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St Andrews Institute for Data-Intensive Research
http://www.idir.st-andrews.ac.uk

Multiplex cities

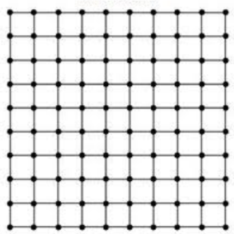
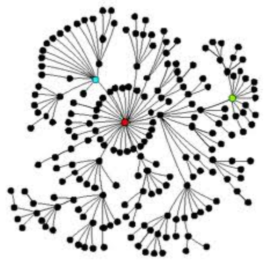
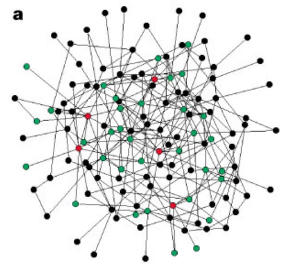
Interacting transport networks in metropolitan areas

Simon Dobson
(Joint work with Saray Shai, Emanuele Strano, and Marc Barthélemy

simon.dobson@st-andrews.ac.uk
http://www.simondobson.org

Complex networks

- Sit at the boundary between order and chaos

regular  complex  random 

Barabasi and Albert. Science **286**. 1999.

- Processes run over the network
  - Local rules
  - Structure makes results unpredictable in detail, but often with statistical regularities
- This talk
  - The complex behaviour of transport networks

Multiplex networks

- Different networks that are *coupled*
  - Process (or influence) can pass between
  - Can affect the behaviour of processes dramatically

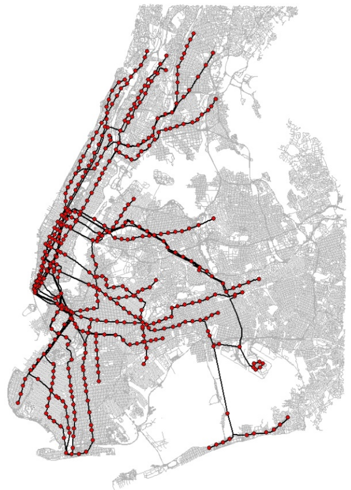
- Rich real-world datasets are increasingly available
  - Simulation and experiment

Buldyrev *et alia*. Nature **464**. 2010.

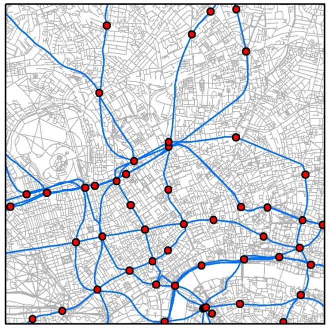
Multiplex transport networks

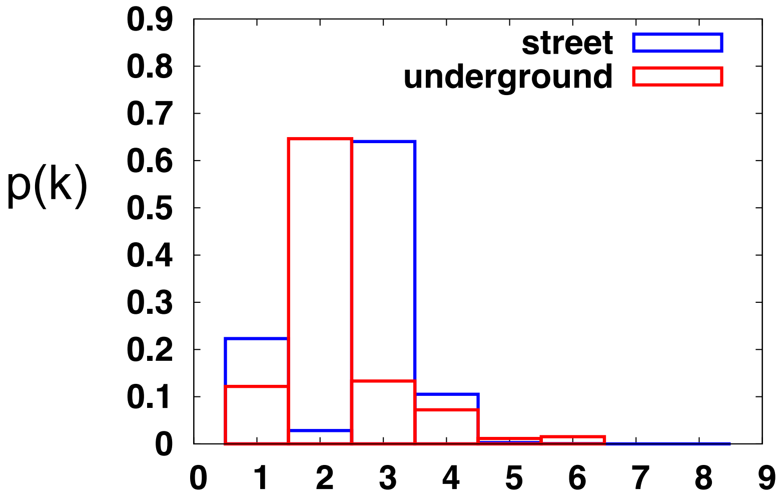
- Road *and* light rail
  - (And potentially other networks layered on)

- Effects
  - On commute times?
  - On robustness?
  - On investment?
  - On behaviours?



Datasets

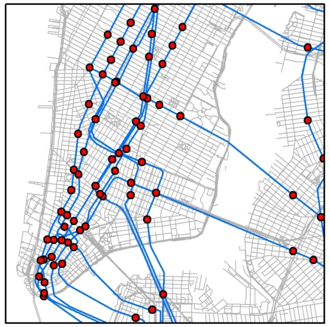


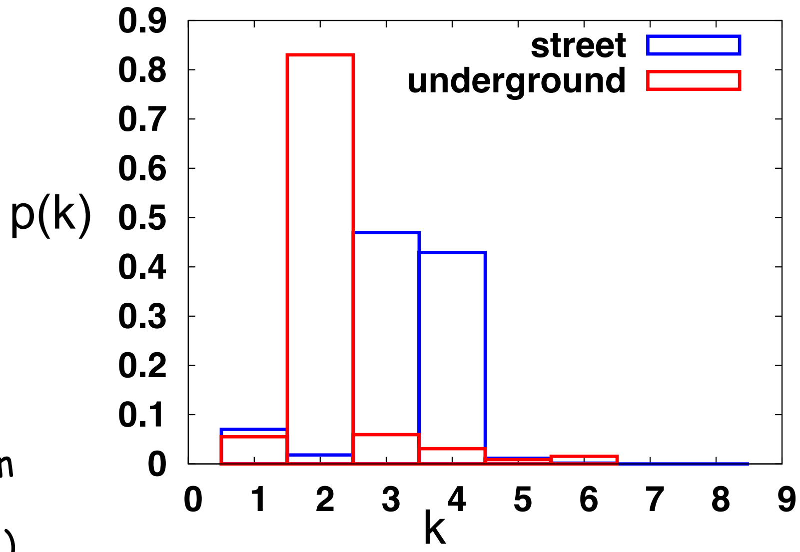


324536 street nodes
427920 street edges

263 subway nodes
296 subway edges

size 73.68 km





68417 street nodes
112827 street edges

454 subway nodes
489 subway edges

size 34.93 km

Original data from OpenStreetMap, cleaned by hand (!)

Quickest paths

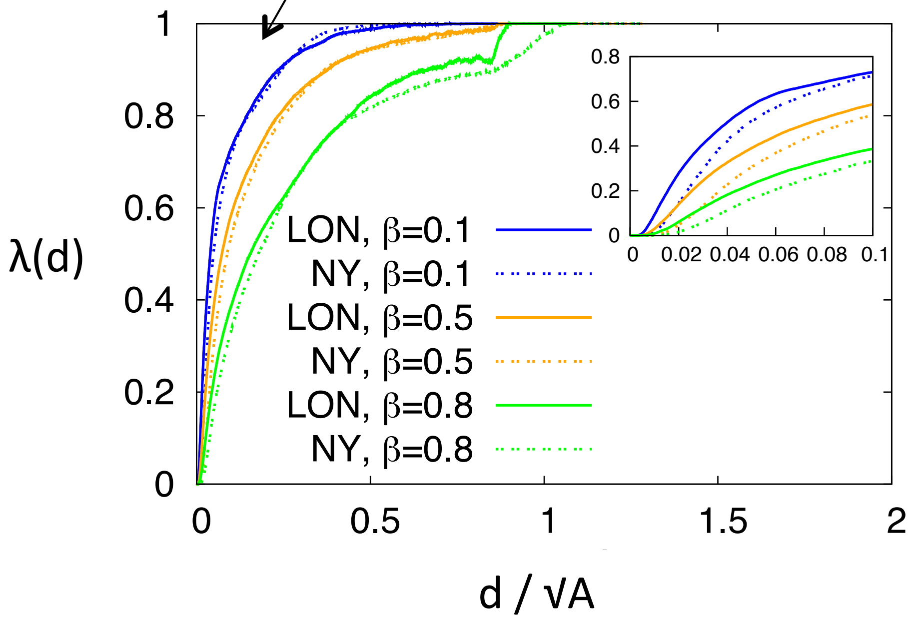
- Travel speeds, network efficiency
  - Speed factor of β makes tube $1/\beta$ faster than street
- Dijkstra's algorithm for shortest paths
  - ~9.4s for a single source = ~35 days for the network
  - Decomposes to ~13 hours on 64 cores

$$w(e) = \begin{cases} l(e), & \text{if } i,j \in V_{\mathrm{s}} \\ \beta l(e), & \text{if } i,j \in V_{\mathrm{u}} \\ d_e(i,j) & \text{otherwise.} \end{cases}$$

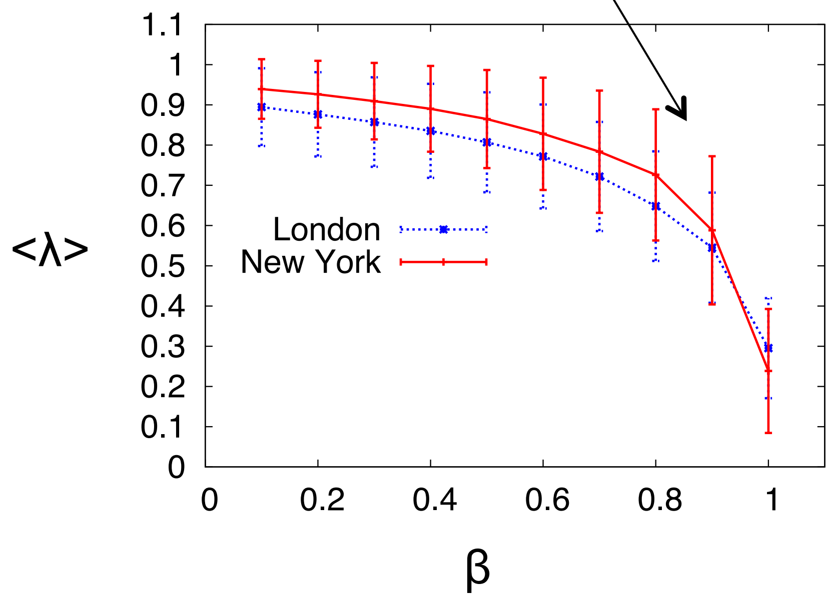
This is using Python's `networkx` library. An alternative library, `igraph`, may be considerably faster. It's still expensive for large networks, though

Results: interdependence

Tube improvement kicks in for quite short routes



Relatively small speed difference captures most of the potential speed-up



λ = fraction of quickest path using the underground

A = total area

Q_λ = fraction of quickest paths of length d using the underground

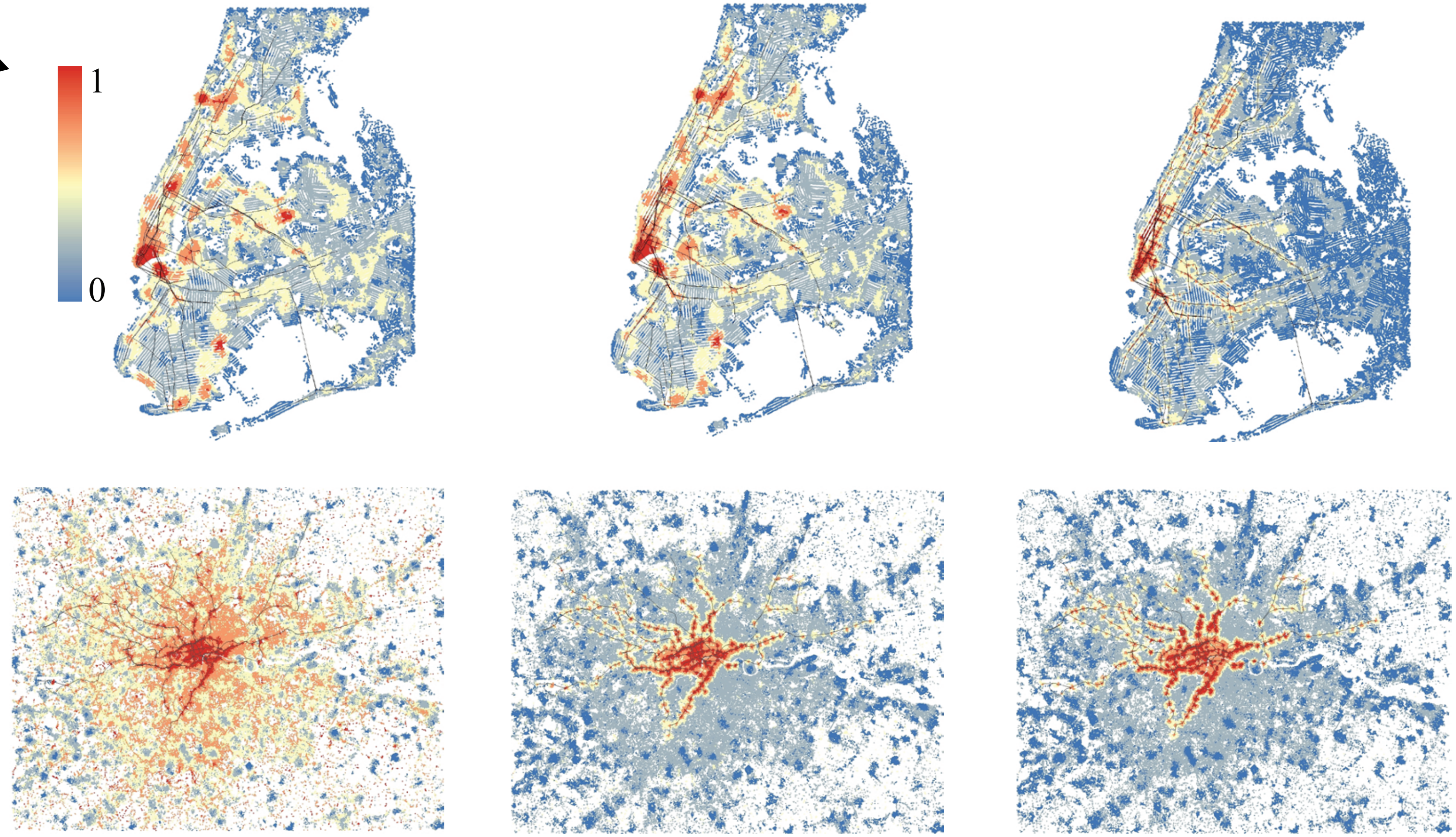
Strano, Shai, Dobson and Barthélemy. Multiplex networks in metropolitan areas: universal features and local effects. Submitted to Nature Scientific Reports.

Results: local outreach – 1

- How far can we get at a given cost?

Can reach the most places at the given cost

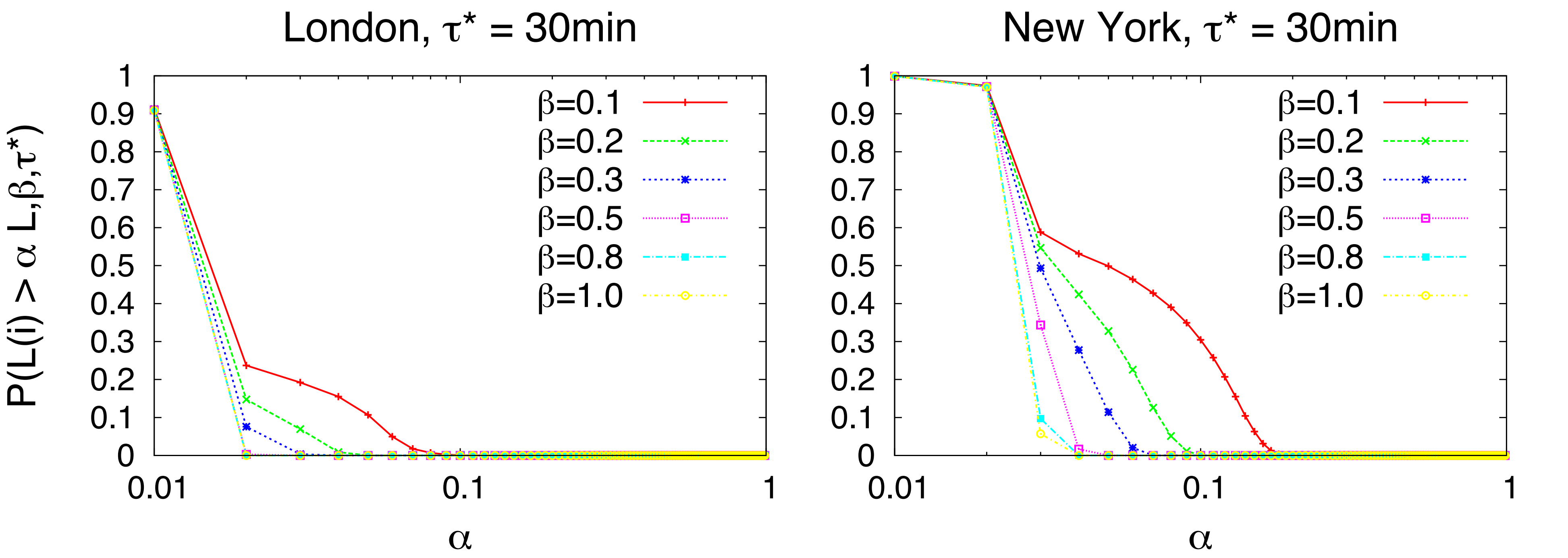
β = 0.8 β = 0.4 β = 0.2



Fast tube has most effect from the centre

Results: local outreach – 2

- How can a city get and still be commutable?

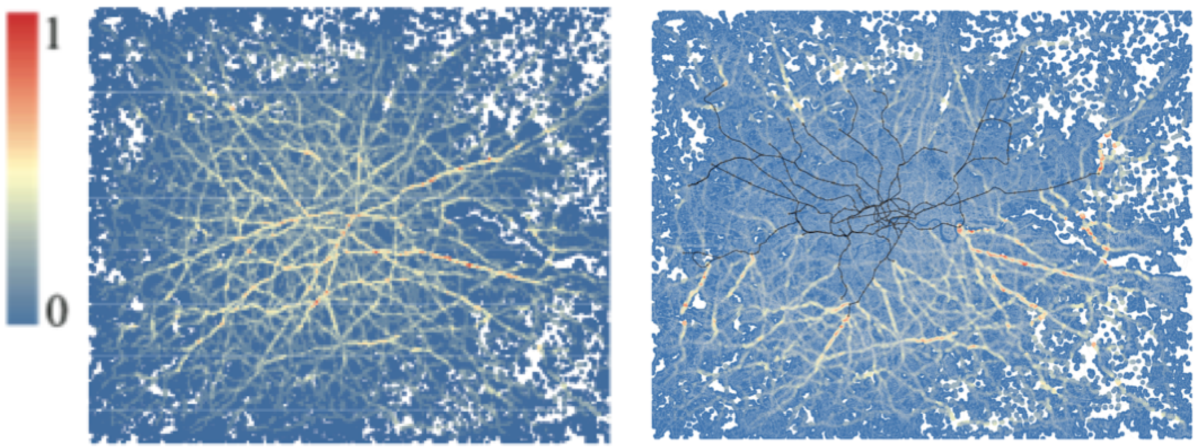


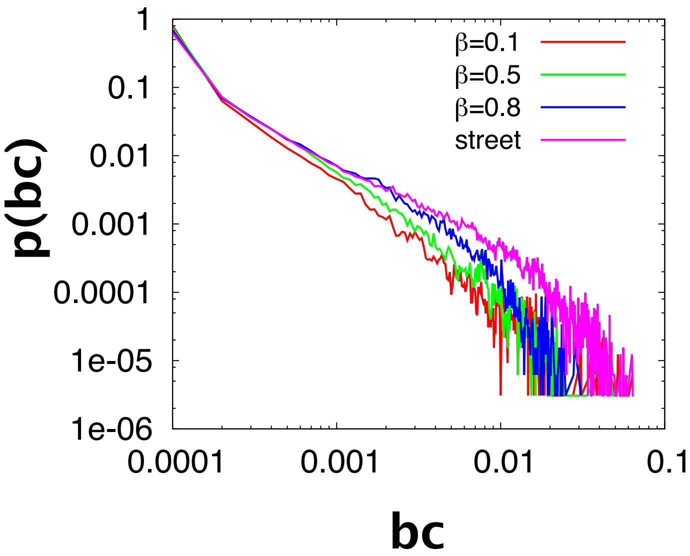
- The value of investment in fast transportation
- Limit to improvements

Results: betweeness centrality

- Identify the “choke points” as people flow through the network

street network **β = 0.5**





  - Remove inner-city congestion
  - Tube “spreads load” more efficiently

Limitations

- Appropriateness of measures
  - Betweeness centrality is all-to-all; commuters don't do this, so need a better travel model
  - More likely to go from suburbs to centre
- Not prohibitively computationally expensive
- Multi-disciplinary, with all that implies
  - Different relationships with computing

Future work

- Make urban planning ideas more formal
  - Local outreach can be given a metric
- Effects of modularity and network structure
  - Non-uniform connectivity
- Couple-in other networks and processes
  - Transport *vs* food supply?
  - Flooding roads or tubes?
  - Other behaviours, *i.e.*, first responders?