Methods and Models for Environmental Conflicts Analysis and Resolution

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Abstract

The present paper contains a brief outline of my PhD thesis that is centered on the critical review of a certain number of basic topics and on the proposal of some formalized methods for the resolution of environmental conflicts.
The paper describes the thesis and presents its foundations, its critical contributions and its main results and ends with some conclusions and a brief description of the open problems.
keywords: social decisions, consensus building, system dynamics, group model building, collaborative learning, knowledge refinement

1 Introduction

The present paper contains a brief outline of my PhD thesis entitled "Methods and Models for Environmental Conflicts Analysis and Resolution" and centered on a critical review of a certain number of issues and the proposal of methods for the analysis and resolution of environmental conflicts.
The paper is structured in a certain number of sections that aim at framing the thesis and at presenting the tools that have been analyzed and used during its devising and its writing as well as the main results that have been obtained and that, in part, have already been presented elsewhere (see the *References*).
Among the results we list here:

1. the use of auctions for the allocations of chores;

2. the use of barter models;

3. the use of Game Theory for the analysis of coalition dynamics and the bottom-up construction of coalitions;

4. some tools for the mapping of multicriteria methods on voting methods.

The thesis contains also a critical review of some of the issues that form its general framework. Among these critical reviews we list here:

1. a critical review of the roles that can be played by System Dynamics in the analysis and resolution of environmental conflicts;

2. a critical review of the main participative and consensus based methods;

3. a critical review of decision processes with a single decider and a plurality of deciders[1] as well as of the multicriteria methods with a comparison with voting methods and an analysis of some impossibility results such as Arrow's and Sen's theorems.

Of course many issues are only hinted and many problems are still open. The thesis indeed does not represent a closed and finished work but rather it is a work in progress with a certain number of tenets.
Among the topics that deserve a further and deeper research we mention here:

1. the analysis of multi agent systems for the simulation of rule based interactions among agents in relation to mechanism design, negotiation protocols (in both task oriented and worth oriented domains), cooperation, coordination and competition (Wooldridge (2002));

2. the analysis of commercial products (such as NetLogo and AnyLogic) for the simulation of simple strategic behaviors;

3. the use of such products for the simulation of strategic behaviors and the definition of theoretical connections with paradigmatic situations (such as prisoner's dilemma and the like) of Game Theory.

[1] With the term **decider** I translate the Italian term "**decisore**".

2 The motivation of the thesis

The present thesis has its roots in many disciplines (among which we list Game Theory, System Dynamics, Decision and Social Choice Theory, Multicriteria decision tools) that we reviewed in order to understand how they can be merged so to define an original proposal centered on the need of collective shared decisions and commitments.
The main motivation of the thesis is to show how a conflicting cooperation is convenient for all the actors (deciders and stakeholders) involved in or affected by complex decision processes. Here we have two seemingly opposing terms: **conflict** and **cooperation**. One of the aims of the thesis is indeed to show that conflict alone is a hindrance but cooperation without conflict may give rise to premature and sub optimal solutions since the urgency to reach an agreement and a general consensus may impede the devising of better solution through the rising of conflicting positions.

3 The structure of the thesis

The thesis consists of an Introduction, three main sections and a set of Appendices.
The Introduction presents the general framework of the thesis, introduces a typical paradigmatic situation, the types of diagrams that are used in the thesis and closes with a brief outline of the thesis itself.
The first section is devoted to the analysis, within the general framework of the thesis, of Decision Theory, Social Choice Theory and Social Decision Theory. In this way we define a path from the **lone decider** (either acting in isolation or within a reactive environment) to a set of **social choosers** (that can be seen as filterers or as voters in a voting context) to a set of **social deciders** that act according to private choice matrices (Cioni (2008h)) and therefore take real decisions.
Then we analyze the possibility to have a **dynamic set of alternatives** (where rejected alternatives can be recovered in the decision process under certain conditions and circumstances) and a **dynamic set of deciders** (and criteria).
In this section we introduce a set of schematic case studies that are used and enriched throughout the rest of thesis.
The middle section examines the role of formal models for the formalization of **procedures**, **tools** and **models**.
Formalizing the procedures means defining fair and effective ways for:

1. choosing the deciders and the stakeholders that participate to a decision process;
2. choosing the criteria to be used in the decision process;
3. choosing the alternatives to be selected in the decision process;
4. defining the rules according to which the alternatives are filtered through the criteria;
5. defining the timings and the phases of a decision process;
6. defining the figures and roles that can act as a guarantee of the decision process itself.

Formalizing the tools means formalizing the ways through which the procedures are carried out. This formalization is required so to guarantee that the procedures are:

1. easy to use also by non trained people;
2. transparent in their functioning and in their outcomes;
3. effective since they allow their users to do the right thing at the right time and at the right decision level;
4. capable of managing complexity;
5. capable of incremental building and validation.

Formalizing the models is a way through which deciders and stakeholders gain a shared knowledge before and during a decision process. Its main goals are:

1. the revealing of hidden assumptions of the deciders;
2. the asserting of the real goals of the deciders;
3. the confessing of the beliefs and biases of every decider.

To this ends we may formalize either the interactions among the deciders (with either **Game Theory** or **Negotiation Procedures**) or the description of systems as a filtered portion of reality with **System Dynamics**.
The last section is devoted to the description and analysis of **participative methods** and **consensus based** decision-making practices (Elliot et al. (2005), Butler and Rothstein (2004) and Cioni (2008g)). In this section we

deal with methods grounded on System Dynamics (such as **Mediated Modeling**, van der Belt (2004), and **Group Model Building**, Vennix (1996)) for the devising of "all-win" solutions to environmental problems and conflicts.
The section closes with the definition of approaches for the participative choice among a set of dynamically defined alternatives from a set of dynamically defined deciders.
The two Appendices are devoted to the concise exposition of the more relevant and correlated theoretical results. Such Appendices contain background materials and well established results with a few extensions so to make the thesis as self contained as possible. The focus of these Appendices is on decision theory, social choice, multicriteria methods and tools, system dynamics and cooperative group model building, but we also comment a little on some basic concepts of Game Theory and the notions of fairness and equity. The last two issues play a central role in the proposed framework since the perception from all actors that the devised solutions are fair and equitable represents the core issue of the proposed framework.

4 The basic ingredients

Among the basic and founding ingredients we use in the devising and drawing up of the thesis we must mention **System Dynamics** (Wolsetnholme (1990), Daellenbach (1994), Cioni (2008d), Cioni (2008e)) as a tool over which tools such as **Group Model Building** (Vennix (1996)) (a way through which a group of deciders and stakeholders may cooperatively build a model that describes a problematic situation) or **Mediated Modeling** (van der Belt (2004)) (an approach based on System Dynamics for the building of consensus about the solution of environmental problems) are based.
The thesis (see also section 5) aims at showing how System Dynamics can play both positive and negative roles in the decision processes since such roles can foster the sharing of knowledge and the in-depth examination of the problems but can even prevent these features since models may be hard to handle and adapt to real situations from untrained deciders that may, therefore, be forced by System Dynamics practitioners to accept exogenously conceived solutions for their problems.
One of the ambitions of the thesis (see Cioni (2008d) and Cioni (2008e)) was to show the use of System Dynamics both as a tool for the definition of models of dynamic systems and as a tool for the description of the decision process itself or as a meta tool, Cioni (2008d). Unfortunately this ambition

has not been fully satisfied and that task is still an open problem.
Other basic and founding ingredients include:

1. Game Theory (Myerson (1991), Osborne and Rubinstein (1994), Bialas (March 2005), Patrone (2006), Fragnelli (2005), Cioni (2006), Cioni (2007a), Cioni (2008a) and Cioni (2008i)) as a tool for the description of the interactions among rational players with a full knowledge of the strategic situation;

2. Negotiation Procedures (Wooldridge (2002), Cioni (2008c) and Cioni (2008f)) as tools for the description of the interaction among players endowed with either a bounded or a very limited rationality and possibly with a reduced knowledge of their strategic situation;

3. decision processes (Arrow and Raynaud (1986), French (1986), Rapoport (1989), Hansson (1994), Saari (2001) and Cioni (2008h)) to describe how either single deciders or group of deciders may succeed in choosing the best alternative (according to some performance criteria) from an open or closed set of alternatives. The problem of the choice is very general and many solutions have been proposed. In this thesis we aim at defining fair solutions in the most general setting where all the elements of a decision process (alternatives, deciders and criteria) can vary dynamically during the process.

5 The main critical contributions

As we have stated in section 1 the thesis contains some critical contributions that are briefly examined in the current section. Such contributions include:

- a critical review of the roles of System Dynamics in the analysis and resolution of environmental conflicts;

- a critical review of the main participative and consensus based methods;

- a critical review of the decision processes with a single decider and a plurality of deciders as well as of the multicriteria methods together with their comparison with voting methods.

We devote a section to each contribution.

5.1 Critical review of System Dynamics

5.1.1 Introduction

The critical review (see Cioni (2008d) and Cioni (2008e)) we made of System Dynamics (SD) was very focused since we essentially aimed at understanding both which are the figures that can be involved in a shared model building process (Vennix (1996) and van der Belt (2004)) and which are the roles that can be played by SD for the solution of environmental problems. The review started from the main features of SD and was carried out in parallel with a survey of the basic reference books on the topic (here we only mention Roberts et al. (1983), Ford (1999), Daellenbach (1994), Wolsetnholme (1990), Vennix (1996), Kirkwood (1998), van der Belt (2004), Gallo (2005) and Gallo (2006)). Afterwards it went on with an analysis of the main keywords that characterize my approach and precisely: role, environment, problem and solution.

5.1.2 The model building process

The subsequent step was to analyze the process that, starting from portions of reality, brings to the definition of **systems** and, through a process of abstraction, to the devising of **models** that must be **validated**, so to increase the **confidence** of the designers and users in the models themselves, and **implemented**. The whole process is, indeed, **goal driven** since it aims at the solution of problematic situations through the devising of **proper policies**. From this perspective the main usefulness of the models is that of generating a **shared** and **well founded** knowledge of both a system, a problem and the possible policies aiming at its solution.
Afterwards we executed an analysis of the two terms that compose SD and therefore *System* and *Dynamics* so to understand in which cases and in which forms it is possible and fruitful to use SD for the solution of [environmental] problems. Then we examined both **qualitative** and **quantitative** SD so to examine both **Causal Loop Diagrams** with their features and possible uses and **Flow Diagrams** with their need of defining the mathematical relations among the elements of the models (the variables) and both the simulation parameters and the simulation algorithms. Together with these issues we examined the various meanings of the terms **problem** (as either an undesirable performance behavior pattern, Daellenbach (1994) or a perceived bad situation, Cioni (2008d) and Cioni (2008e)) and **solution** as a set of policies that steer the evolution of a system toward a desired goal (Cioni (2008d) and Cioni (2008e)). In this analysis we found that both the **level of perception** and the **level of urgency** play a major role as well as

the **temporal** and **spatial** scopes of a problem and its solutions.

5.1.3 The main figures

In parallel with these steps we also carried out an analysis of the main figures (that may play more than one role and be embodied by more than one person) that can be either involved in a decision process and, in particular, in a model building effort or used as supporting figures to those processes.
To the group of model builder we can assign **actors** (the more general category), **deciders** (that take decisions), **experts** (that support or contrast decisions through their formalized expertises) and **stakeholders** (that suffer or benefit from the effects of the decisions).
To the group of supporting people we may assign (Vennix (1996), van der Belt (2004) and Cioni (2008g)) the supporting figures such as the **facilitator** (that conducts the group process leading it without giving his personal opinions), the **peacekeeper** (that pays attention to the mood and tone of a meeting and keeps them under control through breaks or recalls to the common goal), the **agenda planners** (that set up an agenda to be proposed and approved by the other participants) and other minor figures.

5.1.4 The main roles

The last issue we examined is the **roles** that *SD* can play within the overall framework, the "big picture". The main roles we were able to identify include:

(1) *SD* as a **normative tool** or as a tool to describe how things should be in ideal settings;

(2) *SD* as a **descriptive tool** or as a tool to describe how things really are in real and concrete settings;

(3) *SD* as a **prescriptive tool** or as a tool to show how things can be made better and problems solved through the right actions performed on the models;

(4) *SD* as a **cognitive tool** or as tool for knowledge and skills sharing and for the acquisition of better and deeper knowledge of a problem and its possible solutions;

(5) *SD* as a **meta tool** or as a tool for the description of the decision process itself, its trends and its quality or its compliance with a set of well established performance criteria.

Once the roles have been defined and characterized (Cioni (2008d) and Cioni (2008d)) we identified the **arenas** in which these roles can be played as the **technical arena** (where experts use SD as either a descriptive tool or preferably a prescriptive or a normative tool), the **political arena** (where actors use SD as a prescriptive tool), the **critical arena** (where stakeholders, experts and deciders use SD as a cognitive tool) and the **procedural arena** (where actors or experts use SD as a meta tool).

5.2 Critical review of participative and consensus based methods

5.2.1 Introduction

The critical review of participative and consensus based methods has been carried out according to the following outline (see Cioni (2008g)):

(1) we started with an analysis of some of the major participatory methods;

(2) we considered the consensus method as a tool for formal decision-making;

(3) we then examined the possibility of cross fertilization between the points (1) and (2);

(4) we applied the outcomes of the above mentioned analyses to the detailed discussion of the use of one of the participatory methods, the **electronic Town Meeting**, for the [partial] definition of a law about participation from "Regione Toscana" (Cioni (2007b)).

To explain what **consensus based choice** means we can use a toy example. For instance we can use the selection of a restaurant from a set of friends so to solve the individual concerns about the type of food it is served in a proposed restaurant (availability of a vegetarian menu and of fish), the type of beverages (if they serve beer and/or tea and/or milk) and its range of cost. In this case a selection is made (with a call of consensus) when all concerns have been resolved or when those with unresolved concerns say that they do not block the decision and consent to it but they want to be assured that the next dinner will have place in a certain-different-kind-of restaurant (so to satisfy their unsatisfied demands).
The analysis of the participatory methods we made is essentially based on Elliot et al. (2005) whereas the analysis of consensus method relies on Butler and Rothstein (2004) and for the cross fertilization section we referred to Pareglio et al. (1999) where a general framework for the design of policies for

the solution of environmental problems is presented in details and analyzed with the help, also, of a set of case studies. As a general reference another important source was Kluver et al. (2000) where the results of a project for the assessment of technologies are presented and discussed in detail.

5.2.2 Analysis of participatory methods

To analyze the participatory methods we followed this outline (see also Elliot et al. (2005)):

(1) we selected a small set of representative methods;

(2) we chose a certain numbers of parameters as performance criteria;

(3) we described the selected methods as a function of such criteria;

(4) we tried to verify whether it is possible to subdivide the methods in homogeneous subsets through the use of subsets of the performance criteria by considering them equally important;

(5) we tried to verify if it is possible to subdivide the methods in categories through the use of either **lexicographic orderings** or either **ranking** or **multicriteria** methods by assigning weights to the criteria through either a **ranking method** or **rating method** (Cioni (2008g)) or a **common scale and pairwise comparisons** (Saaty (1980)).

Such analysis has been carried out together with an analysis of the meaning of a participatory approach, the reasons for using it, at which level and during which phase of a decision process it can be used and how a method can be chosen and implemented.
As to the parameters we chose, according to Elliot et al. (2005), some parameters that relate more directly to the method itself (objectives, type of the participants, durations) and some others that relate more directly to the issue that is the object of the method (level of knowledge and of maturity of the participants and level of complexity and "controversiality" of the issue).

5.2.3 Analysis of the Formal consensus decision-making method

The analysis of the *Formal consensus decision-making method* (or *FCDM* method) has been carried out using Butler and Rothstein (2004). In this case the main aims were:

(1) to describe the group dynamics in a consensus oriented framework;

(2) to analyze the iterative nature of the *FCDM* process by analyzing its phases, the presence of feedback loops and of evaluation phases as a quality feedback among its participants;

(3) to examine its basic principles and its supporting figures;

(4) to frame it within the parametrized approach that we used to describe the other participatory methods.

The *FCDM* has been analyzed both as a method similar to the others but also as a method to choose methods (or a meta method) and as a source of tools for other participatory methods (as a toolbox).

5.2.4 Possibilities of cross fertilizations

As to the possibilities of **cross fertilization** we decided to follow the following guidelines:

(1) first of all we examined the possibility of integrating the participatory methods (among which we included also *FCDM*) in a web of methods so to define a composed method;

(2) then we tried to see which **principles**, **features**, **techniques** and **roles** can be derived from an *FCDM* method to be applied within other participatory methods or their compositions;

(3) lastly we examined the possibility to use an *FCDM* method as a meta tool for the choice of the methods to be integrated and the ways in which it is possible to integrate them (making a link with (1)).

As to the possibilities of integrating the participatory methods, point **(1)**, to form a composite method so to widen its participants area or its scope or both we examined the following possibilities:

(a) **parallel composition** as a set of methods run in parallel,

(b) **sequential composition** as a set of methods run in sequence,

(c) **mixed composition**,

(d) **heterogeneous composition**,

of composing methods of the same **homogeneous** types or of different or **heterogeneous** types.
With the term **mixed composition** we mean either a parallel/sequential

composition (a set of methods run in parallel followed by a single method) or a sequential/parallel composition (a method followed by a set of methods run in parallel) or a sequential/parallel/sequential composition (a combination of the preceding cases). In all the cases where a closing synthesizing method is missing such a phase is up to the political or administrative deciders.
An **heterogeneous composition**, on the other hand, allows the interconnection of methods according to "free" topologies with the only constraint that the methods are connected in a (preferably acyclic) directed graph with one or more starting methods and one or more closing methods (preferably only one). By definition the starting methods provide the basic formalized knowledge of an issue to the other methods whereas the single closing method (if it is present) performs the synthesis of all the various methods' outcomes and is the direct interface with the political deciders.
For what concerns point **(2)** we note that:

1. the basic principles and features of the $FCDM$ method may be properly used within any other method since they aim at characterizing peer-to-peer relationships grounded on trust, respect, nonviolence, unity of purpose, active participation and other features of general validity if we want to have fair decision-making methods;

2. the main techniques of the $FCDM$ method, both facilitation techniques and group discussion techniques, can be easily exported to any other method since they aim either at assuring a smooth flow of the discussion or at introducing variants (such as "small groups", "brainstorming", "fishbowl" and "caucusing") to the classical "one person at a time to the whole group" scheme of discussion in order to stimulate the discussion, to deal with ticklish issues and to foster the devising of better solutions;

3. the basic supporting roles (such as "agenda planner", "facilitator", "advocate" and "timekeeper") can as well be exported to any other method since they aim at solving general problems common to any decision problem involving wide groups of participants.

For what concerns the use of $FCDM$ method as a meta tool, point **(3)**, we note how it is possible to consider the process of deciding which methods may be used and connected in which ways in a directed graph as the task of a $FCDM$ method. In this way through the use of consensus based practices it is possible either to choose a single method or a group of methods and how they are related (i.e. interconnected) each other for the carrying out of a decision process.

5.3 Critical review of decision and multicriteria processes

5.3.1 Introduction

The analysis of both decision and multicriteria processes (see Cioni (2008h)) has been carried out starting from a set of traditional and consolidated results but moving quickly towards “heretical” and provocative issues at the search of novel results in these well developed fields.

5.3.2 Decision-making processes

As to the **decision processes** as described by **decision theory** we started by analyzing some basic principles and tools then we examined the various conditions under which a decision may be taken (risk, uncertainty and ignorance) and that have no universally accepted definitions in the literature. So we had to make both a survey and a redefinition of such conditions (in accordance with Collingridge (1983)). For every decision process we introduced the sets of the alternatives, criteria and states of the world.
Afterwards we started with the simple situation of a **lone decider** so to describe the structure and the properties of a decision-making process in this case where the decider acts in a sort of private and isolated (though possibly “probabilistic” or [at least partially] “unknown”) world. The next step has seen the introduction of a reactive environment into the decision-making process through the definition of a set of **stakeholders** that can act either as supporters or as opponents or as both of the decisions of the decider and turn an episodic process (where the decisions have no influence on the following and are not influenced by the preceding) in a continuous process where the decisions form a continuous stream of mutually forward (the present influences the future) and backward (the future influences the present) influencing decisions.
The last step was twofold:

1. on one hand we defined decision-making procedures with many deciders that may share or not the alternatives, the states of the world and the criteria;

2. on the other hand we defined the decision-making procedures within a competition framework that can be solved through the use of negotiation procedures.

As to the latter point we may have the following possibilities:

- a set of deciders D_1 propose an issue i_1 that, after its revelation, finds the opposition of another set of deciders D_2;
- a set of deciders D_1 proposes an issue i_1 whereas, after its revelation, another set of deciders D_2 proposes a competing issue i_2.

Of course these are not the only possibilities but represent the cases we dealt with in this thesis.
In the former case we speak simply of **negotiation procedures** whereas in the latter we speak of **double negotiation procedures** to underline the presence of two competing issues though the two cases obviously share many features.

5.3.3 Multicriteria processes

As to the **multicriteria processes** our main aim was twofold:

(1) to examine some of them and analyze their features in practical settings,

(2) to see under which conditions it is possible to "reduce" such methods to voting procedures.

As to the point **(1)**, under the correspondences of criteria as voters and alternatives as candidates, we examined the possibility to use classical voting oriented methods such as the **Condorcet method** and the **Borda rule** but also some "exotic" method such as **single transferable vote** rule. In addition to this approach and disregarding the above mentioned correspondences we examined methods purposely conceived for the treatment of such problems such as $ELECTRE$, $PROMETEE$ and similar methods.
As to the point **(2)** we devoted some attention to the problem of the weights definition in the general case where criteria have unequal importances and examined some of the ways in which this assignment is possible (Cioni (2008g) and Cioni (2008h)). Under the condition of both equal and different weights we then examined under which conditions it is possible to "reduce" multicriteria methods to voting procedures and how classical impossibility results from voting theory (essentially Arrow's theorem and Sen's theorem) may influence this reduction and if they may, in some cases, turn a multicriteria method into a single criterion one. This part of the thesis at the time of this writing is still to be fully developed though some partial results have been obtained.
What we have still to evaluate are the possible influences of the impossibility results of voting theory on multicriteria methods since these can be seen both as decision-making and decision aiding (or supporting) tools (see also section 6.4).

6 The main results

The main results of the thesis have been listed in section 1 and are briefly examined in the following sections.

6.1 The use of auctions for the allocations of chores

6.1.1 Introduction

In this section (Cioni (2008b) and Cioni (2008f)) we present an application of the auction mechanisms to the allocation of a chore to one of the bidders belonging to a given set $\mathscr{B}$. We aim at showing how the classic auction mechanism can be modified and adapted for the allocation of bads or chores instead of the allocation of goods.

6.1.2 The theoretical background

We started with an analysis of some classical auction mechanisms as well as of the notion of chore and its main properties.
As to the auctions (Klemperer (1999), Wooldridge (2002), Milgrom (2004), Fragnelli (2005) and Patrone (2006)) we note how they are usually used for the allocation of goods where a **good** has a (not only monetary) **value** for both a seller and a buyer and this value may turn into the sum of money the seller gets from the buyer if the sale occurs.
Among the classical auction mechanisms we examined we mention here **English auctions**, **Dutch auctions**, **First price auctions** and **Second price or Vickrey auctions**. Then we examined the concept of **chore** as a "a difficult or disagreeable task" within a framework where the seller/auctioneer of the chore is willing to pay somebody else (a bidder or a server) to carry out that chore. A chore has a negative value for both the auctioneer and each bidder so a chore is something that nobody wants.

6.1.3 Modified auctions

After the afore mentioned analysis we extended the classical auction mechanism and devised the following three mutually exclusive mechanisms, the first two of multi shots type and the latter of one shot type.

1. The auctioneer **a** offers the chore and a sum of money m and raises the offer (up to an upper bound M) until when one of the bidders accepts it and gets both the chore and the money. The auction ends if either one of the bidders calls "stop" or if the auctioneer reaches M without

none of the bidders calling "stop". In the latter case we have a void auction sale, though this is not in the best interest of the auctioneer. The auctioneer can avoid this by properly selecting the bidders that attend the auction.
In this case the skeleton of the proposed algorithm is the following:

(a) **a** starts the game with a starting offer $x = x_0 < M$;

(b) bidders b_i may either accept (by calling "stop") or refuse;

(c) if one b_i accepts[2] the auction is over, go to (e);

(d) if none accepts and $x < M$ then **a** rises the offer as $x = x + \delta$ with $0 < \delta < M - x$ and go to (b) otherwise go to (e);

(e) end.

As to the best strategies we note how the auctioneer's best strategy is to use a very low value of x_0 so to stay lower than the lowest m_i (to be defined shortly) and, at each step, to rise it of a small fraction δ with the rate of increment of δ decreasing the more x approaches to$M$.
The bidder b_i's best strategy is to refuse any offer that is lower than his evaluation m_i of the chore and to accept when $x = m_i$ since if he refuses that price he risks to lose the auction in favor of another bidder who accepts that offer.
This algorithm can be used in all cases where the auctioneer wants to "sell a chore" to the "worst offering" or to have a chore carried out by somebody else by paying him the least sum of money.

2. The auctioneer **a** offers the chore and fixes an initial sum of money L (that is the worth of the chore for the auctioneer himself). The bidders start making lower and lower bids. The bidder who bid less gets the chore and the money. Of course the auctioneer has no lower bound. Under the hypothesis that the bidders are not willing to pay for getting the chore we can suppose a lower bound $l = 0$. If this hypothesis is removed we can, at least theoretically, have $l = -\infty$. It is possible to have a void auction sale if no bidder accepts the initial value L. The auctioneer can avoid this by fixing a high enough value L that depends on his willingness to pay. The deeper analysis of this type of modified auction for the moment has been suspended.

3. The auctioneer **a** offers the chore and the bidders bid money for not getting it under the proviso that the one who bids less will get the

[2] Possible ties may be resolved with a random device.

chore whereas the bids of the others will be used to form a monetary compensation for the loser. Also in this case it is possible to have a void auction sale though this is not in the best interest of the auctioneer. The bidders may pay an exclusion fee **f** for not attending the auction (to be explained shortly). In this way we partition the set of the bidders $\mathscr{B}$ as the subset of those who do ($\hat{\mathscr{B}}$) and those who do not ($\mathscr{B} \setminus \hat{\mathscr{B}}$) attend the auction.
In this case the algorithm we devised has the following basic structure:

(a) **a** presents the chore to the[3] $b_i \in \hat{\mathscr{B}}$;

(b) each b_i makes his bid x_i,

(c) **a** collects the bids and reveals them once they have all been collected;

(d) the bidder who bid less gets the chore;

(e) the other bidders compensate him for this and the auctioneer gives him the total fee he received from the bidders of the set $\mathscr{B} \setminus \hat{\mathscr{B}}$ (those who gave up the auction).

The fee **f** is a way to introduce the property of individual rationality (or voluntary participation) in this mechanism and is a sum fixed by **a** that the bidders may pay so to be excluded form the auction.
As to the compensations we note how they are paid by the bidders who won the auctions in this way avoiding the assignment of the chore.
As to the strategies of the bidders we were able to prove that their best strategy is to bid truthfully or to bid a sum equal to their evaluation of the chore.

As **performance criteria** for the modified auctions we decided to use (Rapoport (1989), Myerson (1991), Wooldridge (2002), Klemperer (2002) and Patrone (2006)) **guaranteed success**, **Pareto efficiency**, **individual rationality**, **stability** and **simplicity** and verified if and how each of them is satisfied by the proposed mechanisms.

6.1.4 The framing situation

The mechanisms we devised have been inspired by the following situation. We have an authority (commissioning authority) that wants to find a place

[3] We suppose that the set of current participants that did not pay the exclusion fee $\hat{\mathscr{B}}$ contains at least two bidders. If it is empty the auctioneer can repeat the auction by defining a new set to be filtered with a fee payment mechanism. If it contains only one bidder no auction really occurs and the auctioneer compensates him with the revenue from the exclusion fees paid by the other bidders.

where to implement a controversial plant such as an incinerator, a dumping ground, a heavy impact industrial plant or something like that. The essential feature is that the planned infrastructure is something that nobody wants but whose services, if the infrastructure is effectively implemented, may be used by a wide group of other authorities. From this perspective it could also be a commercial port or a marina or an airport. The discriminating criterion is that the object of the agreement causes problems mainly to the accepting authority but has a use value for possibly that authority also and for a wider group of authorities that may include also the commissioning authority. We therefore explicitly disregard situations where an agreement among a set of authorities is needed for building the infrastructure as it happens in cases such has railway lines, highways, ship-canals and the like.
We have therefore an authority that makes a request and another authority (to be selected in some way) that accepts to satisfy the request by essentially providing a portion of "its" territory.
The commissioning authority therefore can identify such an authority through an auction like mechanism that involves the selection of a certain number of potential contractors (on the base of technical and economical considerations) over which it has no binding authority but with which it tries to achieve an agreement.

6.2 Barter models

6.2.1 Introduction

In this section we present the analysis we made of **barter models** under the hypotheses of absence of any numerary good, any common scale and any common evaluation or evaluator or even a market.
After a theoretical analysis of existing solutions to similar problems (see section 6.2.2) we devised a family of models (Cioni (2008c) and Cioni (2008f)) that involve a pair of actors[4] that aim at bartering the goods from two privately owned pools of heterogeneous goods. Within our framework the barter can occur only once or can be a repeated process with possibilities of retaliation and can involve either a single good or a basket of goods from each actor. We examined mainly the basic symmetric model (one-to-one barter) but also examined its extensions (one-to-many, many-to-one and many-to-many barters), none of which reproduces a symmetric situation. We moreover devised two other "hybrid" models. The basic criteria (from Brams and Taylor (1996), Brams and Taylor (1999) and Young (1994)) we considered

[4]We use the terms **actors** and **players** as synonyms.

both as design and evaluation criteria are **envy-freeness**, **equitability** and **Pareto efficiency** that we adapted to the current context.

6.2.2 The cultural background

We started the analysis of these issues with Brams and Taylor (1996) whose authors propose a lot of tools and algorithms for the allocation of goods for both divisible and indivisible cases. They start from $n = 2$ players and then extend their results to the general cases with $n > 2$. In these models the players aim at more or less fair sharing of a common pool of goods on which they state preferences that can be compared in some way, even on common cardinals scales.

We examined also Brams and Taylor (1999), where authors present various methods for the allocation of the goods from a single pool, starting with (strict and balanced) alternation methods to switch to divide-and-choose and to end with adjusted winner method.

Also all these methods are devised to allow more or less fair divisions between two players of the goods belonging to a common pool (though extensions to more than two players are provided for all the methods).

We note, moreover, how adjusted winner method requires the use of a common cardinal scale among the players since it requires that each of them assigns to each good some points on 100 and that such points are compared (either directly or as ratios) so to determine to which player every good is assigned.

A short analysis of classical solutions for the division of goods can be found also in Fragnelli (2005) again with regard to either one or more divisible goods or a pool of indivisible goods. Again the presence of a common pool of goods among the players makes such tools inappropriate as solutions to our problem.

From the comments made in Fragnelli (2005) about auctions, moreover, it is also evident how such tools are not suitable to solve our problem.

Other solutions to division problems that we found in the literature involve **market games** (Fragnelli (2005)), **assignment games** (Fragnelli (2005)) and **cost games** (Fragnelli (2005)).

6.2.3 The basic motivation

We wished to devise models to describe how an exchange of goods can happen without the intervention of any transferable utility such that represented by money or by any other numerary good. In this way all actors involved do not need to share anything such as preferences or utilities as

shared information but the will to propose pool of goods (or bads, collectively called items) that they present each other so to perform some form of barter.
We underline how we aimed at giving an approach more **descriptive** than **normative** since we were more interested in giving a framework that allowed the description of actors' possible behaviors in various abstract settings than in giving (more or less detailed) recipes through which players can attain their best outcomes.

6.2.4 The basic barter models

The first family of algorithms we devised involves an actor A with his pool I of n heterogeneous goods and an actor B with her pool J of m heterogeneous goods.
A and B assign private (since they are known only to the assigner) values to each own's goods in I and J respectively.
In a similar way we can define the appraisals of the goods of B from A and the appraisals of the goods of A from B. We defined four basic types of barter:

1. **one-to-one** or one good for one good;
2. **one-to-many** or one good for a basket of goods;
3. **many-to-one** or a basket of goods for one good;
4. **many-to-many** or a basket of goods for a basket of goods.

For every type of barter we conceived both the simultaneous (or "blind" or private) requests version and the sequential requests version.
In the case of the **one-to-one barter** with **simultaneous requests** we devised the following algorithm:

1. both A and B show each other their sets I and J;
2. both players negotiate if the barter is [still] possible or not[5];
    (a) if it is not possible (double refusal) then go to step 6;
    (b) if it is possible then continue;
3. both simultaneously perform their blind choice[6];

[5]At the very beginning of the process we suppose the barter is possible though this does not necessarily hold at successive interactions.
[6]Simultaneous requests occur like simultaneous moves in Game Theory.

4. when the choices have been made and revealed (so that A requires $j \in J$ and B requires $i \in I$) both A and B can make an evaluation and say if each accepts or refuses;

5. we can have one of the following cases:

   (a) if both accept then go to step 6;

   (b) if A refuses and B accepts then:
   at A's full discretion

      i. either A executes $I = I \setminus \{i\}$ and if $(I \neq \emptyset)$ then go to step 2 else go to step 6;

      ii. or A only makes a new choice and then go to step 4;

   (c) if A accepts and B refuses then:
   at B's full discretion

      i. either B executes $J = J \setminus \{j\}$ and if $(J \neq \emptyset)$ then go to step 2 else go to step 6;

      ii. or B only makes a new choice and then go to step 4;

   (d) if both refuse then:

      i. $I = I \setminus \{i\}$;

      ii. $J = J \setminus \{j\}$;

      iii. if $(I \neq \emptyset$ and $J \neq \emptyset)$ then go to step 2 else go to step 6;

6. end of the barter.

We suppose that the player who refuses may decide to reduce the set of his offered goods since we implicitly assume that the two players start the barter with the widest possible set of goods.
In the **one-to-one barter** with **sequential requests** we introduced a chance move (such as the toss of a fair coin) to decide who moves first and makes a choice but, apart from this, the structure of the algorithm is basically unchanged. In this case, indeed, at every single refusal there is a new chance move that triggers a new sequential selection.
The other cases of **one-to-many**, **many-to-one** and **many-to-many** barters (with simultaneous or sequential requests) work almost in the same way but for the fact that there are involved subsets of goods and not single goods and that the methods are suitable for the case of "light" goods versus "heavy " goods where the meaning of the terms "light" and "heavy" may depend on the application and must be agreed on during a pre-barter phase by the actors themselves.

6.2.5 Hybrid models with alternating requests

In addition to the models we presented so far we devised the following "hybrid" models:

1. **pure model**, nobody shows, hidden goods;

2. **mixed model**, shown goods, hidden goods.

In the **pure model** case the situation we were interested in can be described in the following terms. One of the two players is interested in giving a good or bad to the other player so to get back a good or a bad (gods and bads collectively may be called items).
Such an exchange may be carried out with a barter where each player in turn proposes a pair of items (i, j) (where one of the two is known to the player whereas the other is fundamentally a guess of the other player capabilities) that can be either accepted or refused by the other. Things go on until:

1. both agree on a proposal and the barter occurs,

2. one of the two refuses without a counterproposal so that the barter closes with a failure.

During the process, the two players reveal each other the items they are willing to barter and this revelation process (Myerson (1991)) allows the definition of a shared knowledge base that can be use to ease the barter itself.
In the **mixed model** case we devised an asymmetric situation where A (for instance) shows his items and B tries to get one or more of them by giving one of her items to A.
In this case the items of A are common knowledge between the two players and we have a certain number of steps during which A tries to acquire the best knowledge of the items of B. The process goes on until either both accept and a barter occurs (so that the process ends with success) or both agree that no agreement is possible and the process ends with a failure.

6.3 The role of Game Theory in its two flavors

6.3.1 Introduction

The adopted approach to Game Theory aimed at the integration of methods from Cooperative Game Theory (CGT) and Non Cooperative Game Theory ($NCGT$) within the following scheme (Cioni (2007a)):

```
initial_set_up
while(problem_exists)
do
   coalitions_interaction;  \\NCGT
   coalitions_dynamics;     \\CGT
end
```

The scheme describes a possibly infinitely lasting cyclical structure in which coalitions interact during a *NCGT* phase (as if they were individual players) that is followed by a *CGT* phase where coalitions may vary their structure. The various coalitions form in the starting *initial_set_up* phase, possibly as single player coalitions, and the cycle is governed by the flag *problem_exists* that assumes a *true* value as long as the problem that caused the raising of the interactions among the players and the forming of coalitions exists. Within this framework (Cioni (2007a)) we examined the dynamics of coalitions that form under the pressure of environmental problems and also devised a bottom-up approach to the solution of problems through the formation of coalitions among players that suffer a problem (**clients**) and players that can solve it (**servers** that can be also clients, see section 6.3.2).

6.3.2 Coalition dynamics in environmental problem solving

Within the framework of both *CGT* and *NCGT* (see section 6.3.1) we therefore examined (Cioni (2007a)) the dynamics of coalitions that form under the pressure of environmental problems. The aim of the analysis was to see how coalitions form as soon as a minimal set of players finds it is either convenient or necessary to join a coalition, last for some more or less long periods of time and then may either widen or shrink so that a coalition becomes an empty shell and loses its reason of being. Keeping a coalition active for long periods of time requires both the use of resources to keep the members convinced that the coalition is useful and the continuous presence of the problem that caused the rising of the coalition. Such resources are necessary for the communication among the members and the sharing of resources, benefits and costs under the form of side payments. A hidden assumption is that members interact repeatedly over time so that their knowledge of previous interactive attitudes can be used in current interactions in order to favor both co-operative and competitive attitudes.
To do this we analyzed the main features of **environmental problems**, **single players** (and the associated concept of rationality in its variants), **coalitions** of n players (with both inner and outer free riders) and **coalition dynamics**. We then examined the issue of environmental problems

solving with costs and benefits also of non monetary nature.
The analysis then moved to the examination of coalitions forming from a starting kernel that can grow up to the grand coalition but also give rise to competing coalitions that threaten each other's stability. Classical solutions concepts of CGT have been examined as well as classical solutions concepts of $NCGT$ with the aim of a strict cooperation between the two basic philosophies.
The possibility of integration of the methods of $NCGT$ with those of CGT has been analyzed through the definition of the **interaction continuum** types among the players. Such a continuum has two ends. At the left end we have independence among players (that can also be coalitions as monolithic entities) and at the right end we have coalitions with their inner dynamics. Inner levels include (from left to right) **coordination**, **collaboration** and **cooperation**. Along this continuum we switch from $NCGT$ on the left half (up to coordination) to CGT from there on.
In parallel with the theoretical analysis we examined practical cases of environmental coalitions and their dynamics as to global problems (such as **Kyoto Protocol**, **Oslo Protocol** and **Montreal Protocol**) or local problems (such as the **Val di Susa** affair or the **incinerator of San Donnino** affair or the **Florence rapid line** affair) so to frame them in the general scheme of section 6.3.1.

6.3.3 Bottom-up coalitions construction and problem solving

A bottom-up model for the building of coalitions for the localized solution of environmental problems is another algorithm that we have started to devise and that, at the time of this writing, must be fully refined and analyzed (Cioni (2008a) and Cioni (2008i)). Also this algorithm, along the same lines of what we have seen in section 6.3.1, is inspired by both Cooperative and Non Cooperative Game Theory.
The basic idea is the following. The starting point is a model that describes how a player can create a coalition for the solution of a problem that affects him as well as other players that can have also the capabilities of acting as solvers of the same problem for themselves and for the begging player.
The process of coalition construction is termed bottom-up since the staring point is a player that tries to form a coalition for the solution of a problem that he is not able to solve by himself. That player contacts other players that:

(1) are/are not affected by the same problem,

(2) are capable/incapable of solving that problem for themselves and for others.

Affected but incapable players can form a coalition and look for a capable player. Once a capable player has been found the members of the coalition can bargain with him (the so called solver) who can either negotiate with the whole coalition or with a sub-coalition. This latter attempt may succeed or fail depending on the stability of the coalition itself. We also tried to describe how the coalition can grow through the addition of more affected and incapable players until when it grows so much that, in lack of a common available solution, it splits in a certain number of sub-coalitions that tend to compete for the access to the available solver[s].
The devised algorithm is structured so that its termination is always guaranteed, given that the players form a finite set, and the probability of success (the affected but incapable players find at least one solver) is maximized though it is usually less that one so that there is no guarantee of success.

6.4 Multicriteria methods as voting methods

As we already discussed in section 5.3.3, during the analysis of some of the existing multicriteria methods (Cioni (2008h)) we examined how it could be possible to see the multicriteria methods as essentially a reformulation of voting rules with the correspondences between criteria and voters and between alternatives and candidates. In this way we can apply all the theoretical results we have for voting systems to multicriteria methods and, for instance, discover when a multicriteria method really is a mono criterion method through the application of the same theoretical impossibility results.
As a starting point we examined the problem of assigning a normalized[7] vector of weights W to the set of criteria C.
Basically this assignment can be made in an easy way or in a more complex way. In the former case the criteria have the same importance and so the same weights whereas in the latter case the criteria have the different importances and so different weights.
If the criteria have the same importance it is as if the weights are all equal to 1. If the criteria have the different importances the assignment of values to the weights can be performed in one of the following ways (Cioni (2008h)).

(1) With a **ranking method** or by defining an ordinal ranking to be mapped an a cardinal ranking. This mapping may be carried out (a) by

[7]With this term we denote the fact that the sum of the elements of the vector is equal to 1.

defining the range of the assigned values, (b) splitting it in the proper number of subintervals, (c) assigning each ordinal but numerical value to the nearest subinterval bound and (d) by normalizing the elements thus evaluated.

(2) With a **rating method** or by assigning to each criterion a certain number of points from 100 and dividing such a number by 100 so to define a normalized vector of weights.

(3) With a **common scale and pairwise comparisons** (Saaty (1980)) by performing pairwise comparisons among the criteria trough the use of a fixed numerical scale so to create a square matrix and solve an eigenvalue/eigenvector problem with some approximate methods whose outcome is the vector W.

Another problem that we examined and to which we gave tentative solutions is that of the independence or dependence among the criteria.
The **condition of independence** is a necessary condition if we want to consider criteria as voters since the existence of a dependence violates the principles of anonymity and uniformity of the voters.
If the criteria are **independent** they can be considered as such whereas if they are **dependent** it is necessary to analyze the type of dependency to see whether it is possible to arrange things so to obtain a possibly different set of independent criteria.
The dependence among the criteria may be of essentially two types:

(d1) group type,

(d2) lexicographic type.

In the case $(d2)$ the transformation of dependent criteria into independent criteria is impossible since criteria have a sort of hierarchic ordering so the alternatives are ranked according to a sort of "benevolent dictatorship" of a criterion over the following ones (if any).
In the case $(d1)$, given the set of the criteria is $C = \{c_1, c_2, \dots, c_n\}$, we can have two cases:

(d1a) the groups of dependent criteria are a partition of the set C,

(d1b) the groups of dependent criteria are not disjoint and do not form a partition of the set C.

Both cases can be dealt with through simple numerical techniques (Cioni (2008h)) so to define independent macro criteria. Each macro criterion contains a subset of the original criteria and can be used to provide a total

ranking of the alternatives. Such macro criteria can be used as if they were single independent criteria though their inner structure may give rise to either lexicographic or more complex relations among the composing criteria. In any case we devised simple computational methods to turn a set of mutually dependent criteria in subsets of criteria where these subsets are independent one from the others. This transformation required the definition of a binary relation of dependence among the criteria and in the verification of its being or not an equivalence relation.
This analysis brought me to identify the following four situations:

(1) equal weights and independence, easy mapping;

(2) equal weights but dependence,

(3) different weights and independence,

(4) different weights but dependence.

In the case **(1)** it is immediate to consider criteria as voters and alternatives as candidates so the mapping of multicriteria methods over voting methods is straightforward.
In the case **(2)** we have to resolve the problem of the dependence among the criteria with one of the methods we have mentioned right above.
In the case **(3)** we have only to convert a set of criteria C with different weights W in a new set of criteria C' with equal weights W'. The procedure may be the following. If to the set C we have associated a set W whose elements w_i are rational numbers of the form n_i/d_i we can convert the weights in a vector W'. The elements of such a vector have the form $w'_i = n'_i/d'_i$ where d'_i is the minimum common multiplier of the d_i and n'_i is the corresponding numerator. In this way we can define a new set of criteria C' by cloning each criterion c_j in n'_i copies over d'_i. In this way we switch from the set C with m criteria of different weights to the set C' with $m' > m$ criteria of the same weight.
Lastly in the case **(4)** we have to perform both conversions.
Once the mapping has occurred we have got a set of independent criteria with equal weights that can be properly seen as voters whereas the alternatives are seen as candidates. In this way it is possible to deal with a multicriteria problem as if it was a voting problem and so by applying to it one of the available voting systems. So doing the final ranking of the alternatives/candidates from the voters/criteria is both the outcome of the electoral process and the final ranking of the multicriteria method.
As we have already noticed, the aim of this is to show how the multicriteria

methods are essentially a reformulation of voting rules so that they suffer from the same theoretical impossibility results.
At the time of this writing this part of the thesis must yet be put right since there are still some theoretical and practical points to be cleared up.

7 Concluding remarks and future plans

In this paper I presented an overview of my thesis. Owing to time constraints I had to plan an end of its development and writing so that some issues have been left open and not all problems and issues have been solved or finished.
From this point of view the thesis can be seen more as an intermediate point of an ongoing work that I hope I can carry on and complete in the next future.
Among the issues I wish to be able to develop and complete I mention here:

1. the use of System Dynamics as a meta tool;

2. the extension and a more accurate formalization of the models of section 6.1.1 with an analysis of their properties;

3. the extension and a more accurate formalization of the models of section 6.2 with an analysis of their properties;

4. the extension of the model of section 6.3.3 to coalitions with constraints of territorial contiguity both top-down driven and bottom-up driven;

5. the analysis of the multi agents paradigm for the simulation of interactions based on rules and in relation to protocols of negotiation, argumentation, mechanism design, task sharing, coordination, cooperation and competition;

6. the analysis and use of commercial products of multi agent systems for the simulation of strategic behaviors with links with Game Theory.

Thanks

First of all I wish to thank Professor Giorgio Gallo who supervised me, in the past, for my Master Degree thesis in "Computer Science" and that, notwithstanding this, accepted the hard task to guide me during my PhD course in "Matematica per le decisioni Economiche" and to act as the supervisor of this PhD thesis.

His contributions are almost uncountable. First of all he suggested the title of the thesis and many of its topics. He also suggested me a lot of good readings and had to correct the uncountable errors and misspellings of the various versions of my thesis. Then he had to contrast my tendency to "creative" digressions so to keep me on track, surely the labor of Sisyphus. Last but not least he spent a lot of time in trying to convince me that my way of writing the thesis was wrong, that I had to be more precise, cite the sources, avoid to reinvent the wheel and to devise strange ways to heat the water, some self evident (but not for me) applications of Occam's razor.
Then I wish to thank Professor Franco Vito Fragnelli of "Università del Piemonte Orientale" for his advice and help.
Last but not least I wish to mention and thank here my colleague and friend Fausto Pascali without whose spur, support and example I could not have been able to finish my PhD course and my thesis.

Availability

Most of the papers of myself are available, at the time of this writing, at *http://www.di.unipi.it/~lcioni/papers* at the proper year.

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