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REPRESENTING GEOGRAPHICAL INFORMATION UNCERTAINTY: EVALUATION OF CURRENT TYPOLOGIES IN GISCIENCE DOMAIN

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ABSTRACT

Over the last twenty years, research in the area of geographical information uncertainty representation focused primarily on visualisation techniques. Significant effort has been invested in assessing suitability of visual variables, static and dynamic solutions, as well as separate or bivariate relationships for uncertainty representation. Considerably less attention has been devoted to typology of representing uncertainty in the geographical information science (GIScience) domain.

This paper presents and evaluates the existing typologies for representing uncertainty. In particular it addresses the role of cartographic design heritage to support a systematic and comprehensive approach to geographical information uncertainty representation. Finally it attempts to consolidate the current efforts and briefly discusses uncertainty representation strategies related to geographical information and their application within the wider geospatial domain.

FRAMEWORKS FOR REPRESENTING UNCERTAINTY IN GISCIENCE

The initial efforts concerning development of a conceptual framework for representing geographic information uncertainty derived from an important work on spatial data transfer standards (SDTS)(NIST, 1992). SDTS work has primarily focused on identification of data quality categories, i.e. positional accuracy, attribute accuracy, logical consistency, completeness and lineage, but its influence on uncertainty representation was immediate. Beard et al. (1991) proposed a framework for visualising cartographic metadata. They linked the above five categories of data quality with three data types: discrete, categorical and continuous, and proposed a set of practical cartographic representation solutions for all possible combinations within the matrix. So far Beard et al. (1991) typology remains as one of the most practical when challenged with representation of uncertainty. It links visualisation directly with the categories of information uncertainty.

MacEachren (1992, 1994) highlighted the importance of matching kinds of uncertainty with the location, attribute and time components of data. He also suggested the inclusion of precision as an important category of uncertainty. MacEachren (1994, 1995) also provided several practical solutions to represent geographical information uncertainty. He expanded the visualisation toolbox by introducing visual variables beyond the original ones proposed by Bertin (1983) and incorporating several other techniques such as e.g. saturation, fog, crispness or resolution.

Another extension to Beard et al. (1991) framework was proposed by Buttefield and Beard (1994) who introduced the location, thematic (termed elsewhere attribute) and temporal components of data as the third dimension of their original matrix. They collapsed the five data quality categories into three, i.e. accuracy (combined for positional and attribute), resolution and consistency. Furthermore, they provided a limited guidance on application of visualisation techniques to support uncertainty depiction.

From the perspective of geographical information uncertainty representation the above typology with its extensions provides a valuable resource for effective and logical symbolisation of uncertainty. It also provides the most comprehensive toolbox for researchers and analysts wanting to address the issue of uncertainty graphically.

Later efforts by Gahegan and Ehlers (2000) were specifically addressing the issue of modelling uncertainty between remote sensing and geographic information systems. They matched five types of uncertainty, i.e. data/value, space, time, consistency and completeness against four models of geographical space – field, image, thematic and object. Their theoretical work, which focused on uncertainty propagation and error, was used in building a simulation package in an attempt to model and assess uncertainty within these two GIScience domains. However, no practical solutions were described to aid expression of uncertainty graphically.

In another research, Leyk et al. (2005) presented a conceptual framework for systematic investigation of uncertainty associated with land cover change modelling from historical map data. Their model consists of three ‘domains’ of uncertainty, i.e. production-, transformation- and application-oriented in which sources of uncertainty are systematically exposed. They can be linked with earlier work on the recognition and assessment of error in spatial data whereby the first two domains are related to the source error and processing error respectively (Walsh et al., 1987), while the third one is related to the use error (Beard, 1989). This framework presents a comprehensive approach to modelling uncertainty, but only a few practical visualisation solutions are mentioned.

FRAMEWORKS FOR REPRESENTING UNCERTAINTY IN OTHER DOMAINS

One of the most useful developments in addressing typology of uncertainty and relevant to GIScience was proposed by Thomson et al. (2005) within the geospatial intelligence information domain. Their research suggested expansion and modification of SDTS categories of uncertainty, by inclusion of precision (mentioned earlier by MacEachren (1992)), credibility, subjectivity and interrelatedness, as well as combining positional accuracy and attribute accuracy into a single accuracy category (MacEachren et al., 2005; Thomson et al., 2005). These categories were then put into a matrix, whereby each category of uncertainty was matched with a distinction among location (position), attribute and time components of data.

Although the above research does not specifically deal with developing visual tools for representing information uncertainty, a follow-up research by Drecki and Maciejewska (2005) provided a useful attempt. They developed a set of specific and explanatory visualisations to support each of the uncertainty categories within the above typology. Drecki and Maciejewska (2005) matched meta-information detailing aspects of topographical data handling with uncertainty categories. For example, information related to the experience of an analyst performing spatial operations was matched with the credibility category, while details on the age of source materials and the time of their processing with the currency category. Since different categories of uncertainty were reported using wide array of qualitative and quantitative measures, a strategy for their consistent representation was critical. This was achieved by adopting a 5-step ordinal scale where a diverging colour scheme (Brewer, 1994) signified the uncertainty distinctions.

However, the above attempt has not provided any insights on matching the representation techniques with distinctions among location, attribute and time components of data suggested by MacEachren (1992, 1994) and incorporated within Thomson et al. (2005) research.

PROPOSED TYPOLOGY FOR REPRESENTING UNCERTAINTY

Following Beard et al. (1991), MacEachren (1992, 1994) and Buttenfield and Beard (1994) lead, the typology for representing uncertainty should address the distinctions among location, attribute and time components of data, the data type, i.e. from discrete to continuous as well as the categories of uncertainty relevant to a particular scenario. While the location, attribute and time components should be matched directly with visual variables and/or cartographic techniques, the data model should dictate the mapping or display type. Finally, the categories of uncertainty should determine which visualisation technique and map type is to be used or prioritised.

For example, in the case of remote sensing image classification, the attribute component of data is critical, while spatial and temporal ones are of less concern. Since the classification algorithm measures the probability of a pixel belonging to a particular class, attribute component displays quantitative characteristics of uncertainty. Therefore, a selection of visual variables that convey ordinal or numerical level of measurement seems logical to express the uncertainty. Following this lead we can narrow our search to say colour value, colour saturation, focus or opacity.

Similarly, the map type can be determined. Again, taking our example of a satellite image classification, the data model itself expresses continuous characteristics and can be mapped for example as a grid-cell choropleth or a dasymetric map.

Lastly, some categories of uncertainty are more relevant to satellite image classification than others. For example, completeness has little relevance unless the scene has been affected by a dysfunctional sensor, while attribute uncertainty is critical in any image classification analysis.

CONCLUSION

The development of visualisation tools and solutions to support geographical information uncertainty representation has been underway for over twenty years. However, these developments lack consistency that could be achieved by appropriate designed typology for representing uncertainty. Early efforts on typology of uncertainty in GIScience domain provided a sound foundation to address this problem while subsequent research slowed down this process.

This paper identified a need to revisit some of the early research and look at other research domains for valuable input. In particular it looked at the typology proposed by Buttenfield and Beard (1994) as the most suitable to address visualisation challenges associated with representation of geographical information uncertainty. The typology of geospatial intelligence information uncertainty (Thomson et al., 2005) identified a very useful extension to the original set of uncertainty categories. Further work is now required to link components of data with map types and uncertainty categories for representational purposes.

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