



Functional Network of the City

Maxime Lenormand

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Functional Network of the City

Maxime Lenormand

CitiNet'14, Lucca, Italy

September 25, 2014



Motivation

Comparison of land use patterns across cities

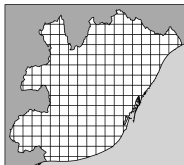
- ▶ Network approach to detect land use using mobile phone data
- ▶ Spatial organization (entropy, Ripley's K...)
- ▶ Land use model
- ▶ Mixing of land use



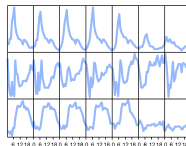
Method used to extract the network



Metropolitan Area

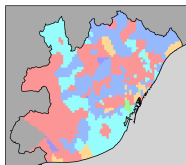


Recordings sites

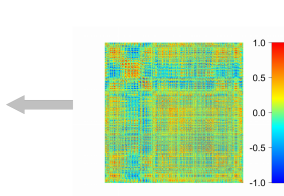
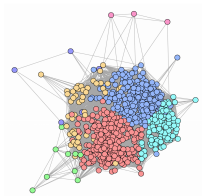


Time of Day

Signals



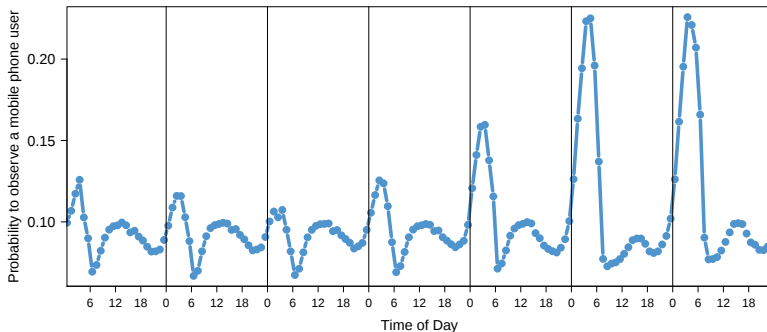
Functional Network



Correlation Matrix

Method used to extract the network

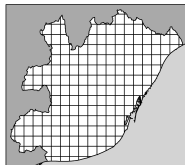
Probability to observe a mobile phone user in a given cell at a given time



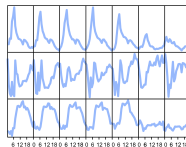
Method used to extract the network



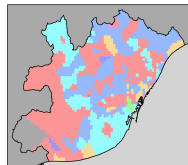
Metropolitan Area



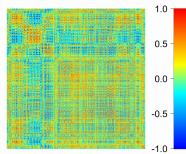
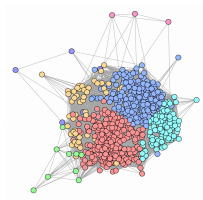
Recordings sites



**Time of Day
Signals**



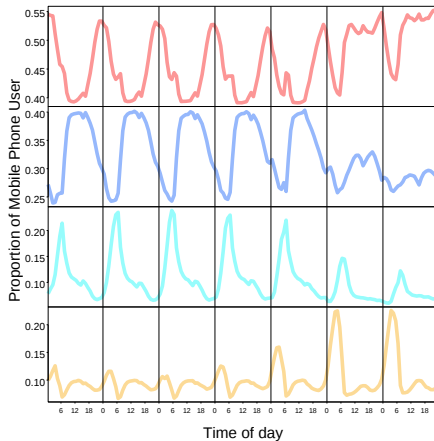
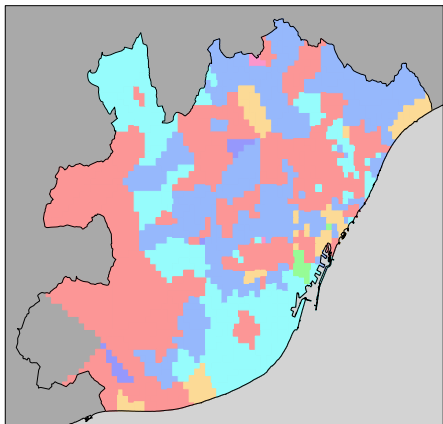
Functional Network



Correlation Matrix

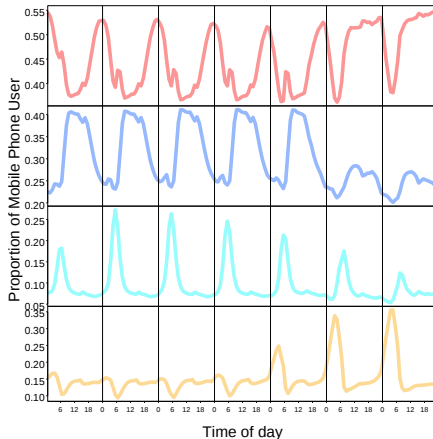
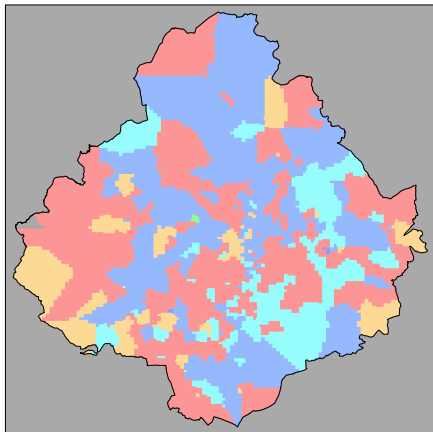
Land use patterns

Barcelona (PGP = 60%)



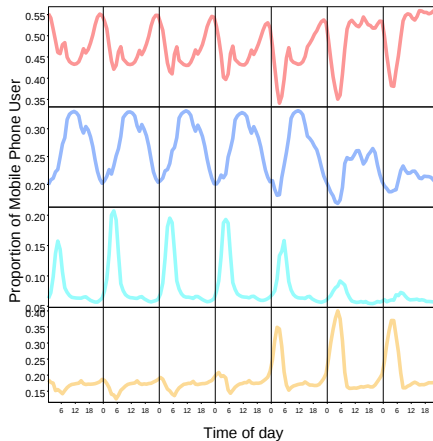
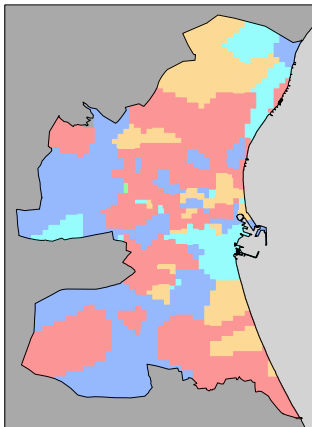
Land use patterns

Madrid (PGP = 65%)



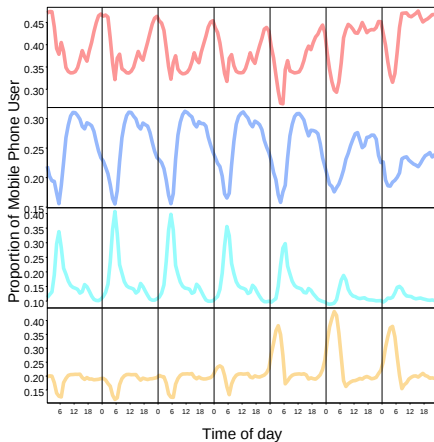
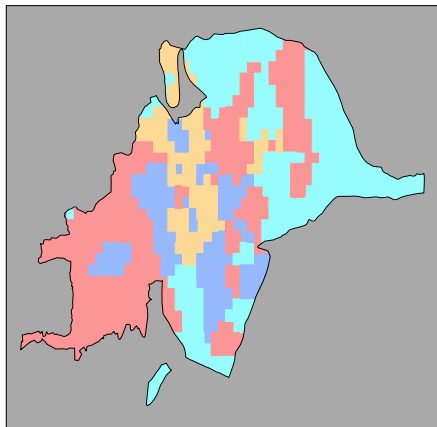
Land use patterns

Valencia



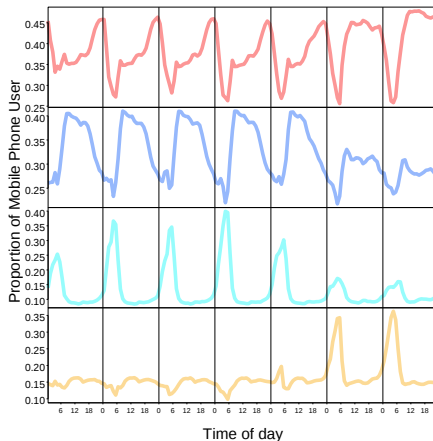
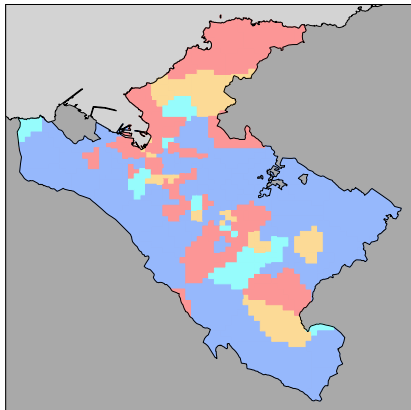
Land use patterns

Sevilla



Land use patterns

Bilbao



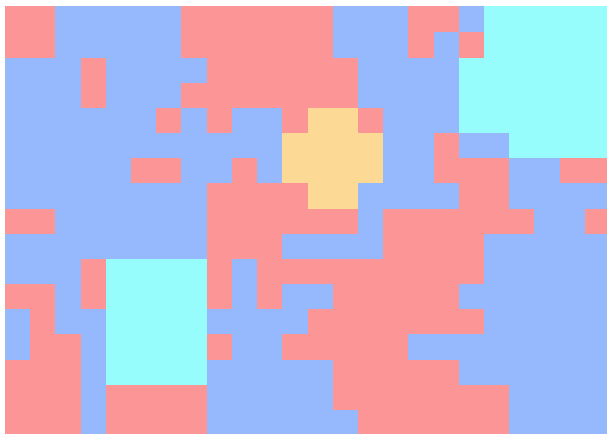
Spatial organization of land use

Three measures of spatial heterogeneity

- ▶ Distribution of the distance between the cells and the city center
- ▶ Ripley's K
- ▶ Entropy index

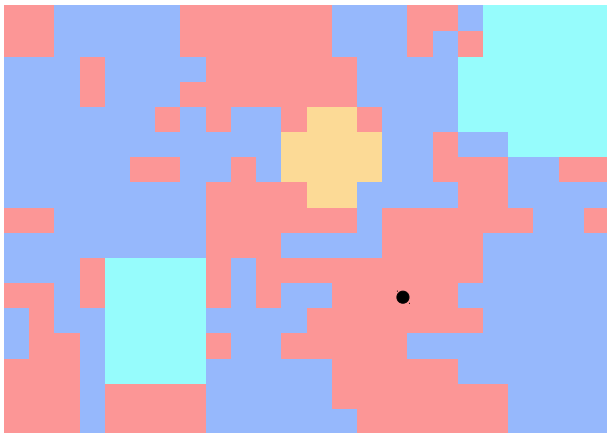
Spatial organization of land use

Distance to the city center



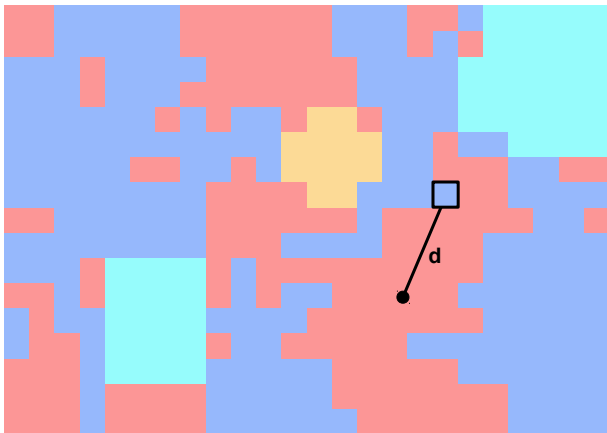
Spatial organization of land use

Distance to the city center



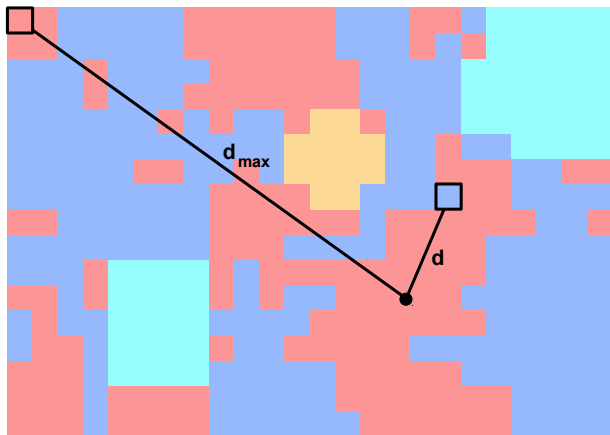
Spatial organization of land use

Distance to the city center



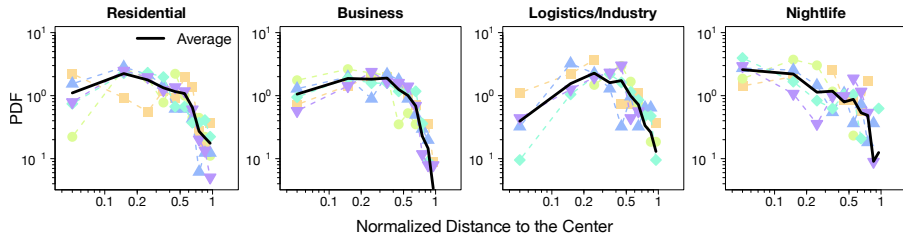
Spatial organization of land use

Distance to the city center



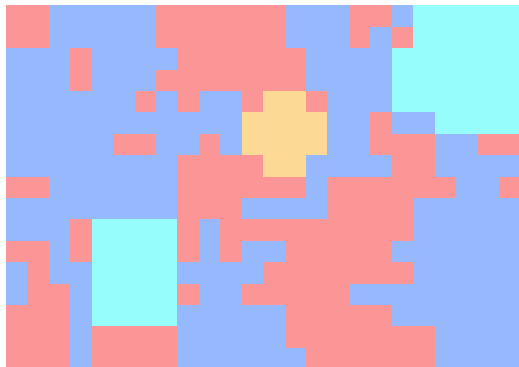
Spatial organization of land use

Distance to the city center



Spatial organization of land use

Ripley's K

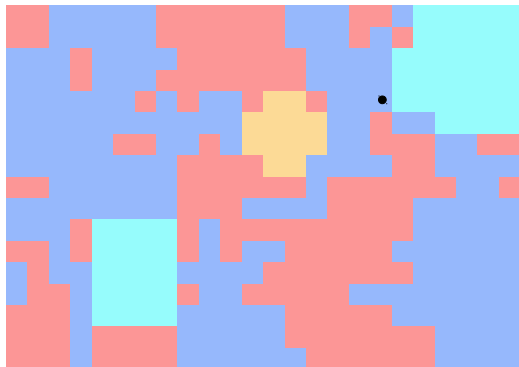


$$K(r) = \frac{A}{n^2} \sum_{i=1}^n N_i(r)$$

$$\hat{K}(r) = K(r)/K(1)$$

Spatial organization of land use

Ripley's K

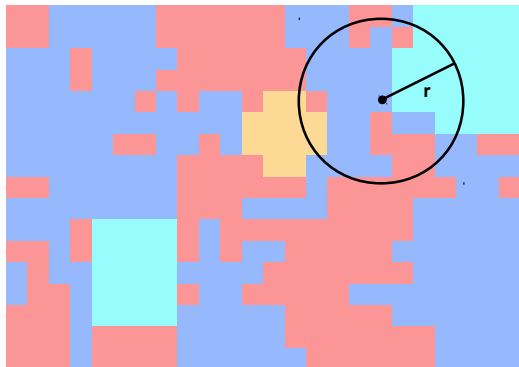


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Spatial organization of land use

Ripley's K

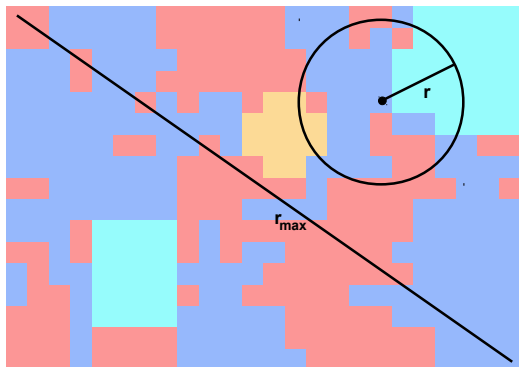


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Spatial organization of land use

Ripley's K

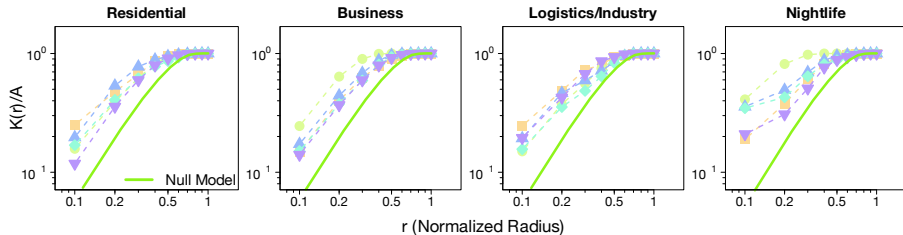


$$K(r) = \frac{A}{n^2} \sum_{i=1}^n N_i(r)$$

$$\hat{K}(r) = K(r)/K(1)$$

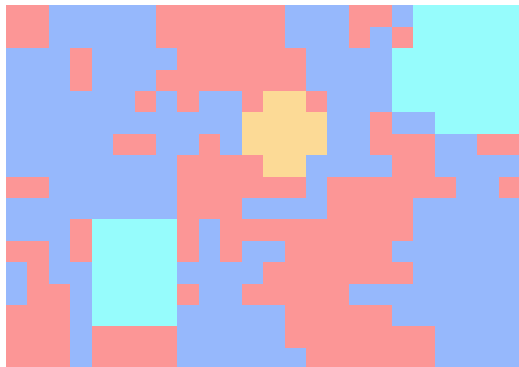
Spatial organization of land use

Ripley's K



Spatial organization of land use

Entropy index

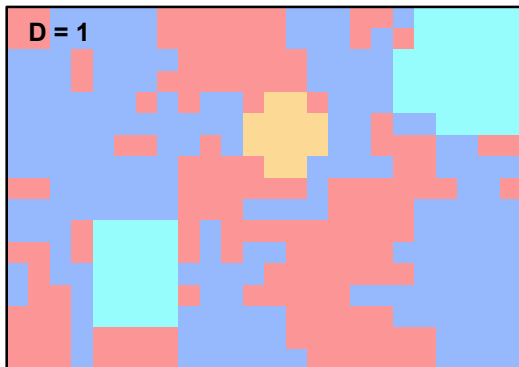


$$E_i = - \sum_{k=1}^4 f_i^k \ln f_i^k$$

$$E(D) = \frac{1}{D^2} \sum_{i=1}^{D^2} E_i$$

Spatial organization of land use

Entropy index

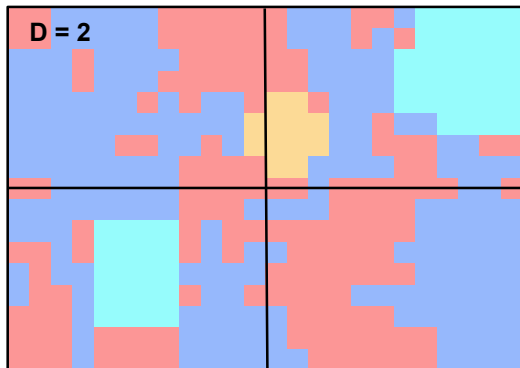


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Spatial organization of land use

Entropy index

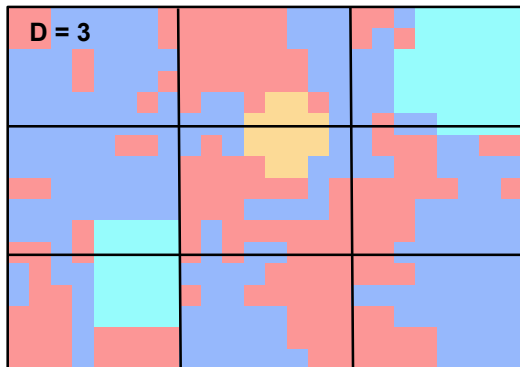


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Spatial organization of land use

Entropy index

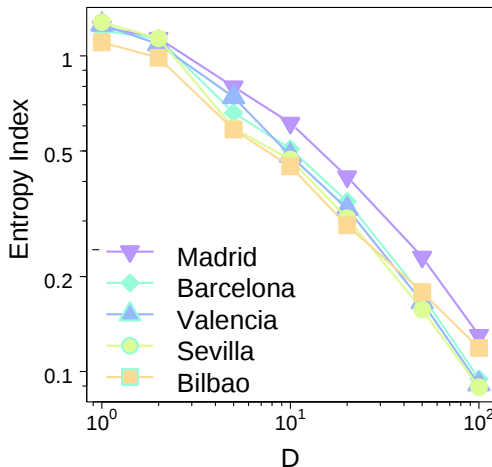


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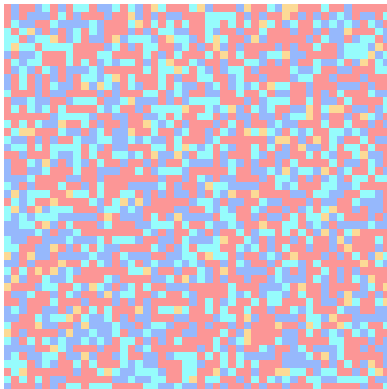
Spatial organization of land use

Entropy index



Land use model

Initial state

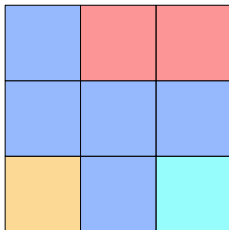


Land use model

Satisfaction index

Satisfaction index S_{ij} of a cell is based on the fraction of land use type among its neighbors

$$p = (p_1, p_2, p_3, p_4)$$

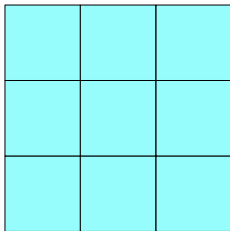


Land use model

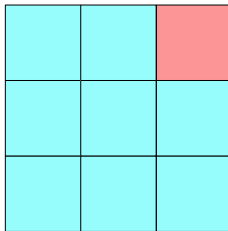
Satisfaction index

Logistics/Industry

$$S_{ij} = p_3$$



$$S_{ij} = 0$$

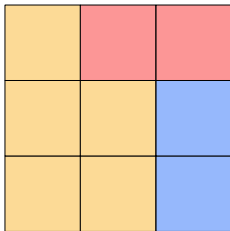


Land use model

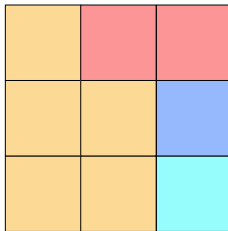
Satisfaction index

Nightlife

$$S_{ij} = p_4$$



$$S_{ij} = 0$$



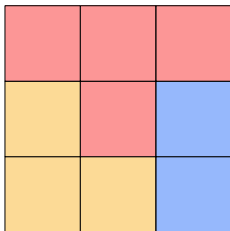
Land use model

Satisfaction index

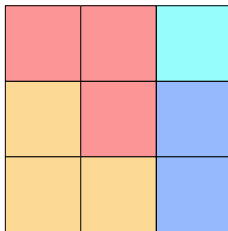
Residential

$$rand() \geq \gamma$$

$$S_{ij} = p_1$$



$$S_{ij} = 0$$



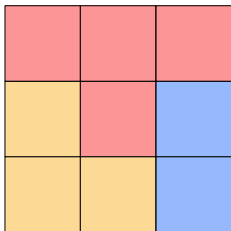
Land use model

Satisfaction index

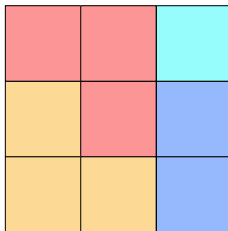
Residential

$$rand() < \gamma$$

$$S_{ij} = 1$$



$$S_{ij} = 0$$



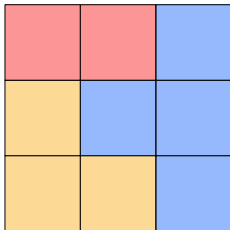
Land use model

Satisfaction index

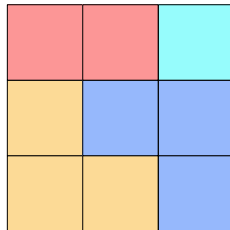
Business

$$rand() \geq \gamma$$

$$S_{ij} = p_2$$



$$S_{ij} = 0$$



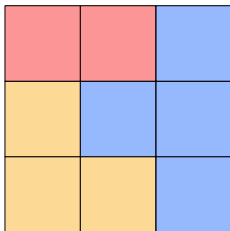
Land use model

Satisfaction index

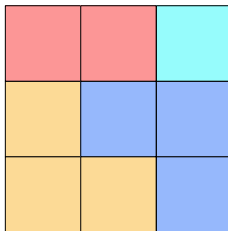
Business

$$rand() < \gamma$$

$$S_{ij} = 1$$

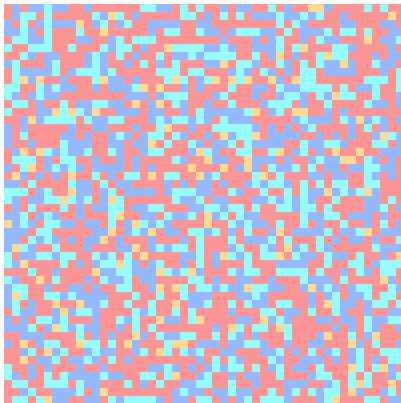


$$S_{ij} = 0$$



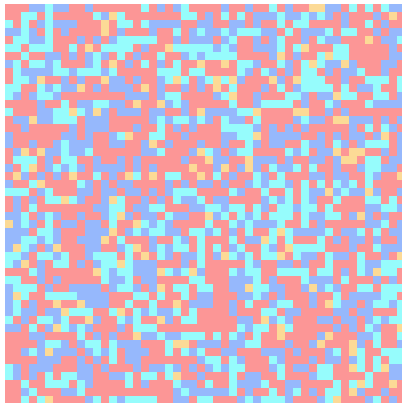
Land use model Algorithm

$t = 1$



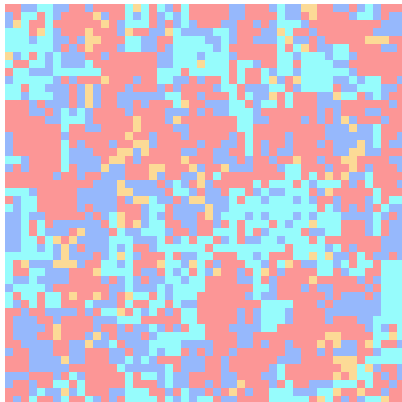
Land use model Algorithm

$t = 1,000$



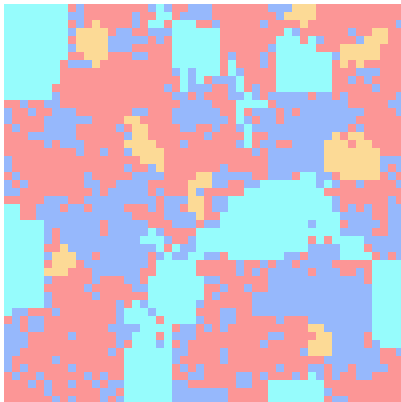
Land use model Algorithm

$t = 10,000$



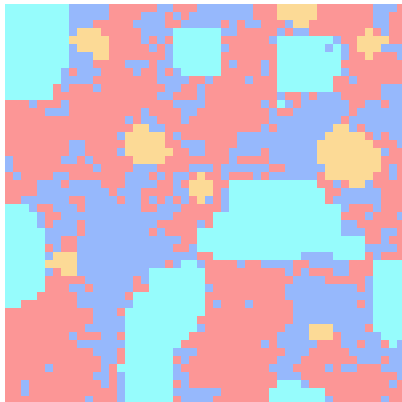
Land use model Algorithm

$t = 100,000$



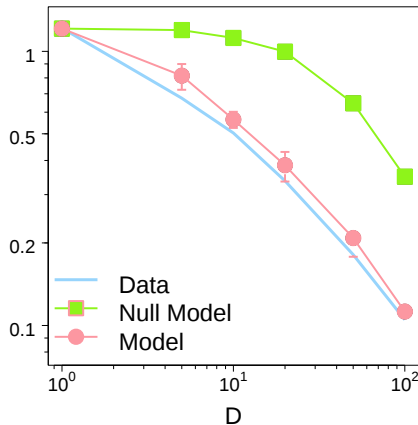
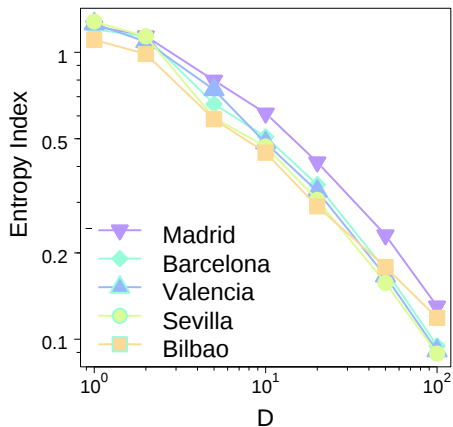
Land use model Algorithm

$t = 300,000$



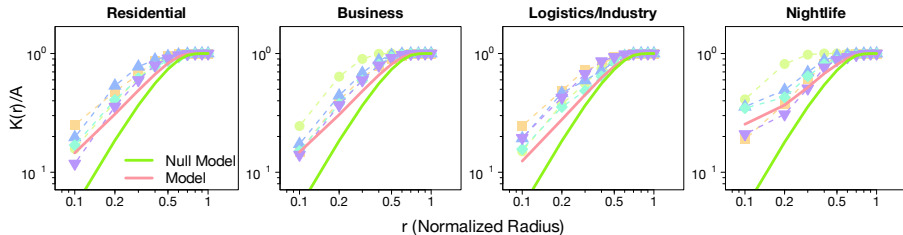
Land use model

Calibration of γ

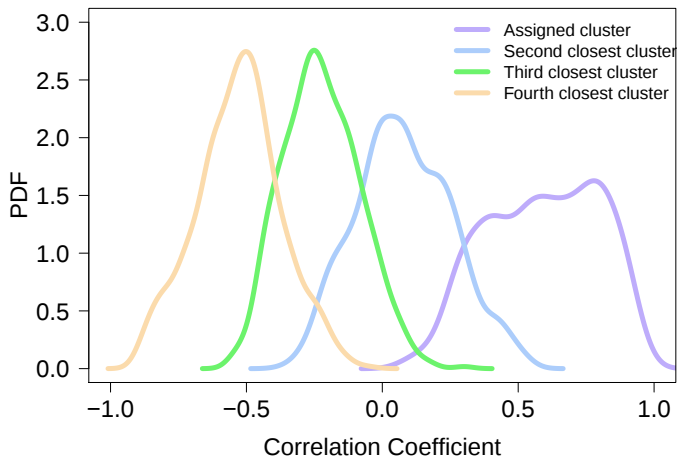


Land use model

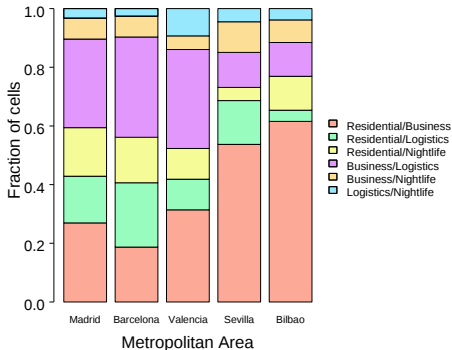
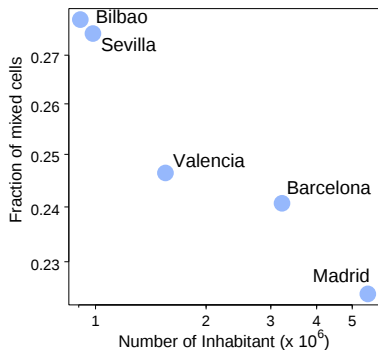
Ripley's K



Mixing of land use



Mixing of land use



Conclusions

- ▶ Network approach to detect land use using mobile phone data
- ▶ Four land use types (Residential, Business, Logistics, Nightlife)
- ▶ Similarities in the spatial organization of land use across cities
- ▶ Land use model based on attraction-repulsion rules between land use
- ▶ Mixing of land use



Miguel
Picornell



Oliva
Garcia Cantu



Thomas
Louail



Ricardo
Herranz



Marc
Barthelemy



Enrique
Frías-Martínez



Maxi
San Miguel



José Javier
Ramasco

Lenormand *et al.* Comparing and modeling land use organization in cities.