



## Functional Network of the City

Maxime Lenormand

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# Functional Network of the City

**Maxime Lenormand**

NetSci 2015, Zaragoza

June 3, 2015



\*  
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Instituto de Física Interdisciplinar y Sistemas Complejos



**CSIC**



**in**sight

Innovative  
Policy Modelling and Governance Tools  
for Sustainable Post-Crisis Urban Development

# Motivation

## Comparison of land use patterns across cities

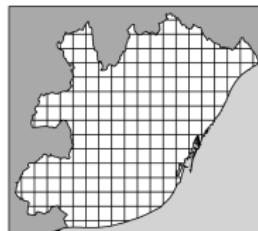
- ▶ Network approach to detect land use using mobile phone data
- ▶ Spatial organization (entropy, Ripley's K...)
- ▶ Land use model



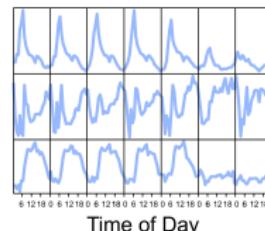
# Method used to extract the network



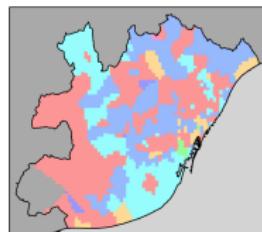
Metropolitan Area



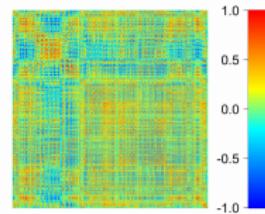
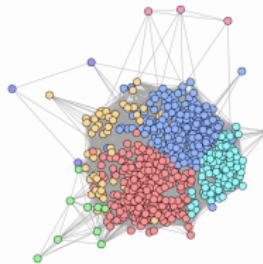
Recordings sites



Signals



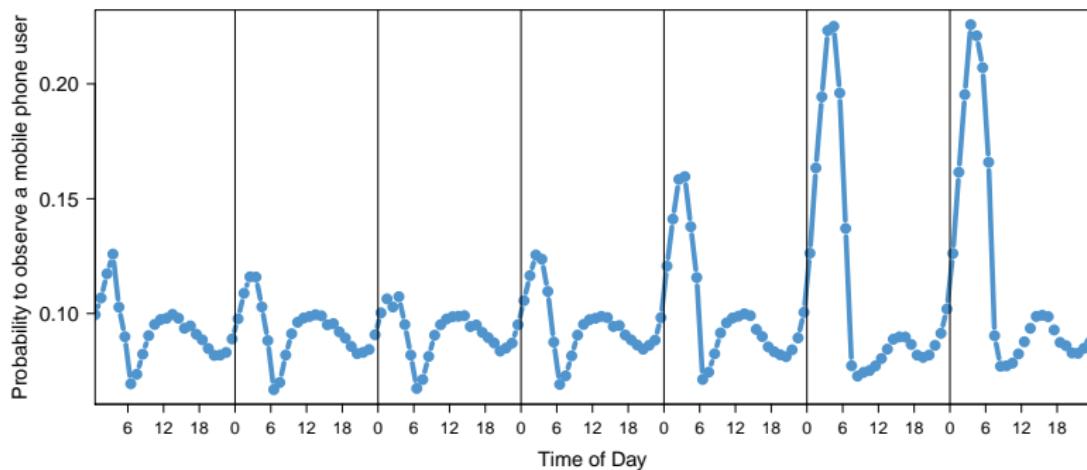
Functional Network



Correlation Matrix

# Method used to extract the network

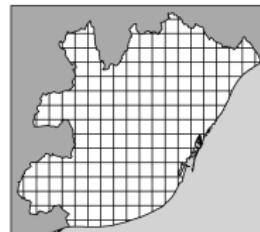
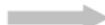
Probability to observe a mobile phone user in a given cell at a given time



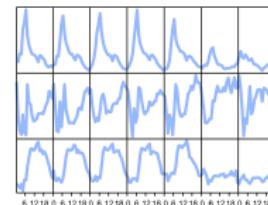
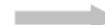
# Method used to extract the network



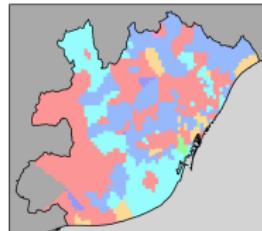
Metropolitan Area



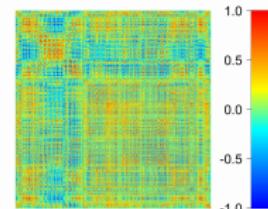
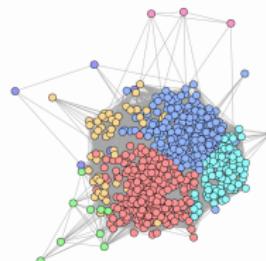
Recordings sites



Signals



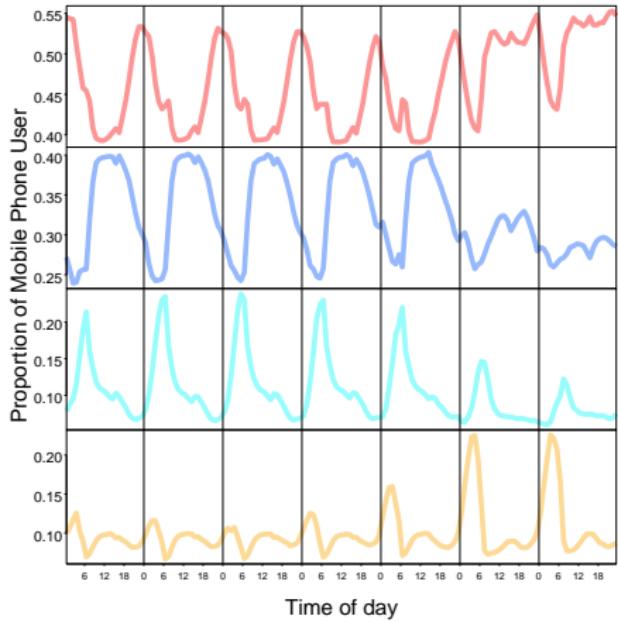
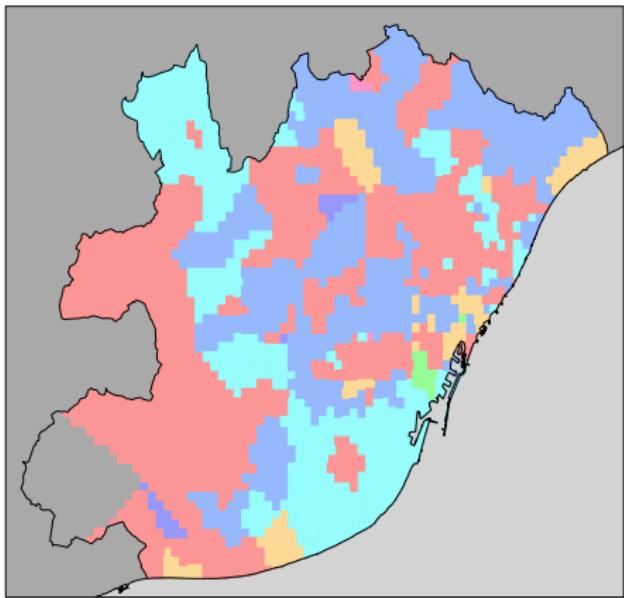
Functional Network



Correlation Matrix

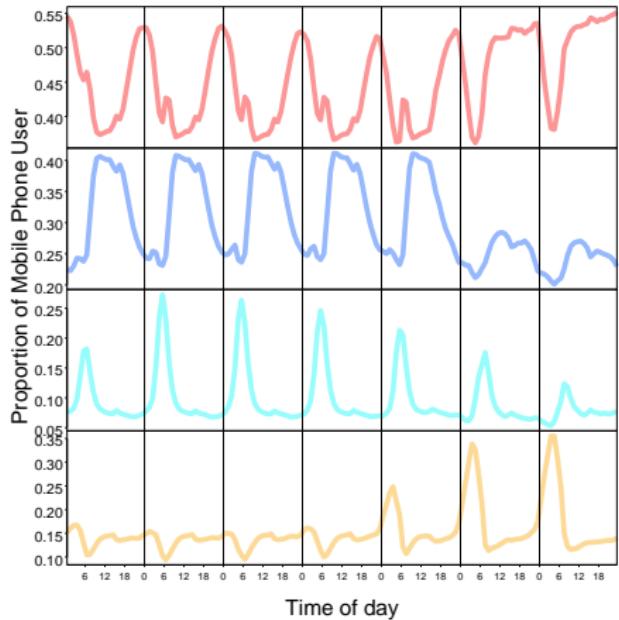
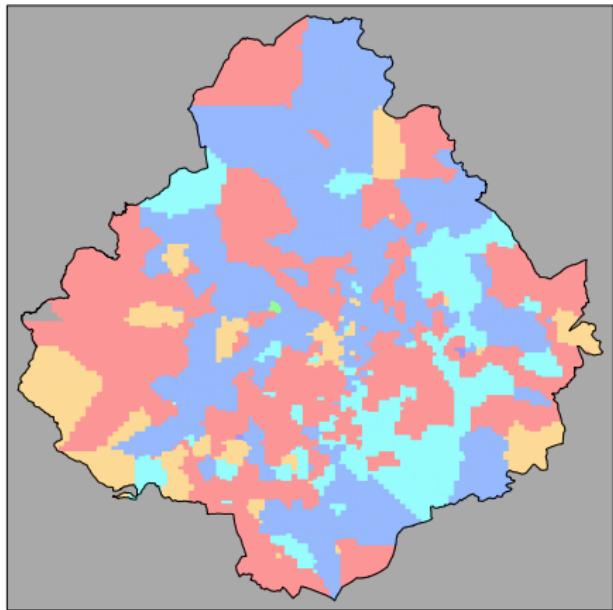
# Land use patterns

**Barcelona (PGP = 60%)**



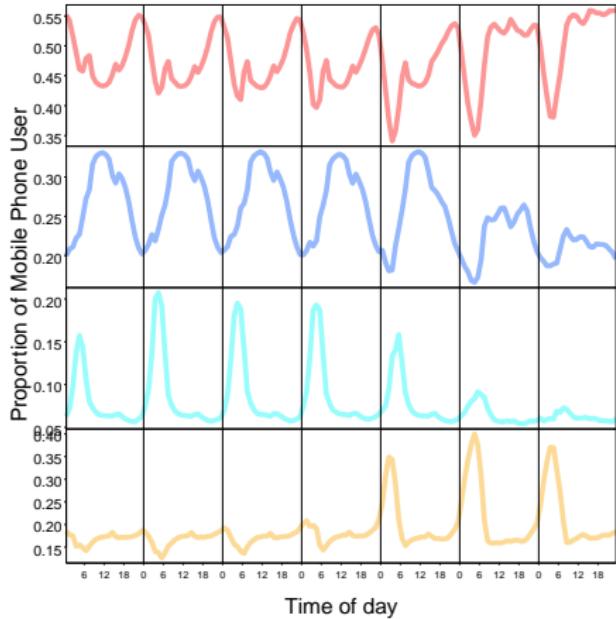
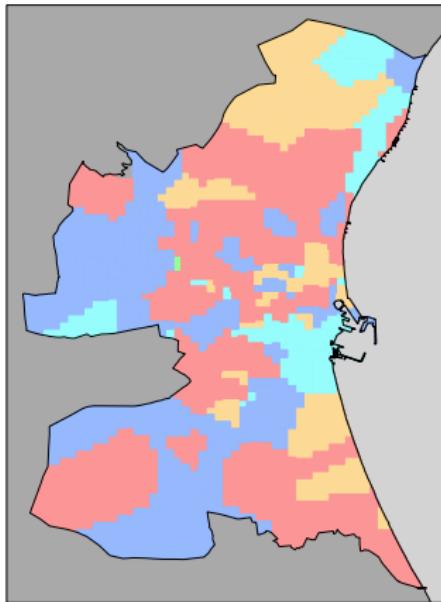
# Land use patterns

**Madrid (PGP = 65%)**



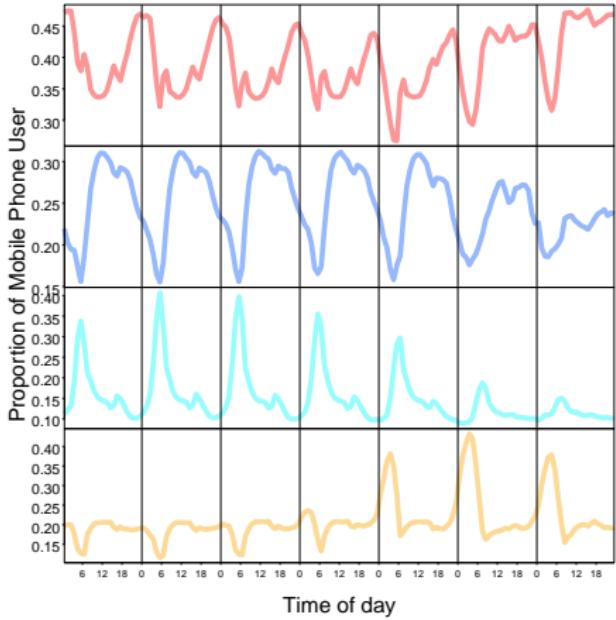
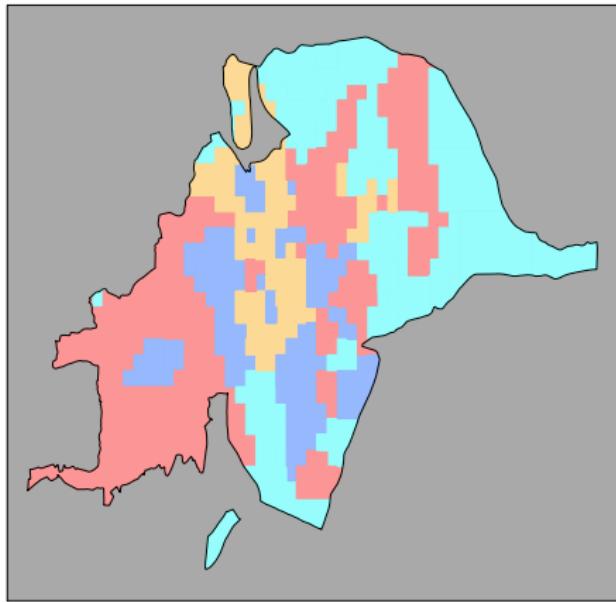
# Land use patterns

## Valencia



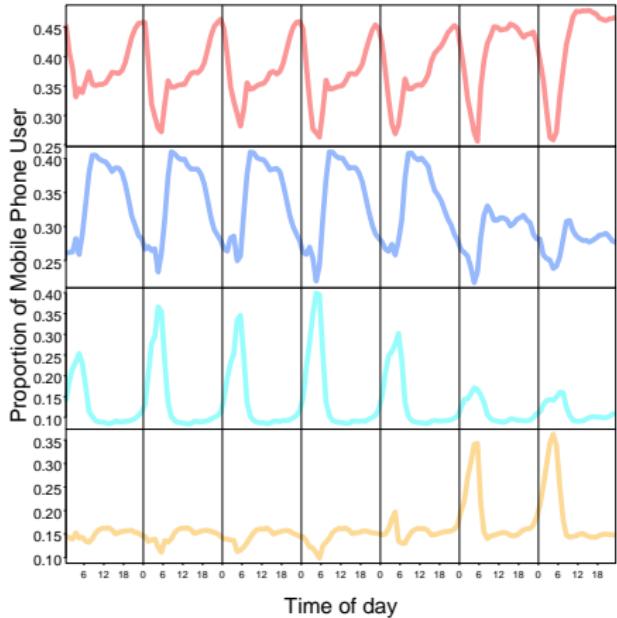
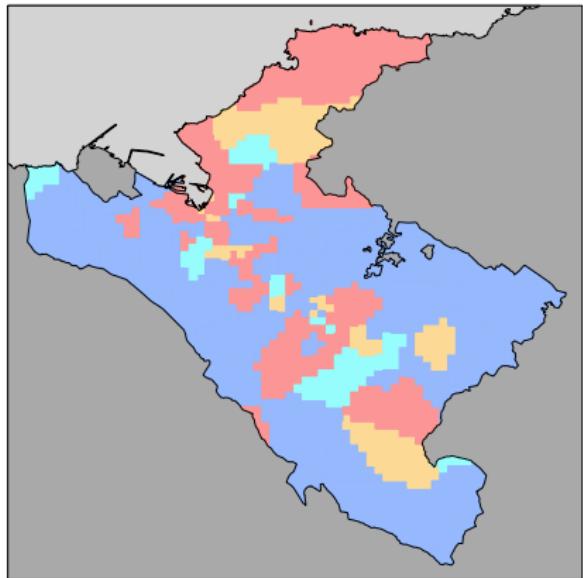
# Land use patterns

## Sevilla



# Land use patterns

## Bilbao



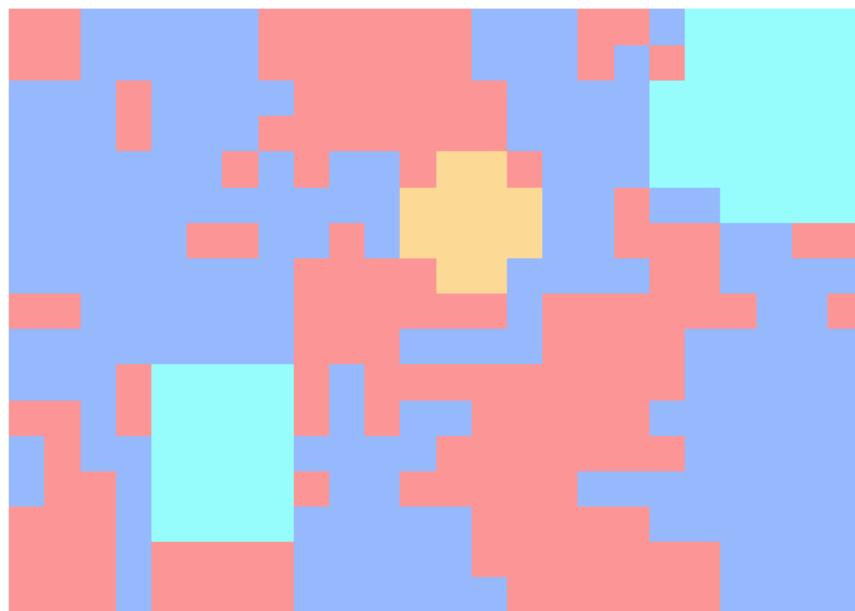
# Spatial organization of land use

## Three measures of spatial heterogeneity

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

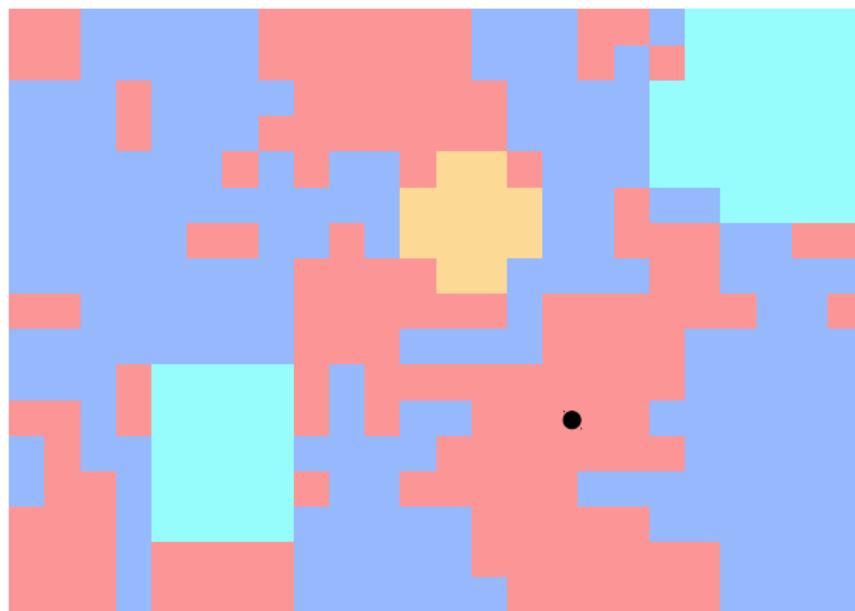
# Spatial organization of land use

## Distance to the city center



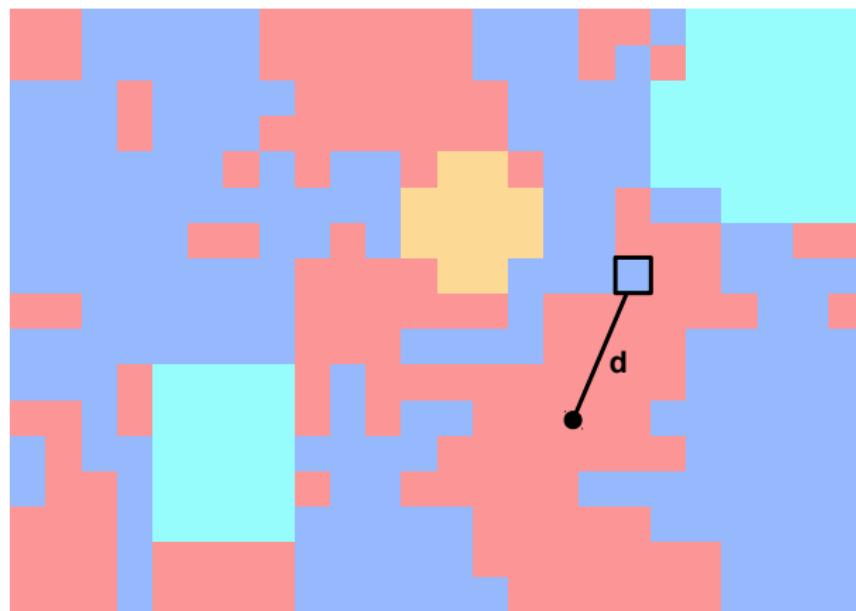
# Spatial organization of land use

## Distance to the city center



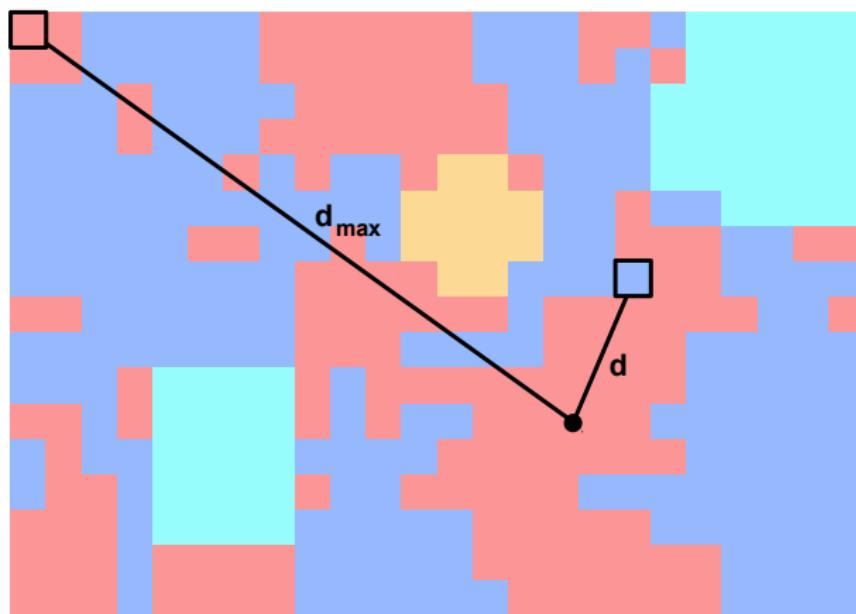
# Spatial organization of land use

## Distance to the city center



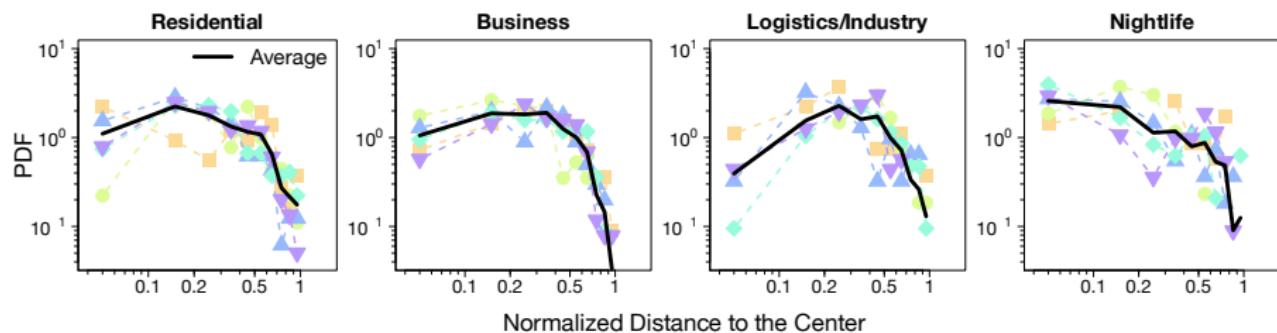
# Spatial organization of land use

## Distance to the city center



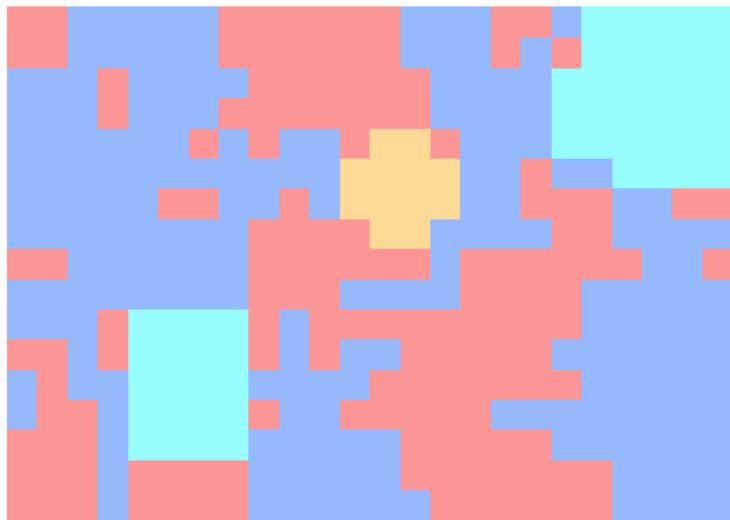
# Spatial organization of land use

## Distance to the city center



# Spatial organization of land use

## Ripley's K

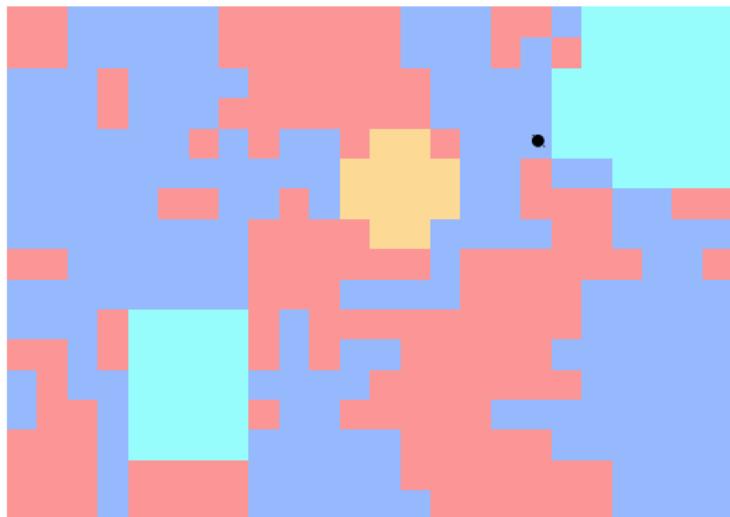


$$K(r) = \frac{A}{n^2} \sum_{i=1}^n N_i(r)$$

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

# Spatial organization of land use

## Ripley's K

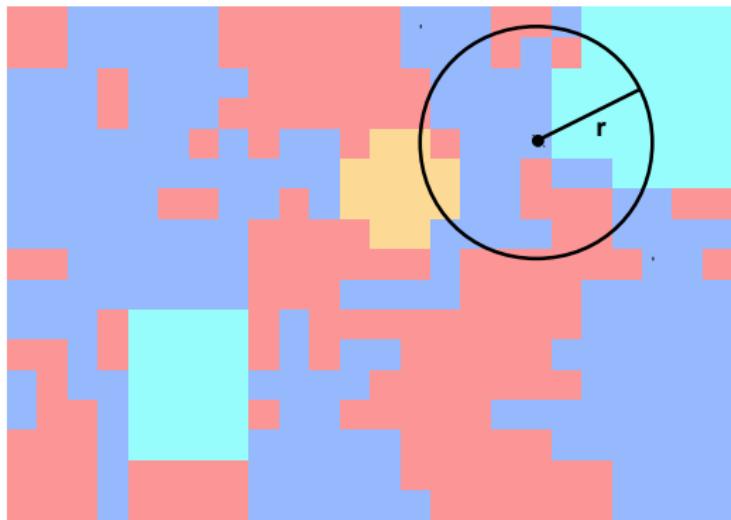


$$K(r) = \frac{A}{n^2} \sum_{i=1}^n N_i(r)$$

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## Ripley's K

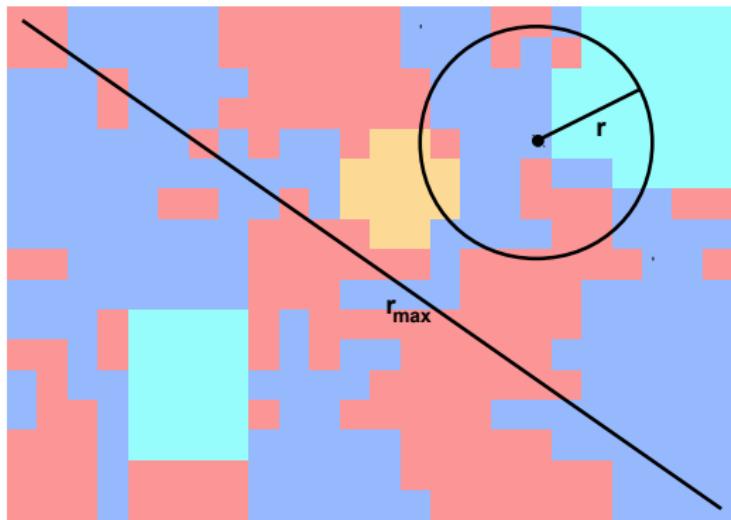


$$K(r) = \frac{A}{n^2} \sum_{i=1}^n N_i(r)$$

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# Spatial organization of land use

## Ripley's K

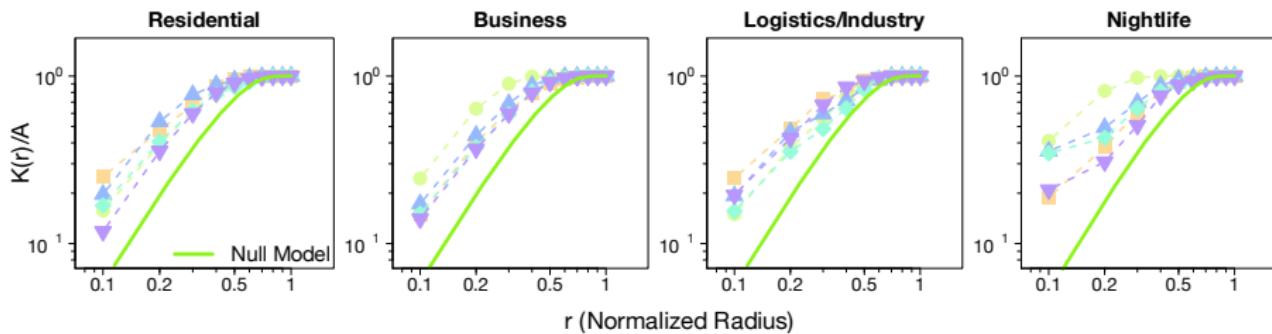


$$K(r) = \frac{A}{n^2} \sum_{i=1}^n N_i(r)$$

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

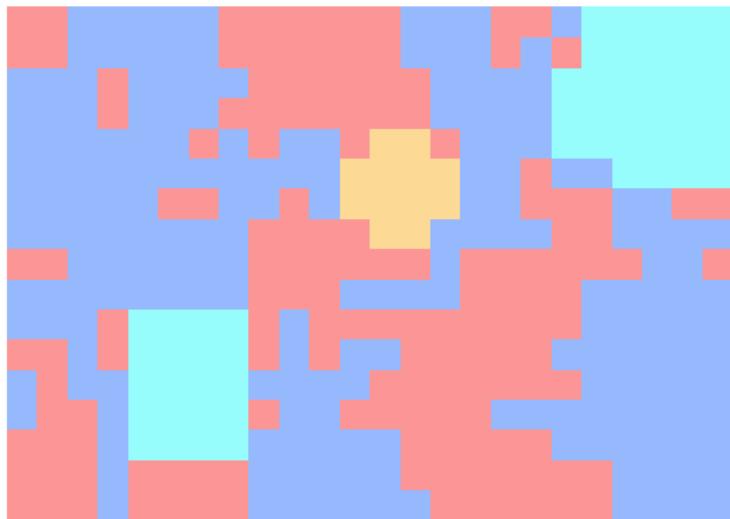
# Spatial organization of land use

## Ripley's K



# Spatial organization of land use

## Entropy index

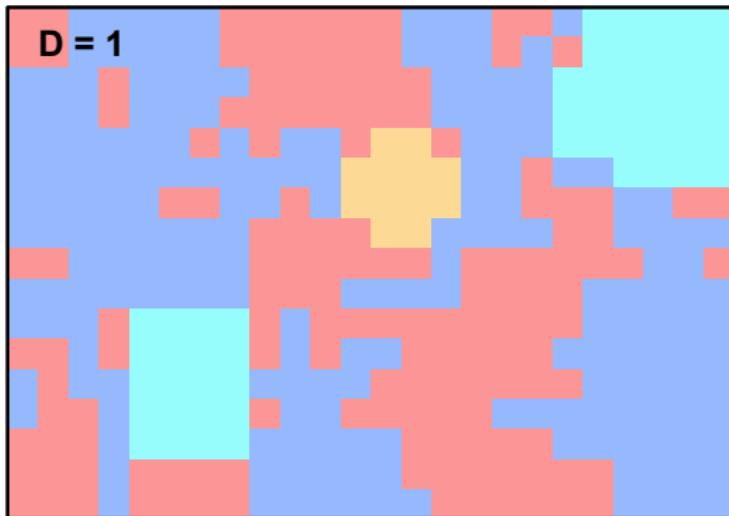


$$E_i = - \sum_{k=1}^4 f_i^k \ln f_i^k$$

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

# Spatial organization of land use

## Entropy index

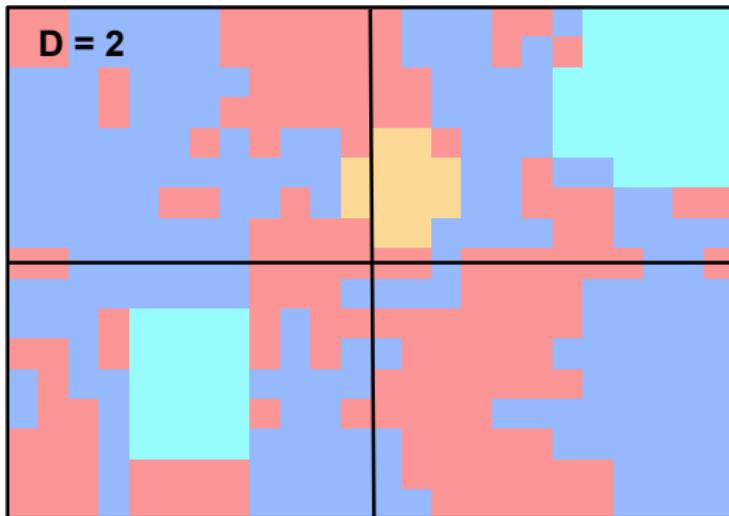


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# Spatial organization of land use

## Entropy index

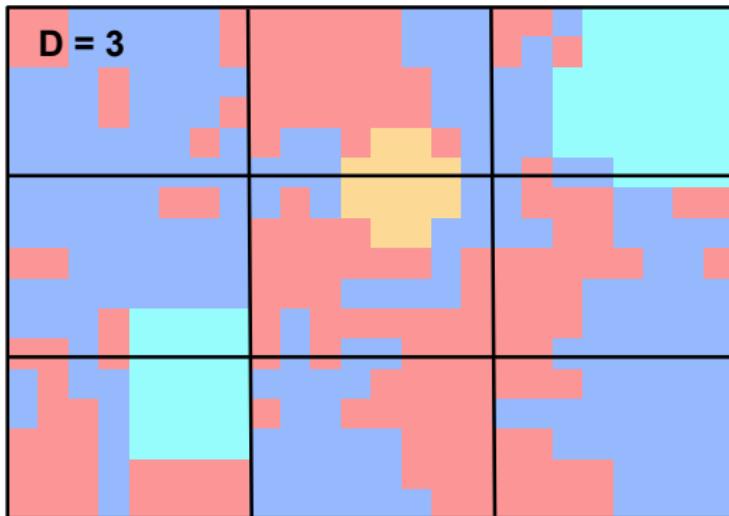


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# Spatial organization of land use

## Entropy index

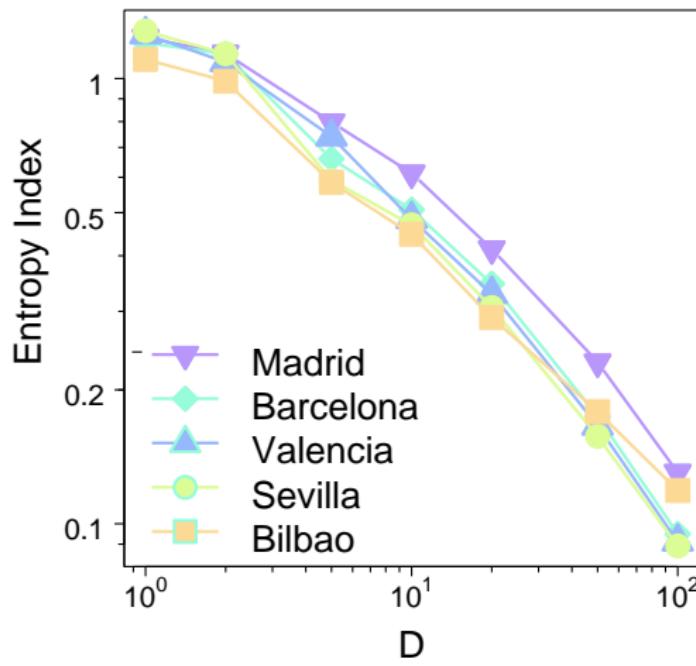


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# Spatial organization of land use

## Entropy index



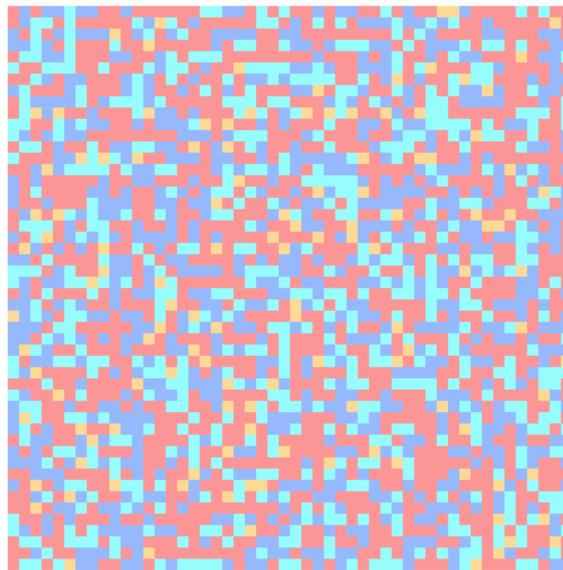
# Land use model

## Simple model inspired by Schelling's segregation model

- ▶ Land use type randomly assigned to each cell
- ▶ Satisfaction index defined for each cell considering cell type and neighbour cell types
  - **Repulsion** between Logistics and the other types
  - **Attraction** between Residential and Business (parameter  $\gamma$ )
- ▶ Model updated by choosing random pairs of cells and interchanging their land use

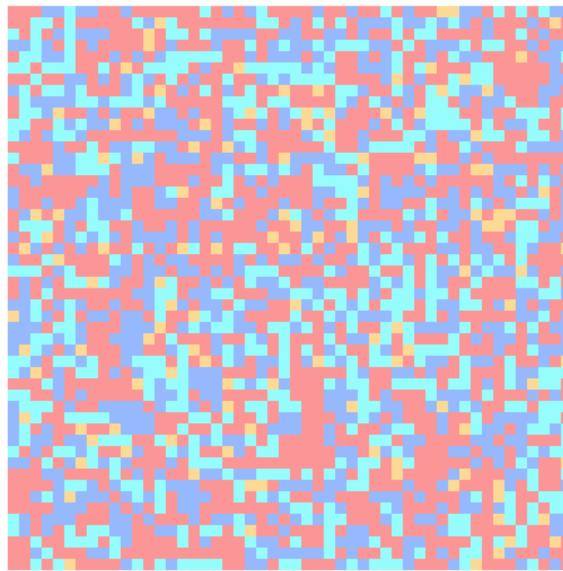
# Land use model

$t = 1$



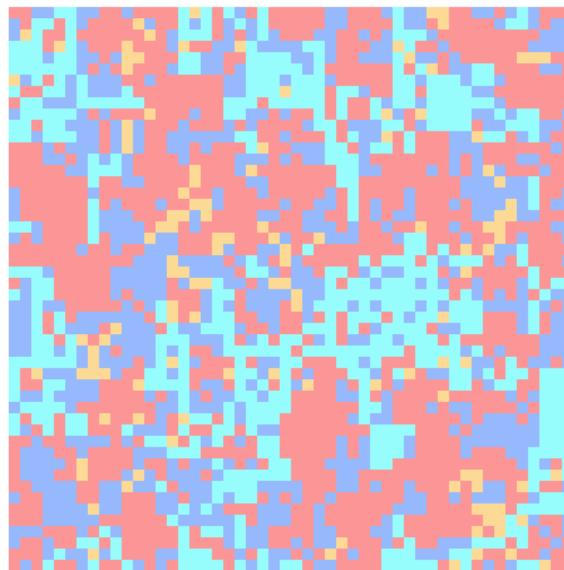
# Land use model

$t = 1,000$



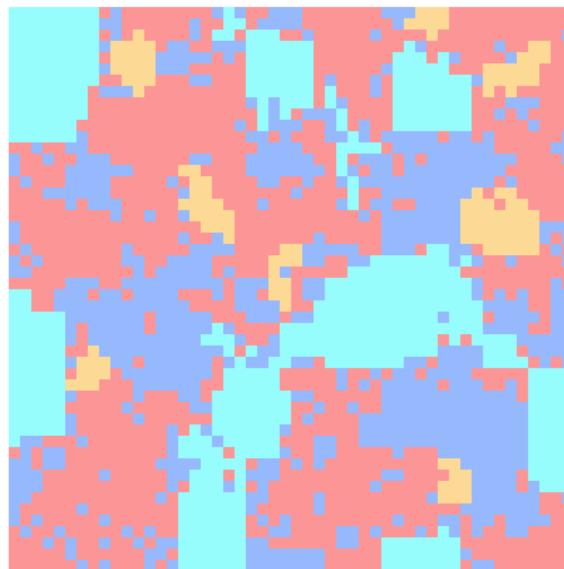
# Land use model

$t = 10,000$



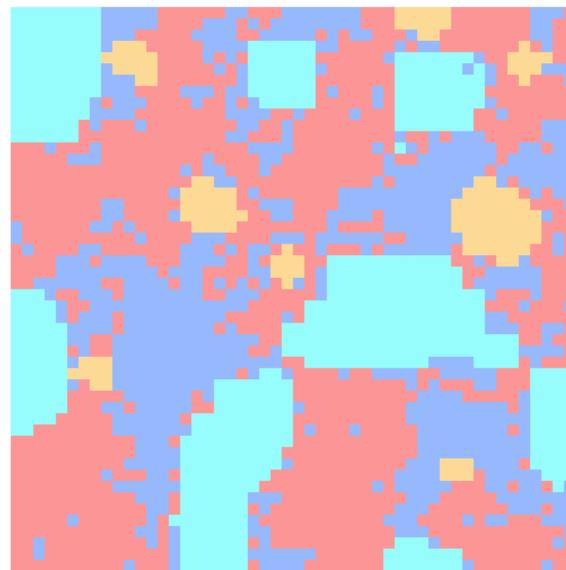
# Land use model

$t = 100,000$

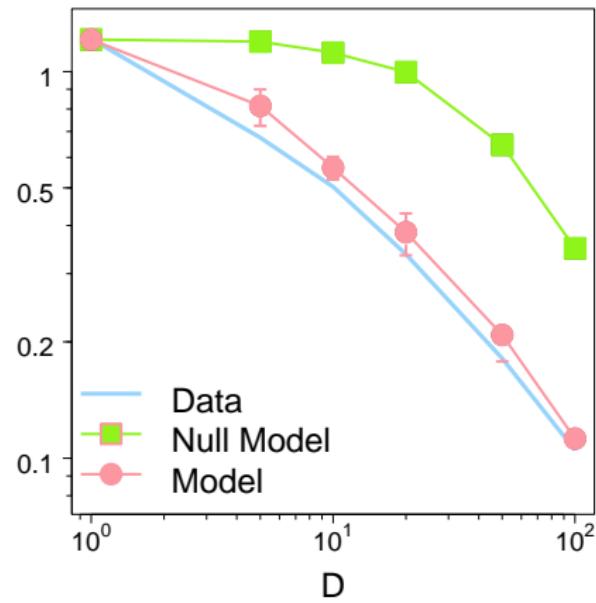
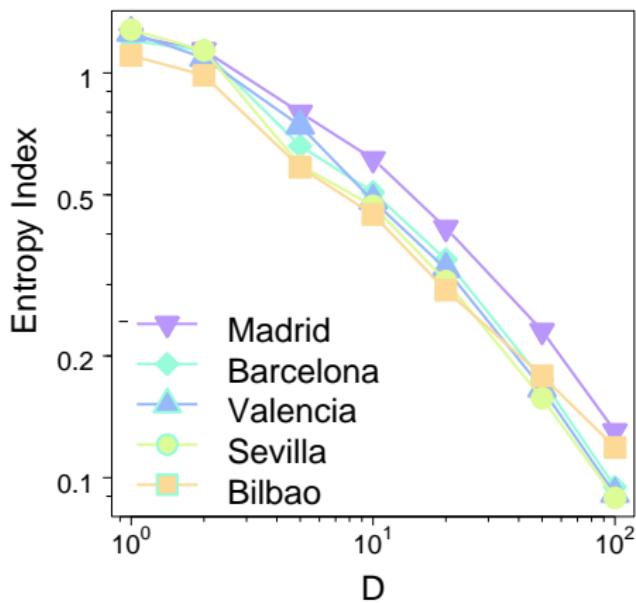


# Land use model

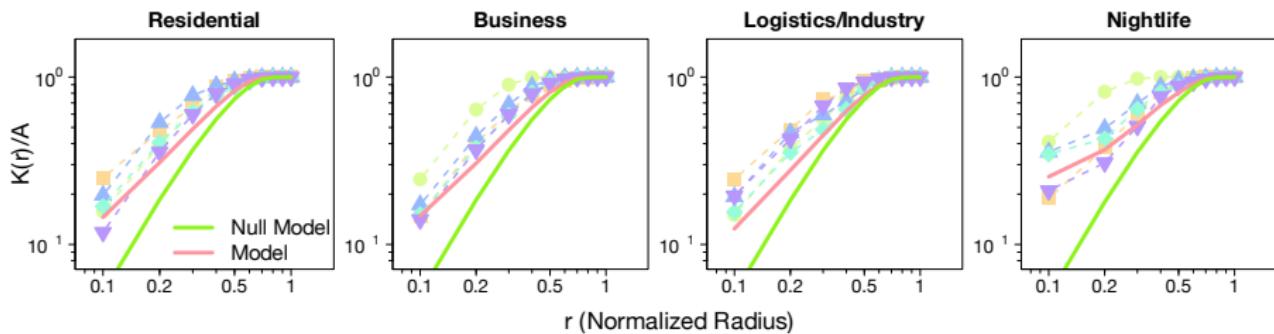
$t = 300,000$



# Land use model Calibration of $\gamma$



# Land use model Ripley's K



## Take home messages

- ▶ 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 between land use.



Miguel  
Picornell



Oliva  
Garcia Cantu



Thomas  
Louail



Ricardo  
Herranz



Marc  
Barthélemy



Enrique  
Frías-Martínez



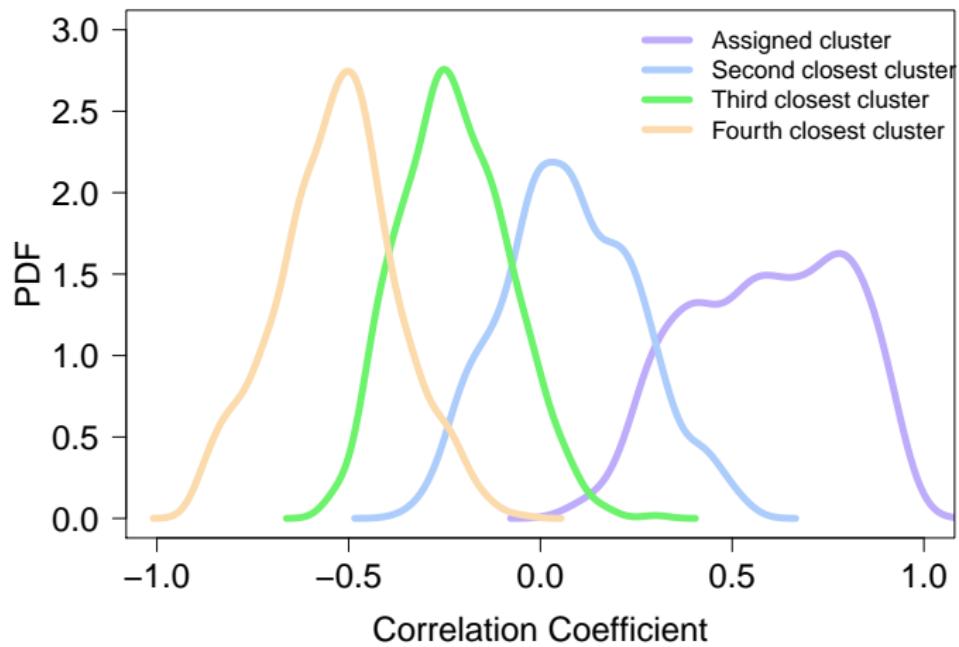
Maxi  
San Miguel



José Javier  
Ramasco

**Lenormand et al.** Comparing and modeling land use organization in cities.  
Arxiv e-print, arXiv:1503.06152

# Mixing of land use



# Mixing of land use

