Simulation and NorMAS

Tina Balke[1], Stephen Cranefield[2], Gennaro Di Tosto[3], Samhar Mahmoud[4], Mario Paolucci[5], Bastin Tony Roy Savarimuthu[2], and Harko Verhagen[6]

1 University of Surrey, UK
2 University of Otago, New Zealand
3 Utrecht University, The Netherlands
4 Kings College – London, UK
5 LABSS, ISTC-CNR Rome, Italy
6 Stockholm University, Sweden

Abstract

In this chapter, we discuss state of the art and future perspective of the study of norms with simulative methodologies, in particular employing agent-based simulation. After presenting the state of the art and framing the simulative research on norms in a norm life-cycle schema, we list those research challenges that we feel more apt to be tackled by the simulative approach. We conclude the chapter with the indications for the realization of a NorMAS simulation platform, illustrated by selected scenarios.

1998 ACM Subject Classification I.2.11 Distributed Artificial Intelligence

Keywords and phrases Simulation, Norms, MAS

Digital Object Identifier 10.4230/DFU.Vol4.12111.171

1 Introduction

In this chapter, we present the state of the art in the agent-based simulation of norms. Simulation is emerging as one of the most important tools in the stock of the social science researcher. Indeed, simulation provides an unique way to advance understanding in theory, by building conceptual models, and at the same time to apply ideas to specific scenarios, by allowing accurate descriptions of the real world mechanisms in the models of the agents and of their interaction. Starting from the definition of the essential components of a simulation-based approach to norms, we propose a selection of conceptual challenges of relevance for the NorMAS community, and we suggest simulative approaches to deal with them. After stating basic definitions of simulation, norms and their interaction, we present an overview of simulation research on norms, then we move on to research challenges, on the basis of which we conclude the chapter with the outline of a NorMAS simulative platform.

1.1 What is simulation?

In the attempt to understand the world around us, predict its future, and build this future by policy choices, we use a modelling approach; that is, the creation of a model as a new object, which is simple to investigate, and at the same time carries some of the properties exhibited by the object of investigation. Simulation is but one of many modelling techniques, using automated computation to represent behaviours and properties of the target.

While several flavours of simulation exist, in this chapter we will focus on agent-based modelling and simulation, and on its application to the study of the norm lifecycle (see

Normative Multi-Agent Systems. *Dagstuhl Follow-Ups, Vol. 4.* ISBN 978-3-939897-51-4.
Editors: Giulia Andrighetto, Guido Governatori, Pablo Noriega, and Leendert W.N. van der Torre; pp. 171–189
DAGSTUHL FOLLOW-UPS Dagstuhl Publishing
Schloss Dagstuhl – Leibniz-Zentrum für Informatik, Germany

[36] and also Chapter 5 in this volume) – creation, identification, spreading, enforcement and emergence. For several reasons, that we will consider briefly now, we believe that the agent-based approach is especially suited to model the norm lifecycle.

The agent-based approach, inheriting tools and objectives of distributed artificial intelligence, is a natural way to describe complex systems: focusing on the individual and the mechanisms that control its behaviour, phenomena can be constructed generatively and puzzling, unexpected, and often enlightening results can emerge. Agent based models can also represent transient phenomena in a natural way, and do not get attracted towards equilibria that are not reachable in practice (because of sensibility issues, or of interminable reaching times; for a famous example, see [22]).

The focus on the individual distinguishes the agent-based approach from the traditional ones based on mathematical and stochastic methods where the characteristics of a population are averaged together [17]; the more complex individuals and their interactions are, the less this averaging is expected to work. Agents, instead, allow maintaining a plausible description of phenomena both at the micro and at the macro level.

Norms have an elaborate lifecycle, in which important steps – recognition, adoption, decisions to punish are examples – happen in the agent's mind. Thus, even with minimally complex norms, issues of autonomy and heterogeneity become crucial. Agents are the only existing approach capable of modelling autonomy [49] in heterogeneous agents, and are a natural paradigm for modelling adaptation, evolution, and learning.

Finally, modelling with agents reduces, with respect to equation based models, the pressure towards oversimplification that the "hard" sciences inherit from more than a century of success in understanding the physical world. This success, however, is not mirrored in the sciences that have applied the same tools to the social world, namely, the economic science, that (rather infamously) has shown to be not yet suited to deal with phase changes or crises. Simulation, and agent-based modelling and simulation in particular, is definitively a different approach to modelling social behaviours; agent modelling, in contrast to equation-based models, enables the description of agent internals in an accurate way – including mental constructs like norms.

1.2 What are norms?

While the research community does not converge on a single definition of norm, for the purposes of this paper we will consider norms as behavioural regularities that guide agents' decisions in a social environment. There are a number of features associated with norms, depending on the focus and the role they play in a multi-agent system. The two most important are:

1. **Expectations**. Norms presuppose the belief that agents around a given agent will abide to the prescribed behaviour, and they expect that agent to conform to it as well [11].
2. **Punishment**. Compliant and deviant behaviours are usually associated with more or less explicit rewards and sanctions. Although authors distinguish between *injunctive* and *descriptive* norms, associating with the latter a lesser importance for sanctions [27], depending on the social capabilities and/or the cognitive plausibility of the artificial agents it is always possible to postulate a form of reward, either positive or negative: be it in the light of the agent's own morals or emotions, social-image or reputation, the blame of his peers or the preservation of his own social-image or reputation, and – in the case of an institutional framework – where explicit fines can be imposed.

These normative aspects find an implementation in the literature in the following entities:

- conventions
- social norms
- legal norms

depending on whether the focus is on the coordination effect achieved through the conditional compliance of individual agents and their reciprocal expectation, the role of obligations and the effects of punishment on agents' decisions, the presence of an institutional authority or the implementation of normative roles in the agent population. However these three categories should not be considered mutually exclusive.

Norm dynamics is an important aspect captured by social simulation. It involves the possibility for norm *emergence* and *transition* from one category to the next (and possibly back to a previous one). For example, something that emerges as a convention can later be explicitly prescribed and enforced, and eventually become part of the legal system. It also involves the possibility of representing scenarios of *normative conflict*, where an agent's behaviour is subject to multiple normative inputs, e.g. a social and a legal norm.

Regardless of the emphasis on the correlated social and psychological phenomena ascribed to norms, they are considered the principal means to achieve social order in a population of autonomous agents, as they offer a solution to situations that pose a social dilemma.

1.3 Social Science Background

A central concern in social science in general and sociology in particular is the relation between the individual level and the societal level. The micro-macro link debate has been at the core of sociology since its creation as an area of scientific research. Mechanisms linking indiduals to societal effects and society to individual behaviour are many, norms being one of them. One of the main researchers within the social mechanisms "school" is Jon Elster. In [20] he describes a whole range of social mechanisms. Among them is the concept of social norms. A social norm is defined as an injunction to act or abstain from acting. The working mechanism is the use of informal sanctions aimed at norm violators. Sanctions may affect the material situation of the violator via direct punishment or social ostracism. An open question is the costs of sanctioning. Apart from social norms, which are followed due to the possibility of violations being observed and sanctioned, Elster describes moral norms, which are followed unconditionally, and quasi-moral norms, which are followed as long as others are observed complying with them. Other connected concepts are legal norms (where special agents enforce the norms) and conventions that are independent of external agent action. In his text, Elster discusses in detail some examples of norms such as: norms about etiquette, norms as codes of honour, and norms about the use of money. For the purpose of this chapter, we will confine the social mechanisms and concepts to social norm related ones.

In 1956 Morris [31] proposed one definition of norms based on 17 characteristics which he grouped in 4 categories. The categories and characteristics can be understood as the first set of conceptual challenges when doing NorMAS-related simulations, as the simulation designer – for each of them – needs to make a decision whether and how to model the respective normative aspect. Summarizing Morris' characteristics, we can derive four building blocks that can be combined in a normative simulation. Different (implementations of) normative systems may have different distributions of these building blocks over the constituents of the system:

1. Ways to distribute/communicate norms
2. Ways of deliberating on norm following (or violating)

3. Ways of detecting violations of norms and norm following
4. Ways of implanting positive and negative sanctions as a consequence of norm compliance or violation (enforcing the norms)

This rather extensive list of characteristics (and indirectly conceptual challenges) was extended by Gibbs, who in 1965 published a norm typology based on Morris' earlier work [24]. One important additional building block Gibbs highlighted was:

5. Ways to detect norms

This building block could be located anywhere on the scale between collective evaluations of actions and situations to the imposed by external sources. This is closely linked to the question about the origin of norms: bottom-up (emergence from behaviour regularities) or top-down (i.e. mostly as a control mechanism aiming for a certain social order). In the former case, further questions arise such as how agents recognize norms and learn about them and how they internalize them after recognition. And even if individual agents recognize something as a norm, how do group norms or generally accepted norms emerge?

In the Dagstuhl NorMAS Seminar in 2007 a final building block was identified:

6. Ways to modify norms

This building block highlights the question of whether norms can be modified in the simulation (or whether they are static), which norms can be modified and furthermore who can modify which norms under which circumstances.

1.4 Simulation and norms

For the NorMAS (Normative Multi-Agent Systems) community, agent-based simulations offer a platform to evaluate the behaviour of different models of norms and normative processes in a dynamic environment. Vice versa, the NorMAS community can supply (social) agent-based simulation studies with formal models of social concepts and mechanisms, especially those related to normative concepts, such as norms proper, roles, values, morals and conventions, and their transmission within a society. Agent-based simulation has had great success in modelling normative behaviour, due to its ability to address the fundamental role of norms by reconstructing the micro-macro link: generating macro-level phenomena from micro-level specifications and vice versa, modelling micro-level behaviour and choices as bound by macro-level phenomena. To date, this has largely been achieved through models based on individualist agents that behave according to their own internal goals, with social behaviour resulting as an emergent phenomenon. For example, the BDI architecture on which many models are based is a strongly individualist architecture. An agent is defined by its individual beliefs, desires and intentions and any social behaviour results by emergence [21] or deterrence [7].

While explicit social knowledge can be added to the BDI architecture, e.g. by explicitly defining a set of obligations an agent has to follow, as in the BOID architecture [13], more advanced models of normative behaviour such as the EMIL-A architecture [4] have recently been proposed to transcend the individualistic nature of an agent to some extent by incorporating both perception of norms and reasoning with norms into the agent. Now the agents are able to avail themselves of a normative interface with the world rather than just a factual one as is the case for a BOID agent. Still, desires and intentions of the agent are defined individualistically, with normative knowledge evaluated according to these desires and intentions. But what if the agent was not quite as individualistic? What if agents have an active interest in social behaviour, in sharing goals, in cooperating? What if agents can explicitly reason about their group structure, their friendship relations, and use them both as a source of norms and a context that drives norm interpretation? And how do we integrate emotions into these frameworks or open them up to create glass-box cognitive models to replace the black box of BDI? And what about emotions? We advocate work on these issues to improve agent simulation models so that:

a) models will no longer analyse whether social behaviour is possible but rather what kind of social behaviour might emerge;
b) models will no longer be based on the long-standing paradigm of 'atomism', i.e. individual agents are no longer seen as social atoms connected by chance but holistically, as inseparable parts of a social entity;
c) models will no longer be purely behavioural, allowing agents to understand their own intentions and goals and those of other agents; and
d) models of human agency will address social, psychological and emotional aspects simultaneously.

2 Overview of Norm Simulation Research

This section provides a brief background on different phases of norm life-cycle and the different mechanisms that have been employed to study those using simulation-based research. Broadly, from the viewpoint of the society, the three important stages of norms are the formation stage, propagation stage and the emergence stage. Researchers employing simulation-based studies of norms have investigated various mechanisms associated with norms with each of these stages. Mechanisms employed in the *norm formation* stage aim to address how agents can create norms in a society and how individual agents can identify the norms that have been created. Mechanisms used in the *norm propagation* stage aim to explain how norms might be spread and enforced in the society. The *emergence* stage is characterized by determining the extent of the spread of a norm in the society.

Based on these three important stages of norms, Savarimuthu et al. [36] have identified five phases (i.e. expanded stages) of the norm life-cycle which are norm creation, identification, spreading, enforcement and emergence. Figure 1 shows these five phases of the norm life-cycle on the left and the mechanisms investigated by researchers for each of the phases on the right. Note that not all the mechanisms shown in the figure are discussed in this chapter. For details refer to [36]; compare also with the model for norm dynamics presented in Chapter 5 of this volume.

2.1 Norm creation

The first phase of the life-cycle model is that of norm creation. The norms in multi-agent systems are created by one of the three approaches. The three approaches are (a) a designer specifies norms (off-line design) [15], (b) a norm leader specifies norms [12, 45], and (c) a norm entrepreneur considers that a norm is good for the society [26].

In the off-line design approach, norms are designed off-line, and hard-wired into agents. This approach has been used by researchers to investigate norms that might be beneficial to the society as a whole using social simulations. An example of a hard-wired norm includes investigations on how different traffic rules emerge by fixing tendencies of agents to drive on the left or the right [43, 41]. Researchers have also investigated a pre-specified *finder-keeper* norm where they compare a society that does not have a norm [16] with a society

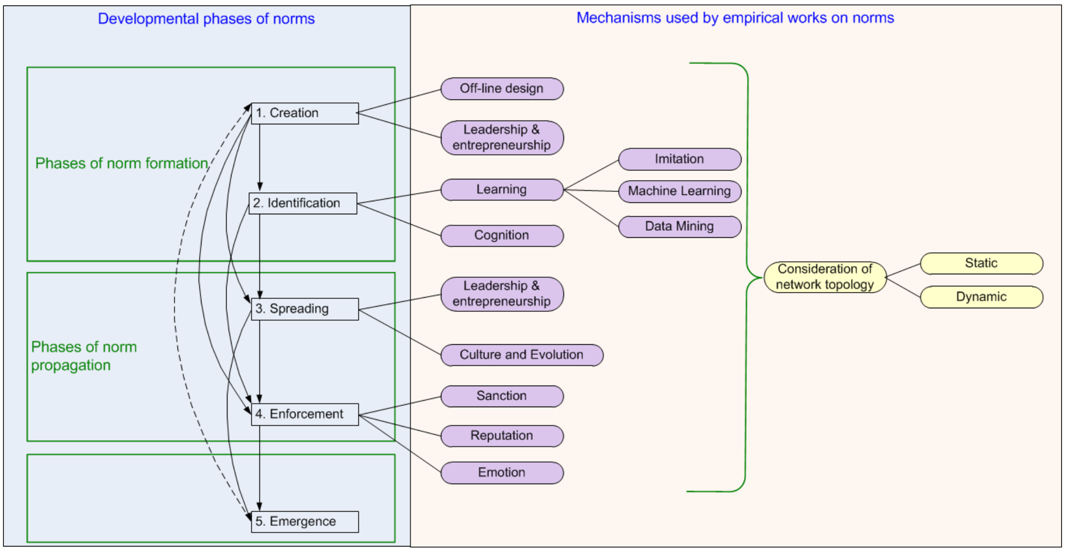

Figure 1 Developmental phases of norms.

that has a norm. In the leadership approach, some powerful agents in the society (the norm leaders) create a norm. The leadership approach can be based on authoritarian or democratic leadership. The leader can provide these norms to the follower agents [12, 44]. Leadership mechanisms are based on the notion that there are certain leaders in the society, who provide advice to the agents in the society. The follower agents seek the leaders advice about the norm of the society.

Boman [12] has used a centralised leadership approach, where agents consult with a normative advisor before they make a choice on actions to perform. Verhagen [45] has extended this notion of normative advice to obtaining normative comments from a normative advisor (e.g. the leader of the society) on an agent's previous choices. The choice of whether to follow a norm and the impact of the normative comment on an agent are determined by the autonomy of the agent. Once an agent decides to carry out a particular action, it announces this decision to all the agents in the society, including the leader of the society, and then carries out that action. The agents in the society can choose to send their feedback to this agent. When considering the received feedback, the agent can choose to give a higher weight to the feedback it received from the leader agent.

In the entrepreneurship approach to the creation of norms, there might be some norm entrepreneurs who are not necessarily the norm leaders but create a proposed norm. For example, Henry Dunant, the founder of Red Cross was the entrepreneur of the norm to treat wounded soldiers in a war as neutrals. When an entrepreneur agent creates a new norm it can influence other agents to adopt the norm [23, 26]. Hoffmann [26] has experimented with the notion of norm entrepreneurs who think of a norm that might be beneficial to the society. An entrepreneur can recommend a norm to a certain percentage of the population (e.g. 50%) which leads to varying degrees of establishment of a norm.

2.2 Norm identification

If a norm has been created in the society using one of the explicit norm creation approaches (e.g. leadership and entrepreneurship) then the norm may spread in the society. However, if the norms have not been explicitly created (i.e. norms are derived based on the interactions between agents), then an agent will need a mechanism to identify norms from its environment based on the interactions with other agents. In game-theory based empirical works [42, 41], agents have a limited number of actions that are available, and they choose the action that maximizes their utility based on some learning mechanism about the behaviour of other successful agents. These mechanisms could be imitation, machine learning (e.g. genetic algorithms) or data mining. The second approach to norm identification considers the cognitive capabilities of an agent to infer what the norms of the society are [5, 3]. In the cognitive approach, one or more cognitive agents in a society may come up with norms. At this stage, the norm exists only in the mind of one agent. It can become a social norm if that is accepted by other agents based on the deliberative processes that they employ. In this approach the other agents have the cognitive ability to recognize what the norms of a society are based on the observations of interactions. Agents have normative expectations, beliefs and goals. It should be noted that the norms inferred by each agent might be different (as they are based on the observations that the agent has made). Thus, an agent in this model creates its own notion of what the norms are based on inference.

2.3 Norm spreading

Norm spreading relates to the distribution of a norm among a group or in the system. Once an agent forms a belief on what the norm in the society or in its group is (i.e. either based on norm creation or identification), several mechanisms help in spreading the norms such as leadership, entrepreneurship, cultural, and evolutionary mechanisms.

Leadership mechanisms are based on the notion that there are certain leaders in the society. These leaders provide advice to the agents in the society. The follower agents seek the leaders' advice about the norm of the society. Thus, the norm spreads in the society. Researchers have experimented with centralized and decentralized models of leadership [45, 38] for norm spreading. Hoffmann [26] has experimented with the notion of norm entrepreneurs who think of a norm that might be beneficial to the society. An entrepreneur can recommend a norm to certain percentage of the population which leads to varying degrees of norm spreading in the society.

Boyd and Richerson [35] proposed that norms can be propagated through cultural transmission. According to them, there are three ways by which a social norm can be propagated from one member of the society to another. They are

- Vertical transmission (from parents to offspring)
- Oblique transmission (from a leader of a society to the followers)
- Horizontal transmission (from peer to peer interactions)

Of these three kinds of norm transmission mechanisms, vertical and oblique transmissions can be thought of as leadership mechanisms in which a powerful superior convinces the followers to adopt a norm. Horizontal transmission is a peer-to-peer mechanism where agents learn from day-to-day interactions from other peers.

Norm spreading based on evolution involves producing offspring that inherit the behaviour of their parents. One well known work in this category is by Axelrod [7]. Other researchers have also experimented with evolutionary models for norm spreading [14, 46].

2.4 Norm enforcement

Norm enforcement refers to the process by which norm violators are discouraged through some form of sanctioning or norm compliers are encouraged by some form of benefits (i.e. the utilization of carrots and sticks). A widely used sanctioning mechanism is the punishment of a norm violator (e.g. monetary punishment which reduces the agent's fitness or a punishment that invokes emotions such as guilt and embarrassment) through regimentation (where the agents are considered as white boxes or it is assumed that their actions can directly be controlled) or with the help of some kind of police agents. Reputation mechanisms or image information have also been used as sanctions (e.g. an agent is black-listed for not following a norm). One final method of enforcement can be administered through the norm violators themselves (by means of self-enforcement[1]). The process of enforcement helps to sustain norms in a society. Note that enforcement of norms can influence norm spreading. For example, when a powerful leader punishes an agent, others observing this may identify the norm. Hence, the norm can be spread. Norms can also be spread through positive reinforcements such as rewards. Some researchers have considered enforcement as a part of the spreading mechanism [8].

2.5 Norm emergence

The fifth phase is the norm emergence phase. We define norm emergence to be reaching some significant threshold in the extent of the spread of a norm; that is a norm is followed by a considerable proportion of an agent society and this fact is recognised by most agents. For example, a society could be said to have a norm of gift exchange at Christmas if more than $x\%$ of the population follows such a practice. The value of x varies from society to society and from one kind of norm to another. The value of x has varied from 35 to 100 [36] across different empirical studies of norms. Emergence can be detected either from a global view of the system or through a local view of an agent (e.g. an agent might only see agents that are one block away on all directions in a grid environment). Spreading of norms with or without enforcement can lead to emergence. Once a norm has emerged, the process can continue when an entrepreneur or a leader comes up with a new norm that replaces the old one. This is indicated by a dotted arrow in Figure 1. The adoption of a norm may decrease in a society due to several reasons. A norm that has emerged may lose its appeal when the purpose it serves does not hold or when there are not enough sanctions or rewards to sustain the norm or when other alternate effective norms emerge. Note that the model presented here is from a bird's-eye view (i.e. an external agent that observes the society). An external agent will able able to observe the norm establishment and de-establishment in the society based on the emergence criterion (i.e. the extent of spread of the norm).

2.6 Consideration of network topologies

An important attribute of the research on norms is the consideration of network topology. The underlying interaction topology of agents has an impact on all phases of norm development. For example the interactions between a leader and his followers have an implicit network topology (i.e. a star network) which governs how norms created by the leader may spread and may lead to norm emergence in an agent society. Hence the consideration of network topology is included as one of the nine main categories in Figure 1. The network structure of the society can either be static or dynamic (i.e. can evolve due to agents joining and leaving).

[1] Balke and Villatoro [9] have pointed out that enforcement mechanisms should not only consider who sanctions, but also observe the violations and who determines the sanctions.

For a detailed overview of different mechanisms employed in the simulation-based study of norms which have not been covered in this chapter such as learning approaches, cultural and evolutionary approaches, reputation-based approaches please refer to the work of Savarimuthu et al. [36].

3 Research challenges

3.1 Methodological Challenges

The methodological challenges for simulation of normative multi-agent systems, apart from the challenges inherent to simulation as a method in general, include the development of measures for the mechanisms described in section 1.4 on Simulation and Norms. Few measures exist in the social science studies of norms and normative processes that can be used here. The development of such measures for use in simulation studies will thus in itself be a contribution to social science in general. The process of *norm adoption* – defined as the processing of an obligation, prohibition, or permission from the part of the individual agent – is a central element in normative reasoning and directly related to the behavioural outputs in norm emergence and enforcement. Its study aims at the *micro-foundation of a normative agent architecture*, an endeavour that connects social simulation with the efforts made in other social sciences, and brings in results from a diverse array of disciplines – psychology, sociology, anthropology, economics, etc. – in order to increase the plausibility of the implemented models.

Validation of simulation results is another important methodological point. Game theory offers a consistent set of tools to capture and analyse the results of agent interactions, especially in the case of social dilemmas. The implementation of the relative game-theoretical concepts in computational models assumes the introduction of principles of economic rationality, however relaxed they might be. For a discussion of the treatment of norms from the standpoint of game-theory, see Chapter 2 in this same volume.

Also, the development of tools for the *visualization of effects* going beyond, e.g., the use of different colours for agents to represent different norms, is one solution will be beneficial for the *interpretation and communication of simulation results*. The same is true for the development of mathematical measures for e.g. norm salience such as developed in [45].

Finally, in research on norm identification, there is a *norm bootstrapping* problem: in order for agents to learn norms, there must already be norms present in the environment or agents must be provided with the means to invent new norms and act on them. In current simulation experiments the researchers already know the norms that their agents are intended to learn, as these were pre-engineered into the system. This can lead to ad hoc solutions that do not generalise to address other scenarios and problems. One possible solution is to designing mechanisms and protocols for humans to control some of the agents in a simulation. Human participants could then be instructed to exhibit specific norms, given tasks that should implicitly lead to normative behaviour, or left to bring their own real-world norms into the simulation. This would provide a much greater challenge for the design of norm learning mechanisms, and may lead to the development of more powerful approaches.

3.2 Topologies

In addition to the type of game that is being played to model agent interactions (e.g. a coordination or cooperation game), the network structure [33] is also a fundamental component of any agent-based simulation, since real-world interactions between individuals are governed by the underlying topology (i.e. we interact with people from our family network, work network and so on). Apart from identifying connections between different components (or agents) within the the system, the network structure also imposes constraints on agent actions, interactions and observations. Networks have been investigated from two different perspectives: as *static* networks or *dynamic* networks.

In static networks, agents have fixed connections to other agents in their environment. Depending on the simulation, these connections define the ability to interact and observe the interactions of others. Various types of static networks [2] have been studied, and their effects analysed in the literature of social norms and agent-based simulation. The main types of static networks commonly analysed are random, lattices, small worlds and scale-free networks. Indeed, there has been a considerable recent effort on analysing the impact of each of these network types on the effectiveness of social norms [18, 40, 30, 47].

In dynamic networks, agent connections are modifiable during the course of the simulation, possibly due to the dynamism of the system under investigation. Dynamic networks are representative of phenomena that can be observed in the real world (agents dying, relocating etc.). For example, Savarimuthu et al. [37] describe the emergence of norms in a scenario in which the network of interactions dynamically changes as the agents move in a two-dimensional abstract social space, with agent connections being formed through collisions in this space. Alternatively, Mungovan et al. [32] propose an interesting scenario in which agents have a fixed interaction network (small-world) and are provided with the possibility of having random interactions.

- **Analysing the influence of different locations in the network**. Much work has focused on identifying the effects of general network characteristics on social norms, yet there has been very little attention on the influence of different locations within these networks. There may be agents in certain powerful locations in the network that can either positively or negatively influence norm emergence. For example, in scale-free networks, *hubs* (nodes with a vast amount of connections) are known to play an important role by either supporting or obstructing social norms. A more detailed analysis of the specific effects of different locations is thus crucial in overcoming any obstacles in the spreading of a social norm in a complex system.
- **Investigating the influence of dynamic networks**. Most current social norm models consider static networks, and seem to consider only interactions between two agents resulting from their unchanging static connection. However, since dynamic networks incorporate many characteristics of real world complex systems, it is important to determine the impact of these types of networks on the evolution of social norms. Dynamic networks thus provide ample research opportunities for work involving social norms and complex systems. In addition, and as done initially for the construction of in-silico social networks ([33, 10, 18, 19]), we need models and algorithms that simulate the dynamic evolution of social networks over time.
- **The existence of different groups and multiple topologies**. In most experimental models, individuals have been considered to belong to only one group, but in reality agents can be influenced from many angles as an individual might belong to several groups (e.g. work group, neighbours and hobby group). Each of these groups can have a different topology and the existence of such many topologies might influence agents' actions. Additionally, the strength of the links from an agent to other agents might be different which may influence norm emergence. The strength of the links can be modeled by assigning weights.

4 Outline of a NorMAS platform

Tools and platforms dedicated to agent-based simulation are now widely diffused in the simulation community. Besides making simulations easier, they favour standardization, sharing of code, and replication of experiments. However, existing tools focus mostly on issues of synchronization, reporting, communication and topology. With the exception of Jason[2], which implements a BDI architecture, these tools are agnostic on the matter of mental structures as the norms that we are describing. We believe that the field could benefit by the introduction of a specialized platform dealing with the whole lifecyle of norms. In this section, leaning on some scenarios presented next, we point out some of the demands and requirements that a NorMAS platform should satisfy.

4.1 Scenarios

Scenario 1: The culture of graffiti artists has a rich social structure that has emerged over time [48]. Based on the goal of "getting up" (gaining reputation), practitioners ("writers") develop their skills by creating graffiti works in various named styles (such as *tags*, *throw-ups* and *pieces*) of increasing complexity and in locations with varying levels of risk of detection and/or injury. Writers can work together in teams (named "crews"), which gives them the chance to participate in more complex works. The creation of works signed with a group's tag also reduces the risk of any individual being held responsible if arrested. There are norms governing when a work can cover another (based on a complexity hierarchy of named styles) and how writers can gain and claim social status, to potentially rise from the status of a *pawn* (or *toy*), through the level of a *knight*, to become a *king* or *queen*. Sanctions such as "slashing" (painting a line through or tagging over another's graffiti) or physical violence may be applied if these norms are breached. There is also a notion of honour among thieves and associated social recognition of those who are trusted not to give any information about other writers to authorities. This culture can be viewed as a microcosm of human society, exhibiting some significant social structures and processes. A simulation implementing an abstraction of graffiti culture would be a useful testbed for evaluating theories of the creation, acquisition and recognition of norms by agents and the spreading and emergence of norms within a society.

Scenario 2: Divya Chandran, a new resident in a virtual environment (e.g. Second Life) wants to explore the rich interactions offered by the new medium. She wants to go to a virtual park and relax by the fountain and listen to chirping birds. She flies to the virtual park and upon looking at the layout starts wondering if there are norms that regulate where to sit in the park (e.g. benchs, wall-like structures, and the grass). She notices some water fountains and some soft-drink fountains from the sponsor of the park. She would like to get a drink, but does not know if there is a norm governing the usage of the fountain. She wonders if she should get a cup from the jazzy sponsor's booth by paying virtual money or if she needs to acquire the skill of making a cup object. Can she take her drink to all the areas of the park or is she restricted to a particular zone (e.g. food permitted zone)? And finally, what should she be doing with the cup – store it in her inventory for further use, destroy it or just leave it around? How can she find what is the norm associated with littering in the park? Can she leave the cup anywhere for some mechanism to collect it or should she find a rubbish bin and drop it there? Also, she is curious to know the social interaction rules that

[2] `http://jason.sourceforge.net/wp/`

apply in this setting. Is she supposed to send a greeting 'signal', to engage in conversation with strangers? If so, what should this signal be (e.g. uttering a 'hi', waving a hand, or an obscure ritual specific to the virtual environment)? Should she also discretely walk away from people engaged in conversation, and if that is the case what distance is considered polite? Finally, once she has learned the norms of the park, will the norms of this particular park be applicable to all the parks in the virtual environment? When she visits the park at a later date will the norms of the park still be the same or will there be new norms?

Scenario 3: As defined by Schollmeier [39], a peer to peer system is a distributed system that consists of members, each of which share some resources (hardware, software or information) with other members. There are many research efforts that address the issue of free riding behaviours in P2P file sharing systems [29, 25, 28], but here we provide an explanation of the problem in relation to the *Gnutella* system. *Gnutella* is a P2P file sharing network, in which each peer plays the role of both a client and a server. As a client, the peer requests files from other peers, while as a server the peer provides files to other peers. When a peer needs access to a file in the network, it creates a query regarding the desired file and passes this query to its neighbours. If the neighbouring peer has the file, it replies to the request. If not, the peer passes the request to its neighbours and returns the response of those neighbours back to the requesting peer. When a peer downloads a file, the informal norm of the system is that it should make the file available to others. A peer does not pay anything to access files and there is no limit on the amount of files that a peer can access nor the proportion of the files it shares. Therefore, it might be rational for peers to not waste their bandwidth responding to other peers' requests as they can access different files on the network without sharing any of their own files, which is known as the problem of *free riding.* As shown by Adar and Huberman [1], 70% of Gnutella peers share do not share any file; they receive files from the network without sharing. A simulation platform can provide vital help in investigating this phenomenon and in analysing various mechanisms that can lead to the preemption of free riding. Researchers can investigate both top-down policy based mechanisms for handling free riding and also can investigate the more interesting bottom-up approaches where norms against free riding may emerge dynamically. This scenario can be used not only to study the emergence of norms but also how the emerged norms can be spread, enforced and eventually be updated (depending upon changing circumstances).

4.2 Agent Internals

To be capable of dealing with norms in a non-trivial way, agents must be endowed with extensive capabilities to deal with cognitive representation of artifacts related to the norm life-cycle. The processes that are executed in the mind of the agent, and that a NorMAS library should provide, are exemplified in the rest of this section, describing norm formation and norm propagation.

Norm formation. Explicit mechanisms of norm formation should be available to the designer. These should cover both norm creation and norm identification. Norm creation is the creative process of an agent generating a new candidate norm. This may happen at the beginning of the simulation, when all agents might randomly draw norms from a more or less large set, or during the simulation, e.g. if "norm entrepreneur" agents invent new norms that they wish to propose to the society, or if agents have their own personal norms that may be motivated by personal emotions and/or goals. For norm creation, following the mechanisms proposed in section 2.1, we could imagine the following:

(a) functions to select, possibly at random, one of the norms provided off-line by the system designer, a selection that could be changed according to the performance of the agent under that norm; for example, in a simulation of peer to peer sharing, choosing between pre-constituted norms defining the appropriate time length one should share a downloaded file.

(b) Functions to create a norm to be induced through authority by special agent figures; for the graffiti example, consider how figures of prominence (artists, *kings* or *queens*) could dictate norms about slashing, enacting thus a collective behaviour in the group they lead.

(c) Functions describing how a norm entrepreneur could envisage the possibility of creating a new norm – possibly by foreseeing some of the collective effects that could benefit himself, the group he belongs to, or both.

This involves inducing norms that may hold in the society, based on the agent's experience and observations. For complex scenarios where many different actions may be observed, this will require a module for the detection of frequent behaviour (regularity detection).

In the virtual world example, some of the regular visitors in the park could try to instantiate an informal norm of precedence in greeting (as in, you wait for the newcomer to greet first, or the opposite, or one based on avatar creation date), trying to assess which norm would contribute better to create a pleasant mood.

Here, we also need to distinguish between personal norms (recognized only by isolated agents) and actual ones. At the collective level, the generated norms are just candidate norms until the population contains a sufficient number of agents with similar personal norms to trigger norm recognition by other agents.

The proposed regularity detection module could be used also as the basis of norm identification (see section 2.2), with different implementations for learning-based identification and cognition-based one. Agents could also be endowed with mental constructs of *candidate norms* populated by the regularity detection module.

At the cognitive level, regularities can be caused by the preferences or goals of the agents involved without the need for a norm to be present; but a norm can be hypothesized if we can interpret an action by an agent as a signal that a violation of accepted behaviour has occurred. Examples of such signals include negative emotional reactions (indicating a potential need for emotion detection) and the explicit invocation of sanctions.

Thus, agents should be endowed with an internal process for keeping track of the relevance of a norm to the agent and the community over time, thus helping the agent to determine when to observe the norm and when the norm should be forgotten [6]. As sanctions cannot, in general, be distinguished from punishments motivated by individual goals, a threshold of independent evidence should be achieved before an agent induces a norm from observation.

However, both candidate and confirmed norms should be available to an agent's introspection, as it may wish to plan actions that test whether a candidate norm is prevalent in the community. With reference to the examples provided, a new agent in the graffiti scenario would need a routine to identify, between the regularities he can detect in the "slashing" acts, which rules of priority are in action. In the virtual world example, the visitor could observe the behaviour of other players, come up with candidates to a norm, and then discuss them explicitly, or even try to enact some slight violation to get confirmed by sanction.

Norm propagation. Norm propagation includes spreading and enforcement (see section 2.3). Norm propagation requires communication between agents and an explicit, transmissible representation for norms. A library for simulation of this process would include, with regard to the agent internals, both agent-to-agent communication (possibly connected by one of the topologies discussed above) and some broadcast mechanism. Propagation should also keep into account possible differences in value structure, for example, when entering in contact with different groups or cultures. The justification of a norm could be based on values that are different between the new agent and the community.
For norm enforcement (see section 2.4), agents would also need routines for performing sanctioning behaviour in relation to norms that they believe to be in effect.

In addition to the specifically normative components above, there are other ingredients that may be necessary or useful for agents internals. These are:

- a connection to the object/enviroment/context level (for agent sensing and acting, for measures of regularity, etc.)
- representation of cognitive artifacts related to norms (i.e. reputation, trust, emotions,and values), in their role of indirect sanctions, salience indications, or conflict resolution between norms. About trust and reputation, identifying oneself with a group can lead the agent to generate goals instrumental to the preservation of this identity, to the strengthening of his affiliation (and of the related trust) through the acquisition of a more central position in the group, and other goals related to reputation building and maintenance. Values confer the agents a moral sense (proto-morality – they are only one component among others along the way a moral architecture). In a simplified process they are able to flag a certain state of the world (W) as being good or bad.
- a norm-aware practical reasoning architecture: the use of a practical reasoning architecture requires extensions to the classic BDI architecture (as with the BOID architecture, [13]); but this is not yet common in the practice of multi-agent simulations which often focus on rather simple scenarios in which agents have only a few actions to choose from, and the choice between them is governed by one or more numeric variables (e.g. representing probabilities of actions). However, to gain a deeper understanding of how norms are created, evolve and emerge in a society, and when and how agents choose to follow norms, it seems necessary to have an explicit connection between practical reasoning and normative behaviour. A NorMAS simulation toolkit could support research in this direction by providing an optional explicit BDI-style execution cycle (along the lines of AgentSpeak [34]), to which additional normative reasoning steps could be added.
- Group identity: affiliations and belonging, besides being a primitive social drives, is also input for the agent cognitive processing. Sharing (a set of) values, adopting and following the same norms, and consequently enforcing them are together process on which group identity is based.

4.3 Interaction Mechanisms and Topologies

In a social simulation, there can be various ways that agents can directly interact (as opposed to influencing each other indirectly by acting in the environment). An MAS simulation toolkit should provide support for a range of interaction mechanisms, including direct agent-to-agent messaging, agent-to-group messaging, and the exchange of utility such as making payments. It may also be useful to provide an interface for registering gossip to be spread automatically to all encountered agents.

Figure 1 shows various mechanisms researchers have been proposed for norm establishment in a society. A good normative simulation system should allow one or more of these mechanisms to be plugged in and experimented with. For example, researchers should be able to experiment with a scenario by setting up an entrepreneurial mechanism for norm creation, an imitation model for norm spreading, a reputation mechanism for norm enforcement, and then observe how norms are established in the society. After achieving this in one particular experiment, the researchers should be able to replace the reputation mechanism for enforcement with a punishment mechanism in the next experiment and study the effects (such as time to converge and efficiency). Such a pluggable simulation architecture will be beneficial to the research community, both for sociologists to understand human societies and computer scientists to deal with artificial agent societies.

The set of agents that a given agent can observe and interact with is dependent on the underlying physical environment and/or social network topology. However, an agent may need to reason about higher level social structures such as connections formed in different social and organisational contexts. These can be viewed as overlay networks on top of the underlying topology, and the platform should offer support for agents to query and update information about these personalised and contextualised views of society.

Support should also be provided for an agent to store its own private data about other agents and to query and configure (e.g. by setting the history length) its record of past interactions with other agents. In a P2P system, an agent might store some information about a free rider agent in order to avoid interacting with this agent again.

As discussed in Section 3.2, topologies impact norms spreading and emergence. Therefore, a NorMAS simulation toolkit should allow the integration of tools that automatically generate network topology. The toolkit should also provide support of various types of topologies that can be used to simulate popular social or computation systems. Such topologies include random, regular, small world and scale-free topologies. Moreover, generating dynamically changing network topology is an important functionality that a simulation toolkit should support in order to facilitate new agents joining, reordering connections or even leaving the network. In the example of P2P, agents might decide to move away from a free rider agent by rewiring the connection with this agent to another agent.

In addition, the definition of multiple topologies that can represent different semantics should be supported. For example, it should allow the definition of a physical topologies, social topologies and observation topologies. A physical topology can refer to agents' physical connection, while social topologies can indicate the existence of multiple social interest topologies (films, music and sport), each represent the relationship and interest of its members. An observation topology can define how agents observe each others behaviour and it can be derived from the constraints imposed by the interaction mechanism. Over the physical network of P2P system, agents might establish different interest network related to their shared interest type of contents.

4.4 The Object Level

The object level is where the basic interaction happens; the norms regulate the object level, normally forbidding or prescribing a course of action. For optimizing agents endowed with an utility function, actions at the object level act on utility directly. For scenarios with fitness parameters (energy, strength, and the such) actions at the object level act on these parameters directly. Finally, for agents with a BDI-like structure, goals will describe an object-level structure. In this case, we have a *pure* object level. Thus, (candidate) norms will be created as restrictions of the agents' autonomy in the operations performed on the object level.

Regarding the examples presented above, the graffiti example would have an object level composed of basic actions as creation of graffiti in the different styles, joining or leaving a crowd, and covering/slashing actions, with reward/penalty. To simulate the object level in the Second Life example, explicit rewards and penalties can be used; but if more details on the internals of the agent are desired, one can imagine agents having as a goal the absence of litter in the park, or, if we start directly at a social level, the goal of being welcomed in a friendly way. In a NorMAS library, these object-level actions would be provided by a set of APIs for fitness modifying behaviors.

The object level will be the target of reasoning at the meta level; in this case, we are talking about a NorMAS meta level. Thus, the constructs at the object level will be examined and recognized by a normative reasoner.

5 Conclusions

This chapter has presented the potential contribution that agent-based simulation techniques and methods can bring to the field of norms, and especially, to norms in multi-agent systems. Based on the descriptions of simulation, the definition of norms with a social science background and the discussion of aspects of norms that are special for artificial agent systems, we have described the relationship between simulation and norms before giving an overview of the norm simulation research centered around the stages of the norm lifecycle presented in figure 1. Following this we presented the research challenges.

First we adressed the methodological challenges. These include the development of measures of spreading of norms, simulation validation, visualisation, and the norm bootstrapping problem. Following this we discussed topological issues. Apart from dynamic versus static networks we also describe the network characteristics such as location influences and the consequences of multiple topologies and multiple groups which an agent can be a member of, causing interacting topologies. While striving for a simulation platform, we finally presented three different scenarios illustrating what we think to be the essential components of such an architecture, that will be the subject of our future work.

References

1 E. Adar and B. A. Huberman. Free riding on gnutella. *First Monday*, 5(10), 2000.

2 R. Albert and A.-L. Barabasi. Statistical mechanics of complex networks. *Review of Modern Physics*, 74(1):47–97, 2002.

3 Giulia Andrighetto, Marco Campenn, Federico Cecconi, and Rosaria Conte. The complex loop of norm emergence: A simulation model. In Shu-Heng Chen, Claudio Cioffi-Revilla, Nigel Gilbert, Hajime Kita, Takao Terano, Keiki Takadama, Claudio Cioffi-Revilla, and Guillaume Deffuant, editors, *Simulating Interacting Agents and Social Phenomena*, volume 7 of *Agent-Based Social Systems*, pages 19–35. Springer, 2010.

4 Giulia Andrighetto, Marco Campennì, Rosaria Conte, and Marco Paolucci. On the immergence of norms: a normative agent architecture. In *Proceedings of AAAI Symposium, Social and Organizational Aspects of Intelligence Washington DC*, 2007.

5 Giulia Andrighetto, Rosaria Conte, Paolo Turrini, and Mario Paolucci. Emergence in the loop: Simulating the two way dynamics of norm innovation. In Guido Boella, Leon van der Torre, and Harko Verhagen, editors, *Normative Multi-agent Systems*, number 07122 in Dagstuhl Seminar Proceedings. Internationales Begegnungs- und Forschungszentrum für Informatik (IBFI), Schloss Dagstuhl, Germany, 2007.

6 Giulia Andrighetto, Daniel Villatoro, and Rosaria Conte. Norm internalization in artificial societies. *AI Communications. (In press)*, 2010.

7 Robert Axelrod. An evolutionary approach to norms. *The American Political Science Review*, 4(80):1095–1111, 1986.
8 Robert Axelrod. An evolutionary approach to norms. *The American Political Science Review*, 80(4):1095–1111, 1986.
9 Tina Balke and Daniel Villatoro. Operationalization of the sanctioning process in hedonic artificial societies. In *Workshop on Coordination, Organization, Institutions and Norms in Multiagent Systems*, 2011.
10 AL Barabasi and E. Bonabeau. Scale-free networks. *Scientific American*, 288(5):60–9, 2003.
11 Cristina Bicchieri. *The Grammar of Society: The Nature and Dynamics of Social Norms*. Cambridge University Press, New York, 2006.
12 Magnus Boman. Norms in artificial decision making. *Artificial Intelligence and Law*, 7(1):17–35, 1999.
13 Jan Broersen, Mehdi Dastani, Joris Hulstijn, Zisheng Huang, and Leendert van der Torre. The BOID architecture. Conflicts between beliefs, obligations, intentions and desires. In *In Proceedings of the fifth international conference on Autonomous agents, Montreal, Quebec, Canada*, pages 9 – 16, 2001.
14 Fabio A. C. C. Chalub, Francisco C. Santos, and Jorge M. Pacheco. The evolution of norms. *Journal of Theoretical Biology*, 241(2):233 – 240, 2006.
15 Rosaria Conte and Cristiano Castelfranchi. Understanding the effects of norms in social groups through simulation. In Nigel Gilbert and Rosaria Conte, editors, *Artificial societies: the computer simulation of social life*, pages 252–267. UCL Press, London, 1995.
16 Rosaria Conte and Cristiano Castelfranchi. Understanding the functions of norms in social groups through simulation. In N. Gilbert and R. Eds Conte, editors, *Artificial Societies: The Computer Simulation of Social Life.*, pages 74–118. UCL Press, 1995.
17 Rosaria Conte and Mario Paolucci. On Agent Based Modelling and Computational Social Science. *Social Science Research Network Working Paper Series*, jul 2011.
18 Jordi Delgado. Emergence of social conventions in complex networks. *Artificial Intelligence*, 141(1-2):171–185, October 2002.
19 Jordi Delgado, Josep M. Pujol, and Ramón Sangüesa. Emergence of coordination in scale-free networks. *Web Intelli. and Agent Sys.*, 1(2):131–138, 2003.
20 Jon Elster. *Explaining Social Behavior: More Nuts and Bolts for the Social Sciences*. Cambridge University Press, 1 edition, apr 2007.
21 J.M. Epstein. Learning to be thoughtless: Social norms and individual computation. *Computational Economics*, 18:9 – 24, 2001.
22 Joshua Epstein, Robert Axtell, and Peyton Young. The emergence of economic classes in an Agent-Based bargaining model. In Steven Durlauf and Peyton Young, editors, *Social Dynamics*. Brookings Press / MIT Press, 2001.
23 Martha Finnemore and Kathryn Sikkink. International Norm Dynamics and Political Change. *International Organization*, 52(4):887–917, 1998.
24 Jack P. Gibbs. Norms: The problem of definition and classification. *American Journal of Sociology*, 70(5):586–594, 1965.
25 R. Guerraoui, K. Huguenin, A. Kermarrec, and M. Monod. On Tracking Freeriders in Gossip Protocols. In *P2P'09: Proceedings of the 9th International Conference on Peer-to-Peer Computing*, 2009.
26 Mathew J. Hoffmann. Entrepreneurs and Norm Dynamics: An Agent-Based Model of the Norm Life Cycle. Technical report, Department of Political Science and International Relations, University of Delaware, USA, 2003.
27 Matthew Interis. On norms: A typology with discussion. *American Journal of Economics and Sociology*, 70(2):424–438, 2011.

28 Sebastian Kaune, Konstantin Pussep, Gareth Tyson, Andreas Mauthe, and Ralf Steinmetz. Cooperation in p2p systems through sociological incentive patterns. In *Proceedings of the 3rd International Workshop on Self-Organizing Systems*, IWSOS '08, pages 10–22, Berlin, Heidelberg, 2008. Springer-Verlag.

29 R. Krishnan, D. M. Smith, Z. Tang, and R. Telang. The impact of free-riding on peer-to-peer networks. In *HICSS '04: Proceedings of the 37th Annual Hawaii International Conference on System Sciences*, page 70199.3. IEEE Computer Society, 2004.

30 S. Mahmoud, J. Keppens, M. Luck, and N. Griffiths. Norm establishment via metanorms in network topologies. In *Proceedings of the 2011 IEEE/WIC/ACM International Conference on Web Intelligence and Intelligent Agent Technology (WI-IAT)*, volume 3, pages 25 –28, aug. 2011.

31 Richard T. Morris. A typology of norms. *American Sociological Review*, 21(5):610–613, 1956.

32 Declan Mungovan, Enda Howley, and Jim Duggan. The influence of random interactions and decision heuristics on norm evolution in social networks. *Computational & Mathematical Organization Theory*, pages 1–27, 2011. 10.1007/s10588-011-9085-7.

33 M. E. J. Newman. The structure and function of complex networks. *SIAM REVIEW*, 45:167–256, 2003.

34 Anand S. Rao. AgentSpeak(L): BDI agents speak out in a logical computable language. In *Agents Breaking Away: Proceedings of the 7th European Workshop on Modelling Autonomous Agents in a Multi-Agent World*, volume 1038 of *Lecture Notes in Computer Science*, pages 42–55. Springer, 1996.

35 Peter J. Richerson Robert Boyd. *Culture and the evolutionary process.* University of Chicago Press, Chicago, 1985.

36 Bastin Tony Roy Savarimuthu and Stephen Cranefield. Norm creation, spreading and emergence: A survey of simulation models of norms in multi-agent systems. *Multiagent and Grid Systems*, 7(1):21–54, 2011.

37 Bastin Tony Roy Savarimuthu, Stephen Cranefield, Martin Purvis, and Maryam Purvis. Norm emergence in agent societies formed by dynamically changing networks. In *Proceedings of the 2007 IEEE/WIC/ACM International Conference on Intelligent Agent Technology*, IAT '07, pages 464–470, Washington, DC, USA, 2007. IEEE Computer Society.

38 Bastin Tony Roy Savarimuthu, Stephen Cranefield, Maryam Purvis, and Martin Purvis. Role model based mechanism for norm emergence in artificial agent societies. In *Coordination, Organizations, Institutions, and Norms in Agent Systems III*, volume 4870 of *Lecture Notes in Computer Science*, pages 203–217. Springer, Berlin/Heidelberg, 2008.

39 R. Schollmeier. A definition of peer-to-peer networking for the classification of peer-to-peer architectures and applications. In *P2P'01: Proceedings of the 1st International Conference on Peer-to-Peer Computing*, pages 101–102. IEEE Computer Society, 2001.

40 Onkur Sen and Sandip Sen. Effects of social network topology and options on norm emergence. In *Proceedings of the Fifth International Conference on Coordination, Organizations, Institutions, and Norms in Agent Systems*, pages 211–222, 2010.

41 Sandip Sen and Stephane Airiau. Emergence of norms through social learning. In *Proceedings of the Twentieth International Joint Conference on Artificial Intelligence (IJCAI)*, pages 1507–1512. AAAI Press, 2007.

42 Yoav Shoham and Moshe Tennenholtz. Emergent conventions in multi-agent systems: Initial experimental results and observations. In *Proceedings of the Third International Conference on the Principles of Knowledge Representation and Reasoning (KR)*, pages 225–231, San Mateo, CA, USA, 1992. Morgan Kaufmann.

43 Yoav Shoham and Moshe Tennenholtz. On social laws for artificial agent societies: off-line design. *Artificial Intelligence*, 73(1-2):231 – 252, 1995. Computational Research on Interaction and Agency, Part 2.

44 Harko Verhagen. *Norm Autonomous Agents*. PhD thesis, Department of System and Computer Sciences, The Royal Institute of Technology and Stockholm University, Sweden, 2000.

45 Harko Verhagen. Simulation of the Learning of Norms. *Social Science Computer Review*, 19(3):296–306, 2001.

46 Daniel Villatoro and Jordi Sabater-Mir. Categorizing social norms in a simulated resource gathering society. In *Coordination, Organizations, Institutions and Norms in Agent Systems IV: COIN 2008 International Workshops, Revised Selected Papers*, pages 235–249. Springer-Verlag, Berlin, Heidelberg, 2009.

47 Daniel Villatoro, Sandip Sen, and Jordi Sabater. Topology and memory effect on convention emergence. In *Proceedings of the International Conference of Intelligent Agent Technology (IAT)*. IEEE Press, 2009.

48 Wikipedia. Glossary of graffiti — Wikipedia, The Free Encyclopedia. `http://en.wikipedia.org/w/index.php?title=Glossary_of_graffiti&oldid=491070208`, 2012. Accessed 8 May 2012.

49 Michael Wooldridge. *An Introduction to MultiAgent Systems*. Wiley, 2nd edition, jul 2009.