How is Space Represented and Analyzed By Scientific Disciplines other than Geography?

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Spatial literacy must deal not only with the human scales typically used by geography, but rather the full range of spatial scales in use across the sciences. The spatial scale continuum is typically divided into four distinct regions:\footnote{http://en.wikipedia.org/wiki/Orders_of_magnitude\_\_\_\_length} (i) subatomic, (ii) atomic to cellular, (iii) human, and (iv) astronomical. Many research disciplines use space (and time) as the primary means for organizing and analyzing their data and so have sophisticated conceptualizations to represent the objects and fields of interest. Examples are physics (at both sub-atomic and universal scales), nano-materials, computational chemistry, bio-engineering and drug discovery.

Thanks largely to the adoption of widespread computational modeling and simulation, all of these disciplines have mature software systems and tools (just as geography has GIS) that can themselves be scrutinized to reveal insights into how space is represented, navigated, manipulated and analyzed. This in turn should lead at least to a deeper understanding of the common ground and the unique approaches to spatial reasoning, and thus improve the design of learning materials aimed at a more general audience.

The approach taken here is to examine the computational systems that different disciplines have developed to represent and compute over space (and time), in order to understand the similarities and differences that these reveal about the conceptualization of space itself.\footnote{This is in contrast to ethnographically-based approaches that work with a community (representatives from a specific culture or discipline) and use interviews, questionnaires or direct observation to surface up the norms of spatial understanding. The author of course acknowledges that his own understanding has also been also developed in part by interactions with researchers with whom he has worked.} The opportunity to do so was created by working directly with these systems and engaging in active research with individuals from these user-communities over the last two years.

There exist many tools and techniques for representing the abstract mathematical properties of space, and for operating on contained objects independently of any assumed scale. For example geometry, topology, qualitative spatial reasoning and scale-space methods in computer vision are all branches of research that are often thought to universally apply across spatial scales.

Two motivating questions drive the work reported here:
1. Do the spatial concepts we might find in GIScience—such as Euclidean geometry, topology, projections and their related analytical functions—play important roles at all scales? And if so, how does scale (and discipline) affect the way they are used?
2. Are there concepts and metaphors in use across other spatial communities that are not usually found in human-scale research such as geography and GIScience?
This research analyzes the representation of space within analytical and simulation systems used by several different science disciplines, including: Star Mapping and Big Bang Cosmology at the astronomical scale along with Computational Chemistry and Materials Science at the atomic to cellular scale and also Bio-Engineering at cellular and human scales. These representations are contrasted with those used in (geographical) cartography.

The following list of concepts is used to derive a comparison between these disciplines:

- The representation of space as a container
- The reference frame(s) by which aspects of this space are brought into focus (such as projections)
- The representation of objects and/or fields within the space
- The role and form of topology and geometry in use
- The typical analytical tasks to be undertaken
- The number of data instances typically represented in the space

**Summary of findings**

The findings show that each of the research communities described uses distinct computational models of space, which have evolved over time to better address particular domain-science questions. These models have many points of similarity, but sometimes imply a different conceptualization of space, and certainly a different degree of importance is given to specific spatial properties and relations. All the systems studied have geometric aspects, but these aspects do not always represent position, nor do they always describe shape and of course they are not all Euclidean. Some systems add topology, but not with the same goals as typical use in GIS. Perhaps the biggest difference is in the reference frames used to establish position, which vary profoundly between disciplines. Any researcher who wishes to understand or work with these models in detail will need a different set of mathematical skills, but there is—I believe—a core of spatial thinking skills that can be useful abstracted.

All the underlying systems investigated deal with large numbers of records and have sophisticated indexing and optimization strategies for search, retrieval and data compression. There are some interesting concepts shared by two or more communities: The ‘Lock and Key’ metaphor used extensively in protein docking (drug discovery) has parallels in some of the spatial reasoning work reported in GIScience, since it utilizes complex (and often partial) shape descriptions; the positioning used in star mapping against reference stars with known trajectories is similar to the positioning strategies used in GPS (satellite derived) navigation. Discovering more of this common ground might be useful in shared educational approaches to spatial thinking and learning, particularly in readying scientists for spatial literacy at more advanced educational levels.

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3 As an aside, there is much that could be learned from these communities to help improve the efficiency of current Geographic Information Systems, particularly when scaling out to larger data collections and in the design of efficient spatial indexing methods.
A summary of the different disciplines and systems described above will be presented, along with a summary table and comparisons to map cartography. Some conclusions will be drawn about what might constitute spatial literacy from a general scientific perspective.