Chapter 23
Working Group I – Requirements and Applications – Position Paper: Requirements for 3D in Geographic Information Systems Applications

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Geoinformation systems (GIS) contain information about objects in geographic space; the focus on geographic space [1] determines the scale of spatial objects and processes of interest at a spatial resolution of approximatively 0.1 m to 40.000 km and to changes occurring once a minute to once a million years. Geographic information is a diverse field which includes many special applications, each of which has special requirements, with special kinds of geometry and particular geometric operations.

The wide variety of requirements of individual geo-applications motivates my first (not new) requirement [2]:

Requirement 1: Construct a fully general 3D (volume) geometry management system based on a clean mathematical foundation (e.g., algebraic topology [3], specifically cw complexes).

Any 3D geometry must be represented with no special cases excluded. Many current packages are optimized for one application (e.g., 3D city models) and restrict the geometry; for example, only volumes with horizontal or vertical boundaries may be accepted. Specialized geometry software, optimized for particular applications, creates difficulties later when data from multiple applications must be integrated to construct a comprehensive view. Restrictions to particular geometries must be possible and the formulation of the corresponding consistency constraints simple (e.g., partitions of 2D, graphs in 3D, 2D surfaces embedded in 3D).

The wide range of spatial objects in a GIS is conceptually structured by level of detail; anybody can experience how one can zoom in on the world untill one sees only one's own front yard (e.g., in Google Earth)! We often conceive this as a hierarchy; however it is better to use a (mathematical)

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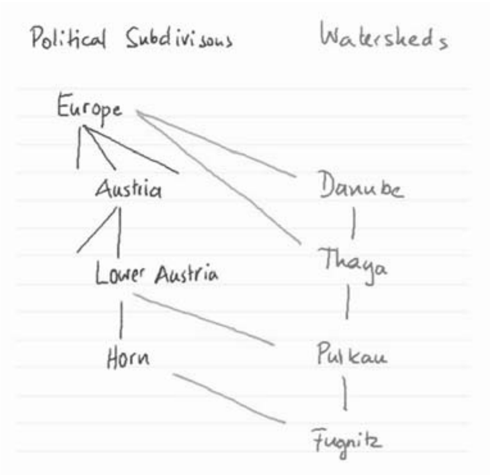
lattice structure [4, 5]. Political subdivisions are typically hierarchies (continent - country - province - county - town), as are watersheds (for example, the watershed of the Fugnitz is part of the watershed of the Pulkau, which flows into the Thaya, which goes to the Danube); if political subdivisions and watersheds are combined, the watershed of the Fugnitz is in the county of Horn, but the watershed of the Pulkau covers parts of several counties and is contained in the province of Lower Austria, whereas the watersheds of the Thaya and the Danube overlap several countries. Hence, a combined representation of the 'part-of' relation of the hierarchical structures of political and watershed subdivisions requires a lattice structure to handle the partial overlaps.



Requirement 2: Support for level of detail: a full or partial containment relation between geometric objects must be maintainable. Applications should be able to view and manage one or a few levels of detail without considration of other levels. Consistency constraints that connect between the levels are important.

GIS Applications show an approximated current state of what exists. The trend is toward including the temporal aspect and focusing on processes that occur in time and change the world[6, 7]. Processes, not states, are the focus of geography as a science [8, 9, 10]! This requires, first, that updates do not overwrite past states, but that time series of previous states are maintained. Tools to visualize and exploit such timeseries statistically and with data mining operations are needed. This requires, second, separately representable processes and the simulation of future states. Management of time series must be completed with representations of processes that can be calibrated with time series of observed past states and used to simulate future states, e.g., to predict unusual events in order to avoid them, preventing catastrophic results.

Requirement 3: Extend the fully general 3D geometry management with level of details to deal with time and processes[11]. The conceptualization of time should be very general and include continuous and discontinuous changes; it must support a lattice of partial containment relations and different temporal granularities.

These three seemingly simple requirements are, judging from past experiences, very difficult to fulfill. I therefore list here points on which I am willing to compromise:

- It is not required for the designed structures to be efficient or highly efficient (first, computer speed increases steadily; second, optimization of a working solution is often automatable).
- The representation does not need be compact, given the low prices of storage media; however, I fear that high redundancy introduces inconsistencies and increases program complexity [12].

I expect some of the current application areas to extend to 3D+T but also new applications enabled by support for 3D or time. The following examples can be used as tests for proposed approaches to see if these approaches are general enough to support all of them:

- Geology: models of the processes of deposit, folding, and erosion[13];
- Traffic management: cars moving along a street graph. Note the frequency of cars entering and leaving street segments and compare with the frequency of changes in the street graph [14]!
- Cadastral systems [15, 16]: Current systems manage a partition of 2D space that is changing in time. Requirements for 3D are emerging, and it is probably a 3D (volume) topology [17, 18];
- Flood protection: a system is needed to model water flow over a 2D surface embedded in 3D; note that water flow disappears from the surface and reappears somewhere else;
- Organization of pictures taken with a digital camera equipped with GPS having references to location in space and time;
- City planning: Visualize how the city grew and changed in the past and simulate the future;
- Disaster mitigation: models to predict the extension of a substance (e.g., oil or a hazardous gas) over a surface or in a volume under the influence of external forces (gravity, wind, water, flow).

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