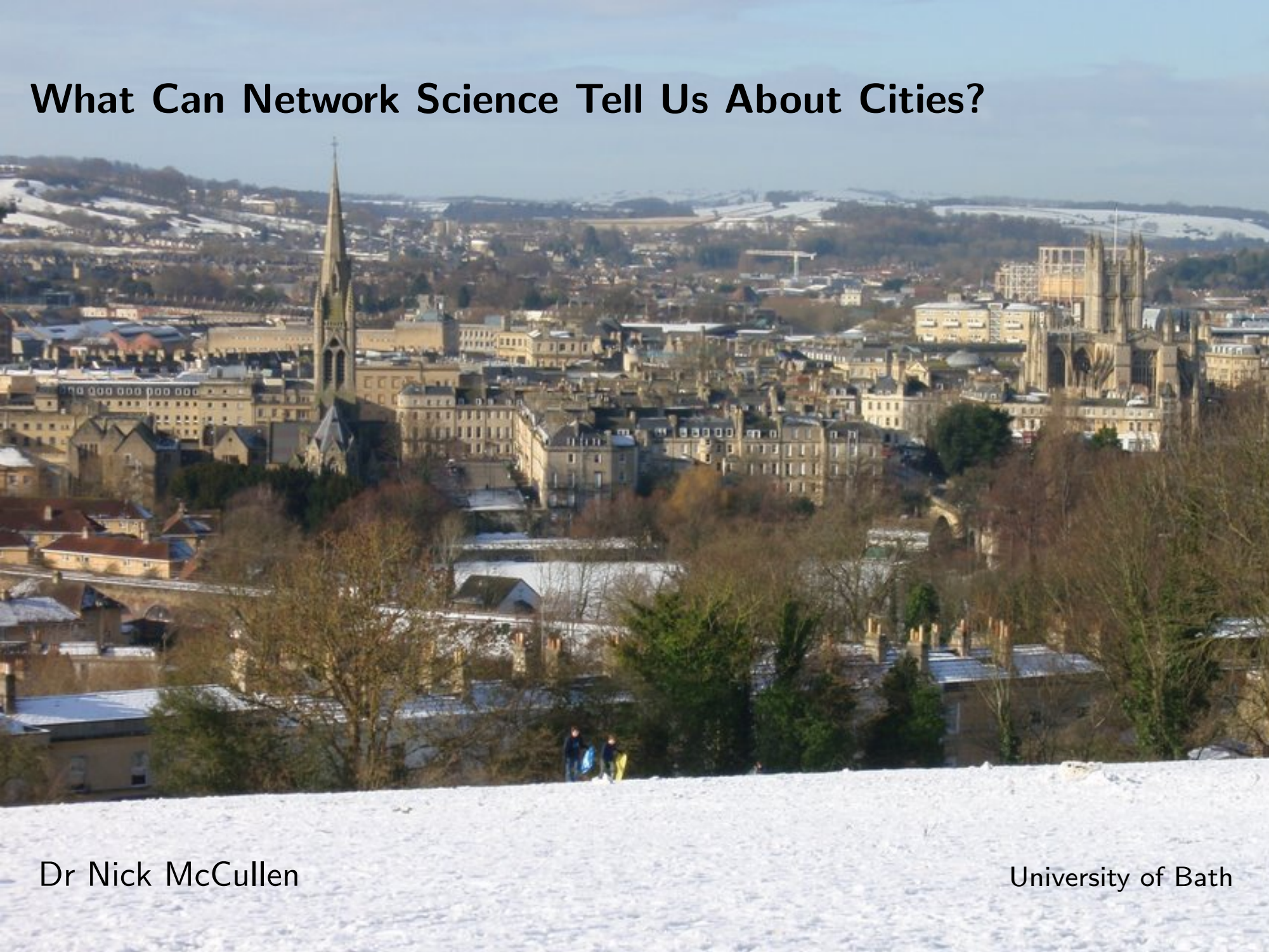
What Can Network Science Tell Us About Cities?



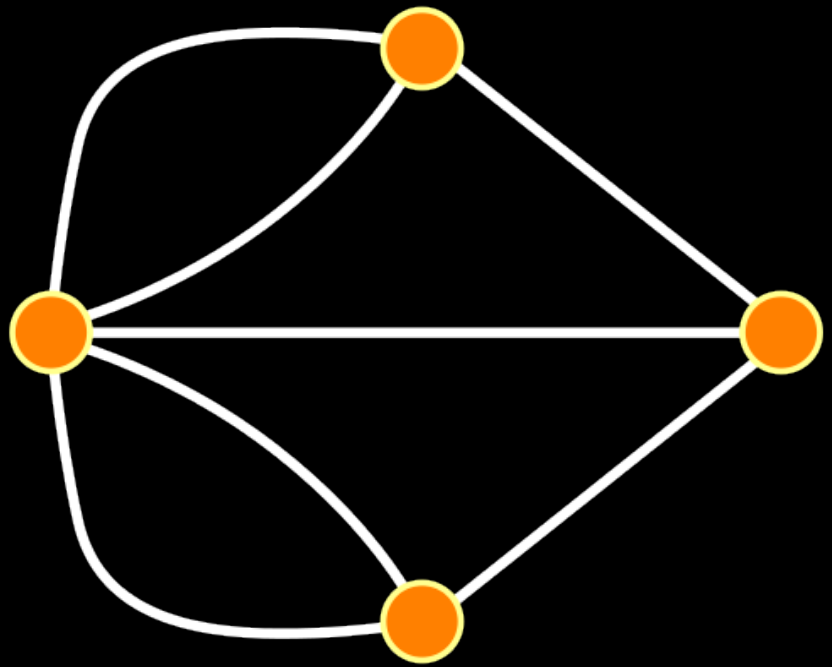
Dr Nick McCullen

University of Bath

Network Theory

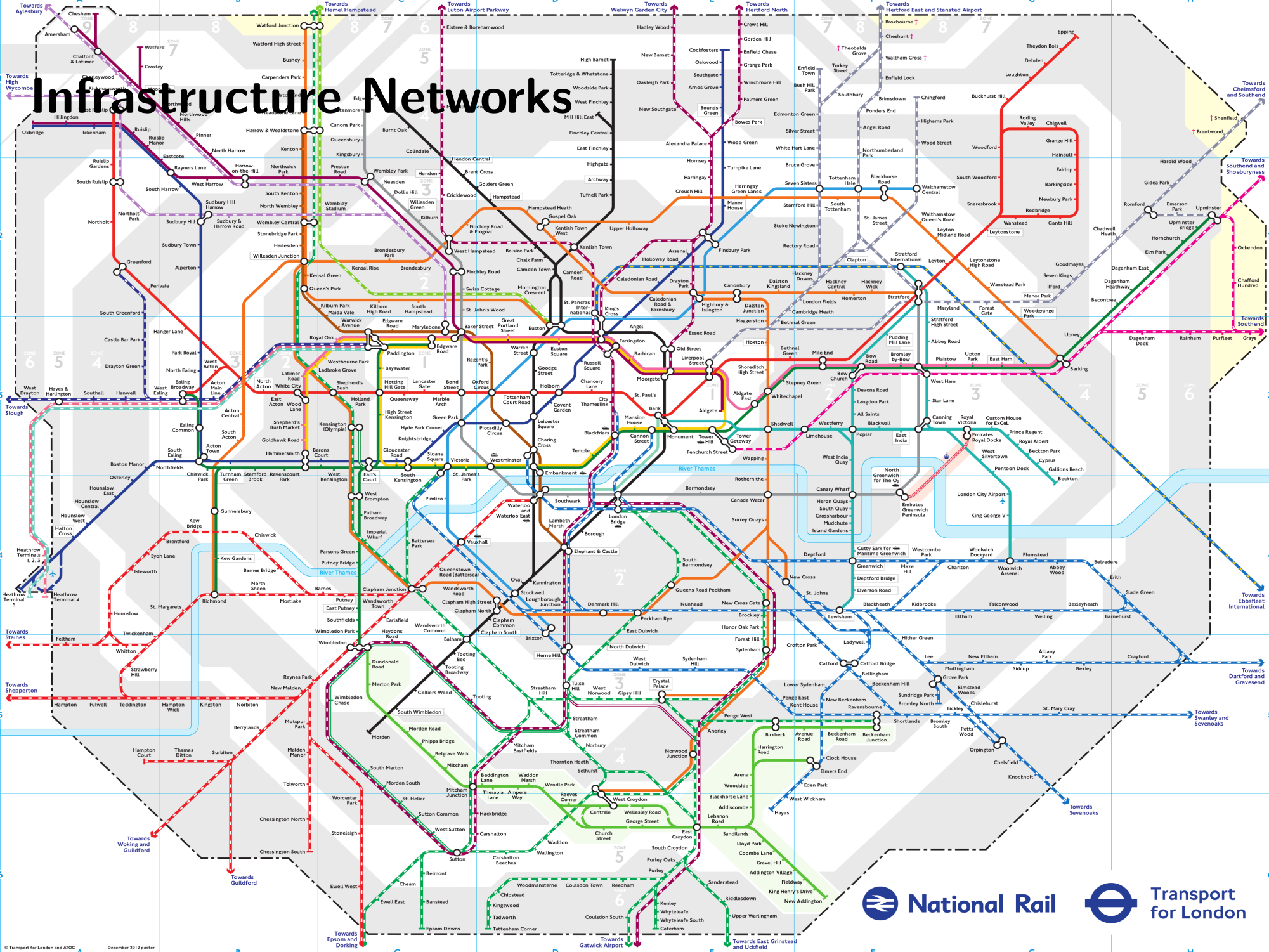
Network Science / Complex Systems Science

- The study of how things connect / interact

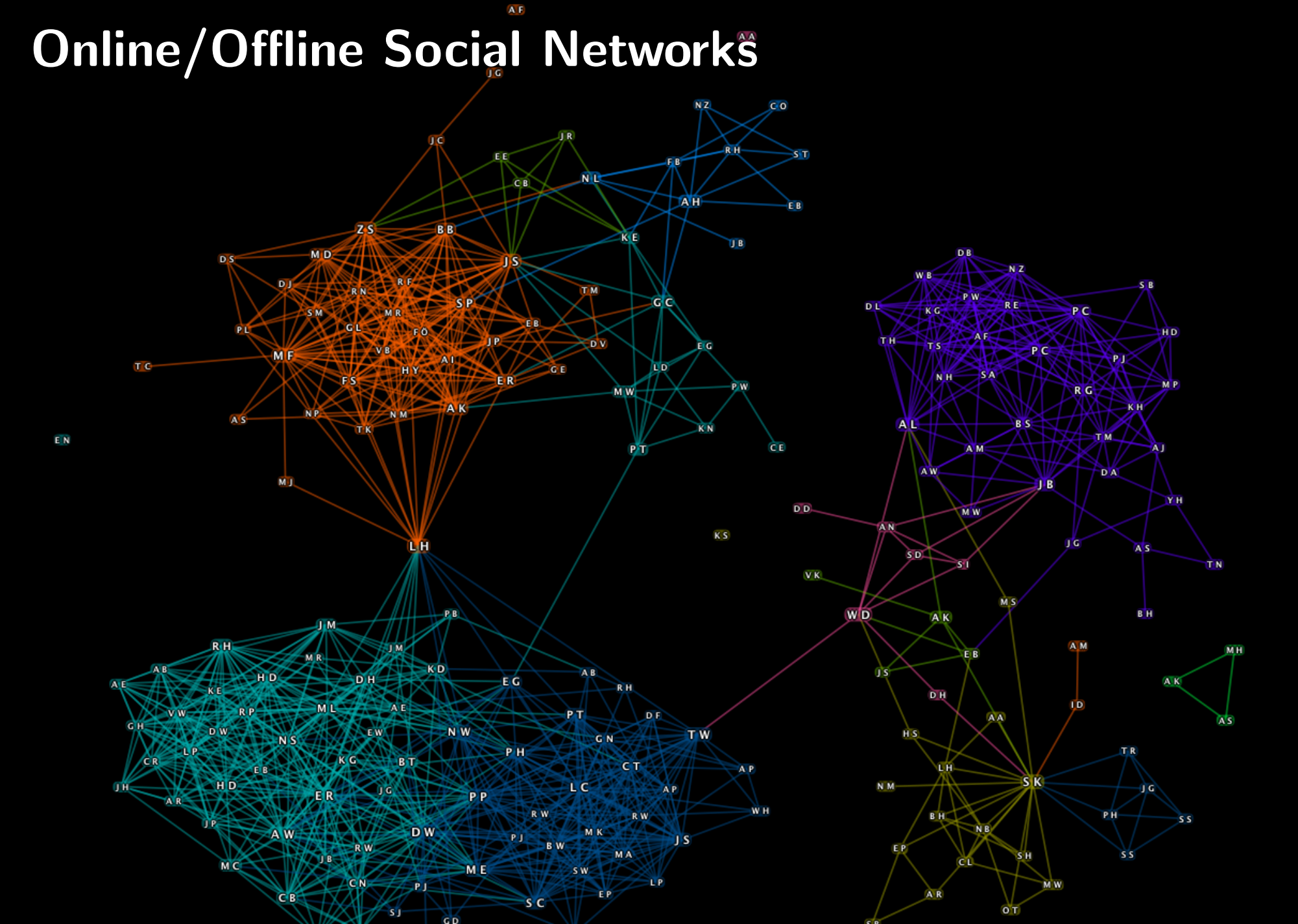


Graph Theory

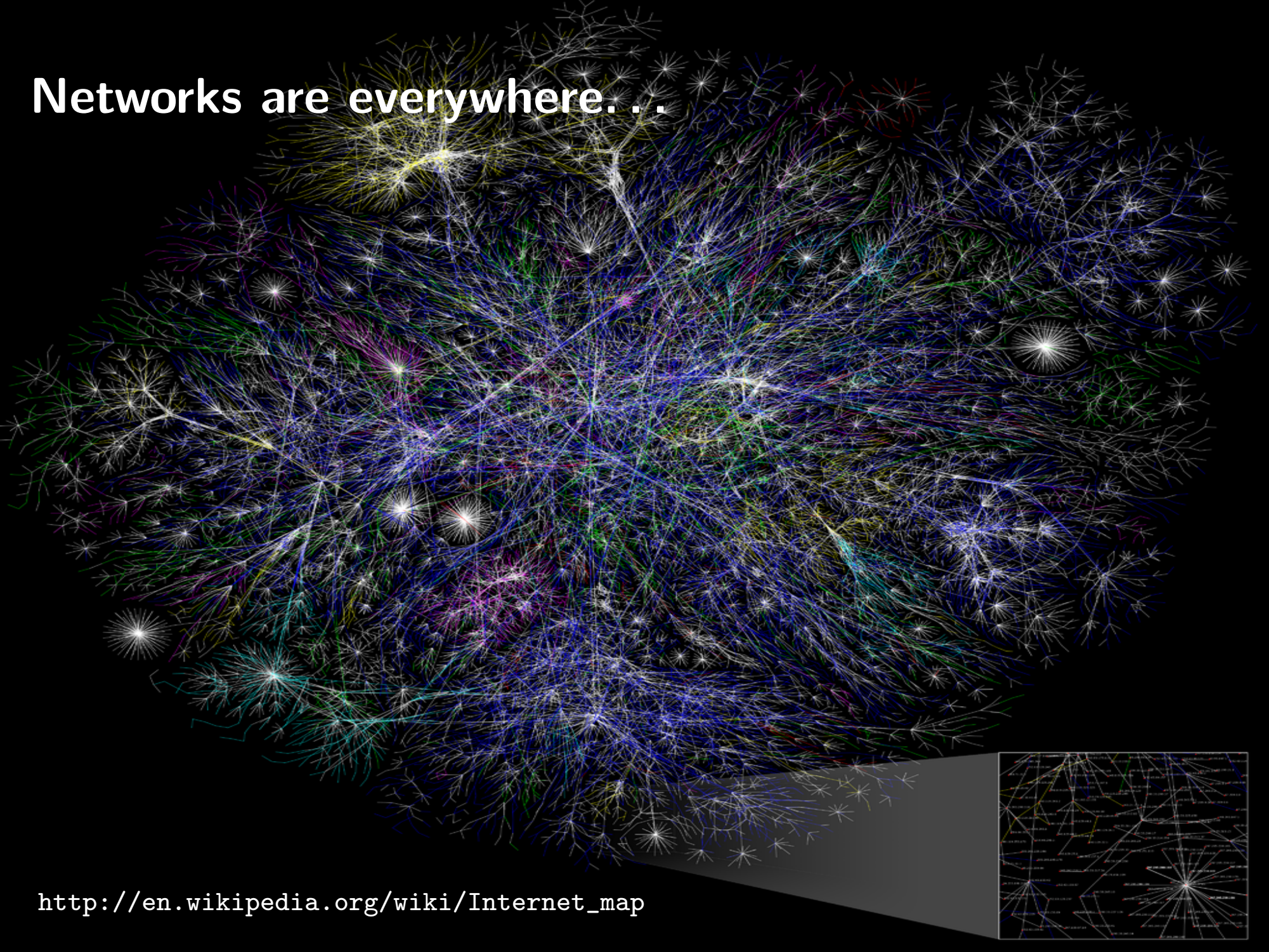
- Nodes: Individuals
- Edges: Links / Connections


Infrastructure Networks
National Rail
Transport for London
© Transport for London and ATOC
December 2012 poster

Online/Offline Social Networks



Networks are everywhere...



http://en.wikipedia.org/wiki/Internet_map

Interconnected Urban Networks

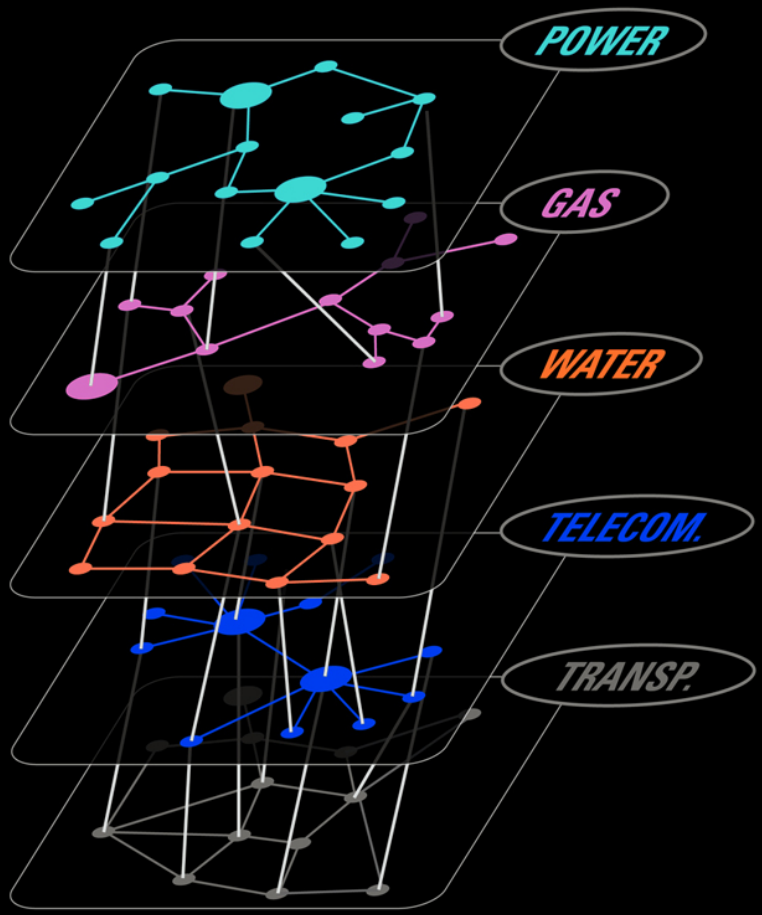
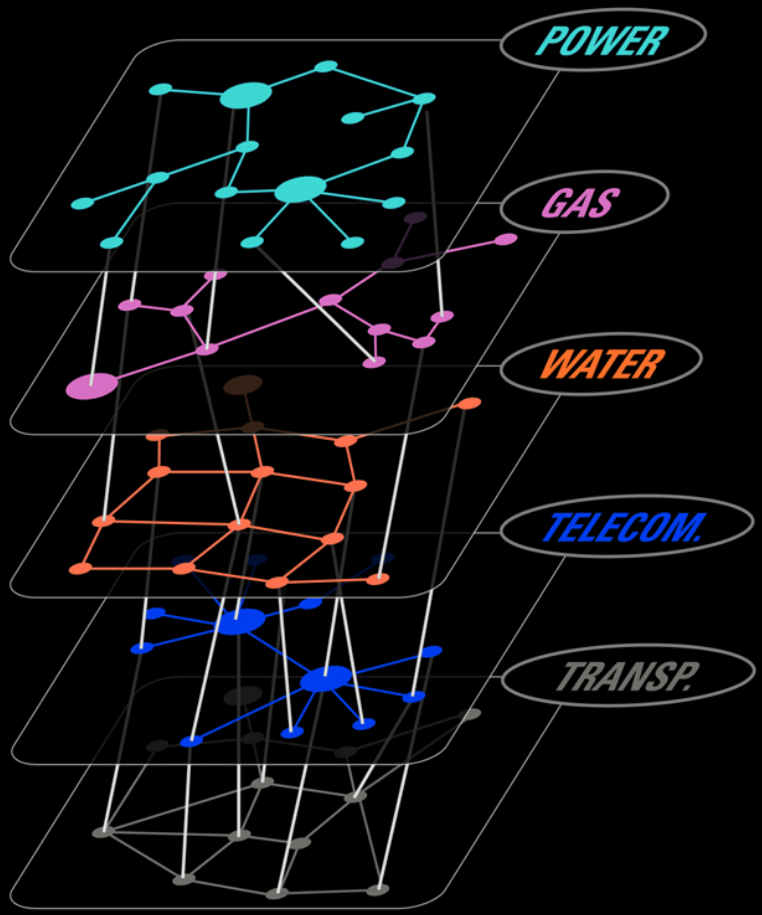


Figure: © Leonardo Dueñas–Osorio.
From: https://simonsfoundation.org/features/science-news/treading-softly-in-a-connected-world/

Interconnected Urban Networks



+

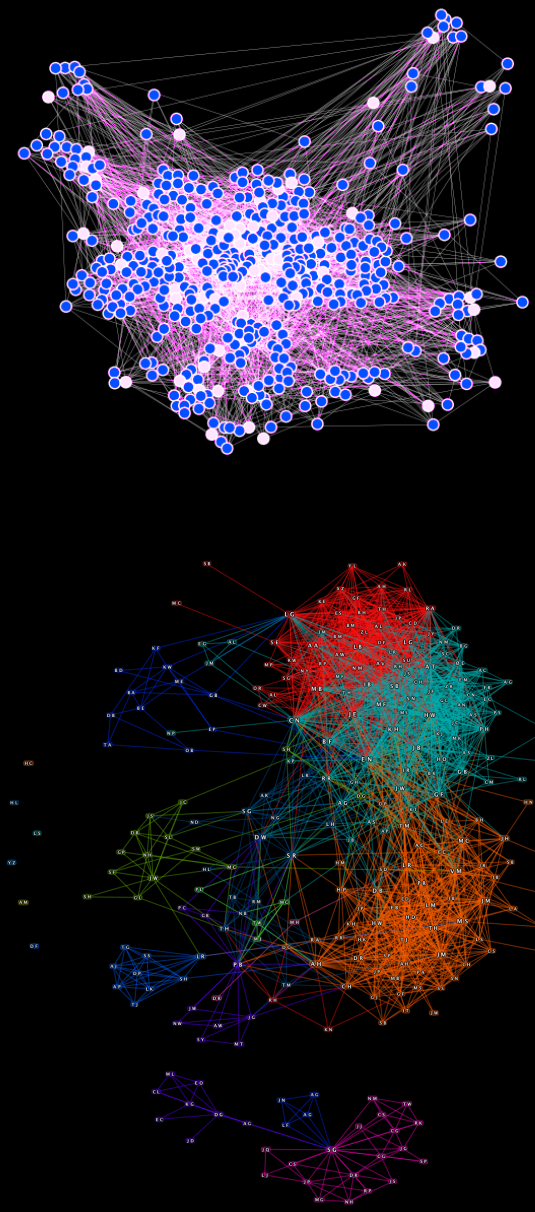
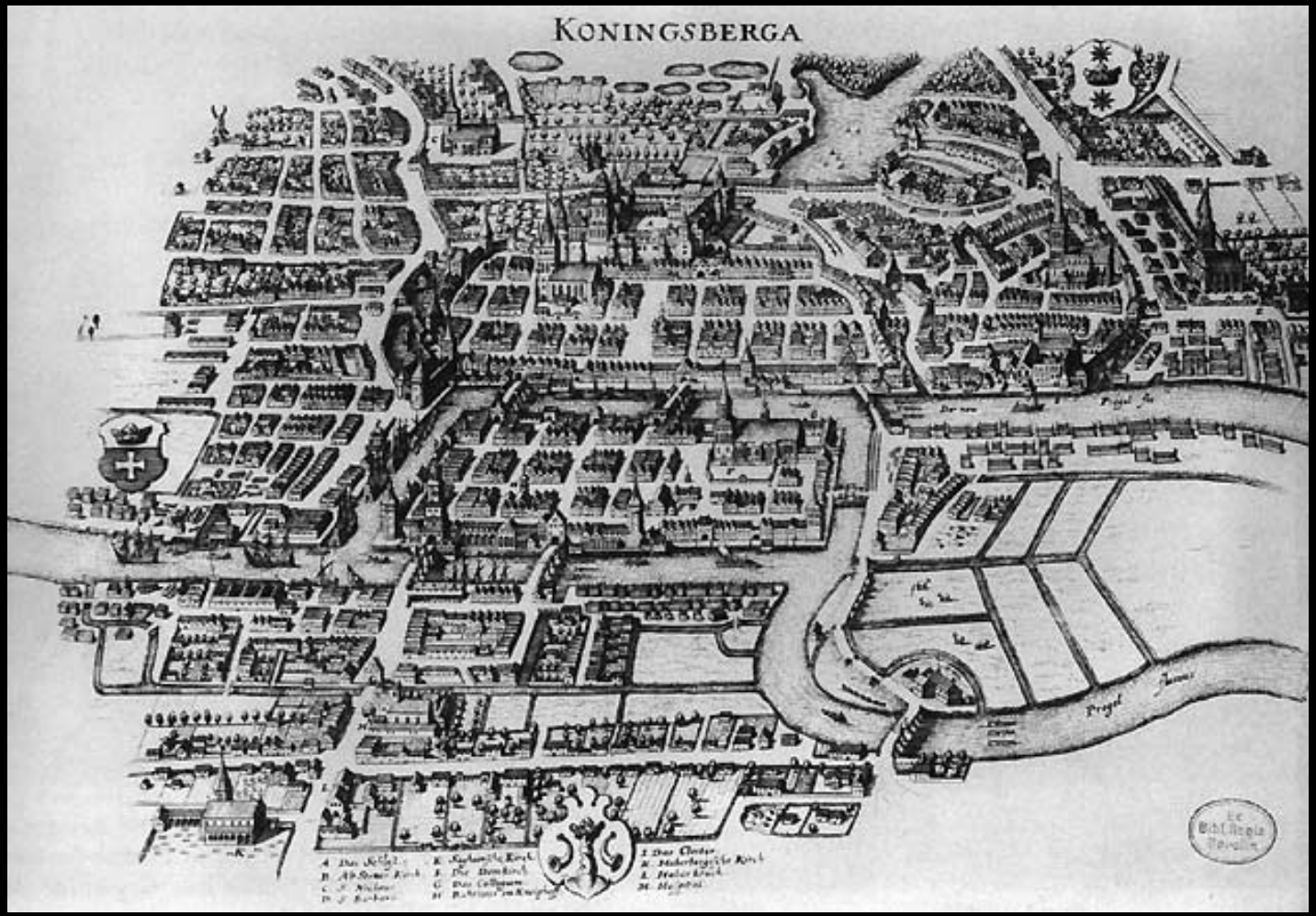


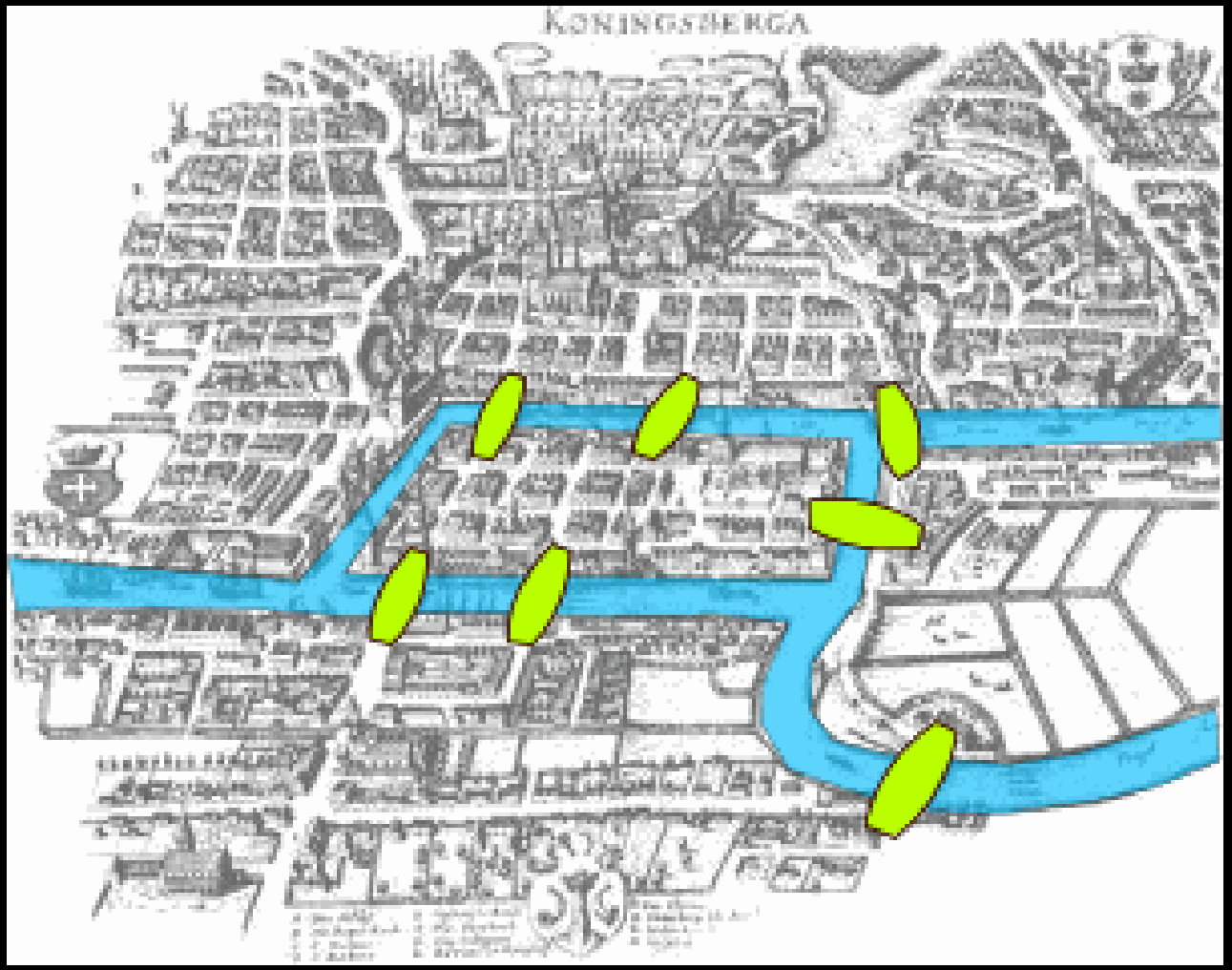
Figure: © Leonardo Dueãs–Osorio.
From: https://simonsfoundation.org/features/science-news/treading-softly-in-a-connected-world/

A Brief History of Network Theory



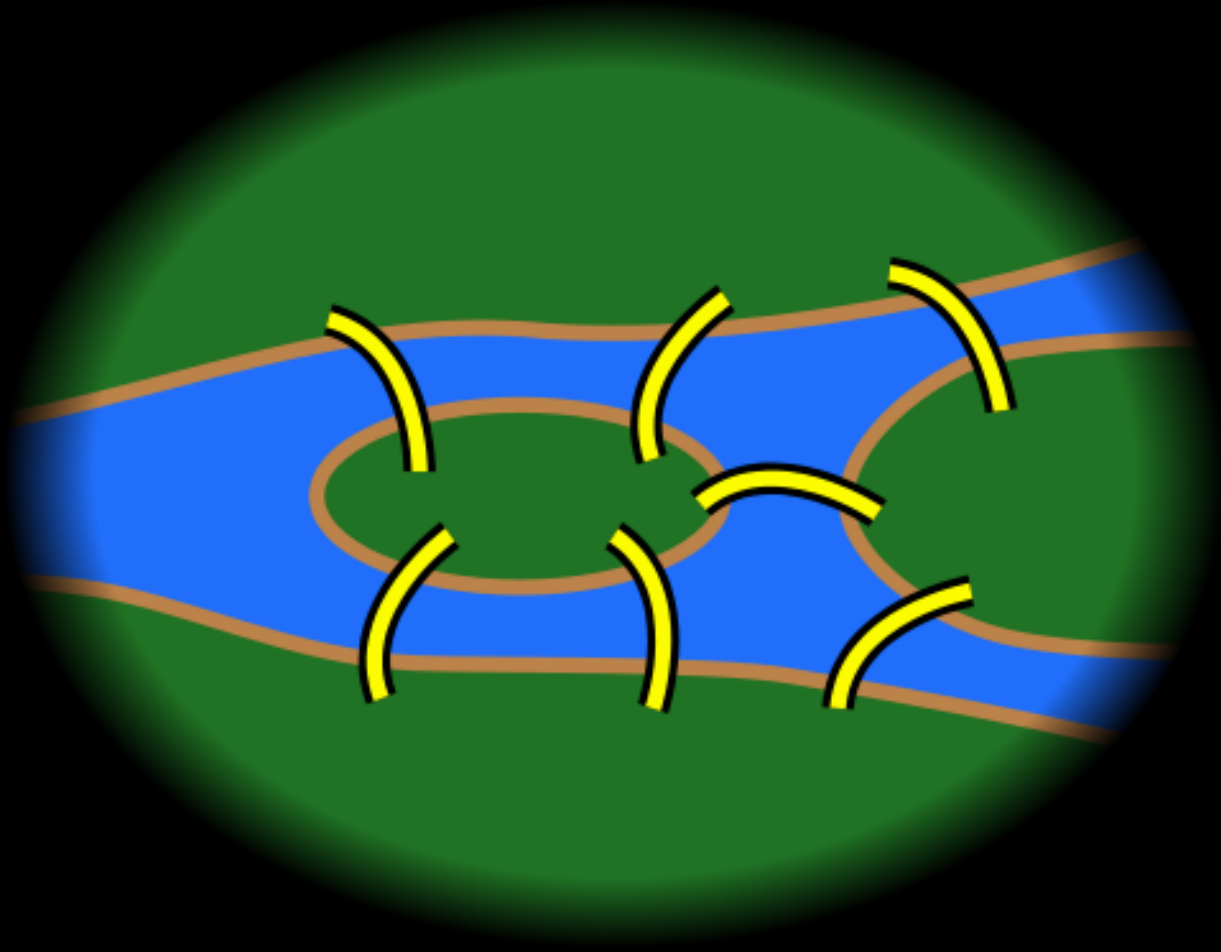
By Merian-Erben [Public domain], via Wikimedia Commons

The Königsberg Bridge Problem



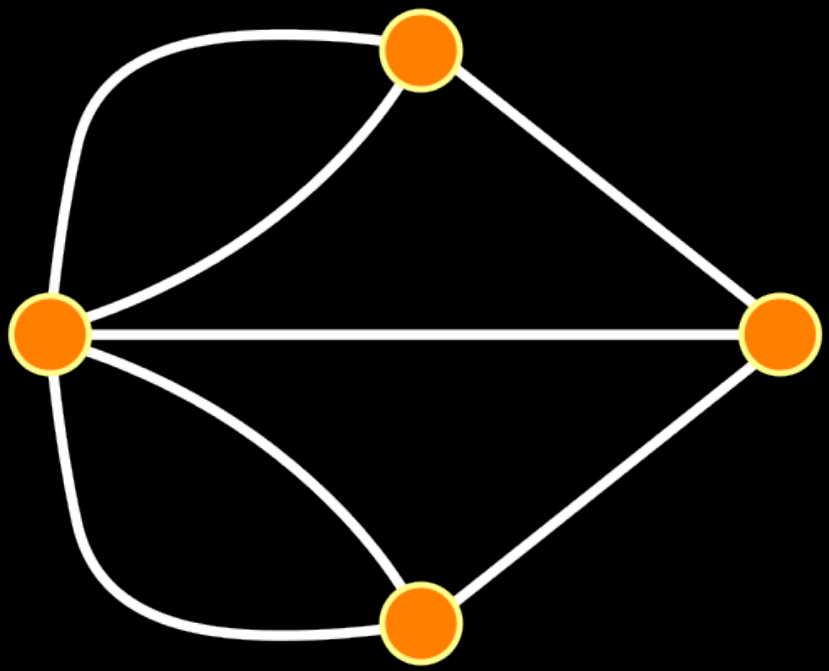
By Bogdan Giuşcă (Public domain (PD)) [GFDL (http://www.gnu.org/copyleft/fdl.html)], via Wikimedia Commons

The Seven Bridges of Königsberg



https://en.wikipedia.org/wiki/Seven_Bridges_of_Königsberg

Resolution by Leonhard Euler in 1736



https://en.wikipedia.org/wiki/Seven_Bridges_of_Königsberg

Modern day Kaliningrad

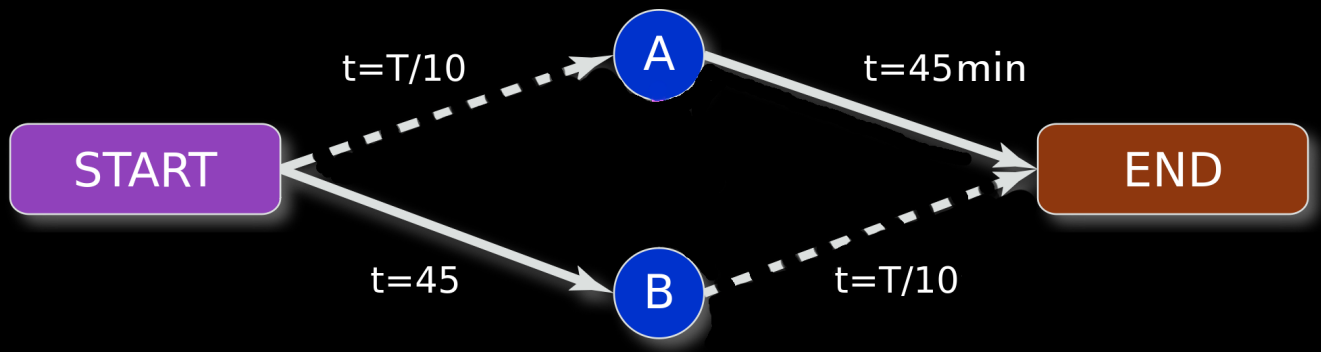
What if They Closed 42d Street and Nobody Noticed?

By GINA KOLATA
Published: December 25, 1990

ON Earth Day this year, New York City's Transportation Commissioner decided to close 42d Street, which as every New Yorker knows is always congested. "Many predicted it would be doomsday," said the Commissioner, Lucius J. Riccio. "You didn't need to be a rocket scientist or have a sophisticated computer queuing model to see that this could have been a major problem."

But to everyone's surprise, Earth Day generated no historic traffic jam. Traffic flow actually improved when 42d Street was closed.

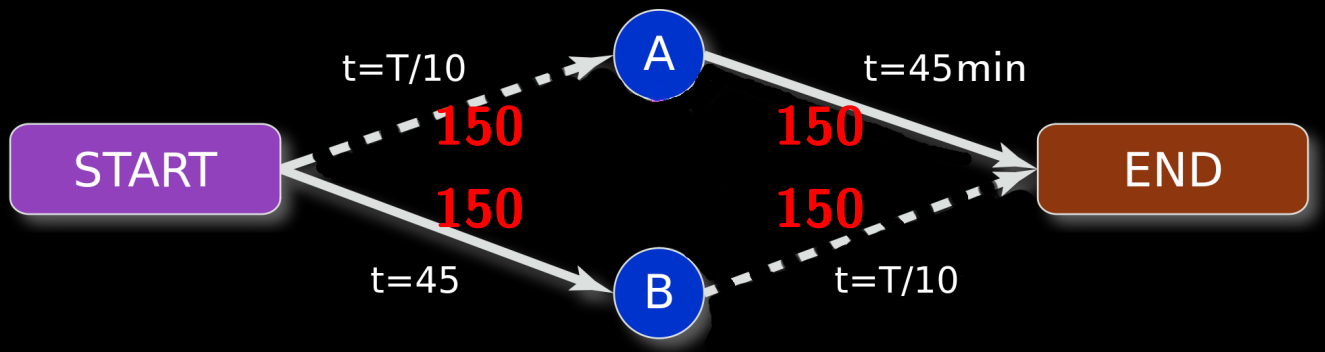
“Braess’ paradox”



T: Number of cars on section

Modified from: http://en.wikipedia.org/wiki/Braess’s_paradox

“Braess’ paradox”

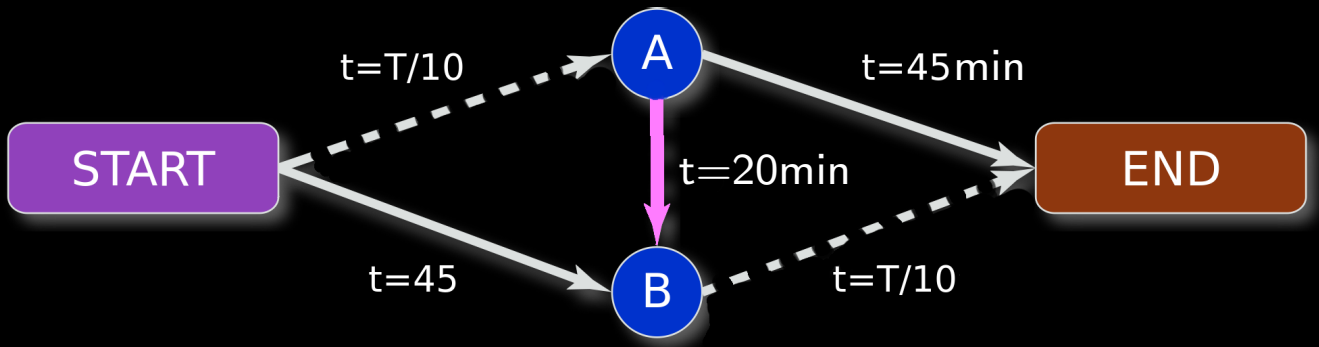


T: Number of cars on section

150 Cars both routes: time $= \frac{150}{10} + 45 = 60\text{min}$

Modified from: `http://en.wikipedia.org/wiki/Braess's_paradox`

“Braess’ paradox”



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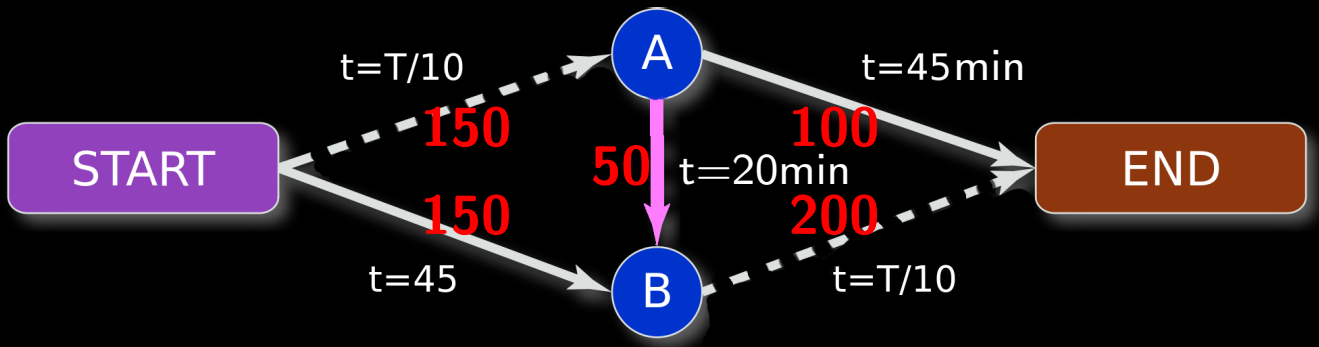
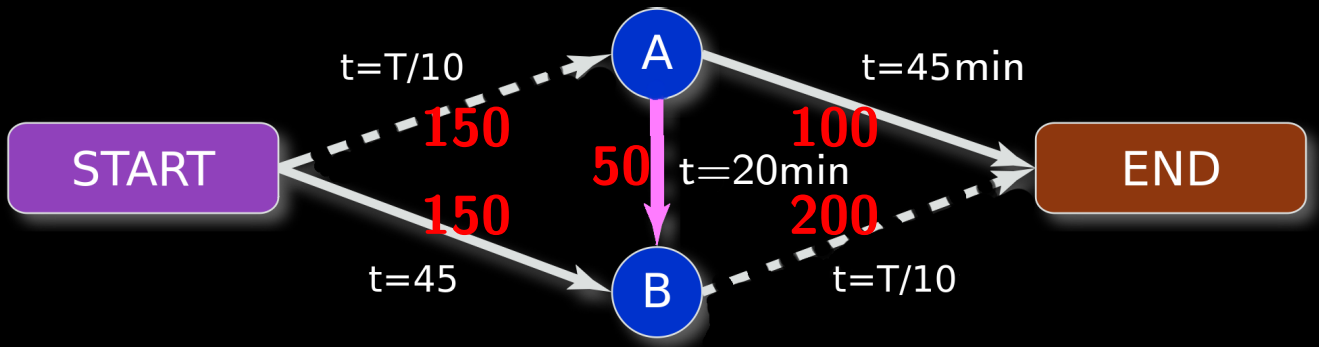


T: Number of cars on section

50 Cars SHORTCUT: $\text{time} = \frac{150}{10} + 20 + \frac{200}{10} = 55\text{min}$

Modified from: `http://en.wikipedia.org/wiki/Braess's_paradox`

“Braess’ paradox”



T: Number of cars on section

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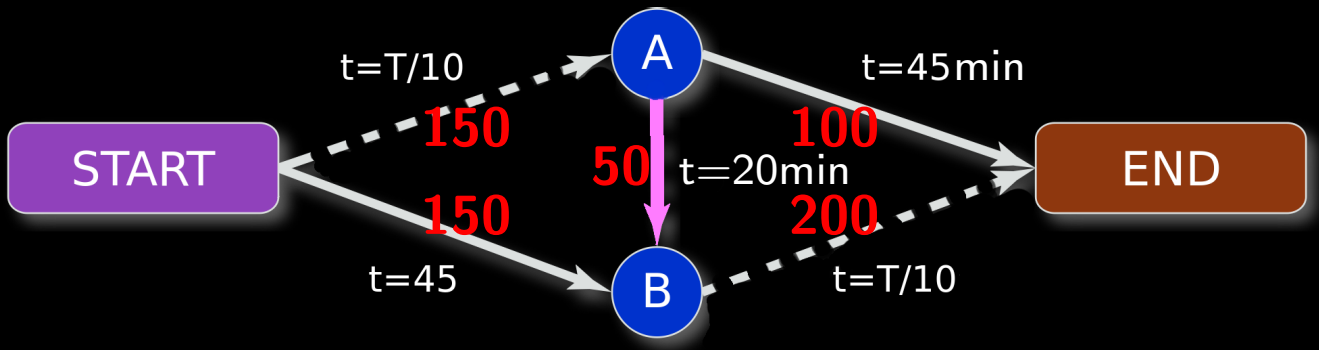
+100 Cars VIA A: time $= \frac{150}{10} + 45 = 60$min

Modified from: `http://en.wikipedia.org/wiki/Braess's_paradox`

“Braess’ paradox”



T: Number of cars on section

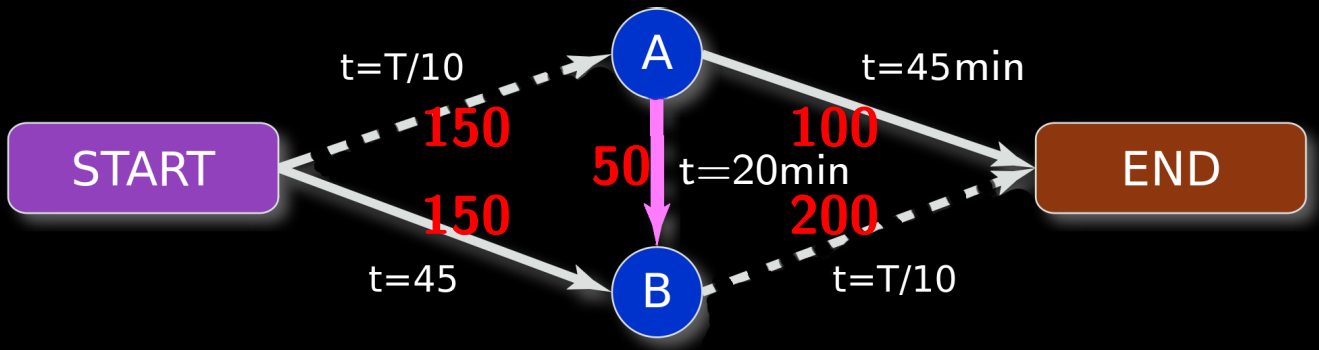
50 Cars SHORTCUT: time $= \frac{150}{10} + 20 + \frac{200}{10} = 55$min

+100 Cars VIA A: time $= \frac{150}{10} + 45 = 60$min

+150 Cars VIA B: time $= 45 + \frac{200}{10} = 65$min

Modified from: `http://en.wikipedia.org/wiki/Braess's_paradox`

“Braess’ paradox”



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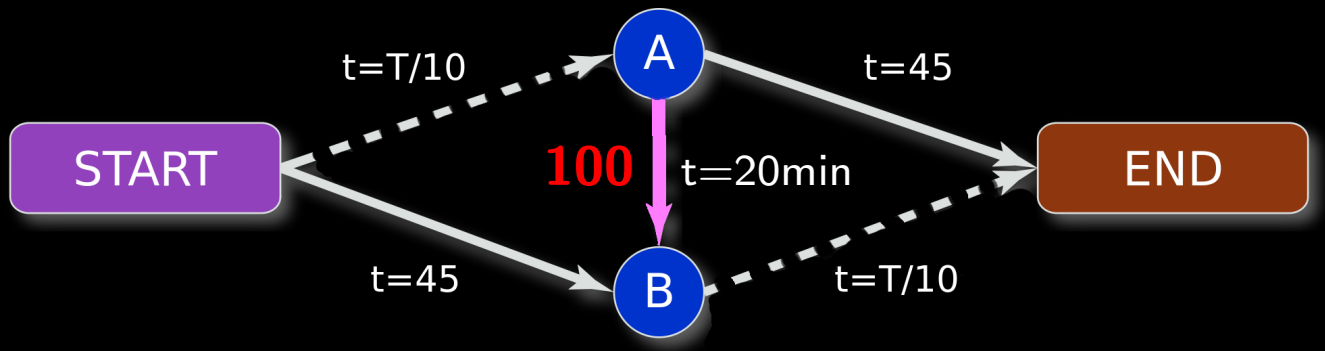
+100 Cars VIA A: time $= \frac{150}{10} + 45 = 60$min

+150 Cars VIA B: time $= 45 + \frac{200}{10} = 65$min

Average: ≈ 62min!

Modified from: `http://en.wikipedia.org/wiki/Braess's_paradox`

“Braess’ paradox”



T: Number of cars on section

150 Cars both routes: $\text{time} = \frac{150}{10} + 45 = 60\text{min}$

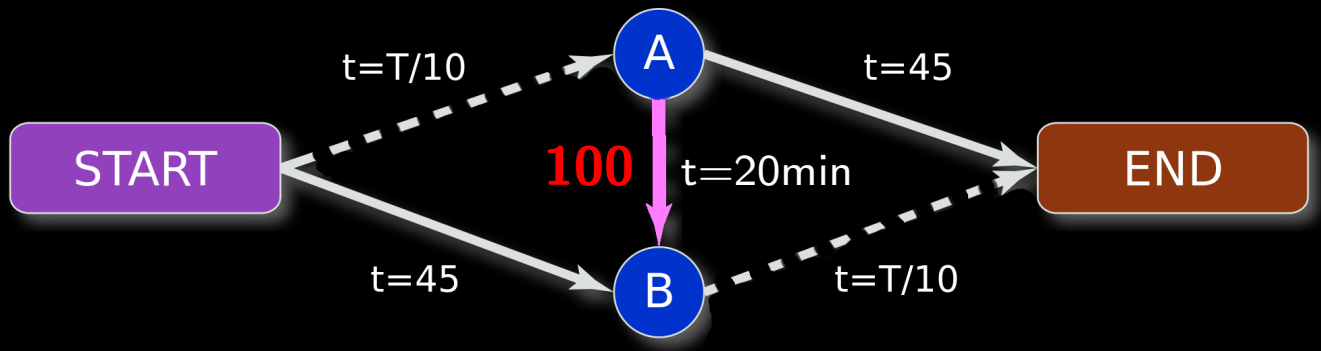
---

50 Cars SHORTCUT: $\text{time} = \frac{150}{10} + 20 + \frac{200}{10} = 55\text{min}$

Average: $\approx 62\text{min}$!

Modified from: `http://en.wikipedia.org/wiki/Braess's_paradox`

“Braess’ paradox”



T: Number of cars on section

150 Cars both routes: time $= \frac{150}{10} + 45 = 60$min

---

50 Cars SHORTCUT: time $= \frac{150}{10} + 20 + \frac{200}{10} = 55$min

Average: ≈ 62min!

---

100 Cars SHORTCUT: time $= \frac{150}{10} + 20 + \frac{250}{10} = 60$min

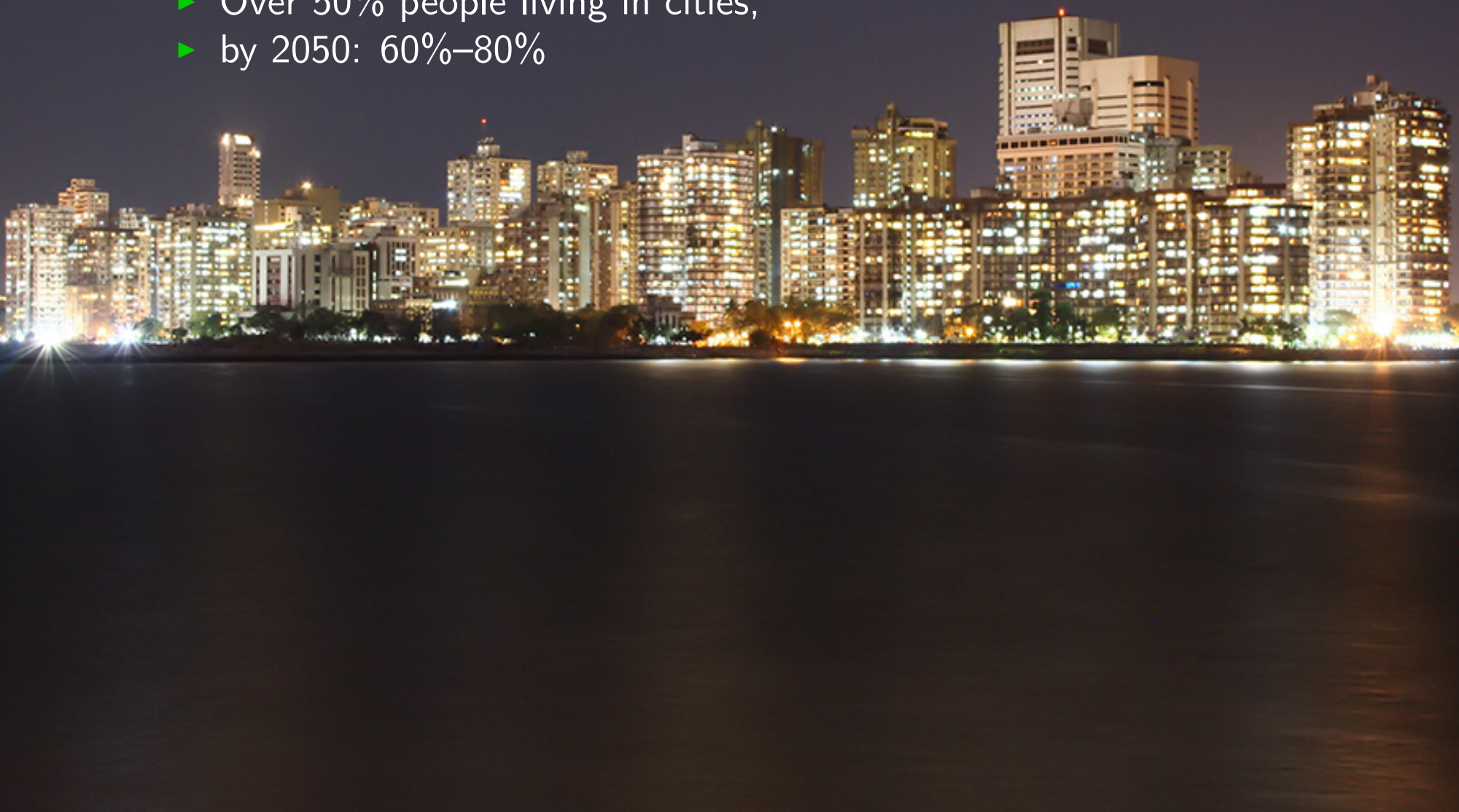
System Average: $= 65$min!

Modified from: `http://en.wikipedia.org/wiki/Braess's_paradox`

Cities are Important

Cities are Important

- Cities are expanding:
  - Over 50% people living in cities,
  - by 2050: 60%–80%



Cities are Important

- Cities are expanding:
  - Over 50% people living in cities,
  - by 2050: 60%–80%

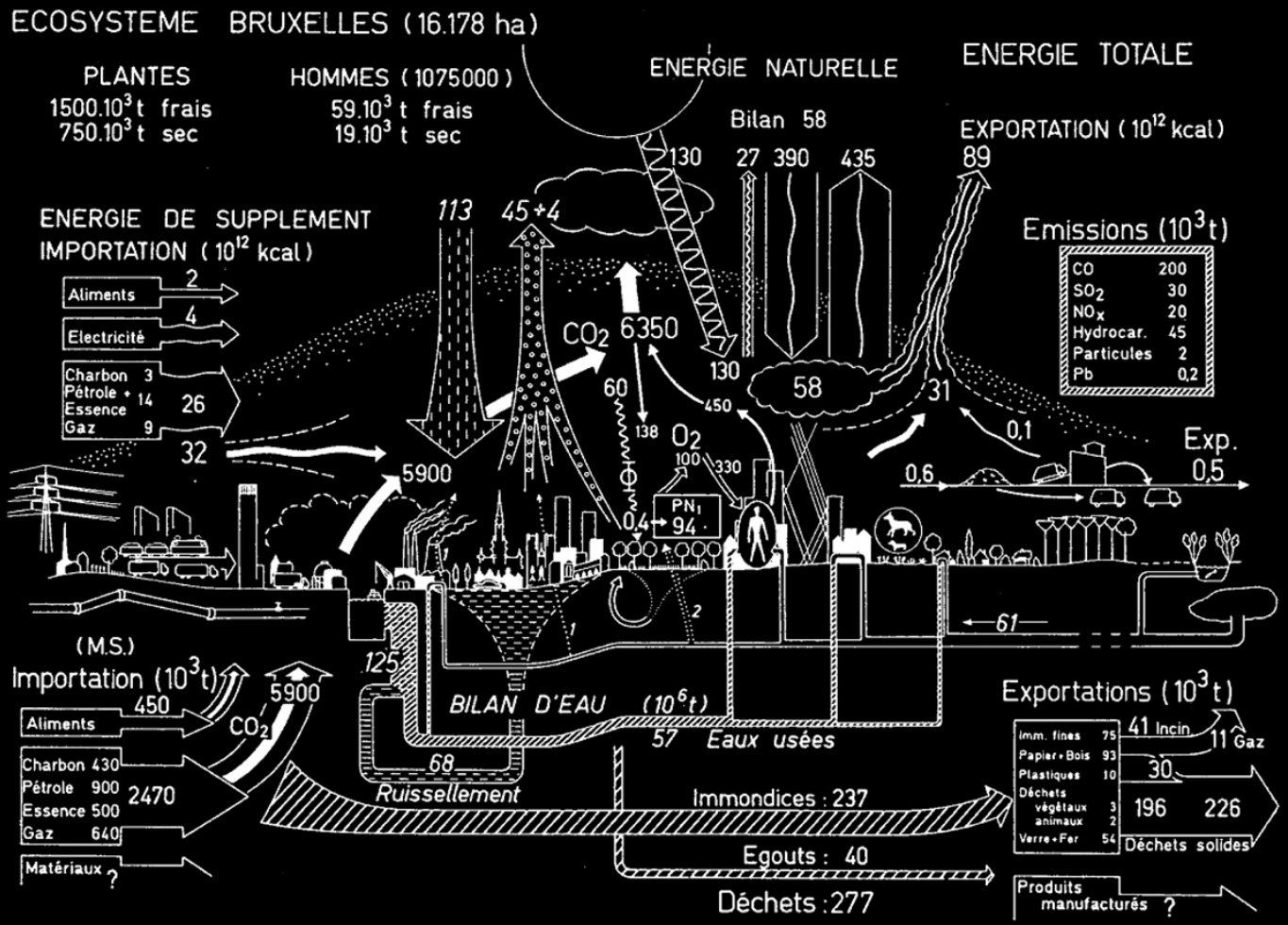
- Buildings consume 20%–40% of total energy.
- Commuting alone accounts for 5%–10%. . .
- Total transport ≈50%

---

‡: Osório, McCullen, Walker & Coley. Sustainable Cities and Society (2017)

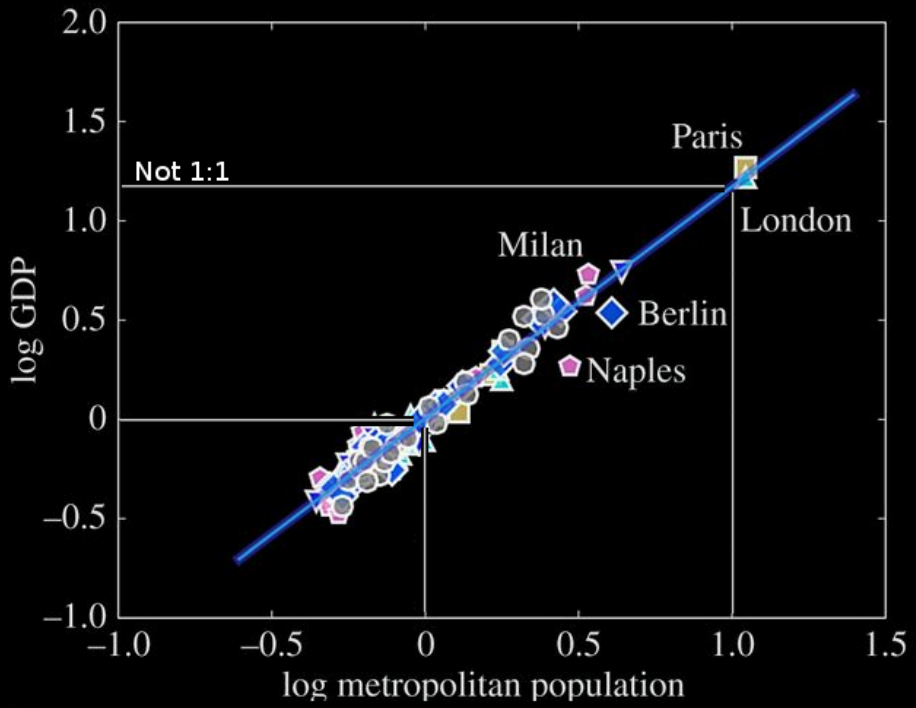
"Integrating the energy costs of urban transport and buildings."

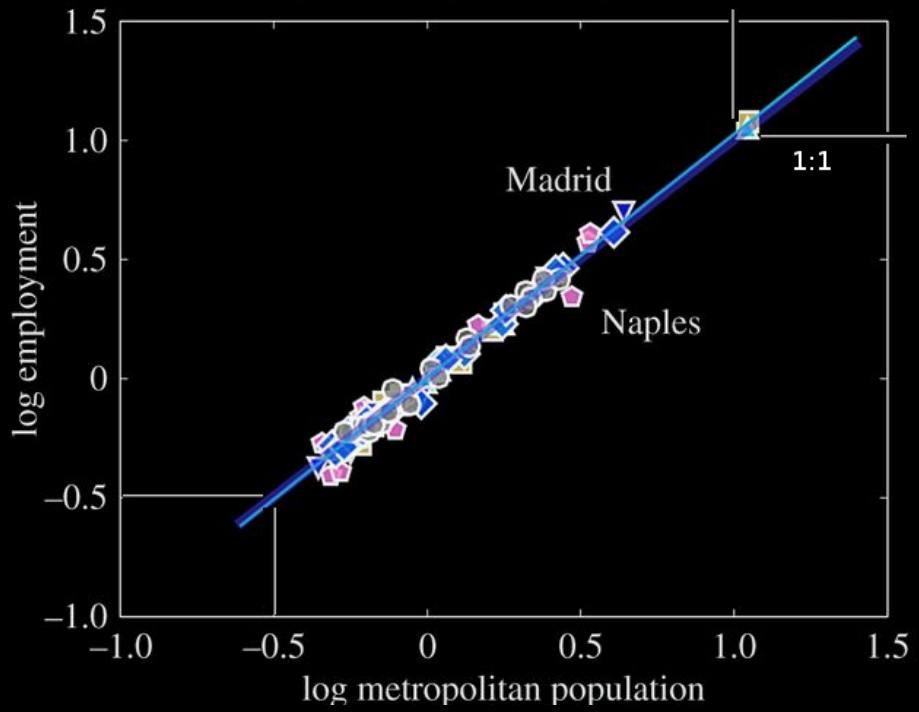
Cities are Complex Systems



Duvigneaud, P., Denayeyer-De Smet, S., 1977. L'Ecosystéme Urbs, in L'Ecosystéme Urbain Bruxellois, in Productivité en Belgique. In: Duvigneaud, P., Kestemont, P. (Eds.), Traveaux de la Section Belge du Programme Biologique International, Bruxelles, pp. 581–597.

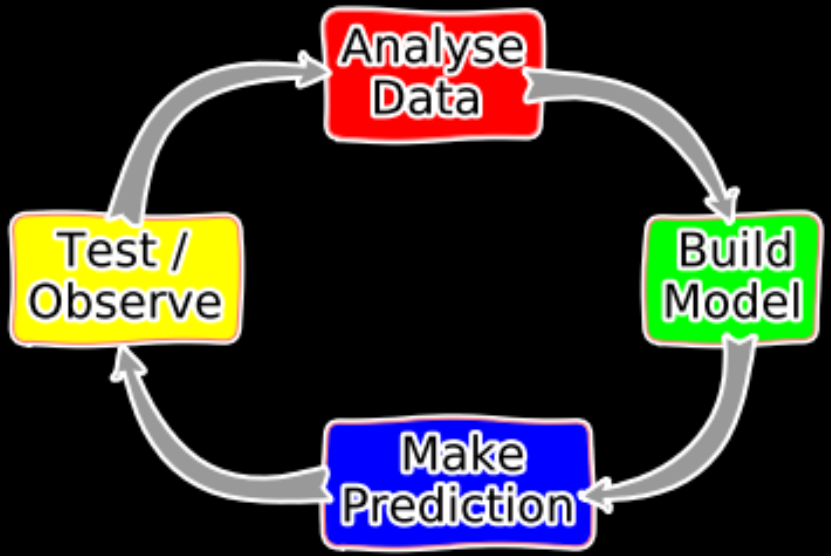
Is there a Science of Cities?





[Luís M. A. Bettencourt, José Lobo "Urban scaling in Europe", Journal of the Royal Society Interface (2016)]

Developing a Scientific Theory



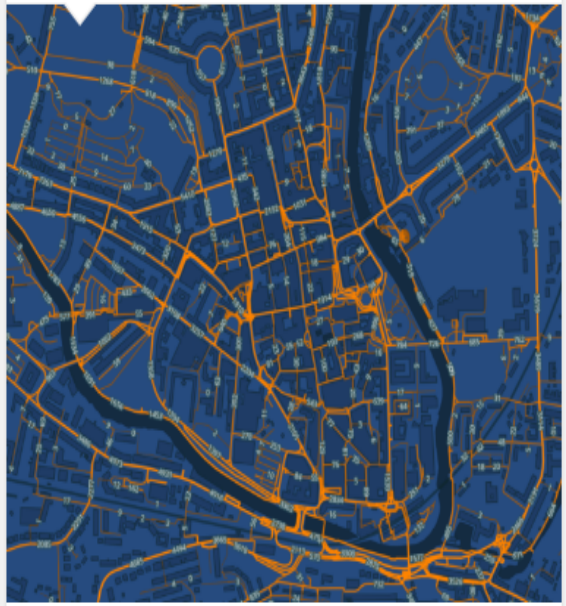
BATH: HACKED

We open local data and make useful things

Annual Report 2016

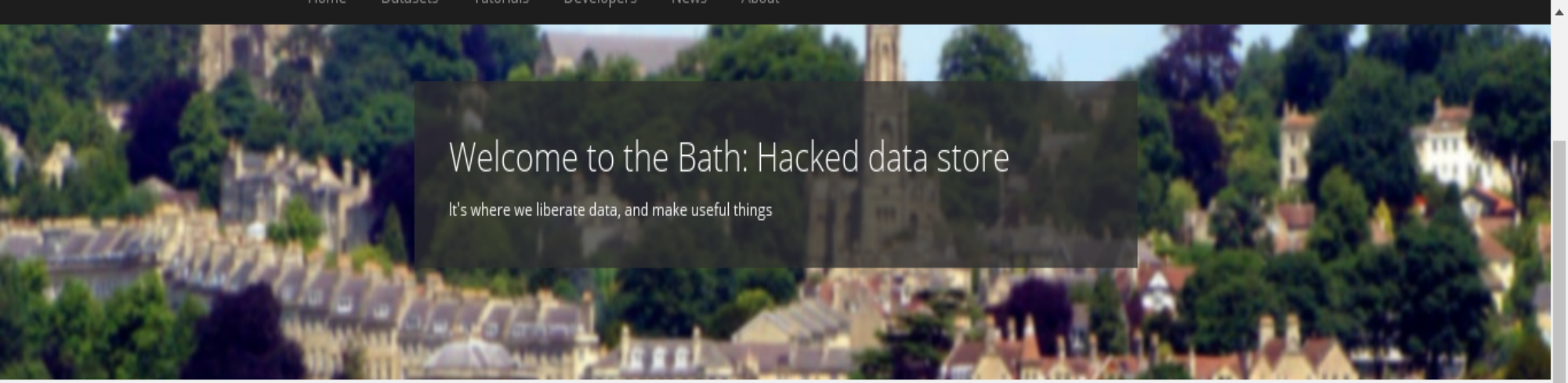
Its now been just over a year since we turned Bath: Hacked from a community

Strava Metro: interacting with the data



Strava Metro: animating the data

Yesterday we looked at some maps of the Strava Metro data for Bath. Different



Welcome to the Bath: Hacked data store

It's where we liberate data, and make useful things

Economy

Education

Environment

Government

Health

Heritage

Population

Transport

Live Air Quality Data

Air quality data taken from sensors sited around Bath

House Prices

House price data from 1995 until the present day

Street Level Crime

Crime reports in the BANES area from police.gov.uk

Live Parking Spaces

Latest occupancy in Bath city car parks and Park n Rides

Unsaved View

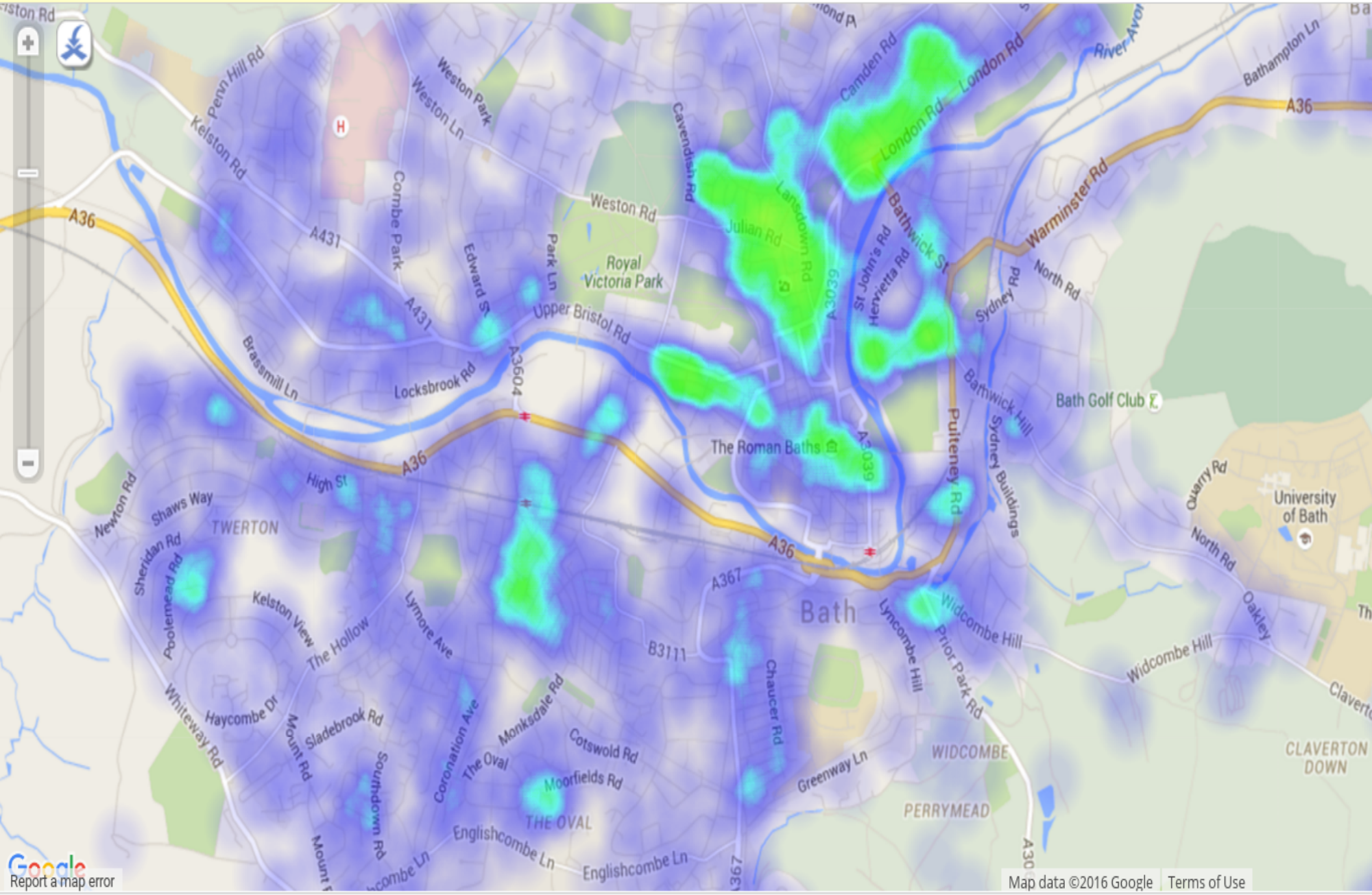
Save As... Revert

Based on Heat map of Median consumption Postcode level electricity estimates

This dataset contain the number of electricity meters and consumption levels in BANES at postcode level.

Find in this Dataset

Manage | More Views | Filter | Visualize | Export | Discuss | Embed | About



Report a map error

Map data ©2016 Google | Terms of Use

Unsaved View

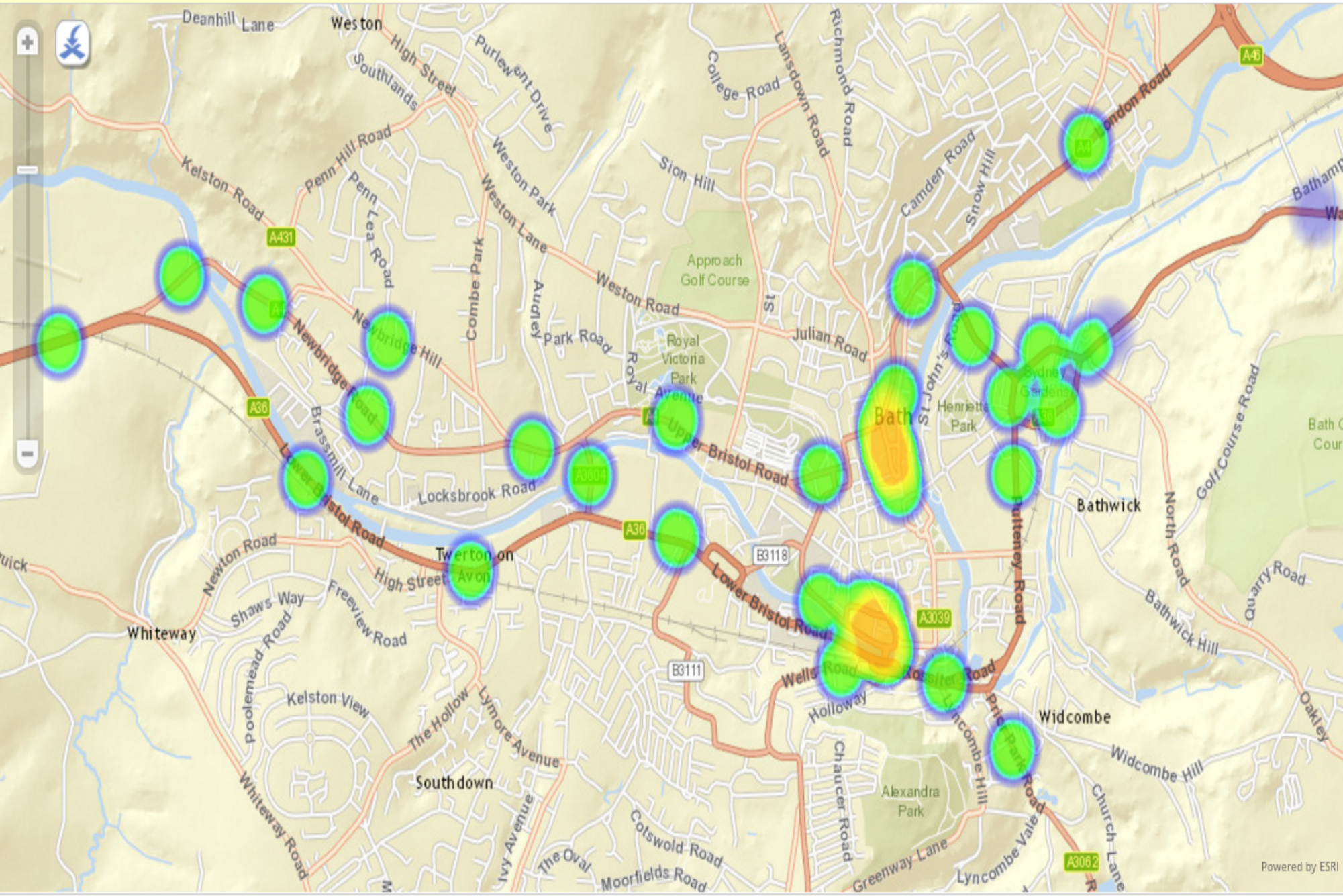
Save As... Revert

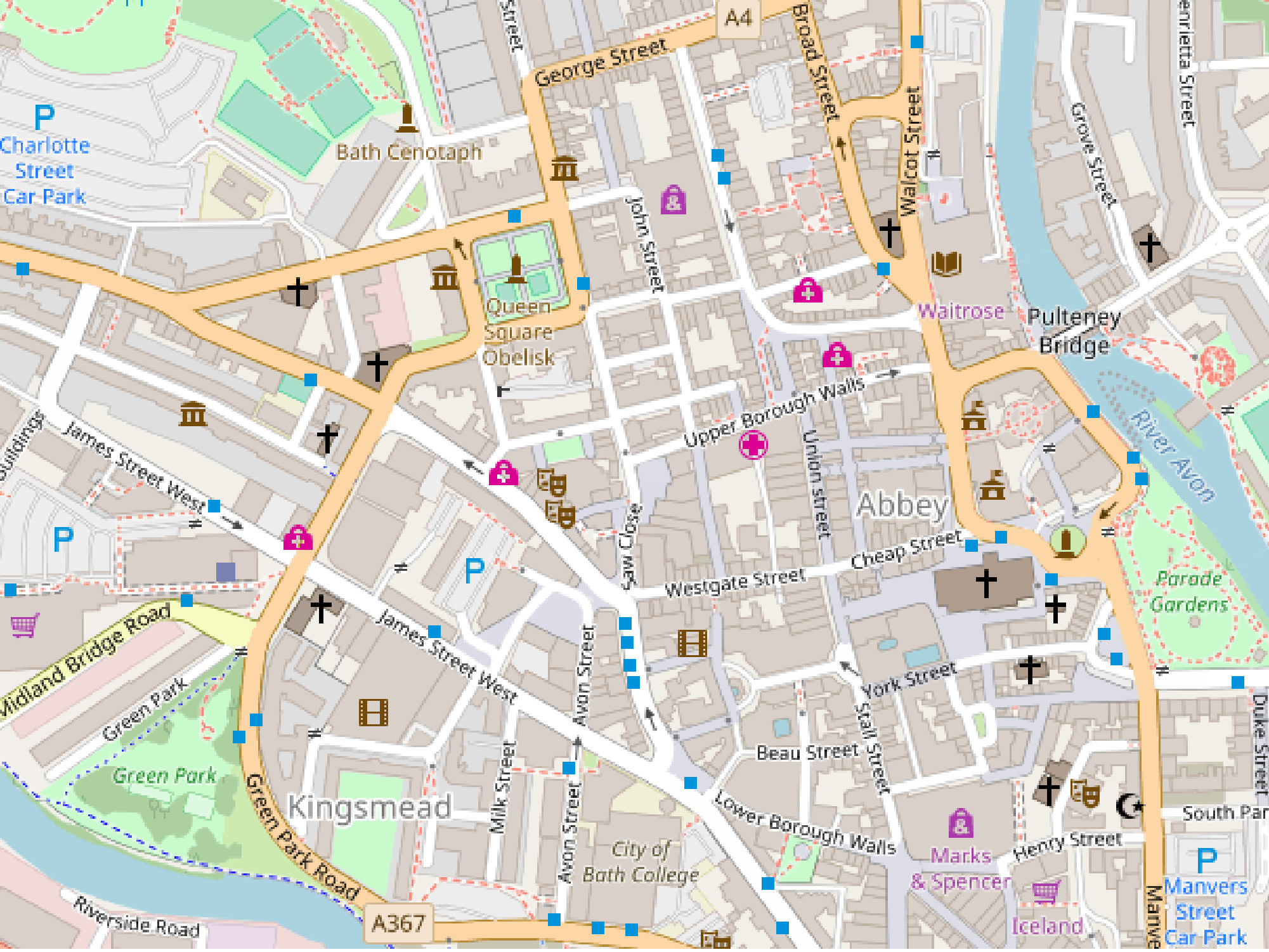
Based on Heatmap of BANES Estimated Annual average daily flows (AADFs) – major roads

AADF figures are produced for each junction to junction link on the

Find in this Dataset

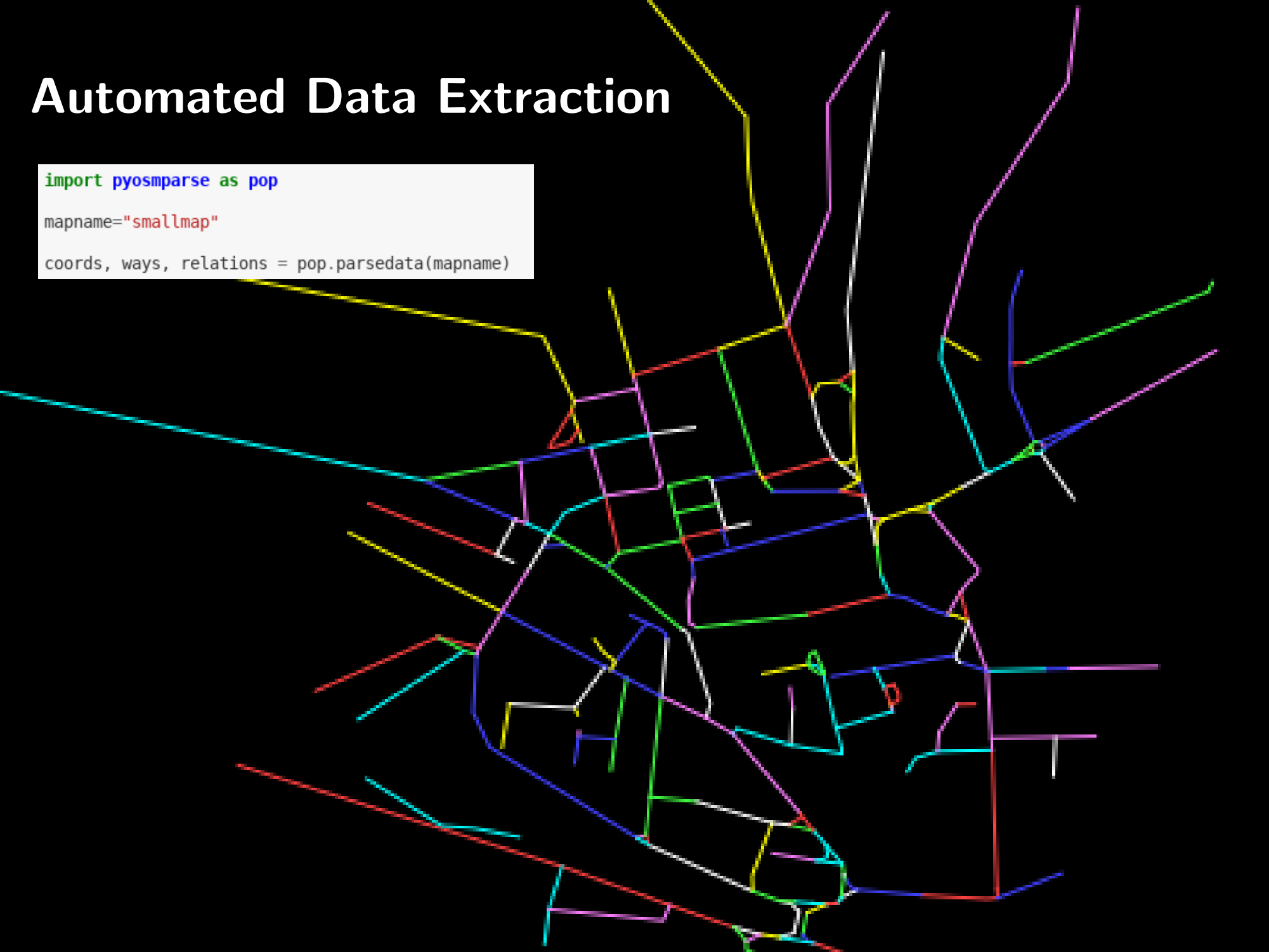
Manage More Views Filter Visualize Export Discuss Embed About




Charlotte Street Car Park
Bath Cenotaph
George Street
A4
Broad Street
Walcot Street
Grove Street
Henrietta Street
John Street
Queen Square Obelisk
Waitrose
Pulteney Bridge
River Avon
Upper Borough Walls
Union street
Abbey
Saw Close
Westgate Street
Cheap Street
Parade Gardens
James Street West
Midland Bridge Road
Green Park
Green Park Road
Kingsmead
Milk Street
Avon Street
City of Bath College
Beau Street
Stall Street
York Street
Lower Borough Walls
Marks & Spencer
Henry Street
Iceland
Manvers Street Car Park
Duke Street
Riverside Road
A367

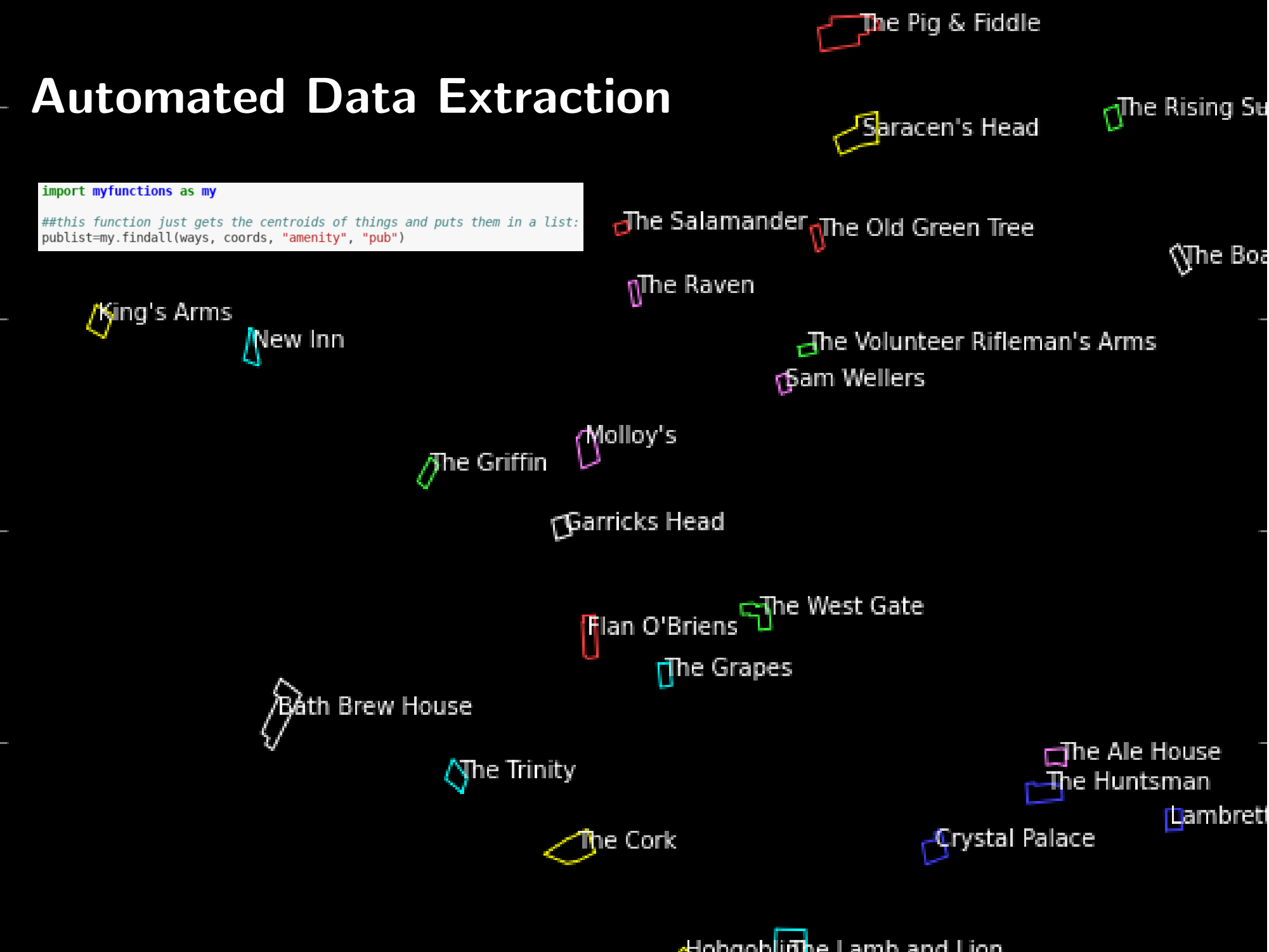
Automated Data Extraction

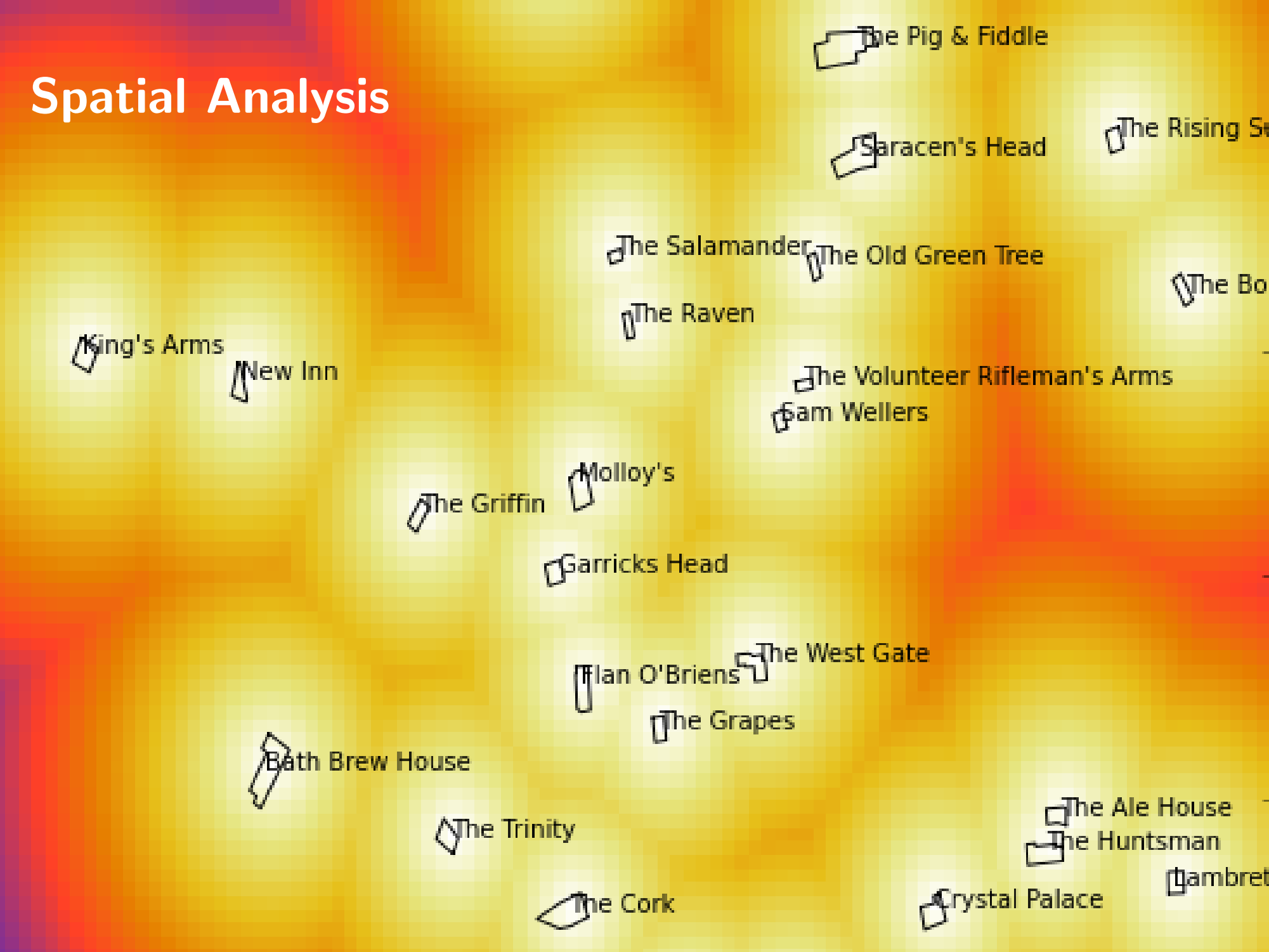
```
import pyosmparse as pop

mapname="smallmap"

coords, ways, relations = pop.parsedata(mapname)
```

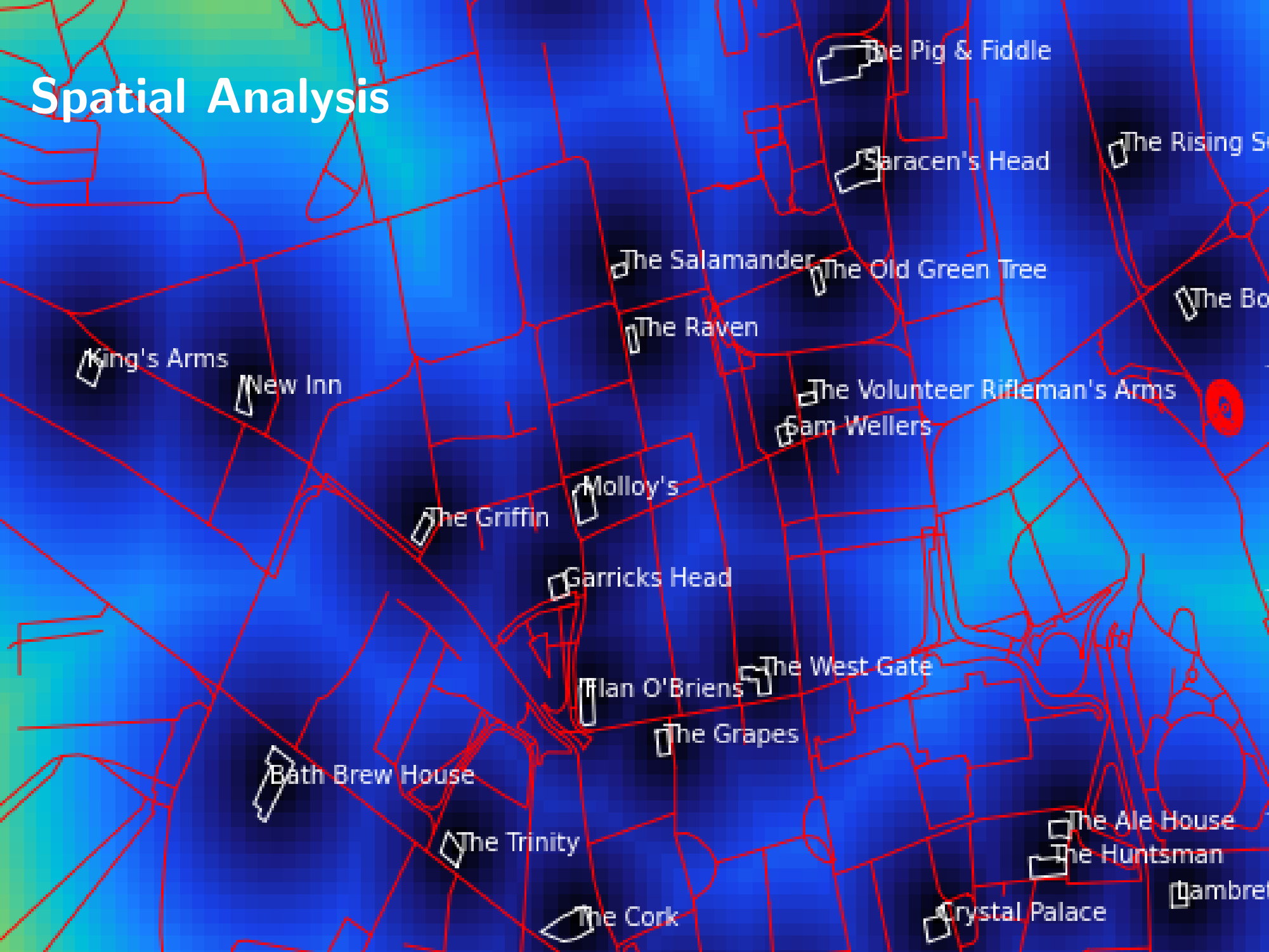


Automated Data Extraction

```
import myfunctions as my

##this function just gets the centroids of things and puts them in a list:
publist=my.findall(ways, coords, "amenity", "pub")
```




Spatial Analysis
The Pig & Fiddle
Saracen's Head
The Rising Se
The Salamander
The Old Green Tree
The Bo
The Raven
King's Arms
New Inn
The Volunteer Rifleman's Arms
Sam Wellers
Molloy's
The Griffin
Garricks Head
The West Gate
Flan O'Briens
The Grapes
Bath Brew House
The Ale House
The Huntsman
The Trinity
Lambret
The Cork
Crystal Palace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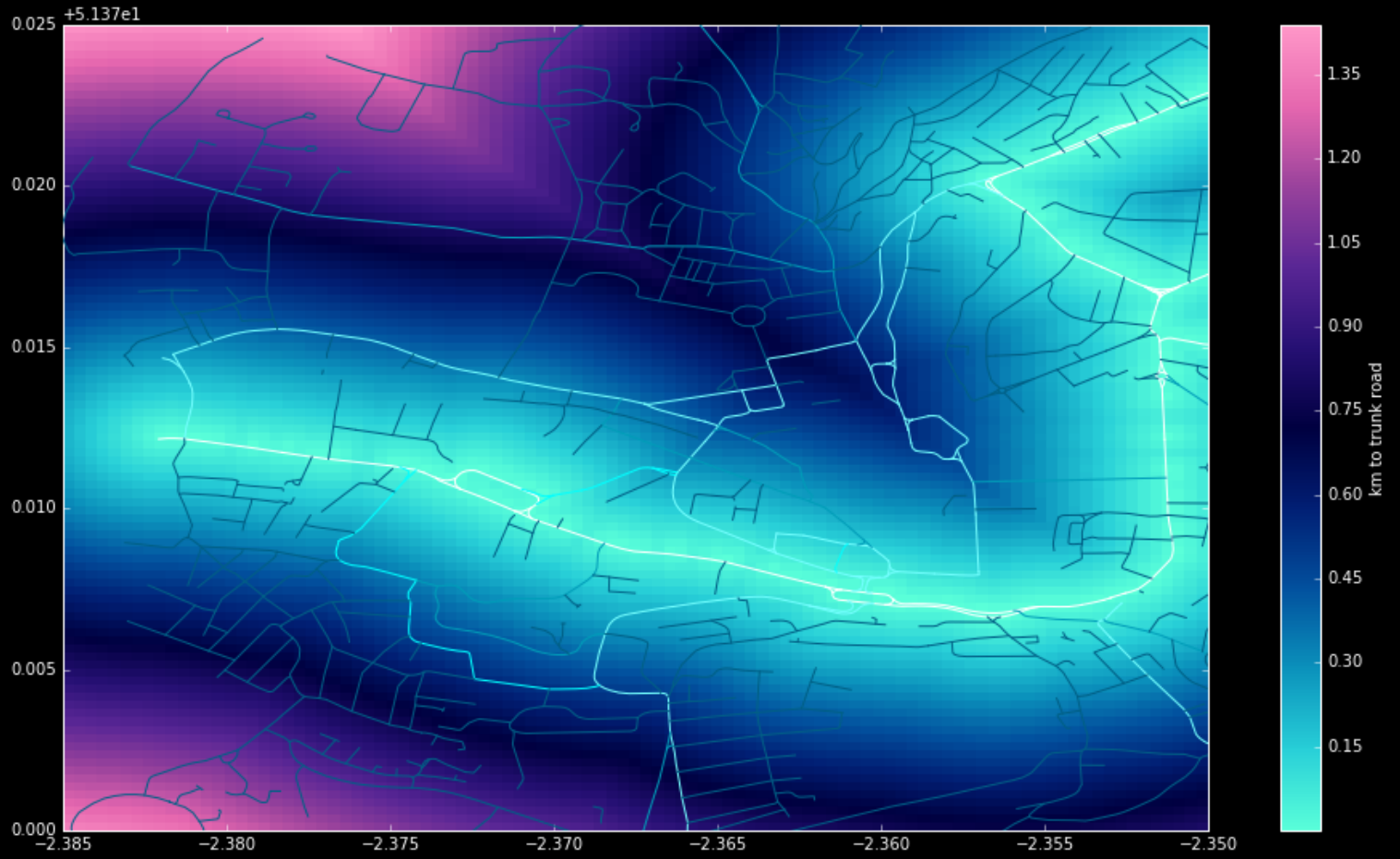
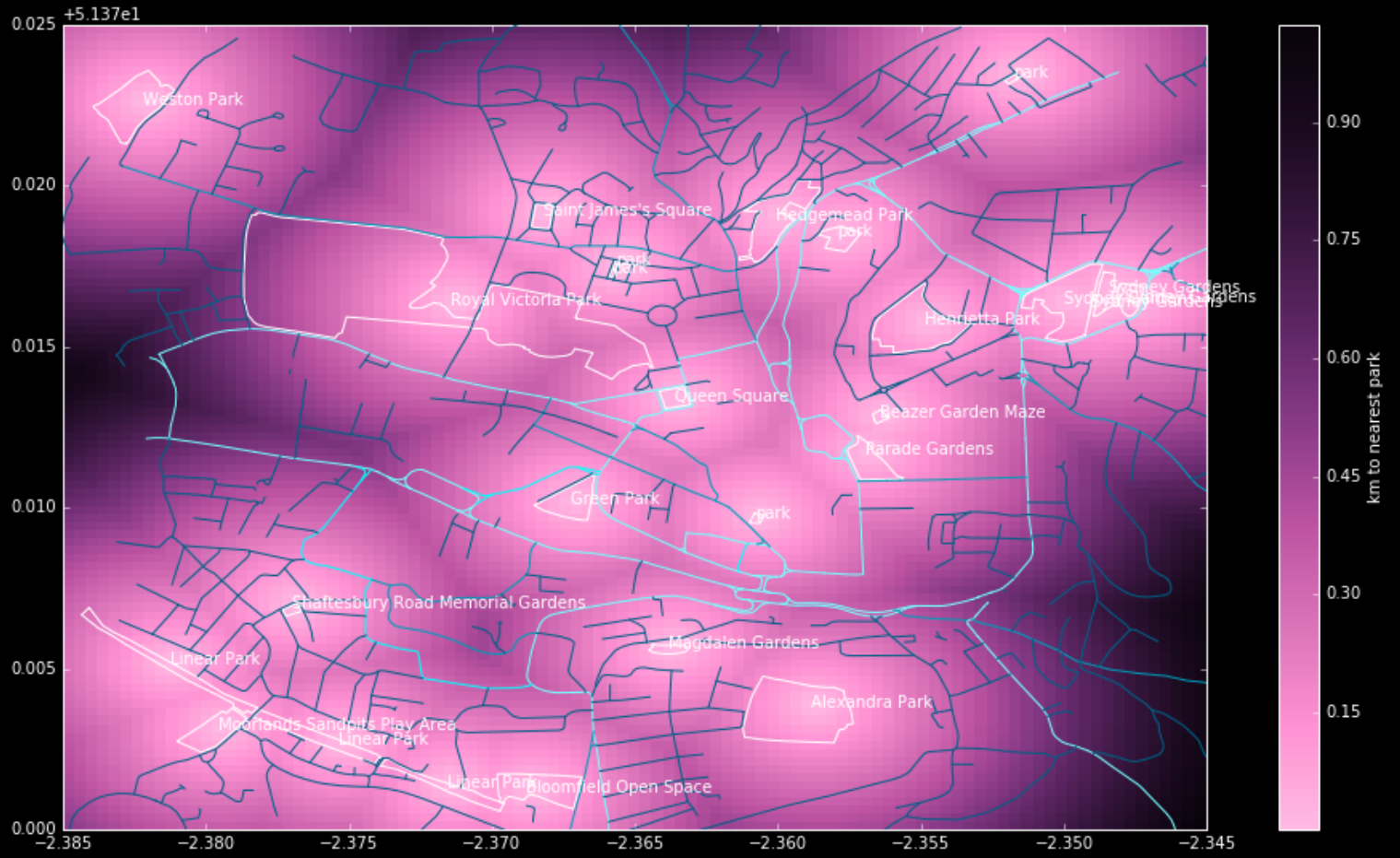
The Cork
Crystal Palace

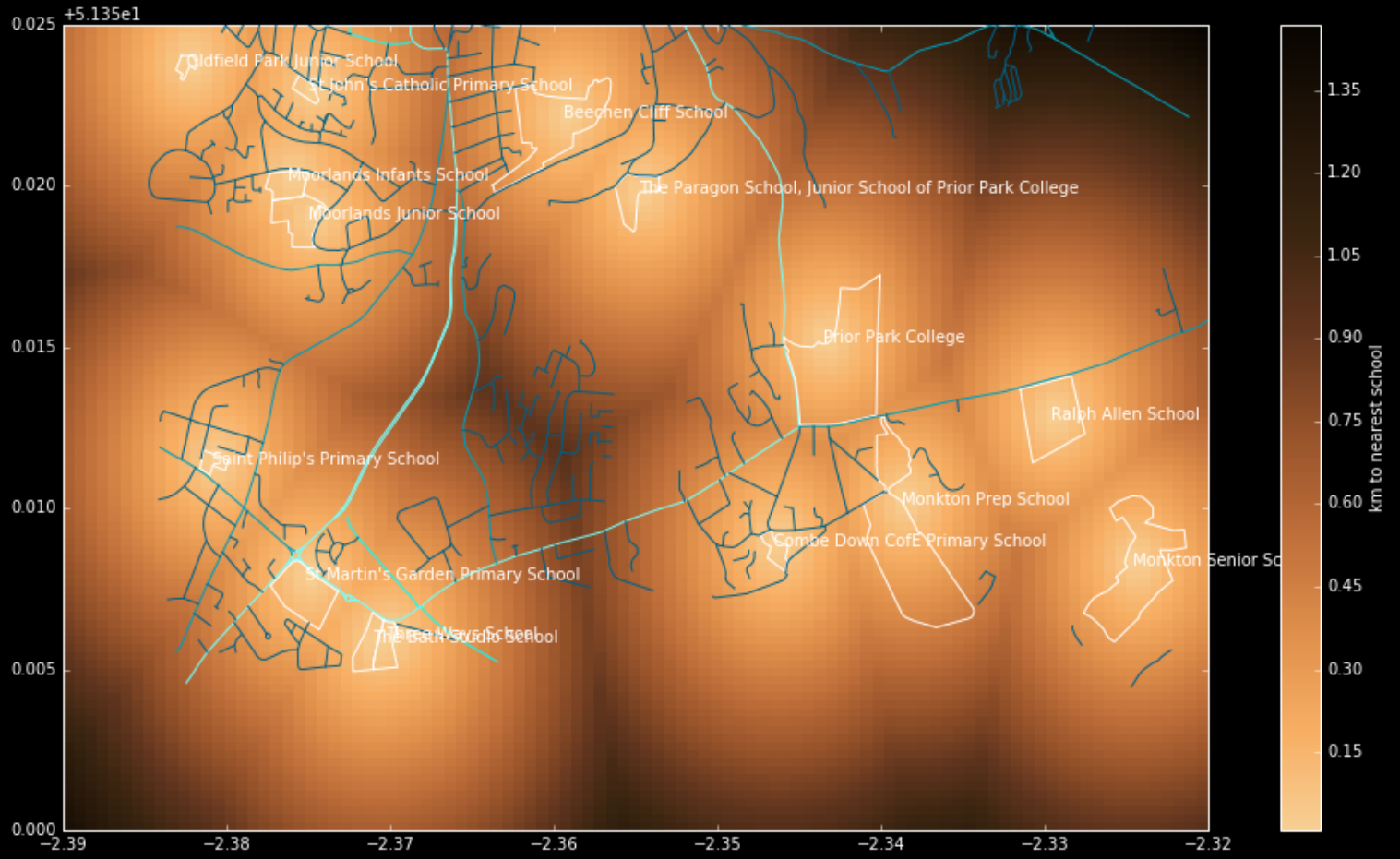
Data/Spatial Analysis



Data/Spatial Analysis



Data/Spatial Analysis



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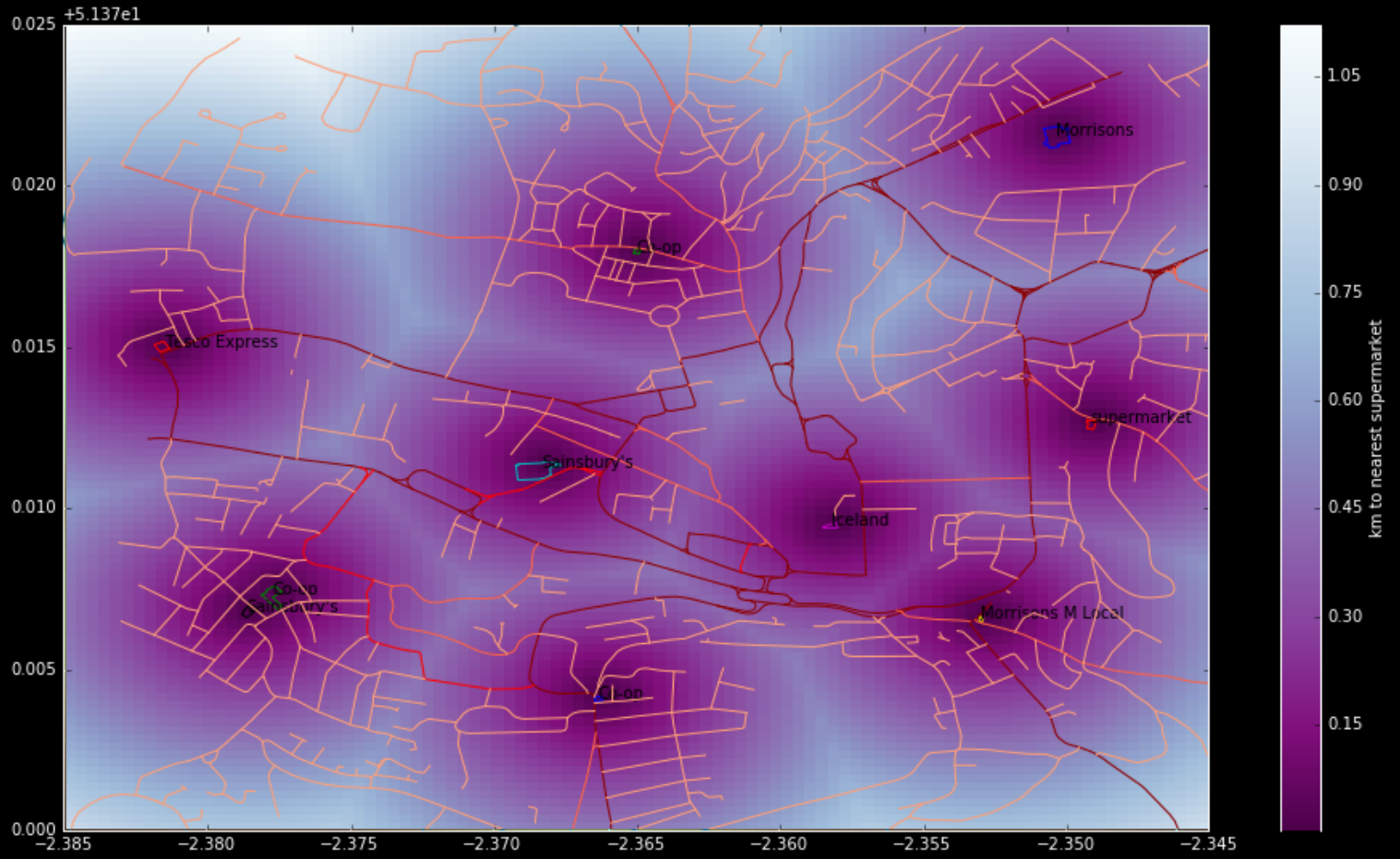
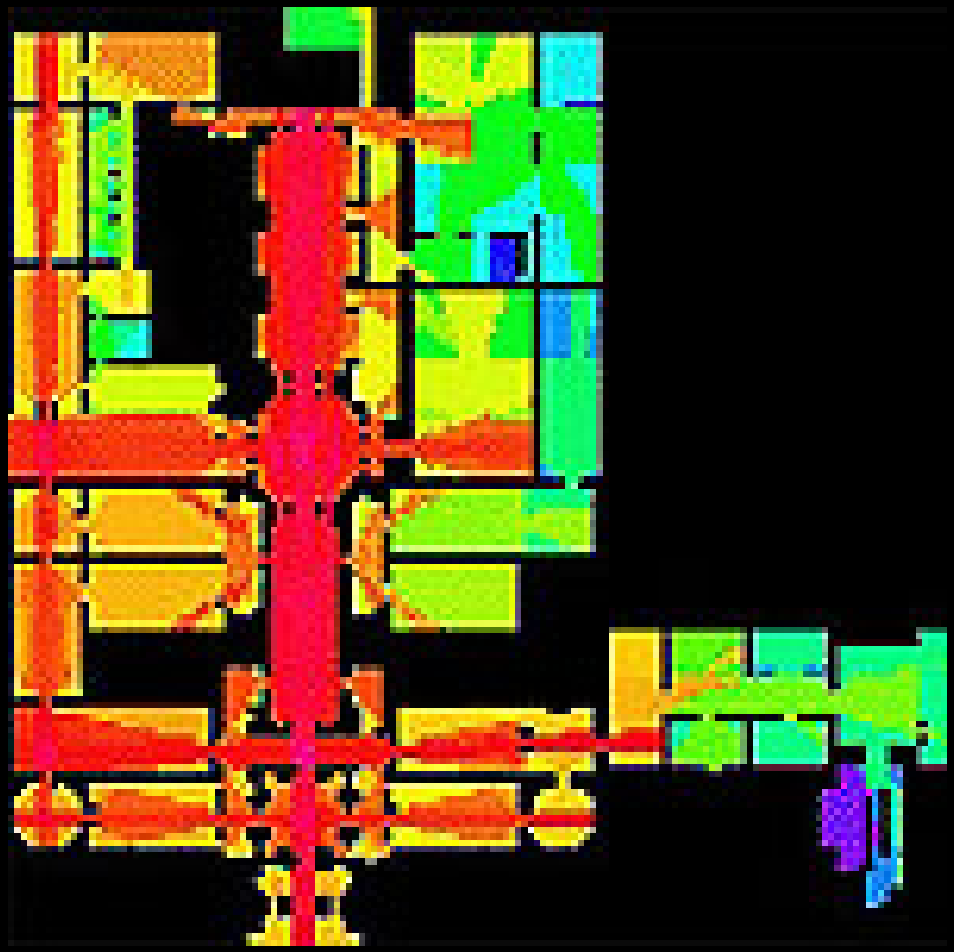
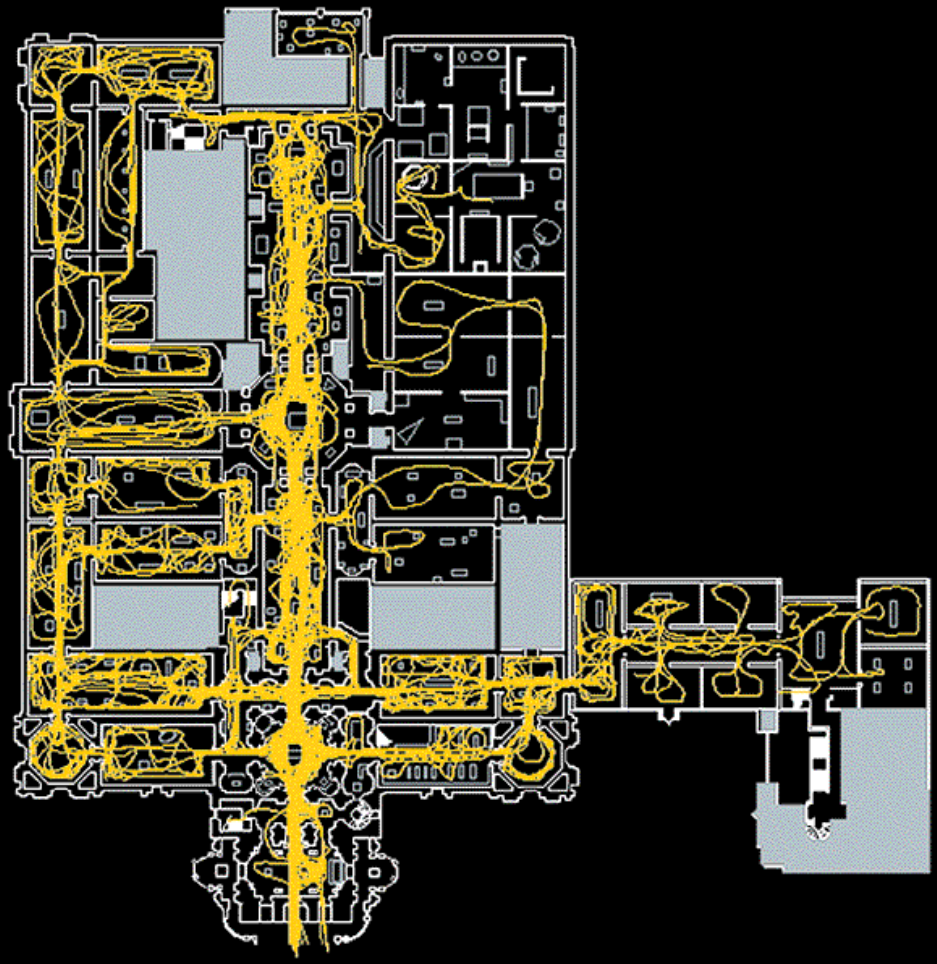


“Space Syntax”



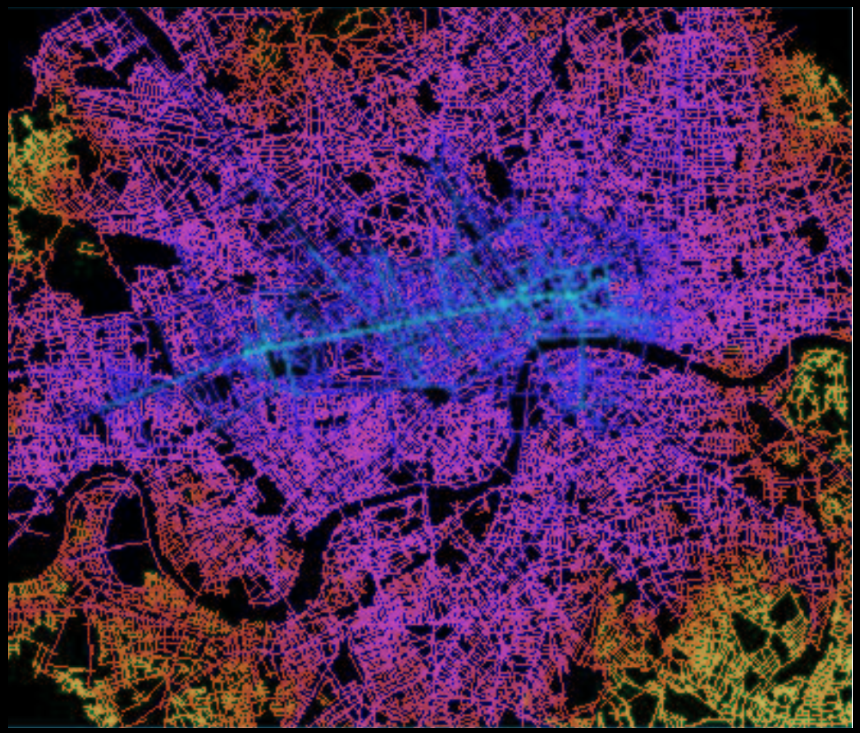


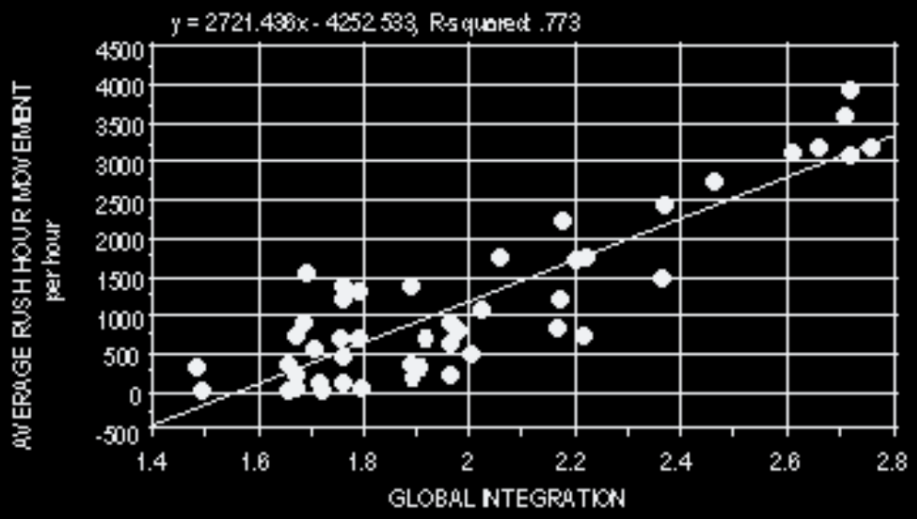
[Batty, M., Predicting where we walk. Nature, 388(6637), 19-20, (1997)]

“Space Syntax”

[Hillier, Bill. ”Space is the machine: a configurational theory of architecture.” (2007)]

“Space Syntax”



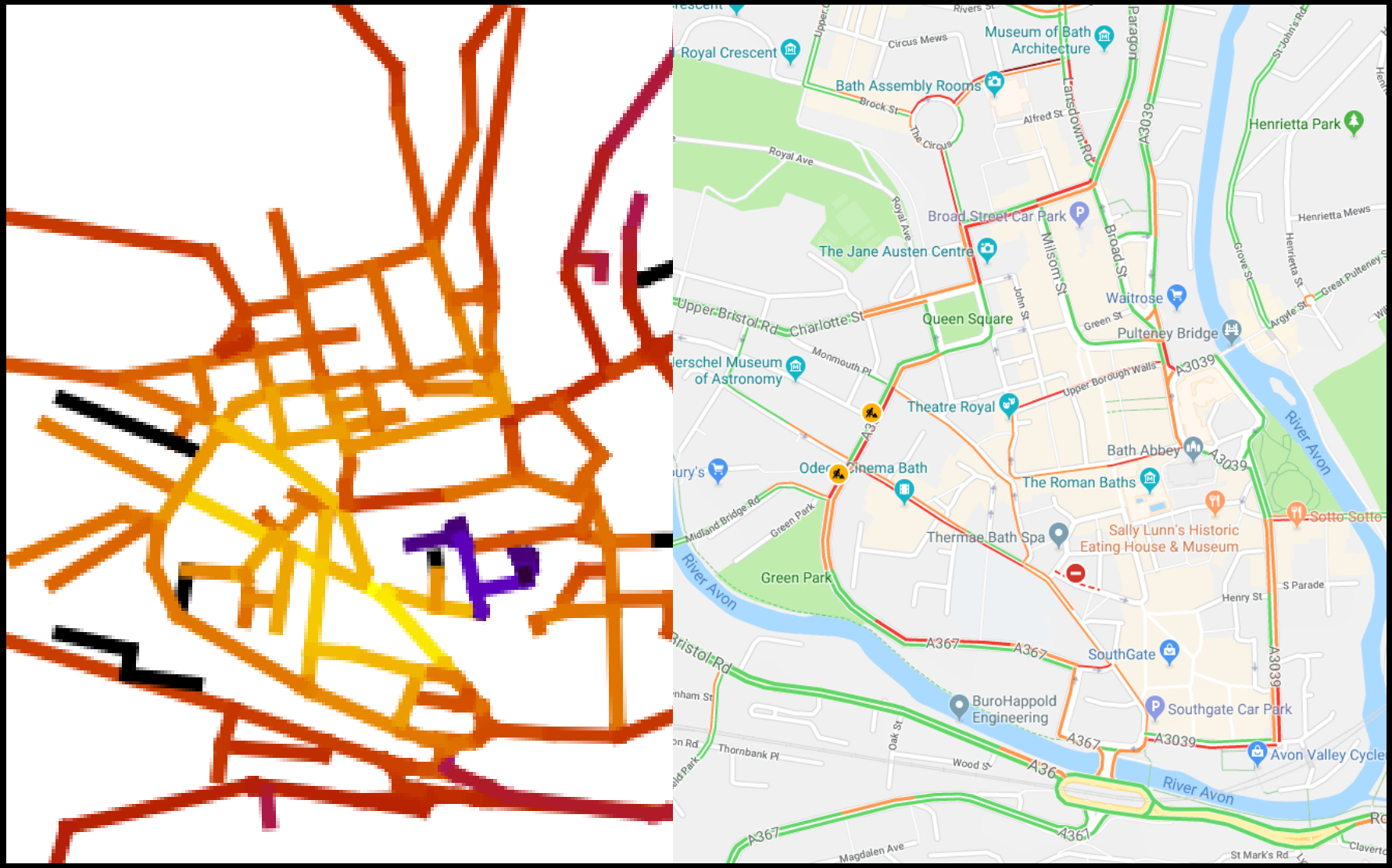


Integration vs traffic flow

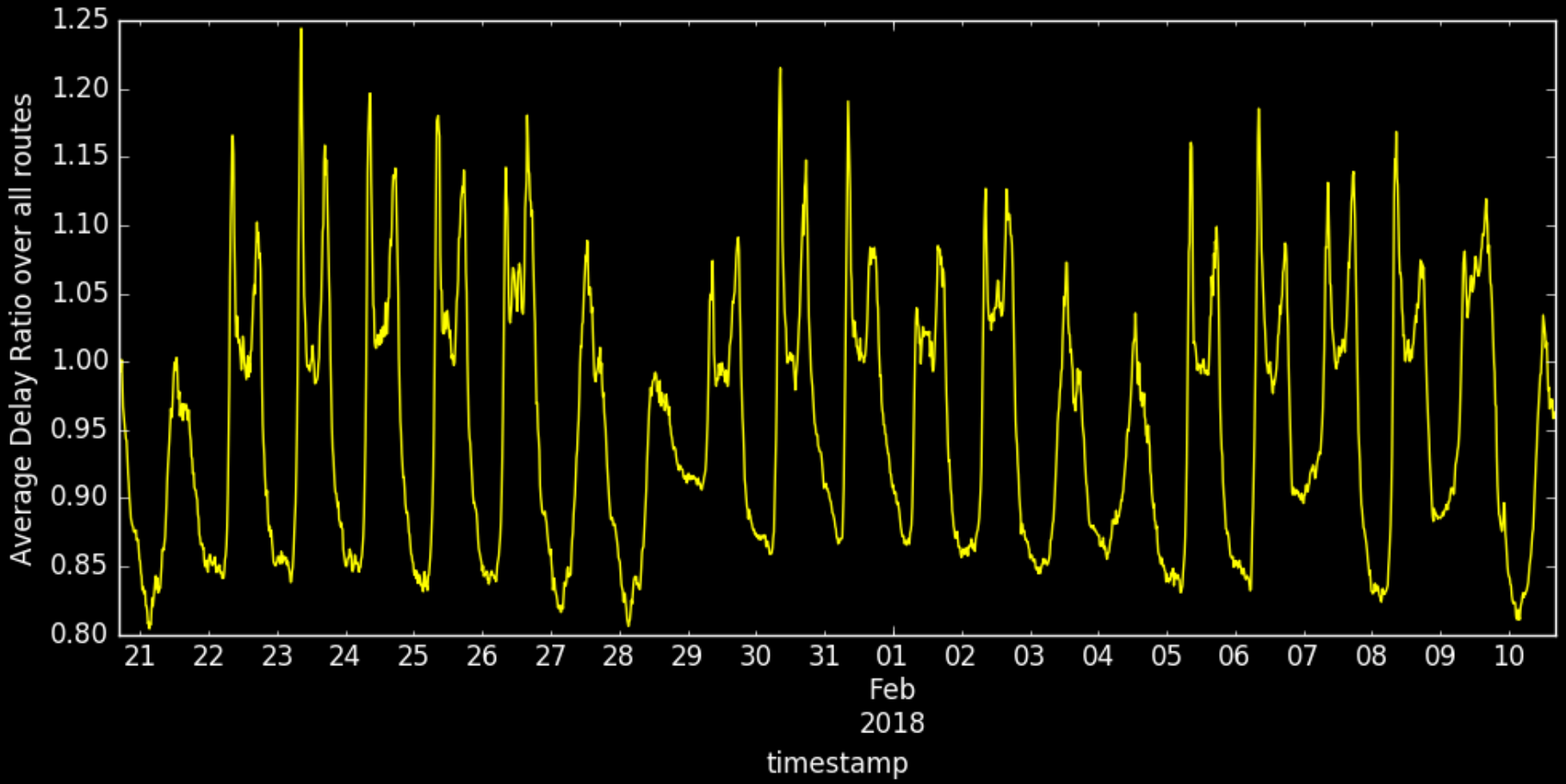
[Hillier, Bill. ”The common language of space: a way of looking at the social, economic and environmental functioning of cities on a common basis.”

JOURNAL OF ENVIRONMENTAL SCIENCES-BEIJING- 11 (1999): 344-349.]

Connectivity and Traffic in Bath



Traffic Flow in Bath



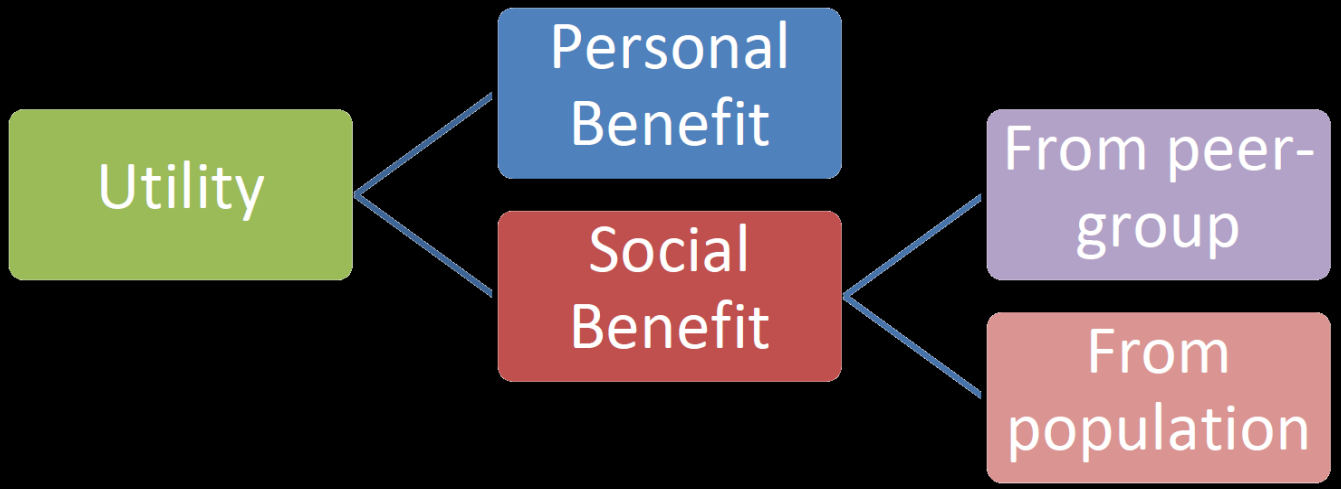
the Atlantic CITIES
PLACE MATTERS

What Math Can Tell Us About Technology's Spread Through Cities

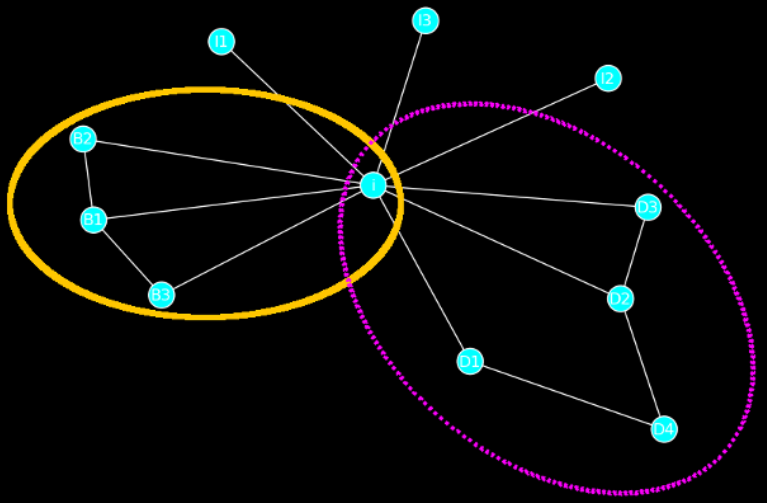
EMILY BADGER APR 10, 2013 COMMENTS

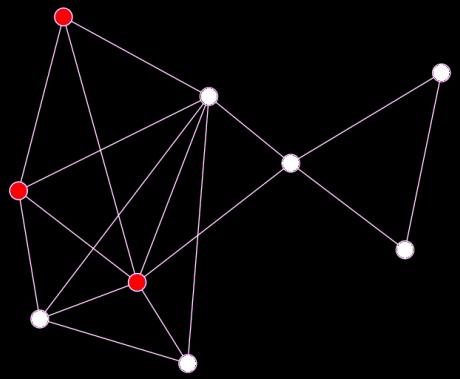
Sociologists have been studying social networks for some 50 years, trying to understand how groups of people connect to each other and how new ideas and tools travel between them. Our understanding of these networks is rapidly evolving, though. "Now," says Nick McCullen, a researcher based in the U.K., "physicists and mathematicians have been getting in on the game with their computer models." And the

Modelling the Spread of Innovation



- Perceived *usefulness* of innovation: $u = \alpha p + \beta s + \gamma m$





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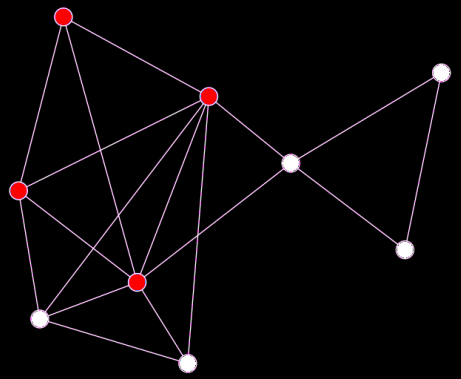
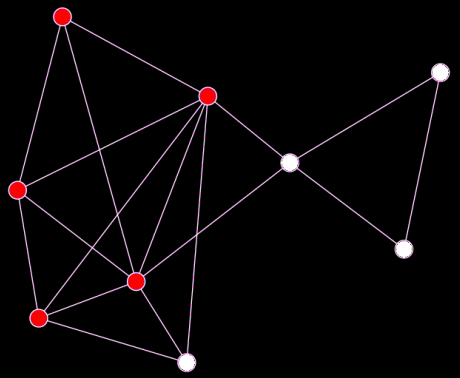


(b)



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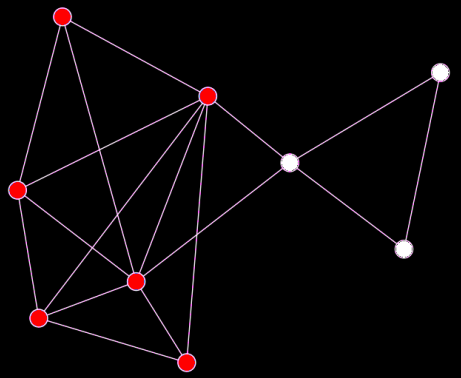

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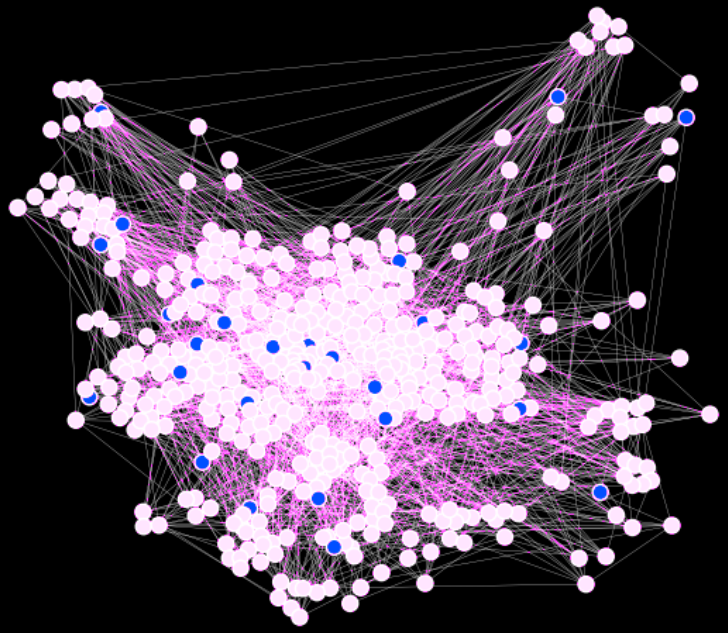
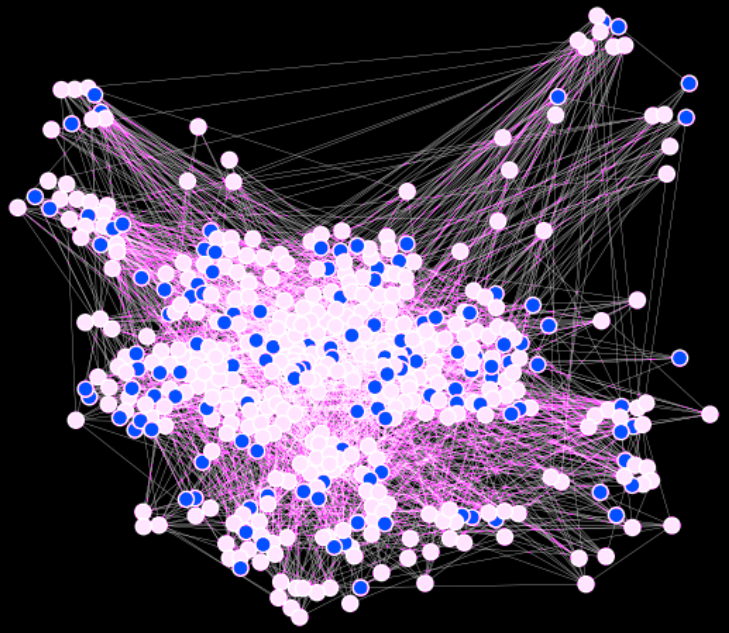


t1



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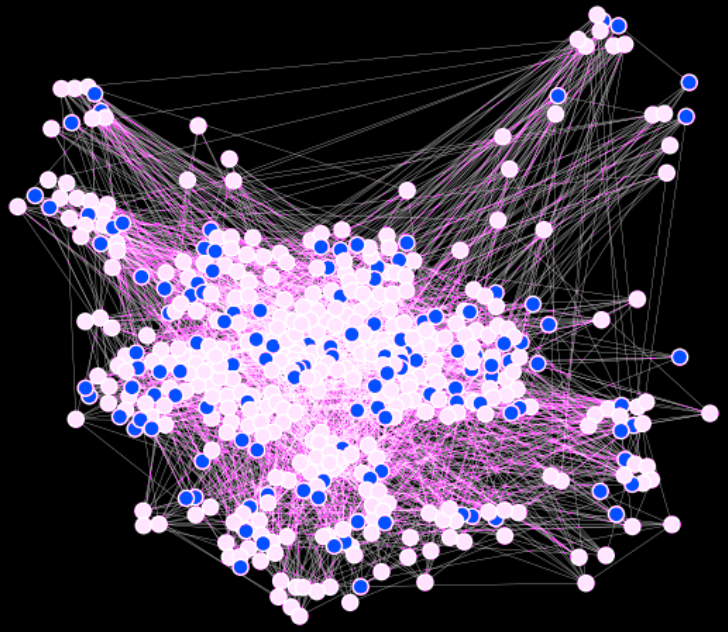
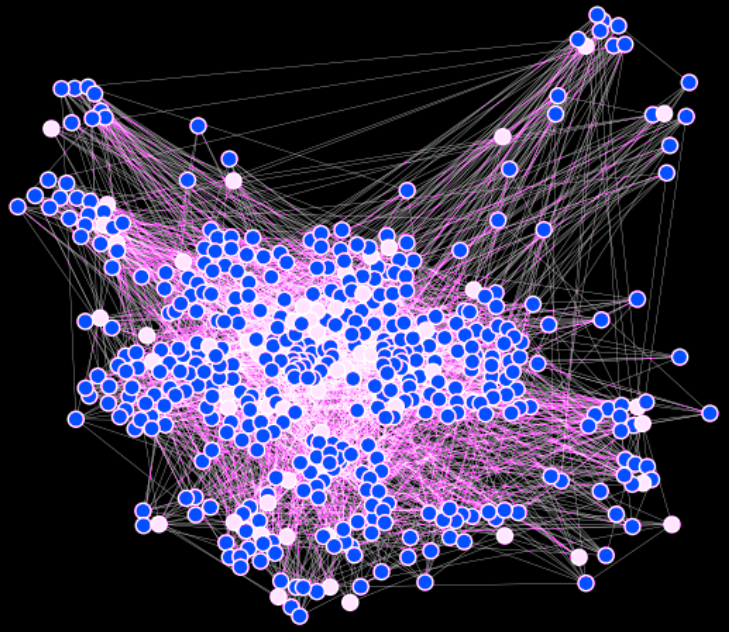
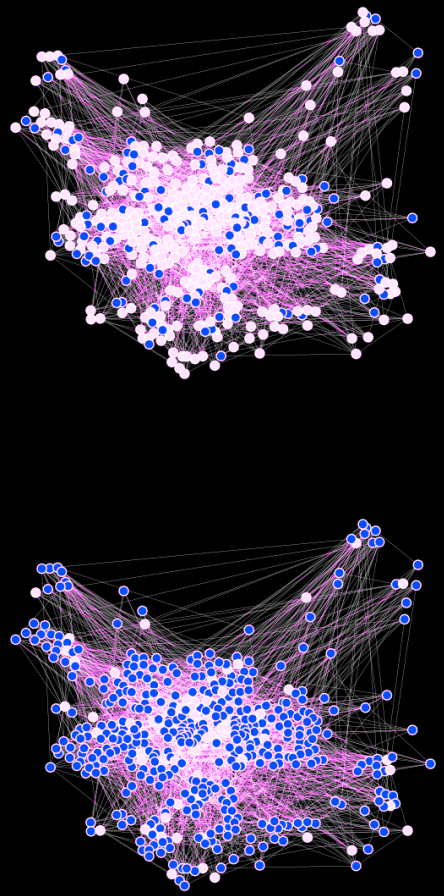


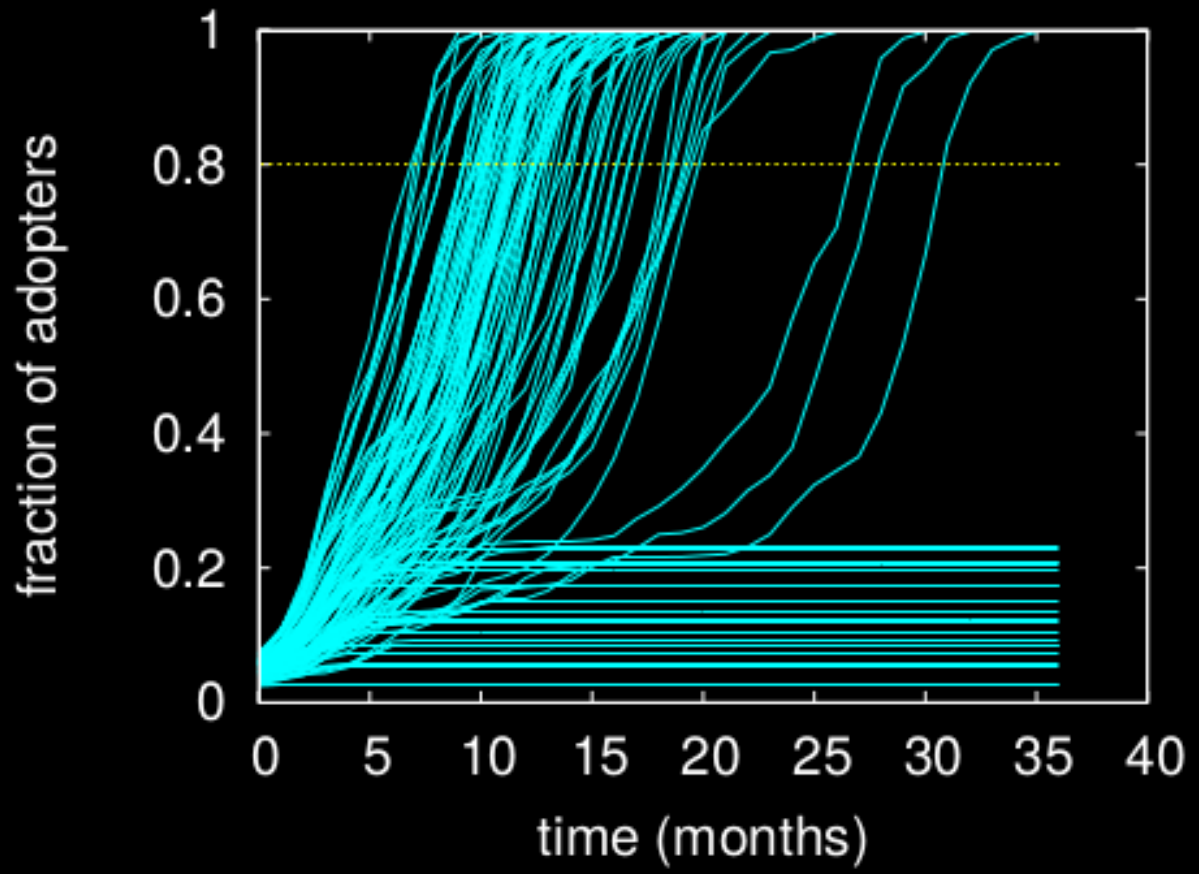
t3



t4

Simulating and comparing scenarios





For More Information

THE NEW SCIENCE OF CITIES

MICHAEL BATTY

SIAM J. Applied Dynamical Systems
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Multiparameter Models of Innovation Diffusion on Complex Networks*

N. J. McCullen†, A. M. Rucklidge‡, C. S. E. Bale§, T. J. Foxon¶, and W. F. Gale§

Abstract. A model, applicable to a range of innovation diffusion applications with a strong peer-to-peer component, is developed and studied, along with methods for its investigation and analysis. A particular application is to individual households deciding whether to install an energy efficiency measure in their home. The model represents these individuals as nodes on a network, each with a variable representing their current state of adoption of the innovation. The motivation to adopt is composed of three terms, representing personal preference, an average of each individual's network neighbors' states, and a system average, which is a measure of the current social trend. The adoption state of a node changes if a weighted linear combination of these factors exceeds some threshold. Numerical simulations have been carried out, computing the average uptake after a sufficient number of time-steps over many randomizations at all model parameter values, on various network topologies, including random (Erdős–Rényi), small world (Watts–Strogatz), and (Newman) highly clustered, community-based networks. An analytical and probabilistic approach has been developed to account for the observed behavior, which explains the results of the numerical calculations.

Key words. innovation diffusion, networks, threshold models, uptake of energy efficiency measures

AMS subject classifications. 91-04, 91F99

DOI. 10.1137/120885371

1. Introduction. Social phenomena, such as the spread of a technological or behavioral innovation through communities, can be modeled as dynamical processes on networks [1, 6, 7, 8, 9, 17]. Our model, introduced in section 2, builds on previous threshold diffusion models (see, e.g., [8, 20, 27]) by incorporating sociologically realistic factors yet remains simple enough for mathematical insights to be developed.

An example of a particular application of this model is the adoption of innovations related to energy behaviors and technologies by individual households. These innovations are often not directly visible to an adopter's peers, but communication of the benefits of adoption may occur through interaction between individuals. The decision to adopt is therefore based on multiple factors, taking into account not only individual preferences but also whether or not an individual's social circle has adopted the innovation. As such, the spread of the innovation will be influenced by the network of social contacts between individuals, including both social peers and wider social trends. Models have been developed along these lines [5], splitting the

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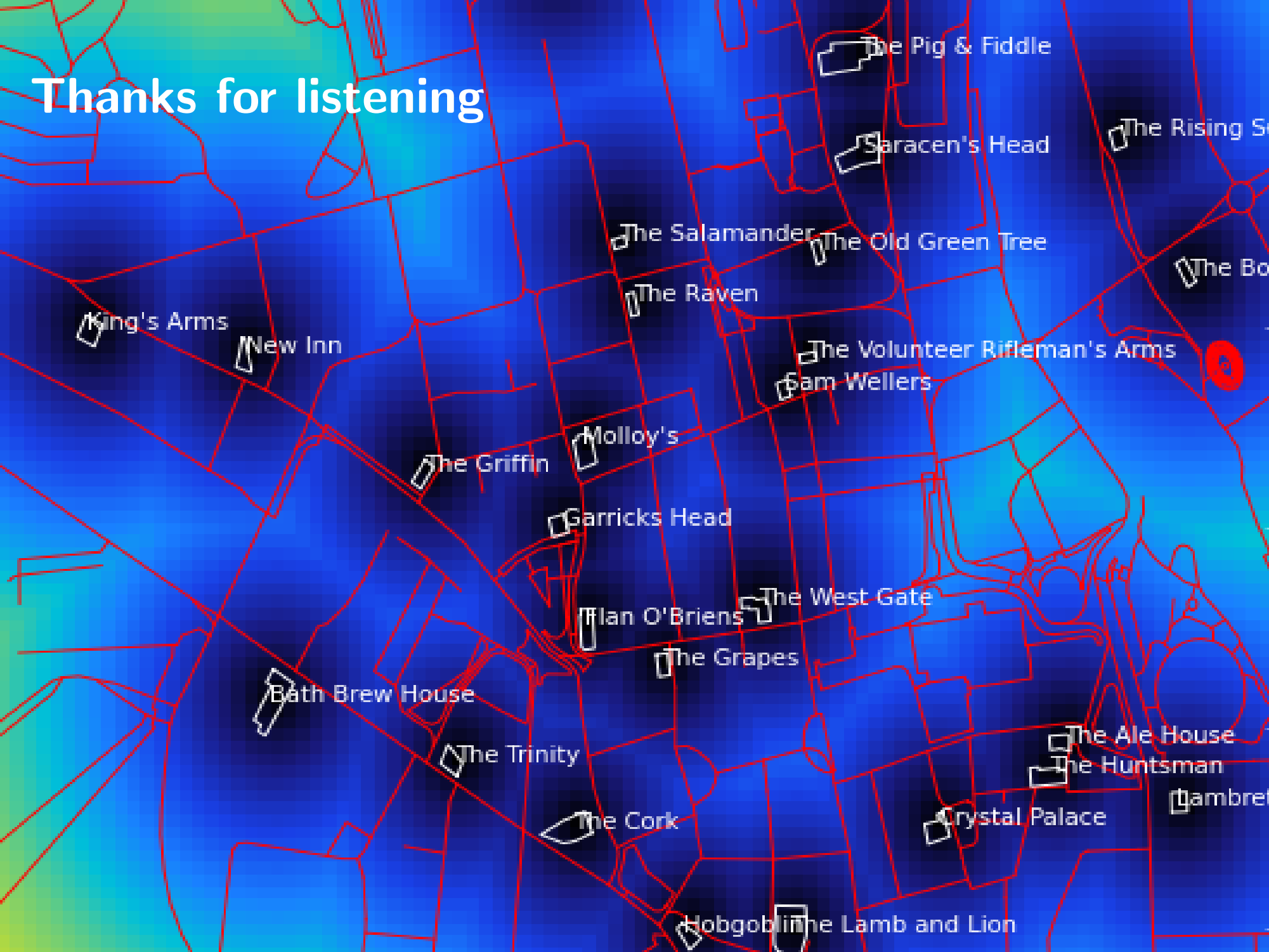
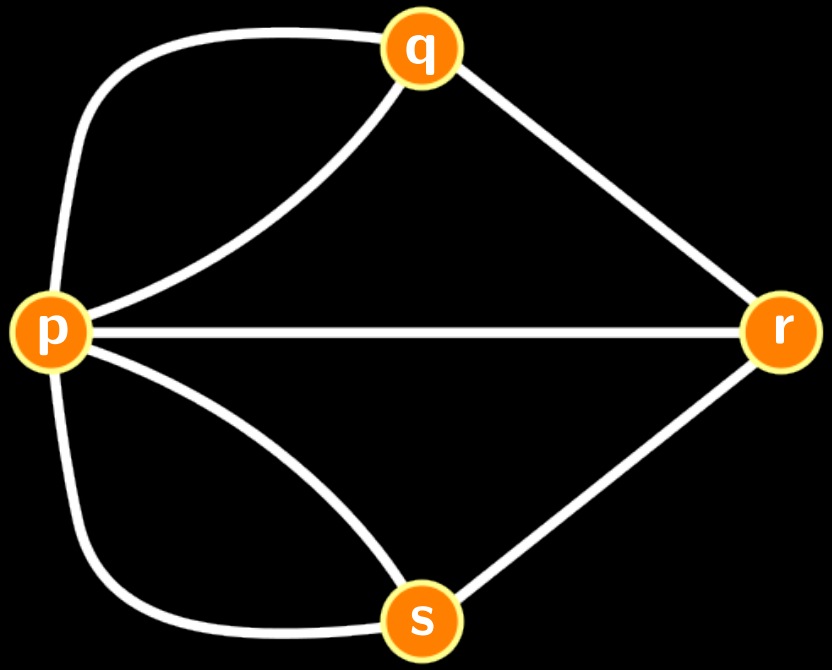
http://www.siam.org/journals/siads/12-1/88537.html

†Research Unit for Energy and the Design of Environments, University of Bath, Bath, UK (n.mccullen@physics.org).
‡Department of Applied Mathematics, University of Leeds, Leeds, UK (a.m.rucklidge@leeds.ac.uk).
§Energy Research Institute, University of Leeds, Leeds, UK (c.s.e.bale@leeds.ac.uk, w.f.gale@leeds.ac.uk).
¶School of Earth and Environment, University of Leeds, Leeds, UK (t.j.foxon@leeds.ac.uk).

Thanks for listening



Where's the Maths?



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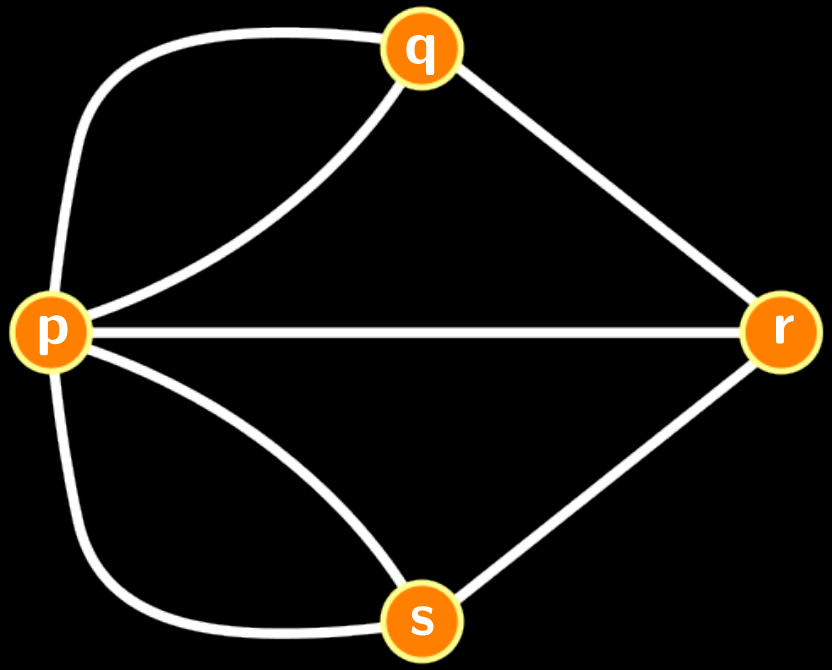

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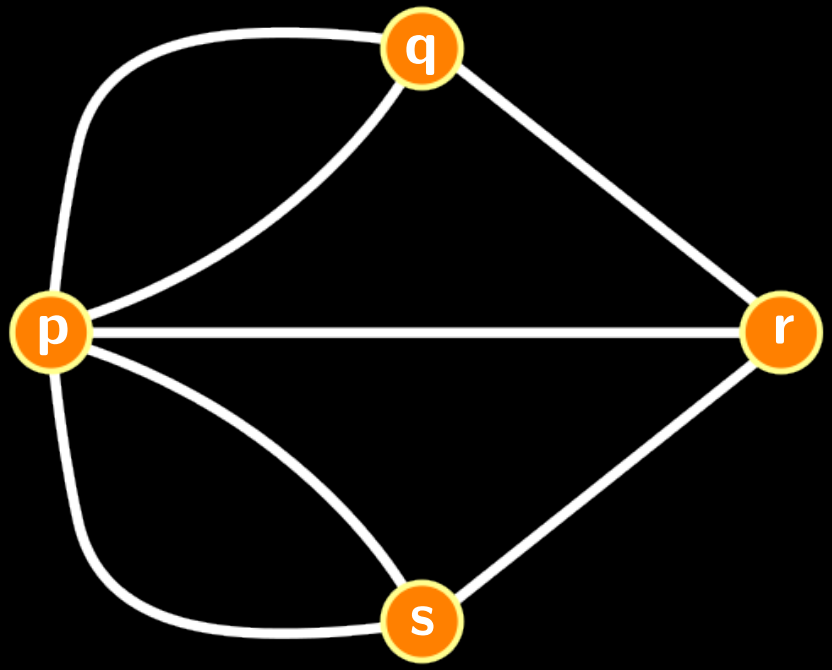

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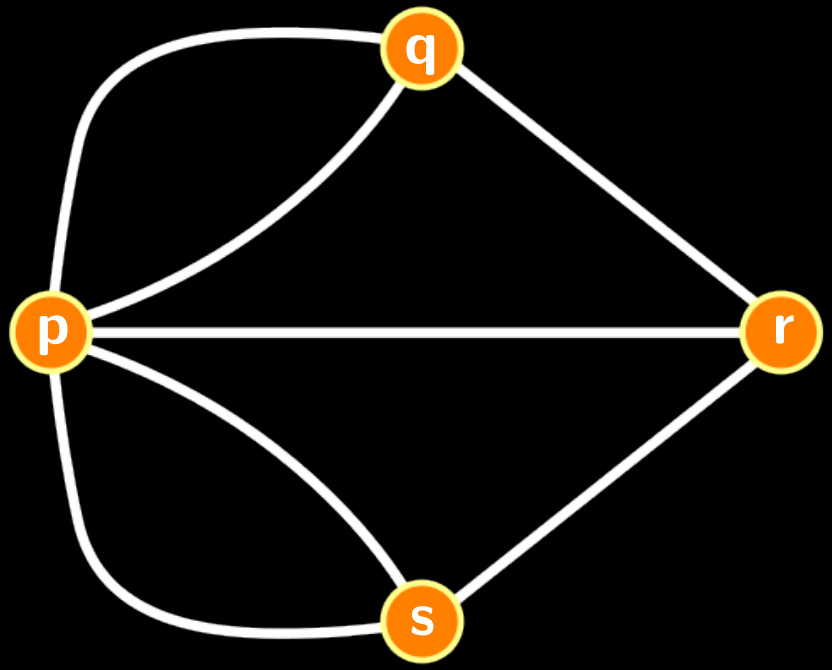

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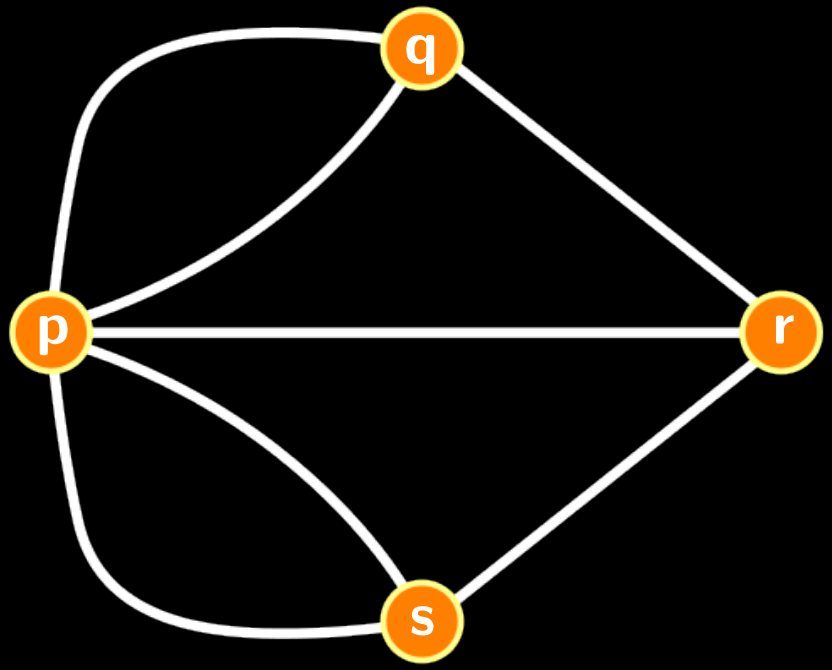

p	q	r	s	
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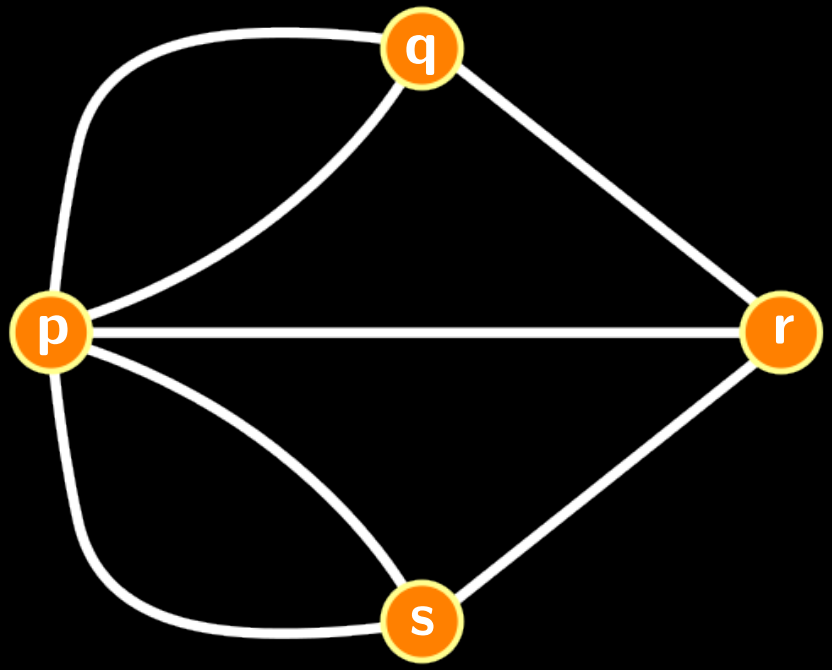

p	q	r	s	
0	2	1	2	p
2	0	1	0	q
1	1	0	1	r
2	0	1	0	s