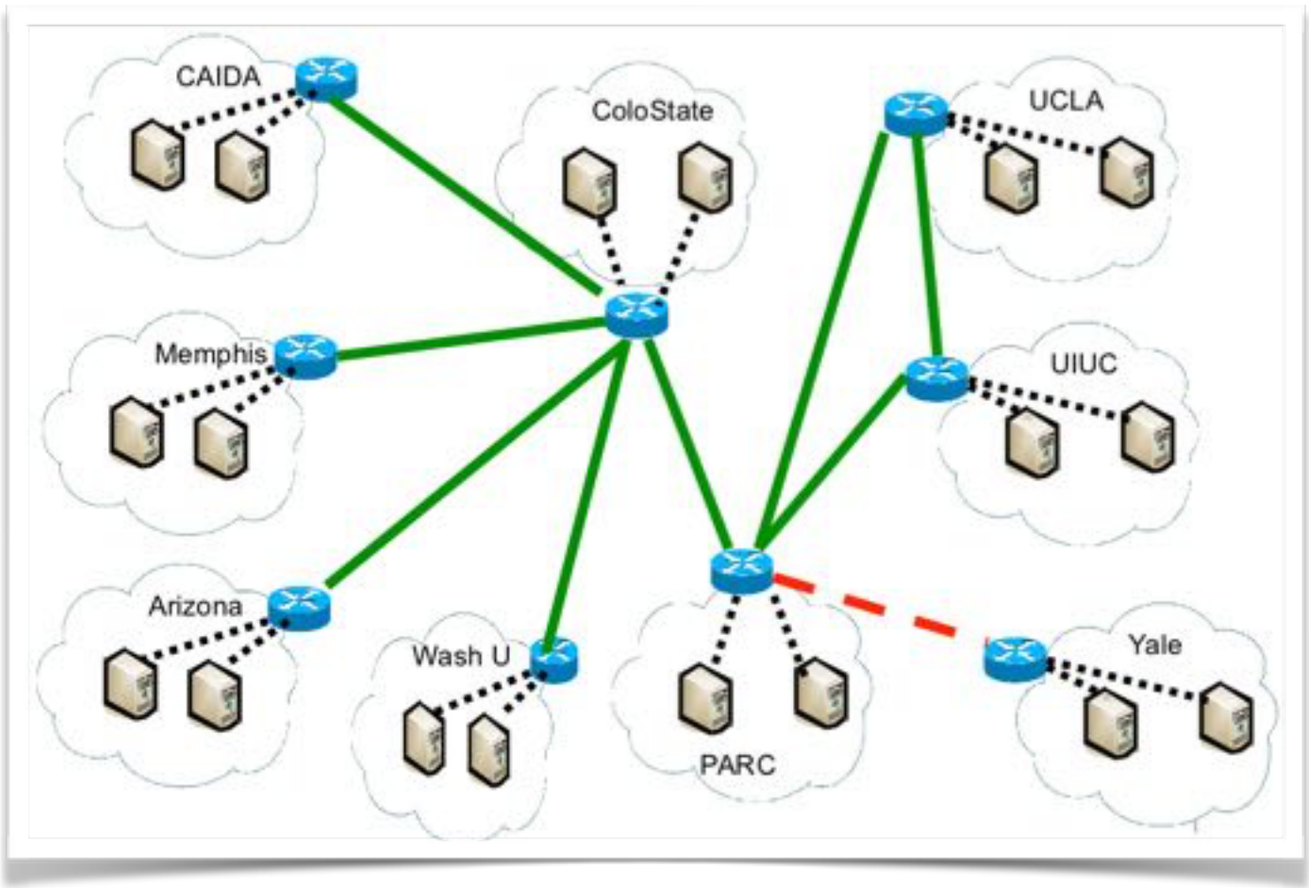
# How connected are you?

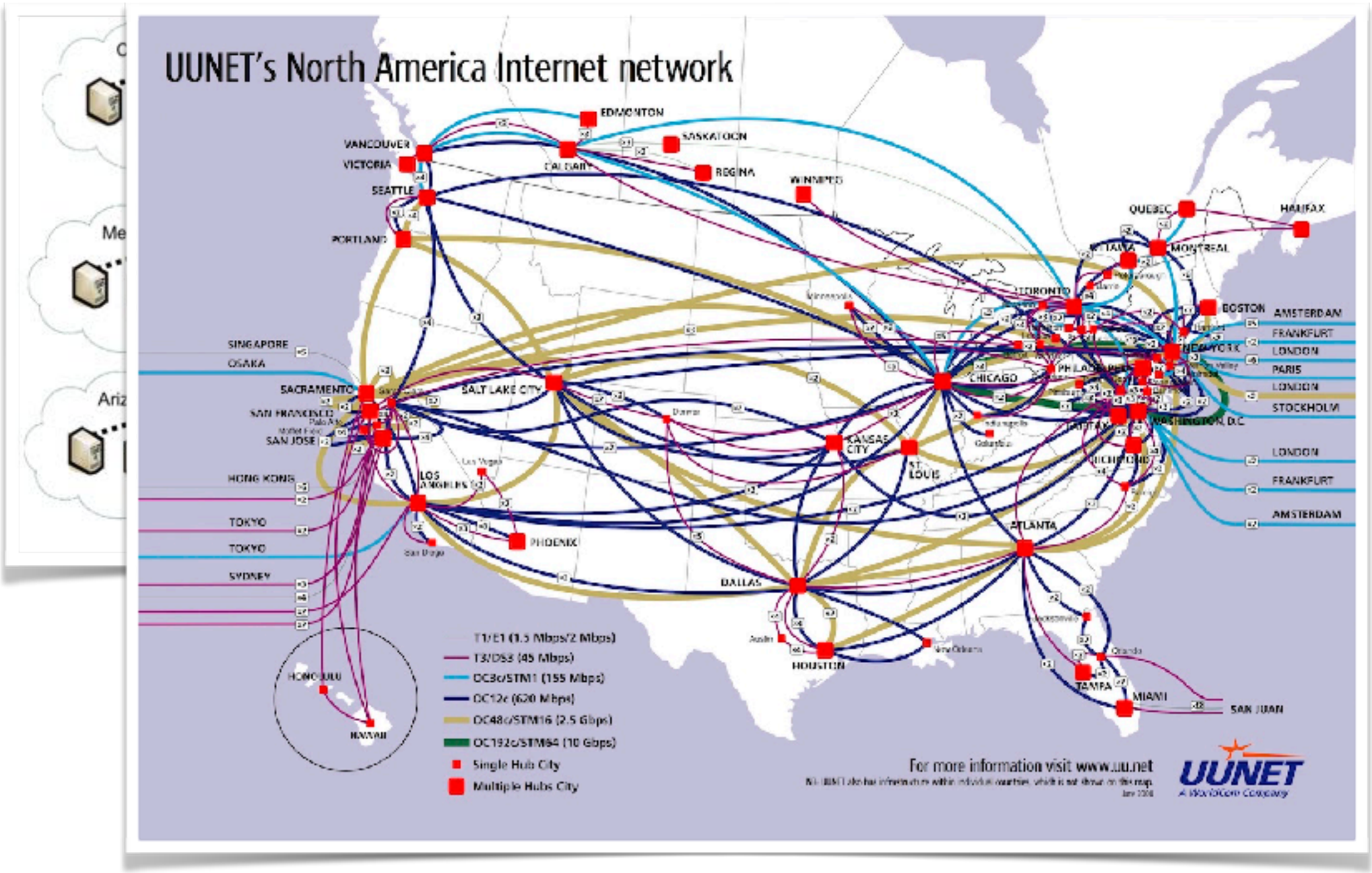
## Putting some network science in your life

Hugo Touchette
National Institute for Theoretical Physics (NITheP)
Stellenbosch

# Internet



# Internet


UUNET's North America Internet network
EDMONTON
SASKATOON
VANCOUVER
VICTORIA
CALGARY
REGINA
WINNIPEG
SEATTLE
PORTLAND
QUEBEC
HALIFAX
OTTAWA
MONTREAL
TORONTO
BOSTON
AMSTERDAM
FRANKFURT
LONDON
PARIS
LONDON
STOCKHOLM
SINGAPORE
OSAKA
SACRAMENTO
SALT LAKE CITY
CHICAGO
SAN FRANCISCO
SAN JOSE
KANSAS CITY
ST. LOUIS
WASHINGTON, D.C
LONDON
FRANKFURT
AMSTERDAM
HONG KONG
LOS ANGELES
TOKYO
TOKYO
PHOENIX
ATLANTA
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HONOLULU
HAWAII
T1/E1 (1.5 Mbps/2 Mbps)
T3/DS3 (45 Mbps)
OC3c/STM1 (155 Mbps)
OC12c (620 Mbps)
OC48c/STM16 (2.5 Gbps)
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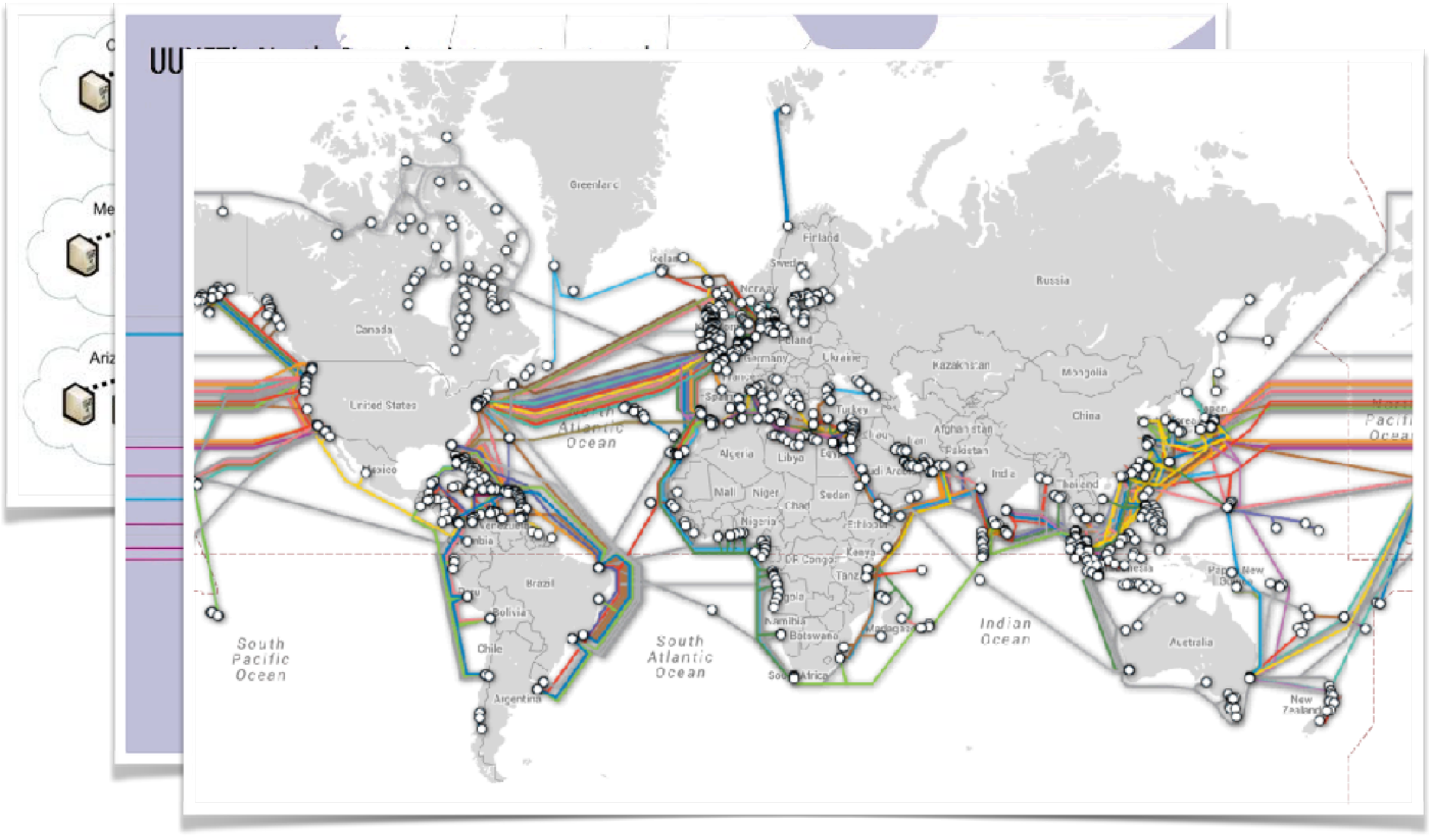
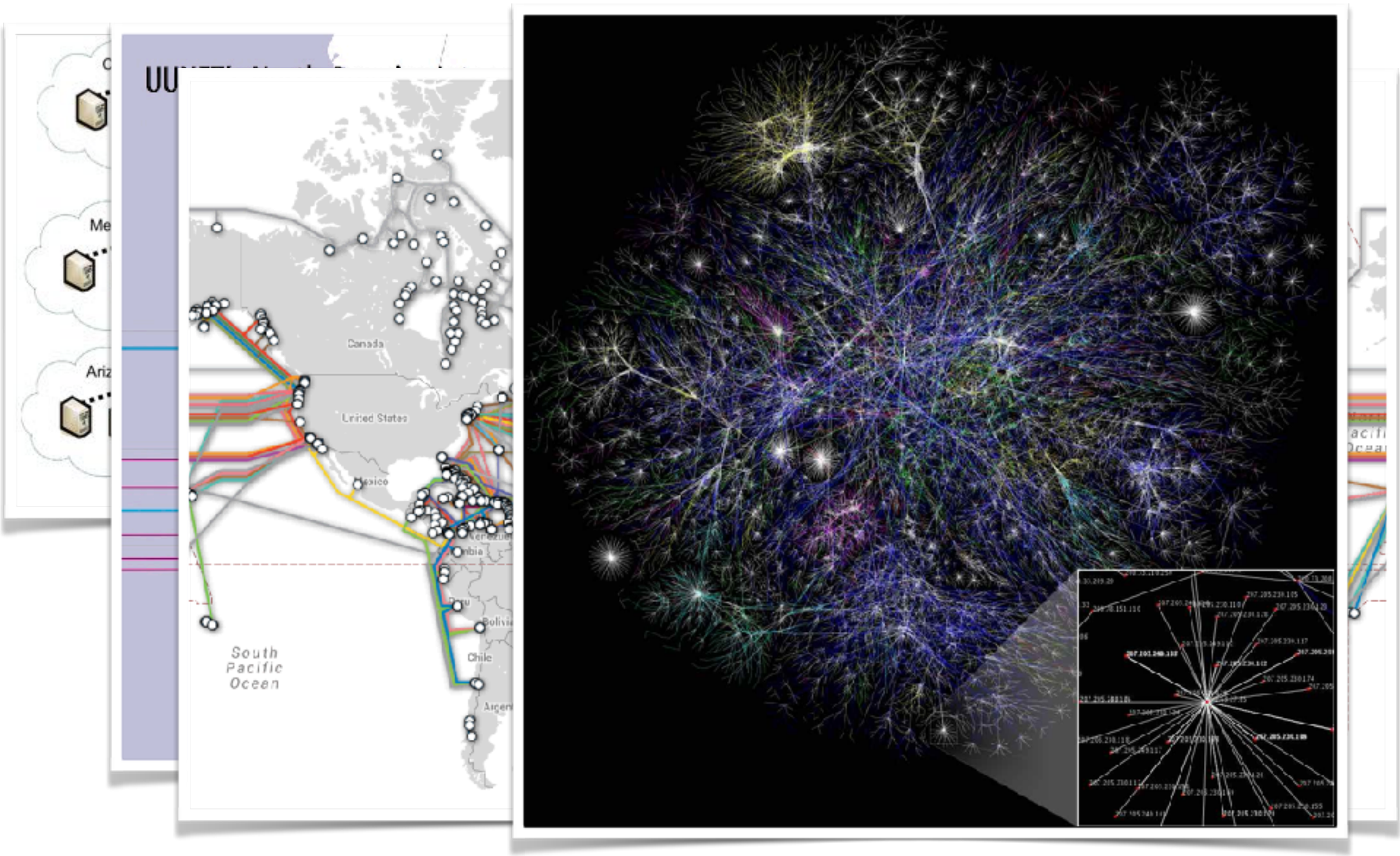
# Internet

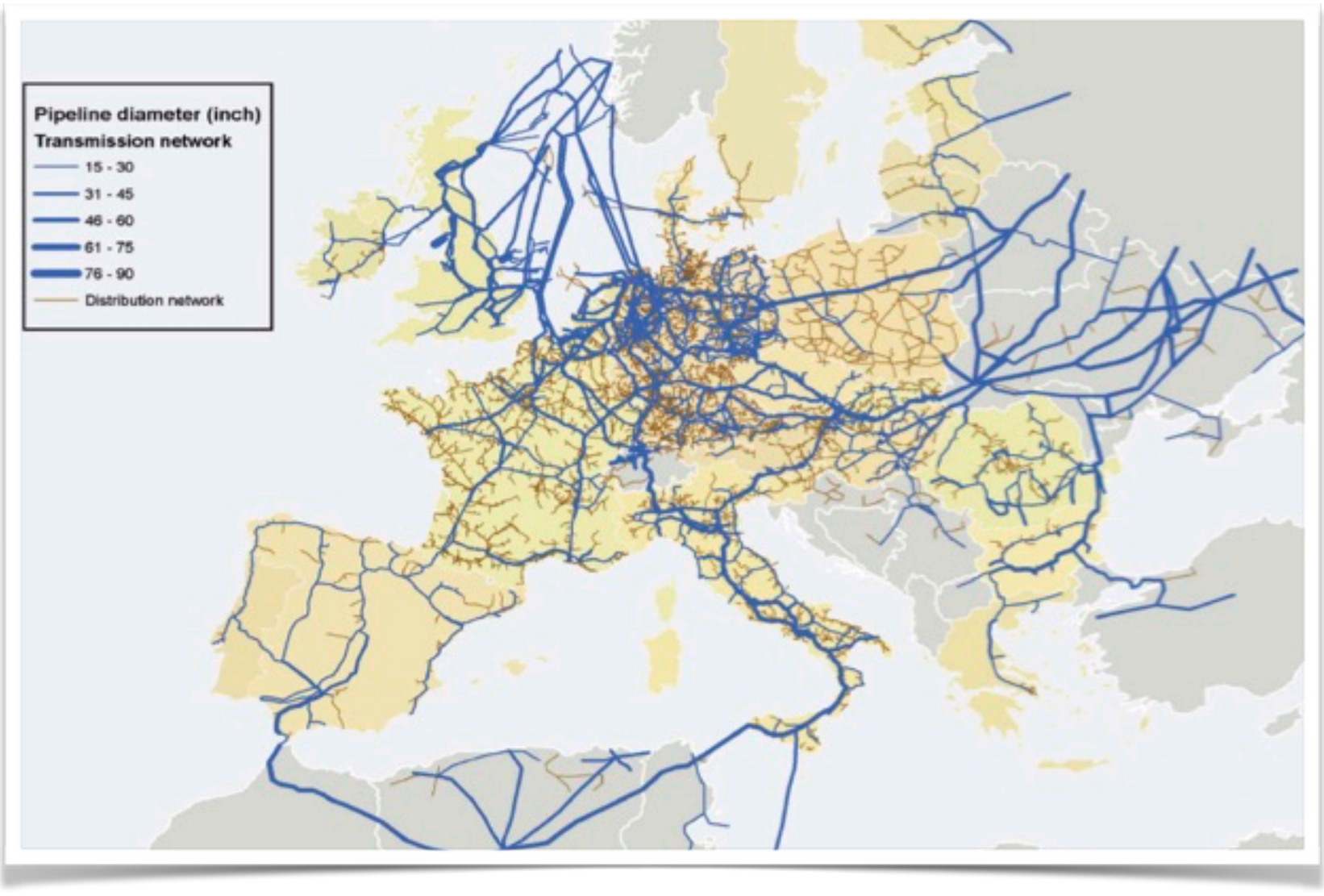

Greenland
Canada
United States
Mexico
Iceland
Norway
Finland
Sweden
Russia
Poland
Germany
Ukraine
Kazakhstan
Mongolia
China
Spain
Turkey
Afghanistan
Pakistan
India
Thailand
Algeria
Libya
Mali
Niger
Sudan
Chad
Nigeria
Kenya
Tanz
Namibia
Botswana
Madagas
Brazil
Bolivia
Chile
Argentina
Australia
New Zealand
North Atlantic Ocean
South Pacific Ocean
South Atlantic Ocean
Indian Ocean

# Internet




IP connection map, 15 Jan 2005 (wiki)

# Other networks



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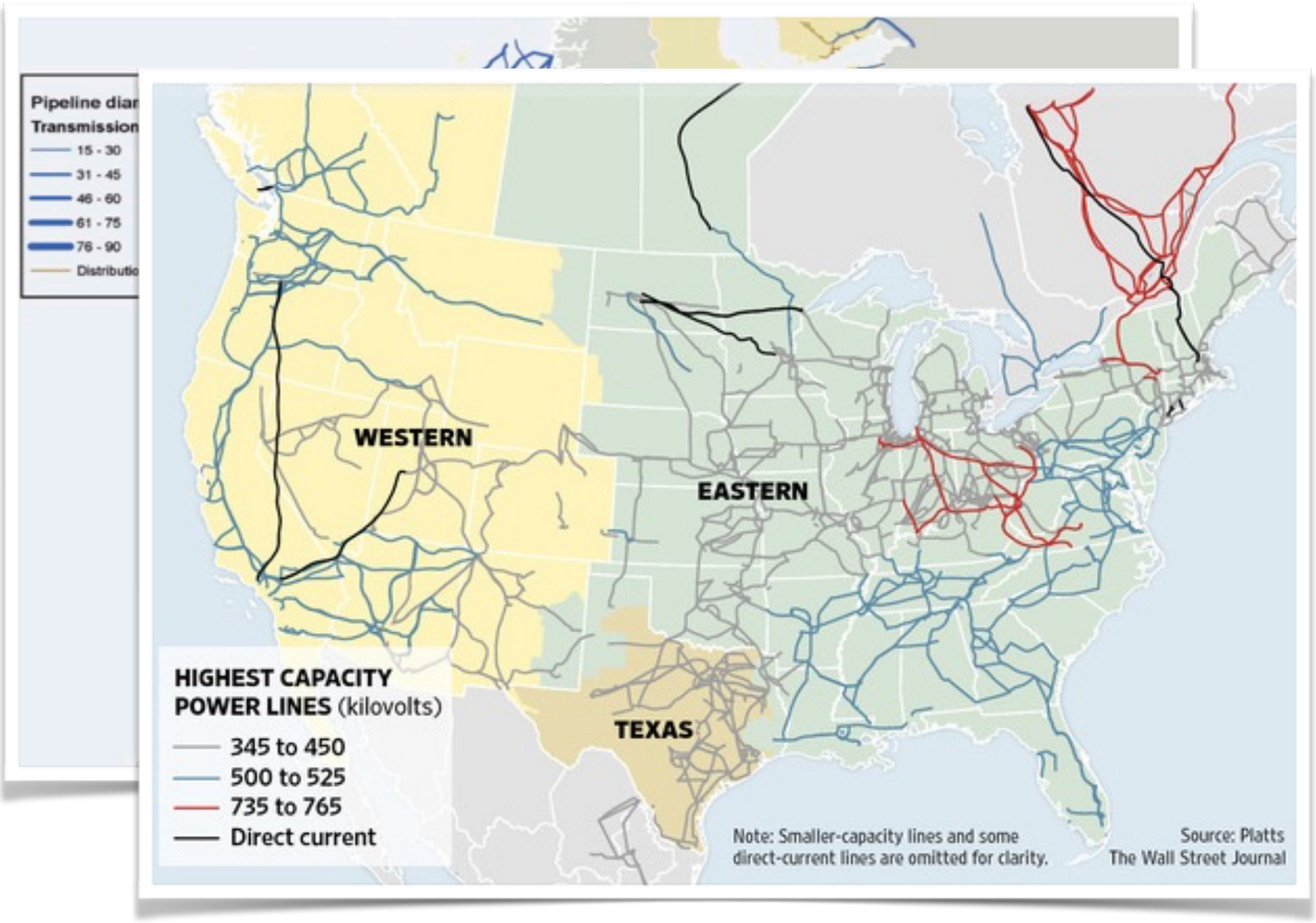

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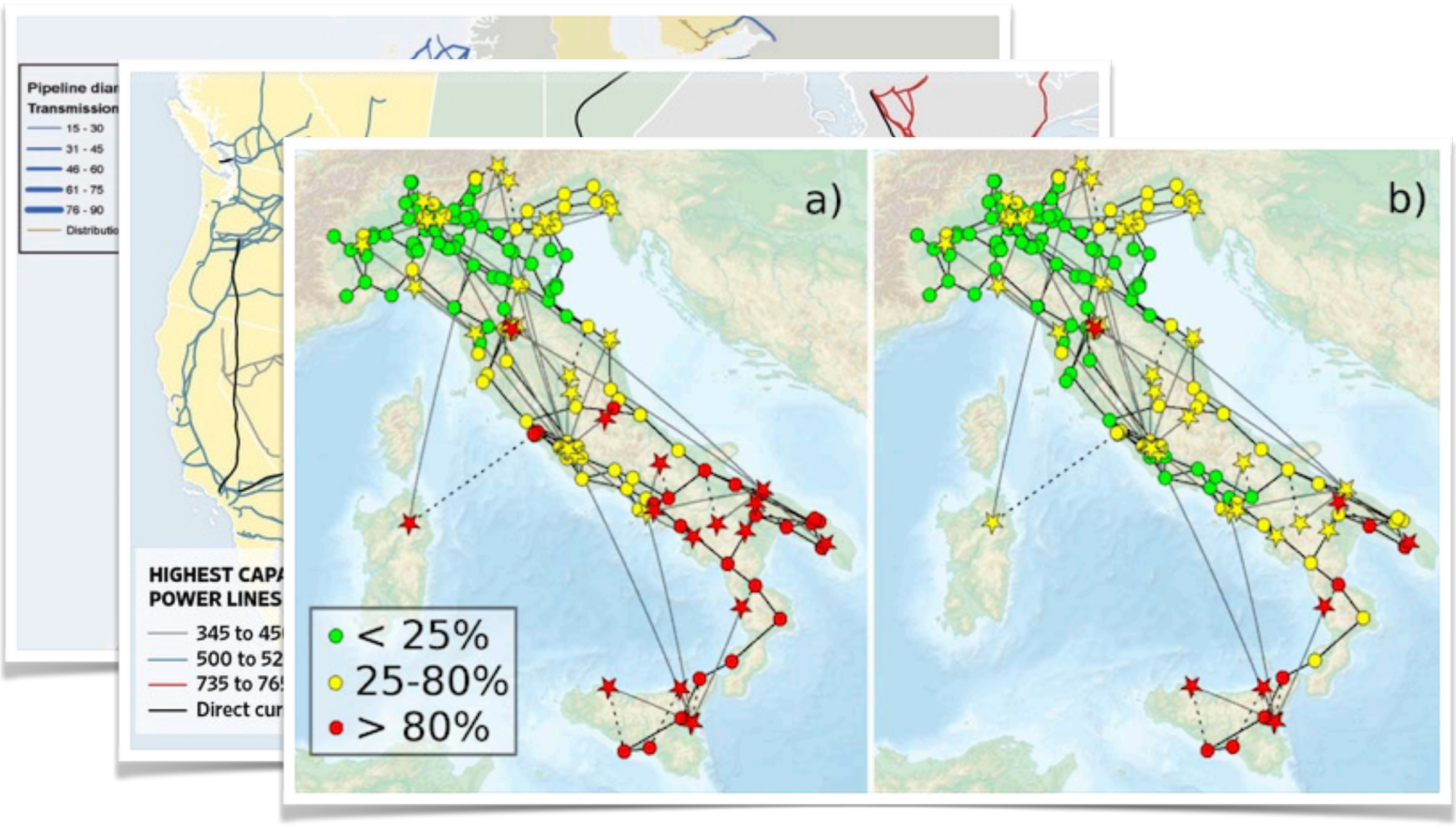

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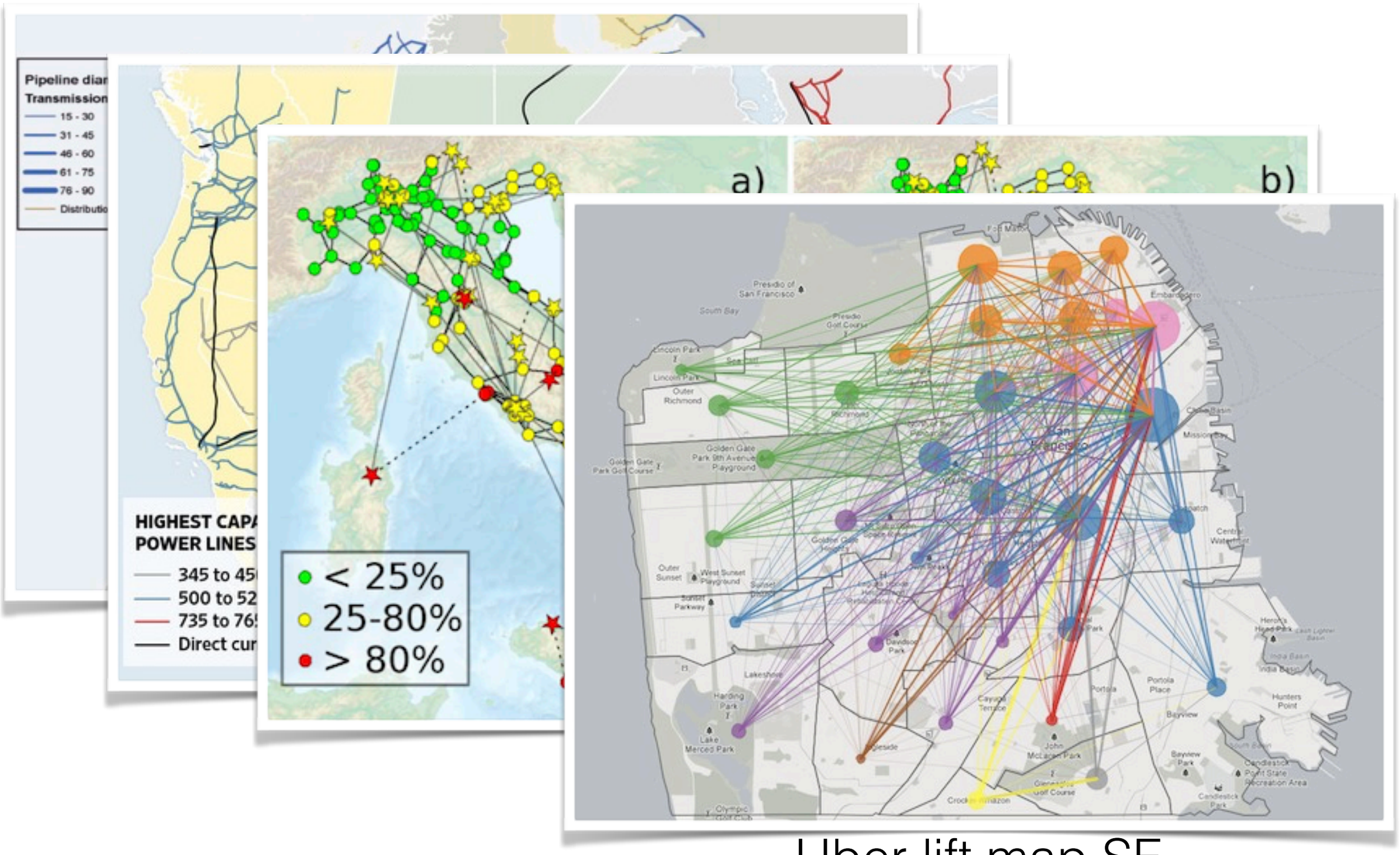
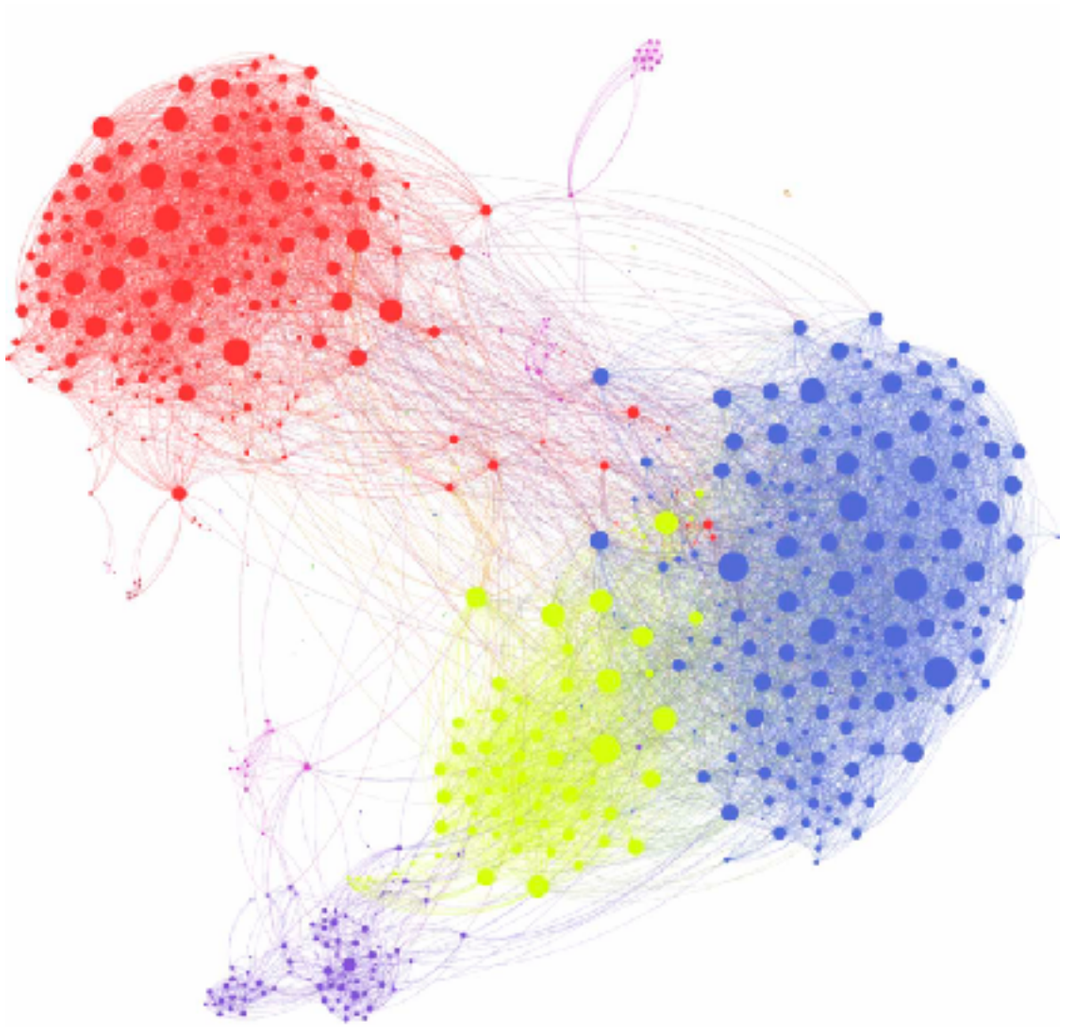


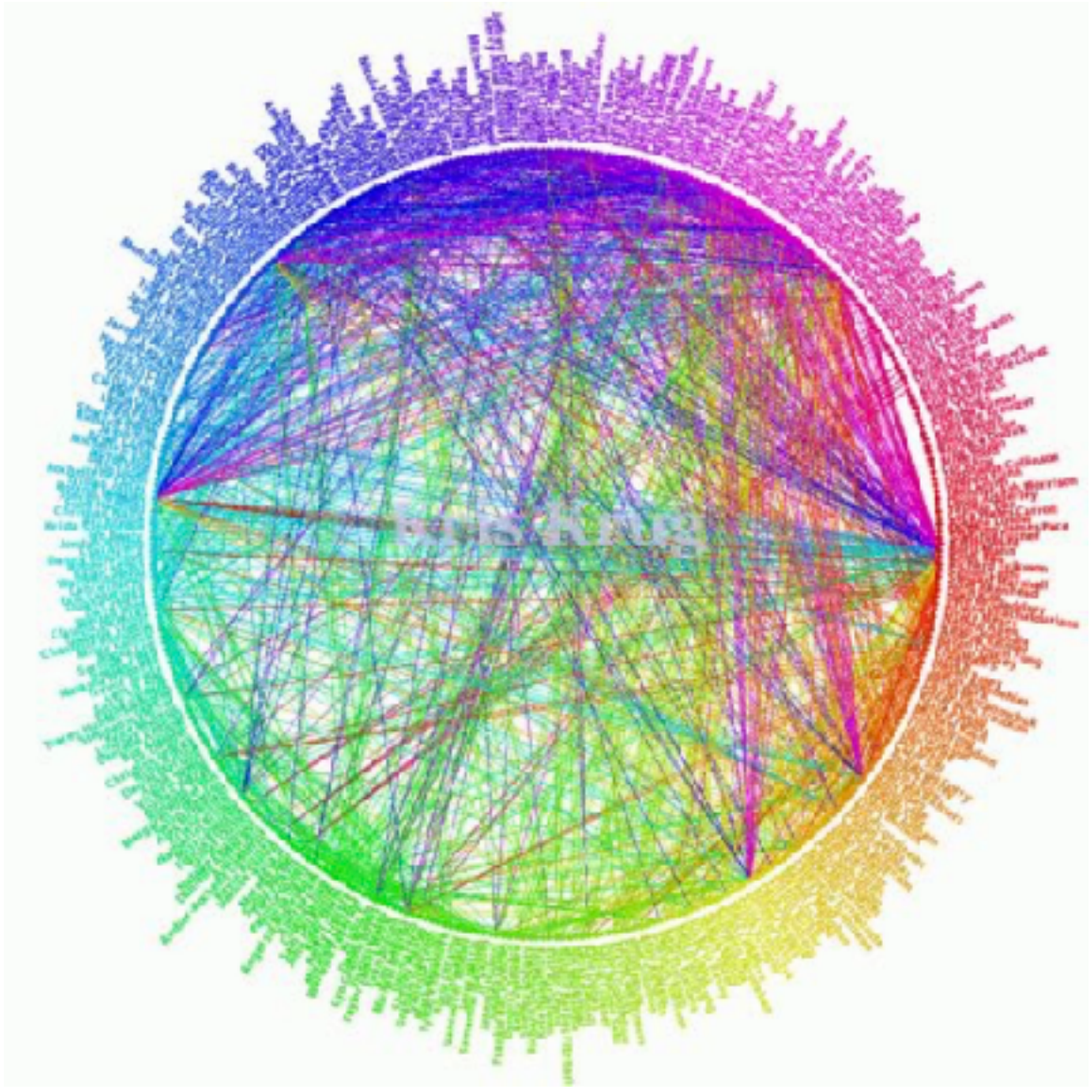

Uber lift map SF

# Facebook

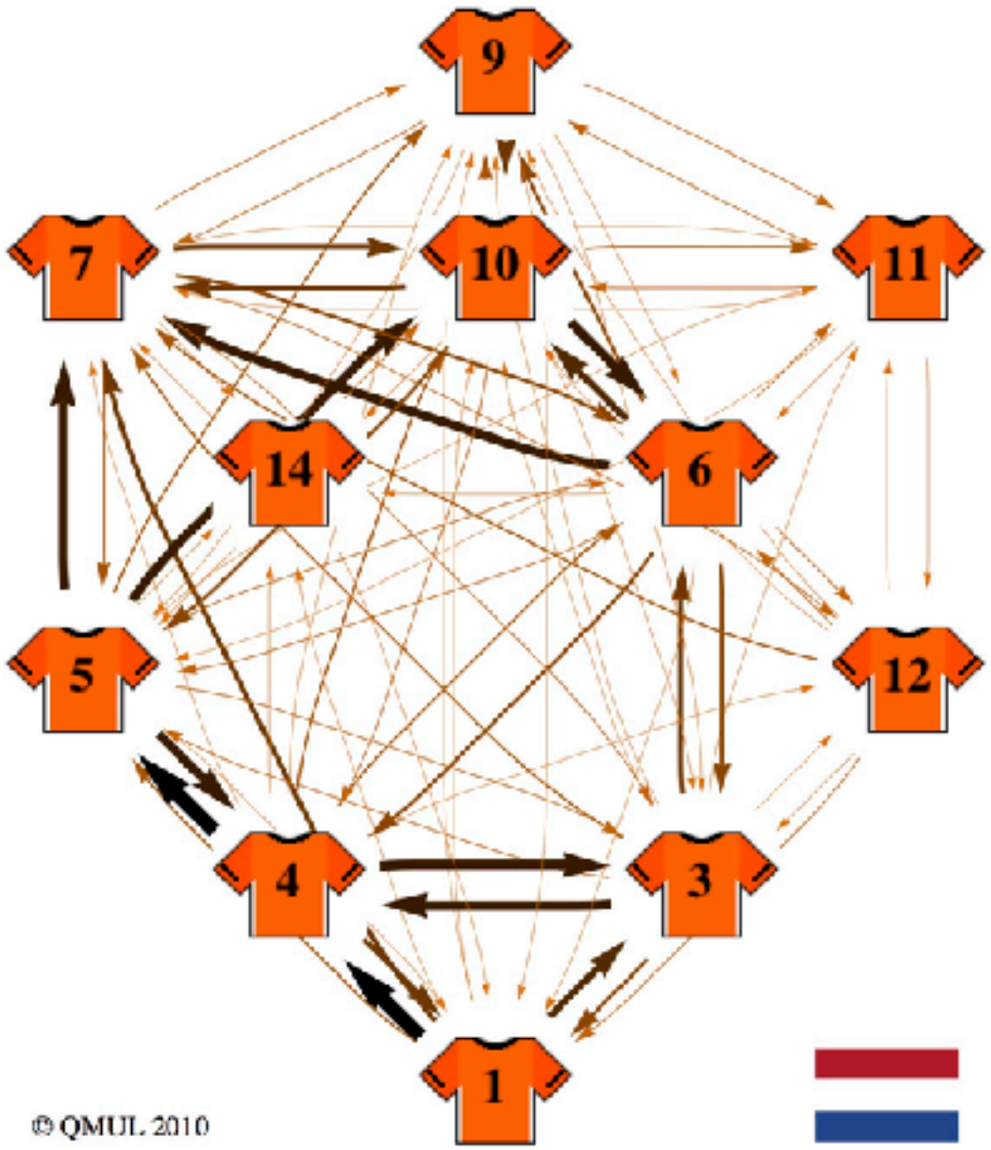
## Brendan Griffen



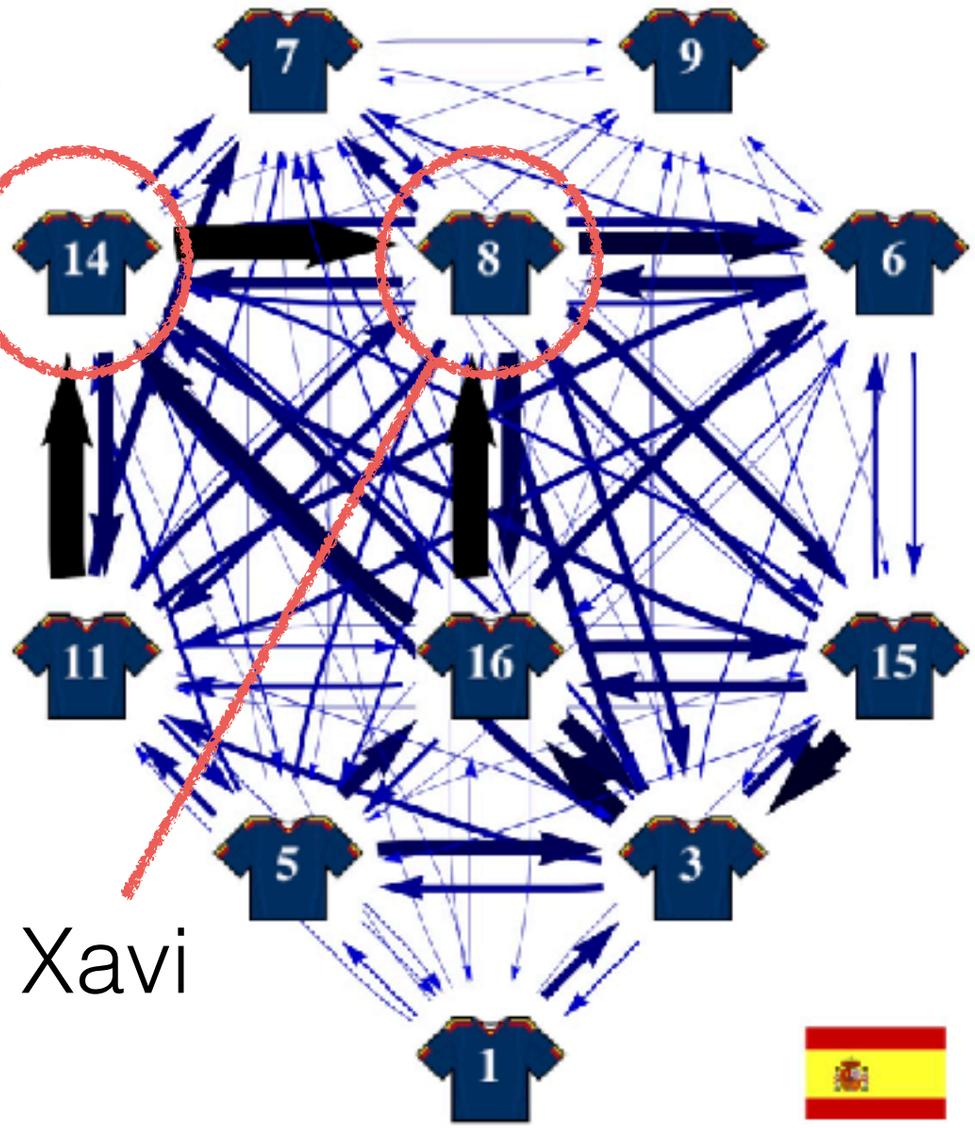
## Kris Krüg



# Football graphs



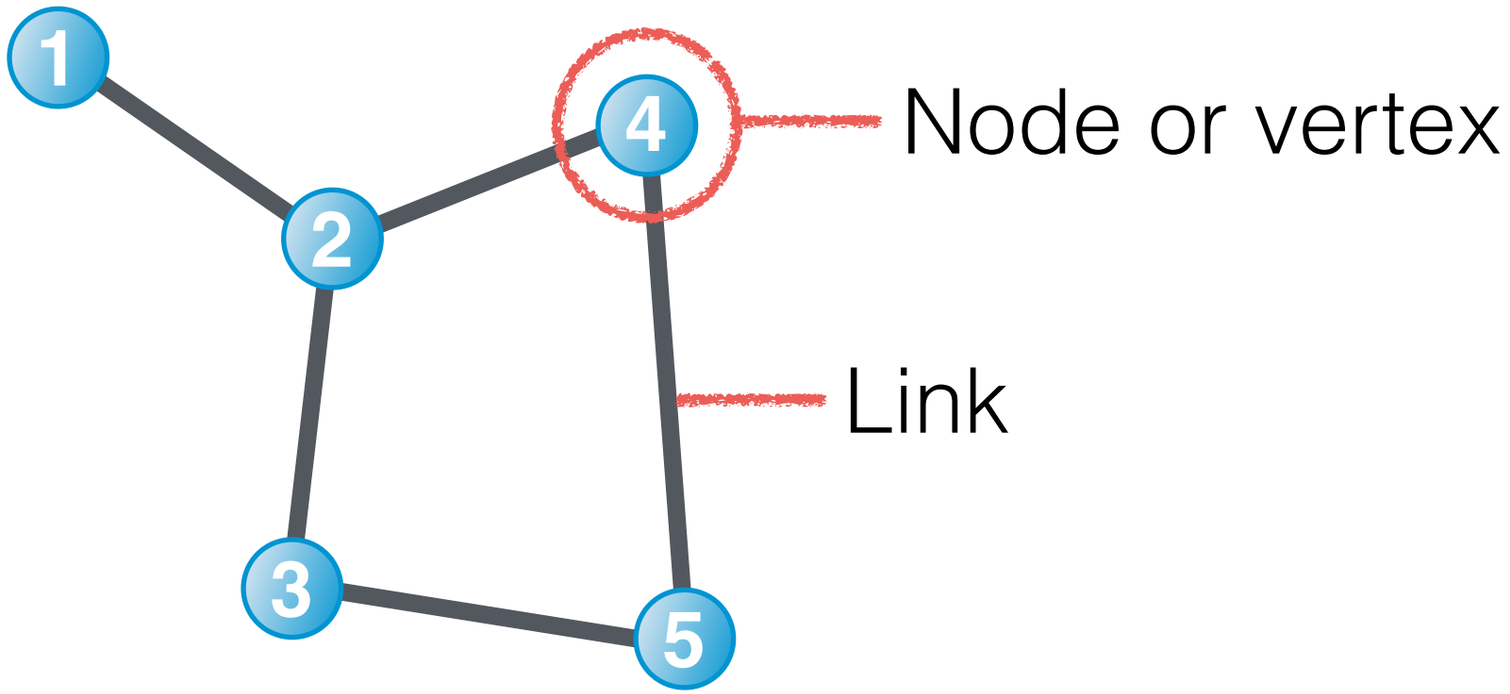

Alonso




Xavi

- With Javier Lopez Pena (now at kickdex)
- http://www.maths.qmul.ac.uk/~ht/footballgraphs/

# Bits of graph theory




**Degree:** $d_i$ = # links from $i$

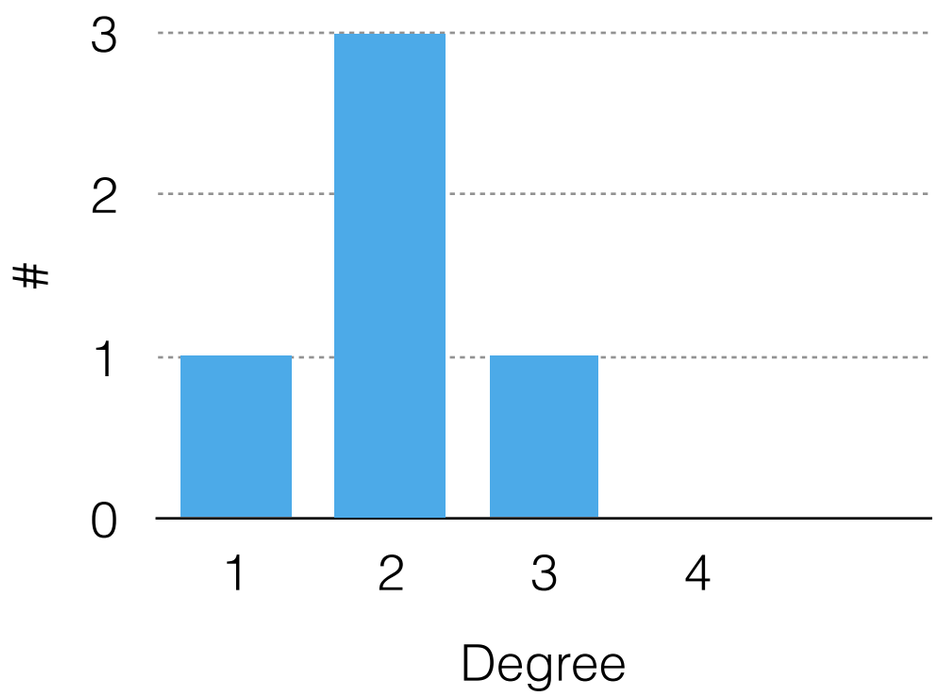
**Degree sequence**

$d$ = (1,3,2,2,2)

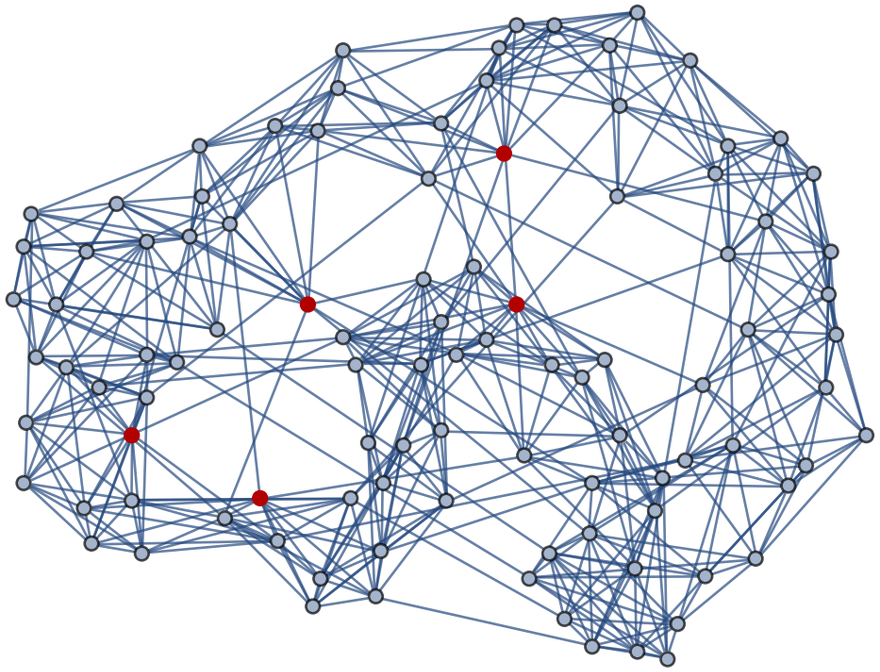
## Adjacency matrix

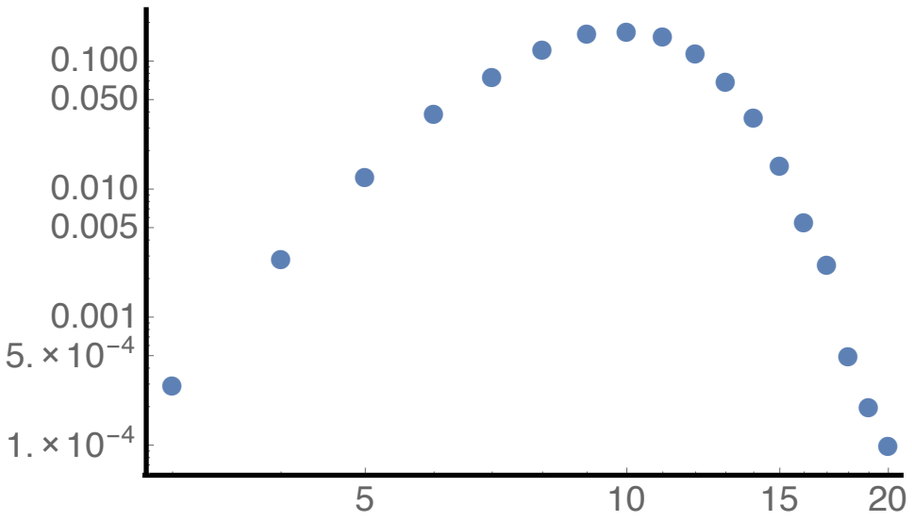
| | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | 0 | **1** | 0 | 0 | 0 |
| 2 | **1** | 0 | **1** | **1** | 0 |
| 3 | 0 | **1** | 0 | 0 | **1** |
| 4 | 0 | **1** | 0 | 0 | **1** |
| 5 | 0 | 0 | **1** | **1** | 0 |

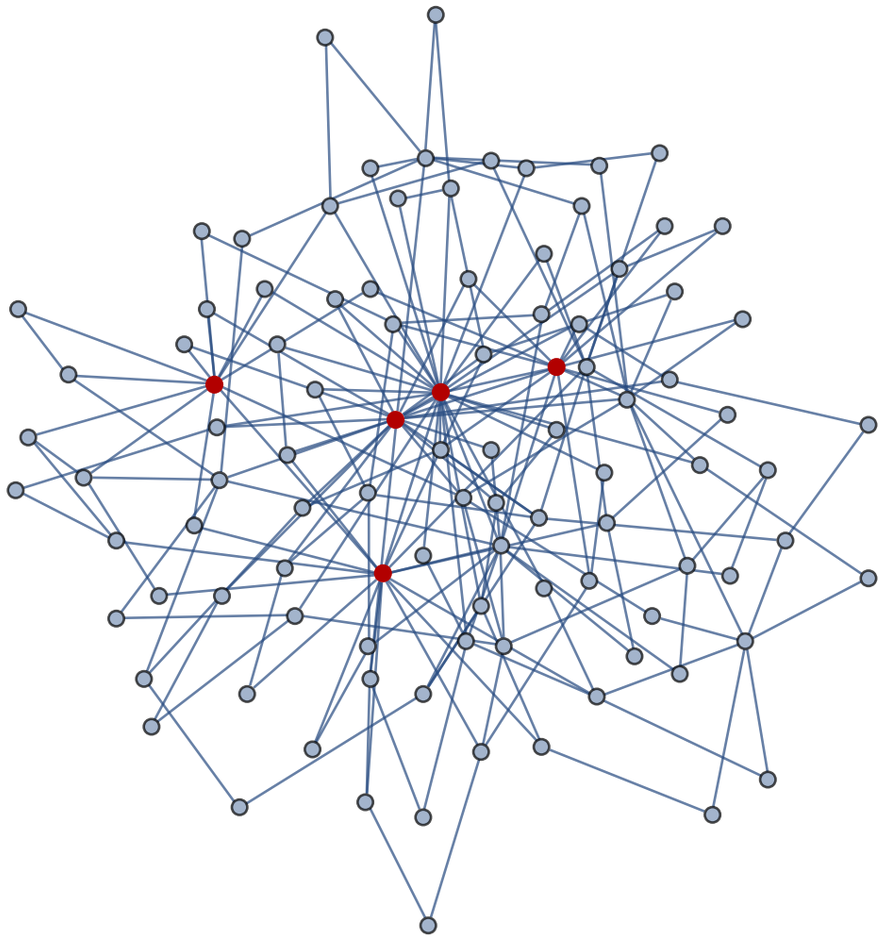
## Degree distribution

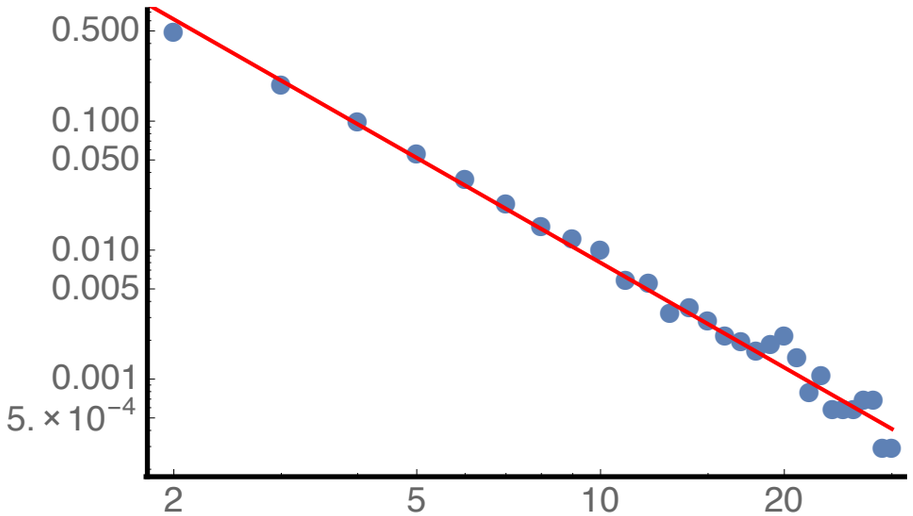


# Degree distribution



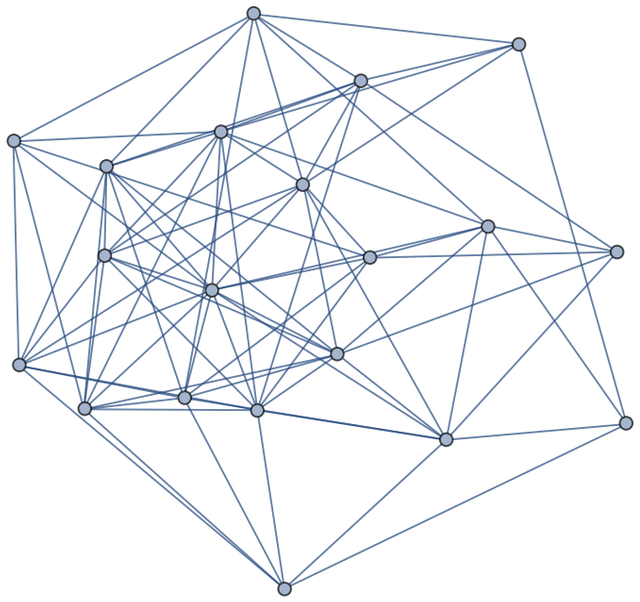


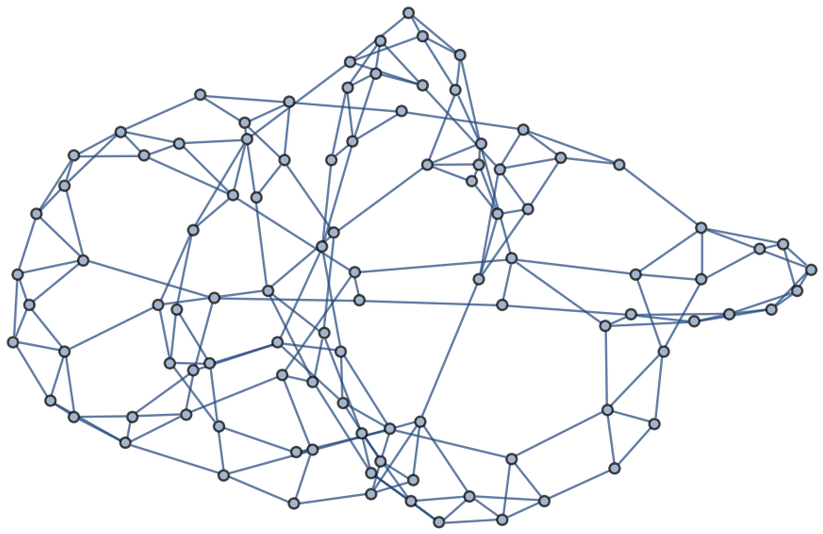


# Types of graphs

## Random

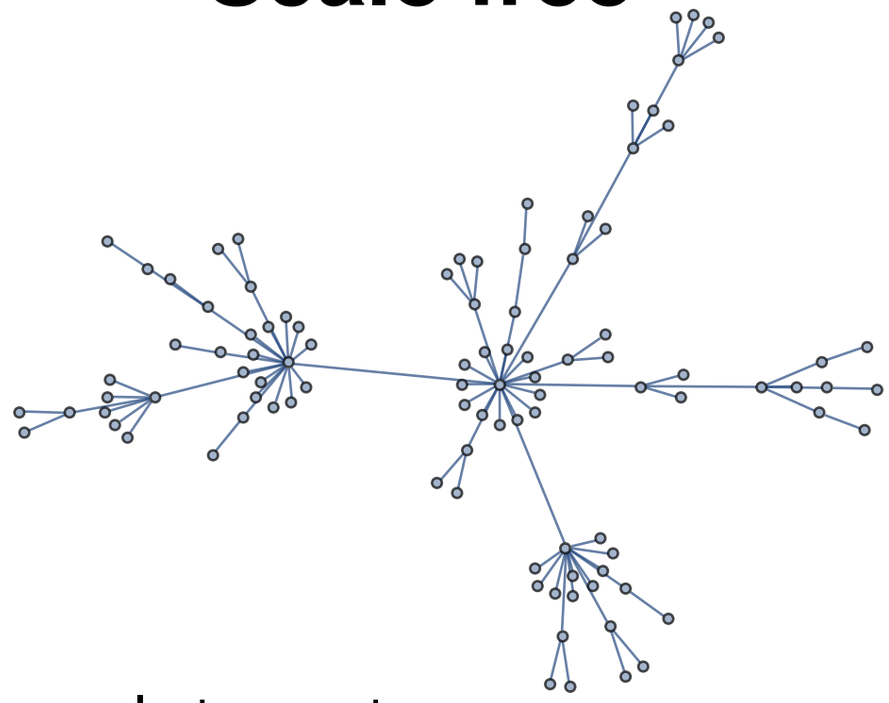


## Small world



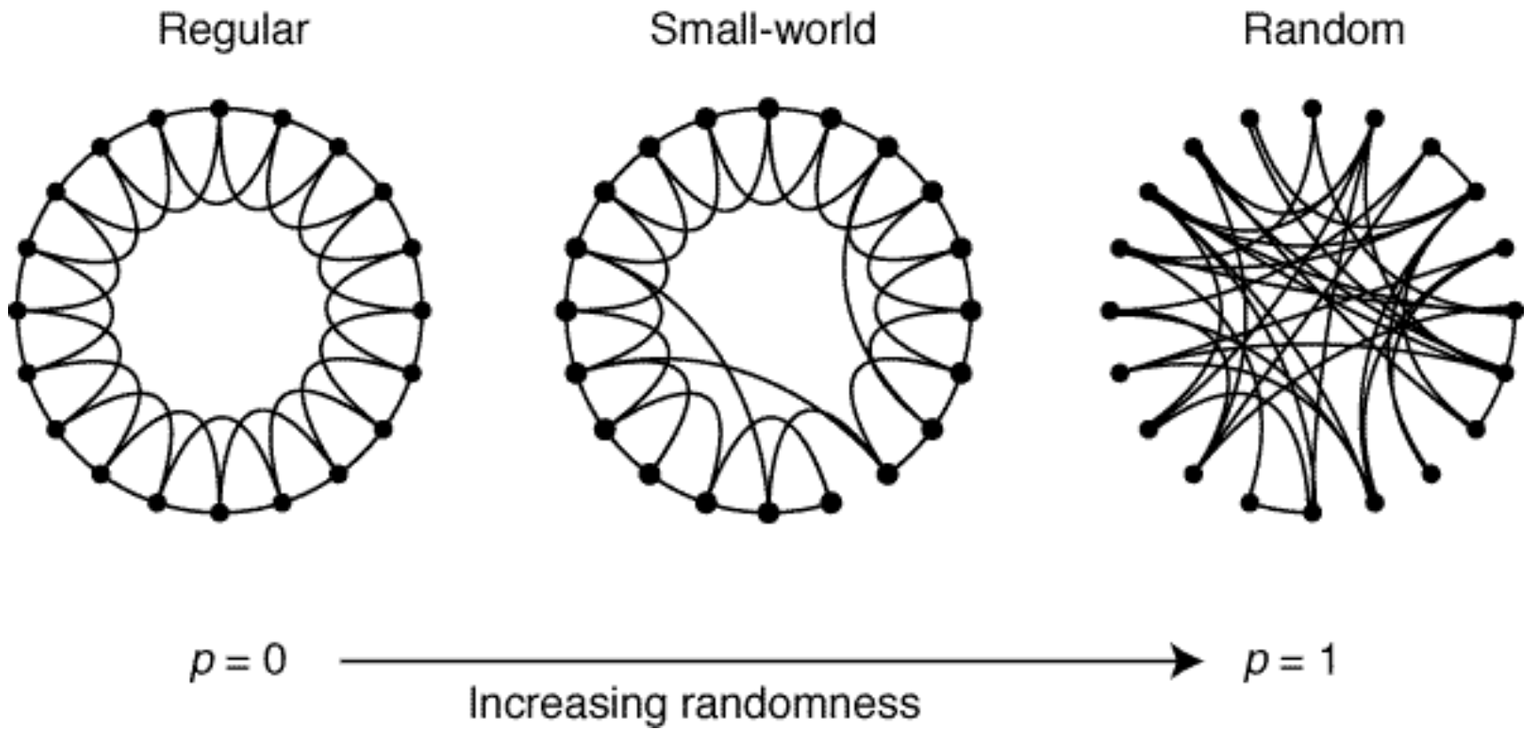
- Social networks
- Electricity grid
- Gene networks
- Between ordered and random

## Scale free

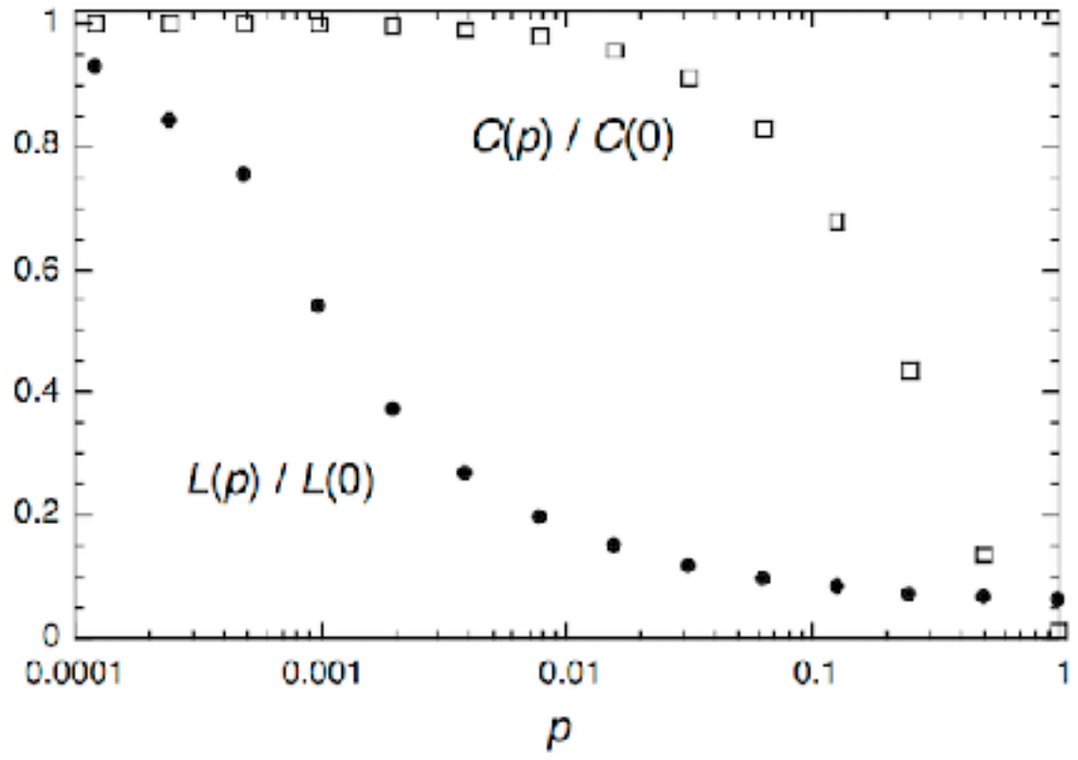


- Internet
- Sexual partners
- Airline connections
- Scientific citations
- Highly connected nodes (hubs)

# Small world networks



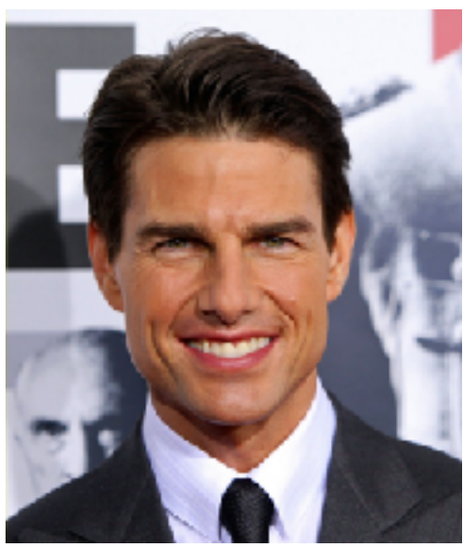

- Re-wire link with probability *p*
- Create **bridges**
- Small distance
- High clustering




Watts & Strogatz, Nature 1998

# Kevin Bacon game

Kevin Bacon is the centre of the entertainment world!



https://oracleofbacon.org

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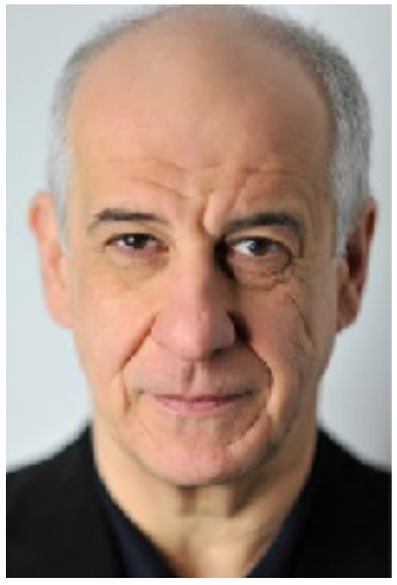
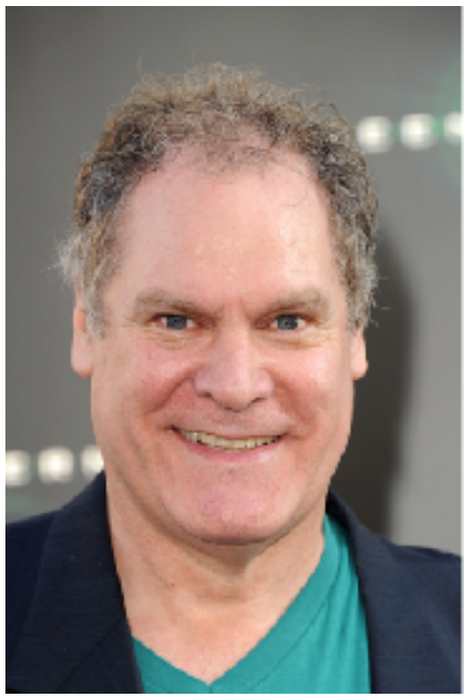
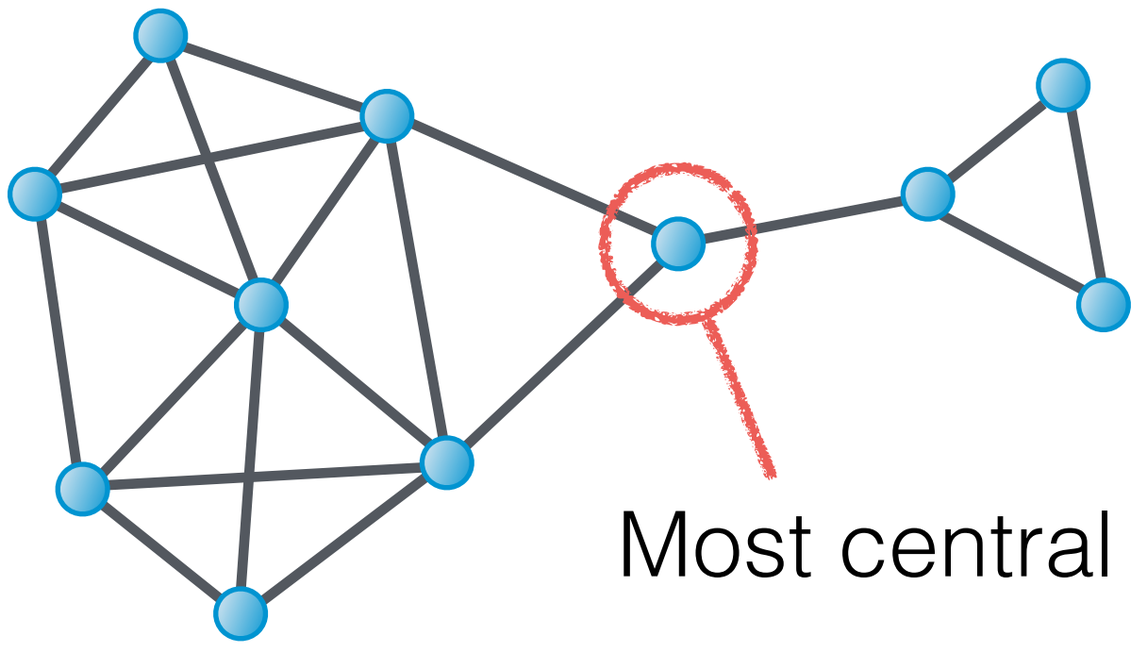




Jay Sanders

https://oracleofbacon.org

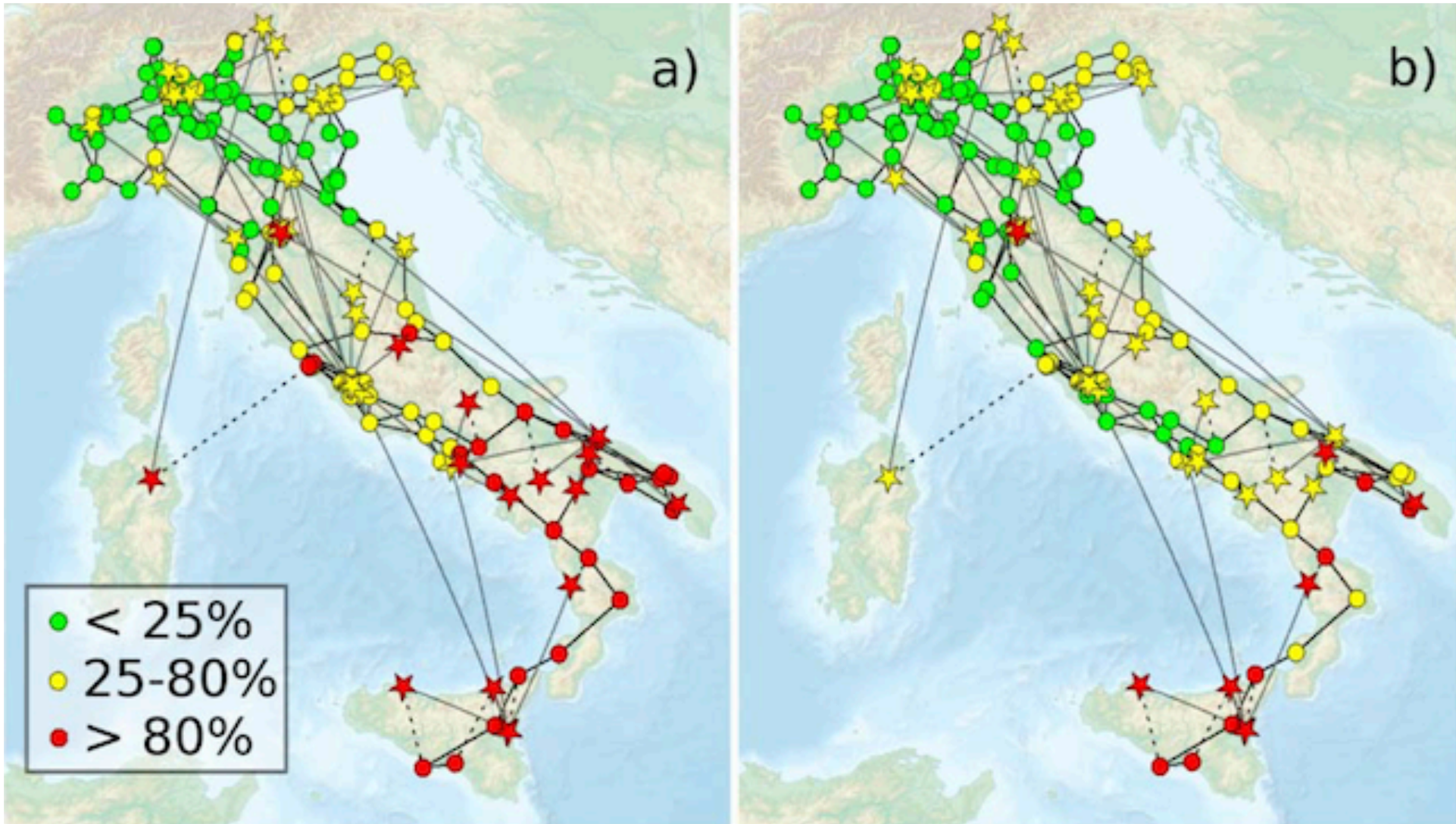
# Centrality




- Most connected = highest degree
- Most central = most effect if removed
- Centrality = Link to many connections

- Different centrality measures $C = F(A)$
  - Betweenness
  - Pagerank
  - Degree centrality

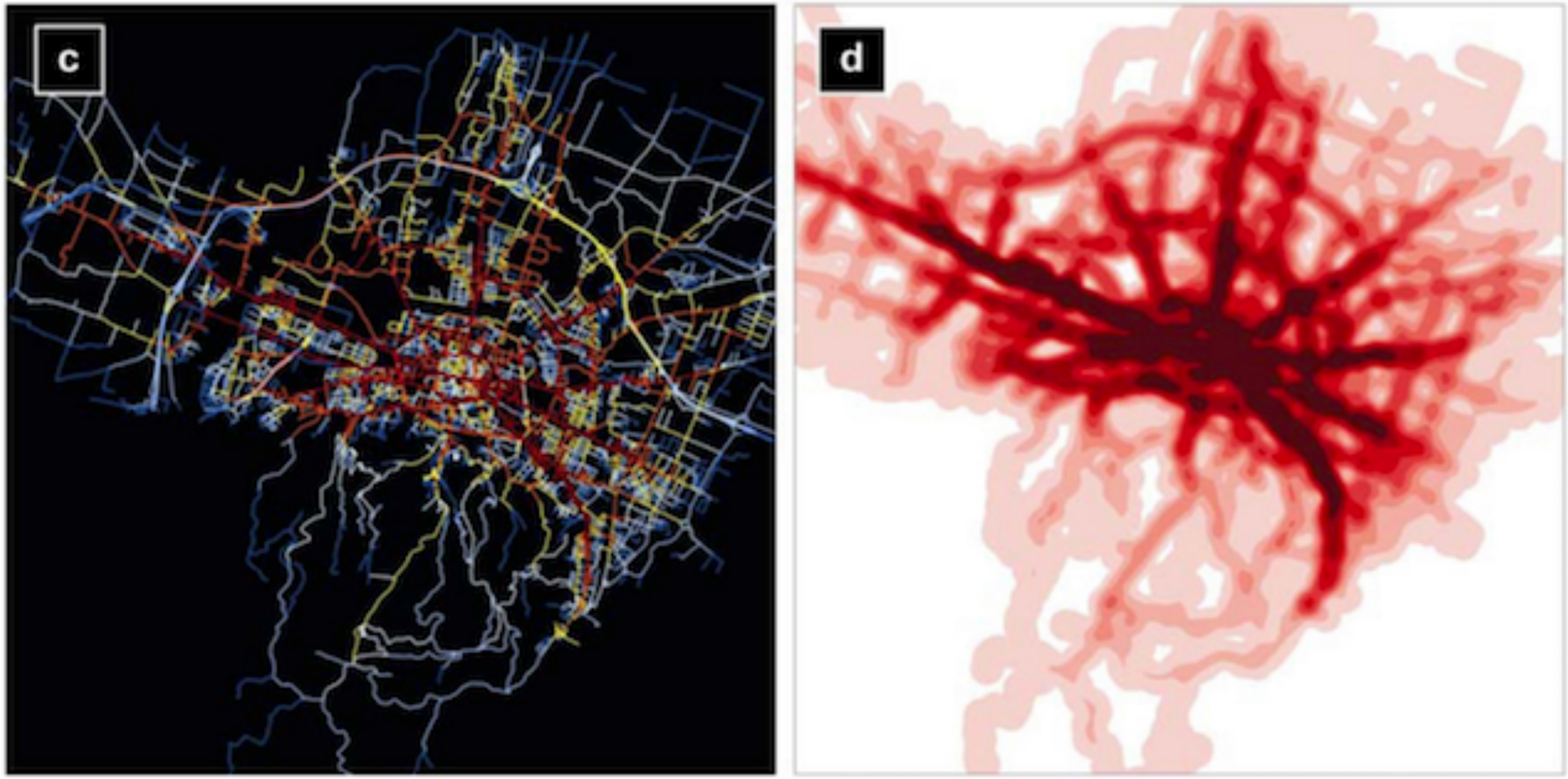
# Examples




- Communication servers (39 stars)
- Power grid (310 circles)
- Failure probability with 14 servers down

Schneider et al., Sci. Rep. 2013

# Examples



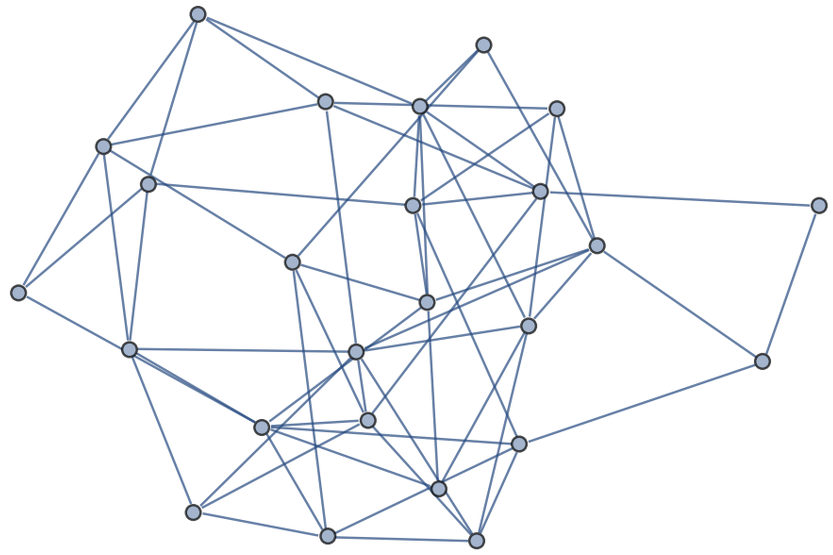

- Left: Betweenness centrality
- Right: Correlation of centrality-activity

Porta et al., Environ. & Planning 2009

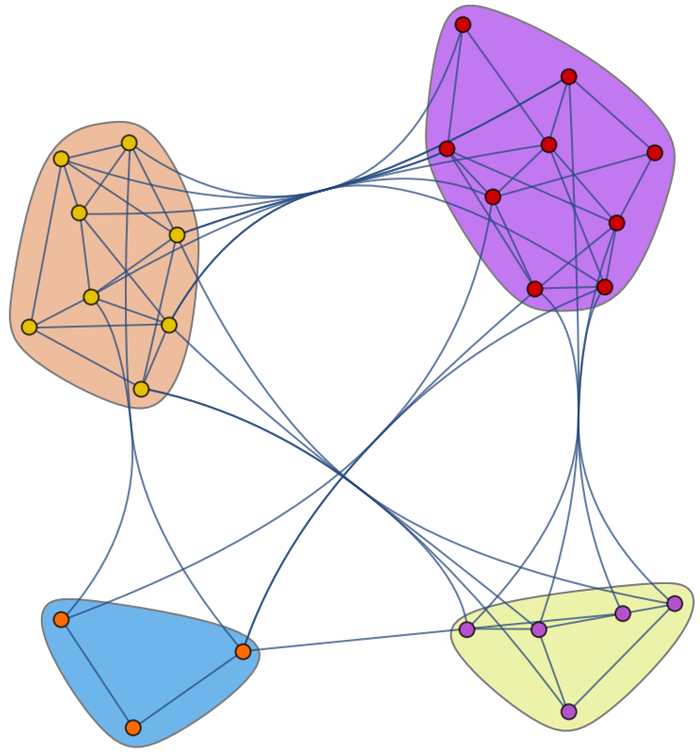
# Current research

Maths + physics + computer science + social sciences

- Community detection
  - Identification
  - Recommendations (Facebook, Amazon, etc.)



- Evolving networks
  - City growth
  - Urban planning



- Dynamics on networks
  - Disease spreading
  - Google search
  - Daily commute

# LONDON IN MOTION

**One day of public transit travel for 3.1 million Londoners, inferred using complete sets of data from the Oyster farecard and the iBus vehicle-location system**

Massachusetts Institute of Technology

Transport for London

jaygordon.net

3:00 AM