Multiplex cities
Interacting transport networks in metropolitan areas

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Complex networks

- Sit at the boundary between order and chaos
- 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

Multiplex transport networks

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

• Effects
  • On commute times?
  • On robustness?
  • On investment?
  • On behaviours?
Datasets

Original data from OpenStreetMap, cleaned by hand (!)

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
Quickest paths

- Travel speeds, network efficiency
  - Speed factor of $\beta$ makes tube $1/\beta$ faster than street
    $$w(e) = \begin{cases} 
l(e), & \text{if } i, j \in V_s \\
\beta l(e), & \text{if } i, j \in V_u \\
d_e(i, j) & \text{otherwise.}
\end{cases}$$
- Dijkstra’s algorithm for shortest paths
  - $\sim 9.4$ s for a single source = $\sim 35$ days for the network
  - Decomposes to $\sim 13$ hours on 64 cores

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

\[ \lambda = \text{fraction of quickest path using the underground} \]
\[ A = \text{total area} \]
\[ Q_\lambda = \text{fraction of quickest paths of length } d \text{ using the underground} \]

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

\( \beta = 0.8 \)
\( \beta = 0.4 \)
\( \beta = 0.2 \)

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: betweenness centrality

- Identify the “choke points” as people flow through the network
- Remove inner-city congestion
- Tube “spreads load” more efficiently
Limitations

• Appropriateness of measures
  • Betweenness 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?