A DISTRIBUTED AGENCY METHODOLOGY APPLIED TO COMPLEX SOCIAL SYSTEMS
A Multi-Dimensional Approach

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Abstract: The methodology refers to the forms in which reality and knowledge can be studied; it does not question knowledge that has been accepted as true by the scientific community but instead concentrates on strategies to expand the knowledge. This work is motivated by need to establish a methodology for the study of complex social systems in situations where conventional analysis is insufficient in describing the intricacies of realistic social phenomena and social actors. The proposed general 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.

1 INTRODUCTION

The 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) (Gilbert, 2007). The modelling 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 ground breaking 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 available computational techniques in the context of DA to represent social and individual behaviour in a contextualized fashion, accommodating agents with limited rationality and complex interactions.

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 behavioural 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 systems are complex entities that represent a whole that cannot be understood by looking at its parts independently (Yolles, 2006). The proposed

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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.

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.

2 METHODOLOGY

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 behaviour and structure formation (Suarez, Rodríguez-Díaz et al., 2007), 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 (Márquez, Castañon-Puga et al., 2011). The methodology proposed consists of eight steps:

2.1 Determining the Levels of Agency and their Implicit Relationships

We analyse 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 (Heylighen, 2008). 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.

2.2 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 modelling process is to define data sets that match the desired architecture (Marquez, Castañon-Puga et al., 2010). 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.

2.3 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. We further propose using the Nelder-Mead (NM) search method, which is more efficient than other available methodologies such as Genetic Algorithms, as has been shown in multiple investigations (Rantala and Koivisto, 2002). The NM method is widely used, mostly because, in general, this optimization algorithm tends to produce more precise models with fewer rules (Stefanescu, 2007).

2.4 The Modelling Based on Distributed Agency

Modelling based on DA allows us to better understand the structures and relevant processes of social systems (Gilbert, 2007). MAS models and artificial societies are currently built on common themes, generally using techniques that stem from dynamical systems modelling, 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 (Drennan, 2005). The modelling process, the researcher must build a basic model of the system to be analysed, 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 behaviour of the agents that are influenced by the decision rules in a probabilistic fashion.

2.5 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 modelling social phenomena. It is capable of modelling complex systems which can independently provide instructions to thousands of interdependent agents operating in a holistic environment (Wilensky, 1999).

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 (Vidal, 2007). It is an appropriate platform for the modelling 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 behaviour of a multiplicity of individuals and the macro patterns of behaviour that emerge from the interactions of the individuals (Wilensky, 1999).

2.6 Validating the Model

Real-world simulations must include some form of validation (Drennan, 2005). 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.

2.7 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 analysed 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.

2.8 Analysing the Outputs

In this last stage, the results of the model are analysed, so that the researcher can understand the aspects of interest in the behaviour 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.

3 MODELING COMPLEX SYSTEMS IN THE COMPUTER

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 (Becker, Niehaves et al., 2005). 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 (Rossiter, Noble et al., 2010).

This growing field is intrinsically interdisciplinary, naturally linked to the sciences of complexity and to systems theory (Miler and Page 2007). 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 (Suarez, Rodríguez-Díaz et al., 2007). 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 (Halloy, 1999). 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 behaviour of the individual parts, whether these are simple components, autarkic agents or rational consumers (Mitchell and Newman, 2002; Ashby, 2004). One of the main challenges of our approach is to provide a methodology to analyze the many different levels associated within a social reality.

The proposition implies that the researcher observe behaviour, 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.

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.

4 OUR CASE STUDY: MODELING THE CITY OF TIJUANA

The principal 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 behaviour 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 Tijuana, Mexico, will be represented by the AGEBS that compose this city.

AGEBS is the terminology used to describe the different areas of the city that are in turn are composed of neighbourhoods.

In our study we use three levels of agency: the upper-level agent is represented by the whole city of Tijuana, 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 level of agency. Originally, when it began to be measured, poverty was defined in static and one-dimensional, 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 (Akindola, 2009). 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 analyse poverty—as a multidimensional concept that cannot be reduced to its individual causes (Akindola, 2009).

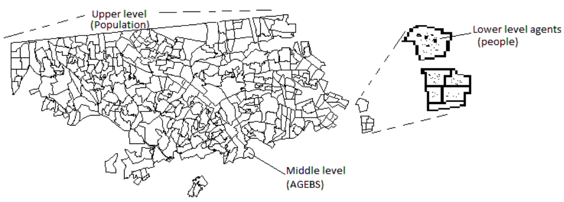

Figure 1: Levels of agents represented on the social system.

In the particular case of the city of Tijuana, 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 Tijuana is divided into 363 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.” (INEGI 2006) 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 48x363 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 Tijuana.

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 much choose an action in an autonomous and flexible fashion (Wooldridge and Jennings, 1995; Drennan, 2005; Gilbert, 2007). 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 behaviour of the global system through the interactions of its existing interactions, such that the system, by itself, generates an intelligent behaviour that is not necessarily planned in advance or defined within the agents themselves; in other words, creating a system with truly emergent behaviour (Botti and Julián, 2003; Russell and Norvig, 2004). 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 (Suarez, Rodríguez-Díaz et al., 2007; Suarez, Castañón-Puga et al., 2010).

5 CONCLUSIONS

The methodology we are proposing 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. 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 modelling 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. (Márquez, Castañon-Puga et al., 2011)

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