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AN IMMUNE SYSTEM INSPIRED THEORY FOR CRIME AND VIOLENCE IN CITIES

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ABSTRACT

Crime is ubiquitous and has been around for millennia. Crime is analogous to a pathogenic infection and police response to it is similar to an immune response. The biological immune system is also engaged in an arms race with pathogens. We propose an immune system inspired theory of crime and violence in human societies, especially in large agglomerations like cities.

In this work we suggest that an immune system inspired theory of crime can provide a new perspective on the dynamics of violence in societies. The competitive dynamics between police and criminals has similarities to how the immune system is involved in an arms race with invading pathogens. Cities have properties similar to biological organisms and in this theory the police and military forces would be the immune system that protects against detrimental internal and external forces.

Our theory has implications for public policy: ranging from how much financial resource to invest in crime fighting, to optimal policing strategies, pre-placement of police, and number of police to be allocated to different cities. Our work can also be applied to other forms of violence in human societies (like terrorism) and violence in other primate societies and eusocial insects.

We hope this will be the first step towards a quantitative theory of violence and conflict in human societies. Ultimately we hope that this will help in designing smart and efficient cities that can scale and be sustainable despite population increase.

KEY WORDS

complex systems, immune system inspired, computational sociology, modelling socio-economic systems, artificial immune systems

CLASSIFICATION

JEL: C51, C65, J18, O21

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INTRODUCTION

Cities are similar to biological organisms [1]. They consume resources and have emergent properties like generation of wealth and violence. Crime is ubiquitous and has been around for millennia. Crime is analogous to a pathogenic infection and police response to it is similar to an immune response. The immune system is engaged in an arms race with pathogens. Similarly law enforcement is engaged in an arms race with criminals.

We propose an immune system inspired theory of crime and violence in human societies, especially in large agglomerations like cities. In this work we suggest that an immune system inspired theory of crime can provide a new perspective on the dynamics of violence in human cities. The competitive dynamics between police and criminals has similarities to how the immune system is involved in an arms race with invading pathogens. Cities have properties similar to biological organisms and in this theory the police and military forces would be the immune system that protects against detrimental internal and external forces.

Such an immune inspired theory or immunological theory of cities has several advantages:

1) There are advantages of looking at complex socio-economic systems like cities from the lens of other complex dynamical systems like the immune system: the observed scaling of a quantity of interest is the result of the complex nonlinear interplay between two different competing systems (pathogen and immune system and criminals and police) [2]. This approach has been also used successfully to derive results for how the immune response against pathogens scales with the size of the complex system (in this case the size of the host organism) [3,4] and how the number of crimes and the response of police against criminals scales with the size of cities [2].
2) Previous work using the immune system as an inspiration has shown the optimal way to locate structures similar to lymph nodes (anatomical structures used by the biological immune system) that facilitate detection of adverse events and response against them in human-engineered distributed systems like mobile networks, peer-to-peer networks and social networks [3-14]. An immune system inspired theory of cities may inform strategies on how to optimally locate police and police stations, and design efficient policing strategies.

The present work lays the foundation for an immune system inspired theory of violence in cities. Such a theory may give insights into how crime, social unrest and civil disorder develops in cities.

Population pressure makes current growth of cities unsustainable. A large percentage of the human population now resides in cities and millions of people migrate to cities each year in search of livelihoods. If cities are to be sustainable and our future growth is to be secured, we must design strategies for smarter and more efficient cities. Ultimately we hope that the present work will be a step towards designing smart and efficient cities that can scale and be sustainable despite population increase. We hope our work will lay the foundation for quantitative theories of conflict in human societies and give insights to help design better and more efficient cities.

IMMUNOLOGICAL PRELIMINARIES

The immune system is involved in an arms race with pathogens that invade the host organism. Cells of the immune system are trained to distinguish self (cells of the host organism) from non-self (foreign particles and organisms considered harmful to the host including viruses and bacteria) [15].

The immune system consists of two arms: the innate immune system and the adaptive immune system. The innate immune system is the first line of defense and consists of cells like macrophages that clear all particles considered foreign and dendritic cells (described later). The adaptive immune system consists of T-cells and B-cells which constitute tailored and more specific responses to pathogens.

Cells of the immune system called dendritic cells search for non-self in tissue (these cells recognize a broad range of pathogens and in that sense are considered generalists). Once they find something considered harmful, they traffick to nearby lymph nodes (which are specialized anatomical structures that facilitate the interaction between different immune system cells) to present this to other specialized cells of the immune system like B-cells and T-cells.

T-cells are specialized immune system cells that have been trained to recognize non-self. Individual T-cells are specific to particular forms of pathogens or particular patterns of chemicals (called antigens). There are only a few T-cells that are specific to the antigen presented by the dendritic cell and this search takes place in the lymph node. Once the rare T-cell recognizes the pathogen it multiplies itself (in a process called clonal amplification). These T-cells then attack infected cells in an effort to control the infection. In a similar process, cells of the immune system called B-cells also recognize antigens presented by dendritic cells and secrete chemicals called antibodies in order to neutralize pathogens. Antibody binds to viruses which are then removed by immune system cells.

The immune system has specialized cells called memory cells which have recognized past infections. These cells allow the immune system to respond faster if the same pathogen is encountered again.

Immune system tolerance is a process by which the immune system is trained to recognize and not attack organisms which are foreign but benign to the host like gut microbes. Specialized cells called T regulatory cells suppress reactions by other immune system cells so that they do not attack these beneficial organisms [15].

IMMUNE SYSTEM INSPIRED THEORY OF CRIME

The arms race between immune system and pathogens is similar to the competitive dynamics between police and criminals. Cities have properties similar to biological organisms and in this theory the police and military would be the immune system that protects against both internal and external forces. The system is depicted in Fig. 1.

Police are activated by crime just like T-cells and B-cells are activated by dendritic cells. Non-criminals are turned to criminals in the presence of crime. Hence crime is like a virus. This specifically simulates a spread of disorder. The police is analogous to the immune system and criminals are like infected cells. Police also remove criminals similar to how T-cells kill and remove infected cells. The analogies between the immune system and police are summarized in Table 1.

MODELS AND METHODS

The dynamics of the immune system is typically modelled using non-linear dynamical models (using ordinary differential equations and agent-based models) that simulate the spread of disease within an organism [3, 8, 13, 16-18].

Cities can undergo major social upheavals as for example in the London riots of 2011, Arab spring revolutions of 2011 through 2013, and the Stockholm riots of 2013, demonstrating that social disorder can spread very fast in cities. Non-linear dynamical models can capture these dynamics [2, 19].

Table 1. Analogies for an Immunological Theory of Crime.

Human Societies	Immune System
Crime	Virus
Non-Criminals	Susceptible normal cells
Criminals	Infected cells
Police	Immune System
Police first responders	Innate immune system (dendritic cells)
Specialized police forces	Adaptive immune system (T-cells and B-cells)
Police taking out criminals	T-cells killing infected cells
Police removing crime	Clearance of virus by B-cells
Crime database	Immune memory
Police crimes against innocent people	Immune system attacking itself
Police stations	Lymph nodes
Patrolling police	Circulating T-cells

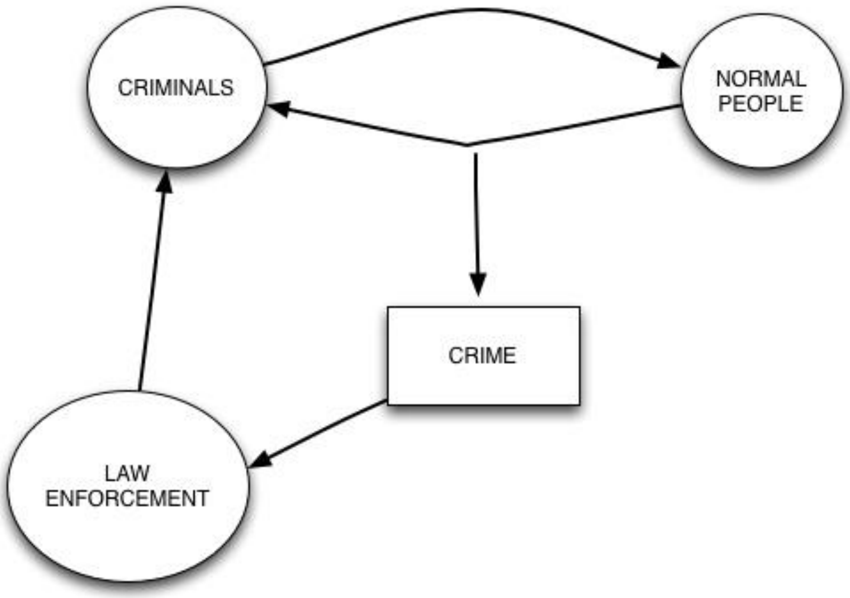

Figure 1. A simplified depiction of the arms race between police and criminals. The interaction between criminals and normal people (non-criminals) causes crime. Crime triggers a police response. Police in turn respond by removing crime and removing criminals (adapted from [2]).

In previous work we used a dynamical model that captures the complex interactions between police and criminals [2].

$$\frac{dC}{dt} = \alpha \cdot D_C \cdot D_{NC} - \beta \cdot C \cdot D_{LE}. \quad (1)$$

We denote the number of criminals per unit city area as D_C (density of criminals). Similarly, the number of ordinary (non-criminals) people per unit area is denoted by D_{NC} (density of non-criminals). Finally, the number of law enforcement officials per unit area is denoted by D_{LE} (density of law enforcement officers). Let us denote the density of crimes as C. We assume that crimes are generated by the interaction of criminals and non-criminals, on which criminals perform a criminal action, with rate constant α. Crimes are prevented by law enforcement at a rate proportional to the density of crimes and the density of law enforcement with rate constant β. The model is diagrammatically represented in Fig. 1.

This model can be simplified under conditions of steady state (holds during normal peaceful time periods and not during times of violence) to yield an equation for crime [2]:

$$C_{SS} = \frac{\alpha \cdot D_C \cdot D_{NC}}{\beta \cdot D_{LE}} \tag{2}$$

where $Crime_{ss}$ is the number of crimes in cities at steady state, $N_{criminals}$ is the number of criminals, $N_{non\text{-}criminals}$ are the number of non-criminal people, N_{police} denotes the number of police in cities and α, β refer to constants of proportionality in the relationship. Equation (2) is a general equation which unites crime in different contexts: from crime in cities to crime in universities [2].

Mathematical models can also be used to simulate the spread of disorder in cities. The following model simulates an increase in police numbers in response to a sudden increase in the number of criminals as is expected to occur in cities during times of social unrest. This has been empirically observed in the London riots of 2011 [19]. This model implements a phenomenon of spreading of disorder whereby non-criminals undertake criminal activities when they observe a lot of crime in their vicinity [20].

$$\frac{dD_C}{dt} = \alpha\big(C(t)\big) - \beta D_C D_{LE} \tag{3}$$

$$\frac{dD_{NC}}{dt} = -\alpha\big(C(t)\big) \tag{4}$$

$$\frac{dD_{LE}}{dt} = \eta\big(C(t)\big) \tag{5}$$

$$\frac{dC(t)}{dt} = \delta D_C D_{NC} - \gamma C(t) D_{LE} \tag{6}$$

$$\alpha(C(t)) = \frac{a_1}{1+e^{-a_2 * C(t)}} \tag{7}$$

$$\eta(C(t)) = \frac{a_3}{1+e^{-a_4 * C(t)}} \tag{8}$$

Non-criminals are turned to criminals in the presence of crime. Hence in this model crime is similar to a virus. This specifically simulates a spread of disorder. The police is analogous to the immune system and criminals are similar to infected cells.

Criminals are generated from the ordinary population at a rate α, which is a function of total crime in cities: this implements a spreading of disorder [20]. Law enforcement fighting crime actively are increased at a rate η dependent upon crime to simulate an increase in police numbers in response to crime in specific areas. Criminals are also removed (e.g. by imprisonment) at a rate proportional to the density of law enforcement and the density of criminals, with rate constant β. Finally crimes are generated by the interaction between criminals and non-criminals with rate constant δ. Crimes are prevented by law enforcement at a rate proportional to the density of crimes and density of law enforcement, mediated by a rate constant γ. The precise forms of the functions α(C) and η(C) would depend on the available data. Here we choose a sigmoidal function to simulate an increase in police (and criminals) till some constraint is met (saturation in police numbers or criminals). A representative model simulation is shown in Fig. 2.

It is also possible to build more complex models where police action produces more crime. Such models can be used to simulate revolts against administrations and civil unrest like in the Arab Spring revolts. We envisage considerable difficulties in estimating parameters for such models. However these models can be used for what-if analysis to guide public policy makers and government bodies in making judicious decisions about how many police to deploy, where to deploy them and how to control adverse effects like police brutality.

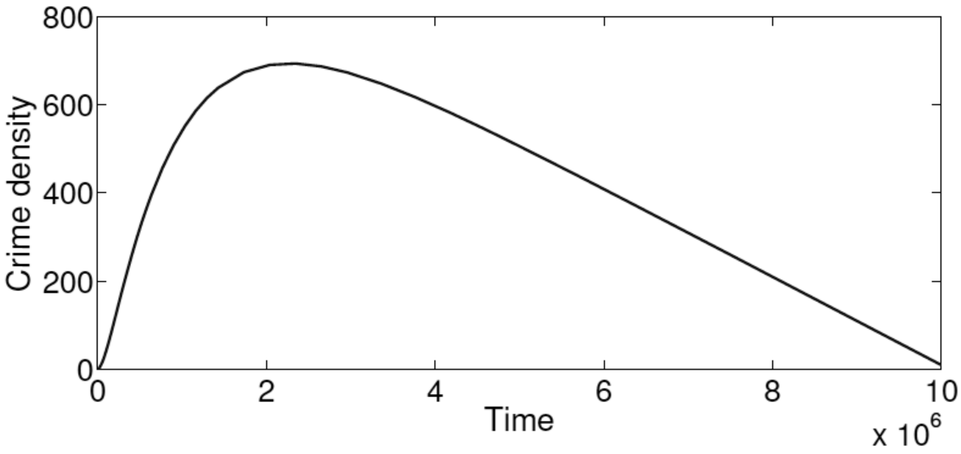

Figure 2. A sample plot of density of crimes (crimes per unit area) over time (in seconds) as predicted by a non-linear dynamical model (see preceding discussion).

DISCUSSION

Crime has been synonymous with cities ever since their inception. The competitive dynamics between police and criminals has similarities to how the immune system is involved in an arms race with invading pathogens. In this work we suggest that an immune system inspired theory of crime can provide a new perspective on the dynamics of violence in human cities.

QUANTITATIVE THEORY OF VIOLENCE AND CONFLICT

We view Equation (2) as a single equation which unites crime in different contexts: from crime in cities to crime in universities [2]. It gives us hope that there may be a more general quantitative model for crime and violence in human societies.

We see that this work as a first step towards a deterministic theory of human behavior and violence in societies. Isaac Asimov had written imaginatively about a field of predictive human behavior which he called psychohistory [23]. Although this remains an extremely ambitious goal, in the era of big data we may be able to predict behaviors of large ensembles of people [21] without being able predict actions of individuals.

PRIVILEGED ROLE OF THE IMMUNE SYSTEM

Our work also raises a question about why immune system cells are apparently able to behave unselfishly. For example why does the immune system not attack the host organism all the time? Equivalently why do police not attack innocent people all the time?

There may be strong incentives at play that prevent such aberrant behavior. Cells of the immune system have privileged metabolism [22], i.e. they have access to more metabolic energy than other cells adjusted for body size. Similarly soldiers and police get a lot of social prestige and status from serving and get additional privileges not available to civilians. This may also explain why soldiers and police are willing to give their lives for their countries and fellow citizens. This is not to say that there is no damage to normal cells. Normal cells are damaged and killed during vigorous immune responses. The cost of such “bystander effects” may be considered acceptable in the immune system compared to the risk of not killing possibly pathogen-laden infected cells.

Nevertheless these incentives are never always enough and sometimes we do observe breakdowns in militaries and police leading to civil war and mutiny. Quantitative models of the kind introduced in this work may inform policies on how to design incentive strategies for police in order to reduce crime as also reduce police corruption and judicial violence against innocent people.

The search for pathogens by the immune system is harder in larger organisms since the search has to be conducted over a larger physical space. However the time taken by the immune system to detect a pathogen and neutralize it does not scale with the size of the organism (scale-invariant detection and response) [3-7]. Organisms also allocate energy to the immune system linearly proportional to their body size. This linear allocation of metabolic energy to the immune system is one reason (among other factors) that helps the immune system achieve scale-invariance [3-12]. This is possibly due to natural selection and the importance of the immune system to the survival of organisms.

This raises the intriguing possibility that if cities allocated more (linearly) financial resources towards police (and hence number of police scaled linearly with city size), then crime would scale linearly with the size of the city; hence the density of crime would be scale-invariant (from Equation 2). However in reality larger cities allocate fewer resources per capita towards crime prevention than smaller cities (sub-linear scaling [2]). Strategies like these can inform policies on how much financial resource to allocate to crime fighting in cities and can also help quantify the economic cost of violence. Ultimately we hope that this will help in designing smart and efficient cities that can scale and be sustainable despite population increase.

APPLICATIONS

Our theory and models can inform strategies on how to pre-position police. If criminals and police are constantly increasing and competing (for example during riots), such models can suggest an optimal number and placement of police. Since police also need to ramp up quickly and police need to be trafficked to a particular place rapidly, there are parallels to how the immune system prepositions cells in lymph nodes. Other specialized anatomical structures like iBALTs (inducible bronchus-associated lymphoid tissue) are also created dynamically by the immune system close to previous sites of infection so as to reduce response times during future attacks (which may likely take place close to previous sites of attack) [24]. In previous work we have shown how the immune system optimally trafficks T-cells to infected sites to minimize the time taken to eliminate pathogens [8, 13]. Our work may be able to suggest immune system inspired “algorithms” to optimally route police to locations of crime.

Specifically the search for pathogens becomes harder in larger animals because the search is now through a larger physical space. As a result the immune system has evolved to have larger lymph nodes in larger animals in order to be able to send out more T-cells to infected regions [3]. Similarly it may be more difficult to track criminals in larger cities. Our work can be extended to determine an optimal size of police stations (number of police per police station) and how that should scale with the size of the city. In an immunological theory of cities, these lymph nodes would be police stations and patrolling police would be analogous to circulating T-cells [8, 13]. Our theory can be extended to make theoretical predictions of optimal placement and size of police stations for a particular city size.

Our models (see Section Models and Methods) can also be used to predict how much crime can be reduced by an increase in numbers of police. The actual predictions will depend on the precise model formulation, policing strategies and model assumptions. Our models can be extended to incorporate geographical spreading of crime, and can be used to recommend ways to optimise police allocation to minimise this spread. Our models advocate for optimal and timely allocation of law enforcement in order to check the geographical spread of crime.

The response of the police need not be centralized as it usually is. There have been proposals for a decentralized response where people respond all together instead of just police (which is similar to how the immune system responds to infections without any centralized control). Some have suggested that a distributed detection and response strategy may be more efficient compared to a centralized policing scheme [25].

More diversity in the workforce is thought to lead to more productivity [26]. However immigrants are also the subject of attacks in various cities around the world. How should modern cities design public policies that balance protection against foreign invaders with the immense productivity that comes from foreigners in a global workforce? It has been suggested that more contact between diverse factions and groups can reduce prejudice and possibly inter-group violence, subject to a number of conditions [35-37]. This is similar to how the immune system learns to tolerate non-self by repeated encounters with certain pathogens (see Section Immunological Preliminaries). This can inform public policy on immigration in cities and lead to practical outcomes like how to reduce attacks on immigrants. Such strategies may also yield insights into how successful cities are able to defend themselves against intruders while incorporating new people with diverse skills.

We also outline models (see Models and Methods) which simulate scenarios where police action elicits a more violent reaction from the ordinary population. These models can be used for what-if analysis to guide public policy makers and government bodies in making judicious decisions about how many police to deploy, where to deploy them and how to control adverse effects like police brutality. Although difficult at present, it may be possible in the future to predict with some uncertainty the effect of specific police actions or policies.

In the immune system adverse effects like T-cells attacking normal cells are controlled by another specialized set of immune system cells called T-regulatory cells which suppress aberrant behaviour. This suggests that another institution (like a government body with oversight or a specialized police force) can be brought in to control errant police behaviour.

The immune system does sometimes cause harm to uninfected normal cells while killing infected cells (called bystander effect). However it is within some bound since unconstrained harm to self would outweigh the benefits of destroying pathogens. Governments and policy makers would do well to keep this in mind and minimize harm to civilians while targeting criminals. Unfettered violence against civilians may ripen conditions for civil wars.

Finally, cities are also engines of wealth creation and vital to national economies. A quantitative model that couples the non-linear interaction between the generation of wealth in cities and violence may help in quantifying the economic cost of violence.

CONCLUSION

Our models are inspired by the biological immune system and we have previously used them to show how the immune system optimally allocates immune system cells (similar to police) to fight off pathogens (analogous to criminals) in a timely and efficient manner [2]. The immune system is engaged in an arms race with pathogens. Similarly law enforcement and militaries are engaged in an arms race with criminals. We propose an immune system inspired theory of crime and violence in human societies.

We believe there are implications for urban planning and policy with regards to how police stations can be placed optimally and how many and how big police stations need to be in order to control crime; there are also implications for urban planning and housing and how to prevent the spread of crime itself.

Our work can also be applied to models of terrorism and secessionism where two or more factions are involved in a co-evolutionary arms race [27]. In future work, we will look at how co-evolutionary arms races between police and criminals may select for more extreme and violent traits in criminals.

We speculate that our model could also be applied to violence in other primate societies [28] and colonies of eusocial insects [29]. For example ants from different colonies have been known to attack each other. Ants also have specialized castes (similar to police) that are dedicated to protecting the colony against invaders and internal strife.

In summary, our work can inform strategies on designing smart and efficient cities that can scale and be sustainable despite population increase. Our work also suggests the power and generality of dynamical systems in being able to simulate complex systems as diverse as immune systems, intra-cellular regulatory networks, violence in human societies and scientific collaboration networks [2-15, 31, 32]. We hope that this work will lay the foundation for a general and ultimately predictive theory of violence and conflict in human society.

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