

Modelling Organisations As Electronic Institutions

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Abstract: In recent times, artificial intelligence and social science have paid closer attention to computational modelling and analysis of organizations. The Multi agent systems community in particular has found organizations to be useful for the design of agent systems in which the regulation of the interaction among autonomous agents is possible. Similarly, social science organizational research has found computational models useful for analysis of structure and dynamics of real organizations. Motivated by this growing interest which is hinged on the importance of computational models for organizations, this paper presents the state of the art approaches to computational models for organizations with emphasis on electronic institutions.

Index Terms: Organizations, electronic institutions, Multi-agent systems, Computational Models.

1 INTRODUCTION

THE notion of *institution* is used in different contexts in everyday language. For example a given hospital is described as a “health care institution”, or we talk about “marriage institution”. These everyday uses and many other forms of institution have been studied and formalised by legal theorists, political scientists, economists, and philosophers (see [37], [4]). Some of the features presented in these conventional understandings include a distinction between institutional facts, for example x owns y , and brute facts for example x has-possession of y , and the assumption that institutions involve regulations, norms, and conventions in which some approaches presented by [34] and [36] take institutions to be the conventions themselves, thereby drawing a clear distinction between institutions and organisations. Others take institutions to be organisations consisting of rules or norms, institutional objects and due processes or procedures, but keep individuals out of the institution. As a result of these understandings and their formalisations, the agents community has used the notion of institutions to model and implement a variety of socio-technical systems serving the same purpose as conventional institutions. The aim is to enable and regulate the interaction among autonomous participants towards achieving some collective goals. This imply that interactions in the agent institution must comply with some conventions, rules, and norms that apply to every participating agent. Regulations control interactions and are applicable to individual agents on the basis of what they do (i.e roles they adopt) rather than on the basis of who they are [22]. The concept of institutions has its root in social science [34] and are regarded as the humanly devised constraints that shape human interaction, thereby reducing uncertainty as they provide structure to everyday interactions among humans. These institutions can be formal constraints such as rules and regulations formulated by humans, or informal constraints such as conventions, norms, and codes of behaviour [34]. Institutions are therefore regarded as the framework within which human interactions take place. They consist of constraints such as prohibitions and conditions under which certain actions are permitted by certain actors. However, in human interactions, it is a known fact that norms, whether formal rules or in formal codes, are usually violated either deliberately or unintentionally. An essential part of an institution therefore is the detection of violations and its effect on the society. In this paper, the focus is not on human society in general but what we consider a subset of the society, an

organisation which is defined as a social unit (or human grouping) constructed deliberately to pursue specific goals [19]. In addition to this we also consider an organisation as a unit which consist of a system of interacting human and technical actors constructed for specific goals. In this domain, there are constraints analogous to the institutions in a human society as discussed earlier, which specify what actions are acceptable and by what actors. There are also constraints that specify conditions under which certain actions can take place. For instance with respect to information security, organisations provide information security policies (ISPs) with the aim of controlling behaviours by providing employees (actors) with guidelines on how to ensure information security while they utilize information systems in the course of performing their jobs and also equipping systems with facilities that will ensure adequate information security [43], [8]. However, these actors are autonomous, heterogeneous, independent, unreliable, and liable. In the light of socio-technical systems, human actors have their own minds and would tend to behave in ways which are divergent from the expected pattern of behaviour. Also, things could go wrong with technical systems, such as hardware failures and software bugs, causing them to exhibit behaviours which are inconsistent with the expected behaviours. These divergent human behaviours and failures in the technical components of a system could make the system vulnerable to security attacks which would not have been determined at system requirement and design time.

2 ORGANISATIONS AND INSTITUTIONS

Institutions provide a structure for everyday life which guide human interactions. Institutions are the framework within which human interact as they define prohibitions, permissions and other conditions such as obligations for participants [34]. In our opinion, the notions of *institution* and *organisation* are closely related. The essential distinction is that the institution is focused on *what can be done*, while organisations focus on *who does it*. The increased complexity of real-world applications, which is exacerbated by the internet has called for the need to incorporate organisational abstractions into computing systems. This would enable the connection between the cyber and the physical due to the potential for conceptual alignment thereby easing the design, development, and maintenance of computing systems. This calls for the use of electronic institutions which provide a computational analogue of human organisations in which agents (representing humans) play different organisational roles and interact with each other and possibly humans to accomplish individual and organisational goals [40]. There are several research groups that see collections of heterogeneous agents as agent societies, and thus try to bring solutions from human

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societies into distributed application scenarios with heterogeneous actors. In these efforts the aim is to model a given society or organisation by defining some kind of (social) structure that establishes the (accepted) relations among agents or roles. This is important for the specification and balance of autonomy and control. These endeavours can broadly be categorised into two main approaches [3]: 1) Organisational approaches which construct the social structure by means of defining roles stating the restrictions to be followed by the agents that enact such roles, and 2) Institutional approaches which create the social structure by an accurate definition of the norms to be fulfilled by a given agent and the relations of deontic influence between agents

3 ORGANISATIONAL APPROACHES

An organisation can be seen as a set of entities and their interactions, which are regulated by mechanisms of social order (institutions) and created by more or less autonomous actors to achieve common goals. According to [15], organisations, as social systems, comprise a factual and a procedural dimension. The factual dimension consists of the observable behaviour of the organisation, that is, high level goals, inputs and outputs. The procedural dimension has to do with how this behaviour is obtained, that is, the division of labour into roles, the determination of authority lines and the establishment of communication links. Organisations are created to provide the means for coordination in order to achieve desired goals. The structuring of an organisation facilitates the flow of information within the organisation in order to reduce the uncertainty of decision making. The structure also should facilitate the integration of organisational behaviour across the different parts of the organisation for easy coordination [7]. Organisational approaches therefore aim at constructing social structures by means of roles and the relations and the restrictions over the agents that enact these roles. The literature abound on organisational approaches. We re view some selected approaches which include OperA [15], [38], OMNI[16], AGR [21], Moise+ [28], [29], [31], and O-Mase [26].

3.1 OperA Framework

In OperA framework [15], agents are seen as autonomous communicative entities that will enact societal role(s) as a means to realize their own goals according to their own internal aims and architecture. Interaction between agents is represented in such a way that: (i) it is independent of the internal design of the agents; (ii) distinguishes organisational characteristics from agents' own goals; (iii) creates dynamic links between organisational design and agent populations; and (iv) allows for the adaptation of interaction patterns to the characteristics of specific populations. That is, the OperA model enables the specification of organisational policies, such as objectives and norms and at the same time allowing participants to have the freedom to act according to their own capabilities and demands. It assumes organisations as being open systems, as such, it does not include constructs for the specification of the actual agents, treating them as "black boxes" that commit to a specific (negotiable) interpretation of the organisational roles [3]. OperA therefore meets the following requirements (adapted from [15]): 1) Internal autonomy requirement: The internal behaviour of the participating agents should be represented independently from the behaviour of the society. 2) External autonomy

requirement: The external behaviour of the participating agents (i.e., interaction with other agents or the environment) should be specified without completely fixing the interaction possibilities in advance. The OperA agent society framework is therefore presented in terms of three interrelated models viz;

- i) Organisational Model (OM)- which represents the organisational structure of the society, consisting of roles and interactions, as intended by the organisational stakeholders;
- ii) Social Model (SM)- in which the enactment of roles by agents is fixed in social contracts that describe the capabilities and responsibilities of the agent within the society, that is the agreed way the agent will fulfil its role(s); and
- iii) Interaction Model (IM) - which describes the possible interaction between agents in a given agent population.

Although OperA is formally founded in deontic logic, it is not executable without an implementation language since it does not specify the internal behaviour of agents and only specifies the "what" and not the "how". An agent-based implementation language such as Brahms [9] is needed to define the "how". [35] presents OperettA as a graphical tool that supports the design, verification and simulation of OperA models. It ensures consistency between different design parts, provides a formal specification of the organisation model, and is prepared to generate a simulation of the application domain. The OperettA prototype is implemented using Meta-Edit+, a generic customizable model driven software development environment suitable for prototyping. The prototype incorporates Racer DL reasoning system [27], SWI-prolog interpreter [44], MCMAS model checker [33] and BRAHMS [9] as a possible simulation environment.

3.2 OMNI

The Organisational Model for Normative Institutions (OMNI) [16] integrates the normative concepts of HarmonIA [41] with the organisational concepts of OperA [15]. OMNI is an integrated framework that can be used to model a whole range of multi-agent systems (MAS), from closed systems with fixed participants and interaction protocols, to open, flexible systems that allow and adapt to the participation of heterogeneous agents with different agendas. This is because it specifies global goals of the system independently from those of the specific agents that populate the system. Also, both the norms that regulate interaction between agents, as well as the contextual meaning of those interactions are modelled. OMNI is composed of three dimensions that describe different characterizations of the environment:

1. Normative dimension, which models all normative and regulatory aspects of the agent organisation.
2. Organisational dimension, which models the social structure, the roles, the intended interactions and the role enactment by agents
3. Ontological dimension, which defines the ontologies for communication and also the ontologies of the concepts appearing in both the normative and organisational dimensions.

The framework is further organized into three levels of abstraction:

1. The Abstract Level: where the statutes of the organisation to be modelled are defined in a high level of abstraction. This step is similar to a first step in the requirement analysis. It also contains the definition of terms that are generic for any organisation (that is, that are in contextual) and the ontology of the model itself.
2. The Concrete Level: where all the analysis and design process is carried on, starting from the abstract values defined in the previous level, refining their meaning in terms of norms and rules, roles, landmarks and concrete ontological concepts. In order to check norms and act on possible violations of the norms by the agents within an organisation, on the normative dimension, abstract norms have to be translated into actions and concepts that can be handled within such organisation. The organisational dimension specifies the means to achieve the objectives identified in the abstract level as an organisational Model. The content aspects of communication, or domain knowledge, are specified by Domain Ontologies and Generic Communication Acts which define the interactions languages used in the organisational Model.
3. The Implementation Level: Describes the implementation of the design in a given multi-agent architecture, including the mechanisms for role enactment and for norm enforcement. The normative dimension provides both the low-level protocols and the related rules that enable agents to comply with organisational norms. OMNI assumes that individual agents are designed independently from the society to model goals and capabilities of a given entity. Agent populations of the organisational model are described in the Social Model in terms of commitments regulating the enactment of roles by individual agents. Depending of the specific agents that will join the organisation, several populations are possible for each organisational model.

The modular structure of OMNI facilitates the adaptation of the framework to different types of domains. In those domains with none or small normative components, design is guided by the organisational Dimension, while in highly regulated domains the Normative Dimension is more prominent and therefore guides the design. However, there is no known tool yet for the implementation of this framework.

3.3 MOISE+

Adopting a different perspective, Hubner et al. (see [28], [29], [31]) presented Moise+ which is designed as an organisational model that explicitly distinguishes three dimensions in the modelling of an organisation namely structural, functional and deontic dimensions:

1. The structural dimension defines the agent's relationship through the notions of roles, groups and links by specifying three levels thus: i) the behaviours that an agent is responsible for when it adopts a role (individual level), ii) the acquaintance, communication, and authority links between roles (social level), and iii) the aggregation of roles in groups (collective level).

In Moise+ model, the adoption of roles is constrained by a compatibility relation between roles. An agent can play two or more roles only if they are compatible.

2. The functional dimension describes how a multi-agent system usually achieve its global (organisational) goals stating how these goals are decomposed (by plans) and distributed to the agents (by missions) and a set of coherent goals that an agent can achieve).
3. The deontic dimension addresses the autonomy of the agents by stating explicitly what is permitted and obligated in the organisation. The corresponding specification describes the roles' permissions and obligations for missions. A permission (P, m) states that an agent playing the role P is allowed to commit to the mission m . Furthermore, an obligation (P, m) states that an agent playing P ought to commit to m .

The Moise+ organisational model is an attempt to join these three dimensions into a unified model where the first two dimensions can be specified almost independently of each other and afterwards properly linked by the deontic dimension. This linkage allows the MAS to change structure without changing the functioning, and vice versa, the system only needs to adjust its deontic relation [30]. Moise+ has been extended with a J-Moise+ agent implementation level which is an extension of the AgentSpeak Jason features [6]. Additionally, SA Moise+ is an organisational middleware that connects the organisational model to the implementation level. It provides agents with the current state of the organisation and allows agents to change the organisation entity (OE) and specification [30]. S-Moise+ is an open source implementation of an organisational middleware that follows the Moise+ model. This middleware is the interface between the agents and the overall system, providing access to the communication layer, information about the current state of the organisation (created groups, schemes, roles assignments, etc.), and allowing the agents to change the organisation entity and specification. Of course these changes are constrained to ensure that the agents respect the organisational specification. S-Moise+ has two main components: an OrgBox API that agents use to access the organisational layer and a special agent called OrgManager. This agent has the current state of the OE and maintains it consistently. The OrgManager receives messages from the agents' OrgBox asking for changes in the OE state (e.g. role adoption, group creation, mission commitment). This OrgManager changes the OE only if it does not violate an organisational constraint. For example, if an agent wants to adopt a role $P1$ but it already has a role $P2$ and these two roles are not compatible, the adoption of $P1$ must be denied.

3.4 AGR

[21] notes that except in very small organisations, organisations are structured as aggregates of several partitions, sometimes called groups or communities, contexts, departments, services, etc. and each partition may itself be decomposed into sub-partitions. They therefore proposed the AGR (agent/group/role) model, based on three primitive concepts, Agent, Group and Role that are structurally connected in an organisation and cannot be defined by other primitives. An Agent is seen as an active, communicating

entity playing roles within groups. An agent may hold multiple roles, and may be member of several groups. An important characteristic of the AGR model, is that no constraints are placed upon the architecture of an agent or about its mental capabilities. Thus, an agent may be as reactive as an ant, or as clever as a human. A group is a set of agents sharing some common characteristics. A group is used as a context for a pattern of activities, and is used for partitioning organisations. Two agents may communicate if and only if they belong to the same group, but an agent may belong to several groups. This feature allows the definition of organisational structures. The Role is the abstract representation of a functional position of an agent in a group. An agent must play a role in a group, but an agent may play several roles. Roles are local to groups, and a role must be requested by an agent. A role may be played by several agents.

3.5 O-MaSE

[26] attributes the lack of widespread industrial acceptance of the many processes for developing MAS to the lack of Computer Aided Software Engineering (CASE) tools that support the process of software design. They therefore presented the Organisation-based Multi-agent System Engineering (O-MaSE) Process Framework, based on the Multi-agent System Engineering (MaSE) methodology [14] with the goal of allowing process engineers to construct custom agent-oriented processes using a set of method fragments based on a common metamodel. The O-MaSE meta-model is based on an organisational approach which is composed of five entities: Goals, Roles, Agents, Domain Model, and Policies. A Goal defines the overall function of the organisation, while a Role defines a position within an organisation, whose behaviour is expected to achieve a particular goal or set of goals. Agents are human or artificial (hardware or software) entities that perceive their environment and can perform actions upon it. In order to perceive and to act in an environment, agents possess Capabilities, which define the percept/actions the agents have at their disposal. Capabilities can be soft (i.e., algorithms or plans) or hard (i.e., hardware related actions). Plans capture algorithms that agents use to carry out specific tasks, while Actions allows agents to perceive or sense objects in the environment. This environment is modelled using the Domain Model, which defines the types of objects in the environment and the relations between them. Each organisation is governed by rules, which are formally captured as Policies. A Policy describes how an organisation may or not may behave in a particular situation.

4 INSTITUTIONAL APPROACHES

All human societies use social constraints to regulate the relations among its members. These social constraints are some sort of conventions and rules which govern human societies by defining the interactions between members of the society. The conventions and rules either originate from the normal practice in the society or from laws that were developed by the society. They are either informal (for instance customs and traditions) or formally defined (for instance laws and regulations). The constraints of a society influence the actions of its members who adopt them, thereby creating patterns of expected behaviour. A collection of these social constraints are referred to as institutions [34]. The integration of institutional constraints in a society allows every

participant to act according to the norms or rules of the institution. We present a review of relevant frameworks which have been proposed for the specification of organisations as multi-agent systems in the context of institutions. These are the E-Institutions [17], [40], [20] and HarmonIA [42], [41].

4.1 E-Institutions

This is a framework for electronic institutions that was first presented in [18]. The framework consists of a formal specification of the institution, a tool for editing the specification called ISLANDER, and a middleware called AMELI for executing the system based on the specifications [17], [20]. The concept of e-institutions include formal semantics for the core notions of the framework. The core notions of interest to us include agents and roles, scenes, and normative rules. Agents are defined as the players in the electronic institution while roles are taken to be standardised pattern of behaviour. Agents are required to adopt some roles and agents are allowed to perform actions associated with the adopted roles. This is similar to our framework in which roles, actors, and actions are defined and actions are associated with actors adopting roles. Scenes describe the articulation of agent interaction through well defined communication protocols. This could be seen as the possible dialogue agents could have. The a priori definition of the interaction protocol makes e-institutions unsuitable for our work. This is because the careful definition of the protocols means that agents cannot interact outside the defined protocols. We are looking at a situation where our actors can freely interact in which case, some of the interactions, such as violations, could lead to vulnerabilities to the system. Normative rules are presented in the context of limitations which are placed on agents as a result of consequences of the agent's previous actions. This is expressed using the deontic notion of obligation. The schema of the norms are therefore built around the notion of obligation. Drawbacks of e-institutions include the fact that most of the norms that define the workings of the institution are flattened and incorporated into the scene and inter-scene structure, without any explicit representation. Also, the implementation has the problem that the governors restrict the agents to the protocol that was defined on forehand, thus severely limiting the autonomy of the agents participating. This decreases the flexibility and robustness of the system overall.

4.2 HarmonIA Framework

The HarmonIA framework is first introduced in [42] as a framework that defines a multilevel structure, from the most abstract level of a normative system to the final implementation of the organisation. It is composed of four levels of abstraction:

1. The Abstract Level: where the statutes of the organisation are defined in a high level of abstraction along with the first abstract norms.
2. The Concrete Level: where abstract norms are iteratively concretised into more concrete norms, and the policies of the organisation are also defined.
3. The Rule Level: where concrete norms and policies are fully refined, linking the norms with the ways to ensure them.
4. The Procedure Level: where all rules and policies are translated in a computationally efficient implementation easy to be used by agents.

The division of the system into these four levels aims to ease the transition from the very abstract statutes, norms and regulations to the very concrete protocols and procedures implemented in the system. It is specially suited for those complex, highly regulated domains where the behaviour of a real organisation or an e-organisation has to follow regulations that define restrictions at different levels of abstraction [41]. In an attempt to solve part of the restrictive nature of the ISLANDER formalism, HarmonIA proposed the use of so-called Police Agents, that will be responsible for the enforcement of the norms. Such an implementation would allow the safety of the norms, while still allowing the agents (enough) autonomy to perform their tasks in manners that were not thought of at design, thus enabling them to handle unforeseen situations and adding a level of robustness to the system [3]. The ideas of [41] were further extended by [2] which applied parts of the methodology to highly-regulated environments (environments governed by lots of complex norms). [2] identified four important aspects of institutional implementations: 1) an ontology to allow communications between agents, and to express the meaning of the concepts used in the norms; 2) an (explicit) normative description of the domain, specifying the allowed interactions in the institution, presented in a format readable by (norm-aware) agents; 3) a set of protocols (conventions) that agents that are incapable of normative reasoning can use to perform their assigned task; and 4) an active norm enforcement mechanism to see to it that the norms specified for the domain are adhered to and that order and safety is guaranteed in the system. These four elements are combined into a methodology that gives the relations between laws and electronic institutions. Moreover, (formal) methods are specified for the implementation of norm enforcement and the (automatic) creation of protocols (based on constraints specified by the norms).

4.3 INSTAL Framework

The INSTAL framework [10] is a normative framework architecture with a formal mathematical model to specify, verify and reason about the norms that govern an open distributed system. The INSTAL approach has opted for an event-driven institutional approach: the norms are expressed on the events/actions of the participants rather than the normative state. Deviation from a norm results in a violation. The premise of the model is that events trigger the creation of institutional fluents. Inspired by Jones and Sergots [32] account of institutional power and the notion of counts-as, the generation relation is used to explain the connection between actions and their interpretation in the context of the institution. The effects of events, actions or institutional events in terms of the initiation or termination of brute facts [39] and institutional fluents is described by the consequence relation. Thus, given an event and a state of the institutional model, represented as a set of (institutional) fluents, the next state can be determined by the transitive closure of the generation relation and the consequence relation. The system was extended to be able to deal with interacting normative systems [11]. The formal model and semantics is translated in an equivalent logic program under the answer set semantics [5]. Answer set programming is a declarative programming paradigm with an operational semantics. To support the designer, an associated action language, InstAL, is provided. Designing a set of norms can be an erroneous process. To support the designer, an inductive logic programming system [12] was developed.

4.4 OCeAN Model

OCeAN (Ontology Commitments Authorizations Norms) [22] is a metamodel that can be used to specify electronic institutions. Those institutions, thanks to a process of contextualization in a specific application domain, can be used in the design of different open systems by enabling the interaction of autonomous agents. The fundamental concepts of this model, which need to be specified when designing electronic institutions are: (i) an ontology for the definition of the concepts used in the communication and in the specification of the rules of the interaction; (ii) the definition of the events, the actions, and the institutional actions and events that may happen or can be used in the interaction among agents; (iii) the definition of the roles that the agents may play; (iv) an agent communication language (ACL) for the exchange of messages; (v) the definition of the institutional powers for the actual performance of institutional actions; (vi) a set of norms for the specification of obligations, prohibitions, and permissions. This model has been formalized using the Discrete Event Calculus (DEC) [24], which is a version of the Event Calculus. Recently some parts of this model have been formalized using Semantic Web technologies [25], [23].

5 SUMMARY OF MODELS

In summary, from the above survey, it is clear that a number of these models are complementary, since each focuses its strength on aspects of the organisation the authors deemed more important and some of them are covered in other models, although given different terminologies. For instance, it is clear that the AGR model corresponds to the structural dimension of the MOISE+ model. Also while MOISE+ places emphasis on the structural and functional dimensions of an organisation, it does not consider the interactive dimension. HARMONIA mainly focuses on the normative aspect of an organisation which is also considered in OperA. However, in a more recent model OMNI [16] present an integrated framework modelling multi-agent organisations based on the two earlier models OperA and HARMONIA. This model tends to complement the strengths of each of the earlier models, therefore covering relatively well the various dimensions of an organisation. Also comparing the ISLANDER language with AGR and MOISE+, aside from the change in terminology from organisation to institution, ISLANDER focus on institutional aspect of organisations which is further expressed in normative aspects (norms that enforce behaviour) and dialogical aspects (dialogic interactions), while AGR and MOISE+ model structural and functional aspects of an organisation [13]. O-MaSE relied strongly on structural and functional dimensions of an organisation. INSTAL and OCeAN focus on the dialogical and normative aspects of an institution while providing formal means for specifying, verifying, and reasoning about norms. Table 1 summarises these relative strengths and weaknesses.

TABLE 1
THE RELATIVE EXPRESSIVENESS OF SOME ORGANISATIONAL MODELS (ADAPTED FROM [13])

Model	Modelling Dimension			
	Structural	Dialogical	Functional	Normative
AGR	++	+	-	-
MOISE+	+++	-	+++	+
O-MaSE	++	-	++	+
HARMONIA	++	+++	+	+++

OperA	++	-	+	+++
ISLANDER	+	+++	-	++
OMNI	++	+++	+	+++
InstAL	+	+++	+	+++
OCeAN	++	++	+	+++

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