Policy assessment and simulation of actor orientation for sustainable development

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Abstract

Understanding, assessing, and simulating behavior requires knowledge of the precepts that are explicitly or implicitly orienting behavior. Human actors can be viewed as (conscious) self-organizing systems attempting to remain viable in a diverse environment containing other self-organizing systems (other human actors, organisms, ecosystems, etc.), all driven by their own viability (sustainability) interests. These fundamental system interests, or basic orientors, have emerged in response to general environmental properties and are therefore identical across self-organizing systems: existence, effectiveness, freedom of action, security, adaptability, coexistence. Even in simulated actors learning to ‘survive’ in a difficult environment, the basic orientors emerge in the (simulated) evolutionary process — but different actors may evolve into different ‘cultural types’ with different orientor emphasis. Since balanced attention to all basic orientors is crucial for viability, the set of orientors can be used to derive indicators that facilitate comprehensive viability and sustainability assessments. The paper outlines the theoretical approach of ‘orientation theory’ and its application to the assessment and simulation of sustainable development issues. The formal approach of mapping indicators on basic orientors and assessing sustainability dynamics is illustrated using Worldwatch indicator time series. In an actor simulation this approach is used to successfully guide a small global model onto a sustainable path with high ‘quality of life’. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Actor simulation; Orientation; Orientors; Sustainable development; System viability; Policy assessment

1. Introduction

Human behavior determines development and the future of the globe. The magnitude of this influence has increased enormously in recent human history. Considering what is at stake, it is essential that we should have a better understanding of the motives of human actors and their impact on decisions and actions. This is necessary for: (1) understanding what our options are; (2) analyzing possible developments and their conse-
quences by including valid simulations of actors and their interactions; and (3) locating cognitive and/or normative deficiencies that might lead to unsustainable development and ultimately destructive behavior of human actors. The model of the rational economic actor maximizing profit or utility is totally inadequate for this purpose, since the scope of his/her attention only covers a minute portion of the total — environmental, cultural, social, political, technological, economic — spectrum of concerns that determine the decisions, actions, and interactions of important actors in the real world. A more complex, and at the same time more realistic, approach is in order.

In the present paper, I will report results that seem to indicate that comprehensive and valid representation and simulation of human actors in realistic decision contexts is possible. The article summarizes work conducted and directed by the author in several research programs extending over many years, beginning with actor simulation as part of the Mesarovic–Pestel world model (Bossel and Hughes, 1974). For this reason, the author’s name appears embarrassingly often in the list of references; for this I apologize. Extensive lists of references to other authors’ publications on which the current work is based are given in particular in Bossel (1977a, 1996, 1998a, 1999), Bossel et al. (1989); see also Eden (1978).

There are two kinds of concepts that orient decisions and behavior of human actors: factual knowledge (correct or incorrect) about the world, and normative orientations (goals, values, social norms, etc.). In nonroutine decision-making, i.e. considered choice, the two kinds of concepts are processed and linked in complex information processing (Kirsch 1970/1971; Bossel, 1977b,d). Only in trivial cases can this process be modeled by approaches such as maximization of profit or utility. For more reliable policy assessments, in particular for dealing with complex issues such as sustainable development, it is necessary to include the following three components in all necessary detail: (1) the normative concepts of the actor; (2) his/her world knowledge; (3) the information processing itself.

Societies and their environments change, technologies and cultures change, knowledge changes, values and aspirations change, and a sustainable society in particular must allow and sustain such change, i.e. it must allow continuous and viable adaptations, which is what we mean by sustainable development. The result of this process, which includes actors making choices from a wide range of possibilities, cannot be foretold. Even though the factors constraining the development process and the processes driving it are known, the path of sustainable development is therefore still the unpredictable result of interactions of coevolving systems and self-conscious actors.

Sustainable development is not arbitrary, however. It has to remain within the strict boundaries of an accessibility space that is defined by physical constraints (laws of nature, causal relationships, physical environment, solar energy flow, material resource stocks, carrying capacity), by constraints of time and system laws (delays, inertia, permissible rates of change, feedback, and self-organization), and by the constraints of human actors (intellectual and organizational ability, culture, ethics and values, technology, social and political system) (Bossel 1998a, 1999). Behavior is shaped by the perceptions of these constraints by the human actors, not by their actual state. These perceptions — the cognitions of actors — are therefore powerful determinants of future development, and must be properly accounted for in policy assessments and development studies.

Because of their crucial influence on decision outcomes, the present paper focuses on origin and content of normative constraints (‘orientors’). At their most basic level, they reflect ‘fundamental interests’ of viable systems, and therefore shape decisions and actions of the human actor decisively. These concepts can be employed in a coherent formal approach for representation of cognitions and for simulation of the decision-making of human actors. Although trying to explain the concepts in an understandable way, I refer the reader to the original publications for details, derivations, and further substantiation. In this paper, the term ‘system’ usually refers to a self-organizing system responding to challenges from its system environment, i.e. an actor or actor system.
2. The need for understanding the ‘fundamental interests’ of viable systems

The ‘rational’ actor maximizing his or her profit or utility may be a convenient hypothesis for simplistic economic theories, but it bears little resemblance to the real world. Human actors — individuals, corporations, governments — always pursue a spectrum of ‘interests’ concerned with their own viability in a world full of other (human and nonhuman) actors and (animate and inanimate) self-organizing systems, each of which is in turn pursuing its own ‘interests’ in interaction with others. Development is shaped by conflict and compromise of interests of the different participating systems. The ensuing coevolutionary process grants viability and sustainability to those that can adequately care for their own interests while sufficiently respecting the interests of others on which they depend. For policy and behavioral assessments, it is therefore essential to understand the ‘interests’ of different actors and systems. If ‘fundamental interests’ can be identified as ‘basic orientors’ of behavior, then it should be possible to deduce likely behavior even in unforeseen circumstances: it will tend to protect the fundamental interests.

Whether a particular interest is violated or not can only be decided by observing indicators relating the state of a system and its environment to that interest (e.g. the interest to ‘avoid starvation’ requires an indicator of ‘available food’). Hence identification of fundamental interests of a particular system, and of derived interests, is a necessary prerequisite for defining a proper set of indicators providing a comprehensive picture of the state of viability and sustainability of an actor or other system. In particular, this approach is important for finding comprehensive and ‘complete’ indicator sets for sustainable development, for all types of studies dealing with future developments, and in particular for actor simulation (Bossel, 1999).

The present paper explains the derivation of ‘basic orientors’ as reflections of universal and fundamental ‘interests’ of (self-organizing) systems, relates the findings to those in other fields, shows the ‘basic orientors’ to be emergent properties in the self-organization of agents, uses assessment of basic orientor fulfillment for assessing alternative development paths, describes the selection of relevant indicators and a numerical assessment method using historical time series, and uses the concepts to supply a simulated actor with cognitive ‘intelligence’ for successfully controlling a simulated world under adverse conditions. However, more realistic simulation of a human actor requires representation of his/her cognitive system and reasoning processes by (mostly nonnumerical) information processing.

3. Basic orientors of systems reflect fundamental properties of the environment

The ultimate goal of any actor system is (usually) survival, viability, and success in its particular environment. How this translates into action-related normative criteria (objectives) for a particular actor system, depends on its structure, processes and functions and on the challenges posed by its environment. A human struggling to survive under arctic conditions will have to follow very different objectives than a corporation attempting to survive among strong competitors. For assessment or simulation of behavior, it is essential to know the normative criteria directing the behavior of the actor. The ultimate goal of survival, viability and/or success is much too general to be of practical use, while the bottom-up approach of identifying all objectives of an actor in a particular environment becomes a formidable task bearing the risk of incomplete and biased representation.

Orientation theory (Bossel, 1977c) argues that there are ‘basic orientors’ just ‘below’ the ultimate goal (of viability) that represent ‘fundamental interests’ and are common to all self-organizing systems, irrespective of their physical nature, because they have developed in response to certain ‘fundamental properties’ that are common to all system environments. Adequate fulfillment of each of the basic orientors is required for survival, viability, and success. The essential idea is that in coevolving with their environment, successful systems evolve structures and functions that allow
dealing successfully with the particular features of the environment. This appears to an observer as if the system’s behavior is (consciously) directed by the ‘basic orientors’ as normative constraints. Conversely — and this is important for actor simulation — if actions are directed by explicit reference to the ‘basic orientors’, they can be expected to lead to viable and successful behavior and development.

A system can ‘perceive’ the static and dynamic features of its environment only in terms of the physical flows (material, energy) and information flows it receives from the environment. There is obviously an immense variety of specific system environments, just as there is an immense variety of specific systems. However, by analyzing the feasible signals from the environment, it is possible to identify six fundamental properties of system environments (Bossel, 1994, 1999):

- **Normal environmental state:** The actual environmental state can vary around this state in a certain range.
- **Resource scarcity:** Resources (energy, matter, information) required for a system’s survival are not immediately available when and where needed.
- **Variety:** Many qualitatively very different processes and patterns of environmental variables occur and appear in the environment constantly or intermittently.
- **Variability:** The state of the environment fluctuates around the normal environmental state in random ways, and the fluctuations may occasionally take the environment far from the normal state.
- **Change:** In the course of time, the normal environmental state may gradually or abruptly change to a permanently different normal environmental state.
- **Other actor systems:** The environment contains other actor systems whose behavior may have system-specific (subjective) significance for a given actor system.

These fundamental properties of the environment are each unique, i.e. each property cannot be expressed by any combination of other fundamental properties. (For example, environmental variety is a feature that cannot be expressed by using any of the other properties, alone or in combination. The same is true for the other properties as well.) In systems theoretical terms, a system’s environment must be described by a six-dimensional vector at the level of the fundamental properties. If we want to describe a system’s environment **fully**, we have to say something about each of these properties. The specific content of these fundamental environmental properties is system-specific, however. The same physical environment presents different environmental characteristics to different systems existing in it: A meadow means different things to a cow, a bee, a poet, or a developer.

**Example, a family:** **Normal environmental state:** A family living in a small town in a particular European country has to deal (and be compatible) with specific economic, social, cultural, legal and political environments different from those, say, in India. **Resource scarcity:** The family needs money, water, food, electricity, consumer goods, medical services, sanitation, etc., all of which can only be secured with considerable effort. **Variety:** The family has to exist in an environment containing a host of very different neighbors, different shops, a multitude of social and cultural offerings. **Variability:** A new neighbor moves in, or members of the family become ill, change their friends, lose their jobs, have to move. **Change:** Economic and social conditions change, new technologies enter the house and the workplace, the members of the family age. **Other actor systems:** The family has to care for pets and aging parents and accommodate the interests of employers, neighbors, or other drivers in traffic.

Systems must be compatible with their system environment and its characteristic properties in order to be viable and to exist sustainably. The environmental properties can therefore be viewed as imposing certain requirements and restrictions on systems, which ‘orient’ their functions, development, and behavior (Fig. 1) (Bossel, 1977c, 1987, 1999).

**Examples:** The physical properties of different **environments** (sea, land, desert, arctic) enforce attention to an orientation of existence, causing organisms to avoid environments with which they are not compatible. **Resource scarcity** (water,
land, energy) imposes an orientation of effectiveness, causing organisms and actors to develop effective and efficient means of using scarce resources. The diversity and variety of environments cause an orientation of freedom of action, allowing actors to respond selectively and appropriately to a multitude of environmental challenges. The unpredictable variability of the weather imposes an orientation of security on humans and animals, causing search for shelter and food storage. Eventual change in the environment (partly a result of the coevolution of systems) causes an orientation of adaptability, enabling organisms, ecosystems and human organizations to cope with changing environments by changing their own structure and processes. The presence and behavior of other systems in the same environment causes an orientation of coexistence, enabling animals and humans to interact appropriately with kin, competitors, or predators, etc.

Specific properties of systems may also impose certain orientations. Self-reproducing systems such as organisms and populations have to pay attention to an orientation of reproduction and replication at either the level of the individual or the population (or both). Sentient beings (animals and humans) can experience stress and pain and other emotions, and corresponding psychological needs appear as a separate orientation. Conscious beings (mainly humans) can reflect about their own actions and their impacts; conscious choice implies application of some normative standard, and hence implies responsibility as an orientation.

Corresponding to the six fundamental environmental properties, there are therefore six environment-determined basic orientors (existence, effectiveness, freedom of action, security, adaptability, coexistence) that apply to all autonomous self-organizing systems. In addition, there are three system-determined basic orientors (reproduction, psychological needs, responsibility) that are peculiar to self-reproducing (autopoietic), sentient, and conscious beings. Each of the basic orientors implies a normative statement to protect and enhance a particular category of vital system interests.

3.1. Environment-determined basic orientors

Existence: The system must be compatible with, and able to exist in the normal environmental state. The information, energy, and material inputs necessary to sustain the system must be available (compatibility of system and environment as prerequisite).

Effectiveness: The system should on balance (over the long term) be effective (not necessarily efficient) in its efforts to secure scarce resources (information, matter, energy) from, and to exert influence on its environment. (This is essentially an expression of the First and Second Law of Thermodynamics.)

Freedom of action: The system must have the ability to cope in various ways with the challenges posed by environmental variety. (This corresponds to the Law of Requisite Variety of Ashby (1956).)

Security: The system must be able to protect itself from the detrimental effects of environmental variability, i.e. variable, fluctuating, and unpredictable conditions outside of the normal environmental state (essentially a call for system redundancy to cope with random fluctuations in the environment).

Fig. 1. Fundamental properties of system environments and their basic orientor counterparts in systems (Bossel, 1999).
### Table 1

<table>
<thead>
<tr>
<th>Basic orientors</th>
<th>Psychological and social needs</th>
<th>Cultural theory lifestyle</th>
<th>Social system concepts</th>
<th>Ecosystem properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Bossel, 1977c)</td>
<td>(Max-Neef, 1991)</td>
<td>(Thompson et al., 1990)</td>
<td>(Luhmann, see Baraldi et al., 1997)</td>
<td>(Müller and Fath, 1998)</td>
</tr>
<tr>
<td>Existence</td>
<td>Subsistence</td>
<td>Fatalist</td>
<td>Environmental compatibility</td>
<td>(Meta)stability, resilience</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>Understanding, leisure</td>
<td>(Organizer)</td>
<td>Code, programs</td>
<td>Cycling, loss reduction</td>
</tr>
<tr>
<td>Freedom of Action</td>
<td>Freedom</td>
<td>Individualist</td>
<td>Variety</td>
<td>Heterogeneity, diversity</td>
</tr>
<tr>
<td>Security</td>
<td>Protection</td>
<td>Hierarchist</td>
<td>Redundancy</td>
<td>Redundancy, storage</td>
</tr>
<tr>
<td>Adaptability</td>
<td>Creation</td>
<td>(Innovator)</td>
<td>Autopoiesis</td>
<td>Genetic diversity, patch dynamics</td>
</tr>
<tr>
<td>Coexistence</td>
<td>Participation</td>
<td>Egalitarian</td>
<td>Double contingency</td>
<td>Landscape gradients, ecotone structures</td>
</tr>
<tr>
<td>Psychological needs</td>
<td>Affection, identity</td>
<td>Hermit</td>
<td>Reflection</td>
<td></td>
</tr>
</tbody>
</table>

Adaptability: The system should be able to learn, adapt, and self-organize in order to generate more appropriate responses to challenges posed by environmental change (essentially an acknowledgment of the process of coevolution).

Coexistence: The system must be able to modify its behavior to account for behavior and interests (orientors) of other (actor) systems in its environment. (This is related to the ‘double contingency’ or ‘social contingency’ of Talcott Parson’s and Luhmann’s theory; see Baraldi et al., 1997.)

3.2. System-determined basic orientors

Reproduction: Self-reproducing (autopoietic) systems must be able to fulfill their need to reproduce (either as individuals and/or as populations).

Psychological needs: Sentient beings have certain additional, truly psychological needs that must be satisfied, and that cannot be explained by the system/environment interaction alone, such as affection, avoidance of stress or pain, etc. Note that according to orientation theory, most needs usually classified as ‘psychological’ (such as ‘subsistence’, ‘freedom’, ‘protection’, ‘creation’) are actually consequences of the system/environment interaction and apply to most self-organizing systems, whether sentient or not (see the comparison in Table 1).

Responsibility: Conscious actors are confronted with having to make choices among options that produce different consequences for the affected systems. This requires a normative reference (even if it is only the rule to ‘flip a coin’) amounting to assigning (relative) weights to the ‘interests’ (basic orientors) of affected systems.

The further discussion will be mostly limited to the six environment-determined basic orientors plus the psychological needs orientor, subsuming reproduction under existence, and treating responsibility as the subject of ethical choice (Bossel, 1998a, pp. 85–97).

At the very least, basic orientors can be used as a checklist of what is important in and for systems and actors, i.e. basic system needs. For example, if we went through the list of basic orientors before embarking on a journey with an unknown car, we could be reasonably sure of discovering any deficiencies:

- The existence orientor would remind us to check the car’s structural integrity and reliability,
- the effectiveness orientor would have us check steering and fuel consumption,
- the freedom of action orientor would let us make sure that we have enough fuel, and that the fuel indicator works,
- the security orientor would have us check brakes, oil-level, and seat belts,
the adaptability orientor would make us test the heater, roll the windows up and down, try out the seat adjustment, and check the spare tire and tools,

the coexistence orientor would cause us to check headlights, brake lights, turn indicator lights, and horn,

the psychological needs orientor would let us choose a make and model agreeing with our personal taste and (perhaps) social status.

In many applications, the nested structure of complex systems has to be accounted for. For example, a firm must be viable in order to contribute to the viability of the economy, which contributes to the viability of a society. This leads to a recursive orientor assessment (discussed in the applications below).

The evidence from much research (see survey below) seems to be that the set of basic orientors is complete (covering all essential aspects), and that each basic orientor is unique (cannot be replaced by others). For example, any amount of ‘effectiveness’ and/or ‘security’ cannot supply what is meant by ‘freedom of action’. The set of basic orientors can therefore be used to represent the fundamental viability interests of a system in a way in which the set of primary colors (red, blue, yellow) can be used to reproduce any picture in ‘full color’. As each basic orientor stands for a unique requirement, a minimum of attention must be paid to each of them. Compensation of deficits of one orientor by over-fulfillment of other basic orientors is therefore not possible.

In the orientation of system behavior, we therefore deal with a two-phase assessment process where each phase is different from the other.

Phase 1: First, a certain minimum satisfaction must be obtained separately for each of the basic orientors. A deficit in even one of the orientors threatens viability and long-term survival of the whole system. The system will have to focus its attention on this deficit.

Phase 2: Only if the required minimum satisfaction of all basic orientors is guaranteed is it permissible to try to raise system satisfaction by improving satisfaction of individual orientors further. However, there are upper limits to basic orientor satisfaction. For example, excessive emphasis on security or freedom of action or adaptability is obviously pathological and reduces viability and sustainability.

Because it is better adapted to the different aspects of its environment, the system equipped for securing better overall basic orientor satisfaction will have better fitness, and will therefore have a better chance for long-term survival and sustainability. Assessment of orientor satisfaction therefore provides an indication of system fitness in its environment, i.e. its viability and sustainability (Krebs and Bossel, 1997).

Viable systems (with adequate minimum satisfaction of all basic orientors) may differ in their basic orientor emphasis. Characteristic differences in the behavior (‘life strategies’) of organisms, or of humans or human systems (organizations, political or cultural groups) can often be explained by differences in the relative importance attached to different orientors (i.e. emphasis on freedom, or security, or effectiveness, or adaptability) in Phase 2 (i.e. after minimum requirements for all basic orientors have been satisfied in Phase 1).

4. Other evidence for basic orientors

The emergence of basic orientors in response to the general properties of environments can be deduced from systems theoretical arguments, as has been done here, but supporting empirical evidence and related theoretical concepts can also be found in such fields as ecology, psychology, sociology, religion, and the study of artificial life.

If basic orientors are indeed the consequence of adaptation to general environmental properties, and therefore of fundamental importance to the viability of individuals, then we can expect them to be reflected in our emotions. This is indeed the case (Bossel, 1978, p. 47; Bossel 1998a, p. 82). Each of the basic orientor has a characteristic counterpart in our emotions.

Also, we find that all societies have developed methods of punishment by selective basic orientor deprivation (Bossel, 1978, p. 47; Bossel, 1998a, p. 83). The spectrum of punishment applied by most societies is an indirect confirmation of the importance of the basic orientor ‘dimensions’ to human
life and well-being: Depending on kind and severity of the offense, the delinquent is denied full satisfaction of one of the basic orientors — society takes away what is most valuable to the individual.

Perhaps the most vivid and striking description of basic orientors and the consequences of removal of orientor satisfaction for the individual and society is found in the Bible (Deuteronomy (5th book Moses) 28, verse 1–69; Müller-Reissmann, 1977, personal communication). In the final section of the explication of Mosaic laws, very explicit blessings and curses are formulated for those that either uphold or violate the laws. They deal with existence (22, 27, 48, 53–57), effectiveness (23, 28–30, 32, 38), freedom of action (41, 43–44, 48), security (52, 65–67), adaptability (22, 24, 27, 35, 44, 48, 51, 59, 61), and coexistence (26, 29, 37-39, 42, 43–44, 53–57).

The empirical findings of psychologists like Cantril (1965), Maslow (1968, 1970), and Rokeach (1973) can easily be brought into agreement with the orientation theoretic framework used here (Bossel, 1977c, pp. 245–253; Hornung, 1988, p. 240). In his work on ‘human scale development’, Manfred A. Max-Neef (1991) has classified human needs according to several categories which can be mapped onto the basic orientors (Table 1). The coincidence of these two (independently developed) lists is striking, but some remarks are in order. As explained above, the first six entries are basic system needs that apply to any self-organizing system, human or not. It therefore comes as no surprise that they also appear as ‘basic human needs’. Since they are manifest in corresponding emotions, they can be interpreted as ‘psychological needs’, although their origin is of a general system nature. However, the items ‘affection’ and ‘identity’ in Max-Neef’s list are truly psychological needs; they cannot be explained by system requirements alone. Why are ‘understanding’ and ‘leisure’ juxtaposed with the effectiveness orientor? Effectiveness is obviously a function of knowledge and understanding. But effectiveness is also a function of rest, contemplation, and ‘creative idleness’.

Cultural theory (Thompson et al., 1990) identifies five types of individuals in the social world, each having characteristic and distinct value orientation and lifestyle: ‘egalitarians’, ‘hierarchists’, ‘individualists’, ‘fatalists’, and ‘hermits’. Orientation theory explains these different lifestyles in terms of different basic orientor emphasis, and furthermore fills two obvious gaps in cultural theory: ‘innovators’ and ‘organizers’ (Table 1). The egalitarian stresses partnership in coexistence with others, the hierarchist tries to gain security by regulation and institutionalized authority, the individualist tries to keep his freedom by staying free from control by others and the ‘system’, and the fatalist just tries to secure his existence in whatever circumstances he finds himself in. The autonomous hermit, stressing his own psychological needs, is of no practical relevance to the social system. The innovator stresses the basic orientor adaptability, while the organizer concentrates on effectiveness.

Although Luhmann’s theory of social systems (Baraldi et al., 1997) concentrates on the cognitive and communicative processes of social systems at the neglect of their material structure and state-determined dynamics, the basic orientor aspects can also be recognized in his theory (Table 1). Müller and Fath (1998) have related general ecosystem properties to the basic orientors (Table 1). These ecosystem properties can be understood as specific processes that emerged in ecosystems in the course of their coevolutionary development in response to basic orientor demands.

One can find solid evidence of the basic orientors even in computer experiments with ‘animats’ simulating the evolution of intelligence in artificial life (Krebs and Bossel, 1997; Bossel 1998b; see the following). These experiments in artificial life show that values are not subjective inventions of the human mind, but are basic system requirements emerging from a system’s interaction with its environment.

5. Emergence and quantification of basic orientors in artificial life simulations

Orientation theory postulates that systems evolving in a given environment can only survive if they learn to cope with the fundamental envi-
The development of the rule set is driven by the requirement to ensure sufficient energy pickup in the given environment (with a given resource availability), while allowing for environmental variety, variability, and change specific for that environment. Other criteria besides efficiency — e.g. security, freedom of action, adaptability — will therefore be reflected as emergent value orientations in the final set of behavioral rules.

Since the study dealt with an individual animat compatible with its environment, only the four orientors effectiveness, freedom of action, security, and adaptability, corresponding to the four environmental properties, resource availability, variety, variability, and change, had to be considered. For these environmental properties as well as for the orientors, quantitative objective indicators had to be defined that reflect the particular problem setting (for details, refer to Krebs and Bossel, 1997).

Resource availability is defined by the ratio relating the amount of resources to the (minimum) travel distance required for harvesting all resources. Environmental variety is defined by the ratio relating the number of diverse sense vectors distinguishable in the environment to the number of spatial positions occupied by 'food' or 'obstacles'. Environmental variability (uncertainty) is defined by the probability that what is perceived as a 'food' object is actually a collision object. Environmental change is expressed by the ratio relating the time constant of environmental change to the time constant of system change.

Animat performance in different environments is compared by using objective measures of orientor satisfaction based explicitly or implicitly on the animat’s energy balance. The animat gains energy units by picking up 'food', and loses certain energy units for the processes of motion, collision with obstacles, and learning. The orientor measures are defined as nondimensional ratios such that values \(< 1\) indicate a threat to survival, while values \(\geq 1\) show adequate orientor satisfaction.

Effectiveness is expressed by a normalized energy balance, i.e. the ratio of energy collected to energy used for life support and activities in a given period: If this measure of effectiveness
drops below 1, the net energy balance of the organism is negative, and survival is at stake. Freedom of action is determined by stopping the learning process in the training environment, and increasing environmental variety to the point where the animat can no longer cope with the greater variety and fails to maintain a positive energy balance (i.e. the effectiveness measure drops below 1, and survival is at stake); the ratio of this critical variety to that in the training environment provides a measure of the freedom of action — the greater ratio, the more freedom of action. Similarly, security is determined by increasing environmental uncertainty until effectiveness drops below 1; the ratio of this critical uncertainty to that in the training environment provides a measure of security — the greater the ratio, the more security. A nondimensional measure of adaptability is defined by relating the time required for adaptation to the time constant of environmental change.

Since the animat’s training depends on a number of random factors, each animat develops a different cognitive system (behavioral rule set), even though final performance may be similar. Animat individuals trained in identical environments therefore evolve significant differences in value emphasis and ‘life style’. These individual variations, while not significantly affecting performance in the standard training environment, provide comparative advantage and enhanced fitness when resource availability, variety, or reliability of the environment change. Three different ‘lifestyles’ in particular became obvious: ‘specialists’, ‘generalists’, and ‘cautious types’. ‘Specialists’ stress the effectiveness orientor. They perform best in the environment in which they were trained, but lose their fitness quickly as environmental variety or variability is increased. ‘Generalists’ stress the freedom of action orientor. They have adequate but mediocre performance in their training environment, cannot deal well with increasing variability, but can maintain adequate performance even for very significant increases of variety. ‘Cautious types’ stress the security orientor. Their performance even in their training environment is low, and they cannot tolerate much environmental variety. But they have learned to tolerate even very significant increases in variability (uncertainty).

Application of orientation theory to animat studies has been found to be useful in analyzing and understanding processes of self-organization and system evolution, and in particular the evolution of cognitive structure, resultant behavior, and the evolution of behavioral diversity necessary for adaptation of a population to changing conditions (Bossel, 1998b). Moreover, the research has clearly shown that the basic orientors emerge as implicit concerns in the evolution of viable systems in complex environments, and that balanced attention to each of these basic orientors is necessary for success and sustainability. This strengthens the argument for using them in actor simulations – and in policy analysis in general.

6. Comparative assessment of alternative development paths, and indicators of sustainability

The basic orientors can be used to develop a general scheme of questions for checking viability and sustainability of a system. But systems are rarely simple or isolated. They are usually made up of subsystems contributing to the welfare and development of the complete system, and that system itself may in turn contribute to the viability of a larger total system. We therefore usually have to answer a recursive, nested set of questions concerning the viability of subsystems, and their contribution to the viability of the total system: (1) ‘What is the viability of each subsystem?’ (i.e. satisfaction of each basic orientor of that system); and (2) ‘How does each subsystem contribute to the viability (the basic orientors) of the total system?’ This often requires the specification of an orientor hierarchy with several layers of orientors, to convert the information from a specific indicator into information about corresponding basic orientor satisfaction (Hornung, 1988). Actors (usually) reflect not only about their own orientor states, but also about those of other actors participating in an interaction. Realistic actor simulations may therefore require the representation of basic orientor satisfaction of several actors or systems in the ‘orientation module’ of a particular actor.
Table 2
General scheme for finding subsystem indicators (Bossel, 1998a, 1999)

<table>
<thead>
<tr>
<th>Orientor</th>
<th>Subsystem performance</th>
<th>Contribution to total system (region)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existence</td>
<td>Is the system compatible with, and able to exist and</td>
<td>Does the system contribute its specific share to existence and subsistence of the total system?</td>
</tr>
<tr>
<td></td>
<td>subsist in its environment?</td>
<td></td>
</tr>
<tr>
<td>Effectiveness</td>
<td>Is it effective and efficient?</td>
<td>Does it contribute to the effective and efficient operation of the total system?</td>
</tr>
<tr>
<td>Freedom of action</td>
<td>Does it have the freedom to respond as needed?</td>
<td>Does it contribute to the freedom of action of the total system?</td>
</tr>
<tr>
<td>Security</td>
<td>Is it secure, safe, stable?</td>
<td>Does it contribute to the security, safety, and stability of the total system?</td>
</tr>
<tr>
<td>Adaptability</td>
<td>Can it adapt to new challenges?</td>
<td>Does it contribute to the flexibility and adaptability of the total system?</td>
</tr>
<tr>
<td>Coexistence</td>
<td>Is it compatible with interacting subsystems?</td>
<td>Does it contribute to the compatibility of the total system with its partner systems?</td>
</tr>
<tr>
<td>Psychological needs</td>
<td>Is it compatible with psychological needs and culture?</td>
<td>Does it contribute to the psychological well-being of people?</td>
</tr>
</tbody>
</table>

The orientor checklist for recursive viability assessment is given in Table 2 (Bossel, 1998a, 1999). It can be employed for making assessments of viability and sustainability at different levels of refinement: We can use it for (1) quick and crude assessments, or (2) detailed grading of orientor satisfaction based on quantitative indicators, or (3) computer-assisted assessments based on formal mathematical assessment functions mapping indicators on orientors (see Section 7). The latter approach is particularly important for actor simulation.

Note that the questions on the checklist can often be adequately answered without an extensive data base of numerical indicators by people with a good knowledge of the systems involved. In many applications it will therefore not be necessary to wait until representative indicators can be defined and an expensive and time-consuming data collection effort is completed. If all orientors are in a satisfactory state, i.e. if all interests of the system are adequately cared for, then we can simply state that the system is 'viable', 'healthy', or 'sustainable'.

For more systematic assessments, indicator sets representing system state can be defined using the orientor checklist — by finding indicators that provide answers to the questions on the list (Bossel, 1997). Sample indicator sets based on this method are presented in Bossel (1999) for Seattle, Upper Austria, New Zealand, and a global region, and in Mothibi (1999) for Botswana. System viability is assessed by reflecting what effect the (current) state of an individual indicator has on the viability of a subsystem and the total system. This approach is more comprehensive, reliable and reproducible than an intuitive overall assessment, and it allows sophisticated assessments even in cases where only detailed qualitative descriptions, but no quantitative data of indicator states are available. An example is the comparative assessment of future development paths (Bossel, 1998a).

Fig. 2. Orientor satisfaction assessments for development Path A dominated by global economic competition and Path B dominated by regional sustainability principles (from Bossel, 1998a). Path A is not viable in the long run and therefore unsustainable. Relative scale from 0 = unacceptable to 4 = excellent.

In the following the method of orientor assessment is demonstrated using empirical time series data for selected indicators. In order to minimize the data collection effort and facilitate indicator selection, the widely available data base of the Worldwatch Institute (1999) is used to develop an orientor assessment for the state of the world’ from 1950–2000 (Bossel, 1999). A set of 21 indicators (seven basic orientors, three component systems) is used. The three major component systems are: (1) the ‘human system’ (social system, individual development, government); (2) the ‘support system’ (infrastructure and economy); and (3) the ‘natural system’ (environment and resources). The relevant assessment questions are now: ‘What is the state of satisfaction of a particular orientor of the total system with respect to (1) the human/social aspect; (2) the infrastructure/economy aspect; (3) the environment/resources aspect of the total system?’ The 21 indicators from the Worldwatch data base were chosen for their ability to provide answers to the corresponding 21 questions. Since the data base was collected for other purposes, it can hardly be expected that we would find indicators ideally matching those questions. The indicators selected for this assessment are listed in Table 3.

Indicator selection using this method is not arbitrary, but it requires (subjective) choice. Another unavoidably subjective component of the method is the definition of the impact functions that map indicator states on orientor satisfactions. Except for simple cases, there is currently no method for objectively measuring indicator impact on orientor satisfaction. These impact functions therefore have to be generated by subjective assessments. To capture the spectrum of subjectivity, it will often be essential to incorporate the viewpoints of different stakeholders in competing assessments and to compare the results — they will often not differ substantially.

The complete assessment procedure, including graphic output, can be programmed on a worksheet. The program consists of the following sections for each of the three component systems and for the total system (details in Bossel, 1999):

---

Table 3
Indicator set using Worldwatch data base (Bossel, 1999) a

<table>
<thead>
<tr>
<th>Basic orientor</th>
<th>Human system</th>
<th>Support system</th>
<th>Natural system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existence</td>
<td>Grain surplus factor (GRNPROD.16/200)</td>
<td>Debt as share of GDP in developing countries (DEBT.57)</td>
<td>World fish catch (FISH.15)</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>Unemployment in European Union (INCOME.83)</td>
<td>Gross world product per person (GWP.11)</td>
<td>Grain yield efficiency (GRNPROD.16/FERTILIZ.14)</td>
</tr>
<tr>
<td>Freedom of action</td>
<td>Share of population age 60 and over (DEMOGRA.188)</td>
<td>Energy productivity in industrial nation (PRDUCTVT.13)</td>
<td>Water use as share of total runoff (WATERUSE.195)</td>
</tr>
<tr>
<td>Security</td>
<td>Share of population in cities (CITIES.14)</td>
<td>World grain carryover stock (GRAIN.126)</td>
<td>Economic losses from weather disasters (DISASTER.37)</td>
</tr>
<tr>
<td>Adaptability</td>
<td>Persons per television set (1 TV per household) (TVS.1)</td>
<td>Capital flow (public funds) to developing countries (FINANCE.14)</td>
<td>Carbon emissions (CARBON.20)</td>
</tr>
<tr>
<td>Coexistence</td>
<td>Income share of richest 20% of population (INCOME.20)</td>
<td>Number of armed conflicts (CONFLICTS.10)</td>
<td>Recycled content of US steel (STEEL.71)</td>
</tr>
<tr>
<td>Psychological needs</td>
<td>Refugees per 1000 population (REFUGEES.17)</td>
<td>Immunization of infants (DISEASE.22 (DPT))</td>
<td>Chesapeake oyster catch (RESOURCE.13)</td>
</tr>
</tbody>
</table>

a The Worldwatch data file numbers for each indicator time series are listed in capital letters.
• table of indicator time series (1950–2000) (one indicator for each basic orientor)
• time graphs of indicators
• impact functions for each indicator
• orientor impact assessment tables for each indicator (time series 1950–2000)
• time graphs of orientor impact for each indicator
• orientor star diagrams for 1950–2000 in 10-year intervals for each component system
• table of average orientor impact (from the three component systems) as measure of the orientor state of the total system
• orientor star diagrams for 1950–2000 in 10-year intervals for the total system.

As an example, one of the 21 assessment functions and its use in the orientor assessment is shown in Fig. 3. The figure shows (a) the orientor impact function mapping system state (grain surplus factor) to orientor state (existence of the human system, X), (b) the (historic) time function of system state (grain surplus factor), and (c) the corresponding time development of the orientor satisfaction (for existence X). All other 20 orientor assessments are treated in a similar way.

It is difficult to discern a coherent picture of the 'state of the world' and its dynamic development...
from 1950 to 2000 from the 21 tables or time graphs of either the indicators or their orientor impact assessments (such as Fig. 3). Developments become much more obvious in the orientor star diagrams for each of the component systems and the total system. Fig. 4 presents orientor stars for the natural system as an example. The time sequence of orientor stars clearly brings out the dynamics of stresses and threats to a system and allows tracing their origins.

The method described here can be used to guide decisions in actor simulations: The impacts of the (current) system state on basic orientor satisfaction are found by mapping relevant indicators on the basic orientors. Orientor satisfaction deficits can be traced back to their causes, and the actor can make appropriate policy changes to improve orientor satisfaction.

8. Simulation of an ‘intelligent’ actor guiding a model world from certain collapse to sustainability

A social actor can be considered as an information-processing system interacting with its environment. In the work reported in the following, a numerical representation was used to relate the system and environmental state to orientor state. Although less versatile than a non-numerical representation using a knowledge processing system, the numerical approach illustrates that system models can be transformed into more or less ‘intelligent’ actors by complementing them with an orientation module to remind them of their current and long-range interests. We have linked Forrester’s system dynamic model World2 (Forrester, 1971) to an orientation module in order to demonstrate how systems orientation can keep a system viable even under severe existential threats (Bossel and Strobel, 1978). A simpler application using the same approach is described in Bossel (1994).

System model (World2; Forrester, 1971) and orientation module are implemented in an interactive program simulating the processes of policy search, trial policy projection, trial policy evaluation, decision, policy implementation, and dynamic simulation of resulting system development. In this specific application, World2 is used to represent both the ‘real’ world (in the dynamic simulation) and its model (in the policy search and evaluation process). (This amounts to the actor having perfect knowledge about the structure and function of the ‘world’ he is trying to control.)

In all runs the planning period was 10 years (i.e. the planning process was repeated every 10 years). The planning and decision process was simulated as a function of two parameters: the planning horizon (i.e. the future time period for which projections were generated) and the decision criterion determining the choice of policy (‘control sensitivity’). Two different planning horizons (10 and 50 years) and two control sensitivities were used (avoidance of either all ‘amber’ (unsatisfactory) or all ‘red’ (critical) urgencies). In the input mode, seven control variables are individually accessible, allowing the input of time-dependent control scenarios.

A constant set of indicators generated by World2 and the orientation module was used to guide the policy development. This set contained five state indicators from World2, their respective urgencies in the categories red, amber, and green (as determined by mapping indicators on orientors), the five orientor-specific satisfactions and dissatisfactions, and the total satisfaction and total dissatisfaction. During the interactive planning process, control policies were developed almost entirely by referring to the indicator urgencies and the total (dis)satisfaction.

At each planning step the policy search process was continued until the projected results of the trial policy satisfied the control sensitivity criteria adopted for the particular run. The first policy to satisfy these criteria was implemented. For this reason the policy found and adopted is not optimal nor even unique: It is to be expected that there exist other policy choices that would provide better solutions while also satisfying the criteria. The development of World2 under the adopted control policy was then computed for the next 10 years. At the end of this period, the planning process was repeated, resulting in a new plan and its subsequent implementation, and so forth. In
this manner a consecutive plan covering the period 1975–2100 was developed.

The following sequence of steps is implemented in the orientation process (for details, refer to Bossel and Strobel, 1978):

**Step one:** The model generates a state projection over the planning horizon $T_H$ from present time $t_0$ to $(t_0 + T_H)$. Time series for selected indicators are handed over to the orientation module for subsequent state analysis.

**Step two:** Using mapping functions, the projected indicator states are mapped on the basic orientors. By taking proper account of the significance (loading) of each indicator-orientor link, the resulting orientor (dis)satisfaction is computed.

**Step three:** The urgencies of indicators are computed by accounting for orientor (dis)satisfaction categories, loadings, and orientor weights.

**Step four:** The satisfactions and dissatisfactions with respect to each orientor are computed. The contributions (loadings) of the different indicators to the (dis)satisfaction of a given orientor are weighted according to the weight of the satisfaction category. Satisfaction and dissatisfaction measures are summed separately.

**Step five:** The total satisfaction and the total dissatisfaction of the system at a given point in time follow after weighting the (dis)satisfaction obtained above by the respective orientor and participating systems weights and summing.

**Step six:** Finally, as a measure of (dis)satisfaction over the whole planning period, the total (dis)satisfactions computed above for each point in time are multiplied by a horizon function representing the actor’s weighting of future events (using a discount parameter), and integrated over the planning horizon. This now provides single measures for the expected satisfaction and dissatisfaction resulting from the projected system development.

**Step seven:** The different measures provide guidance for policy synthesis. Experience has shown that the most useful measures are the (dis)satisfaction integrals and the indicator urgencies, which directly point to problem areas. In the 1978 implementation, the policy search was conducted by the user interacting with the program, but this process can also be relegated to a computer program.

In the model implementation, several simplifications and assumptions apply: (1) There is only one participating system (the ‘world’ as a whole); (2) the system (World2) also serves as its own model; (3) only two dissatisfaction categories (red and amber) and one satisfaction category (green) are used; (4) loadings and (dis)satisfaction ratings are a function of system state only; (5) a decaying exponential is used as horizon function. The basic orientors are assigned relative weights as follows: existence (10), effectiveness (3), freedom of action (4), security (8), adaptability (2). The relative weights assigned to the satisfaction categories are: red (10), amber (3), green (1). The functions mapping states on orientors were obtained in tabular form by subjective assessments (in the manner described above for the dynamic assessment using Worldwatch indicators).

A very severe test was applied to this method of cognitive control: All simulation runs were started with the initial conditions of preprogrammed catastrophe (Forrester’s ‘pollution crisis’). It turns out that control by orientation not only avoids the catastrophic failure in all cases, but can also

<table>
<thead>
<tr>
<th>Run</th>
<th>Planning horizon (years)</th>
<th>Control sensitivity</th>
<th>Quality of life (2100)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>10</td>
<td>Avoid ‘red’ threats</td>
<td>0.75</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>Avoid ‘red’ and ‘amber’</td>
<td>1.00</td>
</tr>
<tr>
<td>C</td>
<td>50</td>
<td>Avoid ‘red’</td>
<td>0.80</td>
</tr>
<tr>
<td>D</td>
<td>50</td>
<td>Avoid ‘red’ and ‘amber’</td>
<td>1.20</td>
</tr>
<tr>
<td>S</td>
<td>World2 standard run</td>
<td></td>
<td>0.56</td>
</tr>
</tbody>
</table>
assist in developing policies leading to much greater system satisfaction than Forrester’s standard run, which did not have to cope with a proposition to failure to begin with. All the planning runs produced better results than Forrester’s (non-catastrophic) standard run S. This is most obvious from the ‘quality of life’ variable at the end of the simulation period (Table 4). The best result (‘sustainable development’ and quality of life = 1.2) is obtained by using a long planning horizon (50 years) and high control sensitivity (responding to ‘unsatisfactory’ as well as ‘critical’ urgencies). By comparison, in Forrester’s standard run S, quality of life continually decreases to 0.56, while in the pollution run, population collapses almost entirely.

This research leads to the following conclusions: (1) The use of an orientation module in systems simulation allows the simulation of ‘intelligent’ actor behavior. (2) In computer-assisted policy analysis the use of formalized state analysis employing an orientation module results in more systematic and more efficient policy search and development, testing, and identification of alternatives. (3) A wider planning horizon permits weaker control policies and results in steadier system behavior (in particular, the wider planning horizon avoids the problems of overreaction). (4) Attention to first signs of emerging problems allows dealing with them at an early stage, and produces more satisfactory solutions.

9. The need for reliable processing of factual and normative concepts

The amount of factual ‘world knowledge’ and of normative constraints shaping behavior and decisions of social actors (human beings or organizations) can be enormous. Such oriented behavior can be broken down into a number of typical components: (1) state perception; (2) state (or policy) analysis and evaluation; (3) policy synthesis; (4) policy choice and commitment (Kirsch, 1970/1971; Bossel, 1977d; Bossel and Müller-Reissmann, 1979).

With the exception of the policy synthesis process, all other processes in this information processing sequence are of a deductive nature: Conclusions are generated by drawing inferences from an existing body of cognitions, subject to the premises describing the situation for which the conclusions are to be generated. Some of these deductive processes can be simulated by numerical analysis, where quantitative relationships yield numerical results, as in models such as World2. But much of human information processing involves manipulation of concepts and cannot very well be simulated by numerical analysis. In order to capture the characteristics of human reasoning in impact analysis and evaluation, a different simulation approach must be employed.

In their information processing, humans mostly manipulate concepts carrying a semantic meaning in a more or less logical (better: psycho-logical) way. These concepts, the chains of reasoning, and the results of reasoning processes are communicable to other human actors by means of everyday language. Hence it seems reasonable to use a qualitative non-numerical approach related to everyday language in attempting to simulate the cognitive processes of reasoning and orientation.

We have developed an appropriate formal language based on the predicate calculus, and the corresponding program system DEDUC for performing the deduction and evaluation tasks on the computer (Bossel, 1981; Müller-Reissmann, 1989; Müller-Reissmann and Rechenmann, 1977). DEDUC uses forward-chaining to deduce all possible consequences from given premises. Its application in policy analysis requires a ‘knowledge base’ consisting of two modules — one module containing interconnected factual concepts concerning the actor and his environment for the state impact analysis, the other containing normative concepts for the orientor impact evaluation.

A knowledge base is a collection of pieces of information from which case-specific models are constructed automatically by the computer in response to case-specific inputs. A knowledge base — and object-oriented simulation in general — therefore offers (in principle) much greater flexibility than a computer simulation model with a fixed structure and sequential processing (such as World2). It may generate new and surprising conclusions which were never envisioned when it was
constructed (see applications to environmental impact assessment in Thailand and social policy assessment in Mexico in Bossel et al., 1989; Bossel, 1989, 1990; Hornung, 1989). But this also means that a knowledge base must be very carefully constructed and validated — one incorrect concept may produce dozens of incorrect conclusions. For actor simulations, however, the essential cognitions of the simulated actors must be captured in the knowledge base — irrespective of whether they are ‘correct’ or not — since they determine decision outcomes. It has been shown that such actor simulations of actual decision-makers can reproduce their actual decisions quite closely (Bossel et al., 1982).

Deductive knowledge processing has a number of important applications, in particular for (1) representing non-quantifiable knowledge in simulation models; (2) using previously prepared ‘knowledge modules’ to determine likely impacts of certain events; (3) representing the (actor-specific) conceptual systems of actors; (4) forecasting the likely behavior of social actors; (5) accounting for psycho-logical mechanisms in reasoning processes.

10. Conclusions

The work summarized in this paper was conducted with the objective of achieving more accurate and reliable descriptions of the decision behavior of human actors — for policy analysis, future studies, and actor simulations in particular. This requires dealing with different aspects of information processing involved in decision-making: state perception and state projection, mapping of perceived state and its possible future consequences on normative orientations for evaluation and for guidance of the policy search, and representation of the cognitive processes of reasoning and evaluation. The research focused on two crucial issues in particular: analysis of the normative orientations of actors, and simulation of cognitive processes using these orientations. This led to the development and application of orientation theory, and further work utilizing non-numerical knowledge processing in complex impact assessment and evaluation contexts. The major conclusions:

The evaluation of system state and of policy impacts requires normative criteria representing the ‘interests’ of the affected systems and actors. Viability and sustainability in a changing environment require balanced satisfaction of the ‘fundamental interests’, or basic orientors of systems. These are identical for all systems; system-specific criteria can be deduced from them. A reliable assessment of basic orientor satisfaction, i.e. of viability or ‘system health’, can be made by using the basic orientors as a checklist. In many cases, time-consuming and expensive data collection is unnecessary.

The results from the work summarized in this paper show that orientation theory contributes to several important tasks:
1. Understanding and predicting behavioral trends: For viability, actors must give balanced attention to their basic orientors. This provides some predictability and can be used in actor simulation. Emphasis on a particular basic orientor leads to development of different ‘cultural types’ or ‘life styles’ of actors.
2. Guiding the search for comprehensive sets of indicators, in particular for sustainable development: Viability and sustainability can be assessed by checking whether the basic orientors of a given system are satisfied, and whether the system contributes to viability of the total system (possibly a recursive process). The orientor-specific questions can be used to define sets of indicators for viability and sustainable development.
3. Assessing and comparing alternative development paths: Using indicators that provide comprehensive information about the satisfaction state of basic orientors, viability assessments and comparative evaluations of development time paths and alternative development paths can be made. This requires mapping of indicator states on orientor satisfaction. Formal assessment functions may be used in this process.
4. Guiding policy development for viability and sustainability: Formal assessments can be computerized to determine orientor
(dis)satisfaction and indicator urgencies. Together with a system model, this information can be used to guide policy development by projecting and evaluating the future impacts of proposed policies.

References


