Mentat: A Data-Driven Agent-Based Simulation of Social Values Evolution

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Abstract. This work presents an agent based simulation model dealing with the evolution of social values in a 20 year period of the Spanish society, approaching it from Inglehart's theories on the subject. Surveys are taken as input to build the model by following a data-driven approach. This has been formalised in a methodology for introducing microsimulation techniques and importing data from several sources. It handles thousands of heterogeneous agents, which have a life cycle, reproduction patterns and complex social relationship dynamics. Its output is consistent with respect to the ideological, religious and demographic parameters observed in real world surveys. Moreover, several extension modules were designed: fuzzy logic for a smoother behaviour; natural language biographies generation; data mining for pattern finding. Thus, Mentat is proposed as a framework for exploring complexity at different levels in the social process.

Key words: agent-based model, data-driven modelling, demography, social values, multi-agent based social simulation

1 Introduction

Agent-based social simulation has proven to be a useful tool for the study of complex social phenomena, as it facilitates a bottom-up approach for the analysis of macro behaviour in societies of interacting entities [1]. This aggregate behaviour is called emergent, as the collective and even individual behaviours could not be predicted or expected from the initial settings of the simulation [2].

As this technology gets mature, new approaches are needed for bringing it closer to the real world, and therefore with an increased potential of being useful for social sciences researchers. With this purpose, an Agent-Based Model (ABM) was developed, aiming at analysing the evolution of social values in the postmodern Spanish society during 20 years. The particularity of this model, coined Mentat and based on the prototype of one of the authors [3], is that it tries to cope with several issues that are commonly neglected by a big part of the community of this field. In particular, most ABMs in literature tend to be overly simple, following the Keep It Simple, Stupid (KISS) principle. However, recently other works [4] claim for a substantial increase on the complexity of the models, taking real data more into consideration.

In this line, Mentat applies a data-driven approach that tries to draw a new methodology for injecting empirical data into Agent-Based Simulations. Specifically, Mentat has been intensively fed with surveys. Besides, several sociologists have been involved in the design of the system, strongly basing the modelling decisions in sociological literature, and even giving some empirically-based equations that support the demographic dynamics.

Mentat also handles complex friendship dynamics, which lead to the emerging of a robust social network. The links of this network evolve over time, both topologically (breaking and creating links) and in strength (strong and weak links can be identified). This process has been implemented with fuzzy logic techniques to obtain the smooth and continuous behaviour characteristic of typical friendship.

Another goal of this model is to provide ways to facilitate the analysis of different views of the system, with the ability to enable and disable different factors/aspects in the model, so that a social scientist can analyse either their impact in isolation or the mutual influence of some factors. Thus, a framework was used where it was possible to integrate, in a controlled way, several modules representing different social processes, and different artificial intelligence techniques, obtaining hybrid systems with richer outputs. Models of social processes are described along the paper, and the introduction of fuzzy logic is addressed in 4.2. Other AI techniques in Mentat fell out of the purpose of this paper. Nevertheless, section 7 goes through some of them: natural language processing for agent-biographies; data-mining for hidden pattern finding and validation; social network analysis for extracting and tracking structural variables.

The discussion of the sociological problem in section 2 provides more insight on the motivation for this work and the issues at stake. Section 3 presents several innovative methodological issues. The following two sections describe the micro and macro levels of Mentat. Section 6 discusses the output of the simulation, comparing it with the collected data. The paper finishes with some concluding remarks and future research lines that are being explored nowadays.

2 The Sociological Problem

Many sociological problems are difficult to be addressed properly with traditional analytical and statistical techniques, due to the diversity and great number of factors involved (e.g. evolution of culture), complicated dynamics (e.g. social networks), non-measurable social processes (e.g. psychological processes, world-size phenomena). Those problems are likely to be handled under the scope of complex systems theory. In this scope, agent-based systems have proved to be a proper framework to model and simulate these social processes [5].

To illustrate these issues with a specific example, this work has undertaken the analysis of the evolution of social values, together with other interrelated factors, in a specific space and time. In particular, we take an existing sociological research [6] on the Spanish society between the years 1980 and 2000. This Spanish period is interesting for social research, due to the big shift on moral values that the society underwent then. At the time of the re-instauration of democracy in 1975, the country was far from Europe in all the progress indicators, including the predominant social values and modernisation level. However, the observed trends of the social values evolution since then are analogous to those found in its EU partners [7]. Furthermore, the change in Spain has been developed with a special speed and intensity during the studied period. The problem faced is to study the shift in values and mentality of this society, in this period.

This issue has two main faces: the intra-generational changes (horizontal influence) and the inter-generational changes (demographic dynamics). R. Inglehart theories on modernisation [8] support that the change of values is driven mainly by inter-generational dynamics and the socialisation process (the assimilation of values in youth, mainly from the family). Thus, adult values would be stable over their course of life, with minor changes produced by intra-generational effects. According to this hypothesis, such elements should be enough to explain the magnitude of mentality change in modern Spain. Thus, this work attempts to model the shift of values taking into account just Inglehart's main factors: the demographic dynamics (i.e. the death of elders, carriers of the most traditional and conservative values, and the arrival of youngsters, bearers of emerging values) and a limited socialisation process (inheritance of values from the parents).

Thus, individuals social values remain constant, as they are not interfered by external influences. However, there are social dynamics (emerging and strengthening of friendships, couples), together with demographical changes (aging, deaths, reproduction). As a result, the values aggregation in the whole society evolved over time. This reflects the mentioned inter-generational changes, but not the intra-generational ones. However, this isolation is the only way to analyse and appreciate Inglehart's predictor effect of the demographic dynamics [9].

The source for modelling and initialization of agents attributes has been the European Values Survey (EVS). This is performed every ten years (1981, 1990, 1999) in all European countries [10], and thus provides a representative sample of the Spanish population. Moreover, as the EVS offers a wide source of quantitative information and periodical results (once every 10 years), it can be used for validation of the simulation model: initialising with EVS-1980, simulating 20 years, comparing with EVS-2000. Besides, for the design of the model and the selection of the relevant attributes, we have counted with the help of an expert in the field and several research studies [9].

The individual attributes that were taken into account have been selected according to their high influence in the subject. Thus, we considered: a general characterisation of the agents, like gender, age, education and economic level; social values-related attributes like ideology, religiosity, or tolerance to sensitive subjects like divorce, abortion or homosexuality; social relationships such as acquaintances, close friends, parents, spouse or children.

3 Methodological Stance: Deepening the Data-driven Approach

Along this research project, we had the opportunity of devoting some thought to how social simulation is conducted and how it should be conducted to enhance the confidence in the obtained results. The search through the space of possible designs of the agents involved in the simulations, as well as their organisation (society) and the experimental set up (the simulations themselves) must be conducted with some guiding principles in mind.

Our starting point was Gilbert's "logic of simulation" [5], in which a target phenomenon is modelled, and simulation data are validated against collected data. We have advocated that when data are available from the real phenomenon, there are more steps in the simulation process that can be informed by their judicious use. In particular, data should be used instead of idealised theoretical random distributions, in an effort to bring the model closer to the real phenomenon. Another use of data is to inform the design and calibration of the model (cf. [11]).

In the search for the appropriate modelling stance, namely in terms of abstraction level and accuracy to the target phenomenon, a common approach is to keep the models as simple as explanation purposes demand (the KISS [1] principle: *Keep it simple, Stupid!*). Another approach, KIDS [4] (*Keep it descriptive, stupid!*) argues that too much simplicity yields useless models, so models should be as close to the real target as possible, and then progressively remove things deemed not essential for the model. The move from KISS to KIDS can be based on more intensive use of data that helps remove the many arbitrary assumptions and abstract simplifications of KISS models.

However, both approaches seem quite unrealistic in terms of the purposes we envisage for social simulation: explanation of phenomena at both micro and macro levels to the point that they can be used for accurate prediction of real world phenomena, and finally used to prescribe policy measures to accomplish desired political outcomes. Starting from Gilbert's principles, Antunes and colleagues have proposed a methodology for multi-agent-based exploratory simulation that proposes series of models designed to progressively tackle different aspects of the phenomena to be studied [12]. This new approach coined 'Deepening KISS,' amounts to start from a KISS model, following Sloman's prescription of a 'broad but shallow' design [13]. Then, through the use of evidence and especially data, a collection of models can be developed and explored, allowing for the designer to follow the KIDS prescription without really aiming at more simplicity or abstraction. This exploration of the design space allows to pick the best features of each model in the collection to design a stronger model, and the process is iterated. Deepening KISS with intensive use of data can be placed middle way in terms of simplicity versus descriptiveness, whilst it acknowledges the role of the experimenter as guide the search for the adequate models to face the stakeholders purposes [11].

4 Zooming in: the Micro Level

4.1 Autonomous Individuals

As we mentioned above, the multi-agent system Mentat was developed using agents with a wide collection of attributes related to the society under study. Most of the attributes are loaded from the EVS (except for social relationships, which do not appear in the survey). But while some are used mainly to be controlled in the final aggregated output (in the form of graphics and statistics), others constitute the key to the micro-behaviour in the demographic dynamics: age, gender and their relationships (together with the position and the neighbourhood, but those are completely random). Friendship dynamics is fed with the aggregation of all the characteristics, as explained in the next section.

The population in the motionless agent society evolves demographically: individuals are subject to life cycle patterns. Thus, they are born inheriting the characteristics of their parents (including the social values following the mentioned socialisation process); they relate to other people that may become their close friends; they can find a couple, reproduce and die, going through several stages where they follow some intentional and behavioural patterns. Therefore, every agent can be child, adult or elder, and, for instance, a child cannot have a spouse, only adults can reproduce, and elder will die at some point.

4.2 Neighbourhood Interaction

Understading Friendship. The most fundamental part of the agents' micro-behaviour is the set of social processes they develop. Each agent can communicate with their extended Moore neighbourhood, and depending on their rate of one-to-one similarity, occasionally arrive to a friendship relationship. Reaching to a certain period of their lives, the agents can search for a couple among their friends, and if they succeed, they can have children. However, the friendship choice and evolution is a complex process (deeply explained in [14]).

Principles of meeting and 'mating' by which strangers are converted to acquaintances, acquaintances to friends, and possibly even into spouse, follow the same rules of the important homophily principle in social networks of [15]. Meeting depends on opportunities alone (that is, to be in the same place at the same time); instead, mating depends on both opportunities and attraction. How readily an acquaintance is converted to close friendship depends on how attractive two people find each other and how easily they can get together. This is well synthesised in the 'proximity principle,' which states that the more similar people are, the more likely they will meet and become friends [16].

Friendship Evolution. We should note that similarity, proximity or friendship are vague or blurry categories. For this reason, a formal model of friendship dyads was developed using the general framework presented above, but considering similarity and friendship as continuous variables. Besides, because friendship

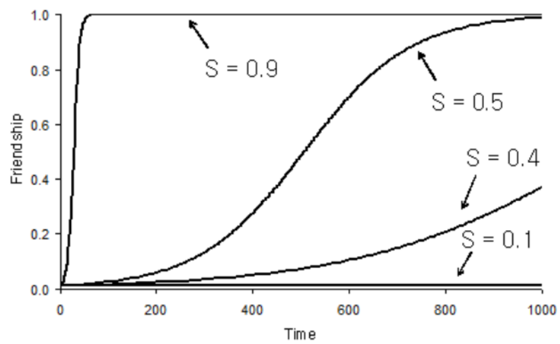

Fig. 1. The evolution of friendship function, for several one-to-one similarity values

occurs through time, we have considered our model in dynamical terms. In order to model formally the friendship evolution a specific logistic function [17] is used:

$$\frac{dF}{dt} = rF(t)\left(1 - \frac{F(t)}{K}\right) \tag{1}$$

At each point in time, *F(t)* defines the minimum degree of friendship that is given as an initial condition ($0 < F(t) < K$); K is the maximum degree of friendship that agents can reach (K can be understood as the level of 'close friends'), and finally r defines the growth rate of friendship. However, this equation does not include the 'proximity principle' described above. We can include this principle in equation 1 by modifying the growth rate r and stating it as follows: the more similar in social characteristics two individuals are, the higher the growth rate of their friendship is (we need to make r sensitive to the similarity value). Further equations of r and an analysis of the values in each formula can be found in [14].

Fuzzy logic in a fuzzy environment. In order to model the uncertainty of similarity and friendship more accurately, fuzzy logic has been used. Fuzzy logic is oriented at modelling the imprecise modes of reasoning in environment of uncertainty and vagueness, an usual feature in the social sciences realm [18].

Therefore, fuzzy sets over each agent attribute have been defined, as well as a fuzzy similarity operator that influences friendship emergence and partner choice. Such operator is defined as follows:

$$R_{similarity}(ind_A, ind_B) = OWA(\forall \mu_i \in ind, N(d(\mu_i(ind_A), \mu_i(ind_B))) \tag{2}$$

This function would express the similarity among two agents in contact, aggregating the similarity in each of their attributes through an Ordered Weighted Averaging (OWA) [19]. E.g. for the attribute Economy, a fuzzy set is defined in both agents, each one with different degrees of membership (let's say 0.8 and 0.1). The distance among them would be 0.7 (as it is defined as a difference), and the fuzzy strong negation of such distance, a 0.3 (1-d). Thus, those agents would be similar in a 0.3 concerning economic level.

The friendship relation is turned into a fuzzy relation, evolving through the logistic function (with K=1), and letting it influence the partner choice as much as the similarity rate (through another OWA). This fuzzification of the operators improves the proximity of results to the qualitative assessments of the theory, achieving a smooth global behaviour. For an insight of the process check [14].

5 Zooming out: the Macro Level

5.1 A Stable Environment: some Technical Details

Due to the relative simplicity of the agents, the system can manage thousands of them, reaching the necessary amount for observing an emergent behaviour that results from the interactions of individuals, leading to the appearance of social patterns than can be studied [1]. Thus, Mentat handles 3000 agents in a grid of 100×100 cells. Agents are spread randomly (uniform distribution) around the space. So, with a resulting density of one agent per 3.3 cells, and an extended Moore radius of 6, each agent can communicate with about 35 agents. This number is consistent with the research on the average personal network sizes (with strong and medium-strength ties) [20]. The time scale is *one year = 50 steps*, so the total simulation time is 1000 steps (20 years).

The model has several configurable parameters: length of warming-up, agent density, Moore radius, linkage probabilities (randomly and if-similar) and similarity threshold (different if fuzziness is enabled). Such parameters were fixed after performing a sensitivity analysis over a subset of the possible range of values, determined by a domain expert in accordance to social theory. The rest of the choices have been empirically grounded (such as the chances for a Spanish 42 years old woman to have children, or how many children she may have), using data from several institutional sources. In order to explore the model space and for testing purposes, it is possible to enable/disable multiple model stages (such as fuzzy friendship or empirical initialisation).

The model has been implemented using the Repast framework, importing the EVS spreadsheets and generating a collection of graphs (which reflect the evolution of the main attributes of the social system) and aggregated statistics. Note that as the system is non-deterministic, the graphical results have some variations at each execution: the outcome should not be taken as a static output. In every execution the trends were very similar, even though the exact data have some small comparison errors. That is, the system has structural similarity [5].

5.2 Demographic Dynamics

It must be pointed out that, as long as Mentat analyses the evolution of moral values and socio-cultural phenomena during a long period of time (20 years), it becomes a need to implement an analog demographic pattern of the Spanish one. These demographic dynamics are synthesised here, more and more deepened following the methodology explained in section 3, and carefully detailed in [9].

Mentat is initialised with the Spanish section of the EVS-1980. However, there is an structural problem: children do not make surveys, but the ABM needs 1980's initial children. Those children would grow in the simulation and maybe reproduce, and so altering the output. In 1980 there was 30% of children in the country, so 700 new agents have been introduced, together with the 2300 of the EVS, hence filling this important gap. Those agents were generated by a domain expert crossing data from the youngest individuals available in the EVS-1980, as it is expected the missing ones will be similar to them.

A second structural change has been carried out because of another EVS issue: the lack of information related to the links among people. A proper simulation of 1980's behaviour should consider that back then some people *were already linked*. A simulation that begins with isolated people that must find their 'first friends' makes no sense. Therefore, a new stage was introduced in the simulation: a warming-up stage, where the individuals have time to relate to each others, but the 'timer' does not count (there is no aging and current year is always 1980). When it is considered 'enough' (the stage length is a free parameter) the actual simulation begins, but with initial friendships and marriages.

A third important point in the demography is that Mentat was first tested with Normal distributions for the typical demographic decitions (life expectancy, birth rate, age for having first child...). However, it was improved replacing them with empirically based probability equations.

With these demographic dynamics, as time goes by, agents will die and be born. Even if there is no horizontal influence (intra-generational changes), the deaths of the elder ones and the new children of certain couples will reveal a change in the global aggregations of the main parameters in the model (inter-generational changes). This change will be further explained in section 6.

5.3 Social Networks: Family and Friendship

Typically, in MABS models, complex networks emerge from the micro agent rules. Mentat's case is not different, and a robust social network can be observed emerging from the micro-interactions of individuals. There are two types of links (visually coloured) and therefore two related dynamics: friendship and family.

Each agent continuously compares itself with its neighbours, by using the fuzzy similarity function. The more similar two individuals are, the bigger are the chances that they become 'friends', i.e. create a friendship binary link between them. However, the intensity of the link matters, and friendship will become stronger depending on two factors: again similarity among them and time that went by. The logistic function described in section 4.2 represents this evolution: as time goes by, the bigger the similarity/likeliness, the faster the growth on friendship intensity. Thus, some people will always be acquaintances, while others will quickly become very close friends.

On the other hand, each agent, in a certain period of their lives, can try to find a spouse. The list of 'candidates' consists of its adult single friends of the opposite sex. The more 'compatible' among them will be chosen, with compatibility defined as the aggregation of the friendship degree and the similarity value. When a spouse is finally found, there is a chance of having children. Those children will be born spatially close to their parents, and as the couple, children and brothers are all connected through family links, family nuclei are built all over. Big concentrations of families and the 'hubs' (agents with lots of friends) are deeply interrelated, as the more friends an agent has, the bigger the probability it will build a family. And the more families a sector has, the more populated it will become and more friends will its inhabitants have.

6 Results and Discussion

As further analysed in [9], the system's output can be compared with two validation points: the EVS of 1990 and 1999/2000, with respect to several indicators. The aggregated measures, such as ideology or religiosity, evolve over time due to the inter-generational demographic changes: i.e. the death of elders, carriers of the most traditional and conservative values, and the arrival of youngsters, bearers of emerging values. Besides, there are more births than deaths, so the population grows and the means and percentages change continuously.

The measures of Table 1 have been extracted from the three different EVS of the indicated years, together with the statistical calculations (over multiple executions) in Mentat for those years. All variables are calculated by considering only the individuals over 18 years, so that they can be directly compared with the EVS. For the sake of readability only a restricted collection of indicators (mostly means) are shown. Even so, the system calculates more than a hundred statistical measures. The high stability of Mentat has simplified the analysis, so it can be assessed that these values have a minimum error among executions.

The analysis of results can begin with simple parameters like the elderly percentage. It can be observed how the system follows a good projection till the 90's. However, as expected, it cannot predict that since 1990 Spain gradually received a young immigration that decreased the percentage of old people in the total population. Therefore, Mentat shows an approximation of the percentage that the Spanish society would have without that increase of immigration.

The percentage of single individuals is a factor related to the social network. A single individual a) does not have any single adult opposite-sex friend to have as a couple, or b) it does not want to have a couple (for example, because it is a child). In the beginning, the main cause of single agents is (a), but with time the network should grow in complexity and cohesion, so the predominant cause is (b). We can see that the singles amount should remain quite stable near 30%.

However, in the start-up Mentat shows N/A (or 100% of singles) because every agent is isolated before the warming-up. Obviously, the size of the warming-up is crucial: the more time they interact, the more couples will emerge. After that, the social network acquires consistence and approaches a lot the ideal value of 30%. It has been measured that the model reaches such ideal after 1500 steps. Taking into account that a year is 50 steps, with a warming-up of 500 steps the ideal is reached by the end of the simulation, but with a warming-up of 1000, it is reached in just 10 years. After the ideal is reached, the percentage remains stable: that is, the situation where the cause (b) is the widely dominant.

On the other hand, the warming period length has another logical effect: the more couples we have, the more children will be born. Anyway, as the most part of the young couples find always someone, it does not have a big influence in the population growth. As we can check in the end of the table, the side effect of the extra 1000 steps yields a bigger error here. It has to be mentioned that there are no other important side effects, so we have not shown the other variables with other sizes different than the usual one of 100 steps.

The political ideology follows a similar trend but with some more slope, in the means and in the different percentages. This is due to several facts. First, we have not modelled the intra-generational changes, so the agents main attributes remain static over time (and these variables are quite sensible to those influences). Second, the simulation is not able to display the slight move to the right that occurred in the Spanish society during the conservative governments (1996-2004). But that would be too much to ask from a simulation drawn from 1981 data, while Spain was still in the period of democratic transition.

One of the best indicators for the evolution of values that we have available here is the religious typology, strongly based on them. As we can see in Table 1, the values are predicted with a pretty good accuracy, especially concerning the different curves that each of the four types follow: rapid fall, hill, smooth rising and smooth growing, respectively. This is supporting Inglehart's hypothesis [8] that religious evolution is deeply related with inter-generational evolution, and not with the horizontal influence along life. Other values are more volatile than these ones: e.g. a 30 years old woman may increase her tolerance against homosexuals, but it is very difficult that she will stop believing (or begin to believe) in her religion.

7 Concluding Remarks

This paper has described an Agent-Based Simulation Model of the evolution of social values across 20 years in the postmodern Spanish society. We have explained the wide sociological underground on which it is based, and the data-driven methodological approach that it follows and encourages. This approach facilitates the construction of the model by using data from surveys (for the initial agent attributes) and equations from social theory (for the demographic dynamics), and it is deeply interrelated with several sociological theories.

Mentat is proposed as a modular framework where each stage can be enabled or disabled so it can be studied in isolation, *ceteris paribus*. Thus, the system can disable the empirical initialisation and test the output with random agent attributes [21]. Or enable/disable the fuzzy logic module to check the improvement in the compatibility of the couples [14]. Each improvement, each new stage, can be enabled/disabled and therefore compared with the other versions, exploring the model space [9].

Table 1. Comparison between the results of the Mentat agent-based model and the European Values Survey three waves: EVS-1980 was used for initialisation, while 1990 and 1999 are validation points.

	EVS waves			*Mentat ABM*		
	1981	**1990**	**1999**	**1981**	**1990**	**1999**
>65 years	16%	18%	21%	15%	19%	23%
Single agents*	28%	29%	29%	N/A	34%	30%
Single agents**	28%	29%	29%	N/A	29%	28%
Population Growth*			8%			8.6%
Population Growth**			8%			10%
Ideology						
Left	29%	33%	31%	29%	33%	36%
Centre	18%	19%	23%	18%	18%	17%
N/A	30%	25%	24%	30%	29%	27%
Right	22%	23%	21%	23%	22%	20%
Religious Typology						
Ecclesiastical	33%	25%	22%	33%	29%	25%
Low-Intensity	22%	26%	23%	22%	23%	22%
Alternatives	14%	17%	19%	14%	16%	16%
Non-religious	31%	32%	35%	31%	34%	37%

*,**: Warming-up of 500 or 1000 steps, respectively

A sociological analysis showed that Mentat highlights the importance of demography in the twist in social values that happened in the Spanish society, supporting Inglehar's theories [8]. The high correlation of the output with observable data may appear counter-intuitive, as it does not take into account the horizontal influence in values among people (intra-generational evolution).

As open issues for Mentat, we are considering technical extensions of the framework by integrating other Artificial Intelligence techniques, like ontologies, data-mining (DM), natural language processing (NLP), or complex social network analysis. On the other hand, it would be interesting to complement Mentat with another ABM simulating the same shift of values but from the intra-generational approach, using opinion dynamics applied to social values.

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