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Design of a Relational Database for Landscape-Ecological Studies.

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Abstract.
This paper presents a preliminary design of a relational database to be used in connection with empirically based landscape ecological research. Landscape ecology has developed more and more towards quantitative studies of complex landscape problems at different geographical scales - it seems that a system based on a relational database offers a good way of handling the complex queries, that are often used in connection with such studies.

1. Introduction.

As the need for a global change in the direction of a sustainable development also means a need for a better technological adjustment to local and regional landscape ecological conditions, landscape-ecological studies have become increasingly important.
At the same time the development in modern computer science has shown many potentials concerning manipulation of spatial data, that have proved very important in connexion with landscape ecological surveys.
This is certainly one of the obvious perspectives for the cooperation within the historically rather untraditional Institute of Geography, Socio-economic Analysis and Computer Science at Roskilde Universitycentre. In the following we will present an example of such a fruitful cooperation combining the two subjects of geography and computer science.

2. The need for relational databases within landscape ecology.

Landscape ecology is an interdisciplinary science dealing with the study of structure, function and dynamics of landscapes at different scales. It has developed primarily from an applicational point of view concerned with the intelligent use of the land.
Landscapes are mostly studied according to a concept, that defines landscapes as repeating patterns of structurally and functionally distinct areas that vary in composition, size, shape and arrangement.
Much basic research and surveys within landscape ecology deals with the mapping of basic areas - land-units - that form the starting points of the landscape investigations within a certain geographical scale (Zonneveld 1989, Jensen 1990, Andersen, Brandt and Jensen 1990). These land-units often have a (quasi-) homogeneous character or specific internal dynamics due to certain functional relations within the complex of natural components or due to common genetic properties. The combination of such land units into heterogeneous landscape units of different scales, often build up as a more or less hierarchical system based on the internal dynamics, is often called *inductive landscape analysis* as opposed to a

deductive landscape analysis based on the recursive division of landscapes into still more detailed levels. The inductive way can be very time-consuming, but gives much more exact information on the internal landscape structure than the deductive method, that rather emphasise the delimitation than the content of the landscapes. The inductive way is often the most relevant from an applicational point of view, because the majority of landscape-forming processes are taking place at the level of the smallest land-units - ecotopes - and the lowest landscape level, that cannot be identified through deductive methods. The typification and clustering of land units into heterogeneous landscapes has up till now mostly been done manually, based on the vaguely defined expertise of skilled scientists, but is through the use of more or less sophisticated GIS moving towards quantitative methods of nabourhood and clustering analysis (e.g. Von den Berg et al. 1988).
A common sort of landscape ecological studies is land capability studies based on the geographical comparison of landscape units, with land use units. Often this sort of comparison is formulated as an evaluation of the use of landscape potentials (Mannsfeld 1983, Brandt 1991). Although these studies are often static, they can indeed be of relevance for the study of landscape dynamics, because the internal dynamics of the landscape units (flow of matter and energy within the natural system) are likely to be important for the maintenance of the landscape structure. It is however important to point out, that the internal dynamics of landscapes only to a somewhat limited degree are reflected in a strictly hierarchic landscape classification.
Even more geographically complicated is the investigation of landscape forming processes, that in most cases are socially induced: Here the impact has to be investigated within *action fields* (Neef 1984), deliminated by factors and processes that seldom relates to landscape units within a hierarchic landscape classification. Even the basic quasihomogeneous land-units may be "heterogenized" by man-induced landscape-transforming processes (e.g. by ground water extraction).
A somewhat other interpretation of the landscape concept, that can be seen as a sort of "cultural overlay" on the above described landscape is related to the structure, function and changes of relatively homogeneous *landscape elements* (whether of natural or human origin) where *patches* and *corridors* form a *network*, that is embedded in a *matrix* of cultivated fields (Forman and Godron, 1986). Based on this landscape concept numerous studies indicate, that the size, shape and arrangement of elements composing a landscape are of importance to the function and persistence of each individual area and/or the landscape as a whole, and that connections between similar areas (e.g. types of noncultivated land) increase the interaction between them (Schreiber, 1988). It has been found, that the size of ecotopes is an important structural aspect which affects species dynamics. Furthermore several investigations have indicated, that connections between similar ecotopes are critical for maintaining viable populations of some animals in fragmented landscapes.
Provoked by a drastic reduction of small biotopes in many intensively used agricultural landscapes a lot of investigations were started in the 70'ies, and has since then formed an important field of empirical studies within modern landscape ecology. These studies have been closely related to practical landscape and conservation planning, for instance as theoretical and practical foundation for the construction of landscape corridors (Løjtnant, 1984). Quantitative characterization of such elements and their spatial relations by use of analytical programmes for measurement of size, perimeter, fractal dimension, edge statistics, indices for diversity, dominance and adjacency etc. within given landscapes has developed in recent years (Turner, 1990).

So, in landscape ecological studies, the need for GIS is related to facilities, that in an integrated and flexible way supports

1. characterization and measurement of linear and areal features,
2. intersection of spatially referenced data, and
3. proximity analysis.

Due to this complexity of needs for topological analysis the landscape ecological use of GIS has developed relatively late (Johnson 1990).

In Denmark, such studies of the structure of small landscape elements (small biotopes) has developed since 1977 (Byrnak et al.,1980, Biotopgruppen 1986, Agger og Brandt, 1987, Agger and Brandt, 1988). By small biotopes is ment hedges, roadside verges, drainage ditches, small brooks, bogs, marl pits, natural ponds, thickets, prehistorical barrows and other small uncultivated areas laying within and between the fields in the agricultural landscape. Topologically they are defined as biotopes exclusively within the agricultural area, with a size of more than 10 m^2 and less than 20.000 m^2 (2 hectares) for patch-biotopes, or a length of more than 10 meters and a width of more than 0.1 meter for linear biotopes.

The great majority of these biotopes are not of "natural" origin, but closely related to functions within the agriculture. Thus changes within the agricultural structure and technology clearly give rise to changes in types, spatial structure and dynamics of the small biotopes. Since the agricultural holdings form the most important action field for the small biotope development as a landscape forming process, the information concerning small biotopes had to be closely linked to the information on the agricultural holdings.
A detailed survey of small biotopes in 13 test areas of the agricultural landscape of the eastern part of Denmark was carried out in 1981. For some of the areas the analysis was extended with historical registrations based on air photos and topographical maps.

The main purpose of these studies was
1. to document the changes in the number, extend and distribution of different types of small biotopes,
2. to give a survey of the status and function of small biotopes within the agricultural holdings, and
3. to analyze the conditions for spatial distribution of small biotopes due to agricultural technology and structure, modified by landscape-ecological variations and different influences of urbanization.

A lot of important results on e.g. extinction rates of different types of biotopes and the relation of biotope structure to the structure of ownership resulted from these studies. They have been of importance for the formulation of strategies on landscape monitoring at different planning levels, and has had a certain influence on legislative proposals concerning natural conservation.

As no appropriate GIS was available at the time, a simple network database system was created. It was implemented in SIMULA, which due to its class-concept at the time was one of the most suited programming languages to handle manipulation of such data. A programme-package "biotoppakke" facilitated the handling of all data of the project in a manner that enabled the user to manipulate data without any knowledge of the actual file-organization.
The handling of the spatial data was very primitive (only one set of UTM-coordinates per biotope, plus a rough direction index for the linear biotopes), and was only given as a simple attribute to the biotopes to support automatic drawing of simplified biotope maps.
Data was organized around two main themes: Biotopes and agricultural holdings. Certain topological references were represented explicitly by a special code-system in a way that supported a limited range of topological queries. The combination of biotopedata with other types of data (as for instance soil type) was however only possible by connecting these data explicitly to each biotope as attribute data.
The problem of this kind of database is it's lack of flexibility, as it is almost impossible to add new types of information or new relations between already existing data. This means that the potentials of the system are determined at the point of the design of the structure.

This did in fact become a problem in the case of using the biotopedata in the search for a natural classification of "biotope structures" (densities and combinations of small biotopes characteristical for different regions or landscape types). It was not possible to add information about the landscape types to the system - so only the crude division into UTM-based squares could actually be used for the statistical analysis (Brandt 1986).

In cooperation with the National Forest and Nature agency of the Danish Ministry of Environment a follow-up study after 10 years will be carried out in 1991. The study has the following main purposes:

1. To map and analyse the changes in biotope content since 1981, based on the same field survey method as used in 1981.
2. To relate the survey of structure and dynamics of the biotopes to inductive derived landscape units and to actual agricultural land-use.

A preliminary project has already been started. The purpose of this project is to develop an appropriate computerbased tool for the registration and manipulation of the data which are to be used in the 1991 biotopeproject. In the following we will touch upon a number of major elements concerning this tool. As this project is a typical example of applied landscape-ecology the associated reflections may well be considered as being of a more general character.

3. Design of a computerbased tool for landscape ecological studies.

From a computer-scientists point of view the demands of the biotope-project concerning data-processing can be summarized in the following three main points:

1. Handling of different kinds of objects with various kinds of attributes in a way that supports maximum flexibility in formulation of queries.
   To mention an example the system must be able to integrate information about agricultural structure and information on the small biotopes in a way that makes it possible to identify patterns of dependencies between the two.

2. Handling of historical changes (dynamics). This is a very important part of the biotope-project and indeed most landscape-ecological studies in general.

3. Handling of the spatial distribution of the objects. In several theories of landscape-ecology both the shape and size of the individual object as well as the possible interrelational patterns in which they may participate play an important role.

General design.

The first step in the process of designing the system is choosing the tools for the implementation. Already from the start we liked the idea of basing the system on the relational database-model (ORACLE with SQL query-language). The obvious advantage of this choice is the flexibility of the relational database.
This flexibility is of great advantage in the handling of the heterogeneous attribute-data (non-spatial data), which includes dealing with the historical data.
One of the main disadvantages of using a relational database is its tendency to slow down when coping with the very large amount of coordinate-data it takes to represent the spatial dimension. This drawback will probably be of less importance as the small biotope-project only deals with very small map-areas. Another disadvantage is that SQL is a set-oriented query-language which can give some problems in the processing of spatial data. Further-

more the SQL query-language does not support any kind of graphical interface or the capability of maintaining the topology which are both essential features.
This could lead to the idea of using completely different datamodels for the handling of spatial and non spatial data, but we find that the advantage of a uniform way of processing the two types of data outruns the disadvantages of using SQL for dataprocessing. This is of special importance for systems devoted to landscape-ecological studies where the analysis of forms and patterns are emphasized.
To cope with the problems of the lacking capabilities of SQL concerning input of spatial data the system must be supplied with an application that includes facilities for graphical user-communication as well as functions for dealing with the topology.

We will now concentrate on a more detailed discussion of some of the critical elements of the design that are specific for geographical / landscape-ecological dataprocessing. We will begin by discussing the structure for representation of the historical dynamics of the small biotopes - and end up by looking at the problems concerning organizing and manipulating the spatial data.

Representation of historical dynamics.
The queries that are needed for the processing of the historical biotopedata can be generalized into two main types of queries:

1. Queries based on data on a single year (e.g. historical mapping of biotope patterns and density).

2. Queries based on data on a specific biotope (e.g. mapping of the historical development of particular types of biotopes).

Supporting the first type of queries requires that information on the time of registration is attached to each biotope-object in either an implicit or explicit way.
The second type of query requires in addition to this, a reference between biotope-objects that represents the same biotope in different periods of time. This reference must be represented explicit in the system, because the historical connection between biotope-objects cannot be generated automatically; it can only be based on a more or less subjective estimation carried out by the user.

The historical development of small biotopes can be of many kinds. This means that the historical references may become rather complex. To describe the patterns of historical references we will draw up a list of possible variants of how a small biotope may change between two registrations.

1. The biotope does not change at all between two registrations.

2. The biotope changes in regard to the non spatial dimension. I.e. there are differences in the attributes of the old and the new biotope; if for example the treevegetation of a dyke has been cut down.

3. The biotope changes in regard to the spatial dimension. I.e. there are changes in the size or form of the biotope, which will be the case if the farmer between two registrations has removed part of a hedgerow.

4. The biotope is split up in two parts. This may happen when a farmer decides to create a passage through a hedgerow. What used to be a single hedgerow has now become two smaller hedgerows, but in reality they are still representing the same biotope.

5. Two biotopes turn into one. This may happen if the farmer from point 4 never really uses the passage. After a period of time the vegetation in the passage will recover and in the next registration it will all be one single hedge again.

6. The biotope is resurrected. I.e. for a period it disappears and then turns up again. This will be he case when a farmer decides to drain a bog to expand the area of arable land. When the drainage system is worn out he may not be able to receive any subsidies for redrainage of the area, and he may decide to give up the land. After some time the area will be registered as a new incarnation of the original biotope.

The difficulties in connection with the historical representation are mostly related to case 4, 5 and 6, and can be summarized as follows.
Because of the biotopes ability to split up and union (case 4, 5) the historical relation between biotope-objects is not a simple "one to one" relation.
The problem of resurrection - or rather the fact that any "new" biotope can be the resurrection of a biotope that has been extinct for any time implicates that it is not enough to know that one biotope is a resurrection of another - we also have to know the point of time at which the original biotope deceased and the current biotope emerged.

The design shown in figure 1 copes with all of the demands mentioned.

BioObjects70

Object#	Attribute
1	pond
2	hedgerow
3	ditch

BioObjects80

Object#	Attribute
1	hedgerow
2	hedgerow
3	"dummy"
4	ditch

BioObjects90

Object#	Attribute
1	pond
2	hedgerow
3	ditch

History70-80

Old	New
1	3
2	1
2	2
3	4

History80-90

Old	New
1	2
2	2
3	1
4	3

Fig. 1. The historical biotope-data are organized as tables of snapshots of each single year of registration. The biotope-objects are linked together by relations between each pair of succeeding registration years. The example shows the development of 3 biotopes. A pond registered in 70 that disappears in 80 and reappears in 90. A hedge registered in 70 is split up and registered as two biotopes in 80 - in 90 they have been reunited. A ditch registered in 70 changes in shape between 70 and 80 and is unchanged between 80 and 90.

As a consequence of the way the data is collected it seems a natural thing to represent the biotope data as snapshots. I.e. one table for each year of registration. In this way queries based on information from a single year (type 1) is made very simple.

The biotopes that haven't changed at all are represented as two identical biotope objects (which seems to be a waste of space).
The splitting and unification of biotopes is handled in independent tables, where each table connects two snapshots in chronological order.
The deceased and resurrected biotopes are handled by introducing a dummy-object that represents a biotope in its period of non-existence.

The drawback of this design is that identical biotope-objects cannot be represented as one single object, and that the dummy-objects of the dead biotopes can be of great nuisance because the amount of them will accumulate. To avoid this, the design can be changed as follows.

BioObjects

Object#	Attribute	From	Until
1	pond	70	80
2	hedgerow	70	80
3	ditch	70	80
4	hedgerow	80	90
5	hedgerow	80	90
6	pond	90	
7	hedgerow	90	
8	ditch	90	

History

Old	New
1	6
2	4
2	5
3	8
4	7
5	7

Fig. 2. A second design: All biotope-objects are represented in one single table "BioObjects", and the historical relations between the biotopes are in the "history"-table.

In this design the period of each biotope-existence is specified explicitly, hereby avoiding duplication of identical biotopes.
In later optimizations of the database it is likely that the biotope table will be divided into two separate tables; one for the current biotope-objects and one for the historical incarnations.
The idea of representing dead biotopes by means of dummy-objects could also be used in this design. But instead of this we have chosen to add the attribute "until". In this way a deceased biotope is represented implicitly by its absence in a given period.

Figure 3 illustrates a typical query directed towards extracting the history of a given biotope.

```
A:      select object#, attribute, from, until
        from bioobjects
        where object# in
           (select old
           from history
           connect by
           prior old = new
           start with new = &1)
```

B:

Object#	Attribute	From	Until
2	hedgerow	70	80
4	hedgerow	80	90
5	hedgerow	80	90

Fig. 3 A. A SQL query resulting in the family-tree of a given biotope.
B. The resulting table of the query (A) with the given biotope being the current hedgerow-biotope (the variable &1= 7).

The design of this structure is however only the first step in the direction of making the analyses of the historical dynamics on the small biotopes possible. Finding ways to quantify the historical biotopestructure is a different problem which is definitely not automatically solved by the designed structure - even though it may ease the task.

Topology.

The primary objectives concerning the design of the topological structure of the database are that:

1. the structure must contain enough information to support all likely topological queries, and

2. the data should be organized in such a way that most processing concerned topological query can be done by ORACLE itself - not by an external data-module.

The first objective is relatively easy to obtain. Even the simple database of figure 4 satisfies this goal.

DESIGN 1

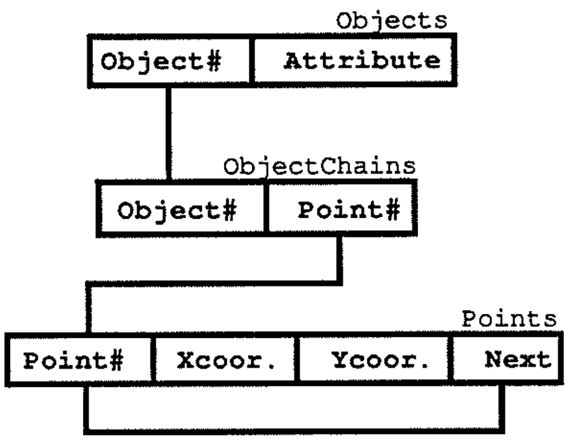

Fig 4. The minimum database schema, that holds enough information to support all likely topological queries.

In the schema of figure 4 the actual data points refer directly to attribute objects without any kind of intermediate structure. Therefore all topological queries must process the actual coordinatedata representing the spatial distribution of the attribute objects. Since this easily can represent substantial amount of processing, a database structure like this is of very little practical use.

The realization of the second objective is of a somewhat more complicated nature, which in practice calls for the use of an intermediate structure between the attribute objects and the datapoints. This intermediate structure representing the topological relationships of the attribute objects can be described as the logical map (Shi-Kuo Chang 89), in contrast to the spatial distribution of the datapoints representing the attribute objects. When designing the database schema for the representation and manipulation of the topological relationship and spatial distribution of the attribute objects, the main issue is to what extend you wish to include a logical map in the design.

The advantage of an extensive logical map is that it eases the formulation and speeds the execution of topological queries, whereas the disadvantage lies in the extra complexity of the database schema. The problem is now how to do the right thing.
Here we have chosen to include just enough of intermediate structures to enable the formulation of topological queries in SQL.
The problem of a further reduction of the logical map is that topological queries no longer can be formulated in SQL. This problem may however be solved by introducing a SQL-dialect which includes the ability to handle topological queries by processing the absolute data-coordinates.
The reason why we have chosen to stick to the ISO standard of SQL is, that this enables us to use a range of SQL based standardapplications such as forms and reportgenerators.

DESIGN 2

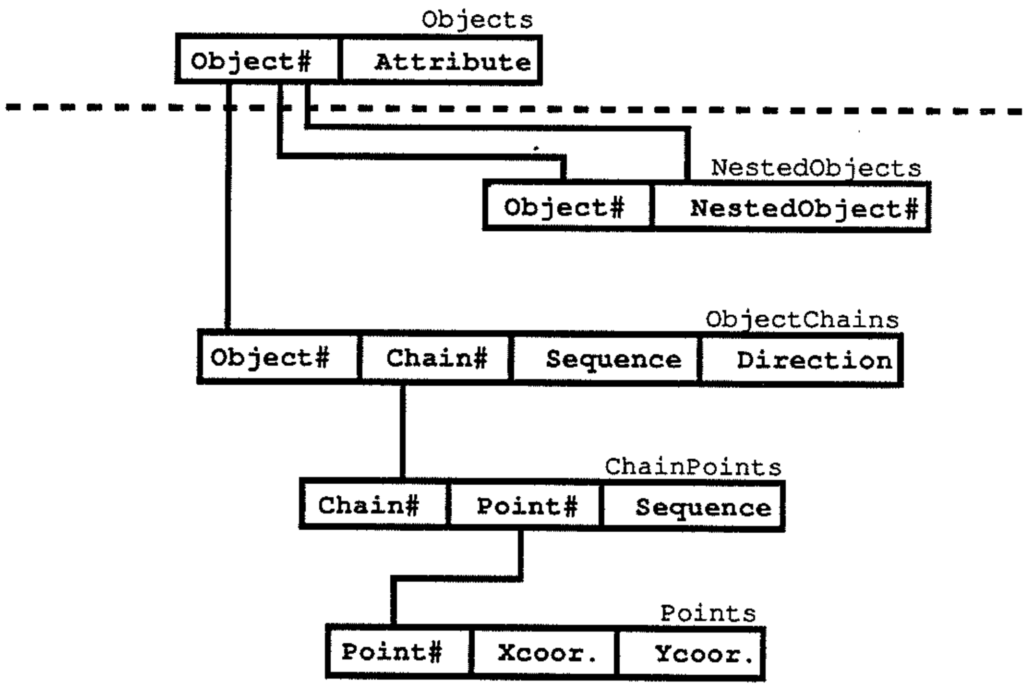

Fig.5. Shows the chosen design which includes a logical map. The logical map consists of:
1. The "nested objects" relation, materializing the nesting of the objects.
2. The introduction of a "chain-entity" represented in the relations "chain-points" and "object-chains".
The tables are divided into two groups. The tables under the dashed line are global tables shared by all overlays, whereas the tables above the line are repeated for each overlay.

An example.
Based on a typical testsite (Tågerup, Sealand) we will demonstrate how data can be represented and queried in the proposed database.

Fig. 6. A map of the landuse structure.

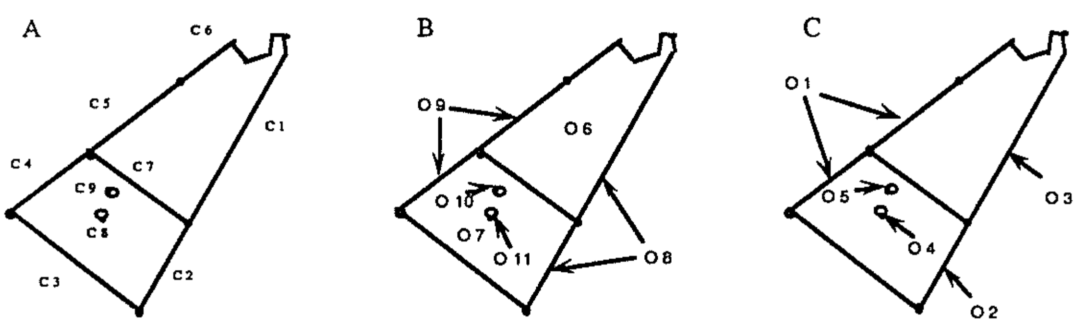

Fig. 7 A. The chain representation of a subset of the area of figure 6.
B. The biotope objects of the same subset area.
C. The landuse objects of the same subset area.

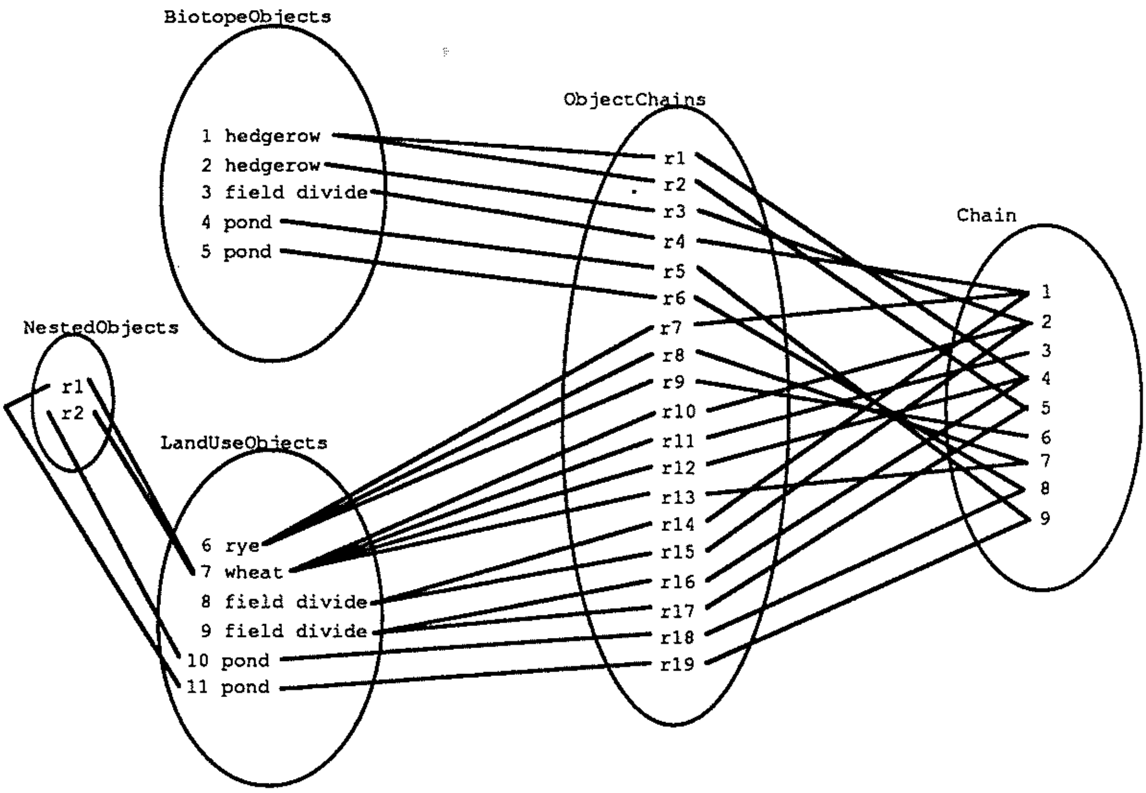

Fig. 8. The set representation of the area described in figure 7 shown as sets.

The following SQL-query demonstrates the systems ability to cope with topological queries.

A:

```
SELECT Chain#
FROM BioObjects, ObjectChains
WHERE BioObjects.Object# = ObjectChains.Object#
INTERSECT
(
SELECT Chain#
FROM LandUseObjects, ObjectChains
WHERE LandUseObjects.Object# = ObjectChains.Object#
AND   LandUseObject.Attribute = 'rye'
UNION
SELECT Chain#
FROM NestedObjects, LandUseObjects, ObjectChains
WHERE NestedObjects.NestedObject# = ObjectChains.Object#
AND   NestedObjects.Object# = LandUseObjects.Object#
AND   LandUseObjects.Attribute = 'wheat'
);
```

B:

```
Object#
-------
2
4
8
9
```

Fig. 9 A. The query: Which biotopes are next to wheatfields, ie. which biotopes are neighbouring the wheatfield and which biotopes are surrounded be a wheatfield.
B. The result of this query.

External applications.
As mentioned earlier a range of important functions are not supported by the ORACLE database - the most important of which are:

1. The digitizing of maps and editing of already existing mapdata.

2. The construction and maintenance of the logical map in connection with changes in the spatial data as the result of input or updating of objects as well as the construction of topology of derived maps that are generated as a result of overlay-operations. These are all well known operations described as early as in 1978 by (Cook,1978)

3. Support for queries based on interactive objectselection by means of a graphic pointing device.

4. Finally it would be of great convenience to the user if the system supported a graphic interface based on the use of menus, windows and the like.

To facilitate these functions we have chosen to include a range of external applications implemented in the objectoriented programming-language C++.

To conclude the discussion of the databasesystem design we would like to point out that the datastructure proposed here is to be considered as a basic design which will be optimized and tailored to the specific needs of the biotope-project. This tailoring will however mainly concern the way that the users see the database, and the fundamentals of the proposed structure will therefore remain more or less unchanged. The first test-runs of the system will be conducted in the early spring of 1991, where the data from the survey of 1981 will be fed into the system.

5. Conclusion and outlook.

The danish small biotope project started as a project, mainly oriented towards a narrow analysis of biotopes as landscape elements in the agricultural desert. In the middle of the 80'ies the investigations were continued from another viewpoint, being one of the main entrances to the study of marginalization processes within the most intensively used agricultural landscapes, namely the young-morainic (Weichsel) landscape of the eastern part of Denmark (Agger and Brandt 1987). This was due to the fact, that the small biotopes here form the main areal reserve for an expansion of the agricultural use of the landscape, and that the dynamics of the small biotopes reflect general changes in the landuse-pattern, thus being a fine detector on tendencies of extensivation or intensivation of the agricultural landuse (Brandt and Münier, 1990).
These studies made it even more important to study the biotope structure as elements embedded in the agricultural land-use, and integrated into the general landscape structure, that forms an important condition for the marginalization process. The tendencies of marginalization of agricultural land is narrowly linked to the emerging changes within the EEC-agricultural policy, which again have a strong influence on the future dynamics of the biotope structure; even at the regional and local level (Brandt and Agger 1988).
This development indicates, that future landscape ecological planning will depend strongly on the ability to uncover how socially induced landscape-transforming processes are realized in different cultural landscapes. Empirically this has to be studied through a systematic search for spatial typification of landscape elements and landscape-forming processes, and through spatial correlation of the distribution of landscape elements, land units and landscape structures, that integrates the two different interpretations of the landscape concept

mentioned earlier. This will only be possible through the extended use of Geographical Information Systems, that in a flexible way can manipulate topological and attribute data in an integrated manner.

References.

Agger, P., J. Brandt, E. Byrnak, S.M. Jensen og M. Ursin (Biotopgruppen), 1986: Udviklingen i agerlandets småbiotoper i Øst-Danmark. Forskningsrapport nr. 48. Institut for geografi, samfundsanalyse og datalogi. RUC. 541 pp.

Agger, P. and J. Brandt, 1988: Dynamics of small biotopes in Danish agricultural landscapes. **Landscape Ecology** Vol. 1 no. 4, pp. 227-240.

Agger, P. og J. Brandt 1987: Småbiotoper og marginaljorder. Miljøministeriets projektundersøgelser 1986. Teknikerrapport nr. 35. Skov- og naturstyrelsen. København . 225 pp.

Andersen, E., J. Brandt og John E. Jensen, 1990: Landskabsøkologisk kortlægning. **Ugeskrift for Jordbrug** 135. Årgang. 29/30 1990. p. 463-467.

Brandt. J.,1986: Small-biotope structures as a synthesizing feature in agricultural landscapes. In: Landscape synthesis - foundations, classification and management. Part 1, Geoecological foundations, pp. 52-61. Ed. by H. Richter and G. Schönfelder. Martin-Luther-Universität Halle-Wittenberg, Wissenschaftliche Beiträge 1986/16, Halle Saale), DDR.

Brandt, J. and P. Agger , 1988: The influence of EEC-agricultural policy on the conditions for development of biotope structures in rural landscapes - some Danish experiences. K.-F. Schreiber Hrsg.): Connectivity in landscape Ecology. Proceedings of the 2nd International Seminar of IALE. Münster 1987. Münstersche Geographische Arbeiten, 29, p. 219-221.

Brandt, J. and B. Münier(1990): The use of GIS and SGEOS-data in landscape-ecological studies of small biotopes and marginal lands. Report from Inst. of Geography, Socio-ecolomic analysis and Computer Science, RUC. 82 pp.

Brandt, J., 1991: Zur Gewinnung landschaftsökologischer Informationen durch statistische Analyse eines Landnutzungssystems: Schafzucht auf den Färöer. **Petermanns Geographische Mitteilungen** . Gotha..(im Druck). 30 pp.

Borrough. Principles of Geographical Information Systems for Land Resources Assesment. Oxford Science Publications, Oxford 1986.

Byrnak, E. et al.(1980): Agerlandets småbiotoper. Forskningsrapport nr. 9. Institut for geografi, samfundsasnalyse og datalogi. RUC. 354 pp.

Chang, Shi-Kuo, Principles og pictorial information systems design, USA, Prentice-Hall, 1989.

Cook, B.G., The structural and algorithmic Basis of a Geographic Data Base. In: First Int. Advanced Study Symposium on Topological Data Structures for Geographic Information Systems, vol.4. Harward papers on geographic information systems, Harward University, 1978. 30.pp.

Holmes, E.W., Larsen, D.K. and Fischer, L., 1988. Polyfiller - Et projekt om udvikling og implementation af algoritmer til polygon-identifikation til brug ved opbygning af geografiske databaser. Datalogi, 1.modul-projekt. RUC 1988. 95 pp.

Jensen, J. E., 1990: Nanochorer i Gundsø kommune. Arbejdspapir nr. 90. Institut for Geografi, Samfundsanalyse og Datalogi, Roskilde Universitetscenter.

Johnson, L.B.: Analyzing spatial and temporal phenomena using geographical information systems. A review of ecological applications. **Landscape Ecology** vol. 4 no. 1 pp. 31-43.

Langran, G. , 1989: A review of temporal database research and its use in GIS applications. In: **Int. Journal of Geographical Information Systems**, vol.3, no.3, Juli-September 1989. pp. 215-232.

Larsen, D.K., Holmes, E.W. and Madsen, M.M.,1987. GISNINGER - Et projekt om geografiske informationssystemer og vegetationsmodeller. NATBAS-rapport, RUC 1987. 87 pp.

Løjtnant, B., 1984 (ed): Dispersal Ecology, Island Biogeography and Physical Planning. Naturfredningsrådet og Fredningsstyrelsen. København 1984.

Mannsfeld, K., 1983: Landschaftsanalyse und Ableitung von Naturraumpotentialen. **Abh. d.Sächsischen Akademie der Wissenschaften zu Leipzig.** Mat-Nat-Klasse Bd. 55 Helt 3.

Neef, E., 1984: Applied landscape research - dedicated to the participants of The First International Seminar of The International Association for Landscape Ecology (IALE), Roskilde 1984.

Roessel, van J. W. Design of a spatial data structure using the relational normal forma. **International Journal of Geographical Information Systems**. vol.1 no1. Taylor & Francis. UK 1987.

Schreiber, K.-F.(hrsg.)1988: Connectivity in landscape Ecology. Proceedings of the 2nd International Seminar of IALE. Münster 1987. **Münstersche Geographische Arbeiten**, 29, 1988.

Sinha, A.K. and Waugh, T.C., 1988. Aspects of the implementation of the GEOVIEW design. In: **Int. Journal of Geographical Information Systems**, vol.2, No.2, April-June 1988. pp. 91-100.

Turner, M.G.: Spatial and temporal analysis of landscape patterns. **Landscape Ecology** vol. 4 no. 1 pp. 21-30.

van den Berg, A.H.F.Stortelder & W. Vos, 1988: Order and disorder in landscape: Tha analysis of the t5ranformation of a submediterranean-Montane Landscape (1993-2035).In: K.-F. Schreiber Hrsg.),1988, p.227-231.

Waugh, T.C. and Healey, R.G., 1987: The GEOVIEW design. A relational data base approach to geographical data handling. In: **Int. Journal of Geographical Information Systems**, vol.1, No.2,April-June 1987. pp.101-118.

Zonneveld, I.S. (1989): The land unit - a fundamental concept in landscape ecology, and its applications. **Landscape Ecology** vol. 3 no. 2 pp.67-86