ENVIRONMENTAL INFORMATICS AS A NEW DISCIPLINE OF APPLIED COMPUTER SCIENCE

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ABSTRACT. For many years, computer-based systems for processing environmental information have been developed in environmental protection and environmental research. A broad range of applications in environmental research and protection is covered by these systems, including monitoring and control, information management, data analysis, as well as planning and decision support. A new discipline, known as *Environmental Informatics*, is emerging which combines computer science topics such as data base systems, geographic information systems, modeling and simulation, computer graphics, user interface design, knowledge processing, and neural networks, with respect to their application to environmental problems.

1. Introduction

Global development and the environmental situation are becoming more and more critical and dangerous. Driving factors are the uncontrolled growth of the world population combined with the increase in consumption in the developed countries. Both trends (more people, more consumption) have been viewed throughout history as unanimously positive. However, this view is now changing. With more than half of the people living on Earth today below the age of reproduction, a time bomb is developing. Even worse, the level of consumption in the developed world is viewed as a target by billions of people around the globe, influenced by modern worldwide communication, while, at the same time, we are already witnessing scarcity of water resources, extension of desert areas, loss of tropical rain forests, and, particularly, the accelerated growth of megacities.

It is quite clear that all these trends can only be broken with very decisive programs, limiting further population increase.

N. M. Avouris and B. Page (eds.), Environmental Informatics, 1–11.

To achieve this, however, will require radical changes in our general attitude. The political and the ethical leaders of the world do not yet seem to be willing or able to fully address these problems. However, the past several years have brought many changes in this direction. Particularly, the Rio Summit has finally led to the acceptance of a point of view that is best characterized by the term "sustainable development". Here, sustainable development means a way of living and a form of using resources that does not discriminate against future generations (WCED 1987).

Sustainable development is an important concept. However, it is difficult to operationalize and to make concrete. We will probably be confronted with quite sophisticated counter-arguments, and it might happen – as it has so often before – that uncoordinated development will actually lead to a state of affairs that is acceptable to no one. It is not at all clear what can be done to help to fight such a negative development.

Certainly, *information* will be a very critical resource in changing attitudes and making decisive political actions possible (Friend 1991). The following trends in environmental information processing are crucial in this respect (Radermacher 1994; Hilty 1994a):

- environmental monitoring by means of remote sensing and the coupling of data streams from all over the world,
- a policy for sharing and integrating environmental information across political and organizational bounderies,
- advanced model-based data analysis techniques, shifting the focus from data to dynamic system structure,
- industrial applications of environmental information processing, aiming at higher ecological efficiency (resource productivity) of the economic system.

On the one hand, advanced computer applications obviously play a leading part in these developments. On the other hand, the growing field of environmental information processing is a great challenge to computer science methodologies and their applications. From this process of mutual stimulation, a new discipline has emerged, known as *Environmental Informatics*.

2. Environmental Informatics

The European term "Informatics" is often regarded as synonymous to "Computer Science". However, the subject of Informatics incorporates more than computer systems and its various applications in information technology (IT). Beyond engineering aspects, Informatics views computer systems as they are embedded in organizations and society. This is especially true for *Applied Informatics* (sometimes also called Applied Computer Science), the branch of Informatics which bridges the gap between information technology and its various application fields.

Figure 1 illustrates the mediating role of Applied Informatics. On the one hand, it analyses real-world problems in a given application field and defines requirements to IT. On the other hand, it brings the problem solving potential of IT to the application field.

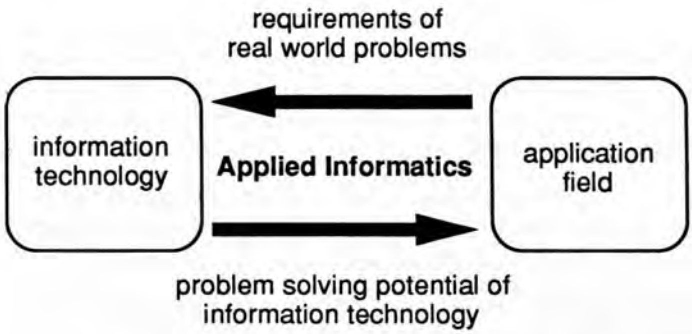

Fig. 1: The mediating role of Applied Informatics

There are some application fields that are strongly influenced by the increasing potential of IT, as can bee seen in medicine, which is the most widely known example. This situation led to the formation of a special discipline of Applied Informatics, known as Medical Informatics. Clearly, this research field – which emerged as long as 20 years ago – combines knowlege from Informatics with medical knowledge and can thus be viewed as an "interdiscipline".

An almost analogous situation can be observed today with regard to the environmental sector, leading to the formation of Environmental Informatics (Figure 2). However, the analogy to Medical Informatics does not perfectly hold, since the environmental sector is by itself an interdisciplinary research field. It incorporates knowledge from physics, chemistry, biology, ecology, sociology, economics, management, public administration, law, medicine, and other disciplines.

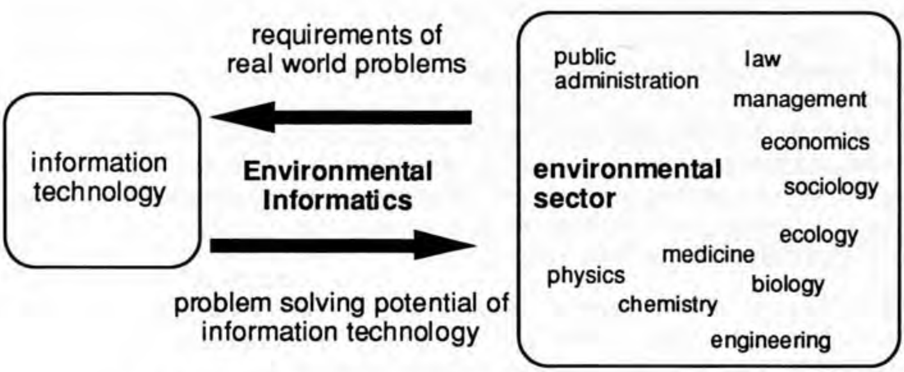

Fig. 2: Environmental Informatics supports an interdisciplinary field of
Information Technology applications

Therefore, a special responsibility devolves upon Environmental Informatics in that it provides the information processing and communication infrastructure to this interdisciplinary field. An important and difficult task for Environmental Informatics is to serve as a catalyst for the integration of data, information, and knowledge from various sources in the environmental sector:

- Integrating *data* means overcoming the heterogeneity caused by the variety of operating and database systems, data formats and documentation conventions, program interfaces and software tools, used in different organizations and disciplines.
- Integrating *information* means to enable data to be interpreted meaningfully in different organizational and disciplinary contexts.
- Integrating *knowledge* is a long-term goal aiming at the compatibility of the conceptual frameworks of different disciplines and traditions.

Environmental Informatics has been maturing since the eighties. In Germany, this is documented by the proceedings of the annual conferences which have been organized by the working group „Informatics in Environmental Protection" in the German Association for Informatics (Gesellschaft für Informatik e.V., GI) since 1987. These conferences and a number of additional workshops have yielded a growing number of participants, projects, and publications (e.g., Jaeschke 1989; Pillmann 1990; Hälker 1991; Schwabl 1991; Denzer 1992; Jaeschke 1993; Page 1994; Hilty 1994a).

It is important to note that Environmental Informatics does not only explore the potential benefits of IT in solving environmental problems, but also considers (and tries to avoid) negative environmental impacts of information technology (Rolf 1992; Hilty 1994d).

Today, Environmental Informatics is an integral part of Applied Informatics. It provides methodological support for computer application in environmental protection by combining advanced research fields such as database systems, geographic information systems, modeling and simulation, computer graphics, user interfaces, neural networks, knowledge processing, and systems integration (Page 1994).

3. A Typology of Environmental Information Processing Systems

There is a broad spectrum of environmental information processing systems which can be differentiated based on the nature of the information to be processed. This includes monitoring and control systems, conventional information systems, computational evaluation and analysis systems, planning and decision support systems, and integrated environmental information systems (Page 1992):

- *Monitoring and control systems* interact directly with environmental objects and processes. Monitoring systems serve in the automation of measurements (including remote sensing) in water, air, soil, noise, and radiation control. This also includes basic data analysis: time series data need to be aggregated, environmental objects need to be classified (e.g., in satellite images), and chemical substances need to be identified based on the measured data. Computerized process control is either directly employed in environmental technology such as in air emission control, sewage, sludge, or refuse processing, or used in production process automation with secondary effects on environmental protection (e.g., energy conservation, emission reduction). Monitoring and control systems often require the processing of vague information, e.g., using the evidence theory of Dempster and Shafer, fuzzy logic, or artificial neural networks.

- *Conventional information systems* are systems for input, storage, structuring, integration, retrieval, and presentation of various kinds of environmental information such as raw measurement data, descriptions of environmental objects (such as geographic objects or chemical substances), as well as formal, semi-formal and informal documents such as environmental regulations or literature references. Spatial and temporal aspects often play an important role in the management of these kinds of information. Various kinds of software tools, including geographic information systems (GIS), hypermedia systems, etc., are necessary for coping with this requirements.

- *Computational evaluation and analysis systems* support environmental data processing using complex mathematical-statistical analysis methods and modeling techniques. This includes simulating various environmental scenarios. Possible applications of these systems are the identification of possible causes of environmental impacts or the derivation of possible effects of different planning measures (e.g., causal models in forest damage research or forecast of emission loads over time and region).

- *Planning and decision support systems* support decision makers by offering criteria for the evaluation of alternatives or for justifying decisions, e.g., for environmental impact analyses, for handling hazardous substances, for water resources management, or for technological risk assessment. For industrial applications, so-called computer-aided environmental information and management (CAEM) systems are currently being developed, which provide the information processing infrastructure for environmental management systems. This development is especially important in the context of the EU "Eco-management and Audit Scheme".

- *Integrated environmental information systems*, as the last category mentioned, cannot be uniquely related to the system types mentioned above, since they consist of multiple components serving various purposes. It can be expected that integrated environmental information systems will be increasingly designed as distributed systems. The integration of various concepts for information processing, which is required for building these kinds of systems, presents a special challenge to the Applied Informatics, with similar importance to other application fields.

The reader will find examples for these systems types and their application in the succeeding chapters of this volume.

4. Interrelations With Methodologies and Research Fields of Informatics

The types of environmental information processing systems listed above are interrelated with various methodologies and research fields of Informatics. Figure 3 shows which topics of Informatics are relevant to which types of systems.

4.1 DATABASE SYSTEMS AND GEOGRAPHICAL INFORMATION SYSTEMS

Database systems and methodology constitute the most basic part of informatics with regard to environmental applications (see Page, in this volume). Geographical information systems (GIS) are database systems specialised on spatially structured data. Because most environmental data is related to space and time, GIS are widely used as a basis for environmental information systems (see Bill, in this volume). However, GIS do not cope with the problem of handling large time series.

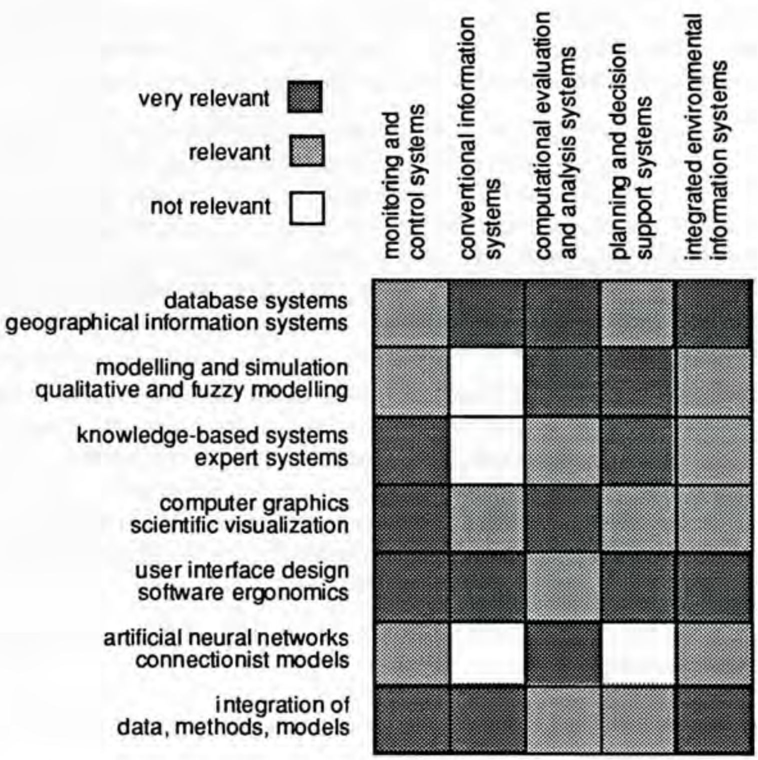

Fig. 3: Relevance of methodologies and research topics of Applied Informatics to system types in environmental information processing

The requirements of environmental information systems (EIS) are not fully covered by GIS nor by relational database systems. New developments such as object-oriented database systems (Cattel 1994; Günther 1993) and the concept of metainformation and metaknowledge (Radermacher 1991; Schimak 1994; see also Voigt, in this volume) may have enough integrative power to overcome the current deficiencies.

4.2 MODELING AND SIMULATION

Modeling and simulation techniques have been employed in the environmental sector for more than three decades. The first applications emerged from water resource management. Today, the following types of simulation models are used for advanced data analysis tasks, for decision support, planning, or for process control:

- dispersion and quality models for air, water, or soil (e.g., Sydow 1994; Fedra 1994; Ames-kamp 1994),
- ecosystem models and models in ecological economics (e.g., Bossel 1994a; Bossel 1994b; Hilty 1994d),
- process models as a part of process control systems (e.g., Gilles 1988),
- models for the prediction of traffic emissions (e.g., Freese 1994; Licitra 1994) and for planning purposes in "eco-logistics" (e.g., Hilty 1994b).

The task of Informatics in environmental modeling is to provide tools that enable experts to build simulation models with minimal effort, i.e. by using graphical modeling languages (Freese 1994), modeling and simulation program packages (Bölckow 1989; Page 1992b), or so-called model base systems, which provide standard modules that can be used as "bulding blocks" for modeling (see also Häuslein, in this volume).

An important issue is to enhance model transparency. Since simulation models are explicit formal representations of theories of real systems, they have a potential to stimulate communication within the scientific community. But this advantage of simulation models is only effective if they are represented in a way that makes clear how the simulation results depend on the model assumptions. Model transparency in this sense can be supported by various concepts, including high-level declarative modeling languages, graphical modelling systems, knowledge-based model analysis techniques, advanced methods of sensitivity analysis, and qualitative simulation. These issues certainly need further development.

4.3 KNOWLEDGE-BASED SYSTEMS

More recently, attempts have been made for applying knowledge-based systems, in particular expert systems, to environmental information processing. Knowledge-based approaches are especially relevant to the interpretation of image data from monitoring systems such as aerial photographs and satellite sensor data.

Expert systems have been developed for decision support or planning applications in the following domains (Page 1990; see also Simon, in this volume):

- waste disposal, valuation of hazardous substances and contaminated sites,
- environmental impact assessment and environmental planning,
- application of environmental laws, regulations, and technical instructions,
- advice in accidents and emergency situations with hazardous chemicals.

However, most of these projects have not yet advanced beyond the prototype state.

4.4 User Interfaces and Software Ergonomics

A general requirement for a wide use of environmental information processing systems is the ergonomical quality of these systems. Unfortunately, badly designed user interfaces often add complexity to the given task instead of reducing complexity. User interfaces must be designed strictly according to ergonomical standards and principles especially in application fields where the user group is non-uniform and the subgroup of occasional users is large, which both is the case in the interdisciplinary environmental sector.

4.5 Computer Graphics and Visualization

Employing computer graphics to visualize environmental data is important because there is still a lack of knowledge about causal relationships and regularities in ecological or socio-economical systems; only a few and usually controversial models can be drawn upon to evaluate and interpret the data. In this situation visualization is an important means to unprejudiced data analysis and to recognize previously unknown structures.

Moreover, graphical presentations are much better suited to communicate environmentally relevant facts to decision-makers and to the public than numerical tables are (see also Denzer, in this volume).

4.6 Artificial Neural Networks

Artificial neural networks, more precisely called connectionist models, have the ability to learn a limited range of tasks instead of being programmed. In Environmental Informatics, they are useful as a means to recognize patterns in large data sets.

Other applications are the prediction of smog situations (Becher 1994, Hartmann 1994) and the optimal control of incineration processes to minimize air pollutant emissions (Keller 1994; see also Keller, in this volume).

4.7 Integration

As mentioned in section 2, integration is a key issue in Environmental Informatics, and it entails more than purely technical problems.

The harmonization of environmental information at national, European, and worldwide levels is of central importance for gaining a reliable description of the environmental situation and, at the same time, is a basic requirement for any reporting system in this context.

These requirements, however, are confronted with the existing heterogeneity of hardware and software environments, database systems, method and model bases, network technology, and programming languages. Approaches for overcoming the heterogeneity, one of the major obstacles to open software solutions, can have a tremendous impact on the productivity in environmental management, and can also lead to a greater stability in system design and system usage.

Doubtless, the development and promotion of standards is of particular importance in this respect. Experience shows, however, that we will still have to cope with competing standards in future. In addition, technological advances will always produce new heterogeneity problems and will require strategies for migrating the software towards new solutions. The proper handling of questions of this kind is very important for obtaining powerful solutions in the environmental domain. A pragmatic usage of the currently evolving architectures such as client/server architectures, object request brokers, hypermedia technology for identifying and accessing services and data, and remote procedure components are important in this field (Riekert 1994).

In some projects, the installation of *metainformation servers* to facilitate access to distributed information systems and to integrate monitoring data from different sources has already proven to be very useful (Schimak 1994).

5. Conclusion and Outlook

The aim of Environmental Informatics is to bridge the gap between Information Technology and the environmental sector. On the one hand, advanced computer applications have a problem solving potential that must be developed into practical solutions for environmental problems. On the other hand, new and challenging requirements arise in the environmental sector that stimulate research and development in Informatics. The main challenge to Informatics is the complexity and heterogeneity of the environmental sector, demanding for innovative approaches to controlling complexity and to integrate existing data, information, and knowledge from various scientific disciplines and organizations.

The role of Environmental Informatics should not be restricted to computer-based investigation of the present state of the environment. Although diagnosis is indispensable, it is useless if no therapy follows. Thus, Environmental Informatics should also accept the challenge to play an active role in the local and global transformations that will be necessary to approach sustainability.

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