Computational Sociology

Discussion and Research

COLECCIÓN INVESTIGACIONES

COMPUTATIONAL SOCIOLOGY

DISCUSSION AND RESEARCH

Antonio Aguilera Ontiveros
Norma Leticia Abrica Jacinto
Coordinators

EL COLEGIO
DE SAN LUIS

Primera edición: 2021

Diseño de la portada:

Parque de Macul 155
Fracc. Colinas del Parque,
San Luis Potosí, S.L.P. 78294

ISBN:

Impreso y hecho en México

CONTENTS

LIST OF FIGURES

ACKNOWLEDGMENTS

All investigative work is the product of a series of facts and wills. This text is no exception. The authors' collaboration and commitment in the topics presented make this book a first contribution to reflective and critical work on Computational Sociology.

A fact that contributed in an extraordinary way to this text's preparation was the postdoctoral stay of Dr. Norma L. Abrica Jacinto at El Colegio de San Luis, A.C. Her stay would not have been possible without the financial and institutional support from the National Council of Science and Technology (CONACYT), which awarded a postdoctoral fellowship through grant 2019-000019-01NACV. Thank you.

Finally, we appreciate the careful examination of the anonymous reviewers, who, with their pertinent comments, helped us to improve the text.

Antonio Aguilera Ontiveros
Norma Leticia Abrica Jacinto

LIST OF WORKS

A reflection on modeling and the nature of knowledge. This work is presented by Jorge Zazueta Gutierrez, he is a Research Professor at Facultad de Economía, Universidad Autónoma de San Luis Potosí, México.

SysML as a language for modeling social systems. This work is presented by Gabriel AWAD, he is Associate Professor at Department of Computer and Decision Science, Facultad de Minas. Universidad Nacional de Colombia – Sede Medellín.

Applied social simulation for public policy. This work is presented by Leonardo G. Rodríguez Zoya, he works at the National Council of Scientific and Technological Research & University of Buenos Aires, Argentina.

Exploring complexity; teaching-learning proposal with methodological isomorphisms in higher education. This work is presented by Mayra A. Bárcenas Castro, Fco. Javier Segura Mojica and, Jorge F. Briceño González. Mayra is a Doctor in Educational Technology from the Mar de Cortés University Center (Culiacán, Sinaloa, México). Fco. Javier is a Research Professor of the Administrative Economic Area at Instituto Tecnológico de San Luis Potosí, México, and Jorge is a professor at the Mar de Cortés University Center.

Social sequence analysis for revealing the complex social web. This work is presented by Damian Valdés Santiago and María del Carmen Pría Barros. Damian is Assistant Professor and Junior Researcher at the Faculty of Mathematics and Computer Science, University of Havana. María del Carmen is a Titular Researcher and Consultant Professor at the National School of Public Health, Havana, Cuba.

The logistical model of a sociosymbolic ecosystem (LSEM)**.** This work is presented by Luis E. Castro Solís and J. Milton Jair Aragón Palacios, members of the Grupo de Investigación en Sistemas Socioecológicos. Luis is a Research Professor at the Facultad de Ingeniería at Universidad Autónoma de Coahuila, México.

Modeling and simulation of cooperation's phenomenon with Individualist Indirect Reciprocity mechanism. This work is presented by Ricardo A. González Silva, Mario I. Glez. Silva and Héctor A. Juárez López. Ricardo and Héctor are Research Professors at Centro Universitario de los Lagos, Universidad de Guadalajara. Mario is a PhD Student at the same institution.

Complex Networks: structure and dynamics of endogenous development in two communities of México. This work is presented by Anthony Pérez Balcázar, he holds a Masters in Ciencias de la Complejidad by Universidad Autónoma de la Ciudad de México. Currently, he is Professor of the División of Desarrollo Sustentable at Universidad Intercultural del Estado de México, Campus Tepetlixpa, Estado de México.

An agent-based model for social uprising. This work is presented by Andrea A. España Tinajero, Edgardo Ugalde Saldaña and Antonio Aguilera O. Edgardo is a Research Professor at Universidad Autónoma de San Luis Potosí. Antonio is Research Professor at El Colegio de San Luis, A.C., Andrea is a PhD Student at Universidad Autónoma de San Luis Potosí, México and at Aix-Marseille Université, France.

A model for rebellion influenced for opinion and applied public policy. This work is presented by Norma L. Abrica Jacinto and Antonio Aguilera Ontiveros. Norma has a PhD in Science and Technology, with Orientation in Applied Mathematics from Centro Universitario de los Lagos. At present, she is a Postdoctoral fellow at El Colegio de San Luís, A.C. Antonio is a Research Professor at El Colegio de San Luís, A.C.

INTRODUCTION

Sociology and other social sciences have been using computational methods to analyze and model social phenomena for about forty years. Computer-assisted social research can help us understand how and why a social phenomenon happens. Computational sociology uses computational modeling and simulation to generate artificial social worlds to investigate the micro and meso level mechanisms that give rise to social phenomena. The potential of computational sociology to explore social theories' coherence and consistency and generate new alternatives for the study of social phenomena should be highlighted.

Computational Sociology originated in the late 1960s and early 1970s when differential equations were used to predict population behaviors based on other social factors. Today, computational sociology feeds on distributed artificial intelligence developments and the full range of agent-based models arisen from them. Thanks to the development of free software such as *Netlogo* or *Python* suites as *Mesa*, computational sociology has begun to morph, from a mathematically intensive field of study, into a multidisciplinary one. Equipped with these tools, the social scientist can develop models that are socially informed and computationally robust.

Computational Sociology is concerned with explaining important social facts such as patterns of social and cultural segregation, the development of beliefs, familiar ways of acting, or opinion formation. This is done by clearly and precisely detailing the mechanisms by which such social events occur. The models that result are the product of a virtuous interaction between social science and computing.

The present work is a compilation of topics around Computational Sociology. We start with a reflection on modeling in Social Sciences; it discusses the role of modeling as a unifying methodology. Such a process provides theoretical advantages by reducing ambiguity and allowing generalization. This reflection emphasizes falsifiability, generalization, and accumulation as basic principles for the creation of knowledge.

The discussion is followed by three works presenting methodologies for modeling and simulating social systems: SysML, SocLab, Methodological Isomorphisms, and Social Sequences.

Then, the power of modeling is demonstrated with five models explaining different social phenomena. The first one is considered an early model of computational sociology, followed by a model that simulates social cooperation under the mechanism of indirect reciprocity. The book continues with a study for endogenous development using the theory of complex networks and simulation and closes with two works that model the phenomenon of rebellion in alternative ways.

These contributions are representative of the ongoing scientific collaboration among the members of the Ibero-American Network of Computational Sociology (INCS), where we seek to promote the use of modeling and simulation as a methodology for the analysis of social phenomena.

Lastly, we want the reader to find this work attractive and realize that it is possible to study individuals' relationships through various computational methodologies.

Antonio Aguilera Ontiveros
Norma Leticia Abrica Jacinto

A REFLECTION ON MODELING AND THE NATURE OF KNOWLEDGE

Jorge Zazueta Gutiérrez

Abstract

We reflect on the criticism that the methods in the natural sciences have been an object of and argue that these very methods, seen from the right perspective, are crucial to the progress of social science. We propose a knowledge generation framework that sets the minimum requirements for a claim to be considered scientific knowledge and sketch an ontology of the objects of study. We present science as an accumulating yet self-revising process and present examples in the social sciences.

Introduction

The reputation of modeling as a formal methodology in the social sciences has fluctuated from being essential to reductionist and even restrictive to theory development. Rather than taking a side, we discuss the role of modeling as a unifying methodology across schools of thought, arguing that the clarity required by the modeling process provides theoretical advantages beyond the specific results of a given prototype by reducing ambiguity and allowing for generalization. An explicit model provides not only structure but a common language and a set of tools to advance the development of social theory by facilitating interdisciplinary discussion and providing a mechanism to understand the impact of our propositions.

Our discussion is driven by developing a framework that relates modeling and knowledge, or theory building, at different levels. The framework emphasizes falsifiability, generalization, and accumulation as the basic tenets of knowledge generation while recognizing various levels of mind-independent reality, from concrete physical objects to abstract social constructs that might be unobservable but detectable.

Throughout our discussion, we classify our models into conceptual, and formal and further subdividing formal models in terms of their output as (1) closed-form, (2) qualitative and (3) numerical, placing formal constructs higher in a hierarchy while recognizing the conceptual component as a necessary condition for model building and computation as, increasingly, the tool of choice to instantiate and explore a given theoretical or analytical construct; noting that the purpose of modeling in this context is not constrained to prediction, but, just as importantly, it aims to explain and to demonstrate plausibility.

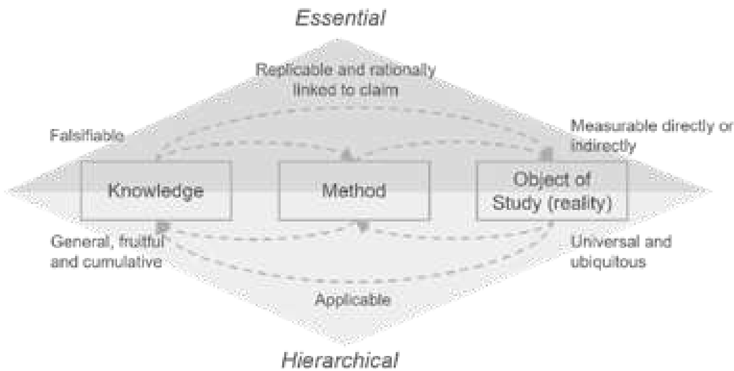
Social theory is represented by a range of worldviews whose proponents are not always in line with the idea of modeling as a unifying research methodology. While recognizing that not all of sociology is quantifiable, we do suggest that, to the extent that a social process can be defined in sufficiently unambiguous terms to be modeled, analytical and computational approaches can contribute significantly not only to the understanding of specific social phenomena, but through the necessary clarity required by modeling, contribute to the identification of structurally similar processes in distinct settings leading to a more integrated, and less divided, general theory.

Base Framework

We adopt a working definition of *knowledge* as a claim about an *object* or a category of objects and thus, only meaningful in the context of the object that is being known. For us to make such a claim, we need a *method* that allows us to gain insights into the object. The relationship among knowledge, method and object is depicted in Figure 1, stressing the interdependence of the three elements.

The recursive nature of this process is the key to what we call *accumulation*. By accumulation, we mean that knowledge is not acquired by a series of independent and isolated acts, but that it grows from an established basis of facts and theories and this process includes the development and improvement of methods as well as the continuous refining of such facts and theories.

Figure 1
Knowledge Modeling Framework



Accumulation is crucial for the development of any significant body of knowledge. In order to claim that dogs are omnivores, it is necessary that we already have the concepts of dog and omnivore. Without accumulation we are doomed to paralysis and any criticism will have to deal with explaining what criticism is without assuming previous knowledge of the term.

Language, culture, religion and even skepticism are a result of accumulation. To be fruitful, this process needs not only to incorporate new elements to our body of knowledge, but to refine and even prune those in need of revision.

Legitimacy of Knowledge

Without basic quality control, claims can be problematic. If I make an assertion about an object, say, that the earth is spherical, you can always make a contradictory statement and assert that it is flat. We would both be making conflicting claims about an object, presumably supported by some research method.

To resolve the conflict, we need our process to display some essential features: (1) the claim is falsifiable, (2) the method is replicable and rationally linked to the claim, and (3) the object under study is measurable. The claim that the earth is flat is certainly falsifiable and has been falsified both directly as observed from a satellite feed or indirectly inferred by looking at a ship "sinking" as it recedes in the distance, contradicting flatness. These and other observations can be replicated by other researchers to measure curvature either binarily or precisely, making every claim provisional and open for revision.

While these essential features legitimize knowledge, they do not necessarily make it relevant or transcendental. We propose a continuous hierarchical characterization based on qualities of the process (see Figure 1). A claim gains status to the extent that it is general and fruitful. Knowing that my dog barks lies lower in the hierarchy than knowing that all dogs bark. Similarly, knowing how an apple falls from a tree is not as impressive as knowing how any object is attracted to any other, anywhere.

A similar criterion applies to the method. Is it specific to the object under study or can it be applied elsewhere? The universality of the object is a more controversial issue and we will spend more time discussing it in the next sections as we delve deeper into the features of our proposed framework.

The Nature of Knowledge

The idea of knowledge has been—and still is— at the center of many philosophical debates, and pretty much any definition is bound to be challenged. There is some agreement on classifying knowledge in three main types: (1) *acquaintance knowledge*, (2) *knowledge-how or procedural knowledge* and (3) *propositional knowledge*. Scientific knowledge is usually tagged as a subtype of the latter, but many agree that procedural knowledge is also an important aspect of science. Our discussion will hover around the loosely defined idea of scientific knowledge, without diving into semantic subtleties. For a more comprehensive discussion, the reader is referred to [1].

Our central focus will be on explanation. While prediction and control are appropriately regarded as critical features of science, explanation enables both. A good discussion on the role of explanation in science can be found in [2].

The Case for Falsifiability

One afternoon in the seventeenth century, Galileo allegedly dropped three balls of steel from the Tower of Pisa. The balls had different sizes and weights and, contrary to common knowledge at the time, they all landed simultaneously.

Even today, there is a variety of classroom experiments and demonstrations to falsify the—still—common belief that heavier objects fall faster than lighter ones[1].

Competing ideas contribute to the accumulation of knowledge because they are falsifiable, if there were not, a mounting body of contradictory factoids will clutter our understanding and impede progress altogether. This is not a philosophical position, but a pragmatic one.

The claim that heavy objects fall faster than lighter ones is an appealing one and is apparently consistent with common sense. Were we to allow this view to share the same factual status as the one claiming that heavy objects will fall just as fast as lighter ones, absent of any external forces, knowledge derived from these premises will be plagued with logical paradoxes and disastrous practical consequences.

As we are allowing a claim to be true and false simultaneously, we can validate all sorts of outlandish conclusions. In a calm and windless afternoon, a light person can jump of a tall building and a proportionally heavier one could jump after her and catch on, given that he is heavier and falls faster than she does. Once he catches on, because it is also true that both fall with the same speed, they can choose to maintain the same velocity and chat. If they are in a hurry, they could hug to

[1] The dynamics of falling objects is a bit more complicated than this, as they are accelerating towards earth according to Newton's laws. But, as we will point out, approximated claims are valid within the context of the problem at hand. Just as Newton's laws can be seen as an approximation to Einstein's special relativity.

speed up, or not. From the perspective of the heavier person, the lighter one could fly up at any time, but also stay still relative to her. This kind of dynamics seem only possible for visitors from Krypton.

Fortunately, both claims are falsifiable, and we can consistently replicate Galileo's experiment to choose one claim over another. The implications to aviation, ballistics and engineering demonstrate the pragmatic importance of this claim and the developments from the time of Galileo illustrate the principle of accumulation.

The Fruitfulness of Some Ideas

While any falsifiable claim is by our definition a candidate to the body of scientific knowledge, some ideas are more influential than others and occupy a higher level in the hierarchy. Stating that my coffee mug is blue, is a falsifiable claim and would likely be validated by countless independent methods but is of little relevance beyond my immediate reality. The idea of evolution, advanced by Charles Darwin in The Origin of Species [3], on the other hand, is one of the most influential theories of all times. Not only as the key to modern evolutionary biology, but as inspiration to theories outside biology such as game theory, linguistics and economics.

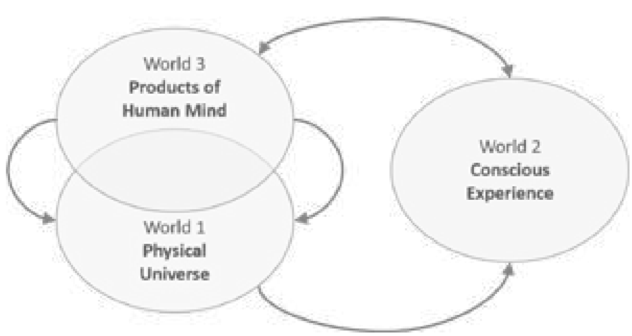
Not every "fact" in an established theory remains untouched. Often, evidence falsifies aspects of a theory and adjustments need to be made. Far from a weakness, this is a perfect example of the tentative nature of scientific theories and the self-updating process of science. In this sense, we can say that the current theory of evolution is the best version available and it represents our current beliefs in that matter.

This is a critical point in our discussion, as accumulation and self-actualization tend to receive less attention in the social sciences. If I want to learn about evolution or classical mechanics, I look for a modern text that incorporates the accumulated knowledge and present the ideas of the discipline from an integrated and current perspective. I would not rely on the original work of Darwin or Newton. Those are important elements of the history of the discipline, and should be understood from that perspective, but not as contemporary guides for a practicing scientist. Why then, should we still hold to an exuberant variety of schools of thought in the social sciences? Is it because the principle of accumulation and self-updating in the natural sciences simply does not apply? We sustain than it does, and that failing to apply it when constructing social theory can have dire consequences, the least of them being stagnation.

Levels of Reality

Does an objective world exist independently from the observer? If so, can it be comprehended? To quote Erwin Schro¨dinger, we assume that "the display of Nature can be understood" [4]. Because if not, the pursuit of scientific knowledge is simply futile. Granted that we are not claiming that this is irrefutably the case, we are simply stating that otherwise the conversation is over. Different views about reality have been advanced by philosophers and social scientists. Karl Popper proposed a three-world ontology [5, 6] . In this view, reality occupies three worlds—which he creatively called world 1, world 2 and world 3, see Figure 2. World 1 comprises the physical universe. This includes the living creatures and humans, who evolved from it. As humans experience the physical world, a new psychological world evolves (world 2), from which, the world of the "products of the human mind" is engendered.

Figure 2
Popper's Three Worlds



Within this ontology, the products of the human mind can either be conceptual (*i.e.*, theories or claims) or physical (*i.e.*, helicopters or cupholders). These three worlds interact among each other with the physical world providing experiences to the human mind and thus enriching world 2, which influences world 3 by generating new products that modify world one (see Figure 2).

All objects in the three worlds are considered objective by Popper. He explains that they exist independently from the observer and that they clearly exert influence on each other. As objects in world 2 and world 3 can and do modify the physical universe, they can be regarded as objectively real. These ideas have been compared with the Platonic view, except that Popper does not claim that the objects in world's 2 and 3 are perfect. One source of ambiguity is that physical objects that are created by men, belong to both world 1 and 2[2]. The distinction of a concept and the physical object that holds it is not crystal clear and has been criticized by some, questioning this idea of reality [7].

In the spirit of accumulation, we will build on Popper's idea to construct a modified ontology that will serve as a backdrop for our discussion of scientific inquiry.

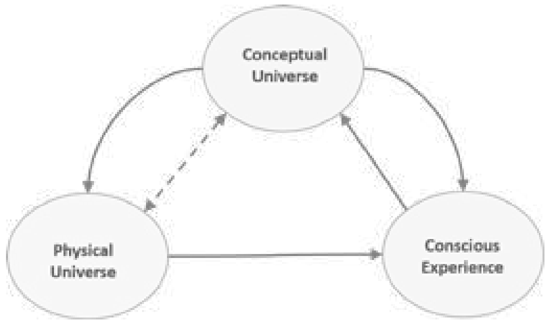
First, we will not become entangled in philosophical reflections about reality and existence and will use these terms casually in order to avoid unnecessary linguistic complications when referring to objects in our ontology, whose only purpose is to provide some structure to what we consider the object of scientific inquiry.

Second, we redefine the content of the three worlds to avoid intersections between them and to clarify their relationships.

Figure 3 depicts our proposed model. The physical universe represents all objects that adjust to our common definitions of physicality, either natural or man-created and we, unapologetically, assume its existence as independent from the observer's mind. This world is continuously changing through the effects of natural processes, such as erosion or volcanic activity, as well as man-made processes, such as the building of dams and bridges.

[2] Typical depictions of Popper's ontology, show the three worlds as non-intersecting. Our depiction stresses the intersection between world 1 and world 3 because, in our mind, is a source of ambiguity.

Figure 3
Modified ontology



An important subset of the physical universe is life. Especially intelligent life. Intelligent beings, such as humans, have a conscious, subjective experience in relation to the physical world they inhabit. These experiences constitute the "conscious experience" universe and are the epitome of interpreted reality or subjectivism. However, these experiences and states of mind trigger into existence what we call the "conceptual universe", in which all human concepts and theories reside.

The three universes interact continuously. The physical universe evolves both naturally and by the addition of man-created objects[3]. The conscious experience world evolves through new interactions with the physical world, but also from conceptual constructs. Consider racism or religion and how they trigger emotions and feelings that go beyond the basic perceptions of our senses. The conceptual universe is critical to scientific knowledge, since it is itself a mancreated concept. Any idea or concept resides in this circle and they can and do directly affect the physical universe. A key difference with Popper's view is that only the concepts belong to this circle and—in our view—to exist, they need to be anchored to an object in the physical universe. In this sense, a theory is an object on its own, and is independent of the observer much as Popper suggested, but it can only exist if enabled by a media. Say, a book, in the physical universe where the theory is documented.

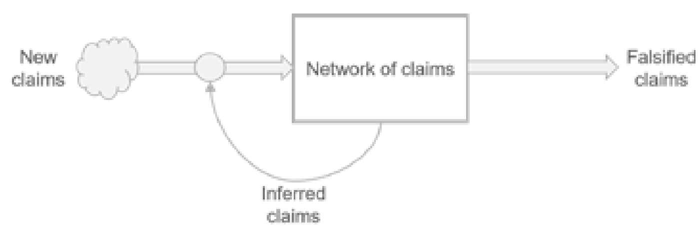
[3] We say man-created because we are the only intelligent species that we are aware of, but the same idea will apply to other intelligent beings from this or other planets, organic or mechanical.

The ontology is comprehensive in the sense that any object exists in one of the three circles, yet not every object is knowable scientifically in the sense that any claim we make about it can be falsifiable. Notice, also, that it is not necessary for an object to exist or a concept to be truthful for it to affect the world (e.g. religion, monsters). So, effect is not a sufficient condition of existence.

We say, then, that the subset of elements within this ontology that are knowable is our object of study and what we call science is not a product but a process that generates claims, assembles theories and most importantly revises itself as claims are falsified. Figure 4 illustrates this process. The box represents the state of the art. A network of claims as they have accumulated up to a specific point in time. We think of it as a network since claims are related to each other and can group in clusters to form theories. Claims from these theories are still related to others and can contribute to the network in different ways. This "body of knowledge" grows from within as new ideas are inferred from others but can also receive completely novel ideas.

FIGURE 4

THE PROCESS OF SCIENCE



As the network of claims grows exponentially from these inputs, it also prunes itself from claims that are found to be false. In this sense, the "most current edition" of science is the most relevant, because not only holds the claims that we consider true, but because it has discarded those that are not. Most of the growth come from within and while any theory is always provisional, it gains credibility in terms of its fruitfulness or the amount of explanations that can be inferred from it.

To Measure or not to Measure

The purpose of studying objects in any of the universes depicted in Figure 3 is to make falsifiable claims about their properties, which implies assigning an objective and intersubjective value to such claims. Representation Theory of Measurement [8] provides a theoretical framework that, at a very basic level, consists on defining a homomorphism between an empirical relational system and a formal one, such that the relationships between the empirical objects are represented congruently by the measurement system defined by the morphism. This representation is consistent with the familiar normal, ordinal, interval and ratio scales introduced by Stevens [9] and is reasonably well accepted today[4] conceptually, despite some criticism to its applicability in actual research. Frigeiro, for example, discusses its limitations and proposes a refinement that is consistent with current metrological practices and definitions [11]. For our purposes, the general notion of measure as the assignment of a formal value to a property of the system under measurement will suffice.

Without a measurement, claims cannot be falsified and hence do not belong to our framework. However, that does not mean that measurements must be infinitely precise. To the contrary, the difference between a measurement and the value of the property being measured is an expected characteristic of it. The level of aggregation at which we study reality, together with the claim we want to make, determine the required accuracy and precision of our measure. Say that we are investigating whether a certain breed of dog can distinguish the colors displayed by a stoplight. We only need a measure that distinguishes red, yellow, green, and "other". Further precision would not only be unnecessary, but confusing. With a finer metric, different stoplights will show a wide variety of "reds" that will not add any new useful information but instead will complicate our problem (was it magenta or crimson?). All that we need is to clearly distinguish red from the other options. All philosophical rants about your and my red are not significant within our definition and a measurement system that is consistent across all

[4] A good review of the evolving theories of measurement is given in [10] which, incidentally, is a good example of the process of science as described in Figure 4.

varieties of stoplights. On the other hand, if our prospective claim is about the human limits to detect different colors, we might want to measure frequencies in the light spectrum.

Measuring is in our view a pragmatic device. It helps us establish claims in a way that they are falsifiable and intersubjective, and it is intrinsically related to the level of reality we are investigating. Scientific knowledge is hierarchical. Imagine trying to explain everything from interactions of elementary particles. In principle, everything from chemistry to psychology and political economy is explainable in terms of quantum mechanics, but that path will not take us very far. Instead, we create different categories and look for explanations —and metrics— at that level. We do not think of societies as groups of atoms or theories as the result of complex interactions among neurons. Reality is constructed at the level necessary for us to measure and understand. Furthermore, measurement needs not to be direct. Many objects in either universe cannot be gauged directly, but their effects can be quantified, as is the case of black holes or the bending of light due to a large gravitational pull. In a way, our earlier assessment of red as a category, is simply a quantification of the effect of a range of wavelengths.

Local vs. Universal

Both the objects of study and our claims about them can be local, universal or anything in between. Generality plays a role in our framework as a measure of hierarchy, as the more general claims explain the more particular. If I study the mug I use to drink coffee every morning, I could conclude that it has a handle and my claim is falsifiable, so it can be regarded as scientific knowledge. However, I cannot say anything about other mugs. My knowledge is decidedly local. If, on the other hand I postulate a theory that claims that all mugs, by definition, have a handle, this is also falsifiable and more general. It explains my mug as well as all others. Some skeptics would say that a claim of universality is one of unfunded vanity, but without generality, progress is challenging. This is a practical issue. Our knowledge that people have two legs and two feet allows us to design pants and cars and shoes and create games like football. Generality spawns knowledge, enables technology and it has undeniably changed all three universes in our framework.

The Method

We have established a working definition of knowledge and sketched an ontology of our objects of study. But how do scientists go about making that connection? Contrary to popular belief, there is not a uniquely defined research procedure known as the "scientific method". As Steven Weinberg put it [12]:

> The fact that the standards of scientific success shift with time does not only make the philosophy of science difficult; it also raises problems for the public understanding of science. We do not have a fixed scientific method to rally around and defend.

To understand the process by which a scientist develops a claim implies understanding inspiration, creativity and even luck among other elements influencing the generation of a hypothesis that are beyond the scope of this paper. We confine the term method to the mechanism that connects knowledge to the object known: (1) measuring the value of a property, (2) making an inference about an object from measurements of its effects, or (3) arriving at a conclusion through logical reasoning from established facts.

For a method to be considered scientific within our framework, it needs to be replicable and provide a rationale for how the results of its application are tied to the underlying claim. Consider the witch scene from Monty Python's and the Holy Grail [13] where Sir Bedevere, quite socratically, helps the villagers conclude that an accused woman is a witch because she weighs the same as a duck, and since ducks are made out of wood, she must therefore be a witch! While the method proposed by Sir Bedevere is clearly replicable, the rationale by which he links its result to the nature of the accused is ludicrously flawed. The range of applicability of a method is supplementary to its validity and lends it hierarchical status.

Modeling as a Method

In a sense, all methods are models. As we formulate or apply any method to generate knowledge about an object, we are running a model. The question is how explicit it is. Making a model explicit, forces us to clearly define the variables involved and the interactions among them. There is less room for interpretation and the model itself serves as a mechanism to reduce any uncertainty about its workings. In the words of Joshua Epstein [14]:

> The choice, then, is not whether to build models; it is whether to build explicit ones. In explicit models, assumptions are laid out in detail, so we can study exactly what they entail. On these assumptions, this sort of thing happens. When you alter the assumptions that is what happens. By writing explicit models, you let others replicate your results.

Explicit modeling, therefore, not only affords clarity and replicability to the process, but is a medium of exploration that can yield results well beyond its initial purpose. The logistic function, for instance, was introduced by Verhulst in the mid-19th century to model the population growth of France, Belgium, Essex and Russia [15]. Since then, it has found applications in economics, chemistry, biology, and sociology to name just a few fields. A Google Scholar search for "application of logistic function" returned $1, 410, 000$ results.

Models can be conceptual or formal. The former, specify the elements of the model and its interactions, without providing a detailed or operational description of such interactions. The figures in this paper are examples of this. The latter describe, in an unequivocal and precise manner, these interactions. They are often classified in terms of the primary toolset as mathematical, statistical, and computational. This can be simplistic, as many models have characteristics from more than one of these categories (Think of stochastic differential equations or Markov Chain Monte Carlo), and, of course, all of them are mathematical.

A useful classification of models can be made in terms of their solutions, as (1) closed form (2) qualitative and (3) numerical. Closed-form solutions are typically represented as mathematical formulas. $K(t) = K_0e^{at}$, for instance, is a solution to the model $dK(t)/dt = aK(t)$ that is both specific —as it can give us a precise answer given the right set of parameters— and general —as it describes a broad range of cases. However, closed-form solutions are not always available and might not even exist. Qualitative solutions provide information about the behavior of the system we are modeling, answering questions about existence, uniqueness, and general behavioral patterns such as fixed points or bifurcations. They can be quite general, but do not provide concrete answers. Numerical solutions on the other hand are specific, providing a concrete answer for given parameter values. They are realizations of the model. They are frequently approximations and often, the only ones we have. Modeling works well as a research method as it forces us to define the objects under study and provides a rationale connecting its results to the property under study. Furthermore, it affords a natural mechanism for inquiry and exploration.

Framework Applications

As we defined our framework and its accompanying ontology, we relied heavily on examples and reflections from the physical and biological sciences. This is natural, as mature, and well-established models abound in these specialties. However, the social sciences present a great opportunity to apply these ideas and considerable success has been achieved in several fields, including our views on positivism, feminism, and language.

Positivism and Critical Realism

Both positivism and critical realism have been criticized for assuming that social phenomena can be explained from simple premises and challenged by feminists of having a masculine orientation of sociological knowledge. Our framework doesn't make any assumptions about the complexity of explanations nor assumes that everything can be explained, but instead it rescues falsifiability of claims and replicability of the method as the basic demarcation criteria between what we call scientific knowledge and other kinds of knowledge. Without these features the process of science lacks a mechanism to purge itself and evolutionarily select the best available explanation and be prepared to revise itself as new evidence becomes available. Our framework defines an ontology from which the objects of study are available, but it doesn't impose a formal notion of reality in a deep philosophical sense, but instead, leverages that ontology along with the process of science as a framework for exploration, discovery and revision. While we do propose a demarcation of science, we do not advance any value judgement and recognize that knowledge generated or acquired outside the scope of science, can and do influence scientific inquiry. We also detach from any ideological background and focus only on the process.

Feminism

As women have been oppressed both physically and ideologically for the better part of modern civilization, suspicion of the establishment are natural reactions as we become more aware of the oppressing circumstances that they have been victims of through history, resulting on much of the discussion to naturally become political. In the words of Michelle Meagher: "feminist theory in the late twentieth and early twenty first centuries is not limited to thinking about the lives of men and women and all those in between, but rather, offers explanations of how gender shapes the entire social world." [16]. In this light, we argue that progress can be made beyond dialectics. A recent paper by Clifton [17] introduces a mathematical model that explores the role of bias and homophily in the progression of women in various professional hierarchies, suggesting policies to achieve gender parity. Another model by Zazueta and Accinelli [18] explores the evolution of the gender gap in the labor market by explicitly modeling cross-bias by gender. The authors' conclusions are falsifiable and their (modeling) method replicable. Their arguments are free from ideology and open to be challenged or supported, informing policy from a non-partisan point of view.

Language

Language is especially suited for scientific analysis and mathematical methods have been extensively applied to study its structure and to understand its messages with minimal human intervention. Applications include measuring political influence on Twitter [19], uncovering what the Chinese government is censoring online [20], identifying authorship based on style [21] or exploring the ideological structure of political parties [22]. As these examples illustrate, language modeling is a powerful research tool with applications well beyond language itself.

Conclusions

We propose a pragmatic research framework that sets minimal requirements for knowledge to be considered scientific and sketch an ontology to help us reflect on the potential objects of research that builds from Popper's original proposal, but refrains for giving reality an objective meaning. Not all objects within the ontology are knowable in a scientific sense, but those that are, can be studied through our framework. The process of science is a feedback loop that accumulates new knowledge, but also purges its content through falsifiability.

By demarcating what we believe is scientific knowledge, we are not making any value judgments and fully recognize that there are many legitimate avenues to knowledge that do not fit our definition of scientific. Furthermore, the creative process by which researchers structure new claims, is to a large extent non-scientific. Is only when we want to label a new claim as scientific, that we need to abide by the minimal rigor defined in this paper.

SysML as a Language for Modeling Social Systems

Gabriel AWAD

To solve a problem, the specific form
of the representation matters
[23, p. 99]

Abstract

The introduction presents the concepts of model and graphical models, sets the paper's objectives and expected contributions, and introduces social systems. The second section describes the main characteristics of SysML and compares its traditional taxonomy with a modeler-oriented taxonomy. The third section presents three SysML diagrams related to purposes, *i.e.*, requirement diagram, use case diagram, and package diagram. The fourth section explains four SysML diagrams associated with the structure, *i.e.*, block definition diagram, internal block diagram, parametric diagram, and package diagram. The fifth section presents how to use six SysML diagrams to depict a social system's behavior, *i.e.*, state machine diagram, activity diagram, sequence diagram, parametric diagram, use case diagram, and package diagram. Finally, the last section presents conclusions and suggests future work.

Introduction

The term "model", despite its widespread use, lacks a consensus about its definition. Every modeler expresses through her/his models an approach to reality [24]. Models are a collection of concepts and relationships about a target [23], and they are valuable both for their conclusions and for their creation method [25]. Modelers use abstraction and simplification to represent the target [26], and as a consequence, not all the features of the target are included in the model.

Models can mix theories from various disciplines to increase our understanding of a problem. As it is tough to formulate complex problems in precise terms [27], graphical models can help us to communicate our ideas and our perceptions. The goal of modeling is not accuracy but usefulness to deliver answers.

As an analytical tool, a graphical model is a set of drawings that serves to organize ideas about something. A graphical model can help exchange ideas among the stakeholders and the scientific community [28], reveal isomorphisms among models, and explicitly declare theories used and assumptions.

OMG Systems Modeling Language (OMG SysMLTM) (The Object Management Group R [29]) is a graphical language. We will refer to it as SysML. Even though the main SysML's focus is engineering analysis, this paper shows how SysML's principles and rules can be applied to social systems modeling. In addition to this, this paper presents a SysML's taxonomy that differs from its traditional taxonomy.

This paper only depicts the major nine diagrams of SysML. Additional information about SysML can be found in: Delligate [30], a soft introduction to SysML; The Object Management Group [29], technical information about SysML; and The Object Management Group [31], technical information about UML.

It is well known that animals can establish social systems [32], but the term "social system" means, in this paper, only human social systems. Social systems include the "natural social environment", *i.e.*, human beings and primordial bodies (diffuse groups such as informal networks); and the "built social environment", *i.e.*, legally-recognized actors such as trade unions [33]. Social sciences study social systems, *i.e.*, the interaction among individuals, not the individuals themselves.

SYSML, A MODELER-ORIENTED TAXONOMIC APPROACH

SysML is a general-purpose graphical modeling language developed by key stakeholders of the International Council on Systems Engineering

(INCOSE) and the Object Management Group (OMG) [29]. It is neither a tool nor a methodology. SysML is an extension and, at the same time, a simplification of the Unified Modeling Language (UML 2). It has nine diagrams, while UML 2 has 13. SysML introduces two diagrams: parametric and requirement diagrams; and, adds four new constructs: flow ports, flow specifications, item flows, and allocations. SysML aims to clear and accurate systems descriptions. It combines UML modeling techniques with precise natural language [29].

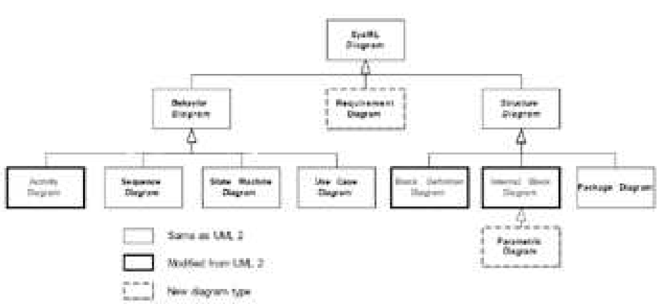
SysML supports the analysis, specification, design and verification of complex systems based on plain and effective constructs, Its main columns are behavior, structure, system requirements and parametric relationships [34].

The traditional SysML taxonomy is meant to facilitate the transition from UML to SysML. This taxonomy is very useful for software and systems engineers, but it is not helpful to social scientists with no prior background in these fields.

Figure 5 displays the traditional OMG SysML Diagram Taxonomy [29, 34, 35][1]. The OMG SysML Diagram Taxonomy groups under "Behavior" the following diagrams: activity diagram, sequence diagram, state machine diagram, and use case diagram; under "Structure", the block definition diagram, internal block diagram, the parametric diagram, and the package diagram; and left alone the requirement diagram.

Figure 5

OMG SysML Diagram Taxonomy



[1] Figure is taken from [29].

A graphical model must help the modelers achieve their goals; so, its taxonomy should clearly state the elements of purpose, structure, and behavior [36]. This taxonomic approach differs from the standard approach [29, 34, 35]; in that they skip the purpose component, group the diagrams under other principles, each diagram only belongs to one category.

Figure 6 shows a Venn diagram with a taxonomic approach to explain SysML based on purpose, structure and behavior[2].

FIGURE 6
A NEW TAXONOMIC APPROACH FOR SYSML

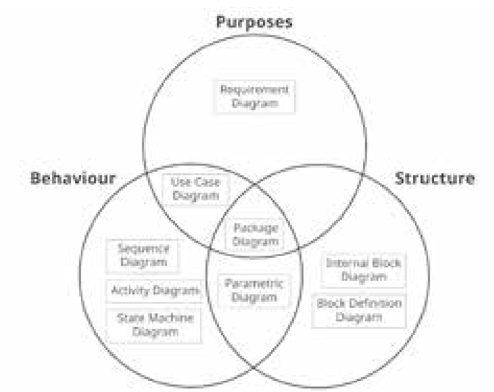


Figure 6 contains three circles marked purposes, behavior, and structure. Each circle contains diagrams that are exclusive to it, while the circles' intersections include diagrams that are common to them. The following sections, called "Purposes", "Structure", and "Behavior", contain descriptions and examples, applied to social systems, of the nine diagrams.

Languages are intended for communication. Their elements and structures are selected and combined searching for clarity. SysML, a language itself, operates as every language does. The purposes and uses of the model determine how many and which of SysML diagrams are included in a particular model [36].

[2] This figure and the following ones are taken from [36].

Purposes

The purpose of the model, instead of verisimilitude, should be the guide through the modeling process [37]. The true usefulness of models depends on their ability to satisfy the stakeholders' purposes. So, the first group will include the three SysML's diagrams oriented to the description of the purposes of the model: requirement diagram, use case diagram, and package diagram.

Requirement diagrams

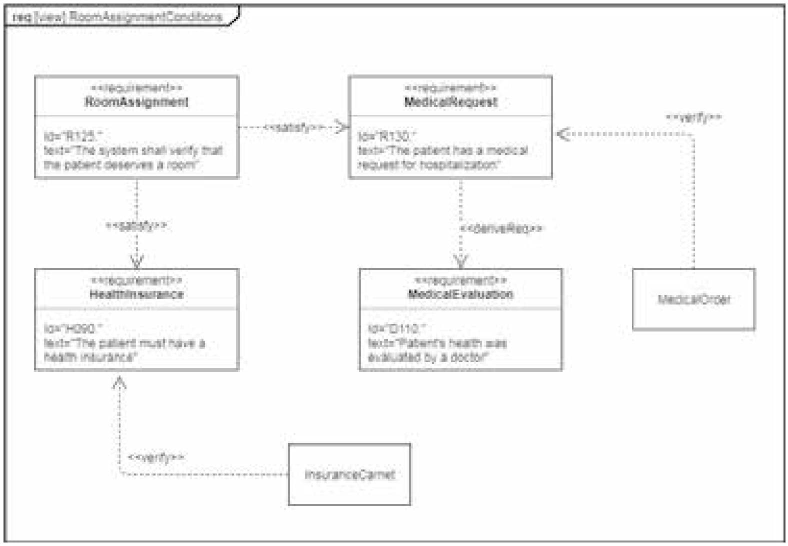
A requirement diagram identifies the stakeholders' requests regarding the model. Requirements truly mean agreements between stakeholders and modelers, and they state what is expected from the model [34, 35]. Requirements can include regulatory, statutory, or contractual reasons, and they can be recycled across models. Requirements can be expressed in many formats (graphics, texts, tables, tree structures). However, they must content their descriptions and their relations to other elements of the model that verify or satisfy them [29].

SysML includes built-in stereotypes of requirements, but it also allows the modeler to define her/his own requirement categories. Some examples of built-in requirements are: derive (sets relationships between to elements: user and provider), satisfy (fulfills a set of specific conditions), verify (a procedure to inspect, analyze, or test the requirement), and refine (modifies other requirements).

Figure 7 shows the requirement diagram of the conditions to get a room in a hospital. Two stipulations must be satisfied. One is related to medical conditions, and the other to payment capacity. The first one implies that the patient needs a room, a derived requirement of a medical evaluation. A medical order verifies it; the second one checks that the patient has health insurance, and an insurance card verifies it.

FIGURE 7

REQUIREMENT DIAGRAM OF THE CONDITIONS OF ROOM ASSIGNMENT



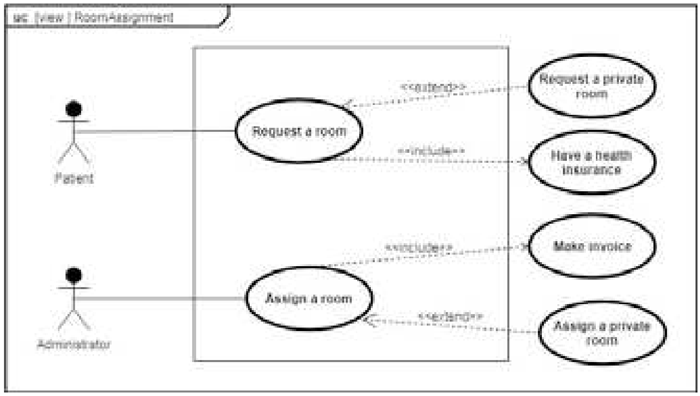
Use case diagrams

A use case diagram states the system functional scope. It shows the capabilities of the system from its users' perspective. Use case diagrams communicate how the activities deliver value to the actors. They should have a stakeholder's approach and not a developers technical perspective [38].

The main elements of a use case diagram are actors and use cases. Actors can be roles, human users, organizations, external hardware, other systems, time, and so on; and a use case is a description of a specific behavior [29]. Figure 8 shows a use case diagram for a room assignment. The patient has associated the use case "Request a room", which includes having health insurance (compulsory) and is extended by the request of a private room (optional). The administrator has associated the use case "Assign a room", which includes making an invoice (compulsory) and is extended by assigning a private room (optional).

Figure 8

Use case diagram for room assignment

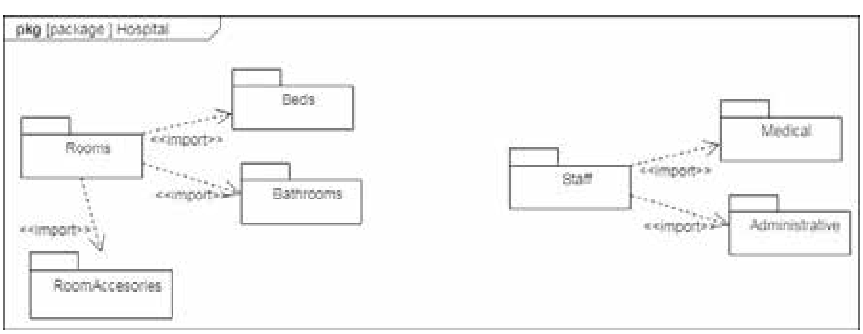


Package diagrams

Package diagrams aim to organize a model from a stakeholder's point of view [38]. Each point of view could require different package diagrams. Figure 9 shows a package diagram of the components of a hospital. The hospital has two main modules: rooms and staff. The module room is composed of beds, bathrooms, and room accessories. Medical workers and administrative workers form the module staff.

Figure 9

Package diagram of the components of a hospital



Structure

The atomic elements of a social system are human beings and the roles (properties and responsibilities) performed by human beings and/or machines. A social system can be thought of as an array of its atomic elements coupled by their relationships (a connection of any kind between a pair of elements).

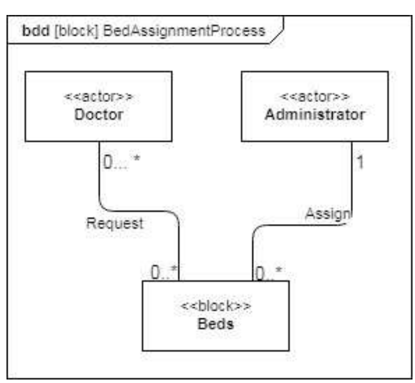
The structure of a social system is the set of its elements and their relations. A social system only exists when, and while, relationships among its atomic elements occur [32]. The second group contains the four SysML's diagrams oriented to the description of the structure of the model: block definition diagram, internal block diagram, parametric diagram, and package diagram. The last diagram was explained earlier, and the remaining diagrams will be presented in this section.

Block definition diagrams

The block definition diagram characterizes the entities and their relationships, such as associations, generalizations, and dependencies (The Object Management Group [29]). Figure 10 shows the block definition diagram for a bed assignment process. It contains three blocks (Doctor, Administrator, and Beds). The doctor needs beds for her/his patients,

Figure 10

Block definition diagram for a bed assignment process

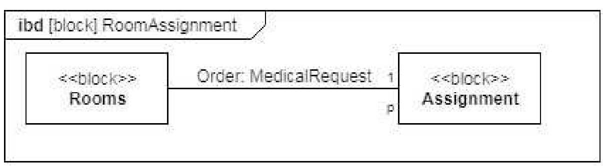


while the administrator assigns the beds. There are many doctors, one administrator, and uncertainty about the number of assigned beds. The number of assigned beds can oscillate from zero (*i.e.*, no assignments), to any positive real number.

Internal block diagrams

An internal block diagram provides an inner view of a system block (parts, ports, properties, and connectors); it specifies all the components of each block, as well as their relationships [35]. Figure 11 shows the internal block diagram of RoomAssignment. It consists of two blocks (Rooms, Assignment), which are connected by an Order: MedicalRequest relationship.

Figure 11
Internal block diagram of room assignment



Parametric diagrams

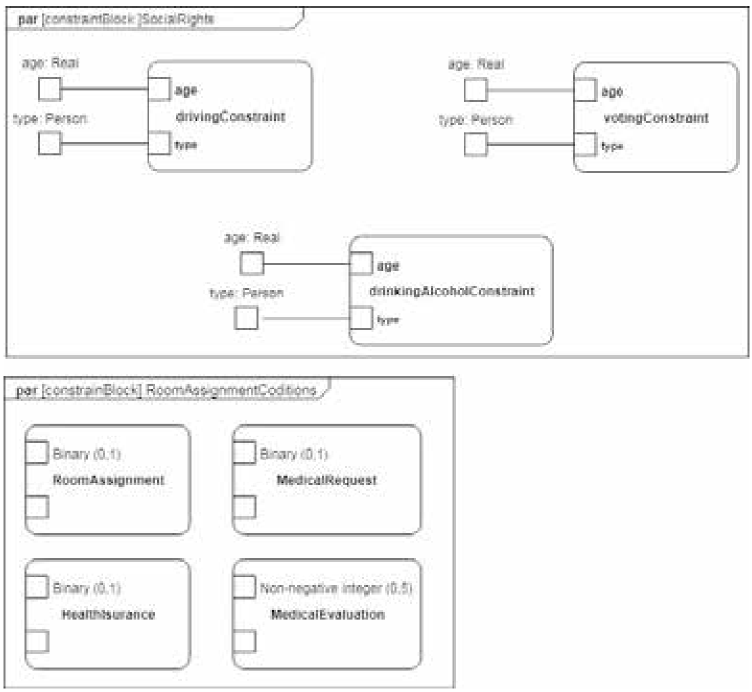
A parameter is a constant. SysML allows two kinds of parameters: system parameters (they are provided, and the modeler cannot modify them) and design parameters (the modeler sets them) [34, 35]. Design parameters help to discover, using simulation, the acceptable range of values of the constants [39].

The restrictions (*e.g.*, logical expressions, mathematical equations, rules) constrain the system's properties and their parameters, [29]. For example, the statement "reception attends 24/7" specifies a restriction: the reception is open every day from 0:00 to 23:59. The restrictions can evolve, both in their values and in their nature. The parametric diagram describes the constraints among the properties associated with blocks. Parametric diagrams support sensitivity analysis and analysis of scenarios.

Figure 12 shows a parametric diagram of the conditions for room assignment. Room assignment, medical request, and health insurance are binary parameters (0, 1); while medical evaluation is a non-negative integer in the range 0 to 5.

FIGURE 12

PARAMETRIC DIAGRAM OF THE CONDITIONS FOR ROOM ASSIGNMENT



BEHAVIOR

Social systems are dynamic entities; they and their components change over time. However, the only relevant changes in social systems are those related to a state change or a behavioral change. Similar structures can give origin to different behaviors, and the same behavior can result from different structures. The exact behavior of a social system cannot be predicted, but the space of potential outcomes can be anticipated.

Behavior is a fundamental construct for modeling the dynamics of a social system. The behavior of systems depends on interactions among components, their internal dynamics, and the stakeholders' intentions. The third group contains the six SysML diagrams to represent the model's behavior: state machine diagram, activity diagram, sequence diagram, parametric diagram, use case diagram, and package diagram [34, 35]. The last three diagrams were explained in previous sections. The remaining three diagrams will be presented in this section.

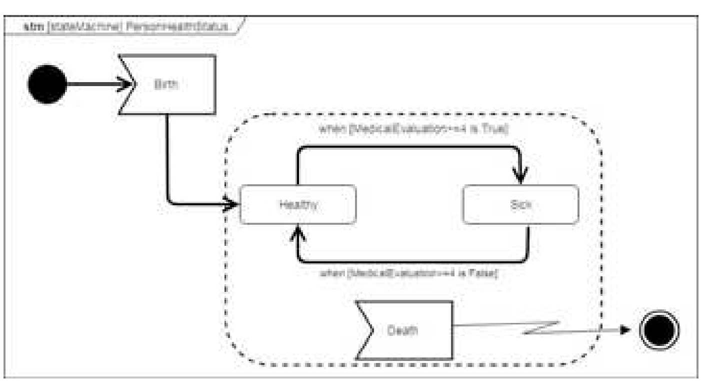
State machine diagrams

The state of any social system, at a specific time, is the value of its relevant properties at that time. A state machine diagram describes the state transitions and actions that a system or its parts perform in response to events (significant happenings) (The Object Management Group [31]).

A state is a phase in the behavior of a system and its elements. State machines show the response of the atomic elements to the events [38]. For example, single, married, divorced, and widowed are potential states of a natural person. A person passes from single to married through a wedding process, from married to divorced by a relationship rupture, and from married to widowed when her/his partner is deceased. It is not possible to pass directly from single to widowed or to

Figure 13

State machine diagram indicating health status of a person



divorced. Each state implies changes in some properties such as place of living, economic responsibilities, family duties, etc.

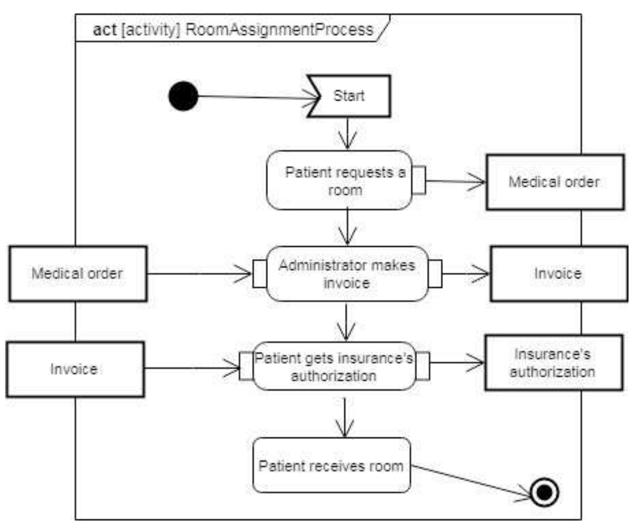
Figure 13 shows a state machine diagram indicating a person's health status during her/his life. The trigger event is the birth of a person, who will remain in one of the two states (healthy, sick) until the stopping event occurs (*i.e.*, death). Medical evaluation conditions the transitions between states.

Activity diagrams

An activity diagram characterizes the inputs required by each activity and the element produced as an output. An activity, a kind of behavior, is a regulated succession of actions that converts inputs into outputs [29]. Events, either external or internal, trigger activities. Figure 14 shows the activity diagram of a room assignment process. Once the process starts, the patient requests a room based on a medical order. Then, the administrator receives this information and makes an invoice. After that, the patient gets authorization from the insurance company; and finally, the patient receives a room.

FIGURE 14

ACTIVITY DIAGRAM OF A ROOM ASSIGNMENT



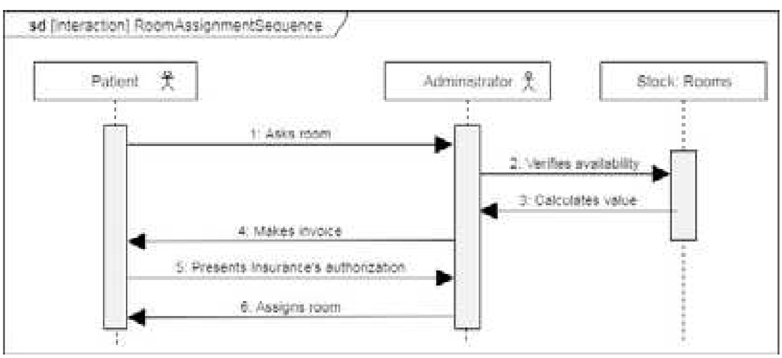
Sequence diagrams

The sequence diagram indicates, in chronological order, the change in social entity states caused by the interaction between collaborating parts of a system. A sequence diagram describes possibilities [40] and serves to represent usage scenarios, *i.e.*, a sketch of a path in which a system could be used (Ambler, 2005).

Figure 15 shows a sequence diagram of an exchange. First, the patient asks for a room. Then, the administrator verifies if there are rooms available to calculate the amount to be paid. After that, the administrator prepares the invoice and sends it to the patient. Next, the patient presents the insurance company's authorization, and finally, the administrator assigns a room to the patient.

Figure 15

Sequence diagram of a room assignment



Conclusions and future work

Social sciences focus on the interaction among human beings. Despite the differences among these interactions, they can be modeled using their common properties. The goal of modeling is to build useful models, not "the right" models.

Social systems, their components, and their interrelationships are dynamic because they change over time. Social experiences result from repeated exchanges among social entities over time, not from social entities' isolated choices.

SysML focuses on engineering analysis, but it can also be applied to the modeling of social systems. Due to its cross-disciplinary approach, SysML could facilitate the integration of different social sciences to build an integrated vision of social systems.

This paper introduces a modeler-oriented taxonomic approach to SysML based on the concepts of purpose, structure and behavior. Some diagrams are exclusive to one concept, while others are common to various concepts.

The purpose of the model is to express stakeholders' requests about the model and the functional scope of the system. The structure of a model shows the logical decomposition of the system's functions. And the behavior of the model reflexes dynamics, states, and processes; of the system.

SysML is a technique-free graphical modeling language. It is not associated with a specific technique (*e.g.*, agent-based models, systems dynamics). However, the user of SysML can design models based on specific techniques.

SysML is a powerful graphic language for modeling social systems, but its use in social sciences is still uncommon. It would be advisable to promote its diffusion among social scientists. As the focus of SysML is on engineering modeling, it could be advisable to customize it to social sciences, especially defining specific social stereotypes. Future works should apply SysML to different social sciences.

APPLIED SOCIAL SIMULATION FOR PUBLIC POLICY

Leonardo G. Rodríguez Zoya

Abstract

This paper's general topic could be summed up with the following question: How and why agentbased modeling and simulation could help us analyze public policies' social feasibility. To tackle this question, we apply an agent-based simulation framework to analyze a concrete public policy's social feasibility. The framework is the *SocLab* platform, and the case study is a public policy developed by the Ministry of Agriculture of Argentina to foster the organization of a Cluster of Fine Fruits Producers in Argentinian Patagonia.

Introduction

SocLab is a theoretical, methodological and computational "framework for the modeling, the simulation and the analysis of power relationships in social organizations, and more generally in systems of organized action" [41, 1]. We propose to use *SocLab* to tackle a relevant problem of public policy analysis: the question of the social feasibility of a policy. The theoretical discourse assigns equal importance to the social, economic, technical, and environmental dimensions of a policy. However, "in practice, little attention is paid to the social dimension: the other dimensions [...] are considered with much more attention" [42, 2].

This paper aims to analyze the social feasibility of a concrete experience with public policy using the *SocLab* framework. The case of study is a Cluster of Fine Fruits Producers in Patagonia, Argentina. We show how and why social simulation in general and, particularly, *SocLab* may help policymakers analyze the social feasibility of public policies.

The work is organized in the following way. First, we briefly introduce the theoretical and methodological framework of *SocLab*. Below, we summarize *SocLab*'s modeling methodology and present the empirical case study: The Fine Fruits Cluster. Then, we carry out a structural and simulation analysis of the Cluster and focus on two *SocLab* indices: power and capacity for action. The latter expresses the degree to which an actor can access the resources he needs to achieve his goals. Power measures the amount of capacity of action that an actor grants to others. In the end, we conclude how *SocLab* allows us to infer a quantitative measure of the social viability of a public policy.

The *SocLab* framework

Let us first argue that *SocLab* can be defined as a middle-range agent-based simulation platform integrating the three components of scientific activity postulated by Hummon and Fararo [43]: theoretical, empirical, and computational. Firstly, *SocLab* is grounded on the formalization of the Sociology of Organized Action (SOA) developed by Michel Crozier, and Erhard Friedberg [44–46]. The *SocLab* framework allows to model different types of organizations (formal and informal), analyze their structure, and simulate the behavior and interactions among the agents that constitute them. Its main goal is to study the organizational dynamics and the forms of regulation of social systems. Secondly, *SocLab* provides a rigorous methodological strategy for using qualitative methods and qualitative data for building empirical models of social organizations. Lastly, in the third place, *SocLab* is a computational platform allowing the researcher to model the structure and simulate a social organization's dynamics. It is important to notice that *SocLab* consists of an intuitive user interface, and no programming skills are needed to use it. Nevertheless, in-depth knowledge of the theoretical framework and qualitative methodology is necessary to use *SocLab* properly. All in all, the *SocLab* computational framework implements the formalized theoretical framework as a meta-model, that is, an abstract conceptual structure that can be used to create concrete models of a case study using empirical evidence produced by qualitative methods.

An interdisciplinary research team of the University of Toulouse, France, led by the sociologist Pascal Roggero and the computer scientist Christophe Sibertin-Blanc, conducted a formalization of the Sociology of Organized Action (SAO). This formalization process implies, on the one hand, a critical definition of a pure qualitative and discursive sociological theory (*i.e.*, the SAO), and, on the other hand, the definition of a meta-model, that is an ensemble of concepts and their relations that can be used to model concrete observed systems [47].[1]

The theoretical framework of *SocLab* can be described through its meta-model, which is presented as a UML class diagram[2] (see Figure 16).

A *social organization* can be defined as a social game composed of "a set of Actors and a set of Relations that are linked by the Control and Depend associations" [41, 5]. Actors are the system's main entities and can be individuals or groups (collective actors: *e.g.*, firms, trade unions, political parties, states). In *SocLab*, an actor is someone that controls at least one resource, that is, something needed to conduct an action. Actors mobilize resources in order to achieve their goals. Since resources are means for actions, in the *SocLab* framework, an actor's sociological status is denied for those who do not control any resource.

It is important to notice that resources can be material (*i.e.*, funding), immaterial (*i.e.*, skills), or cognitive (*i.e.*, information). Thus, resources are objects of exchange, and they are the foundations of social relations. In other words, a relation between two actors is not direct but indirect, meaning that the relation between them is grounded on a resource that is being exchanged.

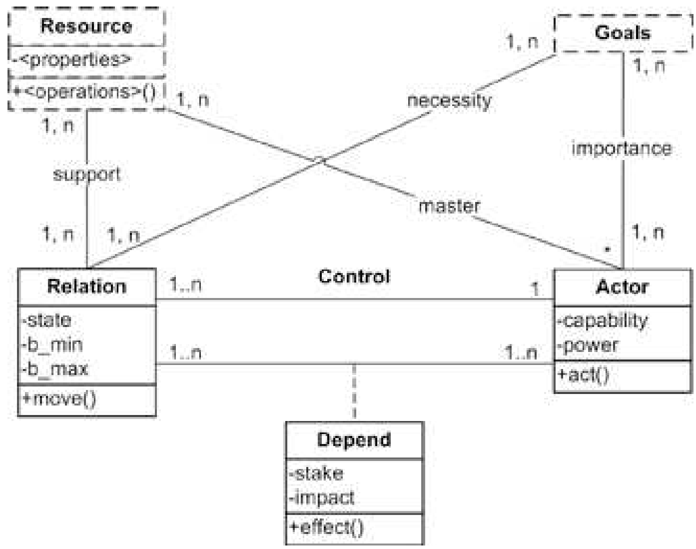
It is important to point out that in *SocLab*, we do not explicitly model neither resources nor goals (see dotted line in Figure 16). On the one hand, we investigate resources in order to conceptualize and model relations; on the other hand, goals are often blurry for social actors. Therefore, we focus our analysis on what an actor does and how he needs to act in order to achieve its goals: the relations.

[1] For a brief introduction to the formalization of the SAO see [48]. For a full description of the formalization, see [49].

[2] Concerning the use of Unified Modeling Language (UML) for modeling social systems see [50]. About the relation between UML and agent-based modeling, see [51]. A deep introduction to UML can be found here [52].

FIGURE 16

THE META-MODEL OF *SOCLAB* AS A UML CLASS DIAGRAM. SOURCE [41]



Having described those theoretical concepts, we are able to explain the meta-model:

- When a social actor *acts()*, he *moves()* the *state* of the relations he controls (on a scale of –10 to 10). The controller actor is the only able to do so.
- The *state* of a relation expresses the controller actor's behavior and defines to what extent the associated resources are accessible for dependent actors. Usually, negative values (0 to –10) characterize a less cooperative behavior; whereas, positive values (0 to 10) describe a more cooperative one.
- Each actor has a *behavioral space* for the relations he controls, which is defined on a scale of –10 to 10. This space represents the set of all possible behaviors the actor can adopt managing a given relation. Therefore, the *sate* of a relation (that is, the behavior of its controller actor) ranges over the *behavioral space*. The parameters *bmin* and *bmax* allow the modeler to modify the numerical limits of the space of behaviors in order to express

contextual, structural, or institutional restrictions on the degree of freedom of the controller actor.

- Each actor distributes *stakes* (on a scale of 0 to 10) on each relation (the sum of the stakes for every actor must be equal to 10). A *stake* measures the importance of a given relation for an actor, considering its goals: "the more a relation is needed to achieve an actor's important goal, the higher the corresponding stake" [53, 133].
- When an *actor* has a *stake* in a *relation*, he becomes *dependent* of it. Thus, the *state* of a *relation* (defined by its controlling actor) has an *impact* on dependent actors that "determines the availability of the underlying resource and to what extent the actor is granted to use the resource according to his goals" [41, 8]. *Impact* ranges over a scale of –10 (worst access) to 10 (optimal access).
- The *effect function* allows associating the state of a relation to the impact. Methodologically, an effect function is needed "for each relation on every actor having a not null stake on this relation" [53, 133]. *SocLab* allows the modeler to draw different shapes of an effect function (linear, quadratic, sigmoid, etc.) without explicitly writing the mathematical equation. This is an outstanding feature and a methodological strength from the point of view of social science researchers.
- Concerning the concepts of *capability* and power, we explain them in Section 3.4.

Methodology

The Ministry of Agriculture of Argentina develops, since 2010, public policy aiming to promote clusters in different regions of the country. The goal of such a policy was to strengthen the productive networks and improve local economies' competitiveness. In the scope of this policy, the Norpatagonian Cluster of Fine Fruits was created in 2012. This Cluster is in the Patagonia of Argentina.

It encompasses three provinces: Neuquén[3], Río Negro and Chubut[4]. Fine fruits include raspberry, strawberry, blackberry, blueberry, cherry, among others.

In 2013 a research team of the University of Tres de Febrero conducted a qualitative investigation of the Norpatagonian Cluster of Fine Fruits. The methodological design was in-depth interviews with key participants of the Cluster: productive, institutional, private, and public actors. In 2018, a research project led by Leonardo Rodriguez Zoya developed a computer model of the Cluster in *SocLab* using the qualitative data of the previous research. It is important to point out that the empirical data was not produced with the aim to build a *SocLab* model. Therefore, we need to interpret the available data in terms of *SocLab*'s theoretical framework.

SocLab's methodology can be summed up in nine steps[5]: (1) identify actors, (2) identify resources, (3) identify relations, (4) actorrelations matrix which specifies the controller actor, (5) actor's stakes on the relations he depends, (6) behavioral space constraints (*bmin* and *bmax* parameters), (7) definition of a qualitative scale for the state of the relation, that implies providing a conceptual interpretation of the value range of the behavioral space, (8) model effect functions, (9) define solidarities[6]. For brevity, we will make some methodological remarks to explain how we model the Fine Fruits Cluster in the *SocLab* platform. For further details, the full methodological documentation and the *SocLab* model is avail able here: https://complejidad.com.ar/simsoc/FineFruitesCluster

[3] In Neuquén province, the Cluster covers the region of "High Valley of the Black River", a fruit tree productive heart. View the region on a google map: https://goo.gl/maps/vsTmUFz6spppD4ro9

[4] In Río Negro and Chubut provinces the Cluster covers the micro-region of "Comarca Andina" which encompasses a group of towns and villages of both provinces, particularly, "El Bolsn", "El Hoyo" and "Lago Puelo". View on a google map: https://goo.gl/maps/kzsFY7RCGcgjwW5s9

[5] A full introduction to *SocLab*'s methodology can be found in Spanish here [54] and in English here [41].

[6] For the sake of simplicity, we do not model solidarities, which allow considering alliances between actors. To go indepth in this topic, see [42].

Actors, relations and stakes

Five actors and eight relations define the model of the Cluster. In Table 1, we summarize the actors in columns and the relations in rows. In the table cells, we show each actor's stakes and bold the relations he controls. As the reader can verify, the sum of actor's stakes is equal to ten. The last column, called relevance, is equal to the sum of the stakes and expresses the importance of each relation.

Let us explain how we generated this conceptualization of actors and their relations from qualitative evidence. Two theoretical remarks are important. First, following the genetic epistemology of Jean Piaget, we can state that knowledge is not a passive reflection of an external reality. On the contrary, there is a dialectic between the subject and the object of knowledge. Therefore, theoretical structures serve as a guide for empirical observation. In our modeling process, the theoretical lenses provided by the *SocLab*'s framework allowed us to interpret and organize the empirical data. Secondly, according to Minsky, a model can be defined as follows: "to an observer *B*, an object *A** is a model of an object *A* to the extent that *B* can use *A** to answer questions that interest him about *A*" [55, 46].

TABLE 1

ACTORS, RELATIONS AND STAKES

	Coordinator of the Cluster	Ministry	Producers of Neuquén	Dynamic producers	Handmade producers	Relevance of the relations
Information	2.0	2.5	0.5	0.5	0.0	5.5
Coordination	3.0	1.5	0.5	0.5	2.0	8.5
Funding	1.0	3.5	3.0	3.0	3.5	14
Regulations	2.0	2.5	0.0	0.0	0.0	4.5
Commercial lobby	0.5	0.0	3.0	0.5	0.0	4.0
Quality and innovation lobby	0.0	0.0	0.5	3.0	0.0	3.5
Critical mass	1.5	0.0	2.5	2.5	3.0	9.5
Handmade lobby	0.0	0.0	0.0	0.0	1.5	1.5

Based on these theoretical remarks, once we have analyzed the public policy of the Ministry of Agriculture and the qualitative data, we arrive at the following question that serves as a guide of the modeling process: What is the possibility for fine fruits producers to collectively construct a Cluster that could be more beneficial to them than remaining isolated from the initiative?

In order to tackle this question, we construct a qualitative typology distinguishing three types of fine fruits producers: The producers of Neuquén, the Dynamic producers, and the handmade producers[7]. Theoretically speaking, producers are different in their production technologies and scales. Moreover, they have different interests and problems, and each of them is distinguishable from others in terms of their world view and idiosyncrasy. Each type of producer controls a lobby relation: *commercial lobby*, *innovation and quality lobby* and *handmade lobby*. In addition, handmade producers control a relation call critical mass since they are the most numerous producers of fine fruits.

Besides the producers, there are two more relevant actors: The Ministry and the Cluster coordinator. The former is the central public actor since it is the creator of the public policy and controls two relations: (i) *Funding*, the amount of money that producers need to achieve its projects, and (ii) *Regulations*, that is, the legal rules that have to be fulfilled in order to initiate the Cluster. The latter is an individual that has been elected by the producers and serves as a nexus between the Ministry and different types of fine fruit producers. He controls two relations: *information and coordination*. On the one hand, he is a kind of informational channel from the Ministry to producers and vice versa. On the other hand, his function is to bring together the producers' different positions and interests.

Concerning the relevance of the relations, *funding*, with 14 points, is by far the most important relation (which it appears to be evident), followed by *critical mass* with 9.5 points (which is less evident).

[7] The producers of Neuquén are in the "High Valley" whereas the dynamic and handmade producers are located in the "Comarca Andina".

Conceptual interpretation of the behavioral space

It is crucial to understand that a computer model is a numerical model. Thus, the output of a simulation is always a set of numerical values. The modeler has the theoretical responsibility to give a conceptual sense to those numbers to make the simulation interpretable. Therefore, it is essential to conceptualize the meaning of numerical values representing the states of the relations. In other words, since an actor's behavior is represented by a numerical value (*i.e.*, the *state*) we need to associate those values with a conceptual interpretation. A simple way to do it is to group the behavioral space's values (on a scale of –10 to 10) into class intervals. Additionally, let us remember that the lower and upper limit of the behavioral space can be modified through the b_{min} and b_{max} parameters. Table 2 summarized the behavioral space of each relation grouped by class intervals with its theoretical interpretation associated. We have modified b_{min} and b_{max} parameters to model contextual constraints that limit the actor's freedom of action.

Modeling effect functions

As we have previously explained, effect functions allow us to model the link between the controller actor's behavior (*i.e.*, the sates of a given relation) and how this behavior affects the dependent actors. Table 3 shows the shape of the effect functions. Actors appear in columns and relations in rows. Grey table cells indicate the actor that controls a relation. An effect function is represented in a Cartesian coordinate system. The state of a relation [–10, 10], is plotted on the *x*-axis, whereas the effect (*i.e.*, the actor's capacity to make use of the resource [–10, 10]) is plotted on the *y*-axis.

Due to space limitations, we only make a few remarks concerning the relation critical mass. By doing so, we will explain the theoretical reasoning underlying the modeling of an effect function. Methodologically speaking, it is advisable to start modeling the actor's effect function that controls a relation since he is the only one who can change its state (*x*-axis). In Figure 17, we model two effect functions, one for the

TABLE 2

BEHAVIORAL SPACE OF RELATIONS GROUPED BY CLASS INTERVALS AND THEORETICAL INTERPRETATION ASSOCIATED

R1. Information		**R2. Coordination**	
Interval	**Interpretation**	**Interval**	**Interpretation**
[−5, −1]	Skimp on information	[−5, 0]	Rather passive position, do not actively seek to articulate the producers
[−1, 1]	Give as less information as possible		
[1, 5]	Give enough information	[0, 5]	Actively seek the articulation, cooperation and dialogue among producers
[5, 10]	Share information thoroughly		
R3. Funding		**R4. Regulation**	
Interval	**Interpretation**	**Interval**	**Interpretation**
[−8, −2]	Weak funding	[−10, −5]	Lack of norms
[−2, 2]	Moderate funding	[−5, 0]	Soft and flexible norms
[2, 8]	Strong funding	[0, 5]	Moderate normative density
		[5, 10]	Rigid and strict norms
R5-R6-R8. Three types of lobby		**R7. Critical mass**	
Interval	**Interpretation**	**Interval**	**Interpretation**
[−7, −2]	Weak lobby activity	[−9, 4]	Balkanization of the Comarca: the producers are atomized, and they do not reach a minimal of organization
[−2, 2]	Moderate lobby activity: the actor seeks to defend its own interests but tends to negotiate	[−4, 2]	Moderate level of organization: a low acceptable level of collective action in order to participate in the Cluster
[2, 7]	Strong lobby activity: the actor is prone to an inflexible position for protecting its own interests	[2, 7]	High level of collective action

controller actor (handmade producers) and the other for one of the dependent actors (Producers of Neuquén). We can pose the following guiding question to orientate the modeling process: What do the negative and positive values of the state of a relation mean for an actor? What is, for a given actor, the most satisfactory, the least satisfactory, and moderately satisfactory situation for the different states of the relation?

TABLE 3

EFFECT FUNCTIONS

	Coordinator of the Cluster	Ministry	Producers of Neuquén	Dynamic producers	Handmade producers
Information					
Coordination					
Funding					
Regulations					
Comercial lobby					
Quality and innovation lobby					
Critical mass					
Handmade lobby					

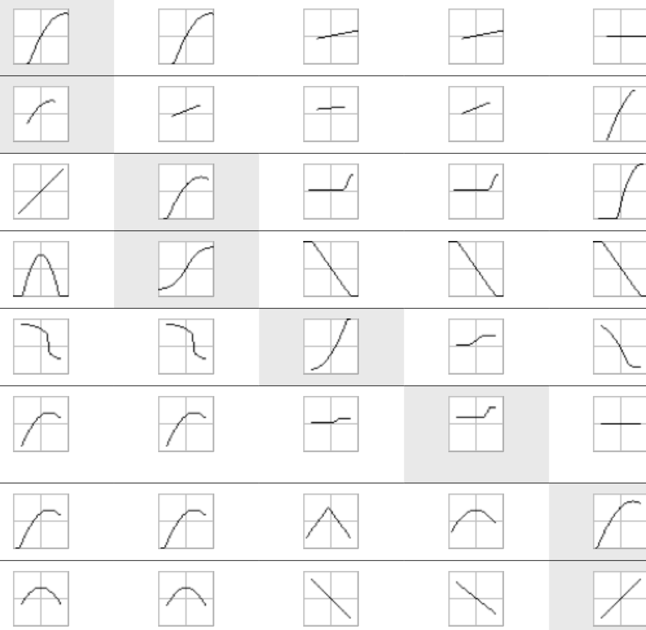
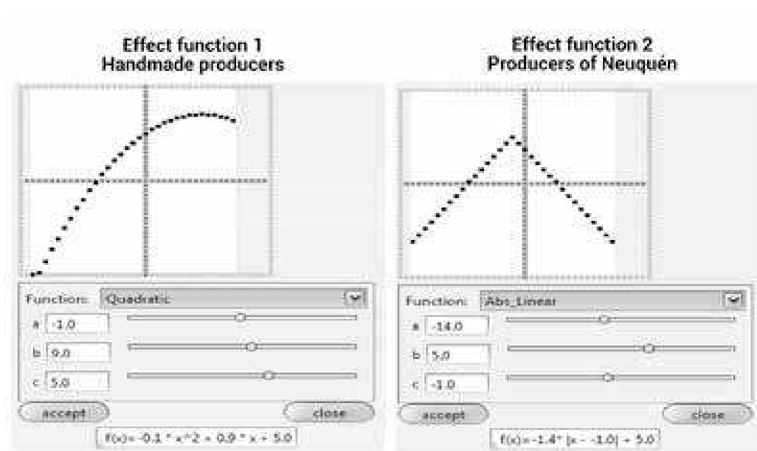


FIGURE 17

EFFECT FUNCTION FOR CRITICAL MASS RELATION



For handmade producers, we have reduced the behavioral space [BS] to [–9, 7] to account for their constraints to obtain high levels of collective organization. They are the most numerous actors (around one hundred producers with one hectare). Thus, their participation is important for making the Cluster possible. However, they face a problem of collective action since none of them can exert a central control of the critical mass. Therefore, the worst situation for them is the Balkanization of the Comarca Andina, that is, to remain atomized without reaching a minimum level of a collective organization [BS –9 to –4]. The actor's capacity improves gradually when they can increase the level of collective action. For that reason, the best situation corresponds to a high level of collective action [BS 2 to 7]. We have used a quadratic function to capture this reasoning (see *Effect function 1* in Figure 17).

From the standpoint of producers of Neuquén, the situation is quite different. For them, the best situation is a mid-level of critical mass' collective organization [BS –4 to 2]. The actor's capacity decreases in two situations: in the scenario of Balkanization and if handmade producers obtain a high level of collective organization. In the first case, the Cluster would not be feasible; whereas, the second one implies that handmade producers can better coordinate their collective action to achieve its goals. We have used an Abs linear function to capture this reasoning (see *Effect function 2* in Figure 17).

Results

The meta-model of *SocLab* presented as UML class diagram (see Figure 16) can also be defined as an algebraic structure [48]. Thus, a social organization (*i.e.*, a *SocLab*'s model) is a finite mathematical structure, including:

- $A = \{a_1, \dots, a_n\}$ a set of actors.
- $R = \{r_1, \dots, r_n\}$ a set of relations.
- *control*: $R \rightarrow A$. A function indicates the actor that controls each relation.

- *state*: $R \rightarrow SBr$ = [–10, 10]. Each relation has a state which value ranges over the space of behaviors [SB]. b_{min} and b_{max} parameters allow to modify the lower and upper limit of the SB.
- *stake*: $A \times R \rightarrow [0, 10]$. Such as $\forall a \in A, \sum_{r \in R} stake(a, r) = 10$
- *Effect ()*: $A \times EC_r \rightarrow \{-10, 10\}$. The function quantifies the capacity that each actor obtains considering the state of every relations he depends on.

We are now able to distinguish between the *structure* and the *state* of a *social organization*. On the one hand, the *organization's structure* is a set of multiple configurations, that is, a space of possibilities corresponding to the different types of behavior the actors may adopt. A social structure defines what actions can happen within the organization and those actions that cannot occur. Let us emphasizes that the social structure of an organization does not determine the actor's behavior. It does not prescribe what the actor must do. On the contrary, the structure defines a space of possible actions, and it concerns the actor to take a decision and choose a course of action.

On the other hand, a *state of the organization* is "one of its possible configurations, as a vector of all the relations' state" [41, 10]. An organizational state can be defined as a moment of a social process. In effect, organizations are social games, and when a social actor plays the organizational game, he acts. By doing so, he changes the state of relations he controls and indirectly changes the state of the whole organization.

SocLab "computes many indicators about structural or state-dependent properties of the organization" [53, 134]. For our analytical purpose, two indicators re-quires our attention: *action capacity* and *power*. When an organization is in a *state s*, *action capacity* measures "how much each actor has the means he needs to achieve his goals" [56, 4], formally defined as:

$$\textit{action capacity}(a, s) = \sum_{r \in R} stake(a, r) \cdot effect_r(a, s_r). \quad (1)$$

Power measures the amount of action capacity one actor grants to others, defined as:

$$power(a,s) = \sum_{\substack{r \in R \\ a\,controls\,r}} \sum_{\substack{b \in A \\ b \neq a}} stake(b,r) \cdot effect_r(b, s_r). \quad (2)$$

If we consider solidarities between actors, two additional indicators can be defined: satisfaction and influence. When an organization is in a *state s*, “the *satisfaction* perceived by an *actor a* is the sum of the *action capacities* of all the actors, weighted by his *solidarities* for them” [42, 8]:

$$satisfaction(a,s) = \sum_{b \in A} solidarity(a,b) \cdot action\ capacity(b,s). \quad (3)$$

Conversely, “influence exerted by an actor *a* on another actor *b* is the sum, over all the actors, of the impacts of the relations controlled by *a*, weighted by the solidarities of *b*” [42, 8]:

$$influence(a,s) = \sum_{b \in A} solidarity(a,b) \cdot power(b,s). \quad (4)$$

Structural Analysis

We have investigated some analytical properties of the Fine Fruits Cluster through structural analysis. Particularly, we focus our attention on global maximum satisfaction and that obtained by each actor (see Table 4[8]).

Let us make some crucial theoretical remarks. On the one hand, the *global maximum satisfaction* (first column) quantifies the highest social satisfaction actors can obtain at the same time (228.2 points). The key finding is that *producers of Neuquén* are by far the most unsatisfied actors with 23.8 points; whereas *dynamic* and *handmade producers* have 52.1 and 44.9 points respectively. This result allows us to hypothesize that there is a structural conflict between producers that may compromise public policy’s social feasibility.

[8] We have included state of relations values for each configuration. Thus, in combination with the theoretical interpretation provided in Table 2, the reader may comprehend how each actor should behave in order to achieve a given organizational state. Let us underline that we are not stating that a given configuration must happen in the cluster. On the contrary, we analyze the socio-organizational conditions under which such a configuration may happen.

Table 4
Maximum satisfaction

	Global	Coordinator of the Cluster	Ministry	Producers of Neuquén	Dynamic producers	Handmade producers
Information	9	9	9	10	10	8
Coordination	5	5	5	–5	5	5
Funding	8	8	5	–2	8	6
Regulations	3	1	10	–10	–10	0
Commercial lobby	7	2	–7	7	7	–7
Quality and innovation lobby	7	7	–7	7	7	7
Critical mass	1	3	–9	–1	0	7
Handmade lobby	7	7	–7	–7	7	7
Cordinator	56.5	60.4	7.4	–20.2	40.5	53.9
Ministry	50.9	44.1	61.5	–2.9	20.6	42.0
Producters of Neuquén	23.8	–9.9	–34.9	64.8	28.0	–55.0
Dynamic producers	52.1	48.3	–0.9	27.3	52.4	27.2
Handmade producers	44.9	66.8	22.5	–65.5	37.5	86.6
TOTAL	228.2	209.7	55.6	3.5	179.1	154.7

On the other hand, columns 2 to 6 show *individual maximum satisfaction*, it means the maximum satisfaction each actor can achieve in the structure of a social organization (*i.e.*, the social structure of the Cluster). It is interesting to compare the maximum satisfaction of producers of Neuquén (column 4) and handmade producers (column 6). When Neuquén producers obtain the highest satisfaction (64.8 points), handmade producers obtain a negative satisfaction (–65.5) (See column 4). Inversely, when handmade producers get maximum satisfaction (86.6), Neuquén producers get negative satisfaction (–55) (See column 6). Here we can make more precise our structural conflict hypothesis:

there is a deep conflict between these two types of producers that may affect the Cluster's sustainability.

Furthermore, in this scenario depicted by column 4, the organization's total satisfaction is extremely low: 3.5 points. For this reason, we can conclude that it is structurally unlikely that producers of Neuquén can achieve their goals in this social game. Conversely, when handmade producers' satisfaction is maximized (column 6), the total satisfaction of the Cluster rises to 154.7. We can infer that the Cluster's social structure benefits more handmade producers than Neuquén producers; thus, it is more likely for the former to achieve their goals.

Simulation Analysis

Simulation on *SocLab* is the dynamic representation of the social game. Social actors have bounded rationality and limited information; thus, they do not know a priori (*i.e.*, before the game) the best way they should behave to achieve their goals. *SocLab* provides a trialerror, and reinforcement algorithm [57]. At each simulation step, "each actor adjusts the state of the relations he controls to obtain from others an acceptable level of "satisfaction"" [41, 16]. If each actor obtains an acceptable level of social satisfaction, he does not modify his behavior any longer (*i.e.*, the sates of the relations he controls); thus, the social organization reaches a stationary state, and the social game is self-regulated. When this occurs, we say that *the simulation converges*.

We conducted one hundred simulations of 25.000 steps. The average number of steps to reach convergence is 19,996.62. We face a quite complex social game since "the length of simulations is a good measure of the difficulty of actors to find how to cooperate" [56, 5]. The first row of Table 5 reproduces global maximum satisfaction, whereas rows 2 to 5 show simulation results. *Absolute power* is the absolute sum of the contributions of an actor to the satisfaction of others. *Cooperative power* is the sum of the positive contributions of an actor to the satisfaction of others.

Let us provide some theoretical interpretation of the simulation results. Firstly, it is relevant to compare the total satisfaction obtained by simulation (196.42 points) with the global maximum satisfaction

Table 5
The satisfactions and power of the actors (simulation results)

	Coordinator of the Cluster	Ministry	Producers of Neuquén	Dynamic producers	Handmade producers	TOTAL
Global max. satisfaction	56.5	50.9	23.8	52.1	44.9	228.2
Satisfaction	42.5	59.18	4.22	40.26	50.26	196.42
Power	76.3	93.0	29.5	18.9	15.5	
Absolute power	76.3	117.0	34.5	18.9	48.2	
Cooperative power	76.3	105.0	32.0	18.9	31.8	

(228.2 points). Thus, the social game reaches a stationary state near its structural possibilities since only 32 points of potential satisfaction (228.2 – 196.42) is not obtained by the social dynamics of the Cluster. Secondly, it is relevant to point out that the Ministry and handmade producers increase their social satisfaction level due to the social game regarding the levels obtained by the structural analysis. The Ministry's satisfaction increases from 50.9 to 59.18, and handmade producers' satisfaction from 44.9 to 50.26. We can conclude that both actors get the most benefits from the social game since they have the highest satisfaction. Lastly, producers of Neuquén get a drastic reduction in their satisfaction (from 23.8 to 4.22 points); therefore, they are the social game losers. These results invite us to question the Cluster's social feasibly, given that the producers of Neuquén were the promoters of the initiative.

Concerning power, it is important to underline that the producers of Neuquén are the most powerful actors among the three types of producers with 29.5 points. In contrast, the dynamic producers have 18.9 points and handmade producers only 15.5 points. All in all, although Neuquén producers have twice the power of handmade producers, it is not enough for the former to exert that amount of power in such a way that could rebound to a higher level of satisfaction.

Conclusions

What have we learned by conducting a computer simulation of a public policy with *SocLab*? Firstly, a *SocLab* simulation model is not a predictive model but a possibilistic one, that is, a research strategy that helps us understand the possibilities and limits of a social game. Secondly, it is possible to use qualitative data to build a computer simulation model in *SocLab*. Even if the data were not collected for *SocLab* modeling purposes, it has been possible to theoretically interpret the evidence to calibrate the model empirically in a reasonable manner. Had *SocLab* been used from the beginning of the research, the evidence would have been even more relevant and precise. Thirdly, we can use the social satisfaction indicator provided by *SocLab* as a quantitative measure of a public policy's social feasibility. This remark allows us to sketch out a theoretical hypothesis: if a social organization reaches a stationary state and some key actors have a low level of social satisfaction, that social system is not sustainable in time, even if the total satisfaction is near the global maximum satisfaction. In the fourth place, a social organization's structural analysis helps us infer deep conflicts between social actors. In the fifth place, simulation analysis allows us to explore the dynamic of a social game and compare the difference between a concrete dynamic and its structural possibilities. Finally, computer simulation is complementary to qualitative research in a double way: on the one hand, as we have shown, qualitative evidence can support a modeling process in *SocLab* and, on the other hand, computer simulation allows us to develop theoretical inferences that we cannot envisage through qualitative analysis.

To conclude, we envision using *SocLab*'s social simulation as a strategy to enhance research on public policies, support the public deliberation process and public decision making. As with any scientific model, a computer model should not be used in a prescriptive and unreflexive way but as a tool for thinking about how to improve our reasoning about the complexity of social life.

EXPLORING COMPLEXITY
TEACHING-LEARNING PROPOSAL WITH METHODOLOGICAL ISOMORPHISMS

Mayra A. Barcenas Castro
Francisco J. Segura Mojica
Jorge F. Briceño González

Abstract

A teaching-learning proposal is presented in higher education using methodological isomorphisms as an introduction to complex systems and the importance of interdisciplinarity. It was found that despite the fact that 93% of the students did not know about complexity sciences and 85% did not consider interdisciplinarity important before conducting the study, there was a 69.27% advance in significant learning.

Introduction

Interdisciplinarity in teaching-learning is an area of opportunity for the study of complex systems in México and the world, particularly for higher education where knowledge is addressed in the resolution of current problems such as education, politics, economics, sociology, biology, physics among others. In this sense, the construction of traditional teaching with the digital age over time has been a challenge for the scientific community in need to address methodologies that allow such interaction between different disciplines.

However, the way to go about it has been an area little explored, even more so in social sciences. Moreover, it is the use of computational methods in social phenomena that has allowed us to expand the horizon of social research [58]. In this sense, training a scientist in computational sociology is not an easy task. In addition to his knowledge in social theories, he must prepare himself in the dialogue of a systemic and critical thinking process that allows him to understand the complex systems under study.

Most computational sociology students are drawn from the physical-mathematical sciences and not from the social sciences, with their respective exceptions. In this context, the present work refers to how to insert the capacities concerning the study of complex systems with a group of first-semester engineering students because the seedbed of scientists who manage to make the step to computational sociology can be visualized in this type of academic profile.

The role of the computational sociologist

For Gutiérrez [59] the subject who aspires to be a researcher in computational sociology must establish a relationship between traditional knowledge and formal science constituted for the attention to social problems. It requires a reflection on epistemic support and interdisciplinary work. On the other hand, Rubio [60] updated the counterargument on the criticism that Systems Theory was ahistorical. He did a theoretical review where he found that Systems Theory and history converge.

However, how can the social science researcher transcend the use of the formal sciences and the modeling of phenomena? According to Gonzalez [61], learning of social sciences is not only to conceive their problems but also to study them methodologically and empirically. Hence, the challenge is the simultaneous, and not separate, study of these points of view. The transformation is achieved when the computational sociologist incorporates technoscience in his proposals.

As can be observed, the formative process is an area of opportunity to contribute to the construction of the computational sociologist. It is worth mentioning that not all sociologists necessarily require this type of training. However, the most significant advantage of carrying it out is the change of paradigm. Highlighting the originality, intercommunication, and transversality of physical, biological, anthropological, and sociological knowledge from the individual human to the collective; besides the metamorphosis of this type of sciences for the emergence or rethinking of concepts, languages, and procedures of social treatment.

Learning in complex systems

Complex phenomena arise from the use of computers, precisely because traditional education has involved knowledge into the possibilities of learning and captured the profound experience of human beings on paper. The arrival of computers allows researchers to perform calculations in minutes that previously required a lifetime. Computers, which are the fundamental tool of ICT's, allowed and generated the possibility of rethinking fundamental concepts that are now transmitted from generation to generation to solve problems in society.

Thus, building a link between traditional and digital education in scientific methodologies has been a great challenge, with numerous debates. It proposes an interdisciplinary approach to study the solution of current problems in society. It involves economic factors, social, environmental, cultural, and ethical, to mention a few. However, it is necessary to ask in which moment of history it became so questionable to solve or even individualize the teaching of each branch of science since it seems that it is not the birth of a new science, but the rethinking of it [62].

On the other hand, Edgar Morín is an author who has worked since the end of the 20th century on the formation of complex thought and complex epistemology for its study. Among the themes that stand out in his studies are theoretical and methodological implications. His relevant work *The Seven Necessary Knowledges for the Education of the Future* has been widely cited by the scientific community. Such knowledge consists of the following: teaching the human condition, the blindness of knowledge, the principles of relevant knowledge, earthly identity, the ethics of the human race, teaching understanding, and facing up to uncertainties [63].

In this context, both the study of complexity science and complex thought emerges as an alternative to understand complex systems in education since practice and theory allow for the formation of critical thinkers to solve problems in daily life.

The role of education in the study of complex systems

The sciences of complexity are sciences, and therefore doing science means scientific research with empirical, not only conceptual, foundations.

They seek to establish systematic empirical knowledge from a conception of reality understood as a fabric or intersection of complex systems.

It offers a new way of doing science among various disciplines and can be considered integrative since it tends to use the same tools of thought in a wide variety of scientific fields. If the sciences of complexity and the complexity of reality require a new language, they also need an alternative methodology. This reference is under construction of models even for the social sciences.

Complexity produces emerging phenomena derived from the interactions of the parts that make it relevant. Therefore, the effects of emergence and transformation of systems are a good area of opportunity for complexity sciences. It can be observed that complexity is visualized from different perspectives; however, it is not clear, which is the didactic guide to understand in a comprehensive way why or how to understand complexity sciences.

De la Reza and Lara proposed "the creation of normative criteria from the concept of isomorphisms to address problem solving through interdisciplinary research". In their study, they state that "interdiscipline is not easy, however, inter-methods can be linked in the definition of a problem according to its isomorphism. In the particular case, these authors used three specialities to build a model of isomorphism: international economy, public policies and international law" [64, p. 224].

On the other hand, Lizier *et al.* [65] explored challenges and opportunities through interviews with teachers and students to understand the field of complex systems in university students, found communities with problems to express and manage strategies in meaningful approaches to teaching. They used active learning as a method or strategy as a conceptual change in the proposals to study complex phenomena. So, learning with creative projects directed to students is needed to achieve good results.

Active learning is a teaching-learning strategy that focuses on the student by promoting participation and continuous reflection through activities that are characterized by being motivating and challenging, aimed at deepening knowledge, developing the skills of searching, analyzing and synthesizing information, promoting active adaptation to problem solving [66].

Previously, Mitchell [67], who produced a book on how to explore complexity science from scratch, explained how to work with the issue of complex systems and experimented with some tools that can be seen as fragmented–instead of unifying– variables in student learning. We recommend experimenting with less rigorous analogies in ecology, information, meteorology, and others.

Complexity sciences and didactics

One of the most important tasks of didactics is to teach everything to everyone, that is, teaching in school systems has been reformulated as a result of the incorporation of contributions from phenomena studied over time. The first attempts to systematize teaching and the reflections of didactics are inextricably linked to the problem of schooling of large populations.

For example, Jacobson and Wilensky [68, p. 2] propose the following points for learning complex systems:

- Experiencing the phenomena of complex systems.
- Manufacturing complex systems within an explicit conceptual framework.
- Encourage collaboration, discussion and reflection.
- Build theories, models and experiments.
- Learning trajectories.

Furthermore, didactics is part of the sociocultural dynamics of learning and knowledge transfer. In this thread, they point out that every 30 years, gaps in articulation appear in scientific knowledge and, in this sense, propose strategies that allow university students to promote the sciences of complexity.

Porlán *et al.* [69, p.2] discuss "the need to change the dominant model of science teaching and the desirability for teachers to build professional expertise". They argued that knowledge is not linear and that different theoretical approaches were required to investigate real problems.

Yoon *et al.* [70] carried out the study of the progression of the teaching of complexity sciences to university students to find the generation of a guide for learning the main concepts of complex systems. They began to implement activities from the most difficult to the easiest to analyze in that field, using the inductive methodology. They argued that there is very little literature on the subject and that the sample size was not significant, because the study was exploratory and involved assessment of students who completed all activities. However, based on the results of this work, they would carry out more robust research.

Systems thinking for teaching and learning in complex systems

Systemic thinking, on the other hand, for Liévano and Londoño [71] is that which contemplates the whole and the parts and the connections between the parts and study of the whole to understand the parts. Systemic thinking tests several mental models, firstly the sum of the parts, secondly the behaviour of people. As can be seen, the way in which critical and systemic thinking interact makes it possible to generate a guided program for the introduction to science teaching and is therefore feasible in the area of complexity.

Carlos Gershenson [72] in his course offered in the COURSERA platform *Pensamiento Sistémico* has a complementary course *Pensamiento científico* that contributes to the first one, it is necessary to emphasize that due to time reasons this last one was no longer considered in this work, besides that it has just been opened to the general public. As for the course *Systemic Thinking*, it consists of four topics that allow any user interested in the subject to learn about complex systems in general, without delving into each of them.

In the first topic, he makes a brief history of systems, how the systemic thought has developed, its comparison to reductionism, and the technological advances that enable its study. In the second topic, he introduces fundamental concepts of systems thinking for management, describing phenomena such as dynamic networks and their feedback.

In the third topic, he reviews systems thinking applications in various areas of knowledge using the concepts already seen. The fourth topic covers applications in engineering, science, philosophy, and everyday life that are worth the student's while for future knowledge acquisition.

Currently, the course is still available and free of charge. In this work, the course was implemented precisely because the material designed by C. Gershenson provided the student with a simpler and different vision from the one he usually knows within her Institution of origin.

Strategies for teaching and learning in complex systems

1. A didactic methodology is proposed for higher education students implementing methodological isomorphisms of the sciences of complexity, using as an example two similar themes, the topics are: Information Theory versus Index of ShannonWiener Diversity and Graph Theory versus Dynamic Programming.
2. Use material in person and online to obtain data that can be statistically analyzed and make a diagnosis implementing a validated questionnaire to find pedagogical strategies that allow the student to acquire the significant learning.
3. Assess the relevance of this work using methodological isomorphisms and the results of the material applied to sampled students.

Methodology

The focus of this work is a cross-cutting study; depending on its purpose is applied, descriptive; by the nature of mixed-type data with quasi-experimental variables.

First, sampled students were asked to develop documentary research on methodological isomorphism topics, such as the mathematical difference between a Linear Programming and Graph Theory model and Theory information of Shannon versus Index of diversity ShannonWiener. This way, the student would begin to understand and identify whether or not there is a relationship among those topics. Second, we applied a questionnaire validated by Gargallo [73] to be analyzed with parametric statistics.

This Teaching-Learning Strategies Questionnaire will identify students' weaknesses in terms of their study schedules, motivations, and consultation from reliable sources and metacognition. Some improvement activities can be suggested before the following tests.

Thirdly, students deepen their knowledge of what complex systems really are and how methodological isomorphisms are powerful tools for understanding. For six months, they took a course on the COURSERA Platform called *Pensamiento Sistémico* consisting of three modules with their respective evaluations.

Once they have completed all the activities, they were invited to take a personal satisfaction survey on the course and the course tutor in general. With the results of the evaluations of the course *Pensamiento Sistémico* the analysis of variance of a single factor was carried out, where the variables are independent; so the null hypothesis is that students sampled by traditional teaching and the difficulty of learning little about the proposed isomorphic topics does not make a significant learning breakthrough; whereas the alternative hypothesis is that active learning as a proposal for interdiscipline and examples complex phenomena with methodological isomorphisms learning emerges and interest in the sciences of complexity.

Results

This research was carried out on three groups of engineering programs in Mechatronics, Computer Science and Mechanics in the first and second semesters. It was proposed to use active learning as a strategy to explore and understand complex systems in an introductory manner.

The number of participants for this work was 77 people, in an age range of 18 to 30 years old; 80% were men and 20% women. According to the questionnaire that was made to the students of Mechanical Engineering (iM), Mechatronics Engineering (iMi) and, Computer Systems Engineering (iSC) of the first semester of the Instituto Tecnológico de San Luis Potosí regarding a first approach with the methodological isomorphisms, the following was found.

It can be observed that in graphs of Figure 18 most of the respondents did not know about complexity sciences; however a small percentage had heard about them in their high school.

Figure 18

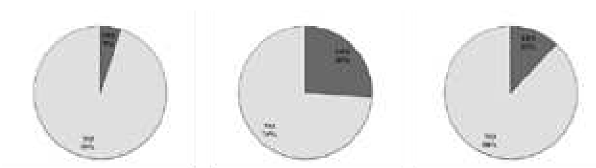
Do you know the complexity sciences?

(a) iM (b) iMi (c) iSC

Graphs in Figure 19 show that most do not consider interdisciplinarity important. Once the students had the documentary research of the two proposed methodological isomorphisms, a pre-test and post-test were applied. See Tables 6 and 7.

Figure 19

Do you consider interdisciplinarity important?



(a) iM (b) iMi (c) iSC

Table 6

Pre-test questions carried out before the students presented their documentary research with the proposed isomorphisms

Pre-test questions	General results
What were the issues that the students found difficult to research in a documentary way?	Information Theory Dynamic Programming
Was enough literature found on the topics researched?	For Information Theory Dynamic Programming, scarce and not very understandable
Would you like to learn about Complexity Science?	90% of the students said yes

TABLE 7

POST-TEST QUESTIONS CONDUCTED AFTER THE STUDENTS PRESENTED THEIR DOCUMENTARY RESEARCH WITH THE PROPOSED ISOMORPHISMS

Post-test questions	General results
Did you see similarities in the two topics discussed?	100% of the students answered yes said yes
Do you think these topics will help you in your career?	90% of the students answered yes
Do you feel that you need more feedback on the two issues raised?	98% of the students said yes

In the table at the end of the chapter, it can be seen how, in some questions, variation is higher than in others. This means that these strategies are the ones that students have the most difficulty with, and with them, a work plan must be generated to learn methodological isomorphisms.

With regard to the reliability of the scale of the questionnaire applied, the following result is obtained from Cronbach's Alpha.

Below are the scores obtained when carrying out the evaluations in COURSERA of *Systemic thinking* per module. It is worth mentioning that the evaluations were carried out in a face-to-face manner, only the course was studied online, the last module did not have an evaluation because it was a general review.

According to the general score, students initially found it difficult to understand basic concepts, in the first evaluation they made 54.15% progress, in the second 57.27% and in the third 69.27%, so it can be seen that as they became more familiar with the subject, they found it less difficult to answer the evaluations.

TABLE 8

RESULTS OF RELIABILITY OF THE QUESTIONNAIRE OBTAINED FROM CRONBACH'S ALPHA

Items	88
Variance summation	0.80896055
Total Variance	10.8537235
Results of Alfa de Cronbach	0.93610455

Table 9
Module 1

Overall Score	54.15/100%
Questions most often missed	What makes predictions difficult in complex systems? What are the simulations for?

Table 10
Module 2

Overall Score	57.25/100%
Questions most often missed	To stabilize a dynamic, what can we use? What is an anti-fragile system?

Table 11
Module 3

Overall Score	69.27/100%
Questions most often missed	What happens is too much robustness?

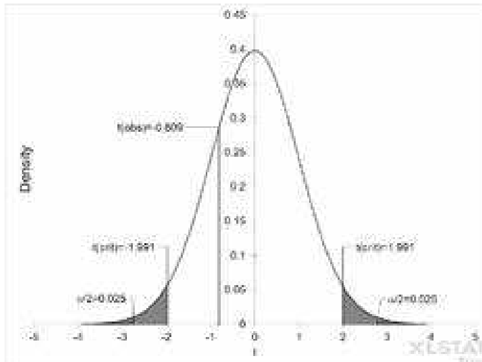
With regard to the results of the *t*-test for two independent samples, the following results were obtained:

- H_0 the students did not have a significant progress with respect to the training of the course *Pensamiento Sistémico*.
- H_a The students made significant progress with respect to the e *Pensamiento Sistémico* training course.
- Interpretation of the test.
  - H_0, the difference between the averages is equal to 0.
  - H_a , the difference between the averages is different from 0.

Since the calculated *p*-value is greater than the significance level α = 0.05, the null hypothesis H_0 cannot be rejected, see Figure 21.

FIGURE 20

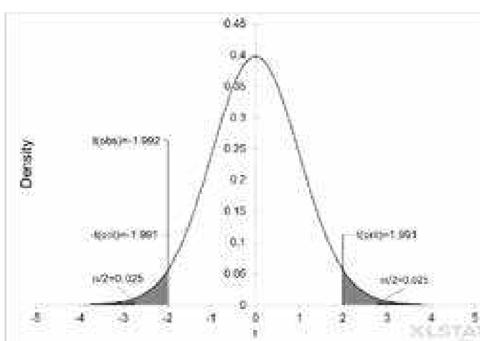
REPRESENTATION OF THE CALCULATION OBTAINED *T* TEST FOR DATA INDEPENDENT OF MODULE 1 VERSUS MODULE 2



Since the computed *p*-value is less than the α = 0.05 significance level, the null hypothesis H_0 must be rejected, and the alternative hypothesis H_a must be accepted, see Figure 21.

FIGURE 21

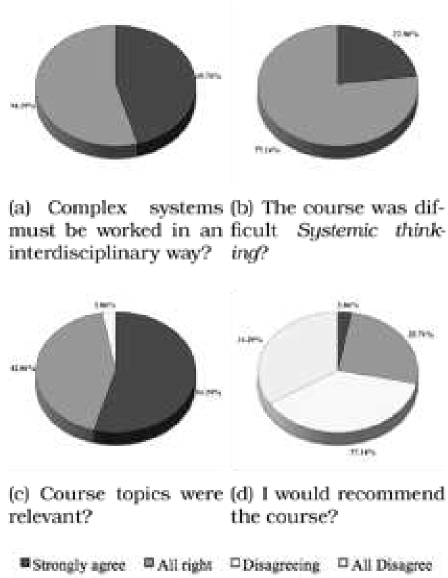
REPRESENTATION OF THE CALCULATION OBTAINED TEST *T* FOR DATA INDEPENDENT OF MODULE 2 VERSUS MODULE 3



At the end of all the work, the students were called to answer a four-question survey. Only 35 students attended and the results are shown in the graphs in Figure 22.

Figure 22

Results in the final interview



However, even though they did not get good grades in the course as the students expected, considered the importance of working with complex systems in an interdisciplinary manner; the subject seemed relevant to them, so they did not hesitate to recommend the course. In addition, the speaker, C. Gershenson, was very clear on the subjects he dealt with on complex systems.

Conclusions

The trajectory of learning in complexity sciences always goes hand in hand with the use of ICT. Remember that they were born with the appearance of computers. Therefore, the student has to access software to understand them, as it would be impossible to visualize these concepts with traditional tools.

The debate on the sciences of complexity and complex thinking is still ongoing. For example, Maldonado [74] British professor argued that it is dangerous for schools to implement a complex theory because complex sciences come from physical sciences and not from social and humanist sciences. However, some studies show how the tools allow to validate the data and, in this way, it insists on reformulating the paradigms. In the end, the complement of both is needed and not their revalidation separately.

The questionnaire presented in this paper allows to generate or get feedback from those learning strategies, particularly active learning, so that for a group of students, the teaching of methodological isomorphisms as an introduction to complex systems will be more efficient if motivational, affective, social interaction characteristics are taken into account, in the search for information and its processing.

The structure of this work can serve as a protocol for the design of active learning of methodological isomorphisms of the sciences of complexity in university students from the first semester and sociologists who seek to enter the study of complex phenomena using models and computer modeling. It can also be reproduced for other similar topics that help studies in complex systems.

As alternate lines of research, we propose generating strategies and protocols of the methodological isomorphisms applied to other types of pedagogical trends such as researchbased learning, challenge-based learning, and collaborative learning. However, this work can be adapted to other types of learning.

What are the strategies that allow the construction of learning of methodological isomorphism as part of the sciences of complexity among university students?

It will depend on the type of validated questionnaire of learning strategies according to the study topics, according to the result of the Cronbach Alpha of this proposal was obtained 0.9361, so that the questionnaire reflected to be suitable for this work in the study of the complex systems, particularly methodological isomorphisms.

In this sense, active learning helps strategy of teaching-learning of the proposed methodological isomorphisms. On the other hand, knowledge of reliable sources of information at the national and international levels must be known, *i.e.*, access to consultation of scientific reservoirs.

Is it possible to generate interdisciplinary work in university students? Are there limitations?

It is possible as long as the work plan includes methodological isomorphisms and access to introductory course materials on the sciences of complexity. Among the limitations is that the teacher who conducts this type of research, has to have introductory knowledge about the sciences of complexity and complex thinking and have collaborated interdisciplinarity in a team of work for the study of a complex phenomenon. In addition to tracking the student in their learning building process. On the other hand, it is very important that the student has access to the Internet in his academic area and that the teacher can have the group to clarify doubts.

Can a protocol based on the construction of active learning of methodological isomorphisms of the sciences of complexity be designed for university students?

This work showed that although 93% of students did not know the sciences of complexity and 85% did not consider interdisciplinarity important, a significant 69.27% in learning was achieved.

Groups	Average	Variance
What satisfies me most is to understand the contents in depth	3.51724138	0.32425892
Real learning is the most important thing for me in college.	3.68965517	0.28796128
When I study I do it with interest to learn.	3.37931034	0.37991531
I study so I don't let down my family and the people I care about.	2.48275862	1.86811857
I need other people - parents, friends, teachers etc. - to encourage me to study.	1.55172414	1.4446461
What I learn in some subjects I will be able to use in others and also in my personal future.	3.44827586	0.32183908
It is important that I learn the subjects because of the value they have for my training.	3.29310345	0.45644283
I think it is useful for me to learn the subjects of this course.	3.22413793	0.35238959
I consider it very important to understand the contents of the subjects.	3.55172414	0.32183908
My academic performance depends on my effort.	3.5	0.39473684
My academic performance depends on my ability.	2.94827586	0.96218996
My academic performance depends on luck.	0.86206897	1.03327284
My academic performance depends on the teachers.	2.24137931	0.92316999
My academic performance depends on my ability to organize.	3.12068966	0.56412583

Groups	Average	Variance
I am sure that I can understand even the most difficult contents of the subjects of this course.	3.0862069	0.60647308
I can learn the basic concepts taught in the different subjects.	3.32758621	0.32940109
I am capable of achieving in these studies what I propose.	3.39655172	0.41893527
I am convinced that I can master the skills that are taught in different subjects.	3.22413793	0.52782819
Intelligence is a set of skills that can be modified and increased with one's own effort and learning.	3.43103448	0.35480944
You either have intelligence or you don't, and you can't do any better.	1.36842105	1.80827068
I usually feel good physically.	2.82758621	0.70659407
I sleep and rest as much as necessary.	1.89655172	1.18209316
Usually my state of mind is positive and I feel good.	2.55172414	1.12885662
I maintain an appropriate working mood.	2.96551724	0.63036903
When I take an exam, I get very nervous.	2.39655172	1.29612825
When I have to speak in public I get very nervous.	2.43103448	1.61796733
While I'm taking an exam, I'm thinking about the consequences of failing.	2.32758621	1.55747126
I am able to relax and be calm in stressful situations such as exams, exhibitions or interventions in public.	2.27586207	1.25589837

Groups	Average	Variance
I know what my strengths and weaknesses are, when faced with learning the subjects.	3	0.73684211
I know the evaluation criteria with which the teachers are going to evaluate me in the different subjects.	2.93103448	0.97761645
I know what the objectives of the subjects are.	2.68965517	0.67392619
I plan my time to work on the subjects throughout the course.	2.24137931	1.09860859
I keep up to date with the study of the topics of the different subjects.	2.5	0.74561404
I only study before the exams.	2.36842105	1.30827068
I have a personal work and study schedule, outside of classes.	2.31034483	1.13006655
I realize when I do things right - in academic tasks - without having to wait for the teacher's grade.	3	0.84210526
When I see that my initial plans do not achieve the expected success, in the studies, I change them for other more adequate ones.	2.77586207	0.80852995
If necessary, I adapt my way of working to the requirements of the different teachers and subjects.	3.03508772	0.60588972
When I have done an exam, I know if it is wrong or right.	2.89655172	0.62068966
I spend more time and effort on difficult subjects.	3.0862069	0.78191168

Groups	Average	Variance
I try to learn new techniques, skills and procedures to study better and perform more.	2.68965517	0.98971567
If I have done badly in an exam because I have not studied well, I try to learn from my mistakes and study better next time.	3.25862069	0.75650333
When I have been given a bad grade on a job, I do my best to find out what was wrong and improve on it next time.	3.35087719	0.44611529
Work and study in a suitable place - light, temperature, ventilation, noise, materials needed by hand, etc.	2.51724138	1.02601331
I usually study in a place where I can concentrate on my work.	2.63793103	1.07713249
I make good use of the time I spend studying.	2.43103448	0.98638838
I create a study environment suitable for performance.	2.55172414	1.02359347
I try to study or do my class work with other classmates.	2.70689655	1.33363581
I usually comment on doubts regarding the contents of the class with my classmates.	2.60344828	1.33121597
I choose suitable partners for teamwork.	2.87931034	1.2307925
I get along with my classmates.	3.07017544	0.56641604
Teamwork stimulates me to keep going.	2.82758621	1.09255898
When I don't understand some of the content of a subject, I ask another classmate for help.	2.98275862	0.9646098

Groups	Average	Variance
I know where to get the necessary materials to study the subjects.	2.74137931	0.93194192
I am very good at the library and I know how to find the works I need.	2.51724138	1.23653962
I know how to use the newspaper library and find the articles I need.	2.06896552	1.08287961
I am not satisfied with the manual and/or the class notes, I look for and collect more information for the subjects.	2.22807018	1.32205514
I am able to select the necessary information to study the subjects with guarantee.	2.79310345	0.65819722
I select the information that I must work on in the subjects but I am not very clear if what I select is the right thing to have good grades.	2.46551724	0.99001815
I am able to separate the fundamental information from that which is not in order to prepare the subjects.	2.67241379	0.75045372
When I search the Internet, where there is so much material, I am able to recognize the documents that are fundamental to what I am working or studying.	3.05172414	0.61131276
When I study the subjects of the courses, I make a first reading that allows me to get an idea of what is fundamental.	2.93103448	0.6969147

Groups	Average	Variance
Before memorizing things, I read slowly in order to understand the content in depth.	3.05172414	0.71657592
When I don't understand something, I read it again until I get it right.	3.4137931	0.35208711
I take notes in class and am able to collect the information provided by the teacher.	3.18965517	0.57743497
When I study, I integrate information from different sources: class, readings, practical work, etc.	2.55172414	1.2692075
I expand the material given in class with other books, magazines, articles, etc.	2.12068966	1.44131881
I try to understand the content of the subjects by establishing relationships between the recommended books or readings and the concepts presented in class.	2.56896552	1.05656382
I make simple graphs, outlines or works to organize the subject of study.	2.17241379	1.44343618
I make outlines with the important ideas of the themes.	1.89655172	1.39261948
I make summaries of the material I have to study.	2.5	1.27192982
To study, I select the key concepts of the topic and I relate them by means of concept maps or other procedures.	2.60344828	1.26104053
I critically analyze the concepts and theories presented to me by the teachers.	2.86206897	0.68239564

Groups	Average	Variance
In certain subjects, once I have studied them and gone into them in depth, I am capable of contributing personal ideas and justifying them.	2.79310345	1.18451301
I ask myself questions about the things I hear, read and study, to see if I find them convincing.	3.0862069	0.78191168
When a theory, interpretation or conclusion is presented in class or in books, I try to see if there are good arguments to support it.	2.75862069	1.06352087
When I hear or read a statement, I think of other possible alternatives.	2.92982456	0.85213033
In order to learn things, I simply repeat them over and over again.	2.5	1.30701754
I learn things by heart, even if I do not understand them.	1.98245614	1.37468672
When I have to learn things by heart (word lists, names, dates...), I organize them according to some criteria in order to learn them more easily (for example, word families).	2.51724138	1.27162734
In order to remember what I have studied, I help myself with outlines or summaries made with my words, which help me to retain the contents better.	2.5862069	1.43980641
In order to remember what I have studied, I use diagrams or summaries made with my palettes that help me to retain the contents better.	2.72413793	1.32607381

Groups	Average	Variance
I make use of key words that I studied and learned, to remember the contents related to them.	3	0.80701754
Before I begin to speak or write, I think and prepare mentally what I am going to say or write.	2.89655172	1.14700544
When answering an exam, before writing, I remember everything I can, then I order it or make an obituary or script and finally I develop it.	2.70689655	0.9476709
I use what I have learned at the university in everyday situations.	3.03448276	0.59528131
As far as possible, I use what I have learned in one subject, among other things.	3.10344828	0.48033878
When I have to face new tasks, I remember what I already know and have experienced in order to apply it, if I can, to that new situation.	3.24137931	0.36176649

SOCIAL SEQUENCE ANALYSIS FOR REVEALING THE COMPLEX SOCIAL WEB

Damian Valdés Santiago
María del Carmen Pría Barros

Abstract

We present the Social Sequence Analysis (SSA) technique as a methodology for studying and analyzing social phenomena and review the literature and applications of social sequence analysis, including the pros and cons, methodological challenges, and available software. SSA is a quantitative technique that works with qualitative and quantitative data, allowing us to analyze it from a complex perspective, visualizing the individual in different contexts or levels according to the input data.

What is a social sequence?

Sequential phenomena fill our world (*i.e.*, things that happen following certain order). In biology, the famous DNA sequence has four elements: *A* (adenine), *G* (guanine), *C* (cytosine), and *U* (uracil). Abbott and Forrest in [75] proposed to analyze social phenomena from a sequential perspective, mimicking the DNA sequences. Since then, this technique has shown its possibilities by describing multiple social phenomena and has been applied in a variety of contexts [76–79].

According to Katherine Stovel [80], social sequences are regularities empirically observed, whose elements' order depends on time. Hence, social sequences can be described as ordered lists of states or categorical variables measured in a temporal axis.

For example, let us take the educational trajectory of a Cuban sample observed during 18 years. We can define sequences with five states[1]: primary educational level (*P*), secondary educational level (*S*), middle educational level (*MS*), military service (*SM*), and university (*U*). With this set of states or alphabet, we can build social sequences like the ones in Table 12. The symbol "–" refers to missing data. This information can be cross-tabulated with other socio-demographic (quantitative or qualitative) variables. Those sequences can also be visualized in a graphic (see Figure 23) where each color refers to a different state.

FIGURE 23

PLOTTING SEQUENCES IN TABLE 12 WHERE EACH STATE IN THE ALPHABET IS REPRESENTED BY A DIFFERENT COLOR. GREEN COLOR CORRESPONDS TO MISSING DATA

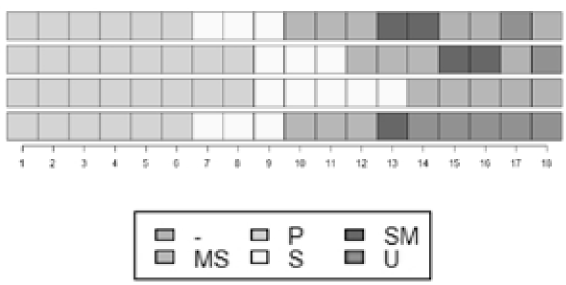


TABLE 12

SOCIAL SEQUENCES OF EDUCATIONAL TRAJECTORIES FOR FOUR CUBANS OVER 18 YEARS

ID	1	2	3	4	5	6	7	8	9
1	P	P	P	P	P	P	S	S	S
2	P	P	P	P	P	P	P	P	S
3	P	P	P	P	P	P	P	P	S
4	P	P	P	P	P	P	S	S	S
ID	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
1	MS	MS	MS	SM	U	U	U	U	U
2	S	S	S	S	MS	MS	MS	–	–
3	S	S	MS	MS	MS	SM	SM	–	U
4	MS	MS	MS	SM	SM	–	–	U	–

[1] Here we present a simplification of the Educational Cuban System, for illustration purposes. Military service is included because the boys have to enroll in the active service for one or two years.

Key questions in an SSA

The goal of an SSA is to detect patterns in social sequences. To do that, we need to define a pattern, determine when this pattern is socially meaningful or not, and how to detect it quantitatively [81]. Answering those questions is not an easy task. We cannot assume that the answers will be the same for describing all social phenomena, but finding and analyzing those patterns could be useful for social scientists, as we will see in the following sections.

To perform an SSA, we need to know our sequences' characteristics (*i.e.*, alphabet, size, sample size, and how frequent are the data gathered, among others). Statistical measures over the sequences, plots to interpret them, quantitative measures to assess the sequences' similarity, and the relation between explanatory variables (co-variables) and sequences are techniques used in an SSA.

How to perform an SSA?

As described above, a social sequence represents a person's trajectory concerning a facet of his/her life. In each trajectory and with a certain periodicity, a series of states can be reached, and they are codified with simple characters.

Algorithms are applied to determine the similarity between all the pairs of sequences in the population under study. Then, the sequences are grouped, and the specialist carries out the analysis. This procedure is known as the *Core Program* [75, 81]. In this scheme, the Optimal Matching algorithm is used to compute the similarity between the sequences, and Ward's algorithm to cluster them [77].

Therefore, it is necessary to decide which of the person's trajectories will be coded in sequences and how this will be done. This process involves establishing an alphabet and the periodicity to gather the data (which can be in fixed or variable time intervals). The data must be taken from the same population at the same time points. The comparison step requires the choice of a mathematical similarity measure, taking into account sociological reasons, defining when a person is "more likely" than another to adopt the trajectory under consideration. In the example shown in Table 12 it can be noted that, under certain criteria, individual 1 could be considered more similar to individual 4 than to individual 2, given that they share the same states in the first 13 years.

The distance or similarity between sequences is calculated with different metrics: Levenshtein distance, Hamming distance, among others. A comparison of the sociological relevance of metrics can be found in Studer's research [82].

Computing similarity between all persons in the sample allows us to obtain a matrix or table of similarities on which a hierarchical grouping algorithm is run. This grouping gathers individuals into clusters that share characteristics with respect to the trajectory under consideration. In the example of Table 12, we have short sequences that are easy to analyze. In general, longitudinal study sequences are long, and algorithms for automatic processing are required.

Of course, the clustering algorithms are subject to classification error. We want to know the optimal number of clusters and have well-differentiated groups, where the elements are as similar as possible. There are several measures to evaluate the quality of a clustering algorithm. One of them is the Silhouette Width (SW) [83], where values close to zero indicate an overlap between clusters, larger positive values indicate that the clusters are denser and well separated.

The procedure for evaluating the clustering quality consists of performing clustering with a variable number of groups and then computing the SW in each iteration. The number of groups that obtains the highest SW, above a threshold value, is taken as definitive. Figure 24 shows that when the number of groups (horizontal axis) increases, the SW values (vertical axis) decreases. Suitable numbers of groups are marked in red[2].

After clustering, groups of individuals can be analyzed within the groups in terms of the defining socio-demographic variables, as shown in Figure 25.

[2] The selection of the optimal number of groups in a clustering algorithm is beyond the scope of this chapter, so we invite the interested reader to consult the literature on the subject [83].

Figure 24
SW behavior when varying the number of clusters in a clustering algorithm

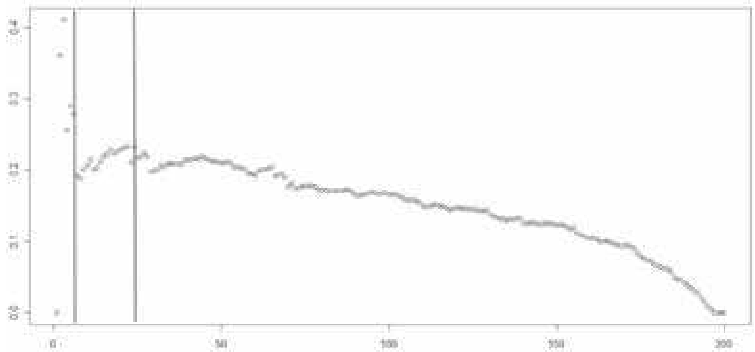
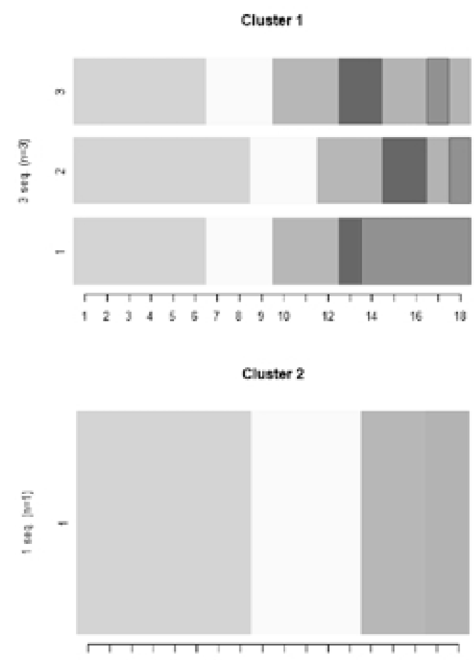


Figure 25
Two groups clustering over the sequences in Table 12. Notice that people who went to university were grouped in the first cluster, while the second cluster grouped people that didn't



How to plot sequences?

There are several graphics to plot and analyze sequences. They are all based on the representation of the sequences using different colors for each state of the alphabet. The primary way of graphing individual sequences is to place them on top of another as recorded in the sample; this approach is known as the sequence index plot [84]. When the number of sequences is large, these charts become difficult to interpret. To address this problem, we can order the sequences according to a covariate's values, such as age. A good option is the distance to the most frequent sequence.

Another type of representation consists of plotting the sequences by their frequency (sequence frequency plot), in increasing or decreasing order. In this type of graph the width of the sequences is proportional to the frequency of each sequence [84].

There are two types of statistical measures on sequences that can be plotted: transversal statistics, which are based on the distribution of states at each position or time point in the sequences, and longitudinal statistics, which express how the sequences are constituted (*i.e.* how complex they are or not.) Cross-sectional statistics graphs include state distribution, state distribution entropy and state modal distribution. In the case of the longitudinal studies, the number of states and duration, the number of transitions, the longitudinal entropy and the complexity index are used [85].

For space reasons, we only show a few examples of these graphs and their interpretation below. We invite interested readers to consult additional sources, such as [81, 86, 87].

What are the methodological challenges in an SSA?

An SSA presents methodological challenges related to data, sequence construction or coding, sample and sequence size (number of states and periodicity), handling of missing data and clustering algorithm issues, among others.

An SSA requires longitudinal qualitative data that are collected retrospectively and annually, as monthly data collection increases the length of sequences, but decreases the probability of sequence variation. There are several ways of coding data into sequences that should be chosen depending on the problem to be solved: typical, multi-channel and hybrid form [85].

The size of the sequences should be chosen according to the probability of change in them. It is recommended to use sequences with at least 25 elements and the length of the shortest sequence should be at least 70% of the length of the longest sequence [88]. The sample size has a small effect, although for large samples the computation may require a lot of time and memory.

Missing data are data that could not be taken in a longitudinal study for various reasons. Within an SSA you can work with missing data in several ways: consider the missing data as another state in the sequence alphabet, eliminate all missing data, or assign values to the missing data taking into account imputation criteria. For example, you can replace missing data at a certain position in time with the modal state for that position. In the case of the option to remove items where the missing data appears, this may be detrimental to sequence size-sensitive methods [81]. Missing data can substantially worsen the results, but only if the percentage of these data is very high. At most 30% of missing data is recommended [88].

Incorrect clustering depends mainly on the size of the sequence. The sample size does not substantially affect the quality of the clusters. Ward's method produces the best solutions [88].

Is there software to make SSA?

Unfortunately, there is still no "user-friendly" software that allows social scientists to use SSA easily [81]. However, there are statistical software packages such as Stata and a software library called *TraMineR* [84] in the *R* programming language.

TraMineR allows the manipulation, description, and interpretation of sequences, and in general, the mining of sequential data for the social sciences. This library allows to import data from SPSS and Excel files, accepts different representations of sequences, and has tools to convert between formats. *TraMineR* presents several functions to compute distances between sequences, perform dissimilarity analysis, recognize the most frequent subsequences, and identify the most representative ones [85]. The library has local support and discussion forums on the Internet.

SSA AND COMPLEXITY

Complex systems are formed by agents, minor, finite, and simple elements that make up a complex machinery of infinite meanings. Similarly, in complex systems, the whole is more than the sum of its parts (the mentioned agents).

These systems function as a dynamic network that adapts to new contexts and situations. The rules of this dynamical system, in the form of a network, are emerging and implicit, so that it is difficult or almost impossible to explain its functioning precisely. Complex systems are self-organizing, and it is not possible to recognize a hierarchy or central node that organizes the operation.

Considering society as a complex system, SSA makes it possible to study this system and obtain results not attainable with other methods. For example, certain social elements are stochastically related so that they appear in vis-a-vis similar positions that can be detected in an SSA. Although different actors may experience social elements in a different order, similar sequence patterns may emerge in individuals that can be detected in an SSA. Specific social elements and experiences (depending on the order in which they occur) indirectly connect agents to each other. The actors connect the elements of the sequence in a network that can be obtained through an SSA.

THE LOGISTICAL MODEL OF A SOCIO-SYMBOLIC ECOSYSTEM (LSEM)

Luis E. Castro Solís
Milton Aragón Palacios

Abstract

In 1992, Luis Castro proposed an Ecosystem Logistical Model (ELM) in code written on one of the first personal desktop computers. Twenty-eight years later, the model is rescued by the socio-ecological systems theory and second-generation systems theory. To decipher the meaning of actions that emerge from the interaction of components, it will be re-interpreted as a computational socio-ecological model, seeking to build a reflection on these types of models, especially around the concept of the process' aura, understood here as the emerging meaning linked to system's symbols interaction and the metaphors that can symbolize reality. Furthermore, the model represents an early contribution to the state of the art of computational sociology.

Describing the Logistic SocioSymbolic Ecosystem Model (LSEM)

The LSE Model materialized as a code in the Borland's TurboPascal-V language for the IBM Intel80286 microprocessor used by PC-ATs (see "ecosim.pas" source code at https://github.com/GISS-droid/ELM), written 28 years ago by Luis Castro, to propose it as thesis's research project on Civil Engineering (as stated in a letter, dated June 22, 1992, addressed by Castro to UAdeC Faculty's Dean). However, for various reasons, this did not happen, and it was abandoned since then.

Structures

The program's objective is to process the content of two boards, or matrix-type data structures, of 50 20 cells: T-Medium (*T*) and FMedium (*F*), under processes regulated by a set *H* of constants.

T Medium

T represents the socio-semiotic system or symbolic exchange space of *T*-beings, defined by attributes in a register, initially stated by the user. Considering that object-oriented programming had not yet been born, the statement in the type declaration (see Figure 26) may be recognized as an implicit object-oriented programming paradigm already present in the code.

Figure 26

Type declaration to define the *T* and *F* objects

```
type serT =  record
             Tipo:char;
             Cmt   :integer;
             Cmv   :integer;
             Crp   :integer;
             Edad  :integer;
             Status:real;
             end;
   medioT = array[1..max_x, 1..max_y] of serT;
   medioF = array[1..max_x, 1..max_y] of real;
```

Where:

Tipo = Type of entity in the trophic pyramid = [*P, H, C, D*].
Cmt = Maintenance coefficient = % of energy spent on endometabolism.
Cmv = Mobility coefficient = (0, 1, 2, 3, 4).
Crp = Reproduction coefficient = Frequency (active cycles).
Edad = Age (active cycles). Status = Energy value ≥ 0.

The program allows a limited and predefined number of configurable entity types by modifying the attribute values in the InitConstants procedure (see Figure 27) that controls its behavior. A later enhancement contains a configuration interface for entities type and characteristics (see “ecosim2.pas” source code at [89]). Those symbolic beings interact with each other and with the substrate, *F*-medium, according to a predefined set of rules; although there is no reason why the rules were not configurable as well, that interface was never implemented.

Figure 27

InitConstants subroutine. Its purpose is to define the values of the attributes of the *T* entities

```
Procedure InitConstants(var tipos:chr4; var
Cmet,Cmov,Crep,EdadM:int4);
begin
tipos[1]:='P'; tipos[2]:='H'; tipos[3]:='C'; tipos[4]:='D';
Cmet[1]:=50;   Cmet[2]:=55;   Cmet[3]:=55;   Cmet[4]:=60;
Cmov[1]:=0;    Cmov[2]:=4;    Cmov[3]:=4;    Cmov[4]:=4;
Crep[1]:=2;    Crep[2]:=6;    Crep[3]:=5;    Crep[4]:=4;
EdadM[1]:=10;  EdadM[2]:=12;  EdadM[3]:=14;  EdadM[4]:=16;
end;
```

F Medium

F represents the substrate, the medium, or even better, the environment of the *T*-beings, each of their cells defined by randomly assigned initial values according to a Uniform (0, 1) distribution.

Set *T*

Additionally to the two previous structures, there is in the program a set of constant parameters that serve as regulators of communicative codes, is valid to say, the coded numeric information that will be added, in some preconceived way, to the status value of the active cells, in both *T* and *F* structures.

From an ecological perspective, we may say that *InitialE* constant is the initial code to couple to each entity, *Light* constant is the interaction of codes for autotrophs, *InputE* constant is the energy input code for autotrophs, *Rm* parameter is the coefficient of return to *F*-medium at death, *Fr* parameter is the frequency of feedback towards *F*-medium, while other parameters that regulate the interaction between *T* and *F* mediums, such as the *CriticalAbundance* (AbundanciaC), that determines the sign of addition in the feedback phase to try to simulate the “aridity” of the environment and the *CriticalGoodness* (BondadC), that determines the eligibility of a neighboring cell to interact with the active cell.

More properly, these operational inputs, in the process of updating the information of the active cell, can be conceived as an analogy of the hormonal system for a symbolic metabolism of sense (decision, exchange, feedback of meaning, produced in the synthetic ecosystem), and its values, depending on whether they are low or high, will notably influence the acceleration of flows there: the rate of expansion and colonization (which appears as certain inertia), the resilience of the *T*-entity, and the spatial selection of interacting agents in the model, Figure 28.

FIGURE 28

SYSTEM OPERATIONAL INPUTS: SET *H*

```
const max_x  = 50;
      max_y  = 20;        {grid dimenssions}
    InputE   = 5;         {autotroph médium input energy}
    Luz      = 500;       {autotroph ligth energy}
 Maxciclos   = 30000;     {max number of mili cycles}
 InitialE    = 1000;      {inital energy neo-born}
 Fr          = 1000;      {feedback frecuency}
 BondadC     = 0.5;       {critical energy factor}
 AbundanciaC= 0.5;        {critical food factor}
 Rm          = 0.70;      {return energy on death}
```

The structures, described up to here, allow us to analogically build communicational interactions for a symbolic ecology of human language. Hence, for this purpose, refer to communicative couplings that allow the operational closure of the socio-semiotic system [90, 91].

Processes

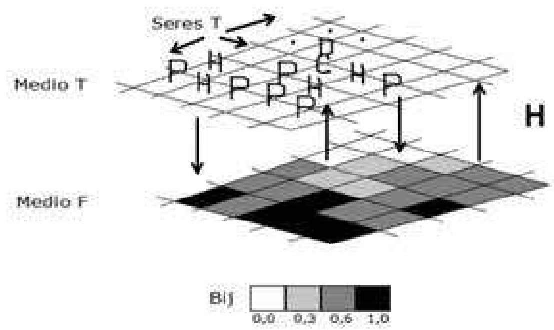
After initialization, the communicative interchanges between the randomly selected *T*-entities in the board, are simulated during a large number of milicycles (150, 000) at a rate of 1 active entity per milicycle, and, since the board has 1000 cells, in the development of a typical run, any *T*-entity may interact about 150 times in the course of the simulation.

The decisions and actions of the active *T*-entity, are determined through coded rationality called in “application code” (see source code for details [89]) comprising energy acquisition processes, whereby the qualifier "logistic" in the model name, seems to be adequate.

The simulation proceeds along two general stages, Phase-I: interaction of the active *T*-entity and, Phase-II: feedback to the *F*-medium.

Phase I. In each milicycle, the information in the active cell updates its energy value (*Status* attribute) by coupling the information with an adjacent cell, also conveniently selected based on its state and environment, through an adequate application code operation, that allows for the update (see source code for details) which, at once, is modulated by the *Bij* value on the corresponding cell in the *F*-medium, Figure 29.

Figure 29
Phase I: *F* - *H* modulated *T*-interaction



Given [*i, j*], the cell coordinates of the active entity randomly selected to interact, the *Ri* operations are:

a) *Birth*. There are two ways in which a symbol enters the niche [*k, l*] of the board: because the experimenter places it in that niche when initializing the model, or when the entity [*i, j*] is reproduced (see *C*).
b) *Aging*. The age [*milicycles*] of the active entity (*i, j*) is increased by 1.
c) *Death*. If the active entity (*i, j*) reaches its maximum age, a fraction (*Rm*) of its energy (*Status* value) is returned to medium *F*

and the entity is removed from the system; another form of natural death occurs if the energy value of the active entity (*i, j*) is null, so the entity is removed from the system, without return to the physical environment. An entity is also removed from the system when it is "eaten" by a predator and a fraction of its energy goes to the predator.

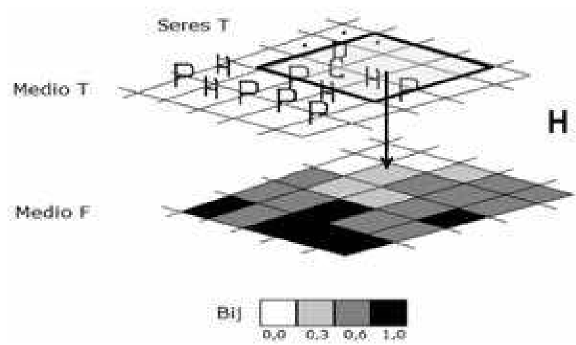
d) *Reproduction and herd instinct*. If it has sufficient energy and in phase with its reproductive cycle, the active entity (*i, j*) generates a descendant in the cell (*k, l*) adjacent to the most favorable empty adjacent cell, that is, the one with the best aura, is worth to say, highest *Bkl* value on the corresponding *F* -medium cell, among the possible ones.

e) *Energy gain or loss*. The active entity (*i, j*) mobile and trophically higher than the one located in the adjacent cell (*k, l*) with the best aura, this criterion could be easily inverted to ingest the weakest, devours it, adding it to its energy (gain exogenous) and subtracting its energy consumed metabolically (endogenous consumption). If the active entity (*i, j*) is trophically inferior to the entity (*k, l*), the operation is done in reverse, being devoured. If there is no adjacent food entity, the active entity (*i, j*) loses energy consumed when moving. If the entity (*i, j*) is not mobile (plant, *P*), it synthesizes food from the energy input and expends energy by its endogenous metabolism. This information is modulated with (multiplied by) the corresponding B_{ij} value of the *F*- medium. Arguably "the entity selects the box that offers the greatest energy gain", taking into account a) the possible interactions, b) the physical environment.

f) *Movement*. The active entity (*i, j*) occupies the adjacent cell selected for interaction (*k, l*), the one with the best aura. Arguably "the entity moves to the best accessible location".

Phase II. Each *Fr* milicycles (1000) the state of the *F*-medium is recalculated, cell by cell, as a *T F* structures feedback, based on the average energy of each group of entities in the *T* -medium, around the cell [*i, j*], Figure 30.

Figure 30
Phase II: Feedback $T \to F : H$



The values of *F* will be recalculated based on the values of *T*; the sum of the status (energy value) of the four side cells to the current cell divided by 400 (or other adequate value) is taken, and if this value is greater (or less) than a certain predefined value (AbundanciaC), it is added or subtracted, to the actual value in *F*, which is then re-normalized to values in the range [0, 1]. Therefore, *F* is an arbitrarily bounded distribution function.

Revisiting the model LSEM

Here the model is revisited, from a modern systems perspective, to go towards a reflection on its content.

Structures

T. Each cell of the *T* stores the state of an information unit corresponding to a symbolic entity in the world of information exchanges around itself (being *T*): Type, Age, a vector of vital characteristics (symbol, longevity, fertility, mobility) and its State: Status (# energy).

F. For its part, each cell of the *F* stores the value of the state of the environment, with a real [0, 1] value, calculated periodically based on its state and the state of *T*, which is, symbolically, a measurement (an observation) of the effect that emerges or emanates from *T* compared to the random initial value (background noise).

H. The set *H* regulates the rigidity of the system, that is, the speed of information dispersion and the amount of information available. Sets with low values (noting that it would be equivalent to high values of the feedback frequency given in milicycles) tend to form islands and unsustainable patches, which we could interpret, in an ecological sense, as high ecosystem aridity, while for high values an explosion (flourishing) occurs, of the information codes by the board and the frequency of interactions. Somehow, the set *H* resembles as a basal or metabolic regulator of processes: A control of acceleration of model flows.

Interactions or links of information

Phase I. Let *R* be a set of *n* operations and operators (application codes or, more simply, interaction rules) and *C* a multi-selector such that the type *Ri* corresponds to the operation *Ri*. In each simulation cycle, the *Status* of the active cell *T*[*i, j*] is recalculated with rule *Ri*; the active cell is selected randomly, for a large number of milicycles, at the rate of one active cell per milicycle: the communication occurs any time a cell is turned on.

Since Active cell [*i, j*]-values are selected randomly and the probability that more than one entity is active in the cycle is null, the pattern of active cells on the board corresponds closely to a Markovian field, it is worth to say, the sequence of *T*-ents moving on the board appears as a Brownian noise.

During operation under pseudo-steady-state saturated system conditions, when the born rate equals the death rate, arguably, the rules follow the sequence:

1. Select randomly Active cell: $(i, j) \leftarrow U(1 \ldots 20; 1 \ldots 50)$
2. Select Operation: $Ri = F(T[i, j], H)$: $Ri \leftarrow f(Ci, T[i, j]: H)$
3. Perform Operation: $T[i, j] \leftarrow g(T[i, j] \cdot F[i, j], Ri)$

As a side note, there appears the possibility of representing the concept of time in the model, by saying how many interactions constitute a unit of time, it is equivalent to defining a unit frequency, or even better, an interaction speed, *i.e.*, if 1 s = 1000 milicycles, then we refer to the frequency of 1000 milicycles/s and since the board has 1000 cells, it is equivalent to process, if not all cells, at least a number equivalent to the maximum number of entities on a board simulation, that is to say, 1 board/s; a value that may change for more or less "accelerated" systems. Thus, "one day" of simulation (86*,* 400*s*) would be equivalent to 86*,* 400*,* 000 milicycles.

To find the best information coupling, symbolic interaction is calculated teleologically using coded rules, in this sense, the subjects of the model are efficient or satisfy logistical behavior, understood as the directed search for the permanence of its code in the system, supposedly granted by the teleology of the given rules, that is, an informed subject (*D* in the model), who can differentiate and designate his "information", will go to the adjacent cell with the best aura, that closest to the climax in their neighbor (which implies the presence of a decision node in the source code) since the individual with the most consumable information (with the greatest amount of energy) lives; if this is not possible, it moves randomly and connects with whatever be on its way. It could be said that the rules of the system are expressed as an observational behavior understandable as a synthetic vitality.

Once the consumptive use of their encrypted information is subtracted, too, *T*-ents will only "reproduce" if the conditions of their information are better than a certain critical value. When "feeding", if compared to their selected neighbor is at a trophic disadvantage, the situation is reversed, and their information is not socially generalized but disappears from the system, giving a certain fraction of its information to the receiver. Ultimately, if not perish, then "dies" when it reaches a certain age, that is, its code disappears from the socio-semiotic system.

In summary, Phase-I corresponds to a period of production of meaning and maintenance of information that allows the evolution of the "synthetic ecosystem" on the board, that is to say, changes in the age distribution and spatial pattern of the *T*-ents, evidenced in the value of their attributes.

Phase 2. *Periodic feedback towards F.* The foregoing is currently considered a mapping or monitoring of the status or condition of *T*, globalized by a value between 0 and 1 in *F*, in other words, as the aura of *T*: the probability of making sense in that cell. This has been observed from the confirmation of hypothesis *H*1: For rules *R*, *C*, given *T* (normed) and uniform *F* (0*,* 1), when applying the interactions during several cycles, we will have a distribution of non-uniform values in *F*. In other words, symbolic life will have a noticeable effect on life capacity.

That effect is the Aura of *T*: the *F*-medium distribution changes from being a uniform, and since the processing corresponds to the sum of the average of values of a random variable, to normalize, arguably around a *Normal* ($u = 1$, $\sigma^2 = 0$), can be said, the constant value 1; the observations (of the observations) of the system seem to confirm this conjecture.

This phase corresponds to a period of spatial expansion in the development of the artificial communicative society that occurs on the simulation board. It can be said from the fact that it is observable that, when the feedback frequency is set to 1 per epoch (*Fr* = 30000 milicycles) corresponding to a low feedback regime, it is visible how the communicative society is maintained (there are sustainable interactions on the board), but without expansion or colonization of the modeling space, while setting *Fr* to low values (high feedback regime) the expansion of the synthetic socio-ecosystem occurs in a pulsating form, naturally synchronized with that value *Fr*. Setting *Fr* at 1000 milicycles, gives the simulated process a continuous organic growth appearance.

Observing the behavior of the LSEM

To observe the aggregate behavior of the symbolic community of *T*-ents in the LSEM, the additional MapAura routine (see ecosimX.pas in [89]) was added aimed at observing the information values, Status in medium *T* and Aura in medium *F*. In a post-process phase, the collected data were conventionally graphed with MS-Excel® to produce the Population time series, Aura (*F*-medium) and Codes (*T*-medium) maps in this section.

Typically, there are three observed "generic" behaviors, naturally, depending on the values of the operating parameters and the distribution and size of the symbolic populations, appear particular behaviors.

This monitoring appears as an observation of observation, or second-order cybernetics since it is the (contemporary) analysis of the matrices that, in turn, observe the symbolic ecosystem, and the meaning-sharing behavior patterns, according to semiotic socio-ecological metaphors.

A symbolically generalized community of "Issuers"

The number of Issuing entities, *P*, increases until the system is saturated according to a pattern of exponential growth in a limited environment (sigmoid or logistical, see Figure 31), then it oscillates around this value, regulated by its processes of birth, death, and synthesis of the information. The auras pattern (*F*-medium) saturates the map for 1's, indicating the climax, Figures 32 and 33.

Figure 31

Logistic saturation

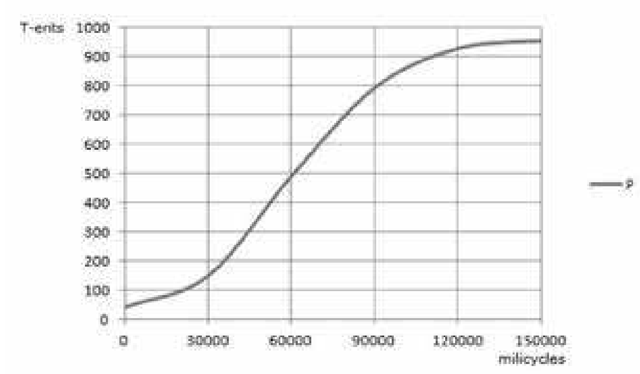


FIGURE 32

MAPPING A PRODUCTION RUN OF THE LOGISTICAL SATURATION ARCHETYPE ($1CT = 10^3$) CYCLES

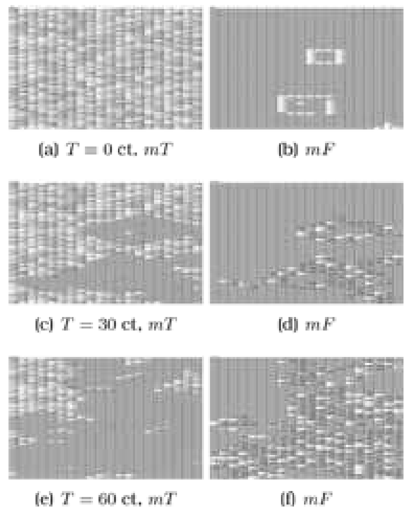
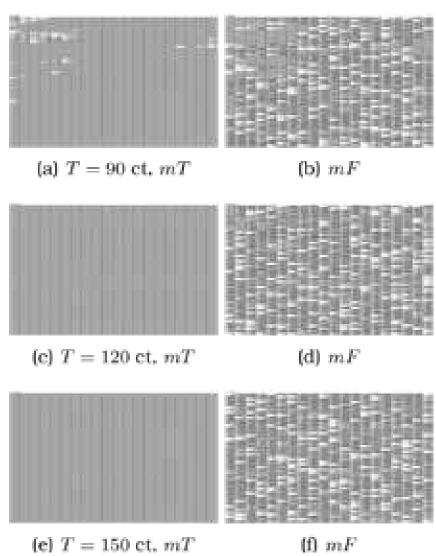


FIGURE 33

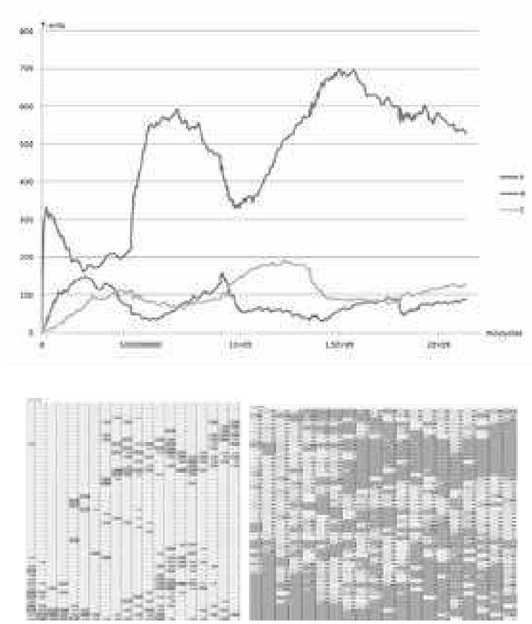
MAPPING A PRODUCTION RUN OF THE LOGISTICAL SATURATION ARCHETYPE ($1CT = 10^3$) CYCLES: MT (LEFT) AND MF (RIGHT)



Interacting communities in a linguistic trophoxic network

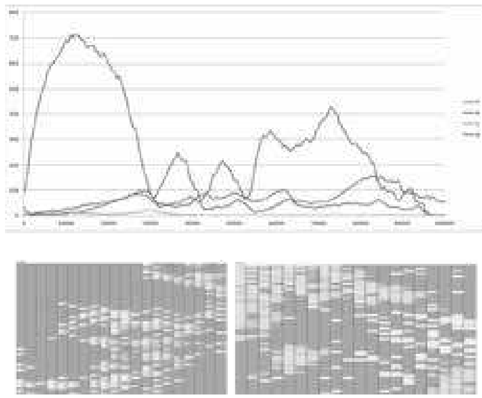
The number of entities varies according to Lotka-Volterra patterns, described elsewhere [92], used to characterize the interaction of the ecosystem populations, with time interspersed cycles of growth and degrowth, in Emitters, *P*, and Receivers, *H*; after a certain additional delay, the number of reported Subjects, *C*, up in the trophic web, increase, with the consequent decrease in the number of emitters, in lower trophic level, and so, until saturating the system, and, perhaps, a pseudo-steady-state. The aura pattern appears in moving patches of variable magnitude, 1 in the regions with the highest communicative coupling, see Figure 34.

Figure 34
Mapping of the linguistic trophoxic pyramid archetype



Another example of a linguistic trophoxic network with four *T*-ents types (*P, H, C, D*) which exhibits a Lotka-Volterra interaction and collapse, see Figure 35.

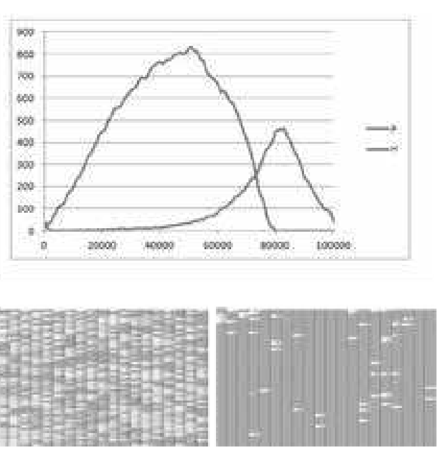
FIGURE 35
ARCHETYPE MAPPING OF A LINGUISTIC TROPHOXIC PYRAMID
(AURA AT 20000 MILICYCLES)



Collapse: Issuers and informed subjects

The number of issuers grows, with the consequent increase in reported subjects, until the number of reported subjects surpasses the issuers and then themselves, collapsing the symbolic socio-ecologic ecosystem. The saturated aura pattern tending to 1's denotes the imprint in the significant space of the interactions that occurred, see Figure 36.

FIGURE 36
ARCHETYPE MAPPING OF COLLAPSE



Initial reflections

The T-medium as a symbolic socio-ecology and the F-medium as a metric of the production of sense of the social aura

In the *T*-medium a "becoming" of the entities that "couple" it develops, according to general rules, yes, but also to circumstantial aspects related to neighboring entities, such as the "aura" of the semiosphere. It could be said, metaphorically, that stratum *T* is the data structure that defines the semiosphere in which they "couple information", while stratum *F* is the network of nodes that census the global condition of stratum *T* after many exchanges, and which happens to be the environment of the socio-symbolic system of interrelations, to some extent ecologically self-distributed according to the operating rules of its linguistic tropholaxis. In this sense, *F* happens to be a mapping of the condition of *T*. An aura? What is interesting here is that the value is not updated with a direct parametric formula but through the process of simulating interactions, implicitly capturing the systemic effect.

An interpretation of the meaning that the basal structure present in the model, the medium-*F*, could have from a perspective of modern systems related to an ecological sociology, that is, to limiting or enabling processes of symbolic communicative interactions, from the monitoring of the status of medium-*T* is that the information modeled by medium-*F* appears as a distribution function of the probability of support of "information couplings". The medium *F* stores the values (real numbers, between (0, 1)) of the symbolic support status in each cell of the model, the basic rule of operation for the values of the medium *F* is such that, if a cell is at 0, then It is turned off, although not irretrievably, since subsequent feedback can reactivate it. If it is greater than 1, it will saturate at value 1.

We could say that this value is roughly equivalent to an arbitrary distribution function, which indicates the global probability that it has that cell of sustaining life, where 0 represents a "poor" condition incapable of functioning as a medium and 1 a "climax" or optimal condition of the medium.

Here the concept of medium or semiosphere corresponds to an evaluation of the status of the medium, the "footprint" on the environment, the modification of what is not the system, due to the effect of the system, organically equivalent to what we could call the "aura" of the system from which the encodings that allow the coupling of information emerge. Quantitatively, what is observed when observing *F* is the probability of "meaningful communication" in each cell of the automaton, product of the coupling (interactions) "occurring" (at a certain speed) in the discrete space of the "subjects" –the symbol of the model.

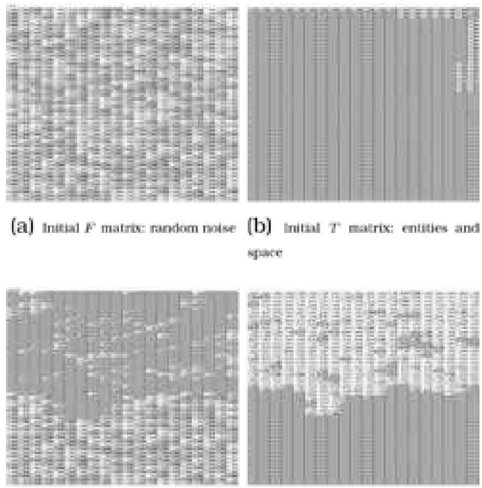
The artificial "socially generalized community" that develops in space *T* and is mapped in space *F* has rules for social interaction *R*. We would say, then, that computational socioecology occurs here. It could be said that the LSEM is a socio-ecological model (communications between symbolic entities) based on agents, where the environment contains the auric signal. Although the systemic aura cannot be observed from within the system, since it is a signal towards the environment, expressed in the environment, here its "observation" appears as an emission value (observation of an internal variable that emits the signal) during the operation that is added to the indifferent value (initial uniform distribution) or, if you want, chaotic noise, the value of the "semic" footprint of the system, corresponding to a new non-uniform distribution, is printed (imprinted): it means that something (the interactions) that disturbed the fund of "signifiers" was communicated and that once that meaning is revealed, there is an imprint or signature on the "significant" space.

When the simulation corresponds to a climax state, the correlate is highly visible, that is even expected, enrichment of 1 and observable correlative pattern, the interesting thing is that when the system reaches a state of collapse, totally devoid of interactions, it is still appreciated, as if it were those fantastic Kirlian structures, if I am allowed the excess, the trace of the interactions that were, in the indifferent background noise, there is an inversion in the morphogenesis of the 1's and there is an enrichment in saturated values (1's) that is abnormal, as can be seen by comparing the distribution of numbers in *F*, at the beginning and at the end (for the case illustrated below, and which I interpret as there are no interactions, but there is the imprint of the interactions or aura).

The following images are frames of the simulation as it progressed from its initial state to the end through steps (*a*) – (*d*), Figures 37 and 38.

Figure 37

Mapping of the Aura of the socio-symbolic ecosystem

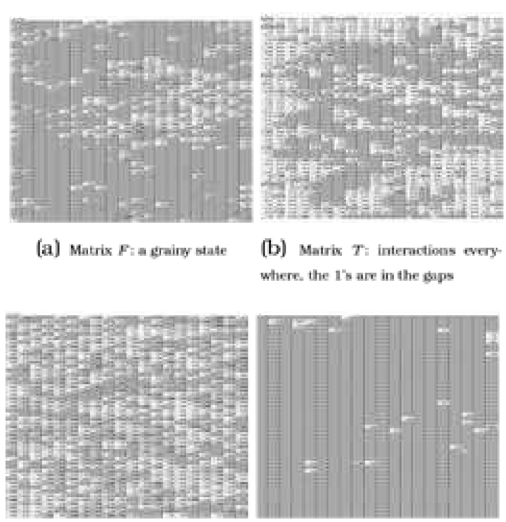


(a) Initial F matrix: random noise (b) Initial T matrix: entities and space

(c) Matrix F: "thermal" footprint of an intermediate state (d) Matrix T: symbols interacting in the communications space

Figure 38

Mapping of the Aura of the socio-symbolic ecosystem



(a) Matrix F: a grainy state (b) Matrix T: interactions everywhere, the 1's are in the gaps

(c) Matrix F: enrichment of 1's (d) Matrix T: no interactions, emptied

Although a "current" module was written to observe the content of *F*, the interesting thing here is that *F* already exists to be observed: *F* itself constitutes a means of observing the imprint or energetic evolution of *T*. We observe it as superusers of the model and it is used by the "subjects" of *T* as a means of decision, while in the rules of interaction there is an interaction modulator of *F* in *T* in each interaction, at the same time that a fraction of the energy of the entity returns to *F* when it dies. Arguably, that is the reason why an enrichment appears in the value 1 in the case of collapse. It would be a hypothesis to start playing with the model. Besides, what does it mean to play with the model? Playing with the model is, by observing its metrics, deducing its rules.

TABLE 13

CHANGE IN THE INITIAL AND FINAL DISTRIBUTIONS OF F

	Distribution of *F* values			
range	**Frequence**		***P* (*Bij* in range)**	
	initial	final	initial	final
0.1	110	52	0.11	0.052
0.2	100	24	0.1	0.024
0.3	84	36	0.084	0.036
0.4	100	43	0.1	0.043
0.5	101	53	0.101	0.053
0.6	109	65	0.109	0.065
0.7	89	60	0.089	0.06
0.8	103	101	0.103	0.101
0.9	115	110	0.115	0.11
1	89	456	0.089	0.456
Total	1000	1000	1	1

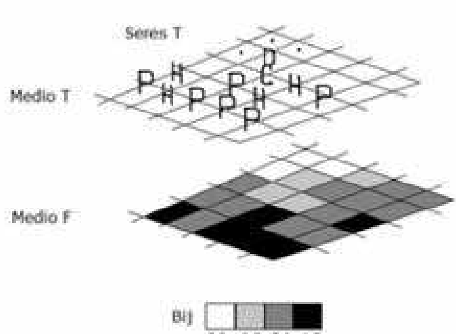
In this case, they are known, but in the case where you only have observations of phenomena in science, what is observing and what is observed? And even more, what is not observed? When looking at a system, these are interesting questions that we think are accessible to modern research in computational sociology and socioecology, and of the utmost relevance to ethics research when considering the problem of existing and communicating in the context of political socioecology.

About the phantasmagoria of the aura and the preponderance of the imaginary. The "germs" of the processes originate in stratum B (symbolic) and materialize in stratum F (semiosphere)

The impact on *F* of the condition on *B* only exists from *B*, not per se; it is a ghost, which gives the notion of the condition that *B* keeps. The artificial entity (the symbol) seeks to overcome the shortage of its condition (increase its information) by interacting with the cell with the best value; interactions are their link. The probability of being active (exchanging information) is the contingent of life; the friction with the means to survive and, in turn, the primer of it by the effect of what has been lived, appears to us, currently, as the aura of the system, in a sense that it keeps the "historical" trace of the flow "of meaning" that occurred in *T* and that was counted and averaged as additions or subtractions over *F*.

In addition to the excess of meaning that occurs, it builds primary and secondary meanings in the magma, a place where the aura could be located and which in turn produces an imaginary. Imaginary that can be represented in the excess of informed subjects and that generates a supposed knowledge that the system collapses, see Figure 39.

Figure 39
Series *T* and Aura of the process



The LSEM: An Early Example of Computational Sociology

Despite the limitations or simplicity inherent in a primitive, perhaps even naive, code, its productivity, at least of metaphors, as a space (unconventional) for modeling symbolic interactions, makes the LSEM an example comparable to the codes of "synthetic life", tessellations and concatenations described in the state of the art modeling of his time, proposed by Varela, around the autopoiesis of living systems [93, 94] and which are computationally rediscovered shortly after the present code was designed [95], then, here we have an interesting example in its own right and perhaps for its correspondence with the spirit of its times of an early computational sociology exercise.

MODELING AND SIMULATION OF THE PHENOMENON OF COOPERATION IN THE MECHANISM OF INDIVIDUALISTIC INDIRECT RECIPROCITY

Ricardo A. González Silva
Mario I. González Silva
Héctor A. Juárez López

Abstract

The mechanism of indirect reciprocity has been studied by making multiple variations of its elements. In this work, we propose a model focused on the agents' attitude known as Individualistic Indirect Reciprocity (MC-RII). In our model, an agent reinforces its strategy to the extent to which he makes a profit. We also include conditions related to the environment, visibility of agents, demand for cooperation, and an agent's attitude to maintain his cooperation strategy. Simulation results show that the discriminatory stance of the agents prevails in most cases. There are few cases where a small fraction of cooperators appear in a world of discriminators. In general, cooperators only appear in conditions of low visibility of reputation and a high degree of demand for cooperation. The results also show that when others' reputation is unknown, and there are high obstinacy and high demand for cooperation, a heterogeneous society is obtained, with high value in payments and average reputation.

Introduction

Why is cooperation between humans so difficult? What is required for cooperation to exist? How to establish cooperation in a world of selfish people without a central authority? Or When should a person cooperate, and when should he be selfish (in continuous interaction)?

Cooperation has been identified as one of the paths for personal and entity development, say for towns, cities, countries, etc. The most important aspect of evolution is the ability to generate cooperation in a competitive world [96].

In several works, five mechanisms for the evolution of cooperation have been identified: direct reciprocity, indirect reciprocity, spatial selection, multi-level selection, and relationship selection. These regularities of interaction are mechanisms for the evolution of cooperation and are very different from behaviors that require evolutionary explanation (such as strong reciprocity, upward reciprocity, and parish altruism) [97].

Indirect reciprocity operates when there are repeated encounters within a population, and third parties observe or know about some of these encounters. Information about these meetings can be spread through communication, affecting the reputation of the participants. Individuals can adopt conditional strategies that base their decision on the recipient's reputation [98]. Nowak and Sigmund present a theoretical framework of indirect reciprocity. They show that individual selection can favor recipient-directed cooperative strategies that have helped others in the past, and that reputation benefits cooperation because it confers value on the cooperating community member.

Wedekind and Milinski showed that cooperation is greater towards those who cooperated the most in previous rounds and studied the level of cooperation through indirect reciprocity under reputation [99]. Milinski *et al.* [100] show through alternate rounds of public goods and indirect reciprocity games that the need for reputation in indirect reciprocity sustains contributions to the public good on an unexpectedly high level. But, if rounds of indirect reciprocity are not expected, then contributions to the public good quickly drop to zero. Alternating the different games leads to higher profits for all players. They conclude that reputation can be a valid currency in many social games. This approach could be used to test social dilemmas for their resolution.

Other research, such as Seinen and Schram, showed that subjects with good reputations were almost always paid, while those who never helped were less helped [101]. Rockenbach and Milinski [102] showed that the majority of participants chose punishment to build their reputation. Sommerfeld *et al.* [103] showed that the original cooperation was a significantly better predictor of participants' responses when they had access to multiple statements (rumors) compared to isolated statements or direct observation.

Ohtsuki *et al.* [104] showed that indirect reciprocity works through reputation. They studied the proposal of a punishment cost among individuals that do not promote cooperation in the indirect reciprocity model and characterized all the strategies that allow the evolutionary stability of cooperation. Ule *et al.* [105] determined that those donors who saw a history of positive cooperation of the recipient cooperated with him, while those who saw a history of negative cooperation of the recipient preferred not to cooperate rather than punish.

The empirical and theoretical work of Pfeiffer *et al.* [106] indicates that a good reputation is valuable because it increases the expected profitability in the future. Their paper explores the repeated Prisoner Dilemma (DP) game, allowing to investigate how the exchange of reputation affects cooperation in the DP, and how the participants assess the value of having a good reputation. His work shows that the more valuable a good reputation is, the higher the market price is. Klempt [107] says that donors did not discriminate whether or not the recipient's last action paid off. Wilkowski and Chai [108] show in all studies that helping decisions were influenced only by their previous behaviors with their interaction partners when the participants explicitly remembered such behaviors.

The study of how natural selection can promote cooperative or altruistic behavior is a fundamental question in the biological and social sciences. Suzuki and Kimura study the mechanism of "indirect reciprocity", working through the construction of reputation [109]. Through mathematical analysis and agent-based computer simulations, they show that natural selection never favors indirect reciprocal cooperation in the presence of the cost of reputation building, regardless of the cost-benefit relationship of cooperation rules or moral evaluation (social norms).

The purpose of this research is to model and simulate the behavior of agents under the individualistic indirect reciprocity mechanism when adding external factors such as the visibility of the agents (or ability to see the reputation of others), obstinacy when changing strategies, and the demand for cooperation to compel them to interact cooperatively. We want to characterize when cooperation is established or not by varying the values of the simulation parameters. We start by introducing the Indirect Reciprocity Mechanism and the definition of the Individualistic Indirect Reciprocity Mechanism. We then specify the Materials and Methods, present all the elements used for this research, the experiment design, and the simulation process. Later, we show and systematically describe and discuss the results of the experiments. Finally, we present our fundamental observations in the conclusions section.

Indirect reciprocity and individualistic mechanisms

Indirect reciprocity mechanism

Richard D. Alexander [110, 111] argues that the essence of moral systems seems to lie in patterns of indirect reciprocity. Indirect reciprocity is what happens when direct reciprocity occurs in the presence of an interested audience. Its main variants are: rewards (why altruism spreads), punishment (why rules spread), and deception (why cheating spreads).

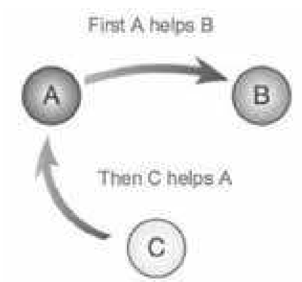
- Rewards (used in this work): If agent *A* helps agent *B*, one or more watching agents will help agent *A* because he showed that he supported someone else in the previous round.
- Punishment: If agent *A* hurts agent *B*, agent *C* will hurt agent *A* in anticipation of being hurt by him, and so on. An agent can help agent *A* when he gets a good reputation.
- Deception: agent *A* appears to be helping agent *B*, agent *C* will help agent *A* waiting for the favor to be returned. An agent *D* watching the previous interaction realizes agent *A*'s plot and does not help him. This process can be repeated, i.e, there can be an agent *A*2 that fools *D*, then an agent *D*2 detects the cheating of *A*2, etc.

The calculus of cost-benefit is not always carried out deliberately or consciously; the return is expected from someone other than the recipient of the benefit.

Indirect reciprocity develops because interactions are repeated or flow among members of a society and because information about subsequent interactions can be gleaned from observing the reciprocal interactions of others.

Indirect reciprocity involves reputation and status and results in everyone in a social group continually being assessed and reassessed by interactants, past and potential, on the basis of their interactions with others, see Figure 40. Indirect reciprocity presupposes rather sophisticated players, and therefore is likely to be affected by anticipation, planning, deception, and manipulation [113].

Figure 40
Indirect reciprocity cooperation mechanism [112]



There are two main research guidelines in the indirect reciprocity mechanism. The first, proposed by Nowak, is based on establishing the cooperation strategy for each agent as an integer value between –5 and 6, where the most cooperative agents are those with the most negative strategy value and those with the largest positive values are opportunistic, or defectors [98]. Some researchers combine cooperation with punishment, condition agents with personalities, change the way they donate, or update their reputation or strategy. Others vary social information or perform actual experiments. The second research guideline, based on Game Theory, can be classified in terms of the types of games used to model the interaction and the type of network in which the agents interact: experimental, theoretical or simulated, punishment mechanism, degree of focus on the visibility of the reputation, social norms, “strong reciprocity”, the evolution of strategies, emotions of the agents, etc.

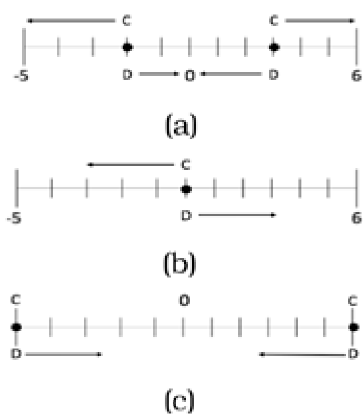
Individualistic Indirect reciprocity mechanism

The individualistic indirect reciprocity mechanism is similar to Nowak's. The fundamental difference is how the strategy is updated; we describe it below.

For a given agent, if its strategy has a negative value, we will call it a *cooperator*. If its strategy has a positive value, we will call it a *defector*. If the value of its strategy is zero, we will call it a *discriminator*. We define the Individualistic Indirect Reciprocity Cooperation Mechanism (MC-RII) as the act in which an agent "reinforces" his strategy based on the instantaneous gains of past interactions, that is, if he is cooperative and someone cooperates with him, he will increase his cooperation index. Similarly, if it is a defector, and someone cooperates with him, its index will decrease [114]. This is represented in Figure 41.

Figure 41

Indirect individualistic reciprocity with reinforcement.



Each mark represents a situation where the strategy of each agent can be (Figure 41); as in case image 41(a) if an agent has the strategy $k = 2$ and someone cooperates with him, he will move his strategy to 3, but if the other does not cooperate with him, he will move towards 1. But when $k = 3$, if someone cooperates with him, the agent will reinforce his strategy by going to the right to $k = 4$, however, if the agent does not receive cooperation, he will move to the left to $k = 2$. Image 41(b) shows when the agents are discriminators, they become cooperators if they cooperate and defectors if they do not. Image 41(c) shows when the agents have extreme strategies $k = -5$ y and $k = 6$, the former are unconditional cooperators and the others are extreme defectors. If an agent has the strategy $k = 5$, if someone cooperates with him, they will stay in their strategy, but if not, he will move to the left.

Materials and Methods

Agent-Based Models

Agent-based models (ABM) are a class of computational models used to simulate the actions and interactions of autonomous agents (both individual and collective entities, as well as organizations or groups), in order to assess their effects on the system as a whole. They combine elements of game theory, complex systems, emergent behaviors, computational sociology, multi-agent systems, and evolutionary programming. ABMs are a kind of microscale model that simulates the simultaneous operations and interactions of multiple agents in an attempt to recreate and predict the emergence of complex phenomena [115].

NetLogo

NetLogo is a simulation environment designed to work with multi-agent systems. It is a dialect of the Logo language for *turtle* graphics, but with the additional ability to manipulate many agents. Hence its prefix "Net", which refers to the type of multi-agent, decentralized and interconnected phenomena that can be modeled in this environment [116]. The program includes a model library that contains a vast collection of simulations that can be executed and modified. This set of models belongs to very diverse fields, both in the natural and in the social sciences (biology, medicine, physics and chemistry, mathematics and computing, economics, and social psychology). It has a programmable environment aimed at the modeling of multiagent systems. NetLogo is free and open-source software under a GPL license. Commercial licenses are also available. It is written in Scala and Java and runs on the Java Virtual Machine.

ABM Simulation Process of the Individual Reciprocity Mechanism

In the model, we established that, with a certain probability, the value of each individual's reputation is known by all other agents (we call to this probability the *visibility*). The agents are randomly chosen at each iteration, and those that interact update their strategy, reputation, and payments.

The population is composed by n agents. Each agent i has strategy k_i (that takes integer values in the range 5 to 6, inclusive), a reputation s_i (that takes integer values in the range 5 to 5, inclusive), and a payment function p_i. At each iteration, there is a fixed number m of interactions of pairs of agents. Within each pair, one agent is randomly chosen to be the *donor* (denoted by i) and the other is the *recipient* (denoted by j). If with probability V, the donor i knows the reputation of agent j, he cooperates based on the cooperation criterion $k_i < s_j$, if not, the demand for cooperation criterion is applied.

When donor i cooperates, the value of her reputation increases by one unit, and if she does not cooperate, her reputation is decreased by one unit. When cooperation happens, the donor pays a cost c, and the recipient gets a profit of b; there is no reward in the absence of cooperation. The donor's strategy and the recipient's reputation remain unchanged. However, the recipient's strategy changes based on the obstinacy parameter.

The model has three controllable parameters: *visibility*, with values 0 or 1; *obstinacy*, with values 0 or 6; and demand for cooperation that takes values {0, 1, 2, … , 6}. We briefly describe each of them.

Visibility parameter (V), with values 0 or 1. In the process of cooperation, a donor agent i will "see" (or know) the reputation of recipient agent j with probability V. If he sees the reputation, he applies the cooperation criterion $k_i < s_j$. If the donor cannot see the recipient's reputation, he will assume that the recipient has a "good reputation" and will continue to cooperate based on the value of the demand for cooperation parameter.

Obstinacy parameter (*O*), with values 0 or 6. In the MC-RII model, a given agent will reinforce her strategy when she obtains a profit and change to the opposite side (cooperator/defector) when she does not. The obstinacy parameter controls this behavior. If the obstinacy parameter is *n*, an agent will reinforce (or change) its strategy only after *n* consecutive times of receiving (or not receiving) cooperation. An obstinacy parameter of 0 means that the agent will change its strategy at each interaction.

Demand for cooperation (*EC*), with integer values from 0 to 6. This parameter forces agents to cooperate. If the demand for cooperation parameter has value *l*, the cooperation is forced for those donor agents that were unable to see the recipient's reputation and hold $k_i \leq l$.

Experimental Design

The following initial conditions are common to all experiments. A population of $n = 100$ agents is setup. The values of strategy *k* are randomly drawn from a uniform distribution. The value of the reputation *s* of each agent, as well as the value of its payment function, are set to 0. The parameters *b* and *c* are set to $b = 1$, $c = 0.1$ (in order to avoid negative profits, we add 0.1 at the beginning of each interaction).

For each experiment, the values of the main parameters are set as follows: *visibility* (0 or 1), *obstinacy* (0 or 6), and demand of cooperation (can be {0, 1, 2, … , 6}. For each experiment, once all the parameters have been set up, we perform 201 iterations (ticks or time steps). At each iteration or time step, we randomly select *m* pairs of agents to interact (in each pair one of the agents is selected to be the donor and the other to be the recipient). Thus, each agent has an average of $2m/n$ interactions.

Once that a pair of agents have interacted, their strategies, payments, and reputations are updated asynchronously. The recipient reinforces its strategy based on her receiving cooperation (or not) and the obstinacy parameter, adds *b* to its payments (if she received cooperation) and her reputation is unchanged. The donor leaves its strategy unchanged, increases her reputation by 1 when she has been cooperative (or subtracts 1 if she refused to cooperate) and subtracts *c* if she cooperates (*c* is the cost of cooperating).

By varying the values of the three main parameters (*visibility V*, *obstinacy O*, and *demand of cooperation EC*), we have a total of 28 possible combinations.

Simulation Results

In order to analyze the cooperation dynamics, we will focus on the final frequency distribution of strategies, and the behavior of the temporal average of payments and the temporal average of reputations. Although the total collection of experiments are 28 cases, the final simulation results can be grouped into 9 situations.

Temporal evolution

Figure 42 shows selected insights of the temporal evolution of an experiment for $V = 0$, $O = 0$ y $EC = 1$. The images 42(a) – 42(c) show the initial conditions of the population ($t = 0$); images 42(d) – 42(f) show the temporal state at $t = 25$; and 42(g) – 42(i) display the temporal state for $t = 100$. Images 42(j) – 42(l) depict the final estate of the simulation. We observe that society is distributed to the side of defectors, decreasing in number as the agents' strategy tends to 6.

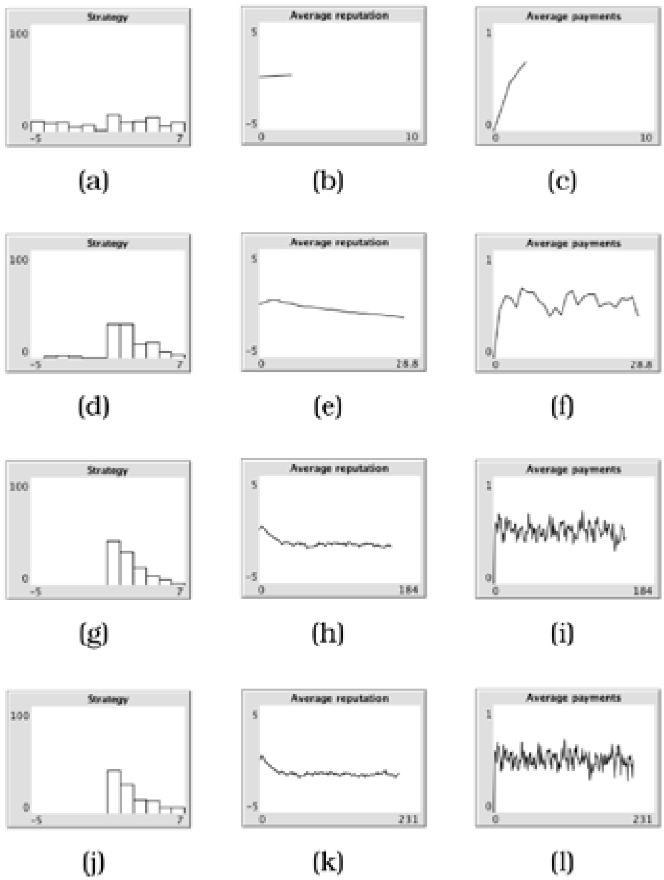
Final Results of the Simulations

The parameters space of the simulations is the set of 3-tuples from {0, 1} × {0, 6} × {0, 1, 2, … , 6}, where the first coordinate stands for *visibility V*, the second for *obstinacy O*, and the third for the *demand of cooperation EC*.

Figure 43 shows a set of cases in which the position of being discriminatory is established. Images 43(a) – 43(c) depict the triads: (0, 0, 0), (0, 6, 0), (1, 0, 0), (1, 0, 1), (1, 0, 2), (1, 0, 3), (1, 6, 0), (1, 6, 1), (1, 6, 2), (1, 6, 3), (1, 6, 4), (1, 6, 5), (1, 6, 6). In all of them, the position of being discriminator prevails, and the reputation of society in general declines. Images 43(d) – 43(f) depict a image that is similar for all triads (1, 0, 4), (1, 0, 5), and (1, 0, 6). Similar to the previous images, the

Figure 42

Temporal evolution $T = 0$, $T = 25$, $T = 100$ and $T = 201$



posture of being discriminant prevails, however, the time evolution of the averages is different, since it remains constant and declines at t = 100. Images 43(g) – 43(i) depict similar behavior for the triads (0, 6, 1) and (0, 6, 2). The posture of being discriminant prevails, however, the time trends of the averages show an increase, unlike the two previous graphs. Images 43(j) – 43(l) show a similar image for the triads (0, 6, 3), (0, 6, 4) and (0, 6, 5). There is a 60% of discriminators, and the rest of the population become cooperators and defectors. The averages of reputation and payments are high.

FIGURE 43
DISCRIMINATORY CASES

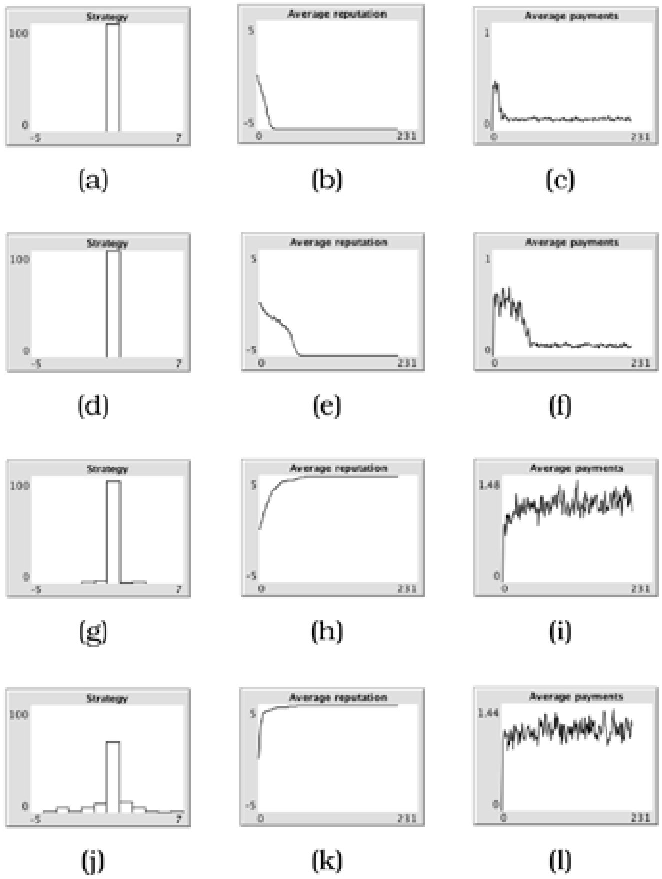


Figure 44 displays all the possible ways (of our model) in which agents are dispersed in the strategies' range. Images 44(a) – 44(c) are the final result for the triad (0, 0, 1). In this case, the agents tend to be defectors, with lower positive values of strategy being preferred. There is a small fraction of severe defectors. Images 44(d) – 44(f) show similar final simulations' results for triads (0, 0, 2), (0, 0, 3) and (0, 0, 4), society is made up of defector agents in a heterogeneous way. The average reputation and average payment are low. Images 44(g) – 44(i) are the final stage of the simulation corresponding to triad (0, 0, 5). By increasing the parameter of demand for cooperation, society becomes almost symmetrically polarized. The final images 44(j) – 44(l) are the simulation corresponding to triad (0, 0, 6). Society is totally polarized. There are high values for average reputation and average payment.

Figure 44

Partial and total polarization

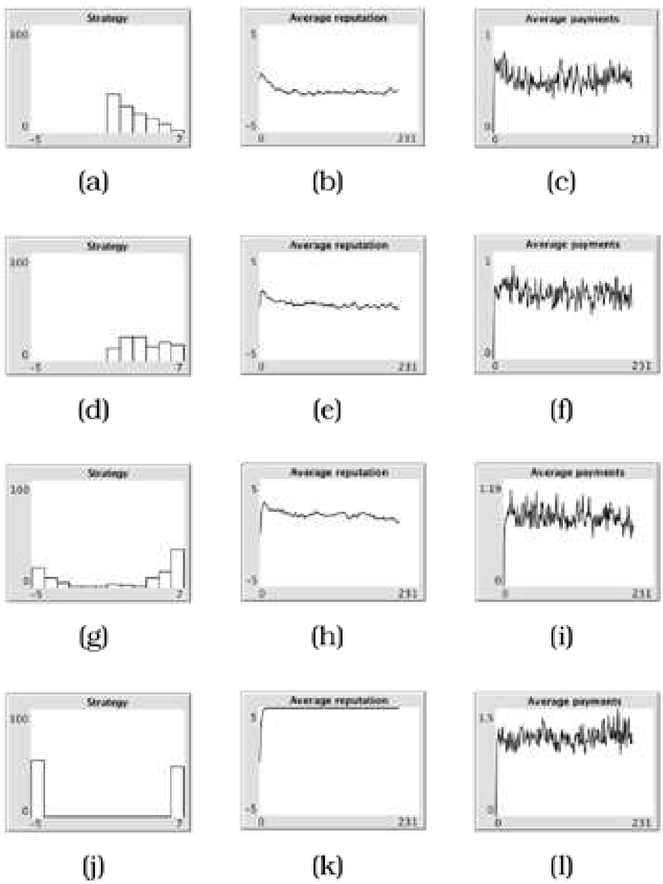
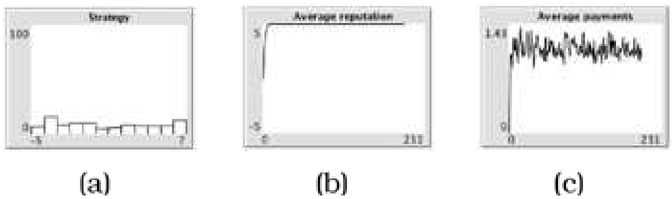


Figure 45 corresponds to the triad (0, 6, 6). Society is heterogeneous, the population's final strategies are evenly distributed across the set of strategies, and average payouts are high.

FIGURE 45

HETEROGENEOUS SITUATION



DISCUSSION

The individualistic indirect reciprocity cooperation model shows a wide variety of behaviors in the frequency distribution of strategies, average payouts, and average reputations.

Considering images 43(a) – 43(i) of Figure 43, we observe that a determining factor to obtain a society of discriminators is to set visibility to 1, that is, all agents know the reputation of everyone else.

With no visibility and obstinacy, the parameter of demand for cooperation becomes a decisive factor to generate society polarization, as can be seen in Figure 44.

From images 43(g) – 43(l) (Figure 43), 44(j) – 44(l) (Figure 44) and images 45(a) – 45(c) (Figure 45), it can be seen that with zero visibility and high obstinacy the result is a society in which practically all agents have an excellent reputation and good average payments. On the other hand, zero visibility and obstinacy, as well as high demand for cooperation, generate a complete polarization of society, with half the population being unconditional cooperators and the rest being severe defectors.

The behavior of the frequency distribution of *k* is stabilized, when the average reputation value or the average value of payments stabilize.

We could say that being discriminant prevails almost 75%, which is the total number of cases of the figures in Figure 43, this is when the "most natural" conditions are in place, that is, that there is little visibility of reputation and agents are slightly forced to cooperate, but all these cases are not equivalent, as the simulations of the situation in images 43(g) – 43(i) of Figure 43 show that it takes more time to achieve the stable state of being discriminant, after more than 100 iterations.

Conclusions

This work presents a variant of the Indirect Reciprocity Model [98], known as the Individualistic Indirect Reciprocity Model (MC-RII). It includes behavior in which agents seek to increment their profit.

Our findings differ from previous results. We can infer that discriminatory behavior is predominant because our model promotes individuality, and since we include social parameters in our model, we have different scenarios. Indeed, by varying the new parameters of visibility, obstinacy, and demand for cooperation, a greater diversity of results was obtained in agents' behavior, as illustrated in the graphs. In a certain sense, we agree with Suzuki [109] since the parameter of demand for cooperation is akin to a social norm.

In general, our results show that agents tend to be individualistic and have a discriminatory stance. Only under special conditions does one have an environment in which there is cooperation.

The simulation results did not show scenarios in which the majority of the agents are cooperators, regardless of how obstinate they are and how strongly they are forced to cooperate.

COMPLEX NETWORKS
STRUCTURE AND DYNAMICS OF ENDOGENOUS DEVELOPMENT IN TWO COMMUNITIES OF MEXICO

Anthony Pérez Balcázar

Abstract

Endogenous development is an emerging property of complex systems, synergized and changing, it is a process of approachability of territorial resources and adaptation to the new demands of global dynamics, driven by the inhabitants of the territory and whose operational qualities are subjective and intangible grouped into nine capitals that synergize with each other to encourage development from the base of the territory. In this sense, endogenous development is a dynamic and complex system and, as such, it should be treated in the same way, that is, under the discursive logic of the quantitative approach, typical of complex systems. Not only its structure can be demonstrated, but also its (dynamic) operation, strengthening the logical-qualitative discourse and facilitating the generation of new public policy initiatives to promote and encourage endogenous development in different territories rather than their control. The present work shows the results of an exploratory-comparative study in two communities in Mexico on the existence of nine intangible capitals, showing that in one of the communities, endogenous development is inert, and in the other, it is successful. In order to formalize this work, the focus of the study of endogenous development is carried out through causal networks and Kauffman's Boolean networks.

Introduction

Today, endogenous development has become a highly relevant, innovative and impacting issue, from a political to an academic framework.

Most regions at the local level are immersed in serious problems such as territorial divergence, economic inequality, increased unemployment, poverty, etc. In addition, the formulation of universal policies of a capitalist nature whose relevance emphasizes neoclassical and Keynesian processes without considering the evolution of the contexts at the local level.

Therefore, in the 80's it was understood that the development of communities should be studied to counteract the uneasiness caused during that time, which led to consider that development should be generated from the local level. However, the study of development to the being of social character has been focused mainly on a process of qualitative order where the intellectual logical discourse has been the main actor; based on the observation and theoretical-empirical description on the subject arriving at considerations such as the individual responsible for their own development, the need of territorial decentralization, the use and exploitation of the endogenous potential, a sustainable and durable narrative, the adaptation of the human capital to the territorial context, the formulation of pertinent and functional public policies, the flexible organization of the production, the design of communities that learn through the generation of territorial clusters, the organization of production in networks, R+D+I processes at a local level, as well as coordination between universities, research centers and institutions focused on the qualification of human capital with the local government and the population, the management of market processes and image design, etc. The only objective is that the territory adapts practically to the complexity and demands of the paradigm of globalization.

From this perspective, the present work focuses on evaluating nine intangible capitals (cognitive, symbolic, cultural, institutional, psychosocial, social, civic, media and human) that synergized among them to encourage endogenous territorial development, which make it possible to generate an adaptive and emergent process in a highly complex system, showing that development is not atomized but a systemic process characterized by the number of interactions between the components of each of the intangible capitals, and whose approach opens up in a multidimensional, complex and global manner.

Given this process, an approach to the study of development from complex systems is made, mainly the use of complex networks as a necessary methodological tool to understand the synergy, connectivity, and organization of each of the feedback networks in question, promoting the graphical and mathematical discussion of each of its properties, which in the first instance were formed by elements of a subjective nature.

Likewise, the use of Boolean networks, where the assumptions affect the understanding and observation, from binary codes, of the new properties that emerge from the dynamics of the possible combinations of each one gives the properties of the territory at time $t + 1$. The purpose is to understand that the structure of a complex network of endogenous development, not only implies an intellectual logical discourse, but a mathematical base of evolution mechanisms, of concentrating agents and causal characteristics, of interaction and self-organization processes that encourage the emergence of new properties.

The work is, therefore, structured as follows. The reference framework of endogenous development, complex networks, and Boolean networks is briefly presented in the first part. Secondly, from complex systems, specifically with networks, the causal and complex structure is shown in each analysis unit, taking into account characteristics such as; the degree of distribution (degree & indegree) and the grouping of communities (maker clusters). For each of the descriptions, the networks of the characteristics and the mathematical results represented in histograms are shown graphically to facilitate their understanding.

Finally, we present the dynamics of endogenous development with Boleyn networks in each of the communities under study. Through the interaction between intangible multi-capitals with strongly associated properties and whose functionality has a cohesive character towards other groups (multi-capital), they encourage the emergence of new properties, strengthening and energizing them adaptively and functionally to the system, which can be represented in new states; whether they are punctual or cycle attractors.

Endogenous Development, Intangible Capitals and Complex Networks

The subject of development took interest and concern in the Third World countries in the early post-war years, sealing a relationship between the

Western world and the countries affected during the war, the First World or developed States and the Third World or underdeveloped countries. Reconstruction and progress were required through the Marshall Plan (1950-1965). "For this reconstruction and progress it was intended that social evolution could be achieved through the voluntary, intentional and planned effort of societies and communities, having as instruments the socio-economic policies" [117] giving rise to the theories of economic development[1] as a process that would encourage mutual aid, both to third world countries and to developed ones.

By the end of the '80s and the beginning of the '90s, in the face of the crisis that showed symptoms of divergence in the level of economic development, there was a drop in growth rates, a decrease in investments, an increase in unemployment, difficulties in human retraining[2], the breakdown of social consensus and the fall of the large industrial centers, mainly the countries of the third world, generated by restrictive macroeconomic policies of globalization, which prevented the participation of the third world regions. In effect, "globalization and productive restructuring affected the productive systems of developed and backward regions, large, medium and small cities" [118]. Therefore, there arises a position practically adapted to the possible scenarios of development, whose denomination was; theory of endogenous growth[3], which considered that the technological advance is an endogenous factor since the monopolistic rents condition the growth processes, which allows them to conclude the diversity of the possible scenarios of growth, likewise they included that the growth rate depends basically on the stock of three factors; knowledge, physical capital, and human capital.

These positions extended from Europe to Latin America with the single idea that development would allow to fight poverty, unemployment, and implement regional development at a local level. Then, it was considered that the regions are the space par excellence for development since a territorial dynamic is created under the game of different forces that interact in a systemic way, transforming and modifying as much

[1] Dependency theory, modernization, world-system, and globalization.

[2] The term human recycling refers to the use of human beings as an asset within the industry, which at a certain time no longer meets the expectations of the company and is replaced by another.

[3] The works [119–121] are considered to be the main precursors of this approach.

of their internal context as the outside. It was stipulated that the individual should become the main actor in developing the territory since there is a direct interaction between actor and system. In this game "the actor generates his margins of action, generating or losing opportunities, managing to diminish the limitations that come to him from the system or on the contrary, being more or less paralyzed by them" [122].

Later, Vázquez-Barquero considered that development corresponded only to the territory considered under four forces: flexible organization of production, dissemination of innovations and knowledge, urban development of the territory, and institutional change and adaptation. All of them work in a systemic way, so that the impulses generated by investment are transformed into increasing returns when there is synergy between these forces. But also "the inefficient functioning of some of these mechanisms can have a disruptive effect on the impact of investment on productivity growth and weaken the growth process" [117].

It is then that the dynamics of regional development extends with opportunities for all territories, but not all territories are in the conditions to develop it, for such, "it was considered that the territory should have a certain process of autonomy as a way to solve the problems of development and economic inequality, promoting the direct participation of small local entrepreneurs in a sense of community progress" [123], "the reorganization of the political-administrative structure [...], the re-articulation of State-civil society (system-actor) and addressing the issue of forms of democracy" [122].

By the beginning of the 21st century, positions were emerging that continued to mark new modalities for regional development. It was highlighted that "the development of regions is based on their endogenous potential, allowing for a lasting and sustainable process" [124] since several resources have already been or are being exploited. On the other hand, Garofoli maintains that development must be based on the local environment and on individuals' abilities to control local resources, accumulation processes, the capacity to innovate, and productive, inter-sectoral and inter-sectoral interdependence at the local level. Thus, the importance of intermediation of the ultimate interface between knowledge and productive actors, which increase R+D+I (research + development + innovation), should be highlighted.

Alburquerque alludes that the introduction of internal productive innovations is an important aspect of local economic development. However, it does not depend exclusively on the result of research and development in large companies or the degree of advance of basic science and technology [...]. The introduction of innovation depends essentially on the degree of linkage with the ultimate users of knowledge, that is, the productive agents. Hence the importance of intermediation to establish these ultimate interfaces between knowledge and productive actors [125] which increase research plus development plus innovation (R+D+I), as well as the external context with which it interacts [126]. This idea also includes the process of innovation, the dissemination of innovations, the interaction of innovations, innovation management, the introduction of innovations, and public administration participation (see [126]). At the same time, innovation depends not only on financial resources but also on the attitude and willingness to change, which can be facilitated by promoting an innovative culture within companies and local society.

Likewise, the university institutions, research centers, technical councils, among others, play a role of great weight within the regions since they are responsible for generating those human resources appropriate to the environment, having a broad knowledge relevant to the formation of the human capital of the community with respect to its endogenous potential, resulting in functionality within the global competition, that is, a system between the community (bonding) and the society (brinding)[4].

"Bonding is an operational version of community, which involves a wide variety of forms of grouping with others with whom we share some part of our identity, expectations and interests" [128]. On the other hand, Brinding refers to the connection between community actors.

In this sense, Storper argues that for markets to be solvent, they need communities. That is, communities tend to play a necessary role in achieving the optimal coordination of a well-functioning modern economy. Since there is a high degree of social capital, sometimes connections are required with complementary skills or technologies since the individual's capital cannot be used in isolation. "Knowledge-endowed

[4] To learn more about society and community, see [127].

(skilled) agents tend to function by elective affinities within economic communities" [128].

Therefore, and rejecting the existence of a single path, a single cosmovision, a western project of universal civilization, the issue of development has been focused on endogenous processes as a local-global and systemic dynamic allowing regions to act and develop in a sustainable way.

Within this aspect, Boisier [129] considers endogenous development as an emerging property of complex systems, highly synergized, adaptive and with a functioning similar to capillarity[5], practically adapted to global complexity. It is a territorial and emergent process characterized by the existence of nine intangible capitals, which are potentialized and articulated by a synergic capital within a highly complex and systemic context; it is a phenomenon of small scale that expands from below, upwards and towards the sides, making possible the adaptation to an increasingly complex and competitive context, in which there are interposed a great variety of elements, increasingly more difficult to understand.

The people, as the main actors of the territory, are responsible for development. However, "development depends on interaction, that is, on the connectivity and interactivity of several factors and processes of smaller scale, of local in the language of complexity" [130], "of a cognitive synergy that is nothing more than the capacity to carry out actions, on the basis of the same interpretation of reality and of its possibilities of change in global competitiveness" [130]. Consequently, Endogenous Development is not based simply on the endowment and accumulation of intangible capital, nor on the endogenous territorial potential, but on these capitals' interaction. Therefore, "the theory of endogenous development has raised a new dynamic in the development process of communities from the local level, practically adapted to the global complexity, synergized and with a process similar to capillarity" [130].

An intangible capital starts from a qualitative instance and subjective factors, in which the actor has collective production skills, a systematic discourse of social self-identification, the way to approach economic processes, a high level of self-confidence, a collective belief in

[5] Consider that the term capillarity relates to the organizational fabric of a society, which presents itself in multiple ways in practically all spheres of daily life and which goes from the base of the territory to the sides.

building futures, an organizational fabric with a desire to develop, the power of the media and the ability to improve skills [129].

On the other hand, a synergic capital is a social capacity, better than the societal capacity (as a more totalizing expression), to promote joint actions directed to collective ends and democratically accepted (in all its sense of the word) by a community, with the well-known result of obtaining this way a final product that is greater than the sum of its components. This capacity is ordinarily latent in any society, that is to say, the capacity to accumulate or in its case create these intangible capitals, and at the same time, it works as a ferment of these, to such degree that makes the synapsis agile among such capitals, the interactivity and the information exchange among the actors, promoting the endogenous territorial development. "This process of synergetic capital is not automatic, it requires an impeller and such actor cannot be but the government of the respective territory, as a concrete agent of the State in that level" [131][6].

Thus, attention must be paid to the fact that the development of territories basically depends on the individual as a property of the territory, referring previously to an intangible capital as such, since each of these characteristics of intangibility constitutes subjective properties, which are defined as follows.

Cognitive capital: "refers to a community's available scientific and technical knowledge. Knowledge about the territory itself (its geography, its history, understood and not merely told) a series of scientific and technological knowledge that can be used in the processes of growth and development from the natural resources of the region" [131].

Symbolic capital: is understood as the power to do things with the word…, is a power of consecration or revelation. "To build region, to generate imaginaries, to mobilize latent social energies, to generate self-reference, even, to build territorial corporate images. To name a territory as region, is to construct it, is to make use of a symbolic capital" [131].

[6] This statement is discussed in the last section of the chapter.

Cultural capital: "is the heritage of traditions, myths and beliefs, language, social relations, modes of production and immaterial products (literature, painting, dance, music, etc.) and materials specific to a given community" [131] and as a culture of development, it is understood as the set of attitudes towards economic processes that in the virtuosity mix cooperation and competition.

Institutional capital: "a set of structural attributes that ideally should be incorporated into the institutions; the capacity to act and make decisions quickly, organizational flexibility, the property of malleability, the resilience of the institutional fabric, virtuality, that is, the capacity to enter and leave virtual agreements and above all organizational intelligence, that is, the capacity to monitor the environment through sensors and the capacity to learn from one's own experience of relating to the environment" [131].

Psychosocial capital: "is the relationship between thought and action, heart and mind of people. Issues such as collective selfconfidence, faith in the future, conviction that the future is socially constructible [...], capacity to overcome individualism and above all the desire to develop" [131].

Social capital: "represents the predisposition to inter-personal help based on trust, that the other will respond in the same way when required, it is a trust possessed by a whole community in which history and tradition indicates that a help to a person or a group, will be at some point, reciprocally returned. It is therefore rational to help each other" [130].

Civic capital: "is associated with democratic political practices, confidence in public institutions, personal concern for the republic or, as one might say, for business and public affairs, of association between the public and private spheres, of the formation of networks of civic commitment" [131].

Media capital: "this capital refers to the mass media, which play such an important role in the success of a development proposal, that is, the enormous power of the media" [130].

Human capital: "understood as the stock of knowledge and skills that individuals possess, as well as their health and education" [131]. The Human capital according to Boisier in his article *Territorial Development from the Construction of Synergetic Capital* mentions that accumulation is due to two forms that Robert Lucas pointed out; dedicating hours of work to this end (going to school) or dedicating them to learn in action or by means of the experience (learning by doing).

Causal Networks and Boolean Networks

From the epistemological point of view, the elements of a network can be any. That goes from people, groups, or institutions to pieces of music, words, or countries. On the other hand, the links extend to; relations of knowledge, commercial transactions, influence, contagion, derivation, violence, traffic, clientelism, etc. "A network describes the interactions between genes, proteins, and metabolisms that integrate the life processes of cells, describes how communication devices interact with each other" [132], etc.

Network theory has a conventional, illustrative, explicit, and rigorous way to understand physical phenomena, as well as, phenomena of another nature (social, economic, cultural, educational, political, and technological). Complex networks, although they have had an antecedent based on graph theory, which has been distinguished by its elegance in explaining things, network theory is distinguished by three important aspects [133]:

a) It focuses on real-world properties [...].
b) Networks are often not static, but evolve over time according to various dynamic rules.
c) Its aim, ultimately, is for networks to be understood not only as topological objects, but also as the framework on which dynamic systems are built.

A network contains two essential characteristics, which function as parameters; the first relates to the number of nodes and the second to the number of links between the nodes. The nodes are denoted as N nodes representing the components of the system and are often called *N* for the size of the network, while the links are denoted as *L*, representing the total number of interactions between the nodes. These links can be direct or indirect. Direct links are those links that go only to one address, for example an email, a phone call, with the use of a location resource between one node to another, this is called direct network. Indirect links are links that go back and forth, for example metabolic networks that have a reversible (two-way or indirect) and irreversible process. In other words, the network is a set of nodes, with connections between them, directly or indirectly, however, the fact that a network is said to be a connection of nodes, not all the nodes can be connected, since in the network there can be isolated nodes without connection without altering the general functioning of the network, these can constitute a great number of nodes, which is called a giant island, that is to say the largest sub-network.

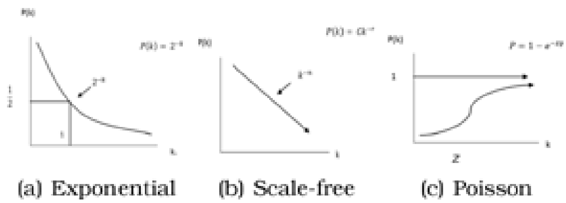
The networks contain properties that can be used for their characterization and modeling[7], in this case the work is focused on the degree of distribution or connectivity (**degree** & **indegree**) and the grouping of communities (clusters maker):

The connection distribution or degree distribution provides the probability of selecting a random node with degree *k*. It considers the connectivity of the node and this is what can determine the type of network typology; scale-free, exponential or Gaussian.According to the distribution of neighboring nodes *P*(*k*), complex networks give the probability that a randomly chosen node has *k* connections or neighbors. Of which, they give three different structures or typologies, see Figure 46:

- *The exponential typology:* which considers an exponential distribution with equal linkage, that is, the probability that a node has many links can fall exponentially, see [135].
- *The scale-free typology:* this type of complex networks implies that through preferential links the new nodes that are added to the network will preferably be concentrated with the existing nodes that have the greatest number of connections, therefore, that there are nodes with few connections and medium connections.

[7] For more information see [134].

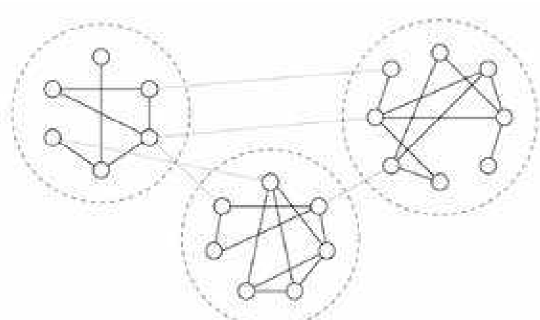
FIGURE 46
TYPOLOGY OF NETWORKS



- *Poisson typology:* has a more random and homogeneous view. In this type of network all *N* nodes have more or less the same number of connections. Some *N* nodes will be more connected than others, but on average they all have the same connectivity, *i.e.*, the connections of a Poisson network are distributed homogeneously among its nodes, see [136].

Grouping of Communities. Historically, the notion of community, and the first formalization of network, is proposed by the social sciences. "Given a *G*(*N, L*) network, a community (cohesive cluster or subgroup) is a *G*'(*N*', *L*') subnetwork, whose nodes are closely connected, *i.e.*, cohesive, since the structural cohesion of *G*' nodes can be quantified in different types" [137]. Communities can be defined with groups of nodes, such that they are a greater density of nodes within the groups of the network, see Figure 47.

FIGURE 47
GROUPING OF COMMUNITIES [137]



However, a different kind of community definition is based on the relative frequency of links. In this case communities can be seen as groups of nodes where connections are dense and where connections are scattered. “The main goal of stopping communities is similar to the participation graphs: we seek to separate the network into groups of vertices that have few connections between them. The important thing is that the number of group types is not fixed” [138].

In a network, the nodes not only are connected but also interact with each other, and these interactions can give rise to fascinating dynamic phenomena. Therefore, “in addition to studying the structural properties of a network, it is also important to study its dynamic properties once we know how the nodes interact” [136].

Kauffman Boolean Networks

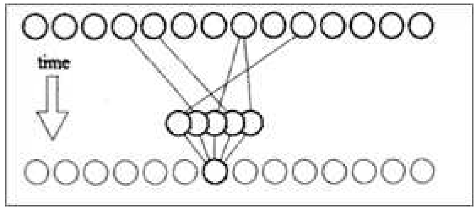
According to Kauffman [139], Boolean networks help us explore the region of the state space in which the conditions of interaction that allow the emergence of ordered patterns of behavior occur, that is, the stability and flexibility that are necessary for the adaptive process. These networks are represented by an arrangement of interconnected elements that can be in two possible states. Active or inactive.

The architecture of random Boolean networks is generally a system or dynamic organization represented by cellular automata or Artificial Neural Networks (ANN). The output connections are “non-local”. However, the two logical inputs may be different for each network element. Each network element updates and synchronizes the values according to the values in a pseudo-neighbor, established by the inputs from anywhere in the network (elements), where each network element can have a different number K of inputs, different structure, and a different rule: it is the network type (N) at time (t) with a wiring scheme with (K) links of a pseudo-neighbor is modified at time $t + 1$ (Figure 48).

The system is iterated [140] wherefore a Boolean network is a set of N Boolean elements that can interact with each other according to rules that tend to generate a matching and coupling structure simply as a function of (0 and 1) becoming binary systems.

FIGURE 48

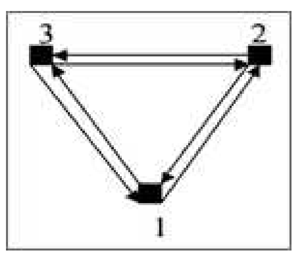
FEEDBACK FROM A NEURAL NETWORK



Kauffman [139] considers that the explanation to dynamic systems should be through the introduction of mathematical concepts, thinking that networks have a great variety of possible states (electrical networks or self-catalysis of the metabolism). Let us think of a simple network of three nodes (Figure 49) where each of these receives "inputs" from two others. The arrows represent signal paths, these arrows come from nodes 1, 2 and 3, so it means that node 1 receives inputs from nodes 2 and 3.

FIGURE 49

THREE NODE DIAGRAM



In addition, it should be noted that to be understood, the nodes of the diagram should be assigned values, say 0 or 1. This type the network can show four types of input patterns that can be received from two neighboring nodes. The inputs can be inhibited (off) if the signal is 00 or in other cases can be; 01, 10 or 11.

Using this information, specific rules can be constructed to observe if the node is activated or turned off (0).

Subsequently, the network can be in two functions or states; it is shown that node 1 is influenced by the functions of 2 and 3 (AND) being inactive, otherwise the function of type OR means that node 1 is activated in a time $t + 1$, node 2 or 3 or both must be active at time t (Figure 50).

Figure 50
Network state or functions

2	3	1
0	0	0
0	1	0
1	0	0
1	1	1
"AND"		

1	2	3
0	0	0
0	1	1
1	0	1
1	1	1
"OR"		

1	3	2
0	0	0
0	1	1
1	0	1
1	1	1
"OR"		

A synchronized update: the variables are simultaneously updated in function of the network values in the previous step.

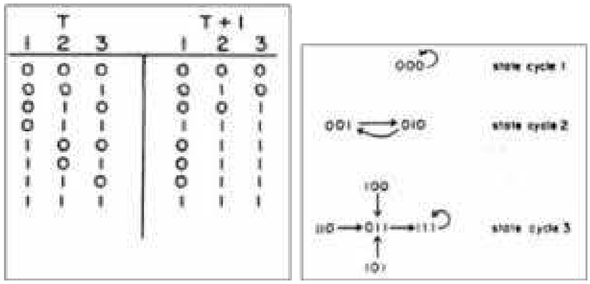
An asynchronous update: only one variable is updated in each step, which can be selected at random from existing variables, or by some pre-established order.

Thus, the first appreciation of the Boolean networks is that any network tends to stabilize into a state cycle. The number of states of each recurrent pattern can be small [...] if the system falls in a small cycle of states, it will behave in an orderly way. If the cycle is too coarse, the system becomes unpredictable [139]. Figure 51 shows three state cycles: 000 there are no trajectories. It is a stationary state. It is possible to arrive only if we start from the same network. In the second state cycle, there are two states (001 and 010) here the network is oscillating between these two, and there are no other states in this attractor[8]. The third state consists of a stable state (111). This attractor is in a basin of attraction of other four states. If the network is started with any of these patterns, the network will flow to a steady-state quickly and freeze; then, there will be three nodes on.

[8] In biological systems, attractors are a prerequisite for system stability and flexibility.

FIGURE 51

STATES OF A BOOLEAN NETWORK WITH DIFFERENT COMBINATIONS [139]



In summary, a Boolean network allows us to find those processes of interaction between the *N* Nodes of a network to find stability, adaptability, and the emergence of properties through its dynamics; its function is selforganized. A Boolean network can not only fall into metabolic processes, light bulbs, etc. but also into social, economic, political, educational processes, among others. In the case of social processes, Boolean networks have the purpose of understanding the conditions of interactivity between Nodes (individuals), the existence of attractors, and processes emerging at a $t + 1$ time state. This can help determine the evolution of the system giving, with greater reliability, a predictability to the space of time[9], that is to say what can happen at time $t + 1$ and what can happen only through two states "active" or "inactive" (1 or 0).

CAUSAL NETWORKS OF ENDOGENOUS DEVELOPMENT IN STUDY COMMUNITIES

With regard to endogenous development, the use of networks aims to show graphically the structure of a territorial system, whose description allows to understand that the networks, in the communities of study, tend to generate new budgets to understand the endogenous territorial development, therefore to determine through a formal framework the representation of a social phenomenon. Then, abandoning the idea of

[9] Consider that predictability is not a forecast, but to verify that the intellectual logical discourse of a qualitative nature coin-cides with a mathematical logical discourse.

the separation of things, of the univocal skepticism, of simplifying processes, and above all, of a unique cosmovision of social processes based on the hypothetical deduction of the intellectual, logical discourse.

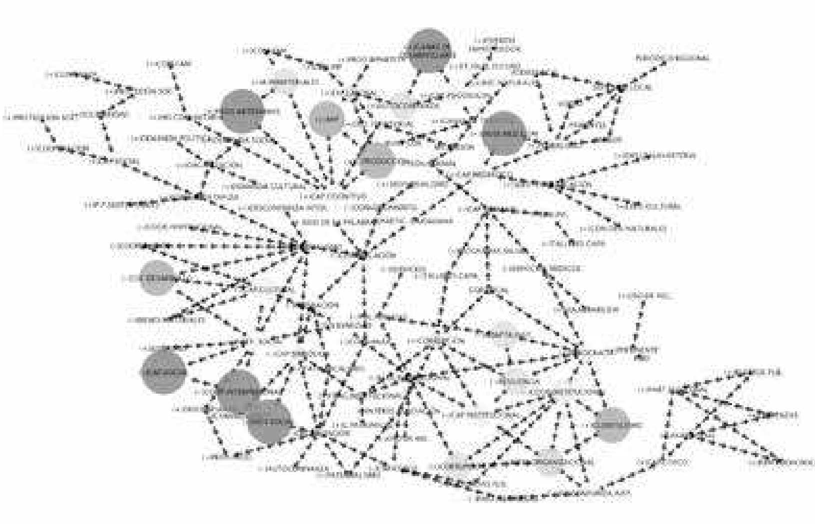
The present section aims to graphically show each of the structures of the causal and complex networks of endogenous development in three communities of México. For the description of the networks, the following characteristics are taken into account; the structure of the genera network, the degree of distribution (*degree* & *indegree*), and the grouping of communities (maker clusters). The networks will be shown graphically, with each one of the characteristics and the mathematical results represented in histograms.

San Nicolás de los Ranchos, State of Puebla

The community of San Nicolás de los Ranchos, Estado de Puebla, belongs to the socioeconomic region IV of the Angelópolis and is located in the central part of the State of Puebla. Its geographical coordinates are: 19°01'24" and 19°08'30" North latitude and 98°28'24" and 98°39'00". It borders to the north with the municipalities of Domingo Arenas, Huejotzingo, and Calpan, to the south with Tochimilco, Tianguismanalco, and Nealticán, to the east with San Jerónimo Tecuanipan and to the west with Amecameca, municipality of the State of México and the Popocatépetl volcano. The municipality has a population of 9749 inhabitants, distributed in three locations: the municipal capital with 5071 inhabitants; Santiago Xalitzintla with a population of 1996 inhabitants, and San Pedro Yancuitlalpan with 2551 inhabitants.

For this case, the network (Figure 52) shows that the feedback processes between the nodes are positive and negative, respectively. Note the existence of a network isolated from the giant network, which represents the Municipal Development Plan (PMD) relevant to the use of Natural and Geomorphological Resources. This process is due to bureaucracy, political patronage, and institutional corruption of the local government causing the lack of interest in implementing the PMD.

FIGURE 52
GENERAL SAN NICOLÁS DE LOS RANCHOS GRADE DISTRIBUTION NETWORK



Now, the cognitive capital is stimulated by a positive process generated by the knowledge of historical events in the community fed back through the family communication, the presence of handmade products, the good handling of instruments for the production (MIP), the knowledge of the cycles of production in the bipartite process[10] and the territorial geography, the feedback by the labor experience, the family communication and the migration of the inhabitants. It should be noted that the migration of the inhabitants reduces informal education, which in turn has a negative impact on human capital, as well as the low level of development, management, and promotion of health programs, medical service days, and training workshops implemented by the local government. On the other hand, work experience is a factor that allows the existence of self-confidence to succeed and the desire to develop, giving a positive feedback process to the psychosocial capital, coupled with faith in the future and the spirit to undertake.

[10] I call it that, since the way of production is divided into two parts; first the sowing of corn and other products and after the harvest the sowing of products adapted to the climatic conditions of the area, for example, the production of lettuce and cauliflower in cold times.

Concerning institutional capital, there is negative feedback from four nodes: increased bureaucracy, low institutional cooperation, lack of organizational intelligence to solve problems, and resilience, the latter as a factor in the ability to overcome adversity, mainly from natural disasters. These four elements are due to the existence of political-administrative processes such as the lack of institutional adaptability to the community context, political clientelism, and institutional fragmentation among supporters due to the patriarchal institutional system.

Now, civic capital is a capital close to institutional capital. Note that the relations generate a double moment of civic capital: on the one hand negative and on the other positive; regarding the first, it is caused by the low interest of association due to paternalism, the low community organization derived from the patriarchal system, the low interpersonal confidence and the participative absence in assemblies due to the institutional distrust; regarding the second, the civic capital is positive, since the social and electoral participation is derived from the offer of quotas of power, pantries and economic remunerations to the voters.

Let us consider the organization node. The low territorial organization is due to the lack of interpersonal confidence and communication among its inhabitants. Then, the territorial organization appears as a node that encourages all a territorial cognitive synergy since it is associated, as much to the civic capital as to the symbolic capital, where this last one depends in part on the organizational dynamics. Its direct causal links are the low power of conviction, the low social mobility and the persuasion to solve problems, as well as individualism. However, the organization and persuasion would not be that way if the representation of the use of the word implied negative feedback, which in turn limits communication.

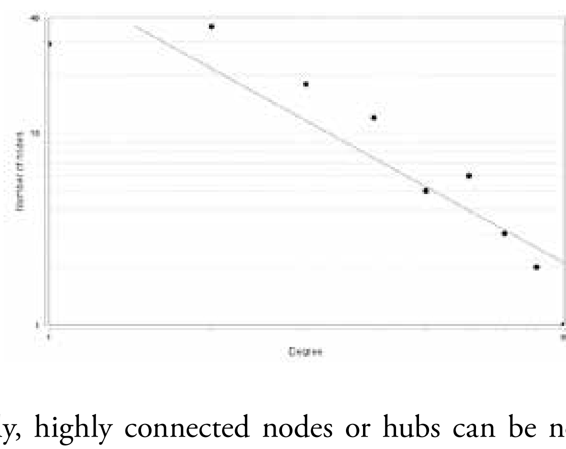
On the other hand, cultural capital contains negative feedback due to lack of cooperation, knowledge of material goods, social participation, lack of solidarity, and the low culture of development encouraged by the individualistic process among the community's inhabitants. Likewise, individualism has had a double impact within the social capital: first, individualism has generated through the years a process of diffuse confidence for the organization that emanated only for the generation of social, cultural, and economic demands, as well as for sustainable, productive projects, on the other hand not for the social participation, at least in the interpersonal cooperation.

Finally, the media capital is positively fed by the media's diversity and pluralism, such as the community voice, friends and family, the regional newspaper, and the community audio. Accompanying these nodes are the external communication services, which have made the community a means of production of saddlery, cultural aspects (material and immaterial), and natural disasters, mainly those caused by the Popocatépetl volcano.

The degree of distribution corresponds to the level of connections that can be seen under the following logic: the nodes of red color are those with more links–both input and output–from there to the green ones. In this case, the node with more links is the one represented by individualism with 9 links (of exit), corresponding to negative feedback towards the diffuse confidence, the communication, the social participation, the material goods, the culture of the development, the cooperation, the institutional coordination, and the interpersonal distrust, most of them indicators of other capitals. This distinguishes, then, that the individualism node is one of the most important in the network (Figure 52).

Figure 53

Log-log histogram of the grade distribution of the San Nicolás network. The straight line shows the adjustment of a power law $Y = AX^B$ where $A = 58.567$ and $B = 1.566$ and whose correlation is 0.951.



Subsequently, highly connected nodes or hubs can be noted; lack of organization, lack of institutional flexibility, institutional cooperation, bureaucracy, work experience, these being the most important within the network dynamics. Thus, determining that few nodes with a large number of links and many nodes with a smaller number of links is a symptom of the existence of a free scale network where new links have a probability of linking to nodes with more links. Then, if we consider the existence of a free scale network, we can affirm the existence of a complex system even when the development is latent (Figure 53).

With respect to the grouping of communities, which indicates the strong association between nodes and thus the cohesion exercised between the groups, it can be noted that in the community of San Nicolás there are ten communities of which eight have a strong relationship to others (Figure 54). The formation of the communities results in the following multi-capitals that correspond to the number of nodes that compose it.

Figure 54

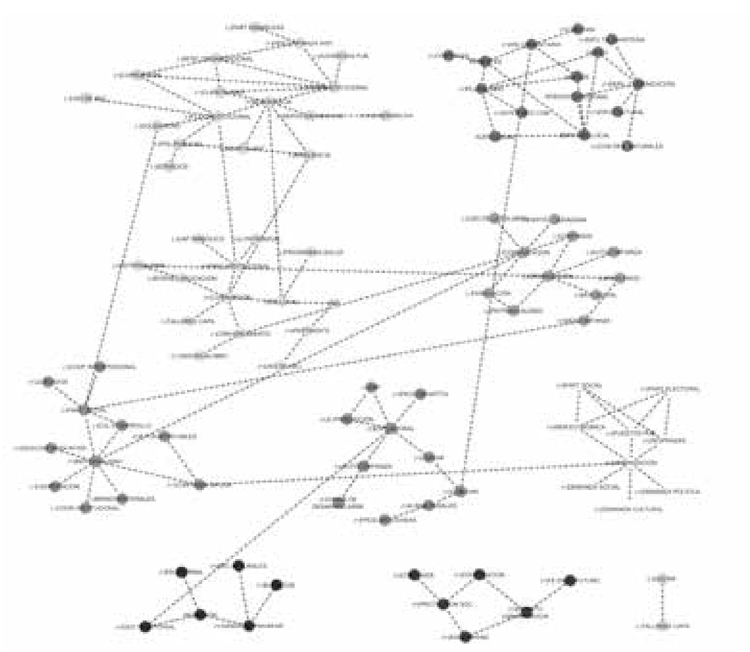
Indicator categorization chart describing multi-capitals hierarchically. San Nicolás de los Ranchos, State of Puebla

MULTICAPITAL 1 16 nodos	MULTICAPITAL 2 15 nodos	MULTICAPITAL 3 14 nodos	MULTICAPITAL 4 11 nodos	MULTICAPITAL 5 11 nodos
(-)FLEX INSTITUCIONAL (-)SOLIDARIDAD (-)USO DE REC (+)BUROCRACIA (-)POL PUBLICAS (-)ADAPTA INST (-)SERVICIOS (+)CLIENTELISMO (-) INTEL ORGANIZACIONAL (+)CORRUPCION (-) COOP INSTITUCIONAL (-)RESILIENCIA (+)DESCONFIANZA INST (-)PART.ASAMBLEAS (-)AUDIENCIAS PUB (-)SERVICIOS MEDICOS	(+)COM FAM (+)HIS COMUNITARIA (+)SERV COMUNICACIÓN (+)CON DES NATURALES (+)DIFU TALAVARTERIA (+)DIFU CULTURAL SERV MED LOCAL PARIENTES AMIGOS AUDIO LOCAL VOCEO PERIODICO REGIONAL (+)PLURALISMO (+)DIVER MED COM (+)CONFIANZA	(-)CONVENCIMIENTO (+) INDIVIDUALISMO (+)C.PATRIARCAL (+)FRAG INSTITUCIONAL PMD (+)PERTINENTE (+)USO DE REC GOB LOCAL (+)CORRUPCIÓN (-)CAP SIMBÓLICO (-)INTERES ASOCIACION (+)PATERNALISMO (-)TALLERES CAPA (-)PROGRAMAS SALUD	(-)USO DE LA PALABRA (-)COMUNICACIÓN (-)CONFIANZA (-)ORGANIZACIÓN (-)MOV SOCIAL (+)PATRIARCALISMO (-)PERSUACIÓN (-)PROY.PROD (+)DESCONFIANZA (-) AUTOCONFIANZA (-)PARTIC. CIUDADANA	(+)INDIVIDUALISMO (-)BIENES MATERIALES (-)CUL DESARROLLO (-)COOPERACIÓN (+)DESCONFIANZA INTER (-)PART. SOCIAL (-)COOR.INSTITUCIONAL (+)CONFIANZA DIFUSA (+)JUZGADOS (-)COOP INTERPERSONAL (+)PP SUSTENTABLES
INST-CIV-HUM INSTITUCIONAL-CÍVICO-HUMANO	MED-SOC MEDIÁTICO-SOCIAL	INST-SOC INSTITUCIONAL-SOCIAL	SOC-MED-PSIC SOCIAL-MEDIÁTICO-PSICOSOCIAL	CIV-COG-CUL-INS CÍVICO-COGNITIVO-CULTURAL-INSTITUCIONAL
MULTICAPITAL 6 **10 nodos**	**MULTICAPITAL 7** **9 nodos**	**MULTICAPITAL 8** **6 nodos**	**MULTICAPITAL 9** **6 nodos**	**MULTICAPITAL 10** **2 nodos**
(+)EXP LABORAL (+)MP (+)PROD BIPARTITA (+)C PRODUCCIÓN (+)COM FAM (+)A INMATERIALES (+)PROD ARTESANIAS (+)CON INF (+)AUTOCONFIANZA (+)GANAS DE DESARROLLARSE	(+)ORGANIZACIÓN (+)DEMANDA POLITICA (+)DEMANDA SOCIAL (+)DEMANDA CULTURAL (+)REM ECONOMICA (+)PART SOCIAL (+)DESPENZAS (+)PUESTOS PUB (+)PART ELECTORAL	(+)GEO TERRITORIAL (+)CAP COGNITIVO (+)REC NATURALES (+)GANAS DE TRIUNFAR (+)BUEN GOB (-)EDU FORMAL	(+)ESPIRITU EMPRENDEDOR (+)FE EN EL FUTURO (+)SOLIDARIDAD (+)PROTECCIÓN SOC (+)CONFIANZA (+)COOPERACIÓN	(-)TALLERES CAPA (-)EDU INF
HUM-COG-CUL HUMANO-COGNITIVO-CULTURAL	INST-SOC-CUL-CIV INSTITUCIONAL-SOCIAL-CULTURAL-CIVICO	COG-PSIC-HUM COGNITIVO-PSICOSOCIAL-HUMANO	PSIC-SOC PSICOSOCIAL-SOCIAL	INST-HUM INSTITUCIONAL-HUMANO

Cohesion between communities is determined by the input and output links between subgroups. Cohesion tends to occur positively and negatively according to the number of links of greater representation (positive or negative). Now, the cohesion with greater weight arises from the humano-cognitivocultural multicapital, since it has two exit links with positive feedback towards the mediático-social multicapital; of family communication and community history. Later, the social-mediático-psicosocial multicapital, whose feedback is negative towards the institutional-social multicapital connected from distrust towards social participation and communication towards the convincing power of the civic-cognitive-cultural-institutional multicapital. With respect to the cívicocognitivo-cultural-institucional multicapital, it can be ob-served that its influence is directed towards the social-mediático-psicosocial multicapital that includes individualism towards communication in a negative way; from

FIGURE 55

GROUPING, HIERARCHY AND COHESION BETWEEN COMMUNITIES OR MULTICAPITALS



diffuse trust towards the organization of the institucional-social-cultural-cívico multicapital; finally the institutional-civic-human multi-capital towards the cívico-cognitivocultural-institucional multicapital from solidarity towards social participation (Figure 55).

It should be taken into account, then, that community six (humano-cognitivo-cultural multicapital), in a qualitative way, represents an essential weight for endogenous development and whose probability of emerging is very wide. Although it has come to be thought that the public institution is responsible for generating agreement with public-private institutions and for providing the community with financial resources, the community network shows that neither the institution nor civic participation are important, but rather the cultural processes which generate transformations at the community level through the transfer of historical knowledge and geographical knowledge, generating a process of socialization from the family nucleus to the social nucleus.

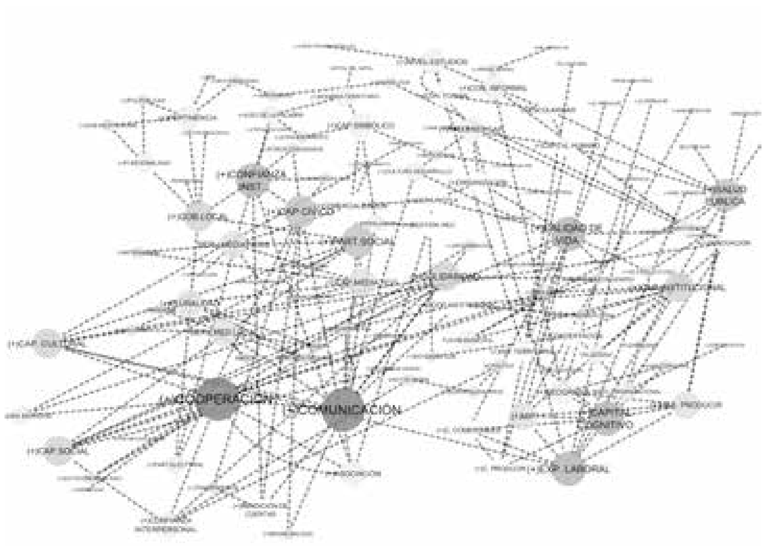
Tlalnepantla, State of Morelos

Tlalnepantla, State of Morelos, is a region located in the north of the State of Morelos on the Ajusco-Chichinautzin biological corridor and whose respective geographical location is; to the north with the federal district; to the east with the municipality of Tepoztlan, to the south with Tlayacapan, to the east with Totolapan and to the northwest with the municipality of Juchitepec, State of México. Tlalnepantla has an average altitude of 2566 meters above sea level, being the highest municipality in the State of Morelos and with a territorial extension of 124.1 km^2. Its population until 2010, according to INEGI sources [141], is 6636 inhabitants of which 3330 are men and 3306 women, being the municipal head the place that concentrates the largest population (3872 inhabitants), followed by it, the delegation (assistants) of Felipe Neri with a population of 1338 inhabitants, El Vigia which houses 832, the rocky 507, subdivisions and other 69.

Tlalnepantla that undergoes endogenous development has as a property a giant network with highly connected positive feedback nodes (Figure 56). In this case, the *cognitive capital*, whose feedback is positive, is due to the direct connection of innovation, the management of production instruments (IPM), knowledge of the territorial geography due to the broad informal knowledge and commercialization processes, the ability to commercialize and produce, work experience, commercialization and production cycles; subsequently, public health and production cycles are nodes that, although they share feedback with the *cognitive capital*, also share feedback with the *human capital*, together with schooling and the ability to produce.

Figure 56

Graphical representation of the degree distribution of the Tlalnepantla Morelos network. The distribution goes from the largest nodes to the smallest nodes, the larger the node, the more links it has



With regard to *cultural capital*, its feedback is due to the connection between work experience and its attribution in training workshops, innovation, political conflicts, social participation, communication, and solidarity among inhabitants. This capital also shares direct connections with *social capital*, which indicates its close relationship. The connections they share come from the nodes of solidarity, cooperation, social participation, and their feedback from the reciprocity of mutual aid, gender relations, and interpersonal trust, encouraging the desire to develop faith in the future and collective progress and success. In other words *psycho-social capital*. The *social capital*, in turn, is related to the *media capital* through social participation and mainly of communication, since without communication between the inhabitants, there is no social participation, likewise feedback is due to the plurality of local and external media services, the interaction between them; friend, community voice, family and local audio.

Respectively, *institutional capital* owes its positive feedback to municipal flexibility in decision making, flexibility and speed in resolving public issues, organizational intelligence, institutional cooperation, and existing resilience to adversity or problems in the community (mainly commercial and political). Although this type of capital does not directly influence other capital, there is a connection through certain nodes. For example, municipal flexibility; it designs and applies public health programs generating feedback towards *human capital* and institutional cooperation to improve services and this to social capital. Finally, the *symbolic capital* is positively fed back by nodes such as; conviction, commercialization processes, social mobility, and persuasion through the use of the word and communication processes.

As we well noticed, the availability of several factors allows stimulating the increase of these capitals. Therefore the failure of a node cannot affect the dynamism of all the network. Since the network tends–through the individuals–to reorganize itself and to adapt to the new conditions, considering, in this room, that the network of the territory does not work in an isolated way, since at the same time there exist in other adjacent configuration spaces others that work simultaneously.

The degree of distribution of the network of Tlalnepantla, State of Morelo,s corresponds to a scale-free typology. Therefore a complex system[11] (Figure 57). The smaller nodes have fewer links, starting from the red nodes to the green nodes. To better explain this statement, note that the two red nodes share the same number of links (13 links, both

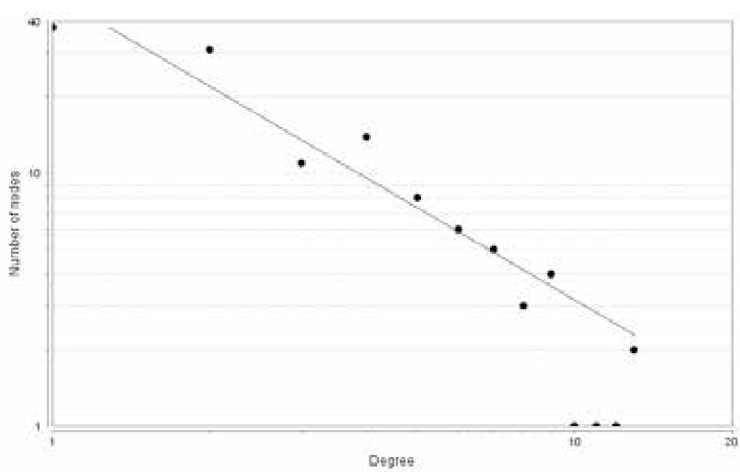
[11] Scale-free in networks implies a complex system, however in a complex system, there is no need for free scale.

inbound and outbound); that is, communication and cooperation are two highly influential nodes towards the network dynamics. The orange nodes (quality of life, work experience, institutional confidence, etc.) with an average of 9 links–both inbound and outbound–, the brown nodes between seven and six links, the yellow nodes between 4 and 5 links, and the green nodes between 1 and 2 links.

Within the network, there are very few nodes with a link. From this perspective, because it is highly connected, the network dynamics may be determined by the links between the nodes. It is likely that if one node (whichever it is) develops negative feedback to the other nodes, it will self-organize and change the dynamics. This means that the network will be resilient to such a disturbance. It may not return to its previous state but may return to a stable state adapted to the new conditions[12] (Figure 57).

FIGURE 57

GRADE DISTRIBUTION AND AVERAGE LINKS PER NODE. WHEN APPLYING A LOG-LOG, THE EXISTENCE OF A SCALE FREE ONE CAN BE APPRECIATED, SO WE SPEAK OF A COMPLEX SYSTEM. THE STRAIGHT LINE SHOWS THE ADJUSTMENT OF A POWER LAW $Y = AX^B$ WHERE $A = 62.824$ AND $B = -1.663$ AND WHOSE CORRELATION IS 0.951



[12] This is demonstrated with Boolean networks in the following section.

When we remove the links representing the intangible capitals, fragmentation in the network could be expected. However, when carrying out the grouping of communities, the network maintains its synergy between the existing nodes showing a strong association between the nodes with similar characteristics. To this extent, the emergence of nine multi-capitals with a strong feature of synergy between all. Figure 58.

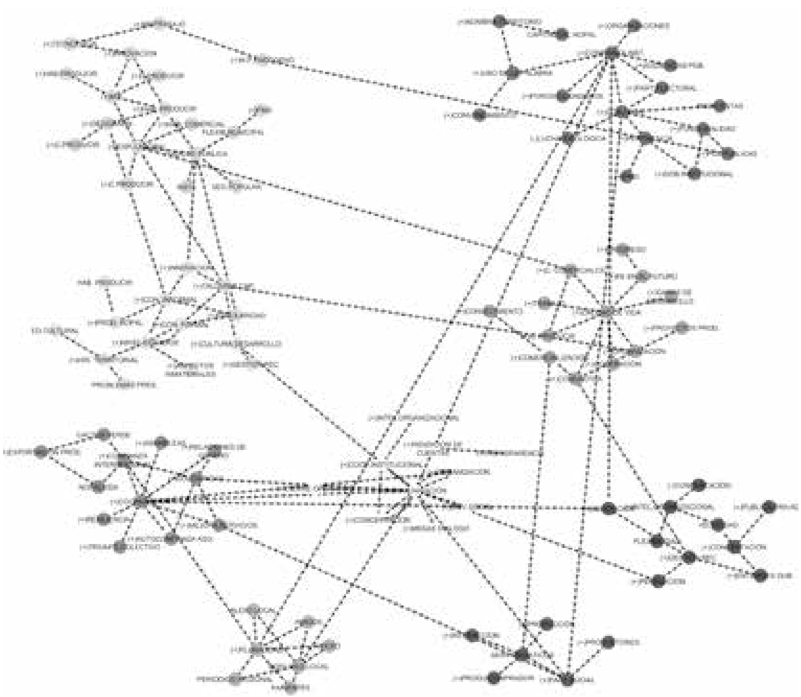
Figure 58

Table of categorization of indicators describing multi-capitals with respect to the network of communities. Tlalnepantla, Morelos

MULTICAPITAL 1 18 nodos	MULTICAPITAL 2 17 nodos	MULTICAPITAL 3 14 nodos	MULTICAPITAL 4 13 nodos	MULTICAPITAL 5 12 nodos
(+)MIP	(+)CONFIANZA INST.	(+)INNOVACIÓN	(+)COMUNOTLA	CACTUS VERDE
(+)HAB. PRODUCIR	(+)ORGANIZACIONES	(+)TALLERES CAP.	(+)COMERCIALIZACIÓN	NOPALVIDA
(+)C.PRODUCIR	(+)GOB.LOCAL	(+)CON. INFORMAL	(+)CONVECIMIENTO	(+)EXPORTACIÓN PROD.
(+)HAB.PRODUCIR	(+)FUNCIONALIDAD	(+)ESCOLARIDAD	(+)C. PRODUCIR	(+)RELACIONES DE GÉNERO
(+)GEOGRAFIA	(+)POL.PUBLICAS	(+)CON. FORMAL	(+)C. COMERCIALES	(+)ASAMBLEAS
(+)C.PRODUCIR	(+)FOROS CIUDADANOS	(+)NIVEL ESTUDIOS	(+)ORGANIZACIÓN	(+)COOPERACIÓN
(+)INNOVACION	(+)AUDIENCIAS PÚB	(+)PROD.NOPAL	(+)CALIDAD DE VIDA	(+)SOLIDARIDAD
(+)EXP. LABORAL	(+)PART.ELECTORAL	(+)HAB.PRODUCIR	(+)FE EN EL FUTURO	(+)MEJORA SERVICIOS
(+)C.PRODUCIR	(-)LUCHA IDEOLÓGICA	(+)EDU.CULTURAL	(+)COOERACIÓN	(+)RESILIENCIA
(+)HAB. COMERCIAL	(+)GOB.INSTITUCIONAL	(+)HIST. TERRITORIAL	(+)GANAS DE DESARROLLO	(+)AUTOCONFIANZA ASO.
SEG.POPULAR	(+)USO DE LA PALABRA	(+)ASPECTOS INMATERIALES	(+)TRABAJO	(+)TRIUNFO COLECTIVO
(+)SALUD PUBLICA ISSTE	(+)CONVENCIMIENTO	(+)CULTURA DESARROLLO	(+)PROGRESO	(+)CONFIANZA INTERPERSONAL
FLEXIB.MUNICIPAL	(+)NOMBRA-TERRITORIO	(+)GESTION-RECURSOS	(+)PROYECTOS PROD.	
(+)TECNOLOGIA	CAPITAL DEL NOPAL	(-)PROBLEMAS PRES.		
(+)MMTRABAJO	(+)PMD			
(+)M.P.ENDÓGENO	(+)PERTINENCIA			
(+)PMD				
COG-HUMANO CCOGNITIVO-HUMANO	INST-SIM-CÍV INSTITUCIONAL-SIMBÓLICO-CÍVICO	CÍV-INST-SIM CÍVICO-INSTITUCIONAL-SIMBÓLICO	SOC-PSIC-COG SOCIAL-PSICOSOCIAL-COGNITIVO	SOC-INST-CIV-COG SOCIAL-INSTITUCIONAL-CÍVICO-COGNITIVO
MULTICAPITAL 6 7 nodos	MULTICAPITAL 7 10 nodos	MULTICAPITAL 8 6 nodos	MULTICAPITAL 9 10 nodos	
SERV.MED LOCAL	(+)MESAS DIALÓGO	(+)PRODUCTORES	(+)PERSUACIÓN	
PARIENTES	(+)RENDICIÓN DE CUENTAS	SERV.MEDIATICOS	(+)CONCERTACIÓN	
AMIGOS	(+)TRANSPARENCIA	(+)PRODUCCIÓN	(+)PÚBLICO-PRIVADA	
AUDIO LOCAL	(+)CIERRE OPERATIVO	(+)INTERACCIÓN	FLEXIBILIDAD	
VOCEO	(+)MOV.SOCIAL	(+)PRODU-COMPRADOR	(-)INTEL.ORGANIZACIONAL	
PERIÓDICO REGIONAL	(+)COMUNICACIÓN	(+)PART.SOCIAL	VELOCIDAD	
(+)PLURALIDAD	(+)ORGANIZACIÓN		()CONCERTACIÓN	
	(+)CONCERTACIÓN		(+)ENTIDADES GUB.	
	(+)COOP.INSTITUCIONAL		(+)GESTIÓN REC.	
	(+)INTEL.ORGANIZACIONAL		(+)ASOCIACIÓN	
SIM-INST-CUL-COG SIMBÓLICO-INSTITUCIONAL-CULTURAL-COGNITIVO	SIM-INST SIMBÓLICO-INSTITUCIONAL	MED MEDIATICO	COG-SOC-CUL COGNITIVO-SOCIAL-CULTURAL	

The structure of the network (Figure 59) shows the cohesion from one multicapital to another. The *cognitivo-humano multicapital* has a balanced cohesion power, since as well as influence towards the *cívico-institucional-humano* and *social-psicosocial-cognitivo* multicapitals, it also has a cohesion process coming from other communities; *cívico-institucional-humano*, and in double average towards it *institucionalsimbólico-cívico*.

FIGURE 59
GROUPINGS AND COHESION BETWEEN COMMUNITIES OR MULTICAPITALS IN TLALNEPANTLA



However, the cohesion in the Municipality of Tlalnepantla, Morelos, is mainly due to the socialization process among the inhabitants, due to the plurality coming from the family (relatives) and friends, this causing their cohesion towards the communication process and the interpersonal trust, which in turn allows the synergy among the other communities. Based on the above, it is considered that endogenous development contains a framework of plurality and interpersonal trust, greatly expanding the generation of communication, cooperation, willingness to move forward, and institutional trust. Subsequently, the cohesion between the other communities should be observed, and the existence of synergy between each one of them should be noted, that is to say, input and output feedback links, therefore a systemic and not atomized process.

From the results obtained, we argue that it is far from justified that the local government has the responsibility to encourage the endogenous development–as Boisier affirms–since the causal networks and the generation of communities show that the institutions within the endogenous development do not have a wide weight. First, note the entry links, which mark the capitals of greater representativeness. In Tlalnepantla, the *civic capital* and the *cognitive capital* have the greater representativeness, leading to say that transparency, cooperation, social participation, and media services joined to work experience, innovation in the production processes, the knowledge of the cycles of production and commercialization, among others in the *cognitive capital*, are elements of wide importance for the endogenous development. Consider that the local public institution only functions in a smaller measure for the development of workshops and processes of resource management for the workers at entities closer to this level.

From this, it should be noted that development is not the same in all regions; its dynamics, causality, synergy, and complexity are different from one region to another. For these communities, the local government is not primarily responsible. Thus, attention must be paid to the fact that endogenous development, far from being an emerging property, is a socially organized, cooperative, supportive, healthy, and participatory system, whose value lies mainly in the communication among the individuals of the territory.

Endogenous Development, Boolean Networks and Attractors

Recall that Boolean networks help explore regions of the state space; they arise through interaction conditions that encourage the emergence of ordered patterns of behavior, represented by a set of cells or Artificial Neural Networks (ANN) and described by input and output signals. Thus, in this section, we present Boolean networks' dynamics in each study community to determine the generation of emerging properties through iteration between the multicapitals and determine new states, whether they are stable, stationary, or cycle attractors.

Of this, to be able to formally and graphically demonstrate that endogenous development is an emerging property of a complex, synergized, and synaptic system generated only in each local dimension of the territory, not generated only by intangible capitals but by the generation of groupings between capitals, for which it will be tried to sustain that endogenous development does not contain intangible capitals but multicapitals, generated and dynamized differently in each territory according to the process of interaction and not of time.

The development of Boolean networks is mainly linked to the multi capital ones elaborated in the previous section's complex networks, whose properties are the cohesion and the number of nodes they have. The directionality of one group towards another depends on the number of positive or negative feedback links. For example, let us assume that we have a group that contains five links, and three are positive feedback links. In this way, becoming the initial condition of each network, this initial condition will be represented with a combination of binary numbers with an interval between $[0 and 1]$, where zero represents an inhibitor and one an activator. Consider that what is taken in this section are synchronized updates. The Artificial Neurons (AN) will be updated simultaneously according to the other AN values in the network over time. For this, only multi-capitals that have links with others will be taken into account, not isolated groups, since these do not determine or influence the network dynamics, Figures 60 and 61.

However, to better understand the dynamics of the Boolean network from the simulation, the following points are described:

- The initial condition of each network is represented according to the multi-capital networks, the red lines represent the negative link, the green lines relate to a positive feedback link, then the red **NA** are inhibitors and the green **NA** are activators.

Figure 60
San Nicolás de los Ranchos Community multicapital network

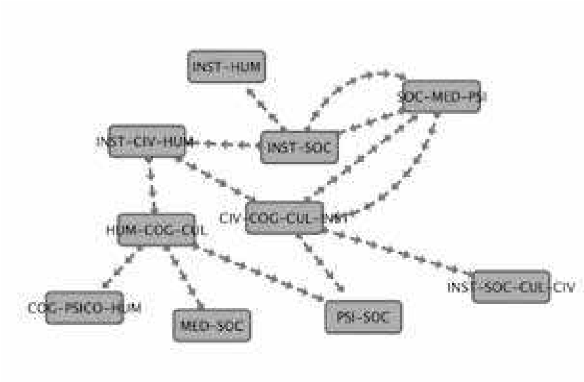
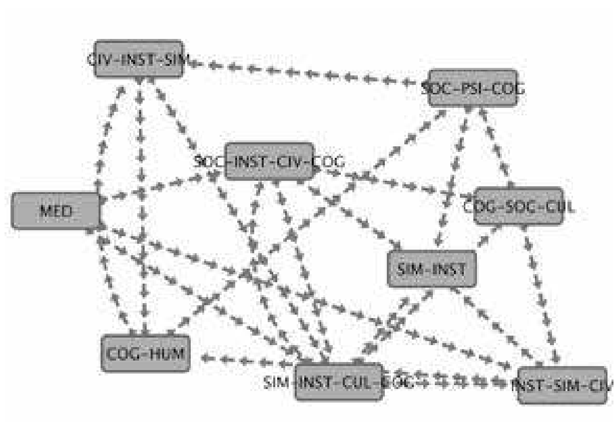


Figure 61
Multicapital network of the Community of Tlalnepantla, Morelos



- The status of the network is represented in the four-digit box (*state*), this status is obtained from the initial condition with the same number of nodes that must be read from left to right. Later, in order to give the dynamics to the network, node 0 (multicapital) is the first number on the left of *initial-condition*, node 1 is the second on the left, node 3 is the third on the left and so on. The box called *state of the network* is the new state the network will be in when iterating the nodes, this network will form the new state and will stop when it finds the attractor.

- From the above, it should be considered, then, that the new states or emerging properties of the Boolean network will be generated through operating rules of adaptation and coupling of the structure as a function of 0 and 1, where 0 is an inhibitor (red) and 1 is an activator (green), then this being iterated will modify at time $t + 1$ to its neighbor and its update will be synchronized until finding a new emerging property or state cycle.
- Finally, by developing these assumptions, it is possible to determine what would happen empirically if one of the multicapitals were to change from an activator to an inhibitor, allowing for a clearer picture of the dynamics in the community. Reiterating and formally grounding that the dynamics of endogenous development is an emerging property of a complex, synergized system that starts from the bottom up and sides, of which Sergio Boisier speaks. However, in these contexts, it is not the public institutions of the communities that generate the process of endogenous development, but the cognitive synergy between the indicators of each multicapital and not of each intangible capital, which is only possible through communication between the individuals of each community.

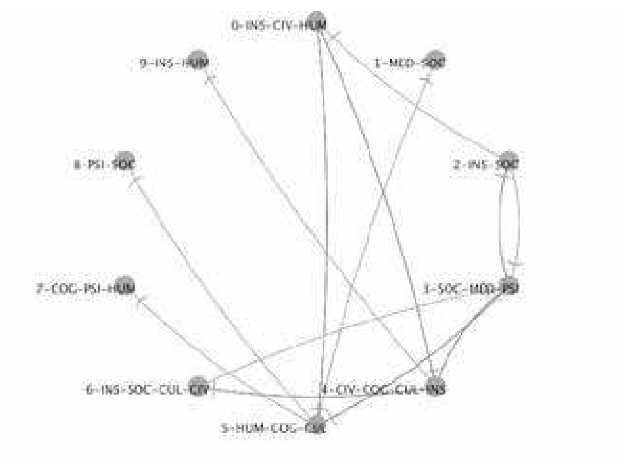
San Nicolás de los Ranchos, State of Puebla

The community of San Nicolás has an inert endogenous development, with the existence of a wide possibility of development emerging through the interactions between its components. It should be said that development is in this state due to the broad polarization between the institution and the agreement with society, based on the instrumental rationalism of the endogenous potential and the inadequate use of natural resources–demonstrated by the causal network.

However, within the complex network elaborated in the community of San Nicolás, we could notice the emergence of subgroups later called multi-capitals. Besides being synergized, these groups contain a system of cohesion towards other subgroups with positive or negative feedback (Figure 60). From here, we start the initial condition of our first assumption: Figure 62 represents the Boolean network corresponding to the network of subgroups. Note that all the NA are on (green), which in numbers represents a combination of 1111111111, and its corresponding state is 1023 characterized by positive and negative feedback being activators or inhibitors.

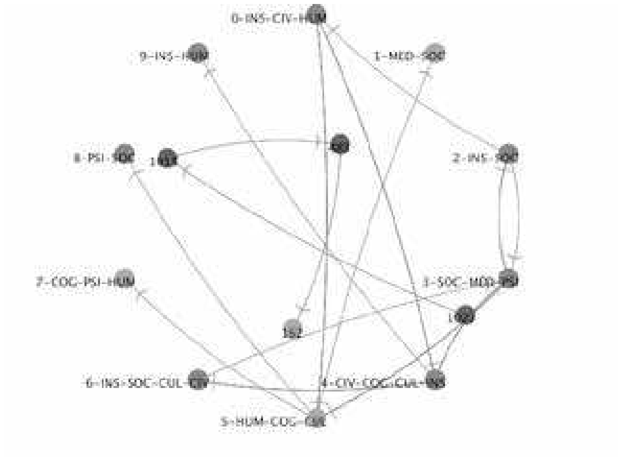
Figure 62

Initial condition 1111111111 of the Boolean network whose status is 1023 corresponding to the complex network of multicapitals or subgroups



The Boolean network in the community of San Nicolás presents an interesting dynamic. Iterating to the first time step $t + 1$, the state of the network passes to 1015 where the NA corresponding to the multi-capital SOC-MEDPSICO is inhibited. Later, to the following time step $t + 1$ multi-capital 2 (INS-SOC), 4 (CIV-COG-CUL-INS), and 9 (INS-HUM) tend to be switched off. Then, according to the interaction, multi-capital 6 (INS-SOC-CUL-CIV) and the 8 (PSI-SOC) tend to be turned off, reaching a stationary attractor, whose state is stationary corresponding to the 162 (0010100010) as shown in Figure 63.

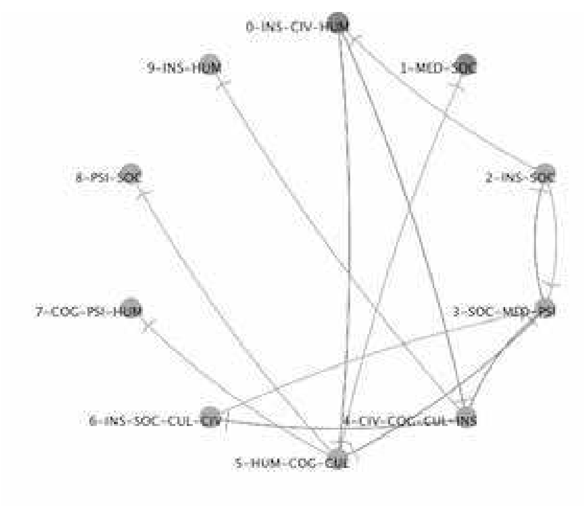
Figure 63
Stationary attractor 162 of the Boolean network, which shows the possible stability of the endogenous development network in the community of San Nicolás according to the initial condition 11111111



From this dynamic, we can say that the endogenous development of the community of San Nicolás will remain inert. Phenomenologically, it can be said that the NA that remains on–or will remain on–contains elements related to a broad process based on individualism, bureaucracy, institutional distrust, and low organizational intelligence, lack of resilience, etc. Added to this are the high political demand processes in social issues and lack of institutional coordination, an issue that has existed in the community as a permanent phenomenon (Figure 63).

Now, let us consider the same feedback dynamic and a small change in the initial conditions. Assuming that we now turn off the NA 0 (INS-CIV-HUM) and 1 (MED-SOC), the state it would be in (1020), and initial condition 11111111100. For this case, it should be considered that multi-capital 0 has a negative feedback connection to other NA, and NA 1 is positively fed by multi-capital HUM-COGCUL (Figure 64). Afterward, when performing continuous iterations, an attractor emerges in a cycle state, since the network oscillates between state 130 and 160 whose respective network conditions are 0010000010 for state 130 and 0010100000 for state 160.

Figure 64
Boolean network with initial condition in state 1020



Now, the properties that emerge from this dynamic are interesting: firstly because the attractor being cyclical the feedback from the NA would only be found between NA 1 (MED-SOC) AND 5 (HUM-COG-CUL). Which, phenomenologically, means the following:

- Being any iteration process due to the existence of individualism, low culture of development, interpersonal distrust, low participation, etc. And whose characteristics are strongly linked to other elements of each NA–or multi-capital–the process that will emerge is that bureaucracy, clientelism, lack of resilience, corruption, etc., will continue to reign. Thus, given these dynamics, this would generate development that is inert or, in its case, fades away, but by remaining the multi-capital MED-SOC has allowed development to be latent since the diffusion of the Talavera, community history, cultural diffusion, media diversity, and family communication are factors that coexist in the community and will hardly disappear. Therefore, according to the dynamics of the network, the attractor that has maintained the system of endogenous development is the multi-capital *mediá tico social*.

- The way this property emerges tends to determine how your process will be. This process will consist of seven steps of time, which may be days, weeks, or months. For this reason, the Boolean network allows us to know with greater assertiveness the processes that will lead to the disappearance and maintenance of the endogenous development of the community of San Nicolás, and from this to be able to solve or generate alternatives of positive feedback such as pertinent and functional public policies.
- However, it can be seen that the multicapital COG-PSI-HUM or NA 7 has no change, this is due to; i) that people cannot lose the process of territorial geography, since the existence of means of interaction with other actors outside the territory is necessary and cannot be broken due to the processes of commercialization; ii) the process of interaction with the natural environment cannot be broken either, since their means of subsistence arise from this, as well as from having self-confidence in succeeding. With this, the Boolean network shows that the possibility of synergy with the territorial environment and its deep self-confidence is impossible to break.
- On the other hand, whatever the initial condition of the Boolean network, as long as the NA 7 corresponding to the COGPSI-HUM multi-capital is not switched off, the final state will be the same, a cycle attractor and oscillating between state 130 and 160, however, If we turn off NA 7 together with NA 3 corresponding to multicapital SOC-MED-PSI the exchange dynamics and the state would reach a stationary state 34 (Figures 65 and 66) where the multi-capital MED-SOC and HUMCOG-CUL would remain permanently on, that is to say, the media would not disappear and the communication processes between the closest individuals, with respect to the social, would hardly be diffused. Likewise, it would happen with the cultural, cognitive, and human question.

Finally, the last emerging property of the community of San Nicolás is a cyclical attractor state that oscillates between state 2 and 32, which shows the relationship and reciprocal feedback between multi-capital 1 (MED and SOC) and 5 (HUM-COG-CUL) without the existence of any other

FIGURE 65
BOOLEAN NETWORK WITH INITIAL CONDITION 11101110111,
NA 7 AND 3 ARE KEPT OFF RESPECTIVELY

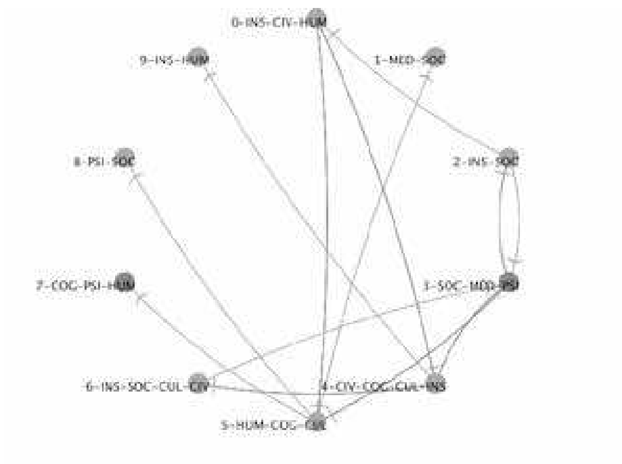
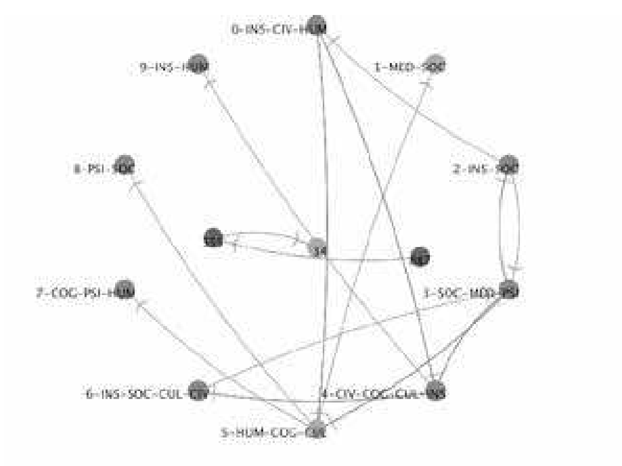


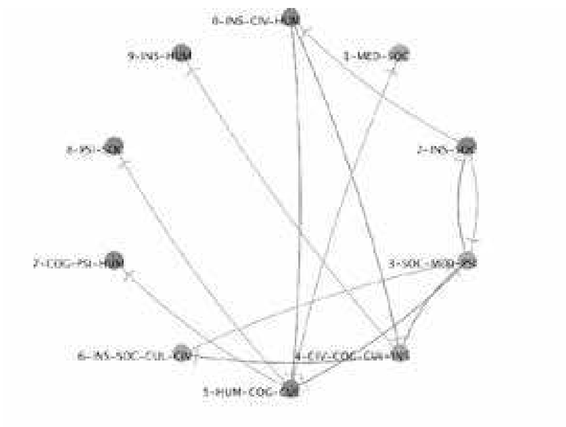
FIGURE 66
REPRESENTATION OF A STATIONARY STATE 34 WITH
TWO SWITCHED NA NOT PERMANENTLY CHANGED



NA on, in other words, the absence of subjective factors that encourage synergy and encourage endogenous territorial development (Figure 67).

Figure 67

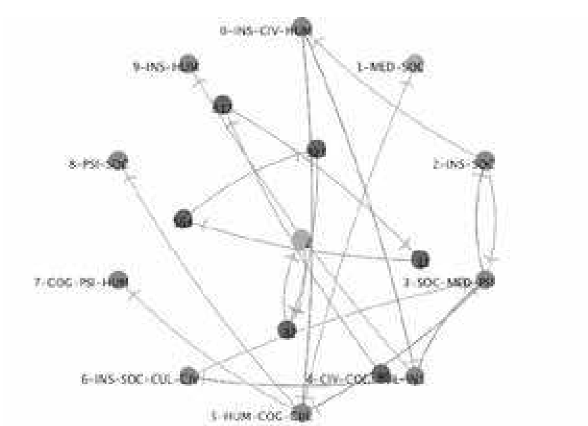
Initial condition of the Boolean network in state 90 representing NA with positive feedback



Said property or state emerges at the moment of iterating four NA with positive feedback and six artificial neurons turned off, which during the iteration do not turn on and generate that at the passage of time $t + 1$ they reach the cyclic attractor (Figure 68).

Figure 68

Cyclic attractor of the Boolean network whose initial condition is state 90



Thus, from the above, San Nicolás de los Ranchos' community has three emerging properties; two cyclical states with oscillatory feedback and one stationary state. These dynamics are phenomena of self-organization and interaction between the parts of the network with components that contribute to these states' formation. So, from this, we consider that the approach to reality is exceptionally narrow since the simplification of the interactions of the Boolean network are conditions of possible combinations between the condition of each Artificial Neuron (AN) whether they are off or on, inhibiting or activating, but that ultimately shows an approach to the phenomenological framework of endogenous development.

Tlalnepantla, Morelos State

Tlalnepantla, Morelos State, is a community that experiences an endogenous development process that emerged through the synergy of a great variety of elements that share information with each other.

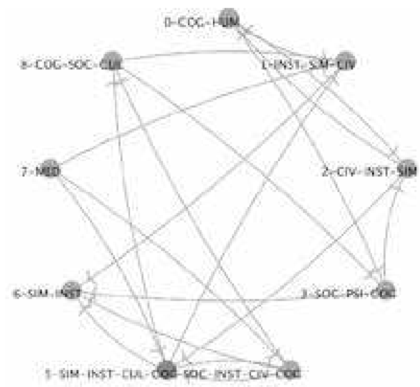
As a first approximation to the dynamics of development, we could mention that the emerging property would be the same (disappearance of endogenous development). However, the dynamics would be different according to the respective initial condition. Thus, let us suppose that in the community, the multi-capital number 5 stops working correctly and contains elements such as organizational intelligence, institutional cooperation with the citizens, organization, social mobility, and, above all, communication[13] (Figure 69) the dynamic would be represented in the following way:

- At time $t + 1$, the dynamics of the NA 4, 6, and 8 would stop, whose elements are directly fed back by this multi-capital, later the NA 3 and 1 until reaching a stationary state where only the multicapital seven represented by elements of the media capital (the plurality of media, local communication services) remains on, this dynamics is founded with the condition that the media

[13] See table of multi-capitals of Tlalnepantla, Morelos.

Figure 69

Initial condition 111011111 of the community of Tlalnepantla, Morelos where only NA 5 (multicapital 6) is turned off. This represents the state 479

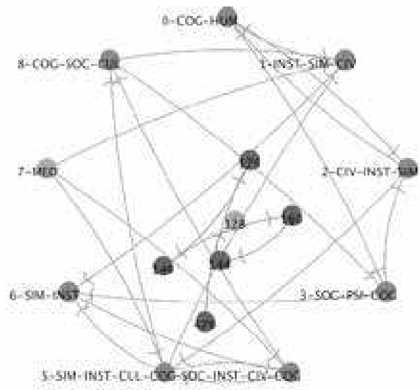


capital is only used–commercially speaking–as a means of commercialization (sale of nopal vegetables and purchase of inputs for its production). Therefore, we can deduce that the media processes as a communication mode are an element of wide importance for the emergence of endogenous development. Therefore, if this capital stopped working, the development would be blurred (Figure 70). It is then that communication is one of the essential elements–and perhaps the one with the greatest weight–to promote development and not so of the institution as Sergio Boisier maintains. However, the institution only functions as a local manager for the benefit of production.

- To support the above thesis, suppose that the initial condition is represented in state 383, where all the NA or multi-capitals are on, and the multi-capital or NA 7 is off (Figure 71). The influence of this capital would be to turn off the first NA with which it has a direct connection, that is, with those that contain greater cohesion; these NA are 1, 5, and 4 corresponding to the multi-capitals INS-SIMCIV, SOC-INST-SIM-COG, and SIM-INS-CUL-COG, respectively. Subsequently, following the dynamics, those close to the latter 6, 8, and 0 -SIM-INST, COG-SOC-CUL, and COG-HUMand finally 2 and 3-CIV-INST-SIM

Figure 70

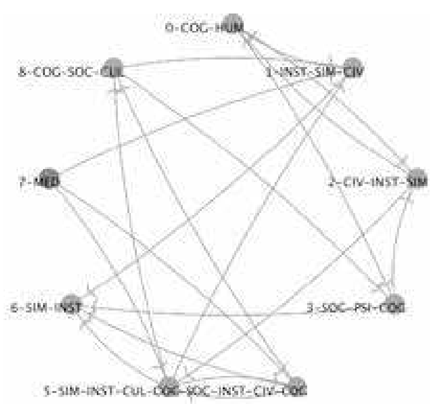
Stationary state with attractor in the state 128. It represents, the emergence of a blurred development, as well as the importance and strength of the NA 7 related to the media capital



and SOC-PSI-COG, reach-ing a stationary state, where there are no more trajectories to follow. Then, as long as this happens, the endogenous development will fade away. The conditions of opportunities to live well in the community will decrease; there will be no opportunity to succeed.

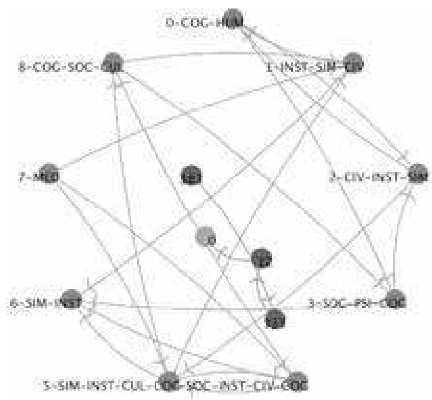
Figure 71

Status 383 with initial condition 101111111 Media Capital Off



Finally, whatever the combination of initial conditions, as long as the NA representative of media capital is not turned off, the property that would emerge will be a stationary state 0, without the possibility of the existence of any other trajectory that would generate new properties. Then, our complex system will be stabilized, and its attractor will always be the same (zero) (Figure 72).

Figure 72
Stationary stabilized 0 state of the Boolean network where endogenous development in the community of Tlalnepantla would be diffused



In conclusion, it can be said that endogenous development in the community of Tlalnepantla, State of Morelos has been encouraged, selforganized and has evolved due to the wide role of the media capital, since it is the one that allows the communicative processes among the inhabitants of the community and with actors not belonging to the territory, that is to say, to other complex systems. This capital allows the synergy and catalysis of the other capitals through communication, which in turn, in a self-organized way, allows the dynamics and emergence of endogenous development, then, being this the most important synergic capital within the community and not the public institution as the closest actor to the territory.

Final Comments

The paradigm of endogenous development has become a highly relevant issue today, but its maturity has largely been centered on the logical, intellectual discourse. In this sense, that the presented work shows an initial trans-disciplinary framework–whose approach is systemic–to be able to give greater support to the qualitative discourse of endogenous development and to contribute a different approach to the problem, this is, a tool that not only graphically presents structures of causal networks, but also its dynamics to the space of time $t + 1$, allowing its mathematical demonstration.

However, from this approach and under the assumptions made in this work, we conclude the following:

1. Endogenous development is a phenomenon that highlights the human being, makes him responsible for his own development, and focuses the public institution as the main factor to detonate the territorial development, to give a local decentralization, of the increase of the Innovation, development, and investment (I+D+i), of intangible and subjective process, as well as of the use of the local resources are these educational, ecological, human, geomorphological, etc. However, as far as this is concerned, the local public institution is not the main actor–as Sergio Boisier states:

> This process of synergetic capital is not automatic, it requires a promoter and such actor cannot be but the government of the respective territory, as concrete agent of the State in that level. [131]

It is demonstrated through complex networks. These show that communication and interaction between individuals is the primary agent, as well as cooperation, transparency, social participation, work experience, media services, and production and marketing processes, *i.e.*, territorial organization. This does not detract from the fact that the public institution is not an essential agent for development; its role is focused on managing resources for the territory's productive needs and formulating relevant and functional public policies, and not as a driving force.

2. Likewise, under the assumptions made here, the work shows that endogenous development is indeed a complex system since its typology represents one free of scale. In this sense, the line formed by the nodes' connectivity in Tlalnepantla, Morelos has a slope where the correlation is close to 1 adjusting to a power law (Figure 57).
3. On the other hand, given the use of mathematical and computational tools (Boolean networks), it is determined that the connection between the elements can be positive or negative according to their dynamics of operation, thus being able to influence that the endogenous development has a deterministic approach, therefore predictive.

AN AGENT-BASED MODEL FOR SOCIAL UPRISING

Andrea A. España Tinajero
Edgardo Ugalde Saldaña
Antonio Aguilera Ontiveros

Abstract

We present an agent-based model of citizens and police agents' behavior in a revolt taking place in a city. We model the citizens as agents capable of joining or quitting the uprising at any time and capable of moving across the physical space of the city as the revolt spreads. The police force is modeled by agents moving across the city, trying to inhibit the uprising in moderated active locations, or running away from a location whenever the rebels exceed them. With those rules, we found that the number of rebellious citizens follows a logistic behavior, such as the one predicted by contagion models based on systems of differential equations.

Introduction

Protests have been used historically as an instrument to make the authorities aware of a need or concern that society has, which in some cases has not been resolved by other instances. They achieve their objective when they manage to capture society's authorities' attention and show signs of the possibility of changes. These institutions generally act because the protests generate a negative image of their figure or what they represent. Despite this, in some occasions, powers are granted to the authorities in charge of protecting the security of a community so that they make use of the public force and dissolve protest demonstrations, justifying themselves in that they assure the order, peace, and tranquility of a larger society. In some cases, these powers are unclear with respect to the use of weapons, resulting in its arbitrary use.

Because protests are a powerful instrument of social communication, with substantial consequences for the development of a society, it is essential to understand their dynamics, particularly when they are affected by the public force's intervention. Studying this type of phenomena requires a multidisciplinary approach recruiting social sciences, mathematical modeling, and computer simulations. Given the multiple interactions between individuals participating in the protests, these are considered complex phenomena, which have been dedicated several studies within the area of modeling, which together we call *Social Conflict Models* (SCM) as in [142]. In this area, the computational approach of the *Agents-Based Models* (ABM), for its qualities in the treatment of heterogeneous phenomena and its formulation accessibility, has been increasingly used in recent times [143]. ABM's main idea is to describe a phenomenon through the interactions of computational entities (agents), which have some attributes and follow some behavioral rules. Within the context of the SCM, agents can be separated into two groups: those who carry out the protest (citizens) and those who try to stifle it (police officers). The behavioral rules are inspired by classical models, which consider a change of status, conditioned to the state of the revolt in its surroundings. For example, each agent A has a threshold *TA* to become "active", that is, to join the protest when the proportion of the other agents exceeds its threshold. The model considers the movement of active agents across the city, leading to a spreading of the revolt.

Theoretical-conceptual framework

Throughout history, people have used *protest demonstrations* to demand their rights and make their needs known. These protests, on many occasions, have triumphed, leading to beneficial changes in political issues. Due to the development and advances in technology, members of the population have used social networks to publicize these events, to call for assistance and to coordinate their activities quickly and effectively. Kuran [144] considers that the protest arises when the people reveal their position in front of an oppressor. It is a spontaneous and collective demonstration where the inclinations or the position in front of conflict situations are staged.

These grievances, suffered by the population, set the tone to call a protest. The public, realizing these events and feeling identified with others' demands, can decide to join the demonstration as if it was a kind of contagion.

General description and planning processes

Let us set-up our agent-based model for a social uprising. First, we will establish what we mean in general by an agent-based model. Then we will specify the qualities and characteristics of our specific model. Finally, we discuss some of the applications of agent-based modeling.

What is agent-based modeling?

Let us start by establishing what in this work we understand by *model*. Following the definition of Wilensky and Rand [145], a *model* is an abstract description of a process, object, or event. Different uses are given to models: to describe, explain, experiment, make analogies, predictions, etc. A model is a *simplified description* of a phenomenon; it does not consider all the details present in the real world. Likewise, a model is *explanatory* when its purpose is to find the essential mechanisms behind a phenomenon's emergence. For example, if we believe that certain rules govern a phenomenon, we model from it and compare the model's behavior with empirical observations. If they qualitatively agree, we conclude that those rules are likely to describe the real interactions governing the phenomenon. Explanatory models provide insight into the possible and the inaccessible behaviors of the system being modeled. Once established that a model can correctly describe and explain a phenomenon, one of its most cherished purposes is*prediction*, in other words, to be able to foresee future scenarios from the data that we already have.

With this idea, we will define the type of modeling we are going to use. According to Aguilera and Posada [146]: Agent-based modeling (ABM) is a computational technique to model phenomena arising from the interactions between individuals, called agents, and between them and the environment in which they evolve.

In the ABM framework, agents are computational entities supplied with a set of *attributes* and subject to specific *behavioral rules*. Usually, agents evolve in an appropriate space, which we call *environment*, where we simulations develop. Agents can represent any individual element of a system, for example, predators and prey, units of chemical substances in a solution, particles that interact with each other, etc.

The main idea of ABM is that many phenomena in the world can be effectively modeled with agents, their environment, and a description of the agent-agent and agent-environment inter-actions. To be more precise, according to Wilensky and Rand [145], an *agent* is an autonomous individual or an object with particular properties, actions, and possible aims.

This type of model implicitly assumes that agents of the same type are computationally equivalent. The same behavior is expected of each of them, having the same rules by which they are governed. There is no place for the total individuality of each agent. The *environment* is the landscape where the agents interact. It can be geometric, a network, or actual data drawings.

The interactions between agents and the environment can be achieved by an exchange of information. As a result of these interactions, agents can update their internal state or take additional actions.

Qualities and characteristics

Computational tools are used to observe the dynamics of ABMs, allowing us to handle a large number of agents and long simulation times. ABMs are more accessible when there are a moderate number of interactions between agents. This type of modeling can be easily implemented for non-homogeneous phenomena, that is, when agents can change their behavior and even their strategies based on past events.

Consistently, a distinction is that since ABM depend on individuals, they can model heterogeneous population, while models based on (difference of differential) equations typically assume homogeneity. For models based on an individual's behavior, the interactions and results are typically discrete and not continuous. These models are designed to understand and explain complex phenomena that from traditional approaches could not be explained.

Moreover, one of the salient characteristics of ABM and computer models in general, is that it is easy to incorporate randomness, which acts as an approximation to real-world indeterminism. Consequently, this allows us to simulate multiple scenarios, and from this, explore them as complex systems. Due to agent dependence to comply with the rules with some probability, ABM belong to the class of *stochastic processes*.

Applications

Wilenski and Rand recognize, in *An Introduction to Agent-Based Modeling* [145], that many people are more likely to accept models formulated from differential equations. Traditionally, they have more confidence in the equations than in simple rules that follow computational entities. However, the AMB approach's pertinence can be attested by urban models like Schelling's [147]. This model was designed to explain the racial segregation observed in some cities of the United States and continue to be the basis for understanding this phenomenon worldwide. Recently, this kind of models has been used to understand the development of public politics and the proliferation of extremist opinions within the population. An example of this is the model of relative agreement of Abrica *et al.* in [148], where she studies the impact of ideological affinity on *opinion dynamics*. Likewise, this kind of models have also been used in practical applications, such as *consumer behavior*, where complex interactions between customers and the products they consume are examined.

The model

Definition

Our model derives from Epstein's work on civil violence [149], with some simplifications and adaptations and it follows the design specifications of Nigel [143] and Shiflet *et al.* [150] about the agent-based models. The population is divided into two active classes, one carrying out the protest and one trying to stop it.

In the protest, citizens who are attached to it try to reach a geographical meeting point, and on the way, they try to add as many susceptible people as possible to the protest. At the same time, authorities are present in places where there is an active population to intimidate them, and thus, some of the protesters may decide to leave the protest. With this structure, we want to study how the agents' activity (in this case, going out to manifest) spreads, depending on the fear/degree of confidence given to the authorities of the city.

Agents/Individuals

Two types of agents are considered: the citizens, who form the population susceptible to carry out the protest, and the police officers, who will try to stifle it. The state variables of citizens are their spatial location, their activity, that is, whether they are attached to the protest or not (we refer to them as active citizens or inactive citizens, respectively); and a rate of confidence in the authorities (would be the opposite of *fear*). The police officers only have their spatial location as a state variable.

Space units

The environment in which the revolt takes place is an artificial city, which is represented by a planar graph. The agents are in the vertices, so their population can be positive or zero, in addition, the citizens move to neighboring vertices, while the police officers can make jumps of any length in the graph.

Environment

At each vertex, there is a preference rate of adhering to the revolt; that is, depending on the place where an inactive citizen is, it would join with lesser or greater ease to the uprising. In addition, active citizens have a preference to move towards a specific vertex of the graph, which we call *target*. The target is fixed in all simulations, and all agents have knowledge of their location.

General description and planning processes

For convenience, the state of all the citizens is updated first, followed by the update of all the police officers' state. The variables are updated *asynchronously*, following a preestablished order. Following that order, the state variable of the next agent is immediately assigned a new value depending on the states of the agents at that time. Otherwise said, citizens will decide to activate, deactivate, move, or remain in the same way, depending on the state of all citizens at that point of the simulation. Asynchronous updating applies to both citizens and police officers. In this model, it is assumed that time runs forward in discrete steps. One step of time elapses when all the agents have updated their respective state. Note that a possible result from an update is to remain in the same state. Below are the rules governing the dynamics of the agents.

For an inactive citizen:

- *Activation rule:* If there are enough active citizens in your position, activate your-self with probability $1 - \beta$.

For an active citizen:

- *Movement rule:* If there are not enough police officers to intimidate you in your position, migrate to an adjacent vertex in the direction to the target vertex with probability $1 - \beta$.
- *Deactivation:* If there are enough police officers to control you in your position, deactivate with probability β.

For a police officer:

- *Movement rule 1:* If there are not enough active citizens and there are enough policemen to control them, go to another random vertex where there are active citizens.
- *Movement rule 2:* If there are enough active citizens and there are not enough police officers to control them, go to the quarters.

Details

Initialization

The initial values of the state variables are: the number of citizens, the number of police officers, the vertices in which the revolt begins (sources), the vertex where the policemen are at the beginning (quarters), the average fear, the list of ease of adherence to the revolt that has each vertex (Tv), the proportion of citizens that each policeman can control ($\tau 1$) and the intimidation rate of the authorities on the citizens ($\tau 2$). Initialization varies between simulations, because the generation of individual fears (through average fear) uses a Poisson probability distribution, which means that the same quantity is not assigned to the same citizen in each initialization.

Submodels

Let $G(V, A)$ be a graph, where each of its vertices has weight $Tv \in [0, 1]$. Let $N, M \in \mathbb{N}$, and consider the arrays:

$$C = ((v_1, a_1), \dots, (v_N, a_N))) \subset (V \times \{0, 1\})^N$$

$$P = (u_1, \dots, u_M) \in V^M$$

The elements of C will be called citizens, and the elements of P police officers. To refer to an element of any of the two sets, we will say agent. For each citizen c_i, where $i \in \{1, 2, \dots, N\}$:

- v_i indicates its position, that is, the vertex of G in which it is located.

- a_i indicates its activity, 0 if it is inactive or 1 if active.
- It will have a fixed value $\beta_i \in [0, 1]$ indicating its fear rate to be signed by the police. If it is close to 1, the citizen has more fear, conversely, if it is close to 0, then the citizen is braver. Because this attribute does not change over time, it is not necessary to trace it.

For each police officer p_i, where $i \in \{1, 2, \ldots, M\}$:

- *ui* indicates its position.

For each $t \in \mathbb{N}$ and for each $v \in V$ we have:

$$A_v = \#\{0 \leq i \leq N : c_i(1) = v \wedge c_i(2) = 1\}$$
$$I_v = \#\{0 \leq i \leq N : c_i(1) = v\} - A_v$$
$$P_v = \#\{0 \leq i \leq M : p_i = v\}$$

Hence, A_v is the number of active citizens in the vertex v, I_v is the number of inactive citizens in the vertex v and P_v is the number of police officers in the vertex v.

Agents can be moved from one vertex to another of G, as long as there is an edge that connects them and the conditions stated below are met. For this, the following *sufficiency functions* are defined.

For each vertex $v \in V$, a function α: $V \rightarrow \{0, 1\}$ is defined, in the following way:

$$\alpha(v) = \begin{cases} 1, & \text{if } \frac{A_v}{A_v + I_v + \frac{P_v}{\tau_1}} \geq T_v, \\ 0, & \text{if } \frac{A_v}{A_v + I_v + \frac{P_v}{\tau_1}} < T_v. \end{cases} \quad (5)$$

Where T_v is the susceptibility threshold having each vertex of its citizens to be condescending to the protest and $\tau 1$ is the ability to control citizens having the police officers.

For each vertex $v \in V$, a function $\bar{\alpha}_1$: $V \rightarrow \{0, 1\}$ is defined, in the following way:

$$\bar{\alpha}_1(v) = \begin{cases} 0, & \text{if } \frac{P_v}{A_v} \geq \tau_1, \\ 1, & \text{if } \frac{P_v}{A_v} < \tau_1. \end{cases} \quad (6)$$

For each vertex $v \in V$, a function $\bar{\alpha}_2$: $V \rightarrow \{0, 1\}$ is defined, in the following way:

$$\bar{\alpha}_2(v) = \begin{cases} 1, & \text{if } \frac{P_v}{A_v} \geq \tau_2, \\ 0, & \text{if } \frac{P_v}{A_v} < \tau_2. \end{cases} \quad (7)$$

Where τ_2 is the ability to tolerate the presence of police officers that citizens have.

We will consider that at the beginning, all the police officers are in a fixed vertex c, named *quarters*.

We must observe that the dynamics of the city depend on the type of agent that is selected:

- Inactive citizen. This citizen can be activated or remain inactive.
- Active citizen. This citizen can be deactivated, move to an adjacent vertex or remain active.
- Police officer. A police officer can move to any vertex (where there are active citizens) or stay in the same place.

Now we are going to define mathematically the behavioral rules that each type of agent will follow.

The *activation function* for a citizen, A: $V \times \{0, 1\} \rightarrow V \times \{0, 1\}$ is defined as:

$$A((v, 0)) = \begin{cases} (v, 1), & \text{if } \alpha(v) \cdot q > \beta, \\ (v, 0), & \text{if } \alpha(v) \cdot q \leq \beta. \end{cases} \quad (8)$$

Where β is its assigned rate of fear and $q \in [0, 1]$ is uniformly randomly selected, that is, the citizen $c = (v, 0)$ will activate with probability $P_A(c) = 1 - \beta$.

The citizens are directed to a distinguished vertex v^* which we call target, with a certain preference, described in the following definition.

Assume that $v \in V$ has k adjacent vertices, that is, $(v, u_i) \in A$, for all $i \in \{1, 2, \dots, k\}$. The distance $d_i = d(u_i, v^*)$ is defined as the minimum number of vertices in a directed path from v^* to u_i. With this, the probability for the selected agent, to move from location v to u_i is given by:

$$P(v \to u_i) = \frac{d_i}{\sum_{j=1}^{k} d_j}. \quad (9)$$

The movement function for a citizen $M_c : V\{0, 1\} \to V \times \{0, 1\}$ where a citizen with fear rate $\beta \in [0, 1]$, that is in the vertex $v \in V$, moves to a vertex $u \in U$ such that $(u, v) \in A$ with a certain preference, is defined as:

$$M_c((v,1)) = \begin{cases} (u,1), & \text{if } \bar{\alpha_1}(u) \cdot q \geq \beta, \\ (v,1), & \text{if } \bar{\alpha_1}(u) \cdot q < \beta. \end{cases} \quad (10)$$

Where the citizen $c = (v, 1)$, moves trying to spread the protest with probability $P_{Mc}(c) = 1 - \beta$.

The *deactivation function for a citizen* $D : V \times \{0, 1\} \to V \times \{0, 1\}$ is defined as:

$$D((v,1)) = \begin{cases} (v,0), & \text{if } \bar{\alpha_2}(u) \cdot q \geq 1 - \beta, \\ (v,1), & \text{if } \bar{\alpha_2}(u) \cdot q <\geq 1 - \beta. \end{cases} \quad (11)$$

Where β is its assigned rate of fear and $q \in [0, 1]$ is uniformly randomly selected, that is, the citizen $c = (v, 1)$ will be deactivated with probability $P_D(c) = \beta$.

The *movement function for a police officer* is $M_p : V \to V$ where an officer who is in the vertex $v \in V$ moves to a vertex $f(v) \in V - \{v\}$, is defined as:

$$M_p(\bar{p}) = \begin{cases} f(v), & \text{if } \alpha(v) = \bar{\alpha_1}(v), \\ v, & \text{if } \alpha(v) \neq \bar{\alpha_1}(v). \end{cases} \quad (12)$$

Where the officer $\bar{P}$, decides to move to $f(v)$, if the proportion of active citizens is very large ($\alpha(v) = 1$) or if there are too many police officers for the active population ($\bar{\alpha}1(v) = 0$). Also, the function $f : V \to V$ is defined as:

$$f(v) = \begin{cases} u, & \text{if } (\alpha + \bar{\alpha_1})(v) = 2, \\ c, & \text{if } (\alpha + \bar{\alpha_1})(v) = 0. \end{cases} \quad (13)$$

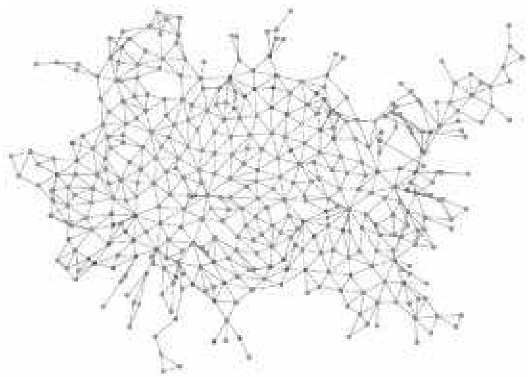
Where the movement is to control more active citizens ($(\alpha + \bar{\alpha}_1)(v) = 0$) or by escape ($(\alpha + \bar{\alpha}_1)(v) = 2$), in which case, they go to the quarters *c*.

Implementation

We built the graph corresponding to the adjacencies among the basic geostatistical areas (AGEB (2018), for its acronym in Spanish) of the San Luis Potosí-Soledad de Graciano Sánchez metropolitan area, as shown in Figure 73, with a total of 413 vertices and 989 edges as in Figure 74. To determine the number of susceptible citizens of each vertex in both cities, the occupied population with at least one degree approved in higher education was considered. This information was provided by the National Institute of Statistics and Geography (INEGI, (for its acronym in Spanish)).

FIGURE 73
SLP MAP

Figure 74
SLP graph



To determine the parameters of susceptibility to adhere to the protest *Tv*, we used the social backwardness threshold by AGEB, provided by the National Council of Evaluation of the Policy of Social Development (CONEVAL, for its acronym in Spanish).

With these two parameters, we see that each inactive citizen of the population $c = (v, 0)$, complies with the susceptibility rule: $S(c) = T_v \cdot P$, where $P = 1$ if the citizen has completed high school and $P = 0$ otherwise. Thus, in our modeling we are assuming that the level of susceptibility of a citizen, depends on their levels of education and social backwardness.

Once these parameters are determined, it is necessary to define the city's location where the revolt will begin. We consider that the sites prone to an outbreak of manifestation would be the informal neighborhoods, which are the places where a person or a community is settled outside the norms established by the authorities in charge of urban planning. These locations are represented by red vertices in Figure 74. This choice is based on the assumption that the levels of grievance are higher in informal neighborhoods. The manifestation will spread throughout the city as the participants move towards its target location, which, in our case, is the State Congress (green vertex) in the center of the city.

The National Survey of Urban Public Safety (ENSU, for its acronym in Spanish) held in December 2017, provides estimates on the perception of public safety in urban areas. For the city of San Luis Potosí, the measure of the sensation of insecurity for fear of crime (perception), averages $\overline{\beta}_{iSLP} = 0.831$, and the Government performance (perception) of the Municipal Preventive Police, is 37.5%. Hence, we will consider the ability to tolerate the presence of police officers who have citizens, $\tau 2$, as:

$$\tau_2 = 1 - \frac{\text{Percentage of trust in the authority}}{100} \quad (14)$$

The police officers will meet at the Municipal South Command (yellow vertex in the Figure 74) and we consider $\tau 1 = 0.1$.

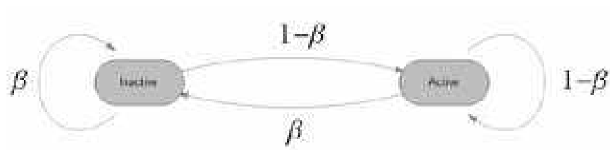
MATHEMATICAL STUDY OF THE MODEL

The asymptotic study of this agent-based model was done in two parts,corresponding to the attributes of citizens: activity and position. We will begin with the study of the citizens activity.

Activity

According to the formulation of the model, an inactive citizen with fear β, is activated with probability $1 - \beta$ if there are enough active citizens in their position. An active citizen is deactivated with probability β. This is summarized in Figure 75.

FIGURE 75
BEHAVIOR OF CITIZENS ACTIVITY



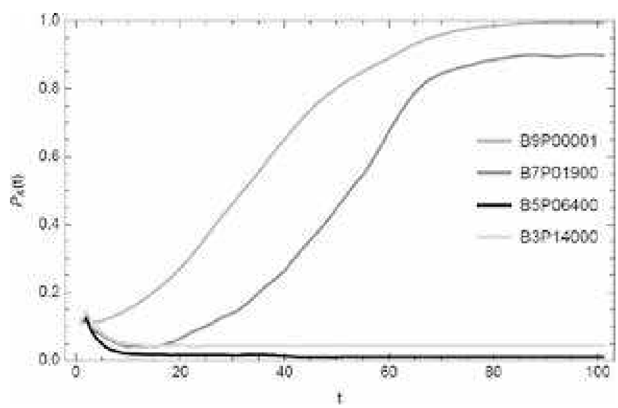
Activation curve

The function $P_A : \mathbb{N} \to [0, 1]$ is the active citizen density in G. Figure 76, illustrates the typical behavior of P_A for different average fear and number of policemen in San Luis Potosí. All these curves fit logistic functions as Equation 15.

$$P_A(t) = P_A(0) + \frac{K - P_A(0)}{1 + \exp(-\frac{t-a}{b})}. \qquad (15)$$

Figure 76

Typical behavior of SLP

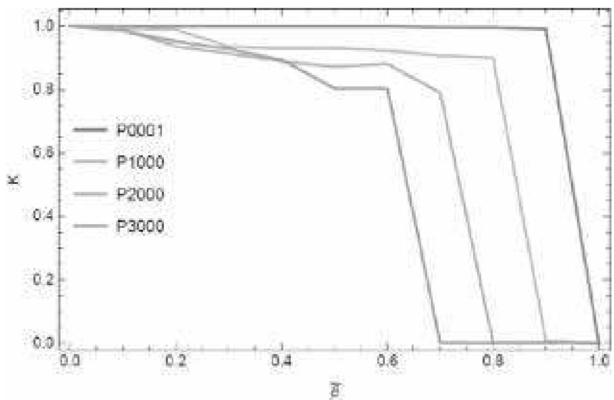


The fitting parameters *a, b, K* depends on the model parameters, the initial density of active population and the number of police officers.

The behavior of the parameter K was fitted from the simulations and is show in Figure 77. Different colors correspond to different numbers of police officers. The axis $\overline{\beta}$ corresponds to the average fear used in each simulation and the vertical axis, to the best fit for K.

FIGURE 77

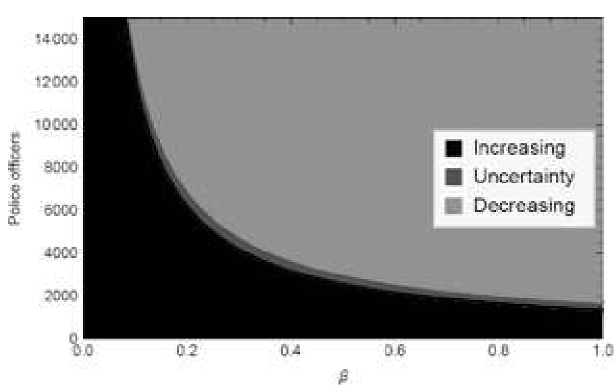
BEHAVIOR OF PARAMETER K IN SLP



In Figure 78, the simulations performed with parameters within the blue zone had an increasing asymptotic behavior, while simulations with parameters in the magenta zone were decreasing. Those with parameters in the purple zone have an uncertain fate as the same initial conditions can lead to increasing or decreasing behavior due to the dynamics' intrinsic randomness.

FIGURE 78

PHASE DIAGRAM OF THE MODEL'S ASYMPTOTIC BEHAVIOR, IN TERMS OF AVERAGE FEAR AND THE NUMBER OF POLICE OFFICERS



Position

Concerning the *position* of the active citizens in the artificial city, we study the flow of active citizens reaching a neighborhood of size three around the target.

Let us remember that only the citizens attached to the protest can move. This does not mean that the inactive citizens cannot move across the city, but that their movement is inconsequential to the protest dynamics. Therefore, for the purposes of the model, we can consider that the inactive citizens remain in their place until they meet the conditions of sufficiency and decide to activate. Remember that the protesters move preferentially towards the target. Let us remark that the initial conditions we used are such that the active population is initially located at the periphery of the city. Hence the protesters are flowing towards the target, and it is precisely the incoming flow of protesters we want to measure. Let us now formally define what we mean by flow, the behavior of which we will depict in Figures 79 and 80.

Figure 79

Flow in a neighborhood of size 3 of the target

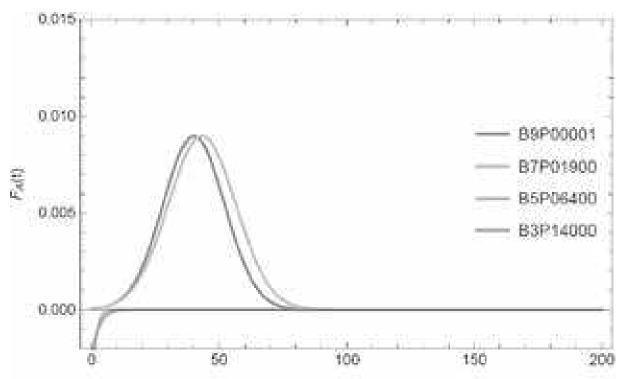
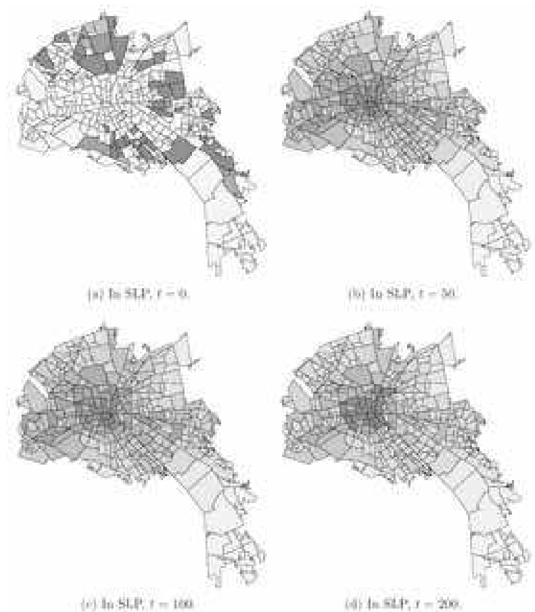


FIGURE 80

SLP ACTIVE POPULATION DENSITY OVER TIME



The flow $F_A : \mathbb{N} \rightarrow [0, 1]$ in a neighborhood $N = N(r, u)$ of size $r \in \mathbb{N}$ and center in $u \in V$ of the graph $G = (V, A)$, is defined as:

$$F_A(t) = \frac{A_N(t) - A_N(t-1)}{\mathcal{N}} \qquad (16)$$

Here, N is the set of vertices at a distance less than or equal to r of vertex u, $\mathcal{N}$ is the total number of citizens and $A_N(t) = \#\{0 \leq i \leq N : c_i(1) = v \wedge c_i(2) = 1 \wedge v \in N\}$ is the number of active citizens in the neighborhood N at the iteration $t \in \mathbb{N}$.

The function $F_A(t)$, is intimately related to the active population density function $P_A(t)$. As already mentioned, only the active population is able to move. We expect the asymptotic behavior of this function to be $F_A \rightarrow 0$, $t \rightarrow \infty$, because if the active population density function of the same simulation is decreasing, then there will be no population that can move, therefore, the flow will be zero. On the other hand, if the active population increases, it will move towards the target and once it reaches its aim, it will stay in that vertex in subsequent iterations. Hence, for sufficiently long times, the entire active population will stay at the target, leaving $A_N(t) - A_N(t-1) = 0$, as shown in Figure 79. In Figure 80 shown in shades of red, the density of active population in the SLP map. We can see that as t increases, the population accumulates at the *target*.

Discussion

Our model derives from Epstein's work on civil violence [149], with some simplifications and adaptations needed to fit our requirements for simulating a pacific civil protest marching towards a target meeting point.

Our results agree with common sense in that the protest's success depends monotonically on the population's fear and the size of the intimidating police presence. We discovered that the two parameters are interlaced so that only one effective parameter, related to the product of the former two, determines the final fate of the uprising. This can be seen in Figure 78, where the global behavior is summarized in a phase diagram. It is worth noting the system's long-run state's bi-stable nature: either the protest succeeds or dismantles completely. There is a thin hyperbolic frontier in the phase diagram where the protest's fate strongly depends on the realization of the dynamics, that is, on the particular choices the agents made during the simulation. But even then, the system's final behavior has to be one of the two possibilities, either a complete success or a complete failure.

Concerning the spatial dynamics of the system, we found that the flow into the target point behaves in a unimodal way in the case of a successful protest. There is a gradual increase up to a maximum flow, followed by a monotone decrease to zero (Figures 79 and 80). This simple behavior can be attributed to two facts: The sources of the revolt start simultaneously, and the topology of the city allows an uninterrupted steady flow towards the target. Our purpose for future work is to study the effect of the topology and asynchrony of the starting point of the protest's spatial dynamics.

Although ours is a simplified model, retaining only some of the main features of the actual phenomenon, it already gives important insight into the behavioral rules governing this complex system. Furthermore, it allows us to go from the microscopic, at the agents' level, to the macroscopic, showing a logistic behavior at the population level, suggesting another direction of research, seeking to derive differential equations for the mean values from the microscopic dynamics. This approach will allow us to establish a rigorous relation between the microscopic parameters (mean fear, police presence, the topology of the city's graph, etc.) and the macroscopic parameters shaping the total population's logistic behavior.

We hope the work presented in this chapter sheds light on the pertinence of the mathematical-computational approach to complex social phenomena. The aim being not to predict but to serve as an explanatory tool as it is a playground to experiment with possible scenarios and change the governing behavioral rules.

A MODEL FOR REBELLION INFLUENCED BY OPINION AND APPLIED PUBLIC POLICY

Norma Leticia Abrica
Jacinto Antonio Aguilera Ontiveros

Abstract

In this paper, we propose a modification to the Epstein model [149] incorporating the opinion of the citizen agents, through a model of dynamics of opinion with bounded confidence [151], which we call ROPP. The ROPP model's objective is to model and simulate the act of resistance to authority or disobedience, through the opinion and intervention of public policies, in artificial societies through the AgentBased Modeling [152].

Introduction

Since the 1990s, the use of computational methods in the study of the social sciences has increased across its various disciplines, including anthropology, economics, sociology, and political science. Modeling and simulation provide the social scientist with a new way of doing research. The analytical discourse is no longer the only way to conduct social research. The use of mathematical and computational models supplement the usual methods [58]. Computational modeling can incorporate many heterogeneous actors and their complex social interactions to help us understand the social phenomena that affect the system.

Modeling and simulating social phenomena constitute a strategy to address social complexity, giving way to interdisciplinary work that incorporates knowledge from diverse areas and disciplines in the social, exact, and computational sciences. The purpose of simulating in Social Sciences is to represent a social process that evolves over time. Such a social process consists of the social interaction between heterogeneous agents and their behavior's temporal dynamics. Social simulation encourages us to consider modeling entities and interactions at the micro-social level to generate macro-social processes and structures and, at the same time, to observe the consequences of such structures on individual action. To abstract an existing social system and analyze it in the laboratory, we use a theoretical representation called artificial society, a synthetic representation of the social system under study. This synthetic representation is an artificial system built to increase our understanding of a specific phenomenon and explain and predict its behavior [153]. Modeling is not intended to mathematize all social aspects, only to provide a perspective and a global and systematic analysis of the known or new facts (possibly) happening through virtual scenarios.

Agent-based modeling has been widely used in different scientific disciplines (economics, finance, natural resource management and ecology, anthropology, sociology, biology, and medicine). The entire system's global properties can be inferred from rules that determine the individual behavior of the agents. One of the computational tools for analyzing agent-based models is the Netlogo software[1]. Created in

1999 by Uri Wilensky, founder of the Center for Connected Learning and Computer-Based Modeling, Netlogo is a programming environment with automatic animation created with the Objective-C programming language and Java in which complex evolving systems can be simulated. Netlogo's programming language is simple and suited to model and simulate phenomena in which many individuals interact. It allows studying the connection between local interactions and the macroscopic patterns that emerge from such interactions. The objective of Netlogo is to provide a prototyping tool for the development of simulation models.

Agreement is one of the essential aspects of the dynamics of social groups. Every day we are presented with different situations in which a group sees the need to reach a consensus on a decision. Consensus makes a position stronger and thus amplifies its impact on society. It is not difficult to infer that the dynamics of agreement or disagreement between individuals are complex, given individual agents' inherent complexity. Given the importance of complexity, there has been growing interest in the application of models and tools, from the discipline

[1] https://ccl.northwestern.edu/netlogo

of complex systems, to study a variety of social phenomena under the names of *generative social science* [154], *computational social sciences* [155] and *socio-physics* [156]. Within socio-physics, the area that deals with these complexities is known as Opinion Dynamics (OD) [157].

The general idea behind the dynamics of opinion models is that individuals (or agents) have opinions that can change under other individuals' influence. An agent can change her opinion on her own (reflection) or driven by the influence of propaganda, advertising, or media [137]. Some of the best-known models of opinion dynamics are the Voter model, Snzajd's model, the model of cultural dissemination, and the models of bounded trust of Deffuant and Hegselmann-Krause. The first three models represent the opinion of agents with discrete values. Deffuant and Hegselmann-Krause (and some extensions of their work) explore the idea of bounded trust. This refers mainly to the fact that another will not influence one agent's opinion if the difference of opinion between the two agents is greater than a given threshold or *level of confidence* [158]. Four elements generally define opinion dynamics models:

1. *Social network*: structure of the environment in which agents relate to each other. Represented by a mathematical structure called graph [159], where nodes represent agents and edges communication or relationship between them.
2. *Opinion space*: numerical representation of opinions in a discrete or continuous, uni or multi-dimensional set.
3. *Interaction dynamics*: local rules governing how an agent affects and is affected by its neighboring agents. This may be by pairs of agents (unior bi-directional) or by neighboring agents.
4. *Update dynamics*: a mathematical representation of the dynamics of the model variables, that is, the equations that describe the dynamics of the model variables.

Therefore, considering agents' opinion in a rebellion model has its relevance since it is through it that agents can express an agreement or disagreement with their present condition or state. This opinion can influence the agents' decisions and generate social and political changes in the social structure.

In politics, a government can be labeled as legitimate or illegitimate. A Government has the power to influence the behavior of the population by enforcing its laws. Also, in speaking of a government's legitimacy, we are not referring in general terms to a favorable popular predisposition, that is, to assume that a legitimate Government performs its mandated functions correctly without abusing the means at its disposal for that purpose. The government's legitimacy presupposes a recognition (social, political, economic), earned through a lawful process of a social and political nature. For example, in a democratic state, a government obtains its legitimacy through the vote [160]. So, we can say that a government that is perceived as legitimate will be largely obeyed, while a government perceived as illegitimate will tend to be disobeyed.

Generally, public policy refers to the programs that a government, whatever it may be, develops according to address a specific problem or situation. Definitions of public policy vary; for example, "public policies are projects and activities that a State designs and manages through a Government and a public administration to meet the needs of a society" [161]. It can also be understood as the actions, regulatory measures, laws, and spending priorities on an issue enacted by a government entity. Political scientist David Easton defines public policy as "the authoritative allocation of values for the whole of society". Political scientist Harold Lasswell and philosopher Abraham Kaplan define politics as "a projected program of objectives, values and practices", and political scientist Carl Friedrick says "it is essential to the concept of politics that there be an objective or purpose [162]. Aguilar [163] defines it as "government decisions that incorporate the opinion, participation, co-responsibility, and money of private citizens, in their capacity as voters and taxpayers".

Generally speaking, and according to Thomas Dye, public policy "is everything that governments decide to do or not to do" [162]. Governments do many things: regulate conflict within society, organize society to conduct conflicts with other societies, distribute a wide range of symbolic rewards and material services to members of society, extract money from society (taxes), etc. Therefore, public policies can regulate behavior, organize bureaucracies, distribute profits or tax, or all these things simultaneously. Dyne also mentions that public policies can reverse, enhance, or inhibit other mechanisms' ability to achieve individual and collective well-being. For example, a public employment policy can weaken or strengthen communities and families and empower or inhibit an individuals' fulfillment through work or study. In other words, there are costs on the one hand and benefits on the other. In this sense, the ROPP model will establish via specific rules (public policies) what regime or state will determine an artificial society's agents.

In addition, public policy enforcement can trigger civil disobedience, leading to disruptive social phenomena, such as revolts, demonstrations, and rebellions. A historical reference is the case of Henry David Thoreau, who refused to pay his taxes. In 1849, Thoreau published a set of writings about his actions against the war, called Resistance to Civil Government. One of the main concepts of his ideology was the idea that government should have no more power than its citizens are willing to grant it. If necessary, he proposes the abolition of all government. Using scientific computation, J. Epstein [149] proposes a model of civil disobedience; this is an agent-based computational model that shows the dynamics of agents in the presence of an established regime. Thus, using the concepts of public opinion, public policies, and civil disobedience through a model of opinion dynamics and a model of civil disobedience, the process of rebellion will be modeled on an artificial society.

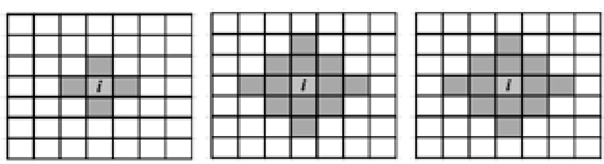
ROPP MODEL

This work seeks to model and simulate the act of resistance (or disobedience) of citizen agents before an established authority or regime. What characterizes this model is the influence of citizens' opinion on the likelihood of arrest and the intervention via public policy to benefit vulnerable agents. It explores how applying certain benefits to citizen agents can become a vulnerability, minimizing rebellious agents' appearance and thus preventing the emergence of rebellion. To this end, the elements that characterize the ROPP model are defined.

Neighborhood of vision v_i of radius r_i

The ROPP model assumes that agents have limited knowledge of the information and position of other agents. Agent-based models define what is known as the agent's neighborhood. This neighborhood can be defined in different ways: spatial proximity, closeness in the agents' variables' values, the number of patches around the agent, etc. In this case, the v_i neighborhood of agent *i* is defined through a local Netlogo variable called *in-radius*. This variable reports the set of agents within a circle of radius of r_i, that is, agents no further away from r_i patches of the current patch. The shape of the neighborhood will depend on the agent's orientation. For more information see the Netlogo manual[2]. Figure 81 shows the neighborhoods and number of patches for an agent located in the center of the world when r_i = 1, 2 and 3.

FIGURE 81
NEIGHBORHOODS *VI* WITH COMMAND
INRADIUS (5, 13 AND 29 PATCHES, RESPECTIVELY)



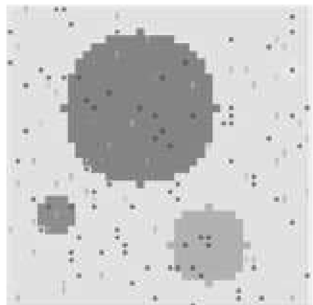
(a) $r_i = 1$ (b) $r_i = 2$ (c) $r_i = 3$

There are two types of agents in the ROPP model: citizens and police. Police officers are not present in every neighborhood. For example, Figure 82 shows the shape of some of the neighborhoods, noting the range of vision of the citizens (in green) and police officers (in blue).

In the yellow neighborhood, a policeman does not see other agents as he is the only one in that neighborhood. The situation is different for the citizen in the grey neighborhood, where he perceives one more citizen and two police officers.

[2] http://ccl.northwestern.edu/netlogo/docs/

Figure 82
Agent's neighborhoods:
R_I = 1 (YELLOW), R_I = 2.5 (GRAY), R_I = 5 (ORANGE), AND R_I = 10 (RED)



Legitimacy of the government L

The ROPP model does not question the government's legitimacy, nor does it question the acceptance of society's political unity. The analysis focuses on the behavior of society when the government implements certain public policies. Consider a society of *N*-agents of two types: citizens and police. Citizens can perceive the legitimacy of government. This legitimacy is equal for all citizens (represented by a value in the range [0, 1]) and is an exogenous characteristic of the model. As representatives of the security force responsible for maintaining public order and the security of citizens, the police are subject to the orders of the regime; they have no legitimacy.

Level of deprivation of citizens H_i

Every citizen *i* has a lack of resources, H_i. This lack of resources is related to the concept of scarcity, defined by the RAE dictionary as "poverty or lack of what is necessary to survive". It is the lack of necessary resources related to subsistence (health, water, food, energy) and protection (security, housing). In this regard, the level of resource deprivation, in general terms, quantifies the lack of resources. For each citizen *i*, the level of lack of resources H_i is a value in the range [0, 1]:

- If $H_i = 0$, it means that the citizen's level of deprivation is zero, that is, that his living conditions are good enough to survive.
- If $H_i = 1$, it means that the citizen's deprivation level is high, that is, that his living conditions are insufficient.

Vulnerable citizens A_V

In any society, there are vulnerable individuals or groups. A vulnerable individual is susceptible to being hurt or injured, either physically or morally. Vulnerable groups are groups of individuals who are at risk or disadvantaged. Based on the level of deprivation of citizens, the ROPP model sets a vulnerability threshold, $V(0, 1)$, to determine which citizens are the most vulnerable in a given society. We define a vulnerable group as the set $A_V = \{i : H_i > V\}$. That is, the group of citizen agents whose level of deficiencies H_i is greater than the vulnerability threshold V.

Implementation of public policy A_V^{PP}

Considering public policies as "projects and activities that a State designs and manages through a government and a public administration in order to meet the needs of a society" [164, p.19-20], The ROPP model simulates the effect of implementing a public policy on the vulnerable group of citizens. Since the popular idea that public policies do not respond to all citizens' needs and demands in a state of vulnerability, we implement a policy that is beneficial to only a portion of the vulnerable group. Let A_V^{PP} be a subset of AV, the public policy (PP) is applied through the following equation:

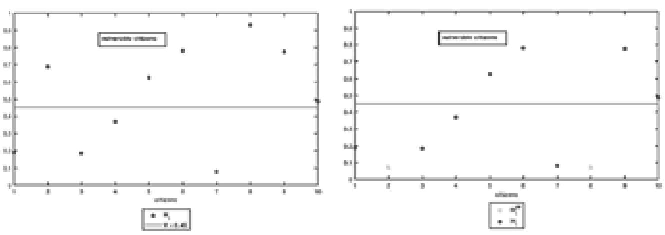
$$H_i^*(t) = 1 - H(t),$$
$$H(t) = \max\{H_j : j \in A_V^{PP}\}.$$

Under this condition, public policy will uniformly help vulnerable citizens. Figure 83 shows the case of a society with 10 citizens, 6 of them in a state of vulnerability, but only 2 of them are subject to public policy through the change in their level of deprivation. As can be seen from the graphs, the level of deprivation of other citizens remains the same. So in the ROPP model, the level of deficiencies is defined as follows:

$$H_i^{PP}(t) = \begin{cases} H_i, & \text{if } i \notin A_V^{PP}, \\ H_i^*, & \text{if } i \in A_V^{PP}. \end{cases} \qquad (17)$$

Figure 83

Distribution of the level of deficiencies: before and after public policy, with vulnerability 0.45



(a) Before PP (b) After PP

Level of complaint Q_i

The level of complaint $Q_i(t)$ of citizens to the given government is defined by the following equation:

$$Q_i(t) = H_i^{PP}(t)(1 - L). \qquad (18)$$

As in Epstein [149], the level of complaints is a product of the level of updated deficiencies and the illegitimacy of the government. This is expected to reduce the level of complaints as public policy H_i^{PP} was implemented for the benefit of citizens.

Opinion of citizens x_i

By its nature, opinion belongs to an individual. However, its dynamic and can be influenced by other individuals, either close or distant. The

ROPP model defines opinion as the level of judgment before the current government and assumes that this characteristic is possessed only by citizens since they are the agents of society prone to revolt. This assumption implies that police officers are agents with a total acceptance of the given regime, whose duty is to arrest rebellious citizens. This level of judgment differs from the level of complaint in that neighboring citizens influence the former, considering opinion as an "inquiry" of the citizen when interacting with his neighbors, while the level of complaint is a "direct exteriorization" in the face of dissatisfaction with the current government.

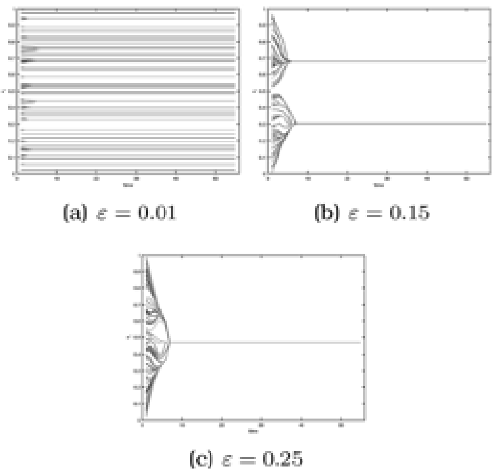
The citizens' opinion is represented as a value within the unit range, *i.e.*, $xi \in [0, 1]$. The value of the citizen's opinion i at time t, shall be denoted as $x_i(t)$. Following Hegselmann and Krause [151], an agent will not share or strictly ignore the opinion of any other agent but will take into account the views of others to some extent in forming his own opinion. Although an agent can converse with anyone else, he will only consider those agents' opinions who are close to his beliefs, ideals, or opinions to make a change in his beliefs, ideals, or opinions. This communicative aspect of the agents is captured by the models of dynamics of opinion with limited confidence. Another agent will not influence an agent's opinion if the agent's difference of opinion is greater than a given threshold or "confidence limit" [151, 165]. From this perspective, the citizens' opinions in the ROPP model correspond to a dynamic of opinion model with limited confidence.

Let $\varepsilon \in (0, 1)$ be the "confidence limit", $\mathcal{N}_i(t) = \{j \in v_i : \|x_i(t) - x_j(t)\| < \varepsilon$ the set of neighboring citizens i close in terms of opinion and $|\mathcal{N}_i(t)|$ cardinality or size of this set. Note that $\mathcal{N}_i(t) = \emptyset$ since by definition $i \in v_i$ and with it $i \in \mathcal{N}_i$. The dynamics of updating the opinion of the citizens are given in function of the Equation 19.

$$x_i(t+1) = \frac{\sum_{j \in \mathcal{N}_i(t)} x_j(t)}{|\mathcal{N}_i(t)|}. \qquad (19)$$

For example, the graphs in Figure 84 show the update of the opinion for a society of 100 agents with 54 time steps, along with the initial condition. In this case, the neighborhood of the agents is not considered, only the situation for which $\|x_i(t) - x_j(t)\| < \varepsilon$ and with it the updating of the opinion is determined.

Figure 84
Evolution of opinion in the HegselmannKrause model [151]



For the ROPP model, if the citizen has $x_i = 0$ it means that the level of judgment of the citizen is *null*. If $x_i = 0.5$, it means that it perceives a certain level of government acceptance, while if $x_i = 1$ the citizen perceives a *favorable* situation, both socially and politically. Such judgments are based on the set of neighboring citizens with whom it interacts.

Level of risk to manifest R_i

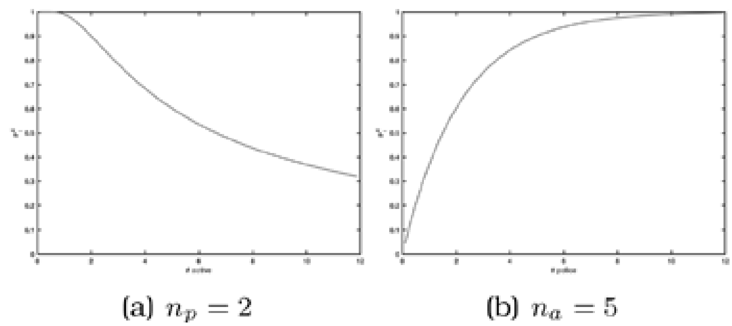
According to Epstein [149], the action of rebelling also depends on the citizens' willingness to demonstrate. For this reason, the level of risk or opposition *Ri* is defined as a value in the range [0, 1]. This value will remain fixed for each citizen during the entire simulation.

Arrest probability P_i

Epstein's model [149] considers the possibility that not every citizen will decide to rebel because they can perceive their environment and assess whether there are policemen within their range of vision. Thus, the probability of arrest $P_i^E = 1 - e^{-k(\frac{n_p}{n_a})_{v_i}}$ decreases as the number of active agents increase for a fixed number of police officers, and the likelihood of arrest increases with the number of police officers and a fixed number of active agents (see Figure 85). The number quantifies the number of police officers and the number of rebellious or active citizens in the vicinity of agent *i*. Since agent *i* himself could be activated, rebelling is met $n_a \geq 1$. Assuming that $n_a = 1$, $n_P = 1$ and $P_i^E = 0.9$, you have to $k = 2.3$.

FIGURE 85

ARREST PROBABILITY FUNCTION IN THE EPSTEIN MODEL [149]



However, the ROPP model takes into account the influence of opinion on the probability of arrest because the citizen's opinion or judgment is also a characteristic that influences whether a citizen activates or not. In the ROPP model, the probability of arrest is given by Equation 20.

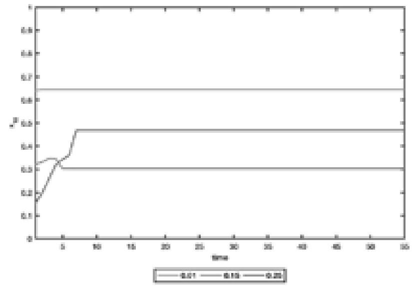
$$P_i(t) = (1 - x_i(t))(1 - e^{-k(\frac{n_p}{n_a})_{v_i}}). \qquad (20)$$

Where, again the constant *k* will be set to ensure an acceptable estimate when $n_a = n_p = 1$, $x_i = 0.05$ and $P_i = 0.9$. In this sense, Equation 20 has $k = 2.945$. This will be the value to be used in model simulations.

For example, consider the evolution of the opinion of a citizen agent (say 10, in Figure 84). Figure 86 shows this for each value of ε.

Figure 86

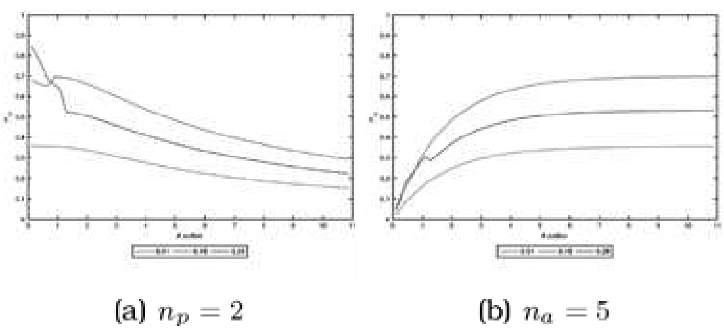
Opinion evolution of citizen 10, for different confidence limit



Now, the probability of arrest according to Equation 20, for the same agent, behaves as shown in the graphs in Figure 87.

Figure 87

Arrest probability function in the ROPP model



Net risk N_i

A citizen with zero perception (x_i = 0) and risk of manifesting (R_i = 0.5) will have little interest in knowing whether or not he can be arrested; unlike a citizen with a favorable opinion of the government (x_i = 1) but is "fearful" at the same time ($R_i \approx 1$), who will mind being arrested. Similarly, in Epstein [149], we define the citizen's net risk as the product of the risk to manifest R_i, the probability of arrest P_i and opinion x_i, see Equation 21.

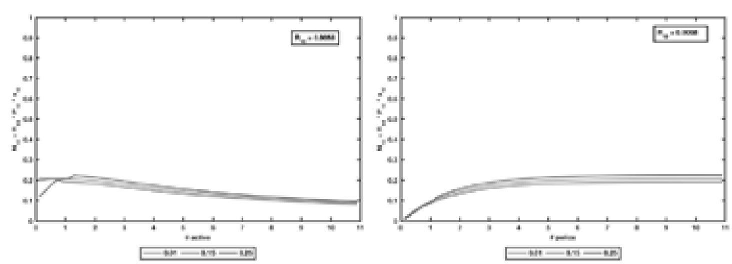
$$N_i(t) = R_i(t) \cdot P_i(t) \cdot x_i(t). \qquad (21)$$

Note that if a citizen has a high risk to manifest ($R_i \approx 1$), with a high probability of arrest ($P_i > 0.8$), then the citizen's net risk will depend only on his opinion (x_i). If $x_i = 0$, he will not be at risk of manifesting ($N_i = 0$). If $x_i \approx 1$, and with the previous antecedents ($R_i \approx 1$, $P_i > 0.8$), the net risk of the citizen will be greater, because although he considers that his social and political situation is favorable, he will not fear to express his total risk. It could be said that these are "those who take the voice of the neediest, regardless of its consequences".

For example, the graphs in Figure 88 show the change in the net risk of a citizen based on the probability of arrest and the opinion of the citizen (Figure 87). Net risk is noted to be lower when more agents are active than police officers.

FIGURE 88

NET RISK IN THE ROPP MODEL



(a) $n_p = 2$ (b) $n_a = 5$

Activation and updating rules

The dynamics of the system, movement and behavior of citizens are defined by the following rules:

- *Rule of movement.* Agents (citizens and police) move randomly within the artificial world.
- *Police rule.* Police officers inspect patches within their neighborhood v and arrest a rebel citizen chosen at random, he will

remain incarcerated (inactive in terms of his complaint level, but even "listening" to the opinion of other neighboring citizens) for a time *t*, equivalent to a number of ticks between 0 and t_{max}.

- *Opinion update rule.* At each step of time or tick, the opinion of all citizens will be updated according to Equation 19.
- *Public policy implementation rule.* For a proportion p_A of vulnerable citizens, public policy will be implemented through Equation 17.
- *Activation rule.* If the difference between the level of complaint of citizens and the net risk to be manifested, is greater than the threshold T , then the citizen agent is activated and becomes rebellious. That is, if $Q_i - N_i > T$, then the agent *i* is activated; otherwise, it remains the same.

Dynamics of public policy implementation

To simulate the behavior of citizens towards the implementation of public policies in the vulnerable group of citizens, two dynamics will be analyzed.

Dynamic 1: without public policy. In this case, it will be observed how opinion influences the probability of arrest and the level of net risk of the citizens comparing the results directly with those of Epstein through the computational model of Uri Wilensky [166].

Dynamic 2: Public policy in $t = 0$. It begins with a uniform distribution in [0, 1] of the shortcomings level $H_i(0)$. In the first time step, the public policy is applied changing the level of shortcomings to a new value H_i^{pp}, which remains fixed throughout the simulation (see Equation 17).

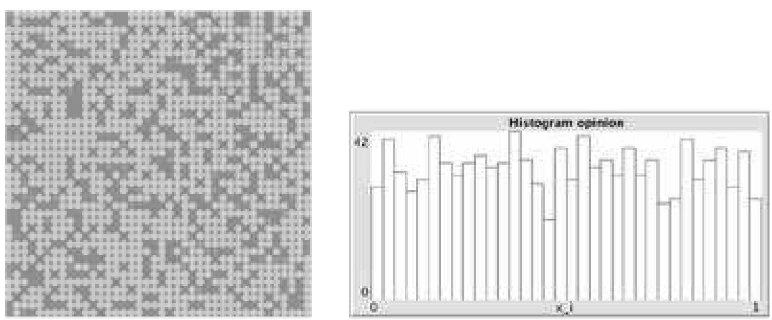
Results of the simulations

The simulations were carried out on the *Netlogo* 6.1.1 platform, a programmable modeling environment designed to simulate natural and social phenomena. Written by Uri Wilensky in 1999, it has been under continuous development since then by The Center for Connected Learning and Computer-Based Modeling.

Figure 89 shows, in general terms, the initial conditions of the spatial distribution of agents and the opinion histogram. Citizen agents are represented with circles that change color from green to red to black according to the probability of arrest; red represents a rebellious citizen, and black means he is in jail. Turquoise stars represent police officers. The initial conditions of the experiments are as follows:

FIGURE 89

AGENTS' SPATIAL DISTRIBUTION AND CITIZEN AGENTS OPINION HISTOGRAM



(a) The world (b) Opinion

- Lattice of dimension 40 40, with 1600 total patches.
- The density of citizen agents is 70% (1120 agents) and 4% the density of police officers (64 agents).
- Toroid topology, *i.e.*, the upper and lower edges of the world are connected, and the left and right edges are connected. If an agent moves beyond the right edge, it reappears on the left of the world. The same applies to the top and bottom.
- The initial values of the opinion x_i of the citizen agents i, come from a uniform distribution in the interval [0, 1].
- The values of the deficiency level H_i of the citizen agents i also come from a uniform
- distribution in the interval [0, 1]. According to the dynamic type to be simulated, this will take the value H_i^{pp}.

- The individual risk level R_i of the citizen agents i, meet a uniform distribution in the interval [0, 1] and these values remain fixed throughout the simulation.
- The threshold value is $T = 0.1$.

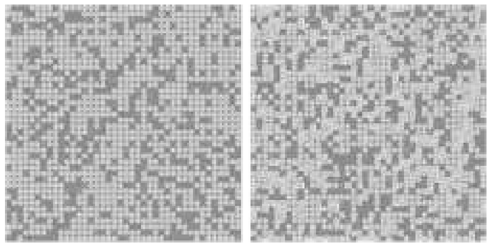
We define two dynamics to simulate the influence of opinion and public policies' influence in the rise of the rebellion: *without public policy* (Dynamic 1) and, *with public policy in* $t = 0$ (Dynamic 2). These dynamics seek to describe how society would act if the government carries out activities for society's good, in this case, for agents in a vulnerable situation.

The model evolves as follows: at each tick or time step, all agents' variables are updated according to pre-specified conditions and rules. That is, when citizen agents are created in Netlogo, they are identified by a label (who, corresponding to a number), in this case, from 64 to 1119. However, the dynamic process is carried out by randomly selecting citizen agents, making the simulation process *asynchronous*.

To better understand how the dynamic works, let us assume that we have a society with legitimacy of 0.42. In Dynamic 1, the world of agents is seen as shown in the image on the left of Figure 90. Suppose the vulnerability limit $V = 0.5$ and the percentage of vulnerable agents to help is 30%. In that case, the world of agents under Dynamic 2 looks like the picture to the right of Figure 90. In the world of Dynamic 2, patches of citizen agents in yellow and orange are the vulnerable agents, that is, those whose level of deficiencies is greater than the limit of vulnerability ($H_i > V$), but only those of orange color. In this case, they are the ones that will be applied to public policy, and their level of deficiencies will decrease, according to Equation 17.

We now describe how some of the model's elements influence opinion distribution and the emergence of rebellious agents.

FIGURE 90
INITIAL WORLD IN THE MODEL ROPP



(a) Dynamic 1 (b) Dynamic 2

Movement of citizens agents and the confidence limit

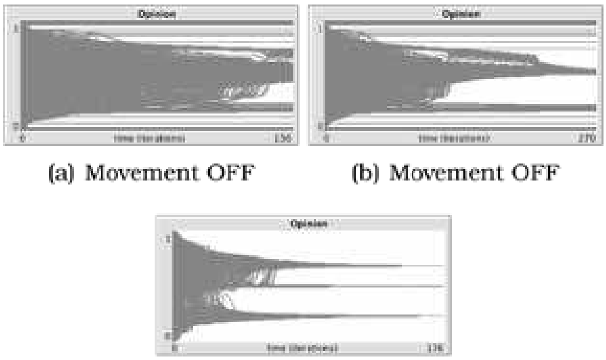
For the formation of opinion groups of citizen agents, we observed that the movement does not greatly influence the number of opinion groups. However, it does influence the time it takes to form or consolidate such groups. In general, for ε = 0.05 there are between 6 and 8 groups; for ε= 0.1 there are between 3 and 4 groups, for ε = 0.15 and 0.2 there are between 2 and 3 groups, and for ε = 0.25 there is only one group. For example, Figure 91 shows the case in which the radius of vision is 2.7, legitimacy is 0.86, prison time of 15 ticks, and the confidence limit of 0.15, based on Dynamic 1 described above. The image on the left corresponds to when citizens have movement, observing the formation and consolidation of three opinion groups. The images on the right correspond when there is no movement of citizens at two different moments, t = 136 and 270, noting that the time should be greater for the consolidation of these opinion groups. Regarding incarcerated rebel agents' activity, since the radius of vision is low (2.7) and the legitimacy high (0.86), these remain almost equal in density, with more agents imprisoned than active. Since the movement helps the formation of opinion groups, citizen agents' movement will be incorporated in the following experiments.

Radius of vision

This characteristic of actors is also important for convergence in the formation of opinion groups. For example, Figure 92 shows the result of

Figure 91

Citizens' opinion evolution



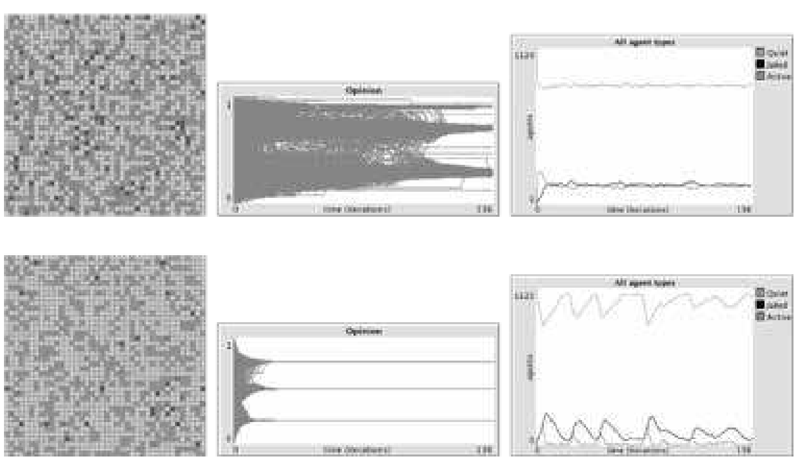
(a) Movement OFF (b) Movement OFF

(c) Movement ON

simulations when ε = 0.15, the government's legitimacy is 0.86, and jail time is 15 ticks (Dynamic 1). For a vision radius of 7 patches, we can observe periodic outbursts of rebellion. For a smaller viewing radius, the level of incarcerated and rebellious agents is kept almost in the same order. We are interested in the periodic phenomenon of outbreaks of rebellion, that is, knowing the conditions that result in rebellion. The radius of vision can trigger these periodic behaviors at the rebel agents' level.

Figure 92

Influence of the radius of vision R_I: 1.7 (top), R_I = 7 (down)

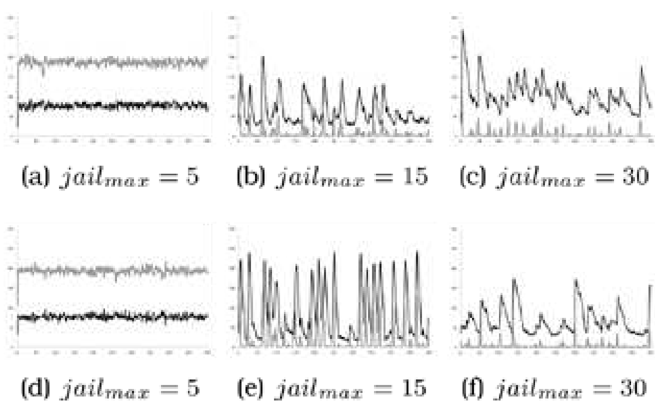


The time of imprisonment

Another feature that may influence the dynamics of the system is the prison time spent by citizen agents. During prison time, citizens can still interact with their neighboring agents and influence their opinion. Therefore not affecting the temporal evolution of opinion for the formation of groups. When prison time is short, agents remain inactive briefly before becoming active again. As prison time increases, the number of incarcerated agents increases. For example, Figure 93 shows the number of agents incarcerated and active as a function of prison time, with a legitimacy score of 0.86, radio of vision of 7 and citizen movement (Dynamic 1). In general, the effect of prison time is that, as it increases, rebel agents' presence decreases; the confidence limit can increase the density of these curves, but the overall behavior is the same.

FIGURE 93

INFLUENCE OF PRISON TIME (DYNAMIC 1): E = 0.05 (TOP), E = 0.15 (DOWN)



Legitimacy of the government

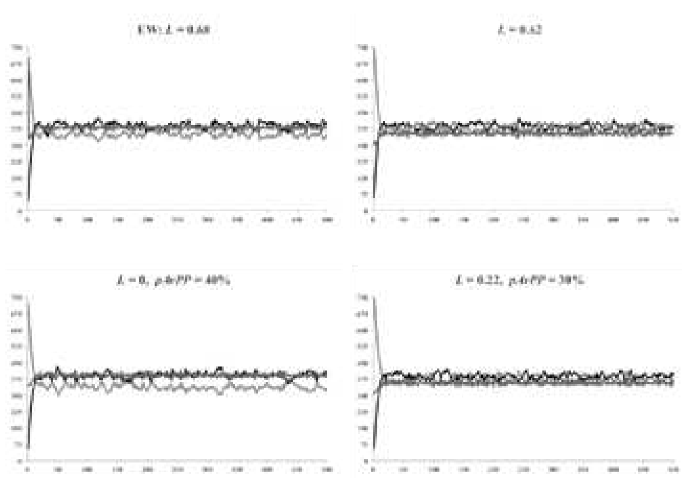
Based on the above, we will see how rebellion arises from a given legitimacy of the government. The initial conditions in each of the experiments are: initial police density of 4% (64 agents), initial density of citizen agents 70% (1120 agents), radius of vision $r_i = 7$ patches, 15 ticks of maximum prison time, the confidence limit ε = 0.15 and a vulnerability limit V = 0.5.

The following figures describe the number of rebellious agents in different states (*i.e.*, red, black, and green). The horizontal axis is time (ticks), and the vertical axis is the number of citizen agents. We performed several experiments varying legitimacy in steps of L = 0.02. For Dynamic 2, we performed experiments varying vulnerable agents in *pAvPP* = 10 steps, *i.e.*, every 10% of vulnerable agents to which public policy applies. The results presented below are the most representative of the dynamics of the system.

The graphs in Figure 94 show the social system's behavior when approximately the same number of quiet, rebellious, and imprisoned agents are present in society. In the EW model, the number of quiet agents begins to increase, starting from L = 0.68, thus decreasing rebel agents' presence. In Dynamic 1, agents maintain this behavior with a lesser legitimacy as the opinion of citizen agents influences, even with a less legitimate government, the increase of still agents and, therefore, decreases rebellious agents' presence. In the case of Dynamic 2, we observe that for an illegitimate government, it is sufficient to support 40% of the vulnerable agents in order to start the decrease of rebel agents. When the legitimacy is higher, L = 0.22, this percentage is lower (30%).

Figure 94

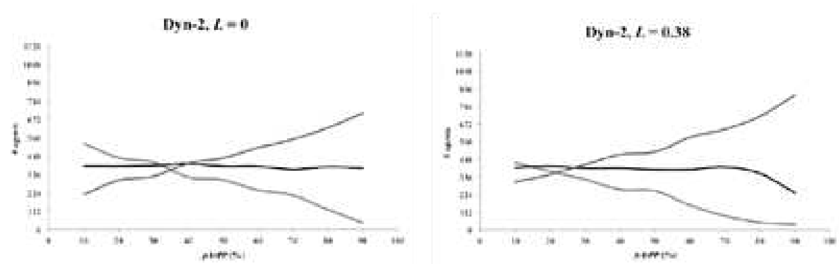
State-level graphs of citizen agents: mixed society



Let us now consider the influence that Public Policy's application can have on an illegitimate government (*i.e.*, $L = 0$). Figure 95 shows the density of quiet, incarcerated, and rebel agents according to the percentage of vulnerable agents to whom public policy applies (*pAvPP*) at t = 500. As we can see, in an illegitimate government, an increase of *pAvPP* reduces the presence of rebel agents. However, this does not stop acting in the agents because the number of agents imprisoned remains constant. A different behavior occurs when the legitimacy of the government has increased ($L = 0.38$). In this case, for lower *pAvPP* values, the decrease of rebel agents is presented, and for *pAvPP* values less or equal to 70%, In addition to the small presence of rebels, the number of incarcerated agents also decreases; both actions increase the number of quiet agents.

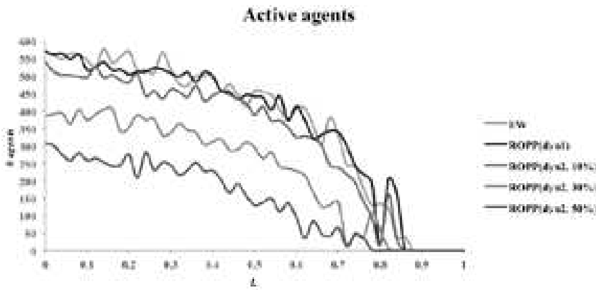
FIGURE 95

DENSITY OF AGENTS IN FUCTION OF *PAVPP* $\in \{10, 20, \ldots, 90\}$



In general, Figure 96 shows the behavior of rebel agents according to the government's legitimacy, considering the initial model of EW, the ROPP model with dynamics 1 and 2, and the latter with *pAvPP* = 10,30 and 50. As mentioned in the previous section (Figure 87), the influence of opinion decreases the likelihood of arrest compared to what is deducted from the EW model. This is shown in the graph of "Active agents" in Figure 10.2. When we simulate Dynamic 2 with different *pAvPP* values, we see that an increase in *pAvPP* significantly decreases rebel agents' presence, which is the behavior that a government seeks: to help its citizens as a vulnerability to avoid revolts.

FIGURE 96
BEHAVIOR OF REBEL AGENTS ACCORDING TO
THE LEGITIMACY OF THE GOVERNMENT *PAVPP*

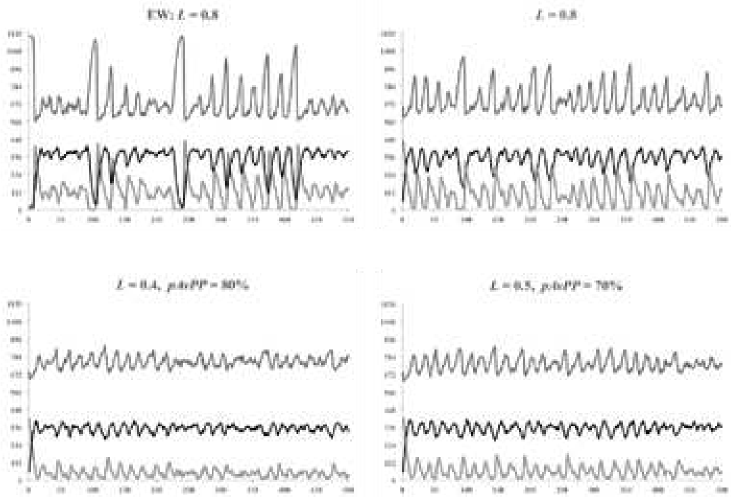


One behavior that is also interesting and that the previous graphs have not been able to express is the outbreak of a rebellion. That is, the behavior of the agents who for a while remain still, and then rebel. Figure 97 shows several graphs representing the values of legitimacy for which we observed this behavior. Something noticeable in these graphs is the density of agents in the first steps of time. With a high legitimacy regime (L = 0.8) in the Epstein-Wilensky model, the rebellious and active agents remain with low presence: t = 1 6 (4,0,0,0,1) active; t = 7 (13); t = 9 (80) active. In the ROPP model, the influence of opinion, active to more t = 1 (416) and retaining a considerable number of incarcerated agents; which means that despite having lapses where there are no rebels, the number of quiet agents is smaller compared to EW. Dynamics 2 shows similar behavior for a smaller legitimacy and a greater percentage of *pAvPP* to have the same effect.

Finally, it should be noted that for L 0.87 in the case of EW, the presence of rebel agents and prisoners is minimal (max. 37 and 90, respectively), decreasing with the increase of L until there are no rebel or imprisoned agents. In the ROPP model with Dynamics 1 and from L 0.86, we have similar behavior (max. 167 rebels and 242 imprisoned), also decreasing with the increase of L. In the case of Dynamic 2, this behavior depends mainly on *pAvPP* : when L < 0.4 does not have this burst behavior, but when L 0.4, this phenomenon will depend on the percentage of agents to implement public policy, as shown in Figure 96.

FIGURE 97

BEHAVIOR OF OUTBURSTS OF REBELLION



CONCLUSIONS

In the Epstein model [149] simulated through the work of Wilensky [166], the number of rebel agents decreases with the government's increased legitimacy. However, there is an interval for which the outbursts of rebellion are present, L [0.79, 0.86]; and for $L \geq 0.87$ the presence of rebel agents is null and void, leaving a society of still agents.

In the case of the ROPP model with Dynamic 1, the number of rebel agents decreases with the increase of the government's legitimacy. However, the interval for which the outbursts of rebellion appear is different, $L \in [0.8, 0.85]$; and for $L \geq 0.86$ it initiates a society of still agents, without the presence of rebels. When Dynamic 2 is simulated in the ROPP model, the legitimacy interval for the presence of significant outbursts of rebellion appear for a legitimacy $L \geq 0.4$, which in turn will depend on the value of *pAvPP*.

Therefore, the influence of opinion on the legitimacy of the government is notorious, since, for lower legitimacy values, we generally have behaviors similar to the EW model. In addition to the influence of opinion, the implementation of a public policy to reduce the level of deficiencies of the agents, generates two situations of interest: *i*) the increase in the percentage of vulnerable agents to apply public policy in illegitimate societies, decreases the presence of rebel agents; *ii*) governments of high legitimacy ($L \geq 0.5$) do not need to support all their vulnerable citizens (50% – 10%) to decrease the presence of a revolt.

REFERENCES

[1] Kevin McCain. *The Nature of Scientific Knowledge: An Explanatory Approach*. Springer International Publishing Switzerland, 2016.

[2] Kevin McCain. Explanation and the nature of scientific knowledge. *Science & Education*, 24:827–854, oct 2015.

[3] C. Darwin. *The Origin of Species by Means of Natural Selection or the Preservation of Favoured Races in the Struggle for Life*. London: John Murray, 1859.

[4] E. Schrödinger. *Nature and the Greeks, and Science and Humanism*. Cambridge University Press, 1996.

[5] Karl Popper. Three worlds. the tanner lecture on human values, 1978. Delivered at the University of Michigan.

[6] Karl Popper. *Objective Knowledge: An Evolutionary Approach*. Oxford University Press, 1979.

[7] G. Currie. Popper's evolutionary epistemology: A critique. *Synthese*, 37(3):413– 431, 1978.

[8] R. Suck. Measurement, representational theory of. In *International Encyclopedia of the Social & Behavioral Sciences (Second Edition)*, pages 9442–9448. Elsevier, 2015.

[9] S. S. Stevens. On the theory of scales of measurement. *Science*, 103(2684):677– 680, 1946.

[10] Eran Tal. Measurement in science. In Edward N. Zalta, editor, *The Stanford Encyclopedia of Philosophy*. Metaphysics Research Lab, Stanford University, fall 2017 edition, 2017.

[11] A. Frigerio, A. Giordani, and L. Mari. Outline of a general model of measurement. *Synthese*, 175(2):123–149, feb 2010.

[12] STEVEN WEINBERG. The methods of science … and those by which we live. *Academic Questions*, 8:7–13, 1995.

[13] T. GILLIAM and T. (Directors) Jones. Monty python and the holy grail. *[Motion Picture]*, 1975.

[14] J. M. EPSTEIN. Why model? *Journal of Artificial Societies and Social Simulation*, 11(4):12, 2008.

[15] J.S. CRAMER. The origins of logistic regression. *SSRN Electronic Journal*, 2003.

[16] MICHELLE MEAGHER. *Contemporary Feminist Theory*, chapter 23, pages 398–416. John Wiley & Sons, Ltd, 2020.

[17] S. M. CLIFTON, K. Hill, A. J. Karamchandani, E. A. Autry, P. McMahon, and G. Sun. Mathematical model of gender bias and homophily in professional hierarchies. *Chaos: An Interdisciplinary Journal of Nonlinear Science*, 29(2):023135, feb 2019.

[18] J. ZAZUETA and E Accineli. Exploring the dynamics of the gender-gap in the labor market: An evolutionary approach. Manuscript in preparation, 2020.

[19] P. BARBERÁ, J. T. Jost, J. Nagler, J. A. Tucker, and R. Bonneau. Tweeting from left to right: Is online political communication more than an echo chamber? *Psychological Science*, 26(10):1531–1542, aug 2015.

[20] G. KING, J. Pan, and Roberts. M. E. How censorship in china allows government criticism but silences collective expression. *American Political Science Review*, 107(2):326–343, may 2013.

[21] PATRICK JUOLA. The rowling case: A proposed standard analytic protocol for authorship questions. *Digital Scholarship in the Humanities*, page fqv040, oct 2015.

[22] J. ZAZUETA and A. O. Aguilera. Exploring the ideological structure within a local legislation process: An application of the structured topic model. Manuscript in preparation, 2020.

[23] PAUL HUMPHREYS. *Extending Ourselves: Computational Science, Empiricism, and Scientific Method*. Oxford University Press, 2004.

[24] R. L. ACKOFF. Towards a system of systems concepts. *Management Science*, 17(11):661–671, 1971.

[25] R. KEITH SAWYER. The mechanisms of emergence. *Philosophy of the Social Sciences*, 34(2):260–282, 2004.

[26] A. Tolk, S. Y. Diallo, J. J. Padilla, and R. Gore. Epistemology of modeling and simulation: How can we gain knowledge from simulations? *CoRR*, abs/1306.5215, 2013.

[27] H.-W. Gottinger. *In W. Leinfellner & E. Ko¨hler (Eds.). Developments in the methodology of social science*, volume 6, chapter Toward fuzzy reasoning in the behavioral sciences. D. Reidel Publishing Company, 1974.

[28] F. Squazzoni. *Agent-Based Computational Sociology*. Wiley, 2012.

[29] Omg systems modeling language (*omg sysml*) version 1.4. The Object Management Group.

[30] L Delligatti. *SysML distilled: A brief guide to the systems modeling language*. Addison-Wesley, 2013.

[31] Omg unified modeling language (*omg uml*) version 2.5. The Object Management Group.

[32] M. A. Bunge. *Treatise on Basic Philosophy. Ontology II: A World of Systems*, volume 4. D. Reidel Publishing Company, 1979.

[33] James S. Coleman. The vision of foundations of social theory. *Analyse & Kritik*, 14(2):117–128, 1992.

[34] Matthew Hause *Et al.* The sysml modelling language. In *Fifteenth European Systems Engineering Conference*, volume 9, pages 1–12, 2006.

[35] Guillame Finance. Sysml modelling language explained. *The Object Management Group(OMG)*, 2010.

[36] Gabriel Awad. *Towards a framework building for social systems modelling*. PhD thesis, Universidad Nacional de Colombia, 2017.

[37] L. Ljung. *Signal Analysis and Prediction*, chapter System Identification. Applied and Numerical Harmonic Analysis, Birkha¨user, Boston, MA, 1998.

[38] Scott W. Ambler. *The Elements of UML(TM) 2.0 Style*. Cambridge University Press, USA, 2005.

[39] L. Ljung and T. Glad. *Modeling of dynamic systems*. Prentice-Hall Information and System Sciences Series, 1994.

[40] C Cioffi-Revilla. Simplicity and reality in computational modeling of politics. *Computational & Mathematical Organization Theory*, 15(1):26–46, 2009.

[41] C. Sibertin-Blanc, P. Roggero, F. Adreit, B. Baldet, P. Chapron, J. El-Gemayel, M. Mailliard, and S. Sandri. Soclab: A framework for the modeling, simulation and analysis of power in social organizations. *Journal of Artificial Societies and Social Simulation*, 16(4):8, 2013.

[42] F. Adreit, P. Roggero, C. Sibertin-Blanc, and C. Vautier. Using soclab for a rigorous assessment of the social feasibility of agricultural policies. *International Journal of Agricultural and Environmental Information Systems (IJAEIS)*, 2(2):1–15, 2009.

[43] N. P. Hummon and T. J Fararo. The emergence of computational sociology. *Journal of mathematical sociology*, 20(2- 3):79–87, 1995.

[44] M. Crozier. *Le phénome`ne bureaucratique: essai sur les tendances bureaucratiques des syste`mes d'organisation modernes et sur leurs relations en France avec le syste`me social et culturel*. Collection Points : série essais. Paris: É d. du Seuil, 1963.

[45] M. Crozier and E Friedberg. *L'acteur et le syste`me*. Paris: Seuil, 2010.

[46] E. Friedberg. *Le pouvoir et la re`gle*. Paris: É d. du Seuil, 1997.

[47] Jean-Pierre Treuil, A. Drogoul, and JeanDaniel Zucker. *Modélisation et simulation a` base d'agents: exemples commentés, outils informatiques et questions theóriques*. Paris: Dunod, 2008.

[48] P. Roggero, C. Sibertin-Blanc, M. Maillard, C. Vautier, F. Adreit, and S. Sandri. Formalisation, modélisation et simulation orienteé agents des syste`mes dáction concrets: approche complexe de la sociologie de láction organiseé. Technical report, Universite` des Sciences Sociales, Tolouse, France, 2007.

[49] M Maillard. *MultiAgents formalisation for the Sociology of the Organized Action*. PhD thesis, University of Toulouse, Toulouse, France, 2008.

[50] Jean-Pierre Müller and P. Bommel. *Agent-based modelling and simulation in the social and human sciences*, chapter An introduction to UML for modeling in the human and social sciences, pages 273–294. Bardwell Oxford, Reino Unido, 2007.

[51] Hugues Bersini. Uml for abm. *Journal of Artificial Societies and Social Simulation*, 15(1):9, 2012.

[52] G. Booch, J. Rumbaugh, I. Jacobson, J. J. G. Molina, and J. S. Martínez. *El lenguaje unificado de modelado: guía del usuario*. Addison-Wesley, 2006.

[53] N. Villa-Vialaneix, C. Sibertin-Blanc, and P. Roggero. Statistical exploratory analysis of agent-based simulations in a social context. *Case Studies in Business, Industry and Government Statistics*, 5(2):132– 149, 2014.

[54] L. G. Rodríguez Zoya, J. L. Aguirre, and P. Roggero. Uso de soclab para modelar y simular el clientelismo político. *Revista mexicana de sociología*, 80(3):639– 673, 2018.

[55] M. Minsky. Matter, mind and models. Paper presented at the International Federation of Information Processing Congress, 1965.

[56] C. Sibertin-Blanc and O. Terán. The efficiency of organizational withdrawal vs commitment. In *Social Simulation Conference*, 2014.

[57] J. El Gemayel, P. Chapron, F. Adreit, and C. Sibertin-Blanc. Quand et comment les acteurs sociaux peuvent-ils coopérer? *Revue dI´ntelligence Artificielle*, 25(1):43– 67, 2011.

[58] Leonardo Rodríguez Zoya and Pascal Roggero. La modelización y simulación computacional como metodología de investigación social. *Polis. Revista Latinoamericana*, 39, 2014.

[59] Juan Fonseca Gutiérrez. La formación de investigadores: oficio y conocimiento pertinente ante los avances de la ciencia y la tecnología. *RIDE Revista Iberoamericana para la Investigación y el Desarrollo Educativo*, 10(20), 2020.

[60] Mónica Eugenia Moreno Rubio. Teoría de sistemas e historia: un acercamiento interdisciplinario para la investigación científica. *Relaciones: Estudios de historia y sociedad*, 40(159):171–192, 2019.

[61] Enrique Luengo González and RED INCOMPLEX. Ciencias sociales y complejidades, hacia un diálogo de mutuo aprendizaje. *Gazeta de Antropología*, 35(2), 2019.

[62] Germán Arango-Forero. Comunicación digital: una propuesta de análisis desde el pensamiento complejo. *Palabra Clave*, 16(3), 2013.

[63] Edgar Morin. Los siete saberes necesarios a la educación del futuro, 2001. Free digital book.

[64] Germán de la Reza and Arturo Lara. Creación interdisciplinaria: el isomorfismo como criterio normativo. *Argumentos*, 2012.

[65] Joseph T. Lizier, P. Giesl, M. S. Harré, M. Mitchell, S. DeDeo, C. Finn, K. Lindgren, A. L. Lizier, and Hiroki Sayama. An interview-based study of pioneering experiences in teaching and learning complex systems in higher education. *Complexity*, 2018.

[66] S. Schwartz and M. Pollishuke. *Aprendizaje activo: Una organización de la clase centrada en el alumnado*. Educación Hoy. Narcea, 1995.

[67] M. Mitchell. *Complexity: A Guided Tour*. Oxford University Press, 2009.

[68] Michael J. Jacobson and Uri Wilensky. Complex systems in education: Scientific and educational importance and implications for the learning sciences. *Journal of the Learning Sciences*, 15(1):11–34, 2006.

[69] Rafael Porlán, Martín del Pozo Rosa, Rivero Ana, Harres Joao, Azcárate Pilar, and Pizzato Michelle. El cambio del profesorado de ciencias i : marco teórico y formativo. *Enseñanza de las ciencias: revista de investigación y experiencias didá cticas*, 28(1):31–46, jun. 2010.

[70] Susan A. Yoon, Sao-Ee Goh, and Zhitong Yang. Toward a learning progression of complex systems understanding. *Complicity: An International Journal of Complexity in Education*, 16:1–19, 2019.

[71] F. Liévano Martínez and J. Enrique Londoño. El pensamiento sistémico como herramienta metodológica para la resolución de problemas. *Revista Soluciones de Postgrado*, 4(8):43–65, 2013.

[72] Carlos Gershenson. Pensamiento sistémico, 2019.

[73] Bernardo Gargallo, Jesús M. SuárezRodríguez, and Cruz Pérez-Pérez. El cuestionario ceveapeu. un instrumento para la evaluación de las estrategias de aprendizaje de los estudiantes universitarios. *RELIEVE. Revista Electrónica de Investigación y Evaluación Educativa*, 15(2), 2009.

[74] Carlos Eduardo Maldonado. Complejidad de los sistemas sociales: Un reto para las ciencias sociales. *Cinta de moebio*, pages 146–157, 12 2009.

[75] A. ABBOTT and J. Forrest. Optimal matching methods for historical sequences. *The Journal of Interdisciplinary History*, 16(3):471–494, 1986.

[76] S. AISENBREY and A. E. Fasang. New life for old ideas: The "second wave" of sequence analysis bringing the "course" back into the life course. *Sociological Methods & Research*, 38(3):420–462, 2010.

[77] P. BLANCHARD, F. Bühlmann, and J.-A. Gauthier (Eds.). *Advances in Sequence Analysis: Theory, Method, Applications*. Life Course Research and Social Policies. Springer International Publishing, 2014.

[78] G. RITSCHARD and M. Studer. *Proceedings of the International Conference on Sequence Analysis and Related Methods*. LaCOSA II, Lausanne, Switzerland, 2016.

[79] G. RITSCHARD and M. Studer. *Sequence Analysis and Related Approaches*. Springer International Publishing, 2018.

[80] K. STOVEL. Thoughts on sequences in comparative historical sociology. *Trajectories*, 22:5–10, 2010.

[81] B. CORNWELL. *Social Sequence Analysis: Methods and Applications*. Structural Analysis in the Social Sciences. Cambridge University Press, 2015.

[82] M. STUDER and G. Ritschard. What matters in differences between life trajectories: a comparative review of sequence dissimilarity measures. *Journal of the Royal Statistical Society Series A*, 179(2):481–511, 2015.

[83] P. J. ROUSSEEUW. Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics*, 20:53–65, 1987.

[84] G. RITSCHARD, A. Gabadinho, N. S. Müller, and M. Studer. Mining event histories: a social science perspective. *International Journal of Data Mining, Modelling and Management*, 1(1):68–90, 2008.

[85] A. GABADINHO, G. Ritschard, M. Studer, and N. S. Müller. Mining sequence data in R with the TraMineR package: A user's guide. Technical Report 1, University of Geneva, 2010.

[86] G. W. Hougham, S. A. Ham, G. W. Ruhnke, E. Schulwolf, A. D. Auerbach, J. L. Schnipper, P. J. Kaboli, T. B. Wetterneck, D. Gonzalez, V. M. Arora, and D. O. Meltzer. Sequence patterns in the resolution of clinical instabilities in community-acquired pneumonia and association with outcomes. *Journal of General Internal Medicine*, 29(4):563–571, 2013.

[87] B. Vanhoutte, M. Wahrendorf, and J. Prattley. *Sequence Analysis of Life History Data*, pages 2–19. Springer Nature, United States, apr 2018.

[88] K. Dlouhy and T. Biemann. Optimal matching analysis in career research: A review and some best-practice recommendations. *Journal of Vocational Behavior*, 90:163–173, 2015.

[89] Luis Castro. Modelo Logístico de un Ecosistema. código fuente en lenguaje pascal, 1992.

[90] Niklas Luhmann. *Introducción a la teoría de sistemas*. México: UIA, 1996.

[91] Humberto Maturana. *La objetividad. Un argumento para obligar*. Ediciones Granica S.A., Chile, 2011.

[92] Markus A. Cirone, Bernardo Spagnolo, and Ferdinando De Pasquale. *Nonlinear Relaxation in Population Dynamics*, chapter 22, pages 217–226. World Scientific Publishing, London, 2002.

[93] F.G. Varela, H.R. Maturana, and R. Uribe. Autopoiesis: The organization of living systems, its characterization and a model. *Biosystems*, 5(4):187–196, 1974.

[94] Francisco J. Varela and Joseph A. Goguen. The arithmetic of closure. *Journal of Cybernetics*, 8(3-4):291–324, 1978.

[95] Barry McMullin and Francisco J. Varela. Rediscovering computational autopoiesis. In *Santa Fe Institute Working Paper*, 97-02-012, 1997.

[96] Martin A Nowak. *Evolutionary dynamics: exploring the equations of life*. Harvard University Press, 2006.

[97] David Rand and Martin Nowak. Human cooperation. *Trends in Cognitive Sciences*, 17(8):413–425, 2013.

[98] M. A. Nowak and K. Sigmund. Evolution of indirect reciprocity by image scoring. *Nature*, 393(6685):573–577, jun 1998.

[99] Claus Wedekind and Manfred Milinski. Cooperation through image scoring in humans. *Science*, 288(5467):850–852, may 2000.

[100] Manfred Milinski, Dirk Semmann, and Hans Ju¨ rgen Krambeck. Reputation helps solve the 'tragedy of the commons'. *Nature*, 415(6870):424–426, jan 2002.

[101] Ingrid Seinen and Arthur Schram. Social status and group norms: Indirect reciprocity in a repeated helping experiment. *European Economic Review*, 50(3):581– 602, apr 2006.

[102] Bettina Rockenbach and Manfred Milinski. The efficient interaction of indirect reciprocity and costly punishment. *Nature*, 444(7120):718–723, dec 2006.

[103] Ralf D. Sommerfeld, Hans-Jürgen Krambeck, and Manfred Milinski. Multiple gossip statements and their effect on reputation and trustworthiness. *Proceedings of the Royal Society B: Biological Sciences*, 275(1650):2529–2536, nov 2008.

[104] Hisashi Ohtsuki, Yoh Iwasa, and Martin A Nowak. Indirect reciprocity provides only a narrow margin of efficiency for costly punishment. *Nature*, 457(7225):79–82, 2009.

[105] Aljazˇ Ule, Arthur Schram, Arno Riedl and Timothy N. Cason. Indirect punishment and generosity toward strangers. *Science*, 326(5960):1701–1704, dec 2009.

[106] Thomas Pfeiffer, Lily Tran, Coco Krumme, and David G Rand. The value of reputation. *Journal of The Royal Society Interface*, 9(76):2791–2797, nov 2012.

[107] Charlotte Klempt. The impact of random help on the dynamics of indirect reciprocity. Technical report, IAW Diskussionspapiere, 2012.

[108] Benjamin M. Wilkowski and Christopher A. Chai. Explicit person memories constrain the indirect reciprocation of prosocial acts. *Journal of Experimental Social Psychology*, 48(5):1037–1046, sep 2012.

[109] Shinsuke Suzuki and Hiromichi Kimura. Indirect reciprocity is sensitive to costs of information transfer. *Scientific Reports*, 3(1):1–5, mar 2013.

[110] Richard D. Alexander. Natural Selection and the Analysis of Human Sociality. In *Changing Scenes in the Natural Sciences,*

1776-1976, volume 12, pages 283–337. Philadelphia Academy of Natural Sciences, 1977.

[111] Richard D. Alexander. *Darwinism and Human Affairs*. University of Washington Press, 1979.

[112] M. A. Nowak and K. Sigmund. Evolution of indirect reciprocity. *Nature*, 473(7063):1291–1298, 2005.

[113] Richard D. Alexander. *The biology of moral systems*. A. de Gruyter, 1987.

[114] Mario I González Silva. Modelación y simulación de un nuevo modelo del mecanismo de cooperación de reciprocidad indirecta. Master's thesis, Universidad de Guadalajara, 2018.

[115] Raman Paranjape, Zhanle Gerald Wang, and Simerjit Gill. Agent-based modeling and simulation. In *The Diabetic Patient Agent*, pages 9–14. Springer, 2018.

[116] NetLogo Home Page.

[117] Antonio Vázquez-Barquero. *Las nuevas fuerzas del desarrollo*. Antoni Bosch Editor, S.A., Madrid, 2013.

[118] Antonio Vázquez-Barquero. Desarrollo endógeno y globalización. *EURE. Revista latinoamericana de estudios urbanos regionales*, XXVI(79), 2000.

[119] Paul M. Romer. Endogenous technological change. *Journal of Political Economy*, 98(5):S71–S102, 1990.

[120] Robert E. Lucas. On the mechanics of economic development. *Journal of Monetary Economics*, 22(1):3–42, 1988.

[121] Robert J Barro. Government spending in a simple model of endogeneous growth. *Journal of political economy*, 98(5, Part 2):S103–S125, 1990.

[122] Juan Ramón Cuadrado Roura. Políticas regionales hacia un nuevo enfoque. *Papeles de Economía Española*, 35, 1988.

[123] Carlos A. de Mattos. La descentralización, ¿una nueva panacea para impulsar el desarrollo local? *Revista de Estudios Regionales*, 26:49–70, 1990.

[124] G Canzanelli. The role of international organizations for the promotion of endogenous development. *Mimeograph. Geneva: ILO and Napoli: University of Naples*, 2003.

[125] Francisco Alburquerque. Teoría y práctica del enfoque del desarrollo local, 2003.
[126] Francisco Alburquerque Llorens. Innovation, knowledge transfer and territorial economical development: A pending politics. *Arbor*, 184(732), 2008.
[127] Michael Storper. Society, community and economic development. *DRUID Summer Conference*, 2004.
[128] Michael Storper. Sociedad, comunidad y desarrollo económico. *EKONOMIAZ. Revista vasca de Economía*, 58(01):12–43, 2005.
[129] Sergio Boisier. ¿hay espacio para el desarrollo local en la globalización? *CEPAL*, 86, 2005.
[130] Sergio Boisier. *Imá genes en el espejo; aportes a la discusión sobre crecimiento y desarrollo territorial*. UAEM, México, 2007.
[131] Sergio Boisier. El desarrollo a partir de la construcción de capital sinergético. En curso Internacional Ciudad Futura II, Plan Estratégico Rosario, 2004.
[132] R. Albert and A. L. Barabási. Topology of evolving networks: local events and universality. *Physical review letters*, 85(24), 2000.
[133] Mark Newman. *Networks: An Introduction*. OUP Oxford, 2010.
[134] Albert Lászlo Barabási. Network science.
[135] Paul Erdo's and Alfréd Rényi. On random graphs. *Publicationes Mathematicae Debrecen*, 6:290–297, 1959.
[136] Proceeding of the XV Summer School in Physics. *Redes complejas: Estructura, Diná mica y evolución*, 2011.
[137] S. Boccaletti, V. Latora, Y. Moreno, M. Chavez, and D.-U. Hwang. Complex networks: Structure and dynamics. *Physics Reports*, 424(4–5):175–308, 2006.
[138] M. E. J. Newman. The structure and function of complex networks. *SIAM Review*, 45(2):167–256, 2003.
[139] Stuart A. Kauffman. *At Home In the Universe: The Search for Laws of SelfOrganization and Complexity*. Oxford University Press, 1996.
[140] Andrew Wuensche. Basins of attraction in network dynamics: A conceptual framework for biomolecular networks. *SFI WORKING PAPER, The Santa Fe Institute*, 2002.
[141] Censo de Población y Vivienda. San Nicolás de los Ranchos, Estado de Puebla.

[142] Carlos Lemos, Helder Coelho, and Rui J. Lopes. Agent-based modeling of social conflict, civil violence and revolution: State-of-the-art-review and further prospects. In *EUMAS*, volume 113, 2013.

[143] Nigel Gilbert. *Agent-Based Models*. Quantitative Applications in the Social Sciences. SAGE Publications, Inc., 2007.

[144] Timur Kuran. Now out of never: The element of surprise in the east european revolution of 1989. *World Politics*, 44:7– 48, 1991.

[145] Uri Wilensky and William Rand. *An Introduction to Agent-Based Modeling: Modeling Natural, Social, and Engineered Complex Systems with Netlogo*. The MIT Press, Cambridge, Massachusetts London, England, 2015.

[146] A.O. Aguilera and M.P. Calvo. *Introducción al modelado basado en agentes: una aproximación desde NetLogo*. Colección Investigaciones. El Colegio de San Luis, 2017.

[147] Thomas Schelling. Dynamic models of segregation. *Journal of Mathematical Sociology*, 1:143–186, 1971.

[148] Norma L. Abrica-Jacinto, Evguenii Kurmyshev, and Héctor A. Juárez. Effects of the interaction between ideological affinity and psychological reaction of agents on the opinion dynamics in a relative agreement model. *Journal of Artificial Societies and Social Simulation*, 20(3):3, 2017.

[149] Joshua M. Epstein. Modeling civil violence: an agent-based computational approach. *Proceedings of the National Academy of Sciences of the United States of America*, 99 Suppl 3:7243–50, 2002.

[150] A.B. Shiflet and G.W. Shiflet. *Introduction to Computational Science: Modeling and Simulation for the Sciences - Second Edition*. Princeton University Press, 2014.

[151] Rainer Hegselmann and Ulrich Krause. Opinion dynamics and bounded confidence: Models, analysis and simulation. *Journal of Artificial Societies and Social Simulation*, 5(3), 2002.

[152] Charles M Macal and Michael J North. Tutorial on agent-based modeling and simulation. In *Proceedings of the Winter Simulation Conference, 2005.*, pages 14– pp. IEEE, 2005.

[153] Luc Steels. Building agents out of autonomous behavior systems. *The Artificial Life Route to Artificial Intelligence,* edited by

L. Steels and R. Brooks, Lawrence Arlbaum Associates, Inc, New Jersey, 1995.

[154] Joshua M. Epstein. *Generative Social Science: Studies in Agent-Based Computational Modeling*. Princeton Studies in Complexity, 2006.

[155] S. Bankes, R. Lempert, and S. Popper. Making computational social science effective: Epistemology, methodology, and technology. *Soc. Sci. Comput. Rev.*, 20(4):377–388, October 2002.

[156] Serge Galam. Sociophysics: A review of galam models. *International Journal of Modern Physics C*, 19(03):409–440, 2008.

[157] Janusz A. Holyst, Krzysztof Kacperski, and Frank Schweitzer. Social impact models of opinion dynamics. *Annual Reviews of Computational Physics*, 9(22):253–273, 2001.

[158] Haoxiang Xia, Huili Wang, and Zhaoguo Xuan. Opinion dynamics: A multidisciplinary review and perspective on future research. *International Journal of Knowledge and Systems Science*, 2(4):72– 91, 2011.

[159] A. Bondy and U.S.R. Murty. *Graph Theory*. Graduate Texts in Mathematics. Springer London, 2011.

[160] Roberto García Jurado. Fundamentos de la legitimidad. *Estudios Políticos*, 24, 2000.

[161] J. Emilio Graglia. *En la bú squeda del bien comú n: manual de políticas pú blicas*. Konrad Adenauer Stiftung, 2012.

[162] Thomas R. Dye. *Understanding public policy*. Always learning. Pearson, 2013.

[163] Luis Aguilar. Antologías de política pú blica. *México: Porrú a*, 1993.

[164] Emilio Graglia. *Diseño y gestión de políticas pú blicas: hacia un modelo relacional*. EDUCC, Ed. de la Univ. Católica de Córdoba, 2004.

[165] Guillaume Deffuant, David Neau, Frederic Amblard, and Gérard Weisbuch. Mixing beliefs among interacting agents. *Advances in Complex Systems*, 03(01n04):87–98, 2000.

[166] U. Wilensky. Netlogo rebellion model. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL, 2004.

Colofón