

Landscape Editing with Knowledge-Based Measure Deductions for Ecological Planning

Jörn Möltgen, Benno Schmidt, and Werner Kuhn

Institute for Geoinformatics, Westfälische Wilhelms-Universität Münster
Robert-Koch-Str. 26-28, D-48149 Münster, Germany
Phone: +49 251 83-31961, Fax: +49 251 83-39763
Email: {moltgej, benno, kuhn}@ifgi.uni-muenster.de

Abstract. The approach presented suggests a new way of supporting planning processes. Planners from various disciplines can test and discuss planning scenarios at a workbench, where a virtual landscape is visualized in a 3-D real-time environment. With the defined paradigm of 'landscape editing', planners can model and manipulate virtual landscapes intuitively. They can transform, add, move and delete by direct manipulation of geo-objects. With the help of such a human-computer interface, planners can specify planning scenarios visually and cooperatively. As soon as a planning scenario finds consensus, the system analyzes the modified model, detects the changes, and deduces measures to be carried out to achieve the specified objectives in the real world. To perform this last step, an interdisciplinary knowledge base has to be set up. Through the use of expert knowledge, planning processes become more transparent and understandable.

Motivation

The use of geographic information systems (GIS) and spatial decision support systems (SDSS) for monitoring tasks and ecological planning processes has become established in recent years. The coupling of GIS techniques and SDSS with 3-D visualization is the natural next step to support landscape planning with the creation, analysis and modification of virtual landscapes. For landscape planners, it is undisputed that a visual impression of the planned object is important, because they develop the object under the consideration of landscape aesthetics. "*In every natural setting these two elements – visual and spatial – combine to create a distinctive view. The landscape designer must have a firm grasp of the visual and spatial character of the setting before he can begin to develop it*" (HIGUCHI 1989). Moreover, 3-D visualization provides more insights to spatio-temporal or thematic relations than a text display or the traditional 2-D map (VAN VORIS ET AL. 1993, WHERRETT 1996). A 3-D approach is indispensable, especially for the task of designing a landscape model and the presentation of planning ideas. On the one hand, it helps the planners themselves to optimize their ideas, on the other hand, it enables planning laymen to assess planning drafts. Taking cognitive aspects into account, 3-D visualization facilitates the acquisition of 3-D information (e.g., terrain gradients or tree heights) and provides a better understanding of spatial relations affecting 3-D objects (e.g., shadowing effects caused by trees). Furthermore, 3-D interaction mechanisms that are intuitively useable can be implemented

The additional opportunity to derive or deduce measures for the restoration or maintenance of landscape elements is yet to be exploited. The traditional focus of SDSS aims at the composition of databases, spatial modeling, graphical display and analysis to support the decision-maker. Approaches should follow that integrate expert knowledge in these systems allowing the investigation of different scenarios before decision-making (RIZZOLI 1997). Knowledge-based SDSS (KBSDSS) represent the knowledge and the experience of experts for a special area of interest and combine "*the ability to simulate the heuristic reasoning of experts with an explanation facility for justifying their reasoning and conclusion*" (ZHU ET AL. 1998). It is well known that human beings with their vast experience are able to make better decisions than machines. However, for complex planning tasks, KBSDSSs are able to demonstrate interdisciplinary causes and effects.

Environmental planning is frequently a collaborative, multi-disciplinary activity. For a wide range of decision-makers, the goal is to reach a "*limited shared understanding of the current state of their geographical area, and threats to it, and the likely outcomes of various future actions...*" (VAN HOUSE ET AL 1998). Hence, along with the prediction of landscape developments, there is a demand for tools that allow "computer-supported co-operative work" (CSCW). "Workbench"-like environments, in particular, (AGRAWALA ET AL. 1997, WESCHE ET AL. 1997) used in the field of Virtual Reality (VR) technology offer big potential to meet this requirement, while providing ways to interact with 3-D landscapes. Consequently, the integration of table-based virtual environments and KBSDSSs is a very promising approach creating a new planning support paradigm.

The development of an interface which combines these abilities raises questions about input and output techniques and the user dialogue. This paper discusses possible answers. The fundamentals of such a visual, interactive knowledge-based system are presented as the landscape editing paradigm. The paper uses a case study in river ecology as a motivation and testbed for the ideas presented.

VR hardware components

For a better understanding of the following ideas, we will explain how the suggested VR hardware works and describe the basic application facilities. Principally, the hardware provided by the SpatialViSC initiative of the University of Münster (SPATIALViSC 1998, SCHMIDT ET AL. 1999) works similar to environments such as the "Responsive Workbench" (developed at the German National Research Center for Information Technology, GMD, and at Stanford University) or the "ImmersaDesk" (Pyramid Systems, Inc.).

The system consists of a projection table which can be regarded as a large monitor (screen size 1,36 m x 1,02 m). Reflected by a huge mirror, the images generated by a powerful projector are projected on the bottom side of a semi-transparent pane. This pane can be aligned horizontally.

A graphics workstation generates stereoscopic image pairs, e.g. at a frequency of 50 Hz per eye. A 3-D rendering toolkit is used to calculate these image pairs. To make sure that the observer's left eye sees only the image calculated for the left eye's position, and the right eye sees the corresponding right-eye view, the user wears glasses consisting of closeable LCD shutters. Image generation and shutter release signals are synchronized using a synchronization signal from the workstation's graphics board. This way, the user gets the impression of 3-D objects floating above the table's projection pane (see figure 1; note that this is a manipulated photo).

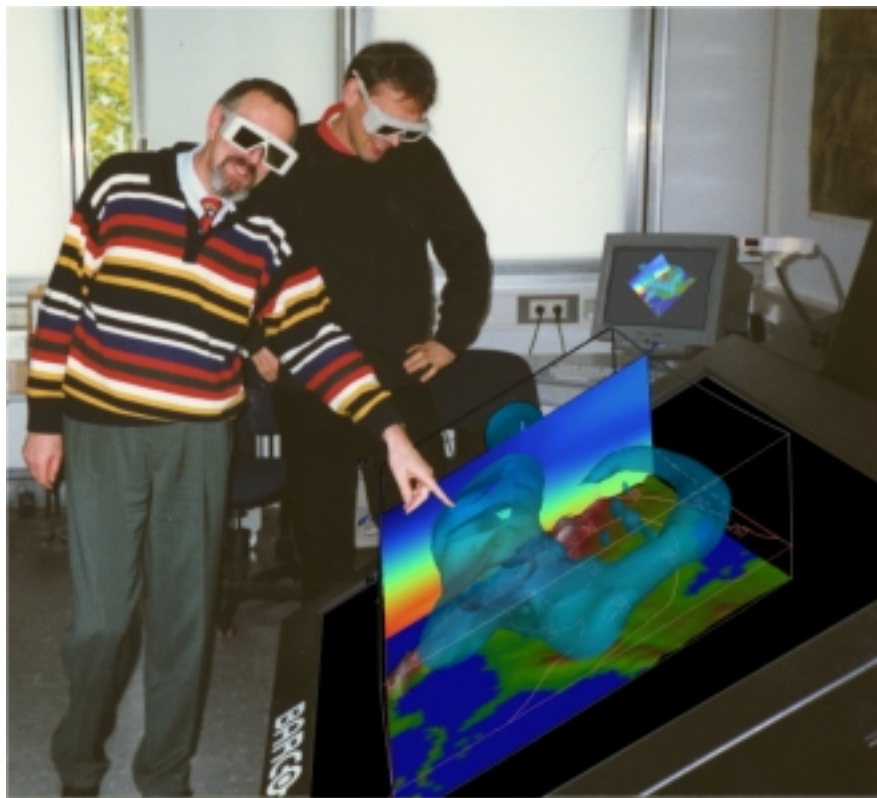


Figure 1: Stereoscopic representation using a projection table and shutter technology

To allow interaction, the user's head position and the position of a hand-held stylus are tracked. A video-based tracking system is used here (DORFMÜLLER & ZIEGLER 1998). Using two cameras situated on both sides of the projection table, the tracking system simultaneously tracks the real-space 3-D position of two infrared LEDs, one fixed on the shutter glasses, the other one at the tip of the stylus. This information is passed to the rendering software that calculates the corresponding images.

In this environment, immersion into the virtual world is limited to the sight pyramid defined by the observer position and the four table corners. 3-D editing operations will be performed intuitively using the stylus.

Since the users still perceive their real-world environment, the configuration offers large potential in the field of CSCW. It is hardly possible yet to render stereoscopic images for more than two tracked simultaneous observers (for n users, a refresh rate of $2 \times n \times 50$ Hz is required to obtain a flicker-free picture). However, observation of the technical evolution of hardware, allows one the forecast that stereoscopic visualization using projection tables and tracking facilities could serve as common basis for discussions for a group of planners very soon.

Task analysis: Ideal model of interaction

This chapter describes a potential use case showing the task flow of an ecological planner using a KBSDSS linked to a 3-D landscape editor. An example from the field of flood plain planning has been chosen for the concrete planning task description. The planner has the objective to work out a concept for the redevelopment of the flood plain into a restored stage.

Our vision comprises the following operation steps. First, a 3-D model of a flood plain is displayed, which gives an impression of the current landscape state. It shows the following objects:

- river bed at a large scale,
- vegetation at the river banks,
- various structures of the river bed,
- surrounding area,
- land use, cultivation,
- housing estates
- road ways.

In addition to these visual objects, various attributes are retrievable from a database. These include hydrological data, data about the water quality, land ownership data or data about the zoobenthos of the river and its structure (e.g., naturalness of its banks, number of barricades, shading, depth and width erosion). All this data can be queried in a typical GIS or database manner.

By exploring the virtual reality visually and retrieving database information, the planner can assess the quality of the flood plain and evaluate the necessity for redevelopment measures. For example the planner, who in fact could be more than just one person, is confronted with an elongated river course. He/she discovers that there is no width erosion at all, just try a small number of barricades, no drift wood and the river temperature is too warm. The planner must to find a solution which takes into account buildings, roads or land ownership while planning the natural redevelopment of the river. Therefore, the planner *edits* the flood plain model in order to try out different planning scenarios and uses different interaction tools from a tool box to manipulate spatial objects with his/her bare hands. In this manner, he/she grabs river sections to bend them out of their original shapes and specifies a new river course with meanders. Creating the meander, the planner might have two options. If old river structures exist, he/she can reconnect an old meander to the course. If not, he/she has to introduce measures which will lead to the growing of the meander. During the model alterations, the plausibility of all interactions is checked. For example, it will be checked if the new river course were directed uphill. In this case, the system would reject the modification. By editing river sections, the planner tries to encourage the erosion processes. Erosion is a characteristic feature of a natural river course with a high diversity of structures.

The following step relates to the vegetation along the river banks which is important for wildlife (e.g., birds), shading (prevents from high water temperatures) and as a natural protection against excessive erosion. The planner can grab trees, groups of trees or bushes from a wide pool of vegetation elements and move them close to the river. This way the planner designs a new flood plain model. He/she re-edits it, until he/she has defined a role model which fits her/his interdisciplinary demands.

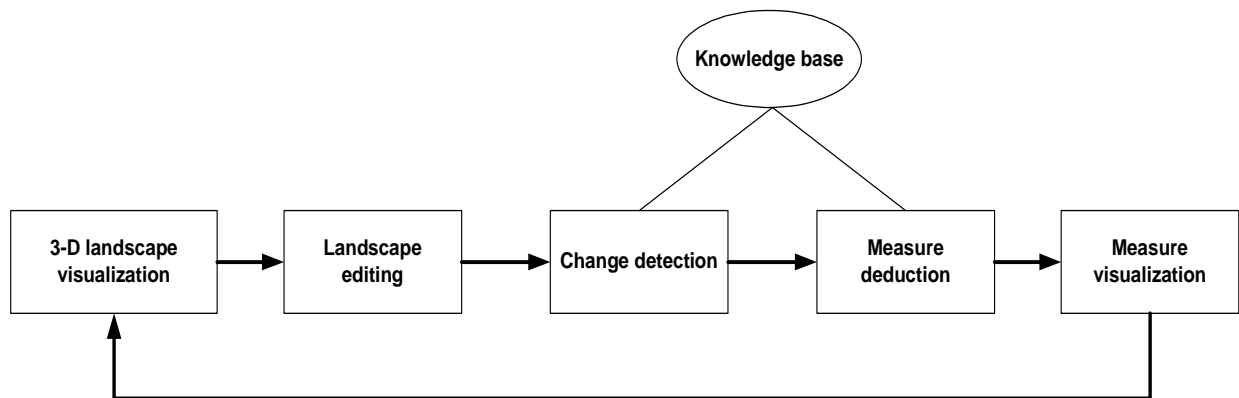


Figure 2: User workflow

As soon as a planning scenario finds consensus with other planners, the system analyzes the modified virtual model, detects the changes (original/edited model), and deduces measures to be carried out to achieve the specified objectives in the real world. To perform this step, a knowledge base starts to work. It compares the starting point with the new role model in order to detect and analyze all changes. The changes serve as input for the rule base which deduces measures to be taken into account for a sustainable river restoration and maintenance.

Measures can be displayed in various ways. Measures such as ‘planting of bank coppice’, ‘toleration of depth and width erosion’, ‘destruction of the bottom sealing’, or ‘rebuilding of bottom and bank stabilization’ could be visualized as cartographic symbols or pictograms. Since the river course is divided into 100 m sections, the symbols and pictograms will be placed at the corresponding river sections. Measures that refer to one specific object are displayed near this object. A sewage pipe which has to be deleted from the river will be crossed out, so that the planner knows what to do and exactly where to do it. Additionally, a list with further instructions could be visualized. It includes information about appropriate species (e.g. tree species) to use and secondary measures such as ‘ask farmer X for interest in land conversion’. This textual measure explanation includes also a list of effected thematically attributes such as water quality, if a waste water pipe is cut from the river.

Knowledge base and inference engine

Measure deduction requires expert knowledge. A catalog containing various measures for sustainable river maintenance builds the basis for the knowledge base. This catalog includes measures such as 'planting of bank coppice', 'reconnection of old/cutoff arms', 'toleration of depth and width erosion', 'conversion of bordering arable farm land into grassland' or 'destruction of the bottom sealing' (MÖLTGEN & HITCHCOCK 1998).

For instance, the placement of meanders at a river course invokes rules that induce measures that could be executed in practice. The following (simplified) example shows some rules for the deduction of measures in order to archive a meander at a river course.

```
if historic water course is known
then

    if Attribute('property can be bought') = true
        then Measure('rebuilding of old water course') := true

    if Measure('rebuilding of old water course') = true
        then Measure('initial planting of bank coppice') := true
            Measure('creation of bank buffer zones') := true
            Measure('toleration of depth and width erosion') := true
        endif

else

    if Attribute('bottom or bank stabilization') = true
        then Measure('elimination of bottom and bank stabilization') := true

    if Attribute('river profile.width') / Attribute('river profile.depth') ≤ 2.0
        then Measure('broadening of river profile') := true

    if Attribute('erosion') = true
        then Measure('toleration of depth and width erosion') := true

    if Attribute('indigenous trees') is valid upstream
        then Measure('placement/toleration of deadwood') := true
        else Measure('placement of troubling stones') := true

    if Attribute('buffer zone') = false
        then Measure('creation of bank buffer zones') := true

endif
```

The example contains both thematic and spatial conditions (see conditions set in italics) and changes that trigger measure deductions. To specify such state changes, the user edits the landscape model visually. The measures deduced by the inference engine are displayed (see figure 3).

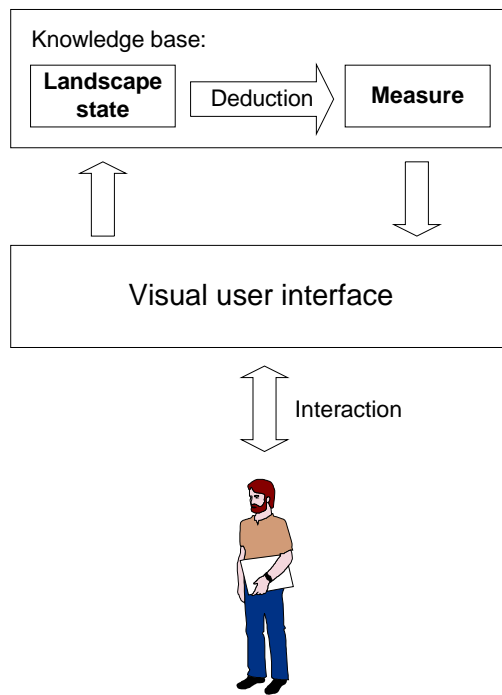


Figure 3: Knowledge base and visual user interface

User interface specification

We can conceive different layers of representation here: the user's mental representation, the external representation, i.e. the displayed image, and the data model used to implement the system (cf. NORMAN 1991). Visualization is used considering two different aspects here. On the one hand, the task is to generate a visual representation of the ideas the planner has in mind. On the other hand, the objects held in the spatial database and deduced measures have to be presented visually (see figures 3 and 4). In the project described here, visualization plays a central role as a human-computer interface (cf. MEDYCKIJ-SCOTT 1994) that facilitates input and output of planning ideas.

In addition to change detection (chapter 6) and knowledge bases (chapter 4), the user interface design is a challenge for the landscape editing paradigm. The components of the user-computer interface are defined using the four-level language model suggested by FOLEY and VAN DAM (1982).

The *conceptual design* defines the key application concepts. This level incorporates the user's mental model of the high-level interaction. Here, the model consists of the overall landscape, landscape states, spatial and thematic entities, a set of (textual) facts and rules, and measures. A prototype system will include spatial entity classes to handle surfaces describing terrain, single trees, shrub groups, river courses, and coverages holding land parcel information (e.g. land use, ownership).

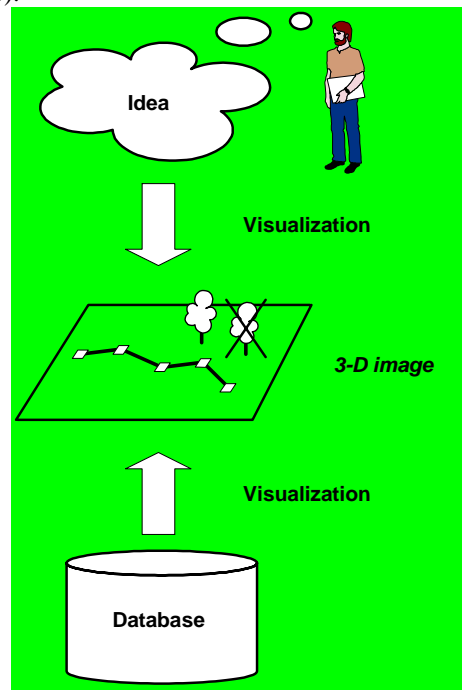


Figure 4: Role of visualization

The relations between these main elements are as follows: A landscape object knows various states S_i . One of these states describes the current state of the landscape (S_0). Further states S_i , $i \neq 0$, may define planning scenarios. A landscape state is composed of spatial entities. In the following, we will use the term geo-object instead of spatial entity. The landscape is linked to the facts and rules holding knowledge about the spatial, temporal and thematic relations between the spatial entities as well as about the measures that have to be deduced to realize the specified state. Since these rules might be valid for different landscapes, they are not part of the landscape, but are associated with it.

The user can edit the visual portion of the landscape by creating geo-objects, changing the spatial extent or positions of geo-objects that already are part of the landscape, or modifying their appearance. The interface design is based on the sand table metaphor, i.e. the user works standing in front of a table with tangible and movable items.

Users will expect the interface to behave according to what their experience has taught them to expect from such a design (cf. KUHN 1992, MARK 1992). For example, spatial objects such as trees, shrubs, and rivers reside on the terrain surface (“gravitational constraint”). The user will know how the system behaves, since he/she can establish a mapping from the unfamiliar to the familiar. Landscape states (especially: planning scenarios) can be specified intuitively in this manner. Table 1 lists the basic entity classes and the corresponding interaction facilities.

Note that the workbench metaphor (AGRAWALA ET AL. 1997, WESCHE ET AL. 1997) resembles the chosen sand table. Since the non-planar, editable terrain surface plays an important role, and the planner wants to sketch river courses on the terrain, stick trees on the “sand” etc., we favored the sand table metaphor.

Table 1: Basic entities and interaction facilities

Entity class	Non-spatial interaction	Spatial interaction
Landscape	(high-level object control only)	via spatial entities
Landscape state	deduce measures	edit spatial entities
<i>Spatial entities:</i>		
Terrain	(not necessary here)	mould
Tree	set/get attributes (tree type, ...)	add, move, resize, remove
Shrub group	set/get attributes (shrub group type, ...)	add, move, mould, remove
River course/sections	set/get thematic attributes (bank/bottom stabilization, substance concentrations, ...)	course editing (place meanders, create curves at river sections, ...)
Flood plain	set/get thematic attributes (substance concentrations, ...)	enlarge (or reduce) extent
Land parcel coverage	set/get thematic attributes (e.g., change land use)	split / merge polygons
<i>Knowledge base:</i>		
Facts and rules	(textual) editing, querying	-
Measures	(deduce “on button-click”)	Visualization

The *semantic design* specifies detailed functionality of the system. Here, functional requirements are described. The signatures of the operations that have to be implemented were specified for the envisioned application. On this level, especially the meanings conveyed by the input commands and the display (i.e., computer output) have to be defined. Moreover, we took into account which semantic errors might occur.

A structural approach has been proposed to handle metaphors in interface design (CARROLL ET AL. 1988). For example, a formal approach based on algebraic specifications was described by KUHN & FRANK (1991). To specify the “electronic” sand-table substitute, the terrain object must be distinguished from the other geo-objects. This way, the “gravitational constraint” can be formulated. Consequently, this constraint constitutes the distinction from related categories such as the 2-D electronic desktop or the workbench metaphor mentioned above.

The implementation of the envisioned user interface will not work if the equations given in the specification do not hold at editing time. For example, moveable objects reside on the terrain surface. There are many more equations that are part of a complete specification, e.g. a tree may not be taller than the tree’s size at its maximum age, water has to flow downhill, and a tree’s crown and the soil below the terrain surface may not overlap. It has to be defined how constraint infringements are handled at editing time.

Apart from the sand-table metaphor, some additional metaphors are needed to provide the required editing facilities to the user. The landscape editor we’ve designed comprises a box containing geo-object templates. To instantiate a geo-object, a template can be taken out of this box, which is located beside the actual landscape visualization. Moreover, so-called *handles* (or *grips*), as known from various CAD and drawing programs, allow geometry editing (e.g., FOLEY ET AL. 1996, AUTODESK 1992). For example, the vertex of a polyline defining a river course can be picked and moved. Another way to define a new river course would be a manipulation based on a “modeling clay metaphor”. The user can deform the river course like a modeling clay sausage. Note that there are many more metaphors inherent in the system such as visual buttons that can be punched to trigger off certain events (e.g., SERRA ET AL. 1995) etc.

The *syntactic design* defines the sequence of inputs and outputs, i.e. the grammatical structure of the “tokens” used to articulate the semantic concept (JACOB 1999). The operations specified on the semantic level can be decomposed into elementary interaction units. The higher-level operations are composed of these units.

The interaction with geo-objects will be performed in the VR environment. We use 3-D stereoscopic output on a projection table. Since the user’s head and hand movements are tracked, he/she can interact with the visualized

objects as if they were real objects located in space in front of him/her. Object selection and manipulation are realized using the hand-held stylus metaphor. To start an editing command, the user has to click at the geo-object he/she wants to manipulate. For this, the hand-held stylus with its (physical) button is used. Subsequently, the manipulation can be done, e.g. using the grips mentioned above. The type of tokens used for input are actions of the following types: 'click on geo-object', 'select geo-object template', 'set initial position', 'hit button "X" ', 'digitize position', and various editing actions. Since this input language is regular (in terms of formal language theory), these actions correspond to the labels of a state transition graph.

The maintenance of the facts and rules needed for measure deduction and necessary to perform the plausibility checks mentioned above, requires an environment that is suitable to handle textual information. The deduced measures will be displayed in the visual environment. Cartographic symbols, signatures and variables will be used as output tokens.

Finally, the *lexical design* determines, how the inputs and outputs are actually formed from primitive hardware operations.

In the VR environment, low-level primitive inputs are the movement of the head and the hand (in the environment described in chapter 2, there are video-tracked infrared LEDs on the shutter glasses and on the stylus the user is holding in his/her hands) and the triggering of events by activating a button fixed on the stylus. The output are sets of rendering primitives that assemble geo-objects, cartographic elements, or UI elements. Table 2 summarizes the four-level design described above.

Table 2: User interface design following FOLEY and VAN DAM's (1982) four-level language model

	Objects	Operations
Conceptual level	<ul style="list-style-type: none"> • landscape, landscape states, and geo-objects on the sand table • facts & rules (plausibility rules and measures) • planning documents (texts, maps, ...), cartographic output elements 	<ul style="list-style-type: none"> • state editing facilities • measure deduction & visualization
Semantic level	concrete classes corresponding to the conceptual objects	complete list of "virtual" (in the software-technical sense) object methods
Syntactic level	<ul style="list-style-type: none"> • geo-objects: Directly manipulable visual objects (shapes, buttons, ...) • knowledge base: text 	<ul style="list-style-type: none"> • geo-objects: Selection, point location • knowledge / measures: text / cartographic elements
Lexical level	<ul style="list-style-type: none"> • visualization: Shutter glasses, stylus • knowledge base: as known from text-editors 	<ul style="list-style-type: none"> • visualization: Head and hand movement, button activation • knowledge base: as known from text-editors

Coupling of knowledge base and visual user interface

The editing of geo-objects might lead to changes in the landscape state. In order to deduce measures, these changes have to be detected by the system. These changes also trigger affected rules. Consequently, new measures will be deduced. These measures will be presented using cartographic design facilities. For this, information about the geo-objects to which the measures refer is needed.

Table 3: Examples for geo-objects triggering measures

Geo-object	Event/Interaction	Relevant changes	Possible measures
Tree	Add a new tree	coordinates, size	Placement of trees, eventually erasure of bank stabilization
River section	Set water quality	change in water quality	All measures which help to improve water quality
River course	Place meander	coordinates, curvature, topology	Planting, toleration of erosion, creation of buffer zones, etc.

The rules held in the knowledge base determine which changes have to be detected after an editing session. These changes may refer to geometric, topological or thematic characteristics. Table 3 shows examples of how geo-object modifications may induce measures. The rule conditions define the task that has to be done by a change detection algorithm.

Consequently, the approach presented requires the combination of

- interactive 3-D real-time visualization
- spatial and thematic query facilities
- a knowledge base and an inference engine.

Existing 3-D real-time rendering libraries such as OpenGL (WOO ET AL. 1997) offer the primitive input and output facilities that are needed to implement the user-interface on the lexical and syntactic level. The main work to be done is to establish the link to the other architectural components. Concerning the data models, these components are usually incompatible: 3-D rendering libraries are based on rendering primitives such as triangles/polygons, textures etc. (FOLEY ET AL. 1996). Sophisticated spatial and thematic queries, require data-models that include topological information and handle thematic information (e.g., GIS technology). Finally, the facts and rules held in the knowledge bases are put into the language of logics, which usually is represented as text. Ways to set up interoperable systems are suggested by BERNARD ET AL. 1998A, BÜHLER & MCKEE 1996, DÖLLNER & HINRICHS 1999. It is known that the data model mismatches might cause difficulties (e.g., erroneous visualizations, see UHLENKÜKEN ET AL. 1999). One of the reasons for this is that the application objects ignore the semantic properties of the corresponding objects in the other data models. As mentioned above, it is very important to maintain semantic consistency at editing time. Moreover, there may be additional constraints that may affect spatial or thematic constraints; e.g., a planned meander may not intersect a housing estate.

Conclusions

The approach presented suggests a new way of traversing planning processes. The interface design is based on a sand table metaphor which enables a very intuitive interaction. Visualization is no longer an additional feature, but becomes an essential part in the processes of problem formulation and decision-making. The interaction facilities described enable consensus-based planning processes in which planners can play out different scenarios. With the implementation of expert knowledge expansion of common knowledge-based spatial decision support systems into a knowledge-based measure suggestion system becomes possible (MÖLTGEN & HITCHCOCK 1998). This step enables planning processes to become more transparent and comprehensible.

The landscape editing paradigm introduced necessitates semantic plausibility checking at editing time. The rules held in the knowledge-based measure deduction component define the task that has to be done by a convenient change detection algorithm.

We have started to implement a prototype system based on the 3-D visualization framework MAM/VRS (DÖLLNER & HINRICHS 1999) and a “virtual” GIS component (BERNARD ET AL. 1998B). A prototype rule-base coupled to a 2-D GIS, is also available (MÖLTGEN & PUNDT 1998).

There is, however, much research still to do. One of the research issues is to find out to what extent the knowledge from the participating disciplines (river ecology, landscape planning, hydraulic engineering, etc.) can be formalized considering all spatial and thematic interdependencies. The issue, to what extent the proposed system will effect the quality of the decisions is unresolved. Moreover, fuzzy data have to be processed to model the investigated landscapes properly, because the knowledge base deceives an exactness which in fact may not be given at all. It is not just spatial heterogeneity, but temporal and thematic variability that makes fuzzy-sets necessary (cf. GRABAUM & STEINHARDT 1998, LUTZE & WIELAND 1997). Finally, temporal aspects (landscape development) have to be considered for a comprehensive landscape state description,.

Acknowledgements

We would like to thank U. Streit, C. Uhlenkueken, L. Bernard, and A. Hitchcock from the Institute for Geoinformatics at Muenster University, and the Ministerium für Schule und Weiterbildung, Wissenschaft und Forschung des Landes Nordrhein-Westfalen for their support.

References

- Agrawala, M., A.C. Beers, B. Fröhlich, P. Hanrahan, I. McDowall & M. Bolas (1997): *The Two-User Responsive Workbench: Support for Collaboration Through Individual Views of a Shared Space*. Proceedings SIGGRAPH '97, <http://www-graphics.stanford.edu/papers/twoviewer>.
- Autodesk, Inc. (1992): *AutoCAD Release 12, Reference Manual*. San Rafael, CA: Autodesk.
- Bernard, L., B. Schmidt & U. Streit (1998b): *AtmoGIS - Integration of Atmospheric Models and GIS*. Proceedings of the 8th International Symposium on Spatial Data Handling (SDH '98) in Vancouver, Canada, pp. 267-276.
- Bernard, L., B. Schmidt, U. Streit & C. Uhlenküken (1998a): *Managing, Modeling, and Visualizing High-Dimensional Spatio-Temporal Data in an Integrated System*. GeoInformatica, Vol. 2, No. 1, Norwell, MA: Kluwer Academic Publishers, March 1998, pp. 59-77.
- Buehler, K. & L. McKee (1996): *The OpenGIS Guide - Introduction to Interoperable Geoprocessing*. Technical report, Open Geodata Interoperability Specification (OGIS), Open GIS Consortium, Inc.
- Carroll, J.M., R.L. Mack & W.A. Kellogg (1988): *Interface Metaphors and User Interface Design*. In M. Helander, ed.: *Handbook of Human-Computer Interaction*, Elsevier, pp. 67-85.

- Döllner, J. & K. Hinrichs (1999): *An Object-Oriented Approach for Integrating 3D Visualization Systems and GIS*. Computer & Geosciences, special issue "Geoscientific Visualization", Elsevier Science, in press.
- Dorfmueller, K. & H. Ziegler (1998): *Video Based Interactions in Virtual Environments*. Computer Graphics TOPICS, 1/98, Darmstadt: Haus der Graphischen Datenverarbeitung, pp. 31-32.
- Foley, J.D. & A. van Dam (1982): *Fundamentals of Interactive Computer Graphics*. Reading, MA: Addison-Wesley, pp. 217-243.
- Foley, J.D., A. van Dam, S.K. Feiner & J.F. Hughes (1996): *Computer Graphics : Principles and Practice*. 2nd ed., Reading, MA: Addison-Wesley.
- Grabau, R. & U. Steinhardt, eds. (1998): *Landschaftsbewertung unter Verwendung analytischer Verfahren und Fuzzy-Logic*. UFZ-Bericht Nr. 6/1998, Leipzig: Umweltforschungszentrum Leipzig-Halle.
- Higuchi, T. (1989): *The Visual and Spatial Structure of Landscapes*. Massachusetts Institute of Technology (MIT), MIT Press paperback edition, USA.
- Jacob, R.J.K. (1999): *User Interfaces*. Encyclopedia of Computer Science, 4th ed., ed. by D. Hemmendinger, A. Ralston, and E. Reilly, Macmillan Reference Ltd., 1999 (in press).
- Kuhn, W. (1992): *Paradigms of GIS Use*. 5th International Conference on Spatial Data Handling, Charleston, SC, pp. 91-103.
- Kuhn, W. & A.U. Frank (1991): *A Formalization of Metaphors and Image-Schemas in User Interfaces*. In D.M. Mark & A.U. Frank, eds.: *Cognitive and Linguistic Aspects of Geographic Space*, Kluwer, pp. 419-434.
- Lutze, G. & R. Wieland (1997): *Fuzzy in der Landschaftsforschung und -modellierung*. In R. Grützner, ed. (1997): *Fortschritte in der Simulationstechnik : Modellierung und Simulation im Umweltbereich*. Braunschweig: Vieweg, pp. 233-247
- Mark, D. (1992): *Spatial Metaphors for Human-Computer Interaction*. 5th International Conference on Spatial Data Handling, Charleston, SC, pp. 104-112.
- Medyckij-Scott, D. (1994): *Visualization and Human-Computer Interaction in GIS*. In H.M. Hearnshaw & D.J. Unwin, eds.: *Visualization in Geographical Information Systems*, Chichester: Wiley.
- Möltgen, J. & A. Hitchcock (1998): *A GIS Application for the Derivation of Measures to Maintain and Restore Lowland Rivers*. Proceedings of the 8th International Symposium on Spatial Data Handling (ed. by Th.K. Poiker & N. Chrisman), Vancouver, Canada, 1998. International Geographical Union, pp. 247-255.
- Möltgen, J. & H. Pundt (1998): *Regelbasierte GIS-Werkzeuge zur Maßnahmenherleitung in der Gewässerpflege*. In J. Strobl & F. Dollinger, Hrsg.: *Angewandte Geographische Informationsverarbeitung (AGIT '98)*, Salzburg, Heidelberg: Wichmann.
- Norman, D.A. (1991): *Cognitive Artifacts*. In J. Carroll, ed.: *Designing Interaction: Psychology at the Human-Computer Interface*, Cambridge Series on Human-Computer Interaction 4, Cambridge, UK: Cambridge University Press, pp. 17-38.
- Rizzoli, A.E. & W.J. Young (1997): *Delivering Environmental Decision Support Systems: Software Tools and Techniques*. *Environmental Modelling & Software* 12(12), pp. 237-249.
- Schmidt, B., U. Streit & C. Uhlenkük (1999): *Zur Einsetzbarkeit von Workbench-Umgebungen für geowissenschaftliche und planerische Fragestellungen*. In J. Strobl & F. Dollinger, Hrsg.: *Angewandte Geographische Informationsverarbeitung (AGIT '99)*, Salzburg, Heidelberg: Wichmann, in press.
- Serra, L., T. Poston, Ng H., Chua B.C. & J.A. Waterworth (1995): *Interaction Techniques for a Virtual Workspace*. ICAT/VRST '95, Japan, <http://www.informatik.umu.se/~jwworth/vrst95-1.html>

- SpatialViSC-Initiative (1998): *Projektbeschreibungen im Rahmen der fächerübergreifenden Arbeiten zu "SpatialViSC"*. University of Münster, Germany, http://ifgi.uni-muenster.de/3_projekte/spatial_visc/workbench_main.html.
- Uhlenkükten, C., B. Schmidt & U. Streit (1999): *Visual Exploration of High-Dimensional Spatial Data: Requirements and Deficits*. Computer & Geosciences, special issue "Geoscientific Visualization", Elsevier Science (in press).
- van House, N.A., M.H. Butler & L.R. Schiff (1998): *Cooperative Knowledge Work and Practices of Trust: Sharing Environmental Planning Data Sets*. ACM 1998 Conference Proceedings on Computer Supported Work.
- van Voris, P., W.D. Millard, J. Thomas & D. Urban (1993): *TERRA-Vision - The Integration of Scientific Analysis into the Decision Making Process*. International Journal of Geographic Information Systems, 7, pp. 143-164.
- Wesche, G., J. Wind, W. Heiden, F. Hasenbrink & M. Göbel (1997): *Engineering on the Responsive Workbench*. Proceedings of the 8th Eurographics Workshop on Visualization in Scientific Computing, April 28-30, 1997, Boulogne sur Mer, France.
- Wherrett, J.R. (1996): *Visualization Techniques for Landscape Evaluation : Literature Review*. Macaulay Land Use Research Institute (MLURI), Aberdeen, Scotland, <http://bamboo.mluri.sari.ac.uk/~jo/litrev>.
- Woo, M., J. Neider & T. Davies (1997): *OpenGL Programming Guide*. 2nd ed., Addison-Wesley.
- Zhu, X., R. G. Healey, et al. (1998): *A Knowledge-Based Systems Approach to Design of Spatial Decision Support Systems for Environmental Management*. Environmental Management 22(1), pp. 35-48.