On the design of *mWater*: a case study for Agreement Technologies

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Abstract. The water management problem is at the forefront of public policy priorities in many countries because of the growing scarcity of water and its considerable economic and social implications. At the core of water policy is the need to foster a more rational use of the resource, and one way of fostering efficiency might be the creation of an agile market of water rights. However, the design and operation of such a market is not an easy endeavor because it needs to coexist in a complex social and legal framework that has evolved to address the different and often conflicting objectives of the many stakeholders involved. We are approaching this problem by building an open multi-agent system, *mWater*, that is designed as a regulated environment where autonomous agents trade rights for the use of water in a closed basin, and resolve the conflicts derived from the trading and use of those rights.
This paper outlines the aims of the *mWater* system, describes its core institutional components and discusses current and future work.[3]

1 Introduction

Agreement is one of those basic social concepts that help humans cope with their social environment and is present in most of our interactions. In fact, agreement is fundamental to cooperation and, ultimately, to the emergence of artificial social systems.

From an intuitive perspective, the notion of agreement involves many aspects: preferences, persuasion, contracts, trust, punishment and blame, among others. From a more theoretical standpoint, agreement processes also involve ontology matching, normative reasoning, negotiation rules, argumentation, learning, collective decision-making, social conventions sanctioning mechanisms, as well as organizational and institutional environments. Finally, from a practical approach, one may be interested in those methodologies and computer-based

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tools and practices to support the processes through which agents interact with one another in order to come to mutually acceptable agreements and put them in practice. We will refer to all these elements as *agreement technologies* (AT) and focus the term even more onto the use of these technologies in the context of agents (human or software) that are autonomous.

Such a focus reveals an ulterior motivation for the study of agreement technologies. Indeed, when we take these agents —human or computational— to be autonomous, agreement technologies may be viewed as enablers of a new programming paradigm for next generation distributed systems. A paradigm that is grounded on two notions: i) a normative context, which determines the rules of the game, i.e. how the interactions between agents are going to happen, and ii) a call-by-agreement interaction method that is based on a two step process: first, the establishment of an agreement for an action between the agents that respect the normative context, and second, the enactment of such an action (Cf. [13]). In fact this is the rationale behind an ongoing research project on agreement technologies, AT, funded by the Spanish Government [14]. Project AT is organized around five core underlying notions: ontologies, norms, organization and institutions, argumentation and negotiation, and trust. Around these five notions, the project is committed to develop formal models and theories cogent for agreement on one hand, and on the other to explore the potential software developments and practical applications of those theoretical results. As a device to coalesce these activities, the AT project includes three case study "demonstrators" that constitute realistic problem domains where agreement technologies need to be applied. Thus, such demonstrators ought to provide inspiration for theoretical research on agreement technologies as well as convenient situations where to experiment and fine tune those conceptual and engineering contributions. The *mWater* system, a virtual market for water rights of use whose structure and functionality we outline in this paper, is one of those demonstrators.

This paper presents a first specification of the institutional framework of the demonstrator. That is, the basic components of the market, the roles participants may play, the activities they may be involved in, as well as the conventions that govern those activities.

The paper is organized as follows. We first motivate the relevance of a market for water rights and the pertinence of trade and use of water rights for agreement technologies research (Section 2). In Section 3, we present a specification blueprint of an institutional framework for that e-market, and in Section 4 we briefly discuss the lines of our current and future work.

2 *mWater*: modeling demand through trade and conflict

Water scarcity is becoming a major concern, 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 many types of use: human consumption, industrial use, energy production, recreation, etc. Underneath this emergent situation, the crude realities of conflict over water rights of use and the need of accurate assessment of water needs and use become more salient than ever.

In countries like Spain, and particularly in its Mediterranean coast, there is a high degree of public awareness of the main consequences of the scarcity of water and the need of fostering efficient use of water resources. Two new mechanisms for water management already under way are: a heated debate on the need and feasibility of transferring water from one basin to another, and, directly related to this proposal, the regulation of *water banks*.[4]

It has been sufficiently argued that more efficient uses of water may be achieved within an institutional framework where water rights may be exchanged more freely, not only under exceptional conditions but on a day to day basis [4, 12, 15]. It has been claimed that if farmers cannot sell their extra water allotment, they have no incentive to use the allotment efficiently and it may become wasteful [7]. Moreover, a straightforward extension to other types of stakeholders would promote trading for industrial uses, aquiculture, leisure or navigation, not only irrigation, thus improving market conditions and hence efficiency of water use [4]. We propose to implement such a market with a regulated open multi-agent system *mWater* whose main features we discuss in this paper.

Our focus is on demand and, in particular, on the type of regulatory and market mechanisms that may have an incidence on it, so that water use is efficient and conflicts are avoided.[5] We are therefore interested in the institutional framework that defines the "rules of the game" as well as the role that regulation, social environment, coordination, conflict resolution mechanisms, reputation or trust play in the decisions participating agents make and their aggregate results. Ideally, such institutional framework should add flexibility without increasing the number or complexity of disputes and we could profit from agreement technologies to understand and guide the behaviour of participating agents. More-

[4] The 2001 Water Law of the National Hydrological Plan (NHP) —"Real Decreto Legislativo 1/2001, BOE 176" (see www.boe.es/boe/dias/2001/07/24/pdfs/A26791-26817.pdf, in Spanish)— and its amendment in 2005 regulate the power of right-holders to engage in voluntary water transfers, and of basin authorities to setup water markets, banks, and trading centers for the exchange of water rights in cases of drought or other severe scarcity problems.

[5] Considerable effort has been invested in the development of sophisticated basin simulation models and in the improvement and innovation of water use practices. Literature abounds in examples of decision support systems for water management [11], sustainable planning of water volumes [3, 8], or the use of shared visions for negotiation and conflict resolution [9]. We explore an alternative approach in which individual and collective agents are an essential component because their behavior (and effects) may be influenced by policy-making. There are few projects along this line but one may point to the NEGOWAT project (http://www.negowat.org/ingles/inicio/Inicio.htm), whose goal is to help negotiations between stakeholders in peri-urban catchment areas when water conflicts arise. Closer to our own approach, is project MAELIA (http://www.iaai-maelia.eu), that involves simulation of socio-environmental impact of norms for the use of water and other renewable natural resources and the environment.

over, we claim a demand-based approach to water management provides a fertile ground for the study and application of agreement technologies. The following is a sketch of four features that, we believe, make the *mWater* demonstrator a good sandbox for AT.

A regulated environment. The *mWater* scenario requires the expression and use of regulations of different sorts: from actual laws and regulations issued by governments, to policies and local regulations issued by basin managers, all the way to social norms that prevail in a given community of users. Some will be regimented as part of the electronic institutional framework specification but others need to be expressed in declarative form so that one may reason about them, both off and on-line, both at design and at run time, and both from the institutional (or legislative) perspective and the agent's individual perspective. Issues that are relevant in this respect range from the choice of expressive formalism to the decision-making strategies that agents might use to comply or disobey regulations. Thus structural aspects like governance, dynamics of norms (also from the legislative and individual's perspectives) as well as criteria to evaluate the effectiveness of norms may and need to be explored in the demonstrator.

Organizational and collective interaction. There are good opportunities to study the interplay between formal institutional aspects (laws, ontologies, sanctioned practices), the organizations that enforce or should abide by them and the individuals that form those organizations or participate in the regulated activities. Also, the scenario involves collective actors that may not only have their own social rules for allocating rights and solving conflicts but also become involved in negotiation as collective entities. That is the case, for instance, of the "comunidades de regantes" (agricultural users assocs.) who interact with a municipal government or a power plant to negotiate transfers of rights, or as plaintiffs or defendants in conflicts over the use of water. Once again there is the possibility of studying organizational and institutional dynamics and individual's immersion of rules and collective emergence of norms. These matters suggest also the opportunity to study collective decision-making, judgement aggregation and other formal and informal ways of social choice. Finally, given the rich sociological content of water use, the scenario should provide enough empirical grounds for playing with notions like trust and reputation, moral authority, power and force that are crucial in practice.

Structured and spontaneous conflict. A significant part of the proposed framework involves the specification of valid negotiation protocols, as we will see below, and therefore the possibility of studying negotiation heuristics, agent architectures adapted to those negotiation capabilities on one side, and on the other the systematic study of the negotiation conventions themselves. Moreover, the framework includes a space —what we call agreement management— where once an agreement for the transfer of water rights has been reached, contracts are negotiated and executed and agreements and contracts may be contested. While the general process for agreement management is properly regulated, the idea is to leave enough flexibility in the institutional framework so that the general notion of an agent-managed contract may be explored in earnest. Likewise, those structured interactions that happen after trading rights are excellent brewing environments to study conflicts (detonators, structure, types) and conflict resolution; in particular, the possibility of using and devising non-conventional forms of on-line dispute resolution (ODR).

Simulation environment. The engineering of the demonstrator requires sophisticated software tools for specification,construction, testing and monitoring of the on-line market and the participating agents. We plan to attach simulation services to the electronic institution infrastructure along the lines of [2] and thus facilitate the coupling of *mWater* as a water demand module of sophisticated basin simulators for water use policy purposes. Another outcome we foresee is the use of our demonstrator as a proof-of-concept prototype for the actual water banks (and banks for other natural resources) envisaged in current legislation.

3 An institutional framework for *mWater*

The demonstrator is rooted on traditional practices and regulations currently established by the Spanish National Hydrological Plan and forthcoming Basin Hydrological Plans for the use and transfer of water rights. However it is somewhat idealized in order to provide a richer sandbox for agreement technologies and a more malleable platform for demand and water use modeling in an hydrographic basin. The core component of the *mWater* demonstrator is an agent-based virtual market for water usage rights that intends to grasp the components of an electronic market where water rights could be traded with flexibility and under different price-fixing mechanisms. However, in addition to trading proper, the demonstrator also includes those activities that follow trading; namely, the agreement on a contract, the use and misuse of rights and the grievances and corrective actions taken therein. These ancillary activities are particularly prone to conflict albeit regulated through legal and social norms, and therefore a crucial objective in policy-making and a natural environment for agreement technologies.

Our immediate goal is to establish an institutional framework for an on-line market of water rights. In this paper we only sketch the institutional framework that regiments trading and the main ancillary activities. It is institutional in the sense that we make explicit the conventions that determine: i) what actions are valid within the market, ii) what are the conditions these actions must satisfy, and iii) what are their intended effects. For the construction of that framework we follow the IIIA *Electronic Institution* (EI) conceptual model [1] where an institution is specified through two main blocks: one that deals with ontological components (the *dialogical framework* that specifies ontology, language, roles and information model) and another for deontological components (the *performative* *structure* that includes, both, interaction models and procedural prescriptions, as well as *rules of behavior* for commitment-making conventions). For the actual specification and implementation of *mWater* we use the EIDE platform.[6] The following subsections describe the main components of the bare-bones market institution.

3.1 Ontological components

The following entities are the basis for the domain ontology:

A **basin** is a directed graph $\Lambda =< N, E >$, where $N = \{n_i : 1 \leq i \leq m\}$ is a set of places where water may be extracted, $E = \{< n_i, n_j >: n_i, n_j \in N \wedge i \neq j\}$, is a set of edges, where a tuple $< n_i, n_j >\in E$ indicates that node n_j receives water from n_i by means of a transportation resource (river or canal).

A **water-right** is a tuple $\omega =< \lambda, u, v, t >$, where λ (subgraph of Λ) is the basin locations where the water-right can be executed (at least one node in λ must be a water source node); u is the type of use allowed; v represents the maximum quantity of water allowed to be extracted there; and t is the time interval during which the water-right may be executed.

A **water-right bid** is defined as the tuple $\beta =< o, \omega, t, t_\beta >$, where the bid-type o can take a Put label to represent a bid to sell, or a $Call$ for a bid to buy; ω is the water-right associated with a bid t is the time interval during which the water-right would be used; t_β is the deadline of the bid.

An **agreement** is a tuple $\alpha =< s, b, \omega', p, d, st >$, where s is the seller of the right; b is the buyer; ω' is the new water-right derived from the agreement negotiation (this water-right will be eventually transferred to the buyer by means of a contract); p is the agreed compensation; d is the agreement date; $st \in \{Public, Contested, Authorized, Suspended\}$ represents the current stage of its life-cycle.

A **contract** is the tuple $\kappa =< A, K, U, d, O, C >$, where A is the set of related agreements (a set of multiple water transfer agreements may be signed in a single contract); K is the set of related sub-contracts, for example transportation resource contracts (if there is no related sub-contracts it is an empty set); U is the set of users that sign the contract; d is the agreement date; O is the set of observation commitments to execute the contract; C is the set of conditions for conflict resolution.

There are three main **roles** in the virtual water market. Firstly, a *Guest* role is a user that wants to enter the *mWater*. The *Guest* may be specialized into a *Water User*, a water right-holder of the basin, and furthermore as a *Buyer*,

[6] EIDE is a development environment for Electronic Institutions developed at the IIIA, http://e-institutor.iiia.csic.es/eide/pub/. It is composed of a set of software tools that support all the stages of an Electronic Institution (EI) engineering. It includes: 1) ISLANDER, a tool for EI specification. 2) A tool, aBUILDER to support the automatic generation of agent (code) skeletons from ISLANDER specifications of an EI. 3) The AMELI middleware that handles the enactment of the institution and 4) SIMDEI a testing and monitoring tool.

Seller and as (an affected) *Third party*. Secondly, there are two governing roles involved in grievances and contract validation processes: *Basin authority* and *Referee*. Thirdly, the *market facilitator* role represents those institutional agents who run standard trading activities for example set up a trading table or mediate in a face-to-face negotiation.

3.2 Deontological components

Procedural conventions in the *mWater* institution are specified through a nested performative structure (Fig. 1) with multiple processes. The top structure, *mWaterPS*, describes the overall market environment and includes three other performative structures, *TradingHall* (Fig. 2) defines a place in which market status can be notified and new trading tables can be solicited, *TradingTables* (Fig. 3) establishes the trading procedures, and *Grievances* (Fig. 6) provides scenes in which a grievance procedure can be initiated that may overturn or modify a transfer agreement.

An outline of their constitutive processes (scene protocols) follows.

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. The former happens when an existing right is legally acquired from its previous owner outside of *mWater* (through inheritance or pecuniary compensation for example). The latter happens when a new right is created by the *mWater* authorities and an eligible holder claims it and gets it granted.This 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. Staff has to validate admission conventions and right-holder variables are given default values. When a right suspension is overridden or an agreement is void, rightful owners need to register again.

TradingHall. Intuitively, in this complex performative structure, see Fig. 2, 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, for example severe drought situations, (*Critical Situations* Scene). Actual trading starts inside the *TradingHall* scene. On 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. 2, users and trading staff can initiate most trading and ancillary operations here (from *Recruiting* scene): open, request trading parties and enter a trading table; query about different agreements and initiate a grievance procedure

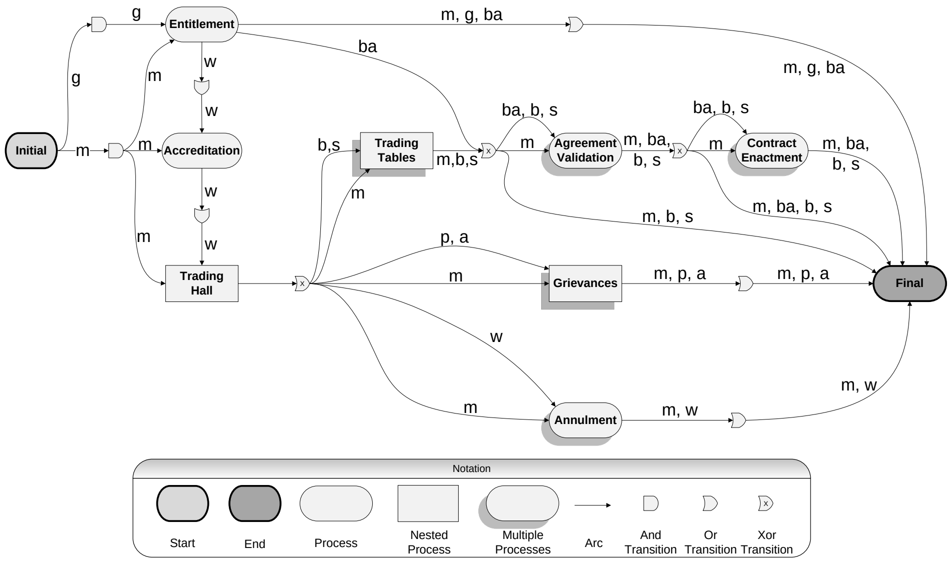

Fig. 1. *mWater* performative structure. Participating Roles: *g* - Guest, *w* - Water user, *b* - Buyer, *s* - Seller, *p* - Third Party, *m* - Market Facilitator, *ba* - Basin Authority.

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 users are inside the market, they have to *stay* permanently in these scenes but they may also *go* (as *alteroids*) to trading table scenes and contract enactment scenes where they are involved: these scenes where user alteroids become involved are created (as a new *instance*

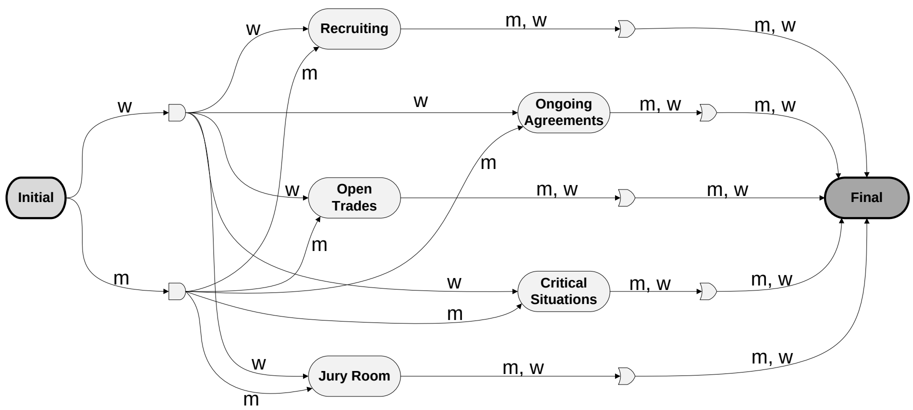

Fig. 2. *TradingHall* performative structure.

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).

TradingTables. In our *mWater* performative structure (recall Fig. 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 (e.g., face to face negotiation, closed bids, standard double auction exchange or any others that are agreed upon). Consequently, 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 instance of a *Trading Table* scene is managed by a *Negotiation Table Manager*, *tm*, who knows the structure, specific data and management protocol of the given negotiation protocol. Among other negotiation mechanisms, we have included face-to-face, Dutch auction, English auction, standard double auction and blind double auction with mediator negotiation, etc. Nevertheless, new negotiation protocols may be easily added providing that the new protocol definition complies with the generic structure.

Every generic negotiation table is defined as a three scene performative structure (see Figure 3). 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 (recall situations when a private trading table is executing or only a subgroup of water users that fulfill a set of constraints may participate in the table). The specific filtering process will depend on the given negotiation protocol and possibly on domain specific features. The second scene is the negotiation 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 are executed, for example registering the final deals, stating the following steps for the agreement settlement, verifying that the leaving party satisfies the leaving norms of the trading table, etc.

The **face to face protocol** mirrors the standard negotiation protocol among irrigators in a basin. If the face to face negotiation succeeds, the result is an agreement between the seller and the buyer that has to be managed in the *AgreementValidation* and *ContractEnactment* scenes.

Blind double auction exchange with mediator (Fig. 5) is a protocol inspired in the work of [10]. In this protocol many buyers and many sellers submit bids to trade goods that are homogeneous. The homogeneity of goods guarantee that the only deciding factor to make an agreement is the price. With this mechanism all trades take place at, or near, the equilibrium price as participants respond to market conditions. The overall auction mechanism can be viewed as a two stage process in which participants engage in a series of mock double auctions and then carry out a final double action where the trades are actually made. Because the blind mock auctions with mediator have allowed the participants to respond to market conditions, trading should converge to equilibrium.

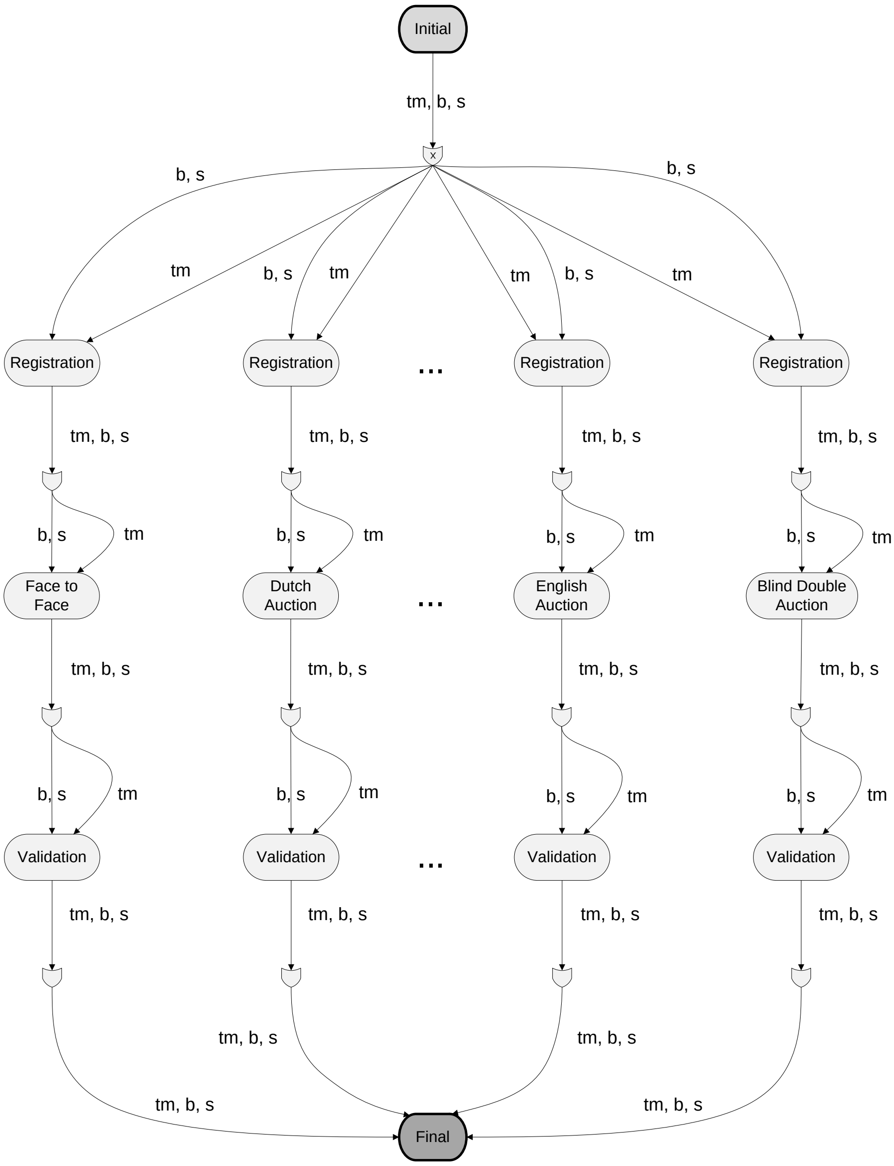

Fig. 3. Performative structure for different trading procedures: *TradingTables*.

Hence trades in the final double auction will come closer to equilibrium. Since in this protocol bids are blind, Sellers and Buyers cannot take into account the reputation of the other contracting part. If the participant's decisions may be improved by using information about reputation and/or trust of the rival, other negotiation protocols, such us face to face or closed bid should be used.

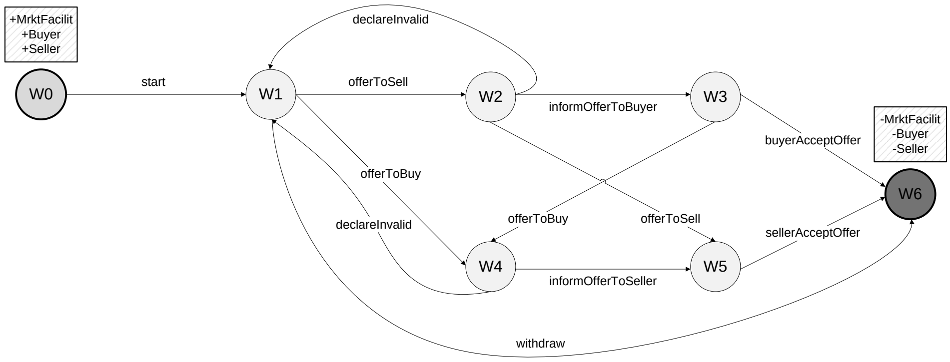

Fig. 4. Scene for *Face to Face* negotiation.

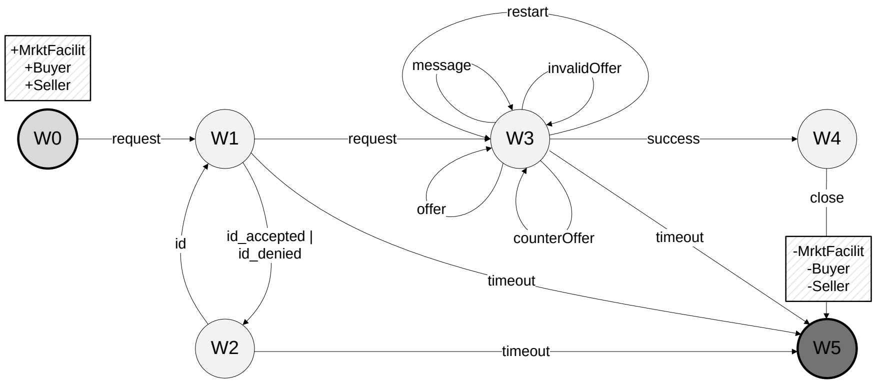

Fig. 5. *Blind double auction exchange with mediator* negotiation.

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 (*Agreement Validation* scene of Fig. 1). 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.

Grievance. 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, Fig. 6, 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.

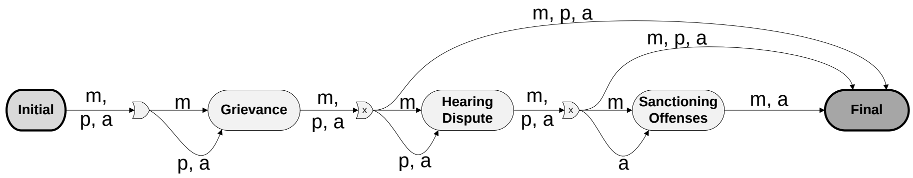

Fig. 6. Performative structure of the process to manage a grievance procedure.

Conflicts are managed in a three step process. In the first step any water user may initiate a grievance process in which he/she exposes its arguments. The complaints may give leave to proceed, in that case, in the second step, the *mWater* staff informs the affected parties of the dispute in order to execute their rights to appeal. A jury and/or a referee hears the dispute among the parties and determines the offenses. Finally, in the third step, the Jury issues the sentence informing the parties the sanction.

The last scene in the top (*mWater*) performative structure, *Annulment*, deal with anomalies that deserve a temporary or permanent withdrawal of rights. These scenes are also multiple because the withdrawal of each right requires its own instantiation.

4 Discussion

As a whole, *mWater* constitutes a rather complex regulated open multi-agent system. It is designed with three objectives in mind. First, as a demonstrator in the AT project, it should provide a testing environment and inspiring problem domain for conceptual proposals and tools. Second, it may be used as the demand component of a sophisticated basin model to visualize and explore water management policies. That is, to explore the interactions between the basin hydrographic resources and infrastructures and the use of water as it is being modulated by market mechanisms and policy directives and regulations. Third, given the possibility of the creation of an actual market for water rights or analogous public goods, *mWater* would be a first proof of concept version to build upon.

The work we report in this paper provides the bare-bones core institutional framework. We are now developing a richer electronic institution where scenes of the trading tables and the agreement management performative structures will be tailored to the two sources of inspiration of the demonstrator: to interaction conventions that are interesting for the testing of ideas developed in other work packages of the AT project, and to interaction conventions that correspond to current practices and legislation. In this process we also improve the social structure of the framework to include specific staff roles (like auctioneer, arbiter, mediator and facilitators) for trading and conflict resolution mechanisms, as well as collective actors. Evidently, the ontology will need to be enriched and we might begin to deal with the problems of anchoring dialogical terms (i.e. giving the pragmatics to constants and relations in the communication language).

We have been able to delay the specification of software agents because we may use a human interface that is possible to build automatically from the specification by the aBUILDER tool. We will now start programming staff agents to manage the trading hall, different trading tables and a couple of on-line-dispute-resolution mechanisms, and pass our specifications out to other teams of the AT project so that they can use the demonstrator to test their agent architectures.

Our current *mWater* implementation reflects institutional normative requirements in different ways through the standard EI constructs. Some non-procedural conventions are reflected in the dialogical framework. Some others are reflected as variable constraints or pre- and post-conditions of speech acts in the specification of scenes. Still some more in the decisional models of internal (staff) agents. We now want to incorporate declarative regulations as part of the scene specifications. This is possible thanks to recent extensions to the EIDE platform that couple an inference engine to the AMELI middleware, along the lines suggested in [6].

An important effort in line with the tasks just outlined, is the compilation of conventional regulatory elements that affect water use: global legislation, local regulations and traditional social practices. One opportunity that we find specially attractive is the study of conflict-related social practices in the La Mancha Oriental basin.

The emphasis on regulatory aspects mentioned in the previous paragraphs is motivated by the fact that the main objective policy-makers have, is to achieve the adequate behavior of users is. And regulations is the main tool that policy-makers have to modify behavior. However, in practice, users are prone to achieve "order without law" ([5]) or at least to keep on adapting to regulations in order to preserve their successful practices while policy-makers keep on adapting regulations to guide users in a constantly changing environmental and political media. Our demonstrator should provide the foundations for the study of that interplay.

The *mWater* version presented in previous sections is intended as the institutional foundation for further developments along the three modes of potential use of the MAS we mentioned at the beginning of this section. Although our immediate efforts concentrate on the test-bed conventions and functionalities, we will be keeping an open disposition towards the policy-simulation requirements. Thus, in future versions we will be including those functionalities that might be worth having in a policy-simulation environment —at the pace and depth the AT agenda indicates— but, for the time being, we neither intend to add simulation capabilities beyond those already available in SIMDEI and in the EIDE simulation service extensions (cf. [2]), nor to merge *mWater* with conventional basin models. With respect to the market prototype, our strategy is to manage it as a by-product of the test-bed and simulation developments until the need or opportunity for an actual product arises. The reason is that we are building the *mWater* test-bed 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.

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