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Simulating Crime: Models, Methods, Tools

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"To me the most interesting aspect of the law and economics movement has been its aspiration to place the study of law on a scientific basis, with coherent theory, precise hypotheses deduced from theory, and empirical tests of the hypotheses ..."[1]

1. INTRODUCTION

Since the advent of computers, the natural and engineering sciences have enormously progressed. Computer simulations allow one to understand interactions of physical particles and make sense of astronomical observations, to describe many chemical properties *ab initio*, and to design energy-efficient aircrafts and safer cars. Today, the use of computational devices is pervasive. Offices, administrations, financial trading, economic exchange, the control of infrastructure networks, and a large share of our communication would not be conceivable without the use of computers anymore.

Hence, it would be very surprising, if computers could not make a contribution to a better understanding of social and economic systems. While relevant also for the statistical analysis of data and data-driven efforts to reveal patterns of human interaction, we will focus here on the prospects of computer simulation of social and economic systems by ABS - Agent-Based Simulation.

It is well-known that the ways in which social scientists analyze human behavior, social interactions, and society vary largely. The methods range from qualitative to quantitative ones, and among the quantitative ones, some communities prefer detailed models with many variables and parameters,

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[1] R.A. POSNER, in Faure M., Van den Bergh R. (eds.), "Essays in Law and Economics", Antwerpen, Maklu, 1989.

while others prefer simple or simplified models with a few variables and parameters only. Overall, each method has its justification, and the choice of the proper method very much depends on the respective purpose. For example, the elaboration of applications such as new systems designs often requires a quite realistic and, hence, detailed description of all relevant aspects. In contrast, simple models may be used to get a better understanding of how social mechanisms work. They serve to reduce the complexity of a given system to an extent that allows to guide our thinking and provide an intuition how certain changes in the system would affect its dynamics and outcome. The application of computational models is currently not common in the social and economic sciences. This is perhaps because many people consider them as intransparent and unreliable (as compared to analytical methods) and/or as unsuitable for prediction[2].

Besides, the benefit of computational models is not restricted to prediction. Joshua Epstein discusses 16 other reasons to build models, including explanation, guiding data collection, revealing dynamical analogies, discovering new questions, illuminating core uncertainties, demonstrating tradeoffs, training practitioners, and last but not least decision support, particularly in crisis situations. In fact, computer models can naturally complement classical research methods in socio-economic sciences. For example, they allow one to test whether mechanisms and theories used to explain certain observed phenomena are sufficient to understand the respective empirical evidence, or whether there are gaps or inconsistencies in the explanation. Morever, they allow one to study situations, for which analytical solutions cannot be found anymore, and to go beyond the idealizations and approximations of simple models. Without the exploration of model behaviors that can only be numerically determined, scientific analysis is often restricted to unrealistic models and to situations which may be of little relevance for reality. For example, the financial crisis may have been the result of approximations and simplifications of economic models, which were not sufficiently justified[3].

[2] H. SIMON, *The Architecture of Complexity*, in "Proceedings of the American Philosophical Society", Vol. 106, 1962, n. 6, pp. 467-482.

[3] J.M. EPSTEIN, R. AXTELL, *Growing Artificial Societies: Social Sciences from the Bottom Up*, Cambridge, MIT Press, 1996.

An ABS is a class of computational models for simulating the actions and interactions of artificial autonomous agents[4] (both individual or collective entities such as organizations or groups) with a view to assessing their effects on the system as a whole. ABSs simulate the simultaneous operations and interactions of multiple agents, in an attempt to re-create and predict the appearance of complex phenomena. The process is one of emergence from the lower (micro) level of systems to a higher (macro) level. A central tenet is that the whole is greater than the sum of the parts. Individual agents are typically characterized as boundedly rational, presumed to be acting in what they perceive as their own interests, such as reproduction, economic benefit, or social status, using heuristics or simple decision-making rules. ABS agents may experience "learning", adaptation and reproduction. Most agent-based simulations are composed of:

1. numerous agents specified at various scales (typically referred to as agent-granularity);
2. decision-making heuristics;
3. learning rules or adaptive processes;
4. an interaction topology; and
5. a non-agent environment[5].

2. ABM - Agent-based Modeling and Crime

In recent years, there has been a growing interest on theoretical, methodological and empirical work to develop analytical and computational models of crime pattern formation. Computational crime models forms a key feature of current approaches to understanding offender behavior and is a tool used increasingly by police departments and policy makers for strategic crime prevention, to guess new policy to prevent crime, to tackle organized crime. However, despite the availability of sophisticated digital mapping and

[4] With *artificial autonomous agent* we refer to procedures that *runs* into a computer. It is not necessary that the agents are physical agents that move in environment (robots).

[5] R. Axelrod, *The Complexity of Cooperation: Agent-based Models of Competition and Collaborations*, Princeton, Princeton University Press, 1997; R. Axelrod, L. Tesfatsion, *A Guide for Newcomers to Agent-based Modeling in the Social Science*, in Judd K., Tesfatsion L. (eds.), "Handbook of Computational Economics", Amsterdam, Elsevier/North Holland, Vol. 2, 2005; M. Wooldridge, *An Introduction to Multiagent Systems*, New York, John Wiley & Sons, 2002.

analysis tools (see Fig. 1[6]) there is a substantial gap in our understanding of how low-level behaviors of offenders lead to aggregate crime patterns such as crime hot spots. Thus, for example, we are unable to specify exactly why directed police action at crime hot spots sometimes leads to displacement of crime in space but, surprisingly, often can also lead to hot spot dissipation and a real reduction in crime incidences. ABM offers a potential avenue for developing a quantitative understanding of crime hot spot formation built from the bottom-up around offender behavior. Agent-based models are not only more consistent with the scale of decisions that offenders actually take, but they also open the door to the development of custom statistics that are designed to answer specific behavioral questions less tractable in general statistical models. However, there is also concern that agent-based simulations can lead to erroneous results either because of poor model design or errors in model implementation that go undetected. A solution to this problem is to design simulations around well-studied analytical models where the model behavior can be tested against sound analytical expectations. Only following such testing should simulation models be extended into areas that cannot be treated analytically and, only subsequent to this, into applied contexts.

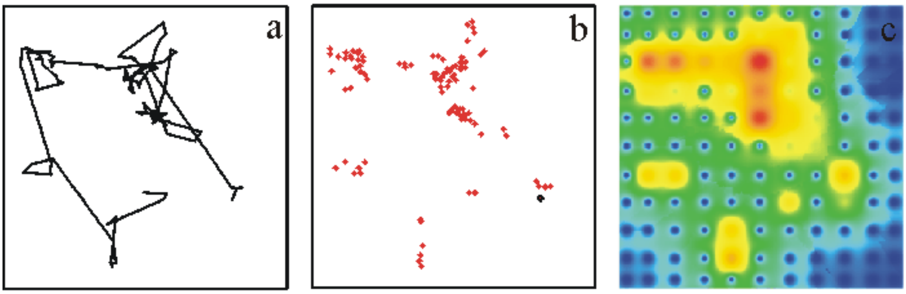

Fig. 1 – Simulated offender movement and abstract mapping of crime locations

The possibilities are many: you could study relationships between criminal behavior, criminal opportunities and policing and may provide insight into how to design better crime prevention strategies, contributing to a

[6] In this Figure the following phenomena are represented: (a) Simulated offender following a Lévy mobility strategy. Lévy mobility shows clusters of short distance flights interspersed with longer distance flights. (b) Mapped crime locations assuming that criminal opportunities are uniformly distributed in space and that offenses occur only at the end points of Lévy flights. (c) Inverse distance weighted interpolation of offense locations showing crime hot spots generated by the underlying Lévy mobility strategy.

broader dialog on homeland security. Simultaneous development of mathematical and simulation models, as well as continuous empirical testing, will provide a guide for the experimental use of these tools in the social sciences, while the broad interdisciplinary foundation of the project will provide a model for collaboration between mathematicians and social scientists. The educational component will provide an excellent venue for developing the research careers of students and postdoctoral associates at all levels.

3. SIMULATING CRIME: METHODS

The basis of the ABM applied to criminal study is the assumption that people involved with the legal system act as rational maximizers of their utility. Since most of the time the choice of the individuals involves uncertainty – the result of a crime is not given as certain beforehand – the relevant economic theory analyzes the decision making in uncertain conditions[7]. Assuming rationality in economics studies or when it is applied to crime, only means that people act on purpose in the search of objectives individually chosen; it means, more specifically, that people prefer more to less, of the things they desire. Economists use the framework of rationality as a description of human behavior, and as a way of identifying the foreseeable reaction of the average individual that composes the group. The *key* for the method is all in the next statement, i.e.

> ...I can draw the criminal activity as the interaction of individual activities, which can individually describe, and the interaction of these with an environment. We are talking about ARTIFICIAL agents (i.e. described by procedures into a computer) and ARTIFICIAL environments (that are described by other procedures).

Sometimes, the rational individual (agent) contrasts with the reasonable individual in what refers to the tradition of legal theory – an individual, who is socialized in the norms and conventions of a community, and whose behavior corresponds to these norms. Laws, as a consequence, should reflect these norms and conventions and therefore, be obeyed by reasonable

[7] I. EHRLICH, *Crime, Punishment and the Market for Offenses*, in "The Journal of Economic Perspectives", Vol. 10, 1996, n. 1, pp. 43-67; G. FIORENTINI, S. PELTZMAN (eds.), *The Economics of Organised Crime*, Centre for Economic Policy Research, Cambridge University Press, 1997; P.W. KINGSTON, R. HUBBARD, B. LAPP, P. SCHROEDER, J. WILSON, *Why Education Matters*, in "Sociology of Education", Vol. 76, 2003, n. 1, pp. 53-70; A.M. LAW, W.D. KELTON, *Simulation Modeling and Analysis*, New York, McGraw-Hill, 1982.

individuals. In this way, those who engage in illegal activities (theft, kidnapping, murder, etc.) are seen as having a deviate behavior in the sense that they have violated or broken those norms and conventions. This approach poses problems in terms of computational modeling. An ABM admits that individuals are capable of criminal activity through social interaction. Such models facilitate deeper analysis regarding the differentials of criminality indexes among regions. In the next Section we will deal with this question. This particular remark is also addressed within the context of the architecture of the agent-based model and how the rules of individual behavior are conceived in order to design an artificial society.

Now we can give a more formal definition of an ABM:

> ...In agent-based modeling (ABM), a system is modeled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents may execute various behaviors appropriate for the system they represent – for example, producing, consuming, or selling. Repetitive competitive interactions between agents are a feature of agent-based modeling, which relies on the power of computers to explore dynamics out of the reach of pure mathematical methods. At the simplest level, an agent-based model consists of a system of agents and the relationships between them. Even a simple agent-based model can exhibit complex behavior patterns and provide valuable information about the dynamics of the real-world system that it emulates. In addition, agents may be capable of evolving, allowing unanticipated behaviors to emerge. Sophisticated ABM sometimes incorporates neural networks, evolutionary algorithms, or other learning techniques to allow realistic learning and adaptation[8].

3.1. An Example

We could try to make these arguments more solid. We take such a model of Berger and colleagues[9]. The model seeks to establish dynamically the relationship between micro and macroeconomic variables. Each singular behavior of any agent within the environmental framework subject to analysis will have an associated cost of transaction. Agents' interaction alters ran-

[8] Citation from E. BONABEAU, *Agent-based Modeling: Methods and Techniques for Simulating Human Systems*, in "Proceedings of the National Academy of Sciences of the United States of America", Vol. 99, 2002, n. 3.

[9] L.M. BERGER, D. BORENSTEIN, G. BALBINOTTO NETO, *The Agent Based Model Applied to Crime: Theory and Evidence*, 2011, in "Economic Analysis of Law Review", Vol. 1, 2011, n. 1, pp. 140-152.

domly their conditions during simulation process and, therefore, the overall macroeconomic performance.

The basic strategy used by agents when engaging (or not) in criminal activity within a given context is Becker's formulae[10] which states formally:

$g > p(f + \lambda t)$

Where:

g = gain a party obtains by engaging in harm-creating activity;

p = probability of detection;

f = fine;

t = length of the imprisonment term;

λ = disutility borne by a prisoner per unit of the imprisonment term.

The model is built upon three agents (or set of agents) that dynamically and randomly interact with each other and with the environment, simulating, as close as possible, real criminal events. The model is conceived as follows:

- *Citizen Agent*. This agent represents some probable perpetrator. It must be stressed that the model does not assume prior criminal condition from the agent. That condition will be given by the simulation process and depends upon the probability distributions more suitable for the case. Therefore, the engagement in criminal activity is a decision the agent takes during the simulation process, depending upon the particular conditions regarding the crime committed, whereas it may be an assault, battery, rape, manslaughter, murder and so forth. The incoming data that feed the simulator parameters is modeled for each particular case, or criminal act.
- *Opportunity Agent*. This agent represents the specific target of criminal activity that is protected by law over which the citizen agent might be interested in. This agent models the specific right, protected by law, subject to simulation. In this study, the agent is represented by vehicles once it intends to model car theft. In this particularly case, the opportunity agent is *a property belonging to another*, according, for instance, to the British law regarding the subject.
- *State Agent*. Represents the Public authority in charge to address enforcement of criminal legal rules. The initiatives or actions taken by state agents may be not just criminal fighting through police means,

[10] G. BECKER, *Crime and Punishment: An Economic Approach*, in "Journal of Political Economy", Vol. 76, 1968, n. 2, pp. 169-217.

but interventions in many social circles that may have intense effect on criminal rates. The agents' interactions regarding the enforcement of law can be seen in the way the citizen agent and the opportunity agent are connected.

3.2. One Result

The authors have not yet begun to exploit the potential of their model (I have chosen to quote this for the clarity with which the agents are defined...). Anyway, we can test the correctness of the code by this simple analysis. In Fig. 2, the x-axis gives the probability of detection (and punishment) p. The y-axis gives the crime rates obtained with the simulation experiments. In accordance to Becker's equation, as increases p, crime rates decrease proportionally, making the results consistent with Becker's framework. Also, as the experiments were performed for agents with different income levels, the simulation tests show a proportional decrease in crime rates as agents' marginal income increases, as theoretically expected.

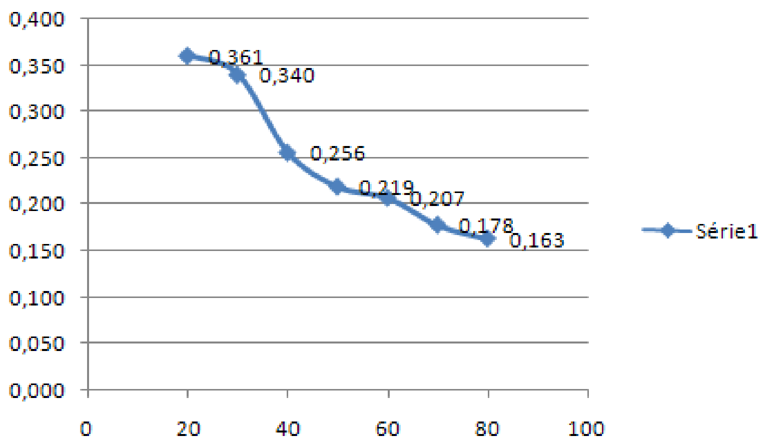

Fig. 2 – One (obvious) results coming from ABM model.
Increasing punish, the crime rates decrease

The simulator-operating console with typical NetLogo (see next Section) features is shown in Fig. 3, which allow performing various kinds of experiments, particularly, simultaneous interaction among microeconomic variables and the macroeconomic outcome. All along the simulation process, the probability functions used to generate random entry data can be fully controlled.

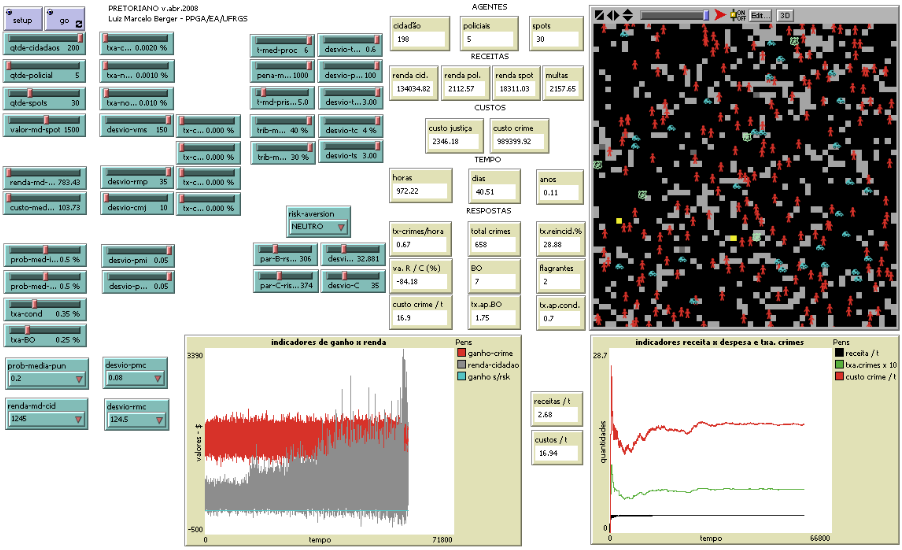

Fig. 3 – The simulation interface

4. Tools

Here is the sketch description of three of the most popular agent-based modeling simulation environments. Except for NetLogo, you need to know Java programming language to write a simulation. Java is a programming language based on objects, that is currently most widespread and general used. This fact gives to NetLogo, rather than the other two environments, an incomparable immediacy of use. So as to make possible the creation of ABM in teams without a specific informatics skills[11].

- MASON is a fast discrete-event multiagent simulation library core in Java, designed to be the foundation for large custom-purpose Java sim-

[11] U. Wilensky, *Center for Connected Learning and Computer-based Modeling*, Evanston, Northwestern University, 1999, http://ccl.northwestern.edu/netlogo/; P. Winotto, *An Agent-based Simulation on the Market for Offenses*, AAAI Technical Report WS-02-10, 2002; W.B. Arthur, *Out-of Equilibrium Economics and Agent-based Modeling*, in Judd K., Tesfatsion L. (eds.), "Handbook of Computational Economics", Amsterdam, Elsevier/North Holland, Vol. 2, 2005.

ulations. MASON is a single-process discrete-event simulation core and visualization library aimed at multiagent simulations with large numbers of agents. The system is written in pure Java and is intended for experienced Java coders who want something general and easily hackable to start with, rather than a domain-specific simulation environment. Some features:

  - Simulations can be serialized to checkpoints (freeze-dried and written to disk), which can be recovered from at any time, even to different Java platforms and new MASON visualization toolkits.
  - MASON can be set up to be guaranteed duplicatable, meaning that the same simulation parameters will produce the same results regardless of platform.
  - Libraries are provided for visualizing in 2D and in 3D (using Java3D), to manipulate the model graphically, to take screenshots, and to generate movies (using Java Media Framework).
  - While the visualization toolkits are fairly large, the core simulation model is intentionally very small, fast, and easy to understand.

- NetLogo. A cross-platform multi-agent programmable modeling environment. NetLogo (release 5.0), is a flexible programming suite to design, simulate, and study agent-based models. The main data structures of NetLogo is the same of the other language (unidimensional vectors, lists, arrays, and tables); it is possible to declare, to initialize, and to manipulate them by creating user-defined procedures and functions; NetLogo has main control structures (branching points and loops). The main feature of Netlogo is the agent-oriented side: it is possible to create Netlogo autonomous entity (patches, turtles, and links) and to invoke them by using "agentsets".
- Repast. Repast Simphony 2.0, released on 5 March 2012, is a tightly integrated, richly interactive, cross platform Java-based modeling system that runs under Microsoft Windows, Apple Mac OS X, and Linux. It supports the development of extremely flexible models of interacting agents for use on workstations and small computing clusters. Repast Simphony models can be developed in several different forms including the ReLogo dialect of Logo, point-and-click flowcharts, Groovy, or Java, all of which can be fluidly interleaved. NetLogo models can also be imported.

5. Conclusions

Agent-based modeling is potentially a very powerful tool for crime study[12]:

- it increases the empirical understanding of how society works and help to exploit the emergence of regularities;
- it increases the normative understanding, since the computing models can help design good norms and mechanisms for many kinds of criminal behavior;
- it increases the methodological tools since they give to researchers a new powerful method to study complex social systems when individuals are cooperative or non-cooperatives at the same time, and when norms and incentives dynamically change; and finally
- it can attain insights to researchers about methods and tools, concerning the functioning of complex systems and societies.

This kind of framework developed is still in its infancy, there is much more work to do, but the insight is very valuable to anyone interested in economics of crime and the implication of law and economics. In other words, agent-based model applied to crime is important to study complex societies and their evolution[13].

[12] R.V. Clarke, *Situational Crime Prevention, Crime and Justice*, in "Building a Safer Society: Strategic Approaches to Crime Prevention", Vol. 19, 1995, pp. 91-150; L.E. Cohen, M. Felson, *Social Change and Crime Rate Trends: A Routine Activity Approach*, in "American Sociological Review", Vol. 44, 1979, August, pp. 588-608; R. Cooter, T. Ulen, *Law and Economics*, Boston, Addison Wesley Longman, 3rd ed., 1999.

[13] N. Mercuro, S.G. Medema, *Economics and the Law: From Posner to Post-Modernism*, Princeton, Princeton University Press, 1997; S. Russel, P. Norvig, *Artificial Intelligence: A Modern Approach*, Prentice Hall Series in Artificial Intelligence, 2nd edition, 2003; J.A. Scheinkman, E.L. Glaeser, B. Sacerdote, *Crime and Social Interactions*, in "The Quarterly Journal of Economics", Vol. 111, 1996, n. 2, pp. 507-548; S. Shavell, *Foundations of Economic Analysis of Law*, Cambridge, Harvard University Press, 2004; S. Shavell, A.M. Polinsky, *The Economic Theory of Public Enforcement of Law*, in "Journal of Economic Literature", Vol. 38, 2000, n. 1, ABI/INFORM Global, p. 45.