Scale of analysis: Micro versus macro urban remote sensing

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1. Micro versus macro urban remote sensing

Research focused on the remote sensing of urban areas using satellite sensor information is at an intersection (*inter alia* Mesev 2003, Gamba et al 2005, Weng and Quattrochi 2007, Xian 2010). In one direction lie *micro* techniques that facilitate precision mapping of urban structural configuration from very high spatial resolution imagery—with a focus on pragmatic applications commonly visited by photogrammetists and scientists involved in civil engineering and planning; and in the other direction lie *macro* challenges for exploring the more ontological questions surrounding the fusion of structural and functional representations—supporting more holistic views of urban growth and urban economic and social sustainability, and the construction of deductive and reductionist urban geographic GIScience models (Benguigui 2004, Aubrecht et al 2009).

The distinction between micro and macro remote sensing is based on the *scale of analysis* and not necessarily on the multidimensionality of the remotely sensed data, in particular its spatial resolution. Indeed, urban remote sensing research was expected to benefit from both micro and macro scales of analysis with the advent of higher spatial resolution satellite sensor data (IKONOS, QuickBird, WorldView). However, to date, the level of expectation for these high spatial resolution satellite sensor datasets seems to have far exceeded the number of practical urban applications. Despite the perceived advances in clarity and detail stemming from pixels representing smaller instantaneous fields of view, most of the criticism, paradoxically, has been linked with the increased spectral heterogeneity resulting from the finer scaled spatial resolution. It means that urban classifications remain highly tenuous and any reliable micro remote sensing, usually in the form of precision mapping, is extracted either directly from the spatial orientation of pixels—in the similar vein to conventional interpretation of aerial photography, but with slightly lower clarity and without stereoscopic capabilities—or with the aid of disaggregate ancillary data from postal, census, or planning sources.

In contrast, the spectral heterogeneity factor is less of a restriction for macro remote sensing, which is more concerned with a generalized view of an urban area such as neighborhoods, zones or even the whole city. Classification accuracy is also less important; with the emphasis shifting towards interpreting generalized land cover/ land use, measuring overall building density, and understanding urban processes such as growth, congestion/pollution, and deprivation. Arguably, it is this understanding of urban processes that many researchers consider as more important benefits of remote sensing when applied to urban areas. However, to fully appreciate the scale of dynamic urban changes remotely sensed data need to be embellished with ancillary information measuring socioeconomic characteristics, housing descriptors, and zoning restrictions. But even the remote sensing-ancillary data combination only provides an essentially empirically-derived model of a static city. What is needed is a theoretical basis from which to interpret and understand urban land cover and land use change; a theoretical basis built on the concept of a temporal lag between what an urban society demands and what urban physical consequences materialize.

This presentation will review the micro versus macro dichotomy in relation to the statistical limitations of data captured from remotely sensed sources when harnessed for contributions to measuring urban structure, understanding urban processes, and perhaps contributions to urban theory at a variety of scales of analysis. It will also explore the potential of measuring the relationship between urban structure and urban function through the notion of a temporal lag, again within the confines of scale 'appropriateness.'

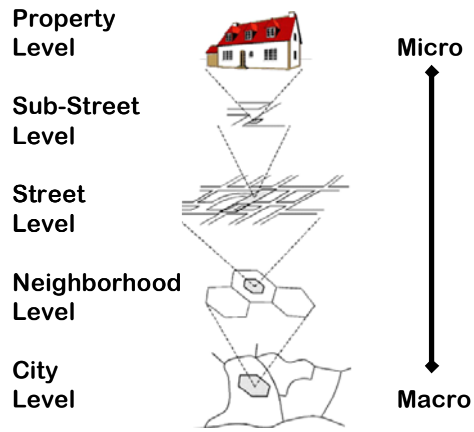

Figure 1. The micro-macro urban remote sensing continuum.

2. Choosing the 'right' scale of analysis

The premise of scale as a dictating factor in urban remote sensing has not attracted as much attention from the research community as Welch's seminal work in 1982 deserved. This is in contrast to technological improvements in sensor engineering which has led to the availability of image data at finer spatial resolutions. Perhaps the question lies more with the scale of analysis rather than the spatial resolution of the sensor data. Surely choosing the sensor data at the 'right' spatial resolution should be inextricably linked to its use–the range of the application. For urban studies this equates to finding a consistent match between the spatial resolution of remote sensor data and its most appropriate urban application. This may sound an overly simplistic and intuitive prerequisite, but determining this data-to-application condition requires a number of considerations. They can be categorized into two groups, one dealing with the measurement of tangible urban structures and features at the micro scale of analysis, and the other dealing with the functionality of urban movements and processes at the macro scale of analysis. Synchronizing these two groups is key to choosing a scale of remote sensing analysis that is most appropriate for measuring the urban structural-functional relationship—and in turn understanding processes and eventually fine-tuning theory. Figure 1 illustrates the continuum of urban scale levels, ranging from the individual property at the micro scale of analysis all the way to the whole city at the macro scale of analysis.

3. A research agenda

The search for the 'right' scale of analysis requires a research agenda that links the statistical measurement of urban structure from remotely sensed data with theoretical underpinnings of urban function across spatio-temporal platforms. In empirical terms, this is tantamount to developing sensitivity analyses of remotely sensed data at various spatial resolutions, linking them with functional data, and then comparing their accuracy levels. These are the so-called structural-functional models and Figure 2 illustrates three types of data sets that are frequently used for such models; high spatial resolution sensor images to measure structure, and point-based mailing addresses and rasterized area-based census surfaces to tessellate socioeconomic characteristics of urban areas. Each of the three types represents the study site of the city of Belfast, Northern Ireland--the high spatial resolution image is from the IKONOS sensor (Space Imaging) and the point-based mailing addresses are from the COMPAS (now superseded by POINTER) database from the Ordnance Survey of Northern Ireland, and the surface is of the 2001 Census Population rasterized at a 200 m grid (Mesev 2007).

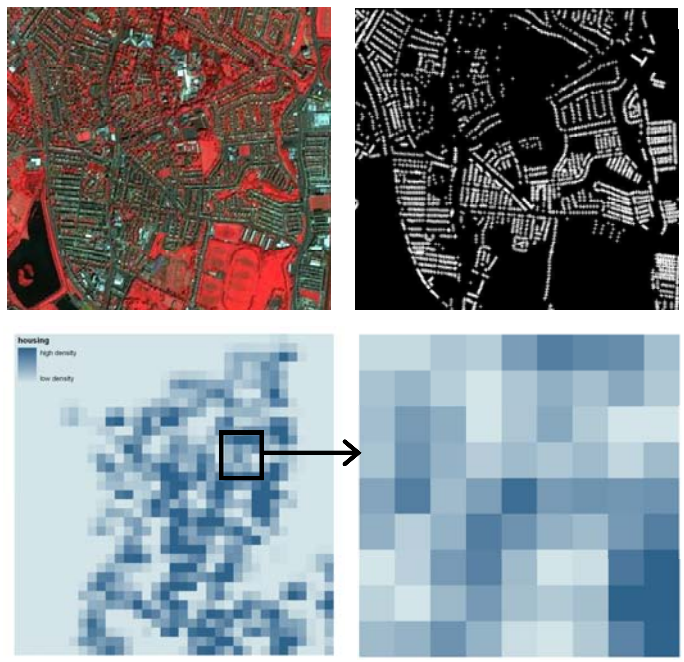

Figure 2. Structural and functional representations of the Belfast study area: IKONOS image (top left), postal addresses (top right), census housing surface (bottom left, for whole of NE Belfast; bottom right, the same spatial dimensions as IKONOS image and postal addresses).

A more recent perspective on research into urban structural-functional models is the pursuit of time-dependence; understanding how temporal lags affect the causal links between societal and political functional demands and physical ramifications. Thus far integrative remote sensor models have assumed temporal equality. This is where the same time period is assumed for both when the image was taken and when functional attributes are collected. Instead, a temporal integrative model is built at two time periods (T1 and T2) formulated by combining urban structural patterns (derived from classified remote sensor data) post T1 as T1+1 and post T2 as T2 +1 and urban functional demands and decisions (derived predominantly from population censuses and urban plans) pre T1 as T1-1 and pre T2 as T2-1 respectively. The relationship states that decisions and trends in urban functions at T1-1 determine the type and density of urban structure at T2-1. Precisely how urban functions determine urban structure (and maybe even how structure determines functions) is reflective of theories of urban process; for instance, demand for new housing type and housing density, suburbanization, decentralization of businesses, segregation levels, deprivation and congestion and pollution. Changes in urban population, including changes in demographic profiles (family, ethnic minorities and affluent levels), demand for housing (both size and value), and local government plans are the main drivers behind urban processes that link function and structure.

4. Conclusions

The distinction micro and macro urban remote sensing is a contrast between precision urban structural (syntactic) configuration and city-wide functional representation using integrative models that link spectral information from high spatial resolution sensor data with spatial and temporal indicators from auxiliary sources. In each the focus is on integrative models that explore metrics and maximization procedures in an attempt to summarize the cartographic and geocomputation potential of the burgeoning urban remote sensing technology. Sensitivity analyses determine optimum lags in multi-temporality to be used as vital components in the monitoring of city-wide variations of social deprivation, housing density, traffic congestion, heat island effects, non-point source pollution and others issues of urban sustainability.

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