Study on Context Understanding, Knowledge Transformation and Decision Support Systems

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Abstract: - The contribution deals with the problem of detecting, interpretation and understanding various contexts on the background of the process understanding and the context applying. Also the problem of multi-criteria evaluation is addressed and the different ways of knowledge integration is discussed. Despite rapid progress in this area, there are still a significant number of challenges that need to be addressed to enable automatic contextual decision making. Those challenges include robust detection of the context, its interpretation, multi-level semantic information and understanding on the base of inference from object interactions. The contribution is focused also on the use of Voronian diagrams in combination with standard spatial data to support the decisions in the field of nearest objects selection with regards to the additional considerations. It is shown that the localized knowledge make possible to aggregate important aspects of defined objects and phenomena and evaluate them in context of different requirements.

Key-Words: - Decision making, contextual modelling, knowledge transformation, Voronian diagram, nearest triangulation, decision support, Delaneu triangulation

1 Introduction

1.1 Decision Making

Decision-making is understood as outcome of cognitive processes leading to the selection of a course of action among several alternatives.

Data can be explained as the product of research or the raw material of information. A single piece of data has no meaning unless the context is considered.

The quality of decision-making is always dependent on the quality and quantity of information about issues, which is available to the person making a decision about them and on the suitable classification methods enabling the best alternative selected from the set of all available solutions [26]. The problem of the selection or the ranking of alternatives submitted to multi-criteria evaluation is not easy problem. Since every decision-making affects the course of further events, it is necessary to pay attention with an appropriate respect to the decision-making process [8], [27].

A sufficient amount of the quality information about the issues to be decided is needed so a quality decision can be made. For this reason certain properties of objects are observed, which are important from the decision-making process aspect; it means, they are being evaluated according to certain evaluation criteria.

Each object typical for a certain decision situation can be described with a terminal sequence of values of the observed attributes, which create the basic information for multi-criteria decision-making [20].

Information about the significance of evaluation criteria has, in many multi-criteria decision making methods and approaches significant importance.

Our decisions are becoming increasingly dependent on understanding of complex relations, deep context and dynamics of phenomena in the world around [3], [17].

1.2 Information System

The purpose of an information system is to answer the questions. Information must be structured and knowledge must be represented so that answers can be found among the information in the system or derived from the information in the system.

The evolution of the Internet and Intranet applications intensely contributes to effective information and knowledge acquisition, incorporation and significantly shapes the role of the technological infrastructure [21].

The good information system is characterized by the simple way of communication with user that allows the interpretation of requests and incorporation of user confirmation when needed (additional conditions). Adaptive ability is requested to the special needs of the user and the specific situation.

We need the system that is able to ask for more information if it is needed to derive a good answer and to answer in easily-understood format.

The good system assists in knowledge acquisition, is able to learn and accept different information structures and to have in disposal a wide range of information processing techniques and methods, and appropriate knowledge presentation tools [10].

The geography plays a very important role in many decision-making situations. Spatial decision making, targeting market segments, planning distribution networks, responding to emergencies, and many other - all of these problems involve questions of geography.

1.3 Context and GIS

A geographic information system (GIS) allows us to view, understand, analyze, interpret, and visualize geographical data in many ways that shows relationships, patterns, and trends in the form of maps, scenarios, reports, and charts. GIS helps to solve problems by data which are quickly looked and easily shared. GIS can be viewed in three ways - the database view, the map view, the model view [18].

The large ability is aided to implement knowledge models from different branches of scientific investigation of around world for wide context of evident as well as less evident connections, models of trends, objects and expected or predicted relations [4]. From this point of view the context and knowledge are the two sides of the coin. To follow context we obtain knowledge and often the way is more than the result.

The integral part of control GIS is the modelling where the information from real, artificial and virtual world are composed together to select optimal scenario or verify given hypothesis or assumptions. GIS application can be one of the three types - data sorting and storing, analysis and processing data, decision-making and knowledge creation.

2 Problem Formulation

Context is very important in recognition and multi-criteria decision at multiple levels. To achieve the highest possible levels of decision performance it means the efficient use of all contextual information. Current technology primarily approaches the problem from the top-down perspective by modelling the structure of context [15], [16].

2.1 Context Representation

The three essential information structures are: sequences, hierarchies and webs. The simplest way to organize information is to place it in a sequence. Sequential ordering may be chronological, a logical series of topics progressing from the general to the specific, or alphabetical, as in indexes.

To represent context we use trees, structures and maps to describe organization, structuring and logical arrangement - Fig. 1-3. The hierarchies are the best way to organize and simplify most complex packages of information and hierarchical diagrams are very suitable to incorporate own point of view on system arrangement.

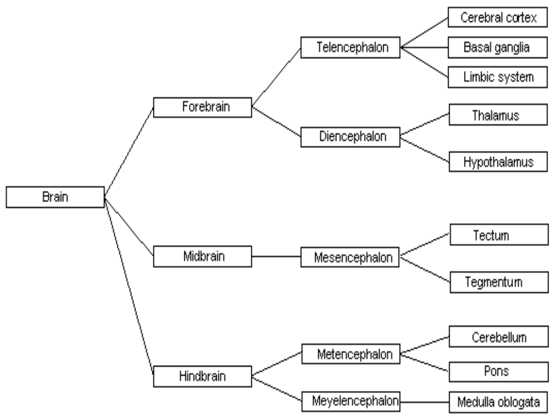

Fig. 1 Composition

Web organizational structures contain only few restrictions on the pattern of information use. In this structure the goal is to follow associative thought and the free flow of ideas, allowing users to keep their interests in a unique, heuristic pattern investigation.

We can meet also mind map a diagram used to represent words, ideas, tasks or other items linked to and arranged around a central key word or idea. It is used to generate, visualize, structure and classify ideas, and as an aid in study, organization, problem solving, decision-making, and writing.

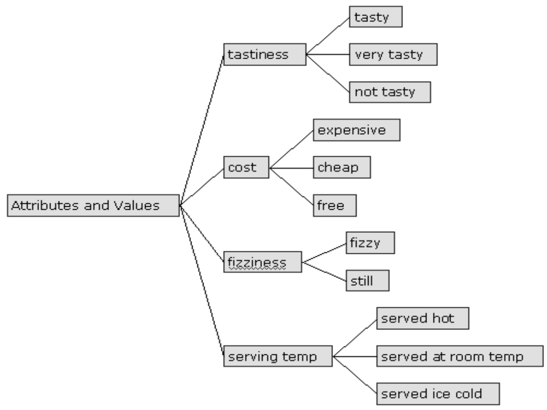

Fig. 2 Attribute structure

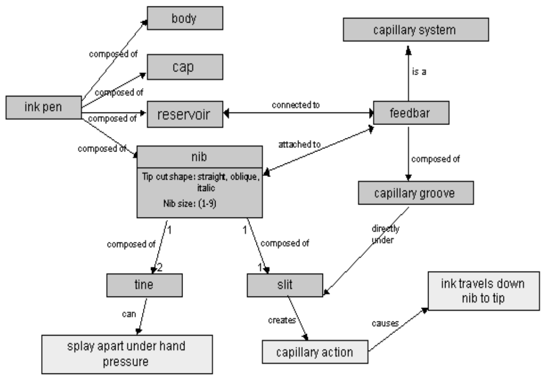

Fig. 3 Conceptual map [32]

3 Multi-criteria Decision Making

Most of the decision problems are multi-criteria. The problem of the selection or the ranking of alternatives submitted to a multi-criteria evaluation is not easy problem. Since every decision-making affects the course of further events, it is necessary to pay attention with an appropriate respect to the decision-making process.

A sufficient amount of the quality information about the issues to be decided is needed so a quality decision can be made. For this reason certain properties of objects are observed, which are important from the decision-making process aspect; it means, they are being evaluated according to certain evaluation criteria [8].

Each object typical for a certain decision situation can be described with a terminal sequence of values of the observed attributes, which create the basic information for multi-criteria decision-making.

3.1 Problem Description

Let $A = \{a_1, a_2, ..., a_n\}$ be a set of alternatives and $K = \{k_1, k_2, ..., k_m\}$ a set of evaluation criteria.

The inputs of a multi-criteria method, whose goal is to find the best objects available, or to put them in an order from the best to the least suitable, are suitability values $x_{ij} = k_j(a_i)$ showing alternative's utility a_i according to a *j*-evaluation criterion.

Each evaluation $k_j(a_i)$ must be a real number. Each object is then characterised with a vector $\bar{x} = (x_{i1}, x_{i2}, ..., x_{im})$ for i = 1, 2,..., n.

The input matrix describing objects then has the form:

$$\mathbf{X} = \begin{bmatrix} x_{11} & \cdots & x_{1m} \\ \vdots & x_{ij} & \vdots \\ x_{n1} & \cdots & x_{nm} \end{bmatrix} = \begin{bmatrix} k_1(a_1) & \cdots & k_m(a_1) \\ \vdots & k_j(a_i) & \vdots \\ k_1(a_n) & \cdots & k_m(a_n) \end{bmatrix}. \quad (1)$$

Many real-word applications can be described by such matrix [6]. In some cases it is an easy task and the matrix is obtained immediately. In other cases it can be a problem implying several months of severe consulting and analysis work.

When implementing multi-criteria decision methods, a significant role is played by a quantitative importance evaluation of each evaluation criterion with a weighted factor. Weights w_1, w_2, …, w_m of such criteria significantly influence the accuracy of a classification.

Determining the correct and responsible weights of each partial evaluation is one from the basic tasks when multi-criteria tasks are being solved.

It is indisputable that this task requires very good knowledge of a certain topic and a significance and effect of each evaluation criterion used for the objects. A range of methods is available for making the weights more accurate, determined by an expert, or a group of experts from the specialized field, at the beginning.

The criterion is more significant, more important, when its weight is bigger, $w_j > 0$ and

$$\sum_{j=1}^{m} w_j = 1. \quad (2)$$

There exist many methods which are able to determine object preferences based on object utility values according to evaluation criterion and its weight e.g. Simple Additive Weighting, Simple Additive Ranking or Preference Ranking Organisation Method of Enrichment Evaluation. Usually the method requests additional information to be able to set up weights and preference functions.

3.2 Parameters Estimation

The access to the selected information (even in form of model), in defined time, verified information and coming from the credible source it is the main difficulty of decision support systems [17], [22].

Also the use of sophisticated modelling functions in GIS (table 1) is strongly depending on exact definition and estimation of parameters:

- Specification of one or more target locations,
- Specification of the neighbourhood that surrounds the targets,
- Specification of the way spatial elements are interconnected,
- Set of rules those specify the allowed movement along interconnections,
- Set of resources, etc.

Set of constraints that places limits on how the objective can be met (speed of travel, time spent delivering the products, etc.) [5], [29].

overlay function	connectivity function
contiguity function	network function
spread function	seek or stream f.
inter-visibility f.	neighbourhood f.
and theirs combinations	

Table 1 GIS modelling functions

The different requirements can be described by the set of factors and coefficients, but these factors are often connected to the critical characteristics coming from the selected area and surrounding objects that can influence the estimation quality [16], [29].

Since the knowledge is specified independently from the application domain, reuse of the knowledge is enabled for different domains and applications. The knowledge modelling connected with knowledge based systems is influenced everyday by new research results.

The model is only an approximation of reality and the modelling process is a cyclic process and new observations may lead to a refinement, modification, or completion of the already constructed model.

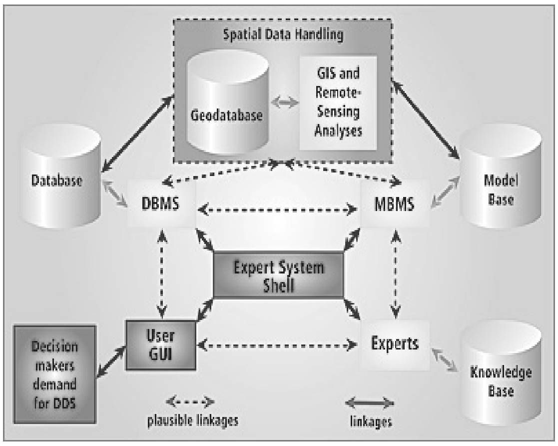

Fig. 4 Structure and interfaces of an advanced computer-based SDSS (Spatial Data Support System, source: esri.com)

Fig. 4 shows the future structure and interfaces of an advanced decision support system. The dash lines designate desired and required linkages and cross connections that are needed to support all levels of decision making processing.

3.3 Voronoi Diagrams

Voronoi diagram is a special kind of decomposition of a metric space determined by distances to a discrete set of points. They specify discrete set of objects in the space as like hospitals, restaurants, post offices, markets.

It is named after Georgy Voronoi, also called a Voronoi tessellation, or a Voronoi decomposition. In the simplest case, we are given a set of points *S* in the plane, which are the Voronoi sites.

Each site *p* has a Voronoi cell *V(p)* consisting of all points closer to *p* than to any other site. The segments of the Voronoi diagram are all the points in the plane that are equidistant to the two nearest sites – see fig. 5.

The Voronoi nodes are the points equidistant to three (or more) sites. In the case of general metric spaces, the cells are often called metric fundamental polygons.

Let *S* be a set of points in Euclidean space with all limit points contained in *S*. For any point *x* in the Euclidean space, there is one point of *S* closest to *x*. If *S* contains only two points, *a* and *b*, then the set of all points equidistant from *a* and *b* is a hyper-plane [7].

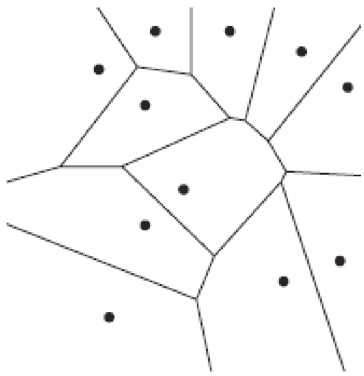

Fig 1 Voronoi diagram of 11 points

It means, if a point q lies in a cell containing p_i then

$$d(q, pi) < d(q, pj) \qquad (3)$$

for all $pi \in S,\ j \neq i$.

Two points in *S* are joined by a Delaunay edge if their Voronoi regions are adjacent. A normal Voronoi cell is defined as the set of points closest to a single point in *S*, an *n*th-order Voronoi cell is defined as the set of points having a particular set of *n* points in *S* as its *n* nearest neighbours – fig.6.

Higher-order Voronoi diagrams also subdivide space.

Main properties are as follows:

- The dual graph for a Voronoi diagram corresponds to the Delaunay triangulation for the same set of points *S*.
- The closest pair of points corresponds to two adjacent cells in the Voronoi diagram.
- Two points are adjacent on the convex hull if and only if their Voronoi cells share an infinitely long side.

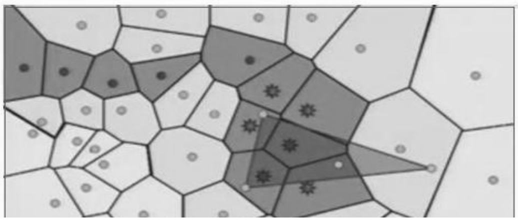

Fig. 6 Nearest neighbourhood for investigated points (corners of triangle and inside)

The generalization of Voronoi diagrams called power diagrams makes possible to assign the weights to Voronoi cell. The geometric correspondences to be described extend to that type in a natural manner. We refer to *d* dimensions in order to point out the general validity of the results [24].

Consider a set *S* of *n* point sites in *d*-space. Assume that each point in *S* has assigned individual weight *w(p)*. In some sense, *w(p)* measures the capability of *p* to influence its neighbourhood.

$$d_w(x,p) = d_e(x,p)/w(p) \qquad (4)$$

is weighted distance of a point *x* from $p \in S$.

Thus, a point having large weight will cover bigger space.

A nice geometric interpretation is the following: for positive weights, a weighted site *p* can be viewed as a sphere with centre *p* and radius *w(p)*, for a point *x* outside this sphere, $d_w(x, p) > 0$, and expresses the distance of *x* to the touching point of a line tangent to the sphere and through *x* [11], [12].

It means that weighted Voronoi diagram it is the subdivision of the plane such that

$$WV(p) = \{x : dw(x,p) \le dw(x,q)\} \qquad (5)$$

for all $q \in S$.

If a point *x* falls in *WV(p)*, then *p* is the weighted nearest neighbour of *x*.

It is commonly agreed that most geometric scenarios can be modelled with sufficient accuracy by polygonal objects. Typical examples: in marketing the strategic placement of chain stores, the description of the workspace of a robot moving in the plane, and the geometric information contained in a geographical map.

In all applications, robot motion planning, geographical information systems and strategic chain stores placement the availability of proximity information for the scenario is crucial.

This is among the reasons why considerable attention has been paid to the study of Voronoi diagrams for polygonal objects [25].

We can construct also line segment Voronoi diagram and medial axis – fig. 7. Let *G* be a planar straight line graph on *n* points in the plane, that is, a set of non-crossing line segments spanned by these points.

For instance, *G* might be a tree, or a collection of disjoint line segments or polygons, or a complete triangulation of the points. The number of segments of *G* is maximum, $3n - 6$, in the last case.

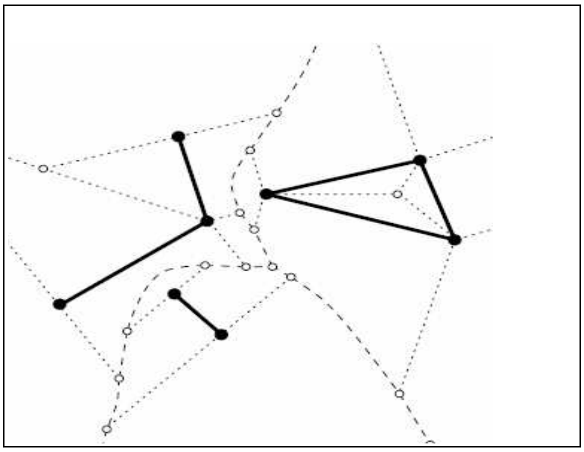

Fig. 7 Line segment Voronoi diagram

There are a wide variety of applications of line segment Voronoi diagrams. Let us suppose the sites as obstacles, then they can be used to determine the best path it means a path that stays at a maximum distance from all obstacles or sites.

The classical type is the closest point Voronoi diagram, *V (G)*, of *G*. It consists of all points in the plane which have more than one closest segment in *G*. *V (G)* is known under different names in different areas, for example, as the line Voronoi diagram or skeleton of *G*, or as the medial axis when *G* is a simple polygon.

Applications in such diverse areas as biology, geography, pattern recognition, computer graphics, and motion planning are known [1].

We have discussed Voronoi diagrams of sites in *d*-space that are defined with respect to the Euclidean distance function. In numerous applications the Euclidean metric not provide an appropriate way of distance measuring.

We can consider the Voronoi diagram of point sites under distance measures different from the Euclidean metric. For example convex distance function is a concept that generalizes the Euclidean distance but slightly. Whereas this generalization does not cause serious difficulties in the plane, surprising changes will occur as we move to 3-space [13].

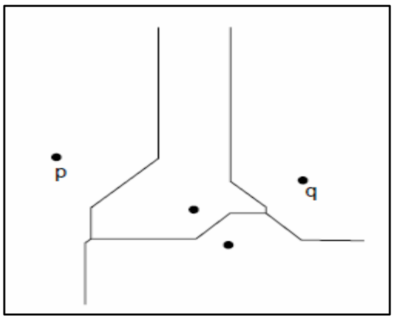

Fig. 8 Four points Voronoi diagrams based on the Manhattan – see fig 9

Let *C* denote a compact, convex set in the plane that contains the origin in its interior. Then a convex distance function can be defined in the following way.

In order to measure the distance from a point *p* to some point *q*, the set *C* is translated by the vector *p*. The half line from *p* through *q* intersects the boundary of *C* at a unique point *q*. The value of *dC(p; q)* does not change if both *p* and *q* are translated.

Another distance problem the Voronoi diagram directly solves largest empty and smallest enclosing circle. Suppose someone wants to build a new residence within a given area, as far away as possible from each of n sources of disturbance.

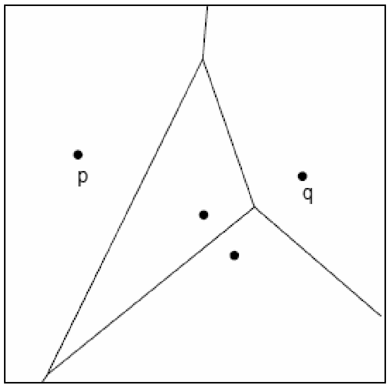

Fig. 9 Four points Voronoi diagrams based on Euclidean distance

If the area is modelled by a convex polygon *A* over *m* vertices and the disturbing sites by a point set S, we are looking for the largest circle with centre in *A* that does not contain a point of *S*. The task of determining this circle has been named the largest empty circle problem.

Very similar is the problem minimum spanning tree. is a planar straight line graph on *S* which is connected and has minimum total edge length. This structure plays an important role, for instance, in transportation problems, pattern recognition, and clustering.

Clustering a set of data means finding clusters whose in-class members are similar, and whose cross-class members are dissimilar, according to a predefined similarity measure.

Data clustering is important in diverse areas of science, and various techniques have been developed. In many situations, similarity of objects has a geometric interpretation in terms of distances between points in *d*-space.

For certain applications, the relevant cluster structure among the objects is well reflected, in a direct manner, by the structure of the Voronoi diagram of the corresponding point sites. For instance, dense subsets of sites give rise to Voronoi regions of small area. Regions of sites in a homogenous cluster will have similar shape.

For clusters having a direction-sensitive density, the regions will exhibit an extreme width in the corresponding direction. A significant stream of research concerns the stochastic properties of Voronoi diagrams for randomly distributed sites. Motivation stems from their relevance in the natural and social sciences.

3.4 Context and Uncertainty

The dimensionality of data and the complexity of objects structure hierarchy are rapidly growing and consequently with these aspects increase the uncertainty entering into the processing.

A great number of existing databases offer a variety of data sets covering different thematic aspects like topographic information, cadastral data, statistical data, digital maps, aerial and satellite images including temporal data. From the philosophical point of view the uncertainty is quite natural part of our life and the surrounding world [6].

Usually we meet uncertainty in the sense of valuation. Uncertainty is a real and universal phenomenon in valuation and the sources of uncertainty are rational and can be identified. Valuation is the process of estimating the value and estimation will be affected by uncertainties. The input uncertainties will translate into an uncertainty of the valuation. From another point of view the fact of uncertainty is very stimulating for the research on the field of defining, measuring, modelling and visualizing uncertainty and data quality analysis.

The uncertainty opens the space for further questions and the answers to this question can help us to do better decision [31]. To gain the relevant answer it is necessary incorporate the various contexts into the analysis of objects, phenomena, events and processes and connect up uncertainty into the knowledge-construction and decision-making process through context cognition.

To reduce uncertainty of data it is mainly the question of the proof of recognized quality assurance. On the other hand the decision making process is always associated with some level of uncertainty. Context sensitive recognition and decision making is a successful strategy to reduce uncertainty.

Important role in uncertainty management needs the new methods, namely intelligent methods with knowledge based approaches and multi-criteria oriented environment where the level of the risk can be defined and kept. For this purpose we distinguish two main types of uncertainty:

- Uncertainty of objects
- Uncertainty of relations

The dynamics of object is very powerful tool to obtain exact results about the object and phenomenon behaviour to support further decision.

4 Conclusion

In this paper, the problem of multi-criteria evaluation is addressed and the different ways of knowledge integration is discussed. Our decisions are becoming increasingly dependent on understanding of complex relations, deep context and dynamics of phenomena in the world around and geographic information technology is able to incorporate these new requirements and produce more valuable results.

The main goal has been to show selected aspects of this process and compare the increasing possibilities of the sources with the difficulties of data contextual structuring. The use of Voronoi diagrams; it means a special kind of irregular decomposition of the metric plane that can be successfully used to solve special tasks in the frame of GIS.

A weighted Voronoi diagram is the one in which the function of a pair of points to define a Voronoi cell is a distance function modified by multiplicative or additive weights assigned to generator points.

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