Functional Network of the City

Maxime Lenormand

Functional Network of the City

Maxime Lenormand

CitiNet'14, Lucca, Italy

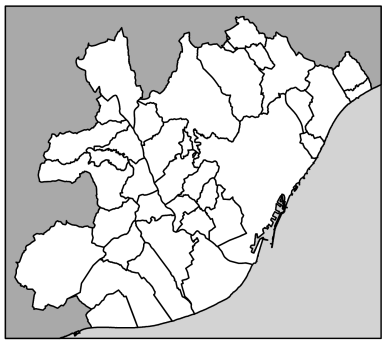
September 25, 2014

Motivation

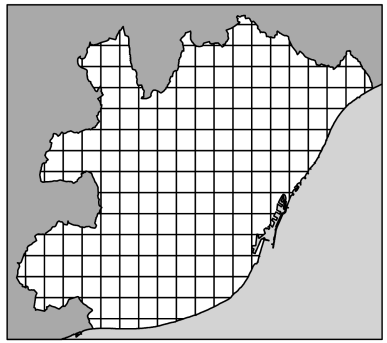
Comparison of land use patterns across cities

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

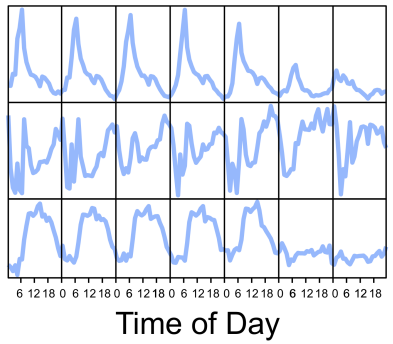
Method used to extract the network



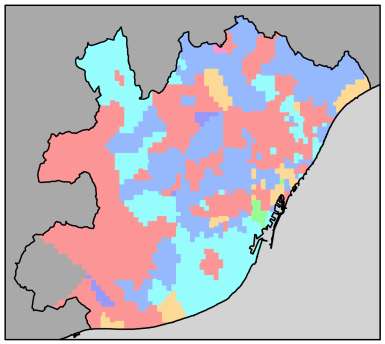
Metropolitan Area



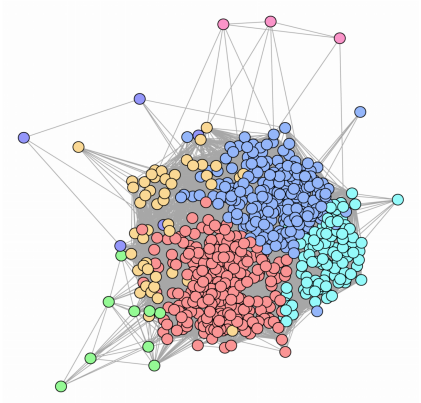
Recordings sites

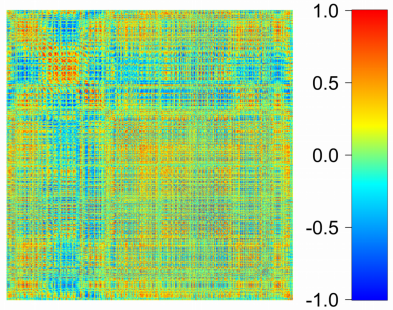


Signals



Functional Network

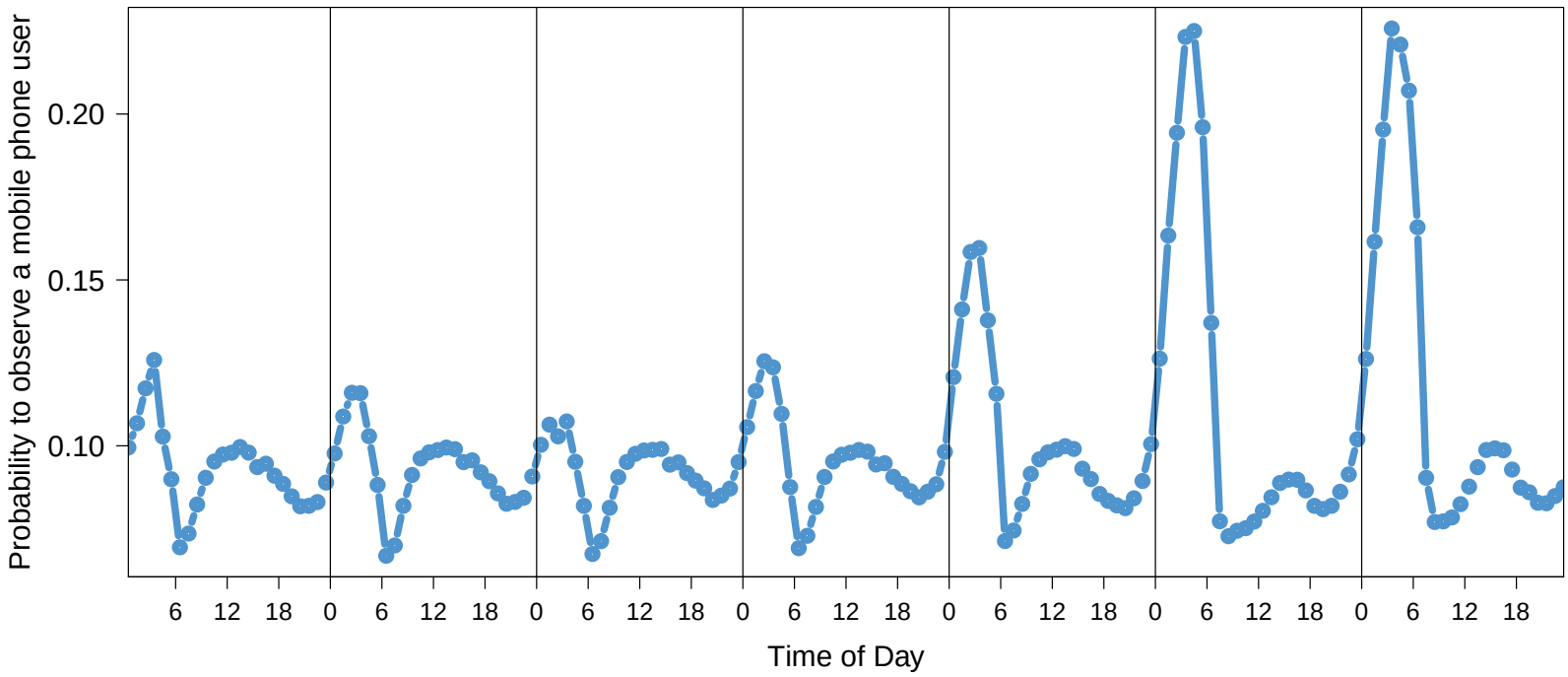




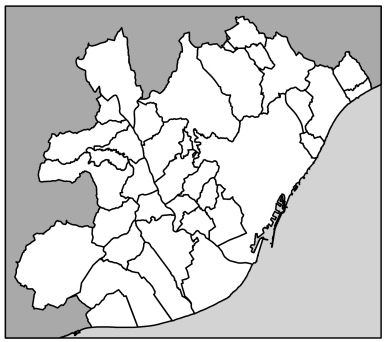
Correlation Matrix

Method used to extract the network

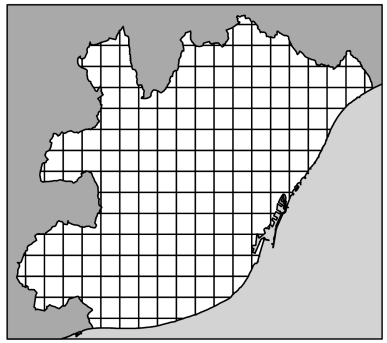
Probability to observe a mobile phone user in a given cell at a given time



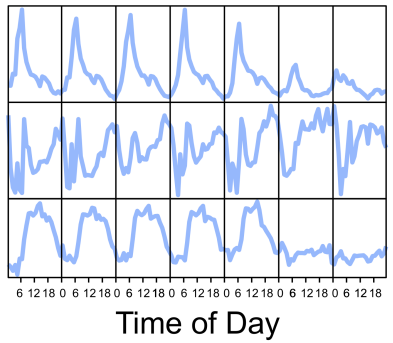
Method used to extract the network



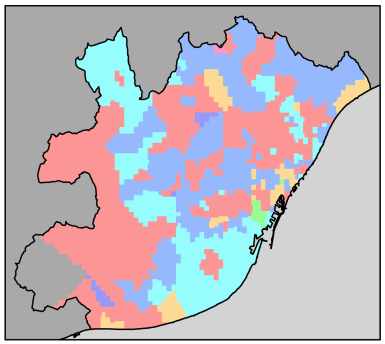
Metropolitan Area



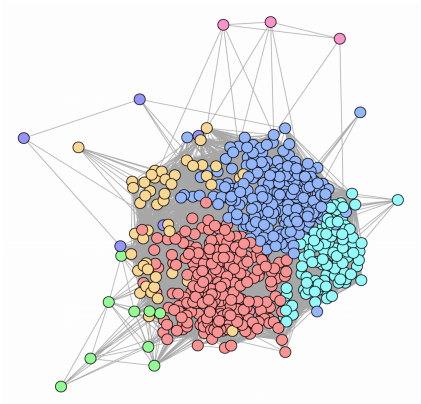
Recordings sites

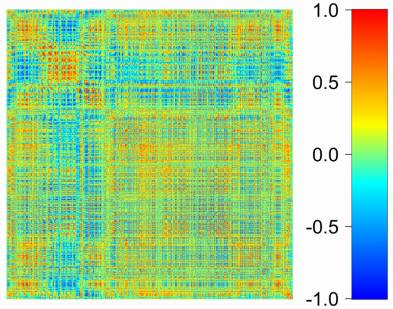


Signals



Functional Network

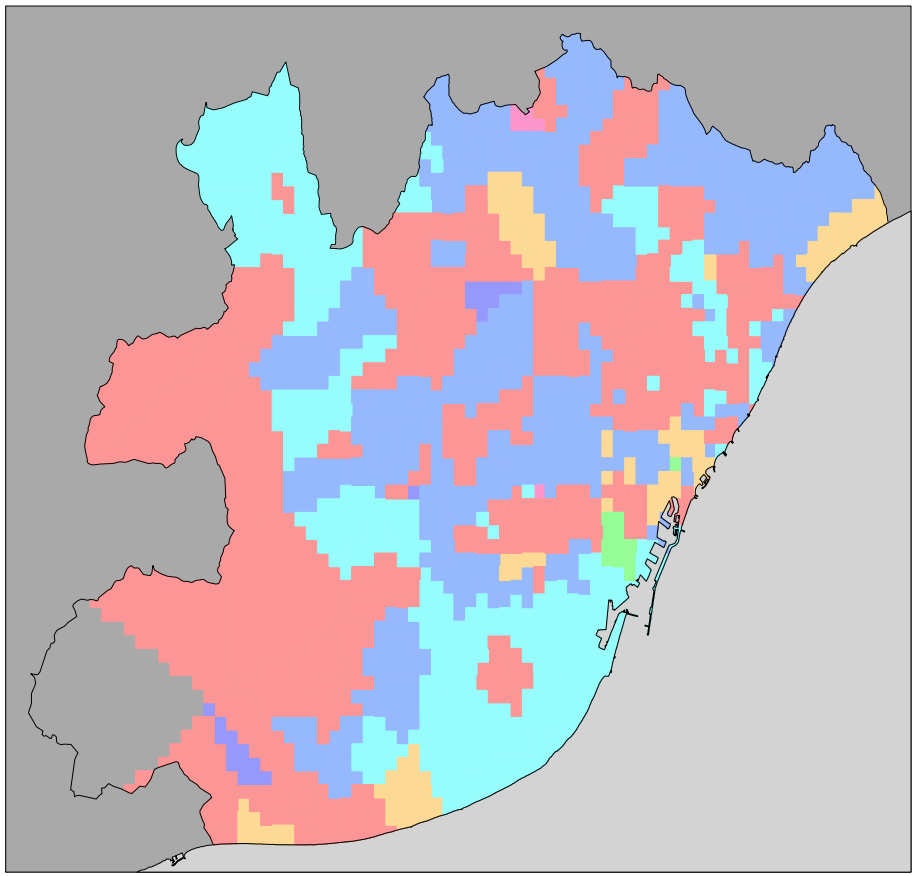


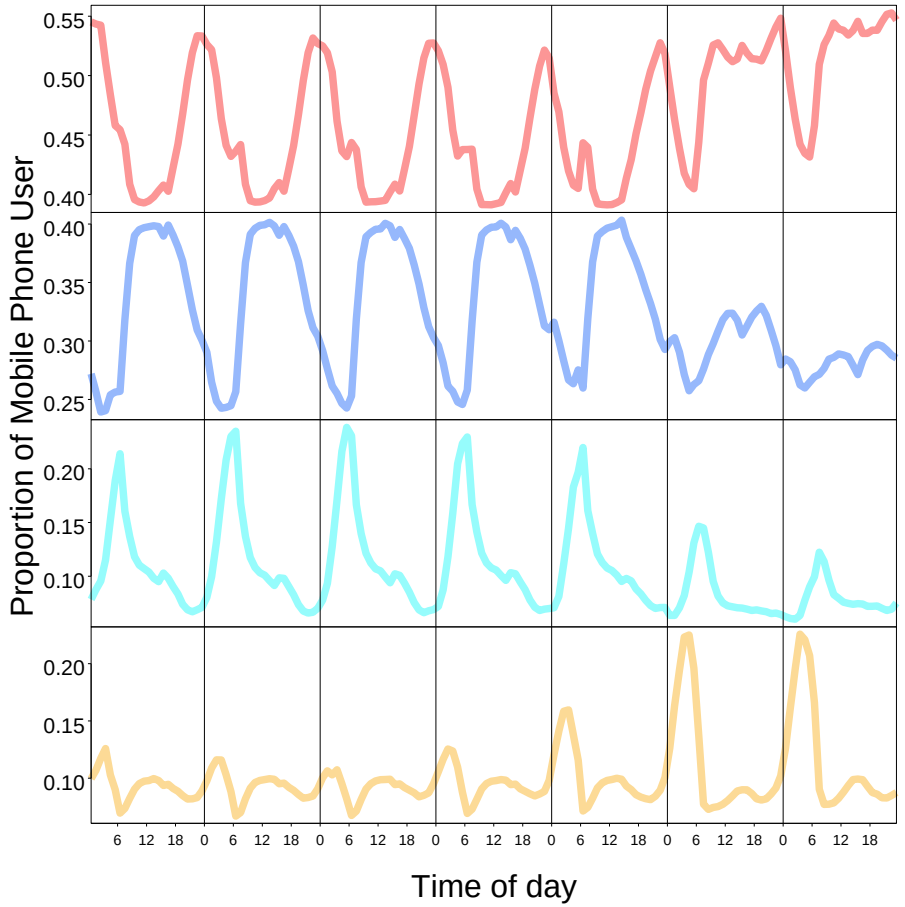


Correlation Matrix

Land use patterns

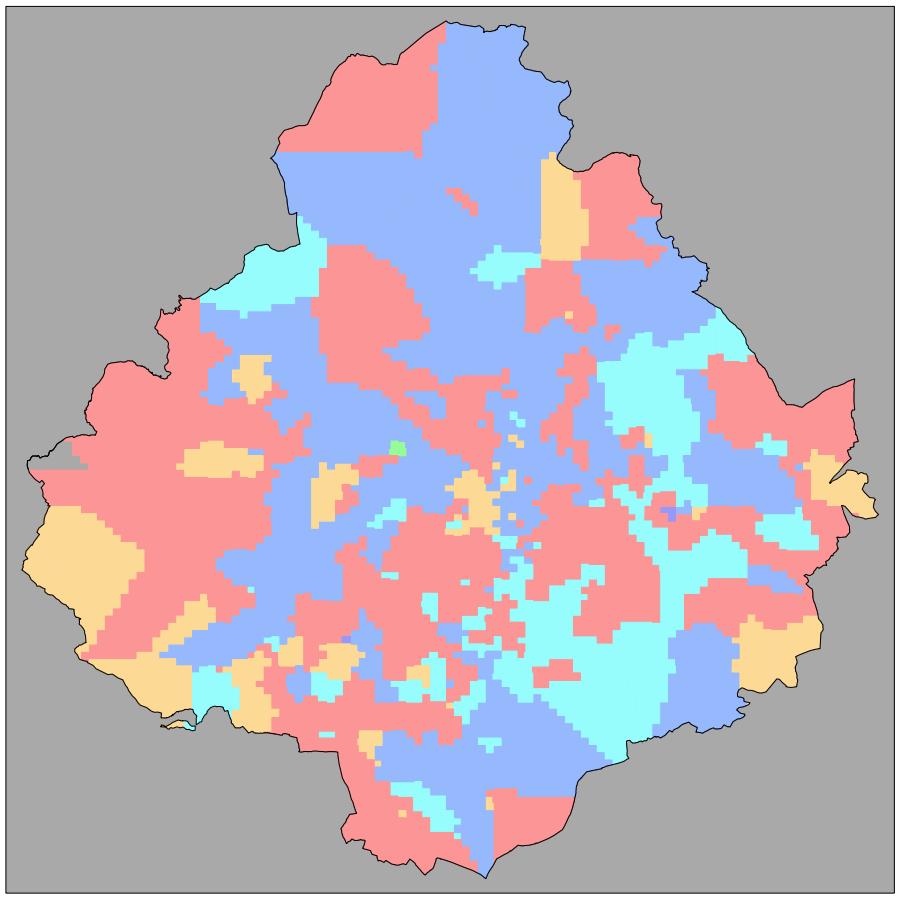
Barcelona (PGP = 60%)

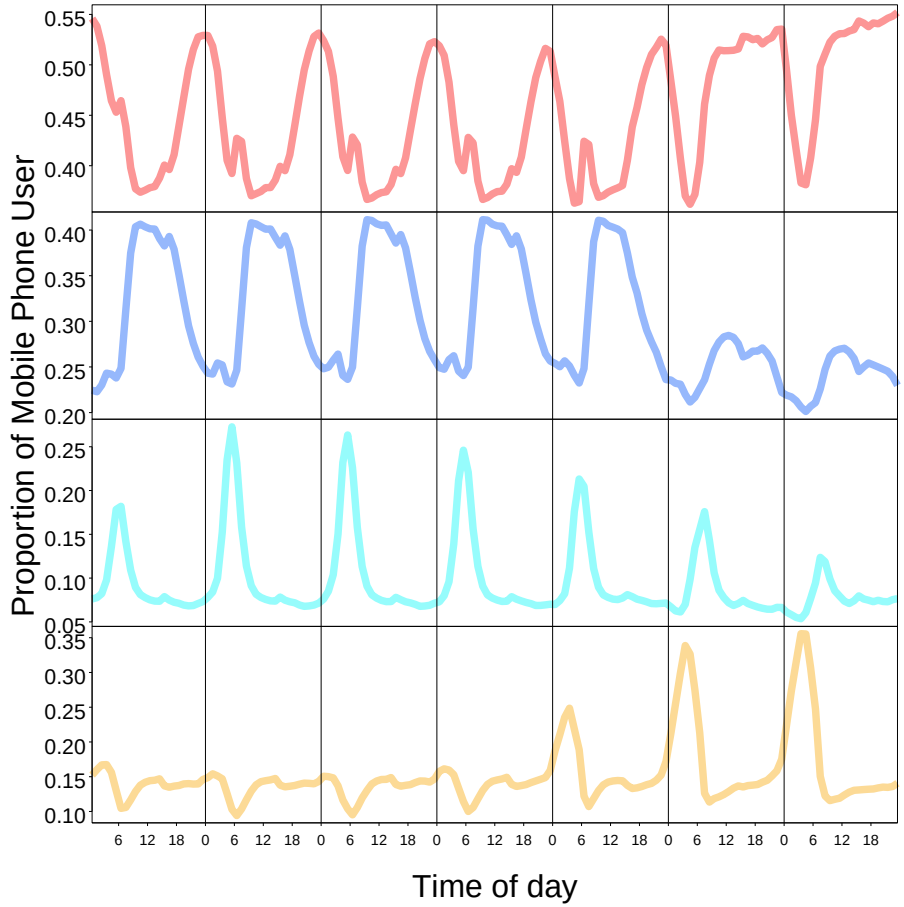




Land use patterns

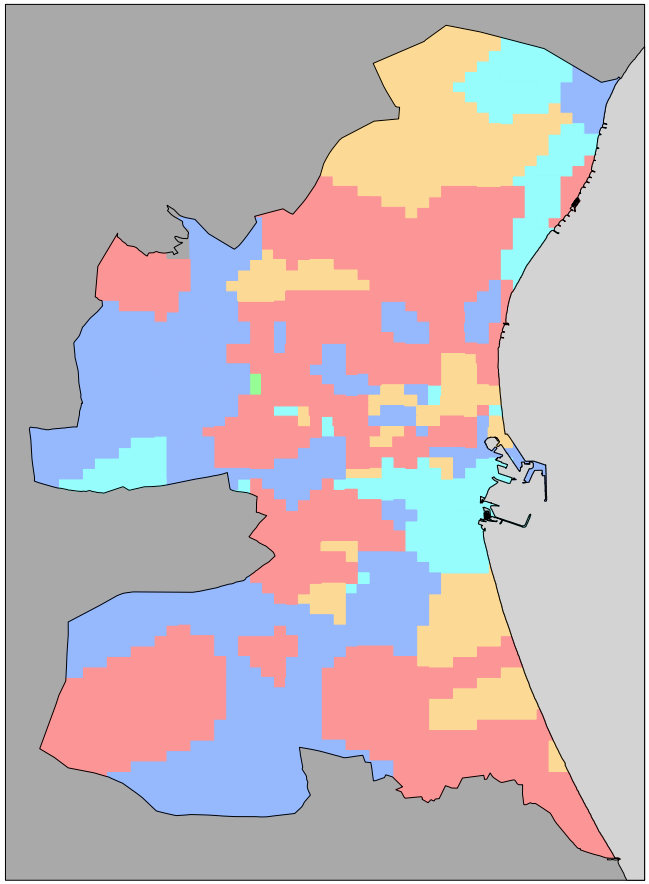
Madrid (PGP = 65%)

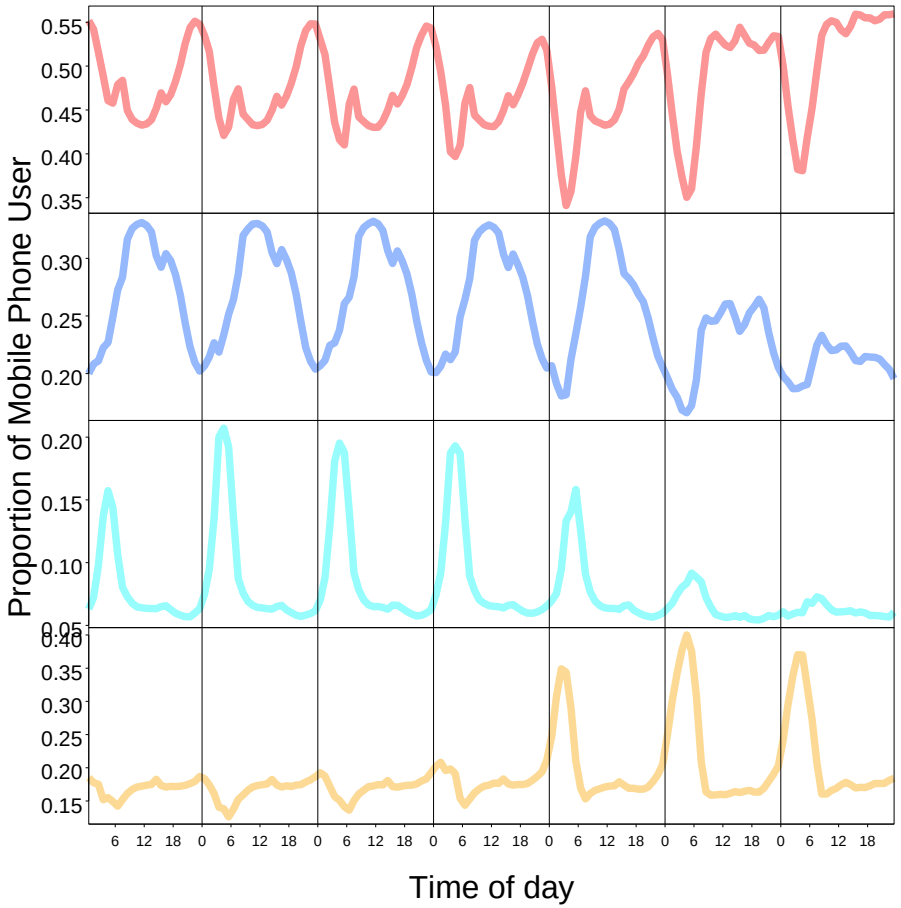




Land use patterns

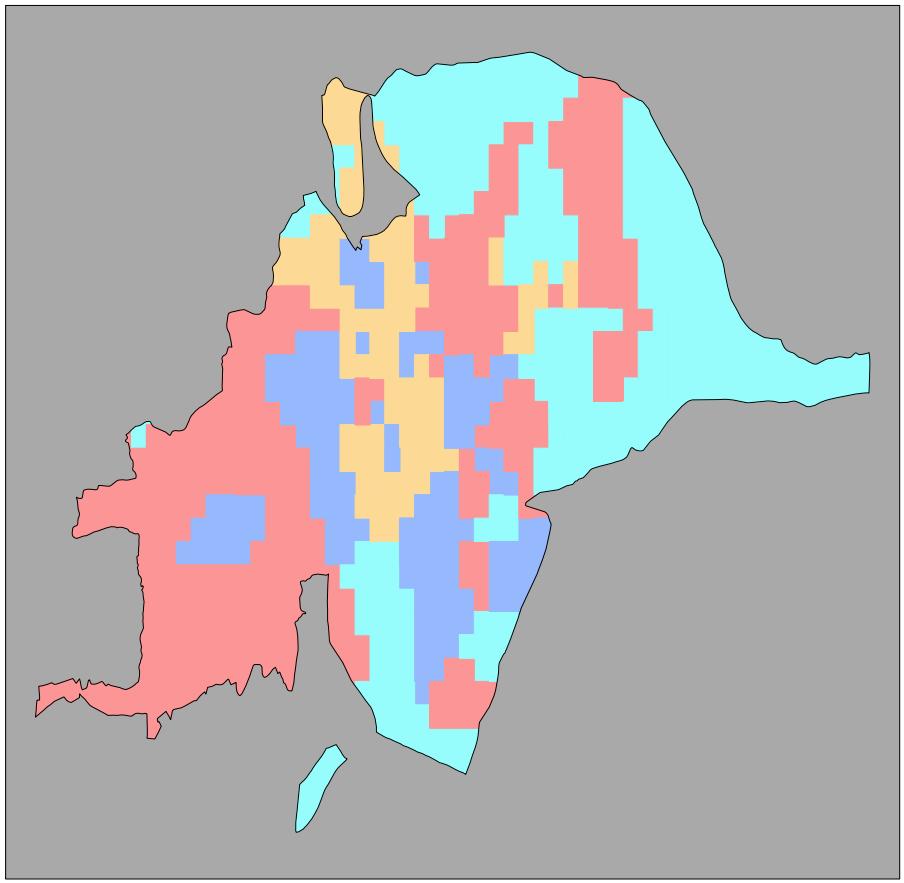
Valencia

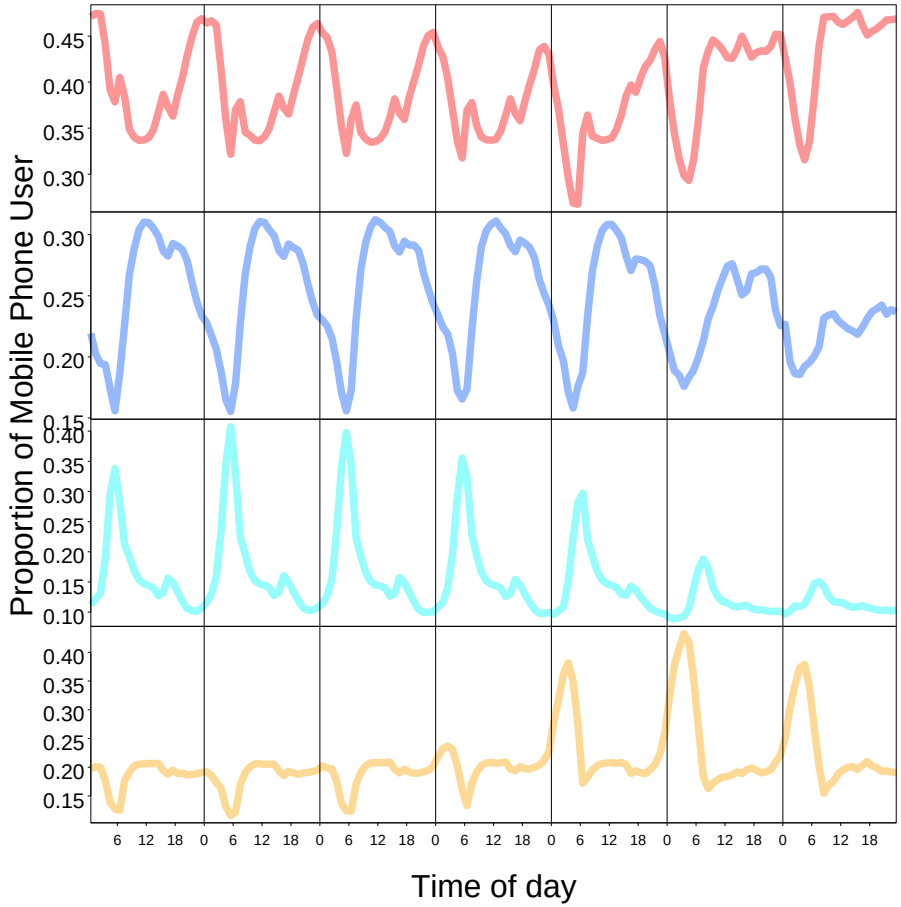




Land use patterns

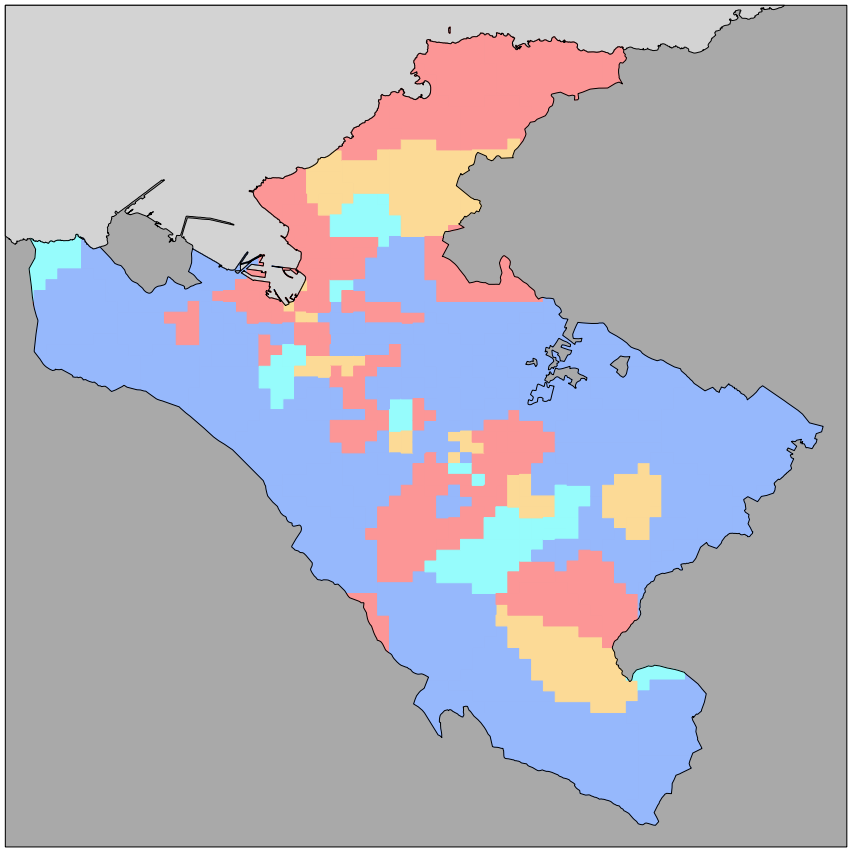
Sevilla

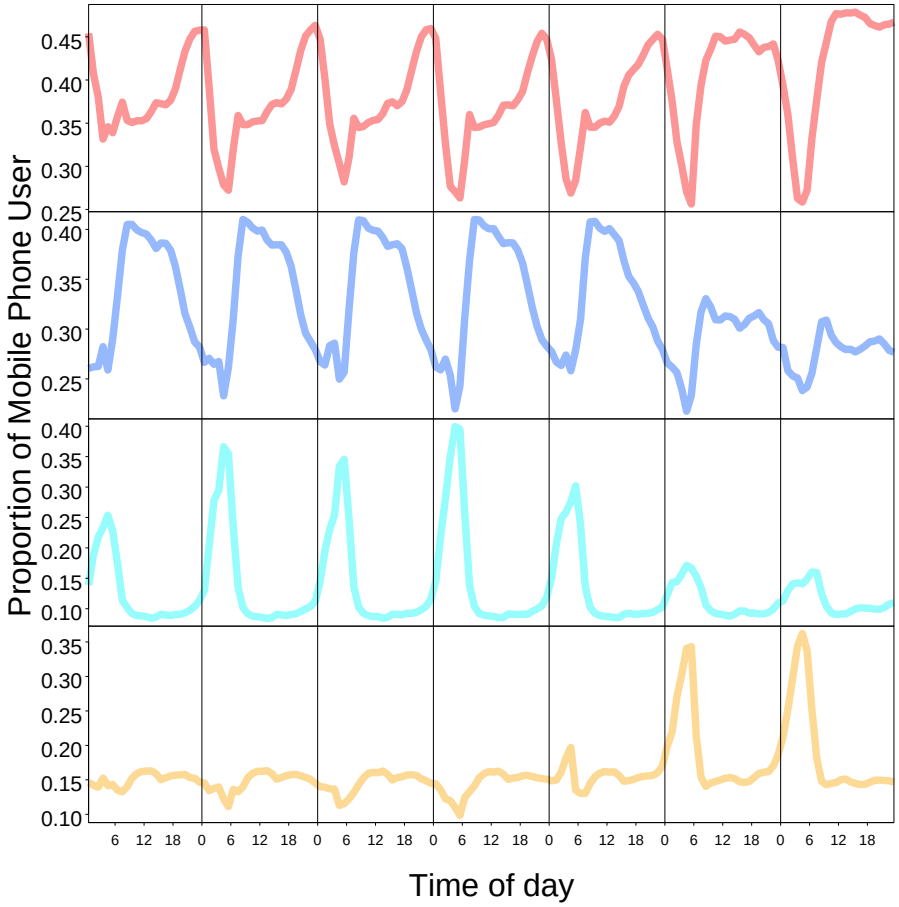




Land use patterns

Bilbao



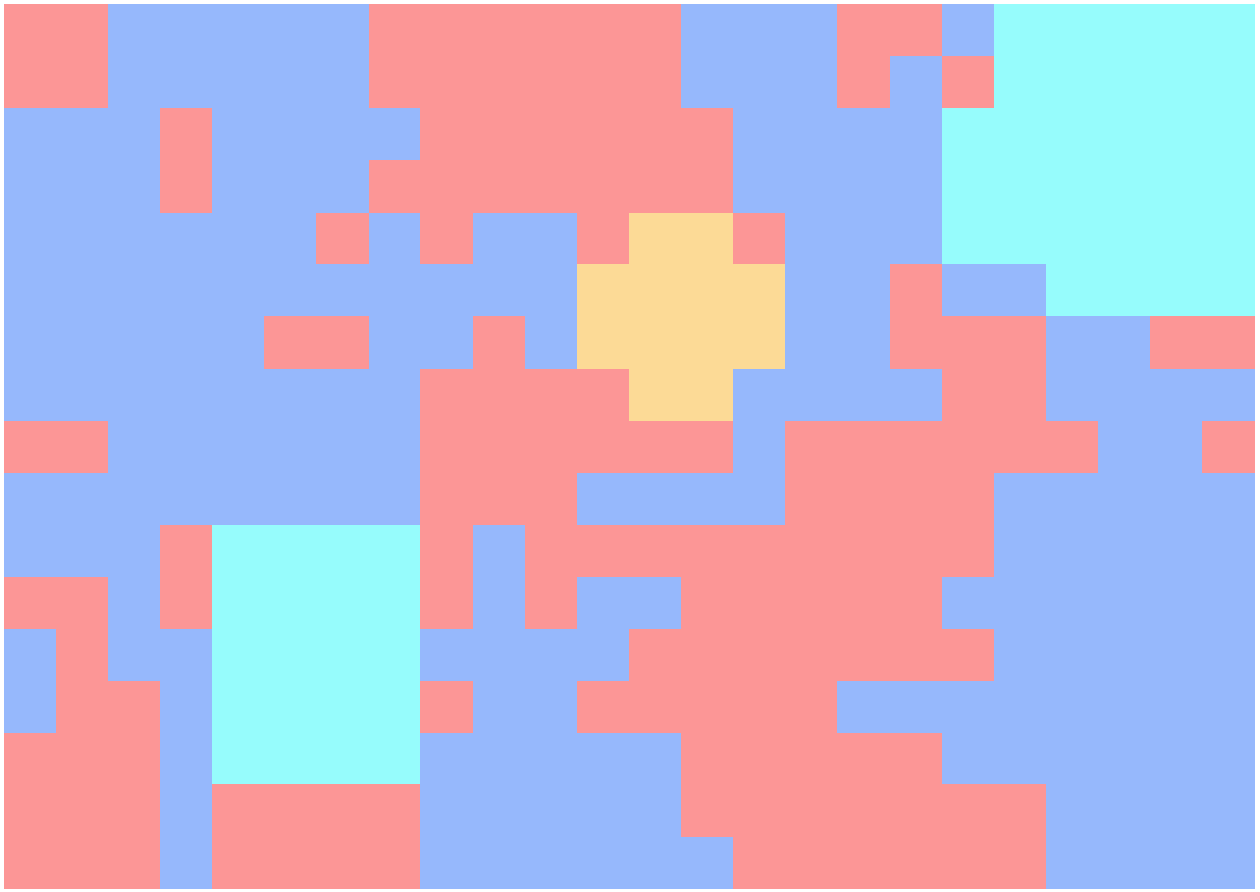


Spatial organization of land use

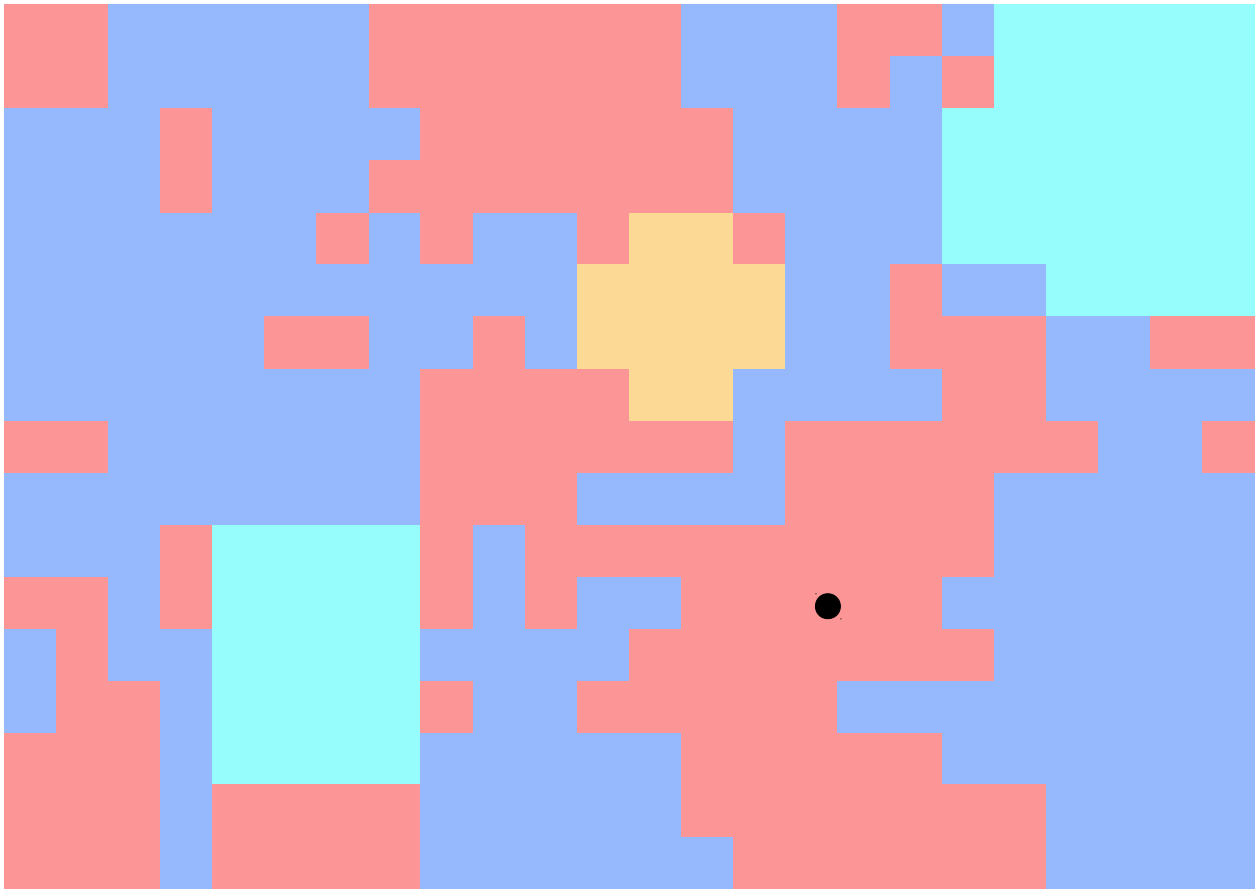
Three measures of spatial heterogeneity

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

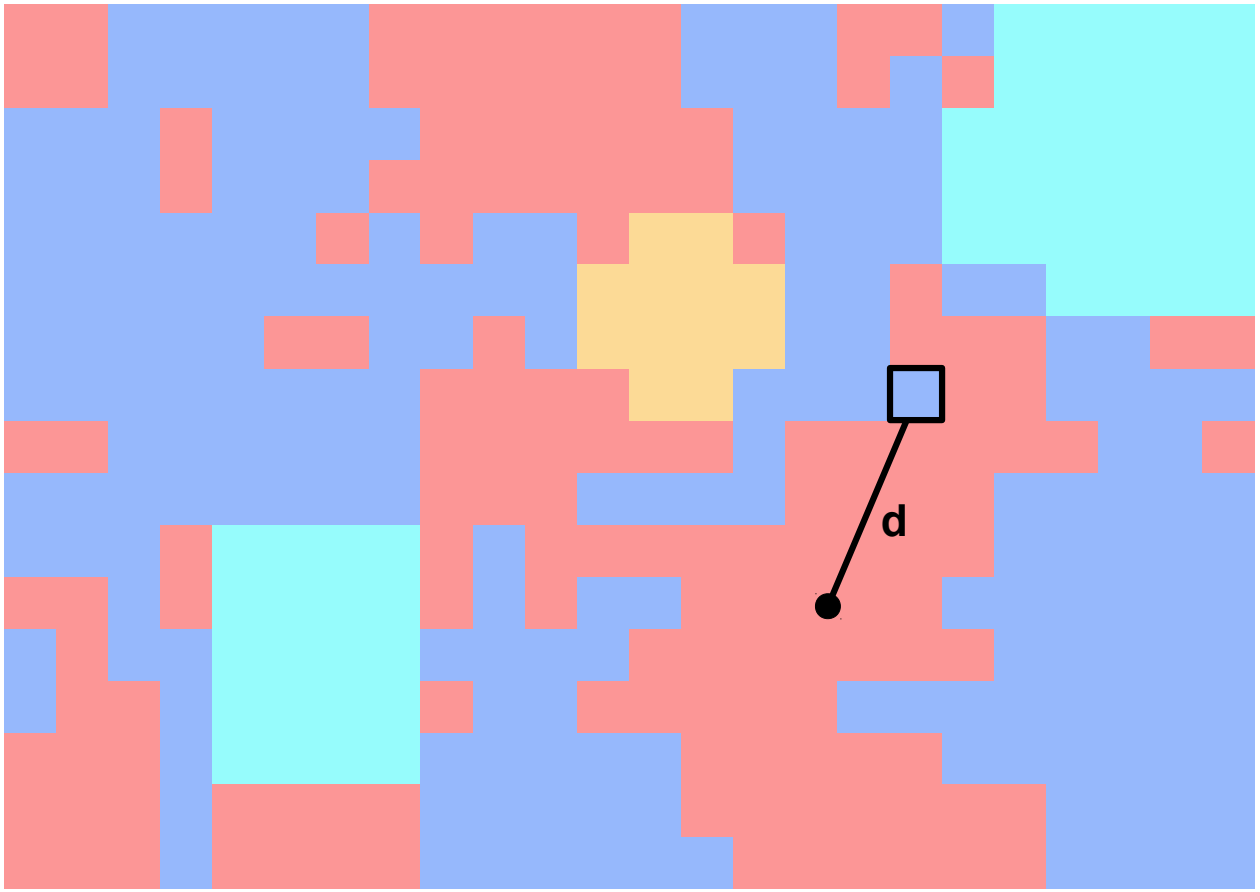
Spatial organization of land use
Distance to the city center



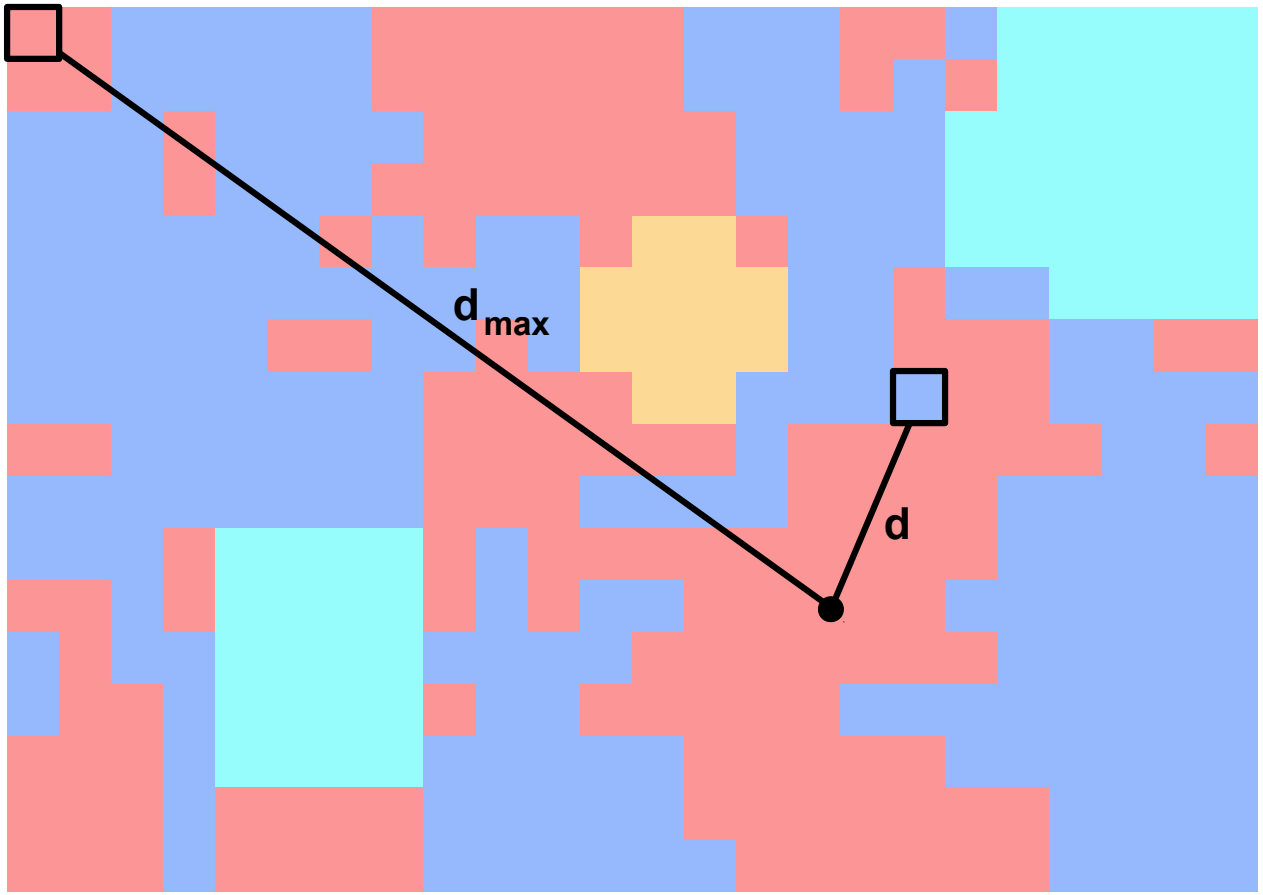
Spatial organization of land use
Distance to the city center



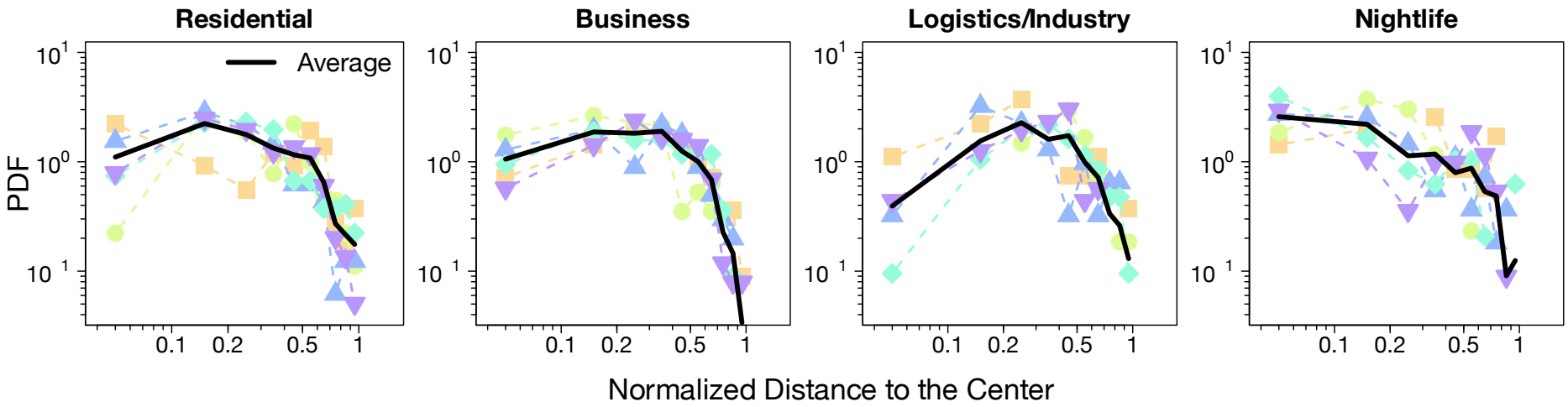
Spatial organization of land use
Distance to the city center



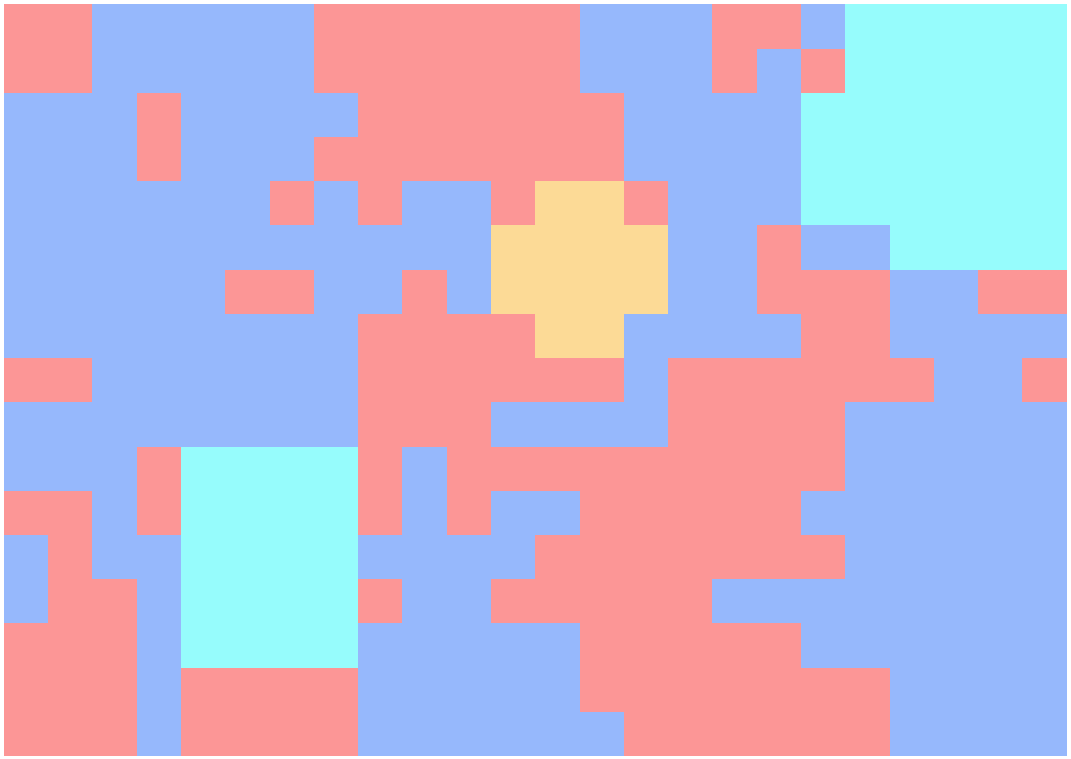
Spatial organization of land use
Distance to the city center



Spatial organization of land use
Distance to the city center



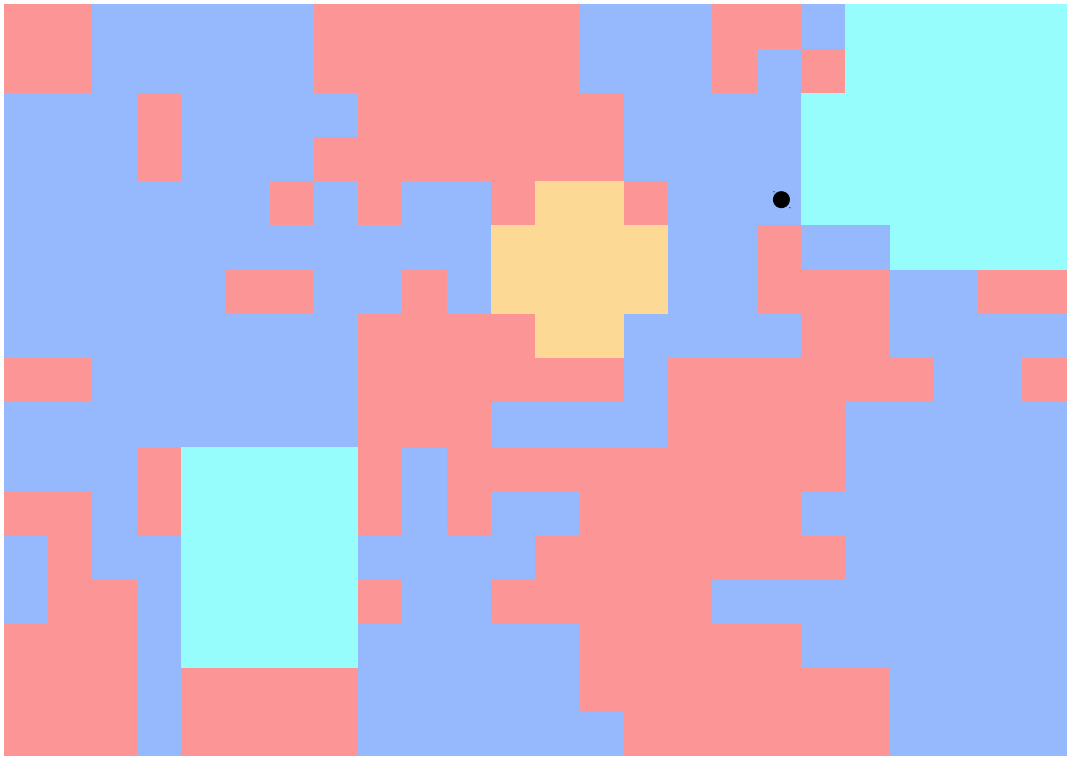
Spatial organization of land use
Ripley's K



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

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

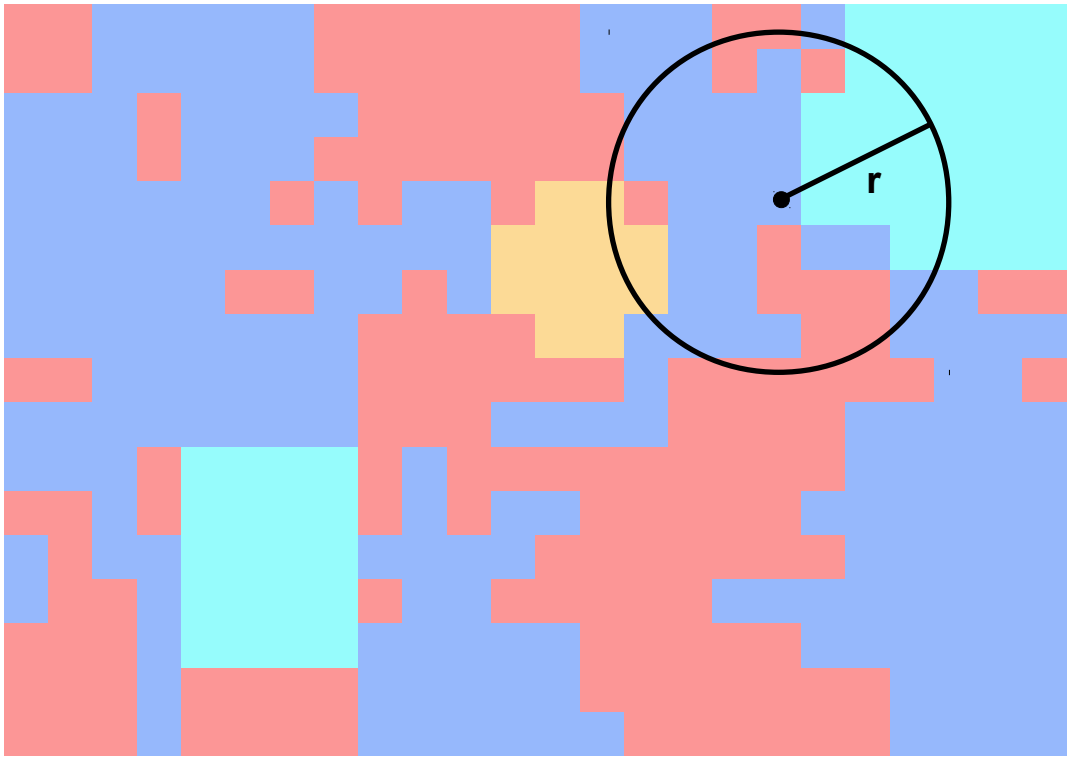
Spatial organization of land use
Ripley's K



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

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

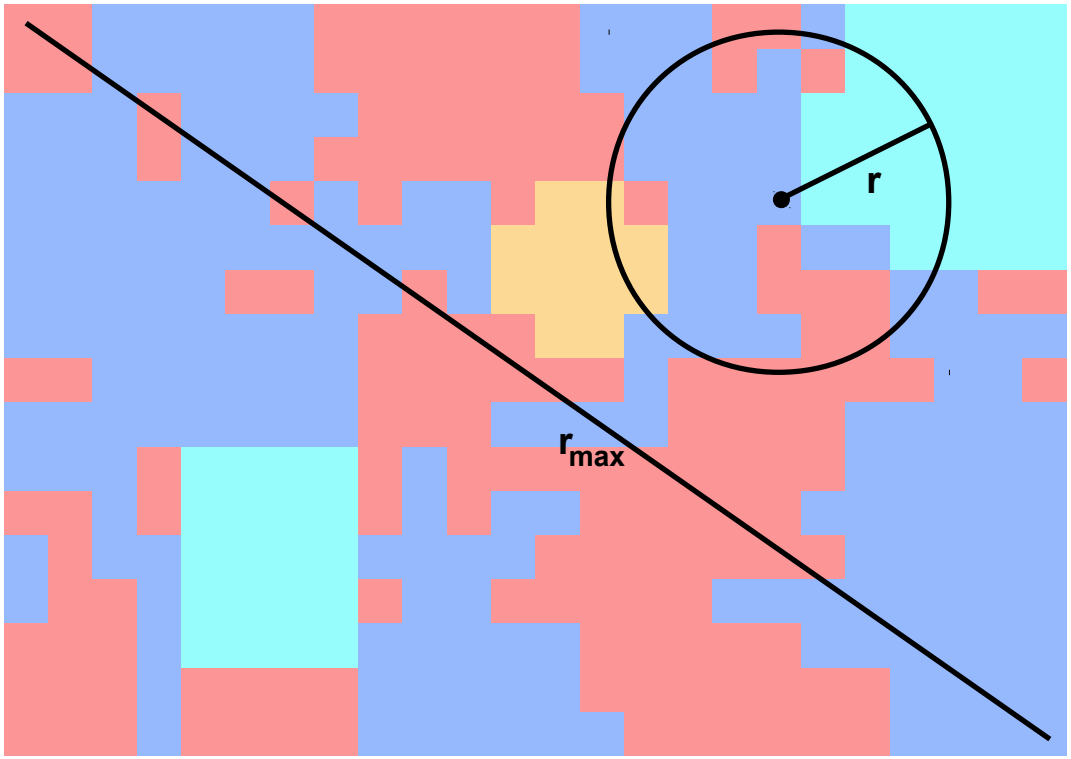
Spatial organization of land use
Ripley's K



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

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

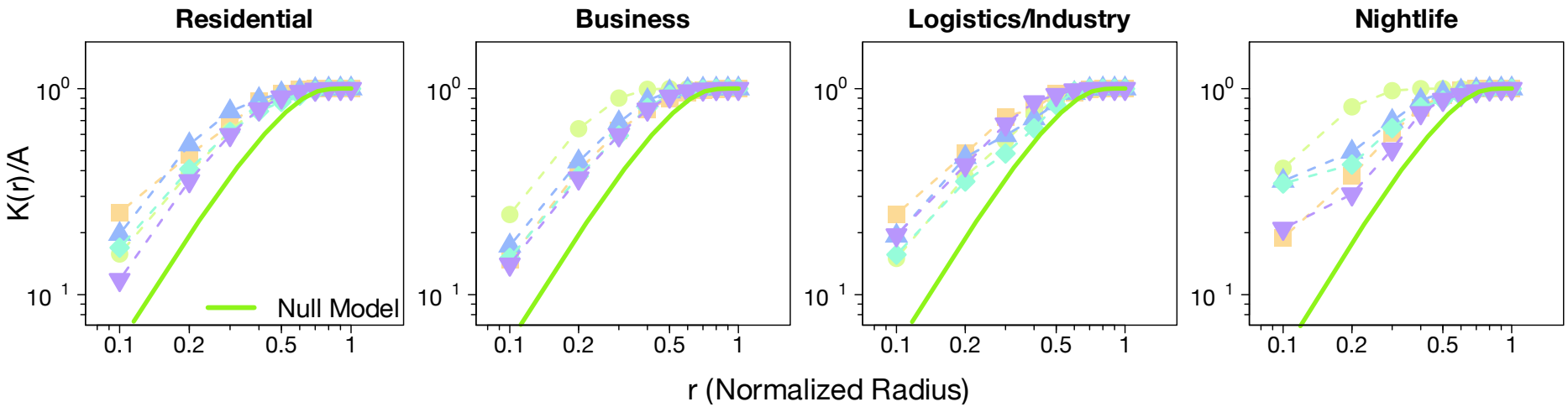
Spatial organization of land use
Ripley's K



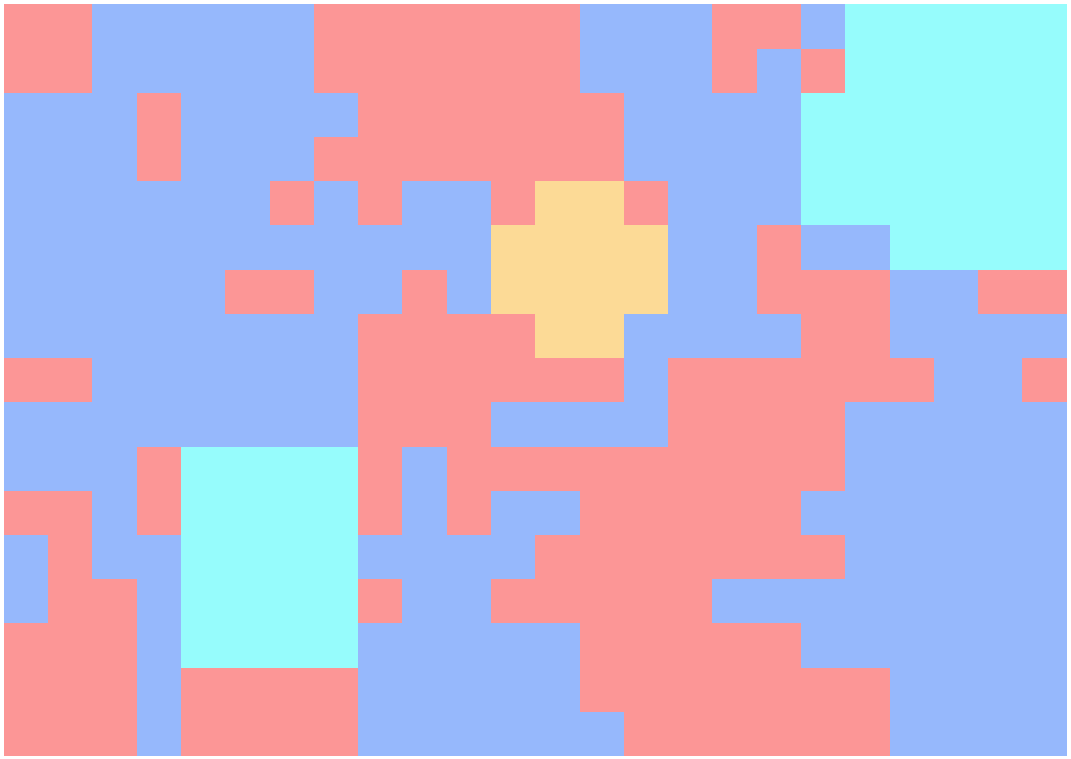
$$K(r) = \frac{A}{n^2} \sum_{i=1}^{n} N_i(r)$$

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

Spatial organization of land use
Ripley's K



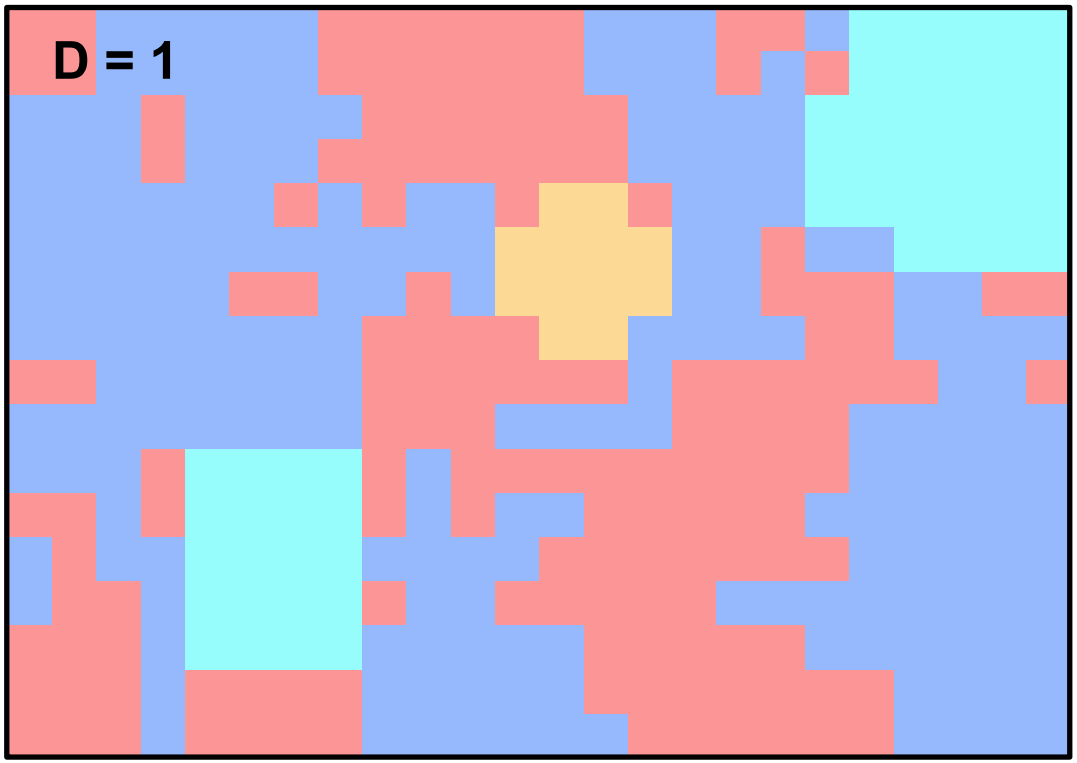
Spatial organization of land use
Entropy index



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

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

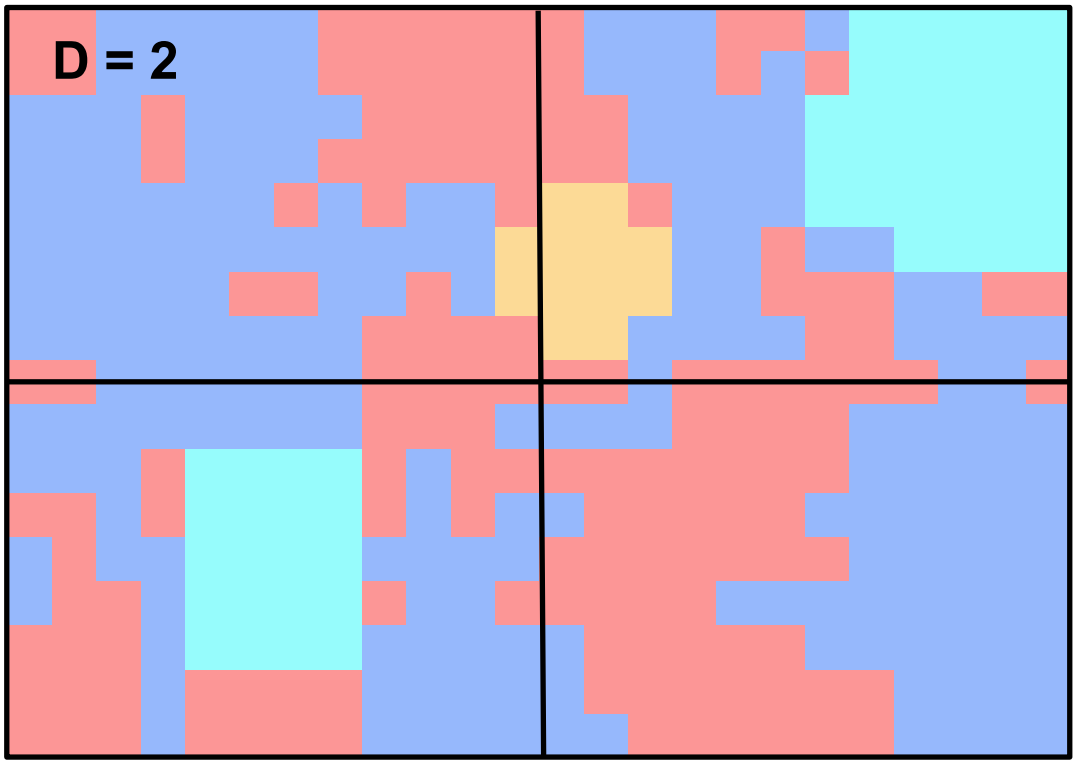
Spatial organization of land use
Entropy index



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

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

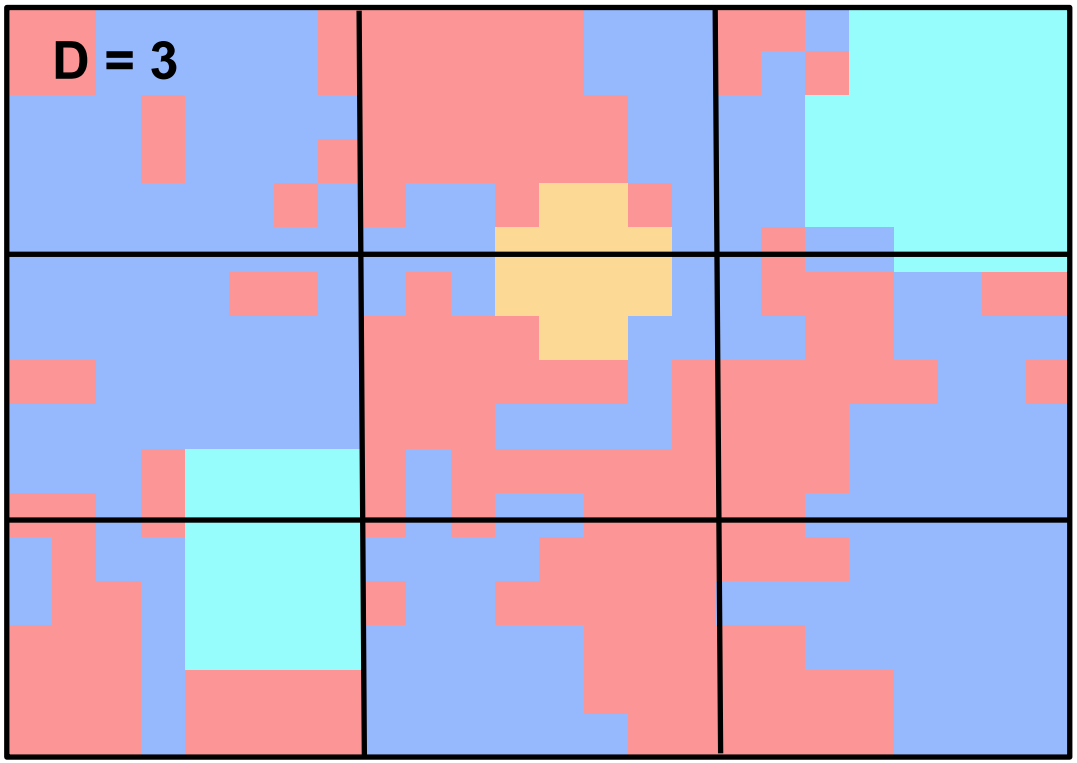
Spatial organization of land use
Entropy index



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

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

Spatial organization of land use
Entropy index

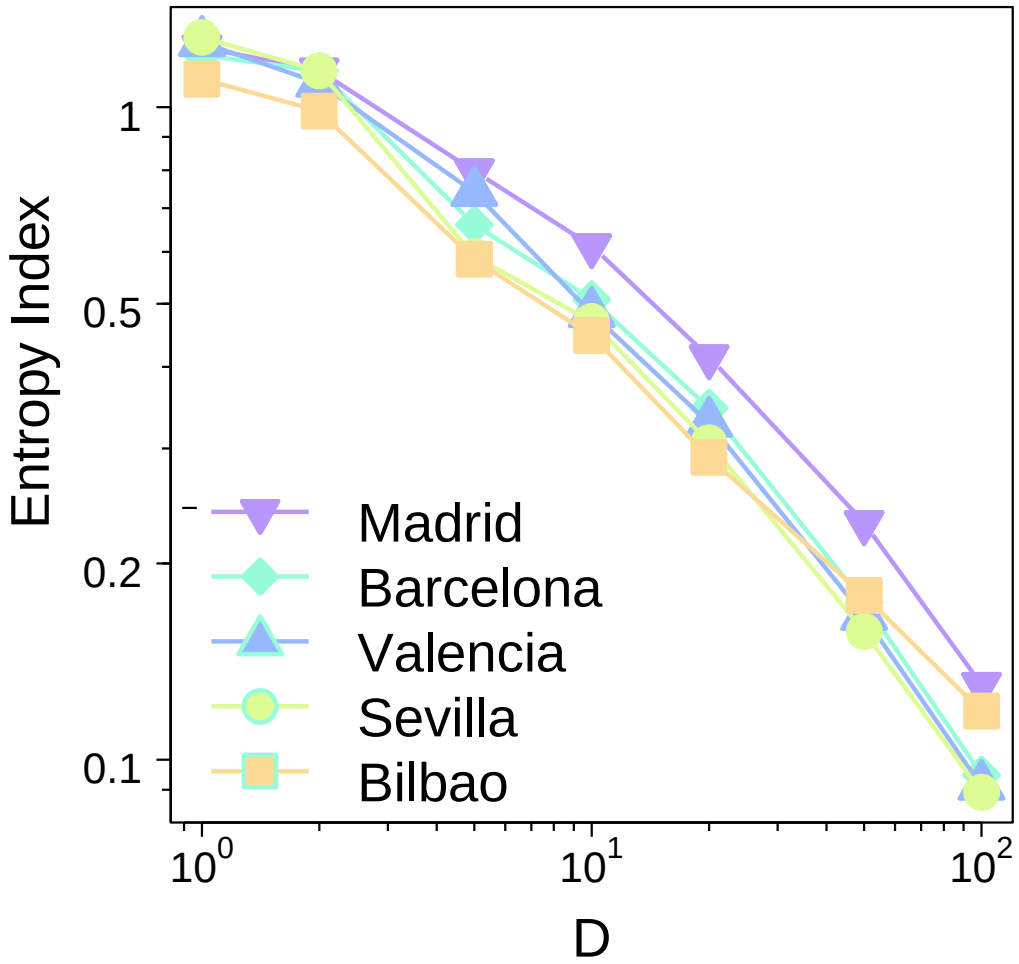


$$E_i = -\sum_{k=1}^{4} f_i^k \ln f_i^k$$

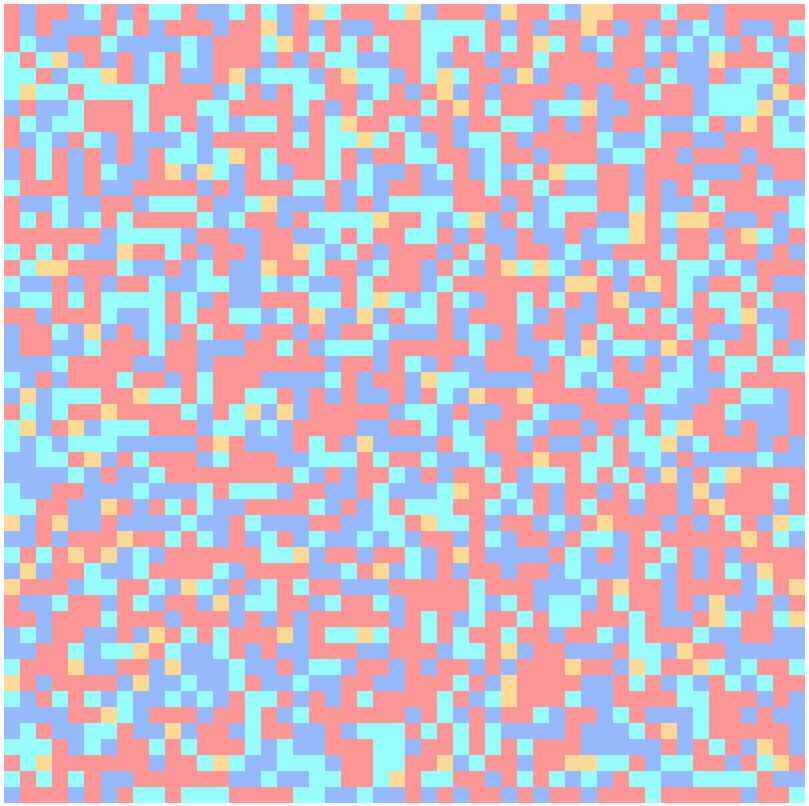
$$E(D) = \frac{1}{D^2} \sum_{i=1}^{D^2} E_i$$

Spatial organization of land use

Entropy index



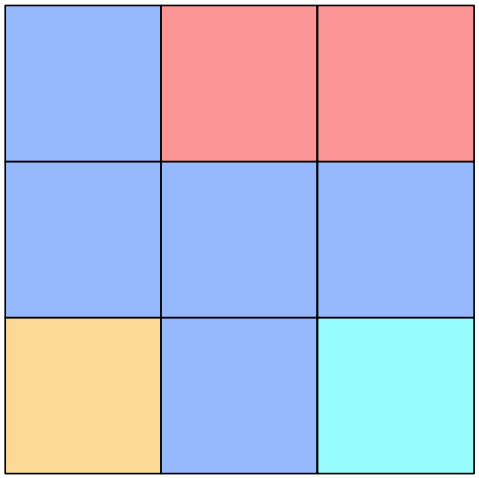
Land use model
Initial state



Land use model
Satisfaction index

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

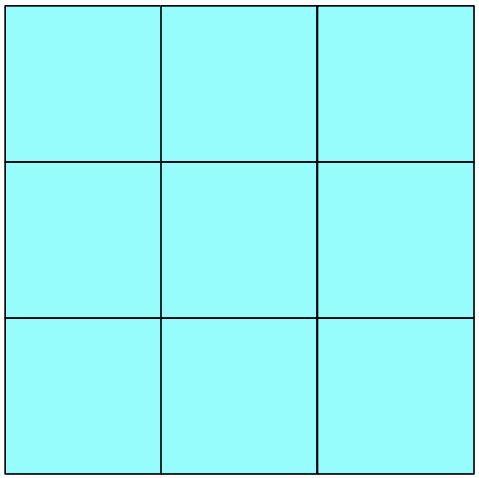
$$p = (p_1, p_2, p_3, p_4)$$



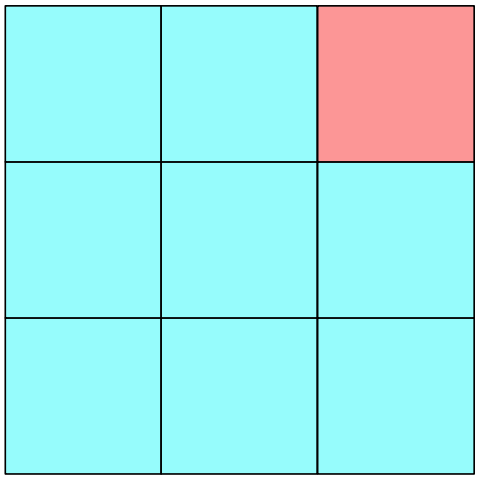
Land use model
Satisfaction index

Logistics/Industry

$S_{ij} = p_3$



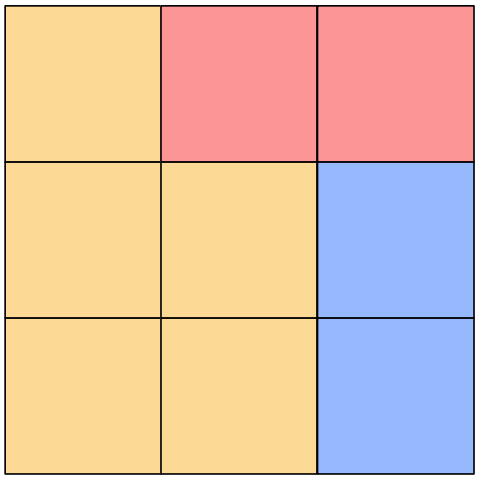
$S_{ij} = 0$



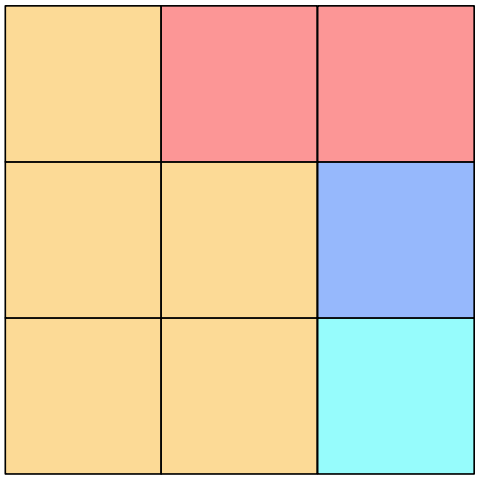
Land use model
Satisfaction index

Nightlife

$S_{ij} = p_4$



$S_{ij} = 0$

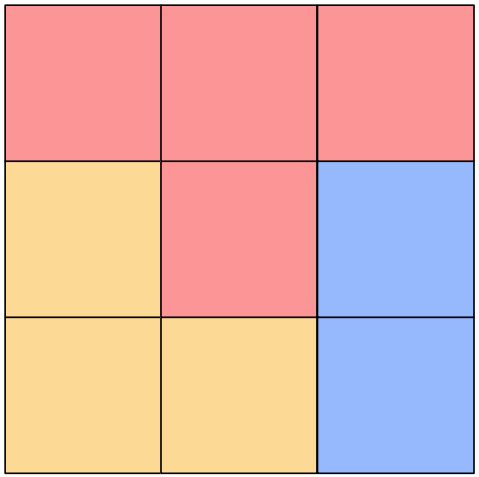


Land use model
Satisfaction index

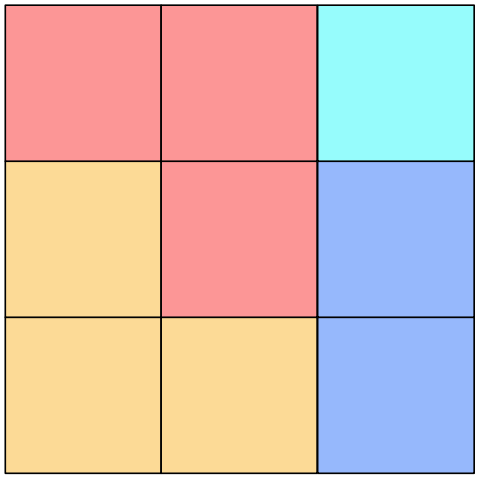
Residential

$$rand() \geq \gamma$$

$S_{ij} = p_1$



$S_{ij} = 0$

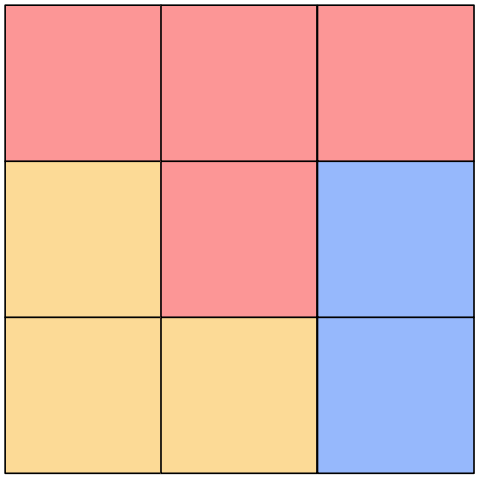


Land use model
Satisfaction index

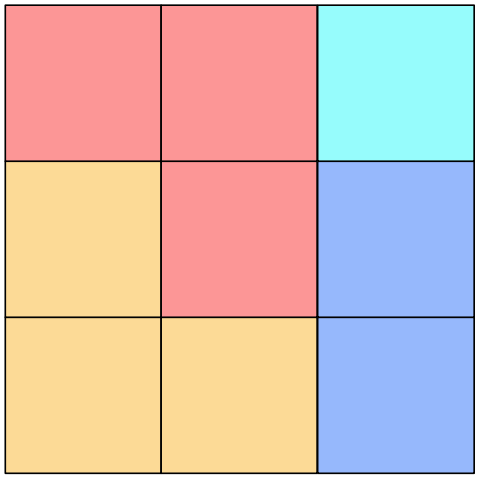
Residential

$$rand() < \gamma$$

$S_{ij} = 1$



$S_{ij} = 0$

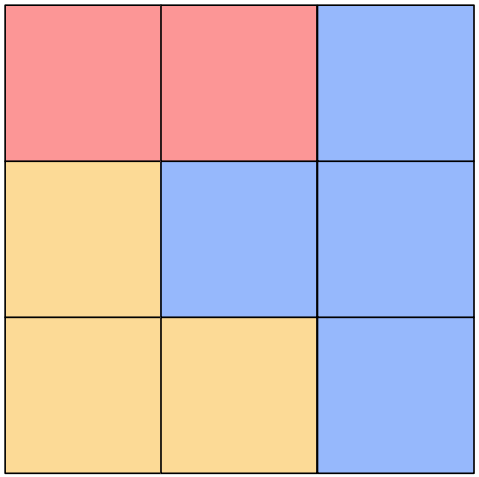


Land use model
Satisfaction index

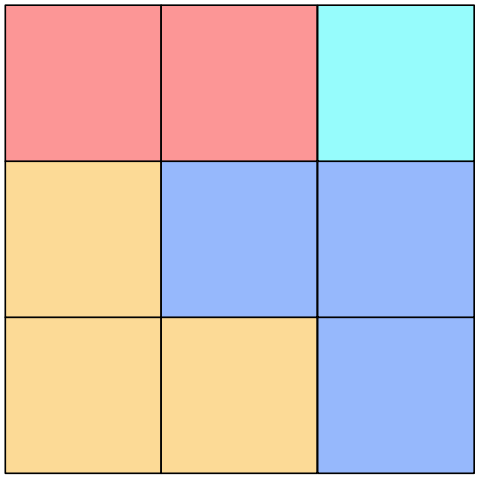
Business

$$rand() \geq \gamma$$

$S_{ij} = p_2$



$S_{ij} = 0$

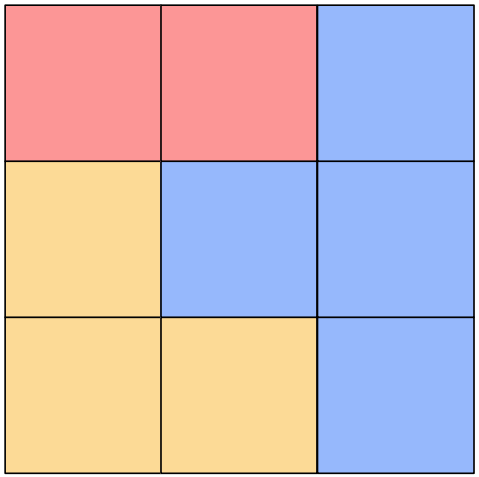


Land use model
Satisfaction index

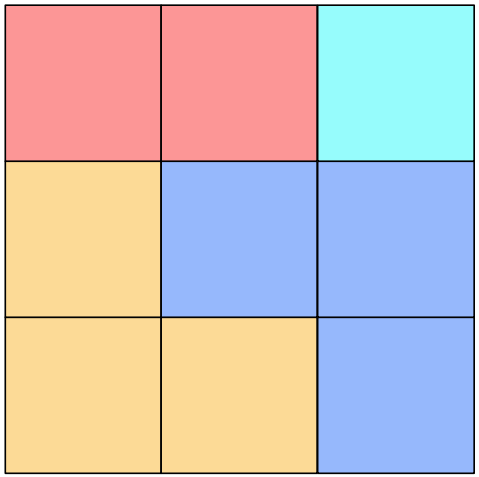
Business

$$rand() < \gamma$$

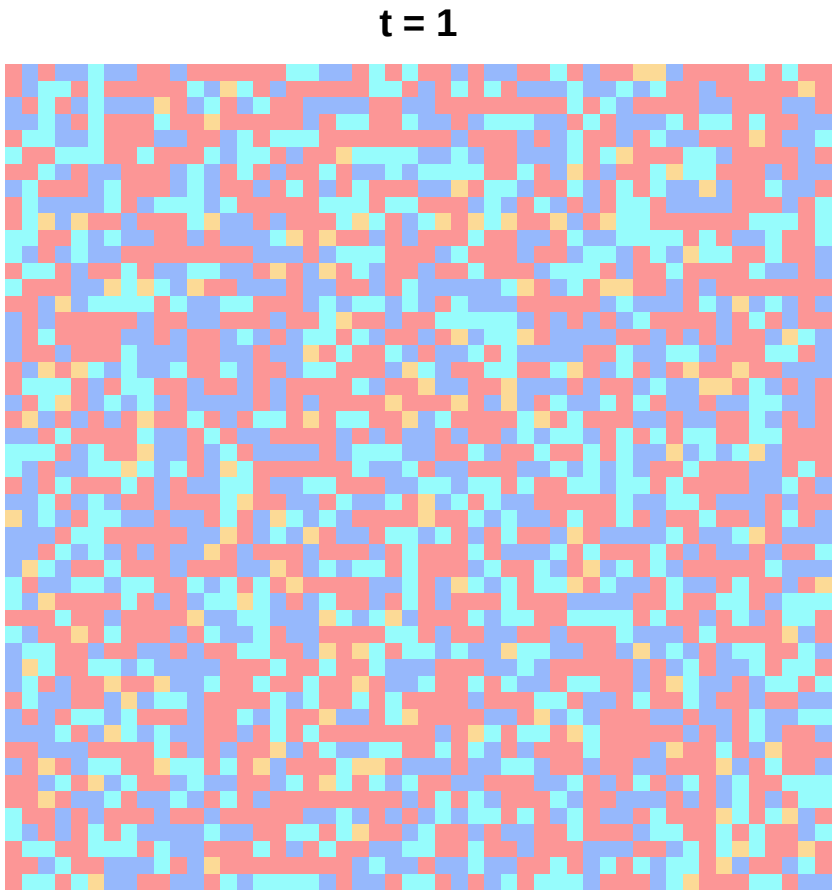
$S_{ij} = 1$



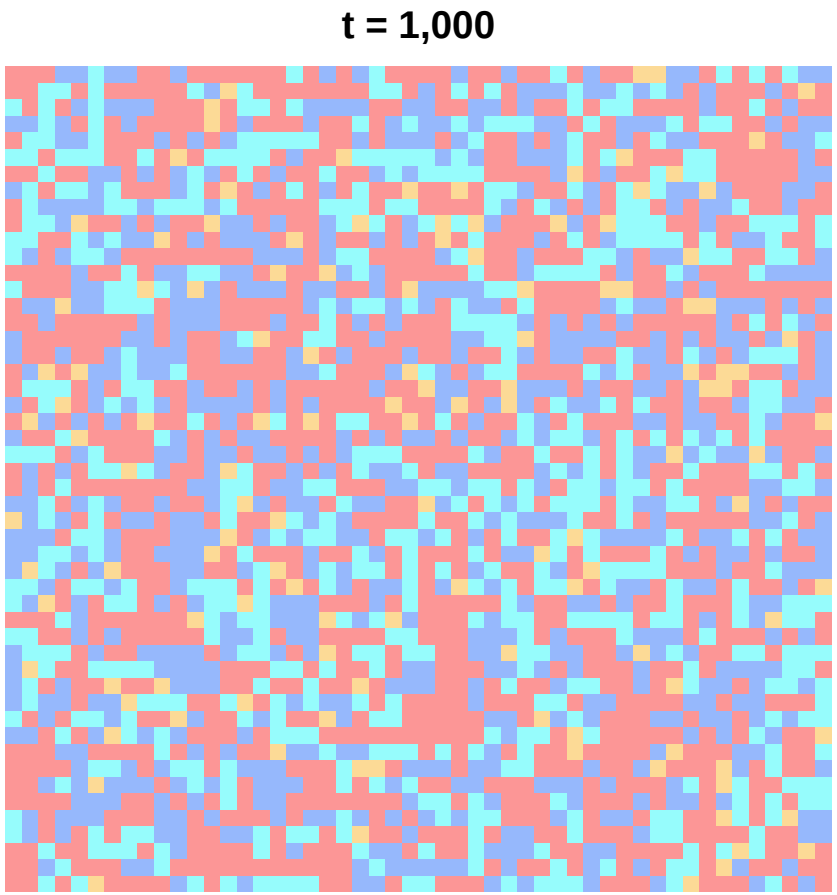
$S_{ij} = 0$



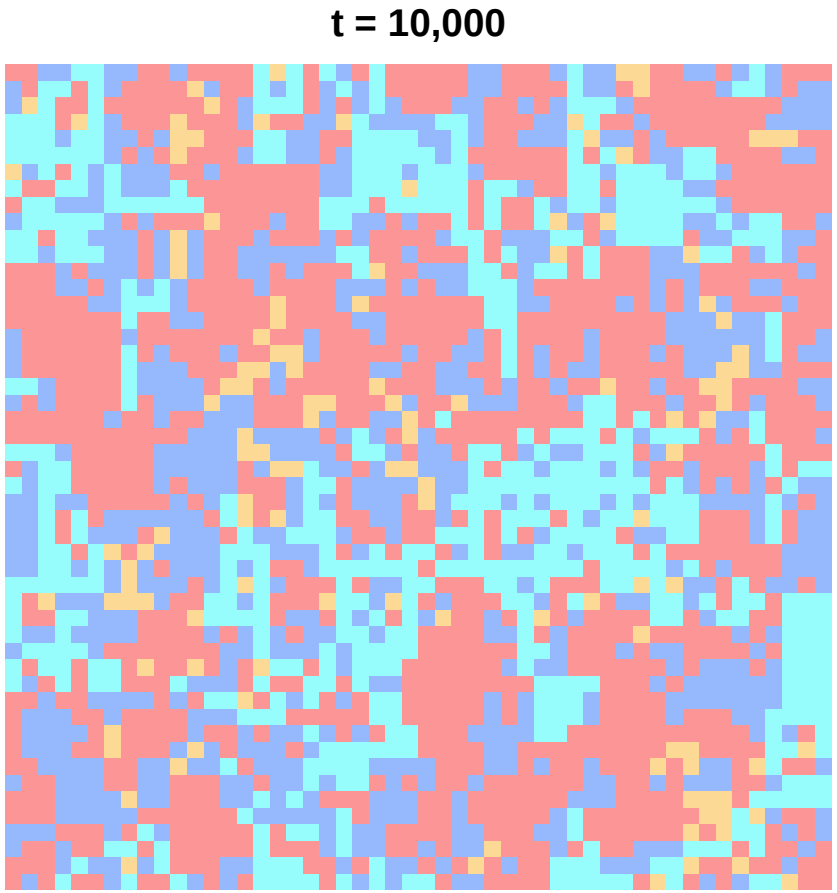
Land use model
Algorithm



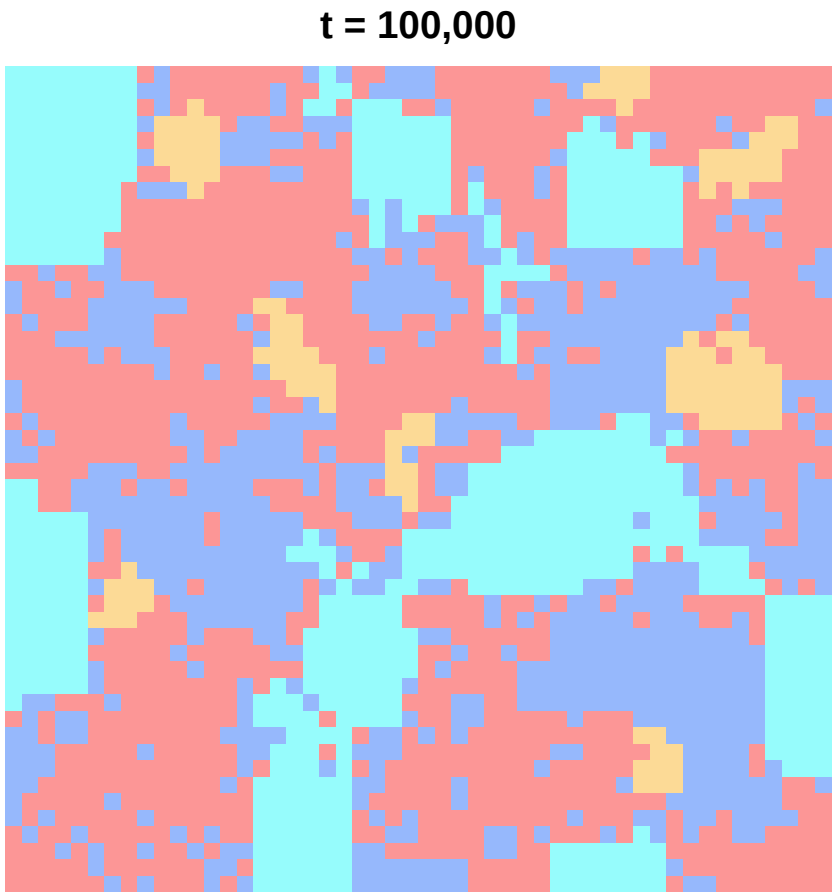
Land use model
Algorithm



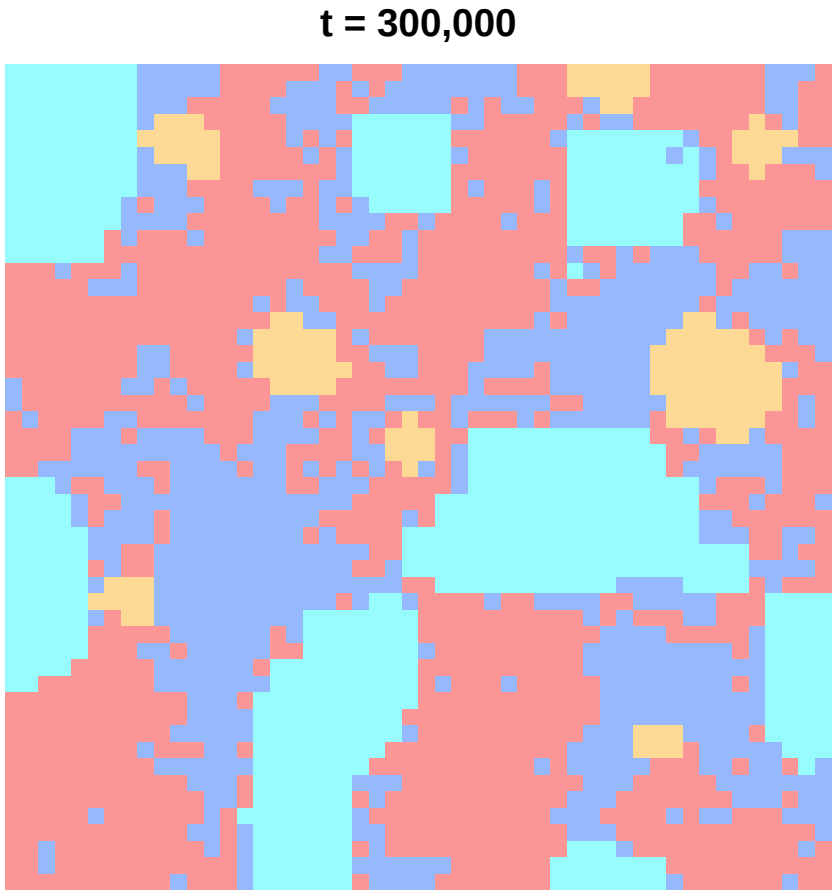
Land use model
Algorithm



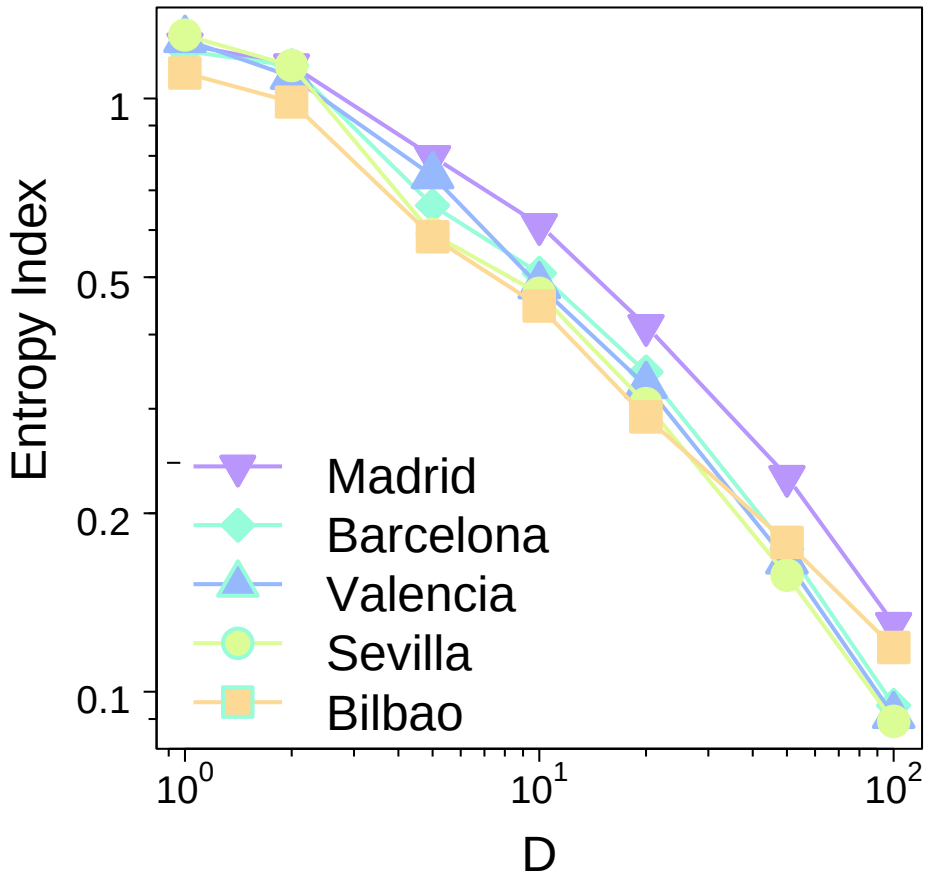
Land use model
Algorithm

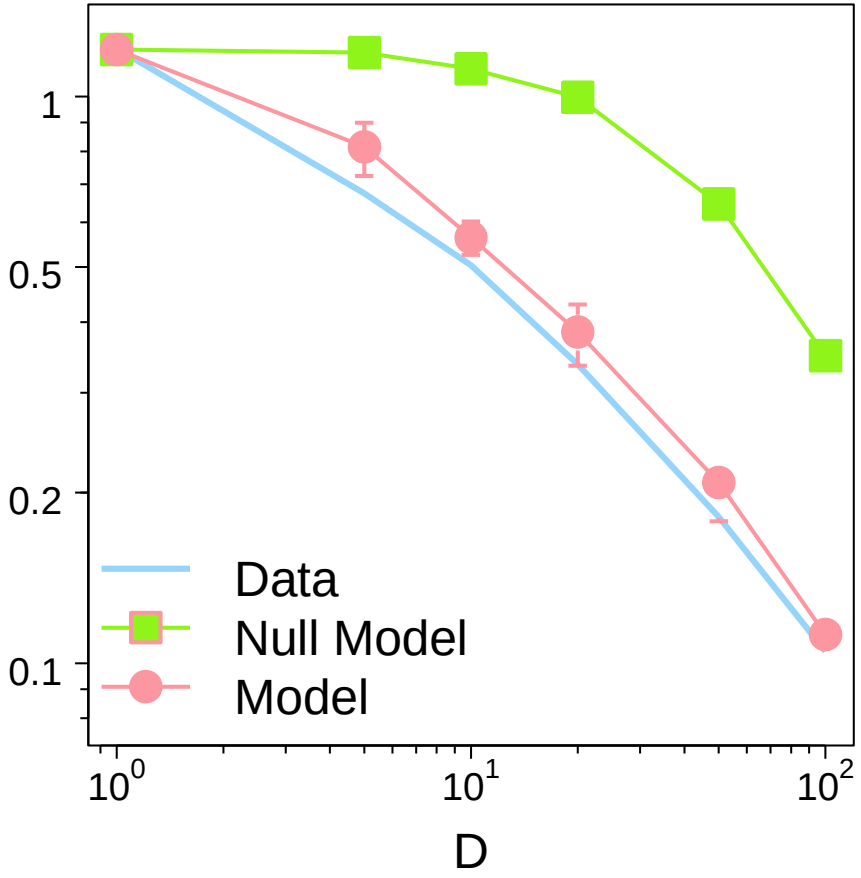


Land use model
Algorithm

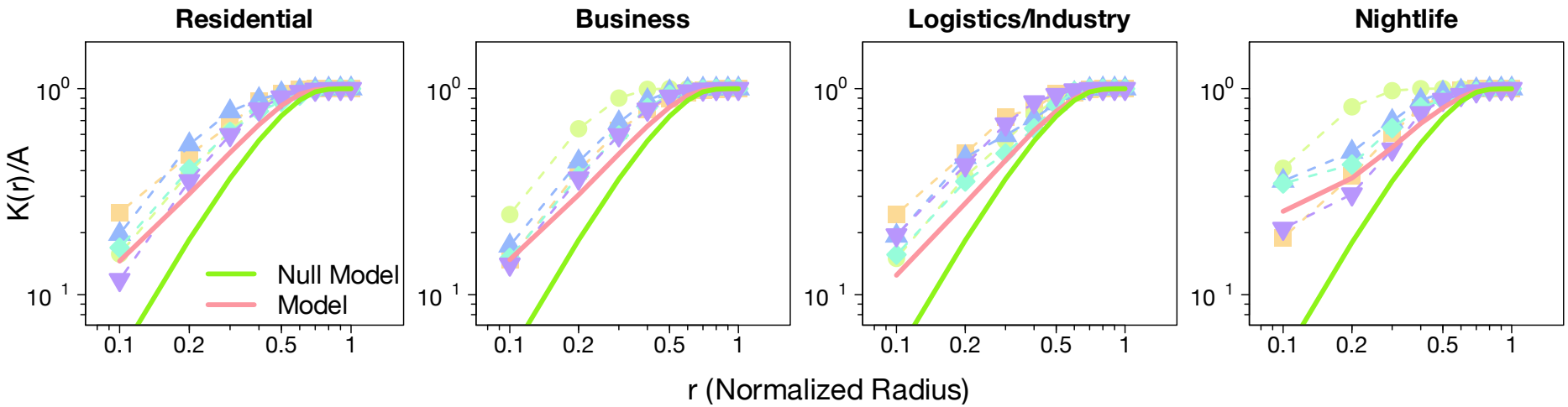


Land use model
Calibration of γ

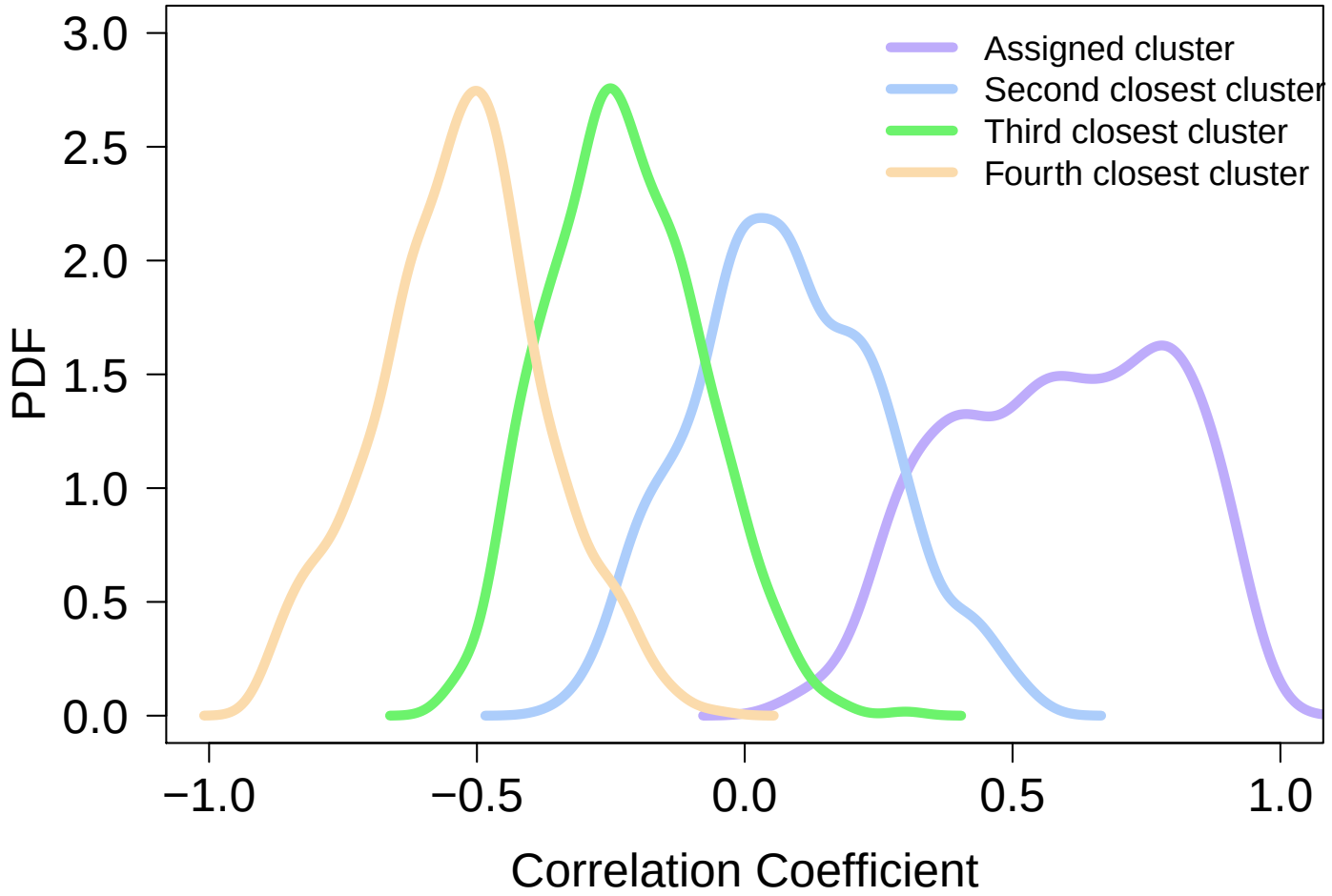




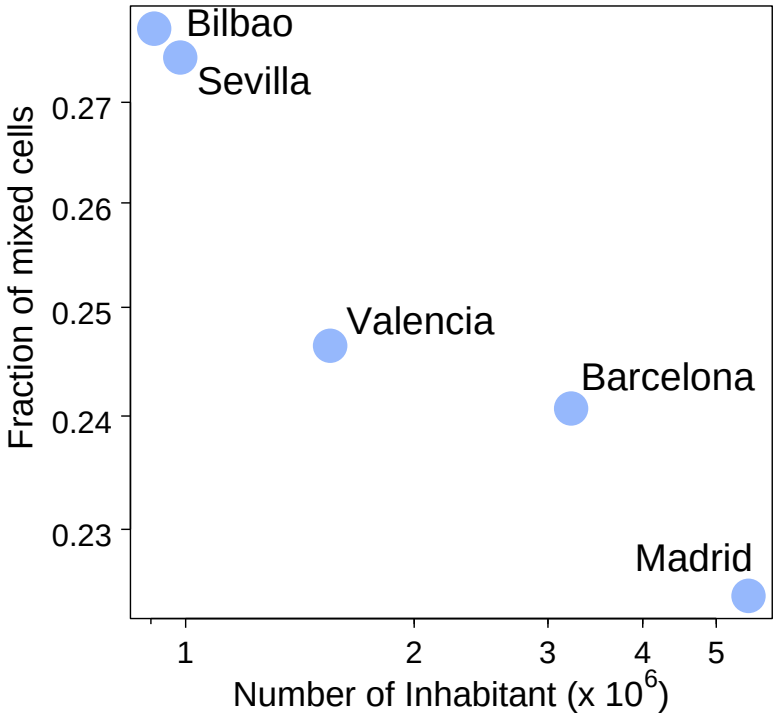
Land use model
Ripley's K

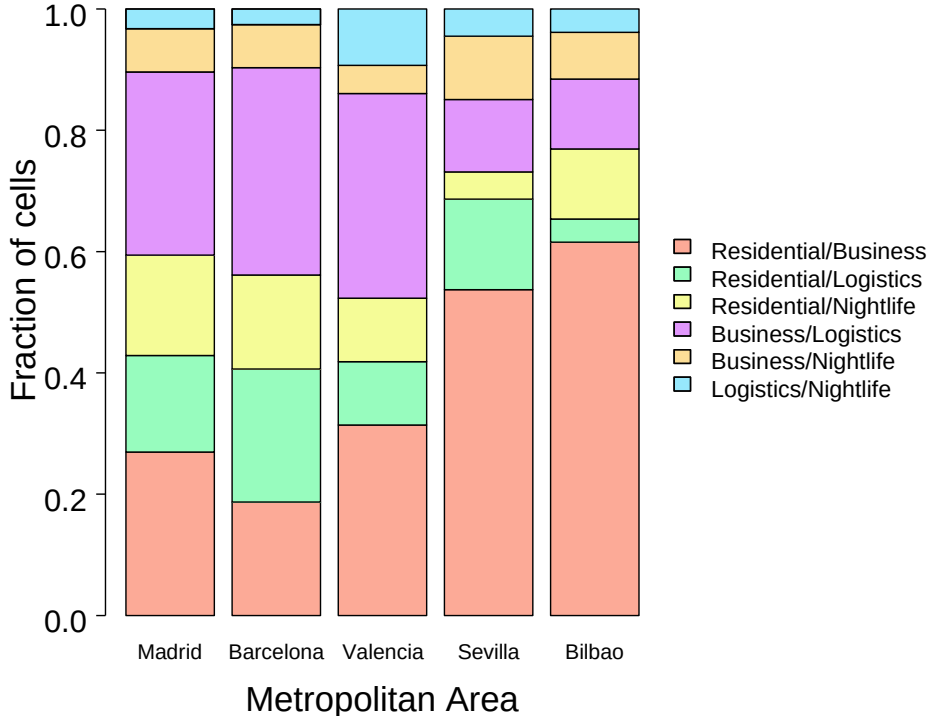


Mixing of land use



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.