Geographic Profiling: Nowhere To Hide

Summary

The study of serial crimes prediction has been a fruitful area of mathematical research for decades. Here we attempt to analyze and model the serial crimes prediction based on the time and locations of the past crime scenes.

Firstly, we divide the serial crimes prediction problem into two small problems: one is to develop different schemes to generate a geographical profile and then develop a technique to combine the results; the other is to generate a useful prediction of the location of the next crime. In addition, we study the Peter Sutcliffe's murder case to illustrate every step of our solution.

For the first problem, based on the least effort principle, we build the **Center of Minimum Distance Model** and obtain the possible residence area of the criminal. Then based on **Bayes' Theorem** and **Rayleigh distribution** function, we build the **Bayesian Model** and get another possible residence area. After that, we design a technique of using a minimum circle to cover the two areas to combine the two schemes.

For the second problem, using **Rayleigh distribution** function, we obtain a preliminary probability distribution of the crime site based on the residence determined in the first problem . Taking geographical character and the offender's geographical preference into account, we utilize **cluster analysis** to divide all the crime sites into 4 zones. In these 4 zones, we construct 4 two-dimensional normal distributions around the 4 circle centers with the standard deviations being the radii of the circles. In view of the influence of the crime time, we add a time factor to the preliminary distribution. As a result, the preliminary distribution is modulated by geographical and temporal factors, producing an ultimate prediction, which is rather satisfactory after validation.

Finally, an executive summary is presented for law enforcement officers.

Contents

1 Introduction

1.1 Background

Serial crimes have a serious effect on people's lives and continuously challenge people's baseline of morality. Thus, how to arrest the criminals before he or she commits another crime becomes an important issue. A number of sophisticated techniques have been developed to generate a useful prediction for law enforcement officers based on the time and locations of the past crime scenes, such as the **"center of a mass"** method.

It is well-known that the focus of any police investigation is the crime scene and its evidentiary contents. What is often overlooked, however, is a geographic perspective on the actions preceding the offense: the spatial behavior that leads to the crime scene. For any violent crime to occur there must have been an intersection in both time and place between the victim and offender[1]. Thus, D. Kim Rossmo advanced a new criminal investigative methodology called **"Geographic Profiling"** in 2000[2].

1.2 Geographic Profiling

Geographic profiling is a criminal investigative methodology that analyzes the locations of a connected series of crimes to determine the most probable area of offender residence. Typically used in cases of serial murder or rape (but also arson, bombing, robbery, and other crimes), the technique helps police detectives prioritize information in large-scale major crime investigations that often involve hundreds or thousands of suspects and tips [3].

1.3 Objectives

Our goal is to develop at least two different schemes to generate a geographical profile. After that, we are asked to develop a technique to combine the results of the different schemes and generate a useful prediction. Our prediction should provide some kind of estimate or guidance about possible locations of the next crime based on the time and locations of the past crime scenes. What's more, we should show how reliable the estimate will be in a given situation according to our model.

2 Problem Analysis

2.1 Overall Strategy

For simplicity, we divide the problem into two small problems

- **Problem I**: To develop at least two different schemes to generate a geographical profile and then develop a technique to combine the results of the different schemes.
- **Problem II**: To generate a useful prediction based on the geographical profile.

Having ensured this, our strategy becomes

- Designing at least two different schemes to search out the residence of the criminal firstly based on the time and locations of the past crime scenes and designing a technique to combine the results of the different schemes.
- Utilizing the residence to predict the location of the next crime.

2.2 The Strategies for Problem I

After literature study, there are two categories of strategies to solve the **Problem I**: one is spatial distribution strategies and the other is probability distance strategies[4].

Spatial distribution strategies include a number of different procedures, all of which predict the home location of a serial offender by calculating a central point from a distribution of crime site locations. Some common spatial distribution strategies include the center of the circle, centroid, median, geometric mean, harmonic mean, and center of minimum distance.

Probability distance strategies begin with the assumption that an offender's crime site locations define their activity space, and that this area contains the offenders residence. Probability distance strategies differ from one another in terms of the shape of the mathematical function applied around each crime site and the assumptions regarding the relationship between where offenders reside and where they commit their offences. Common probability distance functions include the negative exponential, normal, lognormal, linear and truncated negative exponential.

The results of the schemes should be combined by certain technique to produce some useful geographical profile.

2.3 The Strategy for Problem II

It is well known that the next crime is committed at a place where the probability of crime is the highest. So, for prediction, we try to obtain a planar probability distribution of being the next crime site. To accomplish this, several factors should be taken into consideration, including geographical character, the criminal's mentality, the time of previous crimes, and so forth.

3 Center of Minimum Distance Model

3.1 Notations

Tab 1: **Notations**

Name	Description
s	the total number of crimes
x_i	the abscissa of the i^{th} crime site($i = 1, 2, \cdots, s$)
y_i	the ordinate of the i^{th} crime site($i = 1, 2, \cdots, s$)
$\mathbf{z}$	the location of the criminal's residence
m	the abscissa of the criminal's residence
n	the ordinate of the criminal's residence
$D_i(z)$	the distance between the criminal's residence and the ith crime site($i = 1, 2, \cdots, s$)

In order to illustrate the variables more clearly, we draw the following sketch.

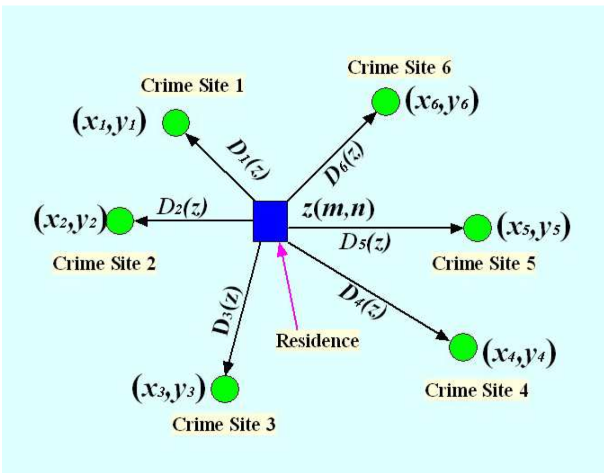

Fig 1: The sketch of the crime site($s = 6$)

3.2 Simplifying Assumptions

- We only take the location of the crime sites into consideration, and we neglect the influence of the criminal's mental state.
- Space is homogeneous, namely, there not exists any special area where the criminal is more likely to commit crimes. The only factor that matters is the distance to the residence place.
- The criminal has only one stable residence **z**.

3.3 Center of Minimum Distance Model

Firstly, we can imagine such a situation: A serial criminal lives in a settled place. Based on criminal psychology, the criminal would like to commit crimes around his or her residence. Also, according to our investigation, we find that the time interval between two crimes for a serial criminal is usually about several months to several years[5]. Therefore, returning to residence is necessary. What is more, on the premise of that the space is homogeneous, the criminal will hope to crime in a least effort principle according to the inertia of people. So the residence is most likely to be the point whose sum of distance to all the crime sites is minimal.

The distance we use here is Euclidian distance. The distance between the residence and the i^{th} crime site can be described with the following equation.

$$D_i(z) = \sqrt{(x_i - m)^2 + (y_i - n)^2} \tag{1}$$

Thus, we can get the total distance of a serial crimes

$$D(z) = \sum_{i=1}^{s} D_i(z) = \sum_{i=1}^{s} \sqrt{(x_i - m)^2 + (y_i - n)^2} \tag{2}$$

3.4 Case Study

Peter William Sutcliffe (born 2 June 1946 in Bingley, West Riding of Yorkshire) is an English serial killer who was dubbed the Yorkshire Ripper. Sutcliffe was convicted in 1981 of murdering 13 women and attacking several others. He is currently serving life imprisonment in Broadmoor Hospital[6].

I: Current Conditions

In 1981 Peter Sutcliffe was convicted of thirteen murders and subjecting a number of other people to vicious attacks. Figure 2 shows the detailed locations of the 23 crimes committed by Sutcliffe.

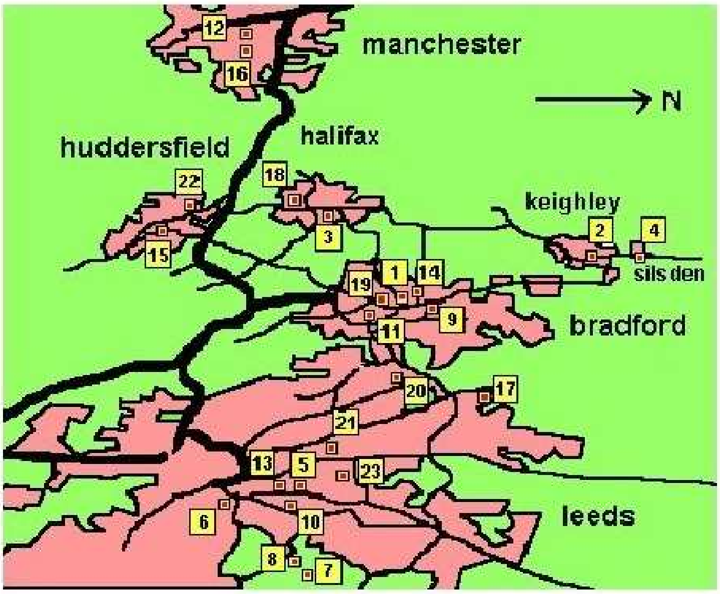

Fig 2: The sketch of the crime site of Sutcliffe

II: Data Available

For the reason that we can't search the detailed locations of the 23 crimes, we utilize the ***Image Processing Techniques of MATLAB*** to determine the pixel coordinate of the 23 crime sites.

III: Application of our Model

In order to solve our problem, we design the following algorithm.

1. **Change Figure 2 into grey-scale map.** This can be easily accomplished by *MTLAB*.

2. **Detect the Gray Value of the crime sites.** We determine the Gray Value of the crime sites and then search the coordinate of all the crime sites.

3. **Search the residence of the criminal.** We take crime site 1 to crime site 22 into consideration, then according to the **Equation 2** to search the minimum sum of distance between residence of crime site i. The 23rd points is preserved for future test.

After running the programme, we find that the predicted residence is only a point, which is not realistic. Thus, we come up with a better solution, we modify the $\mathbf{3}^{th}$ **step** into 3′.

3′. **Search the residence of the criminal.** Firstly, We take crime site 1 to crime site 22 into consideration. Then we expunge the 1st crime site at first time, thus, we can utilize the remaining 21 crime sites to obtain a point in the map represented the residence of the criminal. Similarly, we expunge the 2nd crime site at second time and can obtain another point in the map represented the residence of the criminal. The rest may be deduced by analogy. Consequently, we can obtain 22 points in total. At last, we circle the 22 points with a smallest circle. Thus, we can get an area that the criminal most likely to live in.

For law enforcement officers, they should mainly search this small area for criminal's residence instead of searching randomly in the whole city.

IV: Results

Running computer programme, we obtain some results.

- The locations of the crime sites is shown in **Figure 3**.

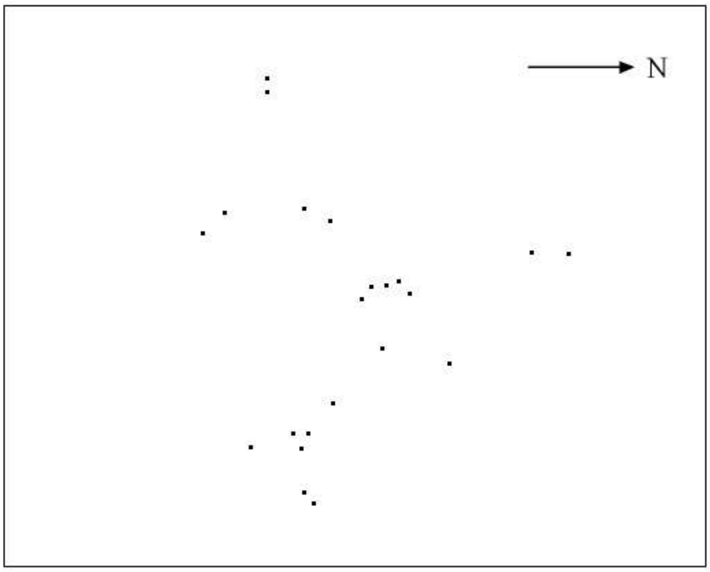

Fig 3: The location of the crime site of Sutcliffe

- The area that represents the possible location of the criminal's residence is shown below.

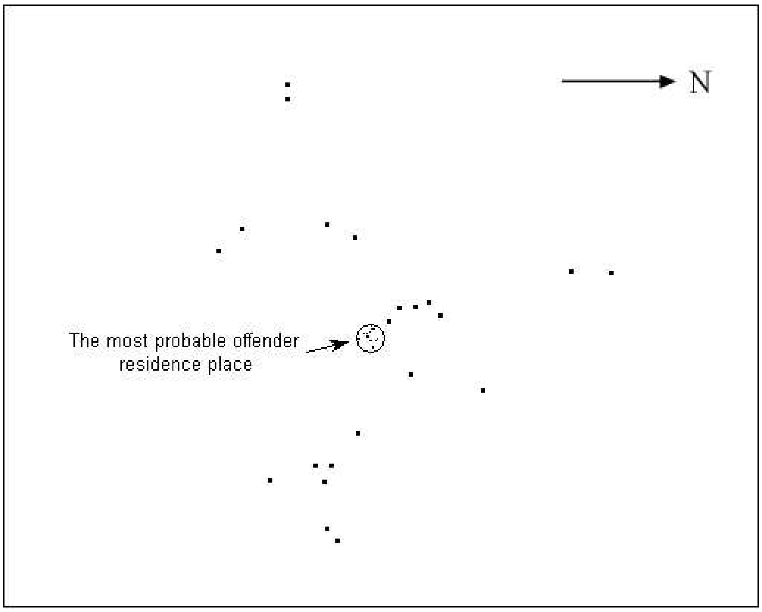

Fig 4: The area of the residence of Sutcliffe

Figure 4 indicates that the predicted area is much smaller than the whole area, which will reduce the workload greatly for the law enforcement officers.

4 Bayesian Model

4.1 Notations and Definitions

- s: **The total number of crimes.**
- $\mathbf{x}_i$: **The location of the i^{th} crime site($i = 1, 2, \cdots, s$).** $\mathbf{x}_i$ is a vector, it is defined by $\mathbf{x}_i$=($\mathbf{x}_i^1$,$\mathbf{x}_i^2$).
- $\mathbf{x}_i^1$ and $\mathbf{x}_i^2$: **The abscissa and ordinate of the i^{th} crime site($i = 1, 2, \cdots, s$).**
- $\mathbf{z}$: **The location of the criminal's residence**.
- α: **The average distance the offender is willing to travel.**
- $P(\mathbf{z}|\mathbf{x}_1, \mathbf{x}_2, \cdots, \mathbf{x}_s)$: The **probability density** that the criminal has anchor point z given that they have committed crimes at the location $\mathbf{x}_1, \mathbf{x}_2, \cdots, \mathbf{x}_s$.
- $P(\mathbf{x}_i|\mathbf{z}, \alpha)$: The probability density of which the criminal chooses $\mathbf{x}_i$ to offend($i = 1, 2, \cdots, s$).

4.2 Simplifying Assumptions

- All of the offense sites are mathematically independent, which is necessary in the derivation of **Equation 3**, and this is approximately true in reality.
- The criminal has only one stable residence $\mathbf{z}$.
- The offender chooses a target location based only on the Euclidean distance from the offense location to the offenders residence.

4.3 Bayesian Model

The Bayesian method is based on Bayes' Theorem. It is used to estimate the probability distribution for the anchor point $\mathbf{z}$, using the information from the crime location $x_1, x_2, \cdots, x_s$.

The probability density that the offender has anchor point at the location z satisfies[7]

$$P(\mathbf{z}|\mathbf{x}_1, \mathbf{x}_2, \cdots, \mathbf{x}_s) \propto \int P(\mathbf{x}_1|\mathbf{z}, \alpha) P(\mathbf{x}_2|\mathbf{z}, \alpha) \cdots P(\mathbf{x}_s|\mathbf{z}, \alpha) H(\mathbf{z}) \pi(\alpha) d\alpha \tag{3}$$

where

- $H(\mathbf{z})$ is the prior distribution of anchor points.
- $\pi(\alpha)$ is the the prior distribution of the average offense distance.

Indeed regions with larger values of $P(\mathbf{x}_i|\mathbf{z}, \alpha)$ by definition are more likely to contain the offenders anchor point than regions where $P(\mathbf{x}_i|\mathbf{z}, \alpha)$ is lower[7].

For the moment, let us set aside the question of how to search for the criminal's residence, and focus on the probability density function of which the criminal chooses to offend. On the one hand, according to the criminal psychology, the criminal don't like to commit a crime in a place far from home. The farther away from home, the fewer crimes are committed. Thus, the probability of the criminal committing a crime in a place far from home is low. This phenomenon can be explained by the least-effort principle. On the other hand, only few crimes are committed in the area immediately around the offenders residence, which reflects the concept of buffer zone[8]. Thus, the probability is also low. We can use **Rayleigh distribution function** to describe this trend.

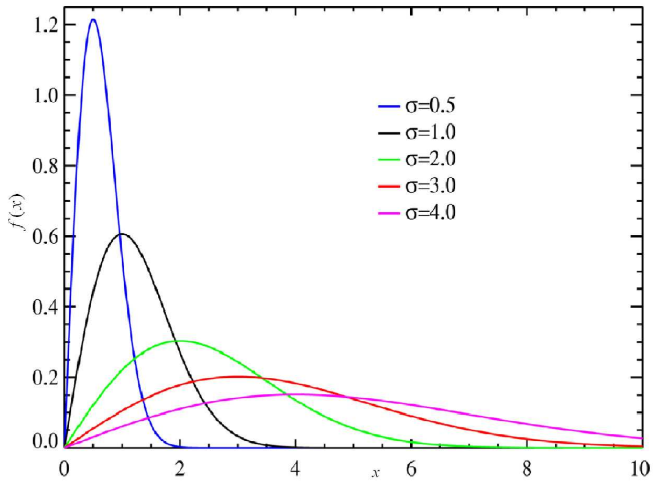

Fig 5: The diagram rayleigh distribution function[9]

The probability distribution function is

$$\begin{cases} f(x) = \dfrac{x}{\sigma}\exp\left(-\dfrac{x^2}{2\sigma^2}\right) \\ \mu = \sigma\sqrt{\dfrac{\pi}{2}} \end{cases} \tag{4}$$

where

- $f(x)$ is the rayleigh distribution function.
- σ is the peak value of the rayleigh distribution function.
- μ is the mean value of the rayleigh distribution function.

Let α be μ and $P(\mathbf{x}_i|\mathbf{z},\alpha)$ be $f(x)$, we get

$$P(\mathbf{x}_i|\mathbf{z},\alpha) = \frac{\pi|\mathbf{x}_i - \mathbf{z}|}{2\alpha^2}\exp\left(-\frac{\pi|\mathbf{x}_i - \mathbf{z}|^2}{4\alpha^2}\right) \tag{5}$$

Substituting (5) into (3), and we make the prior assumptions that all criminals have the same average crime distance α and that that all anchor points are equally likely in the homogeneous crime, we obtain

$$P(\mathbf{z}|\mathbf{x}_1,\mathbf{x}_2,\cdots,\mathbf{x}_s) = \left(\frac{\pi}{2\alpha}\right)^s \prod_{i=1}^{s} |\mathbf{x}_i - \mathbf{z}| \exp\left(-\frac{\pi}{4\alpha^2}\sum_{i=1}^{s}|\mathbf{x}_i - \mathbf{z}|^2\right) \tag{6}$$

Thus, we can utilize **Equation 6** to determine the maximum probability of the criminal's residence.

4.4 Case Study

To illustrate the method, we also use it to study Peter Sutcliffe's murder case. Using **Equation 6**, we write a MATLAB program to obtain the probability of being the anchor point of every pixel point on the map. The critical parameter is α. We temporarily use the value obtained by calculating the mean distance from the anchor point acquired in the first scheme to all the 22 crime sites. We will discuss this parameter in depth later. The result is shown in **Figure 6**. The left is the three-dimensional plot and the right is the two-dimensional plot with different colors representing different values of probability. The P value has been normalized within [0,1], since the actual values' orders of magnitude are too different. The normalizing formula is expressed in Equation 7.

$$x_i' = \frac{x_i - \min(X)}{\max(X) - \min(X)} \tag{7}$$

where $x_i \subseteq X$, X is a set. and x_i' is the normalized value. We will use this formula frequently later in the paper.

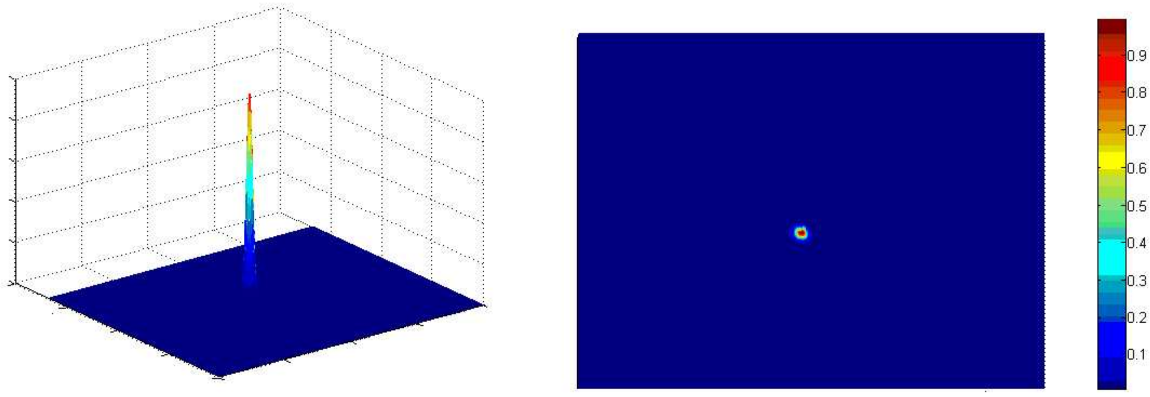

Fig 6: The relative probability distribution of the criminal's residence place.

4.5 The Discussion of α

From the first scheme, we know the value of α is around 22.7. In this section, we will examine the effect of variation of α on the outcome(the most probable point and the probability distribution of the residence place).

We change the value of α from 18 to 23. The coordinate of the most probable point is as follows[**Table 2**]:

Tab 2: The relationship between the coordinate of the most probable point and the value of α

α	18	19	20	21	22	23
coordinate	(188,191)	(188,190)	(188,190)	(188,190)	(188,190)	(188,190)

The probability distributions are also similar to each other. For reasons of space, we do not display every probability distribution.

Now we know the result of this scheme is not sensitive to the value of α, we can believe the reliability of this scheme.

5 Combination of the Results of the Two Schemes

We have obtained two geographical profiles by two different schemes. One is a circle while the the other is a round-shaped probability distribution. In the second scheme, the value far from the center is extremely small compared with the peak. So a small circle can be drawn circling the points with values larger than 1/100 of the peak value.

For the moment, we come to the problem of developing a technique to combine the results of the two different schemes. Our method is to use an excircle of the two circles. The center of the excircle is the most probable point [**Figure 7**].

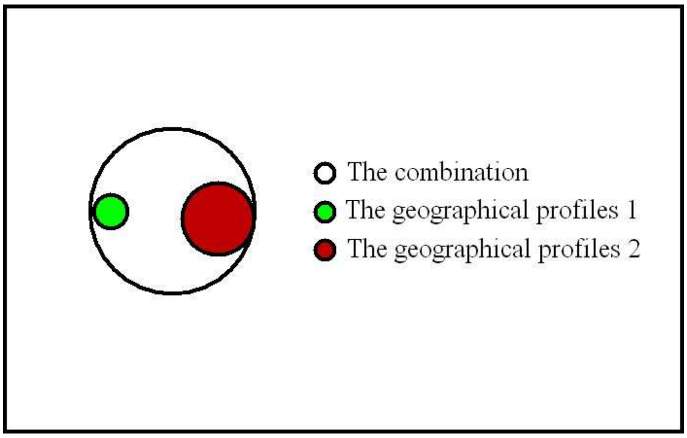

Fig 7: The diagram of combination

Case Study

For Peter Sutcliffe's serial murder cases, from **Spatial Distribution Strategy** and **Probability Distance Strategy**, we have obtained two different circular areas which represent the high probability zone of the criminal's residence. We can clearly know that the two areas are relatively adjacent. Thus we choose the **First Technique** to combine the two circles. In addition, we obtain that the coordinate of the center of circle is **z**(188,191)

6 Prediction of the Next Crime

After the criminal's residence is determined, we come to the problem of utilizing the residence to predict the location of the next crime. Meanwhile, we take the Peter Sutcliffe's serial murder as an example to illustrate the prediction method.

6.1 Initial Prediction Method

In the previous section, we have ensured that the criminal choose crime sites according to a **Rayleigh distribution**. Thus, the criminal choose the next crime site still according to the **Rayleigh distribution**.

In previous analysis, we have ensured that the criminal's residence is in a specifically circular area. For simplicity, we assume that the center of circular area is the residence of the criminal and the coordinate is **z**(188,191). Meanwhile, the average distance the offender travels in the past crime scenes is about $\alpha = 22.7$. Thus, we can draw the curve of the Rayleigh distribution function.

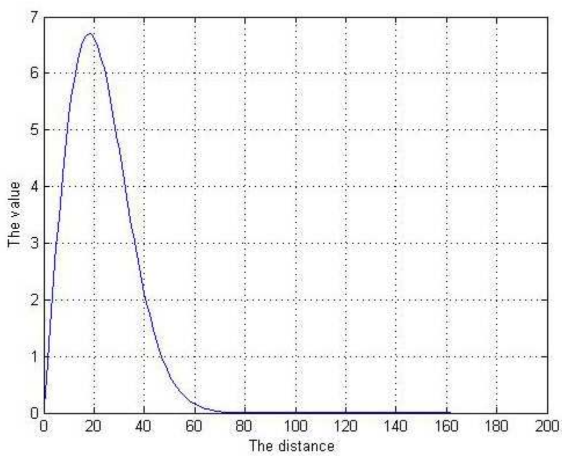

Fig 8: The diagram rayleigh distribution function

Then we consider the three-dimensional situation, and by writing and running MATLAB programme, we obtain **Figure 9**.

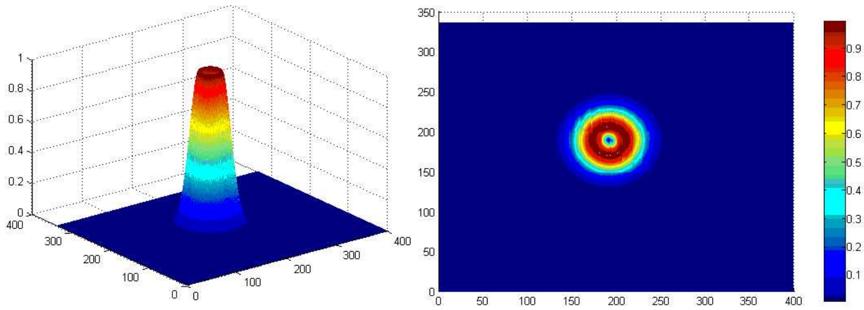

Fig 9: The preliminary distribution

Now we study the actual distribution of the crime sites with the change of the distance from residence to crime sites. Firstly, we divide the whole area into 10 areas according to the distance. Then we calculate the frequency of the crime sites located in all the small areas respectively. Thus, we obtain

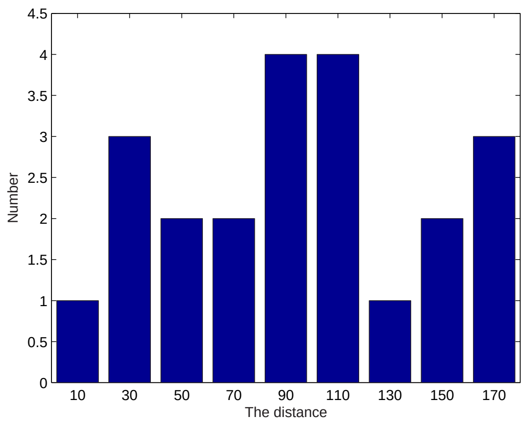

Fig 10: The real distribution of the crime sites

From **Figure 8** and **Figure 10**, we can intuitively conclude that the real trend is different from the **Rayleigh distribution function**. The reason is that we have merely taken the distance to the residence into consideration. To better describe the real world situation, our original distribution should be modified.

6.2 Developed Prediction Method

We have obtained that the idea that the offenders choose offense sites according to a Rayleigh distribution is one-sided. What is more, the crime sites are relatively centralized in one place, while in other places, the crime sites are sparse. Therefore, we try to utilize cluster analysis to divide the whole area into small areas. By analysis, we choose **Hierarchical Cluster** to solve our problem.

There are numerous ways in which clusters can be formed. Hierarchical clustering is one of the most straightforward methods. To form clusters using a hierarchical cluster analysis, we must select:

- A criterion for determining similarity or distance between cases.
- A criterion for determining which clusters are merged at successive steps.
- The number of clusters we need to represent our data.

Step I: **Similarity between Cases**

Because the goal of this cluster analysis is to form similar groups of crime sites, we have to decide on the criterion to be used for measuring similarity or distance. There are many different definitions of distance and similarity such as the Euclidean distance. In this case, we select Euclidean distance.

$$d = |\mathbf{x}_i - \mathbf{x}_j| = \sqrt{(\mathbf{x}_i - \mathbf{x}_j)^2} \tag{8}$$

where

- $\mathbf{x}_i$ is the location of the i^{th} crime site.
- $\mathbf{x}_j$ is the location of the j^{th} crime site.
- d is the Euclidean distance.

Step II: **How Should Clusters Be Combined?**

When we have only one case in a cluster, the smallest distance between cases in two clusters is unambiguous. Once we start forming clusters with more than one case, we need to define a distance between pairs of clusters. For example, if cluster A has cases 1 and 4, and cluster B has cases 5, 6, and 7, we need a measure of how different or similar the two clusters are[10].

There are many ways to define the distance such as Nearest Neighbor Method, Nearest Neighbor Method, Between-group Linkage Method and so on. Different methods for computing the distance between clusters are available and may well result in different solutions. By analysis, we choose Centroid Method in our case.

Step III: **The Number of Clusters**

We write MATLAB programme, and run the computer programme. Thus, we get the dendrogram of the crime sites.

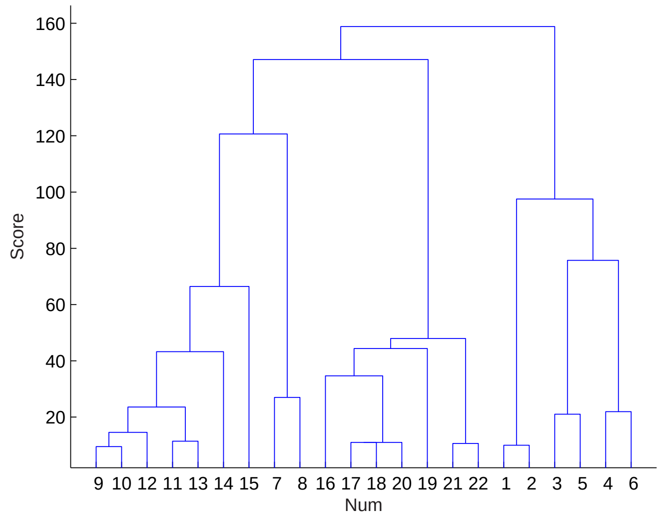

Fig 11: The dendrogram of the crime sites

From **Figure 11**, we can conclude that all the crime sites can be divided into 4 clusters.

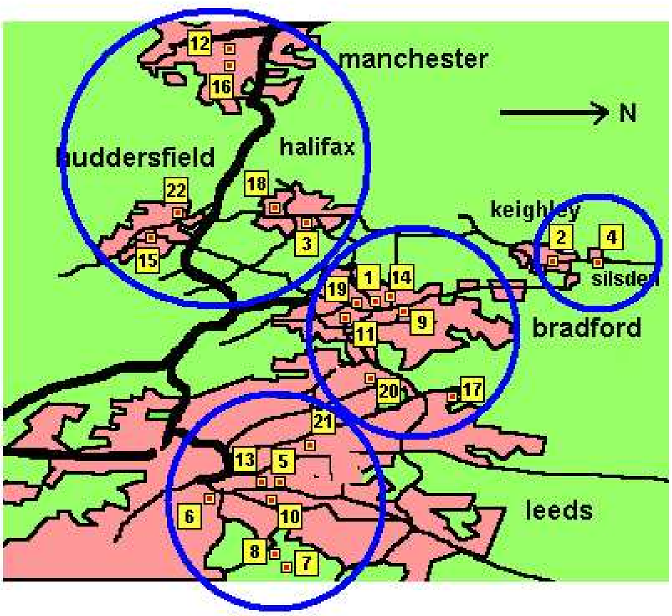

Fig 12: The dendrogram of the crime sites

Now that all the crime sites have been divided into four categories, we attempt to draw four small circles to cover them. A simple idea is the smallest circle that covers all the points in a certain category, but the algorithm to accomplish it is complex. For the sake of simplicity, we draw the circle taking the centroid of the points as the center and longest distance from each points to that centroid. The methods to draw the circles do not make much difference to the result.

The reason why we cluster is to get information about the criminal's habit of committing crimes. A criminal may have preference over certain areas, which may be where he or she is familiar with, or somewhere with dense household or where he or she is less likely to be caught. This corresponds with Rossmo's concept of comfortable zone[1,2]. So we could safely infer that the criminal will most likely to commit a crime in or around those comfortable zones.

Based on above consideration, we construct four two-dimensional normal distributions around the four circle center. The standard deviations are the radii of the circles [**Figure 13**].

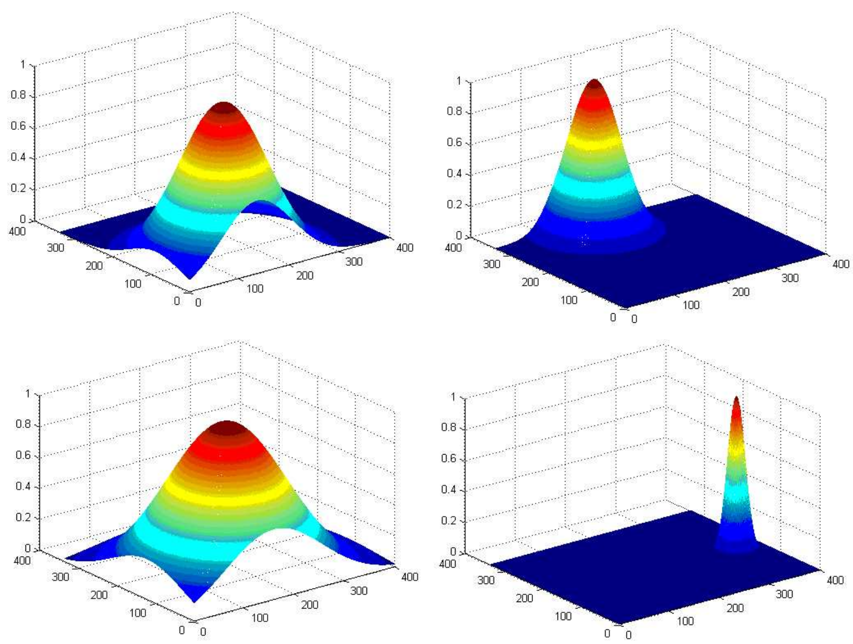

Fig 13: Two-dimensional normal distribution. Similarly, the values have also been normalized.

We take comfortable zone into consideration by multiplying the above four distributions to the original distribution described by **Figure 9**. Thus the original distribution is modulated by four normal distributions. The result is showed in **Figure 14**.

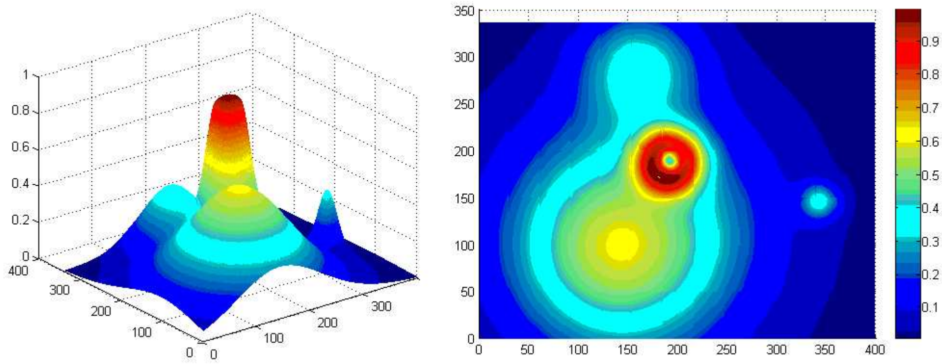

Fig 14: The probability distribution of the next crime site taking comfortable zone into consideration. Similarly, the values have also been normalized.

Among the comfortable zones, some zones encounter crimes more frequently than others, and the criminal will more likely to go to these zones, which indicates the criminal's degree of preference over these areas. To reflect this consideration, we multiply the four normal distribution with the number of crime sites belonging to each zone.

Next, we would like to take time interval between two times of committing crime into account. Empirically we know a criminal is unlikely to commit the next crime too near to the previous crime, both spatially and temporally. This is because people's prevention awareness and police patrol are strengthened in that area and he or she is fear of being caught. On the other hand, people's prevention awareness and police patrol will weaken as time passes, so we assume that a crime is most likely to go to the area where he or she haven't been for the longest time. To express this notion mathematically we multiply each normal distribution with

$$\frac{\Delta t_i}{\sum_{i=1}^{N} \Delta t_i} \tag{9}$$

In the above expression, N is the number of areas the crime sites is divided, and in Peter Sutcliffe's case, $N = 4$; $t_i (i = 1, 2...N)$ is the time interval between the latest crime and the latest crime in i-th area. We notice that the zone where the latest crime was committed will be multiplied by zero, indicating that the next crime will never be committed here. This is not true in reality(consider point 5 8 in the example case). We modify **Expression 9** into **Expression 10**

$$\frac{\Delta t_i}{\sum_{i=1}^{N} \Delta t_i} + \frac{m}{M} \tag{10}$$

where

- m is the number of times that the criminal choose to commit the next crime in the same area as the previous crime. It is obtained from historical data of crime sites. Its value is 3 in the example case.

- M is the total number of times that the criminal have to choose the next crime site. Its value is 21 in the example case

The term $\frac{m}{M}$ represents the probability that a criminal would choose the same area as the previous crime to commit the next crime.

Now we have add preference of the areas and time interval information to our model make more precise prediction. We get following result showed in **Figure 15** , using our method to study our example case.

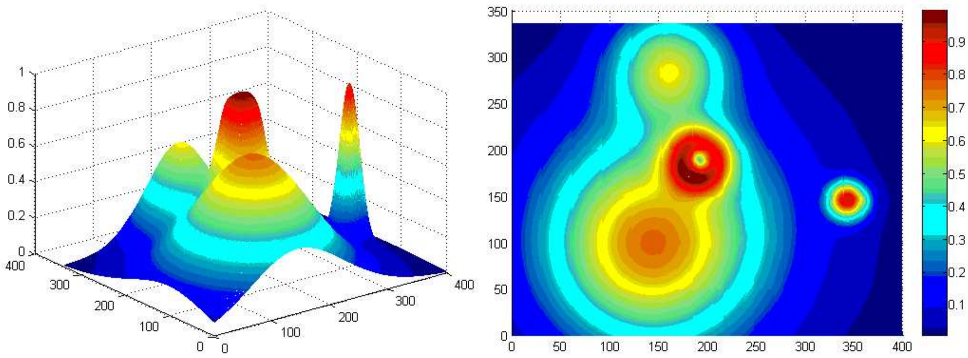

Fig 15: The utilize outcome of probability distribution. Similarly, the values have also been normalized.

7 Validation of Prediction

We use the ultimate result of probability distribution of the next crime scene to obtain the 23^{rd} crime scene with the previous 22 scenes. Although the location of the 23rd point is not in the area of largest probability, its relative probability is not too low(0.4830, and the whole map has a maximal value of 1). So our solutions have rather high degree of reliability.

We continue to predict the 15th sites using the previous 14 sites, then predict the 16th sites using the previous 15 sites, and so forth. The results are all rather satisfactory.

8 Evaluating of Solutions

8.1 Strengths

Firstly, we use two strategies based on very different theories to search for the residence place of the offender and get very close results. In the prediction methods, we take many possible factors into consideration to reflect the real world situation. Our methods have high degree of reliability and practicability.

Secondly, our methods' another strength is their enormous flexibility and commonality. Our models are easy to operate on any cases, provided we have a map containing the historical data of the location and time of crime scenes.

8.2 Weaknesses

Firstly, we have utilized only two methods to generate geographic profile, which weakens our solutions' accuracy.

Secondly, the combining technique is somewhat too simple and lacks strong mathematical support.

8.3 Future Consideration

- There exist many methods for geographical profiling other than the two schemes we have proposed. For example, set theory[1][11] provides a simple and useful approach for addressing this problem.
- In all our solutions, the distance we used is Euclidian distance. Manhattan distance[7] is more appropriate in big cites with numbers of perpendicular streets and blocks. Our models can be easily modified to fit this change.
- Studies indicate that as an offender's crime career matures, journey to crime distance lengthens and size of hunting area increases[12].
- Every type of crime (murder, rape, robbery...) has its own characteristic. Future researches can be conducted to study how to best apply our methods for geographic profiling according to different types of crime.

9 Executive Summary for the Chief of Police

9.1 Preparatory Work

When the serial criminal happens, the first thing for law enforcement officers is to collect the data about the time and locations of the past crime scenes. Then they should mark every crime site on the map clearly. What is more, law enforcement officers should make **Safety Tips** for local people as soon as possible. The **Safety Tips** should include the following items.

- Remind people that there are serial crimes recently in local area.
- Tell people not to be too panic.
- Tell people , especially women and children, not go out alone at night.
- Point out that if somebody has any clues about the serial crimes, welcome him or her to the police station.

9.2 Overview of the Potential Issues

After that, the law enforcement officers should try their best to search the criminal and predict the location of the next crime as soon as possible. A search that starts in the highest (i.e., most probable) area and works down will be more likely to find the offender sooner than a random process would. Our model is aimed to solve these problems.

Our model mainly solve two problems:

- To search out the residence of the criminal based on the time and locations of the past crime scenes.
- To utilize the residence to predict the location of the next crime.

And we have two methods to solve the first problem.

- **Center of Minimum Distance Model**

  We only consider the location of the crime site. Based on the principle of least effort, we can obtain the possible area of the criminal's residence. This strategy is easy to understand and convenient to use. However, it neglect the criminal mentality, thus, the reliability of this strategy is not good.

- **Bayesian Model**

  We take the criminal mentality into consideration. According to the criminal psychology, the criminal dont like to commit a criminal in a place far from home. The farther away from home, the fewer crimes are committed. Meanwhile, only few crimes are committed in the area immediately around the offenders residence. Thus, the probability is low in these area. Based on this theory, we construct a model to search the residence. This strategy include the criminal mentality, thus, it is more realistic.

For the second problem, on the basis of the criminal's residence, we predict the location of the next crime. It is well known that the next crime is committed at a place where the probability of crime is highest among all the area. Thus, we utilize cluster analysis to divide the whole area into several small areas based on the distribution of the crime sites.

9.3 Suggestion

In our model building process, we summarize some experiences for law enforcement officers.

- **In the area where no crime ever happens in a long period of time, there is no need to assign a lot of policemen to this area.** As the criminal psychology, very few criminals will commit two crimes successively in a short time. Thus, assigning a lot of policemen to this area will have no effect to crack the criminal case, but to waste manpower.
- **In the area where a crime don't happen for a long time, it is necessary to assign some policemen to patrol.**
- **When combining the results generated by by the two approaches, the police should consider both areas if one area is far away from the other**.
- **Our model can't predict exactly if we are lack of historical crime data.** As our model is based on the time and locations of the past crime scenes, our model is ineffective in the first beginning stage of the serial crime.

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