutcliffe was convicted of thirteen murders and subjecting a number of other people to vicious attacks. One of the methods used to narrow the search for Mr. Sutcliffe was to find a "center of mass" of the locations of the attack. In the end, the suspect happened to live in the same town predicted by this technique. Since that time, a number of more sophisticated techniques have been developed to determine the "geographical profile" of a suspected serial criminal based on the locations of the crimes. We will create a mathematical model that predicts where the suspect lives by the locations of the random crimes.

For us to develop a model for serial crimes, we need to know more about serial killers. To be a serial killer you need to murder three or more people over a period of more than thirty days. The majority of serial killers are single, white males. They are often intelligent, but have trouble leading a "normal life". Most were abused when they were children, grown up with an unstable family and usually without a father, as well as alcoholic problems. Serial killers usually murder victims that have something in common, like sex, age, race, occupation, or appearance.

Serial killers usually will have a motive behind their killings. There are four general categories they are classified under, but these are not mutually exclusive groups. The groups are visionary, mission-oriented, hedonistic, and power or control. Visionary serial killers are compelled to murder by the devil or God. Mission-oriented killers believe they are "ridding the world" of a certain type of undesirables person. A hedonistic killer derives pleasure from killing. They kill for lust, thrill or comfort. A serial killer's main objective is to gain and exert power over the victim. By knowing who serial killers tend to be and why they kill, we can make a better model to estimate where their residence would be and where there is a higher probability of attack based on the locations of the bodies.

We are going to use Peter Sutcliffe murders and place of residence to help develop our model. We will be looking at who, where, when, how, and any motives that were involved in the thirteen murders Peter was convicted of.

A question we asked ourselves was how do serial killers go out and search for their victims? We did some research and found that serial killers were to kill "randomly" to leave as few clues as possible. Actually, it is really hard for a human to not make a pattern when they are trying to be random. Random means to have no definite aim or purpose, without method or conscious choice. We try to be random, but they are many things that will influence our decisions. For committing murder, you would want to be aware of camera surveillance, law enforcements, large crowds, etc. Also, you would like to create a buffer zone around your house, to have a "safe" zone. These choices are characterized under rational choice theory, which argues that criminals weigh costs/risks and benefits when deciding whether or not to commit crime.

Another aspect that should be considered is having the opportunity to commit the crime. For example, a crime opportunity requires that elements converge in time and place including a motivation, a suitable target, and no witnesses or security cameras to have a lead or evidence for the police. These descriptions of how a criminal thinks can be categorized under the routine activity theory, which explains that any can of crime just needs an opportunity.

The serial killer "hunting" process can be divided into two categories. First is how they look for their victim, and the second is how they attack. Rossmo suggest that there are four ways a killer can search for their next victim:

1. "Hunter – A hunter is defined as an offender who sets out specifically to search for a victim, basing the search from his or her residence.
2. Poacher – A poacher is defined as an offender who sets out specifically to search for a victim, basing the search from an activity site other than his or her residence, or who commutes or travels to another city during the victim search process.
3. Troller – A troller is defined as an offender who, while involved in other, non-predatory, activities, opportunistically encounters a victim.
4. Trapper - A trapper is defined as an offender who assumes a position or occupation, or creates a situation that allows him or her to encounter victims within a location under his control."

These categories are not mutually exclusive, meaning a killer can be in several categories.

Rossmo also explained how there are three victim attack methods can be used:

1. "Raptor – A raptor is defined as an offender who attacks a victim upon encounter.
2. Stalker – A stalker is defined as an offender who first follows a victim upon encounter, and then attacks.
3. Ambusher – An ambusher is defined as an offender who attacks a victim once he or she has been enticed to a location, such as a residence or workplace, controlled by the offender."

We assumed that there would be a safe buffer zone around the residence and the serial killer would not attack near his or her home. To our disadvantage, it is not that simple. The FBI observed that 51% of 76 serial rapists in their U.S. study lived outside of their offence circle. Bust also, a study in British Columbia of 30 of their stranger sexual assaults determined that 43.4% of the cases the offence circle did not contain an offender activity node. These inconsistencies are very frustrating for us. U.S. offenders' vs. British offenders' differences might be because of the urban structure, population density, and travel behavior.

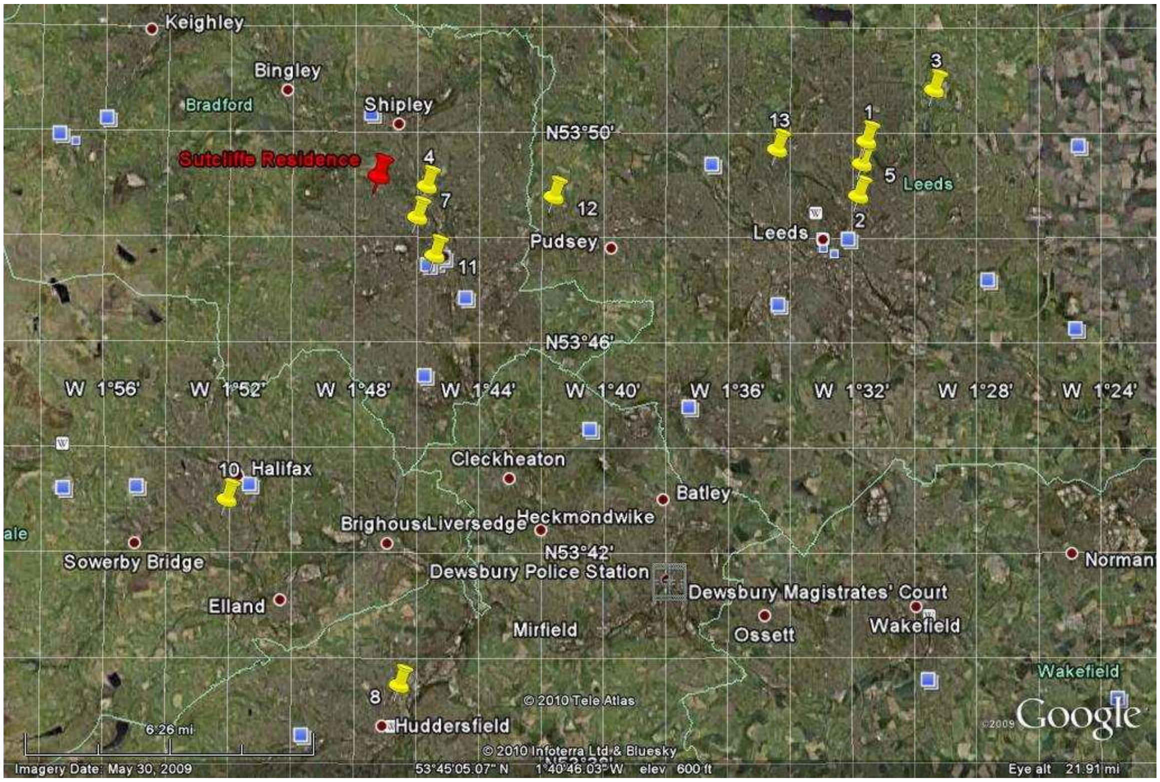
It seems that Peter Sutcliffe commuted to several different areas in different directions to commit the murders. But he also murdered three victims near his residence as well. We need to conclude that killers can use different strategies in finding their victims, based on planning to kill and have the opportunity to kill near their home. We can assume now that Peter was a hunter and a poacher based on where he killed the victims.

Research has shown that the victims are usually located within one or two miles of offender's residence. Because of this, we mapped where all the 13 victims were found and centered a 2 mile radius circle around their bodies. This will give us a better idea on where the killer lived during the killings. Here are the coordinates of the 13 victims as well as Sutcliff residence:

53°49'30.87"N	1°31'43.70"W
53°48'28.75"N	1°31'58.58"W
53°50'29.41"N	1°29'33.00"W
53°48'38.94"N	1°45'52.49"W
53°49'5.35"N	1°31'51.90"W
53°25'42.30"N	2°15'12.25"W
53°48'3.38"N	1°46'10.49"W
53°39'9.05"N	1°46'42.90"W
53°27'43.95"N	2°13'42.35"W
53°42'40.82"N	1°52'14.35"W
53°47'19.70"N	1°45'36.87"W
53°48'27.03"N	1°41'47.39"W
53°49'21.68"N	1°34'35.74"W

Sutcliffe Residence
53°48'50.44"N
1°47'25.04"W

Here is the map with all thirteen victims location of where their bodies were found and Sutcliffe's residence. The mean point is not on this map. The map came from Google Earth.



We also calculated the mean of all the points of the bodies and added that point to our map. Unfortunately, this mean might be distorted by outliers. So, to make the point closer to the cluster of victims, we called out the outliers. Then we re-calculated the mean, and marked it on our map. We want a circle centered at the mean point with a radius that coves all the victims' points plus their 2 mile radius circle. We concluded that the radius of the circle cantered at the mean of the victims (except the out liars) has a radius of 21 miles. We will make a grid center around the mean of the killing excluding the outliers and have it a 21 by 21 mile grid.

W e used Rossmo's formula to find the probability were the serial killer lived. Mathematician Kim Rossmo used geographic profiling as a background to develop the formula. The formula is :

$$p_{i,j} = k \sum_{n=1}^{c} \left[\underbrace{\frac{\phi}{(|X_i - x_n| + |Y_j - y_n|)^f}}_{term\ 1} + \underbrace{\frac{(1-\phi)(B^{g-f})}{(2B - |X_i - x_n| - |Y_j - y_n|)^g}}_{term\ 2} \right].$$

Here, the grid we placed over the map of the killings, the sector $S_{i,j}$ is the square on row I and column j, located at coordinate (Xi, Yj). So the probability if the killer lives in the row I and column j is Pij. Where it sums from 1 to c, where c is the number of kills. The first term "describes the idea of decreasing probability with increasing distance". And the second term takes into account of the buffer zone. "Rho is used to put more weight on one of the two fractions. Beta describes the radius of the buffer zone. The constant k is determined to sum the probability to equal one. The main idea of the formula is that the probability of crimes first increases as one move through the buffer zone away from the *hot zone*, but decreases afterwards. The variable f can be chosen so that it works best on data of past crimes. The same idea goes for the variable g" (Rossmo).

For our variables, we have 13 victims, so our c = 15. For the term that describes "the idea of decreasing probability with increasing distance" and the buffer zone distance, we do not know where the killer live. We only know where the bodies are, so we decide to let rho to be 0.5 to put the same effect on both the fractions. If we saw that the killings get closer to a "center" location, then we would have more emphasis on the first fraction.

The beta describes the radius of the buffer zone, and as stated above, studies have shown that the buffer zone ranges from zero to two miles, so we let beta be dynamic. The more dead bodies you find, the small beat should become. With our model, don't let it equal zero. It's highly unlikely that if you find a body and ruled out everyone that could have killed the victim (the owner of the house), then the serial killer's house is not the house you found the body in.

For the variables f and g, we know g > f .We manipulated these two variables until the results we got form the formula worked very well based on the murders of Peter Sutcliffe and where he lived. The variable values were f =1.2 and g = 3.

We then placed all of information have about the murder sites into JavaScript and generated a heat-map graph. Here is our code:

Javascript for the kills heat-map generation

The heat-map allows us to visually see the location of kills and the proximity to each other.

```
<html>
<head>
<meta name="viewport" content="initial-scale=1.0, user-scalable=no" />
<script type="text/javascript" src="http://maps.google.com/maps/api/js?sensor=true"></script>
<script language="javascript" type="text/javascript">
function initialize() {

var killsArray = [
new google.maps.LatLng(53.825242, -1.528806),
new google.maps.LatLng(53.807986, -1.532939),
new google.maps.LatLng(53.841503, -1.4952),
new google.maps.LatLng(53.810817, -1.764581),
new google.maps.LatLng(53.818153, -1.531083),
//      new google.maps.LatLng(53.428417, -2.253403),  //Outlier
new google.maps.LatLng(53.800939, -1.769581),
new google.maps.LatLng(53.652514, -1.778583),
//      new google.maps.LatLng(53.462208, -2.228431),  //Outlier
new google.maps.LatLng(53.711339, -1.870653),
new google.maps.LatLng(53.788806, -1.760242),
new google.maps.LatLng(53.807508, -1.696497),
new google.maps.LatLng(53.822689, -1.576594)
];


var victimsArray = [
"Wilma McCann", "Emily Jackson", "Irene Richardson", "Patricia Atkinson", "Jayne MacDonald",
"Jean Jordan", "Yvonne Pearson", "Helen Rytka", "Vera Millward", "Josephine Whitaker", "Barbara
Leach", "Marguerite Walls", "Jacqueline Hill"];

var residence = new google.maps.LatLng(53.814011, -1.790289);

var mapLatLng = new google.maps.LatLng(53.705578, -1.761103);

//Average location calculation
var sumLat = 0;
var sumLng = 0;
for (var i = 0; i < killsArray.length; i++) {
sumLat += killsArray[i].lat();
sumLng += killsArray[i].lng();
}
sumLat = sumLat / killsArray.length;
sumLng = sumLng / killsArray.length;
var avgKillLoc = new google.maps.LatLng(sumLat, sumLng);


var myOptions = {
zoom: 10,
center: avgKillLoc,
```

```
mapTypeId: google.maps.MapTypeId.TERRAIN
};
var map = new google.maps.Map(document.getElementById("map_canvas"), myOptions);
// Drawing overlays

//The circles around the kill sites
for (var i = 0; i < killsArray.length; i++) {
var curKill = killsArray[i];
var curTitle = "Kill " + (i+1) + ":" + victimsArray[i];
var marker = new google.maps.Marker({
position: curKill,
map: map,
title: curTitle
});
}



//Circles for each kill
for (var i = 0; i < killsArray.length; i++) {
var iLoc = killsArray[i];
var colorOpacity = (1/(1.2*killsArray.length))*(i+1);
var killHighlight = new google.maps.Circle({
center: iLoc,
radius: mil2mt(2),
map: map,
strokeColor: "#FF0000",
strokeOpacity: colorOpacity,
strokeWeight: 2,
fillColor: "#200000",
fillOpacity:colorOpacity
});

}

//Circles around the average

var avgCircle5 = new google.maps.Circle({
center: avgKillLoc,
radius: mil2mt(12.5),
map: map,
strokeColor: "#FF0000",
strokeOpacity: 0.5,
strokeWeight: 2,
fillColor: "#000040",
fillOpacity: 0.4
});
//House circle

var houseCircle = new google.maps.Circle({
center: residence,
radius: mil2mt(15),
```

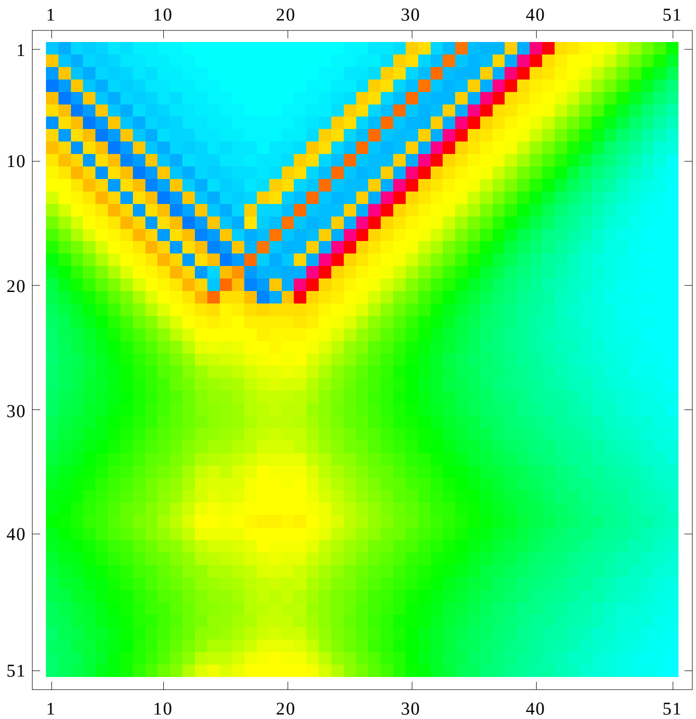
```
map: map,
strokeColor: "#FF0000",
strokeOpacity: 0.3,
strokeWeight: 2,
fillColor: "#004000",
fillOpacity: 0.2
});
}

//Custom function to convert miles to meters
function mil2mt(miles) {
return miles*1609.344;
}


</script>
</head>
<body onload="initialize()">
<div id="map_canvas" style="width:100%; height:100%"></div>
</body>
</html>
```

Analysis for the probability distribution of the killer's location (Mathematica)

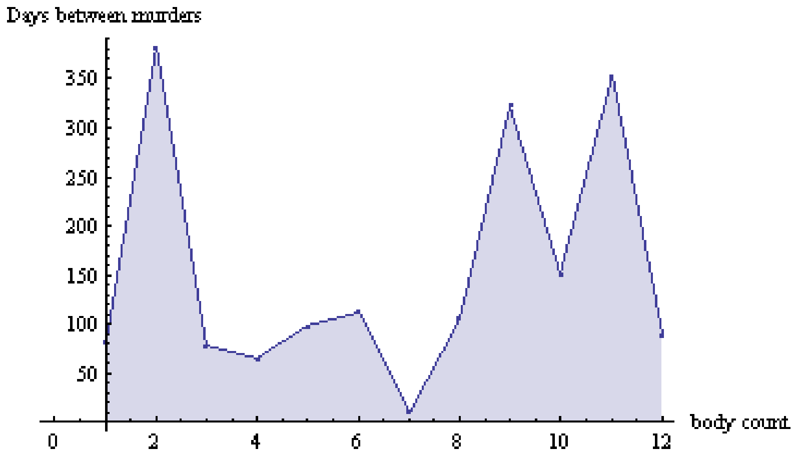
Then with this data and code, we placed the information into Mathematica to graph our probability distribution function on our grid. This is our resulting grid with the higher probability in the darker color:



Our code is on the last page of our solution packet.

We wanted to see if time had an influence in when the murders would take place. So we calculated the time between each murder, the mean, median, and standard deviation. We graphed our data, so we can visually see the distribution and concluded that time was not an important factor. With the data, we could not predict when the next murder would take place. Here is our work in Mathematica regarding the time factor:

> Although our model focuses exclusively on geographical profiling, we felt that it was important to include some discussion of the importance of time. Analysis of time between murders/attacks can give important insight into the thought processes and future plans of criminals.
>
> In the case of Peter Sutcliffe we first collected the number of days between murders. The data was as as follows:
>
> 82,382,77,64,97,112,10,105,323,151,353,89
>
> ListLinePlot[{82,382,77,64,97,112,10,105,323,151,353,89},Mesh All,Filling Axis,AxesOrigin->{1,0},AxesLabel->{"body count","Days between murders"}]



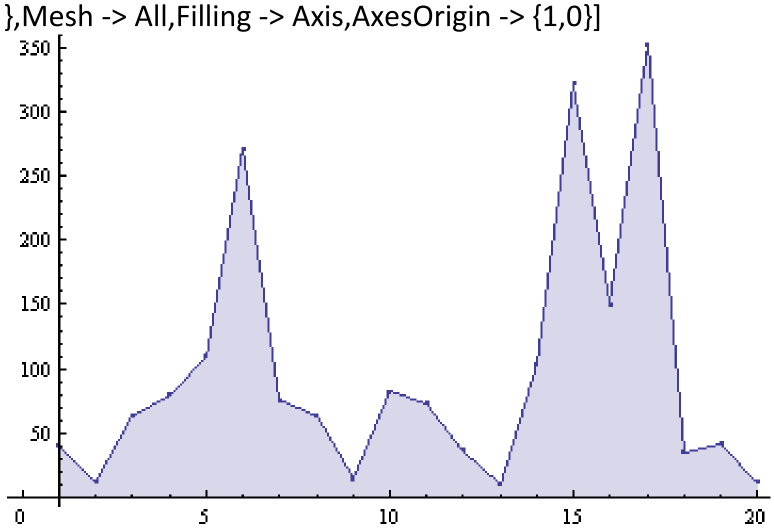
If this plot were to have a generally downward trend, one could conclude that the killer was gaining confidence and beginning to kill more often. Subsequentally the ?, B, and maybe even f and g values in our implimentation of Rossmo's Formula would change. Conversely, if this plot was to show a general upward trend one could conclude that the killer was becoming increasingly paranoid and our buffer size would increase.

All of our attempts to use regression analysis on this data resulted in nasty functions that barely fit the data and would be almost worthless for extrapolation.

This data also has:

mean | 153.8
median | 101
standard deviation | 125

Looking at Sutcliff's murders AND assults:
40,12,63,80,110,271,76,63,14,82,73,37,10,104,322,150,353,35,42,12
ListLinePlot[{40,12,63,80,110,271,76,63,14,82,73,37,10,104,322,150,353,35,42,12 },Mesh -> All,Filling -> Axis,AxesOrigin -> {1,0}]



Again, we see no general trends and have
mean | 97.45
median | 68
standard deviation | 101.5

We concluded that the time between the murders had a very wide range, and we saw no pattern in the length of time compared to how many murders they were. Therefore, to know when the next murder would occur, looking at the past killings time-scale did not help in prediction the time of the next murder.

To reitterate everything we did, in modeling a highly volatile system such as that of a serial killer's attacks, many potential issues arise. Many assumptions must be made and many variables must be ignored. In our models there was little or no mathematical representation of many lurking variables which may have undoubtedly had some effect on the killer's tendencies. Perhaps our killer's sadistic urges are influenced by barometric pressure, domestic conflict, or even the outcome of the latest football game. An attempt to include variables such as these would result in a convoluted, largely meaningless model. In an attempt to arrive at some meaningful understanding, our model uses coordinates of body dump sites as it's only form of input.

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25. ^ "Ripper visits father's ashes site." *BBC News Online*. 20 January 2005.
26. ^ "Yorkshire Ripper stabbed In face." *The Guardian*. 24 December 2007.
27. ^ "Yorkshire Ripper Peter Sutcliffe 'fit to be freed from Broadmoor'." *Daily Telegraph*. 17 February 2009.
28. ^ "Judgments - Brooks (FC) (Respondent) v. Commissioner of Police for the Metropolis (Appellant) and others." *House of Lords Publications*. 21 April 2005.
29. ^ [a] [b] [c] [d] [e] [f] "Sir Lawrence Byford report into the police handling of the Yorkshire Ripper case." *Home Office*. homeoffice.gov.uk.

In[46]:=

```
(* Team #8435 *)
(* The list of points where murders have taken place *)

listX := {53.8252, 53.808, 53.8415, 53.8108, 53.8182,
   53.4284, 53.8009, 53.6525, 53.4622, 53.7113, 53.7888, 53.8075, 53.8227};
listY := {-1.5288, -1.5329, -1.4952, -1.7646, -1.5311, -2.2534,
   -1.7696, -1.7786, -2.2284, -1.8707, -1.7602, -1.6965, -1.5766};

(*The points at which the probability needs to be calculated *)
(* The range can be increased and the
 resolution can be set by using the 2 commands below *)
evalX := Range[50.0, 55.0, .1];
evalY := Range[-3.5, 1.5, .1];

(*Constants for the killer*)

ϕ := 0.5;
B := .89;
f := 1.2;
g := 3;

(*Probability Function*)
```

$$P_{ij} = \left(\frac{\phi}{(\text{Abs}[X_i - x_n] + \text{Abs}[Y_j - y_n])^f} + \frac{(1-\phi)\,(B^{g-f})}{(2B - \text{Abs}[X_i - x_n] + \text{Abs}[Y_j - y_n])^g} \right);$$

```
Pij = Sum[Pij, {xn, listX}, {yn, listY}];
k = Total[Table[Pij, {Xi, evalX}, {Yj, evalY}], 2];
Pij = Pij / k;

(* About time | Get the Output *)
M = Table[Pij, {Xi, evalX}, {Yj, evalY}];
MatrixPlot[M, ColorFunction → Hue]
(* The output is a probability distribution plot *)
```