Information Tools for Sustainable Development: Enabling Distributed Human Intelligence[1]

Aldo de Moor
Infolab, Tilburg University
P.O.Box 90153
5000 LE Tilburg
The Netherlands
tel. +31-13-4663020
fax +31-13-4663069
e-mail: ademoor@kub.nl

Abstract

In the field of sustainable development, numerous information tools, many of them connected through computer networks, support users in their individual activities. However, these tools cannot always be effectively used, as problems occur with the quality and accessibility of the data on which they operate. Another major issue is that these tools are not very well suited to support collaborative problem solving. One solution proposed by some is distributed artificial intelligence. We argue that in many cases groupware provides a more viable approach as it enables strong collaboration between human stakeholders. To optimally support professional communities, network information systems must be constructed. Such systems consist of suites of information tools supporting both individual and group needs. The users themselves must be actively involved in their incremental design. Specification methods must be available to this purpose.

1. Introduction

Sustainable development, meeting the needs of the present without compromising the ability of future generations to meet their own needs, is gaining ever more recognition as the crucial objective for humanity to survive with a reasonable quality of life for everyone. From all sectors of society efforts are being launched to work toward this goal. However, implementing this abstract concept in the real world is difficult, as there is substantial confusion about the precise meaning of the notion of sustainable development. Furthermore, the wide range of stakeholders and of interests involved, contributes to the emergence of serious societal conflicts. Most experts agree that information is of pivotal importance in reducing the effects of the resulting uncertainty and struggle. Its key role was stressed at the United Nations Conference on Environment and Development (UNCED): "Developed countries and relevant international organizations should cooperate, in particular with developing countries, to expand their capacity to receive, store and retrieve, contribute, disseminate, use and provide appropriate public access to relevant environmental and developmental information..." (UNCED, 1992).

[1] A final version of this paper was published in Journal of Failure & Lessons Learned in Information Technology Management, 2(1):21-31, 1998.

Information technology has tremendous potential for amplifying the problem solving capacity necessary for the realization of appropriate global change. It can enable and streamline the widely varying information production and exchange processes of individuals, organizations, and networks working on sustainable development. The technology is thus a significant element in a sound information strategy for sustainability. To put it even more strongly: information technology in this respect can be seen as a transformative technology, that is, it is an indispensable instrument for organizational change, allowing for completely new modalities of operation and relationships (Bezanson, 1994).

A significant trend is that a lot of the information technology comes in the form of information tools, which are standardized software programs that provide a fixed amount of functionality, such as mailers or database search engines. The ongoing development and proliferation of these tools, boosted by rapidly growing computer networks such as the Internet, is essential for building the capacity for global change.

The application of modern information technology is only a necessary, but not a sufficient condition for the actual implementation of a new, more sustainable world order. Most of the current information infrastructure has been built from a 'technology push', rather than a 'demand pull' philosophy. At the moment, the ad hoc availability of specific tools to a large extent determines what this infrastructure looks like. Yet to create more effective ways of information handling, we should adopt points of view in which information system development is seen more as a form of social action (Hirschheim et al., 1991). In this view, technological capabilities are interpreted in terms of the social action interdependencies that they serve, such as how knowledge can contribute to resolving conflicts. Thus, our starting point for analyzing and creating useful information systems should not only be the technical features of the tools on their own. We also need to investigate how these tools can effectively be applied in concrete work situations.

In the field of sustainable development, numerous initiatives are shaping the global information infrastructure of the future (Young, 1993; Eco-Informa, 1996). Surveys of information resources for sustainable development generally focus on categorizing data sets by sustainability themes, such as pollution or deforestation; on classifying the stakeholders who provide the information, like governments or environmental organizations; or on making a very crude subdivision according to the standard Internet tools used to access the data (e.g. Feidt and Roos, 1995). Our approach, however, is to analyze the context in which a wide range of common information tools is used. We will argue that these tools are especially tailored for usage by individuals working on relatively well-defined problems. However, an important class of problems in the sustainable development domain concerns vague, complex issues that need the involvement of many types of stakeholders for their successful definition and resolution. The purpose of this paper is to outline how information technology can be applied to deal with this particular kind of problems by enabling what we call distributed human intelligence.

In Section 2 we give an overview of some of the basic tools that a user needs in order to be able to work on his own. In Section 3, the focus is on the data to which these tools are applied. We will point out that at present due to a lack of data quality and accessibility many applications seem to create more useless data, rather than put them to effective use. To promote the latter, it is argued in Section 4 that more collaborative problem solving approaches are needed as well. One technology-focused such an approach, distributed artificial intelligence, is critically assessed. In order to find more effective ways of collaborative problem solving for so-called wicked problems, a shift of paradigm toward strong collaboration is proposed in Section 5. This concept implies that the focus should be on human agents being supported by the machine, instead of on users having to adapt themselves to the very limited possibilities of their artificially intelligent counterparts. Groupware is the technology most capable of accomplishing this objective. However, it remains very difficult to determine how suites of groupware and other information tools must be optimized to a specific usage context. In Section 6 we briefly discuss one possible approach by outlining work being done on a user-driven specification method. The method could be used for the development of more integrated and customized network information systems. We end this paper with some conclusions in Section 7.

2. Basic Information Tools for the Individual User

In this section, we will discuss some of the core information technologies that can be used to build comprehensive information systems for sustainable development. Each of the tools discussed here embodies a certain amount of information handling functionality that is accessible to single users. This functionality is mostly used for the creation, retrieval or presentation of data, sometimes also for rudimentary data interpretation. Computer networks are first briefly described because they realize basic connectivity among and between people and information tools. Databases store basic data. Different kinds of value can be added to these data by using knowledge bases. Expert systems increase the availability of scarce professional advice. Geographical information systems are important instruments for presenting and interpreting large amounts, and complex types, of data with a spatial dimension.

2.1. Computer Networks

The computer network as an information technological tool is a sine qua non for global cooperation. It provides the glue that can stick together numerous information tools. Standardized protocols for the numerous hardware and software platforms and communication links in use are rapidly being established. The current situation is far from perfect, as many of these standards are only de facto and not systematically aligned. Still, they have already created a relatively reliable and easy to use communications infrastructure, which information tools operating from different locations use to interconnect. Some tools allow users to store and retrieve data or run jobs remotely. A large collection of resource discovery tools helps users to sometimes quite efficiently browse, search and organize information (Obraczka et al.,1993). Other computer network applications, like electronic mail and information navigation tools, allow the end user to communicate with peers.

Until recently, many isolated, often proprietary computer networks existed, such as ARPAnet, EARN, and BITNET. These networks were primarily aimed at satisfying the needs of specific user domains such as the military or the research community. Primitive connections between these networks were possible through so-called gateways, but these were often quite restrictive with respect to the types of information exchange they allowed. One of the most significant phenomena of the past few years, however, is that of the worldwide coupling of networks. This makes it increasingly irrelevant to the user what particular computer network he joins. The user can now get access to many facilities offered by linked networks as well, thus sometimes dramatically increasing the available functionality and data resources. This is especially true for networks that are part of the Internet. The latter is not really a network, but should be imagined as a meta-network: it consists of thousands of independent networks that all support the Internet protocol. If a network offers full Internet access, highly-interactive applications can be supported, of which the popular World Wide Web is one of the most successful examples.

A problem with full-Internet access is that the user needs a fairly high-bandwidth data line to an access provider. This can be a costly affair. Large-scale full access may therefore be wishful thinking, especially in many developing countries where the telecommunications infrastructure is often inadequate. To provide at least a minimum degree of connectivity, several creative solutions have been thought of. Fidonet[2] is a volunteer network (called by some the 'Poor Man's Internet') that uses a robust store-and-forward system to propagate mail messages and files to their destinations. Nodes in the network, which are often plain personal computers, every now and then dial up to other nodes by normal phone lines, which in turn repeat the process. In this way, it may take a relatively long time for a message to arrive, but it also makes Fidonet a much cheaper medium than the Internet. Another solution is packet radio, which broadcasts computer data via normal radio frequencies[3]. Finally, if there are no electronic network facilities affordable or available at all, cheap and high-capacity storage media such as CD-ROMs can be used to distribute data to the intended users. For example, an often heard criticism of current environmental information provision practices is that more information about the environments of developing countries is available outside of these countries than inside them. To help end this undesired situation, the full texts of the UNCED conference have been made available on compact disc (Gordon and Tunstall, 1995).

A tendency can be observed among information tool developers to create ever fancier applications that consume huge amounts of network bandwidth. However, this has serious implications for the many users who do not have the luxury of interactive network access. To serve them as well, developers should also address the large need for improved interfaces that can be used in places where connectivity bandwidth is low (Goodman et al., 1994). One may think of tools that communicate by sending commands via simple electronic mail, such as ftp-by-e-mail[4] . Creating a sustainable society is a serious business, that critically depends on large numbers of stakeholders being able to communicate on a global scale. Networks can be an important means to this end, but not if a large proportion of the human population is left out. In all the superhighway construction fever, paving the information dirt roads should not be forgotten.

2.2. Databases and Knowledge Bases

One of the most important functions of computer networks is to link data resources, which are made available in the form of databases of many different kinds. They can be relational databases accessible through a simple terminal interface, World-Wide-Web servers providing sophisticated data presentation and browse facilities, etc.

Countless topics are covered by databases on sustainable development. They range from environmental information concerning the effects of pesticides to the full text of treaties about the protection of still mostly pristine Antarctica. Also, large amounts of information are available about the second fundamental component of sustainable development, socio-economic development issues, including their relation with environmental problems. Comprehensive overviews of such databases are maintained by respectable organizations as the Swedish Royal Institute of Technology[5] . Still, merely acquiring data and storing them in a database of some kind is not enough. Issues like information overload and data relevance also need to be taken into account, implying that it must be known what actual purpose of use these data serve. Therefore, much more

---

[2] URL: http://owls.com/~jerrys/fidonet.html

[3] URL: http://www.tapr.org/tapr/html/pktfaq.html

[4] Mail to e.g. ftpmail@decwrl.dec.com

[5] Environmental Sites on the Internet, URL: http://www.lib.kth.se/~lg/envsite.htm

attention should be paid to the transformation of existing data into forms that are useful for different groups of users (UNCED, 1992).

One possible approach is to actively research and promote the evolution of simple databases into sophisticated knowledge bases. Knowledge bases include sets of rules that allow more or less intelligent inferences to be made about the available data. This can be a great help to the user, in that otherwise hidden and complex conceptual links between subsets of data can be made visible. A knowledge base on atmospheric measurements could for instance automatically extrapolate air pollution data concerning a certain city and show when critical levels will be reached, so that the proper authorities can be warned. The same knowledge base could provide aggregates of data to scientists studying long-term changes in pollutant concentrations. One of the most advanced projects heavily depending on the use of sophisticated knowledge is the Global Change Data and Information System - Assisted Search for Knowledge project (Rand, 1995). The United States Global Change Research Program aims to analyze and predict global change, so that the results can be used for high quality policy making. Many different databases, accessible through the Internet, can be queried in various ways. Several search modules process the queries, each of them specialized in a specific search process. Such an assisted search module contains a complex search engine, which heavily depends on a range of extendible knowledge bases that model disciplinary and organizational domains, thus considerably enhancing the searches. Exactly how these knowledge bases are to be used and maintained is still open to debate, but as we have seen, at least some progress is being made on tools that are more customizable to the preferences of their users.

2.3. Expert Systems

The rule-based knowledge embodied in knowledge bases is one step on the way toward more intelligent information systems that are capable of helping the user interpret data and formulate well-thought out decisions. However, the depth of this knowledge is often quite limited and does not cover a complete domain. In this case, expert systems may be of use, especially when there is a shortage of qualified professional expertise. In such systems, expert knowledge is captured from a human domain expert by a knowledge engineer. This knowledge is a combination of a theoretical understanding of a domain, and a collection of heuristic problem-solving rules that experience has shown to be useful in that domain (Luger and Stubblefield, 1989). As is the case with knowledge bases, only a relatively small number of successful expert systems have been developed. Hansen (1990) describes a typical example concerning an expert system for the interpretation of environmental health data. It functions as an intelligent interface to a large number of databases. It quite successfully assists the user in formulating a correct search profile and efficiently obtaining relevant answers to queries. A different kind of expert system application is outlined by Thomson (1993), who proposes to use expert systems containing socio-ecological models to evaluate policy.

Despite their relative usefulness, ambitious claims such as that made about the following environmental law expert system, should be considered with the necessary scepticism. The system is supposed to be capable of "...fusing 'documentation' and 'decision-making' to create a unique, complex tool with logical structures capable of making use of data stored in external databases, and to interact suitably with them..." (Fameli et al., 1991). The reason for raising doubts about the concrete applicability of such a system is in fact given by the authors themselves, even though they draw the opposite conclusion: "... environmental law is undoubtedly one of the most fertile terrains of the many where artificial intelligence may be brought to bear, due to the interdisciplinary nature of the field, to the many variables that come into play, and to the interactions produced both within the domain itself and with factors external to it." (Fameli et al., 1991). This is indeed a good characterization of most problem domains related to sustainable development. It can, however, hardly be called a recommendation for the direct application of an expert system. For one of the key strengths of an expert is that she is able not only to solve specific well-formulated problems, but also to put them in a larger context by pre-determining the relevant assumptions before the start of the actual analysis. Cutting out this vague, but all-important background is not something that expert systems are very good at (Winograd and Flores, 1986). This is all the more true of highly complex and change-prone fields like environmental law. Thus, expert systems will at most only play a limited supporting role in sustainable development.. Prominent involvement of human experts remains essential.

A related issue is the often too limited role that the stakeholders, being the sources of the knowledge, play in the traditional view of expert systems. They are too easily regarded as mere passive containers of expertise, to be emptied by an external knowledge engineer, instead of as active participants in policy formulating debates. Very complex, anonymous models are constructed, which often stifle stakeholder discourse because of their inherent complexity and inflexibility. The danger is that only the analysts may still be able to understand and work with these formal models. Therefore, expert systems, valuable as they can be, are not the end solution. They need to be carefully embedded in structured stakeholder forums from which they can draw new expertise, and which can assess the relevance and quality of the inferences made by the expert system.

2.4. Geographical Information Systems

Databases, knowledge bases, and expert systems are important tools in providing useful information about problems related to sustainable development, but they do not suffice. One important characteristic of environmental information is that it is often geographically oriented. Many of the data are bound to specific locations. The implications of these data for decision making and policy formulation become much clearer when the analysis and presentation of these data is done in spatial form as well. Geographical information systems (GIS) are excellent tools to represent this spatial dimension in the information handling process, by processing raw data and presenting the results in the form of dynamic charts and maps.

Besides feeding on input from normal databases, GIS are particularly suited for dealing with data gathered by global positioning systems and remote sensing of the Earth by satellites (Lang and Speed, 1992). Global positioning systems permit very accurate positional data, obtained from satellites, to be added to the actual environmental data being gathered. These additional data allow for example research teams investigating logging damage in forests to quickly correlate their assessments with exact geographical coordinates, thus substantially increasing the quality and usefulness of their work.

Still, one of the most interesting and useful applications of GIS is to help make sense of the mass of data gathered by satellite remote sensing activities. Remote sensing is one of the primary sources of information on sustainability. It allows for the cost-effective and precise coverage of large surface areas. One great advantage of this method of data gathering is the comparability of observations, as standard methods of collecting data can be used worldwide (Günther et al., 1994). Furthermore, regular orbital observations enable trends to be easily detected. This is important as many processes of environmental change are too slow to be observed in real time. Paradoxically, the rental of high-tech satellites is often more affordable to poor developing countries than the lower-tech surface observations. Because of the phenomenal range and speed of remote sensing equipment, the cost per unit of data can be much lower compared to the results obtained from for example airplane or surface observations.

Despite all the advantages of remote sensing systems, they also form no panacea. Exactly because they can provide the material for so many different kinds of useful information, the accompanying GIS must be carefully designed to tailor the data to the specifically intended human use. Furthermore, the focus of satellite observation is on natural processes and events. All too often, however, sustainable development - or rather the lack of it - is determined by social and political forces, of which only the ultimate physical effects on the environment can be captured by telelens. One should be cautious, therefore, not to overly rely on what can be collected automatically, while forgetting to ask what are the causes of the observed changes. Still, provided that these kinds of issues are sufficiently taken into account, geographical information systems can be used as a means to systematically collect, condense and relate data from various sources, and to present the results in a user-tailored way. Instead of users having to waste their time on tedious low-level data processing jobs, a GIS enables them to concentrate on the much more interesting interpretation and analysis of the phenomena underlying the data.

3. Intermezzo: More Useless Data or Data Use?

Many laudable efforts are being undertaken to improve computer networks, data- and knowledge bases, expert systems and geographical information systems. Still, focusing on the technical development of these tools alone, without critically examining the context in which they are being used, would be a dangerous form of myopia. This section focuses on the data on which the tools operate. Two often experienced problems concern the quality of the data as well as their accessibility.

3.1. Data Quality

One major aspect of data that cannot be overlooked is their quality. Many of the environmental data sets provided are neither consistent nor representative (Briggs, 1990). Many data are gathered for specific operational purposes only. It turns out to be very difficult to transform them into a more generalized form that is useful for understanding how our life support system is changing (Atkinson, 1993). Furthermore, many sustainability phenomena are of a border-crossing nature. Most databases therefore should contain data covering several countries at least. As a result, data deficits regularly exist when countries do not participate in international data collection efforts. Furthermore, many times data are incomparable because of the widely varying national formats that are used by their collectors and analysts (Gordon and Tunstall, 1995).

3.2. Data Accessibility

Another issue related to the use of data is that of their accessibility. The concept of data accessibility is often interpreted as information resources being technically attainable. Still, even though data may technically be accessible by potential users, this unfortunately does not imply that they also have the financial, political, and other means to effectively retrieve them. Two important such constraints on data accessibility are data costs and censorship.

Data Costs

One of the factors that determine data accessibility is the cost of the data. Both the use of the infrastructure and the contents of the data themselves influence the total costs. To give an example of the first type of cost determinant, Nostbakken and Akhtar (1994) suggest that the current information technology explosion driven by ISDN and related standards is actually increasing the cost of communication for low-volume users, rather than reducing it. Countries are forced to spend large sums of money on an expensive telecommunications infrastructure just to meet the demands of international competition. This may cause developing countries to lag behind even more in the international development rat race.

Not only accessing the communications infrastructure, but also using the contents of the data themselves has, sometimes far-reaching, financial consequences. Until recently, it was technically not feasible to automatically charge users for accessing many kinds of publicly accessible databases, incluse those on the Web. This meant that much of the free network-accessible information is of inferior quality (although there are exceptions), and that large amounts of much needed data are simply not provided at all. However, now that sophisticated network accounting mechanisms are maturing (Mackie-Mason and Varian, 1993), which even allow users to be charged by the specific document that they access, this situation could change quickly. Indeed, many databases can only be developed and maintained if the user is charged a reasonable usage fee, so more commercial behaviour can induce better resource development and use. However, there is also a clear danger of over-commercialization. In many cases, the high cost of information effectively prohibits stakeholders to acquire and use substantial amounts of data that are clearly relevant to them (Lees and Atkinson, 1993). This results in less powerful and under-funded stakeholders to actually be excluded from the communication process. This worrisome development could have negative consequences for the quality of sustainability conflict resolution outcomes, as only extensive consultation and participation of all - informed - parties will allow for really sustainable solutions.

Data Censorship

Another serious problem related to the accessibility of data is that of implicit or explicit censoring. Some analysts propose facilities to be created for national administrations to vet the use of sustainability data. In the view of Briggs (1990), in order to prevent 'misuse' and 'misinterpretation', the access to large collections of these data should be monitored and controlled. This, he proposes, could be realized by not allowing users direct interactive access to the databases. Instead, all applications for data use would need to be channelled through, and approved of by, a specially assigned system operator group. This, however, is a slippery and dangerous path to go. One drawback is the high cost and slow access time of this anti-interactive way of working. A much more serious problem, however, concerns public interest groups that critically evaluate other societal stakeholders' activities, such as those of governments and corporations. In the proposed approach, such groups could easily be excluded from the free flow of information on sustainability. Inhibiting one's opponents free access to information that should really be public, will jeopardize the urgently needed society-wide generation of balanced solutions and broad-based acceptance of painful decisions. Instead, for sustainable development ever to be achieved, it is essential that we at least partially move away from the 'protectionist and centralised information and decision making paradigm' to a 'community development paradigm' (MacDevette, 1994). This shift would result in information being moved out to the public domain where it can be used by all parties in the societal decision making process. However, until now only scattered and relatively modest information systems have been developed for the grassroots community, even though this is one of the major facilitators of social and environmental change. Concerted efforts are therefore needed to democratize sustainability information distribution and use, so that sustainable development gets a real chance of turning from a dream into reality, instead of into a nightmare.

Although most of these concerns are not unique to the domain of sustainable development, their magnitude and combination is. Information tool and system developers should at the very least be aware of this mixture of issues when designing new applications, and openly discuss these sometimes sensitive topics with their peers, principals and the intended user community.

4. The Evolution From Individual to Collaborative Problem Solving Approaches

The various information tools described in the previous sections have so far mainly been optimized for the creation, storage, presentation, dissemination, and retrieval of information by individual users. Nevertheless, increasing individual productivity is not enough for addressing the complexity of many sustainable development conflicts and challenges. Due to the multidisciplinary nature of the problems, as well as the geographical dislocation between problems and problem solving components, environmental problem solving needs to be cooperative (Avouris, 1995). Another reason why there is an urgent need for more collaborative ways of working, is that too many raw data exist. Because of the increasing information overload, the focus is shifting from merely monitoring and classifying basic data toward the analytical clustering of these items around issues, which requires complex models of natural processes and the effects that humans have on them (O'Connor, 1994). In order to get reliable information, useful for planning concrete action for global change, such models need to be socially agreed upon (Günther et al., 1994). This need for new ways of joint working is not just a theoretical construct, but ever more clearly also felt in the user community itself, where various stakeholders increasingly demand more creative opportunities for collaborative work (Mayer and Gans, 1995).

4.1. Towards Collaborative Problem Solving

The old information technology paradigm, which merely focuses on serving the individual user with computer output, is no longer sufficient. In order to accomplish the objectives of collaborative problem solving and agreement building, innovative new perspectives on information technology must be developed that support complex group interaction processes. In these processes, out of the large volumes of - initially - seemingly unrelated data, issues are identified and consensus on their solution is reached, or at least an understanding of the different positions of the various stakeholders. A key precondition for the success of such group processes is that they are adequately coordinated. The required synergy in group work and focus on concrete results can then occur. Currently prevailing views on the role of information technology do not always sufficiently stress this. A typical description is given by the International Development Research Council (IDRC), one of the world's leading organizations as far as the promotion of sustainable development through information technological means is concerned. They give the following definition: "Information technologies are primarily electronic-based technologies which can be used to collect, store, process, package, and communicate information and provide access to knowledge." (Bezanson, 1994). This - data-oriented - definition is a good and comprehensive characterization as far as satisfying individual information needs is concerned. However, it does not stress the import of the coordination of group collaboration activities.

4.2. Distributed Artificial Intelligence

An approach that claims to be more in line with the cooperative problem solving view is that of distributed artificial intelligence (DAI). This field is concerned with the study and construction of automated systems that support coordinated intelligent behaviour in a group of semi-autonomous computational elements, called agents (Avouris, 1995). To put it more strongly, Avouris even considers it to be the 'natural paradigm' for many complex environmental support systems. Admittedly, DAI pays considerable attention to the problem of coordination. For instance, in one DAI system that he describes, the cooperating knowledge-based system, coordination is achieved by a number of mechanisms. In the hierarchical organization structure, control relations are decided by the agents' role positions. Another coordination mechanism is that of negotiation based interaction, in which the agents compete for resources and task execution through bidding and contractual mechanisms.

4.3. How to Deal with 'Wicked Problems'?

Enthusiasts supporting a strong role of DAI propose that it provides 'emergent intelligence', which means that a group of (computational) agents together can offer something that cannot be produced by the individual agents on their own. This would make it a potentially powerful problem-solving tool (Shaw and Fox, 1993). DAI followers often claim that it is just a matter of more time and research resources before the scope of current systems, which can only deal with very limited types of problems, will expand to include more realistic and interesting domains.

Still, the same criticism as given in our earlier treatment of the individual applications of artificial intelligence (knowledge bases and expert systems) applies here. A major problem that comes to the fore in the light of the previous discussion is the conjunction of the terms 'intelligent' and 'agents'. We argue that there is a fundamental barrier that will prevent workable and comprehensive DAI systems from ever becoming reality on the much larger real-world scale at which information technological support is needed. Characteristic of the sustainable development domain is that it is plagued by problems that are unique and very hard to formalize and solve by standard procedures. These problems are also known as 'wicked problems' (Isenmann, 1993). Typical examples include societal decision making processes on land use management. Wicked problems generally need a distributed problem solving approach, for which, as we have seen DAI can provide some helpful modelling tools. However, machine intelligence can only be considered useful when talking about narrow domains, for which problems and solutions can be precisely formulated, or at least some good heuristics can be defined beforehand. Except perhaps in the most trivial of cases, the scope, complexity, and uncertainty of research and decision making on wicked problems are much too large for computational agents to be of much use in the definition and interpretation of problems and data, let alone the synthesis of their solutions.

5. A Shift of Paradigm: Toward Strong Collaboration

Distributed artificial intelligence, although definitely having potential for executing and coordinating relatively well-defined subtasks, can offer only the most restricted problem solving capacity required in real-world sustainable development situations. The major reason for this deficiency is that the human interpretation and judgement factor is left almost completely out of the equation in current technology-centered applications. The unique cognitive qualities of the human being are often ignored or not rightly valued by tool developers, even though in many situations they are essential in order to formulate relevant problems and conflict descriptions, to determine what information is relevant in a specific context, and how this information could be used. A typical example of this attitude is shown in the case of the Design Fusion system, a group decision support system developed for the improvement of mechanical designs (Shaw and Fox, 1993). The system consists of a group of computational agents ('advisors') who interact with one another and the (human) designer. Instead of concentrating on how a group of people can work more effectively, where possible supported by a set of tools, most attention is paid to how the artificial agents coordinate their work. For this particular, well-articulated domain of mechanical design such a system may perform satisfactorily. However, if the underlying, computational agent-centered orientation is also applied to create information systems for the countless misty and unruly concrete sustainability problems, this approach inevitably comes to a dead end.

5.1. Distributed Human Intelligence

The ideal situation would be one where distributed artificial intelligence supports what we call 'distributed human intelligence'. The group of human beings remains firmly at the helm, determining the focus on and setting the course for the interpretation of complex reality. Artificial intelligence only takes care of the more standardized, time-consuming coordination and information handling tasks. Sowa sees such an - appropriate - application of artificial intelligence as a 'Superclerk', which "'would not rival human intelligence; but [...] would make an excellent assistant for routine chores." (Sowa, 1984, pp.353). So, is there an alternative, or at least complementary information technological view to the current, technology-centered approach? An alternative which would allow for the more human-focused kind of application development just discussed? Is it possible to give back the "power to the people" in the situations where they need more control over the information technology at hand? An exciting new branch of the information sciences has emerged over the past few years that may provide some answers to these questions. It is the field of Computer Supported Cooperative Work (CSCW) (Ellis and Wainer, 1994). Research in this area concentrates on the development of groupware, software that can in short be said to promote strong collaboration. This is collaboration in which a group of people synergistically develops and improves structured artifacts more efficiently than would be possible by the same group working independently (Johnson and Moore, 1994).

5.2. Groupware

Two basic terms, people and synergy, are of specific interest here, as they form the essence of groupware. First of all, the focus of groupware rightly is on the users being the principal agents of the system. This means that this software acknowledges the value of the, in principle boundless human creativity and analytical capacity. Moreover, groupware also can provide some structure to human discourse as it is to create synergy, meaning that the software somehow guides and unites, in other words, coordinates, the activities of the people working together. Note that developing groupware does not imply that advanced technology should necessarily play a less important role than in individual applications. Rather, it means that a much more careful analysis takes place of how - simple or advanced - information tools may support and improve group interaction processes.

A large number of - mostly experimental - groupware applications have already been developed. Their diversity in scope is large, and ranges from message and computer conferencing systems to complete electronic meeting rooms and co-authoring and argumentation systems (Rodden, 1991). However, if we look at what is the state of the art in the kind of human collaboration supporting systems that are actually being used in the field of sustainable development, instead of in the safe haven of the laboratory, we must conclude that not too many advanced groupware projects have been initiated yet. Recent major collaborative projects dealing with addressing wicked sustainability problems make still only little use of sophisticated groupware tools and concepts.

As an illustration, electronic seminars on high-priority issues like the impact of global warming on small island states have been organized by organizations such as the United Nations University[6]. The main tool that these 'conference rooms' use to support the group discussion of position papers, submitted by participants, is a generic mailing list. A more advanced organizational approach has been adopted by the Sustainable Agriculture and Rural Development Forum (SARD), which is a joint endeavour by the United Nations Development Programme (UNDP) and INFORUM, an international NGO that supports global electronic partnerships[7]. SARD uses a matrix of topics, which has as its dimensions a geographical hierarchy (farm, community, etc.), and a scientific disciplinary subdivision. For each of the topic cells there is a separate mailing list. Furthermore, participants in the various subgroups must indicate in the header of their mails what category of item, like 'report' or 'question' their contribution belongs to. As a final example, a large environmental conference is being planned, which is to take place entirely on the Internet[8]. A variety of Web-based tools will be used to supply participants with materials and discussion facilities.

5.3. Finding the Right Balance in Coordination

The relatively unconstrained coordination model that the projects adopt is not all that different from the one used in previous experiments, such as the computer-mediated biotechnology conference organized by IDRC already in the early eighties (Balson et al., 1985). At first, the approach used in these projects may look like a considerable improvement over strongly distributed artificial intelligence ones, as it allows the users of the information tools to take complete control of the coordination of their mutual work. However, another problem now emerges. The issue is that the high complexity of coordinating such goal-oriented group work actually inhibits people from easily participating, as for instance the mailing list has no way to support the identification, creation, and keeping of relevant roles and commitments (De Moor and Van der Rijst, 1996). Thus, in the coordination sense, mailing lists are only very primitive forms of groupware. But then, how to arrive at a proper balance between technological and human coordination? Apparently, more is needed than just returning all control of the communication to the human agent. Weigand and Dignum (1997) argue that it is futile to try and completely formalize all communication supported by an information system. Yet on the other hand they are convinced that the formalization of some interaction processes can make a significant contribution to the optimization of human communication. Determining exactly what parts of communication can be automated is not a trivial task, however. Therefore, instead of merely providing a set of autonomous tools, substantial efforts must be made on the development of integrated and customized network information systems (De Moor, 1996). In these systems, it is very clearly identified what coordination patterns are to be enabled by which constituting information tools or human participants. A good example of such a system is the one supporting the Planning Network for Health Research of the World Health Organization (Greiner et al., 1996). The system is developed by first identifying critical interaction processes and only then defining the services that need to be provided by supporting information technology.

6. *The User-Driven Specification of Network Information Systems*

6 http://sunsite.sut.ac.jp/island/unu-sin.html
7 Mail to: majordomo@undp.org, in body of mail `help'.
8 http://www.environment97.org

In current approaches, network information system development is all too often just driven by coincidentally available information tools. A World Wide Web site is first set up, only then serious thought is given, if at all, to what its individual users, never mind professional communities of users, can actually do with it. This means that the expression of the user information needs is unnecessarily distorted by technological constraints. Furthermore, if the specific tool is replaced by a new version, or by a completely different one, it is generally difficult to assess how the new component should be configured and integrated with the rest of the tools in use, as ever more tools provide partially overlapping functionality. Yet another problem with this tool-driven information system construction is that only that part of the functionality is defined which can actually be enabled by the currently available technology. The, often just as important questions about what the user cannot do, in other words, what are the experienced functionality gaps, are very hard to formulate in this way.

6.1. Involving the User

Useful network information systems in the field of sustainable development typically need to be flexible to accommodate both strongly changing information technologies and information needs (BDN, 1992). To optimally support work processes, the specification of user requirements and information tools need to co-evolve (Moran et al., 1996). For this specification process to be successful, the users need to be actively involved (De Moor and Van der Rijst, 1996). In the domain of sustainable development, some projects have started to deal with user involvement in the modelling of information needs. For example, one of the objectives of the Global Environmental Network for Information Exchange (GENIE) project is to create a metadata retrieval and management system, which, among other things, enables users to better describe their information needs using familiar terminology (Medyckyj-Scott et al., 1993). A metadatabase contains information about the previous activities and user profiles of associated knowledge workers, and is thus a useful resource for assessing how the available information resources must be handled. However, this is only a small step on the way to real network information systems, as the focus is on optimizing data resources for individual users rather than on determining the specific roles that information tools play in communities of users. In general, no systematic attention is paid to what kinds of strong collaboration activities are required and how to implement the required functionality using the different types of available information tools.

6.2. RENISYS: a User-Driven Specification Method

Users trying to make better use of their tools in the end frequently give up, because they cannot make sense out of the data clutter and the bewildering amount of functionality offered. It is obvious that, especially in the case of complex strong collaboration systems, users need to be assisted with the continuous refinement of their evolving information need definitions, as well as with the assembly of the network information system out of available tools. To this purpose, structured specification methods can be of assistance. The methods should allow users to incrementally define the context in which the information tools are operating, after they have experienced a breakdown in their work processes. Work has started on such a method for the research network domain, RENISYS (De Moor and Van der Rijst, 1996, De Moor, 1997). Built on an underlying formalism of conceptual graph theory, an operational RENISYS will enable users to describe - in natural terms - their information requirements. In a discoursive process, called process composition, users define legitimate requirements. The requirements are organized in a reference framework consisting of three interrelated levels: the problem domain (goals and activities), the human network (organizational interaction processes) and the technical information system level (information/communication processes). The method then helps them to map their requirements to the functionality enabling information tools. This approach should allow for both the information requirements and the implementation technologies used to co-evolve more easily.

7. Conclusions

Information technology plays an essential role in the achievement of global sustainable development. Until recently, most attention was focused on the generation of large, relatively autonomous data sets and on the development of a basic technical infrastructure. Yet, many of the current information tools are still quite primitive in the functionality they provide, and there also remains much room for improvement of data quality and accessibility. Fortunately, information science is accepting the challenge, and is working hard to address these problems. Information tools developed mainly for individual usage, such as data- and knowledge bases, expert systems, and geographical information systems will steadily mature and become more accessible to the mainstream user. However, to better support collaborative problem solving, which is a key process in sustainable development, more effective technological support is needed. One conceptual model and partial solution for meeting this important challenge is provided by distributed artificial intelligence. It will provide some of the much needed integration, foster cooperation between individual tools, and take over some of the coordination chores which now are still carried out by human beings.

Nevertheless, distributed artificial intelligence by itself, no matter how useful, is not sufficient for handling the large volume of 'wicked problems': vague and complex problems that require the involvement of many stakeholders for their definition and resolution. Crucial for bringing about a real breakthrough in the role that information technology plays in sustainable development is that the human factor is given a considerably stronger emphasis. Especially the subtle role that human collaboration plays in the group interpretation and solution of complex sustainability problems needs to be supported to a much larger extent. We feel that distributed artificial intelligence must always be subordinated to distributed human intelligence if wicked problem solving is to be effectively supported. As Tonn and White (1996) concisely state it: "Technology cannot substitute for human to human interactions where wisdom is nurtured, applied, and appreciated by others". They give a creative range of examples in the domain of sustainable development of future information systems that could be designed from such an anthropocentric point of view. The future role of sophisticated information tools is thus not to take over the position of human stakeholders, but rather to quietly serve them in the background to the best of their abilities.

Groupware, information technology specifically developed to foster strong collaboration between human professionals, should contribute to the realization of such a new view. Unfortunately, effective combinations of advanced and well-tailored groupware and individual information tools are still rarely found in the sustainability domain. An important reason for this is that the co-evolutionary nature of the complex usage context and enabling tools is not sufficiently taken into account. If really synergetic network information systems are to be created, user-driven specification methods need to play an important role. It is clear that new perspectives for looking at the role of the wide range of information tools in supporting goal-oriented group communication processes urgently need to be developed. We hope that this paper will inspire professionals in the domain of sustainable development, and information scientists interested in the issues raised in the paper, to confront and collaborate on the many challenges ahead.

Acknowledgements

The author wishes to express his gratitude to Willem van Groenendaal, Bryn Lewis, Leo Remijn, and Hans Weigand for their helpful comments. Their remarks have considerably improved the focus of this paper.

References

Atkinson, R. (1993). The Information Revolution and the "Green Watchdog". In Proceedings of the GIS '93 Conference, Birmingham, May 1993.

Avouris, N.M. (1995). Cooperating Knowledge-Based Systems for Environmental Decision Support. Knowledge-Based Systems, 8(1), pp.39-54.

Balson, D., Drysdale, R., & Stanley, B. (1985). Computer-Based Conferencing Systems for Developing Countries - Report of a Workshop Held in Ottawa, Canada, 26-30 October 1981. Ottawa:IDRC.

Biodiversity Information Network (BDN) (1992). Needs and Specifications for a Biodiversity Information Network. In Biodiversity Network Workshop, Campinas, Brazil, 27-31 July, 1992.

Bezanson, K. (1994). IDRC's Experience in Providing Information Technology Support to Developing Countries. In International Seminar on Development Aid Policy Approaches to New Generic Technologies, Stockholm, April 20-21, 1994.

Briggs, D.J. (1990). Establishing an Environmental Information System for the European Community: the Experience of the CORINE Programme. Information Services & Use 10(1/2), pp.63-75.

De Moor, A. (1996). Toward a More Structured Use of Information Technology in the Research Community. The American Sociologist, 27(1), pp.97-108.

De Moor, A. (1997). Applying Conceptual Graph Theory to the User-Driven Specification of Network Information Systems. In Proceedings of the Fifth International Conference on Conceeptual Structures: Fulfilling Peirce's Dream, University of Washington, Seattle, August 4-8, 1997.

De Moor, A., & Van der Rijst, N. (1996). Fostering More Active User Involvement in the Design of Network Information Systems. In Van der Meer, K. (Ed.), Proceedings of Information Science 1996, Delft University of Technology, December 13, 1996, pp.105-118.

Eco-Informa (1996). Proceedings of Eco-Informa '96: Global Networks for Environmental Information, Lake Buena Vista, Florida, November 4-7, 1996. Ann Arbor, MI: Environmental Research Institute of Michigan.

Ellis, C., Wainer, J. (1994). A Conceptual Model of Groupware. In: Furuta, R., & Neuwirth, C. (Eds.), Proceedings of the 1994 Conference on CSCW, Chapel Hill, October 22-26, pp.79-88. ACM.

Fameli, E., Nannucci, R., & Di Giorgi, R. (1991). Expert Systems and Databases: A Prototype in Environmental Law, Informatica e Diritto, 17(1-3), pp.227-247.

Feidt, W., & Roos, C. (1995). Environmental Information Resources on the Internet. Bulletin of the American Society for Information Science, 21(4), pp.22-23.

Goodman, S.E., Press, L.I., Ruth, S.R., & Rutkowski, A.M. (1994). The Global Diffusion of the Internet: Patterns and Problems. Communications of the ACM, 37(8), pp.27-31.

Gordon, S., & Tunstall, D. (1995). The Creation and Distribution of Environmental Information. Bulletin of the American Society for Information Science, 21(4), pp.11-13.

Greiner, C., Hawryszkiewycz, I.T., Rose, T., & Fliedner, T.M. (1996). Supporting Health Research Strategy Planning Processes of WHO with Information Technology. In Sandkuhl, K., & Weber, H. (Eds.), ISST-Report 'Tele-Cooperation Systems in Decentralized Organizations', pp.121-145. Berlin.

Günther, O., Radermacher, F.J., & Riekert, W.-F. (1994). Environmental Monitoring: Models, Methods, and Systems. In Avouris, N.M., & Page, B. (Eds.), Environmental Informatics. Kluwer Academic Publishers.

Hansen, I., (1990). Expert Systems as Tools for Integration and Analysis of Environmental Health Information. Information Services and Use, 10(1/2), pp.53-62.

Hirschheim, R., Klein, H.K., & Newman, M. (1991). Information Systems Development as Social Action: Theoretical Perspective and Practice. Omega International Journal of Management Science, 19(6), pp.587-608.

Isenmann, S. (1993). How to Deal with Wicked Problems Using a New Type of Information System. In Stowell, F. & West, D. (Eds), Systems Science: Addressing Global Issues, pp.367-372. New York: Plenum.

Johnson, P., & Moore, C. (1994). Investigating Strong Collaboration with the Annotated Egret Navigator. Technical Report CSDL-94-20. Department of Information and Computer Sciences, University of Hawaii.

Lang, L., & Speed, V. (1992). Environmental Consciousness. Computer Graphics World, 15(8), pp.57-62.

Lees, A., & Atkinson, R. (1993). Data for Environmental Monitoring. In Royal Geographic Society Conference on Environmental Mapping and National Needs, London, December 1993.

Luger, G.F., & Stubblefield, W.A. (1989). Artificial Intelligence and the Design of Expert Systems. Redwood City, CA: The Benjamin Cummings Publishing Company, Inc.

MacDevette, D. (1994). Country Case: South Africa. In Kouakou, K., & Chee, N. (Eds.), Proceedings of the Sixth Meeting of the Advisory Committee for the Program on Environment Information Systems in Sub-Saharan Africa, Harare, Zimbabwe, April 5-9, 1994, pp.46-47.

MacKie-Mason, J.K., & Varian, H.R. (1994). Some Economics of the Internet. In Tenth Michigan Public Utility Conference, Western Michigan University, March 25-27, 1993, Revised Version.

Mayer, M., Gans, L. (1995). Computer Networking for the Northwest Environmental Movement. Seattle: Brainerd and Bullitt Foundations.

Medyckyj-Scott, D.J., Newman, I.A., & O'Brien, S.M. (1993). GENIE: A Global Environmental Network for Information Exchange. Journal of Information Science, 19(5), pp.403-406.

Moran, T.P., Chiu, P., Harrison, S., Kurtenbach, G., Minneman, S., & Van Melle, W. (1996). Evolutionary Engagement in an Ongoing Collaborative Work Process: A Case Study. In Proceedings of CSCW'96: Cooperating Communities, Boston, November 16-20, 1996, pp.150-159.

Nostbakken, D., & Akhtar, S. (1995). Does the Highway Go South? Southern Perspectives on the Information Highway. Report of the International Institute of Communications Pre-Conference Symposium on Southern Country Interests, Tampere, Finland, September 3-4.

Obraczka, K., Danzig, P., & Li, S.-H. (1993). Internet Resource Discovery Services. Computer, 26(9), pp.8-22.

O'Connor, J. (1994). Towards Environmentally Sustainable Development: Measuring Progress, Defining Sustainability and Measuring Efforts to Attain It. In Kouakou, K., & Chee, N. (Eds.), Proceedings of the Sixth Meeting of the Advisory Committee for the Program on Environment Information Systems in Sub-Saharan Africa, Harare, Zimbabwe, April 5-9, 1994, pp. 69-86.

Rand, R.Y. (1995). GCDIS-Assisted Search for Knowledge (ASK). Bulletin of the American Society for Information Science, 21(4), pp.16-18.

Rodden, T. (1991). A Survey of CSCW Systems. Interacting with Computers, 3(3), pp.319-353.

Shaw, M.J., & Fox, M.S. (1993). Distributed Artificial Intelligence for Group Decision Support: Integration of Problem Solving, Coordination, and Learning. Decision Support Systems, 9(4), pp.349-367.

Sowa, J. (1984). Conceptual Structures: Information Processing in Mind and Machine. Reading, MA: Addison-Wesley.

Thomson, A.J. (1993). Paradigm Green: AI Approaches to Evaluating the Economic Consequences of Changing Environmental Viewpoints. AI Applications, 7(4), pp.61-68.

Tonn, B.E., & White, D.L. (1996). Sustainable Societies in the Information Age. The American Sociologist, 27(1), pp.102-121.

United Nations Conference on Environment and Development (UNCED), Agenda21, Rio de Janeiro, June 1992, Chapter 40, Information for Decision-Making.

Weigand, H., & Dignum, F. (1997). Formalization and Rationalization of Communication. In Proceedings of the Second International Workshop on Communication Modelling: the Language Action Perspective, Veldhoven, The Netherlands, June 9-10, 1997, pp.71-86.

Winograd, T., & Flores, F. (1986). Understanding Computers and Cognition: A New Foundation for Design. Norwood, NJ: Ablex Publishing Corporation.

Young, J.E. (1993). Global Network: Computers in a Sustainable Society. Worldwatch Paper, 115. Washington, D.C.: Worldwatch Institute.