Information sharing for natural resources management

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Abstract. Renewable natural resources shared by competitive actors who have a common interest in the preservation of the resource undergo strong pressure that can undermine the resilience of the resource and the social-ecological system as a whole. These classical social dilemmas can take the form of pollution, free-riding etc. In this preliminary work we study a little considered approach so far in this context: information, and more specifically argument, sharing among actors. We investigate this possible approach with multi-agent simulation. First, we model the system as it is and second, we introduce an information sharing system. In parallel, we study its implementation in an actual socio-ecological system: the Thau basin in the South of France. Information being a somewhat abstract concept, we investigate the use of argumentation theory in multi-agent settings to help actors express a collective viewpoint, fostering dialogue and mutual understanding that would trickle into their daily management, participating in the resilience of the system.

1 A social dilemma in a social-ecological system

The Thau basin in the South of France is the center of two economic activities: oyster and wine farming. Wine growers and oyster farmers have different (and sometimes conflicting) interests. These two categories of actors are geographically organized in a downstream / upstream manner, the actions of the wine producers having an effect on the oysters production.

The practices of the wine growers, notably the use of fertilizers, are noxious for the oyster production. Indeed, depending on the climate and complex hydrological processes, the fertilizers can flow into the water which is the working area of the downstream actors. The oyster farmers have to bear the cost of what can be considered as an externality for the upstream actors.

Moreover there is a feedback effect: pollution damages the global image of the region. Consumers are thus less prone to buy products from the area. A possible consequence is that the prices of the products (both oyster and wine) drop, affecting all producers. This situation produces a social dilemma where some actors that try to maximize their short term interests produce effects at the macro scale that are contrary to their own interest. Such feedback effect may not be known by the wine growers. Some classical problems of common good management are here present: free-riding (actors that use too much fertilizers without bearing the cost of the externalities) and pollution leading to a tragedy of the commons [6]. Free-riding occurs when it is not possible to exclude an agent from taking advantage of the improvements in a system even though she has not beared the costs of such improvements, or when an agent can act in a way that is profitable for her but damageable for the rest of the group.

Local regulatory institutes control the pollution in the area, check that farmers respect the levels of fertilizers allowed, and can sanction agents that do not respect the norms.

This situation fits in the framework developed by Nobel Prize winner Elinor Ostrom, the social-ecological system (SES) framework [10]. She showed that the analysis developed in [6] refers to a specific situation where agents are completely independent from each other, and their interaction limited to the use of the same resource. For tragedies to be avoided it is necessary (but not sufficient) to fulfill some conditions [9], which consist partly in strengthening the links between actors. It has been argued that information sharing could represent a solution to the problem.

2 Information sharing

The implementation of a participative information sharing system may strengthen the links between agents that depend on the same resource, rise their awareness about the state of the resource which, in turn, is supposed to increase their sense of responsibility. However, one of the main risen questions is the possibility that the information sharing system itself may be subject to a second order dilemma: free riding problems again, as often highlighted in the knowledge management literature. Indeed, actors could be tempted to take advantage of information given by others (which is time-consuming and costly) without bothering to participate. Even worse, they may participate, but provide false or inaccurate information. However, proposing information sharing tools to stakeholders is considered as an avenue to ease social dilemmas, with stakeholders providing and using this information in their own actions regarding the common good: knowledge sharing is supposed to make explicit tacit knowledge [8], repeated interactions build trust and increase cooperation [10].

3 Related works

Our project is at the crossroad of several different fields: knowledge management, social network analysis, argumentation theory, multi-agent simulation.

3.1 Knowledge management

Even though they are quite different, SES and corporations share some issues: they are the result of the interaction of several actors with the same global interests (the long run productivity and quality of the resource in an SES, the success of the firm), and personal interests that may conflict with the global ones (short term productivity, willingness to climb the hierarchical ladder or minimize their effort, free-riding effect).

The solution of information sharing has been studied and experimented in private firms. These knowledge management experiences (e.g. [1]), whether they succeeded or failed, can serve as a basis of reflexion to avoid pitfalls while designing an information sharing system in an SES.

3.2 Social network analysis

Social network analysis is the study of the structure of relationships between social entities. Networks are graphs, directed or not, in which nodes are agents, organizations or other social entities. It is possible to study local properties of nodes like centrality, global properties like diffusion on networks, or to define games and study strategic behavior (see [7] for a comprehensive overview). It is natural in our case to introduce networks since we are studying practices evolution and information spreading which behave differently according to the network topology. Furthermore, the actors are linked through different networks (acquaintance, reputation, work, influence) and they act strategically.

3.3 Argumentation theory

For the effective implementation of the information system, we would like to investigate a new approach, to our knowledge, in the context of information sharing for common resource management: the effect of the sharing of arguments, based on argumentation theory. Argumentation theory, first developed by Dung [3], studies graphs $G = < A, \rightarrow >$ where nodes are arguments (the set A) linked by an attack relation ($\rightarrow$). By setting different constraints and rules on the acceptability of arguments, the theory investigates which arguments a rational agent could reasonably hold in front of conflicting arguments. The minimal requirement, for example, is that an agent cannot accept two arguments that are attacking one another. This is called *conflict-free*: $x, y \in \mathcal{E} \implies \neg(x \rightarrow y)$, where $\mathcal{E}$ denotes an extension, i.e., a set of accepted arguments. According to the semantics employed, none, one or several extensions may exist.

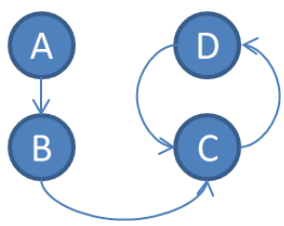

Fig. 1. Example 1: An argumentation framework

Example 1 *An agent has the argumentation framework illustrated in Figure 1. Argument A attacks argument B. The agent cannot accept, i.e. put in her extension $\mathcal{E}$, both arguments A and B.* $\{A,C\}$, $\{A,D\}$ *and* $\{B,D\}$ *are examples of conflict-free extensions.*

Given the specific problem we want to address, we are interested in a multi-agent perspective. Several attempts have already been made [2] but in an abstract way. In [5], the authors study the spreading of a common view between agents linked by a small world kind of network. Agents live in caves (creating cliques) which are linked through weak ties. They all possess an argumentation framework and an extension. The procedure consists in simulating a dialogue between two agents. The agents can agree, accept new arguments and thus revise their extension or disagree. In this situation agents interact but have to accept or reject arguments. This procedure allows the exchange of arguments between two agents and follows the evolution of extensions.

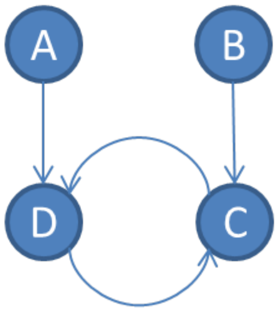

Fig. 2. Example 2: A possible argumentation framework about France

Example 2 *Let A = France led the war in Libya, B = France refused to go to Iraq, C = France is a bellicose country, D = France is a peaceful country. The argumentation framework is described in Figure 2. A and B are true because they are facts. It is then not possible to decide whether C or D is true. These arguments would be excluded from any extension.*

We would like agents to be able to have a degree of confidence in different arguments, even when the arguments are contradictory. For instance, in the case of Example 2, we can consider that France is both a bellicose and peaceful country up to a certain level. This result may show that the argument are not precise enough.

We also would like several agents to be able to share arguments at the same time. Agents need to draw conclusions from their beliefs and act accordingly, the study of exchange of arguments for the sake of exchanging arguments is not the center of this paper. It is a tool. The degree of confidence in arguments is the origin of decisions taken by agents.

We would like to go further and study the change in practices in a situation where there exists an information sharing system. We think that a clear and common representation of a subject by actors having different backgrounds and perspectives is a basis for fruitful and argued debates that can lead to a better management of the common resource.

In that perspective, we need to define another procedure for the agents to debate. The approach defined by Gabbay and Rodrigues [4] is a good starting point, as it defines a way to aggregate several argumentation frameworks. The procedure allows any agent to express and share her argumentation framework. Then weights of arguments and strength of attacks are computed. A second calculation gives a final weight to every arguments, considering the support for the argument and the strength of the attacks against it. Agents are then able to have an idea of the community's opinion over a subject and are able to make informed judgments over their practices. This aggregation procedure could be used at the local level, with one agent's neighbors or at the global level, aggregating all agents' frameworks.

3.4 Multi-agent simulation

To investigate the possible effects of argumentation sharing and compare different scenarios, in future developments of the project we plan to use a multi-agent (MAS) simulation to measure the propagation of information, learning of agents and the change in practices in a network consisting of actors of a SES with different topologies. MAS is a tool which allows the study of the interaction of agents in a small world. These agents act and communicate according to rules that have been defined. As much as a real case study that has its advantages, MAS is a suitable tool to be able to understand the resilience of a more general system thanks to the possibility of a fine study of different network topologies and behavior rules of the agents. MAS allows as well to study different granularity levels: information is often a sensitive subject and it may happen that agents are not willing to reveal it to everyone but would accept to be part of aggregates.

Argumentation theory is versatile enough to support arguments coming from different disagreeing agents. Moreover, it helps in making clear these contradictions by exposing the reasons why they exist. Our goal is to define a multi-agent argumentation able to allow a broader, accurate and comprehensive view of a specific subject thanks to the integration of the knowledge, data and beliefs of agents having different backgrounds than the view of a sole actor limited by her own rationality.

The simulation we consider investigating is a three-step simulation. The first one models the situation as a tragedy of the commons because of actors considered as *homo economicus*, as if the situation consisted of isolated nodes. Then we introduce a social network with links between actors and pairwise strategies and evaluate the result at the societal level. The information diffuse here solely by word of mouth. Finally, the third step consists in introducing a shared information system, a new node that creates a star-like network around it. We will compare the results with the previous simulations: how do practices change? How do the relations between the agents evolve? What are the consequences over the resource?

4 The model

4.1 Situation

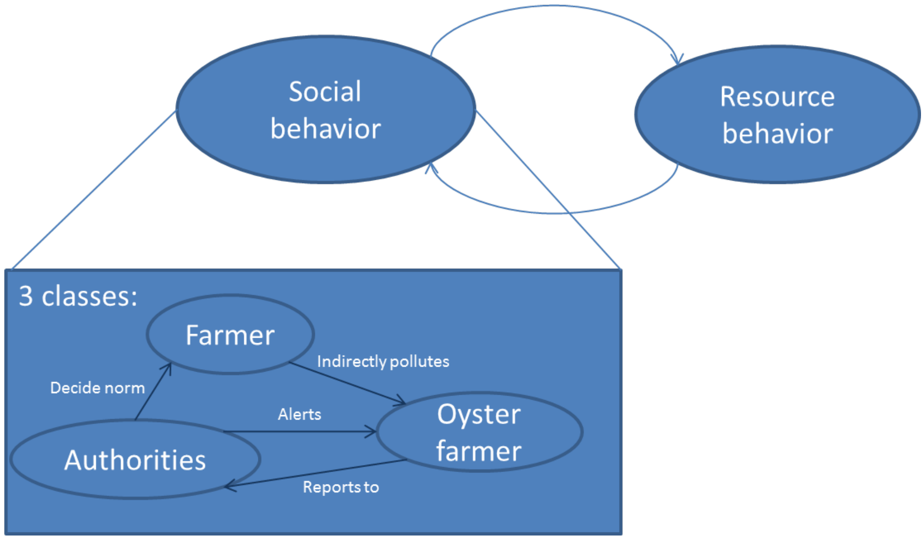

Fig. 3. Interactions

Two major behaviors need be defined (see Figure 3). The behavior of social entities (the agents which are divided into three different classes) and the behavior of the resource itself, which is linked to the agents' actions. The state of the resource has an effect on the agents. If too much pollution harms the oysters, and if such pollution is mainly caused by the use of fertilizers, then farmers need to change their behavior. Awareness of the effects of the actions is a necessary condition for such a change. This awareness can rise thanks to personal knowledge and observations, as well as through exchange with others, whether these are neighbors or the exchange happens via an information sharing system.

As described in Figure 4, we assume that agents all have in their mind an argumentation framework. This framework can evolve according to the events or to exchanges with others. We distinguish tree kinds of agents: farmers, oyster farmers and the legal authority.

– Wine-grower: The wine production is linked to the climate, the quality of the soil, and to the quantity of fertilizer used for the production. However, the quantity is

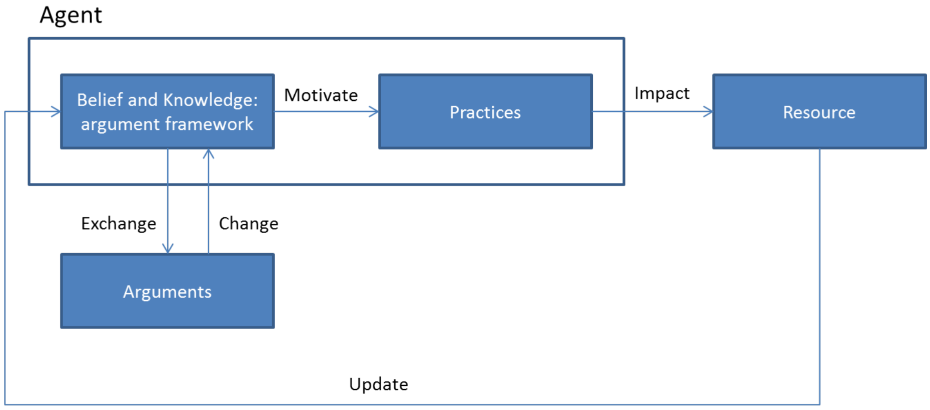

Fig. 4. Process

limited by a norm which applies to everyone. For simplicity, we assume that farmers have to take one decision per year: the quantity of fertilizers that they will put in their fields.
- Oyster farmers: Their economy is threatened by water pollution. If the pollution is too important, then they need to remove the oysters from the lake generating a loss of income. They can measure the quality of the water and are able to hear the authority's alerts. If they discover that the basin's water is polluted, they can decide to privately alert the farmers or to publicly alert the authorities.
- Legal authority: It has two main roles. The first is to decide over a norm, a legal amount of fertilizer that can be used in a field. If too much pollution is spotted, the norm decreases to support the oyster market. The second is to visit the farms in order to control whether a farmer employs too much fertilizers. In this case they are entitled to fine the farmer. However, it has limited means and cannot visit all the farms every year.

The farmer's choice depends on whether he is risk prone or risk averse and the subjective probability that he will be fined.

In the first scenario of the model, we will consider that agents are isolated. They update their beliefs solely through personal experience. In the second scenario, we introduce a social network. Agents are able to communicate their experiences to their acquaintances. Finally, in the third scenario, we add an information sharing system where agents are able to exchange and thus see further in the network thanks to an access to people they do not know.

4.2 Dialogue example

Imagine that three agents, Alice, Bob and Carol, discuss around the topic of the impact of the fertilizers on the oysters. Alice is a farmer, Bob an oyster farmer and Carol a state representative:

– Alice: (arg A) Using a lot of fertilizer helps to have a big yield.
– Bob: (B) Using a lot of fertilizer pollutes the lake and harms the oyster production.
– Carol: (C) Using a lot of fertilizer increases the risk of control.
– Carol: (D) Using more fertilizer than the norm implies a fine.
– Alice: (E) There is no real risk of being controlled because of lack of means.
– Carol: (F) An important polluting event can lead to harden the norms.
– Alice: (G) Lake pollution is not linked to pesticides.

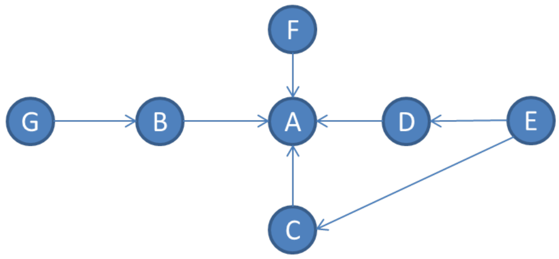

Fig. 5. An argumentation framework about fertilizing

Figure 5 is an argumentation framework built upon these arguments. Two extensions can be accepted: $\mathcal{E}_1 = \{A, C, G\}$ and $\mathcal{E}_2 = \{B, C, D, F\}$. According to their experiences, the degree of belief in each argument can evolve. For instance, argument D can be held true at the beginning, but after several attempts without having been controlled, the agent can decrease her confidence in this argument and then change her decision accordingly (e.g. acting as if there were no norms). The discovery of the true value of the probability of being controlled can occur much faster if an agent is able to exchange with other agents about their previous experiences.

4.3 Formalization

Agent

Definition 1 (Mental states).
Given a group of agents $n : \{1 \leq i \leq n\}$, a tuple of mental states $< \mathcal{B}_i, \mathcal{O}_i, \mathcal{A}_i, \mathcal{D}_i, \mathcal{G}_i >$ corresponds to each agent i, where:

– *$\mathcal{B}_i$ is a set of beliefs which can evolve in time.*
– *$\mathcal{O}_i$ is a set of observations (information) which are known to be true.*
– *$\mathcal{A}_i$ is an argumentation framework.*
– *$\mathcal{D}_i$ is a (possibly inconsistent) set of desires that the agent would like to accomplish.*
– *$\mathcal{G}_i$ is a set of goals, defined as a consistent subset of the set of desires. Goals are consistent with B, O and with an extension of A (if more than one extension exists, one extension is chosen with a mechanism like a tie-breaking rule).*

Definition 2 (Mental states dynamics).
The dynamics of an agent mental states is defined by the tuple $< *, b, d, g >$*, where:*

- $* : 2^B \times O \rightarrow 2^{2^B}$ *is a belief update function that, given an initial set of beliefs and an observation, assigns a new set of beliefs.*
- $b : 2^{2^B} \rightarrow 2^B$ *is a belief selection function that selects a belief set from an agent's alternative belief sets.*
- $d : 2^D \times 2^B \rightarrow 2^D$ *is a desire update function that updates an agent's desires taking into account the changes in her beliefs.*
- $g : A \times 2^D \rightarrow G$ *is a goal generation function that selects as goals a subset of the agent's desires by taking into account the accepted arguments.*

Example 3 *Let us take the case of a farmer. Suppose that her set of beliefs* $\mathcal{B}$ *contains the following items: 'the probability of being controlled is p', 'production prod and pesticides quantity pest are linked through a function f: prod* $= f(pest)$*', 'water is clean'. These beliefs can evolve through time, perhaps more efficiently with communication. Let us assume as well that her set of observations* $\mathcal{O}$ *contains: 'a fine for over-fertilizing is worth x €', 'last year, the oysters suffered 2 majors pollutions'. These observations are fixed and known once and for all. Her argumentation* $\mathcal{A}$ *framework links beliefs and observations. Her set of desires* $\mathcal{D}$ *could include:* d_1 *= 'I want to maximize my income',* d_2 *= 'I want to be respected in the community',* d_3 *= 'I want my production and the soil to be healthy',* d_4 *= 'I want to participate in the sharing of information'. The set of goals is an ordering of* $\mathcal{D}$ *that shows a preference relation between the desires. These desires can be incompatible and the agent wants to fulfill these desires in a lexicographic order.*

As explained above, different kinds of agents will have different focuses. Farmers are less interested in lake pollution than oyster farmers, even though they are indirectly linked to it through a loose feedback embodied by the authorities. However it may be possible that several solutions allow a farmer to fulfill her goal with a different impact on the oyster farmers and that new information given by the latter incline the farmers towards one precise solution

Let us now describe the three classes mentioned in Section 4.1:

Class	Farmer	Oyster farmer	Authorities
Decision	Quantity of fertilizer	Send alert	Send alert Change norm
$\mathcal{B}$	p = probability of control, yield = f(fertilizer)	Possibility to influence norms, useful to share information	Norm is appropriate
$\mathcal{O}$	Norm, previous yields, controls, pollution	Previous alerts, oyster quality	Water pollution
$\mathcal{D}$	Maximize profit Community respect Share information	Maximize profit Community respect Share information	Minimize global pollution Influence region image

Information sharing system (ISS) The situation described in Section 4.2 is ideal but difficult to implement. In our first model, information sharing is the sharing of observations.

An agent has several possibilities to access information: she may have direct access to it; she can learn it from others, or from the information sharing system. When she has an observation (a piece of information) she can either keep it for herself, share it with her neighbors or in the information system.

Observations are first in each agent's mind, linked to the observation of the resource reaction. Second, they will be exchanged with their neighbors in a social network. Third, they will be put into the information sharing system and can thus be used by all. The information system gathers the observation of different willing agents. It is modeled as follows: $ISS =< \mathcal{O}, \mathcal{A}, \mathcal{E} >$ where:

- $\mathcal{O}$ is a set of observations.
- $\mathcal{A}$ is an argumentation framework that has been built by the agents.
- $\mathcal{E}$ is the set of possible extensions.

The observations are the main inputs by the agents. The observations can support different types of arguments and help the learning process: choice of an extension, better definition of the arguments included in the argumentation framework. They are evidence for the arguments and help agents to choose an extension.

Step At each time step, agents observe the environment, through direct observation, through exchanges with neighbors or through the ISS. When these information have been learned, it is possible to make the agent's belief evolve, with mental state dynamics functions. These new goals generate behaviors and actions. Farmer's action consists, for example, in deciding the level of fertilizer used. After this action, authorities control some of the farmers to see if they respect the norm. Fertilizers can be washed by rain events and pollute the lake. In that case, alerts are given and oysters removed from the lake, generating a loss of income for the oyster farmers.

5 Conclusion

A social-ecological system faces pollution due to the practices of some of the actors in the system. In the literature on the free-riding problem, an envisaged solution is to provide a system that allows agents to share information, to create a change in their knowledge and to increase the interactions between them. In this paper we have outlined an initial framework for such information sharing system. A multi-agent simulation, allowing to compare different scenarios around this idea, added to field study (in progress) will help us understand the advantages and the drawbacks of information sharing in this context. During this prototyping phase, we have outlined the ways in which different actors behave in their environment, the way they acquire, share and use information, using argumentation and social network analysis, as well as the interaction with the resource.

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