An Argument-Based Approach to Deal with Wastewater Discharges

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Abstract: In this paper we propose the use of an argument-based model – *ProCLAIM* – that has the potential to minimize ecological impact of industrial wastewater discharges into water bodies. On the one hand, the diversity and unpredictability of many of industrial wastewater discharges and on the other, the complexity of ecological systems that finally receive the discharge (i.e. fluvial ecosystems) illustrates the difficulty to attain a good ecological status of water bodies as required by one of the main priorities of the European Water Framework Directive (2000/60/EC). *ProCLAIM* enables *agents* involved in the wastewater management process deliberate over whether proposed actions (*e.g.* industrial spills) are environmentally safe, thus, making each undertaken action a more informed decision.

Keywords: agents, argumentation, integrated management, wastewater.

Introduction

Daily basis experiences show frequent uncontrolled discharges into the sewer system that sometimes are very difficult to treat and may even cause Wastewater Treatment Plant's (WWTP) operational problems. Consequently, wastewater without a proper treatment is discharged to water bodies, causing the deterioration of aquatic ecosystems.

Furthermore, these wastewater discharges do not account for the fact that *1)* environmental technicians (as well as ecologists and other stakeholders involved) may disagree as to whether a toxic or a wastewater substance is or is not safe for the final receiving media (*e.g.* the river); *2)* different policies in different regions exist (even local regions such as municipalities from the same river basin); *3)* safety of substances in wastewater is not an intrinsic property of that substance, but rather an integral concept that also involves the industry, the receiving media (*e.g.* the river) and all the course of action to be undertaken in the discharge and wastewater treatment process.

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The emergency of these situations due to an increase and diversity of industrial activity makes necessary to provide a tool for a better integrated management and control of the industrial spills in a fluvial basin, taking into account all the agents involved (*e.g.* industries, sanitation infrastructures and water bodies). Among the Artificial Intelligence (AI) technologies available, *software agents* are considered best suited for applications that are *modular*, *decentralized*, *changeable*, *ill-structured* and *complex* [1]. The intended holistic approach of wastewater management bears similar characteristics: multiple users and service levels are involved; it is necessary to integrate data and information from heterogeneous sources as well as to deal with data with spatial and temporal reference and to adapt to changing conditions. Moreover, according to [2], environmental applications inherit both the uncertainty and the complexity involved in the natural environment. On the other hand, argumentation (broadly, the process of creating arguments for and against competing claims) have in recent years emerged as one of the most promising paradigms for formalizing reasoning in the above mentioned contexts [3, 4, 5].

In this paper we propose the use of the agent's argument-based model *ProCLAIM* (see [6]) to support multi-agent deliberation over action proposal. And thus, provide a mechanism to make more informed and safe decisions in the wastewater domain. Accordingly, in section 1 we introduce the *ProCLAIM* model. In section 2 we describe the model's protocol-based exchange of arguments that defines all the legal moves at each stage of the dialog, and more importantly, facilitates the exploration of all possible lines of reasoning that should be pursued *w.r.t.* a given issue. In section 3 we illustrate the model's application in dealing with the industrial wastewater discharge, as part of the whole management of wastewater in a river basin. Finally, in section 4 we present our conclusions and plan for future work.

1. The *ProCLAIM* Model

Broadly construed, the *ProCLAIM* model consists of a Mediator Agent *(MA)* directing *proponent agents* in an argument based collaborative decision making dialog, in which the final decision (a proposed action) should comply with certain domain dependent guidelines. However, the arguments submitted by the proponent agents may persuade the *MA* to accept decisions that deviate from the guidelines.

Three tasks are defined for the *MA*: *1)* The *MA* guides proponent agents as to what their legal dialectical moves are at each stage in a dialogue; *2)* the *MA* also decides whether submitted arguments are valid (in the sense that instantiations of schemes are relevant *w.r.t.* the domain of discourse); *3)* the *MA* evaluates the submitted valid arguments in order to provide an assessment of the appropriateness of the proposed action.

In order to undertake these tasks, *MA* makes use of four knowledge resources, as shown diagrammatically in Figure 1 and described below:

Argument Scheme Repository (ASR): In order to direct the proponent agents in the submission and exchange of arguments, the *MA* makes use of a repository of Argument Schemes (AS) and their associated Critical Questions (CQs). The AS and CQs are instantiated by agents in order to construct arguments, and effectively encode the full *space of argumentation*, *i.e.*, all possible lines of reasoning that should be pursued *w.r.t* a given issue.

Guideline Knowledge (GK): This component enables the *MA* to check whether the arguments comply with the established knowledge, by checking what the valid instantiations of the schemes in ASR are (the ASR can be regarded as an abstraction of the GK). This is of particular importance in safety critical domains where one is under extra obligation to ensure that spurious instantiations of argument schemes should not bear on the outcome of any deliberation.

Case-Based Reasoning Engine (CBRe): This component enables the *MA* to assign strengths to the submitted arguments on the basis of their associated evidence gathered from past deliberations, as well as provide additional arguments deemed relevant in previous similar situations (see [7]).

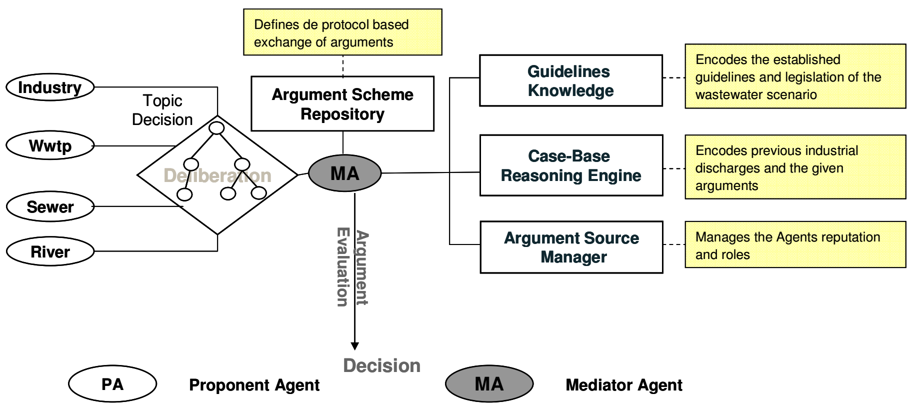

Figure 1. *ProCLAIM*'s Architecture. Shaded boxes identify the model's constituent parts specialised for the wastewater scenario introduced in section 3.

Argument Source Manager (ASM): Depending on the source from whom, or where, the arguments are submitted, the strengths of these arguments may be readjusted by the *MA*. Thus, this component manages the knowledge related to, for example, the agents' roles and/or reputations.

The deliberation begins with one of the agents submitting an argument proposing an action. The *MA* will then guide the proponent agents in the submission of further arguments that will attack or defend the justification given for the proposed action.

Each submitted argument instantiates a scheme of the ASR. The *MA* references the ASR in order to direct the proponent agents as to what their legal argument moves are at each stage of the deliberation. The validity and strength of each submitted argument is determined by the *MA* in referencing the other three knowledge resources, *viz.* GK, CBRe and ASM. Given all the accepted arguments, their strength and their interactions (based on the attack relation, see Figure 4) the *MA* then applies Dung's seminal *calculus of opposition* [8] to determine the justified or winning arguments. Hence, if the initial argument is a winning argument, the proposed action is deemed appropriate, otherwise, it is rejected.

2. Argument Schemes as a Protocol for Argumentation

The ASR is based on one AS for action proposal from which the protocol for the exchange of arguments is defined:

Definition 1: An argument is represented as a *5*-tuple[2]:

<*Context, Fact, Prop_Action, Effect, Neg_Goal*>

Where **Context** is a set of facts that are not under dispute, that is, assumed to be true. **Fact** is a set of facts such that given the context *Context*, then the proposed action (or set of actions) **Prop_Action** result in a set of states **Effect** that realises some undesirable goal **Neg_Goal**. *Fact* and *Effect* may be empty sets and *Neg_Goal* may be equal to nil, representing that no undesirable goal is realised. So, arguments in favour of a proposed action are of the form: <*Context, Fact, Prop_Action, Effect,* nil> whereas arguments against a proposed action, for instance against an industrial spill, highlight some negative goal that will be realised *e.g.*:

<*Context, Fact, Prop_Action, Effect,* fauna_death>

Hence, the arguments used in the dialogue take into account: *1)* the current state of affairs referenced by the facts deemed relevant by the proponent agents; *2)* the proposed actions; *3)* the new state achieved if a proposed action is undertaken and; *4)* the undesirable goals which the new state realises.

In *ProCLAIM,* a proposed action (*e.g.* spill an industrial waste) is deemed to be appropriate if there are no expected undesirable side effects. Thus, a proposed action is by default assumed appropriate. Nonetheless, there must be some minimum set of conditions for proposing such an action (*e.g.* an industry with wastewater, and a receiving media). Thus, the dialogue starts by submitting an argument that claims the appropriateness of an action and the subsequent dialogue moves will attack or defend the presumptions present in that argument by claiming there is (*resp.* there is not) an undesirable side effect.

The six schemes we now introduce are partial instantiation of the more general scheme introduced in definition 1. These more specific schemes are intended to identify the legal instantiation of the more general scheme at each stage of the dialogue.

Let us consider *R* and *S* to be finite sets of facts in the current state and the resultant state respectively. Let *A* be a finite set of actions and G^- a finite set of undesirable, or negative, goals ($\text{nil} \in G^-$).

Thus, a dialogue starts with the submission of the argument:

AS1: < *m_c, {}, p_a, {},* nil>

Where $m\_c \subseteq R$ is a minimum set of facts that an agent requires for proposing a nonempty set of actions $p\_a \subseteq A$.

An argument proposing an action (via AS1) can be attacked via the argument scheme AS2 (see Figure 2). An argument instantiating AS2 introduces a new set of facts, fact, deemed to be a contraindication (*e.g.* a certain toxic in the spill), and thus, attacks the proposed action appropriateness, proposed_actions. To defend the initial proposed action, an argument instantiating AS2 can in turn be attacked by either AS3, AS4 or AS5. These schemes respectively stand for: *AS3)* Current circumstances are such that the introduced set of facts fact, via scheme AS2, will not result in the stated set of effects effect that realise the undesirable goal neg_goal. *AS4)* Current circumstances are such that the stated set of effects effect does not realise the stated undesirable goal neg_goal. And, *AS5)* a complementary set of actions can be undertaken in order to prevent the stated undesirable set of effects effect. Figure 2 illustrates the schemes' structure and interaction. Figure 3 illustrates examples of their use in the wastewater scenario.

[2] This basic argument scheme is in turn based on Atkinson's *et al.* schemes for action proposal [9].

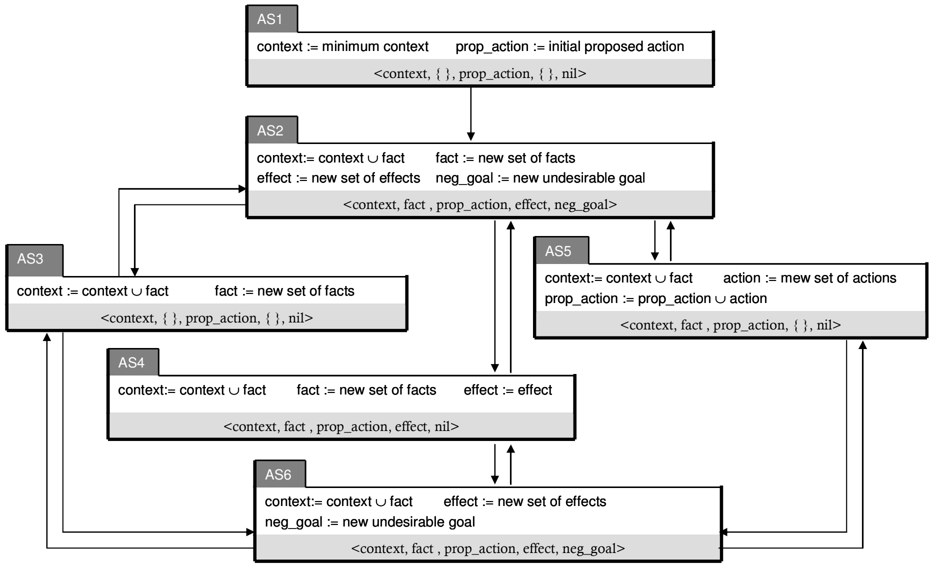

Figure 2. Schematic representation of the dialogue game (adapted from [6])

Arguments instantiating schemes AS3, AS4, AS5, are of the form <*Context, Fact, Prop_Action, Effect,* nil>, with *fact* and *effect* possibly empty. These arguments introduce either a new fact or new complementary actions that may in turn warrant, respectively cause, some undesirable secondary effect. Hence, arguments instantiating these schemes may be attacked instantiating AS6.

An argument instantiating AS6 can in turn be attacked by arguments instantiating AS3, AS4 or AS5. Also, an argument instantiating AS3, AS4 or AS5, alter either the *context* or *proposed action* set. Hence, as depicted in Figure 2 this argument can be attacked by an argument instantiating AS2.

3. Deliberating in the Wastewater Scenario

Decision making in the wastewater domain requires participation of all the actors that affect or may be affected by a wastewater discharge. We now present a simplified example that illustrates the use of the *ProCLAIM* model in supporting deliberation among multiple agents on whether an industrial wastewater discharge is environmentally safe. This deliberation accounts for the fact that agents have different interests and knowledge. Although not covered here, *ProCLAIM* also accounts for the fact that decisions should comply with the domain's guidelines and that previous similar experiences help identify the appropriateness of a decision (see [7]).

Let us suppose an industry (*ind*) represented by the Industry Agent (*Ind_Ag*) arrives to an urgency situation in which it has to deal with a substantial amount of wastewater with high concentration of nitrogen (high_N_load). Now, as stated above, it is not only to *Ind_Ag* to decide what to do with this wastewater. We illustrate this deliberation with the following agents:

- Sewer Agent (*S_Ag*) representing the sewer system (SS) that transports wastewater (ww) from industry to the nearest WWTP.

- WWTP1 Agent (*WWTP1_Ag*) representing the nearest WWTP to industry. This facility cannot nitrify/denitrify properly. Its goal is to spill treated ww below legal limits.

- River Agent (*R_Ag*) representing the final receiving media of treated ww and the river's interest which is to reduce the damage of the arriving discharges.

	ID	Type	Argument
	A1	AS1	<{ww, sewer,wwtp1}, { },{α_0}, { }, nil>
	B1	AS2	<{ww, sewer, wwtp1}, {high_N_load}, {α_0}, {N_shock}, bad_qual_eff>
Example 1	C1	AS3	<{ww, sewer, wwtp1, high_N_load}, {rain}, {α_0}, { }, nil>
Example 1	D1	AS6	<{ww, sewer, wwtp1, high_N_load, rain}, { }, {α_0}, {hydraulic_shock}, bad_qual_eff>
Example 2	C2	AS5	<{ww, sewer, wwtp1}∪{high_N_load}, { }, {α_0, primary_treatment }, { }, nil>
Example 2	D2	AS6	<{ww, sewer, wwtp1, high_N_load}, { }, {α_0, primary_treatment }, {toxicity}, fish_poison>
Example 2	E1	AS3	<{ww, sewer, wwtp1,high_N_load}, {river (pH, T, F)}, {α_0, primary_treatment }, {}, nil>

Figure 3. Two example dialogues resulting from the submission of an argument A1 proposing an emergent industrial discharge to sewer system (sewer).

Commonly, an industry discharges its ww to the sewer system that transports it to the WWTP, which after the proper treatment, discharges the ww to the final receiving media (*e.g.* the river). Let us call this course of action α_0. *Ind_Ag* may thus, propose undertaking to discharge its ww with high_N_load following α_0. This is done submitting argument A1 = <{ind, ww, sewer, wwtp1}, {}, {α_0}, {}, nil> instantiating scheme AS1. However, the high concentration of nitrogen can cause a nitrogen shock to the WWTP1. Consequently, it is of *WWTP1_Ag*'s interest to attack argument *A1*.

Let the sets *R*, *A*, *S*, G^- as introduced in section 2 be R={ind, ww, ss, wwtp1, rain, high_N_load}, A={α_0, primary_treatment}, S={N_shock, hydraulic_shock, toxicity}, and G^- = {bad_qual_eff, fish_poison }. Where N_shock stands for a nitrogen shock at WWTP that receives ww, and bad_qual_eff stands for the fact that a bad quality effluent will result if α_0 is done. Figure 3 illustrates the instantiations of the argument schemes, and Figure 4 their interaction. Succinctly, argument *B1* attacks *A1* identifying a contraindication (high_N_load) in ww causing N-shock at wwtp1 that realises the negative goal of having a bad_qual_eff. However, argument *C1* attacks *B1* claiming that this consequence will not be achieved thanks to the dilution effect caused by rain. But depending on rain intensity another argument, *D1*, can be submitted attacking *C1* arguing that the rain will cause a hydraulic-shock that can produce lost of microorganisms (washout of microorganisms) and so an inappropriate biological treatment at wwtp1. In the second example argument *C2* identifies a new set of actions such as perform only a primary-treatment in order to prevent further problems to WWTP and then discharge the effluent to the river. Of course this new set of actions can cause toxicity problems to the receiving water body, argued by *D2*, but if the river situation (pH, temperature and flow) are appropriate to attenuate the effect caused by the discharge, the propose action will be deemed adequate (argument *E1* depicts this possibility).

In general a submitted argument attacks the argument it replies to. However, the attack can be asymmetrically (→) or symmetrically (↔) depending on the argument schemes they instantiate. In the symmetric cases there is a disagreement in which the new introduced factor (new *set of facts* or new *prop_action*) is or is not a contraindication for the proposed action.

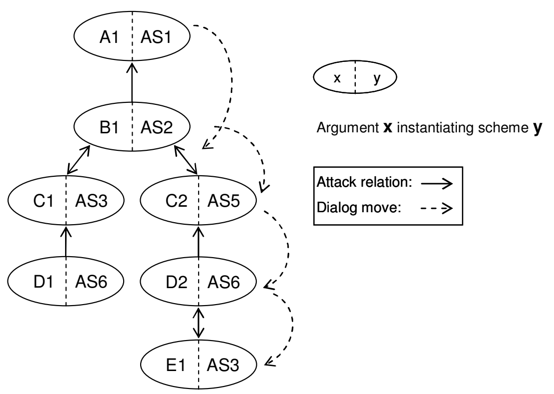

Figure 4. Dialogue graph showing the interaction between the arguments used in the two examples given in Figure 3.

In order to decide whether the agents' proposed action is appropriate, the *MA* has to determine if argument *A1* is a winning argument. In example 1 if *B1*, *C1* and *D1* are accepted as valid arguments, the proposed discharge will be rejected, as *A1* would be defeated by *B1*, and *B1* is defended from *C1* by *D1*. However in example 2 if all arguments are accepted as valid, the discharge will be deemed environmentally safe if and only if, both *E1* is preferred to *D2* (*i.e.* in effect, the river situation attenuates the effect caused by the discharge) and *C1* is preferred to *B1* (a primary-treatment prevents WWTP1's nitrogen shock). *MA*'s evaluation process is described in more detail in [7].

4. Conclusions and Future Work

In this paper we propose the use of a novel argument-based model, *ProCLAIM*, to support decision making in a wastewater scenario. *ProCLAIM* provides an environment for agents to deliberate over the appropriateness of proposed actions, accounting for the domain's guidelines, the agents' role and or reputation and the resolution of previous deliberations.

This paper extends our work presented in [10] where we focused on motivating the need for an integrated management of wastewater in a river basin. Focus here is in the deliberation process that allows agents to argue on whether a proposed action *is or is not appropriate*. That is, whether it will affect negatively any of the actors involved in managing and/or receiving wastewater. This deliberation accounts for the facts that *1)* agents may disagree on the appropriateness of an action or plan of actions; *2)* decisions should comply with the domain guidelines *3)* but there may be exceptional circumstances where deviating from such guidelines may be justified.

One problem in the wastewater scenario is that in many emergency situations (*e.g.* shutdown of and industry implying a punctual overload of some pollutants due to the cleaning process; or a problem during production that result in an emergent undesirable discharge), no course of action exist that can avoid undesirable effects (including doing nothing at all) nonetheless, an action must be taken. In this special circumstances, what accounts as an appropriate course of action is that which has the least undesirable effects (rather than none). Thus, changes need to be made in the *ProCLAIM* model to accommodate this wastewater scenario requirement.

ProCLAIM defines the basic protocol for the exchange of arguments, where a new introduced argument must attack an earlier one. However, this scenario requires that agents exchange messages that may not be *attacking arguments*. For example, an industry agent (*Ind_ag*) may ask the *wwtp_agent* for the most appropriate moment for a punctual discharge, before actually proposing the spill. Namely initiating an information seeking dialog (see [11]). Thus, another task for the future is to define the dialog protocol for the participant agents.

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