The impact of boundary organizations on decision-making under uncertainty: a multi-agent simulation

Denis Boissin, PhD student in Economics

CERAM Business School & GREDEG UMR 6227 CNRS[1]

Abstract: Modern environmental issues imply that decision-makers have the capacity to take into account possibly conflicting information from distinct domains, such as science and economics. As the development of technology increases the temporal and spatial scopes of risks, decision-makers can no longer consider economic and scientific information separately but should encourage experts to work together. Boundary organizations, institutions that cross the gap between two different domains, are able to act beyond the boundaries while remaining accountable to each side (*Guston,* 2001). By encouraging a flow of information across the boundaries, they permit an exchange to take place, while maintaining the authority of each domain (*Cash* et al., 2003; *Clark* et al., 2002).

The goal is to simulate boundary organizations to assess their impact on the diffusion of experts' opinions. The hypothesis tested is whether the existence of a boundary organization eases the decision-making process by reducing the number of opinions expressed. The methodology relies on a multi-agent system based on a model of continuous opinion dynamics (*Deffuant* et al., 2001) extended over two dimensions. The world is defined by two parameters: the uncertainty, that reflects the possible zone of discussion between experts, and the exchange, which represents the openness of discussions. Agents are described by credibility and conviction: the credibility represents how much other agents may be influenced by an agent, and the conviction represents the resistance of an agent to changing its position. Two kinds of agents are left free to interact, modifying their position in their domain (dimension) through one-to-one exchanges. Agents called borgs are introduced: open to trans-disciplinary discussion, they are able to exchange on both dimensions. The results show that the range of expressed opinions is significantly reduced, even at low levels of experts involved in the boundary organization..

Key words: Decision-making, opinion, agent-based simulation, multi-agent, boundary organization

1. Introduction

Decision-making under uncertainty requires an evaluation of all the information available. Modern environmental issues imply that decision-makers have the capacity to take into account possibly conflicting information from distinct domains, such as science and economics. The current development of technology increases the temporal and spatial scopes of risks, therefore enhancing the importance of experts' opinions: decision-makers should encourage experts from different areas to work together all along the decision-making process rather than considering economic and scientific information separately. Boundary organizations are particularly well adapted to these situations of uncertainty and dissent, typical of environmental issues (*Scott,* 2000).

1.1. Boundary organizations

Boundaries are built by experts in order to protect their domain from outside intrusions and to affirm their authority over the inside, while allowing for members to affirm their belonging to an area of expertise. When different domains are involved in an issue, their boundaries come closer to each other and may overlap. In that case, the natural reaction is for each side to reinforce its boundaries, in order to avoid any confusion and to clearly distinguish the domains involved, clarifying the authority of each. Yet, a blurring of the boundaries, rather than the intentional separation, could increase their respective efficiencies (*Jasanoff,* 1990).

Boundary organizations are institutions that cross the gap between two different domains: they are able to act beyond the boundaries while remaining accountable to each side (*Guston,* 2001). By encouraging the production and exchange of information across the boundaries (through the use of boundary objects or standardized packages), without interfering with the way of functioning of each domain, they permit a dialogue and a confrontation of opinions to take place, while maintaining the authority of each side (*Cash* et al., 2003; *Clark* et al., 2002). They do not directly take part in the debates and remain neutral throughout the process: their legitimacy relies on the fact that they allow for all opinions to be expressed, including extreme positions. Their goal is not to reach the final decision, but to encourage the interactions

1 Denis BOISSIN c/o CERAM Bachelors, Rue Albert Einstein, B.P. 085, 06902 SOPHIA ANTIPOLIS Cedex, France

between experts in order to ease the decision-making process. By internalizing the boundary, they are able to act on its permeability throughout the debate: they encourage a cooperation around common interests instead of a fight for control that leads to a division. Their dependence on two distinct domains reinforces their strength of action rather than weakening them. Unlike traditional organizations, their survival through time is not their prime objective: in fact, their disappearance can be a sign of a successful activity, since their presence is no longer justified once the objective is reached.

1.2. Impact on opinion diffusion

The hypothesis that supports the existence of boundary organizations is that the eased and increased transfer of useful information between different domains increases their respective efficiencies. Though never formally proved, this hypothesis is widely accepted based on the observation of boundary organizations such as the Health Effects Institute, the Sea Grant program, the International Research Institute for Climate Prediction or the Subsidiary Body for Scientific and Technological Advice (*Guston* et al., 2000). The goal is to assess the impact of a boundary organization on the experts' opinion diffusion. The hypothesis tested is not whether a boundary organization may change the final decision, but whether its existence eases the decision-making process by reducing the range of opinions expressed among experts.

2. Method

The methodology is based on the observation of simulations of opinion diffusion among experts of different domains: experts positioned on a continuous model of opinion, interact and modify their position through series of one-to-one discussions. As a boundary organization of increasing importance is simulated, the range of expressed opinions is computed to identify an eventual positive relationship.

2.1. Multi-agent simulation (MAS)

The model relies on a Multi-Agent System (MAS), a virtual computer simulation where autonomous heterogeneous agents interact with their environment and with each other. MAS are artificial worlds whose characteristics can be controlled. They allow for replicated series of experimentations over ranges of parameters. MAS have been successfully applied in decision-making, such as traffic, military fight and epidemiological issues, as well as in economics and social sciences, with applications such as learning processes, diffusion of technology, evolution of behavioral norms, formation of networks... They are especially well-suited for simulating behaviors adapting to or anticipating the state of an ever changing surrounding world and they allow us to observe an emerging recurrent macroscopic behavior resulting from microscopic interactions that could not be deduced by simply aggregating the properties of the agents (Axelrod & Tesfatsion, 2006).

In a MAS, each entity, or agent, is able to picture its surrounding environment, and to communicate and interact with other agents, adapting its behavior to its (partial) perception of the world with respect to its characteristics and desires (*Amblard & Phan,* 2006). Our model uses no desire, no motivational component for agents, but a belief that evolves through time with respect to an interaction function between the entity and other agents. Agents A_i have a state vector X_i representing their opinion over the two axes of the graph and a state transition function f_i at each time unit. The reactive agents have a perception-action relation and no representational function of their environment: they show a reflex behavior with respect to one-to-one encounters with other agents.

2.2. The BORG model

The model used is based on previous work done on a single dimensional model of continuous opinion dynamics (*Deffuant* et al., 2001). As opinions can be more or less positive or negative, they are better modeled using a continuum going from an absolute negative to an absolute positive than through a binary approach. The idea has been to extend this model over two dimensions of opinion, representing two independent domains such as science and economics.

The world is defined by two parameters: uncertainty and exchange. The uncertainty reflects the possible zone of discussion between agents, the maximum distance that can separate two agents engaging into discussion. The exchange reflects the openness of discussions: it is used to determine to what extent agents are ready to modify their position after discussion as a percentage of half the distance separating an agent from its interlocutor. Agents are differentiated by credibility and conviction. The credibility of an agent represents how much other agents may be influenced by this agent, with respect to their own credibility. Agents of higher credibility attract interlocutors closer to their position, and the lower the credibility of the interlocutor, the more important this attraction. The conviction represents the resistance of an agent to changing its position after discussion: it is a negative reflection of its uncertainty.

Agents are positioned over a two-dimensional graph whose axes have a range of [-100;100]. At each time unit, each agent (x) chooses an interlocutor (x') so that |x-x'| is less than or equal to the uncertainty of the world ([0;100]), and modifies its position as follows :

$$x_{t+1} = x_t + ((x'_t - x_t)/2) \text{ exchange } (1-\text{conviction}_{(x)}) \ ((\text{credibility}_{(x')} - \text{credibility}_{(x)})/2 + 0.5)$$

where x_{t+1} is the position of the agent after the discussion ([-1;1])

x_t is the position of the agent before the discussion ([-1;1])

x'_t is the position of the agent's interlocutor before the discussion ([-1;1])

exchange, conviction and credibility are expressed as percentages ([0;1])

The position of the interlocutor is modified by the reciprocal transition function.

First, two kinds of agents (scientists and economists) are left free to interact, time units representing series of one-to-one interactions where each agent chooses an interlocutor to engage into discussion in its domain (dimension) and modifies its position as a result of this interaction. The simulations show that the two-dimensional projection leads to results in accordance with the single-dimensional continuous opinion model used as a basis. Then the concept of boundary organization is introduced in the simulation through agents called borgs. Boundary organizations could not be modeled as a spatial zone since it would reduce the diversity of opinions that could be expressed within the organization when boundary organizations must allow for any opinion to be expressed to maintain a high level of legitimacy. As the goal of boundary organizations is to connect experts from different areas, the borgs are open to trans-disciplinary discussion, and able to cross the boundary between the two domains, opening possibilities of exchange on both dimensions between agents, while other agents remain limited to interactions within their domain of expertise.

3. Results and discussion

The simulation is repeated for a ratio of agents involved in the boundary organization going from 1 to 50% with ten simulations realized at each percentage unit and with world parameter values of exchange of 100% and of uncertainty of 100. The results obtained are analyzed in terms of the range of opinions expressed, defined as the distance between the two most extreme opinions, once the positions of the experts are stabilized. The range of final opinions with respect to the percentage of agents in the boundary organization, including the upper and lower limits of the standard deviation, is as follows :

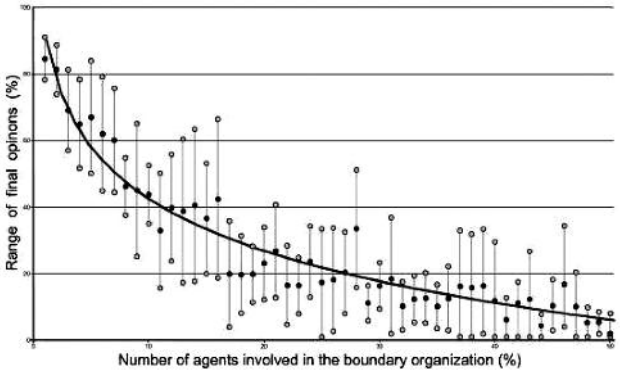

Figure 1: Range of final opinions with respect to the percentage of borgs

The logarithmic regression in *Figure 1* leads to a correlation factor R^2 of 93%. Not only is the positive relation between the number of agents involved in the boundary organization and the reduction of the diversity of final opinions expressed confirmed by this simulation, but the results also show that few agents need to be involved in the organization to impact significantly the global positioning of experts.

Borgs seem to be able to increase the scale of confrontation between groups of opinion: they do not emerge as opinion leaders, but encourage the exchanges between individuals by increasing the interactions and reducing the time necessary for individuals to meet. The diffusion of opinions among individuals observed in the simulation, is similar to the formation of packs among animals: the individuals gather around leaders, without a necessary direct contact with the leader but simply by interacting with nearby individuals, like birds in flocks. The opinion leaders are not active media users trying to convince others, but rather passive naturally emerging centers of opinion whose credibility and conviction encourage others to follow them.

4. Conclusion

This extension of a continuous opinion dynamics model over two dimensions to simulate boundary organizations through a multi-agent system has confirmed their role in easing the decision-making process as they lead to a reduction of the diversity of opinions expressed by experts of different domains by encouraging an exchange to take place across the boundaries. In addition, simulations have shown that the ratio of agents involved in the organization does not need to be important to have a significant impact.

Modifications have been brought to refine the model since these first results, the main one being an agent-related uncertainty, that changes through time with respect to the interactions, in replacement of the conviction characteristic that remained fixed. Results are not only analyzed with respect to the range of final opinions expressed, but also to the number of opinions present, the ratio of experts agreeing to each of these opinions, and the number of exchanges necessary to reach a situation of relative stability of opinions. These quantitative and temporal aspects of the impact of boundary organizations could reinforce the admitted yet not proved hypothesis that boundary organizations are useful in decision-making.

Opportunities to extend this model are anticipated. The most interesting one is to see how alliances between agents sharing means and/or values could influence the resulting opinions with and without a boundary organization, through the introduction of networks and an organizational structure in the simulated world. This could bring up a useful, yet undocumented, additional property of boundary organizations.

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