Chapter 1
mWater, a Case Study for Modeling Virtual Markets

Antonio Garrido, Adriana Giret, Vicente Botti and Pablo Noriega

Abstract We propose an electronic institution approach to build a virtual market as an open multi-agent system that handles several negotiation protocols in a coherent and flexible fashion. This proposal has been inspired by the work in *mWater*, which is developed as a regulated environment where autonomous agents trade rights for the use of water in a closed basin. We also present a generic negotiation framework that is enabled with tools to specify performance indicators, to spawn agent populations and allow humans, as well as software agents, to participate in simulations of water-right virtual trading. This demonstrates an interesting aid for data organisation, and for communication and negotiation among the different stakeholders of a basin.

1.1 Introduction and Motivation

As previously discussed in this book, virtual organisations are an emerging means to model, enact, and manage large-scale computations. They are composed of a dynamic collection of semi-independent autonomous entities, each of which has a range of problem solving capabilities and resources at their disposal [12]. These entities exhibit complex behaviours; they usually co-exist, collaborate and agree on some computational activity, but sometimes they compete with one another in a ubiquitous virtual marketplace.

Virtual markets appear because of the electronic-commerce phenomenon and provide a flexible architecture for autonomous, or semi-autonomous, agents playing

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different roles (standard participants, such as buyers or sellers, and market mediators/facilitators) and protocols governing the interaction of self-interested agents engaged in the market transaction sessions. Interactions among agents, realised as Multi-Agent Systems (MASs), aim at achieving individual and global goals, and are structured via collaboration, argumentation, negotiation and, eventually, via AT, and contracts, which are modeled as a set of (formal) commitments that can have complex nested structures.

The transition from a regulated monopolistic system to a decentralised open virtual market raises many questions, particularly as markets evolve. First, how to develop negotiated semantic alignments between different ontologies meeting the new requirements of the organisation. Second, how to recruit agents or services to form teams or compound services for the market, and how they negotiate in these emerging organisations. Third, how the conventions, norms and negotiation protocols of the market change over time, and how participants in these markets react to these changes. Four, how to extrapolate the empirical outcomes of the market, in terms of economic and environmental impact, to deal with the social (welfare) aspect of the market. On the other hand, existing works about virtual markets put special emphasis on the construction of formal conceptual models, such as goods markets, stock markets, electricity markets and water markets [10, 19, 20], but they do not always report significant advances from a social point of view or a collaborative AI perspective.

In summary, virtual markets provide new areas of opportunities for users (buyers and sellers), while also change the relationships among users and market facilitators, making them more agile. But building these markets faces important challenges to achieve an efficient management of the operation rules, and new capabilities are required: i) rich ontology and semantics; ii) norm reasoning, enforcing and regulating entities; iii) flexible organisation schemes; iv) coordination and cooperation (even dynamic group formation); v) rules for negotiation, argumentation theories and conflict resolution techniques; vi) trust models and reputation mechanisms; vii) control and security; and, finally, viii) a seamless way to integrate all these components. Although this chapter is far from being the last word on this integration, we try to push forward the agenda for innovative disciplines within virtual markets using *mWater*, a real-world water-right market, as a case study [5, 4]. Thus, this chapter is clearly multi-disciplinary and deals with many components from both AI and AT that offer the foundations for an agreement computing solution, including agility, scalability, heterogeneity and reconfigurability issues [16]. The main objective of this chapter is to provide a fundamental study of the means of constructing a formal conceptual model for a virtual market (using water rights as an application example) under a multi-agent perspective.

1.2 A Virtual Market Scenario for Water Rights

A virtual market, as part of a virtual organisation with a general structure, can be seen as a set of entities and roles regulated by mechanisms of social order and created by more or less autonomous actors to achieve some goals.

1.2.1 Description and Objectives

Water scarcity is a significant concern in most countries, not only because it threatens the economic viability of current agricultural practices, but because it is likely to alter an already precarious balance among its different types of use. Also, good water management involves a complex balance between economic, administrative, environmental and social factors. These balance is partially determined by physical conditions like rainfall, water supply and distribution infrastructure, population distribution, land use and main economic activities. However, actual water demand is the determining balancing condition, and actual water use is the outcome to measure the success of an adequate water management policy.

More efficient uses of water may be achieved within an institutional framework where water rights may be exchanged more freely under different market conditions [19]. The willingness of irrigators to buy or sell water highly depends on the difference between the price of water and net revenue each farmer expects to earn by irrigating, and similarly for other stakeholders like utility companies or municipalities. Nevertheless, it is not always a matter of price expectations alone what motivates users to trade water rights. Policy-makers may wish to promote trading that favours outcomes that may not necessarily be directly associated with price expectations. But formulating market regulations that have the intended effects is not straightforward. There are many aspects that may be regulated and many parameters involved and, therefore, the consequences of the many combinations are difficult to foresee, not to mention the oftconflicting interests of the many stakeholders.

In hydrological terms, a water market can be defined as an institutional, decentralised framework where users with water rights are allowed to voluntarily trade them, always fulfilling some pre-established norms (legislation), to other users in exchange of some compensation [10, 19]. Water-right markets allow rapid changes in allocation in response to changes in water supply and demand, and ideally allow to stimulate investment and employment when users are assured access to secure supplies of water. Because of water unique characteristics, such markets do not work everywhere, they are not homogenous since they operate under different organisational and institutional schemata, nor do they solve all water-related issues [11, 19]. Some experiences have shown that more flexible regulations may be desirable but policy-makers need means and methodologies that allow them to visualise the potential consequences of new regulations and fine-tune them before enacting them, in order to avoid undesirable outcomes. Underneath this situation, the crude reality of conflicts over water rights and the need of accurate assessment of water needs become more salient than ever. In order to deal with these issues, the main objectives in *mWater* are to help:

- Find the best conditions and taking the best decisions on the design of the market; even subtle changes are very costly. Since they are difficult and delicate tasks, and cannot be freely applied in the real world, a virtual market provides a valuable environment for testing.
- Deploy a virtual market to simulate the interplay among intelligent agents, rule enforcing and performance indicators. This market also provides a playground for the agreement computing paradigm to easily plug in new techniques, such as trust mechanisms, negotiation, cooperations, argumentation, etc., and assess their impact in the market indicators, which is very interesting.
- Offer a mechanism for policy-makers to evaluate the effects of norms in the market. In general, a policy-maker has little control over the hydrographical features of a basin but (s)he has legal power to regulate water user behaviour to a larger extent by means of: i) government laws, ii) basin or local norms, and iii) social norms. Consequently, one aim of a policy-maker in using such a virtual market is to design appropriate water laws that regulate users actions and, in particular, give users the possibility of exchanging water resources.

It should also be mentioned that, from a performance standpoint, it is unclear which is the best quality indicator of water management as it cannot be measured in terms of one factor. Furthermore, many outcome functions have singularities that are hard to identify, test and visualise by existing analytical tools.

1.2.2 Related Work

Sophisticated basin simulation models are present in literature, particularly decision support systems for water resources planning, sustainable planning of water supply, and use of shared visions for negotiation and conflict resolution [2, 7, 13, 18]. From a hydrological perspective, these works have successfully bridged the gap between the state of the art in water-resource systems analysis and the usage by practitioners at the real-world level. However, the gap is still wide from a social perspective. The need is not only to model hydraulic factors, but also norm typology, human (mis)conducts, trust criteria and users willingness to agree on water-right trading, which may lead to a more efficient use of water.

Most water management models are based on equational descriptions of aggregate supply and demand in a water basin; only a few include a multi-agent-based perspective. This perspective allows us to emulate social behaviour and organisations, where the system is used to mimic the behaviour of autonomous rational individuals and groups of individuals [18]. In this way, complex behavioural patterns are observed from simulation tests in which autonomous entities interact, cooperate, and/or compete. This offers several advantages: i) the ability to model and implement complex systems formed by autonomous agents, capable of pro-active and social behaviour; ii) the flexibility of MAS applications to add and/or delete computational entities, in order to achieve new functionalities or behaviours in the system, without altering its overall structure; iii) the ability to use notions such as organisation, norms, negotiation, agreement, trust, etc. to implement computational systems that benefit from these human-like concepts and processes among others [16]; and finally iv) the possibility to use 3D Virtual Worlds to provide all the necessary means for direct human inclusion into software systems, as proposed in chapter "v-mWater: an e-Government Application for Water Rights Agreements" in this same book.

Under this perspective, we explore an approach in which individual and collective agents are essential components because their behaviour, and effects, may be influenced by regulations. *mWater* is inspired by the MAELIA (`http://www.iaai-maelia.eu`) and NEGOWAT projects (`http://www.negowat.org`) that simulate the socio-environmental impact of norms for water and how to support negotiation in areas where water conflicts arise.

From a technical perspective, there are several approaches to implement MAS applications. Some approaches are centered and guided by the agents that will populate the systems, while others are guided by the organisations that the constituent agents may form. Other approaches rely the development process on the regulation that defines the MAS behaviour, which is usually encoded as an Electronic Institution (EI) [1, 8, 14]. We are interested in this latter approach due to the requirements imposed by the environment, which is presented in the next section. In particular, *mWater* —from the standpoint of a MAS simulation tool, later described in section 1.4.2— implements a regulated market environment as an EI, in which different water users (intelligent agents) trade with water rights under different basin regulations.

1.2.3 An EI Framework for mWater

Our conceptual model for *mWater* virtual market follows the IIIA EI description [3]. In short, an EI is a type of regulated MAS that combines a workflow (scenes and networks of scenes, namely performative structures), and regulation on structural norms. EIs are a way of expressing and implementing the conventions that regulate agent interactions. They may be understood as an interface between the internal decision-making capabilities of an agent and the external problem domain where those agents interact to achieve some goals.

Performative structures.

Procedural conventions in the *mWater* institution are specified through a nested performative structure (see Fig. 1.1[1]) with multiple processes. This top structure de-

[1] At a glance, a performative structure represents complex interaction models and procedural prescriptions. The dynamic execution is modeled trough arcs and transitions, by which the differ-

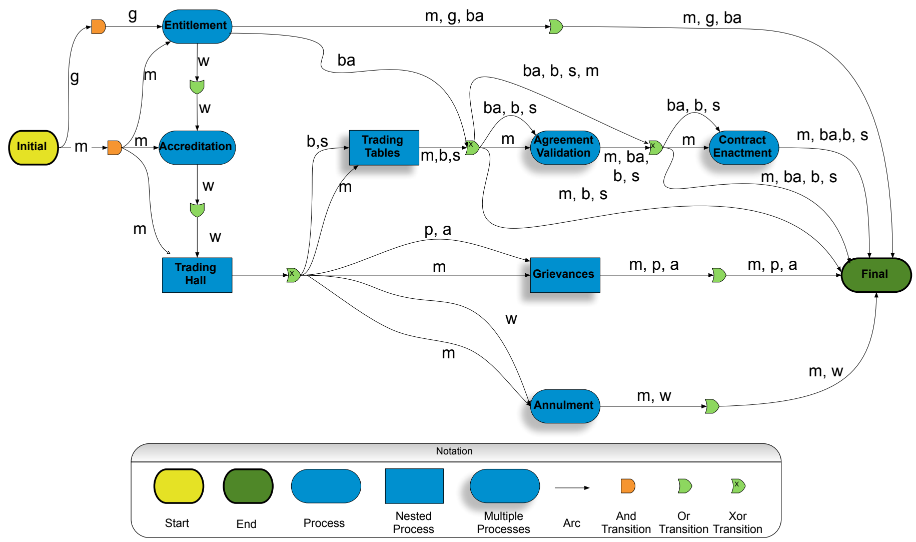

Fig. 1.1 *mWater* performative structure. Participating Roles: *g* - Guest, *w* - Water user, *b* - Buyer, *s* - Seller, *p* - Third Party, *m* - Market Facilitator, *ba* - Basin Authority

scribes the overall market environment, and includes other performative structures and scene protocols as follows.

Top performative structure of the market (Fig. 1.1). *Entitlement*. Only bona fide right-holders may trade water rights in the market and there are only two ways of becoming the owner of a right. Firstly when an existing right is legally acquired from its previous owner outside of *mWater* (through inheritance or pecuniary compensation for example). Secondly when a new right is created by the *mWater* authorities and an eligible holder claims it and gets it granted. *Entitlement* scene gives access to the market to new right holders who prove they are entitled to trade. It is also used to bootstrap the market.

Accreditation. This scene allows legally entitled right-holders to enter the market and trade by registering their rights and individual data for management and enforcement purposes.

Agreement Validation and *Contract Enactment*. Once an agreement on transferring a water right has been reached, it is managed according to the market conventions. *mWater* staff check whether or not the agreement satisfies formal conditions and the hydrological plan normative conventions. If the agreement complies with these, a transfer contract is agreed upon and signed by the parties involved in the *Contract Enactment* scene, and then the agreement becomes active.

Annulment. This scene in the *mWater* performative structure deals with anomalies that deserve a temporary or permanent withdrawal of rights.

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ent participating roles of the institution may navigate synchronously (AND transitions) or asynchronously (OR/XOR transitions). See [3] for further details on this type of notation.

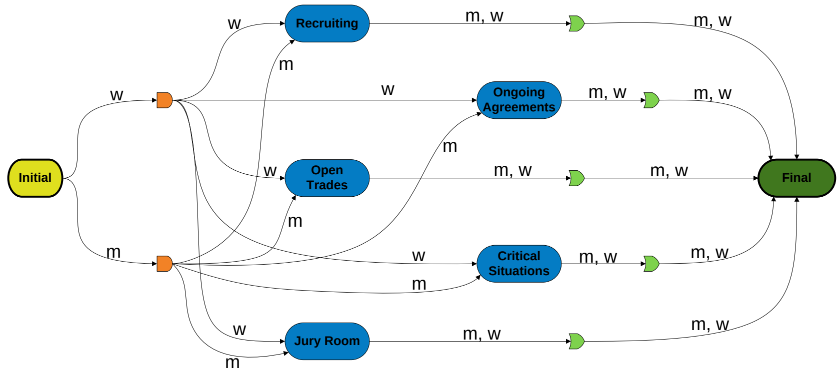

Fig. 1.2 *TradingHall* performative structure

***TradingHall* performative structure** (Fig. 1.2). Intuitively, in this complex performative structure right-holders become aware of the market activity (*Open Trades* and *Ongoing Agreements* scenes), and initiate concurrent activities: get invitations to trade and/or initiate trading processes (*Recruiting* scene), initiate grievance procedures (*Ongoing Agreements* scene), and get informed about anomalous situations (*Critical Situations* scene), for example severe drought situations. Actual trading starts inside the *TradingHall* scene. On the one hand, updated information about existing tradeable rights, as well as ongoing deals, active contracts and grievances is made available here to all participants. On the other, as shown in Fig. 1.2, users and trading staff can initiate most trading and ancillary operations here (from the *Recruiting* scene): open, request trading parties and enter a trading table; query about different agreements; and initiate a grievance procedure from the *Ongoing Agreements* scene or, in the same scene, get informed about a dispute in which the water user is affected. Members of the Jury may also be required to mediate in a dispute at the *Jury Room* scene. Technically speaking, all these scenes are "stay-and-go" scenes. While the users are inside the market, they have to *stay* permanently in these scenes but they may also *go* (as *alteroids*, clone-like instantiations of the same agent that allow the agent to be active simultaneously in different scenes) to trading table scenes and contract enactment scenes where they are involved. The scenes where user alteroids become involved are created (as a new *instance* of the corresponding performative structures) when a staff agent creates one at the request of a user, of an authority, or because of a pre-established convention (like weekly auctions).

***TradingTable* performative structure** (Fig. 1.3). In our *mWater* performative structure (recall Fig. 1.1), a market facilitator can open a new trading table whenever a new auction period starts or whenever a right-holder requests to trade a right outside the auction hall. In such a case, a right-holder chooses a negotiation protocol from a set of available ones In order to accommodate different trading mechanisms, we assemble the *TradingTable* performative structure as a list of different scenes, each corresponding to a valid trading mechanism or negotiation protocol. Each in-

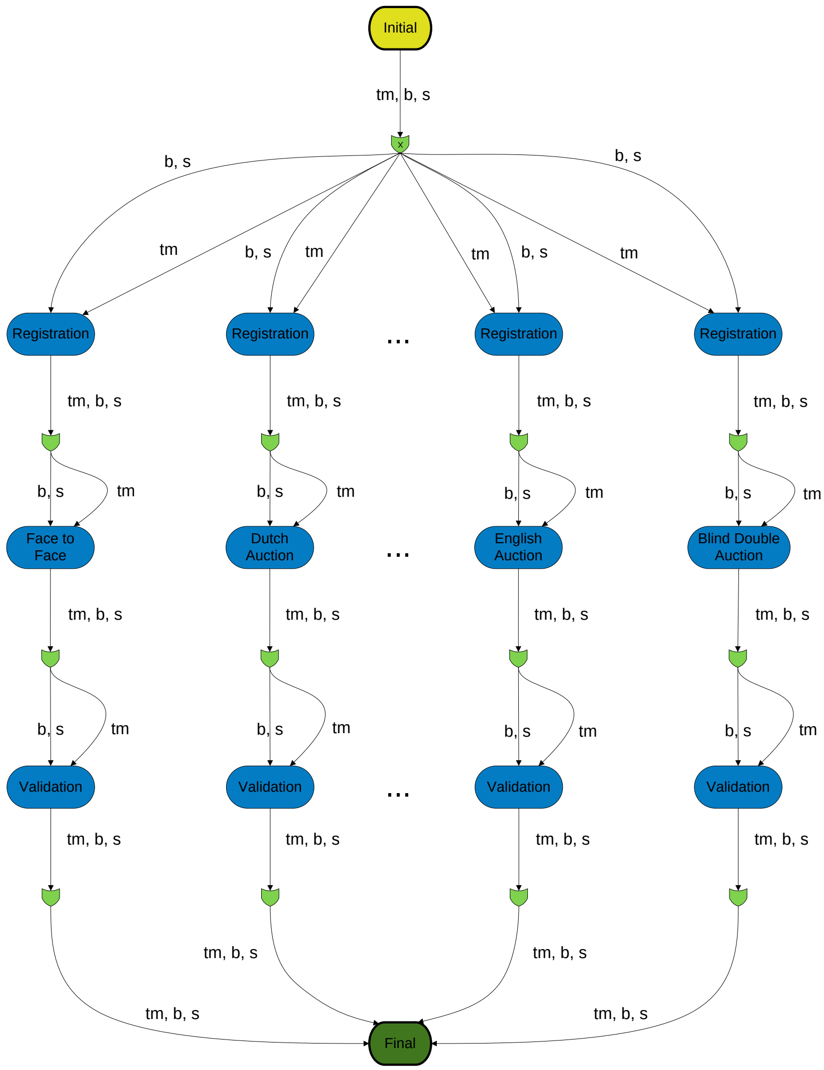

Fig. 1.3 *TradingTable* performative structure

stance of a *TradingTable* scene is managed by a *Table Manager*, *tm*, who knows the structure, specific data and management protocol of the given negotiation protocol.

Every *TradingTable* is defined as a three-scene performative structure. The first scene is *Registration*, in which the *tm* applies a filtering process to assure that only valid water users can enter a given trading table. The specific filtering process will depend on the given trading protocol and possibly on domain specific features. The second scene is the trading protocol itself, in which the set of steps of the given protocol are specified. Finally, in the last scene, *Validation*, a set of closing activities

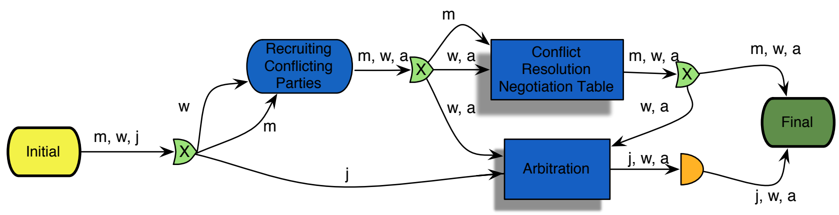

Fig. 1.4 *Grievances* performative structure

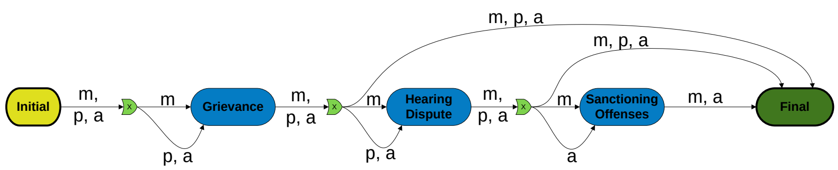

Fig. 1.5 *Arbitration* performative structure

are executed, for example registering the final deals or stating the following steps for the agreement settlement.

***Grievances* performative structure** (Fig. 1.4). Once an agreement is active, it may be executed by the new right-holder and, consequently, other right-holders and some external stakeholders may initiate a grievance procedure that may overturn or modify the transfer agreement. Even if there are no grievances that modify a contract, parties might not fulfill the contract properly and there might be some contract reparation actions. If things proceed smoothly, the right subsists until maturity. In this structure any conflict can be solved by means of two alternative processes (these processes are similar to those used in Alternative Dispute Resolutions and Online Dispute Resolutions [15, 17]). On the one hand, conflict resolution can be solved by means of negotiation tables (*Conflict Resolution Negotiation Table* performative structure). In this mechanism, a negotiation table is created on demand whenever any water user wants to solve a conflict with other/s water user/s, negotiating with them with or without mediator. Such a negotiation table can use a different negotiation protocol, such as face-to-face, standard double auction, etc., analogously to the *TradingTable* performative structure. On the other hand, arbitration mechanisms for conflict resolution can also be employed (*Arbitration* performative structure). In this last mechanism, a jury solves the conflict sanctioning the offenses. The difference among the two mechanisms for conflict resolution is that the arbitration process is binding, meanwhile the negotiation is not. In this way, if any of the conflicting parties is not satisfied with the negotiation results (s)he can activate an arbitration process in order to solve the conflict.

***Arbitration* performative structure** (Fig. 1.5). There are three steps in the arbitration process. First, the *Grievance* is stated by the plaintive water user. Second, the different conflicting parties present their allegations to the jury (*Hearing Dispute*). Third, the jury, after hearing the dispute, passes a sentence on the conflict.

Users and roles.

There are seven roles, which are depicted in Fig. 1.1. This number is not arbitrary and represents the natural interaction of the institution. First, the guest role (*g*) is the user that wants to enter the process. After admission, the guest is specialised into a water user (*w*), which is later specialised as a buyer or seller (*b*/*s*, respectively). There are two staff roles throughout the process. The market facilitator (*m*) represents institutional agents who start the trading activities, such as managing the users data, the specific parameters of the trading protocols, etc. The basin authority role (*ba*) represents institutional agents who are in charge of the last activities, such as agreement validation and contract enactments that are executed as a result of a successful negotiation process. Finally, there is a third party (*p*) role that appears when a grievance is started in the system.

1.2.4 Implementation

mWater uses a flexible multi-tier architecture [6, 9], which relies on the EI model presented in Fig. 1.1. It has been implemented within a higher level architecture depicted in Fig. 1.6 that also includes a policy simulation module explained in section 1.4.2. The persistence tier implements a *mySQL* database with more than 60 relational tables that store the information about basins, markets and grievances. The business tier is the core of the system and allows us to embed different AI techniques (e.g. trust and data mining for participants selection, planning to navigate through the institution, collaboration and negotiation to enhance agreements and minimise conflicts, etc.), thus ranging from a simple to a very elaborate market. *mWater* implements a schema of agents that include both the internal and external roles. There is a JADE (Java Agent DEvelopment Framework, `http://jade.tilab.com`) definition for each class that represents the roles in the scenes. The underlying idea is to offer open and flexible templates to simulate different agents and norms, which provides more opportunities to the analyst to evaluate the market indicators under different regulations and types of agents. These templates also offer an important advantage: we can extend them and implement as many different agents (with different behaviours) as necessary, and assess their impact in the market simulation.

In order to simulate how regulations and norms modify the market behaviour and to evaluate their effects (see section 1.4.2), we include a deliberative module in the staff agents to reason on regulation matters. The presentation (GUI) tier is very intuitive and highly interactive, as it offers an effective way for the user to configure a given simulation, ranging from different time periods, participants and current legislation [5, 6]. The GUI displays graphical statistical information, which is also recorded in the database, which indicates how the market reacts to the input data in terms of the number of transfer agreements signed in the market, volume of water transferred, number of conflicts generated, together with quality indicators based on

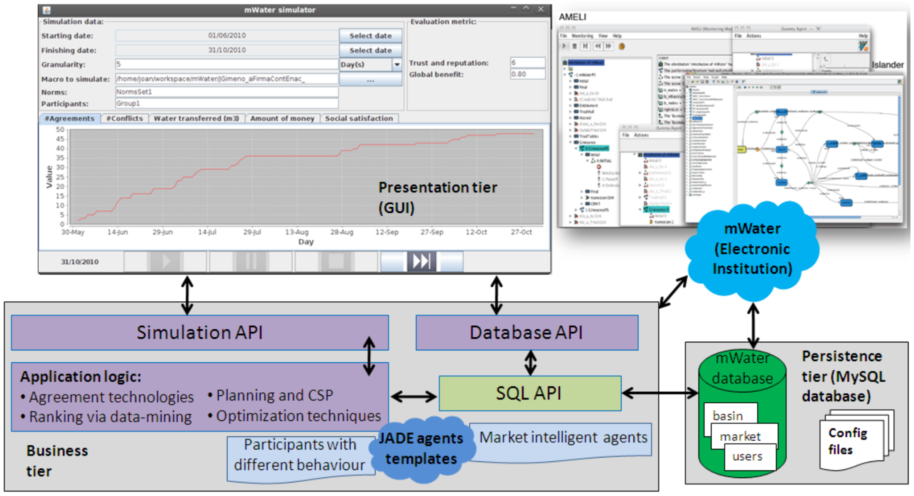

Fig. 1.6 Multi-tier architecture of the *mWater* system

social functions to asses the trust and reputation levels of the market, and degree of water user satisfaction.

1.3 *mWater* as a Testbed for AT

mWater provides a flexible and still powerful infrastructure for a virtual (water-right) market. This way, it can be used as a testbed, i.e. a platform for experimentation of further development projects, to explore techniques and technologies from the agreement computing standpoint. In summary, *mWater* provides answers to different issues:

Norms. How to model and reason on norms within the market, how the regulations evolve and how to include new dispute resolution mechanisms? Current regulations impose certain constitutive restrictions and constitutive regimentations that may be readily regimented into the institutional specification. However, there are regulations that should not be regimented that way and should be expressed in declarative form in order to guarantee some formal properties, and comply or enforce them after some situated reasoning. Then, there is the problem of expressiveness: the type of norms we have dealt with so far have straightforward formal representations that are amenable for formal and computational manipulation but, as the literature in the field shows, questions and alternatives abound. Linked with these concerns, obviously, is the discussion of architectures for norm aware agents, on one side, and different means (logic, coherence theory, satisfying thresholds, etc.) to deal with norm internalisation, adoption and compliance. Also, ensuring norm compliance is not always possible (or desired), so norm violation and later detection via grievances usually makes the environment more open, dynamic and realistic for taking decisions, which is closely related to the institutional aspects.

Institutional aspects. From a theoretical perspective, we need to break loose from the procrustean limits of the EI model in two directions: i) alternative enforcement mechanisms (in addition to internal agent enforcers which are already available), and ii) the evolution of regulations (beyond parameterised protocols and re-usable scenes).

Organisational issues. How beneficial is the inclusion of collective roles, their collaboration (and trust theories) and how the policies for group formation affect the market behaviour? In order to do this, we need to capture all those roles currently recognised by legislation that have any impact on trading and agreement management, specially in grievances and conflict resolution. This involves to deal with ad-hoc and dynamic coalitions to trade and to intervene in conflicts and with a special focus on the by-laws, goal-oriented groupings and goal-achievement features of such organisations. On the other hand, it is also necessary to study the roles and operations of non-trading organisations that somehow affect demand (e.g., water treatment plants, water distribution companies, municipality services, water transport firms and infrastructure).

Collective decision-making, social issues and coordination. Argumentation (rhetorical and strategic aspects), judgement aggregation (not only from the social choice perspective), reputation, prestige and multi-party negotiation (negotiation involving more than two parties, multiple-stages, reconfiguration of parties and mediating roles) are essential elements that have a relevant impact in the market performance.

Integration with other tools. mWater, used as a policy-simulator (see section 1.4.2), allows water policy-makers to easily predict and measure the suitability and accuracy of modified regulations for the overall water market, before using other operational tools for the real floor. Our experiments shed light on the benefits that a collaborative AI perspective for a water-right market may bring to the policy-makers, general public and public administrators.

Applicability to other markets and inclusion of new features. This framework can be the basis for new developments. In particular, Almajano presents *amWater* [1], a simplification of *mWater* that provides an assistance scenario, which has been subsequently extended with 3D graphical environments functionality where humans participate (represented as avatars) and interact by using intuitive control facilities —see chapter "v-mWater: an e-Government Application for Water Rights Agreements" later in this book for further details. Also, our experiences show that this approach is general enough, as described in section 1.4.1, and can be valid for other markets.

1.4 Further Applications of *mWater*

In this section, we present two further applications we have deployed for our *mWater* case study. First, we have extrapolated our water-right market to a generic negotiation framework that condenses both the trading and the conflict resolution process. Second, we introduce our work on how this type of MAS can be used to enhance policy-making simulation within the setting of a decision support tool [5, 6, 9].

1.4.1 A Formal Framework for Generic Negotiation

Picture our water-right market (or any other produce market) where customers are involved in face-to-face negotiation or participate in auctions that must obey different policies. Picture, also, the various ways that conflicts among the users of water resources of a single basin are being solved. These are just two examples of institutions that share some standard features which can be captured in a generic negotiation framework with common roles.

Revisiting the original performative structures.

As pictured above, in many situations we can establish a metaphor with an institution that comprises several negotiation scenarios. Interestingly, the common denominator in all these situations is the negotiation process, e.g. price-fixing encounters or solving conflict resolution, each with a specific negotiation protocol that expresses how scenes are interrelated and how agents playing a given role move from one scene to another. While most negotiations restrict access, there is a large public hall (the market floor or the legislative environment of a hydrographic basin) where participants exchange information, request to open or enter a negotiation table, invite participants or are invited/requested, and where they reconvene after leaving such a table. For this last purpose, they may go to another private encounter to carry other institutional businesses, like enacting agreements, creating/dissolving coalitions, etc. We have integrated this global arrangement as a generic institution for negotiation with generic roles, as shown in the ISLANDER specification of Fig. 1.7 —which is a generalisation of the original one depicted in Fig. 1.1. Procedural conventions in this negotiation institution are specified through a top performative structure which includes both the generic *NegotiationHall* and the *NegotiationTables*. At a glance, *NegotiationHall* captures the public activity that surrounds negotiation, that is, where participants (now *black* and *white*) become aware of any activity by exchanging information, initiate concurrent activities and deal with critical situations. On the other hand, *NegotiationTables* is the core of the institutional framework because it mirrors the conventions and policies that allow different protocols (e.g. auction mechanisms) to negotiate about a deal and co-exist. Specificity is embedded in the negotiation tables and gets propagated all the way to the main performative structure of Fig. 1.7 by the generic negotiation framework. Once negotiation tables are specified in detail, the end product would be one specific EI for some type of negotiation.

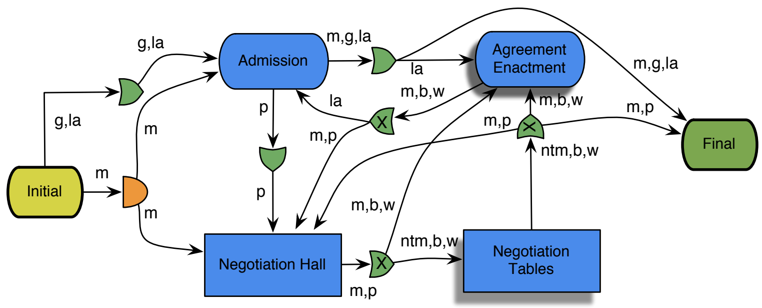

Fig. 1.7 Performative structure of a generic electronic institution for negotiation. Roles: *g* - Guest; *p* - Participant; *b* - Black; *w* - White; *m* - Mediator; *ntm* - Negotiation Table Manager; *la* - Legal Authority.

Discussion.

mWater has allowed us to establish the foundations for the specification of an agent-based negotiation framework that handles multiple negotiation protocols in a coherent and flexible fashion. Although it may be used to implement one single type of agreement mechanism —like a blind double auction or argumentation-based negotiation—, it has been designed in such a way that multiple mechanisms may be available at any given time, to be activated and tailored on demand by participating agents. The underlying objective is to have a generic EI that may be tailored to specific needs and grafted into other EIs. As a by-product, we have created a repertoire of light-weight agreement mechanisms that may be used as "scene-modules" in other EIs and, in particular, as stand-alone interaction plug-ins in peer-to-peer architectures.

1.4.2 mWater *as a MAS for Policy Simulation*

Policy-making is a hard task and it usually changes throughout time due to variations in economic situation, population distribution and physical conditions. To make things even more complex, the outcome to measure the success of a given policy is not always intuitive. It is, therefore, essential to have mechanisms and/or simulation tools in the early phases of the policy cycle, i.e. before the legislators fix the legislation —and policies are really applied in the real world—, to analyse the impact and assess the expected success. In this line of work, *mWater* is implemented as a component of a larger institutional framework designed as a demand module for water management. It also simulates (negotiation) regulations and is enabled with tools to specify performance indicators, to spawn agent populations and allow humans as well as software agents to participate in simulations of virtual trading [6, 9].

mWater as a simulator.

When the *mWater* simulator is in action (see Figs. 1.8-1.9), it allows the water policy-maker to create different configurations (input values that involve simulation dates, participants, legislation, in the form of protocols used during the trading negotiation, and some decision points that can affect the behaviour of the participants[2]) and study the market performance indicators. We have also implemented a specific decision tier for comparing and analysing the indicators of such configurations, as observed in Fig. 1.9. This is very valuable to assist in decision making as we can easy and efficiently compare the results of dozens of configurations, which is prohibitive when done manually.

From the experts evaluation, we can conclude that a simulation tool like this provides nice advantages: i) it successfully incorporates the model for concepts on water regulation, water institutions and individual behaviour of water users; ii) it formally represents the multiple interactions between regulations, institutions and individuals; iii) it puts strong emphasis on user participation in decision making; and iv) it finally provides a promising tool to evaluate changes in current legislation, and at no cost, which will surely help to build a more efficient water market with more dynamic norms. Note, however, that the simulation tool is currently mainly policy-maker-oriented rather than stakeholder-oriented. The reason for this is that we have focused on the possibility of changing the norms within the market and evaluate their outcomes —which is the policy-makers labour—, but not in the participation of stakeholders to change the model of the market itself. But clearly, in a social context of water-right management it is important to include tools for letting stakeholders themselves use the system. In other words, the framework should be also able to include the participation of relevant stakeholders, thus helping validate results, which is our current work.

Discussion.

One of the key problems in policy content modeling is the gap between policy proposals and formulations that are expressed in quantitative and narrative forms. On the other hand, it is difficult to find formal models that can be used to systematically

[2] In our current implementation, these additional decision points rely on a random basis, but we want to extend them to include other issues such as short-term planning, trust, argumentation and ethical values.

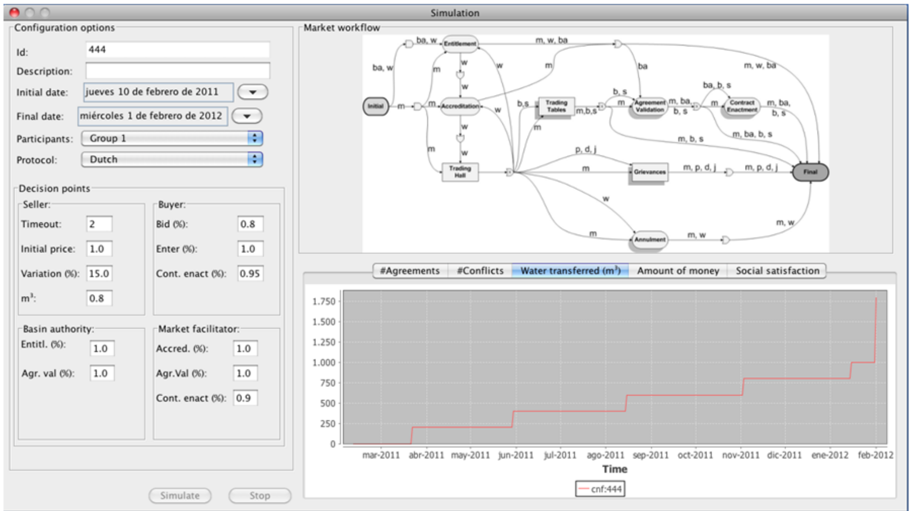

Fig. 1.8 The *mWater* simulator in action

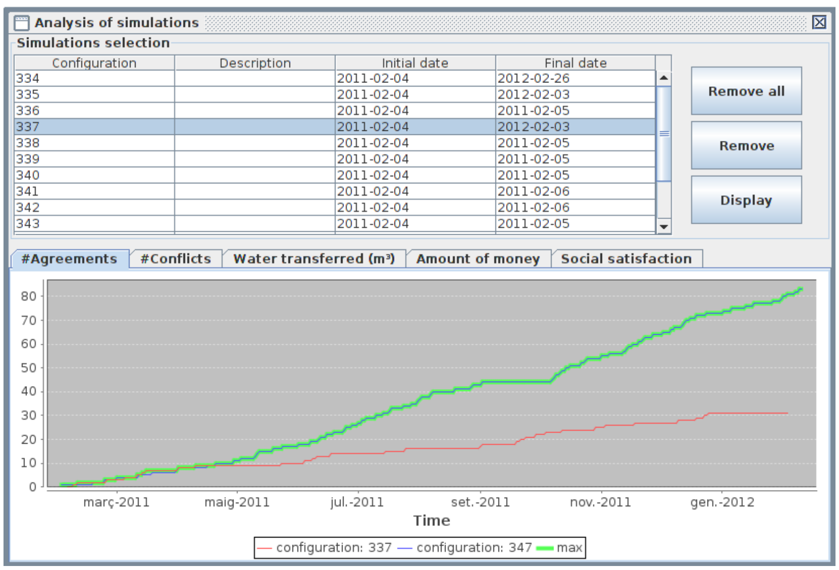

Fig. 1.9 Analysis of different configurations. Thick line represents the optimal solution, in this case the max number of agreements

represent and reason with the information contained in the proposals and formulations. As a by-product, *mWater* offers a tool designed so that policy-makers may explore, monitor and visualise the interplay between: i) market regulations, ii) trader profiles and market composition, iii) the aggregated outcomes of trading under those set conditions, and finally iv) the impact of these multi-agent policy simulations (and arguments about policies) on the outcomes of the market at no real cost. This provides an appealing scenario to manage the water resources effectively, both in the short and medium term.

1.5 Conclusions

This chapter has presented *mWater*, a virtual market that is intended as a MAS implementation to support institutional foundations for further markets and AT developments. *mWater* grasps the components of an electronic market, where rights are traded with flexibility under different price-fixing mechanisms and norms. In addition to trading, *mWater* also includes those tasks that follow trading. The main contribution is that it has been designed around a realistic institutional core with multiple functional add-ons that may be readily adapted to eventual regulations on one hand, and market-design and testing requirements, on the other.

mWater has been thought not only as a test case for a potential actual market but also as a sandbox for testing, development and demonstration of AT techniques, including norms reasoning, virtual organisations, argumentation, trust, use of 3D virtual interfaces, etc. In this line, some authors have used *mWater* as the basis for developing execution infrastructures that facilitate agents' interactions and visual representations [1]. As a by-product, this market has allowed us first to provide a generic negotiation framework as a general multi-agent-based specification. Second, it provides a decision-support tool constructed around a water-right market that integrates a wide range of subcomponents. With such a tool, water policy-makers can visualise and measure the suitability of new or modified regulations for the overall water market.

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