Middle Age Social Networks: A Dynamic Organizational Study

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Abstract. This article describes the main components of the multiagent model and the tool we are designing in order to analyze the structure and the dynamics of an historical social network from the Middle Age. This social network has been built through the discovery of many notarized documents and first studied according to a mathematical approach. Using a customizable multiagent system to simulate the network's evolution and Markov chain calculus to adjust behavioral parameters, we propose a method to assess behaviors' importance and effects on the global network's evolution. From a historical point of view, this multiagent model also aims at explaining this network's dynamics during some specific periods such as the Hundred Year's War where numerous notarized documents disappeared.

1 Introduction

This study began in 2004 and has been involving historians, mathematicians as well as computer scientists with the aim of reconstructing social networks in

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medieval peasant society and highlighting possible different structuring levels [8]. The study is based on exceptionally abundant notarized documents from the Middle Ages covering a small geographic region of southwestern France (more than 8000 contracts for most agricultural and marginally wills, marriage contracts or feudal homages). These documents were collected over three centuries (1250-1550) and archived for most of them in the departmental archives of the Lot. The working hypothesis is that this material allows highlighting relational phenomena between different social strata of rural society medieval peasants and lords, peasants and church, farmhouses and peasant farmers from the villages... or just neighbors. It thus allows the construction of a graph that describe the organization of the society with the simple idea where a node represents an individual named in some manuscript and where a link between two nodes means that two people are listed in the same transaction. This literature does not focus specifically on the ruling classes (clergy, nobility). The peasant world accounts for 90-95% of the population and has left very few writings. This makes difficult to penetrate the private sphere and to try to write a history of peasant societies of the Middle Ages. A database was created, containing 8725 individuals identified during 250 years and situated on parcels of land. The population base is estimated around 3000 people maximum (1330) and half at minimum (1420).

The particularity of this study is the existence of partial social network over a long period of time, but which is barely incomplete and uncertain. Our objectives are to study this network as well as its dynamics, by attempting to recreate its structure and properties through an agent-based simulation. To achieve this, we try to model the composition of the system and then to evaluate different possible local mechanisms to make the network evolve. This involves the study of dynamic organizations, which is a known subject within the multiagent domain [6].

A state of the art of the mathematical analysis of social networks is given after this introduction. We describe in the third section the theoretical choices we made about the problem modeling, and the resulting multiagent model. Then we describe in the fourth section the approach we took in our work over the historical problem and our further expectations. Finally, we conclude on the tool, the historical perspectives and the perspectives over our multiagent approach and model.

2 State of the Art in the Analysis of This Social Historical Network

A relational graph is built from the database in order to represent the peasant social network: each node of the graph corresponds to a peasant named in the transactions. Two nodes are linked together by an edge if they appear in a same contract (rule 1), or if they appear in two different contracts separated by less than 15 years and on which they are related to the same lord or to the same notary (rule 2). Because of this second rule, some main lords have been removed from the network to avoid the creation of large complete subgraphs that show the predominance of a lord in the area. Two separate studies were carried out and are still in progress: one on a small area of 25 km² (2462 nodes for the period 1240-1340) [2, 3, 4, 5, 9, 13] and the other on an expanded territory of 150 km² (3853 nodes for the same period) [10]. These studies are based on two parameters, the node degree (number of neighbors) and the betweenness (frequency of the shortest paths between any two nodes of the graph in which this node occurs), whose distributions are typical of small world networks. We observe that the resulting social network has a low global connectivity and a high local connectivity.

For the small area, we have shown the existence of a hierarchy in the organization of the network. This is measured by a scaling relation between the clustering coefficient and the close to the one that Barabasi proposed as an indication of a hierarchy [1]. Nodes of a *rich-club* (set of the highest degree nodes strongly interlinked) and small communities composed of highly interconnected nodes are linked by the way of high betweenness nodes (called *relay individuals*).

For the large area, we have removed all nodes whose degree was higher than the highest degree reached by a peasant and then we have constructed the graph following the rules 1 and 2. This global graph does not reveal a rich-club but it reveals a correlation between the peasant social network's structure and the geography of the area (studied in [11]).

Structural elements of the society can be observed from these first analyses, but several questions remain. The analysis has indeed been achieved by focusing on the links between individuals and we are just starting to explore other information stored in the database (acts type, relevant geographic areas...). One of the issues is the importance of the relationship that seems to exist between the structure of peasant social networks we have revealed and the geography. Moreover, in the studies we have made of these networks, we did not consider the time and have thus removed all dynamics that might help to explain their high structuring.

3 The Multiagent System Approach

On one hand, the information given by the database is local: each individual has characteristics, such as its profession and social status, and each transaction is linked to specific individuals: farmers, merchants, notaries and lords. On the other hand, the network properties provided by mathematical analysis are global properties: degrees, centrality, distributions, etc. Then, when studying the network dynamically, we have to make assumptions and choices over local properties and to observe and compare global properties. Through multiagent paradigm, we are able to elicit local parameters and to measure global effects on the structures of the system. We could use other methods such as cellular automata modeling, but the incompleteness of the considered data drives us toward a more flexible method than these. The method we consider for exploring and analyzing the real network is to recreate a similar virtual network based on customizable agents and to compare global structures and properties of this virtual network with the real historical network. We first specify a system in which parameters can be adjusted to match the real network. Its structure clearly results from an emergent process based on local rules belonging to individuals. Through guess and evaluation we can give to agents some rules that seem to fit individuals' normal behavior, then measure the properties of the resulting virtual network and compare them to the real network's properties. We then adjust local behavioral models to match the real network's properties through a simulation-adaptation cycle. Then, we might be able to analyze the resulting rules and make historical sense of them.

3.1 The Proposed Model

We describe the virtual system according to VOWELS dimensions [7]: agents (A), environment (E), interactions (I) and organization (O). We rapidly discuss the A E I and then focus on the O.

The real network evolves according to decisions made by individuals. Each individual interacts with other and these interactions are recorded as transactions (basic items of the database). Hence, in the virtual system, each agent (A) represents a unique individual. Because archives are not very precise in time, we can, without bias, propose a synchronous system. The time unit corresponds to one year in the real network, because it is the smaller significant time step in the database. If we consider that life expectancy was about 50 years, each individual could have a social life during 30 years, so each agent has a life time of 30 time units. The virtual environment (E) represents the set of the external forces influencing the population evolution, such as the external mortality factor, which is variable in time because of events such as wars or diseases. It also includes localization for each agent, based on three levels of information: parcels, place names and parishes. Information about each agent's localization can be incomplete or uncertain. During its life, each agent acts accordingly to its behavior specifications by interacting with others. Each interaction (I) between agents is a social interaction, such as a sale or an inheritance. Each interaction between agents symbolizes a transaction existing between individuals, as described in the historical database.

At an organizational level (O), we describe types of agents, relations between agents and organizational mechanisms. Firstly, agents are typed according to their static characteristics, such as their job and social condition. Secondly there is a relation between two agents if they know each other and are likely to formally interact (if they do so, they will then appear in the same transaction, which is materialized in the multiagent system as an interaction). Each relation is typed according to the kind of interaction it can involve in the database: sales, weddings, inheritances, etc. The mechanisms are the central point of the problem exploration. They describe how each agent makes its neighborhood evolve. For example, a farmer should learn to know every merchant that settle in the same village. In order to explore the network structure generation, we define generic mechanisms. Then we try to express how these mechanisms can alter the global network properties to verify if these mechanisms are correct or not, and how they have to be adjusted. In order to minimize the required number of simulations and to simplify the parameters' adjustment, we intend to specify the organizational mechanisms as Markov chains [12]. While this is a loss of information because it goes from exact mechanisms to probabilistic ones, it will allow us to seek indications about global properties by calculating steady state distributions of neighborhoods. These steady state distributions, although theoretical give information about the neighborhood composition, and, by a combination with the transition matrix of the chain, information about the neighborhood dynamics. All this information can be used to guess and try parameters adjustments before running the simulations.

3.2 The Objectives and Methods

The multiagent simulation has to answer to at least three main objectives:

- **Properties conservation:** On a global level, we observed that some global properties exist in the system, such as a *rich club* and *relay individuals* (see section 2). The question raised by the existence of such elements is if they are an intrinsic property of the network or if their existence is contingent. We try to determine if elementary behaviors of individuals are intrinsically the cause of such properties. We choose some individual behavior and make them vary (*e.g.* by changing their probability of occurrence) we can determine if a behavior (a mechanism in the multiagent system) is related to a property of the network.
- **Self-organization:** Another way to proceed is to create a blank system, where agents correspond to the individuals of a given date in the real system, but without any relation. We let the system evolve, given a specification of which social behaviors – organizational mechanisms, in terms of agents – to apply. We then compare the final state of the system to the real one at the chosen date.
- **Family exploration:** Another objective of the work is to better understand the families' evolution in terms of size, influence and situation, for instance. We propose to simulate behavior of families inside the system, given adequate individual behaviors. We measure their evolution given specific parameters, both internal – chosen jobs for the children, localization, etc. – and external – war, mortality, etc. By adjusting the parameters and mechanisms on well-known families by comparing their simulation to their real evolution, we can explore the evolution of families on which we lack information.

4 Conclusion and Perspectives

In order to analyze an historical social network, we have developed the first steps of a particular tool. This tool includes a generic multiagent system model, which has an organizational customizable part, as well as a way to experiment with this model. Markov calculus and simulation are combined to build a faster way to explore various reorganization rules and methods and to define the most appropriate – appropriateness being here the resemblance with the real historical network following given criteria and properties –. The tool is adequate to the application, because it can be used for computational prediction through multiagent systems. The approach follows an iterative method that includes prediction through Markovian model, optimization of the parameters and verification by simulation. This can be applied to different parts of the analysis: understanding the evolution of families through times, verifying the intrinsic nature of properties of the network and filling blanks in badly known periods such as the war.

As a first perspective, our goal is to use the tool to better understand the historical network, and to be able to find historical understanding of the network's evolution. We propose to define, compare and analyze the organizational mechanisms used in the system, and make sense from them. This may lead to the discovery of the impact of each mechanism on the network structure, and so to the understanding of important social relationships to the global historical network.

This tool is not only appropriate for analyzing this particular social network; it also defines a more general approach that could be applied to the analysis of any kind of incomplete social networks where nodes or links are missing. Through simulation and comparison, we propose to study the impact of various organizational and behavioral parameters on the global network configuration and properties. This will permit to study the network both statically and dynamically.

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