AMPLE 2012

Proceedings of the Second International Workshop on Agent-based Modeling for Policy Engineering (AMPLE 2012)

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Preface

Socio-technical systems are complex, adaptive entities in which social systems and technologies co-evolve. In order to attain policy goals in such an environment, social and technical elements must be brought together and any solution should consider both these in a combined way. Further, in order to understand, analyze and design such complex systems, advanced tools are required. Recent years have seen policy makers working together with social scientists, and practioners—including economists, political scientists and sociologists—are increasingly adopting *agent-based models* to develop a better understanding of their problem domains in order to make better decisions. However, building artificial societies to model and study policy design and execution, by combining multi-agent systems with domain knowledge, is a multi-dimensional challenge. Some of the challenges in this area include complexity, the level of granularity in the models, the nature of design (e.g., bottom-up vs. top-down) and the autonomy of participating agents. We believe agent-based technology and in particular, agent-based modelling and computational techniques, are well suited for the evaluation of institutional decisions and policies and the what-if analysis of potential changes such as re-engineering of the tasks, structures, innovations and societal effects of policies.

The Second International Workshop on Agent-based Modelling for Policy Engineering (AMPLE 2012) aims to address some of the issues mentioned above. Towards this end, the workshop connects research in agent-based social simulation and computational social science on the one hand, with policy making, institutional analysis and tools like system dynamics and gaming on the other. By facilitating a forum that brings together researchers with these different perspectives, this workshop aims to explore how agent-oriented research can be used or improved to assist policy making. We believe that bringing together people from different facets will enrich the capability of agent-based models and also the real-life applicability of agent-based modelling and simulation.

Designing and developing policies to facilitate sustainable practices is being addressed by governments and organizations around the globe. In order to contribute to this important issue, AMPLE 2012 has a special theme on the design and development of sustainable policies using agent-based modelling. Policies for sustainable development require complex decision about resource management, balance of economic, environmental and societal needs and involve many countries, interest groups and individuals. Especially for sustainable societies we are interested in simulations that can capture the behavioural patterns, changes and interactions in a society. This can require large scale simulations with relatively rich cognitive agents.

AMPLE 2012 is the second workshop in this series, building on the first edition held co-located with AAMAS'11 (Taipei, Taiwan), and joining forces with the congenial ABSSS-workshop (Agent Based Simulations for a Sustainable Society), which also held its first edition in 2011, as part of the PRIMA conference (Wollongong, Australia). This year the workshop will be held at the European Conference on Artificial Intelligence (ECAI) which will take place in Montpellier, France, August 27–31. The details of the workshop can be found at `http://ample2012.tudelft.nl`.

This year, seven papers have been accepted as full papers for presentation at the workshop. The programme consists of two main sessions: the first on frameworks and methods for policy engineering, and the second on sustainability[1]. The workshop day opens with an invited talk by Frank Dignum (Utrecht).

Four papers were accepted under the theme of *frameworks and methods*. Gailliard et al. focus on proposing a conceptual model to address the specific issue of water governance where agents of different types engage in participatory policy making. Costa and Santos propose a framework for simulating agent-based models of public policies where policies are viewed as artifacts containing norms and plans. Li et al. investigate how conflicts can be detected in policies issued by different organizations especially when these independently designed organizations need to interact in the form of a composite organization. Dinu et al. provide a formal model for multi-agent systems that integrates four views: Individual Interior, Individual Exterior, Collective Exterior and Collective Interior.

Three papers were accepted under the *sustainability* special theme, tackling the respective issues using an agent-based approach. Muller and Aubert assess the impact of resource management plans in different regulatory systems. Metzger and Polakow propose an agent-based cooperative control to create a sustainable biotechnological process. Barreteau et al. investigate the impact of a drought management policy.

The workshop is structured to encourage discussion among the participants. Each paper has a nominated discussant who provides an introduction to the assigned paper and also seeds the discussion after the presentation with some questions. At the end of each of the two main sessions, a dedicated discussion period provides opportunity to discuss (a) the general issues raised by the papers discussed (b) research challenges in the area that can be addressed using agent-based technology, and (c) the future research questions that remain to be addressed. We hope the outcomes and questions from the discussion will influence future workshops in the same series.

We are glad to announce that a special issue on *Agent-based Modelling for Policy Engineering* is to be published by the journal AI & Society (Springer). Authors of the best AMPLE 2012 workshop papers will be invited to submit extended versions for consideration. A generic call for papers will also be issued.

We would like to express our gratitude to all the Program Committee members for their thoughtful and timely reviews. We thank the Steering Committee members and the ECAI workshop chairs, Jérôme Lang and Michèle Sebag, for their help and guidance in the process of organizing the workshop. A special thanks to Virginia Dignum.

[1] See `http://ample2012.tudelft.nl/WorkshopProgram.html` for the full programme.

Francien Dechesne (TU Delft, NL)
Armando Geller (Group W and George Mason University, US)
Amineh Ghorbani (TU Delft, NL)
Bastin Tony Roy Savarimuthu (University of Otago, NZ)
Neil Yorke-Smith (American University of Beirut, LB, and SRI Int'l, US)

Montpellier, France
August 2012

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Armando Geller (Group W and George Mason University, US)

Organizing Chairs

Amineh Ghorbani (TU Delft, NL)
Bastin Tony Roy Savarimuthu (University of Otago, NZ)
Neil Yorke-Smith (American University of Beirut, LB, and SRI Int'l, US)

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Sietse Overbeek (Delft University of Technology, NL)

A generic model to assess sustainability impact of resource management plans in multiple regulatory contexts

Jean-Pierre Müller and Sigrid Aubert

CIRAD GREEN,
Campus International de Baillarguet, 34398 Montpellier cedex 5, France
ESSA
Ampandrianomby, BP 853-99, Antananarivo, Madagascar
{jean-pierre.muller,sigrid.aubert}@cirad.fr

Abstract. Management of the renewable natural resources in Madagascar is gradually being transferred to the local communities. However, these local communities are struggling to assess the consequences of the management plans they must develop and implement on ecologically, economically and socially sustainable grounds. From this Malagasy case, we propose, from a law anthropology perspective, a generic model, called MIRANA, that allows taking into account law pluralism in the analysis of the impact on sustainability of agents' behaviors submitted to concurrent normative orders within multiple layered territories. From a regulatory perspective, we will describe the representations of institutions and norms, and how they are enforced by control/sanction strategies. From an individual perspective, we will describe how an agent deals with a multiplicity of normative and incentive structures. Additionally, individual behaviors are specified as a combination of subsistence economy, market economy and contractual relations.

1 Introduction

The MIRANA[1] model has been developed to simulate the impact of various management plans on the ecological, economical and social sustainability in a multi-institutional context in a broad sense (territorial administrations, natural parks, customary communities, etc.). In [3, p. 43], sustainable development is defined as follows: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The natural environment plays an important role because the definition entails that the usage of the resources the environment provides should not exceed the renewal capacity (ecological sustainability), while maintaining the livelihood of the current and future generations (economical and social sustainability). The usage of the resources plays a central role as it depends both on the practices (the technological dimension), and on the resource access regulations (the normative dimension). Considering the technological dimension as constant, we will mainly focus on the normative dimension. More precisely, the aim is to explore how the introduction of norms (zones, quotas, controls and sanctions) and economical tools (taxes, permits, incentives), impacts the sustainability of a target system on a territorial basis. The impact on the sustainability will be evaluated at the ecological level by the evolution of the exploited species populations, and at the economical and social level by the level of needs satisfaction and/or illegal actions. This model has been applied on the contractualized management of the forests by base communities (VOI for Vondron'Olona Ofotony in malagasy). Therefore the norms and related impact will be considered at the base community level.

To design MIRANA, we had to develop a conceptual model that relies on a fundamental distinction between on one hand the studied system described with its actors, its resources (including spatial and spatialized) and the processes and actions which are taken place therein, and on the other hand their analysis in legal terms as subjects of law (physical or moral persons), of objects of law (for example, properties, deliverables, etc.) and activities (to use, to exploit, to sell, etc.). The heterogeneity of the actors and the multiplicity of the institutions to take into account, brought us to multiply the legal terminologies as as much points of view there are identified actor categories and institutions[2].

[4] in his book on the construction of social reality distinguishes between the regulative norms and the constitutive norms. While the regulative norms describe the rights and duties associated to the various status or roles of the actors, the constitutive rules will describe how various aspects of the reality are counted as pertaining to the categories or concepts used in the expression of the regulative norms. Therefore, an institution not only introduces rules of functioning, but also definitions in the form of a specific terminology and its definition. For example, the constitutive norms have been formalized in [5], using a contextual description logic, consequently allowing to express how a concept in a terminology can count as another concept in another terminology.

In multi-agent systems (MAS), one distinguishes the organizational approach as AGR[6] that defines the notion of groups of agents playing roles, the normative approach where one insists on the regulative norms [7] and the institutional approaches combining both norms and roles.

To represent resource management plans in a multiple regulatory context and its impact on individual behaviors, possibly leading to sustainable development, we propose a two-level description. In the first level, we use the notion of institution as a set of norms covering both the constitutive and regulatory norms. This proposition is an extension of [5] in which the notion of role and territory is naturally represented using contextual ontologies. In the second level, we propose to use the notion of agent to represent both the actors on which the norms apply, and the collective actors associated to each institution who implement the normative constraints. The norms are taken into account both at the individual level by constraining how the activities are planned and carried out, and at the collective level through various mechanisms of control, sanctions and incentives.

We well first introduce our definitions and formalization of institutions and norms. Then, we will describe the agent structure, illustrated by concrete behavioral implementations. Finally, we conclude.

2 Institutions and norms

We understand the notion of institution as a set of legal, practice or custom norms. This set can be recognized as such by the people on which they apply or exist only from a scientist point of view. This definition of institution is used in particular by [8]. The way these norms are used is part of the individual agents definition. The way these norms are enforced is reified as an agent endowed with the collective goals of the associated institution. This collective agent will be described in the next section. In this section we will introduce the norms we want to represent and thereafter its formal account.

2.1 Representation of norms

We are going to reuse the distinction between constitutive and regulative norms as proposed in [4]. Concerning the constitutive norms, we want, for example, be able to express that:

1. "Eucalyptus counts as a vegetal specie" reflecting a classification by a forester or ecologist;
2. "Eucalyptus counts as timber" understood as a relation between the concept of Eucalyptus from the point of view of the forester and the concept of timber from the point of view of a carpenter;
3. "This tree is (counts as) my property" that expresses a property relationship defined between two individuals (here an objet and an agent). This definition associates rights on this tree (to sell, to destroy, to use, etc...) through additional regulative norms;
4. "Paul is (counts-as) a license holder' that associates an individual (Paul) to a concept (license holder) endowing him with a number of rights (in this case to sell its harvest or production). In the same way, "This area is (counts as) a protected zone" expresses an association between an individual (a geographic entity) and a concept (protected zone).

One recognizes the usual structures of the ontologies or description logics, i.e. the concepts (eucalyptus, vegetal species, license holder, etc.) structured by taxonomic (vegetal specie is more general than Eucalyptus) and semantical relationships (to be the property of), and the individuals (this tree, Paul, this area) categorized (instances of concepts) linked among them (for example, an area is included into another). However, the taxonomic, semantical relationships, the links and categorization are contextual: the eucalyptus can be a vegetal specie only for the ecologist, Paul is a license holder or this area is a protected zone relative to a given institution. Finally, these relationships can be defined across contexts; the Eucalyptus from the point of view of the ecologist is considered as fuel wood from the point of view of the coal-man, this area from the point of view of a surveyor is considered as a protected zone from the point of view of an institution (for example, the natural park administration). The most important is the lack of difference between putting an individual (Paul, this area) into a contextually defined category (license holder, protected zone) and attributing a role (the role of license holder, the role of protected zone) in this context. Thus "Paul is a license holder" and "this area is a protected zone" are of the same nature. [9] provides a detailed analysis of the various meaning of "counting-as" in a context, namely the classificatory meaning, proper classification and being constitutive. An analysis of "counting-as" is described as well in [7] but from the point of view of a unique institution. However, in each of those cases, the analysis relies only on the concepts but not the individuals, enabling to account for the first two cases but not the last ones. In [9, 7], it is therefore not possible to account for the notion of role under the form of a contextual categorization as we propose.

The regulative norms are usually specified using deontic operators (permission, obligation, prohibition). Thus, Moise+[10] is focused on the distribution of tasks in an organization with three specifications: the structural specification defining the roles, the functional specification defining a hierarchy of goals and missions, and a deontic specification linking missions to roles. [11] with AMELIA specifies the electronic institutions that impose protocols of interactions among agents defined in deontic forms. A version more sophisticated is proposed in OPERA [12]. In a different way, [7] formalizes the norms by violation criteria, the violation being deductively constructed. Indeed, the regulative norms raise the question of their control. In MAS software engineering, the norms are considered as specifications of high level and are enforced directly in the design of the agents and their interactions. In this case, the deduction of a violation becomes a kind of program proof. Nevertheless, in open multi-agent systems, the case of agents that do not abide with the norms either intentionally or accidentally has to be taken into account[12]. [13] proposes a mechanism of punishments and rewards, which requires the agent to reason on the advantages and disadvantages to obey or not to the norms.

MIRANA has the intent to model the actual functioning of the institutional structures. In Law, for a norm to come into effect, one must foresee a control function that can be systematic or not and possibly leading to a violation record (the police function) and a sanction system in case of such a record (the penal function). In order to do it, we have separated the norm expression from its implementations. Thus a hunting quota can be enforced by a control strategy or by the distribution of licenses. Given the variety of implementations, we were brought to reify each institution by an agent having the status of a moral person and the role of manager of the associated institution. Therefore, we distinguish the institution as as structure, from the agent who manages it. We are now going to present our proposition to represent and implement the constitutive and regulative norms.

2.2 The formalization

We are then going to formalize what precedes by using the contextual ontologies for the constitutive norms, and deontic forms for the regulative norms. Therefore, each institution $i \in I_{SMA}$ is defined as follows:

Definition 1. *The specification of an institution i is a pair $DI_i = \langle O_i, N_i \rangle$ where:*

- *O_i is an ontology;*
- *N_i is a set of regulative norms .*

Having a family of institutions, we obtain a corresponding family of contextual ontologies. We will describe the ontologies and the regulative norms in turn.

Contextual ontologies and constitutive norms To account for the constitutive norms, we equip ourself with a family of ontologies O_i. Each ontology is defined on a language $\mathbb{L}_i = \langle \mathbb{C}_i, \mathbb{P}_i, \mathbb{O}_i, \mathbb{I}_i \rangle$ where:

- $\mathbb{C}_i$ is a set of concept names;
- $\mathbb{P}_i$ is a set of relation names[1];
- $\mathbb{O}_i$ is a set of individual (or object) names;
- $\mathbb{I}_i$ is a set of ontology names.

This definition is usual but the introduction of ontology names to be able to internally refer to other ontologies. To account for the specificity of MAS, we propose to decompose the set $\mathbb{C}_i$ of concepts into four disjoint sets:

- $ARole_i$ for the concepts of agent;
- $RRole_i$ for the concepts of objects (or individuals);
- Act_i for the concepts of activities;
- Loc_i for the concepts of places.

The derived concepts are built by the usual constructors: $\neg c$, $c_1 \sqcup c_2$, $c_1 \sqcap c_2$, $\forall r.c$, $\exists r.c$, $i{:}c$ where c, c_1, c_2 are the concepts, $r \in \mathbb{P}_i$ and $i \in \mathbb{I}_i$. $i{:}c$ denotes the concept c in the ontology i and allows denoting the concepts defined in other ontologies. We impose that the set of derived concepts for the agents, objects, activities and places are disjoint.

Finally, $c_1 \doteq c_2$ and $c_1 \sqsubseteq c_2$ are the terminological axioms for definition and subsumption. Notice that if $c_1, c_2 \in Loc_i$, $c_1 \sqcup c_2$, $c_1 \sqcap c_2$ and $c_1 \sqsubseteq c_2$ have the usual sense of geometrical intersection, union and inclusion. We are now in the position to formulate the first two cases:

- "Eucalyptus counts as a vegetal specie" is expressed as $Eucalyptus \sqsubseteq VegetalSpecie$ in the ontology (the mental universe) $O_{forester}$;

[1] In description logics, they are called roles but we will not use this term to not confuse with the roles in the organizational sense.

- "Eucalyptus counts as timber" is expressed as $Eucalyptus \sqsubseteq j{:}Timber$ where $j \in \mathbb{I}_{forester}$ is the name of the carpenter's ontology from the point of view of the forester, or complementarily, $i{:}Eucalyptus \sqsubseteq Timber$, i being the name of the ontology of the forester from the point of view of the carpenter.

The forester can know that the eucalyptus is timber without the carpenter knowing it, or vice versa. Notice that it is always necessary to mention in which ontology (from which point of view) the axiom is expressed because the denotation is strictly contextual. Thus, we obtain the expressivity of [5]. However, we have added the locality of ontology names. Consequently, an ontology may not be able to designate another ontology and therefore might not know the corresponding concepts.

In the same way, we decompose the set $\mathbb{O}_i$ of individuals within:

- A_i the set of agent names;
- R_i the set of object names;
- P_i the set of activity names;
- L_i the set of place names.

The corresponding assertional axioms (or assertions) are $c(o)$ and $r(o_1, o_2)$ where $c \in \mathbb{C}_i$, $r \in \mathbb{P}_i$ or of the form $i{:}r$, and $o, o_1, o_2 \in \mathbb{O}_i$ or of the form $i{:}o$, where $i \in \mathbb{I}_i$. $i{:}o$ denotes an individual o in the ontology i and allows denoting the individuals as named within another ontology. It is the same for the relations. In $\mathbb{P}_i$, we define en particular a relationship *position* between a place and an individual allowing to situate an agent or an object in the space.

We can now express the last two examples:

- "This tree counts as my property" in O_{owner} can be translated by $i : property(tree_{27}, I)$ where i is the name of the ontology of the institution in which the notion of property is defined, $tree_{27}$ is the name used by the owner to denote the mentioned tree and I is the name used by the owner to designate himself (and of course himself is different for each agent).
- in the same way, one can express "Paul counts as a license holder" by $i : LicenseHolder(Paul)$.

We see in the last example that the notion of role in the organizational sense, being for an agent or an object, is naturally expressed using contextual categorizations.

The introduction of the place as particular objects allows us naturally to introduce the roles of space areas. Thus an expression as $i{:}ProtectedZone(area_7)$ allows to categorize the place $area_7$ as a protected zone from the point of view of i. In geography, it is commonly admitted that a territory is defined as a socially appropriated area. Intuitively, we propose to account for this definition by saying that an ontology O is the expression of a socially or individually constituted point of view, and then that the set of places categorized by using the concepts of O constitutes his territory. The following definition formulates this intuitive description.

Definition 2. *The set of places $c_i{:}l_j$ mentioned in the assertions of the form $\langle concept\rangle(c_i{:}l_j)$ of the ontology O_{c_1} is called the* territory *of c_1.*

The figure 1 illustrates some territories in our application. The park administration, customary lineage and VOI correspond to institution territories. In this case, the park administration and the lineage do not need to decompose the area into subareas. For the lineage, it could be a sacred, forbidden zone. The VOI defines protected zones, cropping zones, etc.. Notice the introduction of territories from the point of view of agents as well. Hence, the villagers only consider the roads between the villages. The ecologist is not an agent within the model, although he defines the notion of habitat to account for flora and fauna dynamics.

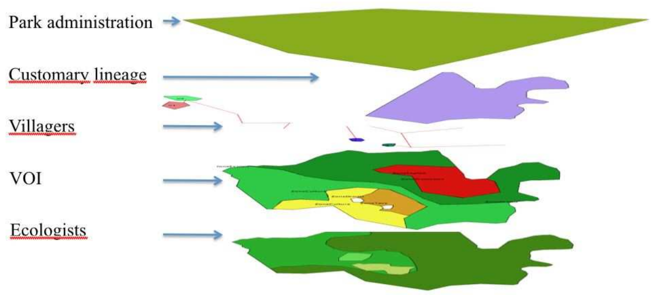


Fig. 1. The various territories.

Finally, we define an ontology as a triple $O_i = \langle \mathbb{L}_i, \mathbb{T}_i, \mathbb{C}_i \rangle$ where $\mathbb{L}_i$ is its language, $\mathbb{T}_i$ is the set of terminological axioms and $\mathbb{A}_i$ is the set of its assertions.

The semantics of a family of ontologies O_i is defined by giving a family M of local interpretations[2] $\Delta_i = \langle \mathcal{A}_i, \mathcal{R}_i, \mathcal{P}_i, \mathcal{L}_i, \pi_i \rangle$ where:

- $\mathcal{A}_i$ is a set of agents;
- $\mathcal{R}_i$ is a set of objects;
- $\mathcal{P}_i$ is a set of activities;
- $\mathcal{L}_i$ is a set of places endowed with a topology;
- π_i is the semantical function defined as follows:
  - $\pi_i(c \in ARole_i) \subseteq \mathcal{A}_i$
  - $\pi_i(c \in RRole_i) \subseteq \mathcal{R}_i$
  - $\pi_i(c \in Act_i) \subseteq \mathcal{P}_i$
  - $\pi_i(c \in Loc_i) \subseteq \mathcal{L}_i$
  - $\pi_i(r \in \mathbb{P}_i) \subseteq \mathbb{O}_i \times \mathbb{O}_i$
  - $\pi_i(o \in A_i) \in \mathcal{A}_i$
  - $\pi_i(o \in R_i) \in \mathcal{R}_i$
  - $\pi_i(o \in P_i) \in \mathcal{P}_i$

[2] It is mainly this locality that grounds the contextual feature of these ontologies.

- $\pi_i(o \in L_i) \in \mathcal{L}_i$
- $\pi_i(i \in \mathbb{I}_i) \in M$
- $\pi_i(\neg c) = \{x \in \mathbb{O}_i | \neg(x \in \pi_i(c))\}$
- $\pi_i(c_1 \sqcup c_2) = \{x \in \mathbb{O}_i | x \in \pi_i(c_1) \vee x \in \pi_i(c_2)\}$
- $\pi_i(c_1 \sqcap c_2) = \{x \in \mathbb{O}_i | x \in \pi_i(c_1) \wedge x \in \pi_i(c_2)\}$
- $\pi_i(\exists r.c) = \{x \in \mathbb{O}_i | \exists y, \langle x, y \rangle \in \pi_i(r)\}$
- $\pi_i(\forall r.c) = \{x \in \mathbb{O}_i | \forall y, \langle x, y \rangle \in \pi_i(r)\}$
- $\pi_i(i{:}c) = \pi_j(c) \cap \mathcal{O}_i$ where $\pi_i(i) = \Delta_j$

The last definition allows defining the semantics of a reference to the expression within another ontology. It depends on the possibility to actually designate that ontology ($\pi_i(i) \neq \bot$) and to share, at least partially, the domain of discourse. For the spatial dimension, we put forward, in addition to the topology on $\mathcal{L}_i$,the semantics of the position relationship: $\pi_i(position) \subseteq (\mathcal{R}_i \cup \mathcal{A}_i) \times \mathcal{L}_i$ that gives the position of the objects and agents.

Finally, the interpretation Δ_i is a model of the ontology O_i under the following conditions:

- $\Delta_i \models c_1 \doteq c_2$ if and only if $\pi_i(c_1) = \pi_i(c_2)$;
- $\Delta_i \models c_1 \sqsubseteq c_2$ if and only if $\pi_i(c_1) \subseteq \pi_i(c_2)$;
- $\Delta_i \models c(o)$ if and only if $\pi_i(o) \in \pi_i(c)$;
- $\Delta_i \models r(o_1, o_2)$ if and only if $\langle \pi_i(o_1), \pi_i(o_2) \rangle \in \pi_i(r)$;

This definition is stated differently than in [5] where the semantics of an axiom is given by the set of its possible models. It is easy to see that it is equivalent.

The regulative norms A regulative norm is expressed in the language $\mathbb{L}_i$ of O_i and of the form $\langle ar_i, mod, act_i, or_i, l_i \rangle$ where:

- $ar_i \in ARole_i$ is an agent category (role),
- mod is a deontic modality (obligation, permission, prohibition),
- $act_i \in Act_i$ is an activity category,
- $or_i \in RRole_i$ is an object category (role) on which the activity applies,
- $l_i \in Loc_i$ is a place role,

A regulative norm states that an agent considered as playing a given agent role (r_i) has the obligation, permission or prohibition to realize the activity act_i on the objects playing a given object role (r_j) in a place having the role l_i. Remind that having a role is equivalent to be contextually categorized as such. For example, given the concepts of $User$ ($User \in ARole_i$) and of $Thing$ ($Thing \in RRole_i$), as well as the activity $ToUse$ ($ToUse \in Act_i$), one can define the norm $\langle User, permission, ToUse, Thing, Territory \rangle$. It expresses that a user has the permission to use a thing all the time on the territory. The name $Territory$ is used instead of "everywhere" because an institution is assumed to be authoritative only on its associated territory. We will see in what follows how to represent that a particular agent plays the role of $User$, a particular object plays the role of $Thing$ and that, therefore, the norm applies. To simplify, we do not consider conditional norms nor temporal restrictions even if this last extension is taken into account, at least partially, in our implementation.

The natural order on the deontic modalities (obligation > permission > prohibition), as well as the subsumption relation $\sqsubseteq$ induces an order on the norms as given by the following definition:

Definition 3. *$\langle r_i, mod, act_i, r_j, l\rangle \leq \langle r'_i, mod', act'_i, r'_j, l'\rangle$ if and only if $r_i \sqsubseteq r'_i, mod < mod', act_i \sqsubseteq act'_i, , r_j \sqsubseteq r'_j andl \sqsubseteq l'$.*

Given that $\sqsubseteq$ is a partial order, $\leq$ also is a partial order. This definition is very important to compute the rights to do something somewhere. Intuitively, if we take a set of norms, all the minimal elements of this partial order define the norms that are actually applicable on the activities of the agent. However, they can contradict each other.

3 Agents

Each agent $a \in A_{SMA}$ is defined in the following way:

Definition 4. *The specification of an agent a is a pair $DA_a = \langle O_a, G_a\rangle$ where:*

- *O_a is an ontology specifying the beliefs of the agent;*
- *G_a is a set of goals expressed in the language $\mathbb{L}_a$ of O_a, as a list of assertions to make true.*

This very general definition of goal is enough to express the needs $access(I, \langle Rice, 100kg\rangle)$ as well as the physical $position(house, l_{34})$ or institutional $ProtectedZone(l_{56})$ goals.

The institutions $\mathbb{I}_a$ are those known to the agent. The affiliation is expressed by an agent counting as playing a given role in the institution. A minima, he is member, a role that subsumes all the others r ($\forall r, r \sqsubseteq Membre$). Thus an agent is member of an institution i is expressed by $i : Member(I)$ (formally, I is the category $Member$ of the institution i). [5] is forced to add a particular predicate $rea(a, r)$ to express that an agent a plays a role r. In our formalism, the assertions of an ontology is sufficient. Moreover, this assertion can be only in the institution (only the institution knows that the agent is member), or only in the agent (the agent believes that it has a role in the institution), or in both.

The set of institutions M of which the agent is member, and the territories in which the agent is situated, specify the set of applicable norms in terms of obligation, permission or prohibition to realize a given activity on a given object category. To account for it, we have to define formally the conditions under which a norm $\langle ar_i, mod, act_i, or_i, l_i, q_i\rangle$ of an institution i is applicable. There are two possibilities:

- the norm is applicable because the agent plays a role in the associated institution;
- the norm is applicable because the agent is situated on a territory regulated by an institution.

The following definitions allow accounting for these two cases from the point of view of the agent and from the point of view of the institution.

Definition 5. *A norm* $\langle ar_i, mod, act_i, or_i, l_i \rangle$ *of an institution* i *is* applicable *from the point of view of the agent* a *if and only if:*

- $i \in \mathbb{I}_a$ *therefore* a *knows the institution* i*;*
- *we can deduce from the axioms of* O_a *that:*
  - $ar_j(I)$ *and* $ar_j \sqsubseteq i{:}ar_i$*;*
  - a *knows at least one activity* $act_j \sqsubseteq i{:}act_i$*;*
  - a *knows at least a category of resource* $or_j \sqsubseteq i{:}or_i$*;*
  - $position(I, l)$ *and* $l \sqsubseteq i{:}l_i$*.*

We here assume that a knows something if it exists a name in its language $\mathbb{L}_a$ to designate it.

Definition 6. *A norm* $\langle ar_i, mod, act_i, or_i, l_i \rangle$ *of an institution* i *is* applicable *for an agent* a *from the point of view of the institution* i *if and only if:*

- $a \in A_i$ *therefore* i *knows the agent* a*;*
- *one can deduce from the axioms of* O_i *that:*
  - $ar_i(a)$*;*
  - a *knows at least one activity* $act_j \sqsubseteq i{:}act_i$*;*
  - a *knows at least a category of resource* $or_j \sqsubseteq i{:}or_i$*;*
  - $position(a, l)$ *and* $l \sqsubseteq l_i$*.*

Being applicable from the point of view of an agent, respectively from an institution, does not mean that it will be actually applied. Indeed, an agent may not honor it and an institution, as an agent, may not control it nor apply any sanction for it.

We will now describe in more detail the behavior of the households, respectively the VOI in MIRANA in order to illustrate the use of the proposed formalism.

3.1 The households

The households are characterized by an available workforce and a set of annual needs ($\subset G_{household}$). These needs include quantities of alimentation, finance, firewood (for cooking and heating), construction wood, medicinal plants and so on. Each year, each household plans its activities and executes them (see figure 2).

An household starts its cycle by selling all or part of his workforce by asking contracts ("contract request" in figure 2) to the VOI. The planning is thereafter composed of three phases:

1. If the contract request is accepted ("get request"), he receives one or more contracts ("contracts") for lumber jacking, planting or surveillance in order to detect possible norm violations. He has consequently to plan the related activities and evaluate the remaining workforce. The objective is to sell his workforce to possibly financially cover its needs;

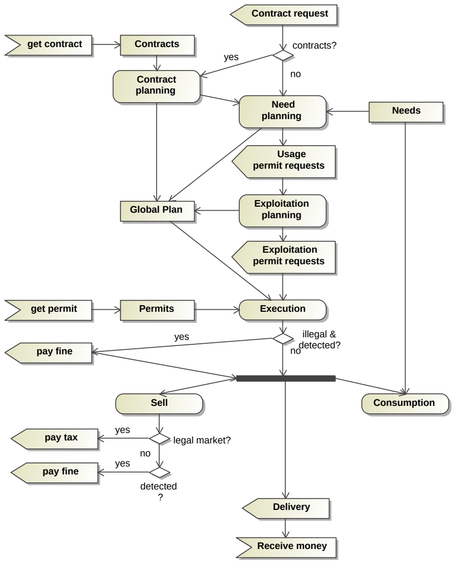


Fig. 2. The household behavior activity diagram.

2. Then, he plans his needs up to its available workforce. The usage permits regulate the satisfaction of the needs. Therefore he asks for such permits up to the necessary quantities of resources. The objective is to fulfill his needs;
3. Then, if some workforce remains, he plans the production of goods to sell on the market. Here also, the exploitation permits regulate the production and, consequently, are requested for. Here, the objective is to maximize his income.

The three phases produce sequences of actions to perform. These actions are added to a global household's plan ("global plan"). Notice that the behavior of the households does not reduce only to income optimization because we take into account two additional important dimensions of human behavior: i) The possibility of selling one's workforce although some optimization could be performed on the choice of contract; 2) The auto-consumption that is not based on optimization but on satisfaction only.

After this planning phase, the planned actions will be executed and the results will be delivered to the employer, consumed or sold depending on whether they were produced for the contracts, for satisfying the needs or for selling. The employee gets paid on delivery and the production sold on the legal market is submitted to a tax. At the end of year, every resource that has not be delivered to the employer or consumed is converted to money by being legally or illegally sold, and constitutes the annual financial result of the household.

We will now describe the regulation of the households' activities by the institutions. However, beforehand, we will make three remarks:

1. Each contract constitutes itself a small institution with limited duration (1 year in our simulations). Each contract defines the role of employer and employee with the associated norms in terms of delivery of goods or services, and payment. In our case, the contracts are made with the VOI who delegates the role of license holder for lumber jacking and the role of police for surveillance only to its members;
2. A part of the regulation is externally achieved by a control mechanism. The households in charge of surveillance dedicate a part of their time to monitor the actions of others. If a violation is observed, a fine is applied and the resulting resources are confiscated and given to the VOI.
3. Each household in its decision mechanism internally achieves the other part of the regulation. The result depends on whether the household is legalist or not and will be described hereafter.

At the planning level, each activity has to take place in a certain place ($\in L_{household}$). Therefore, part of the planning phase consists in choosing a place to carry out the activity. The place to be chosen depends on whether the household is legalist or not. If the household is legalist, the activity can only take place on a place where it is authorized from the points of view of all the defined institutions. This authorization depends on the norms applicable to the corresponding territories or zones that overlay upon it. If the household is not legalist, he may consider doing it on places that are not allowed from the point of view of one or more institutions. Notice that the norms can be equally be seen as constraints or resources for action.

At the execution level, the execution of the planned actions to satisfy the needs depends on the usage permit from the VOI. If the permit is not granted and the household is legalist, the corresponding action will not be executed, otherwise it will be illegally performed. In the same way, the execution of planned actions for commercial production depends on the exploitation permit from the VOI and follows the same rule. If the action is illegal and the violation is detected, a fine has to be paid and the corresponding resources are confiscated.

This behavior allows checking the impact of the imposed regulations on the financial results (economic sustainability) and the households' satisfaction (social sustainability). If all the households are strictly legalists, the level of satisfaction of the annual needs will be a good indicator of the sustainability of the regulations. If none of the households is legalist, the number of violations (detected or not) will also constitute a good indicator for the pressure imposed by the regulations. Another indicator could be the relative importance of the goods sold on the formal or informal market.

3.2 The VOI

The VOI has the objective, through its associated institution to guarantee a sustainable use of the renewable resources on its territory. As a stakeholder and moral person, the VOI is in charge of implementing the norms of the institution. This implementation of the norms relies on a number of tools:

– The granting of lumber jacking contracts and exploitation licenses to implement the exploitation quotas (the quota is assumed to be defined on the basis of the resources renewal speed);
– The granting of usage licenses to implement the usage quotas;
– The grants for plantation to compensate the forestry resource losses, and consequently to restore the ecosystem;
– The grants for intensification of the cultivation to increase the crop productivity and possibly reduce the footprint on the ecosystem;
– The granting of surveillance contracts to implement the norm compliance by the households.

Finally, the VOI ensures his own financial sustainability by gathering the fines and taxes, as well as by selling the contracted production and the confiscated goods on the market.

This behavior is summarized in the figure 3 where no sequential order is given to the activities because most of them are triggered by the arrival of the requests, or the order is not important.

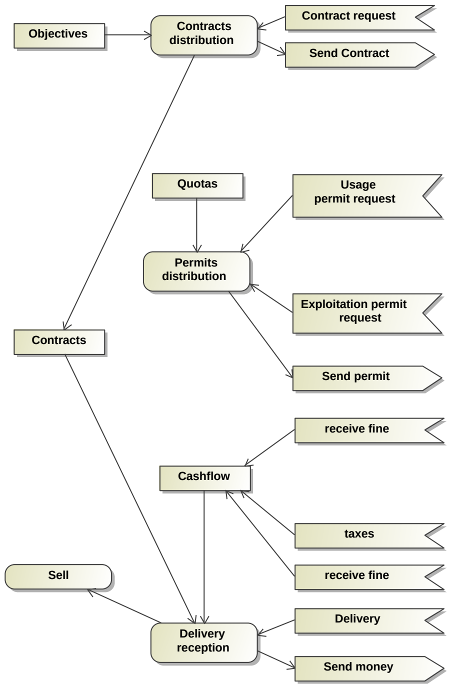


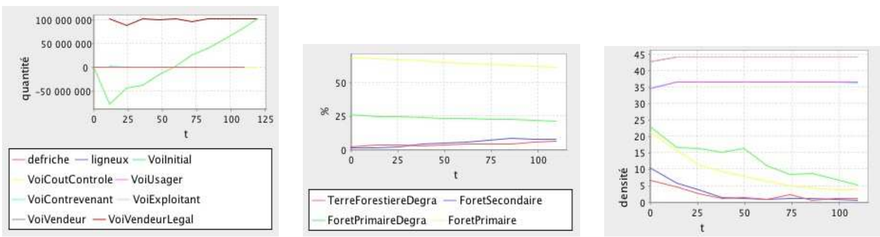
Fig. 3. The VOI behavior activity diagram.

At this level, it is possible to parameterize the regulation policies by the institution norms, including the quotas and the implementation policy and to assess the feasibility of the management plan. Therefore, we are globally able to assess the impact of the management plan on the ecological sustainability by indicators on the ecosystem itself, the economic sustainability of the households and of the VOI, and the social sustainability of the households.

Regarding the VOI economic sustainability, the costs include the surveillance and lumber jacking salaries, and the plantation and intensification incentives, while the revenues include the taxes (both for the permits and on the market sales), the fines, and the timber (both from production and confiscation) sales on the market.

3.3 Some results

We do not have the place to show extensive experiments, but the figure 4 illustrates some simulation results over twelve years (120 months) with non-legalist households and only a small fraction of the area with full conservation. The figure 4 a) shows the VOI financial results. The red line represents the tax incomes that are relatively constant over time, producing an increasing net income (green line). The initial negative result is due to the payment of the first salaries. The figure 4 b) shows the evolution of the habitats in percentage of the total surface. There is only a slow erosion of the primary forest. If the degraded land increases, there is similar growth of the secondary forest. The simulation on 60 years (tree growth cycle duration) shows some recovery of the primary forest. However, the figure 4 c) shows that if we look at the tree species, some are more exploited than others.



(a) VOI financial results (b) Habitat evolution (c) Tree species evolution

Fig. 4. Some results.

4 Conclusion

To tackle the sustainability impact of resource management plans in a multiple regulatory context, we have proposed a two-level description. In the first level, we have proposed the notion of institution as a set of norms covering the constitutive norms, the regulatory norms as well as the role structure, using in particular the contextual ontologies. In the second level, we have proposed to use the notion of agent to represent both the actors on which the norms apply, and the collective actors associated to each institution who implement the normative constraints. As a result, we have shown that the proposed formalization of institutions allows accounting for the multiplicity of legal interpretations necessary to understand the regulations interplay. We also showed the possibility to naturally account for a multiplicity of territories. Finally we have illustrated how the formalism allows expressing the agent account of a multiplicity of regulative structures in its planning and execution mechanism.

The dynamics has been globally defined and the generic specification of the account of norms at the agent level remains to be described. We have, among others, dissociated the institution as a structure from the agent implementing the collective objectives through control strategies of norms and the non-regulatory management methods (incentives, taxes, etc.) that remain to be formally specified. The use of contextual ontologies for the constitutive norms paves the way to a reflection on common knowledge that also remains to be defined.

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Agent-based cooperative control for biocoenosis sustainability in biotechnological processes

Mieczyslaw Metzger and Grzegorz Polaków

Faculty of Automatic Control, Electronics and Computer Science,
Silesian University ofTechnology,
ul.Akademicka 16, 44-100 Gliwice, Poland
{mieczyslaw.metzger, grzegorz.polakow}@polsl.pl
http://terminator.aei.polsl.pl/index_en.htm

Abstract. Biotechnological processes are difficult to control; many different state trajectories can be obtained from the same starting conditions. The two most common processes of this class encountered in the industry are: wastewater treatment process with activated sludge and alcoholic fermentation. In these cases, the quality of process control has a strong direct impact on the natural environment. Moreover, the crucial components of the processes are living organisms, which require appropriate actions to be taken to ensure their sustainability. This paper describes the agent-based approach to the operating control task for the two processes. Extensive theoretical background is provided, and the implemented control system is described, which supports a real-time agent communication protocol based on a blackboard knowledge system. Additional functionalities of the control system include the support for a cooperation between multiple experimenters, and on-line real-time modelling of the system providing the aid in a decision making.

Keywords: Agent and multiagent systems, artificial intelligence, cooperation, distributed computer control, sustainability, biocoenosis sustainability, self-sustained oscillations

1 Introduction

Since the beginning of the twenty-first century, the software agents and multi-agent systems technology constitute an increasingly attractive field of research in the domains of computer science and artificial intelligence. When the pioneer theoretical works [1-4] were published, the main field of the agent technology applications was in networked databases. The agent system concept was also perceived as a new programming paradigm, extending the well-known OOP paradigm. However, since the very beginning of the agent idea emerged, there were attempts to exploit the technology in industrial applications [5]. Applications of the agent technology are especially well established in the industrial manufacturing domain, due to the wide support of the leading manufacturers of industrial instrumentation [6-8], where the paradigm

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seems to fit well to the new approach to the development of distributed control systems using the IEC 61499 standard of function blocks [9].

The agent technology is not easily applicable in the continuous process industry, mainly due to the strict time determinism requirement of the continuous control systems [10]. Nevertheless, in the review [10] a number of interesting attempts is discussed to apply the software agents paradigm for control, modelling and simulation of continuous processes. In the concluding remarks of [10] it is suggested that the agent technology can be particularly useful in continuous process industry for biotechnological processes, where conventional control methods are inadequate. This is because of the fact that in biotechnological processes there are live cultures of bacteria and other microorganisms, which are used to make needed products. This applies to the manufacturing of medicines, alternative fuels, spirits, beverages and also to biotechnological methods of wastewater treatment. During an operation of a plant, appropriate bacterial cultures are stimulated in various ways to exhibit behaviour, which is beneficial for a process. Unfortunately, in many processes the demanded behaviour is also disadvantageous for the bacteria themselves. Therefore, it is crucial to maintain the sustainability of their biocoenosis (i.e. stability of micro-environment).

The problem of sustainability in fermentation processes appeared in the literature in the last few years. In [11] a feasibility of acrylic acid production by fermentation considering the environmental sustainability of the fermentation process is presented. A general discussion of challenges and opportunities in production of biofuels in USA is presented in [12], while challenges of the bioethanol production in Brazil is presented in [13] with discussion of sustainability of bioethanol production. Life cycle assessment has been used in [14] to investigate the environmental and economic sustainability of a potential operation in the UK, in which bioethanol is produced by the hydrolysis and subsequent fermentation of coppice willow. Anaerobic digestion of residue has the potential to enhance bioenergy recovery and environmental sustainability of algal bioethanol production [15]. Sustainability of biofuels is increasingly taken into account; therefore, sustainable production technologies are needed [16]. Despite the advantages in its sustainability and availability, the commercial use of lignocelluloses in lactic acid production is still problematic due to its complexity [17]. The reference [17] also provides an extensive review of bibliography on the subject. Concept of decentralized biorefinery for production of biofuel from wheat straw and clover-grass with emphasize on sustainability, localness and recycling principles is presented in [18]. In the study [19], different bioethanol production processes from sugar beet were analysed to improve energy input/output ratio and process sustainability.

First publications dealing with the problems of the sustainability of the wastewater treatment process were presented at the turn of the century. In [20] the sustainability of the municipal wastewater treatment process was evaluated with the life-cycle assessments methodology. A literature overview of sustainability assessment methods and currently used indicators for wastewater treatment processes was presented in [21]. Based on this, the paper proposes a general assessment methodology that builds on multi-objective optimisation and complete set of sustainability indicators, yielding insight into the trade-off made when sustainable wastewater treatment systems are chosen. The sustainability of a microalgae wastewater treatment plant, modelled when serving a small Swedish town was tested by comparing it to a conventional three-step treatment plant (WWTP), and a mechanical and chemical treatment plant (TP) complemented with a constructed wetland (TP + CW) [22]. Flux criticality and sustainability in a hollow fibre submerged membrane bioreactor for municipal wastewater treatment were discussed in [23], whereas problems of influence of sustainability and immigration in assembling bacterial populations of known size and function were presented in [24]. Anaerobic hydrogen production from organic wastewater, an emerging biotechnology to generate clean energy resources from wastewater treatment, is critical for environmental and energy sustainability. In the study [25], the hydrogen production, biomass growth and organic substrate degradation were comprehensively examined at different levels of two critical parameters (chemical oxygen demand (COD) and pH). Wetlands research and restoration has become one of the critical concern due to their importance in providing ecosystem services. The study [26] proposes a holistic methodology to assess the wetland ecosystem based on cosmic exergy as a thermodynamic orientor. This new approach is applied to two typical wastewater treatment facilities (an activated sludge system and a cyclic activated sludge system) and to a constructed wetland ecosystem in Beijing for comparison.

As listed above, the problem of ensuring the sustainability of biotechnological process is complex, and stimulation of microorganisms while maintaining the sustainability of their biocoenosis requires an extensive research. In this paper it is proposed to exploit an agent-based cooperative control system to support the task. The paper is organised as follows. Section 2 describes the details of the problem under consideration, section 3 states the goal for the control system in the case, and section 4 contains the description of the developed cooperative control system for the task.

2 General problem under consideration

Fig. 1 shows a diagram of the fermentation pilot plant, which is used in the Faculty of Automation, Electronics and Computer Science of Silesian University of Technology (FAECS / SUT) to investigate the control over a stimulation of the fermentation process in continuous stirred tank bioreactor (CSTB). Classical control algorithm ensures that a constant content volume is maintained in the tank, therefore the bioreactor works as a chemostat. Fermentation processes could be stimulated in various ways, but it is always required to ensure the sustainability of the micro-biocoenosis. It should be noted that while the most of typical industrial processes (e.g. thermal or chemical) can easily be disabled and then started again, in case of biotechnological processes, restart of a plant is quite a difficult task because the new culture has to be grown. Hence, the problem of sustainability of such processes is so important.

During both the initialisation of bacterial culture and normal operation, the process operator can change the concentration and amount of substrates as well as the flow rate Q through a bioreactor operating in the chemostat mode. The subsystem for measuring the density of the biomass fraction using a microscopic camera is noteworthy, as it allows for continuous on-line observation of biomass condition. In case of the fermentation processes, it is the biomass which generates products by using substrates, so to improve the quality of the process it is demanded to lower the consumption of substrates while maintaining the amount of biomass. The issue of efficiency of the fermentation process is associated with the presence of the self-sustained oscillations, which has already been presented in [27-29]. These works discuss also the issue of modelling and simulating the initiation and inhibition of oscillations in agent-based systems.

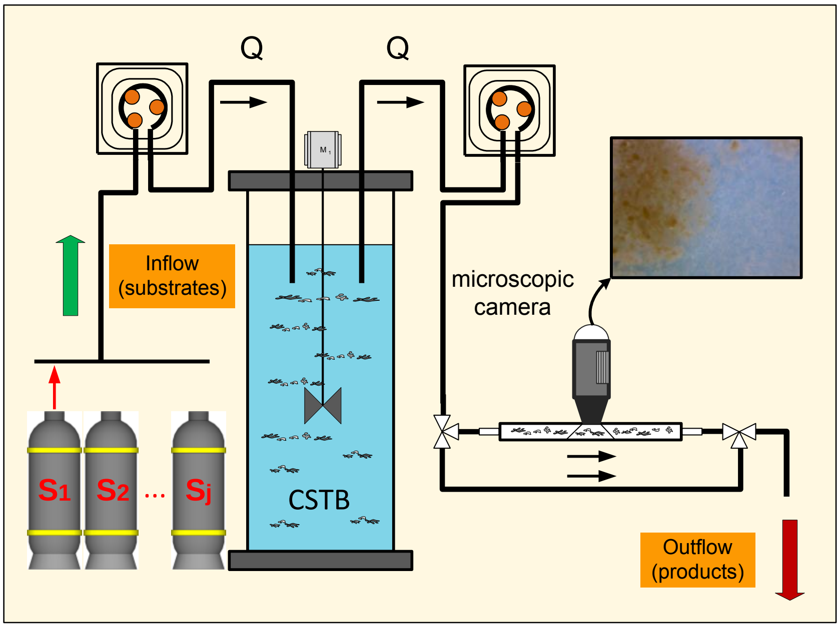

Fig. 1. Diagram of the technological part of the research plant for experimentation in maintaining sustainability of biomass biocoenosis in fermentation process.

Fig. 2 presents the bench-scale pilot wastewater treatment process which was developed and implemented in the FAECS/SUT and is used for research on advanced control systems for such the process. The research pilot plant can be used for various configurations of the process. In the classical layout the tanks are used as a bioreactor with aeration of activated sludge (R1) and as a settler for separation of activated sludge from purified water (R2). The tank R1 can also be used to conduct the process in a sequencing batch reactor mode (SBR). Finally, the tank R2 can be used as a second bioreactor for a two-reactor system R1-R2. Two pumps allow to conduct the process in the tank R1 at a fixed or variable working volume of the bioreactor. The tank R2 is equipped with an overflow outlet. Another microscopic camera enables the on-line continuous measurement of the activated sludge condition.

Problems of the biocoenosis stimulation are complex themselves (e.g. issue of forcing nitrification and denitrification), and at the same time the sustainability of activated sludge has to be maintained. This requirements encourage to seek for new intelligent control methods, which would perform well in this non-standard control problem. Moreover, the demanded optimisation of the WWTP process is the opposite of the optimisation of the fermentation process. In the latter the biomass was the wanted product. In the former, it is the water which is the product, so it is demanded to use as much as possible of the substrates (i.e. the contaminants from the wastewater) with the least possible amount of the biomass (which is a by-product in this case).

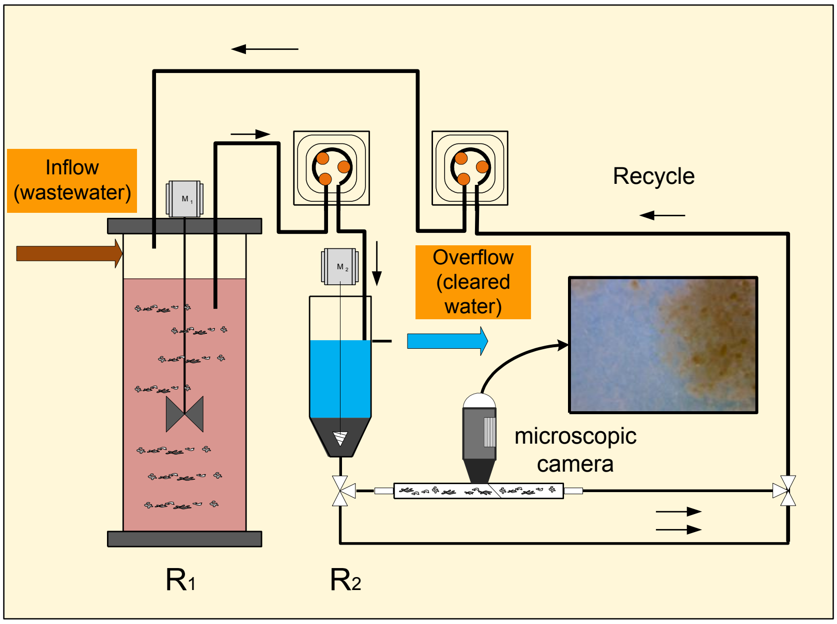

Fig. 2. Diagram of the technological part of the research plant for experimentation in maintaining sustainability of activated sludge biocoenosis in wastewater treatment process.

3 The aim of bioprocesses stimulation control with consideration of biomass sustainability

As it was stated above, the work described in this paper focuses on the stimulation of biotechnological processes in order to initiate or inhibit, in a controlled way, periodic transient states of the processes. The control goal differs between the two processes, as discussed above. In addition to the oscillations stimulation (which usually lowers the strength and vitality of the biomass), control has to ensure sustainability of the biomass. The control algorithm should focus on the quality of the biomass not only when the biomass very life is endangered, but in all the cases when the vitality changes, as it may be a sign of coming major disruptions. Obvious question arises: why, then, induce the periodic responses at all? The answer differs for both types of processes.

In fermentation processes, proper stimulation or inhibition of oscillatory behaviour of the biomass, for specific cases, results in increased average growth of biomass. For the process of alcoholic fermentation with Saccharomyces cerevisiae or Zymomonas mobilis bacteria, there are reports found in the literature on specific sugars that either generate self-sustained oscillations of the biomass or inhibit them. The use of the changing ratio of two such sugars for control of sustained oscillations is discussed in [27]-[29]. It should be noted that in this case the stimulation is "gentle" – it is based on relatively small changes of the ratio. The main goal of the process operator is the choice of the proper ratio of two substrates. The control method proposed for this class of problems is based on three software agents, which support the process operator in the task of decision making [27]. To ensure the sustainability of the biomass a fourth agent is proposed, which continuously monitors images from a microscopic camera, and initiates additional analytical measurements when needed. On this basis, the multi-agent system hints the process operator.

In wastewater treatment processes two classes of oscillatory behaviour stimulation can be distinguished. The first well-known class involves methods of strong stimulation in a macro scale, for example by turning the aeration in the reactor on or off. Common examples of processes from this class include nitrification, denitrification, and dephosphatation. The work described in this paper focuses on the second class, i.e. on precise stimulation of the biomass in a micro scale in order to strengthen the biomass. The process is called a bioaugmentation. The bioaugmentation can be performed directly in a bioreactor, by adding the mixture of easily and hardly degradable lipids to the wastewater [30],[31]. At the same time, such the approach to the process results in the production of the lipase enzyme directly in the bioreactor in the presence of Pseudomonas fluorescens culture. The process can be performed both in a continuous mode water treatment plant with a settler, and in a sequencing batch reactor mode (SBR). However, the bioaugmentation is most effectively carried out in a separate bioreactor, where the sustainability of the biomass is ensured, after which the biomass is redirected back to the main reactor.

A very important role is fulfilled by parallel modelling of the bioprocess on a basis of mathematical iterative model. Such simulated virtual bioprocess aids the operator in the task of predicting the biomass behaviour. Therefore, results from the virtual parallel bioprocess are vital, when the condition of biomass is to worsen. Because of this, parallel simulating capability is very valuable and should be supported by a control system to aid the operators in decision making. The following section describes the control system, which was developed for the two bioprocesses described above.

4 Architecture of multi-agent system for stimulation and parallel real time modelling of bioprocesses

4.1 Protocol for agent communication

Because of the numerous complex tasks, which the control system of the described laboratory stand should perform, it was decided to develop it basing on the software multi-agent dogma. Typical approach for such software in the manufacturing domain usually involves adoption of the well-known standard for software agents development, i.e. FIPA (Foundation for Intelligent Physical Agents). The standard is implemented in the form of working software platform of JADE (Java Agent Development Framework) [32]. The most important advantage of the JADE environment is that it is based on the Java language, which ensures a wide base of compatible hardware platforms. Unfortunately, this construction of the platform makes it virtually unsuitable for use in real-time control systems of continuous processes. In this class of control systems it is absolutely required from the software and communication to be strictly time-determined. This requirement arises from the general idea of semi-continuous systems, where calculations are performed in iterations. In each of the iterations, physical continuous signals are sampled, calculations are performed (e.g. control algorithms), and finally the results of the calculations are processed into physical quantities, which are applied to the system by actuators. This means, that in each of the iterations there are specific communicational tasks of transmitting the sampled values, and these tasks have to performed in a timely fashion, so when the time for another iteration comes, the system is ready to be sampled again.

Complex mechanisms of message processing used in the JADE framework and the fact, that they are executed in a virtual machine, results in a behaviour which is not time-determined, and is not acceptable in continuous control systems. Therefore, it became necessary to develop communication mechanism for a multi-agent system, which would provide time-determined communication capability. This is usually achieved by reducing the number of any intermediary software and hardware layers between the distributed entities. On the other hand, desired protocol should enable the agents to communicate in a way that is adequate for distributed smart agents, i.e. the communication protocol should be a mechanism for knowledge exchange, not just a simple method of network frames transmission.

The proposed solution is based on the previously developed pPDC protocol (parallel producer-distributor-consumer), which was the subject of extensive work on industrial networking and real-time multi-agent systems, and is described in e.g. [33], [34]. The protocol implements a low-level media access functionality of a network to ensure the timeliness of the data flow. The basis for the protocol design was the FIP industrial networking protocol, which was later modified to exploit the additional properties of a switched Ethernet network. Due to the extensive use of the network switches' memory and processing power, the protocol provides a good performance and is quick enough to be implemented even in control systems of fast-changing continuous processes.

When the pPDC protocol is employed as an agent communication language, it provides the model of knowledge exchange based on a blackboard. There is a central resource containing all the knowledge of the control system, and it is stored and managed by a specifically designated agent labelled as a *distributing agent*. The distributing agent cyclically broadcast the content of the blackboard over the network, which synchronises the states of all the agents in the system. All the other agents use the knowledge received by the broadcasts according to its agenda. If an agent's actions result in a modification of the global knowledge, the agent sends a suitable request to the distributing agent using point-to-point message. The distributing agent aggregates all the requests it received during a cycle, and, by broadcasting the modified blackboard again, it begins another iteration of the system. The idea of the cyclical work of the pPDC-based blackboard broadcasting is illustrated in the Fig. 3.

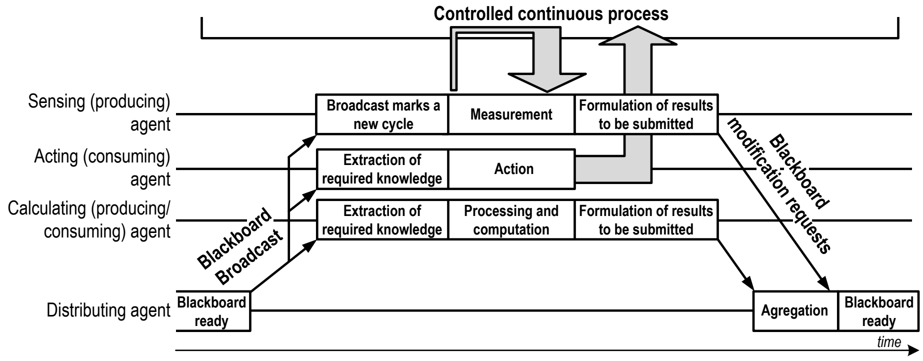

Fig. 3. A single cycle of the pPDC-based blackboard broadcasting.

4.2 Implemented control system

With the presented protocol the integration of a control system based on the software agents concept is straightforward, as each of the components of the control system is represented by an agent. The only requirement for a piece of instrumentation designated to be programmed into an agent is to support the Ethernet networking. The resulting system can incorporate desktop computers, mobile devices, industrial programmable controllers, and even custom made hardware. In the control system for the bioprocesses described in previous sections, the agents are mostly implemented as applications executed on National Instruments hardware, which is programmable in NI LabVIEW environment [35], supporting industrial-grade control instrumentation. Parts of the system are executed on the desktop PCs, i.e. image recognition algorithms used for data acquisition from microscopic cameras, or the user interface for system operators. Specific components of the system usually fall into one of the agents classes, described in the following subsections.

Sensing agents. Agents from this class perform the measurements and send the measured values to the knowledge base. In case of simple measurements, for which there exist efficient techniques and sensors (e.g. level of a liquid in a tank, oxygen concentration in a liquid), the measurements are taken on-line and the interaction with the blackboard is automated. Measurements which are not trivial and require complex sequence of actions and/or participation of many technicians (e.g. concentration of biomass) are taken off-line, and the results are sent to the blackboard on the specific request of the operators.

Calculating agents. Their task consists of performing some actions or calculations on the basis of the blackboard's content. Results of the actions are then immediately sent back to the distributing agent. The most important examples of agents from this class are the agents performing the tasks of control algorithms and online simulation of parallel mathematical model of the plants. The details of the agent-based simulation employing the pPDC protocol can be found in [33]. The reference provides the information on the character of modelled equations, the role of the blackboard, physical distribution of equations amongst separate agents, etc.

Acting agents. They constitute an interface between the knowledge base and the real-world system. In each of the iteration an acting agent reads a particular value form the blackboard and tries to apply it to the plant with an actuator. Any discrepancies between the desired plant state and actually achieved plant state will be detected by sensing agents, and taken into account by calculating agents as disturbances.

HMI agents. They form an intermediary layer between the distributed agents system and human operators. An HMI agent implements a graphical user interface, in which the state of the plants (read from the broadcasted knowledge base) is presented. Users can interact with the provided interface, and all the results of their interactions are sent to the distributing agent to be included in the blackboard.

Other. There are several additional roles, which can be distinguished in particular cases, such as archiving agents, which store the history of system state's changes into an external archive for later analysis. Nevertheless, the agent roles stated in the subsections above are fundamental, as they reflect the role of an agent in the networking protocol, i.e. sensing agents are producers, acting agents are consumers, and calculating agents are both producers and consumers.

4.3 Interactions between the operators

Social interactions between the cooperating system supervisors are reflected in the software layer as interactions between HMI agents, which represent them. Obviously, users' goals could differ, which would result in conflicting blackboard modification requests. Solving the conflicts between HMI agents communicating with the pPDC protocol was thoroughly analysed in [36]. In the reference, the conflicts arising between the agents are described, and the analysis is provided for varying scenarios of cooperation. Moreover, the method of solving the conflicts is proposed, which is based on granting the agents with rights of blackboard modification depending on a predefined hierarchy of priorities and timed tokens. The general idea consists of granting a token to an agent requesting write access to a part of the blackboard. The token entitles the agent to exclusively modify the piece of knowledge, although the token loses validity after a timeout. The timeouts have to be carefully predefined depending on the plant dynamics, and type of cooperation (supporting or competitive).

4.4 General architecture

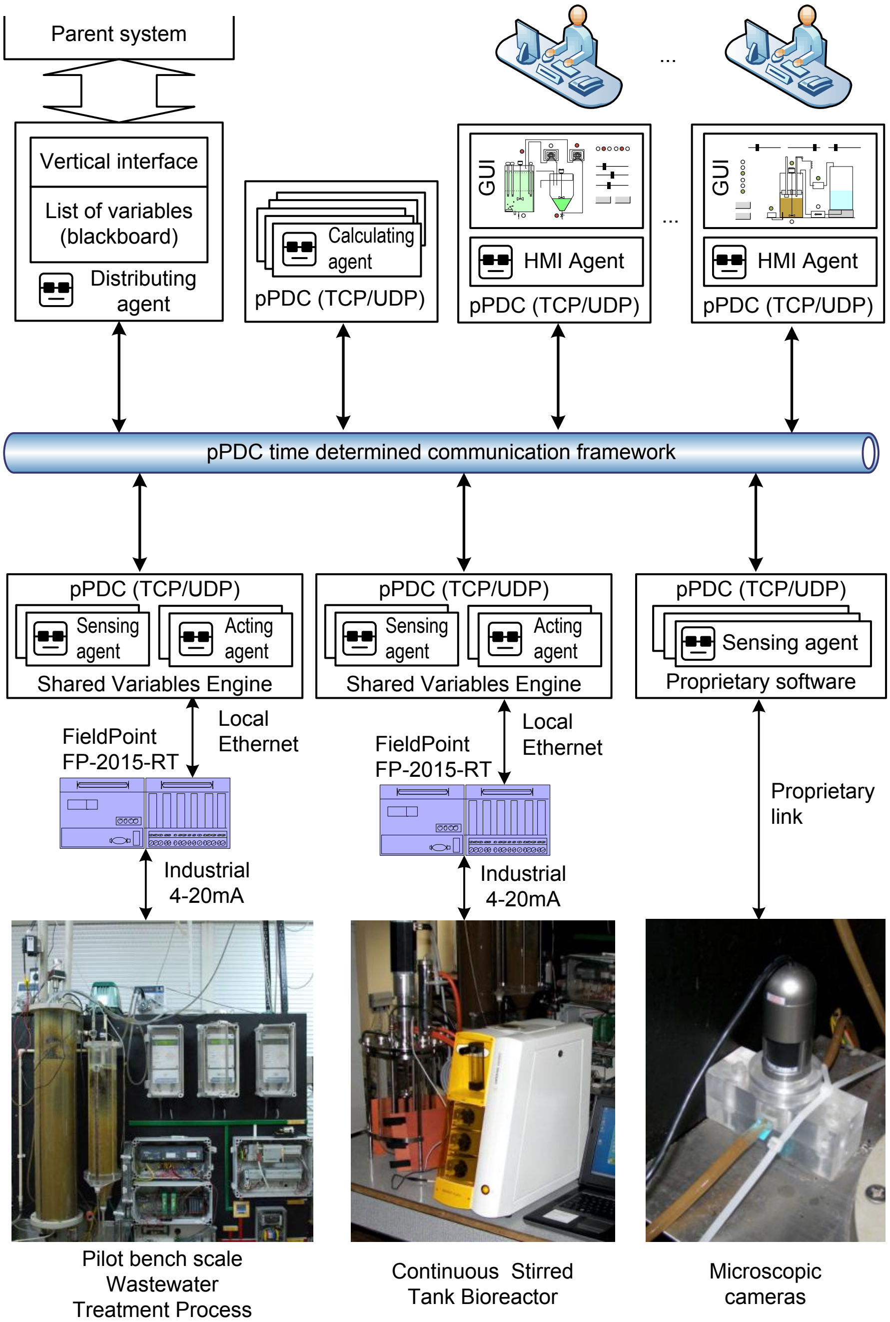

Fig. 4. The structure of the agent-based control system for the plants under consideration.

The architecture of the system which is the result of the above considerations is shown in the Fig. 4. It is worth noting that the distributing agent is a single node, which regularly, once for each iteration, holds exclusive full knowledge about the overall state of the system. The node is therefore predisposed to be augmented with an additional interface to a parent system. It was proposed before to develop such an interface basing on the idea of Web Services, which would enable the control system to become a part of a semantic web. However, much more attractive possibility is to implement the additional software layer compatible with the JADE environment. Such the architecture could improve the cooperative aspect of the system, by providing the translation of terms from different scientific domains with ontologies and folksonomies as proposed in [37]. The whole system then could be seen as a single component of a bigger entity, which could bring the idea of continuous control closer to the general notion of holonic manufacturing.

5 Concluding remarks

The MAS-based approach to the problem stated results in a better modularity and flexibility of the system, as it supports dynamic reconfiguration, particularly valued in the research environment. Current version of the MAS is implemented in the LabVIEW environment, which enables the agent applications to easily access the hardware with the OPC (OLE for Process Control) interface. However, there is work in progress on the implementation of the OPC agents in the JADE environment, which could enable the system to be moved to this well-established software platform.

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Agent Based Simulation of Drought Management Policy in Practice

Olivier Barreteau[1], Eric Sauquet[2], Jeanne Riaux[3], Nicolas Gailliard[1], Rémi Barbier[4]

Abstract. Drought management policy in France is implemented locally. Due to discrepancies between assessment of drought situation by managing agency on one hand and water users on the other hand, as well as to uncertainty in measures and benchmarks, its efficiency is limited. We propose in this paper an agent based model designed to represent the suitable indicators of drought at the suitable spatial scale for any category of stakeholders. Initial test of the model show its suitability to explore sensitivity of efficiency of drought management setting according to its context: population of water users and their attitudes to water restriction rules as well as practical details of implementation.

Keywords. Drought management; rule enforcement; spatial indicators; exploratory simulation

Introduction

The French water act institutionalizes a drought committee at county level. Such committee sets the rules characterizing a situation of drought and how to react when such situations occur. Characterization of a drought situation depends on two different activities: (i) defining benchmarks usually with thresholds and reference to past chronicles, and (ii) assessing current water levels to be compared to these thresholds. These both activities are in practice rather complex, due to several reasons including limited data sets across time and space and multiplicity of resources. Hence, actual characterization of a drought situation is controversial due to the salience of the issue for participants in such committees combined with the multiplicity of possible benchmarks, all incorporating uncertainty. The consequences of the practice of these activities as they are framed by the setting from the local decree are still unknown.

Through a consultancy for the French National Agency for Water and Aquatic Environments (ONEMA), we first made explicit these controversies [1], the origin of uncertainties making them possible [2] and the consequential mistrust in the implementation of local drought management acts [3]. Emergence of controversies is also fostered by the diversity of ways participants to drought committee meetings can assess drought situation by themselves: different places (e.g. where their well is located, or the bridge where they cross the river is) and different resources (groundwa-

adfa, p. 1, 2011.

ter or surface water). Each user comes also with his/her own indicator to characterize drought: water level but also length of riverbed without water.

All come then with their own view gathered in the single possible assessment: drought/No drought. Drought committee will rather ends up with a negotiated assessement. Implementation and respect of rules which is formally generated by this assessement will then depends on the adhesion of watre users to the assessment, even more with the weakness of means for control. This raises an issue of effectiveness and fairness of these drought management acts according to the diversity of possible scenarios for implementing them. These initial empirical studies could make clear this concern of controversies in implementation while it is supposed to have all the rigor of science. To go further, we needed some simulation tool to explore contrasted scenarios of implementation of local drought management policy.

To create this tool, we took a pragmatic stance: explaining dynamics generated by this policy with "situated action" instead of planned action [4-5]. Agent Based Modelling has a suitable format for this [6]. More recently Guerrin [7] proposed a dedicated framework to represent action with a stance close to situated action paradigm. Hence we have decided to go for a virtual case study implemented in an ABM and empirically grounded through previous interviews and ethnographic analyses. The specific requirements for this virtual case include being spatially explicit enough to generate information about the water system according to the diversity of observations: place and type of data collected.

In this paper we present the simulation model that has been designed and implemented and the bottlenecks we had in building it in order to be able to represent knowledge coming from the ethnographic work and how we solved them. A first section comes back to the pragmatic situation of drought management facing controversies due to the diversity of indicators of water level and places to assess them among participants to drought committees (stakeholders and county administration). Second section defines the requirements it implies for modeling this process, with a focus on the perception interface between the natural system and stakeholders. Third section describes the model itself. In a last part we present first simulation outcomes in two situations: without uses in order to validate the environmental dynamics, and with irrigation uses and discrepancies in place of observation.

Drought management act in practice

Main features of drought management in France

Drought management at county level in France is a downscaling of a national frame set by the 1992 water act, leaving up to the county administration to enforce it in specific decrees adapted to local situation. These decrees set local protocols to anticipate for and handle water shortage situations. Major droughts in 2003, 2005 and 2006 made this issue crucial for close to all counties. Hence "drought action plans" have become generalized. These anticipate periods of water scarcity and propose rules to attenuate their consequences or to decrease their occurrence. These protocols involve three main institutions: the administrative authority legitimate to restrict water use (the Prefet and administrative services), a drought committee gathering various water users, and an infrastructure used for assessing the situation, including its rules of use and the knowledge about other users it encapsulates. The drought committee meets up in winter time, out of crisis period, to discuss and occasionally adapt the infrastructure. They also meet up during crisis to discuss the current situation, restrictions activated in consequences (according to what had been agreed upon in winter time), and possible derogations. Infrastructure entails deciding whether there is a crisis or not, and in case its severity. This implies formalizing:

- thresholds of water levels in specific places (exact place and choice between groundwater or surface water) characterizing situation of droughts,
- protocols to acquire the knowledge on water levels to be compared with thresholds,
- a partition of county into subsystems to cope with diversity in resource availability and uses within county, each of them having their own sets of thresholds of referential water levels.

Diversity of indicators and thresholds

This infrastructure for public action [8] looks well tuned to handle drought situations. But in practice, several drawbacks occur, including information gathering and processing. According to farmers, the existing partition is not at a fine enough grain to cope with the diversity of perceptions. They push for a more subdivided partition, conflicting with another trend –and demand- for more solidarity and equity among water users at a larger scale. Farmers know water levels from the places where they pump water, and from what they see in their farm, where they pump water or along their way to the county main city (to go to the committee meeting for example). Stakeholders more concerned by ecological concerns, including representatives of fishermen, observe for example the length of river with no running water. Representatives of administration have a few automated monitoring places, but sometimes less than the number of areas in the partition, due to their cost. Thresholds are characterized from statistics on past chronicles. But due to lack of data, they are often engineered from other data and adapted. This discrepancy between various assessments of drought situations and the mistrust on reliance of thresholds value lead to requests for postponing implementation of restriction rules.

Consequences for enforcement of rules

Hence, the implementation of these local "Drought action plans" consists permanently in crafting adjustments to reality of situations and needs, evolving with experience, needs and knowledge. This permanent renegotiation is a concern for administrative authority whose plan is supposed to prevent from negotiation during crisis time, in order to improve efficiency and equity. It is also a concern for water users who have feeling of an unfair process. They tend to criticize or even disqualify the infrastructure because of three reasons. First, they don't understand what justifies different restriction rules among left and right bank of the same river, because they are not part of the same area in an administratively defined zoning, or they don't understand why water looks being wasted in other parts of the county while they have to restrict in their own. Contestation is also due to the compartment of the environment where water is withdrawn: surface or ground water. Rules based on surface water level (resp. ground water) when water is pumped in ground water (resp. surface water) leads to higher contestation. Second, they can discover during drought committees the light empirical support for determining thresholds, due to lack of relevant data suitable for the chosen zoning, replaced by existing data not always relevant for the drought planning and management purpose in the place for which they are used. Third and last, they become aware that determination of current drought situation depends not only on measures on questionable places, but also on practical adaptations such as preventing from too frequent changes in water uses restrictions. The current confusion between an academic science and a regulatory science [9] and the will to conceal the difference to water users lead to deep criticisms, further tentative to get more derogations and raise concerns regarding actual respect of restrictions.

Paradigm of situated action [5] is then suitable to analyze this process, even though it is named a plan. Attitudes of participants in the Drought Action Plan implementation depend mainly on the on-going context, based on their perception of water availability and needs as well as their perception of some fairness and ecological concerns. They certainly come to drought committee meeting with a plan in mind, but this plan is determined by their current conditions. From a methodological point of view to organize observations in a way suitable with this paradigm, we considered Operational sequences [10] as a means to describe how stakeholders process for crucial activities such as assessing drought situations and drought references [2].

A model to explore drought management patterns

We focus now on the issue of evaluation and agreement on evaluation among stakeholders, including administrative authority and water users. Therefore we leave aside the zoning aspect of the contestation as far as it addresses the number and limits of sub basins. It is an important issue, which we will address in a further stage of the modeling process. Explicit representation of conflicting views on environment and its impact on the evolution on a socio-ecosystem is already a challenge.

Requirements for the model

Efficiency of a drought action plan on drought situation will then depend on the willingness of water users to comply with restrictions activated by crossing thresholds, while they don't necessarily trust the legitimacy neither of the thresholds to represent accurate benchmarks nor of the current values to qualify actual water level situation. As a proxy, water use can be limited to irrigation for it is the main quantitative use at low water times. Other uses will be included in further versions. From a policy engineering point of view, we explore the settings of the policy that helps to ensure its effective enforcement.

Through designing a simulation model of a county drought policy, we aim at analyzing sensitivity of the water system and water uses to various scenarios of Drought Action Plan and individual behavioral patterns of water users in complying with restriction rules. The situation and focus described above generates the following requirements for model development:

- a spatially explicit representation of hydrological dynamics with ground water and surface water and their interactions represented at each point, with a granularity able to cope with the farm scale,
- representation of pumping in surface as well as ground water at farm level according to perception of drought, and knowledge on rules in use at county level,
- representation of the impact of this pumping on surface discharge,
- representation of dynamics of implementation of rules at county level according to drought situation, as assessed by the administration and, possibly, negotiation among stakeholder representatives,
- coupling between physical and social components need to be distributed on each point and at each time step, to represent the diversity of places where information can be grabbed by various water users and where water level may be impacted.

Finally we consider that stakeholders are first related to specific spatial objects. These can be specific places, such as a pump's location, a measurement station or any specific landmark. They can also be aggregated pieces of land, such as a river, with fishermen representatives for example assessing drought through the length of a river without flowing water. The landmarks are usually located in meaningful places, but they don't assume a priori whether it is part of a river aggregate or not. This is important in dry season in Mediterranean basins where several rivers feature actually intermittent flows.

Simulation of drought management policy in practice fosters then the need for specific modeling of resource dynamics: scale of observation of resource by stakeholders provides the scale of spatialisation of flow representation. Hydrological signal needs to be realistic at this spatial scale since it might be used for feedback in the water assessment component. Additionally, model needs to provide a dual representation of levels and flows. These both requirements are rather new for hydrological modeling. We now present how we adapted previous hydrological modeling frameworks to cope with them.

Existing approaches for hydrological modeling

Hydrological modelling is currently divided into two main categories: conceptual models and physically based models. Conceptual models provide a simplified representation of the general behaviour of the catchment based on the continuity equation as well as additional mathematical relationships to simulate the links between rainfall and surface runoff. In this category GR models [11] for example are conceptual models based on relations between data series of inputs and outputs of water and calibrated on past series. Physically based models which try to represent the rainfall-runoff transformation based on the understanding of hydrological mechanisms which control the response through physically based equations. They aim at being explicit on water flows between surface, soil and ground water compartments which ends up in impacting on hill slope flows and river discharge [12]. Most of them are spatially distributed models accounting for the variability in the input variables as well as in the properties which influences the processes across the catchment. These distributed physically based models, such as in [13-14] among others, represent the dynamics of water flows on a landscape represented as a computing grid, from inputs due to rain to outputs including evaporation.

The differences between these two categories models lie in the manner the processes are described, e.g. in the mathematical forms, in the degree of sophistication in how each component of the water cycle are represented (some of them can even be neglected, e.g. snowmelt processes in lowlands). The choice of the modelling approach (conceptual versus physically based models) is governed by the specific objectives of the exercise (engineering versus research issues), the extent of the investigated area (large versus small basins), the practical experience in model handling (no knowledge versus expertise), the well-known performance of the model under similar climates (poor versus good), the data available to parameterise and to run the model (few data versus well monitored area), the required temporal scale of outputs (coarse versus fine resolution), etc. [15-16].

Both categories of models are able to tackle connections between surface and groundwater. When dealing with whole river basins or territories equivalent to the size of a county, distributed models are still at a scale rather too large to cope with farm level, in order to represent the hydrology and the discharge at the outlet of the basin in an acute way.

More recently a few scholars have attempted to represent hydrological process in a fully distributed way, based on techniques such as cellular automata or agent based modeling. Delahaye and colleagues [17] have represented interactions between land use and flows with a cellular automaton featuring a topological graph with the only coded characteristics being the topography. Water then flows on this simulated landscape. A more extreme attempt has agentified “water bowls” in the RIVAGE model. In this model elementary particles of water move according to basic physical laws on a given landscape, they can meet up and aggregate in various form of water bodies

[18]. These both innovative approaches have inspired our work. However they handle much more local scale than our need.

Integrated hydrological models and agent based models

Agent based modeling is currently a common approach to represent the dynamic relations between a hydrological model and water uses. Le Page and colleagues review several of these in a recent chapter [19]. Berger uses them to represent impacts of technical innovation and policy changes in Chile, coupling economic impacts for farmers with new water policy setting in Chilean sub basins [20]. Van Oel and his colleagues use an ABM to represent dependence of land use decisions in arid north-east Brazil on practical water availability. Their model of water uses choice impact on a semi-distributed hydrological model with land cell and rivers represented as sequences of branches [21].

In several cases these models are considered useful for interaction with stakeholders, including because of their adaptability to explore various scenarios for example of water users' preferences or of their context of work such as climate [22]. This interactivity is best represented in participatory modeling cases such as the KatAWARE model designed in a south African basin [23]. These authors design an Agent based Model of a river basin taking in charge the suitable entities to cope with the various viewpoints of stakeholders according to their suggestions in the modeling workshops. Becu and colleagues [24] have proposed a whole method for eliciting conflicting views on what drives farmers in their practice up to including these heterogeneous representations within a single agent based model.

This set of experience proves the suitability of Agent Based Modelling to deal with our requirements. We now need to adapt them for specific assessment of drought situations.

The GESPER model

From existing literature and requirements expressed above we had to go further than most in the direction of a distributed model: any individual represented in the model should be able to take as an indicator the state of any place. We found the direction of RIVAGE model interesting because of its suitability for cases in drought situation, like intermittent rivers, which feature a more acute stake for drought management. In this section we describe the GESPER model, based on a cellular automaton for the physical part and an ABM to include social and behavioral dimensions.

Physical part of the model

The physical layer is made of a grid of cells with a connectivity of four. We assume a cell representing a square of 500x500 m^2. Each square cell is made of three compartments: surface, sub-surface and groundwater. These cells are first described by their altitude, soil characteristics i.e. a soil water capacity, and ground water capacity. We apply to these elementary cells the algorithm of MERCEDES model [12] according to figure 1 below. This means adding further parameters to the cell characteristics to handle interfaces between compartments: infiltration rate, deep release rate and superficial release rate.

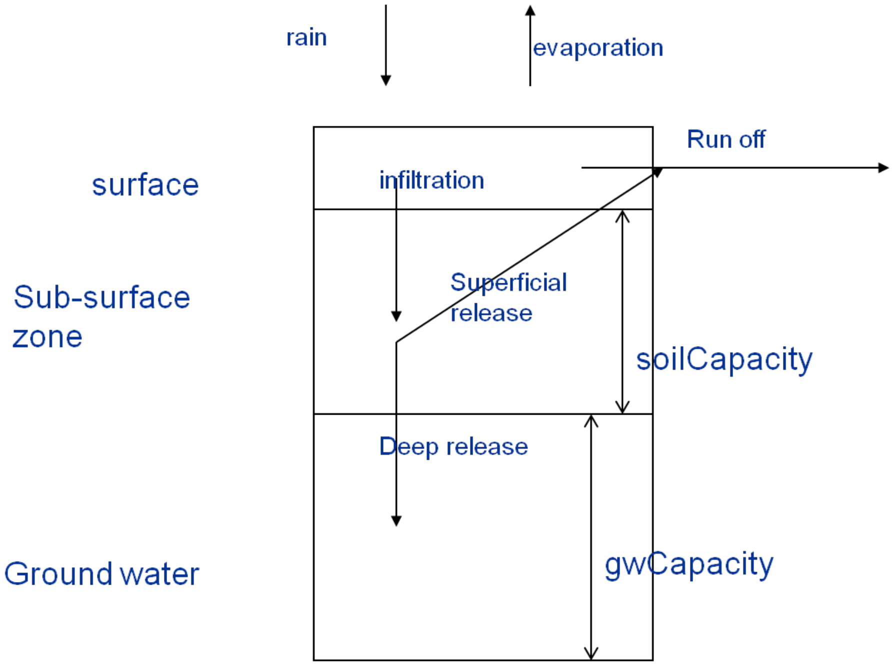

Figure 1: hydrological dynamics at cell level

Surface transfer between cell is adapted from MODCOU algorithm [25-26], a physically distributed hydrological model with variable scale. This model needs to predefine two parameters of transfer of the cell, that depend on cell's hydrological status (part of a river or not). These two parameters, *aDist* and *aVol*, entail specifying the quantity of water is leaving a cell during one time step and the cell this "*water pack*" reaches. The distance of transfer (*distanceTransfer*) and volume of transfer (*volTransfer*) of this *water pack* during one time step is computed according to the equations below, where *slope* is the mean slope between initial and final cell and *volStock* is the current water level on the initial slope.

$$distanceTransfer = (timeStep * \sqrt{slope}) \;/\; aDist$$

$$volTransfer = aVol * volStock$$

When *distanceTransfer* is computed, the transfer path of the *water pack* is determined, according to the lowest altitudes. A key benefit of this modelling approach is the possibility to represent stocks and flows at the same time, since we can compute for each cell the quantity of water going through it during the time step and its time of residence in the cell. Any withdrawing along the flow can also be computed in any cell through decreasing the quantity of water flowing through it. Quantity withdrawn

8

from each *water pack* is proportional to time of residence of this *water pack* on the cell, with constraint of the total quantity of water withdrawn during the time step and quantity of water available for each *water pack*.

Underground flow between cells is adapted from [27]. It features an additional attribute for Cell, *deepTransfer*, such that a cell *c1* will transfer to a cell *c2 deepTransfer * (c1 saturation – c2 saturation)*, if *c1 saturation* > *c2 saturation* and if *c2* is the cell with the lowest saturation in c1 *neighbourhood*. A cell saturation is computed as the difference between its groundwater compartment capacity and its groundwater compartment content. Further each cell has a leakage from its groundwater compartment which is calibrated so that this compartment stays stable in average from one year to another without withdrawals. Calibration has determined this leakage parameter at 1.6mm for each cell. Adding this parameter is needed because there is no outflow from ground water.

Model handles specifically boundary cells to prevent from boundary effects. Each boundary cell goes through the same surface flow process if it can identified a target cell with the rules explained above for non boundary cells. If this identification is unsuccessful, the target cell is a virtual cell, assumed to be 1 m below emitting cell. Each boundary cell goes through the same underground transfer as explained above if it has a neighboring cell with a lesser saturation, otherwise a fix transfer (*deepEmission*) to a virtual neighboring cell is generated.

Topography is adapted from a real county in south of France, the Drôme county. It has been adapted in order to get rid of any endoreism. We consider then that physical interface is a virtual landscape with features close to a real one, enough for comparison with real data. Figure 2 below provides a view of this virtual landscape with an altitude point of view. The cell size is 500mX500m.

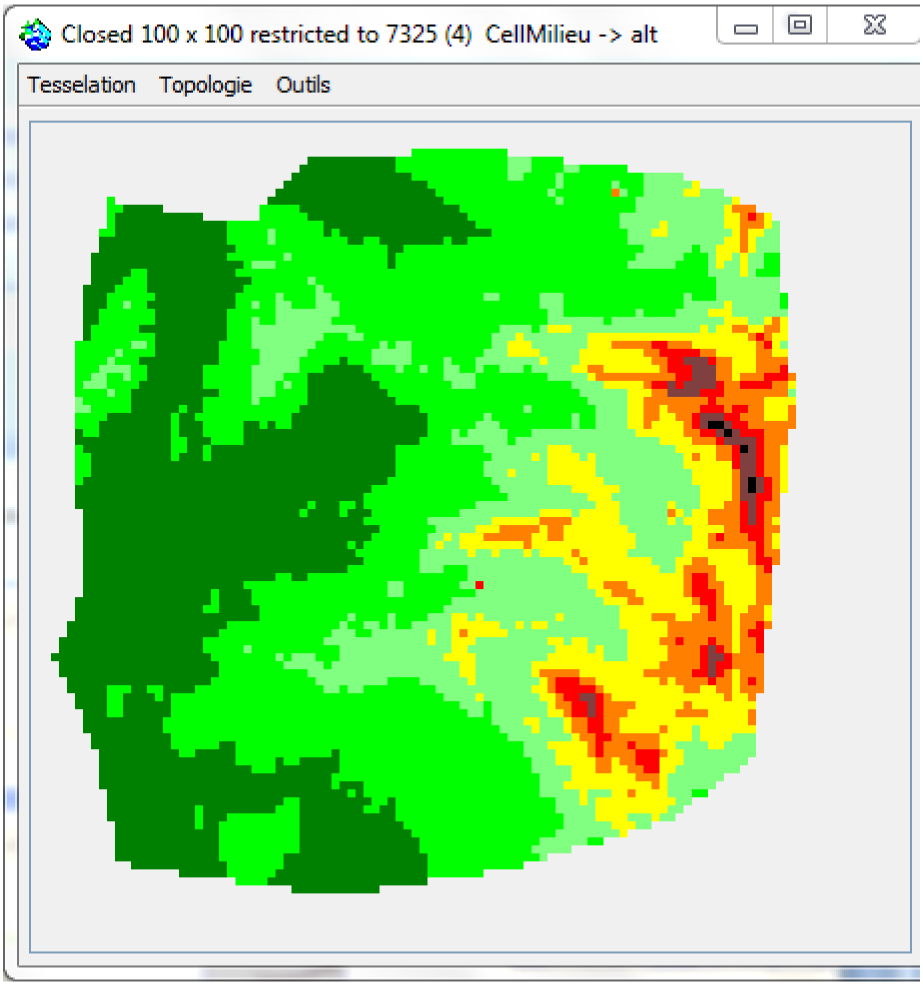

Figure 2: view on altitudes in the virtual landscape. The darker green the lower, the darker brown the higher

Climate is represented by potential evapotranspiration (PET) and rain. Even though we use in this example the same value for the whole area, the model is tailored to represent climate variability, with each cell having its own climate attribute.

Water use interface

We designed and implemented an agent based model, GESPER, in order to represent heterogeneous patterns of qualifying drought situations among policy makers and water users in a shared territory. This modeling work comes after a thorough ethnographic analysis of how stakeholders characterize a situation of drought, share this information with others and use all the gathered information in their actions [2] including patterns of negotiation in drought committee [3]. In the virtual landscape

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described above, each cell is either part of a farm or in public domain. All farms can be fed with water pumped either in surface water or in ground water through a pump entity (i.e. an instance of a class Pump) located on a cell belonging to a farmer and in a specific compartment in that cell (ground or surface). We assume that farmers have a full and perfect knowledge of water needs and are able to pump whenever they need if water is available. Farmers assess drought situation through water level at the location of their pump in the relevant compartment (surface or groundwater) with comparison to their own reference level.

Administration is represented by a single agent, an instance of PolicyMaker, with a limited set of reference points and threshold associated to them and uses. In a first try, we considered only one reference point, the outlet of the largest basin in the area, and one water use: corn growing. When a threshold is crossed, the rule forbids pumping to farmers in the associated area for the stipulated water use. A major assumption for this agent is its complete incapacity of controlling respect of restrictions. This assumption is justified because of the de facto low implementation in France: police means to control are weak and most cases which are occasionally spotted end up with no penalty at the judge level. Other assumption regarding PolicyMaker is periodicity of its activity that is supposed to be weekly: drought situation is assessed only every 7 days.

To mitigate this assumption, water users are endowed with three possible attitudes regarding restriction rule compliance: respect the rule (attitude := respect), respect the rule when agree on drought situation (attitude := ownAssessment), don't respect the rule (attitude := noRespect). At each time step (the day), they decide to pump water according to their needs, the rules, their attitude regarding the rule and their own assessment of drought situation. Figure 3 below features the UML activity diagram of this social dynamics.

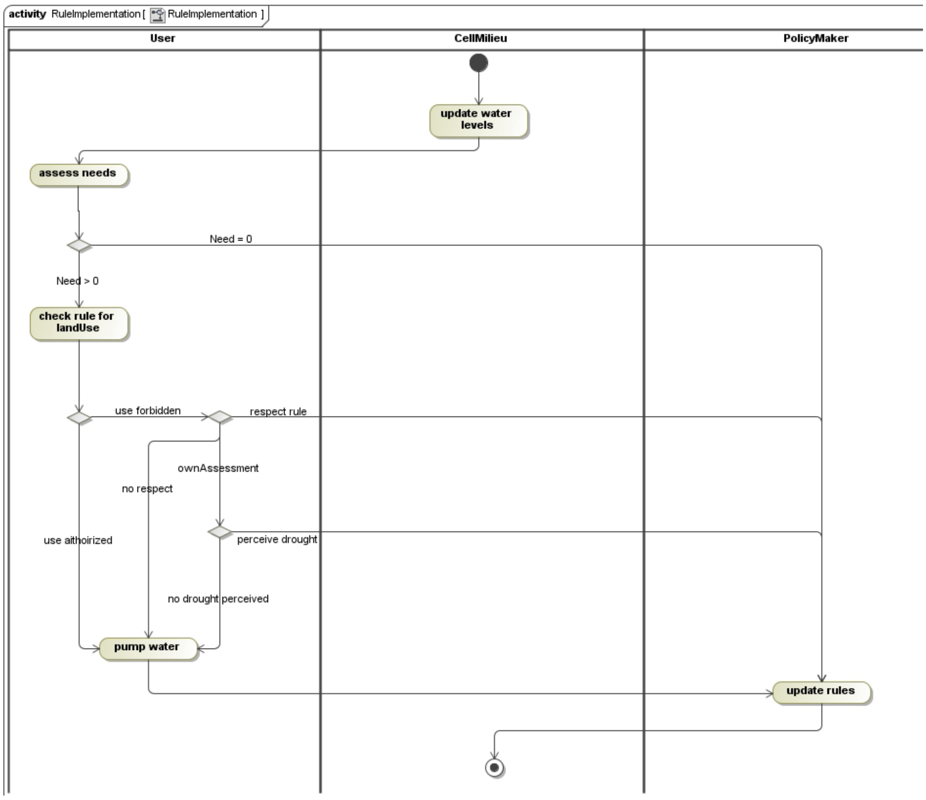

Figure 3: activity diagram for behavioral dynamics within one time step

We assume at this level there are no direct interactions between users and administration.

Model implementation, calibration and verification

Model is implemented with Cormas platform (http://cormas.cirad.fr). It can provide several indicators to check its realism provided empirical data are available: outflow for the various sub basins, groundwater levels in each cell, but also water balance at cell and whole county level. Outflows can be compared to observed discharge levels in the Drôme river basin for orders of magnitude but also specific statistical description of these flows, such as average value, variance, or the annual monthly minimum flow with a return period of 5 years, QMNA5.

First level of model verification is checking that simulations comply with water conservation at any scale. Figure 4 below shows the aggregated balance for the whole basin along 3000 days. Absolute value of this balance is always below 0.2mm, which is less than 1% of the average discharge at the main sub-basin outlet.

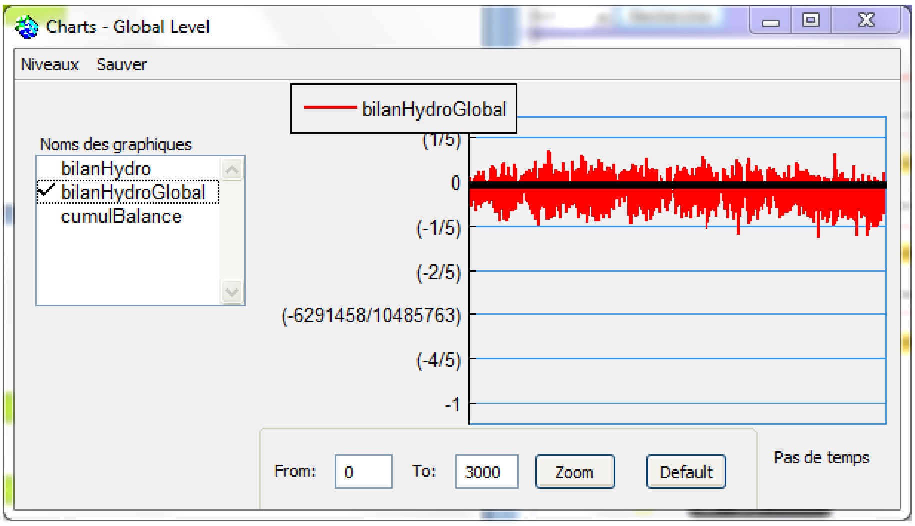

Figure 4: global water balance in mm. X-axis is time (days).

We calibrated the leakage parameter in order to be realistic in order of magnitude of flow. Then we compared simulated mean flows and QMNA5, which is representative of low water period, with observed ones over a 40 years period for the Drome river valley and could calibrate the other hydrological parameters.

Simulation outcomes

First simulation outcomes with this model show some sensitivity to farmers' attitudes with more acute crises when farmers respect the rules only when they agree on the assessment. The variation observed among the scenarios is not striking partly because we implemented a demand concentrated in a few points. Therefore the demand is first constrained by water availability in the place of pumping and not by the attitude of water user. Still we can see difference among scenarios with a higher amount of water pumped and less stress for corn when farmers use their own assessment than when they follow the restriction from the policy maker. This observation on simulation outcomes is not surprising, but it contributes to confirm model's validity. The impact on water level at the assessment place is relatively less important: it is more a delay in crisis when farmers respect the rule, but the crisis is not prevented. This is due to the existence of several sub basins. Several pumps actually have a very minor impact on the monitored sub basin, because they withdraw water from other sub basins while official assessment is in surface compartment. This is also not a big surprise, but might contribute to the debate on subdivision of counties in a number of areas.

Conclusion and perspectives

This experience shows the consequence on the representation of hydrology when we aim at exploring the enforcement of a water policy in practice: fine spatial distribution of representation and coupling of social and hydrological processes at this fine scale. We could provide here the conceptual description of the model to meet this requirement, up to its implementation and initial tests. The verification of the model and the initial set of simulation show that the Gesper model is operational and proposes a sound basis to explore various scenarios of drought action plan and water uses. Capacity to reproduce realistic hydrologic patterns, including statistical description, makes it legitimate to be used to understand the dynamics induced by multiple uses and multiple assessments. As it has been designed for, it meets the initial requirements for developing this tool. In the example above farmers act upon their own qualification of water drought which can be different of qualification on the administration side. These qualifications are locally dependent but this location is encapsulated at each agent level. The outcome, on which the communication can occur, is whether there is a situation of drought or not. The model is fully spatially explicit and generates dynamically the hydrological state of each land cell. Granularity is still a little bit coarse (500m x 500m) for farm representation but it fits the data available for physical environment and allows keeping computing time low.

We expect this kind of tool to be useful at a meta-level. The water and aquatic environment agency considers that it will push water administration at county level to pay more attention to the assessment step in the enforcement of drought action plan. Discrepancies between assessments and the contestation which happens to occur in consequence are not only an issue of strategic game and acting in bad faith. It is also due to a true diversity of perceptions with potential consequences on effectiveness of the plan on drought situation.

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Toward a Framework for Simulating Agent-Based Models of Public Policy Processes on the Jason-CArtAgO Platform

Iverton Adão da Silva dos Santos
Antônio Carlos da Rocha Costa*

Centro de Ciências Computacionais
Programa de Pós-Graduação em Modelagem Computacional
Programa de Pós-Graduação em Computação
Universidade Federal do Rio Grande – FURG
96.203-900 – Rio Grande – RS – Brasil
{iverton.santos,ac.rocha.costa}@gmail.com

Abstract. This paper introduces the concept of agent-based model of public policy cycle and gives an overview of the first version of the MSPP framework, a framework that is being developed to support the simulation of agent-based models of public policy cycles on the Jason-CArtAgO platform, through the use of "policy artifacts".

1 Introduction

This paper introduces the concepts of *agent-based model of public policy process* and of *policy artifacts*, and reports the first version of the MSPP (Modeling and Simulation of Public Policies) framework, a framework which aims to support agent-based models for the various types of sequential and non-sequential models of public policy processes [1].

The MSPP framework consists of a set of programming schemes, classes and API developed for the Jason-Cartago platform [2, 3]. It fits the general idea of "embodying" organizations in systems of artifacts [4], but centering on the idea of "embodying" policy cycles with the help of "policy artifacts".

The agent-based model of a classical, sequential public policy cycle was chosen to help to illustrate the features of the framework. Possibilities for further research toward the extension of the MSPP framework for agent-based models of more complex models of public policy processes are considered in the Conclusion.

The paper is structured as follows. Section 2 reviews some basic concepts concerning public policies, introduces the notion of agent-based model of public policy cycle, and presents the simple agent-based model of public policy cycle used in the paper to illustrate the current features of the MSPP framework.

Section 3 brings a summary of the main features of the Jason and CArtAgO platforms, that we jointly use to implement the MSPP framework.

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The main section of the paper is Sect. 4, which gives the details of the MSPP framework for the implementation of the simple agent-based model of public policy process introduced in Sec. 2.

Section 5 briefly analysis related work, and Sect. 6 is the Conclusion.

2 Public Policies and Agent-Based Models of Public Policies

2.1 Public Policies and Models of Public Policy Processes

In general, a *policy* is conceived as a set of principles that orient and/or condition decisions and actions of the agents that operate in a given context, specially in what concerns the uses of resources available in that context [5].

A *public policy* in a given society, thus, is a policy concerning the uses of resources that are considered to be *public* in that society [1], usually being issued by the government of that society.

There are many different ways to conceive the structure and form of operation of public policies, and many ways to explain how public policies are created and put to operation, the so-called *policy making* process [1].

Some of such *models of public policy process* are *sequential*, in the sense that the process of creation and application of public policies is conceived as a sequence of steps performed, at each time, by one of the different actors, or group of actors, involved in the process (for instance, the several variations of the traditional *public process cycle* [6]).

Some those models, on the other hand, are *non-sequential*, in the sense that the process of creation and application of public policies is conceived as a set of partially independent activities, carried out concurrently by the different actors, or group of actors, involved in the process (for instance, the several variations of the *policy network* model [7]).

We concentrate in our work in the use of sequential models of public policy process. A typical way to picture the sequential cycle of steps involved in such models is as follows [1]:

1. Identification and formulation of the issue to be solve through the issue and implementation of a public policy;
2. Formulation and comparative analysis of various possible alternative policies able to solve the problem;
3. Choice of one of the those policies for implementation;
4. Implementation of the chosen public policy;
5. Evaluation of the effects of the implementation of the public policy, and possible adjustment of the policy, to improve results and reduce negative effects (thus returning the process to step 1).

There are many conceptual problems that arise in the application of this model to the theoretical and empirical analysis of real public policy processes, which justify criticizing it as too schematic [1].

However, since our concern in the present paper is just the preliminary determination of the general possibility of obtaining operational agent-based models of public policies, we acknowledge the overall limitations of this cyclic model, but stick to it here, in a tentative way, for simplicity.

Accordingly, the "policy artifacts" that we introduce here are those just necessary for the modeling and simulation of that model of policy cycle.

2.2 Agent-Based Models of Public Policy Processes

The vocabulary used in the area of Policy Analysis for the study of models of public policy processes (cf., e.g., [6, 1]) makes use of the notion of *actor* to talk about the stake-holders involved in any public issue and any policy making process that may arise to solve it. However, no formal meaning is usually assigned to that notion, the literature normally relying on its common sense understanding.

We aim at a notion of agent-based model of public policy process where the notion of actor is understood in the sense that the notion of agent has in the Multiagent Systems area [8], so that such notion can adequately support systematic models and methodologies for the agent-based simulation of public policy process.

We call *agent-based model of public policy process* such agent-based notion, and the present paper reports the first results we have reached in the direction of that conceptual development.

Since we do not have yet a full-fledged general agent-based model for public policy processes, we content ourselves in the sequel with the presentation of the agent-based model of the restricted, sequential form of public policy process that we have introduced in the Sect. 2.1.

2.3 Agent-Based Model of Public Policies

Besides defining an agent-based model for the process of policy making, an agent-based model for the very notion of public policy is itself needed, if that model is to have a sound basis. That is, we had to define a notion of *agent-based public policy*.

For that, a suitable notion of public policy had to be chosen from vast variations of notions available in the Political Science literature. Since the notion of agent, as it is understood in the MAS area is not used in that area, we had to look for that notion in approaches to public policy processes that allowed for an adequate formulation of the needed definition.

We found in the so-called *tools of government* approach to public policies [9, 10]. In that approach, the *government* is pictured as an agent, able to perceive (*detect*) and act (*effectuate*) in the society, through four main kinds of *tools*:

- *nodality*, that is, the way government is inserted in the social network;
- *authority*, that is, the ways government has to command the social actors;
- *treasure*, that is, the set of financial resources the government has to support its attempts to influence the structure and functioning of the social system;

– *organization*, that is, the set of non-financial resources the government has to support its attempts to influence the structure and functioning of the social system.

We take for our work, what seems to us the general ideas of the *tools of government* approach, where the toolkit constitutes an operational interface between the government and the society. However, aiming at an agent-based model, we consider that such toolkit is made operational through a set of agents that operate under control of the government. Thus, we take that in the context of our simplified agent-based model of public policy process, the toolkit proposed in the tools of government approach can be adequately realized through the following set of agent types:

– *government*: an agent, or set of agents, that produce and control the execution of public policies;
– *government agents*: agents that operate in the society as *detectors* and *effectors* for the government, serving as the interface between the government and the society.

Additionally, we call *societal agents* all the other agents operating in the focused society, which are neither government agents nor the government itself. The resulting picture of the resulting agent-based model of public policy process is presented in the next section (Fig. 1).

On the other hand, besides an agent-based model of the public policy process, we also need to have an agent-based model for the very notion of public policy. Given the restricted scope of this preliminary stage of the work, the following notion proved to be satisfactory, as also explained in the following section:

> A *public policy* is a set of *norms* and *plans of action*, to be adopted and followed by both the *government agents* and the *societal agents* that operate in the social context of concern.

By doing this, we place our work within the current trend of the MAS area aimed at developing and consolidating the notion of *normative multiagent systems* [11].

2.4 An Agent-Based Model for the Execution Phase of the Public Policy Process

We note, initially, that even the restricted, sequential cyclical model of public policy process introduced in Sect. 2.1 is complex enough to be taken as the initial step of this research. To proceed in a successful way, we have had to focus in on particular step of that model.

For its central importance in the study of the connections between the simulation of the public policy process and the simulation of the social system to which a public policy is to be applied, we have chosen to work initially with the *implementation step* of the simplified model of public policy process, that is, the step where the chosen public process is installed and put to work in the social system.

More specifically, we focus in this paper in the *execution phase* of the implementation step, that is, the phase where an implemented policy is being put to work.

Under such restriction, we state that:

- the *norms* that constitute the public policy are supposed to address all the agents operating in the society, both government agents and societal agents;
- the *plans* that constitute the public policy are supposed to address exclusively the government agents, that is, they are the means through which the government controls the detector and effector agents it has at its disposal, to govern the execution of the public policy.

To have a definite notion of *norm*, we take that norms state either *obligations* or *prohibitions* of actions potentially available to the agents in the social and physical environment of the society.

At the end, as we have already mentioned, we come out with three basic types of agents involved in the execution of a public policy:

- *government*: an agent able to issue public policies (we take in this paper, for simplicity, that the government of the society can be modeled as a single agent);
- *societal agents*: those agents to which the public policy is generally addressed, presumably to solve a public issued identified in their social context;
- *government agents*: auxiliary agents that operate as detectors and effectors for the government.

Four special kinds of government agents are also identified:

- *norm enforcers*: detector and effector agents that participate in the process of enforcement of the norms specified by the public policy:
  - *norm detectors*, which capture information concerning the agents' compliances to the policy norms;
  - *norm effectors*, which apply the sanctions prescribed by the norms to the agents that do not comply to them;
- *environmental operators*: agents that perform plans specified by the public policy, aiming at the direct control of aspects of the physical or social environment of the society, in the sense of performing actions that operationally interfere with the structure and/or the elements of those environments (e.g.: actions on physical objects, interferences on social relationships, etc.):
  - *environmental detectors*, which capture information concerning the state of the environment resources;
  - *environmental effectors*, which act on the environment resources, changing their features, allowing or blocking the other agents accesses to them, creating or removing resources, etc.

Of course, in concrete uses of the agent-based model of public policy process, one can relax this strict separation between basic government agent types and allow for government agents that implement two or more of such types simultaneously.

2.5 Architecture of the Agent-Based Model of the Execution Phase of Public Policy Processes

Figure 1 illustrates the architecture of our agent-based model of public policy process. As noted above, the model concentrates on the execution phase of the implementation step of the adopted simplified model of public policy process.

Note that a relevant point not made explicit in Fig. 1 is that the environmental effectors can remove public resources as well as introduce new ones.

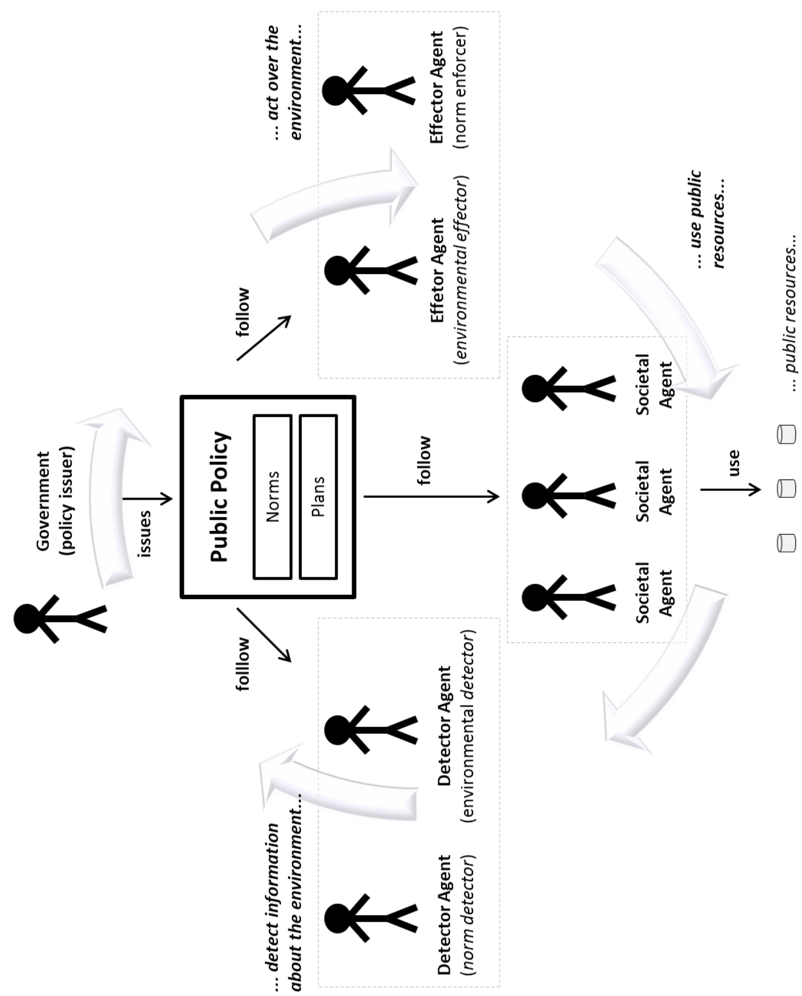

Fig. 1. Architecture of the agent-based model of the execution phase of public policy process.

3 The Simulation Platform

The public policy simulation framework described in this paper is aimed to be implemented in a simulation platform that jointly combines the Jason and CArtAgO platforms, which are briefly described in the following.

3.1 Jason

Jason (A Java-based AgentSpeak Interpreter Used with Saci For Multi-Agent Distribution Over the Net) [2] supports the implementation of BDI agents, the agents being programmed in an extended version of the AgentSpeak language, and the platform supports speech act-based agent communication.

3.2 CArtAgO

CArtAgO (Common ARTifact infrastructure for AGents Open environments) is a platform [3] that supports the implementation of virtual environments for multiagent systems, based on the Agents & Artifacts (A&A) model [12].

The model introduces a high-level metaphor for representing agents that work cooperatively in an environment, where artifacts model the resources and tools that can be dynamically constructed, handled and shared by the agents.

The main features of the artifacts implementable in the CArtAgO platform are: observable properties and operations that allow for changes in observable properties. Observable properties are automatically mapped onto the beliefs base of any agent that performs a `focus` operation on the artifact (allowing for the artifact to inform the agent about changes in the properties, including changes that happened in a way independent of any of the agent's actions – that is, changes caused by other agents).

4 The Basic MSPP Framework

In this section, we introduce the main concepts, program schemes, classes and APIs that constitute the current stage of development of the MSPP framework, as it has been implemented on the Jason-CArtAgO platform.

The essential concept is that of *policy artifacts*, that is, CArtAgO artifacts that reify the public policies that are addressed to the government agents and societal agents of the society, so that the components of public policies are concretely represented as artifacts in the environment of the society.

Given our definition of public policy, given in Sect. 2.2, the reification of public policies as policy artifacts amounts to the reification of norms and plans, so that *norm artifacts* and *plan artifacts* should be defined and instantiated in the CArtAgO platform, together with AgentSpeak program schemes that allow the agents of the society to handle them adequately.

Of course, this idea of reifying public policies as policy artifacts is just a particular application to the public policy process of the idea of reifying *organizational objects* as artifacts, introduced in the JaCaMo platform [13].

In the following, we introduce the various kinds of norm and plan artifacts, together with the associated program schemes. To simplify the presentation, we show the program snippets as flowcharts.

4.1 Obligation Norms

Obligation norms are assumed to have the following content [1]:

- `Id`: the norm identifier;
- `addressees`: specifies the agents to which the norm applies;
- `goal`: specifies a maintenance goal to be achieved by the addressee of the norm;
- `condition`: specifies a necessary contextual condition for the application of the norm;
- `periodicity`: specifies, for periodical obligations, a time period for the checking of the condition;
- `exception`: specifies a condition under which the norm is not to be applied.

Both the obligation and in the prohibition norms (see below), are not addressed to individual agents, but to the social roles that the agents may enact in the society. So, the `addressees` field should contain a list of social roles, not a list of agent ids.

Also, we remark that, as our approach to the simulation of public policy processes takes the point of view adopted in [14], that the essential goals of the agents of any agent society are *maintenance goals*, both the prohibition and the obligation norm artifacts of the MSPP framework refer only to such kind of goals. This is directly reflected in the flowcharts for dealing with norm artifacts that are shown below.

In the MSPP framework, the way to reify obligation norms in CArtAgO is through `OblNorm` artifacts. The possible operations on such artifacts are: `create`, `modify`, and `remove`, to respectively create, modify and remove the norm content.

Figure 2 illustrates the use of `OblNorm` artifacts, which follows the standard way of using CArtAgO artifacts [3]:

- the *government* performs the `create`, `modify`, and `remove` operations on the artifact;
- the *societal* or *government agent* performs the `focus` operation on the artifact;
- the *societal* or *government agent* is automatically notified, in its beliefs base, of changes in the observable properties of the artifact caused by *creation*, *modification* or *removal* operations that change the contents of the norm reified by the artifact (specifically, the agent is automatically notified in the *norms base* part of its beliefs base).

The flowchart for dealing with `OblNorm` artifacts given by the flowchart of Fig. 3 shows how the `addressee`:

[1] Additional content, such as a sanction to be applied in case of violation of obligations, can also be included in the norm.

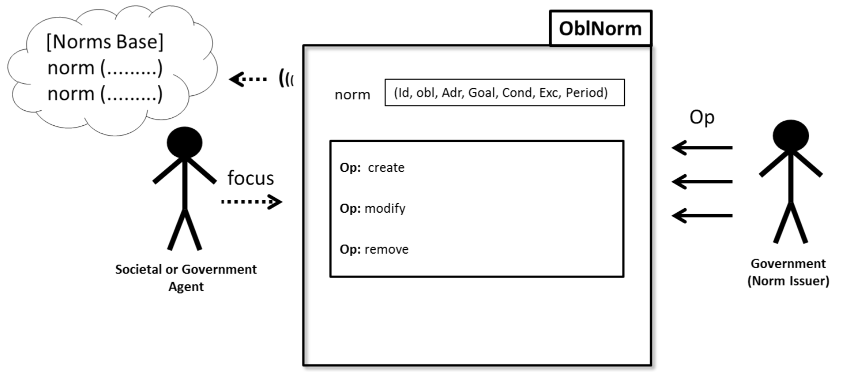

Fig. 2. The use of a `OblNorm` artifact.

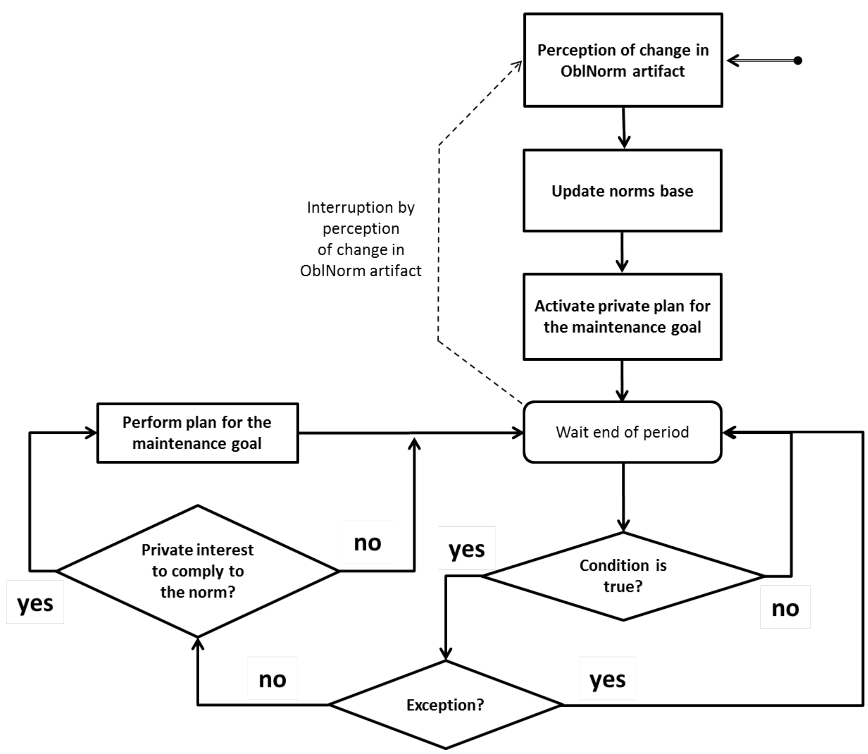

Fig. 3. Flowchart of the program snippet for the handling of `OblNorm` artifacts.

– is informed by the `OblNorm` artifact of the first `create` operation;
– activates the maintenance `goal` specified by the norm;
– checks the `periodicity` of the norm;
– checks if the norm `condition` applies;
– checks if the norm `exception` applies;
– decides, on the basis of its private interests, if it will comply or not to the norm in the current situation;
– activates the agent's private `plan` to handle the maintenance `goal` specified by the norm, if the agent decides to comply to the norm in the current situation;
– is interrupted in its waiting time by the perception of a `signal` sent by the artifact, corresponding to the realization of a `modify` operation.

Norm detector agents can use the `periodicity` parameter of `OblNorm` artifacts to check norm compliance by the norm `addressees`. In case of detection of non-compliance, the norm detector may inform the case to the *Government* (which would be responsible for a decision about the case) or may itself sanction the non-compliante *addressee* (in case the *norm detector* is also a *norm effector*, required to do so by plans or norms addressed to it by *Government*).

4.2 Prohibition Norms

Prohibition norms and their associated *sanctions* allow the *Government* to forbid that certain actions be forbidden.

Prohibition norms are reified through `PrhbNorm` artifacts and are assumed to have the following content:

– `Id`: the norm identifier;
– `addressees`: specifies the agents to which the norm applies;
– `action`: specifies the action forbidden by the norm;
– `sanction`: specifies the sanction to be applied in case of violation of the norm;
– `condition`: specifies a necessary contextual condition for the application of the norm;
– `exception`: specifies a condition under which the norm is not to be applied.

All *public resources* controlled by prohibition norms should be reified by artifacts in the environment and should be implemented so as to generate a CArtAgO `signal` for each operation performed on them.

The reception of a signal by an agent that has focused on a resource artifact generates a specific perception in the agent's beliefs base.

Public resources should generate signals of the form `action(ACT,ACTOR,PAR)` where `ACT` is the action performed on the resource, `ACTOR` is the agent that performed the action, and `PAR` contains any complementary parameter necessary for a full characterization of the action.

A *norm detector* agent should focus on a `PrhbNorm` artifact to be automatically informed about the state of the norm, and should also focus on the controlled public resource, to receive the signals that the resource emits when an operation is performed on it. This way, the norm detector agent can monitor the actions performed on the public resource and can check the agents for violations of the prohibition norm.

Norm effector agents may apply sanctions on norm violating agents, after being informed of the occurrence of norm violations.

The form of use of prohibition norm artifacts is similar to that shown in Fig. 2 and is not shown here. The flowchart to handle prohibition norms is shown in the Fig. 4.

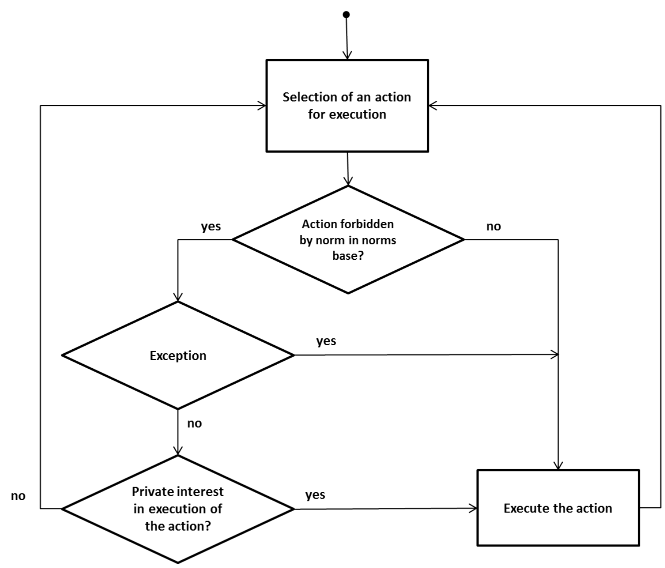

Fig. 4. Flowchart of the program snippet for handling prohibition norms.

The flowcharts for *norm detector* agents (that receive signals and inform the *Government* of violations of norm prohibitions) is given by the flowchart of Fig. 5, which shows how the norm detector agent:

– initially perceives a `signal` emitted by the `public resource` artifact, corresponding to the execution of an action on itself by an agent;
– checks if the action is prohibited, by consulting the norm in the `PrhbNorm` artifact;
– checks if the norm `exception` applies;
– communicates the norm violation to the *Government*, if the violation effectively occurred.

The flowchart for *norm effector* agents (that are informed by the *Government* of sanctions to be applied, and apply the sanctions) is simple enough, so it can also be omitted here.

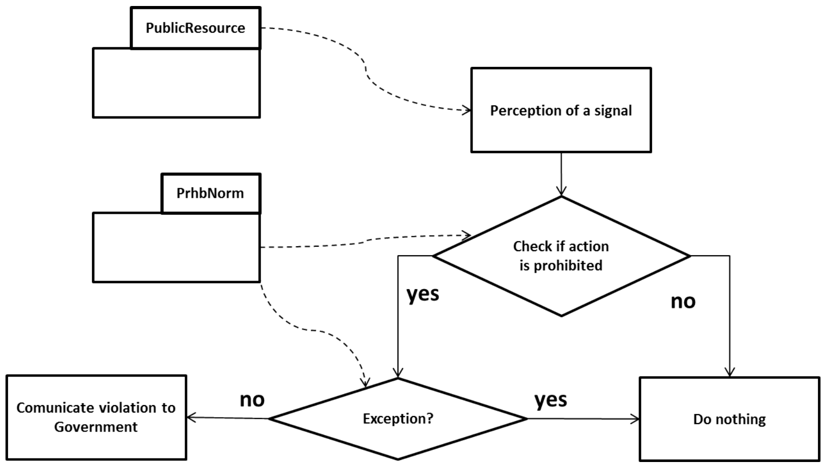

Fig. 5. Flowchart of the program snippet for checking violations of prohibitions.

4.3 Plans

As explained in Sect. 2.2, public policies are conceived to be composed of norms and plans, where *norms* are issued by the *Government* for both *societal* and *government agents*, and *plans* are delegated by the *Government* to *government agents*.

In the MSPP framework, plans are directly represented in the form `context -> planBody`, meaning that the `planBody` is to be executed if the `context` part is true at the time it is evaluated.

Plans are reified and made available to *government agents* through specially defined `Plan` artifacts. Thus, *government agents* focusing on `Plan` artifacts are automatically informed of the creation, modification and removal of plans by the *Government*.

`Plan` artifacts are assumed to have the following content:

- `Id`: the plan identifier;
- `planContext`: specifies the `context` part of the plan;
- `planBody`: specifies the `body` part of the plan;
- `periodicity`: specifies the (optional) periodicity with which the plan is to be executed.

Again, we will not show here the figures illustrating the use of `Plan` artifacts.

The flowchart for the handling of delegated plans by *government agents* is given by the flowchart of Fig. 6, which shows how a *government agent*:

- initially perceives the creation or modification of the plan;
- checks the `periodicity` of the plan;
- checks if the `context` part of the plan is true;
- executes the plan if its `context` is true.

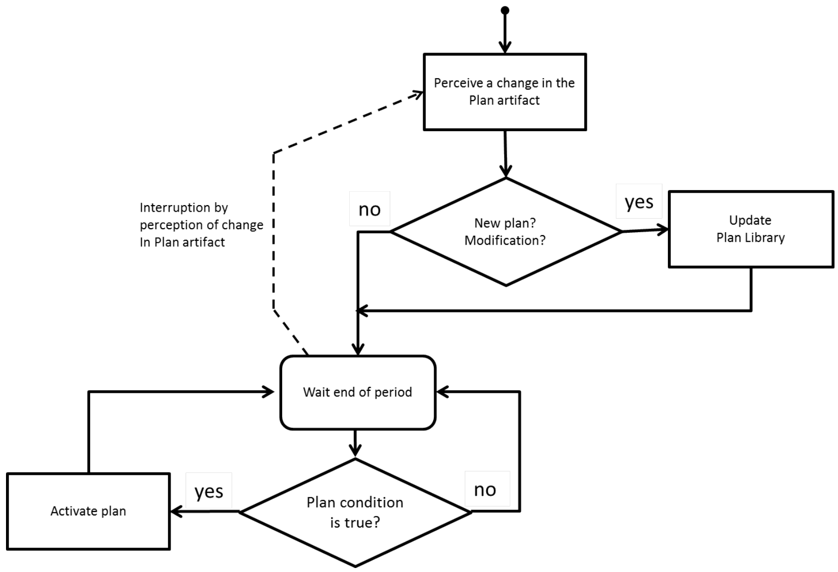

Fig. 6. Flowchart of the program snippet for the handling of delegated plans.

4.4 Public Policies and the Repository of Public Policies

As stated in Sect. 2.2, public policies are seen in the agent-based approach as sets of norms and plans. In the MSPP framework, this is reflected not only in the idea of artifacts to reify norms and plans, but also on the idea of a *public policies repository* to reify the set of public policies currently being applied to the society, and a *public policy artifact* to reify each public policy.

The latter specifies, for each public policy, the set of norms and plans that constitute the public policy and, for each norm and plan, the addressees of the norm or plan.

5 Related Work

There are two main ongoing European projects in the area of simulation of public policies at the moment, namely, the e-POLICY and the OCOPOMO projects, both embedding policy simulation issues within systems dedicated to help the formulation and assessment of public policies.

The first one, e-POLICY (Engineering the Policy Making Life Cycle) [2] aims at the development of a decision support system to policy makers in their decision, in the area of regional planning. The simulation of the effects of public policies aims at helping the assessment of economic, social and environmental impacts during the policy making process.

[2] Cf. `http://cress.soc.surrey.ac.uk/web/projects/59-epolicy`)

The second one, OCOPOMO (Open Collaboration for Policy Modeling) [3], aims at the development of an open collaboration environment for supporting policy makers in the formulation of public policies. Again, public policy simulation enters the system in order to help the assessment of the impacts of proposed public policies.

OCOPOMO makes explicit the need for a formal model of conceptual policy description, and defines a rule-based system to support the policy simulations [15].

Micro-simulation is another approach to public policy simulation, which has its own tradition (cf., e.g., [16]).

We were not able, however, to locate in the literature references for works aiming at results similar to what is aimed in our MSPP project: modelling and simulation of the full public policy processes, and policy simulation supported by cognitive agents and organization-oriented multiagent system platform.

6 Conclusion

This paper presented introduced two main ideas, namely, a notion of agent-based model of public policy process and the notion of policy artifacts, joined in the first version of the MSPP framework for public policy modelling based on cognitive agents and organization-oriented multiagent system platforms.

The notion of agent-based model of public policy process emphasizes the need of direct modelling and simulation of the main policy actors in terms of cognitive agents and their interactions. This allows for the modelling not only of simple, sequential models of public policy processes, as tackled in this paper, but also the more generic, non-sequential models identified in the Policy Analysis literature.

The first version of the MSPP framework introduced basic concepts, program schemes, and policy artifacts for the modeling and simulation of the execution phase of the public policy process. Thus, the simplified model of public policy process adopted in the paper, where all strategic decision processes were concentrated in a single agent, the *Goverment*. A first crucial point to allow for the development of the MSPP framework is the idea of modelling public policies as sets of norms and plans. A second one is the idea of reifying policy objects as artifacts, in the vein of the use of artifacts for the reification of organizational objects, adopted in the JaCaMo platform.

This exaggerated methodological simplification of the model of public policy process, however, allowed us to concentrate the work on the definition of the policy artifacts (norms, plans) and the agent program snippets necessary for working with them, and also on the types of *government agents* (detectors, effectors) that one can find in the interface between government and society, according to the *tools of government* approach to Policy Analysis.

Future research will explore particular issues to complete this first version of the MSPP framework, like the detection of violations of obligations, and also

[3] Cf. `http://www.ocopomo.eu`

to further the MSPP framework itself, expanding the proposed mechanisms to apply them to components of the different organizational levels of the society, beyond the basic level of social roles, like social groups, organizations, etc. This will require the incorporation in the MSPP framework of a model of multiagent systems organization, the Moise+ model of the JaCaMo platform being one possibility.

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A formal model of agent interaction based on MASQ

Razvan Dinu, Tiberiu Stratulat, and Jacques Ferber

University of Montpellier 2, LIRMM

Abstract. MASQ (Multi-Agent Systems based on Quadrants) is a generic meta-model that integrates many of the concepts issued from the research in the multi-agent systems field by defining four perspectives over agent-based interaction according to two axes: internal/external and individual/collective. The aim of this paper is to provide a formal description of MASQ by specifying clear relations between the basic elements of the four quadrants and by analysing the dynamics of a multi-agent system through its transitions and through the classical mind cycle. The proposed formal model has been designed as a theoretical framework and therefore the specifications of many components of a multi-agent system such as the internal architecture of minds, the casual laws of environments or the social laws in organizations and institutions are intentionally left generic to allow for many further concretizations.

1 Introduction

MASQ (Multi-Agent Systems based on Quadrants) [11] is a very generic meta-model for the agent-based interaction that takes its inspiration from the 4-quadrant model by Wilber [15] in social sciences and psychology. MASQ integrates many of the concepts issued from the research in the multi-agent systems field by defining four perspectives over agent-based interaction according to two axes: internal/external and individual/collective. It considers equally the concepts of actions, environments[14], organizations and institutions and integrates them into the same conceptual framework.

MASQ is built on five basic elements (Figure 1): minds in quadrant I (individual-interior), objects and bodies in quadrant II (individual-exterior), spaces in quadrant III (collective-exterior) and cultures in quadrant IV (collective-interior). In addition, a set of relations between the basic elements, that actually form the link between the four quadrants, and a set of laws that describe its dynamics are proposed.

MASQ is an intuitive map to understand the agent-based interaction. The complete scenario in MASQ consists of a mind that acts through a body in a space, where it interacts with other objects or bodies. The culture in which the minds are immersed allows them to collectively interpret the interaction and construct the institutional reality, as proposed by Searle [10]. We acknowledge that among the first proposals of modeling agents with concepts inspired from Searle are [1] and [9] in the context of institutionalized power. From this point of view, a close research effort is [12], but it is only oriented on roles and organizations. Also, in [2] a detailed description of types of norms inspired from Searle's typology of institutional rules is given.

MASQ has been successfully used both in modeling multi-agent systems for real world scenarios and for social simulations. [8] is a good example of using MASQ

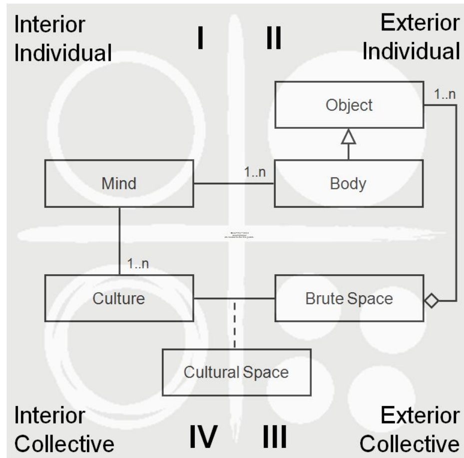

Fig. 1. MASQ meta-model

to model the logistics of a warehouse and show, using the MASQ concepts, what are the most important decisions when implementing such a system. In [4], a multi-agent framework based on MASQ, called Agent-based Business Coordination Lab (ABC Lab), is implemented as a plugin for the Repast Symphony simulation framework and it allows the simulation of trading networks in order to study the role and impact of intermediation. In both [4] and [8] the MASQ meta-model is chosen because it allows on one hand the explicit modeling of individual, economic, social and material factors and on the other hand the design of models that are both modular and extensible.

Even though MASQ has been successfully applied in MAS modeling and simulations it is still used in an ad-hoc manner and every approach makes its decisions about how the different MASQ elements should work together. For instance, the communication between the minds and their bodies is usually neglected or is left as an implementation detail for other underlying frameworks. Also, different existing frameworks, such as OperA[3] (in [4] and [8]) and AGR[6], are used for the collective quadrants but it is not clear how the elements of these frameworks map to the MASQ concepts. The aim of this paper is to make a first step in addressing this issue by proposing a formal characterization of MASQ preserving as much as possible from its generality. Having a clear formal description of MASQ will allow us to better understand the MASQ meta-model, how to construct a model based on MASQ and how to integrate, in an unambiguous way, with different existing frameworks.

In [5] a first step is made towards a formal description of MASQ by identifying a set of seven principles that must be followed when using the MASQ meta-model. Also it discusses the most important design choices that have to be made when creating a formal model based on MASQ and shows that these choices introduce new constraints that were not originally present. That is why in this paper we try to make as few choices as possible. The theoretical framework we propose is therefore very generic so that it could be further concretized with a specific environment and features. It should be noted that some parts of our formalization, especially those related to the relationship between individual and collective intentionality, deal with aspects that are still in open debate in philosophy and social sciences.

In sections 2 and 3 we begin with a clear formal description of the exterior quadrants and their relationship with the mind. In order to be able to go further and define the concepts of the cultural quadrant, in section 4 we propose GMS (Generic Mind based on Strings) as model of a mind and a representation language ($\mathcal{RL}$). They allow us to introduce, in section 5, the *ethos* of a group as well as some concepts inspired from Searle's work [10] such as *count-as* relation, *constitutive* and *regulative* rules and finally *institutions*.

2 Minds and environment

In this section we give clear definitions of *objects*, their state and the relations between them. We regard minds in the most generic way, as simple elements, and their structure is discussed in more details in section 4. Also, we show exactly what elements link the first two quadrants, *actions* and *data sensors*. Finally, a complete description of the environment is given and how it evolves.

To make things more clear, throughout this section we will use the example of a ping-pong game in which two agents use two rackets and a ball to play on a table.

2.1 Minds and objects

Definition 21. Let $\mathcal{M} = \{m_0, m_1, \dots\} \cup \{\mu\}$ be a set of elements m_i called *minds*. μ is called the *null* mind.

Definition 22. Let $\mathcal{O} = \{o_0, o_1, \dots\} \cup \{\omega\}$ be a set of elements o_i called *objects*. ω is called the *null* object.

Minds represent the central element of quadrant I and objects of quadrant II. We suppose that we are given two sets, not necessarily finite, of them. The importance of μ and ω will be outlined in the following sections.

In the ping-pong example we have two players, player one and player two, $\mathcal{M} = \{p_1, p_2, \mu\}$ and a few objects $\mathcal{O} = \{room, table, racket_1, racket_2, ball, \omega\}$.

Definition 23. A binary relation "$\sqsubseteq$" $\subset \mathcal{O} \times \mathcal{O}$ is a *containment* relation and $o_i \sqsubseteq o_j$ is read as "o_i is contained in o_j" if "$\sqsubseteq$" has the following properties:

1. $\forall x, y, z \in \mathcal{O}, x \neq \omega$ such that $x \sqsubseteq y \wedge x \sqsubseteq z$ then we have $y \sqsubseteq z$ or $z \sqsubseteq y$.
2. $\forall x \in \mathcal{O}$, $x \neq \omega$ $\exists! s \in \mathcal{O}$ such that $\forall y \in \mathcal{O}$ $x \sqsubseteq y \Rightarrow s \sqsubseteq y$.
3. $\exists! \mathcal{U} \in \mathcal{O}$ such that $\mathcal{U} \sqsubseteq \mathcal{U}$; $\mathcal{U}$ is the *universe* element.

The containment relation has three properties which we will discuss now. The first one states the an object cannot belong to two branches of inclusion. As it will be more clear in the following section, after defining what a space is, this means that spaces can only include each other and not intersect.

The second property says that for any object o there is a unique smallest object s that contains it and consequently it is included in all other objects that o is included in. Admitting that there are no infinite branches of containment it can be proven that the $\mathcal{U}$ element in property 3 contains all other objects.

The "$\sqsubseteq$" *containment* is actually the connection between the exterior quadrants (II and III) of the MASQ meta-model.

In our example we have the following relations: $ball \sqsubseteq table$, $racket_1 \sqsubseteq table$, $racket_2 \sqsubseteq table$, $table \sqsubseteq room$, $room \sqsubseteq room$.

Definition 24. A binary relation "$\sim$" $\subset \mathcal{M} \times \mathcal{O}$ is an *embodiment* relation and $m_i \sim o_j$ is read as "m_i is embodied in o_j" if "$\sim$" has the following property:
$\forall m_i, m_j \in \mathcal{M}$, $\forall b \in \mathcal{O}$ we have $m_i \sim b \wedge m_j \sim b \Rightarrow m_i = m_j$

The "$\sim$" *embodiment* relation represents the connection between the individual quadrants (I and II) of the MASQ meta-model. In our example we have: $p_1 \sim racket_1$ and $p_2 \sim racket_2$.

2.2 Spaces and bodies

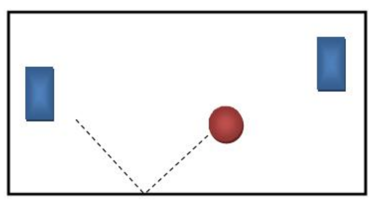

Fig. 2. Ping-pong game environment

Below we identify two particular types of objects: spaces and bodies.

Definition 25. An entity $s \in \mathcal{O}$ is a *space* if and only if there exists at least one object $o \in \mathcal{O}$ such that $o \sqsubseteq s$. Also, if $s \in \mathcal{O}$ is a *space* then $\omega \sqsubseteq s$. Let $\mathcal{O}_S \subset \mathcal{O}$ be the set of all spaces w.r.t. a containment relation "$\sqsubseteq$".

The *null object* ω introduced in definition 22 is actually a marker object in the sense that for a space $s \in \mathcal{O}_S$, $\omega \sqsubseteq s$ can be interpreted as "s can contain other objects".

Definition 26. An object $b \in \mathcal{O}$ is a *body* if and only if there exist a mind $m \in \mathcal{M}$ such that $m \sim b$. Let $\mathcal{O}_B \subset \mathcal{O}$ be the set of all bodies w.r.t. an embodiment relation "$\sim$".

The *null mind* μ introduced in definition 21 is actually a marker mind in the sense that for a body $b \in \mathcal{O}_B$, $\mu \sim b$ can be interpreted as "b is not yet embodied by any real mind, but it can be".

One last thing to notice is that an object $o \in \mathcal{O}$ can be a body and a space at the same time. This offers a great amount of flexibility when designing a multi-agent system and contributes to the genericity of our framework.

In our example we have $\mathcal{O}_S = \{room, table\}$ and $\mathcal{O}_B = \{racket_1, racket_2\}$.

2.3 States and Attributes

Besides its relations with other objects or minds an object is characterized by a state which is associated with a set of attributes.

Definition 27. Let $\Sigma_{\mathcal{O}}$ be a set of elements called *states*. If $O \subset \mathcal{O}$ then a function $\sigma \colon O \to \Sigma_{\mathcal{O}}$ is called a *state function on* O and associates each object $o \in O$ with its state $\sigma_o = \sigma(o)$.

The state σ_o of an object can encapsulate any type of information about the object (a set of name-value pairs, place in a topology, etc.). Type information can be included here too.

Definition 28. Let $\mathcal{A}$ be a set of elements called *attributes*. A function $\alpha \colon \Sigma_{\mathcal{O}} \to 2^{\mathcal{A}}$ is called an *attribute function* and associates each *state* with its set of *attributes*.

The role of attributes is very important as they represent the basic unit of perception for objects' states. A mind will not be able, through bodies, to perceive the whole state of an object but only a set of attributes corresponding to the state of the object.

In our example we won't go into the details of the state of all objects. We just give two examples: $\{color, position\} \subset \mathcal{A}$, $\{\text{"}color = red\text{"}\} \subset \alpha(\sigma_{ball})$, $\{\text{"}position = 50, 100\text{"}\} \subset \alpha(\sigma_{racket_2})$.

2.4 Actions

Now we continue with the part of the environment that allows mind's interaction. The first thing we define is an *action*:

Definition 29. An *action* γ is a function $\gamma \colon \Sigma_{\mathcal{O}} \to \Sigma_{\mathcal{O}}$ that modifies the state of an object. We say γ is applicable in a state σ_o if and only if $\gamma(\sigma_o) \neq \sigma_o$. And let $C_\gamma = \{\sigma_o | \sigma_o \in \Sigma_{\mathcal{O}}, \gamma(\sigma_o) \neq \sigma_o\}$ be the *context* in which γ can be applied.

The above definition of an action is very generic. We leave to the designer of a MAS to choose a more concrete description of actions and also, very important, how minds understand what actions do in order to decide which one to perform. Actions can be associated with bodies and form behaviors.

Definition 210. A set of actions $\beta_b = \{\gamma_{b0}, \gamma_{b1}, \dots\} \subset \Gamma$ is called a *behavior*, where Γ is the set of all actions. If $B \subset \mathcal{O}_B$ then a function $\beta \colon B \to 2^{\Gamma}$ is called a *behavior function on* B and associates each body $b \in B$ with its behavior $\beta_b = \beta(b)$.

The behavior of a body is actually the set of *commands* a mind can use to *influence* the environment. This fits perfectly with the *Influence/Reaction* principle which states that an agent cannot directly modify the environment but only influence it and wait for its reaction [7].

In our example we have $\Gamma = \{move_{up}, move_{down}\}$ and $\beta_{racket_1} = \beta_{racket_2} = \Gamma$.

2.5 Brute Percepts

As described until this point the environment is composed of objects with states that contain attributes and actions associated to bodies that form behaviors. Objects can be included in other objects called spaces and minds can be embodied in bodies. Below we give the definition of *brute percepts* which is the form under which a mind perceives its environment.

Definition 211. Let $\mathcal{P}_b$ be a set of elements called *brute percepts*. Let $\pi\colon \mathcal{O} \cup \sqsubseteq \cup \mathcal{M} \cup \sim \cup \Gamma \cup (\mathcal{O}_B \times \Gamma) \cup \mathcal{A} \cup (\mathcal{O} \times \mathcal{A}) \to \mathcal{P}_b$ be a *brute projection* function such that:

$\forall o \in \mathcal{O} \Rightarrow \pi(o) = o_\pi \qquad \forall o \sqsubseteq s \Rightarrow \pi(o \sqsubseteq s) = (o_\pi, s_\pi)$
$\forall m \in \mathcal{M} \Rightarrow \pi(m) = m_\pi \; \forall m \sim b \Rightarrow \pi(m \sim b) = (m_\pi, b_\pi)$
$\forall \gamma \in \Gamma \Rightarrow \pi(\gamma) = \gamma_\pi \qquad \forall \gamma \in \beta_b \Rightarrow \pi((b, \gamma)) = (b_\pi, \gamma_\pi)$
$\forall a \in \mathcal{A} \Rightarrow \pi(a) = a_\pi \qquad \forall a \in \alpha(\sigma_o) \Rightarrow \pi((o, a)) = (o_\pi, a_\pi)$

One very important thing to notice from the definition of π, which projects the environment into the set of brute percepts, is that a mind can perceive another mind (the existence of m_π and (m_π, b_π) in $\mathcal{P}_b$). This means that a mind is capable of "sensing" there is another mind behind an object, or in other words, a mind can make distinction between objects and bodies. But it can perceive absolutely nothing about what's inside another mind.

2.6 Data sensors

Sensors operate on a state of the environment so before giving the definition of a sensor we will define what an *environmental state* is.

Definition 212. An *environmental state* is a tuple $\sigma_E =< O, \sigma, \beta, \sqsubseteq, \sim>$ where $O \subset \mathcal{O}$, σ is a *state function on* O, β is a *behavior function on* $O \cap \mathcal{O}_B$, "$\sqsubseteq$" is a *containment* relation and "$\sim$" is an *embodiment* relation. Let Σ_E be the set of all such tuples.

Definition 213. A *data sensor* is a function $\delta\colon \mathcal{O}_B \times \Sigma_E \to \mathcal{P}_b$ and it extracts, on behalf of a *body*, some data from an *environmental state* under the form of *brute percepts*. Let Δ be the set of all *data sensors*.

Definition 214. A set of *data sensors* $\rho_b = \{\delta_{b0}, \delta_{b1}, \dots\} \subset \Delta$ is called *responsiveness*. If $B \subset \mathcal{O}_B$ then a function $\rho\colon B \to 2^\Delta$ is called a *responsiveness function on* B and associates each body $b \in B$ with its responsiveness $\rho_b = \rho(b)$.

An important thing when introducing sensors is the principle of *locality of perception*. It is realized by the *data sensor* (that is why it is defined on $\mathcal{O}_B \times \Sigma_E$, to take into account a body too).

Definition 215. Let $M \subset \mathcal{M}$ be a set of minds. A function $\epsilon\colon M \to 2^{\mathcal{P}_b}$ is called a *brute environment function on* M and associate each mind $m \in M$ with its set of *brute percepts* of the environment $\epsilon_m = \epsilon(m)$.

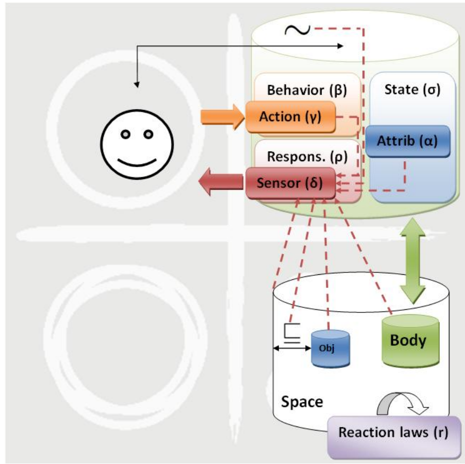

Fig. 3. Environment and relation to minds

ϵ_m represents the *brute reality* that m perceives through its *bodies* and it is constructed by the union of all brute percepts from all sensors from all bodies.

In our example the only sensors needed are *position sensors* that will be able to transmit to a mind the coordinates of the two rackets and the ball ($\rho_{racket_1} = \rho_{racket_2} = \Delta = \{position\}$

2.7 Reaction laws

Definition 216. A *reaction law* is a function $r\colon \Sigma_E \rightarrow \Sigma_E$. We say r is applicable in an *environmental state* σ_e if and only if $r(\sigma_e) \neq \sigma_e$. And let $C_r = \{\sigma_e | \sigma_e \in \Sigma_E, r(\sigma_e) \neq \sigma_e\}$ be the *context* in which r can be applied. Also, let $\mathcal{R}$ be the set of all reaction laws.

In our example we have the following reaction laws $R = \{move_{law}, reflection_{law}, colision_{law}\}$.

Definition 217. An *environment* is a tuple $E =< \sigma_E, \rho, R >$ where σ_E is an environmental state, ρ is a *responsiveness function* on the set of bodies in σ_E and $R \subset \mathcal{R}$ is a set of reaction laws.

The evolution of the environment is seen as a continuous change of its σ_E environmental state through reaction laws. As it can be seen from its definition, a reaction law can change just about everything in the environment except for the set of reaction laws.

2.8 Multi-Agent Systems

Now we are able to give a complete definition of what a multi-agent system is:

Definition 218. A *multi-agent system* is a tuple $S =< M, \epsilon, E >$ where $M \subset \mathcal{M}$ is a set of minds, ϵ is a *brute environment function on* M and E is an environment.

3 Environment dynamics

This section analyzes the dynamics of a multi-agent system as it was described in the previous section. We use the classical system-transitions approach. There are three main types of transitions:

Γ-transitions. When a mind wants to perform a set of actions (send commands to its bodies).
r-transitions. When a reaction law is applied in the environment.
Δ-transitions. When a mind receives data from its bodies.

3.1 Internal evolution

If there are no active agents in an environment the only way it can change its state is by means of reaction laws. Let $S =< M, \epsilon, E >$ be a multi-agent system and r a reaction rule.

Rule 31. Reaction law

$$\frac{\begin{array}{c} S =< M, \epsilon, E >, \;\; E =< \sigma_E, \rho, R >, \;\; r \in R \\ \sigma_E \in C_r, \quad \sigma'_E = r(\sigma_E) \end{array}}{S \to < M, \epsilon, < \sigma'_E, \rho, R >>}$$

3.2 Actions and responses

After deliberating, a mind decides on a set of actions that it wants to perform through its bodies. Let m be a mind and B_m the set of its bodies. Then the system can move to a state $< M, \epsilon, E' >$, by a Γ-*transition*, where the state of the bodies of m have changed.

Rule 32. Action

$$\frac{\begin{array}{c} S =< M, \epsilon, E >, \;\; E =< \sigma_E, \rho, R >, \;\; \sigma_E =< O, \sigma, \beta, \sqsubseteq, \sim > \\ m \in M, \;\; \Gamma_m = \{b : \gamma\}, \;\; b \in B_m, \;\; \gamma \in \beta(b), \;\; \sigma(b) \in C_\gamma \\ \sigma' : O \to \Sigma_O, \;\; \sigma'(x) = \begin{cases} \sigma(x) & \text{if } x \neq b \\ \gamma(\sigma(b)) & \text{if } x = b \end{cases} \\ \sigma'_E =< O, \sigma', \beta, \sqsubseteq, \sim > \\ E' =< \sigma'_E, \rho, R > \end{array}}{S \to < M, \epsilon, E' >}$$

The *data sensors* that are attached to *bodies* send data back to the mind and update the *brute reality* it perceives. Then the system can move to a state $< M, \epsilon', E >$, by a Δ *transition*, where the *brute reality* of m has changed.

Rule 33. Response

$$\frac{\begin{array}{c} S =< M, \epsilon, E >, \;\; E =< \sigma_E, \rho, R >, \\ m \in M, \;\; B_m = \{b \in \mathcal{B} | m \sim b\} \\ \epsilon'_m = \bigcup_{b \in B_m} \bigcup_{\delta \in \rho(b)} \delta(b, \sigma_E) \\ \epsilon' \colon M \to 2^{\mathcal{P}_b}, \;\; \epsilon'(x) = \begin{cases} \epsilon(x) \text{ if } x \neq m \\ \epsilon'_m \quad \text{if } x = m \end{cases} \end{array}}{S \to < M, \epsilon', E >}$$

3.3 Request/Drop body

We also have two special types of transitions: *request* and *drop* body.

Let $S =< M, \epsilon, E >$ be a multi-agent system, m be a mind and b a body. When m requests the body b the system moves to a state $< M, \epsilon, E' >$, by a *request body* transition, where the body b will be assigned to m if it isn't assigned to another mind.

Rule 34. Request body.

$$\frac{\begin{array}{c} S =< M, \epsilon, E >, \;\; E =< \sigma_E, \rho, R >, \\ m \in M, \;\; b \in O, \;\; \mu \sim b \\ \sigma'_E =< O, \sigma, \beta, \sqsubseteq, (\sim \backslash (\mu, b)) \cup (m, b) > \end{array}}{S \to < M, \epsilon, E' >}$$

When m drops body b then the system moves to a state $< M, \epsilon, E' >$, by a *drop body* transition, where the body b will be assigned to *null* mind if it is assigned to m.

Rule 35. Drop body.

$$\frac{\begin{array}{c} S =< M, \epsilon, E >, \;\; E =< \sigma_E, \rho, R >, \\ m \in M, \;\; b \in O, \;\; m \sim b \\ \sigma'_E =< O, \sigma, \beta, \sqsubseteq, (\sim \backslash (m, b)) \cup (\mu, b) > \end{array}}{S \to < M, \epsilon, E' >}$$

4 Interior of a mind

The previous two sections described the exterior quadrants from the MASQ perspective. The reasoning process of minds is responsible for Γ-transitions of a MAS. Even though MASQ makes no assumption about the internal structure of minds, we need a minimal formal model of a mind that will serve us as support to clearly explain how the perception, reasoning and acting phases happen in the mind of an agent and also to introduce the concepts of the forth quadrant: Searle's *count-as* relation, *constitutive* and *regulative* rules, and institutions. In this section we introduce a simple and generic mind model called GMS (Generic Mind based on Strings) that continues in a natural way the formal description of the environment in the previous sections by using a simple and generic representation language $\mathcal{RL}$.

4.1 Reactive agents

Reactive agents are agents that have no memory and act guided by a set of rules. A reactive agent's mind will work directly with the set of brute percepts $\epsilon_m \subset \mathcal{P}_b$. Formally, a reactive mind can be associated with a function $react\colon 2^{\mathcal{P}_b} \rightarrow 2^{\mathcal{O}_B \times \Gamma}$ that maps brute percepts into actions on bodies.

4.2 Symbols and attitudes

On the other hand, cognitive agents will interpret the brute percepts they receive from their bodies by using *symbols* and *attitudes*.

Definition 41. Let $\mathcal{S}$ be a set of elements called *symbols*. They are virtual representations that exist only in agents' minds. Symbols are the basic elements for constructing institutional realities.

As example of symbols we can take a *goal*, a *fault* or an *off-side* in a football match. They do not exist in the brute reality, they are symbols associated with specific situations or things. Most of the symbols will be created by interpreting brute reality and this will be explained in more details in section 5.3.

Definition 42. Let Λ be a set of elements called *attitudes*. An attitude can be thought of as the position an agent has towards something. An agent can have attitudes over brute facts, over institutional facts and even over other attitudes.

As example of attitudes we have: knowledge (K), belief (B), desire(D), goal (G), intention (I), acceptance(A), etc.

A special set of attitudes is $\Lambda_D = \{O, P, I\} \subset \Lambda$ which is called the set of *deontic attitudes* (obligation, permission, prohibition). Its role will be highlighted in section 5.1.

4.3 Representation language

Before we propose our model of a mind we need to specify how the brute percepts, on one side, and symbols on the other side come to co-exist inside a mind and also how attitudes fit in. For this purpose we define a language ($\mathcal{RL}$) in which we can describe both the exterior world (the perceived data through sensors), the institutional reality and the agent's attitudes over them.

The set of atomic symbols for the $\mathcal{RL}$ language is composed of brute percepts (o_π, m_π, etc.), symbols, a set of key words and a few additional atoms.

Definition 43. Let $\mathcal{K} = \{included, embodied, action,$
$attribute\}$ be a set of key words.

Let $Values = \mathcal{O}_\pi \cup \mathcal{M}_\pi \cup \Gamma_\pi \cup \mathcal{A}_\pi \cup \mathcal{S}$ be a set whose elements are called *values*. In other words, all symbols $s \in \mathcal{S}$ and all brute percepts $o_\pi, m_\pi, \gamma_\pi, a_\pi \in \mathcal{P}_b$ are considered values.

Let $Variables = \{x_0, x_1, x_2, \dots\}$ be a set of elements called variables.

The set of atomic symbols for our language is represented by $Atoms = Values \cup Variables \cup \mathcal{K} \cup \Lambda \cup \{(,), \wedge, \rightarrow\}$.

Definition 44. The $\mathcal{RL}$ representation language is defined by the following BNFs:

$$
\begin{aligned}
\varphi \quad &::= \varphi_b \mid \varphi \wedge \varphi \mid (\varphi) \rightarrow (\varphi) \mid \lambda(\varphi) \mid \lambda m_\pi(\varphi) \mid \lambda g(\varphi).\\
\varphi_b \quad &::= s \mid \varphi_o \mid \varphi_m \mid \varphi_\gamma \mid \varphi_a \mid \\
&\quad included(\varphi_o, \varphi_o) \mid embodied(\varphi_m, \varphi_o) \mid \\
&\quad action(\varphi_o, \varphi_\gamma) \mid attribute(\varphi_o, \varphi_a).\\
\varphi_o \quad &::= o_\pi \mid x.\\
\varphi_m \quad &::= m_\pi \mid x.\\
\varphi_\gamma \quad &::= \gamma_\pi \mid x.\\
\varphi_a \quad &::= a_\pi \mid x.
\end{aligned}
$$

where $s, g \in \mathcal{S}$ are symbols, $\lambda \in \Lambda$ is an attitude symbol, x is a variable, $o_\pi \in \mathcal{O}$ is an object and so on. φ_b is called a *basic string* and contains a *value*, a *variable* or relation (*included*, *embodied*, etc.) between two *values* or *variables*.

Both the atomic symbols $\wedge$ and $\rightarrow$ are used to create a new well formed string from two well formed strings and their use will be outlined in the following sections.

We will denote by $\mathcal{RL}$ the set of all valid strings in the previously defined language.

4.4 Types of strings in $\mathcal{RL}$

Now we will outline the most important types of strings in RL language.

A string of the form $\lambda(\varphi)$, $\lambda m_\pi(\varphi)$ or $\lambda g(\varphi)$ is called an *attitude string* and let $\mathcal{RL}_\Lambda$ be the set of all such strings. A string which is not an attitude string is an *information string*. One particular type of information string is a string that contains no symbols, attitudes or variables and it's called a *brute fact string*.

Brute fact strings correspond to an objective description of the environment. Example of brute fact strings: $ball$, $room$, $included(ball, room)$, $attribute(ball, red)$, etc.

On the other hand, *attitude strings* correspond to a subjective description, from a mind's perspective. Examples of attitude strings: $K(included(ball, room))$, $B(attribute(ball, red))$, $A(attribute(ball, blue))$, etc.

4.5 Generic Mind based on Strings

The model we propose is called *Generic Mind based on Strings* (GMS) and has four modules:

Data is a set of strings in $\mathcal{RL}$ language. For a mind m it is denoted by $Data_m$ and the fact that a string $\varphi \in Data_m$ is read "φ exists in the mind m". It is a key module of the model as it actually represents the link between the following three modules.

Interpret module is responsible for receiving the brute percepts from bodies and insert them into $Data_m$ under the form of *brute fact strings*.

Reasoning/Learning module handles all the reasoning and learning performed by a mind. Its input is the current set of strings in $Data_m$ and its output are changes to $Data_m$ (adding or removing of strings).

Action module is responsible for sending actions to bodies by analyzing the current set of strings in $Data_m$.

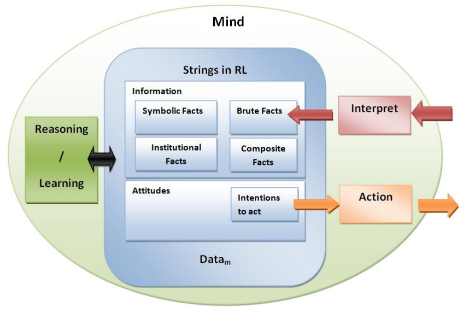

Fig. 4. Generic Mind based on Strings

The main idea of GMS is to have a module for each of the three phases of the classical mind cycle and to link them through a common set of *data* under the form of strings in $\mathcal{RL}$. The language $\mathcal{RL}$ is very important as we will make use of different forms of strings in order to introduce the concepts in the cultural quadrant.

There are three different types of strings that haven't been discussed so far. *Symbolic fact strings* contain symbols and no attitudes (i.e. $goal$, $fault \wedge penalty$), *institutional fact strings* will be defined in section 5.1 and *composite fact strings* represent any string which is an *information string* but is not of any of the other three types.

5 Collective interior

In the previous section we have chosen a very generic model of a mind in order to keep the MASQ generality and we have shown how the classical mind cycle happens in the MASQ perspective. In this section we will use the $\mathcal{RL}$ representation language, whose main concepts are *symbols*, *attitudes* and *strings*, to provide a clear definitions of the concepts in the forth quadrant: *constitutive* and *regulative* rules, *groups* and finally *institutions*.

5.1 Count-as rules

Count-as rules, in the MASQ meta-model, provide the basis for common interpretation and common behavior for a group of agents. We will introduce a special attitude called *count-as attitude* and it will be denoted by " $\Rightarrow$ " $\in \Lambda$.

Definition 51. An attitude of the from $\Rightarrow ((\varphi_c) \rightarrow (\varphi))$ is called a *count-as rule*, where $\varphi_c \in \mathcal{RL}$ is called the *context* in which the rule can be applied and $\varphi \in \mathcal{RL}$ is called the *content* of the rule.

Count-as rules represent the core element of norms and institutions. Before going any further we need to detail what it means for a mind m to apply a *count-as rule*.

Definition 52. For a mind m a count-as rule r of the form $\Rightarrow ((\varphi_c) \rightarrow (\varphi))$ is *applied* if and only if whenever an instance $\varphi'_c = instance_C(\varphi_c) \in Data_m$ then we have $\varphi' = instance_C(\varphi) \in Data_m$. Otherwise it is said that that rule is *not applied*.

So, in other words, the above definition says that whenever an instance of the context (φ_c) exists so must the corresponding instance of the content (φ) of the rule (by corresponding we mean using the same $C = \{x0 : v0, x1 : v1, \dots\}$).

One important thing to remember is that "$\rightarrow$" does not mean "implication" as in logic. It is only a special symbol in the $\mathcal{RL}$ language.

Depending on the form of φ in definition 51 we can identify two types of count-as rules: *constitutive rules* as Searle defines them and *regulative rules* also called *norms*.

Constitutive rules

Constitutive rules allow the creation of *institutional facts* by interpreting the brute reality or other institutional facts.

Definition 53. A count-as rule in which φ has the form $\varphi = (\varphi_x) \rightarrow (\varphi_y)$ is called a *constitutive rule*. In this case, $\Rightarrow ((\varphi_c) \rightarrow ((\varphi_x) \rightarrow (\varphi_y)))$ corresponds to "X counts as Y in context C" in Searle's definition.

Constitutive rules are the basic elements for construction of an institutional reality. One important thing is the definition of an *institutional fact*.

Definition 54. A string of the form $(\varphi_x) \rightarrow (\varphi_y)$ is called an *institutional fact*.

Regulative rules

Regulative rules (*norms*), are used in multi-agent systems to regulate agents' behavior.

Definition 55. A count-as rule in which φ is a *deontic attitude* ($\varphi = \lambda(\varphi_d)$ and $\lambda \in \Lambda_D$) is called a *regulative rule* (*norm*).

5.2 Groups

When talking about groups there are two aspects that need to be considered. On one hand a group, in its classical sense, can only exist in the third quadrant, when minds interact through bodies and get to form a group. On the other hand we need to be able to tell what characterizes a group, besides the set of bodies of agents inside of it. Tuomela calls this the *ethos* of a group as in [13] : "*The ethos of group g in its strict sense is defined as the set of constitutive goals, values, beliefs, standards, norms, practices, and/or traditions that give motivating reasons for action*".

Definition 56. A set $e \subset \mathcal{RL}_\Lambda$ of *attitude strings* is called *ethos*. If $\lambda(\varphi) \in e$, where $\varphi \in \mathcal{RL}$ and e is the ethos of some group g, we say "group g has attitude λ over *information* or *attitude* φ" and write $\lambda_g(\varphi)$.

A mind m can become member of a group g with ethos e only if it *adopts* e. There are two ways a mind can adopt an ethos: a) $\forall\lambda(\varphi) \in e$ we have $\lambda(\varphi) \in Data_m$; b) $\forall\lambda(\varphi) \in e$ we have $\lambda g(\varphi) \in Data_m$.

The former corresponds to what Tuomela calls *I-mode groups* and the latter to *WE-mode groups*. Discussion of the difference between the two modes is not within the scope of this article.

5.3 Institutions

Inspired by Searle [10] who defines an institution as *"a set of count-as rules"* and Tuomela who says *"we can view institutions in terms of the ethos of a social group [...] ethos normatively directs the functioning of the group members, some of the norms being constitutive"* [13] we define an institution as follows:

Definition 57. An *institution* is an ethos that contains only *count-as rules*.

Due to space restrictions we will not develop on the use of groups and institutions in the MASQ model.

6 Conclusions

This paper is the first to give a clear formal description of the MASQ meta-model which was, until now, introduced and applied only in an informal manner.

Clear definitions have been given to the elements belonging to the exterior quadrants and we have shown how they are linked to the first quadrant through actions and data sensors. A simple and generic mind model has been used as a support to explain the classical perception, reasoning, action cycle in the MASQ perspective. Based on a simple representation language we have provided formal definitions for Searle's count-as relationship, constitutive and regulative rules, groups and institutions which are key elements of the cultural quadrant.

Having a formal description of MASQ will allow future works to create more specialized MAS models based on MASQ and also to analyze how the MASQ concepts relate to other existing MAS frameworks, especially in the collective quadrants.

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Conflict Detection in Composite Institutions

Tingting Li[1], Tina Balke[2,1], Marina De Vos[1], Ken Satoh[3], and Julian Padget[1]

[1] University of Bath, Dept. of Computer Science, UK
{t.li,mdv,jap}@cs.bath.ac.uk
[2] University of Surrey, Centre for Research in Social Simulation, UK
t.balke@surrey.ac.uk
[3] National Institute of Informatics, Principles of Informatics Res. Division, Japan
ksatoh@nii.ac.jp

Abstract. Institutions provide a mechanism to specify policies for actors in open distributed systems. From a software engineering perspective it makes sense to group policies based on common goals or expectations. This allows them to be reused and combined. However, the combination of institutions with different agendas will almost certainly lead to conflicts – e.g. one set of policies permitting a certain action while another does not. We propose a way to detect such conflicts by analysing formalized statements of policy, or in the absence of conflicts, to verify that the combination of a given set of institutions is conflict-free.

1 Introduction

Institutions have long been studied in the agent community as a means for governing systems by specifying the policies that guide interactions between agents. Each institution consists of a set of policies. Viewed from the domain of the social sciences, policies are understood as instruments that are implemented with the aim of encouraging society to adopt certain norms [19][4]. In order to encourage society to adopt a certain norm, policies dictate which actions (or outcomes) are in principle permitted, empowered, prohibited or obligatory under given sets of conditions, as well as specifying the consequences of compliance or non-compliance.

Computer science research has largely focused on the modelling of either single institutions or multiple interacting institutions, all of which have been designed by the same designers for a particular system (see for example [3, 4, 12, 18]). So far, we have not found any work addressing the issues of modelling the composition of independently-designed institutions. We define composition as the combinination of the norms of several institutions such that their combined policies are consistent to the user. This could be done in a variety of ways.

The problem when composing different institutions is that each is designed for its own purpose, and not some common objective. This can result in situations where the policies of the individual institutions are inconsistent when they are

[4] Policies are not the only way norms can be implemented. They can also emerge as generally accepted social behaviour.

composed, giving rise to problems for the participants governed by the composed system. For example, it is unacceptable for a participant to have the permission to perform a certain action in one institution, while it is not permitted in another at the same time. This is why it is important to be able to detect and resolve these kind of conflicts at the design stage of the composition, before any agents are interacting with that system. This paper takes the first steps at solving the composition problem by presenting mechanisms to detect conflicts in composite institutions at design time.

Socio-economic systems are a prime example of systems where composite institutions are likely to occur. They are complex systems that can be viewed from different perspectives, each with its own policies on how participants should behave. These differences need to be combined into a coherent set of policies in order to make it workable for the participants. These policies, expressed as institutions, can be used to state for example the legal context, the technical protocols of the system and the social perspective expressing the "netiquette" for the social interaction between actors.

In order to illustrate our approach we present a small example of a virtual community, which we see as a socio-technical system governed by both social and formal institutions, that need to be composed and made conflict-free to meet the social requirements of the virtual community [11]. The essential source of conflict is that governance rules typically derive from two sources: a prescriptive kind of template that captures the general requirements and may be imposed from above and the much more specific rules that represent the desires of that particular virtual community, which taken together provide the means for each community to work out its own community-specific system of governance [16].This customization of policy is of particular importance in virtual communities, as it has been shown that members becoming actively involved in community moderation and standard settings is a necessary condition for the virtual social communities to become self-sustaining in the long run [6, 1]. One important feature of the governance of virtual communities therefore is to detect conflicts between the different set of policies early on when they being composed. According to [15] virtual communities: (i) consist of *people*, who interact socially with the goal of satisfying their own need, but at the same time (ii) have a *shared purpose* such as as an interest, need, information exchange, or service that provides a reason for the community. (iii) are governed by *policies*, both formal (e.g. laws, technical protocols and organizational rules) and social (e.g. rituals and informal interaction rules) and (iv) are enabled by means of *computer systems* to support and mediate social interaction and facilitate a sense of community.

The purpose of this paper is to demonstrate how conflicts can be detected at the design stage in composing institutions and so the remainder of the paper is structured as follows: We start by explaining our view of institutions and the corresponding computational model of a single institution (Section 2.1). These ideas are then extended to capture composite institutions in Section 3.1. Consequently, in Section 4 we focus on the detection of conflicts between the policies of composed institutions. After giving the conceptual and formal description of conflicts and explaining how they can be detected, we use the case study of virtual communities outlined earlier to demonstrate our approach with a worked example. The paper ends with a short summary, conclusions and an outline of future work (Section 5).

2 Institutions

To provide some context for the theory that follows, this section begins with a brief overview of individual institutions and the terminology that we use.

Institutions as mechanisms to regulate systems have been studied at length in the literature (see [12–14, 18] for example). Probably the most relevant fact for this paper is the recognition of *policies* as instruments – use by policy makers – to implement norms and to encouraging society to adopt these norms [19]. In this paper we refer to institutions as a set of policies that encourage specific normative behaviour. We do not assume that participants in the system are necessarily norm compliant nor that they have internalised the norms or policies of the system.

2.1 Individual Institutions

The literature contains a number of frameworks and methods to model institutions (e.g. [7, 8, 10] to cite but a few). We follow the approach presented by Cliffe et al. [2, 3], which uses an event-driven model, where the events derive from the actions of the participants/users of the system. The institution is used by the participants to determine the most appropriate course of action based on the normative information available. The approach is centred around *observable events*, participants' actions and changes in the environment, that are interpreted in a given institutional context. The advantage of this framework is that the formal model can be translated to a corresponding $AnsProlog$ program [9] – a logic program under answer set semantics – allowing for reasoning about and verification and validation of the institution and its policies.

Formal Model The observable events ($\mathcal{E}_{ex}$) used by Cliffe et al. are external to the institution (and therefore also sometimes referred to as exogenous events). They capture the notion of events in the physical world. Besides these observable events, Cliffe et al. introduce institutional events ($\mathcal{E}_{inst}$) that are events generated by the institution, but which only have meaning in the institutional context. To give an example of this: an observable event in the physical world would be "shooting" someone. The corresponding institutional event would be the interpretation of this physical action as murder in the institutional context. The notion of *conventional generation* (by Searle [17] is used to generate institutional events from the occurrence of an exogenous event. Using the so-called "count-as" statements, events in one context count as events in another context. So, using the physical world as the first context and the institution as the second, observed events “generate” institutional events. This can be further extended to institutional events generating other institutional events.

Institutional events are partitioned into institutional actions ($\mathcal{E}_{act}$) that denote changes in the institutional state and violation events ($\mathcal{E}_{viol}$), that signal the occurrence of violations. Violations may arise either from explicit generation, (i.e. from the occurrence of a non-permitted event), or from the non-fulfilment of an obligation.

An institution ($\mathcal{I}$) is represented as a set of *institutional facts* or fluents ($\mathcal{F}$) that evolves over time as a result of the occurrence of exogenous events which are interpreted in the institutional context. These fluents are either true (if present) or considered false (if absent) at a given time instant. Cliffe et al. further identify normative fluents that denote normative properties of the state such as 1. *permission* ($\mathcal{P}$) – which events may occur without causing a violation, 2. *power* ($\mathcal{W}$) – the capability to influence the institutional state, 3. *obligations* ($\mathcal{O}$) – a particular event is must happen before some other event (e.g. a timeout) otherwise a specific violation is generated, and 4. *domain fluents* ($\mathcal{D}$) that correspond to properties specific to the normative framework itself.

Changes in the institutional state are achieved through the definition of two relations: (i) the generation relation ($\mathcal{G}$), which implements counts-as by specifying how the occurrence of one (exogenous or institutional) event generates another (institutional) event, subject to the empowerment of the actor and the conditions on the state, and (ii) the consequence relation ($\mathcal{C}$), which specifies the initiation and termination of fluents, subject to the occurrence of some event under certain conditions on the institutional state.

The semantics of an institution is defined over a sequence, called a *trace*, of observed $\mathcal{E}_{ex}$. Starting from the initial state (Δ), each exogenous event is responsible for a state change, through initiation and termination of fluents. This is achieved by a three-step process: (i) the transitive closure of $\mathcal{G}$ with respect to a given exogenous event determines all the generated events, (ii) to this all violations of non-permitted events and non-fulfilled obligations are added, giving the set of all events whose consequences determine the new state, (iii) the application of $\mathcal{C}$ to this set of events identifies all fluents that are initiated and terminated with respect to the current state, so determining the next state.

For each trace, we can compute a sequence of states that constitutes the model of the institutional framework for that trace. For ease of reference, a brief summary of the institutional model is given in Figure 1(a).

Computational Model The formal model of an institution can be translated to an equivalent computational model using Answer set programming (ASP) [9]. ASP is a declarative programming paradigm using logic programs under the answer set semantics. A variety of programming languages for ASP exists. There are several efficient solvers for *AnsProlog* and like all declarative languages has the advantage of describing the constraints and the solutions rather than writing algorithm to find the solutions to the problem.

$\mathcal{I} = \langle \mathcal{E}, \mathcal{F}, \mathcal{G}, \mathcal{C}, \Delta \rangle$, where

1. $\mathcal{F} = \mathcal{W} \cup \mathcal{P} \cup \mathcal{O} \cup \mathcal{D}$
2. $\mathcal{G} : \mathcal{X} \times \mathcal{E} \to 2^{\mathcal{E}_{inst}}$
3. $\mathcal{C} : \mathcal{X} \times \mathcal{E} \to 2^{\mathcal{F}} \times 2^{\mathcal{F}}$ where $C(\phi, e) = (\mathcal{C}^{\uparrow}(\phi, e), \mathcal{C}^{\downarrow}(\phi, e))$ where
   (i) $\mathcal{C}^{\uparrow}(\phi, e)$ initiates fluents
   (ii) $\mathcal{C}^{\downarrow}(\phi, e)$ terminates fluents
4. $\mathcal{E} = \mathcal{E}_{ex} \cup \mathcal{E}_{inst}$ with $\mathcal{E}_{inst} = \mathcal{E}_{act} \cup \mathcal{E}_{viol}$
5. Δ
6. State Formula: $\mathcal{X} = 2^{\mathcal{F} \cup \neg \mathcal{F}}$

(a)

$$p \in \mathcal{F} \Leftrightarrow \texttt{ifluent(p)}. \tag{1}$$
$$e \in \mathcal{E} \Leftrightarrow \texttt{event(e)}. \tag{2}$$
$$e \in \mathcal{E}_{ex} \Leftrightarrow \texttt{evtype(e, obs)}. \tag{3}$$
$$e \in \mathcal{E}_{act} \Leftrightarrow \texttt{evtype(e, act)}. \tag{4}$$
$$e \in \mathcal{E}_{viol} \Leftrightarrow \texttt{evtype(e, viol)}. \tag{5}$$
$$\mathcal{C}^{\uparrow}(\phi, e) = P \Leftrightarrow \forall p \in P \cdot \texttt{initiated(p, T)} \leftarrow \mathit{occurred}(e, T), EX(\phi, T). \tag{6}$$
$$\mathcal{C}^{\downarrow}(\phi, e) = P \Leftrightarrow \forall p \in P \cdot \texttt{terminated(p, T)} \leftarrow \mathit{occurred}(e, T), EX(\phi, T). \tag{7}$$
$$\mathcal{G}(\phi, e) = E \Leftrightarrow g \in E, \texttt{occurred(g, T)} \leftarrow \texttt{occurred(e, T)}, \texttt{holdsat(pow(e), I)}, EX(\phi, T). \tag{8}$$
$$p \in \Delta \Leftrightarrow \texttt{holdsat(p, i00)}. \tag{9}$$

(b)

Fig. 1. (a) Formal specification of the normative framework and (b) Translation of normative framework specific rules into *AnsProlog*

The basic components of the language are atoms, elements that can be assigned a truth value. An atom can be negated using *negation as failure*. *Literals* are atoms a or negated atoms not a. We say that not a is true if we cannot find evidence supporting the truth of a. Atoms and literals are used to create rules of the general form: $a \leftarrow b_1, ..., b_m, \text{not } c_1, ..., \text{not } c_n$, where a, b_i and c_j are atoms. Intuitively, this means *if all atoms b_i are known/true and no atom c_j is known/true, then a must be known/true.* We refer to a as the head and $b_1, ..., b_m, \text{not } c_1, ..., \text{not } c_n$ as the body of the rule. Rules with empty body are called *facts*. Rules with empty head are referred to as *constraints*, indicating that no solution should be able to satisfy the body. A *(normal) program (or theory)* is a conjunction of rules and is also denoted by a set of rules. The semantics of *AnsProlog* is defined in terms of *answer sets*, i.e. assignments of true and false to all atoms in the program that satisfy the rules in a minimal and consistent fashion. A program may have zero or more answer sets, each corresponding to a solution.

The mapping of an institution consists of three parts: a *base component* which is independent of the institutions being modelled, the *time component* and the *institution-specific component*. The base component deals with inertia of the fluents, the generation of violation events of non-permitted actions and unfulfilled obligations. Furthermore it terminates fulfilled and violated obligations. The time component defines the predicates for time and is responsible for generating a single observed event at every time instance. The mapping uses the following atoms: `ifluent(p)` to identify fluents, `evtype(e,t)` to describe the type of an event, `event(e)` to denote the events, `instant(i)` for time instances, `final(i)` for the last time instance, $\mathtt{occurred(e, i)}$ to indicate that the (empowered institutional) event happened at time i, $\mathtt{observed(e, i)}$ that the (exogenous) event was observed at time i, $\mathtt{holdsat(p, i)}$ to state that the normative fluent p holds at i, and finally $\mathtt{initiated(p, i)}$ and $\mathtt{terminated(p, i)}$ for fluents that are initiated and terminated at i. Figure 1(b) provides the framework-specific translation rules, including the definition of all the fluents and events as facts. For a given expression $\phi \in \mathcal{X}$, we use the term $EX(\phi, T)$ to denote the translation of ϕ into a set of ASP literals of the form ($\mathtt{not}$) $\mathtt{holdsat(f, T)}$, denoting that some fluent $\mathtt{f}$ (does not hold) holds at time $\mathtt{T}$, while the initial state of the normative framework is encoded as simple facts ($\mathtt{holdsat(f, i00)}$).

2.2 Case Study: Virtual Communities

To demonstrate how conflicts can be detected when composing institutions we use, a (necessarily) simplified case study of virtual communities. In particular, we focus on detecting conflicts when composing a technical and a social institution which in combination serve to govern the virtual community from both a social and a technical perspective. In the specific example we look at handling the membership of users making inappropriate posts.

Table 1 provides the formal model of both the technical and the social institution.

From a policy perspective, the main conceptual difference between the two institutions is who is allowed and empowered to end the membership of a user who posted an inappropriate post. The technical institution states that only authorised persons (e.g. moderators) can have the right to remove the memberships of members having posted inappropriate content. By contrast,the social institution might prefer a more community-driven approach and allow all members to take the initiative of enforcing actions when inappropriate content is posted, by specifying that any member of the community can remove another members' membership after the content violation is confirmed by a moderator.

Both institutions have three observed events ($\mathcal{E}_{ex}$) to signal an agent posting, an agent posting inappropriately and the removal of the membership of an agent. The social institution has an additional event to indicate that an agent informs the moderator. Apart from the counts-as institutional actions and standard violations, we have one extra violation event to indicate the occurrence of `postViolation`. Domain fluents indicate who is a member, a moderator and who has posted inappropriately.

The main difference between the two institutions (and the cause for conflicts) is the initiation of fluents after the occurrence of the `inappropriatePost(Agent)` event. In the technical institution, the moderators are given the permission and the power to remove the membership of the `Agent`. In the social one, `inappropriatePost` triggers the initiation of the domain fluent `inappPost` for the offending agent and the permission to inform the moderator is granted to all participants. Upon informing the moderator (`informModerator`), the informing agent receives the permission and power to remove the offending agent from the

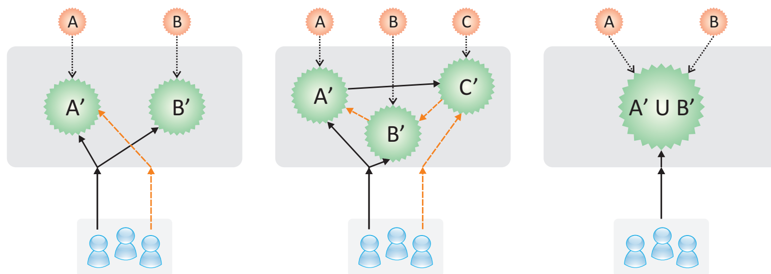

Fig. 2. Three views of composition. *(a):* composite institution. *(b):* Multi-institution. *(c):* merged institution.

community Termination of membership terminates permission to post. The generation function generates the `inappropriatePost(Agent)` when needed and connects the physical world with the institutional contexts. At the start, all agents are given permission and power to post to the community.

Using the translation to $AnsProlog$, Table 2 compares the `removeMembership` policy of both institutions.

3 Composite Institutions

3.1 Combining Institutions

Having presented the single institutions, we now address the issue on how institutions can be combined. The literature suggests there are three ways of combining institutions, which we depict in Fig. 2. The A', B', C' and $A' \cup B'$ indicate the consistent states of the corresponding institutions or their consistent union. The circles around the institutions indicate their state. The arrows indicate triggered events and changes to the state as a result of the actions of two participants, differentiated by the use of solid and dashed lines.The options are as follows: (a) Composite institution: The first option is to treat all the individual institutions as separate individual entities which – if required – have been adjusted to handle policy conflicts. The composite institution thus is not a new institution, but rather a shared governance scope of the individual institutions. (b) Multi-institution: The second option offers a hierarchical structure of several interlinked institutions where one institutional change is triggered by another institution changing state and only influences the virtual community indirectly. The connected institutions have to be adapted to be avoid conflicts. [2] proposes multi-institutions but assumes that designers have avoided the possibility of conflicts. (c) Merged institution: Finally, it is also possible to join the policies all institutions into one "super-institution". In contrast to the first case, the focus is not on maintaining the autonomy of the initial individual institutions, but to create a completely new institution which becomes the interface between the actors in the system.

Technical Institution	Social Institution
$\mathcal{E}_{ex} = \{\texttt{post(Agent)}, \texttt{inappropriatePost(Agent)}, \texttt{removeMembership(Agent, Agent)}\}$ $\mathcal{E}_{act} = \{\texttt{intPost(Agent)}, \texttt{intRemoveMembership(Agent, Agent)}\}$ $\mathcal{E}_{viol} = \{\text{viol}(\texttt{post(Agent)}), \text{viol}(\texttt{inappropriatePost(Agent)}), \text{viol}(\texttt{removeMembership(Agent, Agent)})\}$ $\{\text{viol}(\texttt{intPost(Agent)}), \text{viol}(\texttt{intRemoveMembership(Agent, Agent)})\}$ $\{\texttt{postViolation(Agent)}\}$ $\mathcal{D} = \{\texttt{isModerator(Agent)}, \texttt{isMember(Agent)}\}$ $\mathcal{W} = \{\text{pow}(\texttt{intPost(Agent)}), \text{pow}(\texttt{intRemoveMembership(Agent, Agent)})\}$ $\mathcal{P} = \{\text{perm}(\texttt{post(Agent)}), \text{perm}(\texttt{inappropriatePost(Agent)}), \text{perm}(\texttt{removeMembership(Agent, Agent)})\}$ $\{\text{perm}(\texttt{intPost(Agent)}), \text{perm}(\texttt{intRemoveMembership(Agent, Agent)})\}$ $\mathcal{O} = \emptyset$ $\mathcal{C}^{\uparrow}(\mathcal{X}, \mathcal{E}) : \langle\{\texttt{isModerator(Agent1)}, \texttt{isMember(Agent)}\},$ $\texttt{inappropriatePost(Agent)}\rangle \rightarrow \{\text{perm}(\texttt{removeMembership(Agent, Agent1)}),$ $\text{perm}(\texttt{intRemoveMembership(Agent, Agent1)}),$ $\text{pow}(\texttt{intRemoveMembership(Agent, Agent1)})\}$ $\mathcal{C}^{\downarrow}(\mathcal{X}, \mathcal{E}) : \langle\{\texttt{isModerator(Agent1)}\},$ $\texttt{removeMembership(Agent, Agent1)}\rangle \rightarrow \{\texttt{isMember(Agent)}, \text{perm}(\texttt{post(Agent)}),$ $\text{perm}(\texttt{inappropriatePost(Agent)}),$ $\text{pow}(\texttt{intPost(Agent)}), \text{perm}(\texttt{intPost(Agent)})\}$ $\mathcal{G}(\mathcal{X}, \mathcal{E}) : \langle\{\texttt{isMember(Agent)}\}, \texttt{post(Agent)}\rangle \rightarrow \{\texttt{intPost(Agent)}\}$ $\langle\emptyset, \texttt{inappropriatePost(Agent)}\rangle \rightarrow \{\texttt{postViolation(Agent)}\}$ $\langle\{\texttt{isModerator(Agent1)}, \texttt{isMember(Agent)}\},$ $\texttt{removeMembership(Agent, Agent1)}\rangle \rightarrow \{\texttt{intRemoveMembership(Agent, Agent1)}\}$ $\Delta = \text{perm}(\texttt{post(Agent)}), \text{perm}(\texttt{inappropriatePost(Agent)}), \text{pow}(\texttt{intPost(Agent)}),$ $\text{perm}(\texttt{intPost(Agent)}), \texttt{isModerator(moderator)}, \texttt{isModerator(agent1)},$ $\texttt{isMember(agent1)}, \texttt{isMember(agent2)}$	$\mathcal{E}_{ex} = \{\texttt{post(Agent)}, \texttt{inappropriatePost(Agent)}, \}$ $\{\texttt{informModerator(Agent)}, \texttt{removeMembership(Agent, Agent)}\}$ $\mathcal{E}_{act} = \{\texttt{intPost(Agent)}, \texttt{intRemoveMembership(Agent, Agent)}\}$ $\mathcal{E}_{viol} = \{\text{viol}(\texttt{post(Agent)}), \text{viol}(\texttt{inappropriatePost(Agent)}), \text{viol}(\texttt{removeMembership(Agent, Agent)})\}$ $\{\text{viol}(\texttt{intPost(Agent)}), \text{viol}(\texttt{intRemoveMembership(Agent, Agent)})\}$ $\{\texttt{postViolation(Agent)}, \text{viol}(\texttt{informModerator(Agent)})\}$ $\mathcal{D} = \{\texttt{inappPost(Agent)}, \texttt{isMember(Agent)}\}$ $\mathcal{W} = \{\text{pow}(\texttt{intPost(Agent)}), \text{pow}(\texttt{intRemoveMembership(Agent, Agent)})\}$ $\mathcal{P} = \{\text{perm}(\texttt{post(Agent)}), \text{perm}(\texttt{inappropriatePost(Agent)}), \text{perm}(\texttt{removeMembership(Agent, Agent)})\}$ $\{\text{perm}(\texttt{intPost(Agent)}), \text{perm}(\texttt{intRemoveMembership(Agent, Agent)})\}$ $\mathcal{O} = \emptyset$ $\mathcal{C}^{\uparrow}(\mathcal{X}, \mathcal{E}) : \langle\{\texttt{isMember(Agent1)}\},$ $\texttt{inappropriatePost(Agent)}\rangle \rightarrow \{\text{perm}(\texttt{informModerator(Agent1)})\}$ $\langle\{\texttt{isMember(Agent1)}, \texttt{inappPost(Agent)}\},$ $\texttt{informModerator(Agent1)}\rangle \rightarrow \{\text{perm}(\texttt{removeMembership(Agent, Agent1)}),$ $\{\text{perm}(\texttt{intRemoveMembership(Agent, Agent1)}),$ $\text{pow}(\texttt{intRemoveMembership(Agent, Agent1)})\}$ $\langle\emptyset, \texttt{inappropriatePost(Agent)}\rangle \rightarrow \{\texttt{inappPost(Agent)}\}$ $\mathcal{C}^{\downarrow}(\mathcal{X}, \mathcal{E}) : \langle\{\texttt{isModerator(Agent1)}\},$ $\texttt{removeMembership(Agent, Agent1)}\rangle \rightarrow \{\texttt{isMember(Agent)}, \text{perm}(\texttt{post(Agent)}),$ $\text{perm}(\texttt{inappropriatePost(Agent)}),$ $\text{pow}(\texttt{intPost(Agent)}), \text{perm}(\texttt{intPost(Agent)})\}$ $\mathcal{G}(\mathcal{X}, \mathcal{E}) : \langle\{\texttt{isMember(Agent)}\}, \texttt{post(Agent)}\rangle \rightarrow \{\texttt{intPost(Agent)}\}$ $\langle\emptyset, \texttt{inappropriatePost(Agent)}\rangle \rightarrow \{\texttt{postViolation(Agent)}\}$ $\langle\{\texttt{isModerator(Agent1)}, \texttt{isMember(Agent)}\},$ $\texttt{removeMembership(Agent, Agent1)}\rangle \rightarrow \{\texttt{intRemoveMembership(Agent, Agent1)}\}$ $\Delta = \text{perm}(\texttt{post(Agent)}), \text{perm}(\texttt{inappropriatePost(Agent)}), \text{pow}(\texttt{intPost(Agent)}),$ $\text{perm}(\texttt{intPost(Agent)}), \texttt{isMember(agent1)}, \texttt{isMember(agent2)}$

Table 1. Social and Technical Institutions

	Technical Policies	Social Policies

Permission of removeMembership	`initiated(perm(removeMembership(agent1, agent2)), I) :-`
	`occurred(inappropriatePost(agent1), I),`
	`holdsat(isMember(agent1), I),`
	`holdsat(isModerator(agent2), I),`
	`holdsat(live(virtualcommunitytechnicalspecs), I),`
	`instant(I).`
		`initiated(perm(removeMembershipRE(agent1, agent2)), I) :-`
		`occurred(informModeratorRE(agent2), I),`
		`holdsat(isMemberRE(agent2), I),`
		`holdsat(inappPostRE(agent1), I),`
		`holdsat(live(virtualcommunitysocialspecs), I),`
		`instant(I).`

Permission of intRemoveMembership	`initiated(perm(intRemoveMembership(agent1, agent2)), I) :-`
	`occurred(inappropriatePost(agent1), I),`
	`holdsat(isModerator(agent2), I),`
	`holdsat(isMember(agent1), I),`
	`holdsat(live(virtualcommunitytechnicalspecs), I),`
	`instant(I).`
		`initiated(perm(intRemoveMembershipRE(agent1, agent2)), I) :-`
		`occurred(informModeratorRE(agent2), I),`
		`holdsat(isMemberRE(agent2), I),`
		`holdsat(inappPostRE(agent1), I),`
		`holdsat(live(virtualcommunitysocialspecs), I),`
		`instant(I).`

Empowerment of intRemoveMembership	`initiated(pow(intRemoveMembershipRE(agent1, moderator)), I) :-`
	`occurred(informModeratorRE(moderator), I),`
	`holdsat(isMemberRE(moderator), I),`
	`holdsat(inappPostRE(agent1), I),`
	`holdsat(live(virtualcommunitysocialspecs), I),`
	`instant(I).`
		`initiated(pow(intRemoveMembership(agent1, agent2)), I) :-`
		`occurred(inappropriatePost(agent1), I),`
		
		`holdsat(isMember(agent1), I),`
		`holdsat(live(virtualcommunitytechnicalspecs), I),`
		`instant(I).`

Table 2. Comparison of Social and Technical Policies in *AnsProlog*

In this paper, we are interested in the first type, namely composite institutions. A set $\mathcal{I} = \{\mathcal{I}_1, \ldots, \mathcal{I}_n\}$ of institutions are combined as the composite institution $C_{\mathcal{I}}$. The institutions in $C_{\mathcal{I}}$ do not share state nor are they able to interact with each other (as is the case in multi-institutions).

While provided by different designers, we will assume for the sake of this paper that the individual institutions will use the same terminology to the same concepts. In other words, we assume that the institutions are semantically aligned. From our virtual community example, it should for example not happen that one institution uses the event `post(Agent)` to denote the a message is posted by `Agent` while another institution uses the event `postMessage(Agent)` to refer to same action.

3.2 Composite Traces

While a composite institution is not a institution in its own right (i.e. it does not have its own formal model), the participants can interact with it as if it were one, as shown in Figure 2. The composite institution provides a wrapper around the individual institutions allowing the participants to interact with one entity rather than having to determine which of the individual institutions they wish to interact with. In reality, the composition passes the exogenous events to the correct corresponding individual institutions if appropriate.

To be able to analyse the behaviour of the composition, we introduce the notion of a composite trace. Composite traces are sequences of events created from the observed events of the individual institutions.

Definition 1. *Given an composite institution $C_{\mathcal{I}}$consisting of institutions $\mathcal{I} = \mathcal{I}_1, \ldots, \mathcal{I}_n$. A* composite trace *is a sequence $\langle e_1, \ldots e_m \rangle$ such that $\forall e_i, 1 \leq i \leq m : \exists 1 \leq j \leq n : e_i \in \mathcal{E}^j_{ex}$.*

3.3 Null Events

The composite traces capture the state transitions of each of the individual institutions. From the composite trace, we can separate the traces for each of the individual institutions by selecting those exogenous events that each recognizes. Unfortunately these individual traces could be of different lengths. This means that the states will be associated with different time steps, making it impractical, if not impossible, to reason about institutions in the same "time" frame.

To facilitate the temporal alignment of events, we extend each institution's formal model with a null event. The occurrence of the observed null event does not change the state (i.e. the null event is not used in either $\mathcal{G}$ or $\mathcal{C}$) but when incorporated into the model, it advances the state counter. The null event also needs to be permitted from the start. So for each institution $\mathcal{I}_i \in C_{\mathcal{I}}$ with $\mathcal{I} = \{\mathcal{I}_1, \ldots, \mathcal{I}_n\}$ we have that $e_{null} \in \mathcal{E}^i_{ex}$ and $\text{perm}(\mathtt{e_{null}}) \in \Delta$.

With the addition of null events, we can define synchronised traces by replacing each unknown observed event in an institution's trace by the null-event.

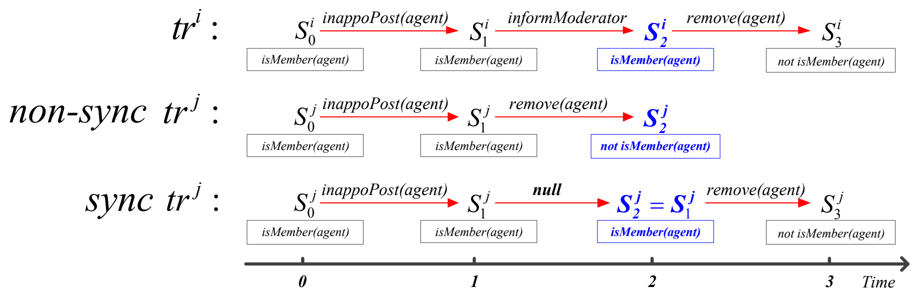

Fig. 3. Example of Trace Synchronization

Definition 2. *Given a composite trace $CTR = \langle e_1, \ldots, e_t \rangle$ for a composite institution $C_{\mathcal{I}}$ and an institution $\mathcal{I}_i \in \mathcal{I}$, the* synchronised trace *for $\mathcal{I}_i$ w.r.t. CRT is the trace $\langle a_1, \ldots, a_t \rangle$ with $a_k = e_k$ if $e_k \in \mathcal{E}^i_{ex}$ and with $a_k = e_{null}$ otherwise.*

These synchronised traces are needed for conflict detection. We demonstrate this using our virtual communities example. Suppose a composite trace $CTR = \langle \texttt{inappropriatePost}(\texttt{agent1}), \texttt{informModerator}(\texttt{agent2}), \texttt{removeMembership}(\texttt{agent1}, \texttt{agent2}) \rangle$. As mentioned in Section 2.2, `informModerator(agent2)` is only observable by the social institution i and not the technical institution j. The separate event traces (tr) for institutions i and j are as below:

$$tr_i = \langle \texttt{inappropriatePost}(\texttt{agent1}), \texttt{informModerator}(\texttt{agent2}), \texttt{removeMembership}(\texttt{agent1}, \texttt{agent2}) \rangle$$
$$tr_j = \langle \texttt{inappropriatePost}(\texttt{agent1}), \texttt{removeMembership}(\texttt{agent1}, \texttt{agent2}) \rangle$$

where the event `informModerator` is missing from the trace of the technical institution j. We assume that `agent2` is a moderator. The states transitions without synchronisation are shown as the first two traces in Fig.3. At time instant 2, both institutions disagree on the membership of agent. We call this a conflict. However, this kind of conflict is not desirable because they are actually caused by the asynchronous occurrence of events. By synchronising the event traces, as shown in the last trace in Fig.3, a null event `null` is generated for the trace tr^j at the time of the occurrence of event `informModerator(agent2)`. The states S^j_1 and S^j_2 are identical, as the null event does not effect the state of j. Consequently we have removed the false conflict on the fluent `isMember(agent)` by synchronising the event traces.

Having defined composite and synchronised traces, we can now define a composite model.

Definition 3. *Given a composite trace CTR for a composite institution $C_{\mathcal{I}}$ with $\mathcal{I} = \{\mathcal{I}_1, \ldots, \mathcal{I}_n\}$, the corresponding composite model is the set of models M_i with $1 \leq i \leq n$ such that M_i is the model corresponding to the synchronised trace of institution i.*

Hence a composite model is a set of sequences over states. Each such sequence contains the state transitions for a synchronised trace obtained from CTR. We refer to the models corresponding to synchronised traces as synchronised models.

4 Conflict Detection

4.1 Conflict Traces

As noted in the introduction, institutions are typically designed to fulfill individual normative goals and are initially expected to work independently. Therefore, composing institutions is likely to cause conflicts between the policies of the individual institutions and causing problems for agents when they interact with the composite institution. Hence the importance of resolving conflicts between individual institutions when creating the composite institution. We start with our definition of conflict w.r.t. composite institutions. While the institutional model is event-based, the conflicts can be detected in the state. We say that a composite institution is in conflict if there exists a composite trace for which two corresponding synchronised models are inconsistent. Inconsistency occurs when in corresponding states a fluent is true in one and false in the other.

Definition 4. *Given a composite institution $C_{\mathcal{I}}$ with a composite trace CTR. CTR is a* conflict trace *iff:*

- $\exists \mathcal{I}_i, \mathcal{I}_j \in \mathcal{I}$ *with synchronised models* $M_i = \langle S_0^i, \ldots S_t^i \rangle$ *and* $M_j = \langle S_0^j, \ldots S_t^j \rangle$ *such that*
- $\exists f \in (\mathcal{F}^i \cap \mathcal{F}^j)$ *such that*
- $\exists k, 0 \leq k \leq t$ *such that*
- $f \in S_k^i$ *and* $\neg f \in S_k^j$

Definition 5. *A composite institution is* conflict-free *iff it does not admit any conflict traces.*

4.2 Detection of Policy Conflict

With all the theory in place, we can now discuss the computational mechanism for detecting conflicts of composite definitions. As mentioned in Section 2.1, we use *AnsProlog* for implementing the computational model of institutions. As a result we can use the same technique for determining conflict traces and detecting conflicts. Instead of answer sets representing all observed traces, we want our answer sets to represent conflict traces, i.e. composite traces and their models that produce a conflict.

For simplicity, we will only introduce our method for two institutions being composed but the method can be extended to as many institutions as desired.

At first sight, one might think that simply putting together the *AnsProlog* implementations of the individual institutions and the constraints for selecting the conflict traces would be sufficient. Unfortunately, since we are looking for inconsistency this impossible. The constraints would be $\texttt{conflict} : -\texttt{holdsat}(\texttt{F},\texttt{T})$,

$\texttt{not holdsat(F,T)}$. and $:-\texttt{not conflict}$. Regrettably, this will never result in an answer being returned. The first rule will never hold, so `conflict` will never be true and therefore the constraint cannot be satisfied. To solve this problem, the events and fluents of one of the two institutions are renamed (this can be done automatically by for example adding `RE` to each fluent or event) and adding a set of facts of the form $\texttt{rename(F,FRE)}$ to the program to indicate that F and FRE are actually the same. For example, $\texttt{post(Agent)}$ becomes $\texttt{postRE(Agent)}$. This allows us to express the conflict selection in *AnsProlog* as follows. To indicate conflict we introduce, for efficiency reasons, two `conflict` atoms, one with no arguments and one with three arguments. We use two rules to take into account that the positive occurrence of the conflicting fluent can either occur in the renamed and non-renamed institution. A constraint is used to express that we are only interested in answer sets representing conflict traces. We also introduce two rules for information purposes, using the atom `conflict/3`. The first of its arguments gives the fluent that appears positively, the second the negative fluent and the third argument the time instance the conflict occurs. This information can be used later to resolve the conflict.

$$
\begin{aligned}
\texttt{conflict} &:- \texttt{holdsat(F,I)}, \texttt{not holdsat(FRE,I)}, \texttt{rename(F,FRE)},\\
&\quad\ \texttt{instant(I)}.\\
\texttt{conflict} &:- \texttt{holdsat(FRE,I)}, \texttt{not holdsat(F,I)}, \texttt{rename(F,FRE)},\\
&\quad\ \texttt{instant(I)}.\\
&:- \texttt{not conflict}.\\
\texttt{conflict(F,FRE,I)} &:- \texttt{holdsat(F,I)}, \texttt{not holdsat(FRE,I)}, \texttt{rename(F,FRE)},\\
&\quad\ \texttt{instant(I)}.\\
\texttt{conflict(FRE,F,I)} &:- \texttt{holdsat(FRE,I)}, \texttt{not holdsat(F,I)}, \texttt{rename(F,FRE)},\\
&\quad\ \texttt{instant(I)}.
\end{aligned}
$$

Individual institutions generate their traces by enforcing that each answer set admits one and only observed atom for each time instance. With observed events possibly being recognised by two institutions, we need two observed events one for the original event and one for its renamed counterpart. So we replicate the original observed event code using a new atom called `compObserved`.

$$
\begin{aligned}
\texttt{compEvent(E)} &:- \texttt{evtype(ERE,ex)}, \texttt{evinst(E,In)}, \texttt{rename(E,ERE)}, \texttt{instRE(In)}.\\
\texttt{compEvent(E)} &:- \texttt{evtype(E,ex)}, \texttt{evinst(E,In)}, \texttt{inst(In)}.\\
\{\texttt{compObserved(E,I)}\} &:- \texttt{compEvent(E)}, \texttt{instant(I)}, \textbf{not}\ \texttt{final(I)}.\\
\texttt{ev(I)} &:- \texttt{compObserved(E,I)}, \texttt{instant(I)}.\\
&:- \textbf{not}\ \texttt{ev(I)}, \texttt{instant(I)}, \textbf{not}\ \texttt{final(I)}.\\
&:- \texttt{compObserved(E1,I)}, \texttt{compObserved(E2,I)}, \texttt{E1!} = \texttt{E2},\\
&\quad\ \texttt{instant(I)}, \texttt{compEvent(E1)}, \texttt{compEvent(E2)}.
\end{aligned}
$$

The first two rules make sure that the observable events of both institutions in their original form can be considered in a composite trace. The third rule generates `compObserved/2` when needed. If generated a matching `ev/1` atom is provided. The first constraint guarantees that least one `ev` is produced for any non-final time instant. The second constraints makes sure it is only one.

These `compObserved` atoms will form our composite traces from which we can generate the synchronised traces using the `observed` atoms. Since the `compObserved` events use the non-renamed version we need to make sure that they are renamed when needed. This is done by the program below:

$$\begin{aligned}
\texttt{observed(ERE, I)} :- &\ \texttt{compObserved(E, I)}, \texttt{rename(E, ERE)}, \texttt{evinst(ERE, In)},\\
&\ \texttt{instJ(In)}, \texttt{instant(I)}.\\
\texttt{observed(E, I)} :- &\ \texttt{compObserved(ERE, I)}, \texttt{rename(E, ERE)}, \texttt{evinst(E, In)},\\
&\ \texttt{instI(In)}, \texttt{instant(I)}.\\
\texttt{observed(enull, I)} :- &\ \texttt{compObserved(ERE, I)}, \texttt{rename(E, ERE)}, \textbf{not}\ \texttt{evinst(E, Inst)},\\
&\ \texttt{instI(Inst)}, \texttt{instI(In)}, \texttt{instant(I)}.\\
\texttt{observed(enullRE, I)} :- &\ \texttt{compObserved(E, I)}, \texttt{rename(E, ERE)}, \textbf{not}\ \texttt{evinst(ERE, Inst)},\\
&\ \texttt{instJ(Inst)}, \texttt{instant(I)}.
\end{aligned}$$

4.3 Conflicts in the case Study

We can now apply our conflict detection mechanism to our use case. Due to space limitation, we only present the conflicts detected at time 3 for the composite trace: $CTR = \langle \texttt{inappropriatePost(agent1)}, \texttt{informModerator(agent2)}, \texttt{removeMembership(agent1, agent2)} \rangle$. Other traces give the same conflicts, but only at different time instances.

The first type of conflicts concerns the permission to remove membership: it indicates that `agent2`, as a normal member, is permitted to remove the membership of others (e.g. `agent1`), under the rules of the social institution, however, this permission is not given with regard to the technical institution, which only allows a `moderator` agent to remove membership.

$$\begin{aligned}
\texttt{conflict(}&\ \texttt{perm(removeMembershipRE(agent1, agent2))},\\
&\ \texttt{perm(removeMembership(agent1, agent2)), 3)}\\
\texttt{conflict(}&\ \texttt{perm(removeMembership(agent1, moderator))},\\
&\ \texttt{perm(removeMembershipRE(agent1, moderator)), 3)}
\end{aligned}$$

The second type of conflict concerns the permission to generate the institutional event `intRemoveMembership/2`. Similarly, this permission for a normal member to remove membership only appears in the social institution, while only the moderator is allowed to remove membership in the technical institution.

$$\begin{aligned}
&\texttt{conflict(}\ \texttt{perm}(\texttt{intRemoveMembershipRE}(\texttt{agent1}, \texttt{agent2})),\\
&\qquad\qquad \texttt{perm}(\texttt{intRemoveMembership}(\texttt{agent1}, \texttt{agent2})), 5)\\
&\texttt{conflict(}\ \texttt{perm}(\texttt{intRemoveMembership}(\texttt{agent1}, \texttt{moderator})),\\
&\qquad\qquad \texttt{perm}(\texttt{intRemoveMembershipRE}(\texttt{agent1}, \texttt{moderator})), 5)
\end{aligned}$$

The third type of conflict occurs with the empowerment of the institutional event `intRemoveMembership/2`. The event is empowered under different conditions.

$$\begin{aligned}
&\texttt{conflict(}\ \texttt{pow}(\texttt{intRemoveMembershipRE}(\texttt{agent1}, \texttt{agent2})),\\
&\qquad\qquad \texttt{pow}(\texttt{intRemoveMembership}(\texttt{agent1}, \texttt{agent2})), 5)\\
&\texttt{conflict(}\ \texttt{pow}(\texttt{intRemoveMembershipRE}(\texttt{agent1}, \texttt{moderator})),\\
&\qquad\qquad \texttt{pow}(\texttt{intRemoveMembership}(\texttt{agent1}, \texttt{moderator})), 5)
\end{aligned}$$

The results presented above show all the expected conflicts between the social institution and technical institution. In contrast to the false conflict on fluent `isMember(agent)` in Fig. 3 caused by the asynchronism of event traces, these detected conflicts are the result of the different goals of the independent component institutions.

5 Summary and Conclusions

When composing institutions written by different designers with possible (slightly) different objectives, conflicts between the modelled policies can occur. In this paper, we presented a mechanism for detecting this, occasionally subtle, differences. Our mechanism is based on the institutional model and *AnsProlog* implementation by Cliffe et al. Based on this existing institutional framework, in this paper we firstly presented our notion of composite institutions and described how conflicts can be detected in them. We applied our approach to a case-study of a socio-technical system – namely a virtual community – in which conflicts between a social and a technical institution needed to be determined for the effective functioning of this community.

In this paper, we only focused on the detection of conflicts. An obvious next step is the resolution of the detected conflicts. This poses several interesting challenges such as including mechanisms to specify which policies or institutions are given a priority in case of conflict; as well as the question to trace back to which policies cause the conflicts we detected. By definition, our mechanism detects conflicts as a result of conflicting fluents (a fluent being true and false at the same time in different institutions). The fluents however are only the result of the exogenous events and the interpretation of those events in the institution through their policies. Thus, we need to determine which policies caused conflicts. One possible avenue for adjusting individual institutions is to use the conflict information as a use-case that can be presented to an inductive learner. In [5], the authors use inductive learning to refine institutions which they call normative frameworks. Another promising future direction is the extension of the current model of composite institution to multi-institution and merged institution.

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A conceptual model of participatory policy making in practice: water governance and boundary workers

Abstract

With current projections of climate change, and an increasing demand for water in response to population growth, water management needs to move towards more sustainable practices.

In France decentralization caused legislative changes. The Water Act of 1992 and the establishment of SAGE (Local Water Management Plan) and river contracts have generated the need for people facilitating them. We consider here a new category of people named boundary worker.

This new approach to public policies is not completely stabilized. Its implementations on the ground are very diverse. Little is known on their efficiency. Our work aims at providing means to improve the assessment of this aspect of participatory governance for public policies.

In this paper we propose a conceptual model to represent consequences of the involvement of a boundary worker in river basin governance, taking in account the context (social, institutional, physical) of this involvement. Our conceptual model is based on considering that boundary workers are primarily fostering innovation among stakeholders and on an adaptation of Ostrom's IAD framework. Final aim of this model is exploration of various conditions of involvement of boundary workers and consequences on the evolution of socio-hydrosystems they are attached to.

adfa, p. 1, 2011.

1. Introduction

Water resources management is increasingly in need for interfaces between different users and resources. The aim is to facilitate an evolution towards greener practices of users towards resources. One of the interfaces mobilized to facilitate this implementation is the boundary worker. In recent years there have been an increasing number of boundary worker from different background in matters of water management. All these new people take with them their own scientific and politic knowledge and also a personal vision of the situation. How the dynamic of socio-hydrosystem evolve with the introduction of these new people into the collaborative management process?

These people facilitate dialogue processes that end up as generators of innovation processes in the sense described by Villani and Serra [1]. For example, they endorse a role in the networking between various stakeholders. This networking generates a process of interaction and then novelty and thus innovation within the socio-hydrosystem. Stringer and Dougill show that a range of participatory mechanisms can be employed at different stages of the adaptive cycle, and can work together to create conditions for social learning and favorable outcomes for diverse stakeholders [2]. Since boundary workers are supposed to generate and increase level of participation, they increase "social learning" which, in turn, generates new knowledge that is considered of an innovation.

There is still little feedback on the consequences of this new trend of socio-hydrosystem governance. From analysis of ex post evaluation and review of simulation situation, we aim at explaining the potential consequences of boundary worker in SHS collaborative government.

This paper will consist of three parts. The first part will discuss the establishment of participatory device and more precisely the role and the actions of the boundaries worker. A second part will present the innovation process and how it is part of political and participatory devices. And in the third part I will detail requirement for an exploratory model and propose a structure of conceptual model meeting these.

2. Participatory device

There is no agreed definition for the “intermediary work”[3] while it has become increasingly popular. In the follow up of this paper we will name “boundary worker” the category of people endorsing activities considered as boundary or intermediate work. When they are involved, a boundary worker is a key part of participatory public policy making. The very setting of introducing boundary work is a crucial issue in engineery participatory policy maker. It is necessary that it appears as a distinct class of people [3]. The animators of watersheds for example belong to this class. These are between water users and policy maker. They are environmental specialists and must possess important relational capacity. They need to harness three types of competences: scientific/technical/ legal.

They are advisers on technical issues and as such participate in project development. They have also to facilitate working groups in order to relay initiatives on a specific study area. They are promoting “good water management” by bringing out a multi-agent system across the watershed. One of their promoting possible roles is to strengthen relations with local stakeholders. They serve as a relay and "buffer zone" between stakeholders. It is now trendy to involve all stakeholders who use the same water resource but in a different way and with various representations. Therefore a major role of animators is to act as translators between users, policymakers and experts. These river basin animator can be considered as key people in the implementation of new water management modalities [4].

This is a new form of cooperation in public space [5]. Consultation and negotiation are central features of actions where the issue of mediation is central. It is a policy of negotiated management environment designed to be implemented.

In public space, the role of boundary worker can be endorsed by different people. It can be someone, like broker, between a naturalist and an expert in facilitation. This work requires a relationship skill, focusing on facilitation, negotiation and construction of partnerships [6] .

The activity of a Broker is to position itself between different groups and demonstrate the advantage of cooperation despite different interests and goals. The role of a broker may still be risky, because he holds two contradictory roles. This role provides them some autonomy relatively to their own institution. But as a “spokesman” that require them to protect the collective interests of their institution. The purpose of these brokers is not only linked to a capacity of negotiator or a technical capacity for action. It is also associated with the ability to switch from one institutional arena to another while working in places where discussions and negotiations operate [7]. He accesses many information captured within the different groups. The broker will learn about the inner workings of the different groups. This is an advantage to know which groups or individuals to connect and those not to connect, how to connect them, and when connect them [8] .Burt calls that "an acquired ability", i.e. the ability to navigate a constantly changing social landscape and coordinate a network. The brokers are powerful actors in the sense that they can control the behavior of social groups and information flows between groups in the network. Brokering is an important position and includes a role of "social criticism" in the adaptive management of natural resources [9]. We may also mention that sometimes he may take the form of an "intermediary merchant" [10].

In the same vein are the project managers that are detailed in [5] and are responsible for shaping knowledge. These agents are the boundary worker between policymakers and stakeholders. The policy of the nature set up by these players is emblematic of a negotiated management of the environment. These new players have to ensure there is ownership of the process. They occupy a rather new and original position in the process of local democracy that is built into the interaction between politics and local actors. These are new agents that have emerged from the process territorialization public policy. In [11] “officer’s developments”, will also play this role of "buffer" giving voice to local actors rather than elected. The first development contract agents are recruited as early as 1970. It will build new exchanges between the public and private. Information meetings in the villages can be identified on the "actors" and local and encourage them to come later participate in thematic meetings (agriculture, trade, tourism).

This intermediate actor can also be represented by a "Local Authorities"[12]. Those actors will transfer knowledge and will include working closely with small businesses in active networks. They can act as "knowledge banks" or "knowledge broker". In some cases they will help companies to contact consultants and technical experts who have knowledge to develop environmental management in business. They provide funding, asset and enable to the different actors to get in touch and exchange knowledge, ideas and experiences.

Susskind & Karl introduced a category of "Science Impact Coordinators" (Susskind & Karl 2008). They even settled a specific course to train them at MIT (http://web.mit.edu/dusp/epp/music/). These are brokers who manage the interaction between scientists, politicians and common policies. Today there are few professionals able to talk about science to the politics and others people. They intend to train a new generation of professionals for the environment with the necessary skills to manage the interactions between scientific experts and people with other types of expertise. A major concern is in handling of scientific data by policy-makers. "Science Impact Coordinators" are supposed [13] to cope with and bridge the gap between these communities, that have their own languages. To conclude this part there is below a board synthesizing all the activities of these various characters.

Type of boundary worker	Action	References
Science impact coordinators (SIC)	Managing the interaction of science, policy and politics.	[13]
Local Authorities (LA)	Transfer knowledge. Work closely with companies active in small networks.	[12]
Broker	- He has a critical regard into the adaptive management of natural resources. - Buffer between competing interests. - Need to involve users in the construction of collective choices. - Intermediate marketer	[9] [7] [10]
Officer's developments	Give free speech to local actors	[11]
River basin facilitator	A job that requires relational skills, focusing on animation, negotiating and building partnerships.	[4]

Table 1: Action and type of boundary worker

Nowadays, it is essential to find a better way to balance the decision-making and political science in the environment [13].The role of the animator of the watershed will also be to ensure the relationship between the world of research and that of politics. The consolidation of the political world and the world's scientific entails the risk of miscommunication. But these interactions are necessary for good water governance, despite the emergence of tension often palpable during interactions between these two worlds[14].

As we have seen we have a wide range of actors who play the same role within the same public policy device.

3. An analysis model: IAD

Previous sections featured the large number of stakeholders in a same space where occur the actions of consultation or interactions. Each stakeholder has his own assessment of the surrounding environment and is subject to rules that manage these uses in the watershed. It seems to me appropriate to rely on the model IAD (Institutional Analysis and Development) by Ostrom to implement our conceptual model. Ostrom's IAD model [15] has designed to analyze this type of situation with common pool resources manage issues. Boundary work comes as an additional element in such common pool resources situation. In this section we describe how the role might fit in according to its diversity of possible endorsement.

IAD has been designed as a framework for analyzing the common-pool resources management situations [16]. It analyzes collective actions within a given institutional environment. It features relationships between rules, people and resource. The analysis begins with an action arena that includes actors, with their own opinions, preferences, and that will interact within the same social space called action situation. Then, Ostrom distinguishes the external factors that will affect the action scene. There are the characteristics of the physical world, community and rules. These rules are a key driver of actions because they can be modified in the short term and some may be created by the people themselves.

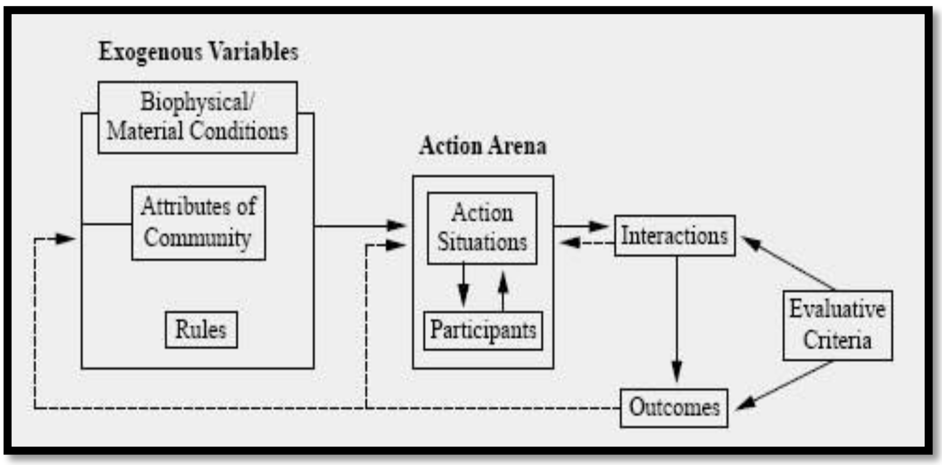

Figure 1: A framework for institutional analysis. Source: Adapted from E. Ostrom, Gardner, and Walker 1994, 37.

How boundary work fits in this framework? All participants have their own jurisdiction within the socio-hydrosystem. All their actions potentially transform the state of the socio-hydrosystem. For example, the water user has knowledge about the physical state of the environment. He is able to assess if it is in danger. The policy maker has legal knowledge and will use it to produce rules. All participants have their own realm, but sometimes, the boundary worker achieves to create a common space to facilitate their interactions. The boundary worker involvement fits in various parts of the IAD framework. He may contribute to enhance the data base about the socio-hydrosystem' state. He may also introduce himself to other participants in order to make an initial contact with them and increase his local social capital. Whenever his role includes facilitation of meetings gathering various stakeholders, his social capital may also get reinforced at the same time as relations among participants. He has a major role in the "action arena" as a facilitator.

4. The conceptual model framework

The choice of modeling is increasingly common in the work on the modeling of complex systems. Management of water resources is a privileged area [17]. The objectives of modeling here is the characterization and exploration of the boundary worker.

4.1 Multi-Agent System

ABM is known as a suitable technique to represent dynamics of heterogeneous entities interact based on assumptions about how individuals interact with each other and their environment [18] . This entails in the same simulation tool dynamics of the hydrosystem in connection with various categories of users as well as boundary worker. It is also well known to be suitable to explore scenarios through simulation. For these scenarios could include the skills of the boundary worker as well as the knowledge of the stakeholders, or the rules for interactions in the participatory mechanism. These scenarios have to be compared according to their impact on some sustainability indicators of Socio-hydrosystems. Main concern relative to the design of such ABM is in the reproduction of dynamics of knowledge. There are very few until now and none concerning participatory process [19]. Some exist in the field of innovation since participatory process potentially induces social learning, we expect to learn from ABM of innovation process to represent participatory process.

We will introduce in the next section how we believe this device public policy is following a process of innovation and that will in turn lead to innovation.

4.2 Innovation process

In [20] the innovation process is generally understood as the successful introduction of something new and useful. This process is emerging thanks to the contribution of different external partners such as the research community, world of university, the industry ... The reflections of these actors will be born of ideas that will become inventions and then innovations. And finally for that this innovation will be disseminated and that it becomes a process in itself, it will go through an adjustment phase.

The theory proposed by Lane and Maxfield is an interpretation of innovation [21]. Thanks to the phenomenon of interaction, agents can invent and share new interpretation based on the discovery of different perspectives and existing uses, and use it to artifacts already present.

Lane and Maxfield reported that in a situation where innovations occur, predicting the future is impossible. A more effective strategy would be to identify these relationships and predict them in order to explore new opportunities that they could generate. The innovation process involves relational transformations between agents on the one hand, artifacts, and between these two entities [1] . Innovation can involve the introduction of a new artifact, but also a change in the relationship between agents, or create a new interpretation of an existing artifact.

This is what is required for this type of model takes into account the theory of innovation:

- Significance of artifacts should be generated by the model;
- The role of agents must be generated by the model;
- The agents should interact with the artifacts and other agents;
- An agent must choose an agent with whom he wants to establish a relationship;
- An agent must have different degree of interaction with another agent.

In this type of model, the role of the agents is in part defined by the social net-work in which they operate. Here, it is envisaged a network of agents producing artifacts that will in turn be used by other agents to build their own artifacts. Each agent has a lot of "recipe" that allows the construction of new artifacts. Each agent has also a "store" where all its productions are stored, and where the users can use them. The Agents can transform artifacts in space "agent-artifact" which are defined by their production revenue and their relationships with other agents.

In addition, agents are able to expand their knowledge, and give birth to new agents. The agents will then transform its artifacts through their own production recipes.

In this conceptual model, we can take for postulate that some agents such as policymaker, boundary workers or stakeholders can product innovation to make favorable changes (or unfavorable) to uses of the hydrosystem. The boundary worker has different "recipes" that allow to play his buffer-role between government policies

and users. He has in his "shop" different tools such as the creation of meeting, the information relay between the actors.
Here we can refer to "social learning" that will be born thanks to the interactions between all users. These exchanges will generate new knowledge. This mechanism can be considered as an innovation process.

Each agent will be able to reuse in their own way these tools to produce their own artifact. The animator may also use a different side of his job, and therefore another recipe for his "store". It can play a more cognitive role where he would be a kind of information processor where he would receive information from the political Agent and he will translate the result at the user agent.

To conclude with this process we can take an example of innovation which is developed by a policymaker. This one has bet on cooperative planning of watershed to manage water as a common heritage. For this the agent will create another agent represented by the boundary worker. This new artifact, which is boundary worker, will be able at his turn use their own tools, such as negotiation, to complete his "mission". This negotiation, which can be regarded as an artifact of innovation, will enable the emergence of a common management of water as a common pool resource. Negotiation is also a concept that potentially allows decrypting the dynamics of interaction [22].

5. A conceptual model of boundary work

We describe in this section a conceptual agent based model meant to serve first as a basis for field work investigation and then to be revised in a second version to be implemented and used according to a protocol of exploration. With these models we aim at understanding the possible paths taken by a socio-hydrosystem with various of boundary workers.

5.1 Dynamic interaction between participant and the system

At first, we would like to set up and analyze the dynamic interaction between different people and the system.

5.1.1Users and environmental interactions

We want to describe the capacity of perception of people, including showing their ability to perceive their surroundings. For example the water users can perceive their environment with sensors that will provide numerical measures, such as the water level in a river. The water user could have a lot of knowledge: environmental, practical uses, legal, economic, and social ... After making their own assessments of the system, the water user will go to the meetings that will be the interaction space involving all stakeholders concerned by the watershed management. Following these exchanges we'll see at the end of the meeting if the knowledge of users has been modified by interactions with other actors. It will specifically look at the role and influence of the boundary worker in this meeting and try to quantify the share of responsibility in relation to possible changes in knowledge of the actors.

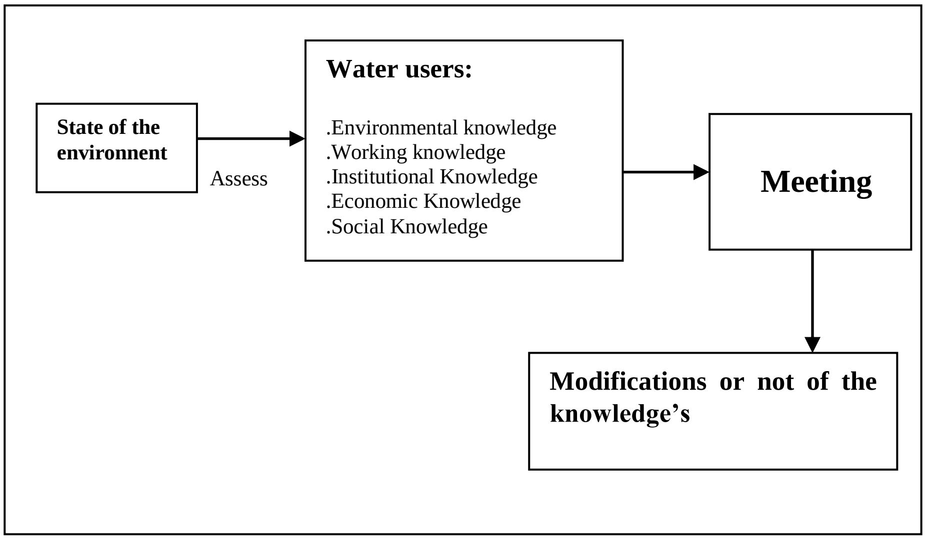

Figure 2: The action capacity of the water users.

The environmental perception can also be evaluated directly by the boundary worker. In this process, the boundary worker has his own assessment of the environment. In case he believes that there is a problem several choices may be considered. Either he decides to make a meeting with all actors. Either he decides to make meetings between users, or only with a user, or to arrange a meeting between water user and policymaker.

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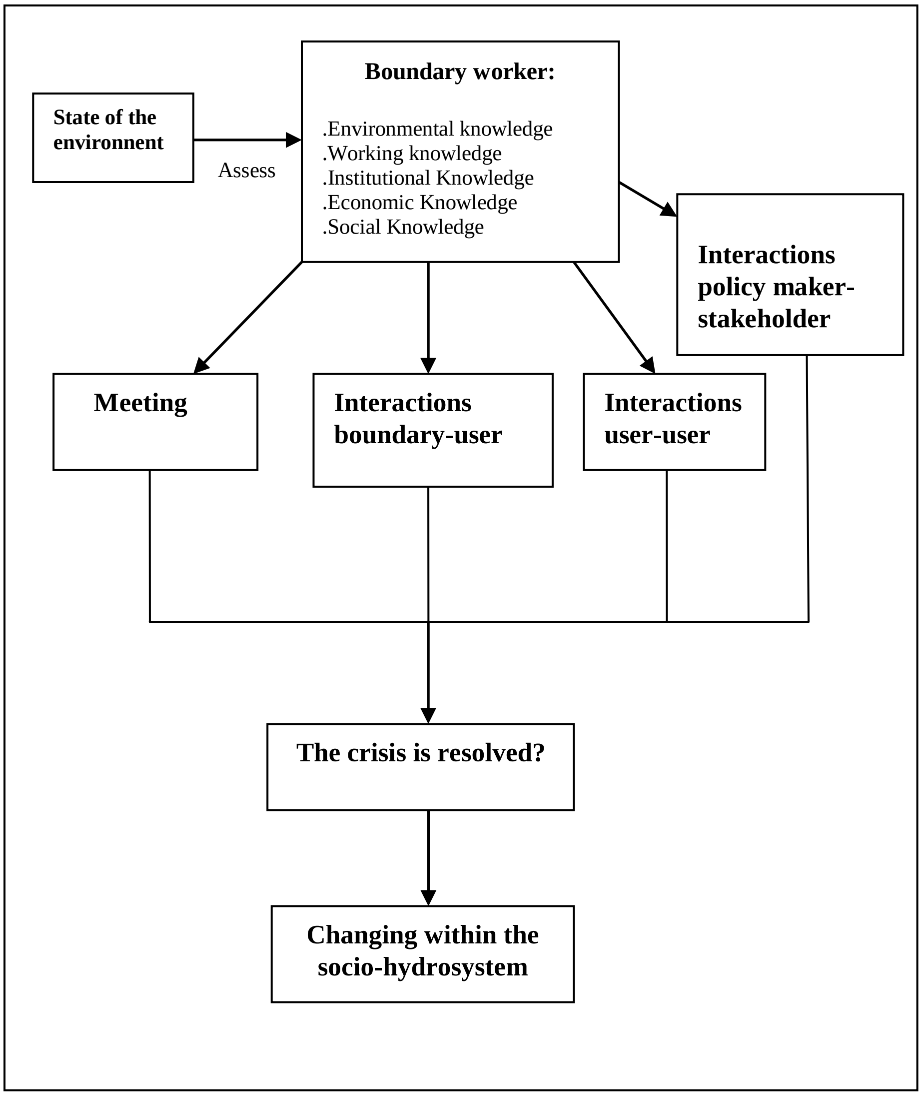

Figure 3: The action capacity of the boundary worker.

5.1.3 Changes induced by interactions

Nowadays various settings of water resource governance increasingly involve interfaces between water users and resource. All these people who are involved come with new knowledge. Among them, boundary workers thanks to their multiple roles can lead to an evolution of the dynamics of a socio-hydrosystem. They transform the social network participants, thanks to their opening discussions or proposing

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meetings and debates. Boundary workers interact with the set of participants being part of the socio-hydrosystem, and generate reactions from them. A specific characteristic of boundary worker involvement is then the degree of interaction they are able to propose.
In a meeting, people meet to discuss a specific topic. The role of the boundary worker is to facilitate the discussions between users and policymaker and to translate the representations and expectations of everyone. Meetings transform a priori participants' knowledge. Our conceptual model is tailored to grasp this evolution of knowledge, with a focus on the contribution of the boundary worker in this process.

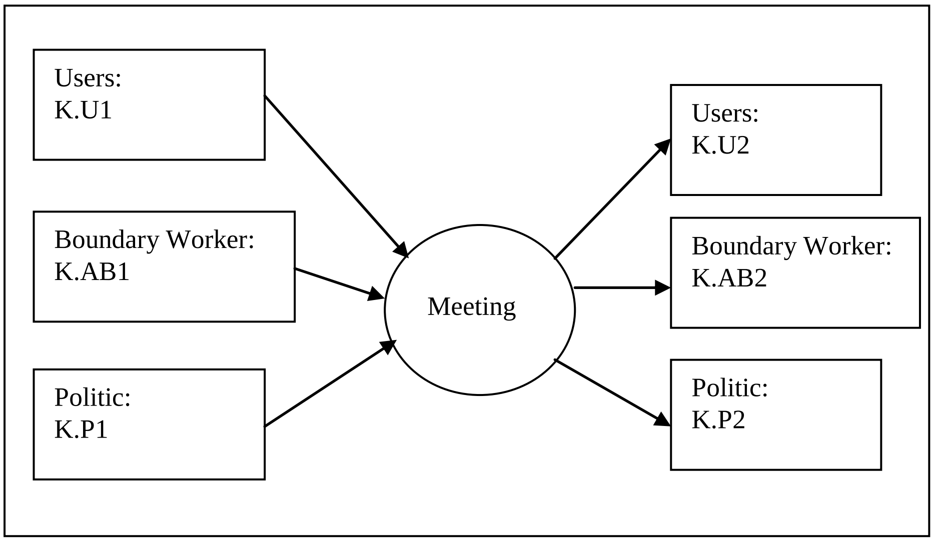

Figure 4: The evolution of knowledge at a time t (K1) then at the time t+1 (K2) after the meeting.

5.2 Towards an integrated conceptual model

In AD framework, figures 3 and 4 details the exogenous variable and the action arena. In our concptual model, the exogenous variables are the assesment of the environment by the water user. An other variable are the rules promote by the policy maker. The action arena is constitute of several action situations as the meeting, the interaction boundary-user, the interaction user-user and the interaction policy maker stakeholder. Figure 5 zoom in a specific action situation : the meeting. It makes clear the central role of knowledge is the process with feedback outcome of the action situation or these characteristics of participants. Meetings are a key component of action of the boundary worker. Narrative generated throught simulation of such ABM

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would be a cascade of that kind of action situation and other action situation mentioned in figure 3. Participant knowledge is the main indicator for changes in the SHS.

Conclusion

In this article we have proposed a conceptual model to represent the consequences of the involvement of a boundary worker within a socio-hydrosystem. This conceptual model uses the Ostrom's IAD framework and the theory of innovation in order to show that this participatory device is close to an innovation process.

This model aims at describing interaction processes in order to simulate consequences on the trajectory of the socio-hydrosystem.

As shown by a review of literature many possibilities of roles or types of involvement exist for this category of boundary workers. Further stages of this on-going research will complete knowledge on boundary work on the ground in order to further specify the model and then simulate scenarios of associations between a type of boundary work and various situations of the socio-hydrosystem.

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