Methodology for the Modeling of Complex Social System Using Neuro-Fuzzy and Distributed Agencies

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***Abstract*—this work is motivated by the need to establish a general methodology for the study of social systems in situations where conventional analysis is insufficient in describing the intricacies of realistic social phenomena and social actors. The distributed agency methodology we describe requires the use of all available computational techniques and interdisciplinary theories. This growing consensus must be able to describe all aspects of social life as well as serve as a common language in which different theories can be contrasted.**

***Index Terms*—Complex systems, distributed agency, social simulation, sustainable systems theory.**

I. Introduction

The construction of the model of a social system must take into account several aspects of reality. Social organizations are conceived as systems within systems. These systems are complex entities that represent a whole that cannot be understood by looking at its parts independently [1]. Another characteristic is the interdependence of the parts that make the whole: a change to one of the components in the system may potentially affect all others. The internal and external interactions of the system reflect a multiplicity of control and autonomy layers [2].

Furthermore, one of the most important aspects of the objective function of an organism is the need to find a steady state or "Homoeostasis." This state refers to the point where the organization reaches an equilibrium that does not change [2].

Another aspect that could be considered is that the system gets increasingly complex as a result of this process, in a dynamic setting where the relationships among the parts co-evolve and thus jointly become better adapted and capable of affecting their environments. The field of complex adaptive systems is precisely devoted to the study of these last shorts of evolutionary processes, which have been studied in the last two decades and have contributed to the creation of artificial systems, artificial life, and evolutionary computation, [3] [4] [5]. Finally, the development of such a general platform must clearly accept the notion that due to the chaotic and complex nature of social systems, all description must be non-deterministic [6].

The ultimate objective of our study is to develop a methodology and corresponding computational platform that incorporates available mathematical and computational theories that have not been appropriately considered in models of complex social phenomena. Even though applications of Multi-Agent Systems (MAS) have been developed for the social sciences have been widely considered in some areas such as Artificial Intelligence (AI) [7], the state-of-the-art in computational capabilities has not has been incorporated in multiple areas [8], particularly as it refers to distributed systems and distributed agencies [9].

II. Distributed Agency

A. Distributed Agency

Modeling of a realistic social system cannot be achieved by resorting to only one particular type of architecture or methodology. The growing methodology of Distributed Agency (DA) represents a promising research avenue with promising generalized attributes, with potentially groundbreaking applications in engineering and in the social sciences—areas in which it minimizes the natural distances between physical and sociological nonlinear systems. In this work we thus lay the foundations for a DA description of socioeconomic realities, in a process that weaves different computational techniques in the context of DA to represent social and individual behavior in a contextualized fashion, accommodating agents with limited rationality and complex interactions. We believe that this research avenue will improve our understanding of social complexity, as it moves the discussion in the field towards the capability of describing the vast array of linear and nonlinear realities, interlocking levels and currently non-consilient theories in existence.

Manuscript received March 10, 2011. This work was supported in part by the Mexican National Council for Science and Technology (Consejo Nacional de Ciencia y Tecnologıa, CONACYT)..

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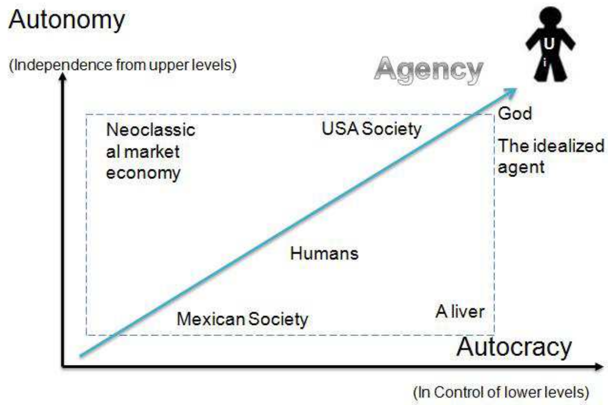

Fig. 1. Levels agents represented hierarchically

The methodology we are aiming to create represents a novel approach to simulation architectures, creating a language that links the social sciences to programmable terminology and that can thus be broadly applied. The methodology of DA represents a general theory of collective behavior and structure formation [6], which intends to redefine agency and reflect it in multiple layers of information and interaction, as opposed to the traditional approach in which agency is only reflected in individual, atomized and isolated agents.

B. Intermediate agent

We consider a disentangled agent that is formed by multiple and relatively independent components. Part of the resulting agent's task is to present alternatives, or 'fields of action' to its components. Correspondingly, the composed agent is itself constrained by a field of action that the superstructure to which it belongs presents. We therefore drop customary assumptions made in traditional social disciplines and MAS about what is considered a decision-making unit. To arrive at this, we redefine what a unit of decision is by unscrambling behavioral influences to the point of not being able to clearly delineate what the individual is, who is part of a group and who is not, or where a realm of influence ends; the boundary between an individual self and its social coordinates is dissolved.

The proposed intermediate agent can be thought of as a person, a family, a social class, a political party, a country at war, a species as a whole, or a simple member of a species trying to survive. The archetype of the agents we attempt to describe can be summarized as a group of colluded oligopolists, such as the oil-producing countries of OPEC. As a whole, they share the common interest of jointly behaving like a monopoly and restricting their production, but they cannot avoid having an incentive to deviate and produce above their quota.

C. Multiple levels

Reductionist linear science has concentrated on the study of entities that are clearly delineated, where one could separate what belongs to an agent's nature against the backdrop of what does not. The relevant agent is taken to be exogenous, and therefore disconnected from the system to which it belongs. At their core, these traditional disciplines are based on a selfish and unitary agent, or atom of description. Implicitly or explicitly, these paradigms claim that all aggregate complexity can be traced back to the lower level of the system: the strategies and actions of the selfish agent. In other words, these represent research agendas that purposely de-emphasize the existence of any level other than that of the individual.

D. Irreducible levels of interaction

On the other hand, the idea of emergence reflects the fact that different and irreducible levels of interaction will naturally

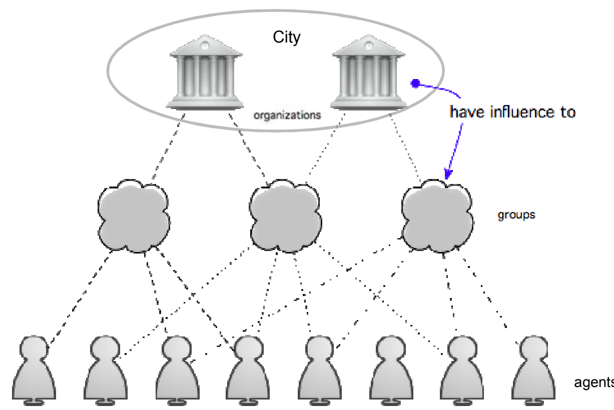

Fig. 2. Representation of multiple levels

arise in complex systems such as the ones studied by social disciplines, and thus the agent, as we define it in this work, is a combination of levels of interaction. It is through this lens that we would like to consider humans, who will partly be independent creatures, possessors of free will, but who are also partly created by an array of upper levels that 'suggest' agreeable utility functions. This conception stems directly from the concept of complexity, in which wholes are more than the sum of their parts. If we believe in that proposition, then we should expect to find a world full of emergent phenomena, with distinctive levels of interaction that have agency of their own. The proposed language redefines agents in two ways. First, there are no obvious atomic agents, for all actors represent the emerging force resulting from the organization of relatively independent subsets. Second, agents are not created in a vacuum, but are rather the result of what an upper level spawns [10].

III. Methodology

The methodology proposed consists of eight steps:

A. Determining the levels of agency and their implicit relationships:

In this phase we analyze the social system and the existing relationships to determine the necessary number and topology of the necessary levels of description. To this end, we first identify the problems to solve, so that we can describe their operation within a physical framework. This process will in turn allow us to identify the input and output variables of the system as a whole as well as all necessary subsystems, whether these variables are decision variables or other measurable parameters.

In this process, it is imperative that we adopt a holistic approach that does not attempt to reduce the system to its individual components. In the real world, no phenomenon exists in isolation [11]. We must therefore in this step of our methodology establish the objective functions of all levels of agency that are considered, as well as the interactions that are prevalent in the corresponding networks.

B. *Data mining:*

Studies within the social sciences (and in particular in economics) are normally performed on a large data platforms, in situations in which there is too much rather tan to few data points. The most problematic aspect of this stage of the modeling process is to define data sets that match the desired architecture [12]. The continuous expansion of available information for social simulation makes the use of data mining unavoidable. In our case study, for example, we have access to many different sources of quantitative and qualitative data describing both economic as well as sociological aspects of reality. Many of these data sets are readily available from governmental sources.

Data mining provides us with the process for extracting implicit information, such as social patterns, that reveal ingrained knowledge [13]. The use of these techniques has had significant progress in the last decade, with many research agendas and efforts devoted to the development of efficient algorithms to extract relevant information out of data sets [14].

C. *Generating a rule-set:*

We propose the use of a Neuro-Fuzzy system for the automatic generation of the necessary rule-set of our simulation. This phase of the data mining process can become complicated and computationally intensive, as the Fuzzy system must determine the necessary number of layers to describe the norms and variables to keep track of in the simulation[15-16].

D. *The modeling based on Distributed Agency:*

Modeling based on DA allows us to better understand the structures and relevant processes of social systems [7]. MAS models and artificial societies are currently built on common themes, generally using techniques that stem from dynamical systems modeling, but also using tools from cellular automaton platforms, genetic algorithms and DA systems. The difference in available approaches are normally concentrated in the idiosyncrasies of the particular model and the design of the research methodology [17]. In this phase of the modeling process, the researcher must build a basic model of the system to be analyzed, where the most important aspects to be represented are stressed. This can normally be achieved using an approximate dynamical representation in terms of stocks and flows in the system, focusing on points where information a decision making can be transformed into decision rules. The process of rule generation that will stem from this original framework refers back to the previous step (defined in step 3), and it is focused on the behavior of the agents that are influenced by the decision rules in a probabilistic fashion.

E. *Implementation:*

The implementation of the simulation can be done in vast array of platforms, but the social scientist that does not want to spend a large amount of time working on code may simply choose to base this step in the NetLogo simulation platform, which is free, readily available, easy to understand and widely used. Because of its voluminous library, this platform is ideal for modeling social phenomena. It is capable of modeling complex systems which can independently provide instructions to thousands of interdependent agents operating in a holistic environment [18].

The NetLogo platform also allows us to easily assign geographical information, that is, by creating simulation data that represents vectors of information that include a special component [19]. It is an appropriate platform for the modeling of a wide range of complex systems that have temporal dynamics, allowing the researcher to assign independent instructions to different agents at any given moment. This relevant characteristic of NetLogo can provide the researcher with opportunities for finding the connection between the micro level of behavior of a multiplicity of individuals and the macro patterns of behavior that emerge from the interactions of the individuals [18].

F. *Validating the Model:*

Real-world simulations must include some form of validation [17]. This validation will ultimately reflect the consistency between the real world and the artificial model. Based on the results obtained during the validation, the process must then go back to the beginning, so that the problems found can be addressed and the model refined.

G. *A simulation and optimization experiment:*

In this phase of the process the researcher must provide a statistical evaluation of the models outputs to determine the quality of the simulation based upon some pre-established evaluation criteria of performance measurement. As part of this process, it is important to verify whether the object of interest reflects seasonal aspects, in which case the data must be transformed so as to analyze the transformed stationary data. Finally, in this stage a methodology for experiment design must be adopted, and it must be based on repetitions of the simulation performed with the exogenous variables set at significantly different levels.

H. *Analyzing the outputs:*

In this last stage, the results of the model are analyzed, so that the researcher can understand the aspects of interest in the behavior of the system. It is these outputs and their ultimate understanding that can then be used to make sense of the social system in study.

IV. Modeling complex systems in the computer

A. Computational modeling:

Computer Simulations can aide in the understanding of social phenomena, by explaining and predicting many aspects of its chaotic nature. This methodology is academically young, but it has been consistently growing in the scientific field and has already been used successfully in a number of research projects [20]. Furthermore, available computational techniques can facilitate the selection of relevant data as well as aide the processing of information, in processes that involve high performance computing. It is through this process that social simulation is developed and potentially the most efficient way of making sense of the vast amounts of information available today [21].

B. Representation that can make reference to different levels:

This growing field is intrinsically interdisciplinary, naturally linked to the sciences of complexity and to systems theory [5]. To carry out a useful simulation of a social system the methodology must be holistic. The intention is to create a representation that can make reference to different levels within a given reality within a general methodology; taking into account that each level is separated from others in ways that cannot be described in a reductionist fashion, that are to some extent in different dimensions and thus following different rules and temporal granularities [6]. One of the corollaries of this approach is that an entity that is represented as a multiplicity of agents in one level may be considered a unitary agent in another level of description.

A complex system is composed of subsystems that may be simple and complex, linear and nonlinear. Simple, linear systems are in turn composed of particles and the system. On the other hand, complex systems require at least three hierarchical levels: particles, agents and the system [22]. In a complex system—such as that of a group, an organization, a growing population or a market economy, where the self-created organization comes about from of the interaction of many component parts—the macro patterns are not easily discernible or understood from the understanding of the behavior of the individual parts, whether these are simple components, autarkic agents or rational consumers [23-24]. One of the main challenges of our approach is to provide a methodology to analyze the many different levels associated within a social reality.

C. Distributed agency architecture:

The proposition implies that the researcher observe behavior, and then use backwards induction to portray the forces at play that could have given rise to the decisions taken, as well as patterns and structures that emerged. Traditionally, we have begun with a clearly defined agent and tried to understand its actions as a maximization of objectives given constraints. In the proposed paradigm, we assume maximization occurs, and then work towards the delineation of the benefited entity. As such, this proposition is not a theory or hypothesis, but rather a language in which different models can be expressed. The complexities of the proposed architecture can be endless. This notwithstanding, the paradigm for a new pandemic and inter-disciplinary science built in a distributed agency architecture would accept the intercommunion by means of a parsimonious model that is broad enough to accept the nature of realistic agents, but at the same time tractable enough for the capabilities of an appropriate MAS simulation, expressed at a minimum desired level of realism. The methodology therefore intends to advance the development of a common language in which novel ideas can be transmitted across disciplines.

D. The language of distributed agency:

Such a language allows us to compare a model in which disentangled humans in a given culture have some degree of independent agency, but are also to some degree objects of their social circumstances—to another one in which countries are trying to position themselves in the evolving global arena, but are nonetheless fighting with their internal political differences, as well as with established international norms and existing treaties. In sociology, for example, the individual is ascribed little agency when compared to the group or social structure; classical economics, on the other hand, grants zero agency to upper level creatures, as the selfish actions of individuals are carried by an invisible hand to an efficient allocation. As it applies to evolutionary biology, this distinction represents the core of the controversy between individual selection theory and group selection theory. The language of distributed agency can also serve as a common ground in which individual vs. group selection theories can discuss their visions of evolution. Just as the process of evolution perfects individuals, it must as well have the same effect in groups and societies. The surviving members of a cooperating group, however, will not be 'fittest' at an individual level; their individual traits and natures, for example, only make sense within the context of the cooperating group.

V. Case study: Modeling the city of Juarez

The main difference between MAS and our proposed approach is that in our methodology the space includes transformations performed by a higher level of agency. This upper-level agent is composed of lower-level subcomponents the may enjoy agency in their own right. It is the responsibility of this intermediate agent to present its subcomponents with individual phase-spaces that are tailored to induce the desired behavior from the lower-level agents which inhabit it, when it chooses according to its own objective function.

Therefore, for our proposed work-in-progress case study, if we consider a municipality an agent, this upper-level agent is composed by subcomponents, which in our case study of the city of Juarez, Mexico, will be represented by the AGEBS that compose this city. AGEB is the term used to describe the different areas of the city that are in turn are composed of neighborhoods.

A. Case of study levels of agency:

In our study we use three levels of agency: the upper-level agent is represented by the whole city of Juarez, the intermediate agents are represented by the AGEBS and the lower level agents are the individual inhabitants of the city.

The purpose of this approach is to define poverty in each

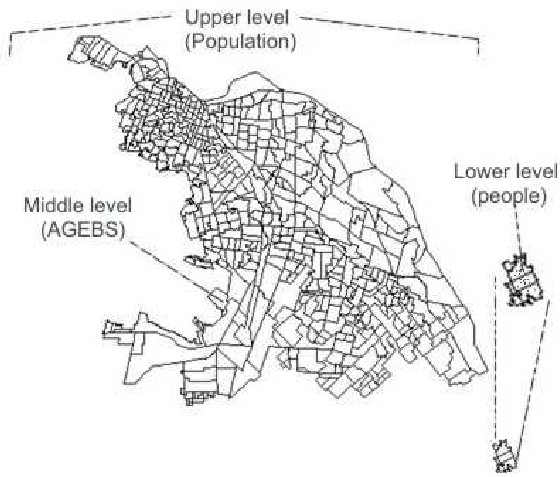

Fig. 3. Levels of agents represented on the social system.

level of agency. Originally, when it began to be measured, poverty was defined in a static and one-dimensional way, and was mostly studied in economic terms, only referring to what where incomes lower than was considered to be a minimum level acceptable for society [25]. It is for this reason that we consider necessary to propose a concept defined in terms that are dynamical, diffuse and multidimensional, as recent studies demonstrate that poverty is not only determined by income levels but also by the lack of certain non-monetary resources and opportunities for improvement, such as education and access to appropriate living conditions. It is through this light that we want to analyze poverty—as a multidimensional concept that cannot be reduced to its individual causes [25].

B. Case of study data sets:

In the particular case of the city of Juarez, the data set used came from the *Instituto Nacional de Estadística y Geografía* (INEGI), the Mexican governmental organization in charge of gathering data at a federal level including aspects that are geographical, socio-demographic and economical. The data set of the city of Juarez is divided into 549 areas, known as AGEBS. "The urban AGEB encompass a part or the totality of a community with a population of 2500 inhabitants or more… in sets that generally are distributed in 25 to 50 blocks."[26] For each AGEB we determine the degree of poverty taking into account 10 income and employment variables, 23 variables dealing with education and 15 variables related to the resources available in the household, such as a television, a telephone or a refrigerator, among other articles. The resulting matrix has a total information size of 48x549 variables.

The data sets for this case study were originally compiled in an information system that is intrinsically geographical. These systems helped in the generation, classification and formatting of the required data—a fact which facilitates the edition of the different thematic layers of information, in which one can quantify the spatial structure to visualize and interpret the areas and different spatial patterns in Juarez.

C. Case of study Neuro-Fuzzy Inference System:

Using the Neuro-Fuzzy system for the automatic generation of rules, this phase of the data extraction from the data may become complicated, as the process needs to appropriately establish the number of sufficient norms and variables that the study needs to take into account. Using this grouping algorithm, we obtain the appropriate rule-set assigned to each agent representing an AGEB or a inhabitant of it, the agent receives inputs from its geographical environment and in turn must choose an action in an autonomous and flexible fashion [7] [17] [27].

$$HP2 = [(P_1^{\alpha} + P_2^{\alpha} + P_3^{\alpha} + +P_4^{\alpha})/4]^{1/\alpha} \quad (1)$$

The fuzzy inference system consists of a set of rules to solve linguistic input variables. The inputs are converted through a fuzzy system that transforms a numerical value to a linguistic variable [28]. Thus, the outputs are converted now through a fuzzy system that transforms the linguistic value to a numeric value. Figure 1 shows outline poverty with a set of inputs. This

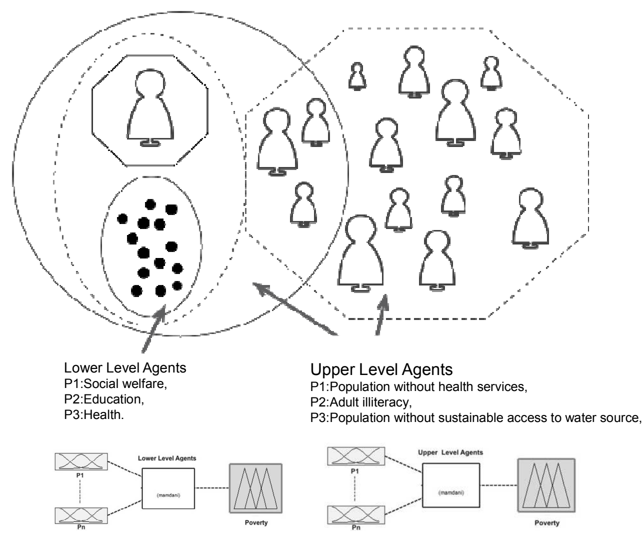

Fig. 4. Multiple levels of poverty identity.

is a set of rules, a set of inputs consisting of membership functions and a set of outputs also formed by a set of membership functions but at different levels.

It is possible to reference different aspects of reality within a general framework, taking into account that each level is potentially affected by a different set of laws. In terms of agents, the idea is that a group of interacting and distinct individuals (considered the lower-level of description) can create yet another level (an upper-level), in which the group itself can be considered an individual.

The purpose of this structure without central control is to garner agents that are created with the least amount of exogenous rules and to observe the behavior of the global system through the interactions of its existing interactions, such that the system, by itself, generates an intelligent behavior that is not necessarily planned in advance or defined within the agents themselves; in other words, creating a system with truly emergent behavior [29] [8].

D. Case of study distributed agents:

Distributed agents do not necessarily define agents in lower-levels of description, but rather consider all levels of agency that are interconnected in a type of organism that spreads throughout the system [30-31].

The realistic simulation of such a complex entity as a large city requires months of effort, particularly as it refers to the cost of gathering data, constructing, verifying and validating models, and designing experiments to interpret and evaluate the results. Simulation costs often run high, as they include the gathering of all kinds of qualitative as well as quantitative information [32]. Furthermore, the establishment and maintenance of the simulation's capacity normally involves expert personnel, software, hardware, training and other costs.

Since simulating each person under such circumstances is unattainable, as it is the case of modeling the sustainable development of a city like Juarez, the total population and all those relationships that accompany it, such as migration and birth-rates, must be analyzed with some sort of macro or "top-down" model. On the other hand, all low-level interactions at a micro level, such as partner selection or the decision to form a family with a given number of children, must be captured with a "bottom-up" model.

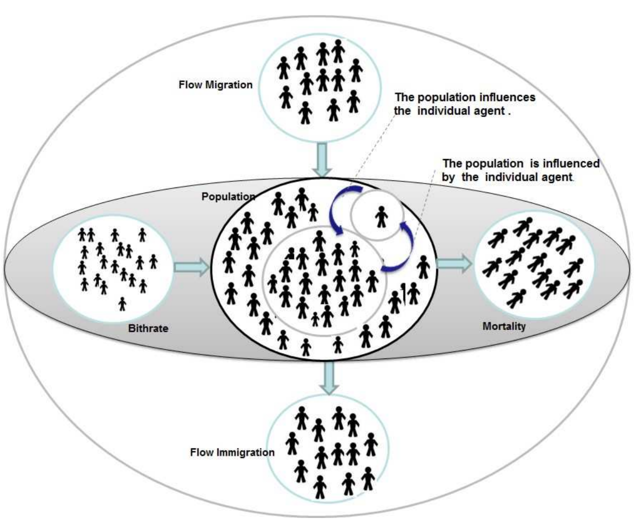

Fig. 5. Bottom-up model and top-down model at population.

To form the general structure of the simulation, we use dynamical systems to model the top-down aspect of the architecture. The dynamical system allows us to represent all aspects and relations of the structure of the sustainable system and its evolution in time. Also, the dynamical system allows for the creation of mathematical equations that describe the model at a macro-level, recreating stylized facts and the most important variables to be described. On the other side of the spectrum, at the micro level, a Distributed Agency methodology will allow us to represent contextualized agents, interacting with each other, their environment, and other levels of agency.

Referring to this case of study, we can subdivide the growth of a city as the sum of two main components: "Vegetative growth + migratory remnant". Both of these elements shall be studied making use of tools provided by the scientific discipline of demography, taking into account that city growth is fueled by economic development [33]. A large-scale model with minimal simplifications can be used to appropriately study the growth and optimal size of cities. As population grows, so does the scale of production, the labor market, research and development, as well as the efficiency of public services. The dark side of growth is that problems increase with it. These diseconomies of scale include unemployment, traffic jams, pollution, crime and other social disturbances; all of which represent negative externalities, or consumption which costs are not fully borne by the agent making the decision.

In studying urban growth, it is important to analyzing the process from its inception, without losing sight of important factors such as the advent of industrialization, the generation of employment opportunities, migratory flows, as well as the trends in housing prices and the corresponding demand for public services [34].

The process of development and growth of cities is accelerated by the advent of industrialization. This in turn is a process that generates employment and increases the demand for services, since the people employed in the factories will want to locate themselves close to the place of production. The people flocking towards the work magnet will demand living quarters, urban services, food, malls, drugstores, etc. Urban agglomerations thus prop up as a result of these human forces.

Aside from what is known as vegetative or natural growth, the phenomenon of urban growth is further fueled by migratory inflows. These migration rivers are composed of people that come from the rural areas into the city in search of better living conditions. Aside from rural to urban migration, immigrants will normally come from other areas or other countries that are relatively less developed [12].

E. Results of Case of study:

Considering the use of agent-based models, is the fact that they are very similar to artificial societies sharing the same techniques, their main differences focus on the simulation of systems, and design research programs [17]. Thus considering all the properties of the agents are suitable for the purpose of our research [35]. Each agent has an independent function depending on the rule that is assigned and the geographic environment where it is deciding the tasks dynamically, so there is no global control system.

The purpose is to provide agents with the least possible rules and observe the operation of the system by the interactions, the system itself generates intelligent behavior that was not necessarily planned or defined within the agents themselves. Achieving an emergent behavior

The rules obtained from the clustering algorithm can tell us which agents have more income, which are at a higher or lower educational level, and the resources available to each agent.

Agent-based technology has been considered appropriate for the social development of distributed systems [29]. Distribution agents are a promising strategy that can correct an undesirable centralized architecture [8]. Distributed Agents do not define independent agents, but sees the body that extends throughout the system. The idea behind the agency distributed modeling language stems from a worldview that is ubiquitous in the appearance, in which we find groups that are irreducible to their parts, and exist in different dimensions where different rules apply [6].

Fig. 6. Results of poverty in Juarez.

Therefore, the next step is for the agencies to try and solve problems distributed among a group of agents, finding the solution of the result of cooperative interaction among agents. Communication facilitates the processes of cooperation. The degree of cooperation between agents can range from complete cooperation to a hostile[7].

In the first case might be agents of a given area that share certain resources for the mutual good, in the second case it may occur that agents blocking the objectives of other due to fear of sharing resources and may have a lack of resources in their area. For cooperation and coordination mechanisms to succeed in a system of agents there must be an additional mechanism: negotiation, by which, members of a system can reach an agreement when each agent defends its own interests, leading to a situation that benefits all, taking into account the point of view of all.

VI. Conclusion

The development of a general methodology for the description and analysis of complex systems remains an open research task for computer scientists and all other scholars interested in the subject matter. Naturally, such a task will imply the use of different techniques and theories, given that the perspectives of each scientific discipline–and ultimately of each researcher–may vary greatly. This growing new paradigm will necessarily destroy the monopoly that current linear approaches have on many social sciences, since a reductionist approach is insufficient in the analysis of many complex phenomena.

The proposed distributed agency methodology is developed in a holistic manner, originally focusing on the description and interconnection of different levels of reality, whether these refer to either different dimensions or different time granularities. The applications of the approach are ultimately very general, but they are particularly useful for interdisciplinary analysis, where different disciplines overlap or interact in their description of natural or social phenomena. This general language links together the developments in computational science with those in the social sciences, as they pertain to the nascent paradigm of complexity.

We reviewed distinct techniques in the computational study, for develop a general methodology for complex social simulations, the methodology provided systematic guidance for developing complex models from start to finish.

The resulting methodology represents a powerful alternative for complementing, substituting or augmenting traditional approaches in the social sciences. The study of interdisciplinary connections, of consilience, and of modeling several levels of reality jointly remains an area of research with vast fields of unexplored territory. The growing disciplines of Computational Social Science and Social Simulation should be trail blazers in this effort.

Thus, it is possible to observe and analyze the interactions between the multiple levels amongst the different dimensions. To visualize all of this in a global or macro level, and at the same time to observe specific scenarios and the interpersonal relationships between agents, a multi-level complex system analysis is necessary.

Acknowledgment

We would like to thank the many people who made this research possible as we as the Mexican National Council for Science and Technology (Consejo Nacional de Ciencia y Tecnologıa, CONACYT) for the economic support granted for this research.

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