Rationalizing police patrol beats using Voronoi Tessellations

Arvind Verma*, Ramyaa Ramyaa†, Raminder Singh‡ and Suresh Marru§
*Department of Criminal Justice, averma@indiana.edu
†Department of Computer Science, ramyaa@indiana.edu
‡Pervasive Technology Institute, ramifnu@indiana.edu
§School of Informatics and Computing, Pervasive Technology Institute, smarru@indiana.edu
Indiana University, Bloomington, IN, USA

Abstract—Computational criminology as such is an emerging inter-disciplinary field that applies computer science and mathematical methods to the study of criminological problems. The paper discusses the solutions with these multidisciplinary aspects of criminology, geography, mathematics and computer sciences. In order to understand its nature one has to comprehend not only its spatio-temporal dimensions, but also the nature of crime, the victim-offender relationship, role of guardians and history of similar incidents. In this position paper we explore a problem in rationalizing police patrolling beats using Voronoi Tessellations. Voronoi Tessellations provide a powerful technique to explore variety of criminological perspectives and understand the geography of crime and its control mechanism. The paper presents a method to rationally design an equitable workload amongst the police patrol beats to handle a specific nature of crime.

I. INTRODUCTION

Crime is a multidimensional, complex, and dynamic activity. In order to understand its nature one has to comprehend not only its spatio-temporal dimensions, but also the nature of crime, the victim-offender relationship, role of guardians and history of similar incidents. Crime analysis involves massive computing challenges due to the large volume of data and complexity of the human behavior [1]. For example, a set of serious crimes for a period of 6 months in Indianapolis metropolitan area amounts to 30,000 plus data points [2]. Rationalizing police beats based on this kind of sample crime data along with physical and resource constraints is a gigantic data analysis task. This cannot be done except by applying latest computer simulation techniques and clustering algorithms to achieve customized patrol beats for equitable workload.

Multi-Disciplinary collaborations are needed to address criminological problems like crime pattern analysis, target selection by motivated offenders, awareness space of serial criminals, offender profiling, movement patterns of victims and offenders that lead to hot spots. A mash up of experts from Criminal Justice, Mathematics, Data Mining, Visualization, Geographic Information Systems, Distributed Computing are required to come together and apply complex algorithms and computer simulations. By describing a specific criminology problem on customizing assignment of police personnel for specific objectives, we demonstrate various multi-disciplinary aspects and will discuss possible solutions. The paper presents a method to rationally design an equitable workload amongst the police patrol beats to handle a specific nature of crime. The paper further outlines extensions of this technique to meet other policing objectives and to address specific nature of problems.

II. RELATED WORK

A number of different teams around the globe are trying to use computational criminology perspective to validate criminological theories as illustrated in the book on Artificial Crime Analysis [3]. These approaches are related to simulation and visualization of the crime data and to study the behavior of the criminals using different dimensions of crime. The book is a collection of multiple individually contributed chapters. Verma et al from Indiana University have described multiple windows technique to visualize criminal data efficiently. Other researchers have conceptualized Agent based modeling to use offenders as agents and attach different attributes to simulate their behavior in real environments. Some authors have also taken the factors of Agent learning and adaptation algorithms to make their simulation model more accurate. A project Mastermind by Simon Fraser University, Canada has taken multi-agent based modeling to study multiple criminal offenses and develop a formal framework for semantic modeling and systematic integration of the theories for crime analysis and understanding crime patterns. Yet another chapter [4] discusses the use of geographic information systems, real-time data sets and the ability via GPS [global positioning systems] to identify locations of patrol units. It is argued that this will provide the environment to discuss the concept of an intelligent patrol routing system that can combine crime data utilizing Map Algebra and structure spatial dimensions using Voronoi Tessellations. Their proposal allows all patrol units to function in concert under a coordinated plan, keep in mind the limited patrolling resources, and provide the means of evaluating current patrol strategies. Further improvements are suggested by incorporating distance measure in the determination of Voronoi diagram; by assigning weighs for each spatial layer utilizing advanced data mining algorithms or perhaps neural networks and by creating paths of greatest need while still meeting time arrival requirements. These suggestions are potentially to be solved with massive parallelism.
III. RATIONALIZING POLICE PATROL BEATS

The division of a given police jurisdiction into a set of patrol beats for equitable workload is an exercise in the partitioning of the space where the total weight of the crime sites is the same for every beat region. Geometry is the appropriate mathematical technique to partition the space into a set of regions based upon some criteria and proportionality. The line, arc, radius, circumference, angle, area, projection, distance between points are some of the building blocks that have found wide spread applications in civil engineering, organic chemistry, nuclear physics, archaeology and even in the efforts to determine the shape of the universe. In criminology too, the spatial distribution of criminal events, offender residences, police patrol beats, location of courts have been studied through geometrical techniques [5], [6], [7], [8], [9]. However, most of the criminological studies have treated crime sites as point objects and have been restricted to the distributed patterns of these points. Clearly, for analytical purposes, particularly for purposes of patrolling, one must take into account the neighboring space around the points too. Thus, for a crime site or an activity node, the interest is not only in the exact location but in the immediate surrounding space as well. A crime occurs at a shopping mall or at a street corner due to the isolation or lack of guardianship of the surrounding area and opportunities accorded to the motivated offender [10]. For these and other reasons we need a geometrical technique that can suggest methods to construct and consider the sphere of influence around the point like and other shaped objects.

A. Voronoi Tessellations

The mathematics of the Voronoi diagram and spatial tessellation, variously known as Thiessen polygons or Dirichlet domains provides an appropriate technique to examine the distribution of point objects and take into account the surrounding regions. These tessellations are formed by associating with each point in the pattern, all locations in the study area that are closer to it than to any other point in the pattern space. These contiguous spaces represent the partitioning of the area into the neighborhoods of the points. Such a partitioning of space has found wide spread usage in such diverse fields such as anthropology, archaeology, astronomy, biology, crystallography, geography, meteorology, operations research, physics, physiology and urban planning [11].

In this paper, we discuss the applicability of this mathematical technique in the proper management of police resources. Random but targeted patrolling has been an important preventive method used by almost all the police departments. Focused patrolling of crime hot spots [12] and paying attention to temporal rhythms [13] are suggested to be more effective. However, police patrol beats were established historically based upon the distribution of limited resources and population of local communities [14]. Commonly, these patrol jurisdictions remain unchanged as organizational structure, built around them is rigid and does not permit frequent changes [15]. The task of fashioning these units for customizing deployment to address varying needs, such as serious crimes, demands for special services, festivals or major events is difficult. This is also compounded by the fact that availability of officers fluctuate daily due to demands of court work, health issues and other uncertain factors [16]. Consequently, workload and criminal incidents handled by various units differ considerably causing problems of performance, burn-outs and dissatisfaction with deployment policies [17]. A rational and simple technique to customize police patrolling beats could go a long way in alleviating these problems.

B. Proof of Concept - Sample Data

As a proof of concept, the jurisdiction of Indianapolis police department data is illustrated as a test case while considering the partitioning of patrol beats to account for the distribution of a particular type of crime. The chosen crime subset data is for illustration purposes only and we argue that the solutions can be extended any form of crime data. A weight of one for minor offense and 2 for major crime is assigned to the crime data suggesting that some cases are more serious than others due to the greater loss of property value or threat to physical body. The police jurisdiction is partitioned separately to account for the total cases of minor and serious crimes. This partitioning allows to prioritize and optimally allocating police personnel according to the weight. Further in the paper we discuss the solutions with the multidisciplinary aspects of criminology, geography, mathematics and computer sciences. Using the ArcView GIS program a crime map of Indianapolis police district and its sub-divisions of smaller patrolling beats are plotted. The acquired sample of crime data for one year, between January and December of 2008, constituting N cases [and involving n1 cases of minor crimes and n2 cases of serious crimes n1 + n2 = N] is mapped. The serious cases are assigned double the weight of other crime sites to suggest that these constitute greater consideration by the police department. The following snapshot illustrates one such mapped crime data.

C. Constraints for clustered beats

The number of police beats per city will specify a required number of clustered beats. The crime sites are combined into the pre-defined number of clusters based upon the total weight of the mapped points. The centroid of each cluster on the spatial map is then calculated. Along with the sample data analysis, following additional categorized information is accounted into the distribution of beats:

- Crime Types
  The ‘work’ associated with each crime is calculated based on the severity of the crime type.
- Crime Data
  Geographic coordinates of the crime are analyzed along with time stamp of the occurrence and the type of crime.
- Crime Groups
  Various information like ‘Gangs’, ‘Strong Political Activity’, ‘Drug dealings’ can be considered.
D. Goodness Measures

Principles of Voronoi Tessellations are applied to divide the entire city space using the calculated cluster centroids as the basic building block (seed) of each Tessellation. The creation of these Voronoi Tessellations is governed by objectives of the police management and the above mentioned constraints. For instance, the objective could be to equitably distribute the number of crimes falling into each patrolling unit. Or it could be to distribute the crime sites to obtain equitable distribution based upon the weights of the crimes. A goodness of measure algorithm ensures the partitions based on criteria of equitable distribution of workload accounting for the seriousness of crimes. We use this algorithm to test incremental changes in the partitioning of space for improving the goodness measure.

1) Equitable Workload: Each cluster should have roughly similar work load. The workload is measured by the time taken to deal with the crime and the crime’s severity - this uses the "work" calculated from crime type data. A single cluster's work load can be calculated as the sum of crimes taken place in the cluster weighted by the "work" associated with the crime. Standard deviation of the workload will provide a measure of how equitable the load distribution is.

Further considerations can include the time of crime. This additional information results in a different work load for different periods of time resulting in possibilities of:

- Designating different beats based on time of day/week/year.
- Different beats during events like elections, sporting events or other crime prone activities.
- Avoid work clotting by shuffling police officers for differently loaded patrol blocks.
- Geographical spread of different crime groups and their varied impact.

2) 911 Response Time: The patrol beat locations also has an impact on the first responders response time. Various factors include:

- Size(area) and Shape(length) of the cluster - A bigger or a longer cluster will have a longer 911 response time. These distances can be predicted using a standard distance metric such as Manhattan distance. A convex hull is drawn around the cluster, and an algorithm such a rotating clippers will be used to calculate the maximum response time.
- Within a cluster or beat, it is conceivable that there are sub clusters of crime. For instance, a long cluster running from east to west may be sub divided into clusters of crimes. If a sub-cluster is on the eastern end, then the average/maximum time taken to reach the crime points is higher than a scenario where the sub-cluster is located near the center of the e-w cluster. In the later case, the maximum time taken to reach the high-crime rate sub-cluster is roughly half the maximum time taken to reach an arbitrary point from another arbitrary point in the cluster.
- Geographical Constraints like a river will vary measures within a cluster impacting the maximum response time, the average time and the time to high-crime-rate sub-clusters. Similarly, among clusters there will be a variance of average and maximum responses.

3) Geographical Area Fit: Urban areas are typically divided into regions or big blocks. These regions matching the partition can be measured.

4) Citizen Satisfaction: The population density of a cluster can be a policy factor. Other indirect factors like the nature of the geography on residential, malls, schools etc can be measured.

5) Constraint Satisfaction: A goodness measure based on the previously discussed constrained such as the need of a patrol near courthouse can be computed to generate a need index. This need index can thus be incorporated into the equation.

6) Derived Police Beats: Finally, we transfer this geometry onto the GIS constructed map to sketch the new patrol areas for the police department. The final outcome is a new set of patrolling beats rationalizing the deployment of officers for the customized objectives.
IV. Future Roadmap

A. Extending Voronoi Tessellations

Voronoi Tessellations provide a powerful technique to explore variety of criminological perspectives and understand the geography of crime and its control mechanism. The algorithms will be designed to be extensible to meet emerging objectives for the police. One such consideration is to rationalize the boundaries of the patrol beats by taking account the road network and physical landscape such as river and one-way streets. The other design that we are considering is to bring an equitable workload for other policy objectives. For instance, each crime site could be assigned a time interval for the officer to address the problem. Rather than equitable number of crimes, the workload may be uniformly distributed based upon expected time spent in handling these crimes.

B. Extending Applicability

The solutions are being considered to apply to other forms of crime data to develop other applications such as to partition the police district accounting for offender residences for better surveillance; partitioning the space to match the territorial boundaries of gangs and to deploy police for complete surveillance of areas affected by serial offenders. Voronoi Tessellations also provide a powerful mechanism to test the validity of criminological theories such as the Rational Choice theory or the Routine Activity theory. These theories hypothesize that physical landscape shape the movement patterns of victims and offenders and create opportunities at specific places and time periods. Most crimes are located in such regions of high opportunities. The partitioning of the given space in terms of the routine activities of the residents would identify specific places where the victim and the offender are likely to meet one another. According to these theories these should be the hot spots of crimes that can be tested by reference to the available police data.

C. Scaling and Parallelizing of Data and Algorithms

As the problem (hence data) size and number of constraints increase, the computational needs increase proportionately. Various parallelizing and distributed system techniques will be pursued.

References