

Supporting Spatial Decision Making in a Dynamic World: A Computational and Visualization Framework

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During the past several decades, geographical information systems have become the *de facto* platform for supporting spatial decision making. Though such an achievement has advanced the theory and applications of spatial thinking, some critical limitations still remain. First, most of the spatial decisions are made based on the assumption of a static geographic domain. Decisions made in this way may not be reliable in a dynamic environment. Second, many decisions are generated using mathematical optimization formulations. However, it is well known that many social, economic, and environmental factors are difficult to be incorporated into optimization formulations. Solutions to these ill-structured decision problems may not meet real-world requirements. Third, when multiple, often conflicting objectives must be considered in the decision making, existing spatial decision support systems normally employ a weighting technique that convert multiple objectives into a single objective. Though effective in many piratical cases, such an approach may ignore the preferences of some particular stakeholders. Finally, many existing spatial decision support systems are not design to foster public participation. They are either developed as a stand alone software package that does not allow multiple users to collaborate, or are designed using expensive group collaboration techniques that may not be accessible to many regular stakeholders.

Research Vision and Synopsis

To address the limitations discussed above, it is important to develop a conceptual framework for a “next generation” spatial decision support system. Such a framework must satisfy the following general requirements:

- Efficiency. Many decision problems require a significant amount of computation time to solve. Developing efficient approaches to these problems holds a key toward the success.
- Effectiveness. For multiobjective decision problems, there often exist a set of optimal solutions in which no solution can be considered to be better than the others. It is therefore important to generate optimal solutions and present them to stakeholders for discussion and exploration.
- Public participation. Many spatial decision problems (e.g., political redistricting and landfill siting) must be discussed by a wide range of stakeholders with different spatial and aspatial preferences before a final decision is reached. For some decision problems, the stakeholders may not know each other and their discussion/negotiation is not necessarily conducted in a physical conference setting.

- **Optimality.** The final solution should outperform other alternatives under a variety of dynamic, uncertain changes caused by the spatial-temporal characteristics of the geographical system.

This research includes the development of two closely coupled components. The first component is an efficient search engine that can be used to generate a set of optimal or near-optimal alternatives to the decision problem. To accomplish this, a variety of search algorithms should be developed. In particular, the use of evolutionary algorithms (EAs) have become relatively popular in the past several years in the geography literature. The major reasons for such popularity is the capacity of EAs in generating a diverse set of solutions that are interesting to decision makers from different background with different preferences.

The second component contains a suite of visualization and data mining utilities hosted on a web server that can be used to 1) visualize the (possibly large number of) alternative solutions generated by the search engine, 2) help decision makers explore, identify, and compare interesting solutions, 3) develop *new* alternatives based on existing ones, and 4) facilitate group discussion among decision makers to achieve a compromised decision. A variety of widely used server-side programming (e.g., Tomcat, JavaServer Pages, and Active Server Pages) and visualization (e.g., Scalable Vector Graphics and Macromedia Flash) techniques are appropriate for these purposes.

To successfully support the type spatial decision making discussed above, a number of key research questions must be identified and addressed. The following is a list of these issues that would be also of interest to many participants of the UCGIS workshop on Computer and Visualization for the Understanding of Dynamics in Geographic Domains:

- **Unified optimization solution approach.** A drawback of many existing optimization approach (both exact and heuristic) is that they are designed for a particular type of problem and are difficult to apply to other problems. By designing a unified solution approach, it is possible to address a variety of optimization problems under one framework.
- **Spatial representation.** The key to designing a unified approach is a flexible and coherent spatial representation strategy that is suitable for different kinds of spatial problems. Graph theory can be adopted to capture spatial structures (entities and spatial connection) and their dynamics.
- **The spatial semantic web and its ontology.** Facilitating discussion among a group of decision makers requires a software system that can “understand” the language used by its users. The semantic web can be used to formally define the meaning of terminology used in a decision process. A sound spatial ontology (i.e., an explicit and formal specification of domain knowledge) must be developed to fulfill this goal.
- **Interoperability.** A distributed public participation spatial decision support system must accommodate a variety of computing environments. In this case, the system must be able to response equally to requests from different places. A web-based application will be an appropriate choice.
- **Data mining techniques.** Alternatives generated by the search engine are likely to be in a large number, which may exceed human ability to comprehend. Though visualization techniques can be used to eliminate some of such cognitive burden, “smarter” techniques are still needed. Data mining techniques will prove to be useful in this case because they

can be employed to search for interesting patterns in a huge solution space and present them to the users.

Potential Contributions to and Expectations of the Workshop

Making better decisions for spatial optimization problems with multiple objectives and public participation represents a fundamental “test” to our understanding of the dynamic world under various scales. The research outlined above reflects challenges that must be addressed to succeed in this test. The workshop is (eagerly) expected to provide a unique forum in which researchers from different GIScience fields will work together to develop a coherent view (hopefully in a form of edited books or special journal issues, with the latter more preferred) about the role of computation and visualization in understanding geographical systems.

Applicant’s Professional Development and Research Leadership

Dr. Ningchuan Xiao received his Ph.D. in geography from the University of Iowa in 2003. He is currently an assistant professor at the Ohio State University. He has a strong research interest in geocomputation, geovisualization, spatial decision support system, and spatial analysis. He has published articles in leading geography journals such as *Annals of the Association of American Geographers*, *Geographical Analysis*, and *Environment and Planning A*. He developed efficient evolutionary algorithms that can be used to solving a variety of spatial optimization problems. He has also developed visualization techniques that can be used visualize alternatives for different multiobjective optimization problems. He recently received a three-year funding (as a Co-PI) from NASA in which he will be developing web-based visualization tools to help scientists and the general public understand the impact of land use and cover change in Southeast Asia on aerosols and air pollution. Below is a list of his five representative articles:

- Xiao, N. 2006. An evolutionary algorithm for site search problems. *Geographical Analysis*, 38(3): forthcoming.
- Xiao, N. and Armstrong, M.P. 2006. ChoroWare: a software toolkit for choropleth map classification. *Geographical Analysis*, 38(1): 102-121.
- Xiao, N. and Armstrong, M.P. 2005. Supporting the comparison of choropleth maps using an evolutionary algorithm. *Cartography and Geographical Information Science*, 32(4): 347-358.
- Bennett, D.A., Xiao, N. and Armstrong, M. P. 2004. Exploring the geographic consequences of public policies using evolutionary algorithms, *Annals of the Association of American Geographers*, 94(4): 827-847.
- Xiao, N., Bennett, D.A. and Armstrong, M.P. 2002. Using evolutionary algorithms to generate alternatives for multiobjective site search problems. *Environment and Planning A*, 34(4): 639-656.