# Sampling Urban Mobility through On-line Repositories of GPS Tracks

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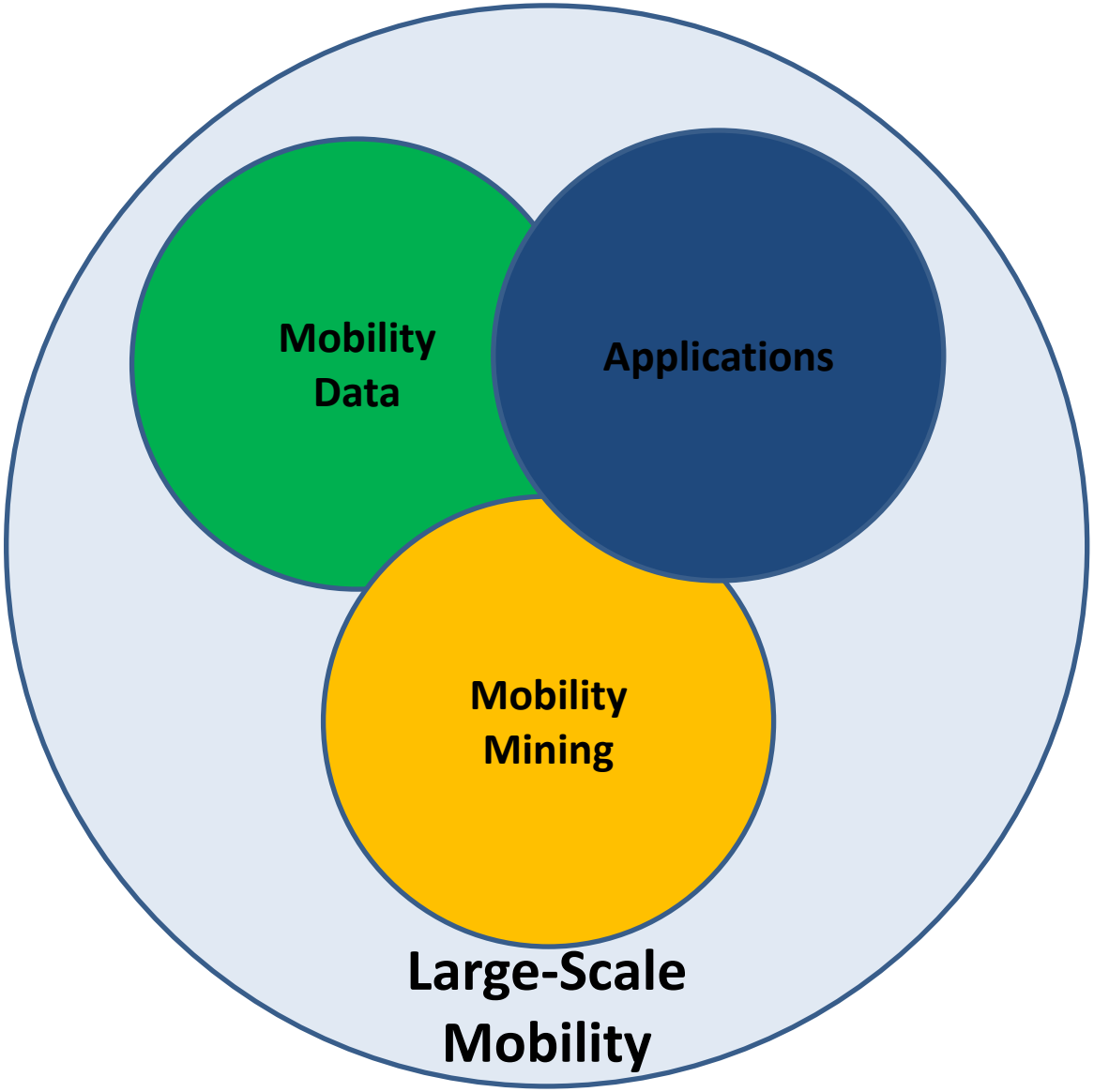
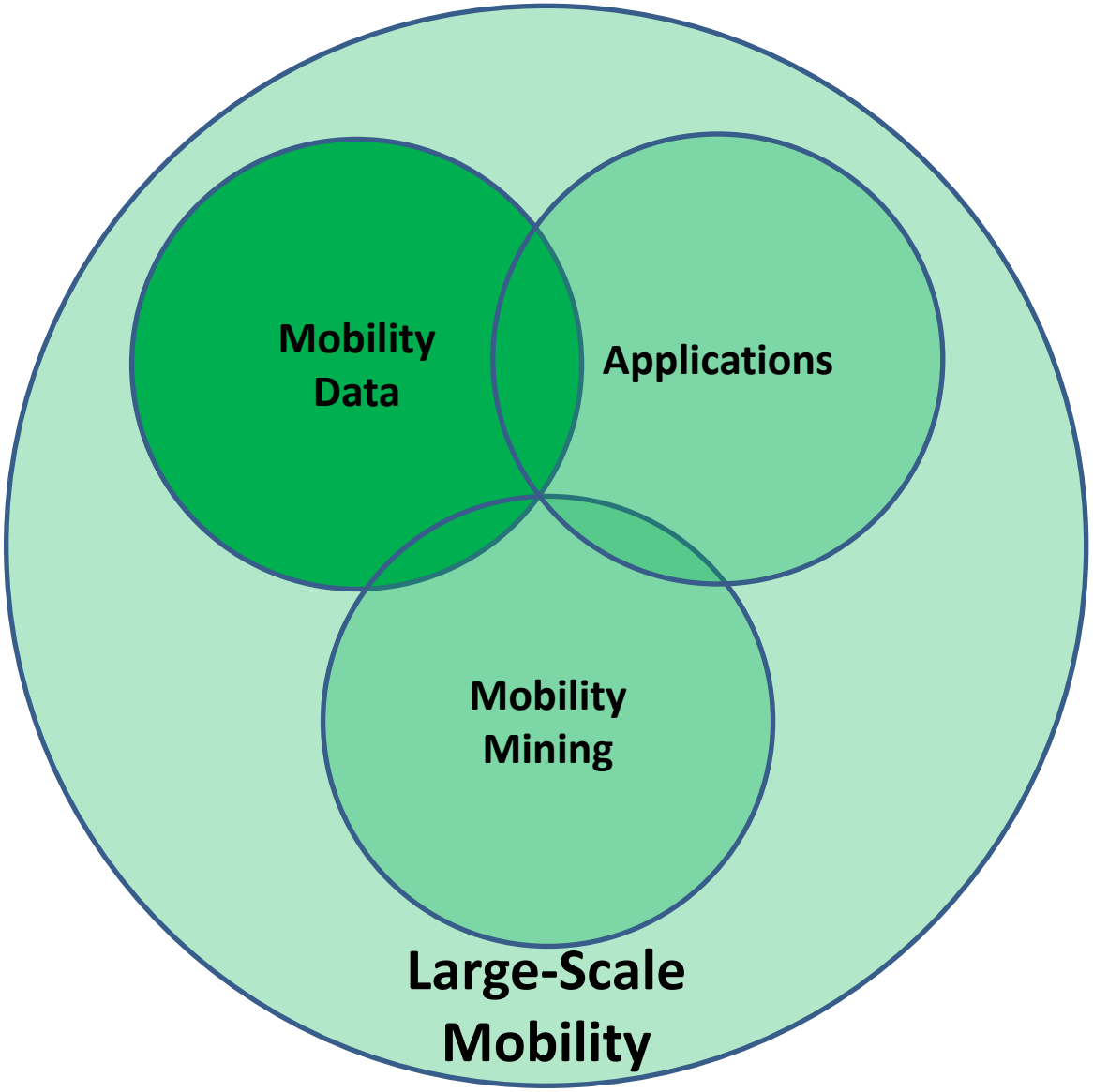
Hot Topics of Planet-scale Mobility Measurements

# Motivation

- *Mobility mining* for:
  - Mobility **modeling**
  - Communication protocol **design**
  - Mobile system **evaluation**
- *Mobility mining* <u>not only</u> for networking:
  - Social science
  - Urban planning
  - Epidemiology

# Outline


Mobility Data
Applications
Mobility Mining
Large-Scale Mobility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# Large-Scale Mobility Data

- Types
  - *Contact-based* (Bluetooth)
  - *Track-based* (geo-location, AP/BS association)
  - *Usage-based* (phone calls, WiFi data traffic)

- *Where to get it from?*
  - Personal interviews [HsuMSHH05]
  - Telecoms, WLAN operators [BalazinskaC03], [GonzalesHB08]
  - Controlled experiments [EagleP06], [JangYZ08]

# Large-Scale Mobility Data

- **Problems**
  - Scalability
  - Recruitment
  - User's Privacy
  - Spatiotemporal Granularity

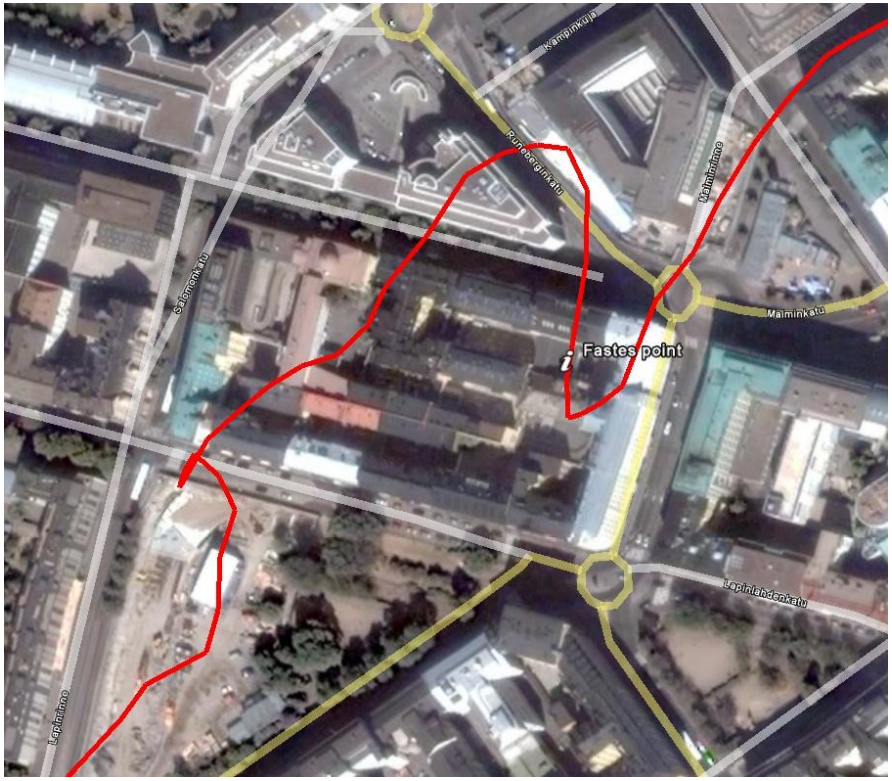
- **Solution**
  - Rely on self-contributed mobility traces available through on-line repositories of GPS tracks

# Mobility *Data*


- Short-term mobility
  - ***Nokia Sports Tracker*** (NST) http://sportstracker.nokia.com
    - Since April, 2007
    - >2.5 million downloads (February 2009)
    - The best mobile Internet service (Mobile World Congress 2009)
  - Dataset:
    - 125’000 traces worldwide in **`kml`** files
    - 15 months: June 2007 – September 2008
    - Context: *walking, running, cycling, driving, etc.*

# Mobility *Data*

- NST track data
- GPS errors unavoidable




| | |
|---|---|
| user | nickname |
| type of activity | e.g. walking |
| start time | date hh:mm |
| duration | hh:mm:ss |
| traveled distance | km |
| average speed | km/h |
| maximum speed | km/h |
| average pace | 1/km |
| maximum pace | 1/km |
| the route | set of waypoints |

# Mobility *Data*

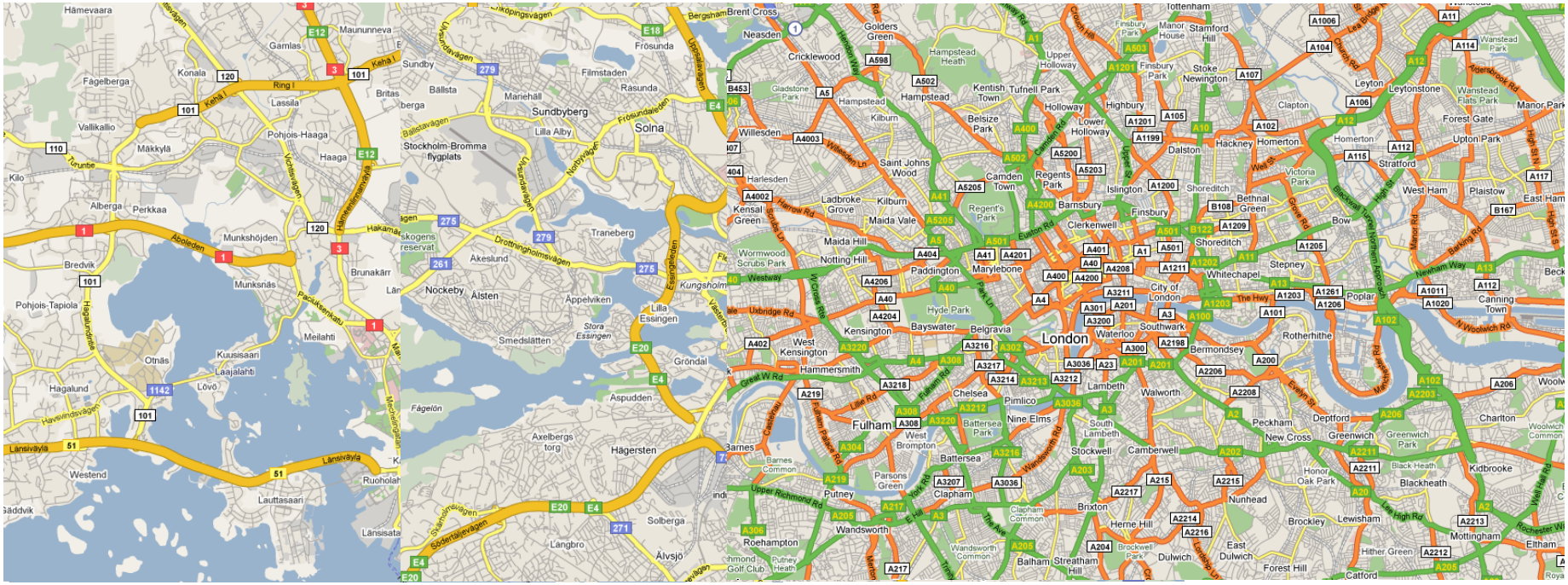
- Filtering spurious tracks

| | | Raw [km/h] | | Filtered [km/h] | |
|---|---|---|---|---|---|
| | | $\hat{\mu}_v$ | $\hat{\sigma}_v^2$ | $\hat{\mu}_v$ | $\hat{\sigma}_v^2$ |
| Helsinki | Walking | 7.75 | 180.15 | **6.37** | **46.11** |
| | Running | 10.83 | 551.24 | **9.85** | **4.10** |
| | Cycling | 18.81 | 69.82 | **17.59** | **35.26** |
| Stockholm | Walking | 6.65 | 191.22 | **6.18** | **10.52** |
| | Running | 11.19 | 45.59 | **10.35** | **11.89** |
| | Cycling | 18.16 | 41.70 | **16.98** | **23.82** |
| London | Walking | 8.08 | 321.23 | **7.48** | **24.70** |
| | Running | 11.05 | 11.70 | **11.07** | **6.33** |
| | Cycling | 19.27 | 614.94 | **18.29** | **36.62** |

[Bramble04] D. M. Bramble, D. E. Lieberman, **Endurance running and the evolution of *Homo***
*Nature,* November 2004

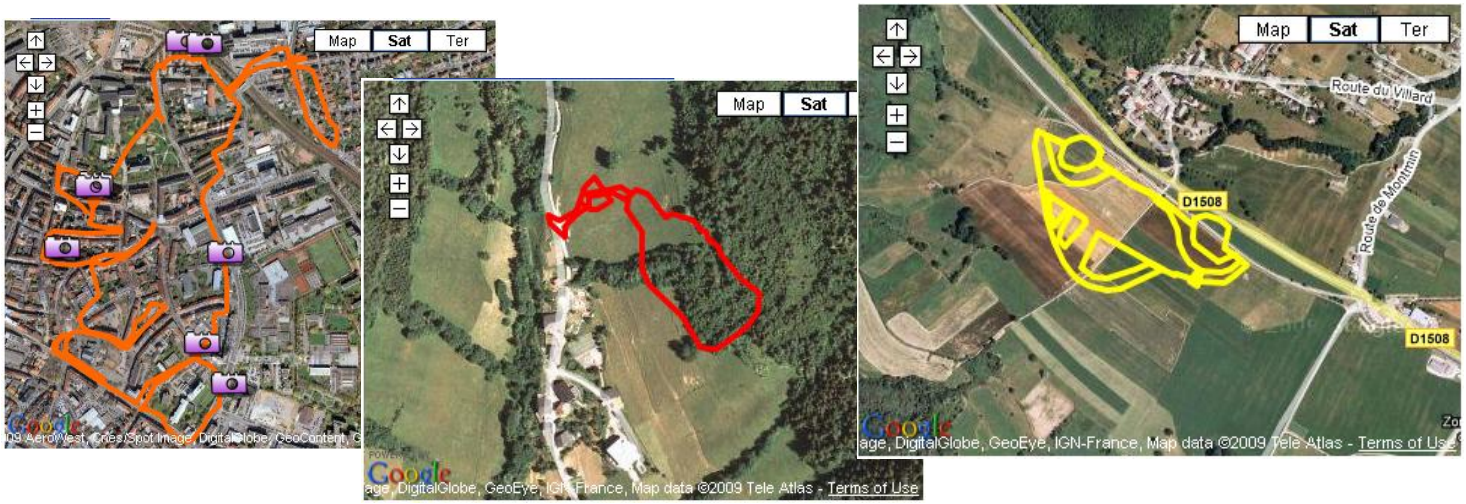
# Mobility *Data*

- Helsinki: **731** users, **3757** traces
- Stockholm: **157** users, **1056** traces
- London: **504** users, **2488** traces



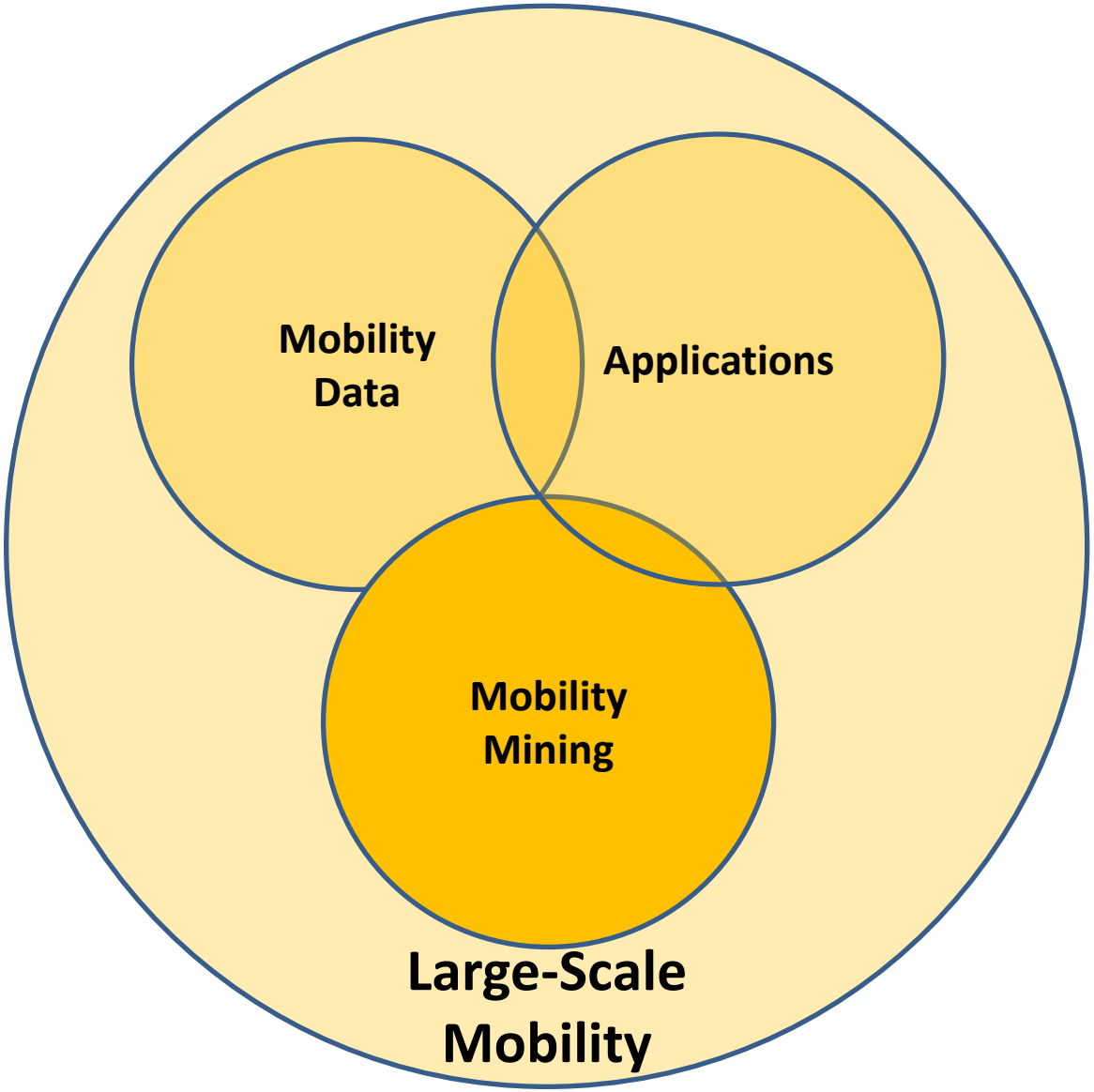
# Mobility *Data*

- Is NST based data *representative*?
  - Utility cycling vs. recreational cycling
  - NST position art by Peter Rullmann




NST no longer *Sports* but *Life* Tracker

**"How Nokia Users Drive Innovation"** *Business Week*, April 30, 2008 (http://bit.ly/V6A9h)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# Mobility *mining*

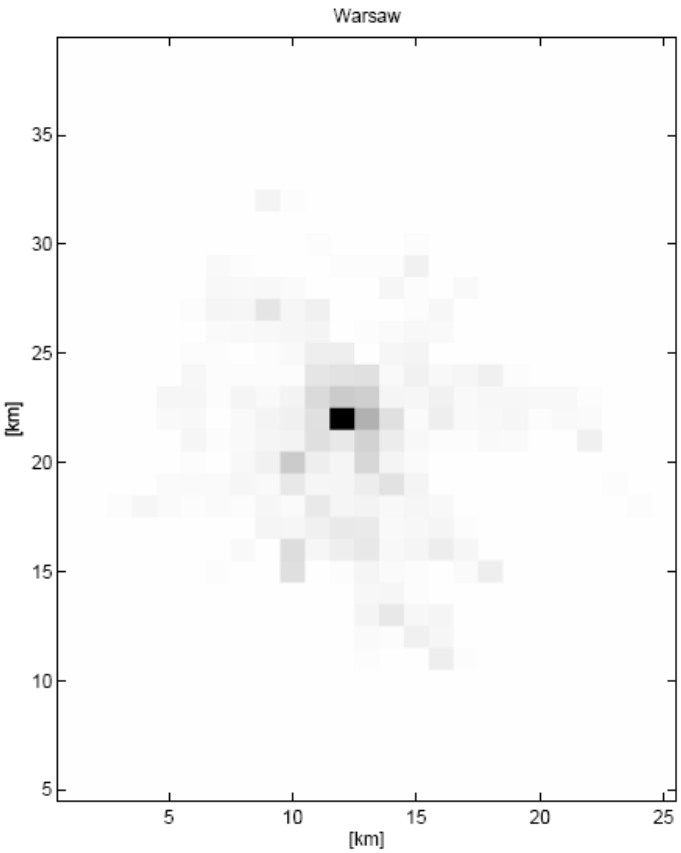
- *Short-term* vs. *long-term* mobility
  - *Long-term:* locations of individuals recorded on regular basis independently on their activities
  - *Short-term*: occasional snapshots of long-term mobility

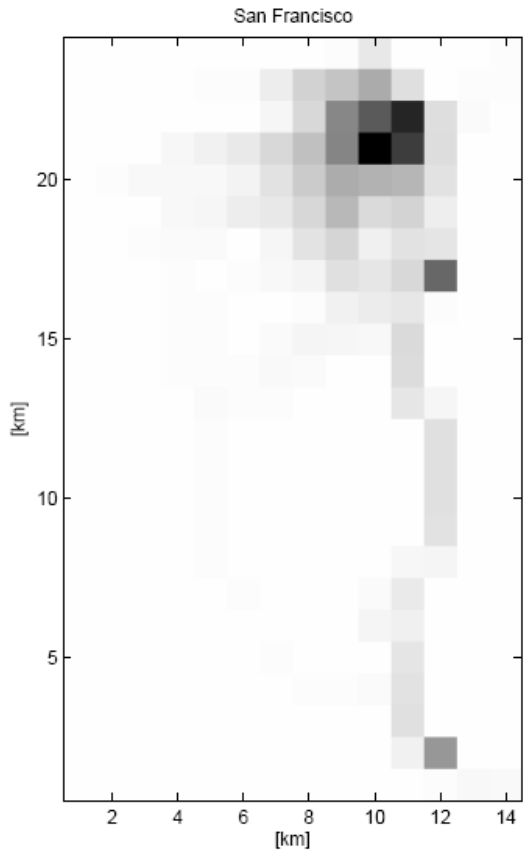
Do mobility patterns, inferred from short and long term mobility traces, share similar *macroscopic characteristics*?

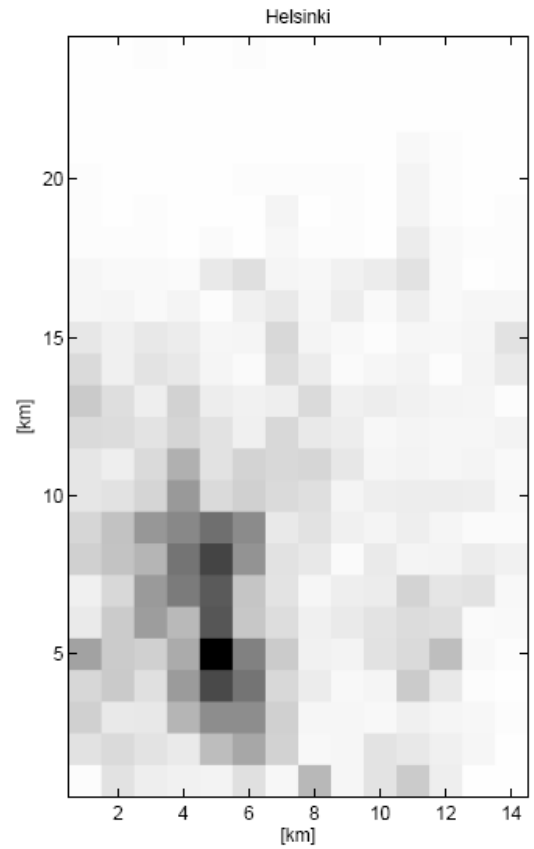
# Long-term mobility

- Warsaw [Sarafijanovic-DjukicPG06]
  - 825 cabs
  - 92 days
  - >517 km$^2$
- San Francisco [PiorkowskiSDG09]
  - 536 cabs
  - 26 days
  - >600 km$^2$

# Spatial Heterogeneity



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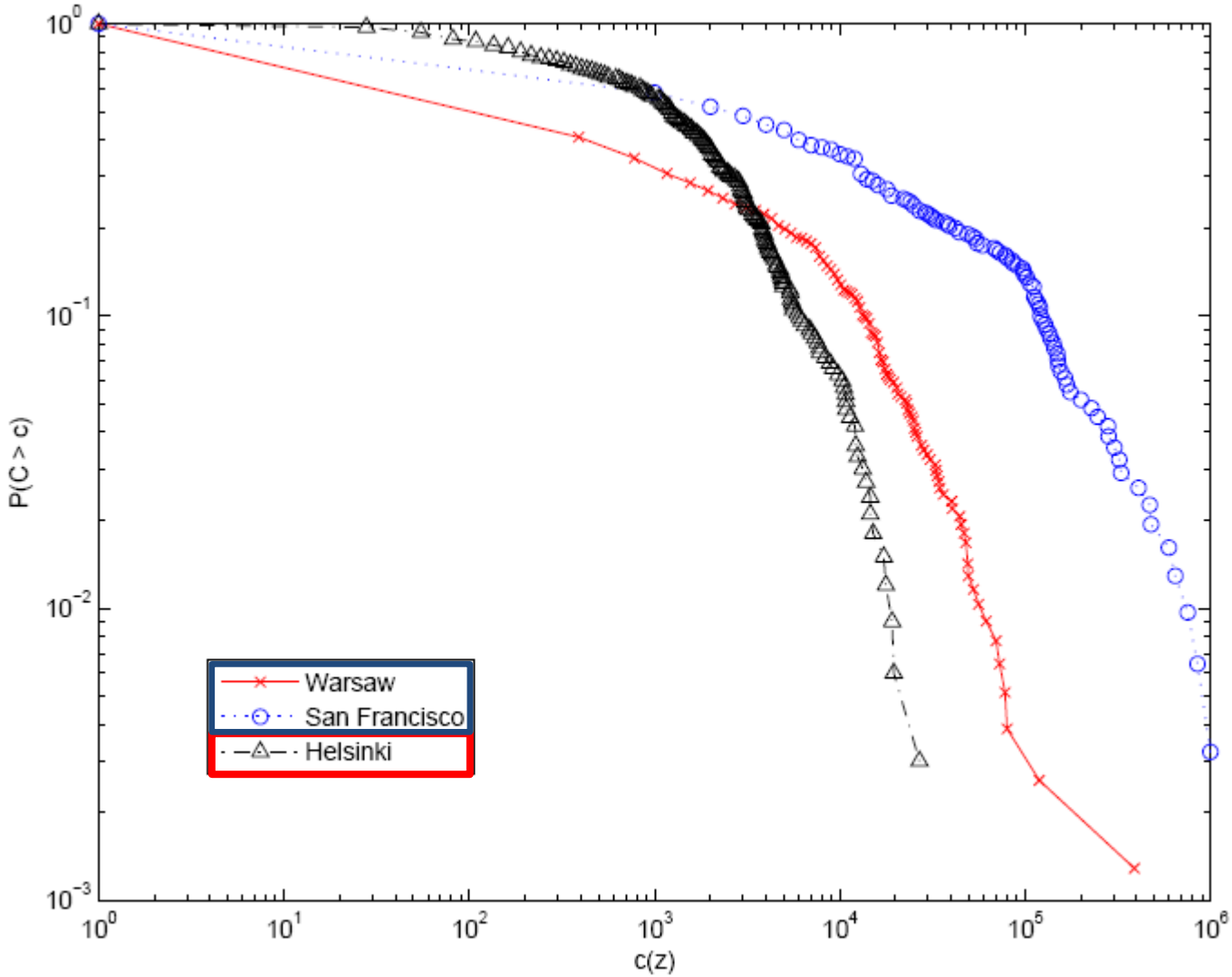
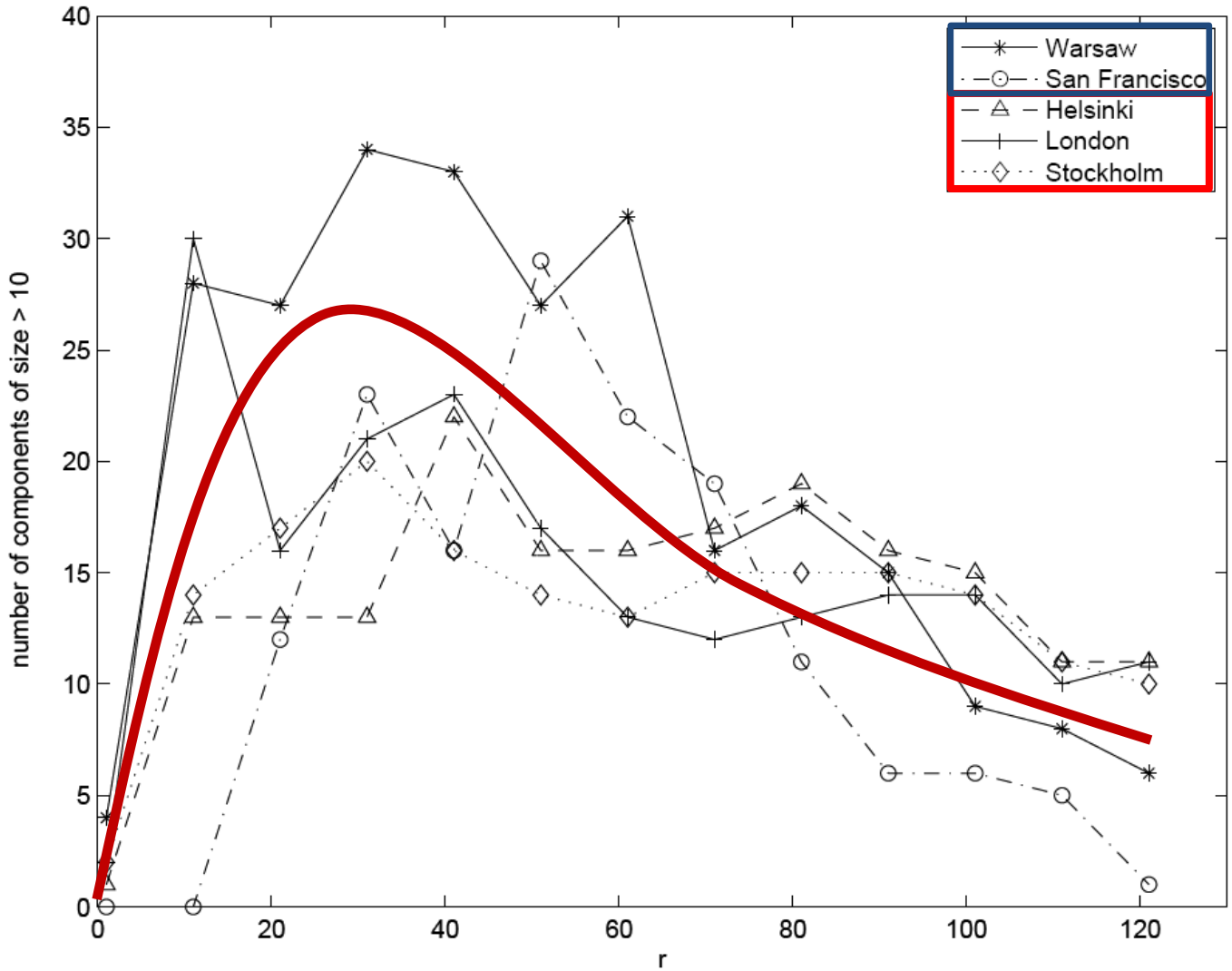
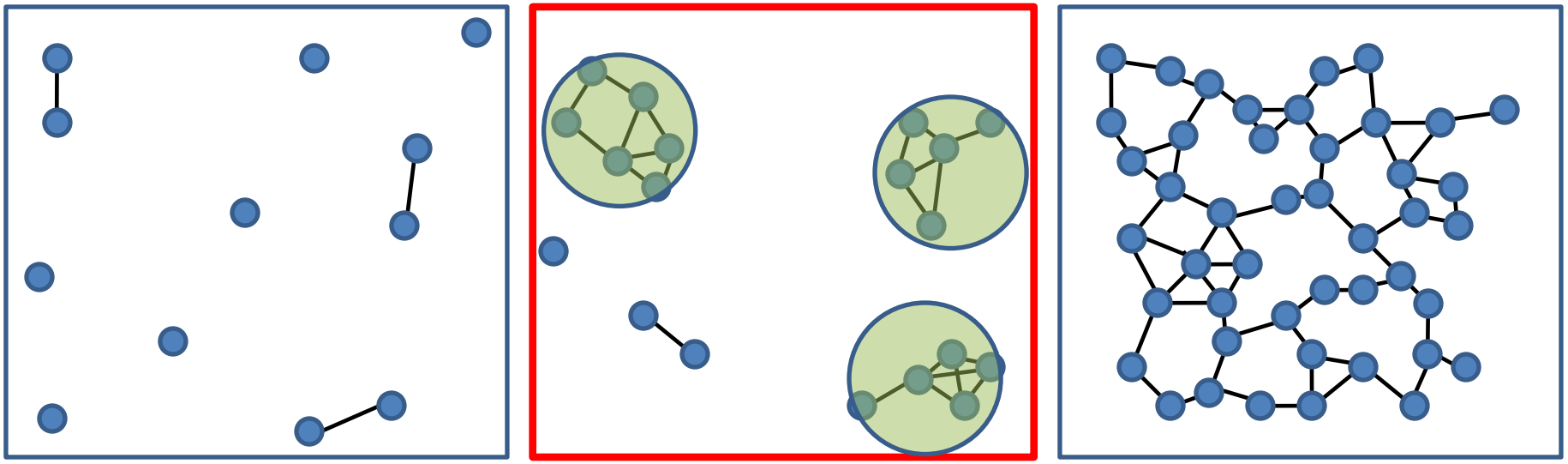


# Connectivity



# Mobile Partitioned Networks

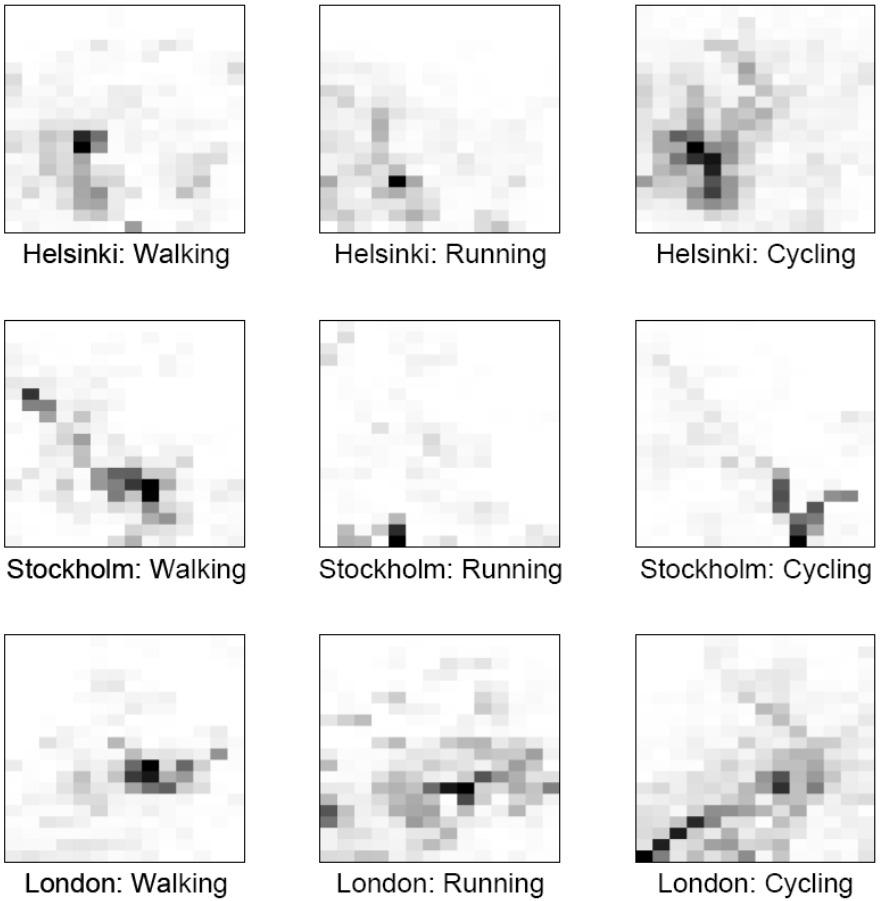


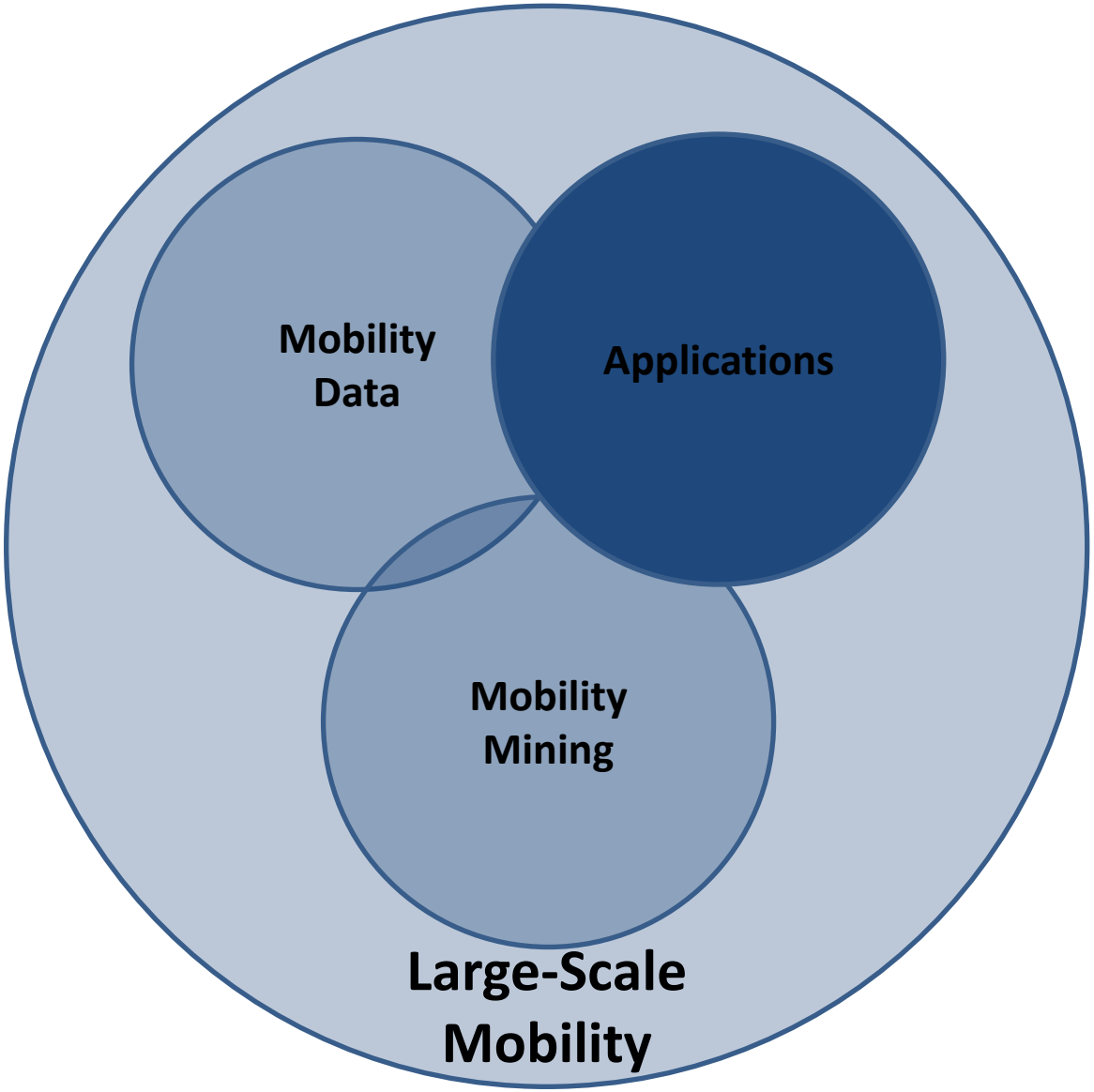
- Clustered networks equally realistic as sparse and dense
- Cluster formation attributed to environmental features
- Heterogeneous Random Walk mobility model [PiorkowskiSDG09]

[PiorkowskiSDG09] M. Piorkowski, N. Sarafijanovoc-Djukic, M. Grossglauser **A Parsimonious Model of Mobile Partitioned Networks with Clustering**, COMSNETS, *January 2009.*

# City-Specific Mobility Profiles

- Collection of places with specific mobility attributes:
  - Node density
  - Activity type
  - Travel time
  - …

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# Application: Location Privacy

- How to enhance user's privacy in location-based services?
- Individuals use pseudonyms for identification
- Adversaries track user's locations by *in-situ* pseudonym monitoring

- **Existing solution:** individuals should change pseudonyms in *Mix Zones* (regions obfuscating relation between entering and exiting individuals) [BeresfordS04]

[BeresfordS04] A. Beresford, F.Stajano, **Mix Zones: User Privacy in Location-aware Services,** *PerSec* 2004

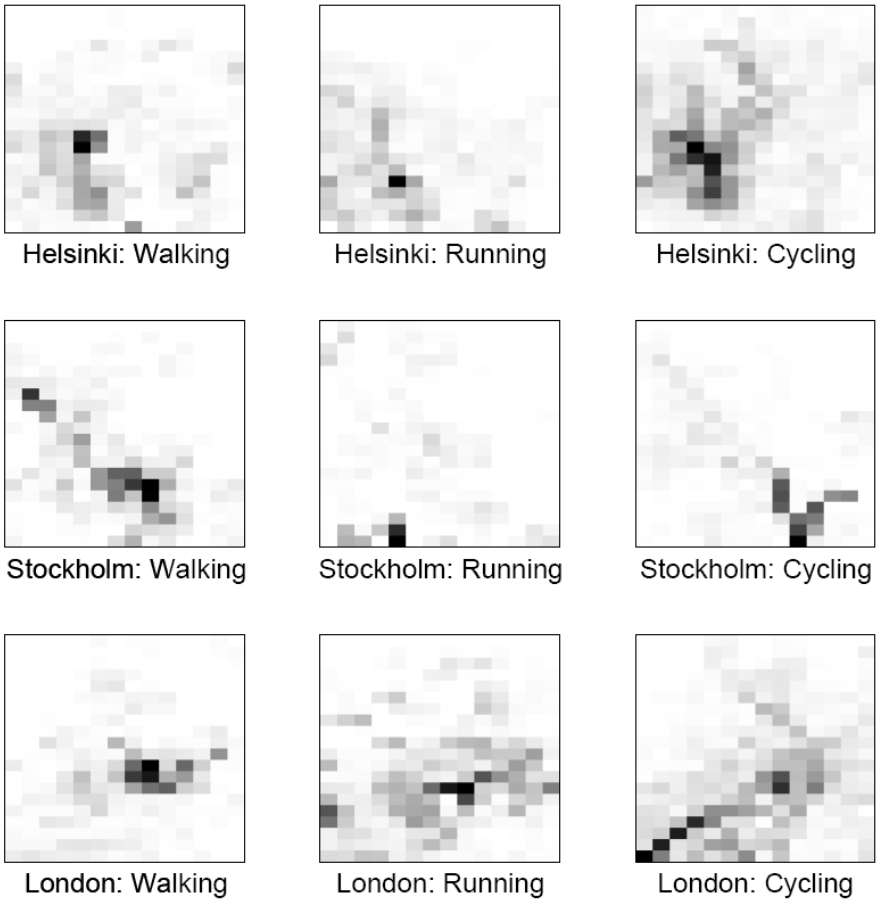
# Application: Location Privacy

- Improving Location Privacy by:
  - Increasing the number of individuals in *Mix Zones*
  - Placing *Mix Zones* at locations where individual mobility profiles are the same
- Optimal placement of *Mix Zones* [FreudigerSH09]
  - Adversary's tracking success is decreased when *Mix Zones* are well placed

In reality, how do we know that a particular location is optimal for a *Mix Zone*?

[FreudigerSH09] J. Freudiger, R. Shokri, J.-P. Hubaux, **On the Optimal Placement of Mix Zones,** *Privacy Enhancing Technology Symposium*, 2009

# Application: Location Privacy



# Conclusions

- Novel method for gathering large scale mobility data
- Short-term vs. long-term mobility – similar macroscopic mobility characteristics
- City-specific mobility profiles inferred from collection of short-term mobility traces
- Improving privacy in mobile networks

# Outlook

- More data: flickr [CrandallBHK09]
- Activity cycles
- Individual vs. collective mobility
- New context-aware services
- Malware propagation in mobile networks

[CrandallBHK09] D. Crandall, L. Backstorm, D. Huttenlocher, J. Kleinberg, **Mapping the World's Photos,** *ACM International World Wide Web Conference WWW'09*, April 2009

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- [PiorkowskiSDG09] M. Piorkowski, N. Sarafijanovoc-Djukic, M. Grossglauser **A Parsimonious Model of Mobile Partitioned Networks with Clustering**, *COMSNETS,* January 2009.
- [Sarafijanovic-DjukicPG06] N. Sarafijanovic-Djukic, M. Piorkowski, and M. Grossglauser, **Island Hopping: Efficient Mobility-Assisted Forwarding in Partitioned Networks**, *IEEE SECON*, 2006

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http://people.epfl.ch/michal.piorkowski