# Agents Shaping Networks Shaping Agents: Integrating Social Network Analysis and Agent-Based Modeling in Computational Crime Research

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**Abstract.** The paper presents a recent development of an interdisciplinary research exploring innovative computational approaches to the scientific study of criminal behavior. The attention is focused on an attempt to combine social network analysis and agent-based modelling into *CrimeMiner*, an experimental framework that seamlessly integrates document-enhancement, visualization and network analysis techniques to support the study of criminal organizations. Our goal is both methodological and scientific. We are exploring how the synergy between ABM and SNA can support a deeper and more empirically grounded understanding of the complex dynamics taking place within criminal organizations between the individual/behavioral and social/structural level.

**Keywords:** Agent-based modeling · Social network analysis · Computational crime analysis

## 1 Introduction

Over the years, the theoretical debate about the foundational issues of social science has been marked by a move towards the integration of different research approaches to the investigation of social phenomena. The idea of overcoming what has been called the "war of paradigms" [19], has gradually led to the emergence, in discipline after discipline, of a pluralist perspective [18] according to which social research is ever more understood as the integration of different scientific traditions. Faced with the impossibility to identify common epistemic foundations for all the social sciences, researchers are adopting an "eclectic" [35] stance, geared towards discovering the complementarities across concept and

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visions belonging to different research communities. Far from being limited to the epistemic dimension, the choice of an eclectic research approach involves also the methodological dimension as the sharing of different methods [38] is proving to be crucial in enhancing the scientific investigation of social phenomena. This is true not only in the more traditional areas of social science research, but also in the emerging field of the computational social science [12] where the integration of heterogeneous research perspectives and methods is essential to gain a deeper understanding of foundational issues of social science spanning from the emergence of collective phenomena to the dynamics of social learning. In this scenario, following substantially the same line of thought, researchers are increasingly often exploring the combination of different computational techniques to better deal with the problems arising from the empirical investigation of crime.

This paper presents a development of a research in the direction of exploring innovative and cross-methodological computational approaches to the academic and investigative study of crime. Our objective is a first attempt to combine social network analysis (hereinafter SNA) and agent-based modeling (hereinafter ABM) into *CrimeMiner*, an experimental framework that seamlessly integrates document-enhancement, visualization and network analysis techniques to support the study of criminal organizations starting from real data. Our goal is to explore how the synergy between ABM and SNA can support a deeper and more empirically grounded understanding of the complex dynamics taking place within criminal organizations both at individual and structural level.

## 2 Theoretical Background: Three Premises

From a theoretical point of view, our research is rooted into three main premises that can be summarized as follows.

### 2.1 From Instrument-Enabled Science to Science-Enabled Instruments

A first theoretical premise behind the work presented in this paper originates from the relationship that links the scientific investigation and the development of new methodologies and research tools. The scientific endeavor has been over the centuries mediated by increasingly complex artifacts offering new and more insightful representations of the world. Research can be conceived an "instrument-enabled" activity, the result of an iterative process in which technological development is at the same time an enabling factor and an outcome of scientific progress. On this process depended the birth of entire research areas: the nano-sciences, to give just a recent example, would not have come into being without the invention of the electronic microscope.

In the same way, the computational investigation of social phenomena has been marked since its origins by a strong relation between the technological-instrumental and the scientific dimension. As underlined in [11], even in social sciences, doing research also means designing new methods, new tools, new ways of processing data. Instruments enable science but, at the same time, the adoption of new scientific perspectives leads to the creation of new tools that will in turn bring about new knowledge. Against this backdrop, our analysis tries to explore how the creation of new tools and the combination of different scientific perspectives can result into a deeper understanding social phenomena.

## 2.2 Strange Loops: Agents Shaping Networks Shaping Agents

The second premise of our work is connected with the longstanding clash between individualism and structuralism, the two opposed metatheoretical positions that have marked so far a large part of the contemporary history of social science. As is well known, while individualists assume that only individuals exist and that sociological objects and properties are nothing but combinations of the individual participants and their properties, in the structuralist perspective, society is somehow the sum of interrelations in which individuals stand with respect to one another [32].

The debate has remained substantially unresolved despite a long history also because of the lack of research methodologies [4] allowing to bridge the gap between two research perspectives looking at phenomena belonging to different ontological levels: the individual and the social structure. What has been missing so far is the possibility to explore how individual behaviours turn into social networks and networks shape individual behaviors. Agents and networks are locked into a perpetual coevolution, a dynamic that can be well depicted through the illuminating metaphor of "*strange loops*" [28], a paradigmatic concept developed by Douglas Hofstadter to describe "*the phenomenon that occurs whenever, by moving upwards or downwards through the levels of some hierarchical system, we unexpectedly find ourselves right where we started*". The struggle to shed new light on this loop is a worthy effort: social influence is crucial in all social phenomena. In this scenario, while useful to explore the causal path connecting individual/micro and social/macro emergent phenomena, ABM alone may be insufficient to account for the role played by the structure and the features of social networks in shaping human behavior. Agents change under different types and degrees of social influence as entities at the macroscopic level network affect them and their behavior: we therefore "*must understand how this can happen if we want to drive, enforce, or prevent such an influence*" [14]. It is no coincidence at all, in this scenario, the attention paid by the simulation study of norms to the topology of social networks, growingly considered as a "*key factor of all phases of norm development*" [2].

## 2.3 Networks in Criminological Research

The third theoretical premise is related to one of the main goal of criminological research: understand the relationship between social networks and criminal behavior. As a matter of fact, social influence processes taking place in social networks are traditionally considered as one of the main factors responsible of different aspects of criminal behavior ranging from the development of an individual's own deviant behavior to the micro criminality as well as the spreading of some forms of criminal patterns [34].

Sutherlands Differential association theory [37] states that criminal behavior patterns (motives, attitudes and techniques of committing a crime) are learned in interaction with others. Differential association theory can be seen as a specific instance of the more general network theory of social learning. The role of the social environment is crucial within the explanatory framework of situational models of crime. Both the Routine activity theory [13] and the Situational Action Theory [39], for example, suggest that some social environmental conditions are more criminogenic than others. According to these approaches, acts of crime are an outcome of the convergence between people and setting and social networks are considered a natural way to explain the emergence of criminal offending [9, 33]. In addition to providing a highly visual and detailed way to describe a set of relations and actors, social network analysis facilitates the testing of structural hypotheses about criminal patterns emerging from patterns of relations.

## 3 Methodological Background

### 3.1 Agent-Based Modeling and Crime

The use of Agent-Based Social Simulation (ABSS) in the social sciences has grown over the past 15 years [25] proving to be successful also for the study of the social dimension of crime [31]. Early applications of simulative approach to crime analysis appeared in the field of Environmental Criminology [8].

There are many reasons to investigate the relationship between Agent-Based Simulations and crime analysis. The principal argument in criminology is the need for complementarities between the experimental or quasi-experimental approach and the simulation one [31]. An important argument is the possibility to advance, test or refine theory [27], to anticipate consequences coming from one type of intervention over another [3] as well as to provide new policy evaluation tools. ABM allows researchers to create artificial societies [20] and to explore how individual-level criminal action might translate into observable macrolevel crime patterns. As already highlighted, social scientists can grasp within a formalized model those relevant features of the complexity of social systems: autonomy and heterogeneity of agents, adaptive rationality, spacial and local interactions, non-equilibrium dynamics [36]. In the field of crime research, for example, the spatial nature of crime and interaction between agents (criminal, police, victim, etc.) often requires the agent-based models to include space and time [26]. An important challenge is in fact to investigate the spatio-temporal dynamics of crime [7,31]. Within this area, the key object is the study of crime, criminality, and victimization as they relate to particular places and how offenders, targets (victims), and guardians (control agents) shape their activities spatially. In this field, a relevant question is which factors influence the emergence of hot spots [6,24]. Computer simulations of criminal patterns are implemented to identify potential hotspots and flashpoints. As a consequence they can supply support to police forces in order to allocate resources to areas where particular crimes are most likely to occur. After this brief overview, it emerges how agent-based simulations have becoming increasingly important in crime research since they allow us to overcome some of the limitations which characterize the traditional research methods in criminology bounded both temporally and spatially.

### 3.2 From Social to Criminal Network Analysis

Recent years have witnessed a growing interest towards the use of SNA techniques in the study of criminal organizations both for scientific and investigation goals. SNA made a key contributions to criminological issues in several areas such as, the role of peer selection and influence in delinquency, gang boundaries and collaboration among gang members, the structure of criminal and terrorist organizations. Criminal Network Analysis (CNA) is today a well-established interdisciplinary research area in which network analysis techniques are employed to analyze large volume of relational data and gain deeper insights about the criminal network under investigation. There are many examples of application of the principles of SNA in the analysis of criminal organizations [5,17,22,34,40]. As an example, in [5] authors found out that drug trafficking networks tend to spread from a relatively dense core in short chain-like structures. Their studies also show that these structures are apparent across the drug distribution system. Disruption strategies targeting individuals with high centrality and human capital are likely to include the leaders and other visible members of the drug distribution network, and this should, lead to a more successful crime control.

## 4 Integrating ABM and SNA

The scenario described makes easier to understand the reasons that led us to explore the intersections between social simulation, network analysis and criminal research. ABM and SNA can be mutually beneficial and their integration can result into a significant contribution to the explanatory and predictive power of social research. SNA allows to better investigate the evolution of social phenomena in all the situations in which topological properties of the network become a key factor affecting social outcomes - think about the spread of epidemics [41] or opinion dynamics [10]. This is even truer when the structural knowledge provided by SNA is based on the analysis of real data, a circumstance that makes more empirically rooted the investigation. ABM, on its own, allows to account for the individual attributes and the internal, cognitive dynamics of the agents involved in the target social phenomenon, a possibility that becomes crucial whenever we deal with events for which individual behavior is relevant and we want not only to predict and understand but also to somehow affect the process e.g. by shortening, delaying or preventing it [14]. The project here presented has to be seen in this perspective: the experiment described in the following sections is based on *CrimeMiner*, an experimental computational crime analysis environment dealing with data coming from real investigations.

### 4.1 The CrimeMiner Project

*CrimeMiner* [29,30] is an ongoing research project aiming to explore innovative computational methods to support the study of the societal dimension of crime for both scientific and investigative purposes. In more details, the goal of the research is to see how the combination of data mining, SNA, and data visualization techniques can contribute to a deeper understanding of structural and functional features of criminal organizations starting from the analysis of even simple relational and investigative data. The considerations developed during the project led to a holistic approach deployed into a computational framework intended to be used in investigative and research settings to gather, markup, visualize and analyze all the information needed to apply SNA techniques to criminal organizations. The environment has been validated during a case study based on data coming from real criminal investigations (telephone and environmental tapping used to map the social structure of a criminal organization belonging to the Italian Camorra). System requirements were discussed with domain experts involved in the project and then translated into several functionalities that can be summarized as follows.

- *Document-enhancement.* Its goal is to structure the content of documents (in our case study, a set of procedural documents belonging to a criminal trial) providing all the metadata needed to implement SNA and visualization features [40]. We implemented a structured Text Editor combining the traditional word-processor facilities with the background creation of structured data containing relevant information for CNA (e.g., police records, etc.).
- *Graph visualization, interactive charts, tabular visualization.* Data currently handled by *CrimeMiner* consist in people records and telephone/environmental tapping: people are transformed into vertices (or nodes) of a graph; telephone and environmental tapping depicting a relationship between two or more people are represented as edges to be analyzed using SNA metrics. To make the graph visualization easy to read, drawing inspiration from experiences already made [15], we have implemented some algorithms for force-directed graph drawing allowing users to filter nodes by a minimum threshold degree. *CrimeMiner* generates also line charts showing the trends of the communications between given nodes (see Fig. 1). The whole list of the persons and tapping can be also browsed in the form of interactive tabular data with an advanced filtering feature.
- *SNA, statistical analysis, GIS features. CrimeMiner* offers a set of SNA metrics to allow the study of the distinctive features of the criminal organization and the identification of the role of single individuals within it. The current implementation supports the most popular features such as the dominance, subordination, influence or prestige of social actors [23]. Among the implemented measures we can mention: degree centrality, betweenness centrality, Page Rank and Modularity. The network can be plotted into a geographical map to better understanding the relations in popular place and known location (see Fig. 1).

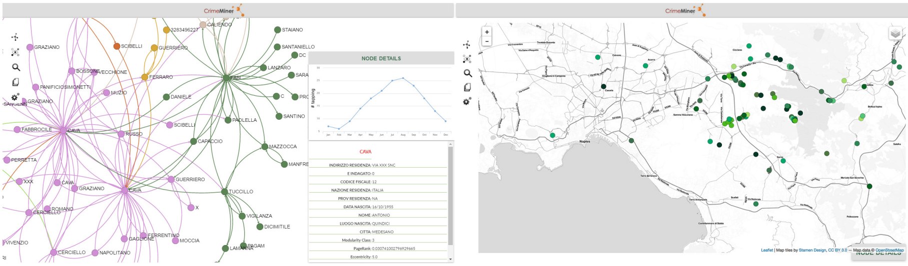

**Fig. 1.** *CrimeMiner:* screenshots of the SNA and GIS user interfaces

## 4.2 Widening the Scope of the Research

Starting from the work above described, we decided to widen the scope of the research complementing former *CrimeMiner* functionalities (mainly devoted to data collection, visualization and network analysis, see Fig. 2) with a simulation component. The goal was twofold: (i) Enhancing ABM theory making: a first goal of our experiment is to support and enhance the ABM exploration of criminological theories by adding to the simulation both empirical evidences and topological properties of criminal networks derived from the analysis of real data; (ii) Making SNA more "generative": a second goal is to add a generative dimension to the analyses underway within our project, by making it possible to complement the structural analysis with the study of the interactions taking place between agents and the environment. The overall outcome of our effort is sketched in Fig. 2 where research goals (level 1) are wrapped in four macro-sections (Data

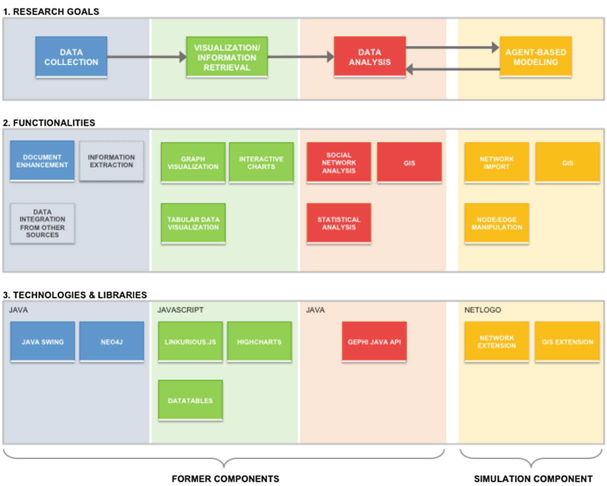


**Fig. 2.** An overview of *CrimeMiner* project: research goals, functionalities and technologies. Dotted boxes at level 2 represent functionalities under development.

collection, Visualization/Information retrieval, Data Analysis, ABM), each of which is mapped into a group of system functionalities (level 2). Level 3 finally lists the technologies used for each research goal.

We have implemented an extension of *CrimeMiner* (the "Simulation component") enabling a two-way, circular communication between the original system and an ABM environment (in this case NetLogo). The attempt resulted into a set of features that can be described as follows.

*Data Exchange Between CrimeMiner and ABM Environment.* A first group of functionalities allows to export from *CrimeMiner* and import into an ABM environment the whole set of real world and network data stored and produced within *CrimeMiner* in the SNA stages of the research:

- Real data about individuals and their criminal profile: personal data of individuals brought into the investigation (name, age, residence, criminal records etc.); criminal records.
- Real data about social interaction and criminal activities: date and time of telephone tappings; date time and location of in person meetings harvested by means of environmental tapping
- Network data: topological features of the network identified by *CrimeMiner*. These data include nodes/individuals measures (Degree, Betweeness, Page Rank etc.), edges/social interactions (orientation and weight) and overall network (e.g. density, sub-communities, etc.)

Depending on the research goals, users can select and export, in standard structured format (csv and XML), only the information considered to be relevant for the design and the implementation of the simulation experiment. Even in this preliminary stage of the project, it's easy to imagine different experiments based on the fusion of real/network data and ABM models. It is for instance possible to recreate the real world network topology into a simulation assigning to the agents specific behaviors depending on real data like personal attributes (e.g. criminal records); values of SNA measures or position of the agent in real space. In the same way, it's possible to model in the simulation the nature of social interactions (e.g. the frequency of communications between agents) so as to reflect the actual properties of the interaction in real world.

*User-Graph Interaction Within ABM Environment.* A second group of functionalities allows user to interact with the graph depicting the criminal network within the NetLogo environment. Users can add, remove or modify the properties of both nodes and edges. This allows to explore, within the simulation, the effect potentially produced by structural modifications of the network under investigation.

### 4.3 Experimenting with ABM Criminological Models

We are working, both at a theoretical and application level, on a first set of experiments aiming to understand how the workflow and the tools so far developed can support both the analysis of the implications of criminological theories and the study of real criminal organizations. To move in this direction, we have decided to merge SNA and ABM using, on the one hand, the data coming from the *CrimeMiner* project (network data, attributes and properties of individuals involved into the investigation) and, on the other, an agent-based model of criminal dynamics [34]. We have chosen a model investigating the mechanisms of social influence and their effects both on individual criminal choices and on the spread of crime on social networks. The study started from the hypothesis that of different criminal outcomes generated by different mechanisms of imitation at the micro level of social interaction. In particular, the model introduces a distinction between *rational imitation* (based on the performance observed) and *social imitation* (based on the degree of connectivity observed) on the basis of the motivations that are behind the imitative behavior. To test this hypothesis, the model simulates individual agents interacting in their social networks. Individual decisions to be engaged in crime and their consequent behavior towards crime, are influenced by both personal and social learning factors. The model formalizes the structure of different social network topologies (random, scale-free and small-world) on which agents are connected. The main substantive implications emerging from the study concern the different effects of rational and social imitation mechanisms on crime. Summarizing some of the main results, the network topology seems to have more influence on crime when individuals influence each other through social imitation. In such cases, as already said, agents imitate other actors connected on their network, on the basis of their degree of connectivity. Secondly, results suggest that a small world network structure allows to better account for the spreading of crime through social imitation.

Starting from the model just sketched and exploiting the functionalities described in Sect. 4.2 we imported *CrimeMiner* data into a *NetLogo* implementation of the model so to start a series of simulation experiments that can be traced back to the two research directions above listed:

(i) *Enhancing ABM theory making:* a first set of experiments is and will be devoted to place the conceptual insights and hypotheses of the theoretical model taken as reference into a more realistic environment. The goal is to explore the outcomes produced by the imitation mechanisms presented in [34] in different experimental conditions variously connected with topical issues in criminological research. Here below a list of both started and forthcoming experiments grouped by topic.
   - *Network structure:* network topologies (random, scale-free, small-world) already tested have been replaced with the topology derived by real data in the *CrimeMiner* project. The attention is focused on monitoring of how different and more realistic topologies affect specific features of the simulated phenomenon (first of all the emergence and spread of criminal behaviors, the speed and the diffusion of crime at the end of the simulation). Other experiments will be done adding/deleting specific nodes/edges so to explore the effect produced on the evolution of the network (emergence or disappearance of sub-communities) and give an answer to questions like the following. How does criminal models/leaders

and participation relate to behavioral patterns? Which types of ties predict social status, power, or influence within the group, and how do these translate into collective action?
- *Nodes attributes:* behavioral profiles (e.g. the propensity to commit a crime) and individual attributes (e.g. the criminal prestige) will be assigned to simulated agents according to the attributes (e.g. type of criminal records) of the corresponding real individuals/nodes as defined in *CrimeMiner*. This will allow to give a "realistic flavour" to the ABM exploration of fundamental theories of crime like, just for instance "social learning theory" [1].
- *Environment:* agent behavior will be varied not only depending on the imitation mechanism taken into account, but also according to the spatial information (of the agents, of the criminal activities) derived from *CrimeMiner* GIS data. We will imagine new *in silico* explorations of the role played by the environmental/spatial dimension in the genesis/evolution of crime [21].

(ii) *Making generative SNA:* another set of experiments will be devoted to explore the potential evolutions of the criminal network under investigation exploiting the expressiveness and the simplicity of ABM. This will allow to complement more complex and less "semantic" (at least for social scientists and investigators) approaches like probabilistic approaches to link prediction [41].

## 5 Conclusion

Even if in its early stages, the work presented in this paper has already produced interesting preliminary results depicting the integration of ABM and SNA as a promising way to support the study of criminal organizations both for scientific and investigative purpose. The merging of these methodologies seems capable to enhance criminological research offering new ways to investigate how the evolution of crime relates to the structural features of criminal organization and to the dynamics of agency (autonomy, learning etc.). In that direction, evolutionary techniques, that we applied in other research areas [16], could be used to gain more and different insights about the phenomenon under investigation. Advances in this field could not only shed a new light on the core dynamics of crime, but could also result in the creation of more effective tools to be gradually introduced into the daily activity of crime researches and public agencies involved in the fight against organized crime. In more general terms, the integration of heterogeneous research methods like ABM and SNA appeared to be helpful also in other ways: providing more chances for communication between otherwise bounded communities, teasing out complementarities across problems sliced in different ways in separate scientific and application areas. The experience made provided us with a meaningful example of how scientific perspectives, methods and tools evolve together in a continuous and circular process. So far we have focused our attention on extending the functionalities of *CrimeMiner* devoting a still limited time to the experiments. The network data and the simulation model have been correctly merged in *NetLogo* and the first simulations performed so far have produced results that, in addition to being different from the ones presented in [34], have given us food for thought bringing about new challenges for research areas spanning from criminology to computational social science, from legal informatics to computer science. It should not come as no surprise. According to the scenario above sketched speculating about epistemological issues, the future of social science is not only computational, but also eclectic.

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