Why and How Mathematics Can Be Connected to Crime

Charlie Strausser

College of William and Mary

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Professor CK

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1. What Makes Crime and Mathematics Such a Great Fit?

Over the past 20 years, criminologists and mathematicians have enjoyed an ever-flourishing relationship connecting their two fields. The work produced by taking criminological theories and describing and verifying them using statistical models has created results that have permeated the scholastic realm. Private companies have built upon this literature to produce their own models currently used to predict and even successfully prevent crime. In turn, this work has had an immediate impact on the patterns of policing employed throughout the United States. Mathematical results are currently being used to impact and effect the fight against crime. Despite this success, many other sociological fields have failed to connect their theories to mathematics. What has made criminological theories so easily connected and applied to mathematical models, and what would it take for other fields to accept their methodology?

In a livestream conducted by the American Scientist, Fenella Saunders interviewed Dr. Andrea Bertozzi and Dr. Jeffry Bantingham, two of the first academics to connect mathematics to crime, asking them what has made their collaboration so fruitful (The Mathematics of Crime). They explained that there were two different elements necessary for a productive relationship between a mathematician and a sociologist, one social and one mathematical. Socially, there must be a willingness to be flexible amongst both parties. Dr. Bertozzi stated that criminologists had to learn to condense their theories, accepting a loss in the "richness and complexity" of their theories. As mathematical models can only be so nuanced, sociologists had to learn to deal with a loss of subtlety, sociologists had to learn to "think statistically." Bertozzi believes that, incorrectly, there is a distinction created between people who like math and people who like the social sciences. Many people are forced, as early as high school, to either decide to like math and in turn despise the social sciences, or vise-versa. Bertozzi believes that instead these two

mindsets should be viewed as interchangeable, with both providing value in a synergistic relationship. One interesting idea she poses to emphasize the connection of the social world and mathematics would be to teach statistics to young adults rather than calculus, an interesting idea also supported by Arthur Benjamin in his famous TED talk "Teach Statistics before Calculus!" (Benjamin 2009). On the other sides of things, mathematically, Dr. Brantingham stated that there must be a rich and complete data set in order to generate these statistical models. Criminology produces remarkably large and complete data sets. As seen in sections below, criminal reports form a great data set to do computations. Every reported crime has an associated date, time, and classification. These components can be used to generate an accurate data set describing all of the crime that is reported in the United States. Despite some moral and potentially human limitations to this data set, also discussed below, this was a great starting point for developing a mathematical model for predicting and preventing crime.

Finally, Dr. Bertozzi and Dr. Brantingham do believe that their work can be replicated to other sociological fields. Stating that there exists many data sets, the only thing that lacks is a willingness for compliance between the two researchers. Stating that an unwillingness to take a loss of complexity and an inability to think statistically has been the problem hampering many fields from joining forces with the mathematical world to produce results. Personally, I believe that there are two large problems that prevent mathematics from joining forces with the social sciences. The first being similar to the problem stated by Dr. Bertozzi, many people hate math and do not want to think statistically. I think it is a great idea to attempt to foster a statistical view of the world by teaching statistics rather than calculus. I also believe that mathematicians have failed to in the case of crime research accept that a loss of complexity has lead to a problem

in some of their models, these problems will be discussed below. But first, a short description of the mathematical concepts that have been used in crime research.

2. Introductory Work Connecting Math and Crime: Poisson and Hawkes Models

One of the first and most basic approaches that attempted to describe crime was using a Poisson Distribution to model criminal activity. A Poisson distribution is one of the most fundamental distributions in statistics. It is used to describe a random even over time. One example utilizing a Poisson distribution would be in Jimmy's model that described customer's entering a store. If it is assumed that customers enter randomly at an average rate of some people per hour, then the Poisson distribution is one of the best to describe what are the probabilities that a certain number of people will enter the store over a period of time. The Poisson distribution assumes that these events are all random and independent. This is where there are many problems with the Poisson distribution is describing criminal activity. It is both a long held criminological belief as well as a well analyzed phenomenon that crime causes other crime. Connecting this to Jimmy's store idea, a crime is like if a celebrity is seen entering a store. This could change the pattern of people entering this store as more people would enter the store upon seeing this celebrity. When a crime is committed, many crimes will follow in that area. So, for this reason the Poisson distribution fails to describe crime.

So, researchers turned to the Hawkes distribution in order to describe criminal behavior. The Hawkes model was first used to study earthquakes. Earthquakes can be seen as very similar to crime as if an earthquake happens, it is very likely that there are subsequent aftershocks. Similar to in crime one crime can lead to an "aftershock" of subsequent crime. The Hawkes distribution is a modification of the Poisson distribution, adding in a few different terms to describe how the rate of earthquakes, or in this case the rate of crime, changes after an event. There is both a

weighting coefficient, and a dissipating coefficient that affects the described rate. So by assigning a certain weight and a certain dissipating factor is can describe how much more crime can be expected, and for how much longer this crime increase will happen over time.

To look at a few of the most famous papers using this model one can look at *Self Exciting Point Process Modeling of Crime* (Mohler et al., 2011). The DOI can be found in the works cited. Also note that self exciting is another name for a Hawkes process. Or for more information on the details of both the Poisson and Hawkes distributions have been used in crime, one can check out the Numberphile video "The Mathematics of Crime and Terrorism," as well as the corresponding paper by Fry that describes how a Hawkes distribution fits that rate of IEDs, improvised explosive devices, used by the IRA (Tench et al., 2016). The DOI can also be found in the works cited.

3. Modern Approach Connecting Math and Crime: The Reaction-Diffusion Model

One of the more modern attempts to model crime has been modeling criminal activity using a reaction-diffusion model. This model makes a lot of intuitive sense. An instance of crime can be seen as a reaction, that produces some sort of aftershock-like effect that can be seen as some sort of diffusion. Two of the most influential papers relating crime to a reaction-diffusion model along with their DOI's can be seen in the work cited. They are the 2009 study named *Dissipation and Displacement of Hotspots in Reaction-Diffusion Models of Crime* by Short et al., as well as the 2008 study *A Statistical Model of Criminal Behavior* also by Short et al..

The main question that was answered in these papers was not only how to model crime, but how can police distribution affect crime. There is a commonly known criminological idea known as hotspot policing where more police officers are sent to a specific region in order to prevent

crime for happening. The concept of hotspot policing had previously sparked a lot of debate amongst criminologists. The question was whether or not hotspot policing was effective. One perspective was that hotspot policing was effective as once police were present anyone who had planned on committing crime upon seeing police would decide that it was not in their best interest to commit crime and would desist. While the other side argued that upon seeing police in a specific area, the person who planned on committing crime would simply move to an area where less police were present and commit their crime in that new area. The research done by Short et al. had an immense impact on the ideology behind hotspot policing. They found that there were two different points, subcritical and supercritical. If a point was subcritical, then adding police would deter all crime, while if a point was supercritical, then adding police would simply move crime linearly to another area. So, this model helped to support and distinguish between both perspectives, it also provides valuable information for knowing where to place police officers. It would be a waste of a policeman's time to go to a supercritical area of crime, as compared to subcritical place. This model and this ideology has been improved on and even implemented by a private company called PredPol.

4. PredPol: The Leading Crime Predictor and Preventer

PredPol, short for predictive policing, is a private company that created an algorithm to predict crime with the goal of selling this product to police forces around the nation. PredPol states that is uses previous research, even mentioning that its "main" formula is a reaction diffusion models, combined with a machine-learning algorithm in order to predict crime. PredPol's data set uses only three points, the type of crime, the location, and the date/time of the crime. Sadly, it is impossible to do any analysis of PredPol's algorithms or any of its ideologies as they are all hidden and proprietary. This is one of the many controversies that surrounds

PredPol and its applications throughout the United States, these will be discussed later, but first PredPol has developed some studies stating that their algorithm and predictive policing in general has had many positive effects on crime rates.

PredPol states on their website the many successes of implementing their algorithm. The Los Angeles Police Department's Foothill Division saw a 13% decrease in crime over of 4 months, compared to a .4% increase in surrounding areas. After a release in Atlanta, crime was reduced by 9%. Similar results were seen in Alhambra, California, Norcoss, Georgia, and Santa Cruz, California. Now, the only problem that despite these positive results, these studies have only been conducted by PredPol themselves. I talked to an economics professors who specializes in criminological policy analysis and asked him about what he thought about the results of PredPol and whether or not they were legitimate, and he thought that most of the logic behind the software is very sound, but more testing would be needed. It is possible the professor and I collaborate to attempt to verify the results of PredPol, and any interesting results will be further communicated.

5. Criticism of Predpol and Predictive Policing in General

Recently, on top of questions surrounding the validity of the results published by PredPol as well as questions surrounding the lack of publication of any algorithms, the company has been under question surrounding the morality and potential racism of the algorithm. Now, it might seem counterintuitive that an algorithm that has almost no human interaction would be immoral, or even could possibly be racist, but many publications have started to report a wide variety of concerns over the ideology behind predictive policing.

In a 2018 study published by Ensign et al. titled *Runaway Feedback Loops in Predictive Policing*, these authors argued that predictive policing was not solving any crime, but rather simply replicating police biases and errors. The main argument of this paper was that if police members are biased or potentially racially motivated, they will inherently police areas with a higher percent of racial minorities both more frequently and more aggressively. This will lead to an increased reporting of crime in that area, and this will in turn lead the policing algorithms to suggest the presence of more police officers, who either also racially motivated or are now expected to see crime. These officers now expect to see crime in the area, leading to more reports of small offenses and even potentially spurious criminal activity, leading to a never ending loop of excessive and incorrect policing.

The combination of the study as well as a 2016 ProPublica study titled *Machine Bias* by Angwin et al., has lead to a significant amount of media attention questioning the apparent racism of all crime predicting algorithms. This study states that this bias spreads to many different tools surrounding criminal justice that use statistical techniques including both PredPol and another popular crime predicting software called COMPAS. For more information on this topic, I have linked a few of the more prominent/popular articles below. The two studies above mentioned are linked in the Works Cited.

https://www.theatlantic.com/technology/archive/2018/01/equivant-compas-algorithm/550646/

https://www.smithsonianmag.com/innovation/artificial-intelligence-is-now-used-predict-crime-is-it-biased-180968337/

https://www.theverge.com/2018/4/26/17285058/predictive-policing-predpol-pentagon-ai-racial-bias

https://gizmodo.com/study-finds-predictive-policing-no-more-racist-than-reg-1823733844

6. Bringing Math to the Public Using Crime: The Popular Television Show Numb3rs

Another connection between mathematics and crime is the popular television show Numb3rs. The show ran from 2005 until 2010 and followed the story of an assistant professor, Charlie Eppes, and his efforts aiding the LAPD in solving crime. The show was quite popular, and brought a lot of attention to the potential applications of math in real life problem solving, and in this particular case the uses of mathematics in solving crime.

It might be initially thought that any Hollywood show that pertains to mathematics would not be particularly mathematically sound, as Hollywood is known for gross physical exaggerations. But, Wolfram Research, the parent company of Wolfram Alpha, was in charge of verifying and developing all of the math that is presented in the show. In turn, the show presents a large variety of interesting mathematical topics in a factually correct manner. To see some of the mathematical concepts included in the show, two links are presented below. Clicking around shows that many mathematical connections topics and presentations can be linked to certain episodes, such as fractals, the prisoner's dilemma, etc., implying that this show brought mathematical connections talks to the general public.

http://numb3rs.wolfram.com/

http://pi.math.cornell.edu/~numb3rs/

7. Criticism of Numb3rs

Due to the factual accuracy of Numb3rs, it has received much praise from the mathematical community as bringing mathematical concepts to the average viewer. Despite this, Adam Rosenberg in his article titled, "A Mathematician Looks at "Numb3rs", The TV Show," takes one fault with the show. He states that the ability for Charlie Eppes, the main mathematician, to pull mathematical concepts magically out of his brain to seemingly instantly solve complex

crimes, leads to a disconnect between the viewer and the mathematical world. They view mathematics as some magical formula that only certain geniuses can see that would manage to solve all of the world's problems. Where as can be seen in the mathematical research on predicting and stopping crime, mathematics can biased, unclear, and even political, and it most definitely does not appear out of thin air.

Personally, I think that many of these problems can be tied back to the idea of "thinking statistically." Statistics, while it is a very valuable field of mathematics, is much less black and white when compared to the world of pure mathematics. Statistics can be used to create spurious correlations, that can be used to manipulate or even push political agendas. Once people have some training in statistics and are able to see the downfalls of attempting to model the complexities of the world and human behavior they would be able to have a more clear view of mathematics. As a very pure art that can be used to describe the world, but one that also possesses inherent flaws.

8. Conclusion

The goal of this paper was to introduce the interesting mathematical research connecting mathematics and crime. Mathematics has progressed the ideology of criminology greatly, but it has not come without any backlash. Mathematics, and statistics in general, can be very valuable in solving and explaining many of the world's social phenomena, but can also be susceptible to many biases and flaws. This paper took a critical look at the role of statistics and social sciences, hopefully giving the researcher many questions regarding the role of mathematics in not only research, but in both also in the public realm.

9. Thoughts on Math 400 as a Whole

Overall, conceptually I really enjoyed the ideas behind Math 400. I thought the idea of attempting to connect everything that we had done throughout our time at William and Mary to something in the real world/the world of research was a great idea for exiting seniors. In execution, I thoroughly enjoyed writing the discussion board posts, as well as putting together my presentation. I felt as if I learned a lot in this class about how to gather mathematical information, as well as gaining some interesting perspectives into the "real" world of math. The only problem I had was that it seemed as if the class never really built upon itself. It felt as if each student had their own opinions and there own topics of interest, but there was very little interplay/learning between each student. I think that potentially breaking discussions after presentations down into smaller groups, or having people write group reviews of a presentation would be a good way to increase student participation. I felt as if no one really wanted to talk after a presentation and that was potentially due to being uncomfortable in such a large person setting, whereas if they were talking to friends and then potentially forced to share their opinions this could be a stronger format. I also think designating a percentage of the grade to participation would help. In order to make this more achievable, I think potentially having the criticism for each presentation be done the class after the presentation. As in, each class starts with some criticisms/discussion, and then there are two presentations. This would allow for people to gather their thoughts/questions and would potentially make discussion less one-sided and more diverse. In general though, I really enjoyed taking this class and for it being a first-time thing I thought CK handled himself very well and made the class quite fun.

Works Cited

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