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Simulation of solidarity in a resource sharing situation

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Abstract. In this paper we present a first attempt to represent social behavior of actors in a resource sharing context in such a way that different forms of solidarity can be detected and measured. We expect that constructing agent-based models of water-related interactions at the interface of urban and rural areas, and running social simulations to study the occurrence and consequences of solidary behavior will produce insights that may eventually contribute to water and land resource management practice. We propose a typology for solidary behavior, present the agent-based architecture that we are using, show some illustrative results, and formulate some questions that will guide our future work.

Keywords: agent-based model; social simulation; solidarity; typology; values.

1 Introduction

Is it conceivable that a farmer voluntarily gives up irrigation to improve the surface water quality in the city downstream? Or agrees to let his fields be inundated to reduce flood damage in urban areas? And will upstream city dwellers of their own accord invest in a separate system of rain water retention to avoid sewer overflows? Intrigued by these and other questions concerning water-dependent individuals who live at the interfaces between urban and rural areas, we have started to explore the issue of solidarity around water sharing and maintenance of water resources during an interdisciplinary workshop in January 2007 in Montpellier¹. The participating researchers brought a variety of case studies in very different geographical and political contexts to the table, and a variety of definitions of solidarity as well.

To sort out this diversity of situations of water-related interactions in which some form of solidarity becomes apparent or is called for, we decided to develop a decontextualised simulation model of solidarity with agents seeking to uphold various

¹ This workshop benefited from the participation of Géraldine Abrami, Olivier Barreteau, Bettina Blümling Pieter Bots, Catherine Carré, Flavie Cernesson, Raphaële Ducrot, Katrin Erdlenbruch, Patrice Garin, Patrick Le Goulven, and Cathy Wery. We wish to thank them for numerous contributions to the discussion, some of which provided inspiration for this paper. However, only the authors are responsible for the views and ideas put forward in this paper.

values, living in either an urban area or a rural area, and sharing a resource. The purpose of these models is to allow analysis how different types of solidarity (can) play a role in the dynamics of a system that comprises an urban area and a rural area linked by a shared resource. This analysis is expected to provide useful feedback to the initial interdisciplinary group, allowing the researchers to focus on common questions regarding solidarity about water, questions that need to be answered not only to improve water resource management, but also to strengthen the social cohesion of territories.

This paper presents the first stage of this work: a sketch of an urban perspective and a rural perspective on the role and use of land and water resources, a categorization of different types of solidarity, the So-Si-So modeling platform that we are developing to represent and analyze behavioral patterns of solidarity, and an embryonic version of Solid'Eau, a simulation model that eventually should allow us to study the social behavior of agents located in a system around a shared water resource. The first results obtained with this model show that the So-Si-So model architecture indeed allows identifying and measuring different types of solidarity, and lead to several questions that will guide our future work in this area.

2 Solidarity at the Interface between Urban and Rural Areas

The social phenomena that we are interested in spring from the tension between two opposing perspectives on water issues: an urban perspective and a rural perspective. At a first glance, this tension leads to attempts from one group to impose constraints on, or get compensations from, the other group. Looking more closely, a variety of more specific and refined stakeholder perceptions can be distinguished within each perspective. Moreover, at the level of individuals, the boundary between an urban community and a rural community is not so clear as it is sometimes claimed: there is always a peri-urban area where individuals are difficult to categorize as urban or rural, individuals migrate at various speeds from urban areas to rural areas and vice versa, and they are linked to both types of areas in intricate ways. To emphasize interdependency and the potential for conflict, however, the two perspectives are characterized as follows:

Urban perspective:

- Cities are the centers of modern human society. Their complex social structure is essential for technological, economic and cultural development.
- Water is a necessity of life. Citizens are entitled to adequate drinking water supply and sanitation.
- Rural areas are indispensable for food production, but large scale agriculture reduces the ecological and recreational value of the landscape.
- Rivers are a drinking water supply as well as a discharge channel for rainwater and wastewater, but also a potential threat that needs to be contained by adequate flood prevention measures.

- The natural water system has a high capacity for regeneration, but balances are threatened by the extraction of irrigation water and heavy use of fertilizers and pesticides in agricultural production.

Rural perspective:

- Not only historically, but also today, the modern, human society has its roots in small agricultural communities. Without agriculture no food, and without food no cities.
- Water supports natural vegetation and wildlife as well as agriculture and human life. The traditional rural life style is in harmony with nature and uses water resources in a sustainable way.
- The growth in population, which is strongest in urban areas, puts greater demands on agricultural production as well as on facilities for recreation.
- Urbanization creates a new hydrological environment (buildings and roads replace vegetation and soil, sewers replace stream channels), reducing infiltration and groundwater recharge while increasing runoff and the probability of flooding.
- Urban areas produce high volumes of faeces and other organic waste, heavy metals, and mineral oil products. Although sewage systems and wastewater treatment plants mitigate emission to surface water, high peak discharges generate sewer overflows. Also, industrial and household consumption of electricity causes thermal pollution that threatens aquatic wildlife.

These outlines of the urban and rural perspectives clearly show a number of interdependencies and tensions that underlie many water resource management issues. However, these interdependencies and tensions may not be obvious at the stakeholder level. Any attempt to cope with undesirable impacts from one perspective is likely to generate unexpected feedbacks on other aspects of the other perspective. For example, if an urban group succeeds in imposing constraints on rural water use for agriculture, this will impact on landscapes which are valuable for residents of urban areas.

Given these more or less straightforward physical interdependencies, we want to question whether any social link between both parties exists or can be created or reinforced that could manage these physical interdependencies. Institutions in the sense of Ostrom (1990) may exist that already provide or could establish this social link. But what we are presently even more interested in are loose forms of interaction such as *solidarity*.

Our work is based in the assumption that raising awareness of physical interdependencies *and* social links is a way towards a management of the resource better for the whole system. In this perspective, we think that models are effective tools to reveal and make explicit those situations where the heterogeneity within each group, and the existing relations at the individual level between persons associated with one group or the other is providing opportunities (1) to find institutions to manage the interdependencies, and (2) to find synergies among various perspectives. Meanwhile, we see our modeling work also as a means to achieve a better formalization of solidarity situations and of the solidarity concept itself. This paper reports our progress in this formalization to date.

3 Categories of Solidarity

The capacity to resolve the tensions as water resources become scarce is largely determined by the willingness of stakeholders to share. It is at this point that the concept of solidarity becomes interesting. Solidarity is a loose form of social binding characterized by *latent* reciprocity: the interdependencies need not be explicitly known or understood by those involved. Solidarity is a feeling, rather than a calculated attitude.

On the individual level, solidarity can be defined as “a sense of community between persons who, despite their differences, believe to have the same objective(s) that one has achieved more than the other, from which rises the voluntary obligation to support the other, coupled with the entitlement to support from the other should the situation be reversed” (Hondrich & Koch-Arzberger 1992, p. 14-15). Segall (2005) sees solidarity as a relation between the individual and the collective: “[Social solidarity] comprises the following phenomena:

- Integration – Identification on the part of the individual with the goals and features of the collective (Miller, 1999, p. 26);
- Commitment to the common good – Willingness to forgo self-interest for the sake of the common good (Mason, 1998);
- Empathy – concern for the wellbeing of other members who are less well off than oneself (Cohen and Arato, 1992, p. 472; Mason, 1998);
- Trust – the willingness to suspend suspicion of others, at least until receipt of evidence to the contrary (Misztal, 1996, p. 209; Seligman, 1997, p. 94; Warren, 1999, p. 330).” (Segall 2005, p. 362, the references are his).

Thus, solidarity may be a relation between two individuals or a relation between an individual and the collective that the individual is part of. When considering the (potential) solidarity between urban and rural areas, both relations need to be examined.

In this paper, we focus on solidarity at the individual level, where solidarity involves a voluntary action of person A in support of another person B where A by performing this action knowingly incurs a cost to himself. The definition by Hondrich and Koch-Arzberger is quite precise with regard to the mechanism that leads to solidary action: The sense of community that leads A to support B stems from A’s belief that A and B share certain values and objectives. When A furthermore believes to have achieved these objectives more than B, A experiences a *voluntary* obligation to support B, coupled with the *implicit* entitlement to support from B should the situation be reversed. This precision allows us to distinguish the following categories of solidary behavior:

- The action of A is an act of altruism, rather than one of solidarity, when it is motivated *solely* by the belief that this action will contribute to the realization of B’s objectives (absence of the shared objectives aspect). *Example*: A is wealthy and donates, for no particular reason other than to do good, to a charity organization that funds B to recover from flood damage.
- The action of A is an act of ‘heartfelt solidarity’ when it is motivated by the sense of community due to A’s belief that B shares some of his own objectives. *Example*:

Village A does not lie in a flood-prone area and its inhabitants nonetheless contribute to a flood damage compensation fund for village B because they believe that those who live in village B aim, just like they do, to preserve their characteristic houses as part of their cultural heritage.

- The action of A is an act of ‘opportune solidarity’ when A and B have the same objective and A values this objective even more than B (dominance of self-interest). *Example:* Some inhabitants of A contribute to the flood damage compensation fund for village B because they value its cultural heritage even more than the inhabitants of B.
- An action of A is an act of ‘calculated solidarity’ when A takes this action motivated by his expectation of possible future benefits should he find himself in a situation similar to B (absence of the *latent* reciprocity aspect). *Example:* Village A and B are both situated in a flood-prone area and their inhabitants choose to contribute to the flood damage compensation fund because that will cover their own flood risk.
- The action of A is an act of ‘self-interested solidarity’ when A’s actual motivation to support B does not stem from B’s objectives, but from A’s own, different objectives. *Example:* Village A does not lie in a flood-prone area and yet some of its inhabitants contribute to the flood damage compensation fund for village B, but they do so merely to increase the fidelity of their customers living in the flood-prone village B.
- An action of A is an act of ‘imposed solidarity’ when A takes this action as a result of some contract or social rule (absence of the voluntary aspect of the action). *Example:* The people in villages A and B all pay a national income-based tax, the revenues of which are used to compensate people who incur flood damage.

These definitions of solidarity provide categories for *individual* behavioral patterns. In the present stage of our research, we focus on these patterns to study the conditions that lead to different forms of solidarity, and the effect on a group level. In a later stage, we will also consider group solidarity, that is, the degree to which individuals in a group comply with corporate rules in the absence of compensation (Hechter, 1987, p. 39).

4 So-Si-So: A modelling Platform to Analyse Solidarity in Behavioural Patterns

In this section we describe the modelling platform called So-Si-So (Social Simulation of Solidarity) that we have developed to study the simulated behaviour of cognitive agents, situated in physical spaces, and interacting in social spaces.

To be able to distinguish between the different types of solidarity defined in the previous section, the observer must have access to the mental state (beliefs, motivations) of both A and B. Our agent-based models should therefore allow inspection of the motives for agents to take action. The design of So-Si-So agents should otherwise be as simple as possible. This led us to the following choices:

- Agents derive their ultimate motivation for action from values, which they seek to uphold. Some values are intrinsically individualistic (e.g., one's own survival), other values are intrinsically collective (e.g., peace).
- Agents have concerns that define relations between their values and indicators that give them insights on aspects of the physical spaces and/or the social spaces that they have access to.
- Agents acquire factual beliefs about these indicators through their sensors. Being actor-bound, sensors are subjective: different agents may construct different factual beliefs about the same situation.
- Agents become privately concerned when, according to their factual beliefs, one or more of these aspects appear to be in bad shape.
- Agents may also become socially concerned, that is, consider the concerns of other agents situated in their social space(s). Agents will become socially concerned only if they have some inclination towards altruism.
- To address concerns (their own and/or those of other agents), agents evaluate their causal beliefs, looking for actions that they expect to ameliorate the aspects of their environment about which they are concerned.
- For each of their 'active' concerns, agents choose the action (insofar available) that seems best to them.

This agent design permits the modeller to trace for each action taken the values that motivated the agent to perform this action, and therefore also to detect solitary actions (actions that address the concerns of others) and distinguish between different types of solidarity. To demonstrate this, we must define more precisely the way in which So-Si-So agents come to act:

- An *agent* is represented as an 12-tuple $a = (\text{Val}, \text{Con}, \text{Sen}, \text{Bfact}, m, \alpha, \text{Cp}, \text{Cs}, \text{Cw}, \text{Bcaus}, \text{budget}, \text{Soc})$ where **Val** is a set of values, **Con** a set of potential concerns, **Sen** a set of sensors, **Bfact** the set of factual beliefs, **m** the agent's memory depth (represented as a non-negative integer value), α the agent's inclination towards altruism (represented on the interval $[0, 1]$), **Cp**, **Cs** and **Cw** sets of, respectively, private, social, and weighted concerns, **Bcaus** a set causal beliefs, **budget** the agent's financial resources (represented as a non-negative real value), and **Soc** the set of social spaces that a is part of.
- A *value* is represented as a 3-tuple (**idea**, **type**, **importance**), where **idea** expresses something that the agent holds dear, for example: 'survival', 'wealth' or 'environment'. The value type is either **IND** (for individualistic) or **COL** (for collective). When an agent has multiple values, their relative importance can be represented on the interval of $(0, 1]$.
- A *potential concern* is represented as a 3-tuple (**indicator**, **value**, **intensity**) that expresses the subjective relation that the agent sees between some aspect of the world and what the agent holds dear. When an agent considers multiple indicators to be related to the same value (for example, both quality and quantity of the water resource relate to the value 'ecology'), the relative intensity of their relations with this value can be represented on the $(0, 1]$ interval.
- A *factual belief* is represented as a 3-tuple (**tick**, **indicator**, **judgement**) that expresses how the agent perceives some aspect of its environment at a particular

tick (time step as counted by the model's clock) in the simulation. An agent's factual belief list cannot contain beliefs older than the agent's memory depth. New factual beliefs are added to the agent's factual belief list by the agent's *sensors*, where a sensor typically compares one or several variables in the agent's environment with pre-defined threshold values, and produces a judgement on some scale. In our experiments, we used this scale: AWFUL=-1, BAD=-0.5, NEUTRAL=0, GOOD=+0.5, GREAT=+1, but other scales can be defined, as long as they map onto the same interval of [-1, 1].

- The three lists of *actual concerns* (private, social, and weighted, respectively) contain 2-tuples (concern, state) that express for the current time step the degree (represented by the numeric field state) to which the agent is actually concerned about certain aspects. For example, when in time step 25 an agent has a factual belief (25, 'water quantity', BAD), and the potential concern $c = ('water\ quantity', 'ecology', 1)$, its private concern will be $pc = (c, -0.5)$. Private concerns are created from the agent's own potential concerns, social concerns are created from other agents' potential concerns. The set of weighted concerns contains the weighted average of an agent's private and social concerns. It is this set of actual concerns that the agent used for taking decisions.
- A *causal belief* is a 3-tuple (action, effects, cost) that expresses the relation that the agent sees between an action, its effects on one or more indicators, and the costs involved. For example, the causal belief ('SELF:produce', {'water quality', BAD}, {'income', GOOD}), 50) represents that the agent believes that its own action 'produce' affects two indicators and will require 50 of the agent's budget units. The list of causal beliefs may be incomplete (thus representing what an agent conceives as possible) and even incorrect (agents may wrongly estimate effectiveness and/or cost). Agents may also have causal beliefs about actions that can be taken by other agents.
- An *action* represents what agents can do. The actual consequences of actions are calculated by the physical space entities and/or social space entities that the agent has access to.

Physical spaces, social spaces and their autonomous evolution (i.e., state changes that are not the immediate result of actions of agents) are defined by the modeller (see the example in section 5). Once physical spaces, social spaces and agents have been initialised, a So-Si-So model iterates through this cycle:

1. *The agents get the opportunity to act.* In the experiments reported in this paper, this happens in a fixed sequence: the order in which the agents were created.
2. *The social spaces coordinate collective actions.* Collective actions are actions that require more than one agent to be effective, so agents can only 'announce' their intention to perform such an action in a social space. When all agents have had the opportunity to act, each social space checks whether the conditions for successful collective action as specified by the modeller (e.g., at least five agents are needed for this action to be effective) are met, and only if that is the case will the consequences of the action be effectuated as changes in the state of certain physical and/or social spaces. In the experiments reported in this paper, this feature has not been used.

3. *The physical spaces evolve.* Although the immediate consequences of agent actions have all been effectuated, the state of the physical spaces may still change autonomously.
4. *The agents evolve.* Similar to physical spaces, certain attributes of agents may also change as a function of time, independently of agent actions.
5. *The model advances to the next time step:* $\text{Clock.tick} = \text{Clock.tick} + 1$

A So-Si-So agent a comes to act by in a sequence of steps:

1. *Forget.* Agent a removes all factual beliefs fb from $a.\text{Bfact}$ for which $(\text{Clock.tick} - fb.\text{tick}) > a.m$.
2. *Perceive.* Agent a activates each of its sensors; each sensor in $a.\text{Sens}$ may add to $a.\text{Bfact}$ a new factual belief about the state of a 's environment.
3. *Appraise.* Agent a checks to see whether its factual beliefs activate one or more of its potential concerns: for each factual belief fb in $a.\text{Bfact}$ the agent checks whether it has a potential concern c in $a.\text{Con}$ with $c.\text{indicator} = fb.\text{indicator}$; if that is the case, the agent checks to see whether it already has a private concern pc with $pc.\text{concern} = c$; if not, such a private concern pc is created (with $pc.\text{state}$ initialised to 0) and added to the agent's set of private concerns; the state of the (new) private concern pc is then updated as follows:

$$pc.\text{state} = pc.\text{state} + c.\text{intensity} * c.\text{value.importance} * fb.\text{judgement}$$

4. *Survey socially.* The agent a considers the concerns of those agents with which it has a social relation: let n be the sum, for each social space ss in $a.\text{Soc}$, of the number of other agents that are also part of ss ; then for each social space ss in $a.\text{Soc}$, the agent a checks for each other agent b in ss whether it has one or more weighted concerns wc in $b.\text{CW}$ with $wc.\text{state} < 0$ and $wc.\text{concern.value.type} = \text{COL}$. For each such wc , agent a checks to see whether it already has a social concern sc with $sc.\text{concern} = wc.\text{concern}$; if not, such a social concern sc is created (with $sc.\text{state}$ initialised to 0) and added to $a.\text{Soc}$; the state of agent a 's (new) social concern sc is then updated as follows:

$$a.sc.\text{state} = a.sc.\text{state} + b.wc.\text{state} / n$$

The division by n makes that the scale for the **state** attributes of the agent's private concerns and its social concerns is the same. Note, however, that if some other agent is part of more than one of the agent's social spaces, its concerns will be considered several times. We see this as appropriate, as it reflects that in reality those other agents with multiple relations will also have more influence on the agent.

5. *Weigh up private and social concerns.* Agent a 's parameter α is used when the agent merges its private and social concerns into its set of weighted concerns CW : starting with an empty set, the agent first adds for each of its private concerns pc a new weighted concern wc with $wc.\text{state} = pc.\text{state} * (1 - \alpha)$; then for each of its social concerns sc , the agent checks to see whether it already has a weighted concern wc with $wc.\text{concern} = sc.\text{concern}$; if not, a new weighted concern wc is added with $wc.\text{state}$ initialised to $sc.\text{state} * \alpha$; otherwise, the state of the existing weighted concern wc is updated as follows:

$$wc.\text{state} = wc.\text{state} + sc.\text{state} * \alpha$$

6. *Deliberate*. For each of its weighted concerns wc (in order of increasing **state**, so as to deal with the worst problem first) agent a checks its causal beliefs looking for actions that are believed to alleviate this concern. More precisely: the agent selects those causal beliefs b with $b.effects$ containing a 2-tuple $e = (indicator, impact)$ with $e.indicator = wc.concern.indicator$ and $e.impact > 0$ (i.e., GOOD or GREAT). Agent a then selects the action that is still affordable ($b.cost \leq a.budget$) and has the highest utility (taking into account its consequences for its other concerns), adds it to its action list, and computes its remaining budget. The utility u of an action is calculated as follows: starting with an initial value $u = 0$, the agent checks for each of the action's effects $e = (indicator, impact)$ whether it has one or more weighted concerns wc with $wc.indicator = e.indicator$ and $wc.state < 0$, and for each such concern $u = u - e.impact * wc.state$. This reflects that a only considers the indicators a is concerned about (ignoring all other indicators), and will favour those with a (strong) positive effect on indicators whose state is (very) negative.
7. *Act*: the agent performs the actions on its action list. Note that the actual consequences of each action for the agent's own attributes (notably $a.budget$) as defined by the modeller may differ from the anticipated consequences, that is, the effects according to the agent's causal beliefs.

This architecture makes it possible to detect different types of solidarity because it allows scrutinizing an agent's motivation for taking certain actions.

The basic characteristic of an act of solidarity action is that agent a takes this action to support agent b , and that a makes some kind of sacrifice by doing so. In the So-Si-So architecture, agents are aware of the concerns of other agents, but on an aggregate level only. Where a 's private concerns $a.Cp$ are its own and therefore individual, a 's social concerns $a.Cs$ are a 'weighted union' of the weighted concerns of a set of other agents. Thus, the 'other agent' b in our definitions of solidarity is the aggregate of all agents in a 's social spaces, rather than an individual agent.

The terms 'support' and 'sacrifice' both entail a concept of utility: an action of a supports b when it produces positive utility for b , and it constitutes a sacrifice for a if it produces negative utility for a . By the same type of reasoning, a supports b by *not* taking an action that would produce negative utility for b , even though it would produce positive utility for a . The foregone utility for a then constitutes a 's sacrifice.

While deliberating, agent a constructs an action list, selecting (insofar as a 's budget permits) for each of its weighted concerns $a.Cw$ the action with the highest utility. To see whether a makes a sacrifice, a second action list is constructed according to the same procedure but now based on a 's private concerns $a.Cp$. The former (from now on called the 'weighted action list' of a) represents what a does, the latter (a 's 'private action list') represents what a would have done if b had not existed. Likewise, a 's 'social action list' is constructed on the basis of a 's social concerns $a.Cs$.

Using these three action lists, we can now define the following types of utility:

- Being based on a 's weighted concerns, the utility of an action x on a 's weighted action list is called the 'weighted utility' of action x . The 'private utility' and the 'social utility' of x are defined likewise.

- *U_{soc}* cumulates the social utility of actions in *a*'s weighted action list that are *not* in *a*'s private action list PLUS for those actions *x* that are in both lists the 'social utility surplus' defined as the difference (if positive) of social utility of *x* – private utility of *x*.
- *U_{neg}* cumulates the negative private utility of actions in *a*'s weighted action list. Having a negative private utility, such actions will *not* be in *a*'s private action list.
- *U_{asoc}* cumulates the negative social utility for actions in *a*'s weighted action list. When an action *x* has a social utility < 0 and yet occurs in the weighted action list, it must be motivated by private concerns only, hence *U_{asoc}*, which stands for 'anti-social utility'.
- *U_{opp}* cumulates for actions in *a*'s weighted action list that are also in *a*'s private action list (but only those driven by the same concern, with the state of *a*'s private concern being worse than the state of *a*'s social concern) the 'private utility surplus' defined as the difference (if positive) of private utility of *x* – social utility of *x*.
- *U_{self}* cumulates the private utility surplus for the remaining (i.e., not used for *U_{opp}*) actions in *a*'s weighted action list that are also in *a*'s private action list.
- *U_{foregone}* cumulates the private utility of actions in *a*'s private action list that are not in *a*'s weighted action list. Motivated by social concerns, *a* decided not to take these actions, hence the term 'forgone utility'.

As shown in Table 1, these different types of utility allow us to detect and measure four of the six types identified in section 3.

Table 1. Operationalisation of different types of solidarity

Type of solidarity	Detection/measure
altruism	$U_{soc} + U_{neg} + U_{foregone}$
heartfelt solidarity	The distinction between altruism and heartfelt solidarity can be made in step 4 (<i>survey socially</i>). Altruistic actions are precluded by making agent <i>a</i> consider only those social concerns that are related to a value that also occurs in <i>a.Val</i> . As the present Solid'eu model includes only one collective value, the difference cannot occur.
opportune solidarity	U_{opp}
self-interested solidarity	U_{self}
calculated solidarity	Not represented in So-Si-So models, as in the present architecture agents cannot anticipate on other agent's actions and therefore not foresee reciprocity.
imposed solidarity	Not represented in So-Si-So models, as presently agents are driven only by their own values. This will change once we have extended the architecture with social norms.

In view of the categories of solidarity we want to test, we did not need to make agents foresighted with respect to expected social behavioural patterns. Agents are myopic and act only upon their knowledge of consequences of potential actions they might perform on their own concerns or on concerns of others. They do not take into account any belief or expectation regarding others' actions like in Conte and Paolucci

(2002) or in Dittrich *et al.* (2003). As noted in Table 1, such sophistication will be needed to detect calculated solidarity.

Agents in So-Si-So compute their perceptions according to their values only, their concerns according to their actual perceptions (and some of their previous perceptions, since agents can keep their factual beliefs for memory depth time steps), and their actions according to their causal beliefs based on actions. Figure 1 below is expanding the Perception-Deliberation-Action cycle from Jacques Ferber (1999) as it is activated in So-Si-So agents. If more cognitive agents are required, the deliberation stage might be more refined, for example through the identification and choice of actions, taking into account more than causal beliefs only.

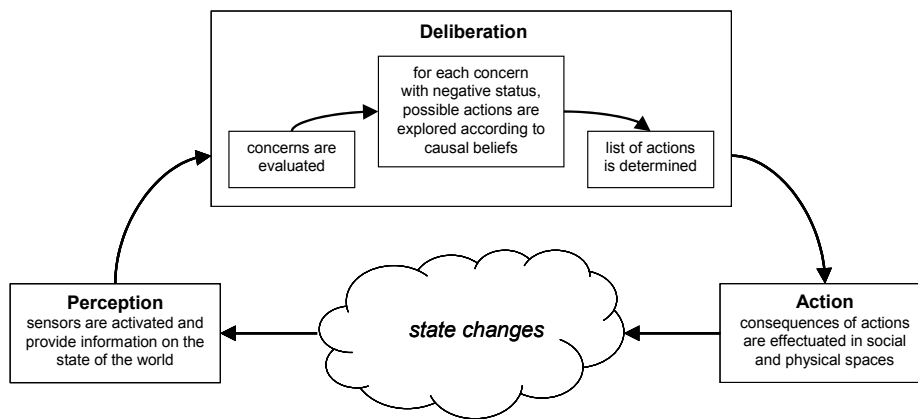


Fig. 1. Extension of Ferber's Perception-Deliberation-Action cycle in So-Si-So

5 A simple Test Model

We tested So-Si-So with what we see as an embryonic version of Solid'eau: a simple decontextualised model of a set of individuals, equipped with the previously described cognitive capacities, located in an urban or a rural area, in which they have a productive activity using units of a shared resource. To facilitate analysis, we use no stochastic parameters. The two areas (modelled as physical spaces) are linked by a water resource. This resource is localized, with a flow from an upstream space to a downstream one, depending on resource availability in the upstream space. As it is the most frequent case, we assume that the rural physical space is located upstream. The connection between the two spaces is described by the two following rules:

- a constant ratio of resource level, ϕ , disappears from upstream space and flows in downstream space,
- if the resource availability in the upstream space after resource renewal exceeds its maximum capacity, the surplus flows to the downstream part.

The resource in the upstream physical space renews at a fixed rate ρ relative to its maximum capacity.

Agents are localised in either one of the physical spaces. The population is then described by the total number, N , and the ratio in urban area, θ . Urban agents and a part of rural agents (those who have social ties in the urban area) share a social space.

Agents are described by their localisation, the weight α they attach to social concerns, and their thresholds to determine how they assess the information received from their sensors. All agents are driven by three values: ('survival', IND, 1), ('environment', COL, 0.33) and ('wealth', IND, 0.33), the numbers indicating relative importance, with potential concerns ('subsistence', 'survival', 1), ('budget', 'wealth', 1) and ('resource', 'environment', 1).

Possible actions of agents are production at level 0, 1, 2, or 3, where production at level 0 means: do not produce. Production in a rural area consumes π_r level units of resource and generates Y_r level units of budget, respectively π_u level and Y_u level in urban areas. Agents also incur production costs of γ level, the base production cost γ being equal for urban and rural areas.

All agents have the same causal beliefs:

- ('produce.0', {'subsistence', AWFUL}, ('resource', GOOD)), 0)
- ('produce.1', {'subsistence', GOOD}, ('budget', GOOD)), γ)
- ('produce.2', {'subsistence', GREAT}, ('budget', GOOD), ('resource', BAD)), $2*\gamma$)
- ('produce.3', {'subsistence', GREAT}, ('budget', GREAT), ('resource', AWFUL)), $3*\gamma$)

At each tick, all agents spend the same fixed amount of budget for their cost of living, λ .

Table 2. Parameter setting of the Solid'eau model

Parameter	Value
ϕ , flow rate	0.2
ρ , resource renewal per tick	0.2
SmaxR, maximum resource level in rural area	100
SmaxU, maximum resource level in urban area	100
N , total population	30
θ , fraction of urban population	0.7
π_r , production factor in rural area	3
π_u , production factor in urban area	2
Y_r , production yield in rural area	200
Y_u , production yield in urban area	250
λ , cost of living	50
α , altruism	0.4
β , initial value of agent budget	250
γ , base production cost	50
SB, budget threshold below which sensor yields ('subsistence', BAD)	250
SA, budget threshold below which sensor yields ('survival', AWFUL)	175
BB, budget growth threshold below which sensor yields ('budget', BAD)	0.2
BA, budget growth threshold below which sensor yields ('budget', AWFUL)	0.1
RB, resource threshold below which sensor yields ('resource', BAD)	60
RA, resource threshold below which sensor yields ('resource', AWFUL)	42

The order in which agents can act (and therefore co-determines their actual resource use, given a chosen production level) is fixed for each physical space. All agents have sensors that generate factual beliefs $fb = (\text{indicator}, \text{judgement})$ for the indicators ‘resource’ (to assess the resource availability in the physical area where the agent produces), ‘subsistence’ (to assess whether the agent’s budget is sufficient to cover its cost of living), and ‘budget’ (to assess whether the agent’s budget is on average increasing, with a desired percentage per year. These sensors return judgements based on threshold values. In the model we have used so far, all agents to have the same thresholds for the same concern, but these threshold values may be individualised. Table 2 shows the threshold values used, as well as all other parameter values for the model used in the simulations referred to in the next section.

6 Simulation Results

Even though this work is still ongoing, we have been able to verify that the So-Si-So model architecture permits identification and measurement of the various categories and subcategories of solidarity, even with a model with but few options in terms of values and the structure of social spaces. The model’s outcomes have been verified through code proofreading and comparison of outcomes with expectations.

Figure 2 and 3 show two scenarios, the only difference being that in the second scenario some of the rural agents do not share the urban-rural social space. As the aim of this paper is to propose a categorisation for solidary behaviour and ways to measure it, the model results are illustrations that hold little surprises. In both scenarios, stimulated by their desire for wealth (a budget increase of at least 10% and preferably 20% or more of their initial budget each time step), the agents who can use the resource first produce at high levels, while those who then see the resource dwindle become concerned about it and produce less. Around tick 30, the least fortunate agents start to produce merely to survive (this causes the high peaks of self-interested utility: production serves both survival and wealth). As more agents become very concerned about the resource, agents who share their social space start foregoing high production (this causes the peaks of foregone utility that first appear around tick 40) and by consequence fall back in wealth. Looking at both the resource level plot and the budget units graph in Fig. 2, it can be seen that gradually more rural agents forego production even when their resource (upstream) would permit it.

As was expected, the first scenario shows more solidary behaviour. In the second scenario, a resource crisis occurs between tick 110 and 125, when more than half of the urban agents run out of budget. In the model used, this makes them become inactive, which represents that the inhabitants leave the region, or—worse—starve. Inactive agents are ignored, so their concerns no longer influence the deliberation of other agents. As a result, the three rural agents who were sensitive to the urban agents’ concerns feel less need for solidarity pick up their production.

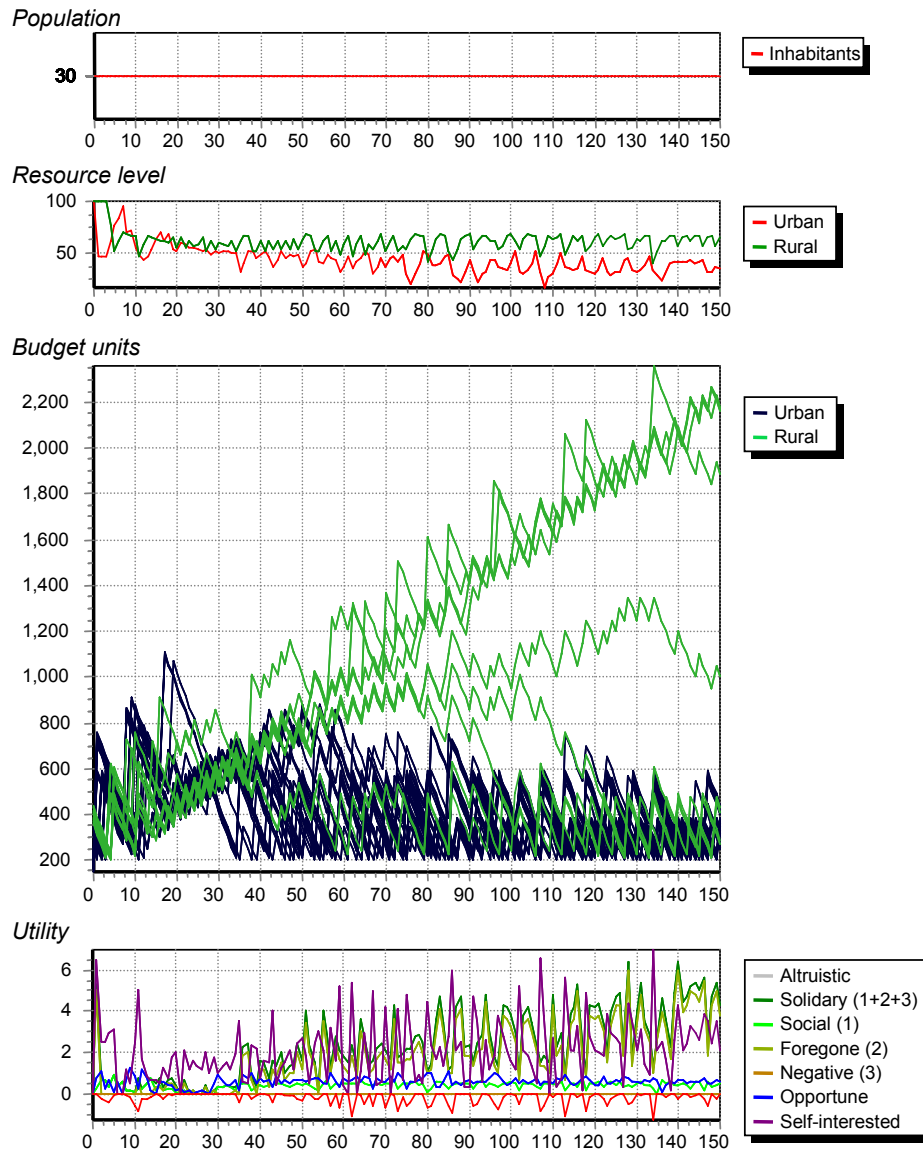


Fig 2. Scenario in which all agents are part of one and the same social space

The steady alternation in Fig. 3 between production at level 0 and level 1 shown by the six rural agents without a social space reflects their own concern with the resource only; they are the last to access the rural resource, and their budget drops only when the three rural agents who do share a social space with the other agents pick up their production.

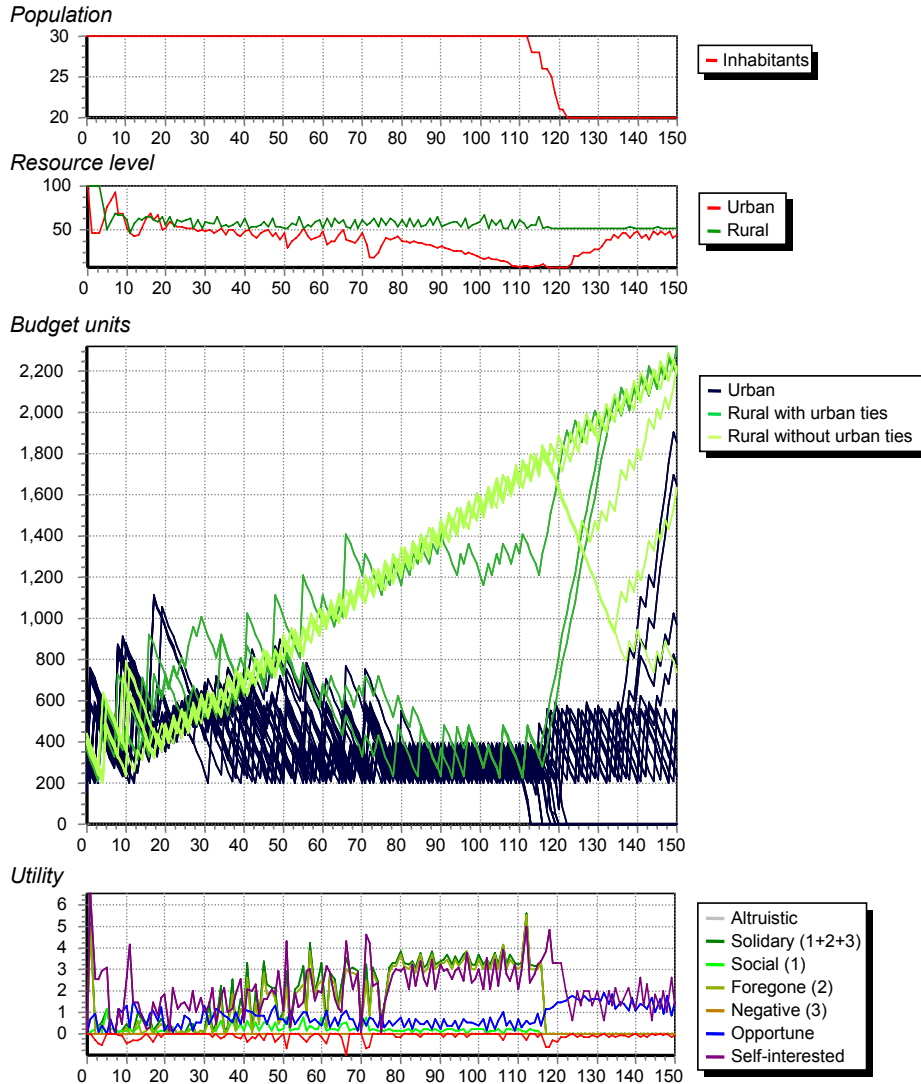


Fig 3. Same scenario, except that 6 of 9 rural agents have no social ties with the other agents

6 Conclusion and perspectives

With this tentative framework to represent solidarity at an individual level we have succeeded in identifying and distinguishing solidary actions in a simple virtual world, and we have paved the way for an evolution towards a more grounded representation of resources and networks of relations between agents (via social spaces) as well as between agents and these resources (via physical spaces).

To achieve this evolution we need to couple this framework with a more structured description of the virtual world, and to include concepts that will permit representation and analysis of other forms of solidarity. For example, to represent imposed solidarity, we will have to include norms.

We aim at incorporating this work in a policy perspective, through the identification of existing social networks which might serve as driving belt for solidarity actions and joint preservation of resources across physical spaces.

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