Preface
An Overview of Crime Simulation

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Artificial crime analysis and crime simulation is an emerging research area that has the potential of revealing hidden processes behind urban crime patterns and criminal justice system operations. This book takes an interdisciplinary approach, combining criminology, computer simulation, and geographic information systems to examine how crime patterns form and what can be done to prevent crime.

In the last decade there has been a phenomenal growth in interest in crime pattern analysis. Geographic information systems (GIS) are now widely used in urban police agencies throughout industrial nations. With this, scholarly interest in understanding crime patterns has grown considerably. The central problem of empirical crime analysis, both applied and academic, is that many of the underlying processes that give rise to crime patterns are not visible, and so are not well understood. To address this problem, a number of crime researchers have drawn from the experience of other disciplines to create virtual cityscapes to model artificial crime patterns within a computing environment. This new and exciting area has no guiding text or repository of experience. This book seeks to fill this need, and thus accelerate the rapid growth in this area.

BACKGROUND

Artificial crime analysis and crime simulation is an up-and-coming research area that was started about six years ago by a relatively small group of environmental criminologists and geographers. It aims to study mechanisms that generate individual crime events and give rise to crime patterns by operationalizing criminology theories in a GIS-based computing environment. This new interdisciplinary research field typically involves criminology (especially environmental criminology), geography (especially GIS), and computer science (especially agent-based modeling and simulation).

The collaboration between the Department of Geography and the Criminal Justice Division at the University of Cincinnati represents one of the leading efforts in initiating the research in this area. Liang (2001) constructed the first crime pattern simulation for his dissertation, supervised by Liu and Eck, and publicly presented his analysis at the UCGIS Summer Assembly in 2001 (Liang, Liu, & Eck, 2001).
His simulation implements aspects of routine activity theory with two types of agents: store robbers and store managers. Managers are immobile, but update their protection based on tension of robberies transmitted using cellular automata. Robbers move randomly around a street grid representing a small area of Cincinnati and decide to rob a store based on a comparison of their capabilities with the store’s protection level. The resulting pattern of robberies looks surprisingly similar to the actual pattern of robberies in the same geographic area (Liu, et al., 2005).

Following this simulation Wang (2005) developed a simulation of street robberies, also under Liu and Eck’s supervision. In Wang’s simulation both the targets of crimes (pedestrians) and the offenders are mobile. Pedestrian agents assess the costs of distance and crime risk in choosing their routes. Offender agents choose their routes by assessing the availability of pedestrians. Routine activity theory, crime pattern theory, and rational choice perspectives inform the construction of this simulation. Agent based modeling is used to orchestrate agent mobility and cellular automata to communicate crime risk. The latest work is presented in a chapter by Wang, Liu, and Eck in this volume.

Another leading effort in developing artificial crime analysis is centered at Simon Fraser University, where collaborations between Patricia Brantingham and Paul Brantingham’s group at the School of Criminology and Uwe Glässer’s group at the School of Computer Science have produced very useful simulations of crime patterns (Brantingham, & Brantingham, 2004; Brantingham, Glässer, et al., 2005). Their latest works are presented in two chapters in this volume.

The objectives of these efforts are to simulate the micro-level decision processes that give rise to patterns of crime. In artificial crime analysis, researchers model criminological theories of micro-level behavior in computer environments to determine if these theories can produce patterns that mimic observable macro-level patterns in the real world. Specifically, researchers want to determine whether the actions of individual agents (i.e., offenders, targets, handlers, guardians, managers, and others) are sufficient to give rise to the crime patterns we detect in empirical investigations. The theoretical bases of many crime simulation models are routine activity, rational choice, and crime pattern theories.

Offenders and targets are modeled as individual agents. These agents are intelligent and adaptable in their behavior and spatial movement; they make decisions based on forms of bounded rationality. They learn from past offending and victimization experience, and adjust their future behavior accordingly. For example, target agents move along street as part of their routine activities. The exact travel path they take is influenced by network proximity and crime risk. As new crime events change the spatial distribution of risk, target agents adjust their path using a heuristic reinforcement learning algorithm. At the same time, offenders seek opportunities and adjust their spatial movement based on the reward/penalty of their past experience.

The prototype systems developed in these early efforts have been used as virtual laboratories to uncover the interplay of multiple criminology theories. Analysis of simulated data reveals plausible crime patterns and helps generate hypotheses. It is widely accepted that the distributions of criminal behavior among offenders are highly skewed—a few offenders commit most of the crimes. Research has also shown that a relatively few victims are involved in a far larger proportion of crimes, and that a few places where crimes take place are responsible for a very large proportion of all crimes. In fact, most crime related data appears to follow a power-law distribution. The prototype systems are able to replicate these power-law distributions, and to simulate spatial crime patterns that resemble those observed in empirical studies.

The models are also used to examine possible future crime patterns based on different policing and crime prevention strategies. They have the potential of providing insight for testing applied theories of crime prevention, teaching students and practitioners, carrying out what-if analysis of proposed prevention programs prior to implementation, and assisting in the evaluation of implemented crime prevention measures.
Despite these initial successes with crime pattern simulations, there are still many challenges ahead. Due to the non-linear nature of crime simulation models and the large number of parameters, calibration of the model is extremely difficult. Although the models can be adjusted to match simulated patterns to real crime patterns that may advance understanding of how to calibrate and validate simulation of complex spatial systems, the calibration method is far from satisfactory. Part of the problem is that simulated crimes with no measurement error are compared to police records of actual crimes that contain massive amounts of measurement error. One challenge is to model the measurement error process in the simulation such that two forms of patterns can be produced: patterns based on error-free artificial crimes, and patterns on artificial crimes measured with substantial error.

So far, the models are mostly theory-driven and need verification. The simulation models can be productively expanded in a number of ways: incorporating police and other agents; improving the detail of street configurations and the built environment; incorporating accurate information on the number, value, and spatial distribution of crime targets; and modifying the basic simulation to address a wider variety of violent and non-violent crimes. To accomplish these challenging goals, there is a need to draw experience and knowledge from simulation studies in other disciplines such as GIS, computer science, engineering, and transportation.

To help meet these challenges, this book has attracted contributions from criminologists, geographers, computer scientists, urban planners, transportation planners and engineers. The authors of these chapters confront a wide variety of issues concerning artificial crime analysis: validation and calibration, crime specificity, the types of background (substrates) upon which the agents act, and a host of other topics. When we first envisioned this volume, we expected to receive a few manuscripts. We were pleasantly surprised by the number and diversity of the submissions. This speaks to the rapid growth and high interest in artificial crime analysis. It is our hope that this book stimulates more interdisciplinary collaborations and accelerates interest in artificial crime analysis and crime simulation.

**THE STRUCTURE OF THIS BOOK**

We have divided the chapters in this book into five parts based on their topics and themes. Though this division is helpful, most chapters speak to themes in more than one part. Section I focuses on general principles, methods, and controversies; Section II examines the simulation of the background environment and explanatory variables, such as streets networks, target distributions, and spatial-temporal autocorrelation; Section III, the largest part of the book, consists of eight chapters presenting state-of-the-art simulations of crime events and crime patterns; Section IV showcases recent developments in the simulation of criminal justice agencies and systems; The final section consists of a single chapter summarizing the current state of crime simulation research—both internally and in comparison to more traditional forms of criminological research—and providing theoretical frameworks for future research. The following sections describe each of these parts in detail.

**Section I – The Role of Simulation in Crime Research.** The four chapters in Section I address critical topics in using simulation to understand crime patterns and criminal justice processes.

In Chapter I, *The Need for Systematic Replication and Tests of Validity in Simulation*, Michael Townsley and Shane Johnson examine the potential role simulation methods in making valid causal inferences in the study of crime. They contend that only validated models can be used to make such inferences. They discuss a variety of issues related to the validity of simulation models and conclude that replication is a
general method to validate simulation models and facilitate the generation of valid findings. Validation is a topic picked up by a number of the authors of other chapters.

Henk Elffers and Pieter Van Baal, in Chapter II, *Spatial Backcloth Is Not That Important in Agent Based Simulation Research: an Illustration from Simulating Perceptual Deterrence*, take on a controversial topic—the level of detail needed in the geographic environment in order to generate useful results. They claim that the use of real geographic backgrounds in simulations is not only unnecessary but is detrimental to the understanding of underlying processes that generate crimes. The conceptual discussions are followed by an illustration of a perceptual deterrence simulation. As can be seen in the chapters that follow, there is no general agreement on this important issue. Some authors share the view of Elffers and Van Baal, but others seem to disagree. This critical and controversial issue is examined in detail in the concluding chapter.

In Chapter III, *Visualization of Criminal Activity in an Urban Population*, Alex Breuer, Joshua J. Hursey, Tonya Stroman, and Arvind Verma present an interactive visualization that provides an accurate and intuitive view of the criminal activity in a cityscape. Their approach is based on a set of linked displays, each representing a particular aspect of urban crime. The implementation of their visualization system is coupled with ArcGIS, one of the most widely used GIS software packages.

Md Mahbubur R. Meenar provides a survey of simulation and visualization for landuse planning in Chapter IV, *GIS-Based Simulation and Visualization of Urban Landuse Change*. Meenar argues that urban landuse is a vital backcloth for the study of crime, therefore crime simulation should benefit from many of the techniques used in studying landuse change.

**Section II – Streets, Networks, and Crime Distribution.** The second section of this book focuses on conditions that might influence crime patterns. In particular, its chapters look at ways simulation can be used to model target distribution, methods for simulating traffic flow, the influence of urban landuse changes on crime, and how one might model spatio-temporal autocorrelation.

In Chapter V, *Modeling Pedestrian Movement to Measure On-Street Crime Risk*, Spencer Chainey and Jake Desyllas study street crime rates based on accurate on-street pedestrian population estimates. Street segment level pedestrian counts are modeled from key indicators of pedestrian movement and sample observations. The result of their analysis suggests that the crime rates derived from their approach are more accurate than the ones using residential population as the denominator.

Just as street robberies are closely associated with pedestrian flows, vehicle related crimes are influenced by street level traffic flows. Heng Wei presents a comprehensive review of micro-level traffic simulations in Chapter VI, *Core Models for State-of-the-Art Microscopic Traffic Simulation and Key Elements for Applications*. This chapter summarizes microscopic simulation models such as vehicle generation and car-following models, as well as other important models such as lane-choice, lane-changing, and route-choice models. Wei also examines model calibration and validation, two of the most critical issues in traffic simulation.

Urban dynamics can influence crime. In Chapter VII, *Simulating Urban Dynamics Using Cellular Automata*, Xia Li applies cellular automata (CA) to simulate urban dynamics. He argues that forecasts of urban changes provide useful inputs to crime models. One of the challenges in simulating realistic urban growth is the calibration of urban cellular automata. To overcome this difficulty, Li incorporates neural networks to CA to improve model calibration.

Chapter VIII, *Space-Time Measures of Crime Diffusion*, by Youngho Kim, introduces space-time diffusion measures for crime simulation. As the spatial pattern of crime changes in time, it important to investigate both spatial and temporal processes that lead to crime. Kim examines the spatial and temporal aspects of crime by extending local spatial autocorrelation measures to the temporal dimension.
Section III – Crime Event and Pattern Simulations. This section presents eight studies of creating crime simulations. The authors use a variety of approaches to a number of different types of crime, showing that there is no single method of artificial crime analysis and that many different crimes can be simulated.

In Chapter IX, *Synthesis over Analysis: towards an Ontology for Volume Crime Simulation*, Daniel J. Birks, Susan Donkin, and Melanie Wellsmith examine the use of agent-based modeling as a tool for criminologists. They argue that this type of models has the potential to help examine, test, validate, and refine criminological theories. By way of illustration, they present two proto-type systems—one for robbery and another for domestic burglary—using agent-based modeling.

In Chapter X, *Offender Mobility and Crime Pattern Formation from First Principles*, Jeffrey Brantingham and George Tita develop a series of elegant mathematical and agent-based models to examine the relationship between basic movement decisions of offenders and emergent crime patterns. They show that it is possible for crime patterns to arise solely from different movement strategies deployed by offenders. This chapter also nicely illustrates a major point made by Elffers and Van Baal: that much can be learned by keeping the simulation very simple.

To investigate the interaction of robbers and targets, Xuguang Wang, Lin Liu, and John Eck display a multi-agent based simulation system (named SPACES) in Chapter XI, *Crime Simulation Using GIS and Artificial Intelligent Agents*. Their approach is based on the integration of agent-based modeling and cellular automata. The targets visit a set of activity nodes as part of their routines, while offenders seek opportunities. The movement of both agents along streets is guided by a reinforcement learning mechanism. A simulated tension surface mimics the propagation of the fear of crime in space and time. The agents interact in a small neighborhood area of Cincinnati. The results suggest that SPACES is capable of generating crime patterns that are similar to those found by empirical investigation.

In Chapter XII, *Characterizing the Spatio-Temporal Aspects of Routine Activities and the Geographic Distribution of Street Robbery*, Elizabeth Groff examines how the spatial patterns of simulated street robberies vary as she experiments with different methods for operationalizing routine activities of the agents. The movement and the awareness spaces of agents are set by agents’ routine activity schedules. An application of this model to the City of Seattle generates spatial patterns that are consistent to empirical crime data.

A team led by Patricia L. Brantingham presents their interdisciplinary research in Chapter XIII, *Mastermind: Computational Modeling and Simulation of Spatiotemporal Aspects of Crime in Urban Environments*. They use abstract state machines (ASM) formalism and multi-agent based modeling to devise a formal semantic modeling framework for crime simulation and analysis. Their prototype system, named Mastermind, is capable of modeling the movement of offenders in an abstracted real street network. It is demonstrated in a hypothetical analysis of motor vehicle theft.

In Chapter XIV, *The Simulation of the Journey to Residential Burglary*, Karen L. Hayslett-McCall’s team simulates the journey to residential burglary. They build their simulation on two foundations: social disorganization and routine activity theories. Their simulation model integrates cellular automaton and multi-agent system. With the initialization and parameterization using real crime data from Dallas Police Department, the model is capable of generating plausible spatial patterns.

Inspired by the swarm intelligence paradigm, Vasco Furtado’s team introduces a multi-agent-based crime simulation model in Chapter XV, *Simulating Crime against Properties Using Swarm Intelligence and Social Networks*. They model criminals as agents who interact in their social networks. Their behavior is influenced by both individual and social learning factors. Results from simulation experiments reveal the impact of social networking in producing plausible spatial patterns of crime.
The final chapter of Section III deals with white-collar crime. In Chapter XVI, *FraudSim: Simulating Fraud in a Public Delivery Program*, Yushim Kim and Ningchuan Xiao develop an agent-based model (named FraudSim) to simulate fraud in public delivery programs. In their model, recipients of a public delivery program exchange government issued vouchers for food at participating vendors. Both recipients and vendors are modeled as agents. Results from experiments demonstrate that FraudSim is capable of closely replicating the statistical and spatial patterns of fraud. The simulation shows how crime simulations can be expanded beyond modeling street crimes.

Table 1 compares and summarizes the eight simulations by the following characteristics. We can see that these eight chapters use a variety of approaches, but we can also see some commonalities.

- **Continuity**: Is the modeled process continuous or discrete process? Most continuous processes require the use of differential equations. Discrete processes rely on computer algorithms, instead of mathematical equations. Agent-based models are discrete.
- **Environment**: Is the model based on a real environment or an artificial environment? Can a real environment such as a street network be used as an input to the simulation?
- **Foundation**: Is the model theory driven or data driven? Theory driven models tend to be process based, while data driven models are mostly pattern based. It is possible to combine their two approaches in a single simulation.
- **Substrate**: A substrate is a network that connects agents, allows them to communicate or move, and upon which patterns form. A substrate can be spatial such as street networks, aspatial such social networks, or a combination of the two.
- **Movement**: Are agents stationary or mobile in the simulation? Agents can move randomly in space, or move with intelligence through learning and adaptation.
- **Probabilistic**: Is the simulated process deterministic or stochastic? A deterministic model generates the same results every time, while a stochastic model generates slightly different results every time due to a random process built in the model.

Table 1. The characteristics of the simulations in Section III

<table>
<thead>
<tr>
<th>Chapter*</th>
<th>Continuity*</th>
<th>Environment*</th>
<th>Foundation*</th>
<th>Substrate*</th>
<th>Movement*</th>
<th>Probabilistic*</th>
<th>Scale*</th>
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<tbody>
<tr>
<td>9</td>
<td>discrete</td>
<td>both</td>
<td>theory</td>
<td>spatial</td>
<td>mobile</td>
<td>stochastic</td>
<td>micro &amp; macro</td>
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<tr>
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<td>theory</td>
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<td>mobile</td>
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<td>micro</td>
</tr>
<tr>
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<td>micro</td>
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<tr>
<td>12</td>
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<td>real</td>
<td>theory &amp; data</td>
<td>spatial</td>
<td>mobile</td>
<td>stochastic</td>
<td>micro &amp; macro</td>
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<td>13</td>
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<td>spatial</td>
<td>mobile</td>
<td>stochastic</td>
<td>micro</td>
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<tr>
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<td>theory &amp; data</td>
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<td>mobile</td>
<td>stochastic</td>
<td>micro &amp; macro</td>
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<td>theory</td>
<td>mostly aspatial</td>
<td>mobile, but limited</td>
<td>stochastic</td>
<td>micro &amp; macro</td>
</tr>
<tr>
<td>16</td>
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<td>artificial</td>
<td>theory &amp; data</td>
<td>spatial</td>
<td>mobile, but limited</td>
<td>stochastic</td>
<td>micro &amp; macro</td>
</tr>
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*Simulation characteristics adapted from Liu (2007).

** Chapter IX - Birks, Donkin, and Wellsmith; X - Brantingham and Tita; XI - Wang, Liu, and Eck; XII – Groff; XIII - Brantingham, et. al.; XIV - Hayslett-McCall, et. al.; XV - Furtado, et. al.; XVI - Kim and Xiao
• **Scale:** Is crime modeled at the person and place level (micro) or at some aggregate level, such as population or neighborhood (macro). Micro level simulations rely on local knowledge, while macro level simulations make use of global knowledge.

These characteristics are addressed in more detail in Chapter XX, *Varieties of Artificial Crime Analysis: Purpose, Structure, and Evidence in Crime Simulations*.

**Section IV – Criminal Justice Operation Simulations.** Simulating crime patterns is only one application of artificial crime analysis. Computers can also be used to simulate how agencies and systems of agencies behave. There is a longer history of such simulations (reviewed in Chapter XIX) compared to crime pattern simulations, but recent developments in computer software and hardware has renewed interest in this area.

In Chapter XVII, *Development of an Intelligent Patrol Routing System Using GIS and Computer Simulations*, Joseph Szakas and his team use GIS and Global Positioning Systems to facilitate smart patrol routing for a police department. A Voronoi diagram layer is generated at a given point of time, with each Voronoi polygon representing the service area of the patrol unit in the polygon. Armed with this information, all patrol units can coordinate with each other to make better use of limited patrolling resources.

In Chapter XVIII, *Drug Law Enforcement in an Agent-Based Model: Simulating the Disruption to Street-Level Drug Markets*, Anne Dray’s team presents an agent-based model, called SimDrugPolicing, to compare and analyze three law enforcement strategies—standard patrol, hotspot policing and problem-oriented policing—on a street-based illicit drug market in Melbourne, Australia. Users, dealers, wholesalers, and outreach workers are modeled as agents, and their properties and behaviors are defined by a panel of interdisciplinary experts. In addition to examining the relative effectiveness of the three drug law enforcement strategies, the chapter analyzes outcome indicators such as the number of committed crimes, dealers’ and users’ cash, overdoses, and fatal overdoses. The simulated results suggest that the problem-oriented policing strategy is the most effective approach to disrupting street level drug markets.

In Chapter XIX, *Using Varieties of Simulation Modeling for Criminal Justice System*, a team led by Azadeh Alimadad introduces three different approaches to modeling and simulating criminal justice systems: process modeling, discrete event simulation, and system dynamics. Complex criminal justice systems—including police, courts, and corrections—are inherently difficult to model. The chapter takes advantage of recent advances in these modeling techniques and applies them to simulate the British Columbia criminal justice system by exploring different types of “what-if” scenarios. These simulations facilitate the evaluation and test of various policy proposals prior to implementation.

**Section V – Conclusion.** This section consists of a single chapter. It draws general conclusions from the literature and the chapters in this volume. Chapter XX, *Varieties of Artificial Crime Analysis: Purpose, Structure, and Evidence in Crime Simulations*, summarizes the approaches presented in the book, contrasts simulation methods to other research methods, and look at the process and prospects of simulation methods for the study of crime and related phenomena. It addresses six questions:

1. What are the purposes of artificial crime analysis?
2. What are the characteristics of crime simulations?
3. How does artificial crime analysis compare to other research methods?
4. When should simulations be used?
5. Who should construct simulations?
6. What is the future of artificial crime analysis?

CONCLUSION

Artificial crime analysis is an exciting new development in the study of crime and prevention. In a relatively short period of time researchers from around the globe have found a variety of ways of simulating different forms of crime, as well as criminal justice processes. As illustrated by the backgrounds of the members of the authoring teams, artificial crime analysis is multidisciplinary. Because no single discipline owns artificial crime analysis we should expect substantial progress in this area from the resulting interplay of ideas. But members of different disciplines have different ways of conversing and this can often create barriers to communication. We hope that this first book on the topic will help break down some of these barriers by showing what can be accomplished and by pointing to some of the exciting problems ahead.

REFERENCES