# Integrative spatial-spectral-temporal remote sensor models of urban configuration and sustainability

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## 1. Introduction

Urban remote sensor geocomputation is at a crossroads. In one direction lie opportunities for developing models for detailed mapping of urban morphology from very high spatial resolution imagery; and in the other the possibility of creating broader integrative models that link spectra with functional variables for measuring urban growth and sustainability. The former overlaps with traditional photogrammetry and has many civil engineering applications while the latter is far more in line with urban geography issues that deal with deprivation, accessibility, and quality of life.

In both, the direct and automated inference of urban function from land cover categorization provides one of the most challenging arenas for urban remote sensing. Successful breakthroughs in research are essential for deflecting criticism and restoring flagging confidence in the applicability of remote sensing in urban applications. Zone-based and pixel-based population models have done much to restore credibility, especially in combination with the new generation of super high spatial resolution satellite sensor data (Harvey, 2002). However, for precision 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. In addition, 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.

### 1.1 Spatial-spectral syntactic inference

Urban neighbourhoods exhibit distinctive spatial expressions in terms of their architectural, structural, and morphological composition. 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 structural configurations within spectral limitations. The disaggregated models are based on point-based GIS data, from both 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). These are measured using spatial metrics, adjusted by the contagion index, a measure of fragmentation, and fractal dimensions, used to measure the degree of space filling and the level of irregularity within neighbourhoods. Table 1 summarizes metrics generated using the modified linear nearest neighbour index to demonstrate compactness and linearity (Mesev, 2007).

Within the urban environment there are a number of different neighbourhoods that are distinguishable in architectural, structural, economical, and spatial terms. The complex assemblage of different land covers (bare soil, concrete, tarmac, grass, water etc.) within these neighbourhoods give rise to unique spatial expressions that can be quantified through the use of spatial metrics – measures originating from landscape ecology to describe the structure and pattern within landscapes (Herold et al, 2002). This study demonstrates how quantifying the spatial arrangement (pattern) of buildings, through the use of spatial metrics, provides a platform from which second-order urban land use may be inferred from classified high spatial resolution IKONOS imagery. Commercial neighbourhoods exhibit different levels of complexity and irregularity to residential neighbourhoods, so too does high density residential from low density residential. Further still residential housing ‘eras’ are made distinguishable as different architectural and structural styles are reflected within their morphology. This can be seen within even the most elementary metrics such as area, density, and percent land cover. More stringent metrics used include the fractal dimension (D), the contagion index, and Lacunarity (Myint et al, 2006). Fractal geometry is well suited to measuring the morphology of urban neighbourhoods where increasing irregularity is reflected in dimension. A useful compliment to the D is the contagion index, which measures the degree of fragmentation within the neighbourhood.

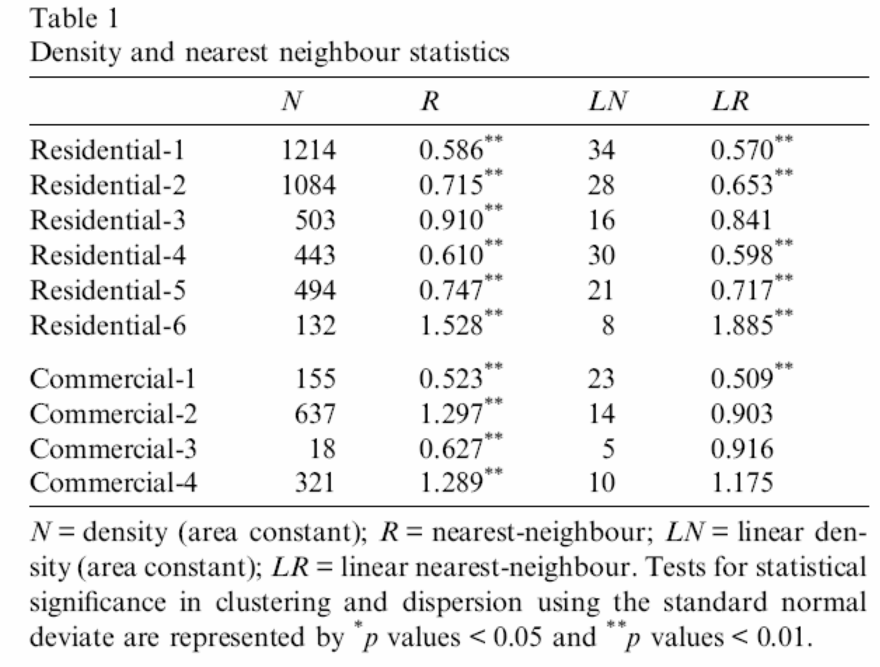

Table 1
Density and nearest neighbour statistics

| | *N* | *R* | *LN* | *LR* |
|---|---|---|---|---|
| Residential-1 | 1214 | $0.586^{**}$ | 34 | $0.570^{**}$ |
| Residential-2 | 1084 | $0.715^{**}$ | 28 | $0.653^{**}$ |
| Residential-3 | 503 | $0.910^{**}$ | 16 | 0.841 |
| Residential-4 | 443 | $0.610^{**}$ | 30 | $0.598^{**}$ |
| Residential-5 | 494 | $0.747^{**}$ | 21 | $0.717^{**}$ |
| Residential-6 | 132 | $1.528^{**}$ | 8 | $1.885^{**}$ |
| Commercial-1 | 155 | $0.523^{**}$ | 23 | $0.509^{**}$ |
| Commercial-2 | 637 | $1.297^{**}$ | 14 | 0.903 |
| Commercial-3 | 18 | $0.627^{**}$ | 5 | 0.916 |
| Commercial-4 | 321 | $1.289^{**}$ | 10 | 1.175 |

*N* = density (area constant); *R* = nearest-neighbour; *LN* = linear density (area constant); *LR* = linear nearest-neighbour. Tests for statistical significance in clustering and dispersion using the standard normal deviate are represented by $^{*}p$ values < 0.05 and $^{**}p$ values < 0.01.

By establishing relationships between image pixels and building spatial distributions, the long-term research goal is to facilitate reliable and accurate spatial pattern recognition and object-based multispectral classification methodologies to a level that renders resulting output irresistible to planners and policy makers (Couloigner and Ranchin, 2000). Encouraging results are documented from preliminary empirical testing on IKONOS imagery using aerial photography at 15cm spatial resolution. Figure 1 is an example of an iterative computational procedure that links the spatial delineation of buildings from high resolution sensor data (the dashed lines) with the functional characteristics from postal records (bold lines). Also, using the software e-Cognition, a spectra-spatial classification based on nearest neighbour contextual rules produced accuracies of 95.4% compared to 90.7% from a multispectral-only classification (Table 1). 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.

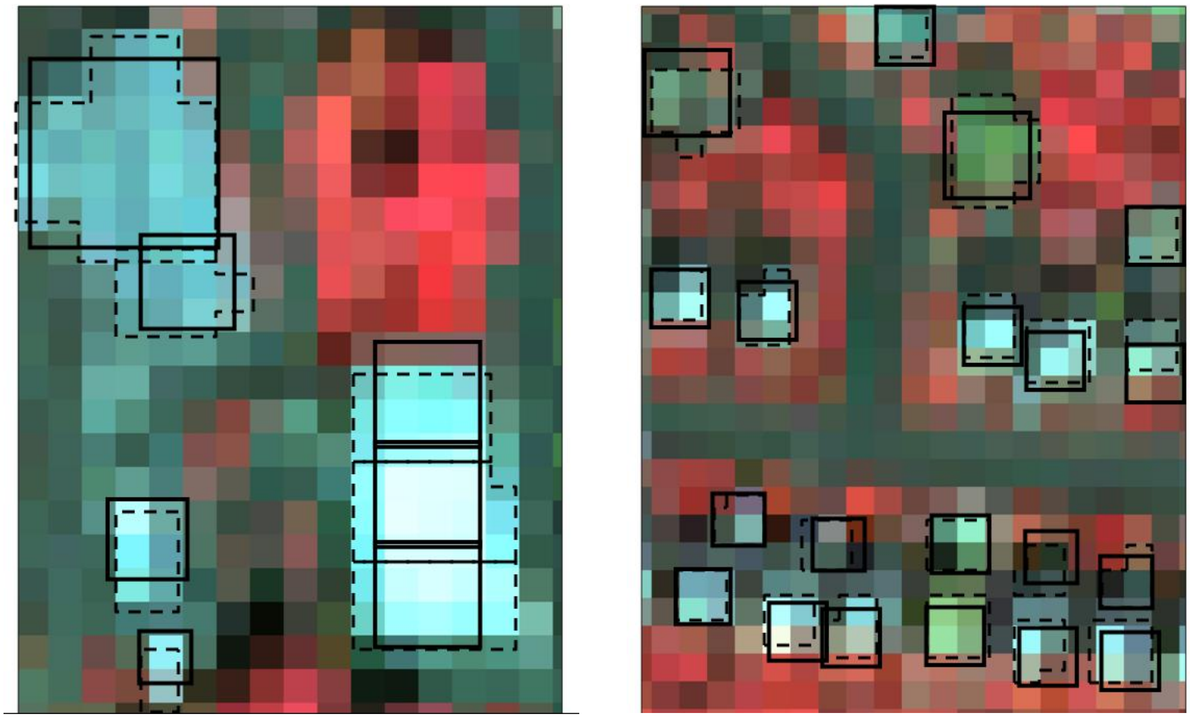

Figure 1. Spatial-spectral entropy maximization routine of COMPAS and Ikonos imagery.

## 1.2 Integrative sensor models of urban growth and sustainability

In contrast to detailed mapping of urban configuration, the other direction for integrative sensor models is to continue research into augmenting spectral representations of urban morphology with functional information from censuses (Chen, 2002). Either by zone-based or pixel-based methodologies, extraneous socio-economic characteristics are capable of defining the population and economic geography of cities well beyond the limitations of land cover classification. In addition, such models contribute heavily to issues of sustainability, density and environmental quality of life. However, one aspect that has yet to receive adequate research is recognition of the temporal lag between sensor data capture and census surveys. Censuses are a record of socio-economic and housing changes over a ten year period, immediately prior to the date of the sensor image and as such represents an ideal situation to both calibrate the integrative model as well as validate zone-based and pixel-based techniques of urban representation.

## 2. 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 syntactic configuration and city-wide functional representation using integrative models that link spectral information from 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 geocomputation potential of the burgeoning urban remote sensing sub-discipline.

## 3. References

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