Engineering Autonomic Electronic Institutions

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Abstract. In this work we introduce the EIDE-* framework to support the engineering of a particular type of self-* systems, namely *autonomic electronic institutions*: regulated environments capable of adapting their norms to comply with institutional goals despite the varying behaviours of the participants.

1 Introduction

A particular approximation to the construction of self-* systems is represented by the vision of autonomic computing [5], which constitutes an approximation to computing systems with a minimal human interference. Unfortuntately, there is a lack of frameworks that support the intricate task of developing systems with autonomic capabilities (an exception begin the Living Systems framework [6]). Nonetheless, it is hard to conceive a general-purpose development framework for self-* systems. Therefore, our endeavour can be eased if we depart from a particular model of open system [4] that can eventually be endowed with self-management capabilities. Electronic institutions (EIs) [1], regulated environments wherein the relevant interactions among participating agents take place, have proved to be valuable to develop open agent systems. Indeed, EIs do even count on a development environment (EIDE) to ease their engineering [1]. However, the challenges of building open systems as EIs are still considerable, not only because of the inherent complexity involved in having adequate interoperation of heterogeneous agents, but also because the need for adapting regulations to comply with institutional goals despite varying agents' behaviours.

In this work we introduce the EIDE-* framework to support the engineering of a particular type of self-* systems, namely *autonomic electronic institutions*: regulated environments capable of adapting their norms to comply with institutional goals despite the varying behaviours of the participants. EIDE-* must be regarded as an extension of EIDE. Furthermore, we illustrate the capabilities of the framework through the analysis of an electricity market inspired on the actual operation of the Spanish one. We show how EIDE-* can support self-configuration policies to avoid a lack of production that can leave customers without supply and an unwanted overproduction.

The paper is organized as follows. Section 2 introduces the formal concepts around autonomic electronic institutions. Section 3 describes EIDE-*. Section 4 presents the electricity market problem along with its engineering and the required self-configuration policies. Finally, we wrap up conclusions in section 5.

2 Autonomic Electronic Institutions

Loosely speaking, EIs are computational realizations of traditional institutions; that is, coordination artifacts that establish an environment where agents interact according to stated conventions, and in such a way that interactions within the (electronic) institution would *count as* interactions in the actual world.

According to the basic definition of an electronic institution (see [1]), an EI is composed of three components: a dialogical framework that establishes the social structure, the ontology, and a communication language to be used by participating agents (playing either institutional –staff– or non-institutional –external– roles); a performative structure defining the activities (also named scenes) along with their relationships; and a set of norms defining the consequences of agents' actions.

MAS applications are usually concerned with some external environment. The environment is application-specific and refers to the part of the world that is relevant to the MAS application. For instance, in the electricity market example that will be presented in section 4, the power demand is modeled by an equation-based tool that simulates real electrical consumption patterns. Environments are plugged into EIs as institutional services [2]. In our approach, agents cannot directly sense and act over the environment. Instead, and likewise all interactions of external agents in the realm of an EI, they are *mediated* by the institution wherein they interact.The link of an institution with an environment enriches the functionality of the EI components.

2.1 Self-Organizing Capabilities

From this basic definition of an EI we have extended the model to support self-configuration [3]. The notion of Autonomic Electronic Institutions (AEIs) has been proposed as a model for providing self-configuration capabilities to EIs. AEIs incorporate three new main components: en explicit set of *institutional goals* G, an *information model* I, and a *normative transition function* δ that allows to transform interaction conventions.

The main objective of an AEI is to accomplish its goals. For this purpose, an AEI has to be able to both dynamically observe/analyze the performance of the institution and to adapt its interaction conventions. Thus, from the observation of environmental properties, institutional properties, and agents institutional properties, an AEI maintains the information model I required to determine the fulfillment of goals. Formally, we define the goals of an AEI as a tuple $G = \langle V, C \rangle$ composed of : (i) a set of reference values $V = \langle v_1, \ldots, v_q \rangle$ where each v_j results from applying an evaluation function h_j upon the information model; $v = h(I), 1 \leq j \leq q$; and (ii) a finite set of constraints $C = \{c_1, \ldots, c_p\}$ where each c_i is defined as an expression $g_i(V) \triangleleft [m_i, M_i]$ where $m_i, M_i \in \mathbb{R}$, $\triangleleft$ stands for either $\in$ or $\notin$, and g_i is a function over the reference values. In this manner, each goal is a constraint upon the reference values where each pair m_i and M_i defines an interval associated to the constraint. Thus, the institution achieves its goals if all $g_i(V)$ values satisfy their corresponding constraints of being within (or not) their associated intervals.

Finally, the normative transition function δ defines the set of actions allowed for re-configuring the institution at runtime. The re-configuration is performed by changing the interaction conventions. Specifically, δ actions will have effects over the performative structure and the normative rules. For instance, the role flow policy among activities can be modified by the normative transition function. Nowadays, we are not dealing with the re-configuration of the dialogical framework (i.e. the social structure, the domain ontology, and the communication language are invariant). Because staff agents are those in charge of the institutional activities, only staff agents will be allowed to observe the fulfillment of the institutional goals and will be able to change the interaction conventions.

3 Development and Simulation Framework

In order to facilitate the engineering of AEIs we have developed a set of software tools that give support to all the design and execution phases. These tools are integrated in the Development Environment for Autonomic Electronic Institutions (EIDE-$*$). EIDE-$*$ allows for engineering both the institutional rules and the participating agents. Figure 1 depicts the EIDE-$*$ framework. The tools provided by the EIDE-$*$ framework are: a graphical tool that supports the specification and static ver-

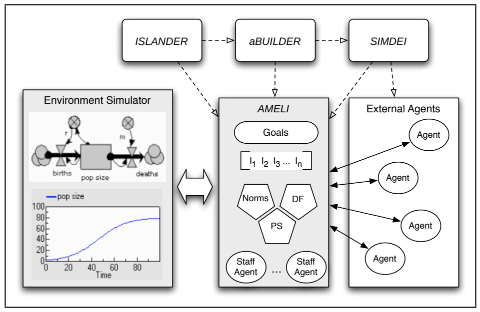

Fig. 1. The EIDE-$*$ Framework.

ification of institutional rules (*ISLANDER*); an agent development tool (*aBUILDER*); a simulation tool to animate and analyse *ISLANDER* specifications (*SIMDEI*); and a software platform to run EIs (*AMELI*). All these tools have been enhanced to provide the new requirements of autonomic electronic institutions.

The core of EIDE-$*$ is *AMELI* [1], an institutional engine that provides a run-time middleware for the agents that participate in the enactment of a given institution. The middleware is deployed to *guarantee* the correct evolution of each scene, to *warrant* legal movements between scenes, and to *control* the obligations or commitments that participating agents acquire and fulfill. Furthermore, the middleware *handles* the information agents need within the institution. The *AMELI* generated middleware *mediates* between agents in order to facilitate agent communication within scenes. Broadly speaking, *AMELI* achieves those functions because on the one hand it generates the staff agents and the institutional *governors* that mediate all communications with external agents and, on the other hand, it handles all the institutional communication traffic by wrapping illocutions as messages that are handled by a standard agent-communication layer. *AMELI* has been extended so that staff agents can observe the fulfillment of the institutional goals and change the interaction conventions at run-time.

We have developed an extended version of *SIMDEI* (introduced in [1]). *SIMDEI* allows to run discrete event simulations of *AMELI* interleaved with environment simulations. *SIMDEI* can exploit parametrised agent skeletons to generate agent populations by setting the number of agents to create from a given skelenton along with the means to set up values for their parameters. An agent's action can be parametrised in two ways:

(i) by defining whether an action is carried out or not as a parameter; (ii) by defining (some of) the actual values of each action as parameters.

4 Electricity Market

We illustrate the capabilities of the framework through the *Power Electricity Market* problem. The main goal of an electricity market is to provide a set of rules to conciliate the demand of electricity and its generation. There are two issues that must be avoided: a lack of production that can leave some customers without electricity and an unwanted overproduction. Moreover, these goals have to be achieved while maintaining a reasonable electricity price. We model an electricity market as an electronic institution where the power demand is the environment where the institution is situated and the market is only able to partially observe the impact of their decisions in the environment.

Market Goals. As mentioned above, the first goal of the electricity market AEI is to guarantee that the energy demand is always satisfied and that the overproduction is minimized. Because each producer is obliged to guarantee a safety power that is a 10% of its production, we are interested in minimizing the amount of safety power required. The second goal of the market is to keep the power cost in a reasonable interval. Given these goals, we define four reference values in the AEI: the power deficit percentage (PDP); the overproduction percentage (OPP); the power cost average (AvgC); and the power cost deviation (DevC). Because we are interested in experimenting with different scenarios, the constraints associated to the reference values (the maximum and minimum ranges) are parameters to set when enacting specific institutions.

Market Players. The *producers* use different technologies for electricity generation in order to satisfy the demand. The three main types of power stations modeled are: Thermic stations, Nuclear stations, and Hydroelectric stations. Each type of power station has its own production features. For instance, nuclear and hydroelectric are cheap and come on stream rapidly. However, if nuclear plants are backed-off significantly, recovery time is slow. Producers are external roles in the institution.

The *consumers* that participate in an electricity market are large industrial companies and local energy wholesalers that sell the energy to smaller or domestic consumers. The main goal of the consumers is to buy energy for half an hour periods according to the information provided by the demand model. Consumers are external roles in the institution.

The task of the *system operator*, as an institutional role, is to guarantee the voltage level and the dynamic security of the electricity network. Specifically, the system operator controls that the power deficit is never greater than a 10% of the total production, which is the obliged safety power that each power station must fulfill. Notice that, in our example, producers are autonomous about deciding their own production and the system operator is only responsible for the distribution of the demand.

Market Activities. The *primary market* performs periodic auctions of transmission rights, in the form of tickets valid for the injection or extraction of energy over the next half an hour period. We have modeled it as a double auction. Every half an hour a new auction is launched.

Once the auction has taken place, the goal of the *secondary market* is to provide an additional round for the trading of transmission tickets. It supports the trading of a ticket until half an hour before the ticket time.

The *balancing market* exists to permit the system operator to adapt the plans of production to the quality and security restrictions. Based on the analysis of the tickets held in the previous markets, the system operator can identify shortfalls or excesses of energy that may arise during the ticket window. The only actions available are: the dispatching of additional generation and the back-off of scheduled generation.

Environment. The power demand has been modeled following the electrical consumption in Spain every hour. The information has been obtainedfrom the "Red Eléctrica Española" (http://www.ree.es) which controls the electrical power distribution in Spain. The power demand has been simulated using the EJS tool. We have modeled four diffenent consumption patterns: working days, Saturday, Sunday, and holidays. Moreover, some perturbations can be introduced arbitrarily into the simulated patterns. We have developed the `MarketForecast` service that offers forecast methods for expected demand, energy production, and MWh price; as well as a method to retrieve past market price on a particular date. Furthermore, it provides a method for acting into forecast calculi to set the contract information corresponding to a market cleared by the system operator. This method influences the demand simulation and, consequently, the subsequent forecasts. The idea behind this method is to disturb the estimation of the next expected price by means of analyzing the production and consumption mismatches. The `ForecastProfile` profile only allows external agents to obtain information about past market prices on particular dates, and the expected energy demand and production. Consumers can access the production forecast, whereas only producers can access the demand forecast.

4.1 Self-Configuration Policies

The system operator tracks the fulfillment of the institutional goals and the one responsible for re-configuring them when necessary.

The interest of the institution is the market autonomy, i.e. that producers and consumers would reach all the required agreements in the primary and secondary markets with the minimum mismatch between offer and demand. The intervention of the system operator in the balancing market has to be minimized and the task of the system operator is to dynamically adapt the institutional rules for enforcing this result.

After each execution round in the balancing market, the institutional goals are automatically updated by *AMELI*. First at all, the result of a balancing market round fires the updating of the reference values: the power deficit percentage (PDP); the overproduction percentage (OPP); the power cost average (AvgC); and the power cost deviation (DevC). Then, the fulfillment of the goals is updated by checking the constraints related to each goal, i.e. by contrasting position of the reference values into the desired intervals.

The most important goal of the institution is to minimize the amount of reserve power consumed (PDP). Because the guaranteed reserve power is only a 10% of the production, the priority of the system operator must be to avoid the usage of this reserve. The system operator uses the `MarketForecast` service for assessing whether a usage of the reserve power is the product of a punctual demand peak (the power demand usually has two maximum peaks per day) or reflects a problem between offer and demand. Only this second phenomenon is considered as an indicator to re-configure the institutional rules. We assume that producers and consumers follow a rational behavior. Producers are interested in offering all the energy they are able to produce when demand peaks arise because the price in those situations is usually high. On the counter part, consumers are aware that they have to pay an extra price when the global demand is high. Thus, the main reason of this market mismatch is the partial awareness that each consumer or producer has about the global market behavior. The scope for action of the system operator focuses the secondary and balancing markets. The system operator may change the role flow policies for enforcing the participation of producers in the secondary market and for re-configuring the protocol parameters in the secondary market providing more flexibility to consumers.

The overproduction is preferable to the lack of production but also has to be minimized. Assuming again a rational behavior in producers and consumers, the system operator will change the role flow policies for inhibiting the participation of producers in the secondary market. Furthermore, the system operator may change the window of the demand forecast the producers are able to access, i.e re-configuring the `ForecastProfile` for helping the producers in the planning of their optimal production.

Finally, maintaining the energy cost in a reasonable interval should be a natural consequence of any balanced market. Because of the openness of participants this hypothesis cannot be assumed and the system operator has to prevent also unexpected low/high prices. The way a system operator may enforce reasonable prices is by modifying the normative rules of the institution by increasing/decreasing punishments.

5 Conclusions

In this paper we have tried to make headway in the engineering of self-* systems by introducing the EIDE-* framework to support the development of *autonomic electronic institutions* (AEIs). We have introduced the formal concepts around autonomic electronic institutions and described the set of tools we provide for helping in the engineering of autonomic electronic institutions. We have also illustrated the capabilities of EIDE-* through the analysis of self-configuration policies in an electricity market.

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