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From minds to law: Agent-based modeling and the interplay between cognition, society, and the legal world

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Abstract

The paper presents the computer simulation of social phenomena as a promising approach to investigate the links tying human cognition, society and law. The focus is on agent-based modeling (ABM), a research paradigm offering new ways to explore how the interaction between individuals (and the cognitive mechanisms governing their decisions) leads to the emergence and evolution of complex, macro-level social constructs. After an introduction to the theoretical and methodological framework grounding our proposal, which we situate at the intersection of complexity theory, computational empiricism, and computational social science, the paper delves into the basic features of agent-based simulations. It then examines, by way of example, the application of ABM to the study of phenomena – ranging from the effects of sanctions to social dilemmas and crime dynamics – that not only are relevant to socio-legal research but also clearly connect micro-level cognitive processes with macro-level social outcomes. The review serves as an opportunity to reflect on the scientific and methodological frontiers of legal sociology and, more generally, on the prospects for the empirical development of legal science.

Key words

Cognition; agent-based models; computational legal empiricism; computational social science; complexity theory

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Resumen

El artículo presenta la simulación por ordenador de fenómenos sociales como un método prometedor para investigar los vínculos que unen la cognición humana, la sociedad y el derecho. Se centra en el modelado basado en agentes (ABM), un paradigma de investigación que ofrece nuevas formas de explorar cómo la interacción entre individuos (y los mecanismos cognitivos que rigen sus decisiones) conduce a la aparición y evolución de construcciones sociales complejas a nivel macro. Tras una introducción al marco teórico y metodológico en el que se basa nuestra propuesta, que situamos en la intersección entre la teoría de la complejidad, el empirismo computacional y las ciencias sociales computacionales, el artículo profundiza en las características básicas de las simulaciones basadas en agentes. A continuación, examina, a modo de ejemplo, la aplicación del ABM al estudio de fenómenos —que van desde los efectos de las sanciones hasta los dilemas sociales y la dinámica de la delincuencia— que no sólo son relevantes para la investigación sociojurídica, sino que también conectan claramente los procesos cognitivos a nivel micro con los resultados sociales a nivel macro. La revisión sirve como una oportunidad para reflexionar sobre las fronteras científicas y metodológicas de la sociología jurídica y, de manera más general, sobre las perspectivas para el desarrollo empírico de la ciencia jurídica.

Palabras clave

Cognición; modelos basados en agentes; empirismo jurídico computacional; ciencias sociales computacionales; teoría de la complejidad

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> Sieh, nun heißt es zusammen ertrag. Stückwerk und Teile, als sei es das Ganze.
> [Our task now is to connect parts and fragments as if they were the Whole].
> (Rainer Maria Rilke, *Die Sonette an Orpheus, Erster Teil*, 1922)

> Today the network of relationships linking the human race to itself and to the rest of the biosphere is so complex that all aspects affect all others to an extraordinary degree. Someone should be studying the whole system, however crudely that has to be done, because no gluing together of partial studies of a complex nonlinear system can give a good idea of the behavior of the whole.
> Murray Gell-Mann - International Society for the Systems Sciences Seminar (12 October - 10 November 1997)

1. Cognition, society, law: speculations on a simulation-based research approach

The relationship between cognition and the realm of law is undoubtedly a fascinating topic. Whether it is the decision-making mechanisms underlying the emergence of early forms of legal order or the biases that shape the perception of norms, the links binding mental processes to the legal phenomenon pose questions by which legal scholars are increasingly drawn (Gneezy and Rustichini 2000, Greene and Cohen 2004, Goodenough and Tucker 2010, Lettieri and Faro 2015, Cominelli 2018). There are many reasons for this interest: the purpose of law is ultimately to guide behaviors and decisions while, at a more fundamental level, the origin and implementation of legal orders can themselves be interpreted in terms of mental processes.

In truth, issues just evoked initially gained attention in areas outside traditional legal studies. The analysis first developed in the context of the behavioral sciences – in particular, behavioral economics – as well as social psychology, cognitive science, and neuroscience. Only in recent years have scholars of a more strictly legal background (positive jurists, philosophers, and sociologists of law, experts in artificial intelligence) begun to explore the boundaries between cognition and law in a targeted and systematic way. Thus, a process has been started, which, although extended to several disciplinary domains, still appears to be in its infancy both from a scientific point of view (themes, research questions) and from a methodological one.

Some lines of research, as anticipated, are already well established. The psychology of eyewitness testimony (Loftus 1996), the modeling of legal reasoning (Bench-Capon and Sartor 2003), or the applications of *nudge theory* in the legal domain (Alemanno and Sibony 2015) are only those that have had the greatest following and resonance to date, thanks in part to results that are undoubtedly interesting and promising. However, a whole series of questions remains to be explored that has mainly to do with the collective, dynamic, and interactive dimension of cognition; a topic, this one, of particular interest for the sociology of law that aims to understand the legal system in its interactions with society and the individual. In this respect, there is still much to be discovered about the processes through which an individual's cognition, by interacting with the cognition of other individuals, turns itself into collective action, macro-level phenomenon, and, finally, legal fact.

A promising scientific and methodological perspective we would like to draw the attention to is represented by *artificial societies*: computer simulation models in which populations of artificial agents are used to explore the origins and the evolution of complex social facts spanning from economic to cultural dynamics, through the "in silico" (i.e. "within a computer simulation", to adopt the expression first used in biology by Sieburg, 1990) reproduction of individual actions, choices and interactions thereof.

Fed by the convergence of research traditions ranging from statistical physics to cognitive science and complexity theory, social simulations appear today as paving the way to a deeper understanding of the links tying cognition and society: they not only enable new ways to formally model biases and other relevant cognitive mechanisms, but also to explore the empirical implications of such mental constructs as they interact in a collective dimension.

Based on these premises, the article introduces simulation as a potential ally to deal with issues that are gaining increasing relevance in socio-legal research and are closely intertwined with the cognitive dimension, such as the biases and heuristics that influence legal decision-making, the ways in which social and cultural factors shape legal systems, or the impact of policy and rule making on human cognition and behavior. The reflection builds upon a research trajectory on the possible intersections between simulation and law, which began over a decade ago (Lettieri 2013, Lettieri and Parisi 2013, Carillo *et al.* 2013, Lettieri and Vestoso 2015, Lettieri *et al.* 2015) and has since evolved theoretically (Lettieri 2016, 2020, 2024, Lettieri and Pluchino 2024) and experimentally (Lettieri *et al.* 2017, Zaccagnino *et al.* 2025), drawing increasingly on complexity theory and computational social science.

The paper, it bears emphasizing, is not intended to exhaust the subject; rather, it limits itself to outlining a research horizon, while trying to offer some pointers for further exploration and to lay the groundwork for future debate. The analysis unfolds as follows. Section 2 sketches the theoretical and methodological background that underpins our proposal. Section 3 introduces artificial societies, their potential, and the scientific opportunities they present. Section 4 reviews a range of simulation studies, variously exploring the link between decision-making processes, individual cognition and phenomena that matter for the law. The final section offers some concluding remarks on the possibilities now emerging for an empirical evolution in legal science.

2. Setting the stage: Theoretical and methodological background

Our idea of using simulation to explore the cognitive dimension of the legal phenomenon is grounded in a scientific and methodological horizon that extends well beyond the boundaries of law, psychology and cognitive science. The claim does not stem from eclecticism for its own sake but rather from the conviction that a genuinely scientific approach to reality cannot but lead to engaging with all that science reveals about the world in its entirety, beyond disciplinary boundaries.

On the other hand, at its core, the explanatory power of science largely relies on the ability of the latter to explain phenomena observed at one level of reality – here understood as an ontological level characterized by its own dimensional, temporal, and energy scale – and studied within one discipline, in terms of processes occurring on another level of reality and studied in other research fields.

The explanation of chemical properties and reactions in terms of atomic and molecular processes, or the discovery that migratory birds navigate thanks to quantum processes that occur in their retinas and allow them to perceive the Earth's magnetic field, are just two seemingly trivial yet deeply significant examples of this circumstance.

The same perspective can be applied to the topics we are dealing with: socio-legal dynamics can be understood and studied in terms of cognitive interactions that take place among individuals and together give rise to increasingly complex social entities from groups to legal institutions. To head in this direction, sociology, psychology and law alone are insufficient. However advanced their analyses may be, they are still unable to offer reliable, rigorous and non-siloed representations of the causal links and processes connecting the micro, cognitive dimension with the macro, socio-legal one. From this perspective, looking at research fields and scientific perspectives capable of shedding new light on this type of connection is an inevitable choice.

In the following sections we examine what can be seen as the pillars, along this line of thought, of the perspective we propose: complexity theory; the epistemological perspective known as "computational empiricism," advanced by the philosopher of science Paul Humphreys; and the computational social science paradigm. Two considerations motivate this choice: the first is that, on a practical level, these fields provide powerful tools and methods for the empirical study of human societies and their institutions; the second, more fundamental, is that, taken together—and with complexity theory playing a primary role—they articulate conceptions of reality and scientific practice with which legal science and, more generally, all social sciences would do well to begin to seriously engage.

2.1. Complexity theory

The first element of our background is complexity theory, a multifaceted and interdisciplinary field of research that, since the mid-20th century, has contributed gradually but profoundly to reshaping our understanding of reality. Rooted in a scientific and intellectual *milieu* ranging from thermodynamics to computer science, from theoretical biology to cybernetics and chemistry, complexity theory has brought to light a fundamental truth that we have only recently begun to truly grapple with: whenever we consider *ensembles composed of multiple entities* that interact with each other, nature behaves in surprisingly similar ways (Mitchell 2009, Pluchino 2015). Complex systems – this is the definition of the ensembles above – not only exhibit common properties (emergence, adaptation, non-linearity, and self-organization, as we will see shortly) but, at least in some respects, lend themselves to being studied exploiting the same conceptual and methodological apparatus.

Complexity theory brings these phenomena within a common theoretical and methodological framework, providing scientific insights and mathematical principles that now allow us to conceptualize and study phenomena belonging to the most diverse ontological, temporal, and dimensional scales in new ways. Complexity, on the other hand, is everywhere. To quote Nobel Prize-winning physicist Murray Gell-Mann (1994), examples of complex systems include not only "biological evolution" or "cognition" in animals and humans, but also intrinsically collective, planetary-scale processes such as "scientific enterprise".

This awareness is rich in implications: complexity, with all its characteristics, is a distinctive feature not only of physical systems, but of reality at all levels, including the social domain. Understanding its fundamental mechanisms can prove invaluable in exploring the most diverse emerging social constructs, including the invisible web that connects human cognition and the broader legal and social structures in which it operates.

Starting from this consideration, we will now examine some of the most salient properties of complex systems. The following is obviously not intended to be an exhaustive taxonomy, but rather an introductory overview of concepts that can inspire new ways of exploring social complexity, including, as is of specific interest to us here, using simulation models.

2.1.1. Emergence

Emergence is arguably the most discussed and defining feature of complex systems (Humphreys 2016). The term refers to the appearance, under appropriate conditions of interaction and organization, of macro-level properties, structures, or behaviors that are not – or not fully – inferable from inspecting the system's micro-components in isolation (we set aside, for the moment, the distinction between weak and strong emergence). Novel at the system level, emergent properties are typically produced by recurrent, nonlinear interactions and the formation of constraints and become intelligible only at the appropriate scale of description. A canonical illustration is the liquidity of water: a mesoscale property, absent at the level of a single molecule, arising from intermolecular interactions among countless atoms. Analogously, in biology, the coordinated activity of cells yields tissue-level functions (e.g., cardiac pumping) that no isolated cell possesses. In social systems, to come to topics of interest to us, examples of emerging dynamics can be found in social norms, conventions, or market prices, all phenomena that are not identifiable in the state of a single agent but that materialize, at the system level, thanks to dynamics that hold together the cognitive and collective dimensions.

2.1.2. Non-linearity

Non-linear behaviors in complex systems encompass all the cases in which the output or response to an input is not directly proportional to the initial conditions or stimuli, so that small changes can lead to disproportionately big or unexpected outcomes, such as *phase transitions* and *tipping points* (times when the system abruptly shifts into a new state). Non-linearity is also integral to understanding complex systems, as it implies sensitivity to initial conditions, famously exemplified by the so-called "butterfly effect" (Lorenz 1963) in chaos theory. This property makes it difficult to predict and control phenomena in fields like, for example, ecology and economics, in which nonlinear responses can lead to cascading effects and far-reaching consequences.

2.1.3. Self-organization

Self-organization is a phenomenon that occurs when the elements of a system organize themselves into structured patterns or forms, without the intervention of a central authority or an external control. The process occurs across many domains — from physics to biology to social systems — and is typically driven by local interactions and feedback mechanisms among the system's components. A canonical physical example is the formation of Bénard cells: convection patterns that arise in a fluid layer heated from below, where hexagonal structures emerge spontaneously as a response to the temperature gradient. Illustrative examples also come from biology. One may cite, for instance, the foraging behaviors observed in ant colonies where, despite internal role differentiation playing a role in other scenarios, coordination remains fully decentralized. Other well-known biological examples include bird flocking, fish schooling, and the formation of honeybee swarms. In social systems, self-organization helps explain emergent phenomena such as traffic patterns, market fluctuations, or collective behaviors in online environments. What makes self-organization particularly relevant in the context of complexity is that it often underpins the resilience and adaptability of complex systems, allowing them to evolve and reorganize under changing or uncertain conditions.

2.1.4. Adaptation and evolution

Adaptation is the ability of a system to modify its internal configuration and actions based on changes in the environment, enhancing its ability to survive and function effectively. In biological systems adaptation is the process influenced by Darwinian natural selection, where organisms develop characteristics that ensure (and increase the likelihood of) their survival in a particular habitat. It is now widely applied in fields like artificial intelligence and other engineered systems, in which the performance improvements happen through iterative learning from data using algorithms. Evolution in complex systems entails incremental or abrupt changes that build up over time, allowing the system to adapt to new obstacles and prevent obsolescence. Adaptation and evolution are also essential for enduring resilience, as they guarantee that complex systems stay sustainable amidst ongoing change.

All the properties above give a sense of the dynamic, unpredictable and interdependent nature of complex adaptive systems, illustrating how such systems can maintain order and functionality despite their inherent sensitivity to external and internal influences. The implications of such a nature are profound and far reaching.

The first is purely epistemological: complexity theory challenges the Newtonian—mechanistic, reductionist, deterministic—worldview (Louth 2011) that still grounds much of the way we understand reality. The horizon of scientific inquiry is no longer populated only by isolated components, proportional causes, and context-independent laws, but by interaction structures, multi-level descriptions, heterogeneity, and feedback loops.

The second one is methodological: the study of complex systems calls for new research methods, since many of their features elude traditional approaches alone. In this respect — and without fear of lapsing into what might be taken as a form of "computational reductionism" — it can be plausibly maintained that a significant share of the effort will need to be directed toward the development, exploration, and refinement of computational methods, above all simulation. Indeed, the "in silico" reproduction of complex systems — alongside methods on which we will not dwell here, such as complex network analysis and complexity modeling—currently represent one of the most promising ways to investigate collective and emergent properties that otherwise would be hard to analyze.

This epistemological and methodological awareness has now extended to the study of complex social phenomena (for example, among others, opinion and crowd dynamics, cultural changes, cities' evolution and financial crisis). In fact, works have already appeared in the literature (see, for example, Byrne and Callaghan 2022, and, more specifically for sociology, see Page 2015, Edelmann *et al.* 2020) that actually contribute in shedding new light, thanks to the intuitions and discoveries of complexity theory, on the ways in which social processes develop, and on the role that the interactions between the components of the social group, be they individuals, groups, institutions, play in them.

The concepts of emergence and non-linear causality, from this point of view, have contributed to radically redefining, on the epistemological level, not only some key concepts of social theory, such as those of structure and *agency*, but also more generally our complete understanding and perception of the social universe in which we move. All this, as we have anticipated, has non-trivial consequences also on a methodological point of view: in addition to encouraging the adoption of a more holistic, systemic approach, aimed at breaking down barriers between disciplines and fields of study (not only between the social sciences themselves, such as sociology, economics, psychology, etc., but also between social and natural sciences), it also contributed to promote the adoption of tools, such as agent-based simulations (see further) and complex networks analysis, which allow to study social interactions in a more realistic way, considering both qualitative and quantitative aspects of making a research at the same time.

2.2 Computational empiricism

The second "mainstay" of our reflection is provided by Paul Humphreys (2004), philosopher of science and author of important contributions to the epistemology of emergence, computational science, empiricism, and realism. In a work published some twenty years ago but still extremely relevant today, Humphreys puts forward a vision of the role of computation within scientific practice that, we contend, offers a useful conceptual grounding for the argument we are developing around the use of computer simulation in socio-legal research.

The focal point of his analysis is what Humphreys defines as "computational empiricism," an epistemological perspective that assigns to computation broadly understood the task of supporting the empirical investigation of reality. For Humphreys — who recalls other cases in which science has been enhanced by technology, citing the role played by telescopes and microscopes in the study of the physical world — computation is an instrument whose ability to enhance our understanding of facts and to shift the "boundaries between what is empirically observable and what is not" must be understood and valued. "The dividing line between the observable and the unobservable," in his words, "is not fixed but is moving, with the trajectory being determined in part by technological advances." The thesis is developed around two concepts that are worth recalling: "epistemic augmentation" and "empirical extension".

Computation acts primarily as an "epistemic enhancer": it amplifies our memory, calculation, and inference capabilities, taking them beyond the limits of human cognition. Computational methods allow us to tackle more complex and larger-scale problems, enabling knowledge extraction from data, pattern recognition, and predictive analysis in contexts where the volume of information to be processed would largely exceed our cognitive abilities. However, the *epistemic enhancement*, the contribution of computation to science is not limited to speeding up and refining data analysis. As Humphreys points out, it can also enter into the formulation and validation of theoretical hypotheses, opening up entirely new horizons to scientific inquiry. In this regard, Paul Humphreys' main reference — reflecting a long-standing tradition (Simon 2019) — is computer simulation. As a matter of fact, a simulation model is a theory made executable, a theory embodied in an artifact (Parisi 2010). that can be run and manipulated enabling what-if and counterfactual experiments and the exploration of possible worlds by sweeping rules, interaction structures, and initial conditions to map dynamic regimes and regions of parameter space otherwise out of reach (Winsberg 2019).

The second concept developed by Humphreys is that of "empirical extension," an expression he uses to capture a point with far-reaching implications for the argument we develop here: in addition to increasing our cognitive abilities, computation can play another scientifically crucial role, namely, expanding the horizon of phenomena that can be observed, measured, and controlled experimentally. The examples cited by Humphreys span different domains of science. In astrophysics, just to cite one scenario, large-scale computational processing of signals from space allows us not only to isolate very weak signals from background noise — for example, gravitational waves produced by the coalescence of black holes or neutron stars — but also to extract information from those signals, as in the image of a black hole's event horizon obtained only a few years ago.

A similar argument can be made today about the social sciences: the application of sentiment and social media analysis techniques to large text corpora and the digital traces of our online interactions allows for the observation and measurement, on a planetary scale, of emotional states, cultural dynamics, and political orientations that would otherwise never have been accessible. In light of this, Humphreys's position is clear: to the extent that it extends the range of observable and measurable facts, computation undoubtedly represents an extension of the domain of the empirical. Humphreys further suggests that this computational expansion of the empirical domain has also profound implications for the blossoming of theoretical science. As computational tools make more dimensions of reality tractable and measurable, they simultaneously open new avenues for hypothesis generation and theory refinement. This shift is particularly significant in disciplines where empirical data collection is foundational.

Seen as a whole, the philosophical implications of Humphreys' analysis extend beyond practical advantages and deserve attention. His work invites us to reconsider the essence of scientific inquiry, urging us to view computation not as a mere accessory but as a driver of a deep change in how we conceive and structure — even mentally — the production of knowledge.

The stakes are high. We live in an era in which, when combined with ever-increasing computational power, the data deluge seems to herald — borrowing Chris Anderson's (2008) provocative metaphor — "the end of theory": a set of complex scientific and cultural shifts (namely, the prioritization of correlation over mechanism, the incursion of automation into hypothesis formation, and the eclipse of explanation by prediction) that warrant careful scrutiny. These shifts are particularly delicate in the legal domain, where, seduced by predictive analytics and LLMs, and despite a number of notable contributions — some explicitly involving ABM (e.g., Schwartz 2020, Benthall and Strandburg 2021, Grim *et al.* 2024) and others reflecting more broadly on the computational turn in law (Luckner and Fikfak 2021, Lie and Langford 2024) —, we have succumbed to a view in which computation is primarily a practical tool, a means, for example, of making predictions (Lettieri 2020b), rather than a tool that enables new forms of empirical exploration of socio-legal reality (Lettieri and Pluchino 2024).

2.3 Computational social sciences

The third and final pillar of our framework is Computational Social Sciences (CSS), an interdisciplinary field drawing on computer science, the social sciences, and complexity theory, which, in our view, can be seen as turning "computational empiricism" into concrete methods to observe, model, and experimentally probe social phenomena. CSS provides tools to discover patterns, behaviors and hidden interactions within societies, by utilizing the large amounts of digital data produced by the human activity online, such as social media interactions or economic transactions. These techniques allow researchers to go beyond the conventional qualitative methods, because they offer some good paradigms to clarify, comprehend and sometimes anticipate dynamic social processes in innovative ways.

Over the last ten years, CSS has seen a sharp increase in growth thanks to improvements in computing power, the greater accessibility of detailed datasets and the creation of advanced analytical tools. This unexpected development is leading to a change in the social sciences (in general Wallach 2018, and more specifically in sociology, Macy and Willer 2002, Keuschnigg *et al.* 2018, Flache *et al.* 2022), which are approaching a similar level of quantitative precision and accumulated knowledge to that of the natural sciences, such as physics or biology. Researching society using computational methods has provided a great opportunity for researchers from various fields like physics, economics, cognitive science and behavioral science, to collaborate. This meeting is focused on creating new and forward-thinking models of social situations that were not easily studied with traditional social science methods, and offering also more than just a few ideas in favor of the interdisciplinary approach in science.

At the core of this change is the two-fold function performed by data and computational modeling. Researchers use data from ICTs to track various individual and collective behaviors such as movement patterns, communication trends and decision-making processes. Conversely, the chance to make use of computational power and sophisticated tools, like machine learning and agent-based simulations, supports the development of both explanatory and predictive models of society that often appear to be very useful in studying a lot of heterogeneous social facts.

From a methodological point of view, CSSs refer to a well-defined and diverse background that spans from several key research techniques to specialized subfields (Lazer *et al.* 2009, Conte *et al.* 2012). As outlined by Cioffi-Revilla (2010, 2014), these methodologies could be used to stand for the systematic computational analysis of social systems. Apart from techniques such as visualization, visual analytics and sonification, which could become separate research methods in the future, he distinguishes five main methods:

- *Automatic Information Extraction*: involves the use of methods in natural language processing (NLP) and machine learning, which are utilized for the processing and analysis of unstructured data, like text or multimedia content, to facilitate the detection of trends, subjects and emotions within huge datasets.
- *Complexity-Theoretic Modeling*: inspired by complexity science, this method is here to consider social systems as adaptive, emergent and non-linear systems, emphasizing interactions and feedback mechanisms representations over stagnant ones.
- *Social Network Analysis (SNA)*: SNA is a tool that looks at how relationships, within and among social groups, are organized and change over time. It provides interesting insights, in the form of graph theory, into concepts like influence, spread of information and birth and stabilization of communities.
- *Geographic Information Systems (GIS)*: GIS is a tool with the ability to analyze spatial data and allows for the merging of geographic information with social factors, in order to examine how human behavior is distributed throughout different locations.
- *Social Simulation Models*: Simulation methods, like agent-based and system dynamics models, are employed to mimic and investigate the dynamics of social systems. They offer virtual settings for testing scientific hypotheses and/or policy interventions.

Although these methods are commonly utilized separately, combining them could greatly enhance progress in the field. For instance, when network analysis is combined with GIS, it enables the examination of spatially embedded social networks, and the merging of social simulations with complexity-theoretic models allows for a more thorough investigation of emergent phenomena. Nevertheless, there is still a significant opportunity for creativity, as numerous methodological combinations and applications are yet to be investigated.

In the future, CSS is supposed to have a crucial impact on facing urgent social issues. Primarily, in social research, which we think should precede any type of legislative intervention one wants to try to implement, it could be pivotal because in addition to exploiting new data sources, this new approach also (and perhaps above all) aims to develop new theories of human behavior (see Edelmann *et al.* 2020) to gain a deeper and more nuanced understanding of it, both in its individual and collective dimension, thus producing a new type of knowledge that could be used to develop more 'human-suited' policies. The role of CSS in policy-making, in fact, could turn out to be indispensable, especially if we want to embark on big projects such as facing climate change or modifying urban configurations: CSS makes it possible thanks to its ability to offer practical insights on complex and interconnected problems. As the field grows older, its ability to combine different disciplines and different methodologies will probably keep leading to today unexpectable breakthroughs in our comprehension of the dynamics of social systems.

3. Artificial societies: social science from the bottom up

As we anticipated above, social simulations, like system dynamics and agent-based models (ABMs), have become valuable instruments for reproducing, and so grasping and (occasionally) foretelling, complex social systems' behaviours. These computational methods allow scientists to develop models that somehow realistically simulate real-life processes and interactions, and so doing they provide insights that are typically beyond the capabilities of traditional methods.

While *System Dynamics* models emphasize aggregate variables and feedback loops, ABMs offer a more granular perspective, because they can simulate the behavior of individual agents interacting within a specified environment. This unusual bottom-up approach makes us attend to the emergence of intricate macro-level behaviors from relatively simple micro-level rules.

ABMs actually work by creating a sort of "*in nuce* society", in which agents — which can stand in for social actors like people, families, organizations or even nation-states — interact without centralized authority and in accordance with preset rules. These agents may be typically heterogeneous, possessing varying attributes, goals and behavioral rules, which may include cognitive capabilities, such as learning, memory and decision-making, and adaptive skills, based on their interactions with the environment and observations of others (see Figure 1). Such heterogeneity allows ABMs to better capture the diversity and complexity of real-world systems.

A clear merit of ABMs, as we anticipated above, lies in their ability to show how macro-level outcomes, often unexpected or counterintuitive, emerge from micro-level processes. This feature makes ABMs particularly well-suited for exploring minimal conditions, or typical moments, under which specific social phenomena occur: in fact, by adjusting agent rules or environmental parameters, researchers can test the robustness of theoretical assumptions, and so identify hand in hand the mechanisms driving emergent behaviors.

The relevance of ABMs in (social) science has effectively been widely recognized among the academic community. Conte and Paolucci (2014) identify three primary functions of ABMs, which can be used at the same time as:

- Operational platforms for transforming theoretical frameworks into formalized, testable hypotheses;
- Experimental laboratories for systematically testing theories and exploring counterfactual scenarios;
- Multi-layered environments for observing emergent effects at multiple levels of analysis.

Similarly, epidemiologist Epstein (2008) in a famous work titled *Why model?,* highlighted the generative potential of ABMs and underscored and emphasized their role in both explanation and theory building. In fact, he contended that by simulating the micro-level mechanisms that give rise to these patterns, ABMs allow researchers to replicate and monitor expanding macro-level patterns, in contrast to traditional approaches that mainly concentrate on prediction. Because of this "generative sufficiency", researchers are able to follow the complete causal chain, providing a deeper comprehension of the mechanisms underlying intricate occurrences.

Applications of ABMs, being a very versatile tool, involve a broad array of domains. For instance, ABMs have been used in public health to help model the spread of infectious diseases (Eubank *et al.* 2004), among other things, allowing for more effective interventions, and in urban planning to predict traffic patterns and optimize infrastructure design. ABMs have also provided insight into systemic risks and market dynamics, including those seen during financial crises, in the fields of economics and finance. The diffusion of information in online networks (Rand *et al*. 2015), the evolution of social norms (Savarimuthu and Cranefield 2011), and the emergence of political movements (Epstein 2002) are additional social areas where ABMs have provided significant insights.

In conclusion, ABMs could represent a very transformative approach in social science research, bridging the micro-macro divide and offering a unique lens through which explore the intricacies of human behavior and social dynamics. By enabling researchers to observe, test and refine theoretical models in a controlled yet dynamic environment, ABMs really contribute to a deeper and more nuanced understanding of the complex systems in which we are, consciously or unconsciously, diving.

In discussing various modeling approaches, we anticipate that, upon reviewing the literature on agent-based models (both general and norm-related), readers will encounter a range of model types and architectures — such as neural networks, genetic algorithms and belief-desire-intention (BDI) frameworks, among others.

Each of these modeling approaches is rooted in different scientific premises, perspectives on reality and technical components. It is important to note that addressing the transferability of one modeling solution to another in abstract terms is not feasible; the selection of a model depends on specific research questions, as well as the conceptual view of reality that underlies the model itself. From the outset, then, it is crucial to acknowledge the plurality of modeling solutions, recognizing the need to make informed choices based on the research questions that from time to time come into relief.

Choosing one type of model over another — for example, a genetic algorithm-based model instead of a neural network — not only affects implementation, but also has important implications for the understanding of the phenomenon which is being represented. The choice of the model influences the metaphorical and scientific framing of the subject, potentially impacting outcomes. This observation is not intended to introduce purely technical distinctions relevant only to computational social science or computer science, but to underscore the scientific and semantic significance of model selection. Indeed, the chosen model type reflects particular perspectives on the phenomenon under study and has implications for the model's expressive power and the nature of the results obtained.

FIGURE 1

AGENT-BASED MODEL

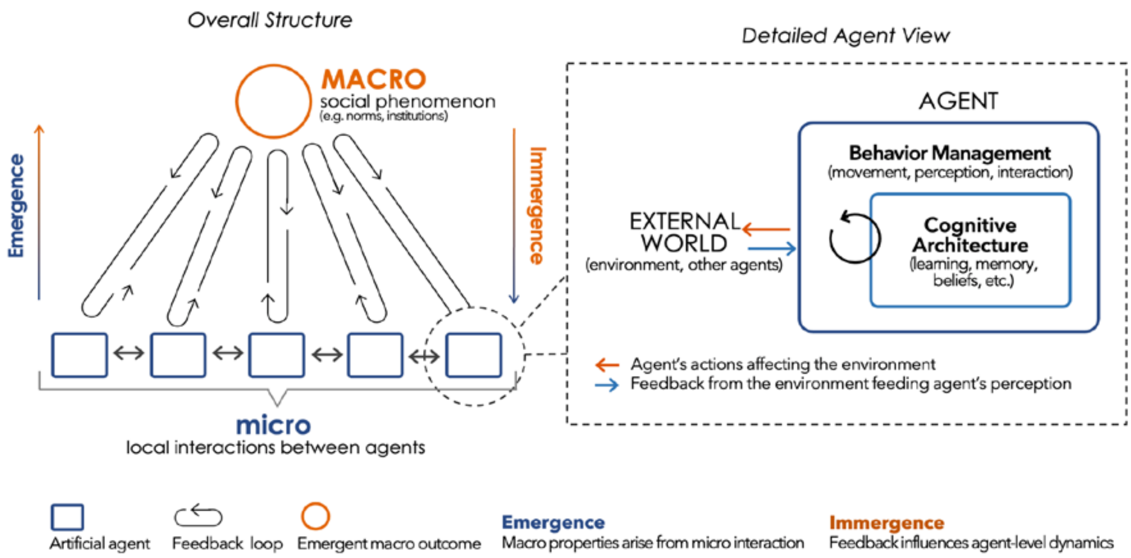

Figure 1. Abstract structure of an agent-based simulation modeling the interplay between the micro cognitive level and the macro level of social dynamics.

4. ABM at the intersection of cognition, society, and law: Some experiences

This section offers an overview of simulation models that relate in various ways to the legal world. Our aim, obviously, is not to be exhaustive; rather, we seek to offer a glimpse into the current possibilities for studying the legal phenomenon, broadly understood, through new available tools. Thus, the objective is not to comprehensively catalog the existing body of work in social simulation specific to norms but rather to provide points of reflection for legal scholars from fields such as computational social sciences and simulation studies.

The connection between computational social sciences (CSS), particularly agent-based modeling (ABM), and law — including cognitive aspects — can be explored through examples such as Conte *et al.*'s *Minding Norms* (2014), Xenitidou and Edmond's (eds.) *The Complexity of Social Norms* (2014), and Elsenbroich and Gilbert's *Modeling Norms* (2014).

To illustrate the proximity between the use of simulation methods, especially agent-based simulations, and topics relevant to law, we cite several studies that demonstrate this trend. Notably, these examples often come from fields outside of legal philosophy, legal sociology or traditional legal studies. As we will see, nearly all the cited examples, in varying degrees of abstraction, involve cognition — an element that naturally emerges in agent-based simulations. This underscores the relevance of individual decision-making, and by extension cognition, across models, regardless of their specific design.

4.1. Game theoretical models of social norms and social cooperation

One of the most well-known applications of game theory to the social sphere is Robert Axelrod's 1986 model on the evolution of norms (Axelrod 1986). Building on his well-known book *The Evolution of Cooperation* (1984), this study examined the factors that could promote cooperation and social order in decentralized and self-interested systems. Axelrod's first research concentrated on the iterated Prisoner's Dilemma game, a famous game theoretic paradox according to which two individuals acting in their own self-interests do not produce the optimal outcome, that over the years has become a fundamental means for comprehending strategic interactions. During his study, Axelrod asked well-known game theorists to provide tactics for a computer-run competition in which these strategies faced off in repeated matches of the Prisoner's Dilemma.

The tournament outcomes demonstrated the surprising effectiveness of the "TIT-for-TAT" approach, which involves cooperating initially and then imitating the other player's last move. This approach, primarily collaborative but willing to retaliate as needed, surpassed more complicated options. The success of the project proved that cooperation can exist among self-interested agents striving to maximize their benefits. Axelrod's research showed that cooperation could arise naturally without the need for central enforcement if certain conditions were met, like anticipating future interactions, remembering past behaviors and having a stable environment.

Nonetheless, Axelrod admitted the constraints of his original model. The tournament's interactions were limited to just two players, making it difficult to apply his conclusions to more intricate social systems. Real-life situations frequently include environments with multiple agents, where the decisions made by individuals can impact larger networks in a domino effect. Acknowledging this, Axelrod broadened his studies to investigate the development and reinforcement of social norms, which play a vital role in maintaining cooperation in bigger and more interconnected communities.

In his subsequent work, Axelrod provided a behavioral definition of norms: a norm exists when most individuals in a group behave in a particular way, and those who deviate from this behavior face social penalties. Norms are informal frameworks designed to regulate behavior, reduce conflict, and promote the welfare of a group. However, in egoistic settings without a centralized authority, it could be challenging to enforce regulations. People may be discouraged from acting as enforcers due to the financial and potential recrimination costs of punishing norm breakers. This creates a dilemma: without consistent enforcement, norms are vulnerable to erosion and this could lead to the breakdown of the cooperative structures.

To tackle this problem, Axelrod created a simulation model that experienced a new method to maintain cooperation. In this model, agents were supposed to punish not only those who broke norms, but also those who didn't uphold them. This mechanism of "second-order punishment" was significant, he discovered, in maintaining the durability of cooperative behavior throughout time. By imposing penalties on individuals who fail to fulfill their enforcement duties, the model established a situation where following norms and enforcing them became interconnected steps.

Axelrod's approach marked a significant departure from the presumptions of perfect rationality found in traditional game theory, and not only. Instead of assuming that agents have all the information they need to instantaneously and logically optimize their plans, his method included an evolutionary process. The tactics' gradual modification and social learning mirrored the collective experience of future generations. This evolutionary perspective allowed for a more nuanced understanding of how cooperation and norms could emerge in complex, distributed systems.

Axelrod's research has implications that go beyond just theoretical insights. His theories have been utilized in various fields, such as political science, sociology and economics, to clarify occurrences like international agreements, issues with collective action and the preservation of social harmony in societies.

4.2 Underpinnings of normative cognition

While Axelrod's seminal work has been instrumental in illuminating the dynamics underlying cooperation and coordination in human societies, it falls short in addressing key aspects of the emergence, evolution and circulation of social norms. Axelrod's game-theoretic simulations have laid a foundation for exploring behavioral patterns in structured interactions, but they lack the explanatory depth to capture the cognitive and socio-psychological processes inherent in normative phenomena.

In particular, game-theory-based models often ignore the internal mental processes according to which norms are represented, reasoned about and acted upon, in favor of modeling norms as external restrictions enforced through conformity dynamics or sanction mechanisms. In order to overcome these constraints, studies led by Cristiano Castelfranchi and Rosaria Conte (2006) have established a cognitive method for examining norms in simulations, providing fresh perspectives on how they form and operate. Their theoretical contributions, when combined with computational modeling, have created a robust framework for analyzing a wide range of social, legal and ethical-religious standards. This perspective marks a paradigm shift in the study of norms as it moves beyond crude notions of behavioral regularities toward a more complex understanding of norms as socio-cognitive constructions.

Developing a general theory of the cognitive processes underlying norms not only offers significant advances in understanding normative behavior but also enables simulations of interactions between social and legal norms, with applications ranging from sociology and psychology to computational law and policy design.

As we anticipated, Conte and Castelfranchi (2006) challenged the conventional view of social norms as patterns of behavior upheld by obedience or fear of punishment. According to them, this perspective misrepresents a number of ideas, including the difference between autonomous norm adoption and forced compliance, behavioral regularities and actual normative behaviors, and internal drives against external constraints. Their approach reinterprets norms as cognitive artifacts and holds that a normative conduct is the result of certain mental processes. These mechanisms, which include internal representation of norms and ability to reason about them, allow agents to consciously decide whether to adhere to or deviate from standards. As a result of this process, norms are represented as complex socio-cognitive objects presenting two parts: an external, social dimension that manifests as behavioral standards compliance, and an interior cognitive component that comprises the mental processes that support normative judgments. This viewpoint assumes that a norm is only considered established when people freely decide to adhere to it after becoming aware of its validity.

At the core of this mental representation of norms, Conte and Castelfranchi identify three key cognitive elements: (i) normative beliefs, referring to an agent's belief about the existence or validity of a norm; (ii) normative goals, which pertains to the agent's motivation to achieve the objectives promoted by the norm; and (iii) normative intentions, which involves the deliberate commitment to act in accordance with the norm. These components form together a "cognitive architecture" that somehow mimics the complex interactions that in human normative behavior take place between motivation, beliefs and volition. Heading in this direction, this approach overcomes the limitations of previous ABM models, where such cognitive intricacy was often overlooked, providing a more sophisticated lens through which to examine social facts including the interactions between social and legal norms.

Over the years, the perspective has led to the development of increasingly sophisticated cognitive architectures of normative reasoning and action (Andrighetto *et al.* 2007, 2010), such as those designed within the European project on normative innovation dynamics (EMIL), mental representations designed to enable autonomous, intelligent software agents to adapt their behavior to emerging norms in artificial societies. By integrating the cognitive components of normative beliefs, objectives and intentions, the architecture enables agents to dynamically evaluate norms, reason about their significance and decide whether to internalize or reject them. Importantly, this approach incorporates and extends the "Beliefs, Desires, Intentions" (BDI) paradigm (Boella and van der Torre 2004), a widely used technique for modeling cognitive processes in multi-agent systems.

One significant evolution of the BDI paradigm in this context is the explicit inclusion of an "obligations" component. Instead of depending solely on beliefs or intentions, this invention allows agents to identify and consider normative constraints while making judgments. One significant problem with current models is that they frequently do not give agents the ability to determine whether or not external inputs, at a first "sight", should be regarded as norms. When examining the internalization of norms in complex situations where several, potentially competing norms coexist, this mistake undermines the theoretical validity of such models.

The ability to identify and assimilate rules becomes particularly crucial in circumstances when social and legal standards intersect. Unlike merely social standards, legal norms are institutionalized and typically codified, making it more difficult to accept and represent them cognitively. In these circumstances, individuals must choose whether an external instruction is a legitimate norm in the first place in addition to whether to abide by a specific rule. An understanding of this divergence is necessary to comprehend the dynamics of normative pluralism, where conflicting norms may live within the same cultural setting, and to look at how people resolve these conflicts. Findings from this area of research have significant implications for both socio-cognitive theory and legal studies, particularly when it comes to analyzing the mechanics of innovation, resistance and norm conformity.

4.3. Damaging behaviours and the effects of sanctions

Also the study of law has been, throughout its history, impacted by the traditional Newtonian idea of linear and proportionate reactions to stimuli. In fact, somehow according to this school of thought, people act logically and consider the benefits and drawbacks of their decisions, hence applying sanctions to discourage undesirable behavior appears to be the right and desirable solution. This concept is central to the conventional deterrence theory, which maintains that punishment reduces misbehavior by providing a rational assessment of risk and reward. However, studies in behavioral science have begun to challenge this idea of perfect reason. For instance, Daniel Kahneman's seminal work on cognitive biases shows how heuristic and emotional factors frequently affect human decision-making, which normally deviates from logical models. These results raise questions about the overall effectiveness of punishment-based behavioral control strategies.

Even if we stand for more traditional penal theories, it is anyway somehow obvious that there are inherent issues with punitive systems. How someone responds to a punishment can be greatly influenced by their personality, living situation and belief in the punishment's fairness. Punitive actions could exacerbate perceptions of injustice or have unexpected consequences, such as disobedience or the emergence of deviant subcultures, which could exacerbate instability rather than advance social harmony.

Aware criminal policies require an effective understanding of the social context in which individuals merge. Humans are social beings by nature, thus social behaviors, cultural norms and peer pressure all have a big influence on how people act. Ignoring these social elements often leads to punitive, incentive-based, or behavioral nudge-based techniques not producing the desired outcomes. For example, laws that ignore entrenched social norms or the dynamics of social networks may fail to produce meaningful or sustained behavioral change.

Lettieri and Parisi (2013), placing themselves in this vision, in 2013 used an ABM to simulate a society of 200 agents, each characterized by a propensity for either honest (H) or dishonest (DH) behavior. Honest agents worked largely for their own benefit without hurting others, whilst dishonest agents tried to exploit others for their own gain. Given that agents with higher levels of well-being were more likely to pass on their behavioral patterns to their progeny, the model established an evolutionary feedback loop. To evaluate the long-term effects of punitive measures on the prevalence of dishonesty, DH agents were randomly exposed to penalties of different intensities over 30 generations.

The results demonstrated that only when there was a 100% chance of punishment did dishonest behavior cease. However, this enormous government investment on punitive measures is not only unsustainable, but it is also impractical in real-world scenarios. More importantly, the model showed that it was much more effective at reducing dishonesty when it was feasible to establish a setting where moral behavior led to a happy life, as evidenced by factors like opportunities for personal fulfillment, social rewards or financial stability. In scenarios where honest agents thrived, the prevalence of DH behavior declined even when the frequency or severity of punishment was relatively low.

A subsequent experiment within the same model explored the role of sub-communities, analogous to "criminal subcultures", in sustaining dishonest behavior. These sub-communities were essentially insulated networks of deviance made up of groups of DH agents who mostly interacted and shared knowledge with one another. The findings demonstrated the tenacity of these subcultures, particularly in contemporary settings when communication technology enables interactions across national borders. It seems clear that if these networks continue to promote and facilitate unethical behavior, the effectiveness of the current regulatory framework would be compromised.

All these results demonstrate the need for an all-encompassing behavioral management approach that is capable of taking social, legal and cultural aspects into account. Punitive measures alone are insufficient in densely populated locations where deviant subcultures are robust and flexible. In order to achieve long-term compliance and social cohesion, strategies that capitalize on the benefits of pro-social behavior — such as building trust, pursuing justice and eliminating systemic inequalities — may prove more successful. In this perspective, behavioral science and computer modeling insights can help policymakers create more complex, context-sensitive regulatory frameworks that balance positive reward and deterrence.

4.4. Social dilemmas

In 1968, the famous ecologist Garrett Hardin coined the expression "Tragedy of the Commons" (ToC) so qualifying the social conundrum that arises when people misuse common resources out of self-interest, ultimately hurting society as a whole. Later, this idea developed into a fundamental framework for researching relevant topics in a variety of fields, such as economics, social behavior and environmental management. Through the example of how unchecked use of shared resources can lead to their depletion and degradation, the ToC illustrates the fundamental conflict between human reason and the welfare of society in the absence of controlling authorities or cooperative norms.

To study the dynamics of the ToC, Lettieri and Vestoso (2015) used an agent-based simulation with 100 autonomous agents operating in a tokenized environment. Each agent's primary objective was to collect tokens; the more tokens they acquired, the more fit they were. Agents with higher fitness were more likely to reproduce and pass on their genetic traits to their offspring. In rare cases, spontaneous mutations during reproduction increased population diversity and progeny fitness. Evolutionary dynamics are reflected in this approach since features that improve token collection are selected for across many generations.

However, the simulation introduced a critical trade-off: agents' movement speed was tied to pollution. Faster-moving agents were able to collect more tokens but at the cost of generating greater pollution. The environmental degradation caused by pollution reduced the overall fitness of all agents, including those that contributed minimally. This created a core dilemma: agents needed to balance the short-term advantage of increasing token collection against the long-term disadvantage of environmental degradation, which diminished the carrying capacity of the system.

The interactions between the agents showed a well-known free-rider issue. Faster agents that nearly ignored environmental costs in favor of short-term profit maximization outperformed slower agents who chose to reduce pollution and preserve the environment. The devastating impact of the unrestricted resource extraction was demonstrated by the fact that all agents, regardless of their method, experienced a decline in fitness as the environment became more contaminated.

To explore potential solutions, the study introduced sanctions targeting excessive movement speeds, with penalties applied to agents' fitness in proportion to the pollution they caused. The findings showed that the timing and design of these sanctions had a major impact on their efficacy. Delayed fines had no appreciable impact on agent behavior since they were only implemented after significant environmental harm had already been done. Players' repeated insistence on putting short-term financial gain ahead of long-term benefits exacerbated environmental devastation.

Conversely, real-time fines that were suitable for the fitness levels of the agents were more effective in encouraging cooperative behavior. These timely and appropriate sanctions created a direct feedback loop between individual acts and their outcomes, incentivizing agents to slow down, so reducing pollution. Interestingly, even when fines were given gradually, agents were still able to detect a direct association between their behavior and fitness results, showing that the fines were proportionate enough to promote more sustainable behavior.

In conclusion, results from the research highlight the vital role of developing solutions that maintain a balance between the greater good of society at large and the rewards of the individual. Authors further investigate the link between individual actions and group sustainability by stressing the value of time in punishing and feedback loops in creating collaborative dynamics. The findings demonstrate the potential for certain strategies, such enforcing appropriate sanctions in real time to mitigate damaging (ecological) behaviours. In practical contexts such as resource management, environmental policy and public health, this information may be useful in addressing relevant problems.

4.5. Study of crime

The study of crime represents another domain in which social simulation is emerging as a valuable research tool. On the other hand, over the last decade, the use of computational methods to gain new perspectives on the complex social dimension of crime has grown significantly, both in terms of relevance and heterogeneity in areas that span from pure criminology to computational social science (Neumann and Elsenbroich 2017, Elsenbroich *et al.* 2017, Lettieri *et al.* 2017, Gerritsen and Elffers 2020).

The reason is clear: a considerable number of illegal activities that cause serious public concern, from drug trafficking to cybercrime and terrorism, originate within the social fabric, in an intricate dynamic web of individuals and relationships whose evolution plays a key role in the emergence or containment of criminal behaviors. In this context, understanding the genesis and evolution of crime calls for multidisciplinary approaches that combine theoretical modelling, empirical data, and computational tools to capture the dynamic nature of social and criminal processes.

A notably striking example of works heading in this direction can be found in a computational model created by Székely, Nardin, and Andrighetto (2018), where the authors simulate mafia extortion dynamics in a neighborhood designed to mirror the situation in Palermo, Italy. This agent-based model includes essential participants, such as entrepreneurs, customers, the State, mafia figures, and a non-governmental organization (NGO) that opposes the mafia. Every actor has particular decision-making processes and objectives: business owners face the choice of complying with mafia demands through “protection” payments, consumers select shopping locations influenced by perceived safety and social norms, the State takes action by probing extortion cases and arresting mafia individuals, while the NGO aims to foster non-compliance with mafia demands and nurture anti-mafia values in the community.

The model assessed three intervention strategies to decrease mafia extortion and related violence: a legal method, a social approach, and a hybrid strategy. The legal strategy concentrated mainly on law enforcement actions, including enhancing investigations and boosting the number of arrests of mafia affiliates. Although this approach successfully captured offenders, it demonstrated minimal effect on decreasing lasting adherence to mafia demands from business proprietors. In contrast, the social approach aimed to impact community norms and behaviors by encouraging collective opposition to extortion and advocating anti-mafia principles through public awareness efforts and the initiatives of the NGO. This strategy should be shunned: despite its minor benefits, it significantly increases punishment and aggression against the public. Finally, the combined method incorporated legal and social measures, utilizing the advantages of each approach. Findings from the simulation showed that the integrated approach was the most successful in decreasing extortion and violence, as it not only diminished the mafia’s operational strength but also undermined its social acceptance in the community.

The implications of this study extend beyond extortion by the mafia. Such models provide a robust framework for examining systemic crimes, such as organized cybercrime, human trafficking, and corruption, by integrating cognitive, social, and institutional elements. As demonstrated in this work, computational criminology gives academics useful instruments for forecasting crime and confirming theoretical theories. Agent-based simulations reduce the hazards and moral conundrums associated with real-world trials by allowing researchers to test intervention tactics in virtual environments. These methods also make it possible to study new phenomena, including feedback loops and tipping points, which are crucial for understanding how policy interventions affect criminal systems over the long run.

The application of computer models to criminology is a significant development, which helps to support the importance of interdisciplinary collaboration in (also social) science. Researchers can better address the complexity of crime as a societal issue by combining data from political science, psychology, and sociology using computer methods, and communities may become safer and more resilient if this technique is used to direct more effective and long-lasting crime prevention programs.

5. ABM: All that glitters is not gold

At the end of our review, it makes sense to formulate some closing remarks to take stock of what has been said and foster reflection on the scope and potential impact of agent-based models in socio-legal studies. Taken as a whole, the works outlined in the preceding sections seem to provide sufficient grounds to view agent-based simulations as a methodology worthy of attention by anyone open to exploring new approaches to the study of socio-legal phenomena and their connections to cognitive processes.

Such a claim, however, deserves to be explored in some detail. In the following, we present some arguments that support our assertion while also raising some critical issues to which attention should be paid in the future. To improve readability and encourage engagement with the issues we raise, we present our thoughts in the form of a structured list designed to facilitate interpretation and foster a clearer understanding of the topics under discussion.

5.1. ABM as gateway to complexity theory in socio-legal research

The first consideration relates to the theoretical framework of complexity. Over the years, as highlighted above, the topic has gained increasing attention in the social sciences, with a growing number of authors explicitly drawing on complexity theory to conceptualize and analyze social dynamics. Despite many insightful and intellectually stimulating analyses (see, just by way of example, Innerarity 2025, however, the vast majority of works published in this field has refrained from engaging practically with the design and adoption of research methodologies capable of operationalizing the fundamental tenets of complexity theory.

In such a scenario, agent-based models represent a promising tool even considering the limitations we will soon dwell on. With their ability to support the exploration of emergent behaviors, adaptive dynamics, and non-linear interactions, they stand out as a promising means to bridge the gap between purely theoretical discourses and the actual investigation of complexity in the social sciences, paving the way not only for novel developments in sociology (Squazzoni 2012) but in the exploration of any kind of social fact, including those falling into the scope of legal science.

5.2. ABM as empirical enhancement of legal research

As a matter of fact, agent-based models could potentially complement methodologies already adopted in any empirically-oriented area of legal research. This makes sense in particular for the sociology of law, whose main goal is to understand how law emerges, is internalized, and operates by examining it, beyond formal rules, as a living phenomenon resulting from concrete social interactions. The same could be said, however, for many other research fields spanning from *Law and Economics* to the anthropology of law or *Empirical Legal Studies*. *Law and Economics* (Shavell 2004) could, for instance, utilize agent-based models to explore how regulatory frameworks influence market behaviors or how economic incentives interact with legal norms in complex adaptive systems. Similarly, in legal anthropology, agent-based models might help investigate how informal legal orders emerge and interact with formal legal systems — simulating processes of norm diffusion and the co-evolution of plural legal orders (Moore 2000). In the context of *Empirical Legal Studies*, ABM offers a novel methodological approach that could complement traditional statistical and case-based analyses by enabling controlled simulations of legal decision-making, institutional dynamics, and enforcement strategies over time (Cane and Kritzer 2010).

5.3. ABM as an interdisciplinary research platform

Another feature of ABM is their capacity to act as a bridge across disciplines, serving as a novel tool for interdisciplinary integration. This stems from an essential property of simulation models worth highlighting: the design of agents and the simulation environment can integrate insights, theories, and empirical evidence from diverse fields, incorporating them into a single model that describes the target phenomenon.

A notable example of this can be found in the agent-based model developed by Axtell *et al.* (2002) to study the collapse of the Anasazi civilization. Highly regarded as a success story for the accuracy of its retrodictions — specifically, its ability to reproduce historical population fluctuations, settlement patterns, and the socio-environmental factors leading to the civilization's decline — this study combined archaeological, environmental, and social data to simulate population dynamics and settlement patterns, offering a tangible demonstration of how ABM can bridge disciplines by integrating diverse empirical sources into a unified computational framework. Today, this capability allows scholars to investigate potentially any social process in ways that traditional research methods alone cannot achieve, shedding new light on the analysis of complex phenomena that no single discipline can fully capture in its entirety. In all such contexts, agent-based models provide researchers with a platform for crafting hypotheses and theories that transcend disciplinary boundaries, opening new pathways for a deeper understanding of the social world.

The interplay between cognition, social norms, and legal systems fits perfectly within this framework: it calls for a synthesis of cognitive science, social theory, and legal analysis. This capacity for integration positions simulation as a critical resource for addressing the challenges in the study of the legal universe, from the purely theoretical to the more application-oriented, such as the design of more empirically and scientifically grounded policy-making (Sileno *et al.* 2021, 2022).

Of course, recognizing these strengths does not imply an uncritical endorsement of agent-based simulations. Many conditions must be met for simulations to translate into an actual advantage for law, sociology of law, and the study of the role played by human cognition in shaping legal experience. It is worth then briefly dwelling on some critical aspects, not only to acknowledge the key challenges at stake but also to reflect on possible responses to them.

5.4. The risk of computational reductionism and fallacy

One of the concerns most frequently voiced when discussing the potential adoption of computational methods in social science research relates to the risk of new forms of reductionism, i.e. the risk that quantitative approaches lead to overly simplistic representations of the world, ultimately steering us away from understanding of reality. The concern is well-founded and should not be dismissed as the skepticism that usually characterizes those a priori opposed to innovation or technology. A look at recent history and the case of Big Data serves as a reminder: if left unchecked, data mining (Kitchin 2014, O'Neil 2017) can easily put before our eyes fallacious representations of reality, false evidence made all the more insidious by the sort of uncritical confidence that often characterizes our relationship with the results produced by computational heuristics or automatic information processing. As Benjamin Bratton aptly puts it (Bratton 2016), computers can function both as "tools of perception" and "tools of blindness".

A similar issue arises with simulations. Their impact on science is undeniable (Winsberg 2019), but they also raise the issue of the relationship between computational abstraction and reality (Anzola 2021, Anzola and García-Díaz 2023). Simulations rely on operational models of reality designed for execution within a machine. This process necessitates the translation of target phenomena into computable terms, employing abstractions and simplifications that — regardless of other issues such as software implementation or the execution of experiments — can easily cause the model to diverge from the complexity of the phenomena it seeks to represent.

The challenge becomes even more critical when dealing with complex systems where — as Stuart Kauffman repeatedly states in relation to the biosphere (Kauffman 1995, Longo *et al.* 2012) and economics (Koppl *et al.* 2015), there can be no "entailing laws," but only "enabling laws": faced with complexity, science cannot yield deterministic answers but merely outline spaces of possibility, within which different trajectories might unfold. All this has clear implications for the epistemic value of simulations: when the *explanandum* is a complex social construct — such as a norm or a socio-cognitive dynamic — the risk of oversimplification is concrete.

6. Closing remarks: Preparing the vessels

The response to all the issues above unfolds on different levels. Some responses pertain specifically to the practice of simulation as a method and its application to the study of social phenomena — the rigor of verification and validation; the transparency of the modeling process; and the empirical validation of simulation outcomes (Gilbert and Troitzsch 2005, Lettieri 2013).

Another fundamental response, however, concerns the broader stance that should guide the integration of simulation within socio-legal research. It is essential to adopt from the outset a research framework aimed at integrating agent-based models with other methods of inquiry. The goal is not to treat simulations as isolated analytical instruments but to combine them with complementary approaches that, together, offer a more comprehensive understanding of reality.

A viable perspective is what has been defined as *methodological eclecticism* (Sil 2000, Della Porta and Keating 2008), a methodological and epistemological perspective which recognizes that no single method can fully capture the complexity of reality moving beyond the "war of paradigms" (Eckstein 1998), which opposes different methodological traditions as if they were mutually exclusive.

From this standpoint, agent-based simulation should not be regarded as a self-sufficient explanatory framework but as one of several methodological strategies that, in combination, enable a deeper investigation of legal and social dynamics. What is at stake, on the other hand, is not the mechanical transposition of social research of quantitative and computational methods borrowed from other areas of science. The challenge is to rethink and expand how we conceptualize and study the complexity of the social world, the very world from which law emerges and upon which law operates and aims at operating also by leveraging cognitive processes that shape individual behaviour.

Potentially, ABM can allow us to experimentally explore the cognitive underpinnings of social order, simulate the interaction between norms of different nature and function, or even dynamically model what legal philosophers define as the *deontic noema* (Conte 2007, Passerini Glazel 2019) tracing its origins, evolution, and dynamics. The possibilities are boundless, the challenge is one well worth accepting.

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