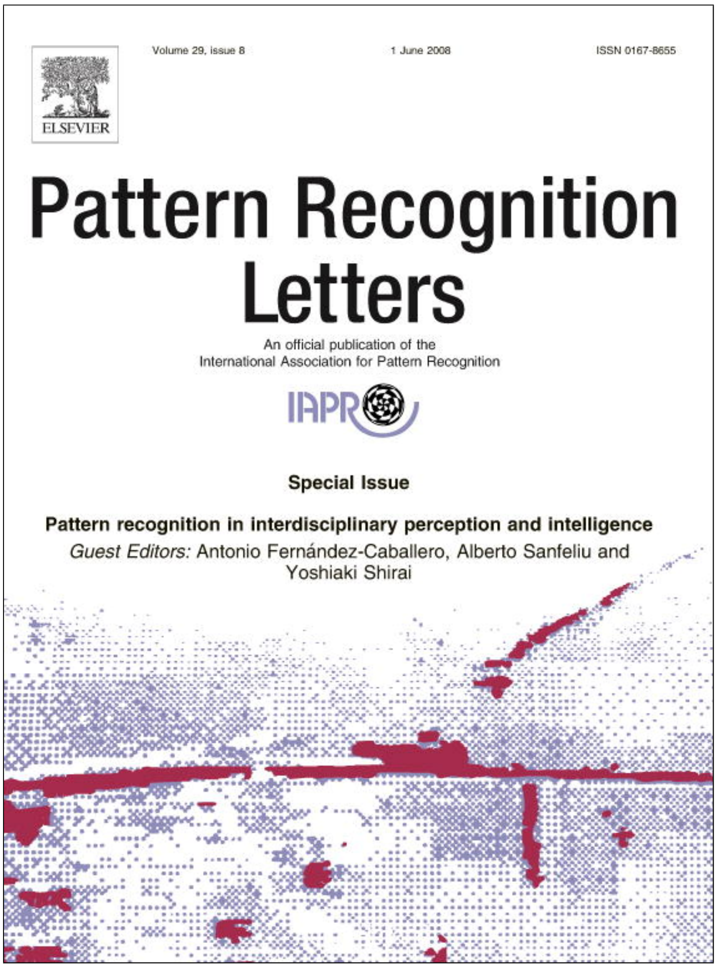
ELSEVIER
Volume 29, issue 8
1 June 2008
ISSN 0167-8655
Pattern Recognition Letters
An official publication of the
International Association for Pattern Recognition
IAPR
Special Issue
Pattern recognition in interdisciplinary perception and intelligence
Guest Editors: Antonio Fernández-Caballero, Alberto Sanfeliu and Yoshiaki Shirai

Available online at www.sciencedirect.com
ScienceDirect
Pattern Recognition Letters 29 (2008) 1039–1048
Pattern Recognition Letters
www.elsevier.com/locate/patrec

Agent-based modelling and simulation for the analysis of social patterns

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Available online 19 August 2007

Abstract

Agent-based modelling facilitates the implementation of tools for the analysis of social patterns. This comes from the fact that agent related concepts allow the representation of organizational and behavioural aspects of individuals in a society and their interactions. An agent can characterize an individual with capabilities to perceive and react to events in the environment, taking into account its mental state (beliefs, goals), and to interact with other agents in its social environment. There are already tools to perform agent-based social simulation but these are usually hard to use by social scientists, as they require a good expertise in computer programming. In order to cope with such difficulty, we propose the use of agent-based graphical modelling languages, which can help to specify social systems as multi-agent systems in a more convenient way. This is complemented with transformation tools to be able to analyse and derive emergent social behavioural patterns by using the capabilities of existing simulation platforms. In this way, this framework can facilitate the specification and analysis of complex behavioural patterns that may emerge in social systems.

Keywords: Agent-based modelling; Agent-based simulation; Social simulation; Behavioural patterns; Social patterns

1. Introduction

A social system consists of a collection of individuals that interact among them directly or through their social environment. These individuals evolve autonomously and are motivated by their own beliefs and personal goals, and the circumstances of their social environment. This environment also contributes to shape their beliefs (values and knowledge about the world), which can evolve in time. The population in a society also experiments demographic changes, which have impact at macro and micro levels. At micro level, individuals are subject to some life-cycle patterns: they match with others, reproduce and die, going through several stages where they follow some intentional and behavioural patterns. These demographic trends, at macro level, have implications on the social system (they have an influence on it and are influenced by it) and have dynamic interactions with other social processes. It has also to be taken into account that social phenomena are contingent, so they are unpredictable and changing. They are not subject to laws, but to trends, which can affect individuals in a probabilistic way. Indeterminism on social processes and systems is greater than in physical and biological systems. All these facts contribute to make social systems highly dynamic and complex. For this reason, abstracting them to mathematical models (by using, for instance, structural equation modelling, multivariate statistical analysis or statistical processing of temporal series) should be complemented by other techniques that consider how global behaviour can be derived from the real subjects' behaviours, which are fundamental in any social system. The dynamic effects of processes with high feedback are not well captured by statistical analysis techniques, although these kinds of processes are inherent to real social systems. In particular, we are interested on observing the emergent behaviour that results from the interactions of individuals

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doi:10.1016/j.patrec.2007.06.021

as a way to discover and analyse the construction and evolution of social patterns.

On the other hand, a multi-agent system (MAS) consists of a set of autonomous software entities (the agents) that interact among them and with their environment. Autonomy means that agents are active entities that can take their own decisions. This is not the same with objects, as they are predetermined to perform the operations that someone else requests them. An agent, however, will decide whether to perform or not a requested operation, taking into account its goals and priorities, as well as the context it knows. In this sense, the agent paradigm assimilates quite well the individual in a social system. In fact, there are numerous works in agent theory on organisational issues of MAS. Besides, theories from the field of Psychology have been incorporated to design agent behaviour, being the most extended the *Believes-Desires-Intentions* (BDI) model, on the work of Bratman (1987).

With this perspective, agent-based simulation tools have been developed in the last years to explore the complexity of social dynamics. An agent-based simulation executes several agents, which can be of different types, in an observable environment where agents' behaviour can be monitored. Observations on agents can assist in the analysis of the collective behaviour and trends of system evolution. This provides a platform for empirical studies of social systems. As simulation is performed in a controlled environment, on one or several processors, this kind of tools allows the implementation of experiments and studies that would not be feasible otherwise.

There are, however, some limitations when trying to simulate real social systems. The main issue is that the individual, with regard to a software agent, is by itself a complex system, whose behaviour is unpredictable and less determined than for an agent, whose behaviour and perception capabilities can be designed with relative simplicity. Moreover, it is not possible in practice to consider the simulation of countless nuances that can be found in a real social system with respect to agent interaction, characterization of the environment, etc. For this reason, it is impractical to intend the simulation of a social system in all dimensions. On the other hand, we should and can limit to simulate concrete social processes in a systemic and interactive context. Therefore, the simulation of social systems should be considered in terms of focus on a concrete process.

In spite of these limitations, the agent paradigm offers many advantages to express the nature and peculiarities of social phenomena, and to overcome limitations of statistical modelling. However, social scientists that want to use this new methodology must confront a difficulty of practical order that should not be minimized. The use of existing agent based simulation tools is not simple as models have to be specified as programs, usually with an object-oriented programming language. This makes the definition of models a complex task for sociologists, as they have not usually the skills for computer programming. With this purpose, some tools start to offer some graphical modelling capabilities. For instance, SeSam (www.simsesam.de) allows the graphical specification of state machines and provides a library of basic behaviours. In addition, Repast Py (repast.sourceforge.net/repastpy) facilitates the visual construction of simple simulations out of some component pieces, although at the end the user needs to write Python scripts. The problem with these solutions is that they already require some programming skills and the type of systems that can be modelled are quite simple (they are mainly rapid prototyping tools).

Agent-oriented software engineering, however, offers powerful modelling languages, at a more abstract level. Concepts in these languages are closer to those that a sociologist would use, and this makes them more appropriate to solve this usability issue. With this hypothesis, we build an agent-based modelling and simulation framework by extending a concrete agent-oriented methodology, INGENIAS (Pavón et al., 2005). This framework allows the specification of social systems with a graphical modelling language, the simulation of these systems by exploiting the capabilities of existing agent-based simulation tools, and the identification and analysis of social patterns in terms of the elements of the social system specification. The advantages go further than usability. As it has been discussed in Sansores and Pavón (2005) this solution facilitates the replication of an experiment on different simulation engines, in order to contrast results. The availability of a graphical view of the system facilitates its understanding too and improves the identification of patterns in the system.

There are two main reasons for the choice of INGENIAS in this work. First, its modelling language (Pavón et al., 2005) supports well the specification of organisation structure and dynamics, as well as agent intentional behaviour, characteristics that are present in social systems. This language is supported by the INGENIAS Development Kit (IDK) with a graphical editor, which can be extended to introduce new modelling concepts. Second, INGENIAS promotes a model-driven engineering approach (Pavón and Gómez-Sanz, 2006) that facilitates the independence of the modelling language with respect to the implementation platform. This is especially important here as we intend to abstract away programming details and concentrate on modelling and analysis of social patterns. With this purpose the IDK supports the definition of transformations between models and code for implementation platforms.

Using INGENIAS, the analysis of social patterns is performed as follows. The user will specify a social system model with the IDK editor. Then, in order to analyse social patterns of this system, an IDK analysis module can be invoked. This module takes care of transforming the model to code, that will be executed on a simulation toolkit. The results of this execution will then be presented as social patterns in terms of the elements of the social system model.

The next section presents the INGENIAS approach, its tools and the MAS modelling language, with focus on the concepts that facilitate the modelling of social systems. Some extensions have been necessary in order to model features of social systems that were not considered initially for MAS in INGENIAS, and this is discussed in Section 3. This considers some concepts that are useful to model social patterns, and corresponding literature is reviewed here. The application of this modelling language is illustrated in Section 4 with an example that has been developed with the collaboration of experts from the Faculty of Sociology in our University. In Section 5 we summarize the main contributions of this work and issues for improving this framework.

2. INGENIAS modelling language and tools

INGENIAS is a methodology for the development of multi-agent systems (MAS) with a strong concern on the relevance of support tools for all activities of the development life-cycle, from analysis to implementation. These tools, which are integrated in the INGENIAS Development Kit (IDK), rely on a MAS modelling language. This is specified with a meta-modelling language, MOF (Meta-Object Facility), a standard by OMG (Object Management Group, 2002). If changes are applied to the specification of the modelling language (i.e., to the meta-models), tools can be automatically re-generated. This facilitates the evolution of the methodology or its adaptation to concrete domains, as in this case for the analysis of social systems (we will see that new elements have to be considered in the meta-models for social pattern analysis). The IDK offers a graphical editor to work with MAS models. Once a model has been drawn by the user, IDK provides some modules (or plugins) that can perform analysis or transformations on the models. These are commonly used to automate code generation for concrete implementation platforms. Specific modules can also be provided for social pattern analysis. As explained in the previous section, these modules take care of transforming the model into executable code for a simulation engine, running the simulation, collecting data and interpreting it back in terms of model elements.

The INGENIAS modelling language is structured in five packages that represent the viewpoints from which a MAS can be regarded (see Fig. 1): Organization, Agent, Goals-Tasks, Interactions, and Environment.

The organization of a MAS establishes the framework where agents, resources, tasks and goals coexist. It defines structural relationships (groups, hierarchies), social norms (constraints and forms in the behaviour of agents and their interactions), and workflows (how agents collaborate when performing tasks in the organization).

Groups may contain agents, roles, resources or applications. There may be several ways to structure an organization. For instance, a MAS can be structured according to its functional needs, or, at the same time, agents can be grouped by a geographical distribution. An agent, therefore, can belong to several groups at the same time. Assignment of elements to a group obeys to some organizational purpose, i.e., because the grouping facilitates the definition of workflows or because its members have some common characteristics.

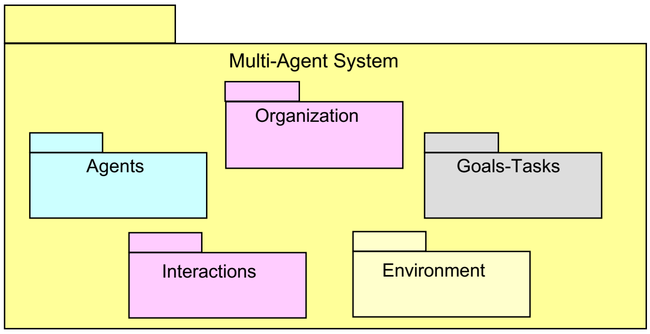


Fig. 1. MAS viewpoints in INGENIAS.

In general, the concept of role is used to provide more flexibility in the definition of organizations. A role represents functionality or services in an organization structure. Agents play roles in the organization. And several agents may play the same role, each one according to its abilities and strategies.

The functionality of the organization is defined by its purpose and tasks. An organization has one or more goals, and depends upon its agents to perform the necessary tasks to achieve them. How these tasks are related, and who is responsible of their execution, is defined in workflows. Workflows show the dynamics of the organization. They define associations among tasks and general information about their execution. For each task, a workflow defines which are its results, the agent or role responsible for its execution and which resources are required. This is useful to gain knowledge on the relationships between agents through tasks, and the assignment and availability of resources in an organization.

Both aspects, structural and dynamic, define the macro view of the MAS. This perspective facilitates the management of complex systems as it allows determining the context and norms for the behaviour of agents, similarly to what happens in human organizations.

Agent behaviour is described in the agent viewpoint. It is determined by the agent mental state, a set of goals and beliefs. Also, an agent has a mental state processor, which allows the agent to decide which task to perform, and a mental state manager to create, modify and delete mental state entities. INGENIAS does not state specifically how to define the mental state processor as it considers that there may be many ways to implement it. For instance, it could be a rule based engine, a case based reasoning system, or a neural network. It depends on the needs of the application or the mechanism that best fits according to the developer.

Agents are intentional entities; this means that they act as they pursue some goals. As they are also social entities, they collaborate to satisfy organizational goals. When designing a MAS, it is possible to start with the identification of organization (system) goals. These goals can be refined into simpler goals up to a level where it is possible to identify specific tasks to satisfy them. Another possibility is to identify individual goals for agents, which could be refined in a similar way. In both cases, there will be a relationship of goals and tasks, which is described in the goals-tasks viewpoint.

As social entities, agents interact. Their interactions can be produced in several ways, being the most common message passing, which is normally asynchronous, and shared spaces, where agents can act (produce modifications) and perceive (the modifications) as it is the case in shared tuple spaces. This is described in the interaction viewpoint. In INGENIAS, apart of indicating the types of messages and protocols in an interaction, what is important is to show the intentionality of the interaction: which goals are pursued by the parts in the interaction, and how this can contribute to their satisfaction.

Finally, the environment is where agents perceive and act. Depending on the application, perception and acting can have very different meanings. The environment consists of a set of resources, applications, and other agents. In many situations, the environment can be specified as a set of application programming interfaces, which would be the classes that wrap it to allow interaction with it.

These modelling capabilities are illustrated in the example in section 4.

3. Using INGENIAS for social systems modelling and simulation

The simulation of social phenomena implies the specification of computer programs that model the evolution of social processes. This involves modelling of the individuals and groups, and the processes of social interaction. In INGENIAS, individuals are modelled as agents, and groups and workflows in the organization viewpoint serve to model the structure and dynamics of the social system. Some characteristics of social phenomena, like emotions, social pressure, etc. are difficult to be approached and can be modelled only at some reasonable level of abstraction for specific purposes.

Currently, social patterns under consideration in our work refer to the evolution of human beliefs and individual decision making in society (see, for instance, the case study that is presented in Section 4 in this paper or a study about altruism in Sansores et al. (2006)). This requires the ability to represent social interactions that give rise to the emergence of sociality like cooperation, competitions, groups, organization, etc. Therefore, the level of abstraction of the language we will be using is the individual's social action and mind (Castelfranchi, 1998).

The language for modelling social systems can be defined on ontological concepts of the micro-sociology category of the sociological perspectives on Society. Under this perspective, a human being is capable of having conscious thought and self-awareness. Human action is not simply a reaction to external stimuli, but the result of the *meanings*, *theories*, *motives* and *interpretations* brought into a social situation by the individual. Accordingly to this, we need to conceptualize an *individual* with *mental states* and not just like a behavioural entity. We agree with Castelfranchi when he states that an individual should be modelled like a goal-oriented agent whose actions are internally regulated by goals and whose goals, decisions, and plans are based on beliefs. Both goals and beliefs are cognitive representations that can be internally generated, manipulated, and subject to inferences and reasoning. This is basically the approach that the INGENIAS agent viewpoint supports.

The individual attributes may include emotional or character attributes. For example, a numeric stress level variable that determines the agent's behaviour at a given time. There are many possibilities of attributes to define an individual, and depending of their values the individual could perform a variety of predefined actions associated to these values.

The social environment includes the resources that the individual may count on. In INGENIAS, resources are described in the environment viewpoint by the set of actions that agents can perform on them, and in the organization viewpoint for their property and sharing.

Two aspects have required a refinement and extension of the environment viewpoint in INGENIAS. These are related to the simulation, where agents usually require considering their location in the environment and the evolution of time. The temporal perspective deals with the progress of time in the model when executing the simulation. In this case we are assuming that simulations are time driven rather than event driven as most agent based simulation toolkits work with this schema (a reason for this is that an event driven schema would require a central coordinator for events or a complex synchronization among agents). This means that there is a need to model constant time steps to simulate the cycle perception-reaction of agents along the time. The spatial perspective describes how agents are situated in the environment. In general, simulation toolkits provide two and three dimensional spaces with diverse configurations. These extensions have required modifications in the original INGENIAS MAS meta-model and re-generation of the IDK tools. In this way, it has been possible to get a new personalized IDK for agent based simulation.

Fig. 2 shows how the user, an expert in a social domain, edits and defines some model of a social system with IDK editor. From this editor it is possible to invoke several types of modules to work with the model. Normally, before running a simulation of the model, the user should verify that the model satisfies certain properties. For instance, that all the elements that are required for the simulation have been defined, or that there are no isolated agents in the system. Other types of properties that can be consid-

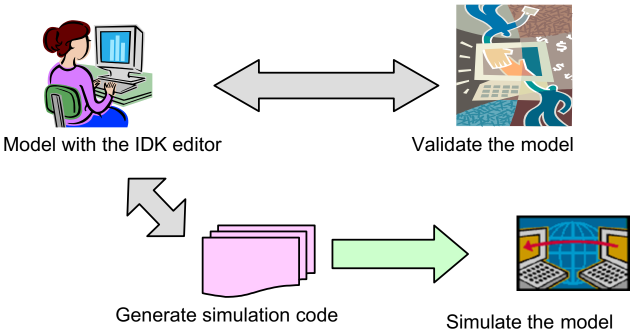


Fig. 2. Modelling and simulation of social systems with IDK.

ered as useful can be verified by creating the appropriate IDK plugin.

Once all models satisfy the required properties, the user can invoke the code generator module for running a simulation under a particular toolkit. Sometimes it can be useful to run the same experiment on different platforms, to get more confidence on results. This has been done with RePast and Mason toolkits as reported in Sansores and Pavón (2005). From this moment, the simulation toolkit can be used to obtain results. These have to be interpreted in terms of the model. This interpretation could be done directly by the user or, better, supported by the IDK module in order to be presented directly in terms of the model entities.

4. Example of social patterns analysis: A study of the religious change in Spanish society

With the purpose of validating the INGENIAS modelling language and its ability to discover and analyse social patterns, we have chosen a real and challenging case from Social Sciences. This is the study of the evolution of religious attitudes in a concrete European society, as it is the case of Spanish society. There are several reasons to consider this example. One is to be able to check the usability of the agent-based modelling language to cope with a sociological discourse, and with this purpose we have started from an existing sociological study (in concrete, Arroyo Menéndez, 2004). Moreover, this case study shows a complex social process, where multiple factors are so much intertwined that it is not possible to explain religious change in terms of a causality relationships network. Religious differences among individuals and their evolution have to do with values, political ideology, or gender differences, among others. These phenomena are mutually intertwined in processes where it is difficult or impossible to establish the cause and the effect. It is more appropriate to reason in terms of feedback and interdependence. At the same time, some of these phenomena may be related to other ones, such as individual socio-economic situation, the degree of development and welfare state of the country, the demographic evolution, etc. These phenomena are also extremely complex when looking for an explanation on them (they are multi-factorial and many-sided, as far as historically contingent) and in their configuration may have themselves been influenced (partially) by some aspects related to values and religiosity itself.

To illustrate how to deal in INGENIAS with this complexity and understand the potential of a bottom-up approach, from modelling individuals to analyse emergent social patterns, we have to state precisely the object under study: it is not possible to simulate everything, but the most relevant in the social process under study and the structure of human interactions of individuals involved in such process. We have proceeded by first discussing existing survey data, from which some categorization of religious patterns have been defined by sociologists. Then these patterns are specified in terms of agent mental state patterns, as well as interactions, behaviours, the environment and the organization, by using INGENIAS modelling language. The resulting model is translated to code for the simulation engine, whose execution shows how characteristics of the behaviour of individuals and the environment affect the evolution of social patterns. This is explained in the following paragraphs by using the sociologist discourse and how this is represented in terms of INGENIAS modelling concepts.

In Spain, as in the other countries of West Europe, significant transformations in the religious field occur. Several surveys show that during the last thirty years the religion, mostly catholic, is losing the influence it had in the recent past both in society and individuals. Religious practice (and more specially, attendance to the mass) and the confidence on ecclesiastical institutions are diminishing. However, other dimensions on religiosity have decreased in a lower degree, as it is the case on beliefs, feeling a believer or religious person, giving importance to God in life, or looking for more spirituality. Most significantly, population is moving further away the Church as an institution and its influence on life, moral principles or the way to perceive the world. But non-religious identity is spreading only moderately, without becoming the major trend.

By considering the results of the European Value Survey (EVS), four main religious patterns can be stated, and there is a confirmation of a migration of the population from some patterns to others (Arroyo Menéndez, 2004). The four patterns are:

1. A *strong* religiosity, close to the ecclesiastical institutions (diminishing). Individuals tend to practice regularly, to believe most of Church precepts, and have confidence on ecclesiastical authorities (priests, the Pope, bishops, etc.) Individuals consider that religion is a central part of their lives, and religion tends to influence and determine other aspects of their lives.
2. A *low-intensity* religiosity (it has been increasing until recently, but now has ceased to increase). Individuals practice occasionally, without regularity. Usually, only in special occasions, in celebrations (such as baptisms, communions, festivities) or to find strength in religion

to face difficulties in life. Religion is not a central part of their lives. It is something else, with some importance, but the individual has other centers of interest in the life as much important as religion or even more important than it.

3. An *alternative* religiosity (increasing). More and more Spanish people turns back on the Catholic Church and give up listening and believing their authorities, although they do not cease of being religious or do not loose their religious intensity. Usually, they do not loose their identity as Christian or Catholic, continue to pray, but they have stopped to attend mass regularly. Their religiosity is no more inspired in Church, but they have other sources of inspiration and their mentality is closer to that of non-religious individuals.
4. *Non-religious* pattern (increasing). This is characterized by individuals that do not practice religion and have given up the Church. They can be atheists, agnostics, or indifferent (some of them may manifest some religious beliefs or identify themselves as believers). They have in common that they do not give relevance to religion in their lives and are not identified with Church.

These religious patterns can be described with INGENIAS as agent models. Fig. 3 shows an agent diagram for the *Strong religious* pattern and Fig. 4 shows an agent diagram for the *low-intensity religious* pattern. In each agent diagram, a pattern is characterized by a *concrete agent* with a *mental state* (*Strong Rel MS pattern* and *Low-Intensity Rel pattern*, respectively) and *roles* (*Practicing* and *Exceptional practicing* in these examples). The mental state in INGENIAS is defined as a set of mental entities, such as facts (information that expresses past experiences of the agent) and beliefs (asserts that are not certainties, just expectations). In the case of a pattern of values, this is better formulated with the concept of belief in INGENIAS. Mental state patterns represented in the diagrams are defined as a combination of answers to concrete questions of the European Value Survey. Each question can reflect some beliefs of the pattern. For instance, the question "how much confidence you have in Church", with possible answers "a great deal", "quite a lot", "not very much" and "not at all", can be used to characterise a belief of the *Strong Rel MS pattern* by qualification of belief *Confidence in Church* as *great deal* or *quite a lot*. Similarly, other beliefs are modelled according to the available answers in the questionnaire. The categorization of these patterns, and the elements that characterise each one are established by the sociologist (and it is not in the scope of this paper to argue about whether the ones presented here are appropriate or not). The behaviour associated to each pattern can be also modelled, by using roles. Each role has associated one or more tasks which are performed with some frequency. In the example of *Strong religious pattern*, the role *Practicing* is defined as performing the task *Attend mass* at least once per week.

Each pattern marks differences in beliefs, attitudes, values and behaviours, which are coherent among them.

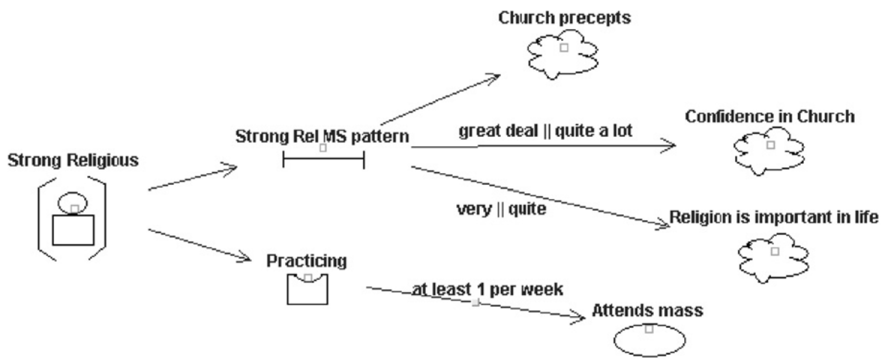


Fig. 3. Modelling of the *strong religious* pattern.

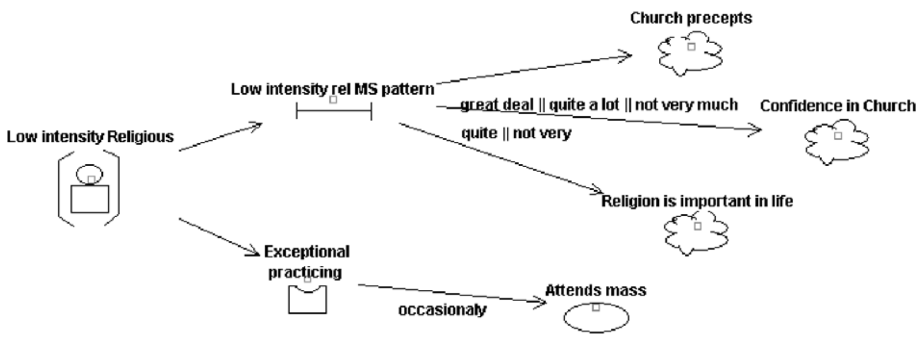


Fig. 4. Modelling of the *low-intensity religious* pattern.

This means that each pattern represents a stable structure, complex and identifiable, of cognitive, normative and behavioural aspects. However, there is a migration of the population from some patterns to others. This migration may happen during the life of individuals, who may move from one pattern to other, as well as a generational change (young people is moving further away from Church). The purpose of the social simulation is to understand better how and why these changes from one pattern to other occur, as a way to know the evolution of religiosity in Spanish society.

A quantitative approach to this evolution, taking into account available data, can be appreciated in Table 1. Data to build this table have been obtained from the three applications of the European Value Survey.

Distancing from Church is related to some social processes and facts. It is mainly linked to a change in values. The dynamics of cultural modernization are determining that people tend to be less religious, especially one of the dimensions of cultural modernization called *social individualization*. Some empirical studies show that as far as cultural modernization advances, religiosity diminishes (Halman et al., 1994; Inglehart and Norris, 2004; Arroyo Menéndez, 2004).

There are other accompanying factors to the level of religiosity, such as political ideology (usually, the more left-wing views, the less religiosity, and vice versa) and gender differences (women are usually more religious than men). On the other side, there is another important relationship between cultural modernization and political ideology (there is a tendency to modernization or individuality in left than right wing views), cultural modernization and gender (in Spain women are more traditional than men) and gender and political ideology (in Spain women are more conservative politically than men).

It must not be considered that religiosity is just a function of cultural modernization, political and gender levels (as well as other factors) although they are useful to predict the degree of religiosity. Sometimes the degree of religiosity will provide an explanation for non religious values (such as low cultural modernization, for instance) and others will result in the level an individual has internalized certain non religious values, and this internalization will determine a change in the religious pattern of the individual.

By analysing surveys on the population, each of the four religious patterns has relationship with factors mentioned here, especially with those of cultural modernization: ecclesiastical are clearly the most conservative, followed by low-intensity. Then, alternatives have a more modernized mentality, while the most modern are those non-religious.

Data gathered in the three applications of the European Value Survey serve to determine the evolution of changes, although with some limitations, concerning the understanding of why and how they are occurring. They have been used to apply multivariate statistical analysis that provide some information on the prediction capacity of the above mentioned factors to explain religiosity levels, as it has been followed by the teams of the European Value Survey and of the World Value Survey (Inglehart and Norris, 2004) when trying to relate the evolution of religiosity with the evolution of values. But survey data do not suffice to explain how and why changes in religiosity happen, given the interdependent nature of the relationships in the social processes. Survey data are not able to explain, for instance, how an individual moves from a strong religiosity pattern to a low-intensive or alternative pattern, or from any of these to a non-religious situation. They do not explain which socialization mechanisms contribute to this movement away from religiosity, or in the most important changes between generations. Explanations about this issue hardly refer to the theory of Inglehart, who states that in periods of early socialization (around adolescence) is when an individual configures her/his patterns of values, and they will tend to remain relatively stable, without expecting sudden changes. But there is not more knowledge about this. These issues have not been well explored empirically yet, and scarce qualitative research (by means of open interviews and group sessions), at least in Spain, only allow to sketch some hypothesis, which have to be confirmed.

Trying to understand this complex system, the sociologist will make some assumptions and consider the influence of different factors. These assumptions can be analysed by defining a model of these interrelationships. Using INGENIAS, this can be expressed as a task diagram, as in Fig. 5. This diagram shows a central task, *Church confidence change*. This task affects one of the beliefs, *Confidence in Church*, which is a component of the religious pattern. The diagram shows also which elements may take part to change the qualification of the belief. There are

Table 1
Evolution of religiosity patterns in Spanish society

	1980	1990	1999
Ecclesiastical	33	25	22
Low-intensity	22	26	23
Alternatives	14	17	19
Non-religious	31	32	35

Data elaborated from European Value Survey.

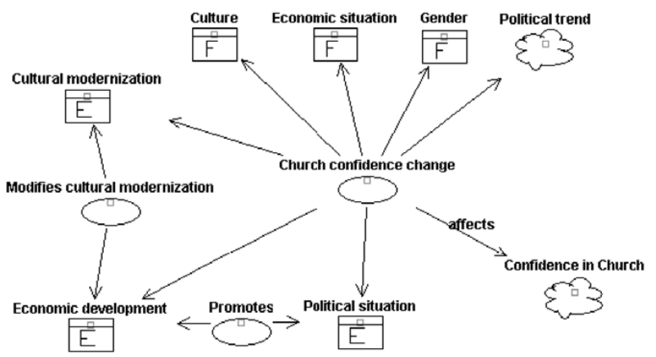


Fig. 5. Tasks diagram representing factors that affect the change in belief *Confidence in Church*.

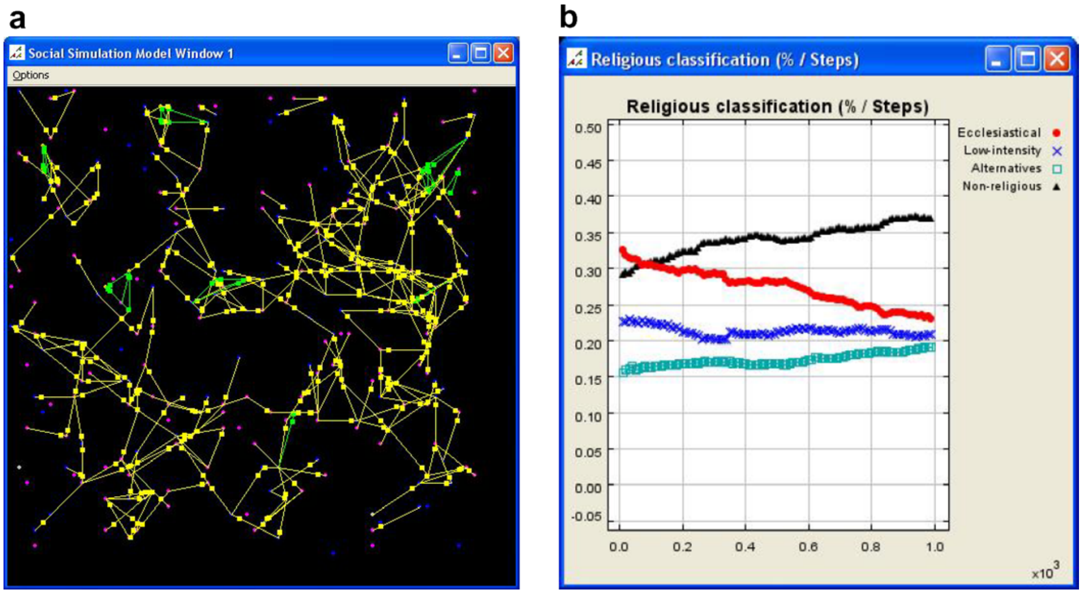


Fig. 6. Results of running the simulation with 500 agents in a environment of 60×60.

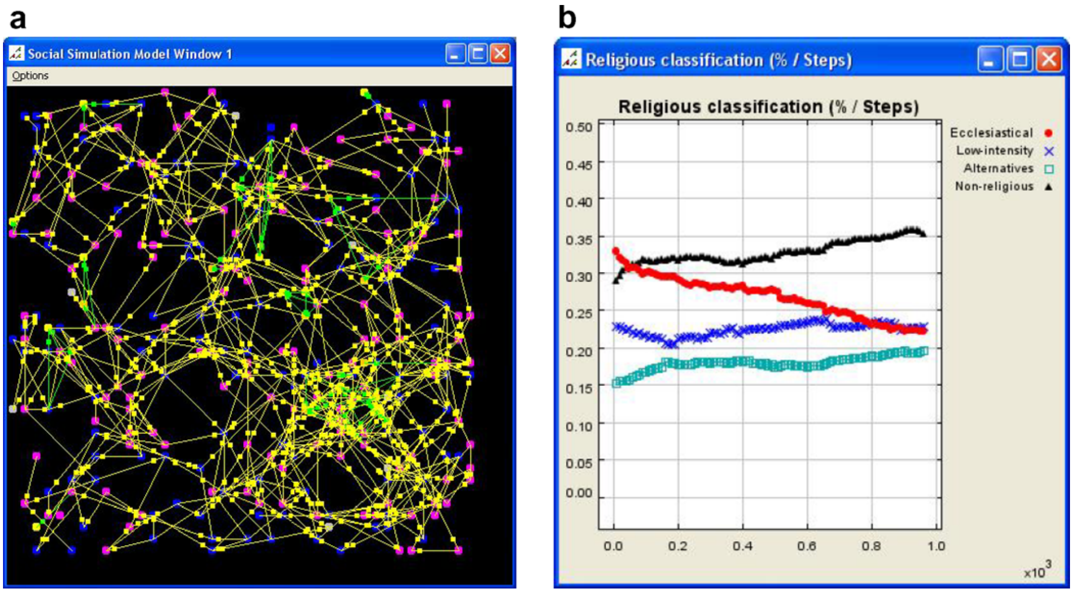
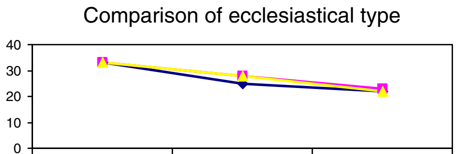


Fig. 7. Results of running the simulation with 500 agents in a environment of 40×40.

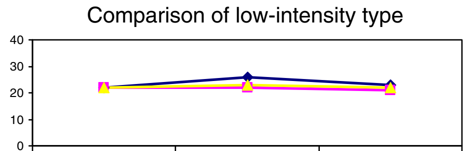
environmental factors, such as *Cultural modernization*, *Economic development* and *Political situation*. Note that some tasks imply that there is some interdependence between these environmental factors. Besides, some facts about the individual influence the possible change, such as *Culture*, *Economic situation*, and *Gender*. And other beliefs can contribute also, such as the *Political trend*. With all these factors, the task has to be configured in order to determine how the change in values and beliefs may occur. This configuration can be simulated in order to contrast with empirical data, so it can be validated and tuned.

For the simulation, the characteristics of the initial population take as a reference several values and religiosity indicators from the European Value Surveys for the year 1980, as well as some socio-demographic variables. With this, it is possible to define the initial distribution (specified as a deployment diagram in INGENIAS, not shown here). This information, together with the other diagrams, serves as input to the code generation plugin for RePast in the IDK, and several classes are obtained, which can be run on the simulation kit. The code generation is explained in Sansores and Pavón (2005).

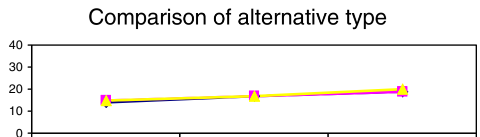
More diagrams participate in the specification of the system, but are not shown here for space limitations, among others: organization diagrams to show different groupings such as family units and friendship social



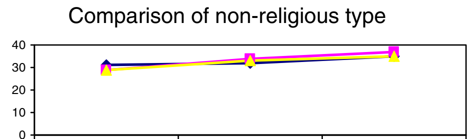
	1980	1990	1999
ESV-Ecc	33	25	22
SS6-Ecc	33	28	23
SS7-Ecc	33	28	22



	1980	1990	1999
ESV-Low	22	26	23
SS6-Low	22	22	21
SS7-Low	22	23	22



	1980	1990	1999
ESV-Alt	14	17	19
SS6-Alt	15	17	19
SS7-Alt	15	17	20



	1980	1990	1999
ESV-Non	31	32	35
SS6-Non	29	34	37
SS7-Non	29	33	35

Fig. 8. Data from European Value Survey (EVS) and results from simulations (SS6 and SS7).

networks, task diagram to model generation of new individuals from pairs in the society (mostly in the context of family units), interaction diagrams to model establishment of family units and of friendship relationships, and interaction diagrams for exchange of mental state entities between individuals in a friendship group.

The simulation of a configuration with 500 agents is shown in Fig. 6. The graphs, generated by RePast, show (a) social networks of agents, i.e., relationships among agents (yellow[1] for friendship and green for family) and (b) in x-axis the number of steps when running the program (1000 steps correspond to the period 1980–2000) and in y-axis the percentage of each religious pattern. It can be seen here that non religious beliefs are growing smoothly, something more (two points) than in reality. Alternatives experiment a light increase in both cases. Low-intensity religious get similar results at the beginning and end, but there is some increase in the'90 that the simulation does not follow. With respect to strong (ecclesiastical), although limit values are similar, it does not follow the same slope.

By increasing the density of the population of agents, there will be more interactions among them. This is shown in Fig. 6a, which uses a 60×60 space for 500 agents, while Fig. 7a considers a 40×40 space. More interaction contributes to establish more friendship relationships, and therefore, agents can better find their match to form families, which contributes to more homogeneous families. In this case, results in Fig. 7b are closer to real data than those of Fig. 6b. We can compare these two simulations (SS7 from Fig. 7, SS6 from Fig. 6) with EVS data in Fig. 8, in a division by year and religiosity type.

[1] For interpretation of color in Figs. 1, 2, 6–8 the reader is referred to the web version of this article.

A point that has to be mentioned is that the system is non-deterministic. Therefore, the graphical results will vary in each execution: the trends will always be similar, even though the exact results will have some minor deviations. In this sense, we can consider that the simulation model satisfies structural similarity (Gilbert and Troitzsch, 1999).

5. Conclusions

This kind of tool for sociologists complements certain limitations of survey techniques in particular and empirical research in general. More specifically, the simulation facilitates testing theories and hypothesis under circumstances for which there are not enough empirical data, and the analysis of assumptions that sociologists may consider to explain the evolution of certain social patterns.

The process and tools here described facilitate the specification of social patterns and the relationships of social elements with a graphical language instead of a programming language, as it is the case of existing agent based simulation toolkits. In this way, the sociologist can work at a greater level of abstraction, which is closer to the problem domain. This is illustrated with a real example in Section 4 where the sociologist discourse is modelled with INGENIAS diagrams. Besides, the modular architecture of IDK tools facilitates the provision of new modules to check for new social patterns. Although building such modules requires the participation of a software engineer, who should be experienced in INGENIAS meta-models and Java programming, the final user only needs to know how to use the graphical editor and the way to interpret results from simulation, which could be more or less guided by IDK modules.

Another advantage of this approach is that it allows replication of simulations on different platforms. As modelling is performed with a graphical language, then transformed to code, by doing the transformation on different simulation platforms, it is possible to compare results. In this sense, we have experimented with RePast and Mason (Sansores and Pavón, 2005), where we have studied the effects that different scheduling strategies have on simulation results. Note that once code generation modules have been developed, simulation of an abstract model on any of them is a trivial task.

Currently, the IDK does not provide modules to interpret results from simulation. We have seen that presentation of results using directly the facilities of the simulation environment is enough. This comes from the fact that entities in the simulation code are named similarly to corresponding entities in the model. In this way, diagrams generated by the simulation environment are easy to understand by the final user.

It is also possible to make a direct simulation of the models with IDK, by using the module for code generation on the JADE agent platform, but in this case execution is driven, step by step, by the user. This can be a tedious work but it is useful to debug and validate the model (to check that it does what it is intended to do). We have not considered making a more powerful simulation engine for IDK as we consider more interesting to reuse those existing, which are much more advanced.

Acknowledgements

This work has been developed with support of Dirección General de Universidades e Investigación de la Consejería de Educación de la Comunidad de Madrid (Spain) and Universidad Complutense de Madrid (Grupo de investigación consolidado 910494) and the project TIN2005-08501-C03-01, funded by the Spanish Council for Science and Technology.

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