Paradigm Green: AI Approaches to Evaluating the Economic Consequences of Changing Environmental Viewpoints[1]

ABSTRACT. Success of many projects depends on inclusion of socio-cultural viewpoints (paradigms) at the policy formulation and project planning stages. Semantic networks may be used to represent relationships among individuals and groups to evaluate hypotheses about paradigm change in the social systems within which policies are enacted. Expert systems may then be used to determine parameter values in socio-ecological models formulated to evaluate the economic consequences of policies reflecting environmental management paradigms.

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Changing public attitudes towards environmental issues may override ecological considerations in determining resource management policy (Halleran 1990). In managing all public policy issues, the societal background provides the context within which policy is ultimately determined (Barrows and Morris 1989). Consideration of viewpoints is now regarded as essential in the planning process (Boshoff 1989). However, difficulties in combining socio-cultural and biophysical knowledge have resulted in a significant gap in knowledge necessary to formulate sound policies and programs (Lovelace 1985a).

In this study, I first discuss the manner in which paradigms and policies interact. I then suggest ways in which AI applications, specifically semantic nets and expert systems,

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can help bridge that knowledge gap by guiding the setting of parameter values in economic and socio-ecological models. AI methods may also be used to evaluate the performance indicators of such models.

Paradigms

People's views on their relationship with nature is one of the most important aspects of any strategy for human development (Colby 1990). A five-stage evolution of such views, or paradigms, was described by Colby (1990), who provided a four-part definition of "paradigm":

1) "a criterion for choosing problems... that can be assumed to have solutions. Other problems are rejected as metaphysical, as the concern of another discipline, or sometimes as just too problematic to be worth the time";
2) "the entire constellation of beliefs, values, techniques, and so on shared by members of a given community, or one element in that constellation, the concrete puzzle-solutions which, employed as models or examples, can replace explicit rules as a basis for the solution of the remaining puzzles of normal science";
3) "not the same as shared rules; the existence of a paradigm may not even imply that any full set of rules exists (Kuhn 1970)";
4) "a worldview or mode of perception; a model around which reality is organized (Berman 1981)."

The early, diametrically opposed paradigms of "frontier economics" and "deep ecology" are viewed as evolving through an "environmental protection" and "resource management" paradigm towards an "eco-development" paradigm in which "human activities ... (are) synergetic with ecosystem processes and services" (Colby 1990). Smith (1990) suggests that successful strategies for sustainable agriculture in the tropics will hinge on use of an eco-development type paradigm in which advances in scientific research are combined with traditional societies' knowledge of natural resources and their management.

The Model Village

There are two basic frameworks or models of society for viewing the context within which policy is created: the "consensus theory" resulting from a dominant set of shared values, and the "conflict theory" based on domination and constraint (Barrows 1989). For agrarian societies, these two models are reflected in the opposing views outlined in *The Moral Economy of the Peasant* (Scott 1976) and *The Rational Peasant* (Popkin 1979).

In defining his intermediate viewpoint between the moral economic and rational economic viewpoints, Little (1988) discusses a model village with five features common among village societies in a wide variety of cultures. The model village is purely conceptual; there are no quantitative relationships of the type described by Miller (1982). The five features of Little's conceptual model are:

1) The model village is a relatively stable society, in that its basic institutions, social relations, and ecological and technical circumstances may be expected to change only very gradually.
2) The model village is relatively isolated from outside intervention and resources, whether economic or political.
3) There is a high level of information available to each villager about the history and present activities of others.
4) The model village embodies a fairly high level of shared values (familial, moral, religious, or political) and organizations corresponding to these values (kinship organizations, temple groups, political parties).
5) Social relations within the model village are multi-stranded, in that villagers have a variety of different sorts of social relationships.

AI offers a method for representing and evaluating such multi-stranded relationships. Complex interrelationships may be represented by systems of nodes and links known as semantic networks. The nodes represent objects, actions, or events, and the links represent the relations among the nodes (Scown 1985). An object can belong to more than one net. The different nets, known as "perspectives," represent the different contexts in which the object can be described. Semantic nets facilitate inheritance of values.

A village could be represented by a set of nodes representing individuals or groups of like-minded individuals. Each node can be defined in terms of membership of particular nets. For example, an individual could belong to the nets male, member_of family_X, small_landholder, member_of_religious_group_Y, member_of community_group_Z. Each individual has a set of attributes, which together make up the representation of his or her paradigm.

An individual's attributes that are relevant to the functioning of the net may be identified, such as a group leadership measure that could weight the final contribution of that net to the overall village decision-making process. The individual can inherit default values of an attribute over the network, with inheritance being possible over many levels. If family X is part of clan XX, then an individual could inherit clan attributes through his membership of the family net. Knowledge of the conditions under which default values are not inherited may be important for policy development.

Properties of a policy can be defined in terms of their relationship to the attributes of the various nets, and the overall response of a village to these properties estimated through assumptions of the relative weightings of the networks in the village decision-making process. Such an approach would make explicit the value sharing and multi-stranded relationships of Little's (1988) conceptual model, in a form that permitted evaluation of alternative hypotheses.

Socio-Ecological Models

Paradigms may not be known a priori. However, response of any individual or group to an issue is based on the paradigm of the individual or group towards that issue. Models can be formulated to include empirical specification of alternative hypotheses about the response, rather than about the underlying paradigm, and model performance can then be tested against empirical data. In this way, the paradigm of the individual or group can be inferred (Paarsch 1989).

Assumptions about group responses which reflect the underlying paradigms may be evaluated using the class of computer simulations known as socio-ecological models (Holling 1978, Miller 1982, Walters 1986), which capture the interaction of human activities and the environment in the form of mathematical equations. The social component of such models includes economic aspects of the system; e.g., Miller (1982) gives the following equation for the emigration rate (EM) of salmon fishermen from a village as

$$EM = UI^{*}(c/AVFI^{**}k)^{*}d/\log(RES)$$

where UI is the unemployment rate, AVFI is the average fishing income ($), and RES is the residential stability (average numbers of years of residence). Values of constants c, d and k are a reflection of the paradigm of the fishermen.

Simulation models written in procedural languages such as FORTRAN or PASCAL may include IF-THEN-ELSE structures or CASE structures to guide modification of parameter values. However, this approach does not make the knowledge base, as distinct from the data processing algorithm, as explicit as in a separate expert system. Algorithmic aspects of the system should be kept separate from the knowledge base.

Establishment of policies is the major route through which economic changes result, and Holling (1978) describes the manner in which socio-ecological models can be used to evaluate policy. As a preliminary step, all possible actions are listed, such as harvest trees, build a fish hatchery, spray insect pests, or release x cubic feet of water from a reservoir. Policies are defined as the rules by which these actions are initiated, and state at what time or under what conditions actions are taken; e.g., cut all trees above a given age or release enough water from a reservoir to maintain a given minimum flow downstream. Indicators are defined as measures of system behavior in terms of meaningful and perceptible attributes; e.g., crop loss due to insects or costs of a program. Preferences are the trade-off rates between one indicator and another, and objectives are the desired goals in terms of indicators; e.g., the catch to sport fishermen to stay above 1965 levels, or the cost of management to grow at a rate less than the national budget. Decision structures are hierarchical: a goal at one level may be a policy at another (Holling 1978). Paradigms can influence all aspects of socio-ecological model development.

Policies can be coded into models by having specific sections of the program examine the current status of appropriate indicators in relation to policy-defined threshold values, and if the threshold is passed, then a section of code simulating the policy-related action is invoked, changing the values of indicator values in ways defined by the equations in the program. The behavior of the indicators under different policy specifications can then be evaluated.

Socio-ecological models are often developed through an interdisciplinary workshop procedure (Holling 1978). Rules are required to adjudicate arguments of principle, arguments of dogma, and arguments of detail that arise during these workshops (Holling and Chambers 1973). Arguments of principle are based on the premise that each individual has a unique weighting that he or she assigns to goals. Each individual should be allowed to weigh the information generated by the system in the way he feels best reflects his unique value system. Arguments of dogma emerge because of differences in background and training, and may be resolved by coupling each viewpoint with a policy that can be manipulated in runs of the model and contrasted with the results of policies reflecting other viewpoints. Arguments of detail may be resolved by running the model with conflicting hypotheses encoded separately. The rules and preferences discussed above may be dealt with explicitly using expert systems.

Expert Systems

The scientific paradigm shift from data through information towards knowledge processing is reflected in changes in the computing technology used for resource management (Grey 1990). Use of expert systems or knowledge-based systems is increasing in many areas of resource management (Davis and Clark 1989, Kourtz 1990, McKinion and Lemmon 1985, Mills 1987, Noble 1987, Rauscher and Hacker 1989, Schmoldt and Martin 1986, Starfield and Bleloch 1983). System output may be in natural language format, with the information content and format geared to the paradigm of the output recipient as perceived by the system developers (Thomson and Taylor 1990).

An expert system is a computer program that solves problems in a specific field at a level comparable to human experts (Feigenbaum 1979), and can deal with uncertain or incomplete information. The most widely applied type of knowledge representation is the rule-based form (Buchanan and Duda 1983), in which knowledge is encoded as a set of condition/action links of the form

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IF <condition(s)>
THEN <consequence_set_1>
ELSE <consequence_set_2>
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While the domain knowledge in an expert system may be captured in the above format, to form the knowledge base of the system, a separate part of the system, the inference engine, processes the information in the knowledge base. The inference engine attempts to confirm each condition in the IF section, and if all conditions are confirmed, then all the assertions of the THEN section are inferred to be true. If one or more conditions in the IF section cannot be confirmed, then all the assertions of the ELSE section are inferred to be true. A condition in the IF section of one rule may be in the consequence set of another rule, so a number of rules may be examined, in a process known as "chaining," in processing a particular rule. Probabilities or confidence levels may be assigned to the inferences of the consequence sets.

Note that the language of expert systems includes many of the terms, such as "rules," "rules-of-thumb," and "knowledge," which abound in studies such as Colby (1990) and Barrows and Morris (1989), indicating that the proposed expert systems methodology is compatible with the philosophical basis of the topic.

An example of a paradigm-related rule from Colfer et al. (1989) is

RULE NUMBER: 11

IF: Ethnicity is Javanese transmigrant

THEN: Landowner is normally considered to be a male household head
and Land is viewed as very limited
and Rights to land are traditionally certified and private
and Women's agricultural labor is recognized as necessary but not preferred
and Ethnicity is symbolized by farming and small-scale female trade
and World view is hierarchical and authoritar ian
and Domestic animals may include <2 cows and goats and chickens and 2 or more cattle
and Most crops planted probably require intensive management
and People value fertilizer and hoeing and cattle

Subsequent rules could then make inferences based on the knowledge, for example, that the world view of the subject group is hierarchical and authoritarian. It is evident, therefore, that expert systems offer a means of dealing with the qualitative and subjective aspects of paradigm-related hypotheses.

Expert systems and socio-ecological models can interact in a number of ways, reflecting the above issues. An expert system could be used to define paradigm-specific parameters for relationships in the model, or to determine actions under a given policy given the current state of the model. Note that as well as an expert system running the model, the model may itself run an expert system; e.g., the model could write a status file of all indicators for the current iteration, then run an expert system to evaluate the indicators. Results of the evaluation could then be passed back to the model for processing in subsequent iterations. Again, the separation of the knowledge-based processing from the algorithmic processing is emphasized. Finally, an expert system could be used to evaluate the performance of a model embodying a particular philosophy, and may entail storage of output from simulation runs with all policies for comparison at this stage. This last type of expert system could be linked with utility analysis (Keeney and Raiffa 1976).

Discussion

In the absence of adequate studies, perceptions of paradigms may be inaccurate to varying degrees. The extent to which the paradigms of a group being studied are inferred correctly and the extent to which they are misunderstood has a critical effect on policy formulation, especially when it is government's perception of a paradigm (Dove 1985).

The AI approaches discussed here would amply meet the requirements for systems models of human ecology identified by Lovelace (1985a), and the need for methodologies for evaluating socioeconomic factors influencing acceptability to rural people of social forestry interventions (Rao et al. 1985). Uses could include identification of potential difficulties where policy makers and planners view an issue as a problem, while certain rural groups view it as an opportunity (Lovelace 1985b). While the importance of socioeconomic aspects of resource management is well established in underdeveloped countries, there are also many potential applications in North America, such as in forest management programs on Indian lands, where the issue is not numbers or dollars and cents (although these are important), but rather the revitalization of a way of life (Hopwood 1988).

For many issues, knowledge of the pertinent alternative paradigms may reside in a discipline such as anthropology or sociology where the ability or willingness of an individual to frame his knowledge in a mathematical or statistical formulation may be limited. Encapsulation of such knowledge in the English-like format of expert system rules is a method of knowledge representation more acceptable to such disciplines and has been used to capture anthropological knowledge of paradigms in an expert system for advising on agricultural research policy (Colfer 1989), which fits well with part 1 of Colby's definition of "paradigm" (Colbyet al. 1990).

In other domains, paradigms of terrorist groups have been the subject of an expert system to combat international terrorism (Waterman and Jenkins 1986), and paradigms of litigants have been captured in expert systems for legal decisionmaking (Waterman and Peterson 1986). The present study proposes an expert system-based methodology for evaluating the economic consequences of policies reflecting environmental management paradigms. In addition, use of another AI approach, semantic nets, is proposed to define the social systems within which the policies are enacted.

Table 1. *Questions indicated by Popkin (1979) as being answerable by political economy and not by moral economy approaches. Many of these are suitable for expert system treatment.*

How are norms derived?
Why do groups decide to adopt some sets of norms and reject others?
What is an enforceable norm?
When will norms be bent or broken?
What determines subsistence level?
How are village resources allocated?
How are competing claims of need assessed?
How do you determine if a good year + a bad year is worse than two average years?
How is work shared?
How is sloth distinguished from an act of fate?
How are responsibilities allocated: village vs. family, friends, children, patrons?
How is work for others allocated?
How is "ability to pay" determined?
How are "need" and "inability to pay" distinguished?
How is a "needy" scale defined?
- young couple who cannot afford children
- large family with sick child
- poor person who cannot afford a wife
- old person with irresponsible children
- inefficient farmer whose crop fails due to negligence
How are gambles vs. risks evaluated?

Table 1 lists a number of questions indicated by Popkin (1979) as being answerable by the political economy approach and not by the moral economy theory. Answers to all these questions are implicit in village decisions such as the number of animals each family can pasture, or, when fields are intermingled and unfenced, when planting, harvesting or grazing of each field should occur, or, when fields are irrigated, apportionment of work on the irrigation system. Little (1988), however, argues that Popkin's negative case for the moral economy view is too sweeping, and proposes an intermediate model based on collective action by rational peasants.

Many of the issues of Table 1 are suitable topics for expert systems treatment. For example, development of a "needy" scale is a categorization problem. Categories are regarded as central to a person's picture of reality and to knowledge representation and reasoning in AI (Thompson and Thompson 1991). Fuzzy logic is an AI approach designed to handle such concepts that are relative and approximate (Mishkoff 1986), and promotes constructs such as "moderately needy" or "very needy," descriptions that cannot be handled by formal logic, but which are analogous to human thinking.

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