Functional Network of the City
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Functional Network of the City

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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

Functional Network of the City

- Metropolitan Area
- Recordings sites
- Signals
- Functional Network
- Correlation Matrix

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CitiNet’14
September 25, 2014
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

1. Metropolitan Area
2. Recordings sites
3. Signals
4. Functional Network
5. Correlation Matrix
Land use patterns

Barcelona (PGP = 60%)
Land use patterns

Madrid (PGP = 65%)
Land use patterns

Valencia

Proportion of Mobile Phone User

Time of day
Land use patterns

Sevilla

Proportion of Mobile Phone User

Time of day
Land use patterns

Bilbao

Proportion of Mobile Phone User

Time of day
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 $K$

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

\[
\hat{K}(r) = \frac{K(r)}{K(1)}
\]
Spatial organization of land use
Ripley’s K

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

\[ \hat{K}(r) = \frac{K(r)}{K(1)} \]
Spatial organization of land use

Ripley’s $K$

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

$$\hat{K}(r) = \frac{K(r)}{K(1)}$$
Spatial organization of land use
Ripley’s $K$

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

\[
\hat{K}(r) = \frac{K(r)}{K(1)}
\]
Spatial organization of land use
Ripley’s K

- Residential
- Business
- Logistics/Industry
- Nightlife

K(r)/A vs. r (Normalized Radius)
Spatial organization of land use

Entropy index

\[ E_i = - \sum_{k=1}^{4} f_{ik} \ln f_{ik} \]

\[ E(D) = \frac{1}{D^2} \sum_{i=1}^{D^2} E_i \]
Spatial organization of land use
Entropy index

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

\[ E(D) = \frac{1}{D^2} \sum_{i=1}^{D^2} E_i \]
Functional Network of the City

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

- Madrid
- Barcelona
- Valencia
- Sevilla
- Bilbao
Land use model
Initial state
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

\[ \text{rand}(\cdot) \geq \gamma \]

\[ S_{ij} = p_1 \]

\[ S_{ij} = 0 \]
Land use model
Satisfaction index

Residential

\[ \text{rand}() < \gamma \]

\[ S_{ij} = 1 \]

\[ S_{ij} = 0 \]
Land use model
Satisfaction index

Business

\[ \text{rand}(\cdot) \geq \gamma \]

\[ S_{ij} = p_2 \quad \text{or} \quad S_{ij} = 0 \]
Land use model
Satisfaction index

Business

$$\text{rand}() < \gamma$$

$$S_{ij} = 1$$

$$S_{ij} = 0$$
Land use model
Algorithm

$t = 1$
Land use model
Algorithm
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 $\gamma$

![Graph showing entropy index vs. D for different cities (Madrid, Barcelona, Valencia, Sevilla, Bilbao)]

![Graph showing data and model comparison for entropy index vs. D]

- Madrid
- Barcelona
- Valencia
- Sevilla
- Bilbao

$\gamma$ Entropy Index

- Data
- Null Model
- Model
Land use model
Ripley’s K

- Residential
- Business
- Logistics/Industry
- Nightlife

$K(r)/A$ vs $r$ (Normalized Radius)

- Null Model
- Model

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Mixing of land use

![Graph showing mixing of land use with correlation coefficient and PDF distributions for assigned and closest clusters.](image)

- Assigned cluster
- Second closest cluster
- Third closest cluster
- Fourth closest cluster

Correlation Coefficient vs. PDF distribution.
Mixing of land use

- Madrid
- Barcelona
- Valencia
- Sevilla
- Bilbao

Number of Inhabitant (x 10^6)

Fraction of mixed cells

Fraction of cells

Metropolitan Area

- Residential/Business
- Residential/Logistics
- Residential/Nightlife
- Business/Logistics
- Business/Nightlife
- Logistics/Nightlife
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
Lenormand et al. Comparing and modeling land use organization in cities.