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Data Quality for Spatial Planning – An Ontological View

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1 INTRODUCTION

Space is not an arbitrarily reproducible good. Although we can intensify the use of land by adding different levels like tunnels, our capabilities to use space are limited. Therefore planning the use of space is an important task. Planning in the small scale can be done by try-and-error. I can, for example, change the arrangement of the furniture in my living room to see if the new arrangement suits me better. This is not possible for planning in public space for two major reasons:

- Financial considerations: Moving furniture is much cheaper than providing necessary infrastructure to use space in a specific way.
- Temporal considerations: Try-and-error is time consuming. Since the arrangement of using land takes time, a frequent change would disrupt the use of land. Therefore the land will not be used efficiently. Too frequently changes may even lead to unused land or to ignorance towards spatial planning results.

The outcome of spatial planning should support the intended use. On the other hand, spatial planning should also guarantee that the solution is accepted by population since they have to use the space.

Recently data of the world became more detailed and has been used to create virtual worlds (recent results have been shown by Altmaier 2004; Ferko, Martinka et al. 2004; Ftáčnik, Borowský et al. 2004; Poesch, Schildwächter et al. 2004; Dorffner and Zöchling 2004; Hagen, Steinebach et al. 2005; Zeile, Schildwächter et al. 2005). This development required sophisticated methods (see for example Busch and Lüthy 2004; Holzer and Forkert 2004; Forkert, Haring et al. 2005; Kranz, Siegert et al. 2005) and programs (see for example Hesina, Maierhofer et al. 2004; Steidler and Beck 2004; Borovsky, Hesina et al. 2005; Mantler, Hesina et al. 2005; Steidler and Beck 2005) for the creation of such models. The models can be used for planning urban development as shown in the city of Baltimore (Cavicchia 2004), for comparing the impression of alternative solutions on the spectator (see for example Mambretti, Lange et al. 2004), or visibility analysis (Kerschner 2005). In addition new tools were necessary to manage the models and allow public participation (Arleth 2005; Warren-Kretzschmar, Neumann et al. 2005) and cross-border planning (Tchistiakov, Jellema et al. 2005; Von Wirth and Schrenk 2005).

The drawback of this development is the dramatic increase in data volume. Paar, Schoth et al. showed the contradiction between the quality of map documents as the legal basis for spatial development and the quality of 3D-visualizations (Paar, Schroth et al. 2004). The problem becomes even more serious if we do not only consider spatial aspects but also include the time as demanded by Drewe (2005) because changes over time must be reflected in the data thus again increasing the volume. This is why methods have been investigated to remove unnecessary data from existing data sets (Cromley 1988; Erickson 1996; Weiss and Dorffner 2005). In contrast to the development in public participation processes Dapp showed that political decisions are done without being able to present spatial (Dapp 2005). This observations lead to the following question: What are the quality requirements for spatial planning?

Assessing quality of data is difficult because it involves many different aspects. Frank proposed a tiered ontology to differentiate these aspects (Frank 2001). His ontology separates physical reality, observations of the physical reality, objects formed from the observations, socially constructed objects, and the subjective view of cognitive agents. The tiers have different methodologies for quality treatment and the structure thus provides a connection between the process of spatial planning and data quality.

The process of spatial planning varies depending on the problem to be solved. This also influences the data used the and the data quality needed. Planning the general course of a new highway, for example, needs data on physical obstacles like mountains, rivers, or built areas. Detailed information like a precise terrain model will not be necessary at this stage. The requirements for the quality of the obstacle's positions are also low. It does not matter where exactly the highway meets a river, it is only necessary to know that there is a river and a bridge will be needed. The highest quality is necessary when simulating observations. Thus the quality demand increases during the planning process.

The goal of this paper is to show the connection between the problem specification and the requirements for data quality. Thus after an introduction to the 5-tier ontology and data quality, section 4 establishes a rough separation of problem specifications. This separation does not claim to be complete and shall only serve as a reference frame. The next section then discusses the types of spatial planning in the context of the 5-tier ontology. Then quality requirements are discussed based on the quality descriptions shown in section 3. Some conclusions complete the paper.

2 5-TIER ONTOLOGY

Frank proposes a tiered ontology to describe phenomena in the real world (Frank 2001). The ontology consists of 5 tiers:

- Tier 0: Physical environment
- Tier 1: Observations of the environment
- Tier 2: The world of objects
- Tier 3: Socially constructed reality
- Tier 4: Subjective reality of cognitive agents

Tier 0 describes the physical environment we live in. The underlying assumption is that there is only one single physical environment. The problem is that we do not know much about tier 0. Tier 1 contains the results of observing tier 0. The separation of these two levels dates back to the Greek philosopher Plato. Plato already pointed out the necessity to separate reality from our knowledge about it. Frank assumes that each point in tier 0 has determined properties in space and time. Observations of these properties will be incomplete since it is impossible to observe all properties for all points in space and time. Tier 1 therefore contains our limited knowledge about tier 0.

A simplification process is necessary due to the enormous amount of data in tier 1. Tier 2 contains objects formed from the observations in tier 1. This is, for example, done in the human brain for visual observation. We do not see points reflecting light of specific wavelength. Tracking each point of some phenomenon would require enormous brain capacity. Therefore we simplify our observations by forming objects and tracking these only. Objects are defined by uniform properties for regions. Since the properties are observed in tier 1 the formation of objects is based on that tier. One of the definition criteria for objects is that they continue in time. Temporal constructs for objects have been defined by Al-Taha and Barrera (1994), extended by Hornsby and Egenhofer (1997), and formalized by Medak (2001).

Figure 1: Aerial image of the city of Nicosia

An example shall clarify the difference between tiers 1 and 2. Figure 1 shows an aerial image of the southern part of the city of Nicosia. The image is the result of an observation process and thus belongs to tier 1. What can be seen theoretically is a rectangular raster of points in different shades of grey. However, we do not identify these points. We automatically form objects and recognize houses, streets, and vegetation. All these elements belong to tier 2.

Tier 3 describes the socially constructed reality. Society is based on social processes. These processes may require external names like 'Gerhard Navratil' as the name for the author. Within tier 2 the author belongs to the classes mammal, human being, man, etc. This is not enough for social processes like spatial planning because it does not allow to distinguish between the same person in different roles (e.g. as a planner and a land owner).

Social rules may create institutions and relationships between them. The institutions are only valid within the context of social reality. An example for an institution is money (Searle 1995). A piece of paper with specific properties counts as 'money' in the social context of specified countries. Outside the corresponding social context this piece of paper cannot be used as money. This context may change over time. An example in the planning realm is the building regulations. Restricting the height of buildings is possible in several ways (e.g. by restricting the number of levels or by specifying the maximum height). Different countries use different methods and thus provide a different social context. In addition these methods are changed if necessary.

Finally tier 4 is the subjective reality of agents. Agents have to make decisions. They use their knowledge of the world to derive other facts and make decisions. Agents acquire their knowledge gradually by observations. They directly observe reality or obtain observations indirectly from other agents by observation, e.g., by using maps as shown by Frank (2000). A planning process relates to several types of agents. Planners propose solutions, politicians put the solutions into action, and citizens adopt their plans to the situation created by planners and politicians. Each of these agents has a different perspective depending on the acquired knowledge and the agent's goal.

3 QUALITY OF SPATIAL DATA

As shown in the last section we investigate properties of the physical environment by observation. The properties in the physical environment have a defined value and are thus called "real" values. Values gained by observations are called data. Unfortunately data deviate from the "real" values. Morgan and Henrion (1990) give the following reasons for these deviations:

- **Incomplete data**: What will be the U.S. defence budget in 2050? There is no observation describing this property.
- **Disagreement between different data sets**: What was the Soviet Union defence budget in 1987? There are different observations and the values are different.
- **Linguistic imprecision**: What is meant by "The river is wide"? The classification scheme used to classify the result of the observations may be unknown.
- **Variability**: What is the flow rate of the Ohio river? The property of the phenomenon varies according to which specific value has been observed.
- **Quantity**: What is the focal length of an optical lens? How precise do we determine the value?

The description of deviations in data must consider the data capture process. Two steps can be separated: Data is observed (or measured if quantifiable). Objects are classified and their boundaries generalized. Discussion of observation processes (Helmert 1872) and their accuracy leads to statistical methods and data quality (Guptill and Morrison 1995; Wang and Strong 1996; Veregin 1999). We separated the following aspects of data quality

- **Lineage**: What were the methods used to obtain the data and which processes were used to create the data set at hand?
- **Accuracy**: Variations in the observation process are inevitable. Accuracy is a description of the variation of position and attribute values based on a statistical approach.
- **Completeness**: Completeness describes the relationship between the occurrences of the phenomenon represented in a data set and the abstract universe of all occurrences of the phenomenon. Data completeness describes the omission observed between database and specification. It is the number of missing elements that should be in the data set. Model completeness refers to the agreement between the database specification and the abstract universe (Brassel, Bucher et al. 1995). Completeness also describes errors of commission. Commission is the fact that elements are in the database although they do not match the specification (wrong classifications).
- **Logical** Consistency: Data sets can be checked if there are logical contradictions. Parcels of cadastral data sets, for example, should not overlap.
- **Semantic Accuracy**: Semantic accuracy deals with cases where the phenomenon represented by a specific class in the data set does not fulfil all requirements for this class (Salgé 1995). Woodlands, for example, that are stored as oak woodlands in a database may not match the definition of oak woodland on which the database is based.
- **Currency**: Temporal accuracy or currency is an indication how up-to-date the data set is.

Classification of objects is based on the concept used to think about space. Discussion of these concepts leads to uncertainty measures because many concepts used in everyday life do not have crisp boundaries. We cannot specify, for example, how high a protuberance must be to be called a mountain. It is also difficult to specify the number of trees necessary to form a forest. Fisher separates four main aspects of uncertainty (Fisher 1999; Fisher 2003):

- **Error**: The idea of errors is that data emerges from measurements and these measurements may be wrong. In contrast to accuracy in data quality here we do not assume normal distribution for the measurements. We include systematic deviations and gross errors as well. The different aspects of error include accuracy, reliability, bias, precision etc.
- **Vagueness**: Lotfi Zadeh introduced the concept of fuzzy set theory (Zadeh 1965). A classification may result in an ambiguous situation if based on vague concepts. Classification of spatial objects may not be possible unambiguously. A protuberance, for example, may be both, a mountain and a hill.
- **Ambiguity**: Ambiguity arises if a classification produces different results if using the same classification but different procedures. The boundaries between the classes may be vague but the difference emerges from the classification process and not from the vague boundary itself.
- **Discord**: As shown with the concepts of vagueness and ambiguity classification schemes are used to form sets. It may happen that different classification schemes are used when creating different data sets. Contradictions between data sets emerging from differences in classification schemes are called discord.

The deviations influence decisions based on the data. Let us assume the following example: We navigate in an unknown city by walking through the streets. While walking we observe the layout of the streets and memorize these data. We can use that data to navigate between points in the network. However, we may face problems while driving a car in the same network since we usually do not observe driving restrictions while walking. Similar situations may occur with spatial planning if the data used was acquired for a different purpose. Data on the soil, for example, may be gathered for agricultural purposes and may ignore facts restricting the load capacity of the soil. This may lead to situations where buildings or parts of buildings start to sink.

A question to be answered when using data is the following: Does the data contain all information necessary to solve the problem? The answer to this question is called fitness for use as introduced by Chrisman (1984). A data set is fit for use if the amount of deviations is small enough to produce a useful output. In above example of a street network the data was useful for a pedestrian but not for a car driver.

4 TYPES OF SPATIAL PLANNING

Planning Portal, the internet portal of the UK Government for planning information, gives the following explanation for spatial planning: Spatial planning goes beyond traditional land use planning to bring together and integrate policies for the development and use of land with other policies and programmes which influence the nature of places and how they function (UK Government 2005). Spatial planning thus deals with development and use of land. Spatial planning shall also guarantee that the necessary processes can take place. The processes vary with the planning area. Spatial planning for small areas like the central place in village deals with local processes and may serve as a place for shopping, meeting other people, or celebrations. Planning for large areas must consider processes within a larger framework like nature preservation or transit. Spatial planning must include a verification to guarantee that the processes can be performed in the intended way.

Two approaches can be separated for the verification. The traditional approach produces models of the planned situations and presents them to the public for discussion. The models can be 2D or 3D, static (pictures) or dynamic (animations), analogue or digital. Geertman and Stillwell show the changes induced by the introduction of GIS in the 1990s (Geertman and Stillwell 2000). The basic idea of this type of planning is to represents reality with a model and to plan within the model. Rottenbacher proposes a different approach (Rottenbacher 2003). She suggests planning in the field. The focus is on the processes as understood by the citizens and grounds these processes in common experience of the reality.

We can separate two different cases of spatial planning. In the first case the planner faces a specific situation, that does not work properly. Examples for such situations are traffic situations where the increase in traffic density leads to breakdowns of traffic flow or destroyed infrastructure after a natural disaster like flooding or hill slide. The second case shall provide guidelines for future development. The planner provides a framework that must be filled successively by others whereas in the first situation the planner directly creates a new situation.

When dealing with a specific situation the planner must look closely at the situation at hand and must compare the existing objects with the objects necessary to fulfil the functions needed by the society. The objects in this case will usually be different areas of land. The areas must be bounded by visual obstacles like height differences, fences, rows of poles, or vegetation. Additional separation may come from the material covering the area. Meadows provide a different kind of use than areas covered with concrete or stone floor. The planning thus must be very specific and the definition of the objects is important. Depending on the situation it may be more convenient to

- create a solution as a common decision of the group affected or
- prepare a number of solutions and select one (e.g. in a public participation process).

The first case presents a communication problem. A group of persons must communicate and together develop a solution that meets their common demands. The method proposed by Rottenbacher works that way. The group commonly experiences the area by walking through it and discussing historic events, present structure and future development. The drawback of this method is the limitation to a small group of persons and a small area. It is possible to discuss if the group consists of a few dozen individuals and walking is possible if the area can be explored within a couple of hours. If the area or the group of persons is too large, other methods of communication must be found. This leads to the second case where an expert prepares a number of scenarios and only these scenarios are discussed in a larger group. The presentation of these scenarios usually include the virtual models mentioned in section 1. A solution between those extremes could utilize the Internet as a medium for discussion and creation of a solution (Navratil and Harnoncourt 2004).

It is impossible to experience the current situation directly if spatial planning shall provide a guideline for future development of a large area. This type of planning must rely on data describing the existing situation. Since the planning shall guide future development, the objects in the result can only be classes of objects and not physically existing instances. A development plan, for example may contain areas for housing and may even specify the density and height of the buildings or give some guidelines on the placement of the buildings. However, he development plan does not specify the buildings itself. The classes used in development plans are defined in laws.

We have seen three different types of spatial planning:

- Type A: Planning for future development
- Type B: Planning for dealing with a specific situation where planners propose solutions and a discussion leads to a decision
- Type C: Planning for dealing with a specific situation where the affected agents develop a solution

5 SPATIAL PLANNING IN THE CONTEXT OF THE 5-TIER ONTOLOGY

Planning is done by cognitive agents. The agent may plan according to his personal interests or as a representative of the society. An example for the first case is planning a vacation. The agent defines the goal and plans the vacation accordingly. After performing the vacation he checks if the goal was reached. Missed goals will typically lead to a change in the planning process. In the second case the agent acts on behalf of the society. The result of the planning process must fit the goals of the part of society affected by the planning.

The agents deal with socially constructed objects or physical objects while planning. A typical example for planning of type A is development plans for a region. The development plan separates the land into different classes, which are socially constructed. The definitions of these classes are written down in laws and can be formalized (Navratil 2002). The result of such a planning process is a subdivision into socially constructed objects like an area for housing. At the time of creation it may not be different from areas intended for other purposes like recreation, production, or transportation. The membership of that area to the class area for housing provides functions, which may result in legally created houses. These houses then are physical objects whereas the originally described area is only socially constructed.

Planning of types B and C includes dealing with real world objects. The goal of the planning process must support the functions needed by society. This requires socially constructed objects like lanes, sidewalks, pedestrian crossings, traffic lights, or parking lots. Although there may be no difference between the surface and shape of lanes and sidewalks they support different functions. These functions separate them from each other and thus they are socially constructed. Some of the functions required by society may include real world objects like vegetation or benches. The collection of objects depends on the functions that must be provided. The result of the planning shall be a working environment. The planner must arrange real world objects, where some of them must have special properties to serve a specific social purpose. Bands of asphalt, for example, must have a minimum width to serve as lanes.

The depiction of a possible solution as in planning type B is done for cognitive agents. The goal is to simulate an observation of the changed situation. The planner creates a model of the solution and shows it to the group of persons deciding about the solution. Contrary to the method where the involved persons experience the reality and use their imagination to discuss about the arrangement, the persons now has a clear understanding. The model thus must contain representations of all relevant real world objects to give the correct impression. This method has the advantage that each agent has the same observations and differences in the imagination cannot lead to misunderstandings. The disadvantage is that in general the reality will differ from the model. Especially wear can change the impression of constructions dramatically and buildings, that look nice when they are new may look deterring after a few years.

6 QUALITY REQUIREMENTS

Planning of type A starts from an existing situation and uses defined classes to streamline future developments. The description of the existing situation should include existing use of the land and parameters that conflict with specific types of use. It may not be a clever idea to dedicate swamps to industrial use, for example. It is therefore important to know about the properties of the land and changes should be documented in the data. Thus the data set must completely describe all influential parameters and contain all occurrences. Commission may create a problem if the correct situation conflicts the intended use. This fact becomes more important if the planner is far from the area he is working on. The larger the area of planning the higher is the probability that an error of omission or commission will go undetected and may create problems when trying to implement the plan.

The requirements for positional accuracy are rather low for planning of type A for large areas. This type of planning must be complemented by local planning and finally leads to planning of types B and C. During this process the requirements for positional accuracy increase and end in checking the legal compliance of determined buildings, where deviations of observations are ignored by judges (Twaroch 2005). Especially when creating virtual worlds of planned situations positional accuracy is important because gaps may result in image errors and may cause the spectator to reject the solution.

Semantic accuracy is an important aspect for defining the current situation in the planning type A. Differences between the semantics used to create the data set and the semantics used to read it will lead to misinterpretation. This may cause planning results that cannot be implemented or create high costs when implemented. Planning of type B is less critical on semantic accuracy. The reason is that the planner can visually check the reality and compare it to the data he works with. Differences in the semantics will be detected by the planner and can be eliminated before the planning process starts. This becomes even more evident in the planning type C, where the involved persons do not use data to create a solution but use direct observation of the reality.

Requirements for concurrency are similar to those on semantic accuracy. Since planning of type A requires complete sets of data the demands for up-to-data data sets are high. If it is possible to compare the data to reality, concurrency becomes less important.

Vagueness occurs with real world objects only. Socially constructed objects cannot be vague since the concepts separating the objects are clearly defined in the laws. Therefore the results of spatial planning of type A does not contains vagueness. The basic data, however, may be vague and thus clear definitions are important to deal with this problem. An example for such a situation is the definition of forest. The Austrian law links the class 'forest' to the economy of forestry. Areas are part of the class 'forest' if they are used for forestry. This eliminates problems like:

- How many trees are required to form a forest?
- How dense must the trees be to be called a forest?
- Is a street crossing a forest part of the forest or does it split the forest in two parts?
- Etc.

Problems of ambiguity and discord are avoided by using a single data set and a single classification scheme. This leads to higher quality demands concerning completeness and semantic accuracy since automatic checks of correctness are impossible if there are no independently created data sets.

7 CONCLUSIONS

We have separated three types of planning. Each of these types has specific quality requirements. Demands on semantic accuracy and completeness increase with the distance between planner and reality or with the size of the area. The demand for spatial accuracy, however, increases with the planning detail.

We have also seen that the problems of uncertainty are changed into problems of data quality. The use of adequate definition methods for the classes creates unique data sets. Problems of fuzzy boundaries are solved by unambiguous legal rules. As a result of this procedure the requirements for completeness and semantic accuracy become more important. Since the problem of currency also leads to an increase in the demands for completeness and semantic accuracy, these two are the most important quality parameters for planning situations where the planner cannot verify the data used for planning.

Planning of specific situations has lower requirements on completeness and semantic accuracy but has an increased need for positional accuracy. This fact is also reflected by the selection of scales in analogue approaches. Planning of large areas used scales of 1:20.000 and smaller whereas local planning was usually done using 1:10.000 and planning of concrete situations like single houses used 1:500. Since the pens used to draw these maps where the same in all cases the positional accuracy changed dramatically. Unfortunately with the use of computer systems and their unlimited zooming capacity this close connection between planning and positional accuracy was lost.

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