RECONCILING CARTOGRAPHIC REPRESENTATIONS OF URBAN STRUCTURE AND FUNCTION FROM REMOTE SENSOR MODELS

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1. CARTOGRAPHIC REMOTE SENSING

Remote sensing is rapidly developing as a technology for reliable cartographic representation. With the launch of high spatial resolution sensors, such as Ikonos, Quickbird, and WorldView-1, images now contain sufficient spatial detail necessary for the routine delineation of objects and features on the earth's surface. For complete cartographic requirements, this amount of spatial detail from remotely sensed imagery needs to include crisp boundaries between objects and inclusive homogeneous coverage of features. These cartographic requirements are stringent but necessary if the field of remote sensing is to finally fulfil its potential of a provider of map-quality information directly from sensors, as well as fully contribute to the growing debate on the integration of remote sensing with GIS (Mesev, 2007). Whether such lofty aspirations can be realized, even from today's super high spatial resolution imagery, is still debateable but nonetheless exciting and worthy of further investigation.

Traditionally, the strengths of remote sensing have been the ability to provide global coverage at high temporal resolution and with multidimensional spectral information. The so-called "surveillance technology" has evolved rapidly over the past decade to the point where remotely sensed imagery are now vital components in many projects that analyze data from various sources. What is coined as the "integrative age" is a situation where spatial data are collected from various technologies and devices (including, aerial photographs, satellite images, GPS positions, ground surveys, and a myriad of GIS-sourced maps), analyzed by "integrative geo-systems" and the results reproduced by "integrative geo-visualization" tools (hyper-media, Internet, etc.).

This paper will explore the potential of high spatial resolution sensor data for producing cartographic-quality maps of urban landscape, the fastest changing parts of the earth's surface. It will also explore and demonstrate the interaction of high spatial resolution remotely sensed with other geo-spatial datasets and, in search of a more complete urban representation, the links between structure, function and temporality of urban land use and urban behavioural changes.

2. URBAN CARTOGRAPHIC REMOTE SENSING

The theoretical development of urban remote sensing is at an intersection. In one direction lie opportunities for developing models for precision mapping of urban structural configuration from very high spatial resolution imagery—with a focus on pragmatic applications; and in the other lie the challenges of exploring the more ontological questions of fusing structural and functional representations—ones that help reveal far more holistic views of urban growth and urban economic and social sustainability. The former is a domain commonly visited by photogrammetists and scientists involved in engineering applications (Couloigner I. and Ranchin, 2000) while the latter is far more in line with the construction of deductive and reductionist urban geography models (Harvey 2002).

In both directions, substantial research is required before accurate and reliable cartographic representations of urban form and urban behavior can be generated to a level that deflects criticism and restores flagging confidence in the applicability of remote sensing in urban theory and applications. Linear pixel/census models have done much to restore credibility, especially in combination with the new generation of super high spatial resolution satellite sensor data. However, for more socially responsive and updateable urban mapping more disaggregated auxiliary data sets are required to support the spectral inference of land use from land cover. Such integrative GIS-based data sets hold key spatial parameters, essential for the development of object-based, spectra-spatial pattern recognition systems. When expanded, integrative models based on census information are capable of representing urban changes at the city and regional levels by focusing on population change, identifying economic imbalances and defining flow bottlenecks.

3. STRUCTURAL-FUNCTIONAL LINKS

Urban neighbourhoods exhibit distinctive spatial expressions in terms of their architectural, structural, and morphological composition—the complex assemblage of different land covers (bare soil, concrete, tarmac, grass, water etc.). By employing spatial metrics to quantify these attributes it is possible to demonstrate how individual urban neighbourhoods may be distinguished and delineated from second order imagery (Barnsley *et al*, 2003). On-going research is exploring an agenda for building disaggregated urban models that infer spatial urban syntactic structural configurations within vector-determined spectral limitations using high spatial resolution Ikonos imagery. Many of the early disaggregated models are based on point GIS data—from the United Kingdom (postal records) and the United States (parcel records). Knowing the spatial distribution of these point data introduces a number of key indicators that measure parameters such as density (compactness versus sparseness) and arrangement (linearity versus randomness) (Mesev, 2007). Commercial neighbourhoods exhibit different levels of complexity and irregularity to residential neighbourhoods, so too does high density residential from low density residential. This can be seen within even the most elementary metrics such as area, density, and percent land cover (Herold, et al, 2002). Fractal geometry is well suited to measuring the structural irregularity of the morphology of urban neighbourhoods where increasing irregularity is reflected in less space-filling and greater fractal dimension (D). A useful compliment to D is the contagion index, which measures the degree of fragmentation within the neighbourhood, and a reciprocal to D is the Lacunarity measurement of the spatial distribution of gaps and holes in the urban fabric (Myint et al, 2006).

So far research has been focused on *structural* pattern recognition systems by establishing relationships between image pixels and building spatial distributions. But the long-term goal is to facilitate methodologies to a level that renders resulting output irresistible to planners and policy makers. For this the *functional* characteristics of the city are also integrated in attempts to produce models that link urban physical land cover with causal political and economic decisions that drive physical changes. Encouraging results are documented from preliminary empirical testing on Ikonos imagery using aerial photography at 15cm spatial resolution. An iterative computational procedure is being operationalized which links the spatial delineation of buildings from high resolution sensor data with the functional characteristics from postal records. Using the software Definiens, a spectra-spatial classification based on nearest neighbour contextual rules is currently reporting accuracies of 92.8% compared to 86.6% from a multispectral-only classification. Further, more extensive testing is continuing that allows the temporal dimension to both calibrate and validate the spatial-spectral links, as well as provide measures of urban change.

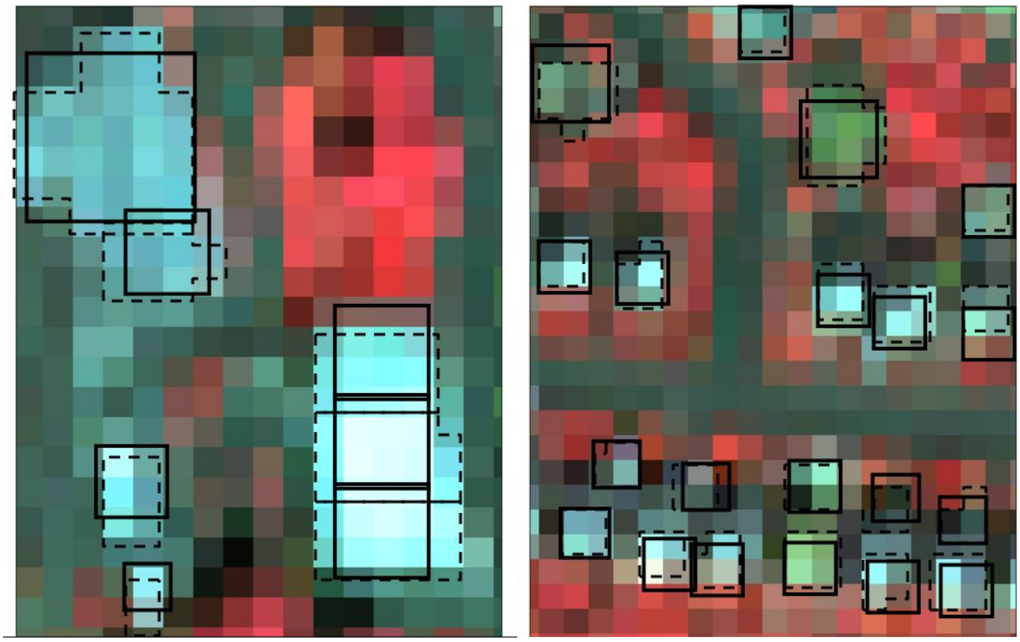

Fig. 1: Spatial-spectral entropy maximization routine of compas and Ikonos imagery (residential on the left, commercial on the right)

4. MULTI-TEMPORAL STRUCTURAL-FUNCTIONAL LINKS

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 when the image was taken and when functional attributes are collected. Instead, urban theory suggests that this relationship is far from linear and that physical structures are an eventual consequence of functional manifestations taken and decided upon years and sometimes decades earlier.

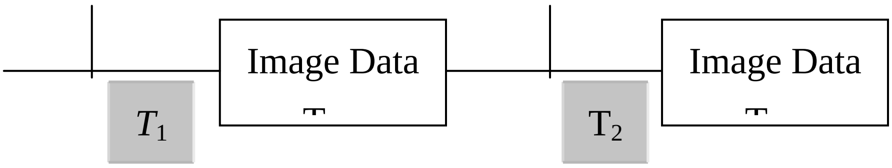

Fig. 2: Multi-temporal structural-functional relationship

The diagram above illustrates how integrative models at two time periods (T_1 and T_2) are a result of combining urban structural patterns *post* T_1 as T_{1+1} and *post* T_2 as T_{2+1} (derived from object-classified remote sensor data) and urban functional demands and decisions pre T_1 as T_{1-1} and pre T_2 as T_{2-1} (derived predominantly from population censuses) respectively.

Such multi-temporal structural-functional models are designed to create more complete cartographic representations of urban morphology and socio-economic characteristics where temporal lags are non-linear indicators of land cover/use changes. Sensitivity analyses are currently determining optimum lags and it is hoped models of multi-temporality will become 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.

4. CONCLUSIONS

Urban remote sensing is gaining in prominence at the world stage yet it has far to go before being able to foster rigorous and reliable models of the urban hierarchy – the most spatially diffuse and functionally dynamic landscapes on the earth's surface. This paper outlines a choice 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.

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