Mobility Analysis and Modelling

Mirco Musolesi
Department of Geography, UCL
m.musolesi@ucl.ac.uk

Objectives of the Lecture

- I will provide an introduction to the field of mobility analysis.
- I will discuss the concept of mobility models, providing some examples and applications.
- I will discuss how real traces can be used for mobility modelling.
- An introduction to macro-scale modelling will be introduced considering the radiation and giration mobility models.

Mobility Analysis at Different Scales

- Mobility analysis can be done at different levels:
  - Individual mobility
  - Group mobility
  - Macro-mobility
    - Country-wide mobility
    - But also between and across states
      - Flights
      - Shipping routes

Data Sources

We can identify a variety of data sources:

- GPS data from specialised devices, phones, etc.
- Online social network activities (e.g., posts with location information);
- Transportation infrastructure (e.g., Oyster card);
- Cameras (e.g., city centre congestion charge cameras);
- Census data;
- …

Spatial Resolution

- The detection of spatial patterns is also directly related to the spatial scale at which data are measured.
- Spatial scale has at least two aspects:
  1) the size of the study area (extent);
  2) the sampling unit used to collect the data (granularity).

- Several studies have showed that spatial statistics are very sensitive to both of these resolution aspects.

Applications

- Urban planning and transportation
- Understanding populations and human behaviour at large
  - Single individual;
  - Communities;
  - States.
- But also:
  - Ecology studies;
  - Animal behaviour studies;
  - …

Applications

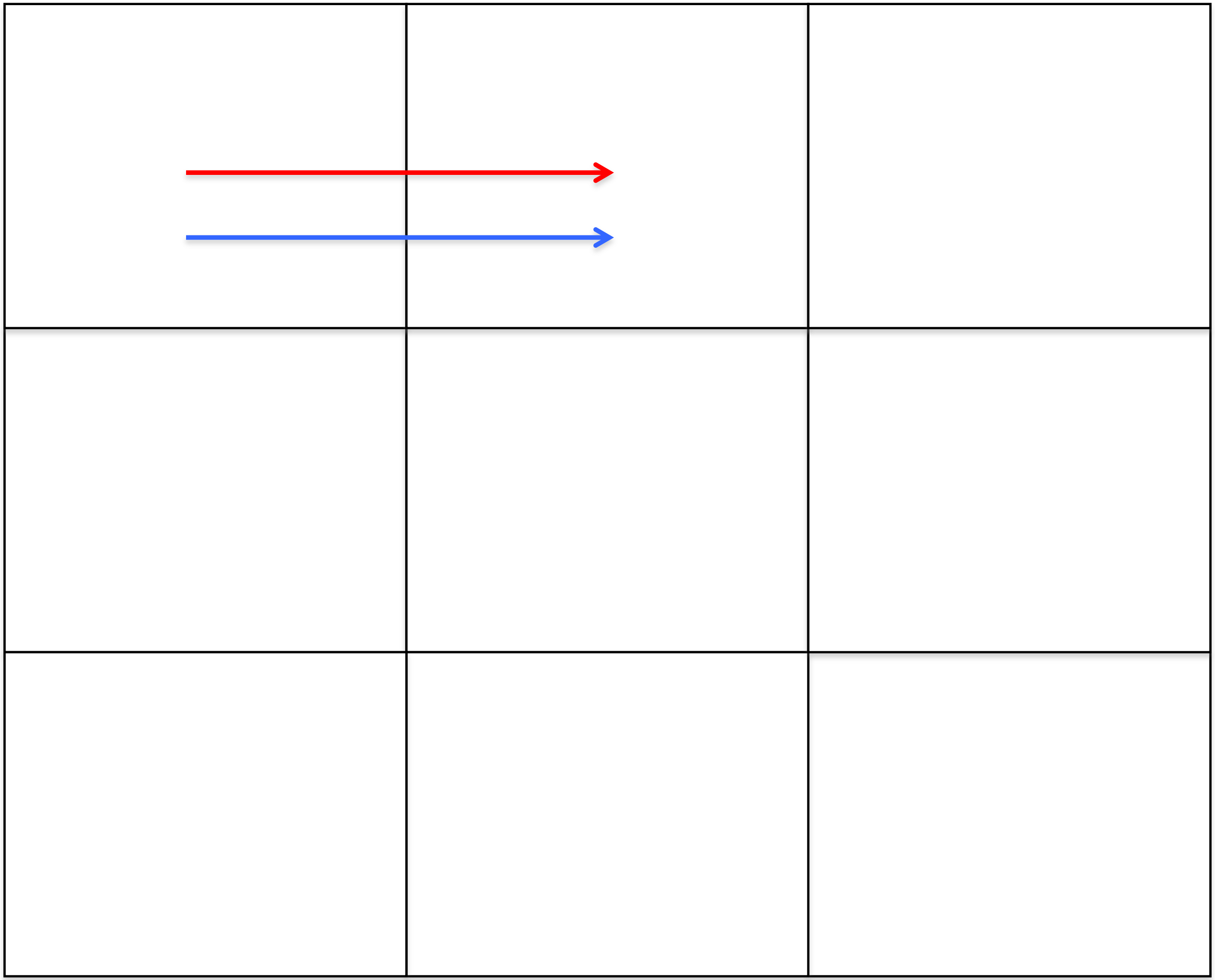
- Emerging applications in marketing and geo-spatial services.
- Geo-social networks (Swarm/Foursquare)
  – Data about trajectories of individuals are the real assets of these companies

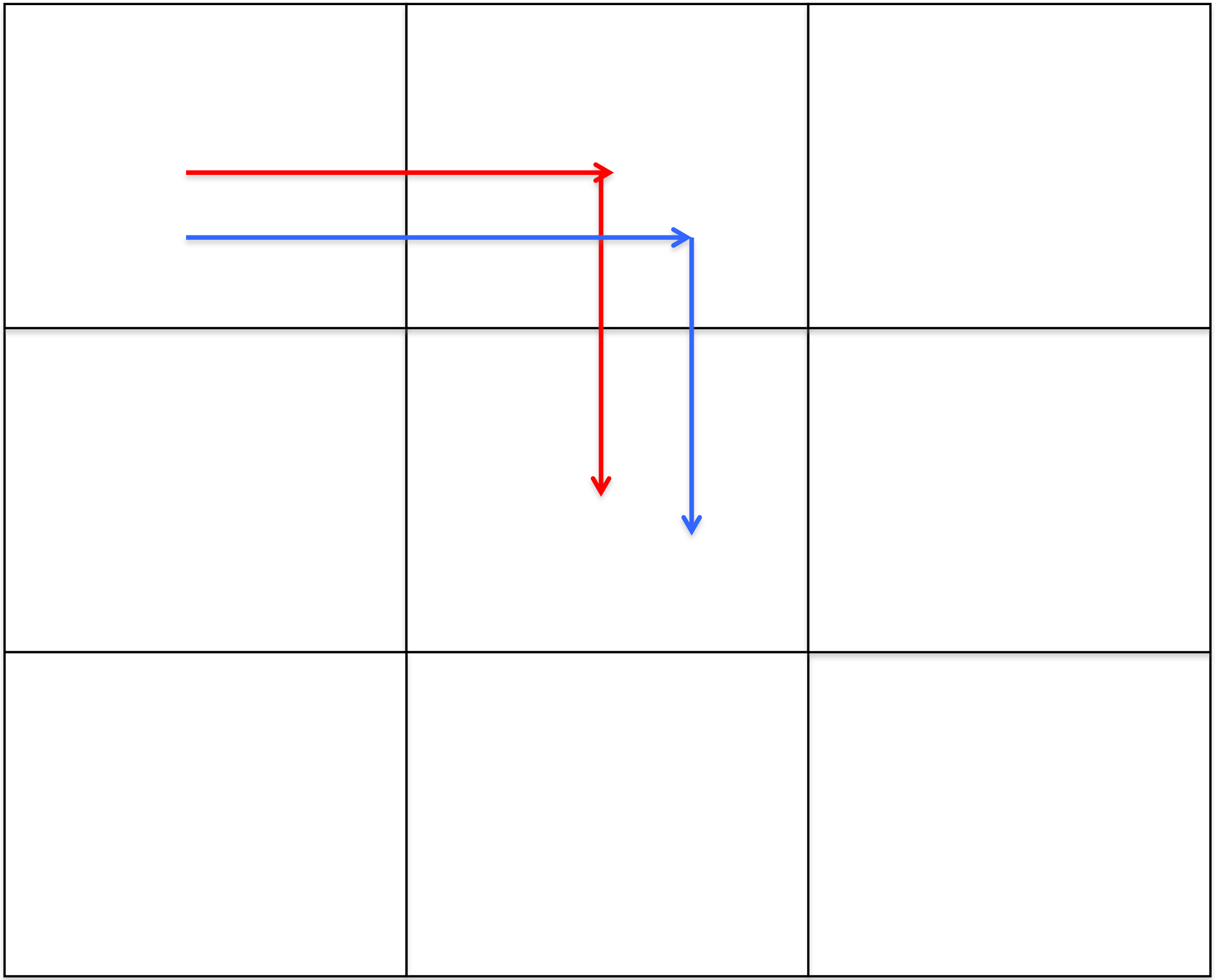
Individual-based Mobility Models

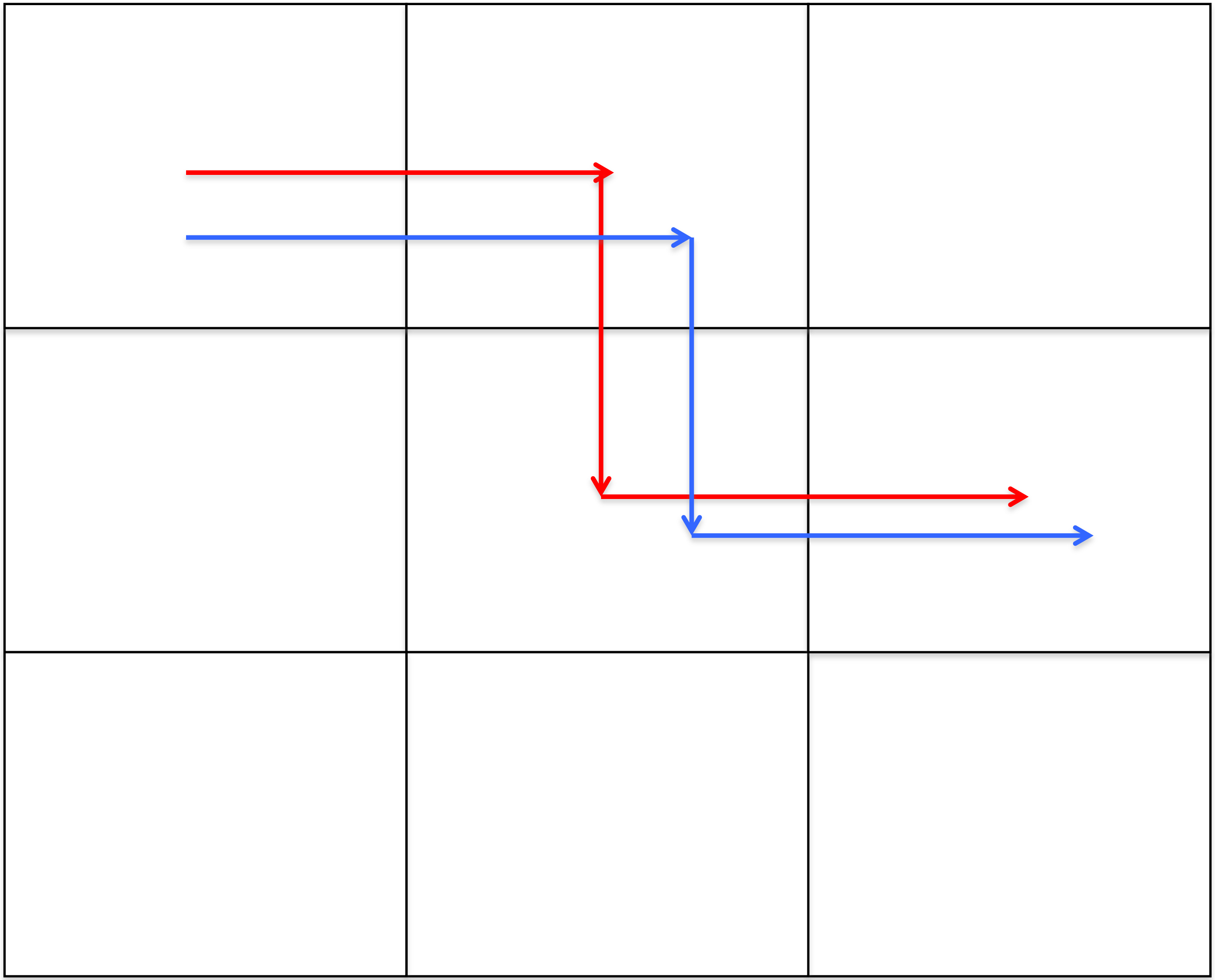
- They are used to model the behaviour of the single individuals.
- They can be used for example in **agent-based modelling** for urban simulation and, more in general, simulation of the behaviour of single individuals.
- Every person moving in a city is an “agent” which follow particular rules.
- The behaviour can be extracted from the data!

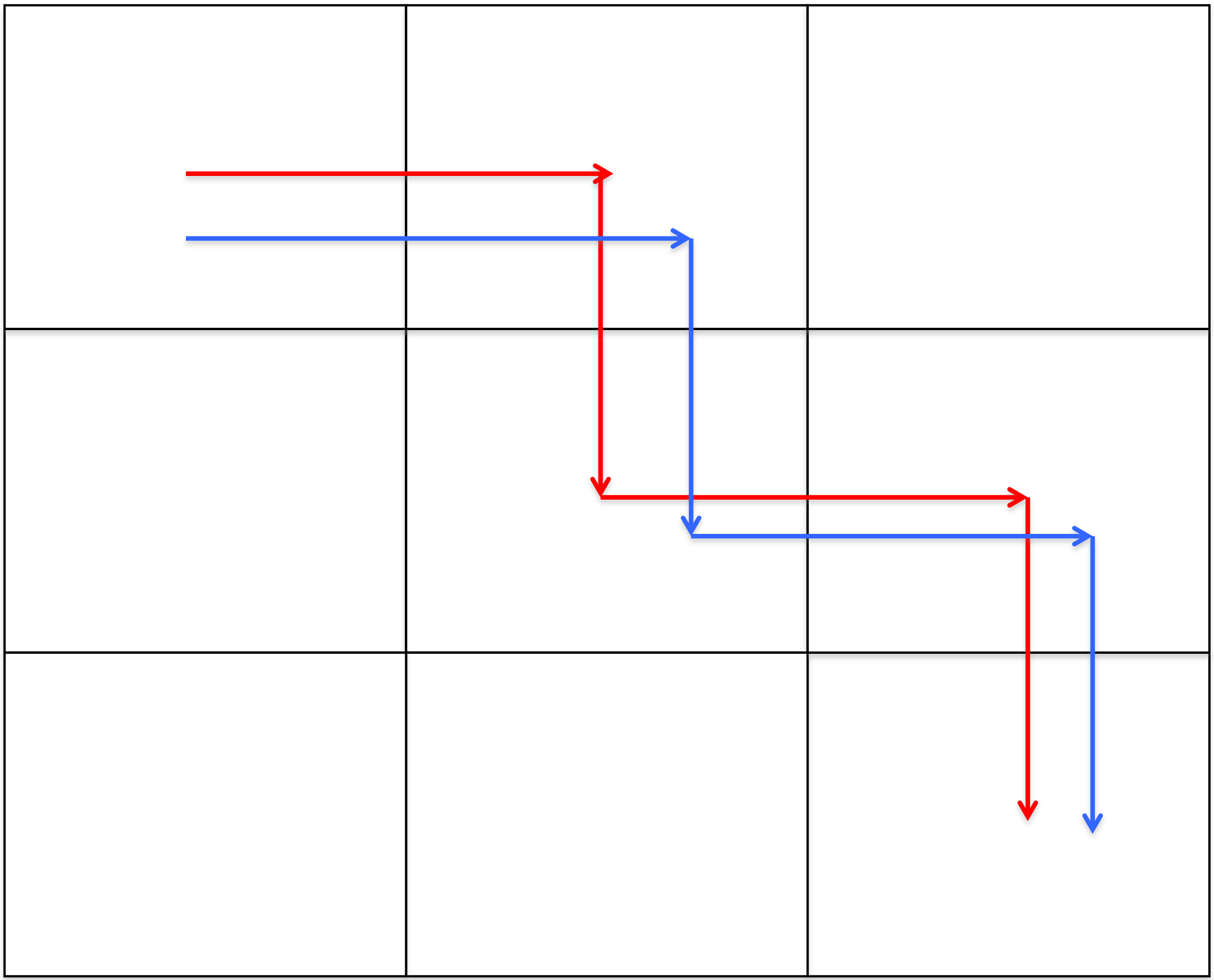
Example: Synchronised Movement of People

- We can for example model the behaviour of a person (blue) that follows the behaviour of another person (red).
- This is a basic model but it can be extended to model multiples users at city level for example considering their interactions with each other.
- The design of the model should be based again on real data and observations.









Agent-based Models and Simulations for the Social Sciences

- More in general, agent-based models are suitable for social sciences because usually a social system (e.g., a city) has the following two properties:

1. the system is composed of interacting agents;
2. the system exhibits emergent properties, i.e. properties that arises from the interactions of agents (think about traffic).

Simulating Cities and Societies

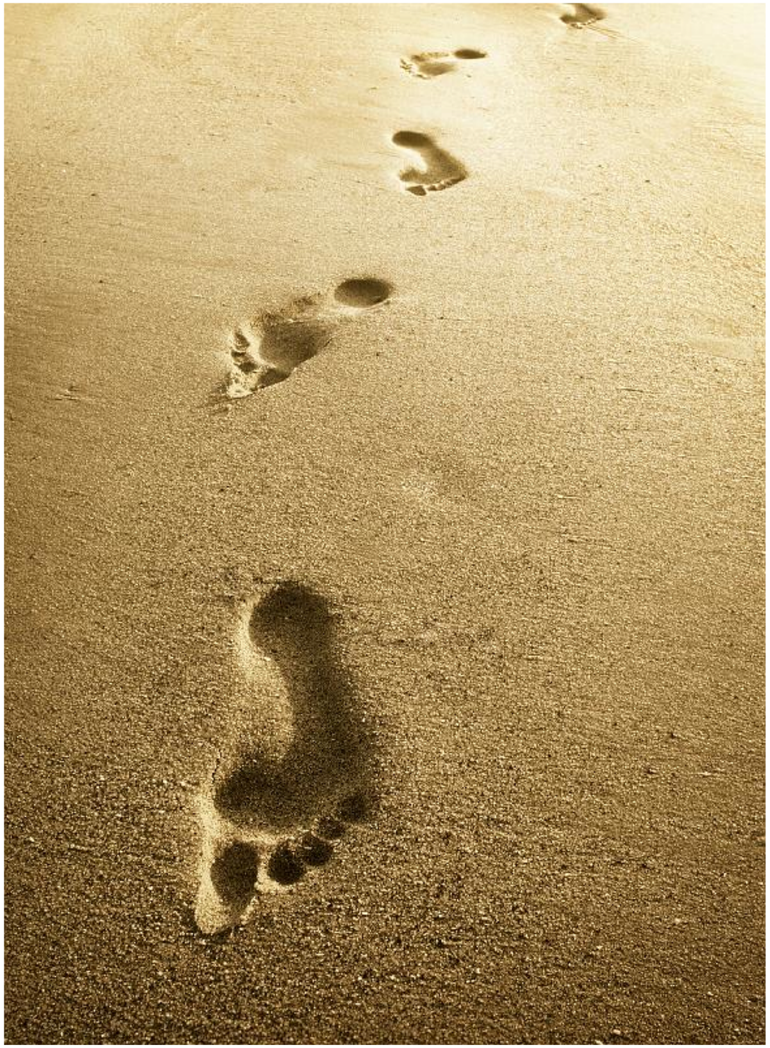
- Using real data you can try to recreate and simulate individuals but also societies.
- This is an area of the emerging field of computational social science.
- An application of particular interest is the simulation of cities.
- This type of analysis is very useful in case you want to understand “what if scenarios”.
- It is possible to observe the effects of policies for example building societies and cities in a lab in a sense.

Why Mobility Models?

- Prediction of movement for marketing/advertisement applications, telecommunications, etc.
- Intellectual interest:
  - How do people move? Why do they move in that way?

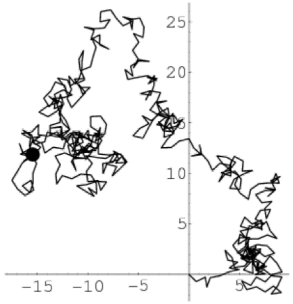
Why not Just Using Real Traces?

- Real traces are not available:
  - Datasets and measurements are not released by telcos (competitive advantage for them)
- They are related to very specific scenarios.
- They do not allow for sensitivity analysis.



Two Classes of Mobility Models

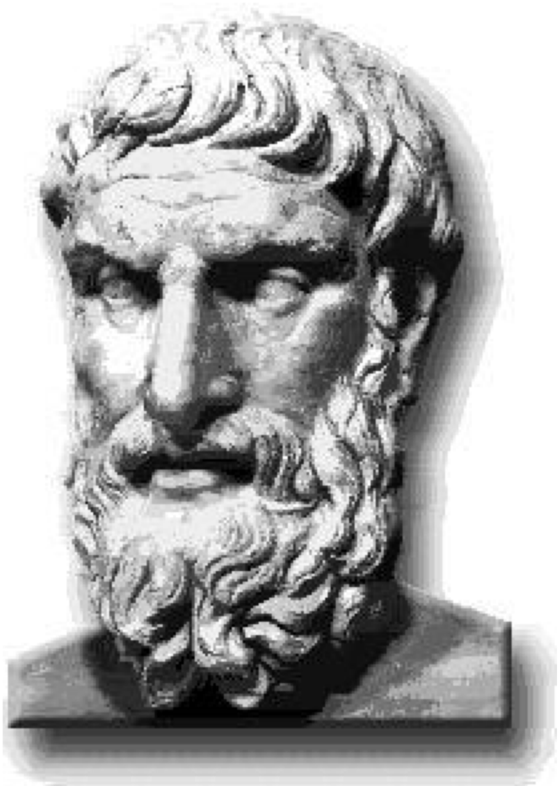
- Two classes of synthetic mobility models:
  - Random individual movement models
    - Usually based on a set of (stochastic) mathematical equations



  - Trace-based models
    - Given a set of measurements (such as GPS or Bluetooth contact logs), the model tries to capture (and reproduce) the essential characteristics of movements.

The First Study on Random Mobility Models

Observe what happens when sunbeams are admitted into a building and shed light on its shadowy places. You will see a multitude of tiny particles mingling in a multitude of ways... their dancing is an actual indication of underlying movements of matter that are hidden from our sight... It originates with the atoms which move of themselves. Then those small compound bodies that are least removed from the impetus of the atoms are set in motion by the impact of their invisible blows and in turn cannon against slightly larger bodies. So the movement mounts up from the atoms and gradually emerges to the level of our senses, so that those bodies are in motion that we see in sunbeams, moved by blows that remain invisible.



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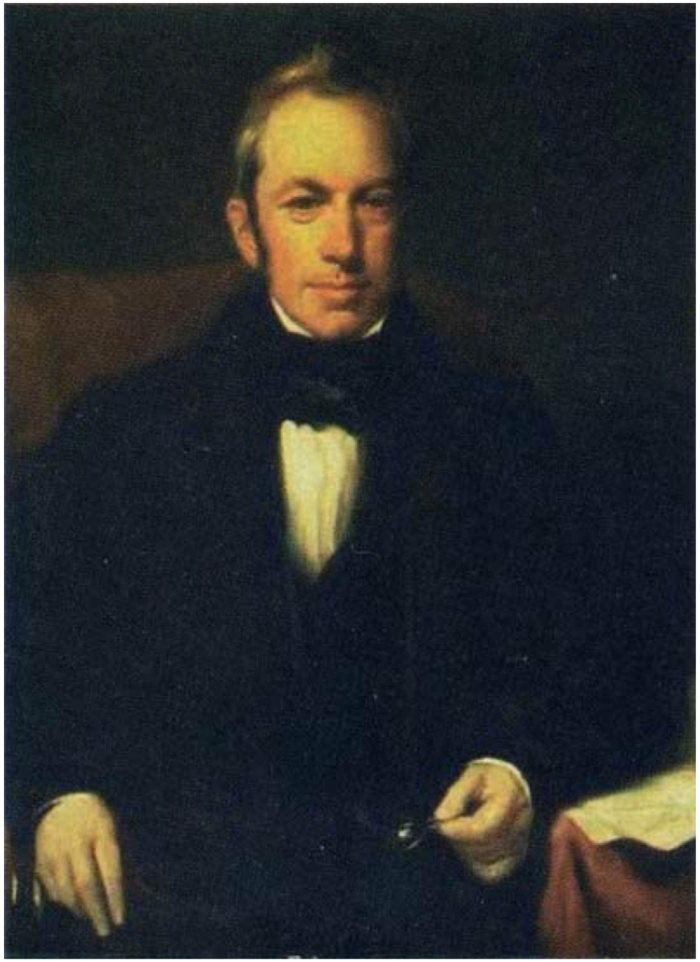
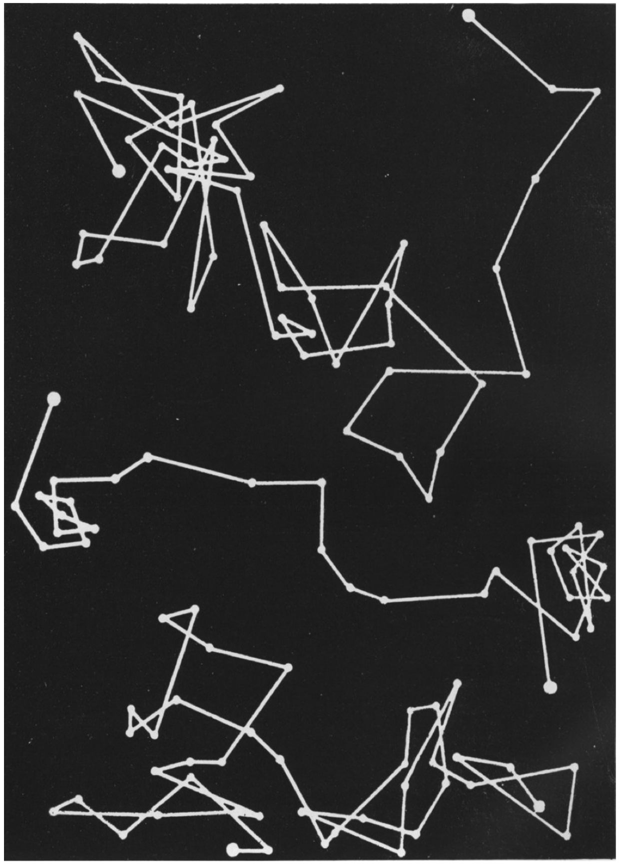
Lucretius, De Rerum Natura

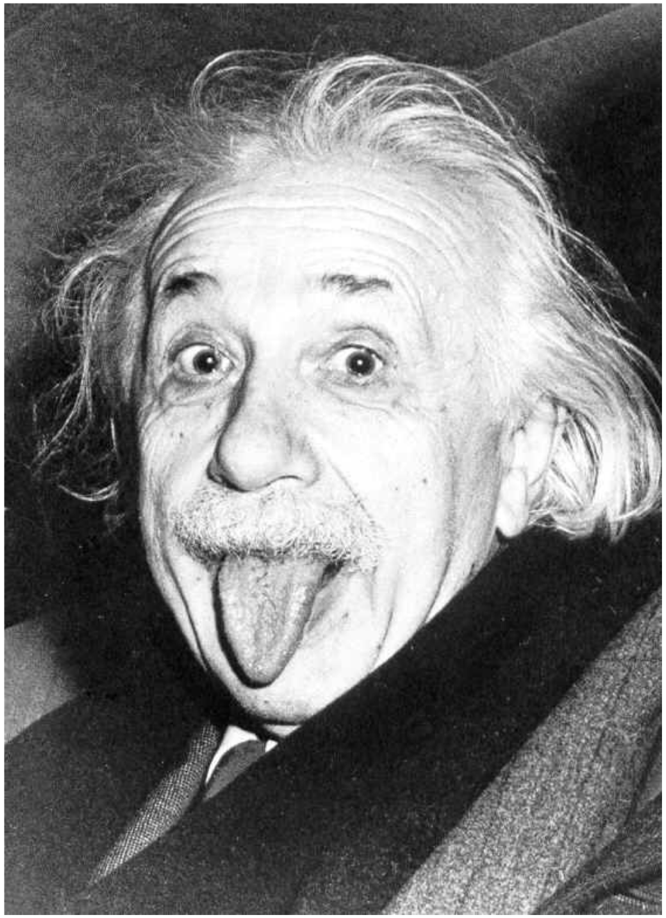
Random Mobility Models



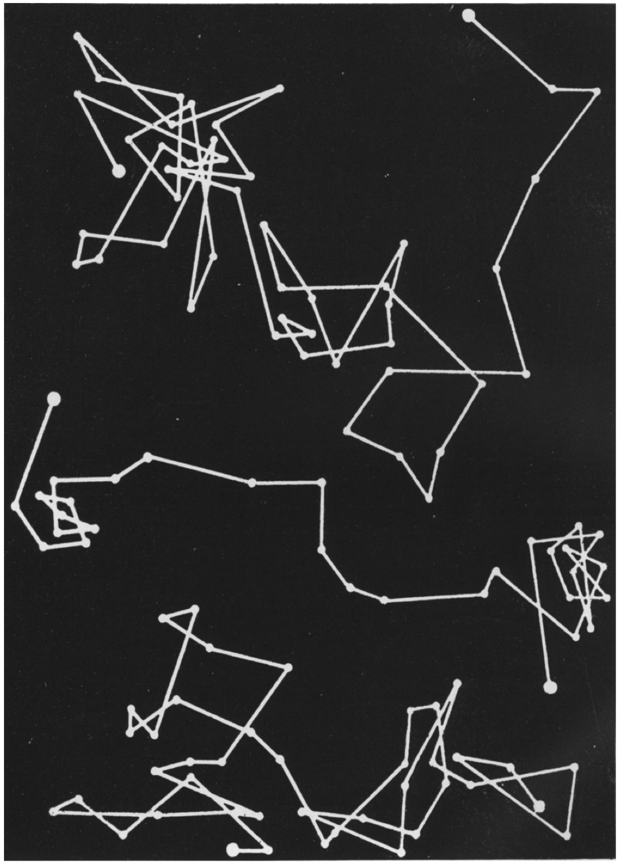
Robert Brown (1773-1858)



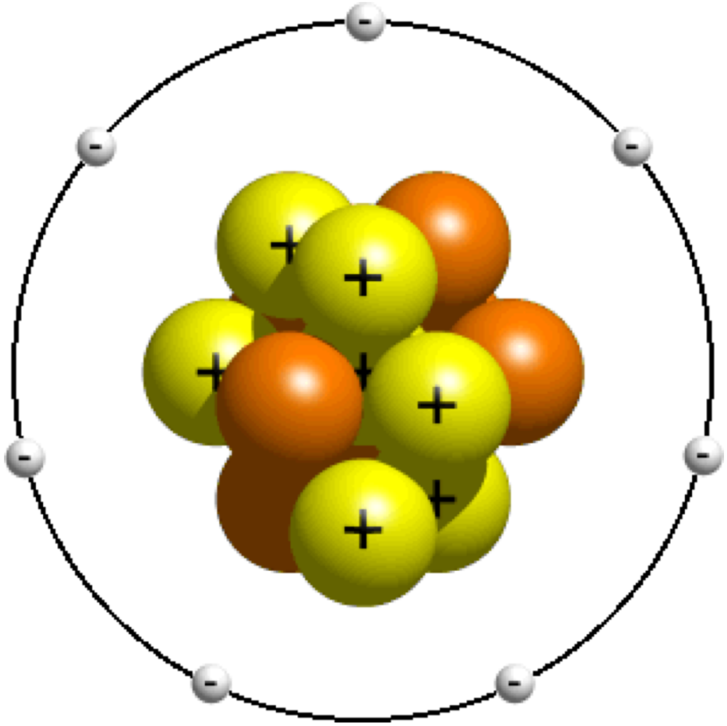
Random Mobility Models



Albert Einstein (1879-1955)



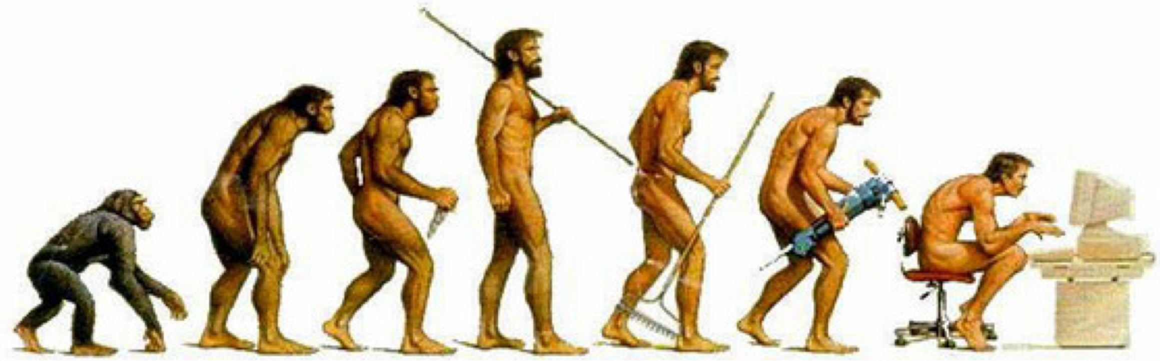
When Can we Say that a Model is *Good* Model?



Source: Thomas Jefferson National Accelerator Facility

What do They Have in Common?

What do They Have in Common?



A Probability Distribution?

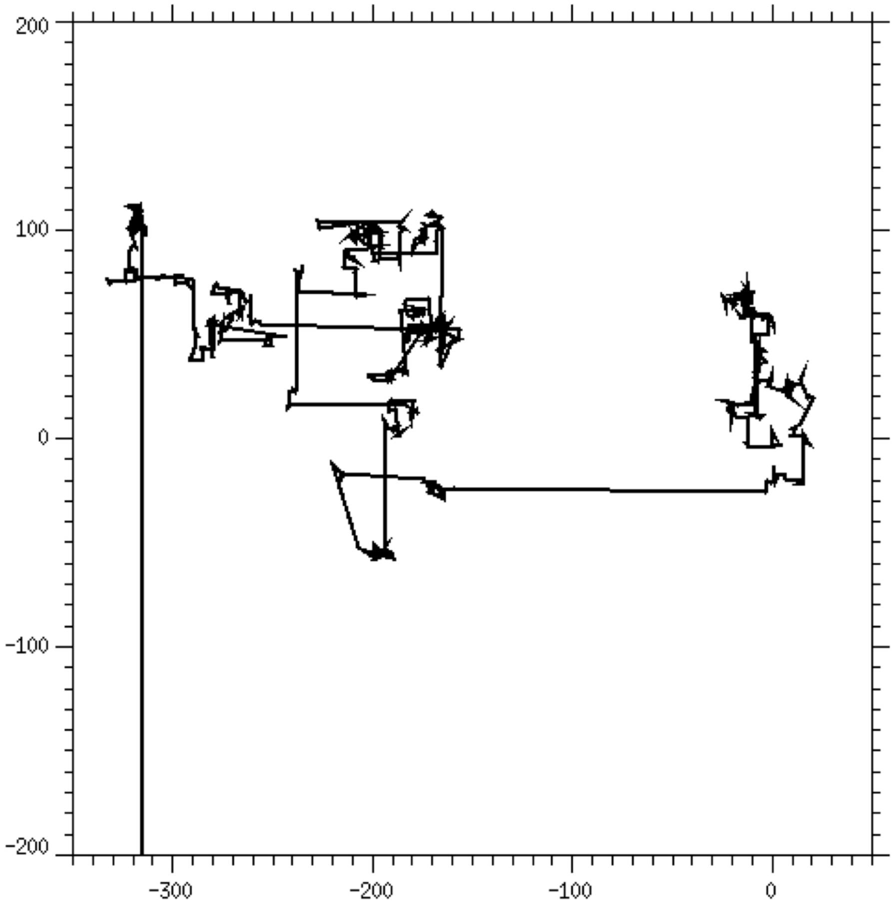
$$P(x) = x^{-\alpha}$$

This is a power law distribution: it says that the probability of small displacements is much higher than the probability of large ones.

Movements that follow this law are called “Levy flights” from the name of the mathematician Paul Levy.

Power law distributions are characterised by **long tails**: long jumps are rare, but still they do happen.

Levy Flights



Validation using Phone Traces

Vol 453|5 June 2008|doi:10.1038/nature06958 nature

LETTERS

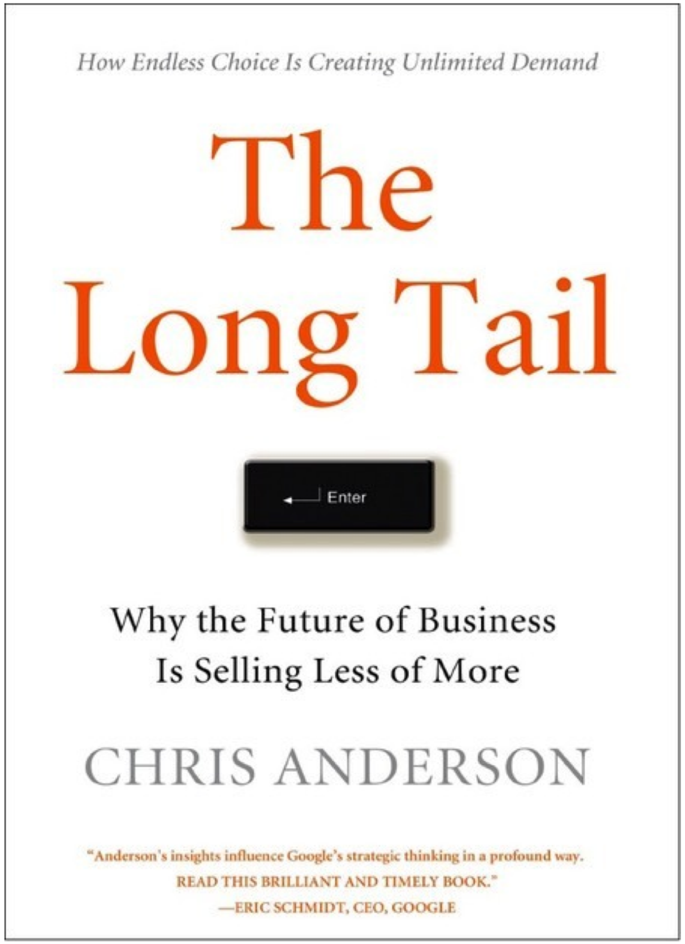
Understanding individual human mobility patterns

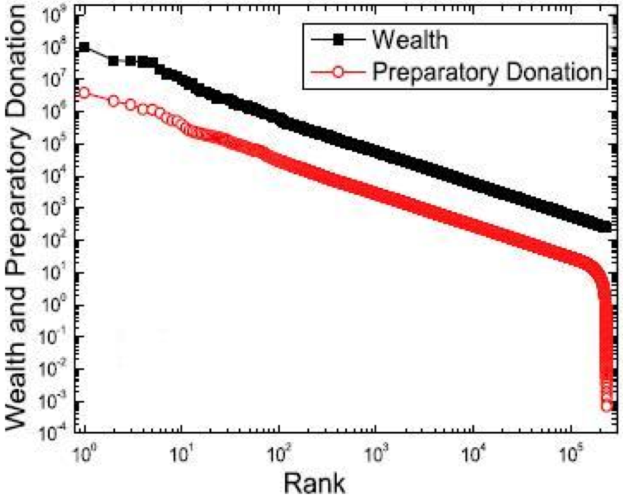
Marta C. González[1], César A. Hidalgo[1,2] & Albert-László Barabási[1,2,3]

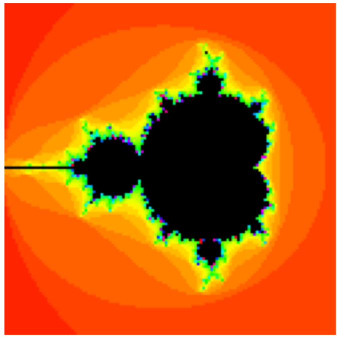
Despite their importance for urban planning[1], traffic forecasting[2] and the spread of biological[3–5] and mobile viruses[6], our understanding of the basic laws governing human motion remains limited owing to the lack of tools to monitor the time-resolved location of individuals. Here we study the trajectory of 100,000 anonymized mobile phone users whose position is tracked for a six-month period. We find that, in contrast with the random trajectories predicted by the prevailing Lévy flight and random walk models[7], human trajectories show a high degree of temporal and spatial regularity, each individual being characterized by a time-independent characteristic travel distance and a significant prob-

a six-month period for 100,000 individuals selected randomly from a sample of more than 6 million anonymized mobile phone users. Each time a user initiated or received a call or a text message, the location of the tower routeing the communication was recorded, allowing us to reconstruct the user's time-resolved trajectory (Fig. 1a, b). The time between consecutive calls followed a 'bursty' pattern[20] (see Supplementary Fig. 1), indicating that although most consecutive calls are placed soon after a previous call, occasionally there are long periods without any call activity. To make sure that the obtained results were not affected by the irregular call pattern, we also studied

Seeing Power-Laws Everywhere

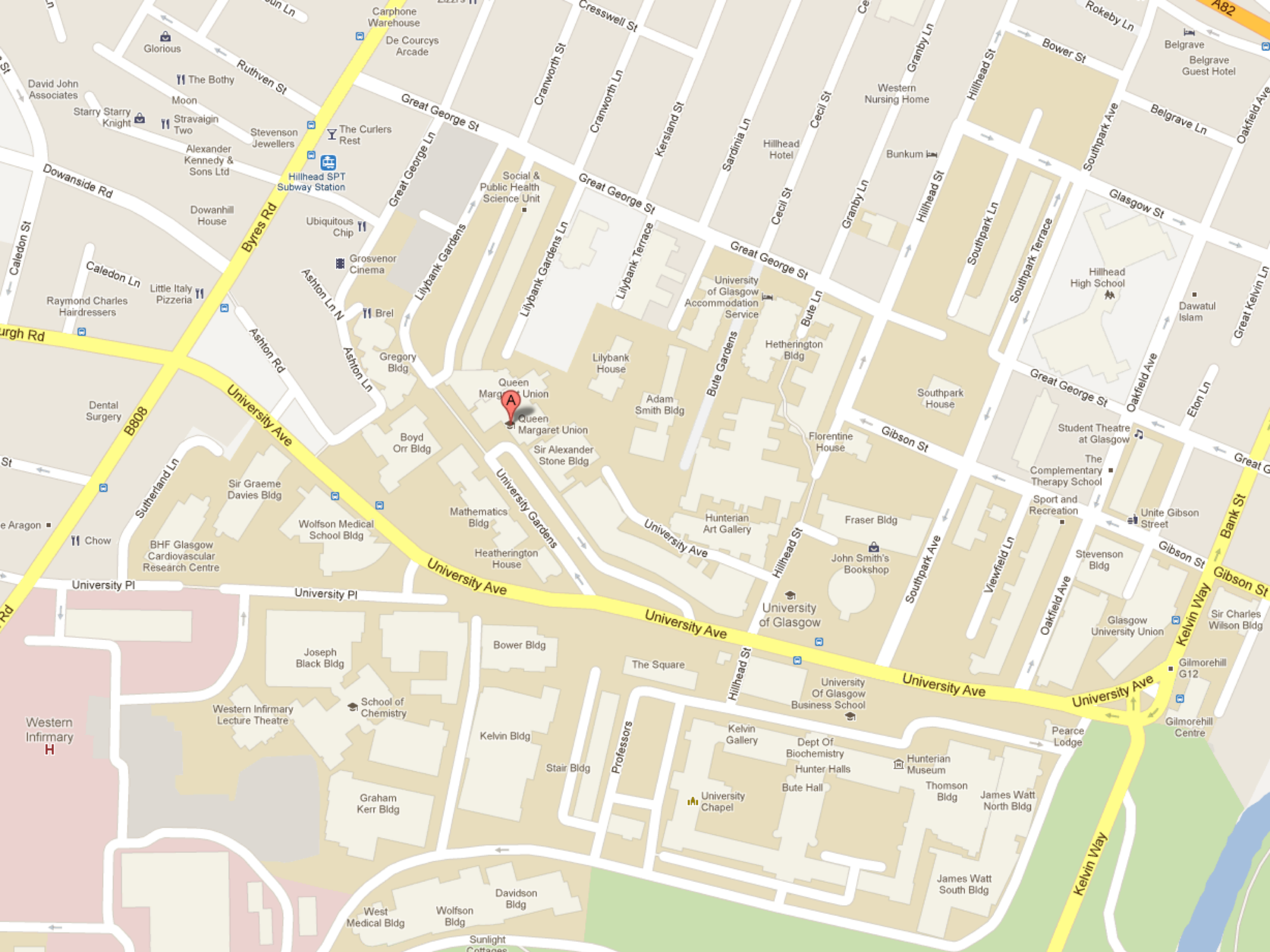






Markovian Model

- Based on discretisation of the geographic space.
- A matrix is used to describe *transitions* from a certain area of space to another one.
- Memory-less random process.
- Large body of theoretical results about these models.



Carphone Warehouse
De Courcys Arcade
Glorious
Ruthven St
The Bothy
David John Associates
Moon
Starry Starry Knight
Stravaigin Two
Stevenson Jewellers
The Curlers Rest
Alexander Kennedy & Sons Ltd
Hillhead SPT Subway Station
Great George St
Cresswell St
Cranworth St
Cranworth Ln
Kersland St
Sardinia Ln
Cecil St
Granby Ln
Hillhead St
Rokeby Ln
Bower St
Belgrave
Belgrave Guest Hotel
Belgrave Ln
Oakfield Ave
A82
Western Nursing Home
Hillhead Hotel
Bunkum
Southpark Ave
Glasgow St
Dowanside Rd
Dowanhill House
Ubiquitous Chip
Grosvenor Cinema
Byres Rd
Caledon St
Caledon Ln
Little Italy Pizzeria
Raymond Charles Hairdressers
Ashton Ln N
Ashton Rd
Ashton Ln
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Gregory Bldg
Social & Public Health Science Unit
Lilybank Gardens
Lilybank Gardens Ln
Lilybank Terrace
University of Glasgow Accommodation Service
Bute Ln
Bute Gardens
Hetherington Bldg
Lilybank House
Adam Smith Bldg
Southpark Ln
Southpark Terrace
Hillhead High School
Dawatul Islam
Great Kelvin Ln
Southpark House
Eton Ln
Queen Margaret Union
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Queen Margaret Union
Sir Alexander Stone Bldg
Boyd Orr Bldg
Florentine House
Gibson St
Student Theatre at Glasgow
The Complementary Therapy School
Sport and Recreation
Unite Gibson Street
Bank St
Dental Surgery
B808
University Ave
Sutherland Ln
Sir Graeme Davies Bldg
Wolfson Medical School Bldg
Mathematics Bldg
University Gardens
Hunterian Art Gallery
Fraser Bldg
John Smith's Bookshop
Viewfield Ln
Stevenson Bldg
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BHF Glasgow Cardiovascular Research Centre
Heatherington House
University Pl
University of Glasgow
Glasgow University Union
Kelvin Way
Sir Charles Wilson Bldg
Gilmorehill G12
Joseph Black Bldg
Bower Bldg
The Square
University Of Glasgow Business School
Gilmorehill Centre
Western Infirmary
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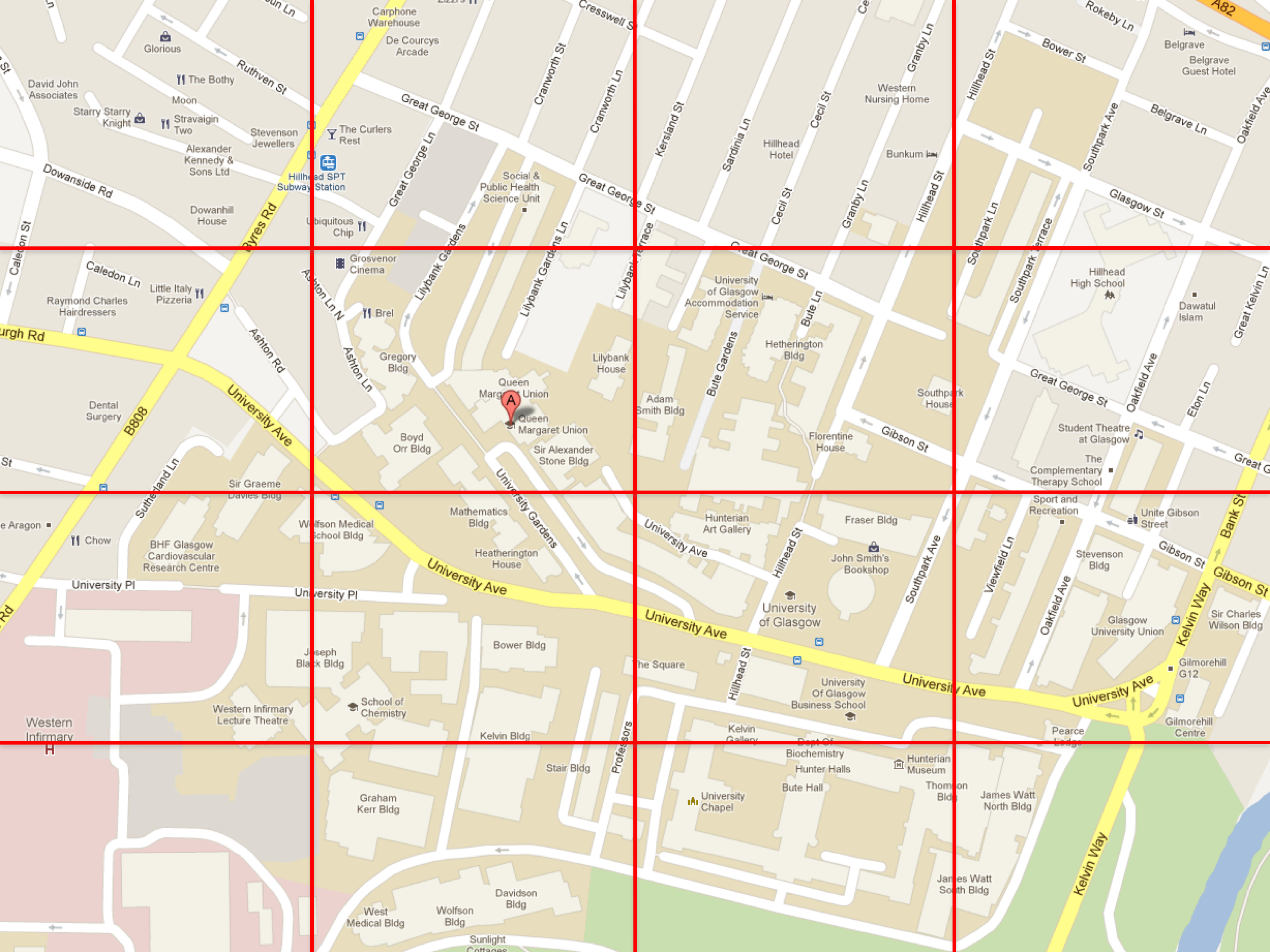
Western Infirmary Lecture Theatre
School of Chemistry
Kelvin Bldg
Stair Bldg
Professors
Kelvin Gallery
Dept Of Biochemistry
Hunter Halls
Hunterian Museum
Pearce Lodge
Bute Hall
University Chapel
Thomson Bldg
James Watt North Bldg
Graham Kerr Bldg
James Watt South Bldg
Davidson Bldg
West Medical Bldg
Wolfson Bldg
Sunlight Cottages



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Wolfson Bldg
Sunlight Cottages

Transition Matrix

Probability of transition from cell i to cell *j*

$$T = \begin{array}{cc} & \begin{array}{cccc} j & & & \end{array} \\ i & \begin{pmatrix} 0.1 & 0.3 & 0.2 & 0.4 \\ 0.4 & 0.2 & 0.15 & 0.25 \\ 0.1 & 0.3 & 0.4 & 0.2 \\ 0.1 & 0.2 & 0.2 & 0.5 \end{pmatrix} \end{array}$$

Transition Matrix

- Transition matrix can also be used to model movements between significant places, i.e., places where the users spend a considerable amount of time.
- Examples include very important places in campus such as home department, library and gym. Using a transition matrix extracted from data we can predict the next location of a user.

Mobility Prediction

- The Markov model is a simple model, which also does not have memory (i.e., it is based on the current location and not on the history of the previous locations).
- More complex mobility models are possible, for example based on machine learning techniques that we discussed during the future lecture:
  - You can train your model with your data/observations;
  - Then you can try to predict the future location of a user from the history of his/her movements.

From Individual-based Mobility Models to Aggregate Mobility Models

- The models that we discussed in the first part of the lecture describe the movement of single individuals.
- However, we might be interested in modelling movement of people using aggregate data from multiple users (for example, we might want to model commuters between cities).
- Emerging models are again data-driven, using for example data from cellular/mobile networks.

Gravity Model

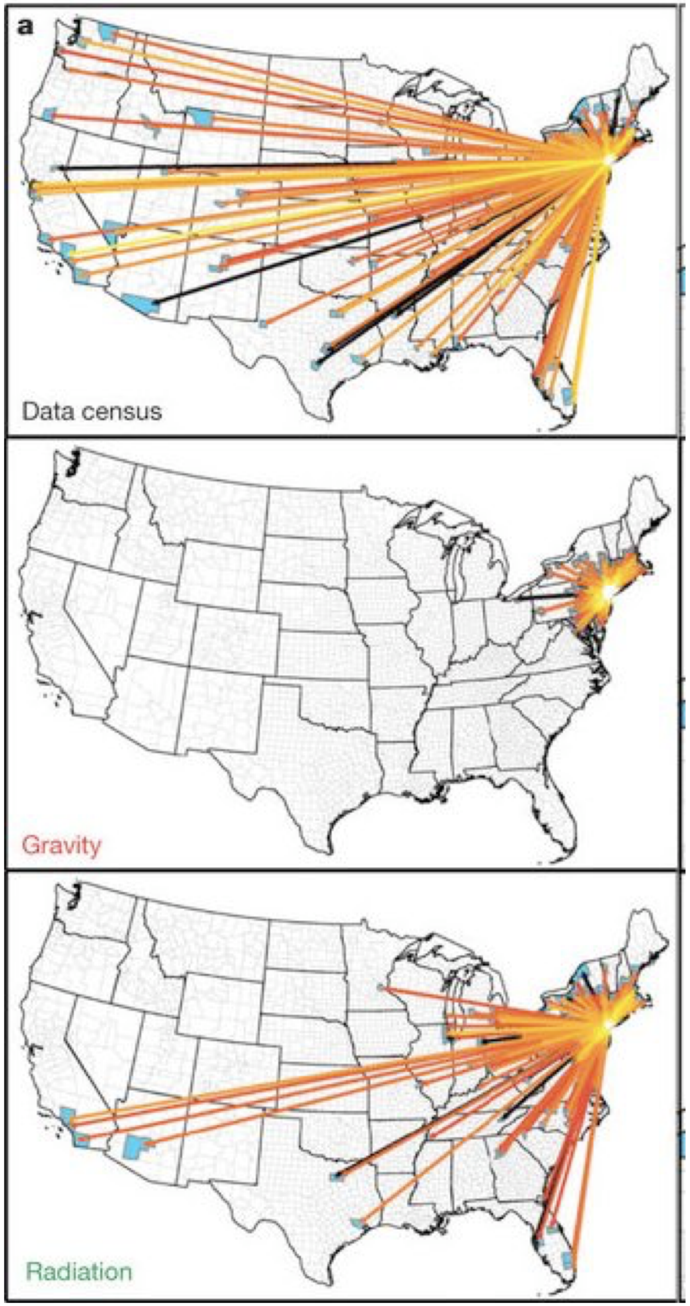
- This is the classic model of inter-city mobility.
- It has been used to predict patterns of mobility and modelling epidemics spreading for example.
- Following Newton's gravitation law, the Gravity Model assumes that movement between two cities would be frequent when their populations are large and the distance between them are small.

Radiation Model

- Proposed recently (2012) to better model the fact that distance is not the only factor to be considered in modelling human movement.
- The density of "opportunities" (such as cities close by also influence the choice of people in terms of movement).
  - Example: commuters in South-East England vs commuters in Scotland.

Radiation Model

- The radiation model tracks its origin from a particle diffusion model in physics, where particles are emitted at a certain location and they have a certain probability p_j of being absorbed by a nearby location j.
- In other word a person (a “particle”) has a certain probability not null of being attracted by a location that is small for example in terms of population because there are good opportunities there (think about commuters from London to Cambridge or Oxford).



Gravity vs Radiation Model

[Source: Filippo Simini, Marta C. Gonzalez, Amos Maritan & Albert-Laszlo Barabasi. A Universal Model for Mobility and Migration Patterns. Vol. 484. Nature.]

Gravity vs Radiation Model: What is the Best Model?

- In the paper by Simini et al. the authors showed that the radiation model is more effective in modelling mobility.
  - Authors used data from US Census as ground truth data.
- More recently, this result has been questioned by Masucci et al. using data from England and Wales
- This is in a sense a very open problem!
- Better data will lead to better models.

References

- An introduction to Computational Social Science can be found in:

Lazer et al. Life in the Network: The Coming Age of Computational Social Science. Science. 323(5915). February 2009.

References

- The following three are the key papers about gravity and radiation models. Please note that they are not required readings for the exam.
- Zipf presented his original model about movement of people in:

George Kingsley Zipf. The P_1 P_2/D Hypothesis: On the Intercity Movement of Persons. American Sociological Review. Vol 11. No. 6. December 1946.

References

- The radiation model can be found in:

Filippo Simini, Marta C. Gonzalez, Amos Maritan & Albert-Laszlo Barabasi. A Universal Model for Mobility and Migration Patterns. Vol. 484. Nature.

References

- The evaluation of the radiation model using mobility traces from England and Wales can be found in:

A. Paolo Masucci, Joan Serras, Anders Johansson and Michael Batty. Gravity versus Radiation Models: On the Importance of Scale and Heterogeneity in Commuting Flows. Physical Review E 88. 922812 (2013)

References

- If you want to read more about agent-based modelling in the social sciences, a good resource is:

Online Guide for Newcomers to Agent-Based Modeling in the Social Sciences by Robert Axelrod and Leigh Tesfatsion:

http://www2.econ.iastate.edu/tesfatsi/abmread.htm

Questions?

Mirco Musolesi

Intelligent Social Systems Lab
Department of Geography
University College London

W: http://www.ucl.ac.uk/~ucfamus
E: m.musolesi@ucl.ac.uk
T: @mircomusolesi