How do different science disciplines represent and compute over 'space'?

Mark Gahegan [1]

Centre for eResearch
University of Auckland, New Zealand
Phone: +64 9 923-1819
Email: m.gahegan@auckland.ac.nz

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1.0 INTRODUCTION

GIScientists and spatial information theorists are certainly not alone in their fascination for spatial representation and reasoning. Many research disciplines use space (and time) as the primary means for organizing and analyzing their data and so have sophisticated conceptualizations (and related computational systems) to represent and analyze the objects and fields it contains. One might reasonably expect that the conceptual models developed by these diverse research communities to exhibit differences, but are there also universal concepts and relations that might form a common ground among the various sciences?

The answer could have important implications for the teaching and learning of spatial concepts, and also for the design and implementation of multi-scale (inter-disciplinary) spatial systems, as well as to facilitate interoperation and sharing of analysis and storage methods.

The approach taken here is to examine the computational systems that a variety of different disciplines have developed to represent and compute over space, in order to understand the similarities and differences that these reveal about the conceptualization of space itself. Working with researchers in many disciplines to utilise high-performance computing and eScience capabilities has presented the opportunity for the author to study both the conceptual models methods and the application codes used to represent space across the sciences. This is in contrast to the ethnographically-based approaches that work with a research community and use interviews, questionnaires or observation to surface up the norms of spatial understanding. In this sense this study is not about what researchers say they do, but what they actually do, algorithmically, when they do spatial computing.

Many abstract methods exist for representing the mathematical properties of space, and for operating on contained objects independent of any assumed scale. For example geometry, topology, spatial information theory and scale-space methods in computer vision are all branches of research that are thought to universally apply across spatial scales. Montello (1993) argues that whereas the abstract nature of many spatial properties allows them to be considered in a scale-invariant manner, scale nevertheless has an important effect on the perception and cognition of space. And while neither premise is disputed here, it begs the question: are spatial properties indeed addressed in a scale-invariant way across the sciences? If they are, this suggests there are universal aspects to the representation and analysis of space—and to objects in space (for example see Myers et al., 2005).

2.0 SCIENCE AT DIFFERENT SCALES

So how do different science communities represent, and analyse spatial concepts? We begin by examining the range of scales involved. The range of spatial scales is typically divided into four distinct regions: (i) subatomic, (ii) atomic to cellular, (iii) human, and (iv) astronomical, as shown in Table 1, below.

Table 1. The continuum of scale: http://en.wikipedia.org/wiki/Orders_of_magnitude_(length)

Section	Range (m)		Unit	Example Items
	≥	<		
Subatomic	0	10^{-15}	am	electron, quark, string, Planck length
Atomic to cellular	10^{-15}	10^{-12}	fm	proton, neutron
	10^{-12}	10^{-9}	pm	wavelength of gamma rays and X-rays, hydrogen atom
	10^{-9}	10^{-6}	nm	DNA helix, virus, wavelength of optical spectrum
Human scale	10^{-6}	10^{-3}	µm	bacterium, fog water droplet, human hair[1]
	10^{-3}	10^{0}	mm	mosquito, golf ball, football (soccer ball)
	10^{0}	10^{3}	m	human being, football (soccer) field, Eiffel Tower
	10^{3}	10^{6}	km	Mount Everest, length of Panama Canal, larger asteroid
Astronomical	10^{6}	10^{9}	Mm	the Moon, Earth, one light-second
	10^{9}	10^{12}	Gm	Sun, one light-minute, Earth's orbit
	10^{12}	10^{15}	Tm	orbits of outer planets, Solar System
	10^{15}	10^{18}	Pm	one light-year; distance to Proxima Centauri
	10^{18}	10^{21}	Em	galactic arm
	10^{21}	10^{24}	Zm	Milky Way, distance to Andromeda Galaxy
	10^{24}	∞	Ym	visible universe

Obviously, geography and GIScience are concerned with problems that relate almost exclusively to the human scale. But across the full range of spatial scales, different scientific challenges may change how space is conceptualized and analyzed. In GIScience, for example, our conceptualization of space typically includes, geometry (shape, distance, direction), topology, proximity, coordinate and georeferencing systems, projections, and a duality between field- and object-based representation.

3.0 QUESTIONS SPECIFICALLY ADRESSED

In this talk, the use of computational models of space, related algorithms and data structures are reviewed for the following science disciplines (in increasing scale order):

- computational chemistry (quantum chemistry),
- bio-molecular modelling,
- geography (GIScience),
- star mapping and
- cosmology.

Findings are presented for spatial computing as used by each community, and in conclusion a table is presented that compares their: (i) model of space, (ii) reference frame used, (iii) decomposition and sampling approach, (iv) measurements and (v) instances used in analysis.

Two motivating questions drive the work reported here:

1. Do the above spatial concepts that are common in GIScience play important roles at all scales, and how does the scale (and the discipline that works at a particular scale) affect their relative importance?
2. Are there concepts, algorithms and data structures in use across other spatial communities that are not usually found in GIScience but might be useful?

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