Complex-Network Modelling and Inference

Lecture 1: Introduction and Course Summary

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https://roughan.info/notes/Network_Modelling/

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Section 1

Course Introduction

Who is teaching this course

Course Coordinator: Prof Matthew Roughan
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Administrative Enquiries: School of Mathematical Sciences Office,
Level 6, Ingkarni Wardli

Course philosophy

You can see the Uni's graduate attributes on the web.
I think more in terms of the AMSI Industry working groups findings regarding what they NEED in applied mathematicians:

- logical/critical thinking
- practical ability to do problem structuring and solving, often beginning with messy data, or a messy problem description
- data analysis skills, ability to work effectively with data
- ability to work collaboratively, in multi-disciplinary teams
- communication skills
- ability to code/program

These are the things I am aiming to teach in this course
+ something about networks

You Responsibilities

Lectures

This course was originally a 3-hour/week lecture course. We have 2 hours booked each week. So we won't be doing it like a traditional lecture course. You will NEED to read the material in advance, and we will discuss it in the f-2-f timeslots.

Plan:

- Weeks 1-8
  - 2 "seminars" a week
  - 1 assignment a week
- Weeks 9-12
  - a few advanced lectures
  - guest lectures
  - 1 mini-project

That is, I plan to "front load" the course

Outline

This course is an amalgam of an Applied and a Stats course, so while parts of it might be easy for you, they might be difficult for others.

We'll go fast, because lots of this stuff is pretty easy, but slow me down if we hit a patch that is causing confusion.

Best reference text:

1. "Networks: An Introduction", M. Newman, Oxford Uni. Press, 2010

But we won't be following this exclusively.

Lecture notes

Almost all materials for this course will be available via MyUni, or through the course web page at
https://roughan.info/notes/network_modelling/

- notes are already there
- assignments need to be updated
- announcements via MyUni

The lecture slides cover all examinable material in this course.

Assessment

1. 60% for assignments (7 + 1 mini-project)
2. 10% competition
3. 30% test

with the goal that you learn to DO something, not just be able to do pen-and-paper calculations.

Note also that

1. All written assignments are to be submitted online on MyUni.
2. The expectation is that they will be typed and nicely formatted:
   - LaTeX is the standard tool we use for writing mathematics.
   - Have a look at Inkscape for producing professional figures.
   - There are various tools for producing graphs from data (I use GraphVis)
3. Late assignments will not be accepted, except by prior arrangement (for a good reason).

Policies

- Plagiarism – **Note:** Plagiarism applies to computer code as well. When I ask you to write code to do a task, I expect you to write your own code, not to use a package or otherwise avoid writing your own code.
- Diversity and Inclusion – https://roughan.info/course/
- ...

Programming

- This course will require some computer programming
  - We will be coding in `Julia`
    https://julialang.org/
  - I can provide some help to get started
- You must write your own code!
  - plagiarism applies to writing code as well as other handins
  - in particular, don't use packages to avoid writing detailed algorithms

What are we trying to teach

- Translate real-world problem into maths
  - may involve some approximation
  - have to deal with tradeoff between accuracy and simplicity
- Algorithms
  - how particular algorithms work
  - general algorithmic strategies
  - what is important in design and implementation
    - ★ *e.g.*, complexity
- Proofs
  - how can you show you definitely have the right answer?
- Content
  - Classical graph theory
  - Stochastic models of graphs and networks
  - How to use graphs and networks in practical problems
  - Statistical techniques on and for graphs

Section 2

Graphs and networks

Some motivating examples

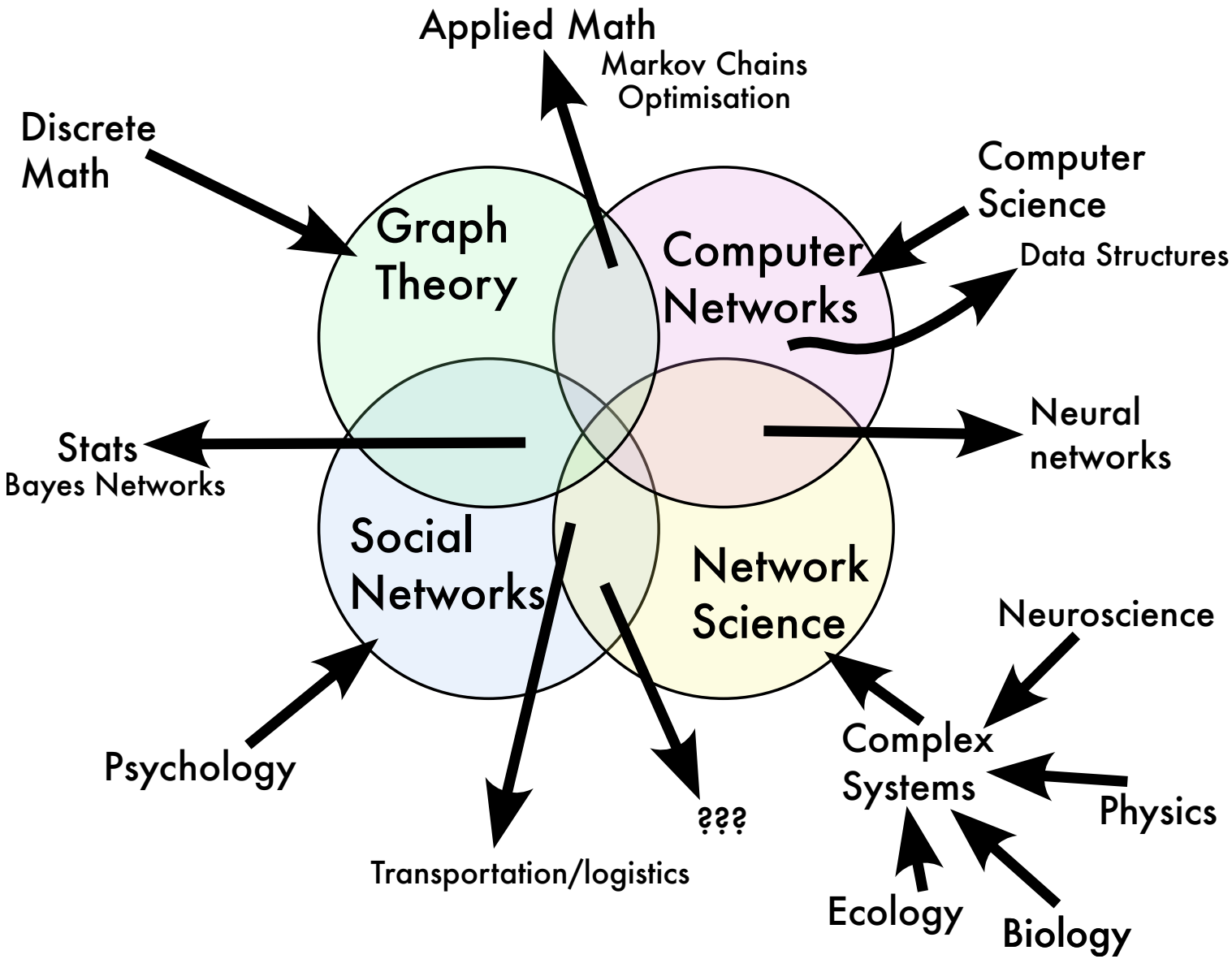
TRC projects planned or already happening

- Defence – modelling and simulation of defence networks $\sim$ \$2 million
- SA Electricity grid modelling $>$ \$1 million
- Provable network cyber-security $>$ \$2 million
- Telstra network planning $\sim$ \$250 thousand (but more than \$20 million in the past)
- Office of National Intellgence $\sim$ \$600 thousand
- Defence department CANBus modelling $\sim$ \$1 million

Other motivations

- Why did Optus's network fail last year?
- How did Taylor Swift "Break the Internet?" https://www.abc.net.au/news/2024-02-23/taylor-swift-melbourne-sydney-show-internet-mobile-phone-103497378

Complex Networks



Complex Networks

More than just telephone networks ...

Engineered networks

- Telephone (telegraph)
- Transportation
  - cars, buses, rail
  - sea, air
  - postal network
- Distribution
  - electricity, water
  - TV (cable/broadcast)
  - radio
  - newspapers
- Internet
- Mobile Ad-Hoc (MANets)
  - sensor networks
- Protocol Relationships
- Electrical Circuits
- Program interdependencies
- Mine tunnels

Natural networks

- Science Citations
- International Trade
- Production/supply chains
  - food production/processing and distribution
  - car production
- Corporate interactions
  - competition/co-operation
  - stockmart interactions
- Food web
- Biochemical reactions
- Neural networks
- Social interactions
  - political alliances
  - sexual contacts
  - facebook friends
  - twitter followers
  - school yard
- Nervous system
- Circulatory system
- Disease transmision
- Family trees
- Philogenetic trees

Physical vs Virtual

Neural network
Internet (layer 1-3)
- L1 - physical
- L2 - links
- L3 - network

Science Citations
Internet
- L4 - end-to-end connections
- Autonomous Systems

Social interactions
Internet (layer 7)
- WWW
- email
- peer-2-peer
- online social network
  - facebook
  - myspace
  - linked in

Characterised by
real costs => optimization
physical constraints
comparitive stability

Characterised by
dynamic behaviour
high variability

Transport vs Information

Transport networks

Information networks

Cars/buses/pedestrians

Distribution
- water
- electricity

Disease transmission

Social interactions

Internet
- WWW
- email
- etc.

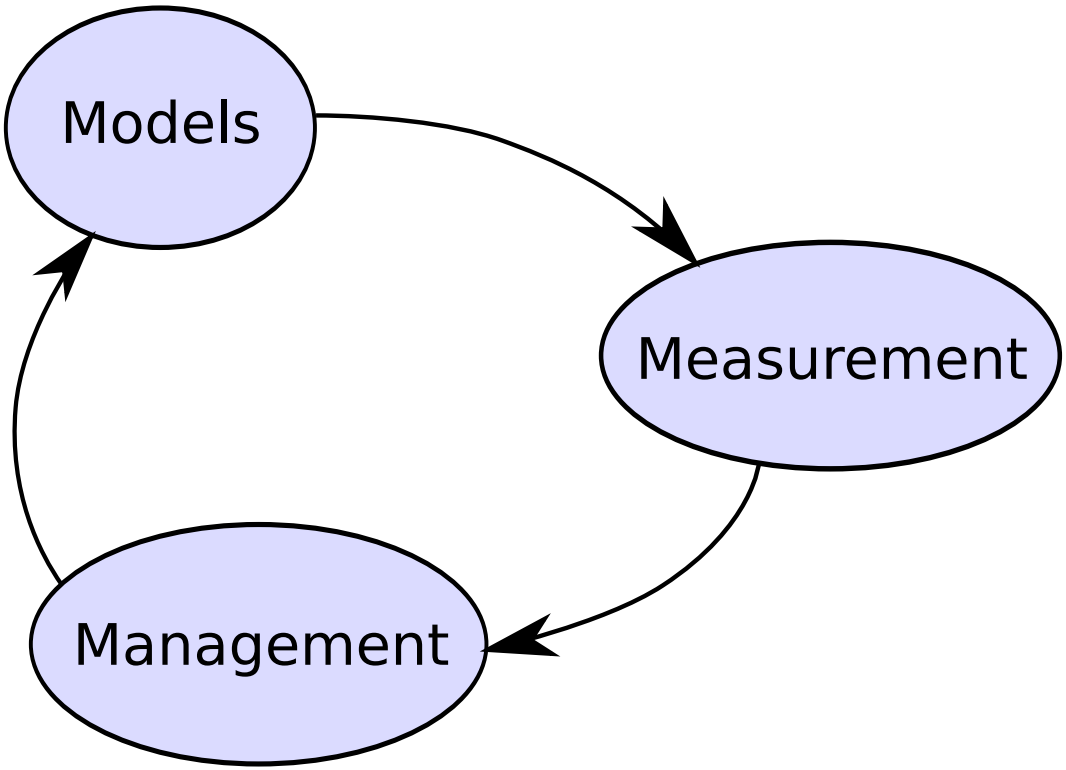
Characterised by

transport of physical objects

Characterised by

transport of information

We need to understand everything



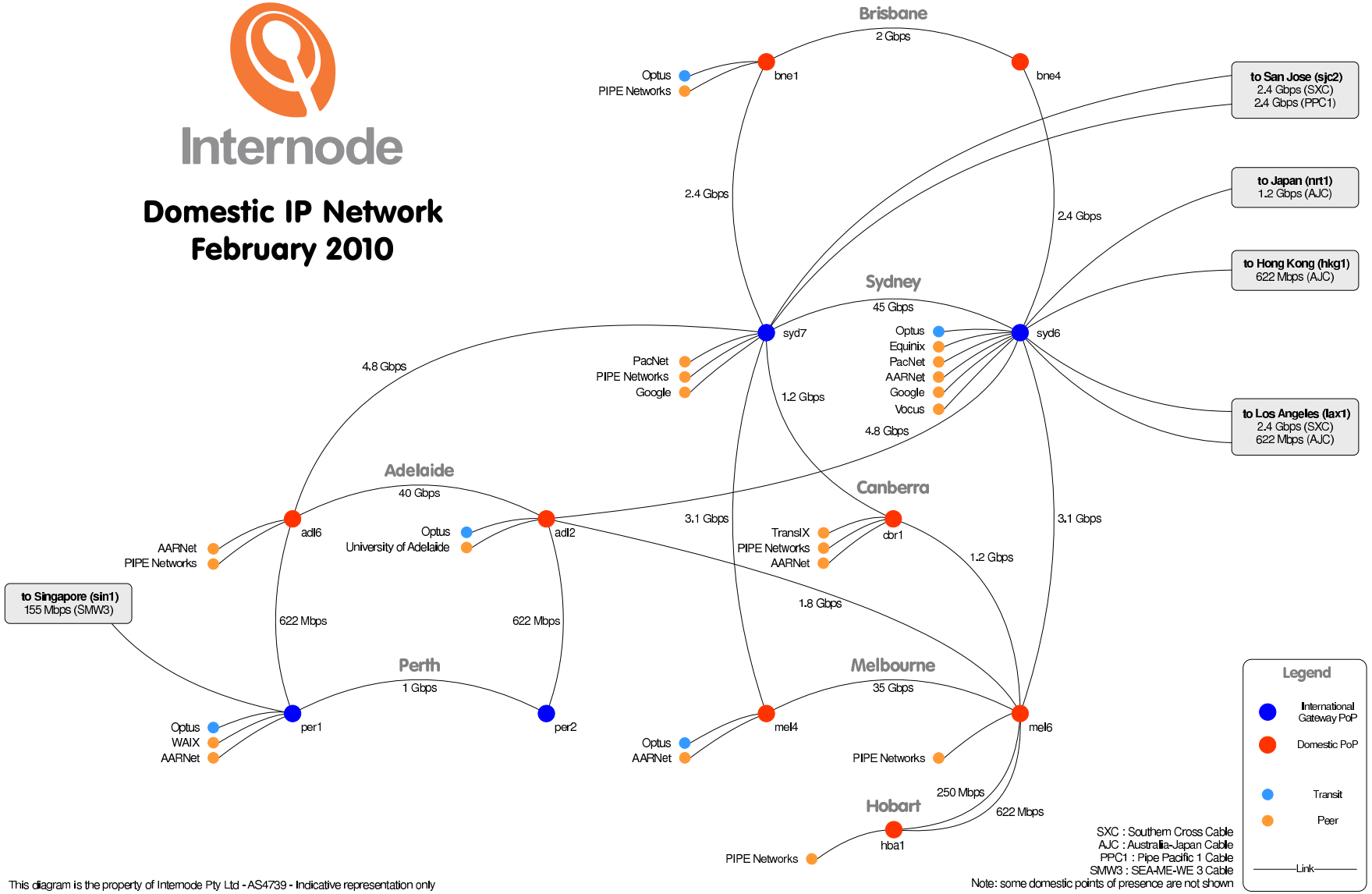
Focus

- main example: the Internet
  - made up of lots of components
  - my main area of experience
- want to bridge gaps
  - where do analogies hold?
  - where do they break down?
- interactions
  - inside network
  - between networks
- emergence
  - complexity
  - surprise

Section 3

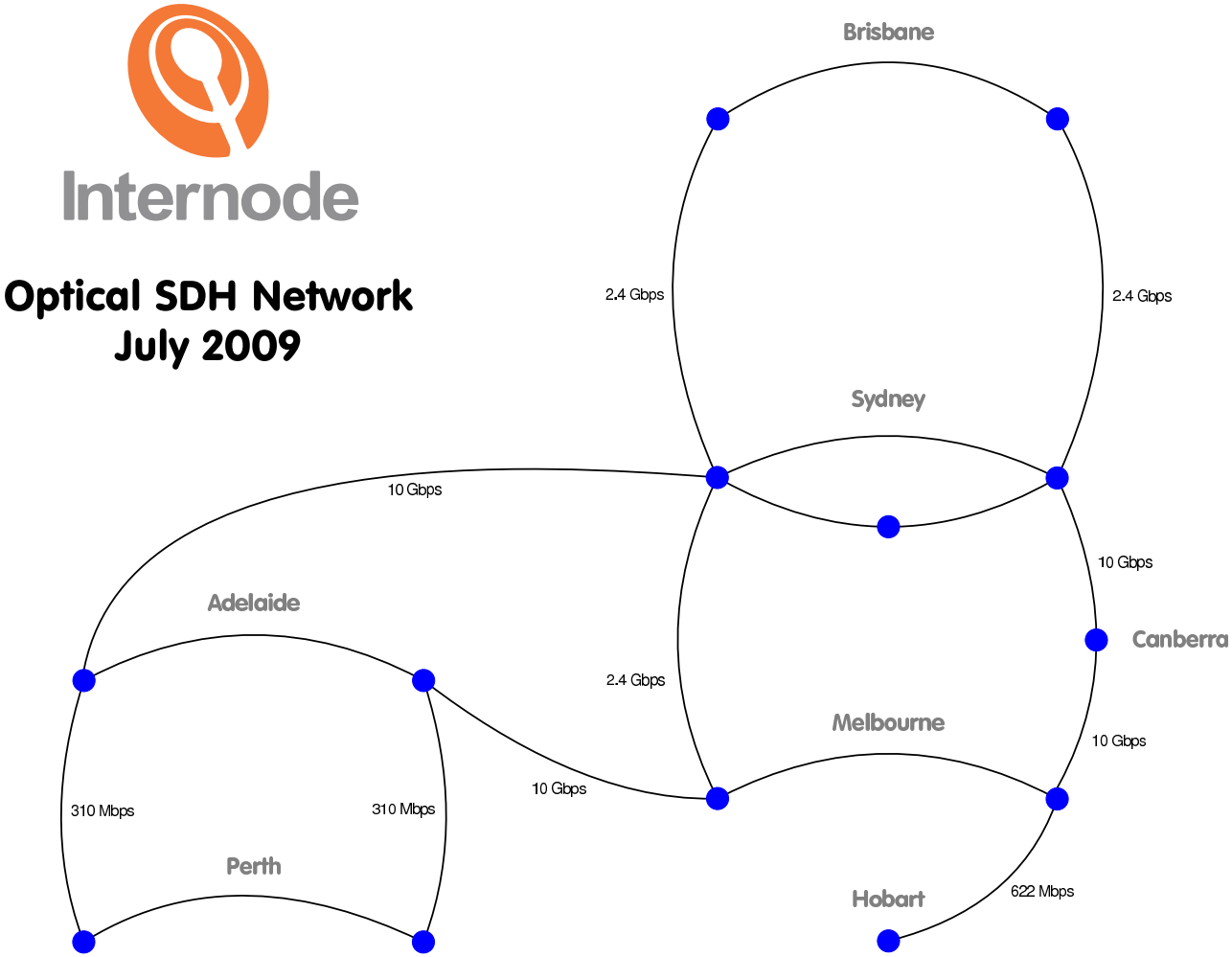
A set of examples in no specific order.

ISPs: Internode: layer 3



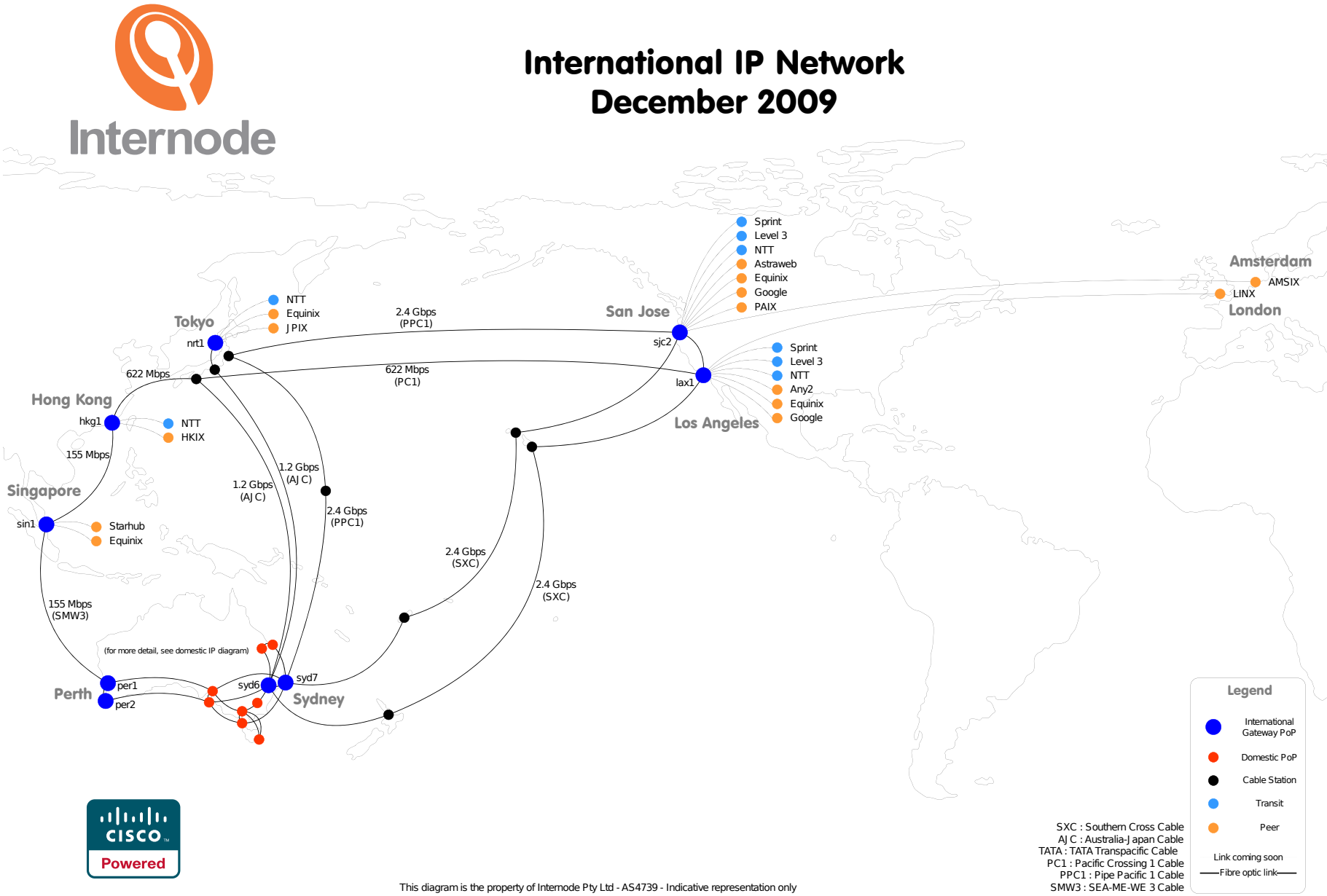
http://www.internode.on.net/pdf/network/internode-domestic-ip-network.pdf

ISPs: Internode: layer 1



http://www.internode.on.net/pdf/network/internode-sdh-network.pdf

ISPs: Internode: international



http://www.internode.on.net/pdf/network/internode-international-ip-network.pdf

ISPs: Level 3 (NA)

http://www.fiberco.org/images/Level3-Metro-Fiber-Map4.jpg

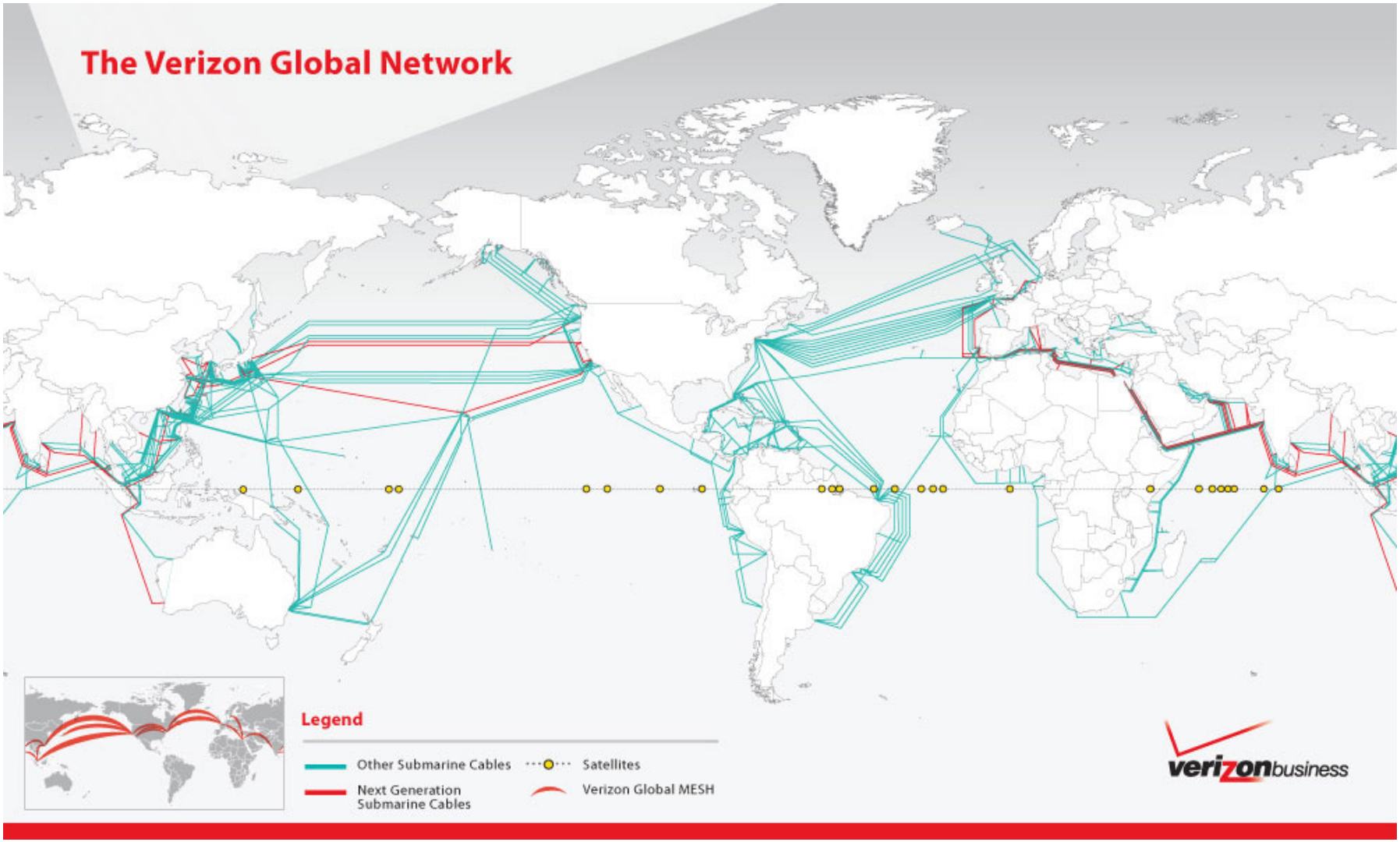
ISPs: Level 3 (Europe)

http://www.fiberco.org/international.html

ISPs: Williams

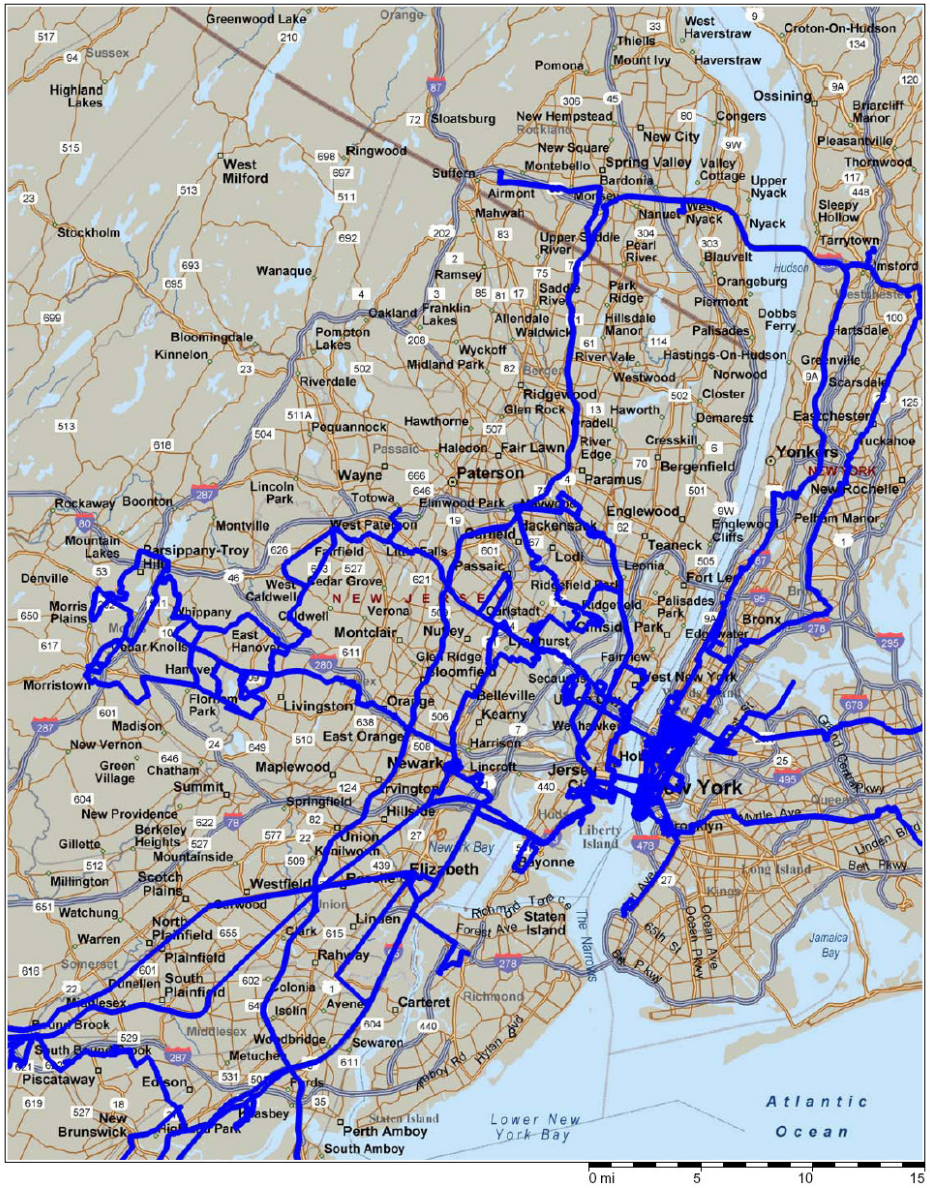
http://personalpages.manchester.ac.uk/staff/m.dodge/cybergeography/atlas/williamscommunications_large.gif

ISPs: Verizon/uunet (global)



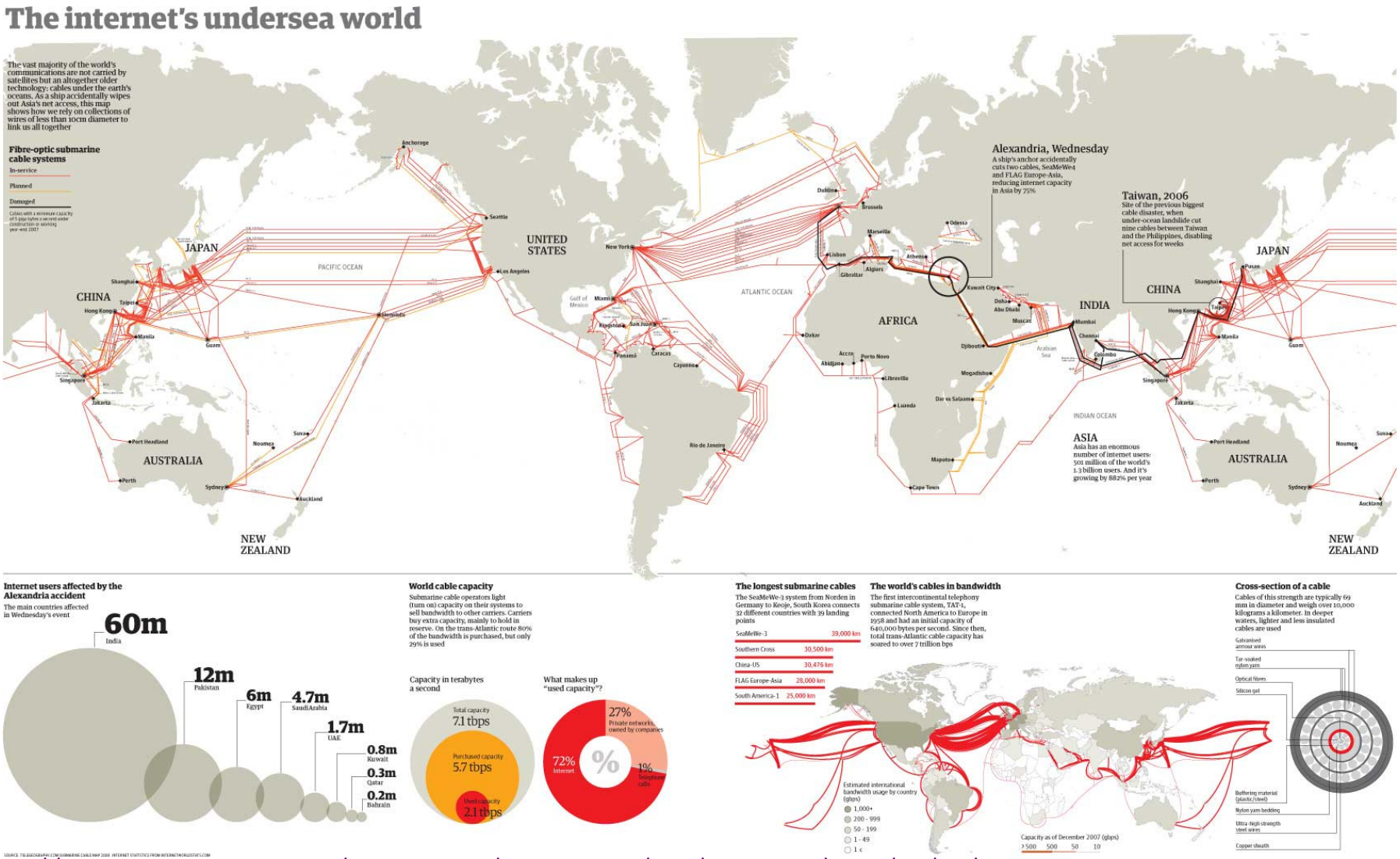
http://www.verizonbusiness.com/ca/about/network/

AboveNet Fibre (NJ, USA)



http://above.net/maps/maplist.php

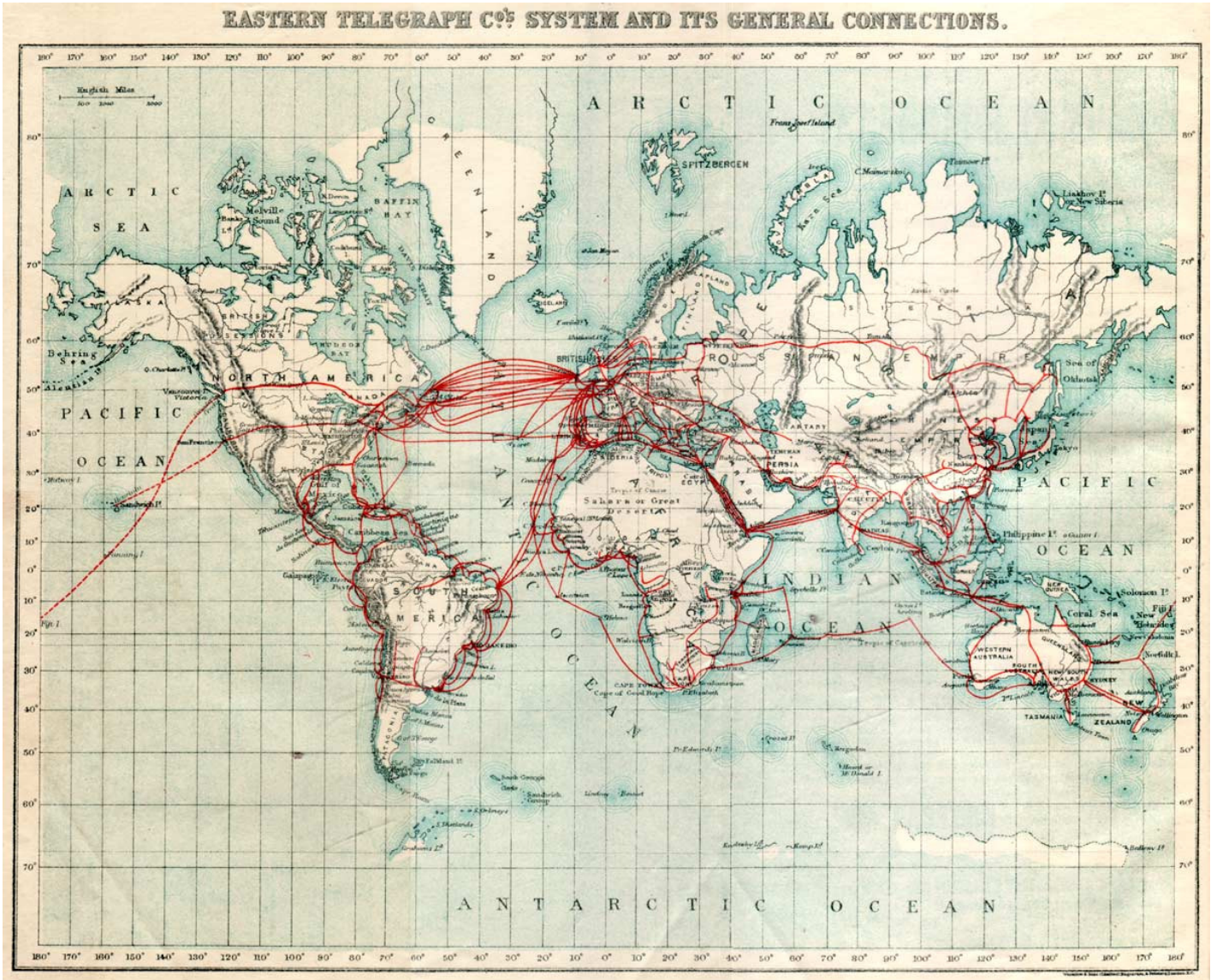
Submarine cables



http://image.guardian.co.uk/sys-images/Technology/Pix/pictures/2008/02/01/SeaCableHi.jpg

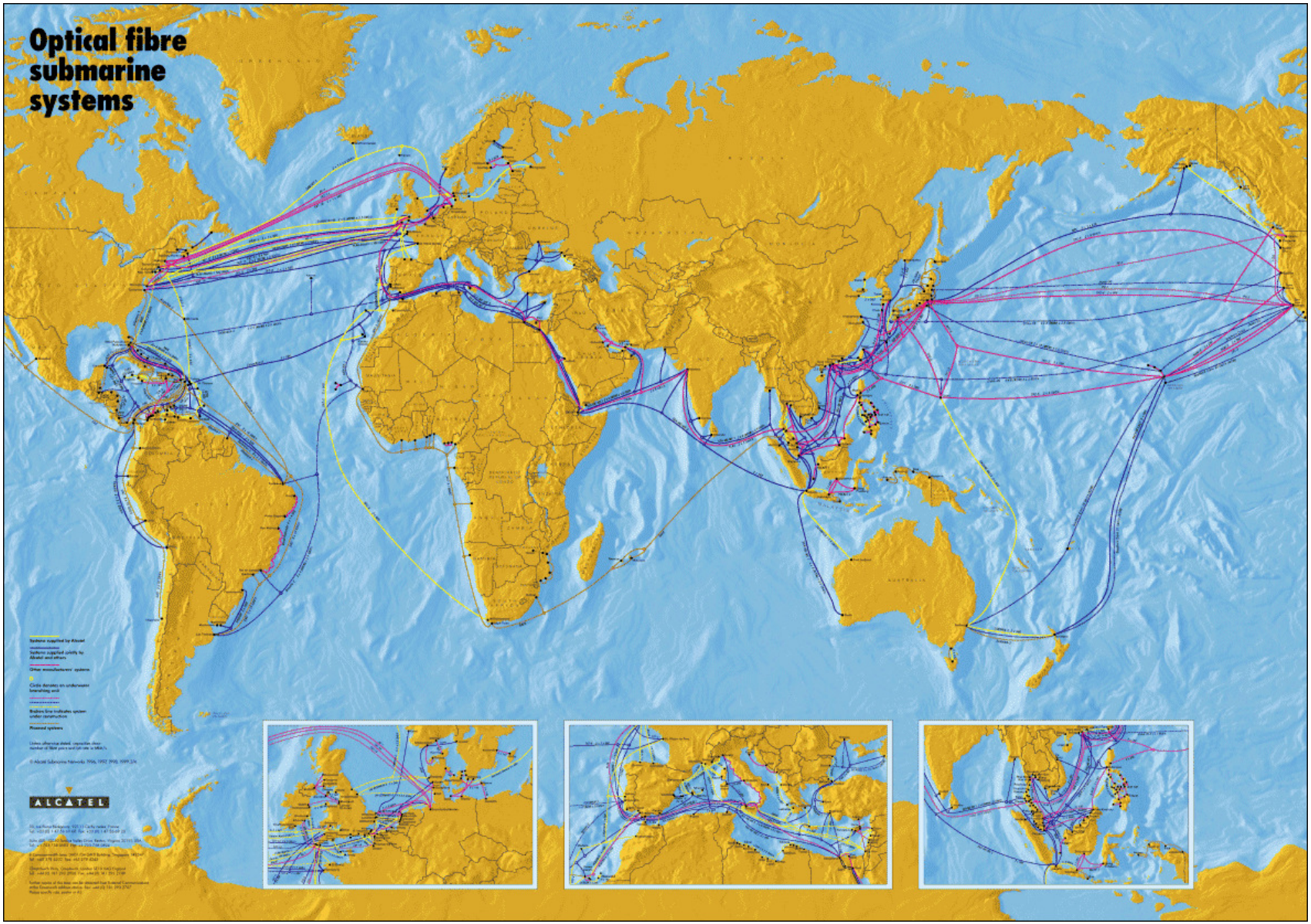
http://www.telegeography.com/product-info/map_cable/index.php

Telegraph submarine cables



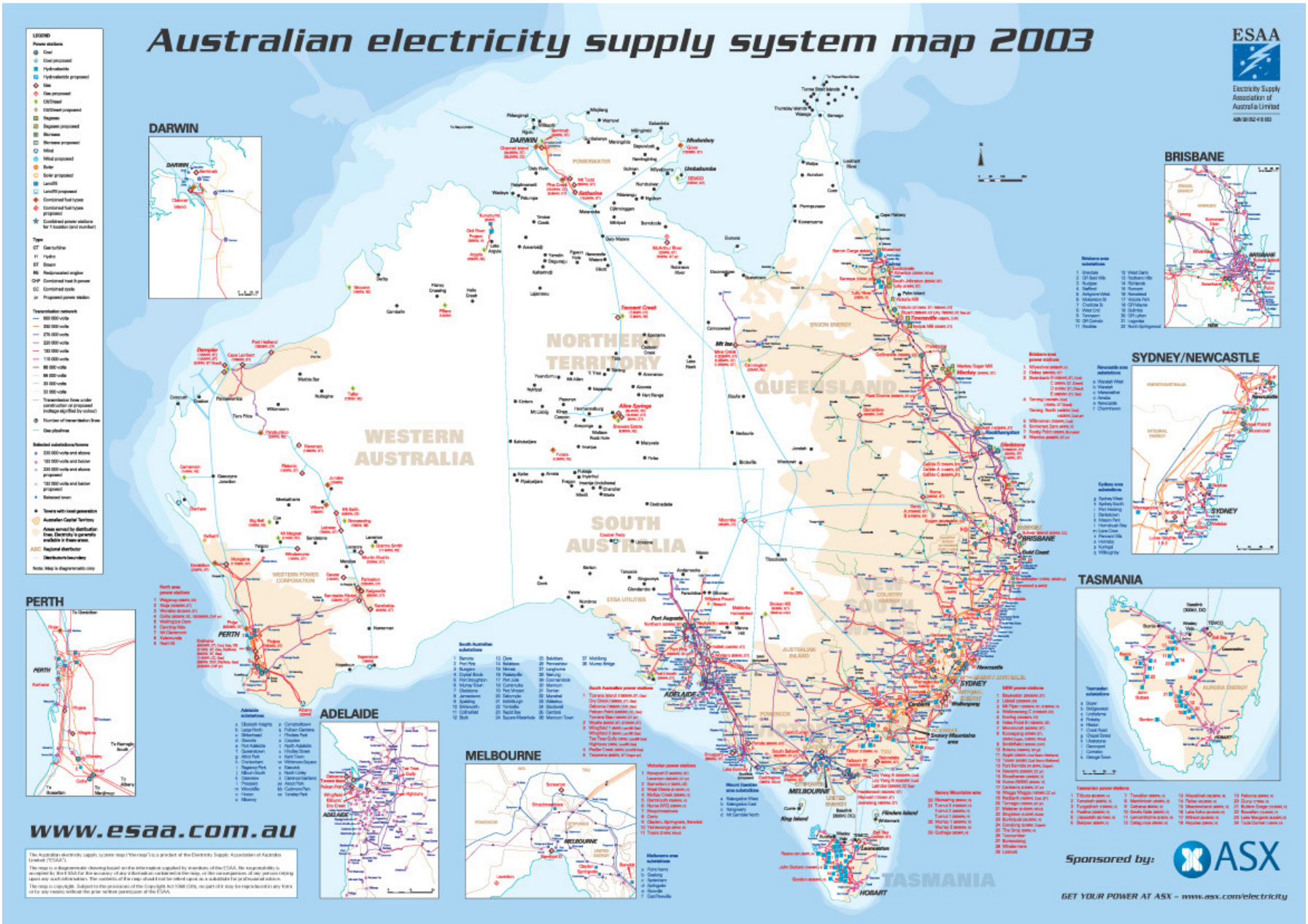
http://en.wikipedia.org/wiki/File:1901_Eastern_Telegraph_cables.png

Alcatel

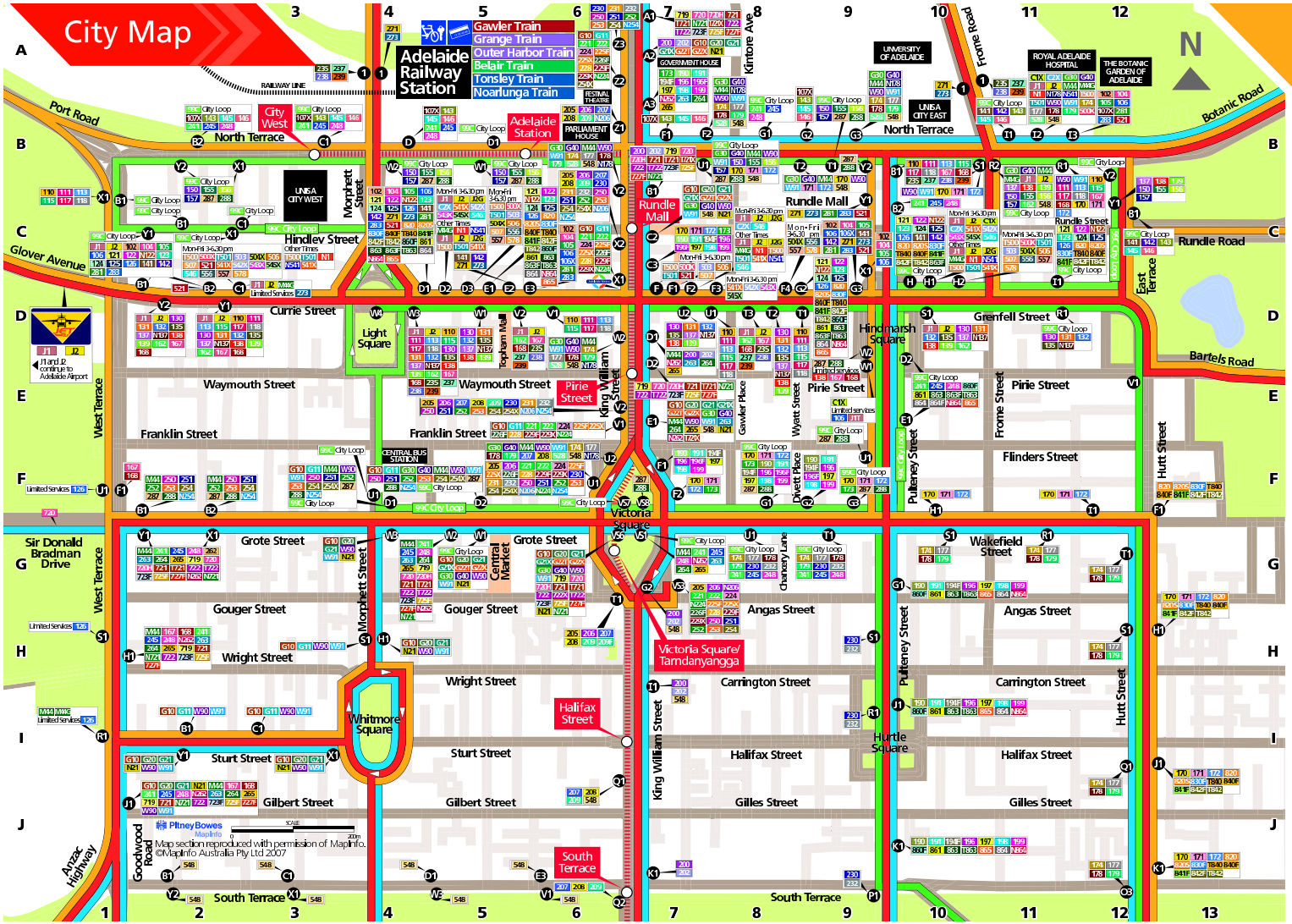


http://personalpages.manchester.ac.uk/staff/m.dodge/cybergeography/atlas/alcatel_large.gif

Electricity grid



Bus network (Adelaide CBD)



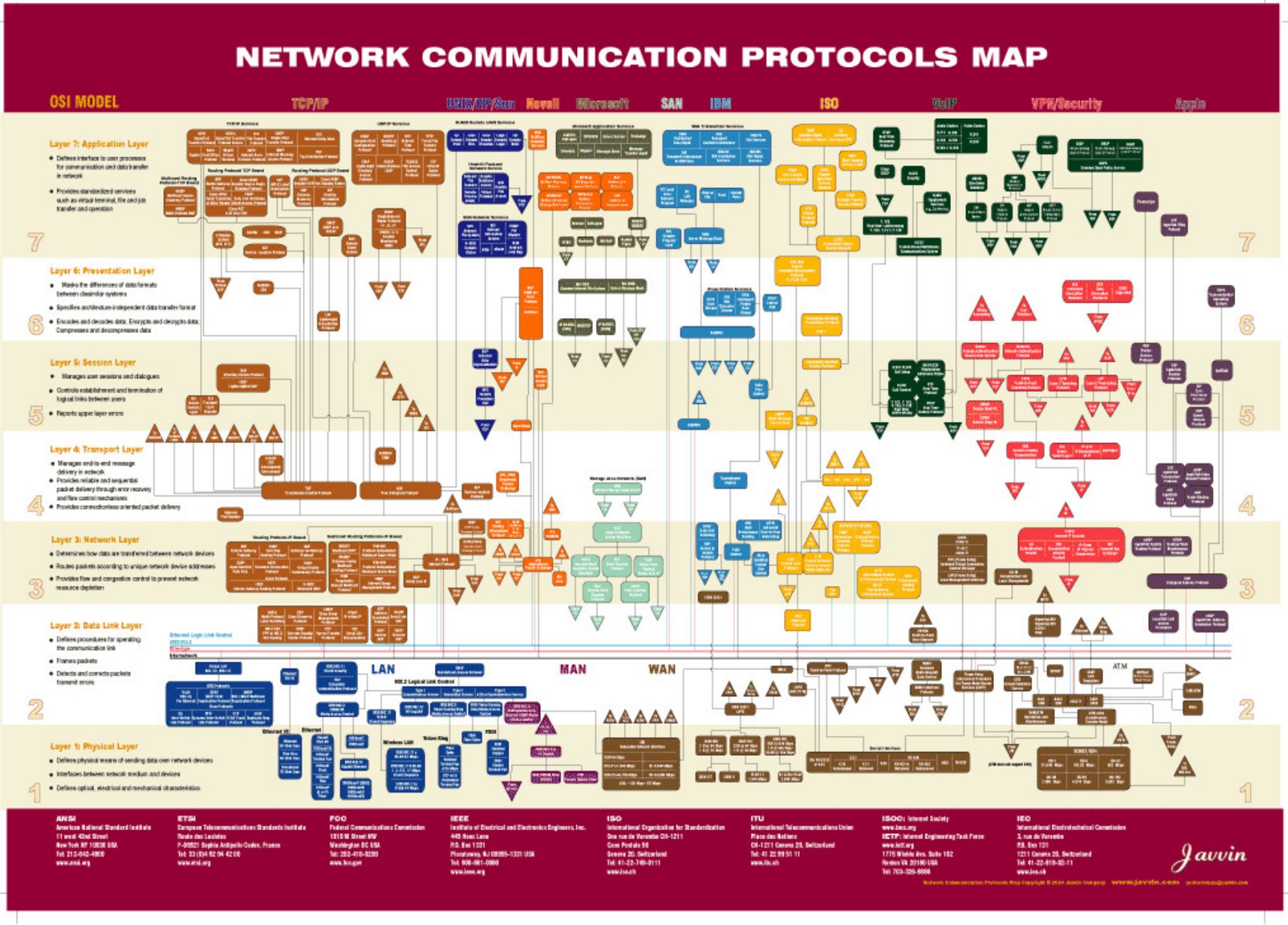
French Rail

http://www.alleuroperail.com/europe-map-railways.htm

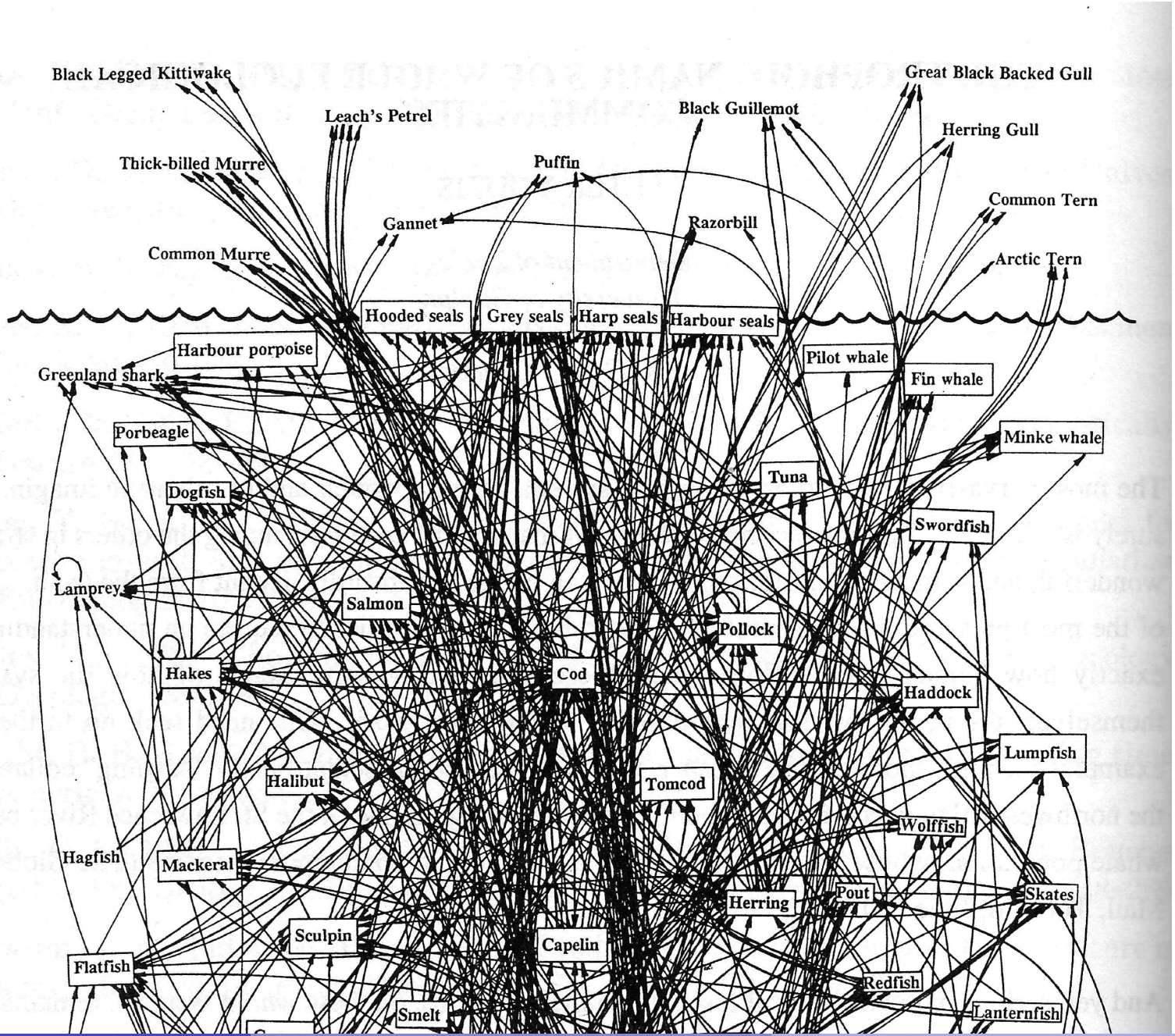
UK Rail

http://www.alleuroperail.com/europe-map-railways.htm

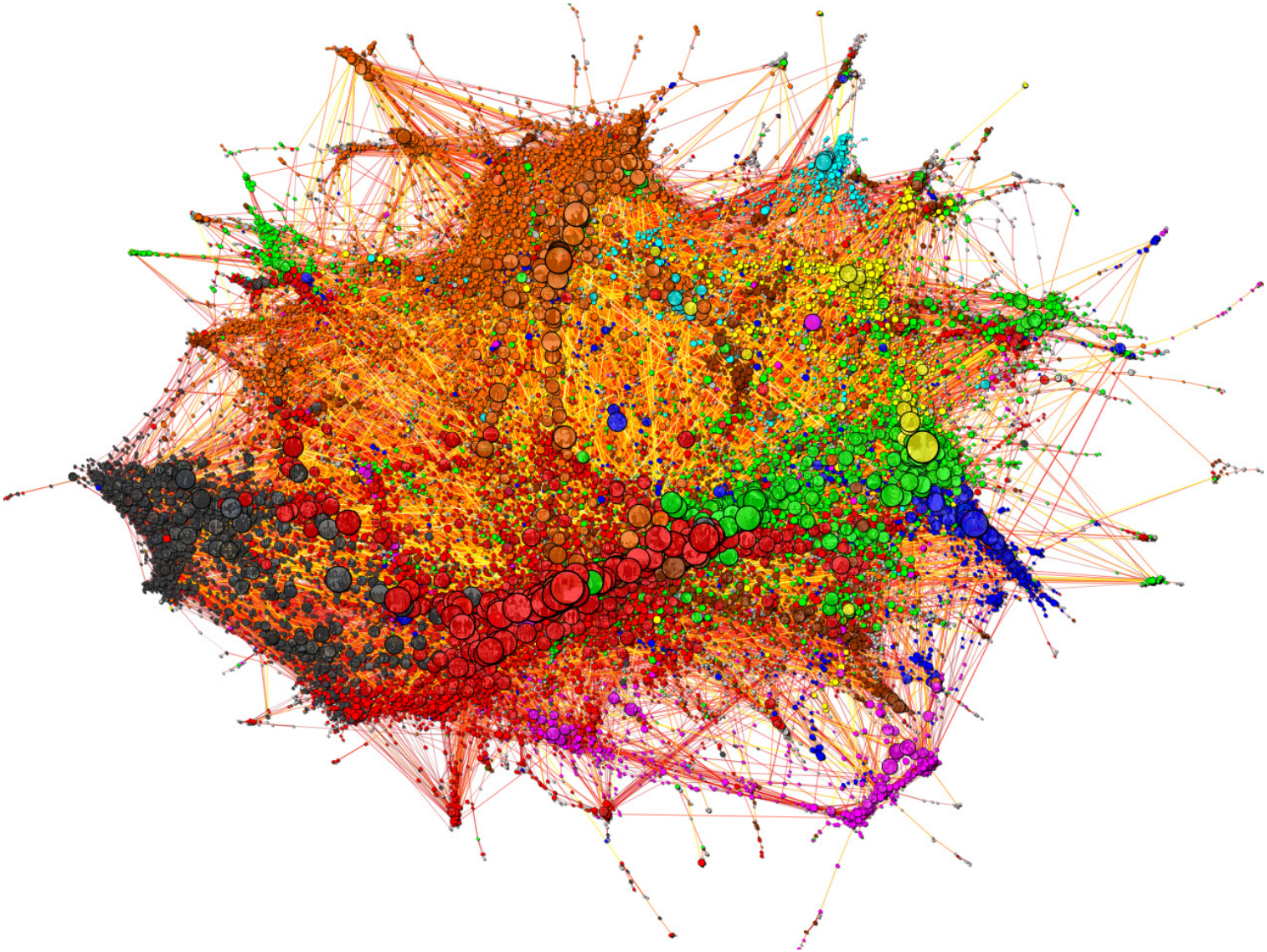
Protocol relationships



Food web?

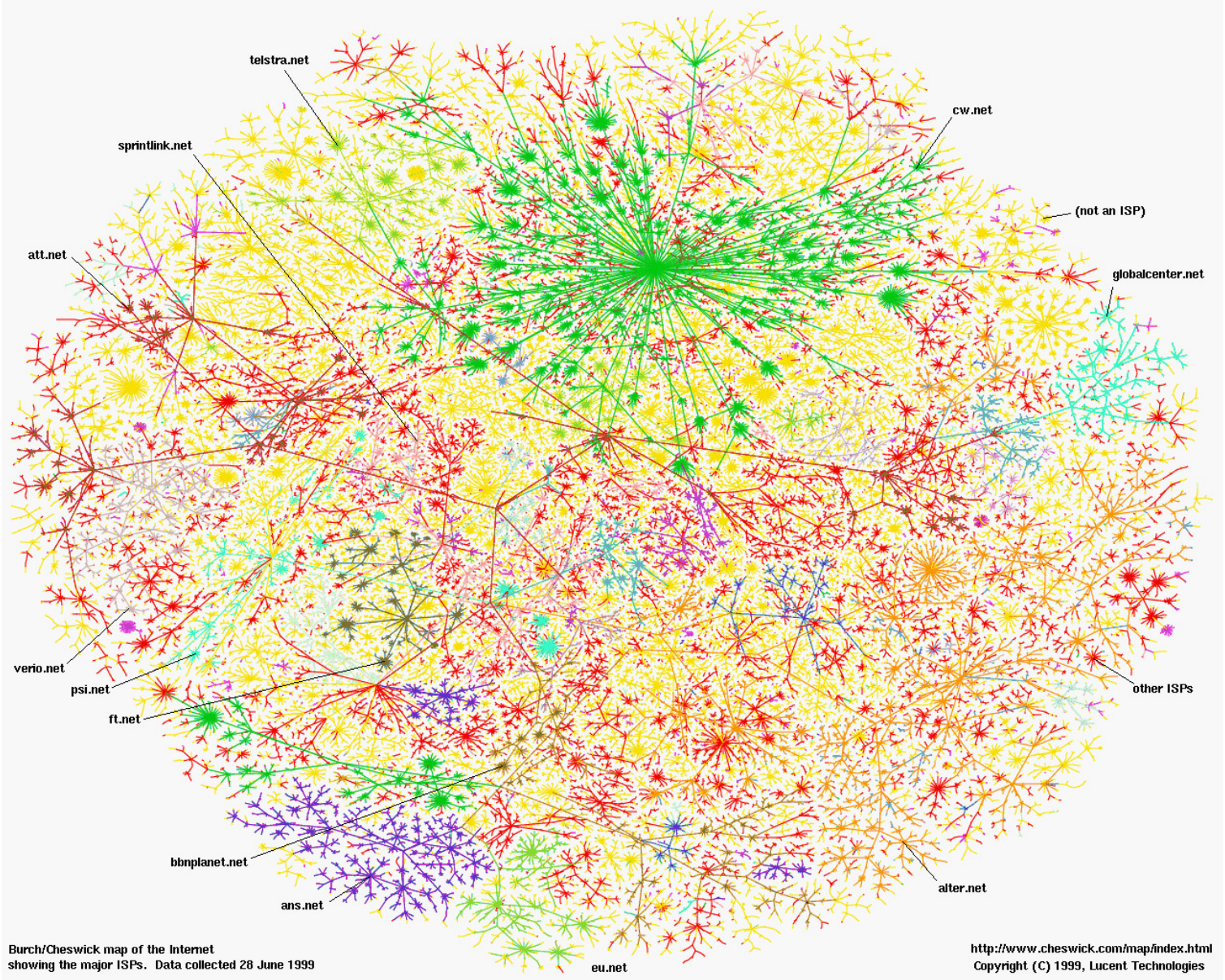

Black Legged Kittiwake
Leach's Petrel
Thick-billed Murre
Puffin
Black Guillemot
Great Black Backed Gull
Herring Gull
Common Tern
Gannet
Razorbill
Common Murre
Arctic Tern
Hooded seals
Grey seals
Harp seals
Harbour seals
Harbour porpoise
Greenland shark
Pilot whale
Fin whale
Porbeagle
Minke whale
Dogfish
Tuna
Swordfish
Lamprey
Salmon
Pollock
Hakes
Cod
Haddock
Lumpfish
Halibut
Tomcod
Wolffish
Hagfish
Mackeral
Herring
Pout
Skates
Sculpin
Capelin
Flatfish
Redfish
Smelt
Lanternfish

Network of Musicians (last.fm)



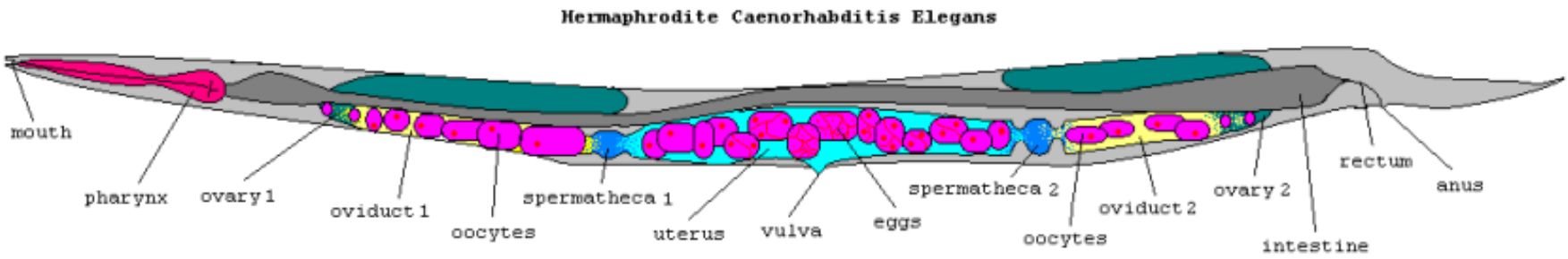
http://sixdegrees.hu/last.fm/

Internet Mapping Project (c1999)



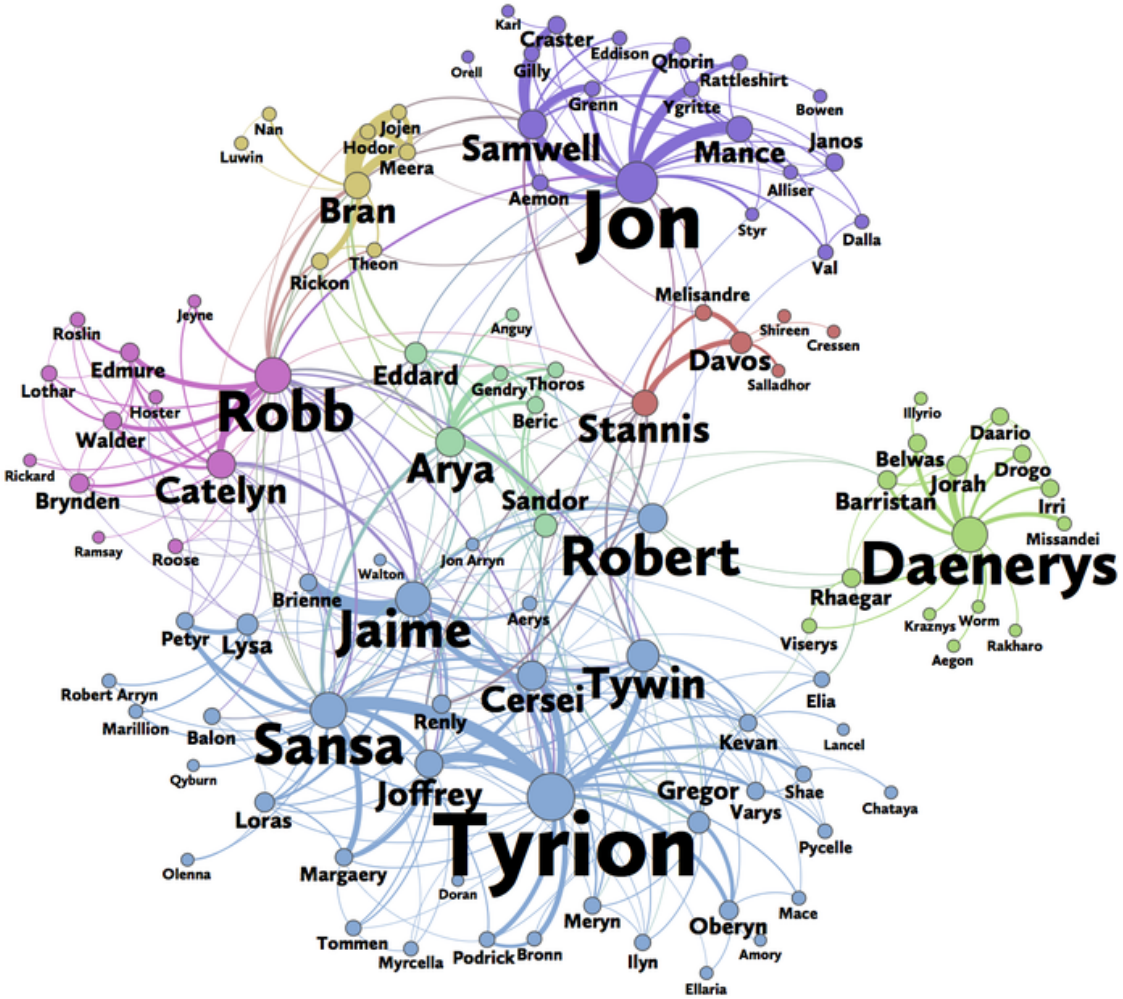
http://www.cheswick.com/ches/map/

Caenorhabditis elegans



- *C. elegans* [SH77, SSWT83] is a small (∼1mm) soil nematode (worm)
- its very simple (only 959 somatic cells)
- its neural network was mapped in the 70's and 80's [AT76, WSNB86]
  - 302 neurons
  - database available
    `http://ims.dse.ibaraki.ac.jp/ccep/`

Network of Thrones



http://www.npr.org/2016/04/16/474396452/how-math-determines-the-game-of-thrones-protagonist

Others

- More of the Internet at www.topology-zoo.org
- Road networks [PO72, p.7]
  - As with Internet we can also look at traffic
- Collaboration Networks: http://www.oakland.edu/enp/

  http://snap.stanford.edu/data/
- Social networks: http://www-personal.umich.edu/~mejn/netdata/

  http://vlado.fmf.uni-lj.si/pub/networks/data/UciNet/UciData.htm

  http://www-2.cs.cmu.edu/~enron/

  http://deim.urv.cat/~aarenas/data/welcome.htm

  http://snap.stanford.edu/data/
- Film networks: http://www.imdb.com/

  http://oracleofbacon.org//

Some random points to think about

- by the time they are interesting, they are too complicated to draw a good picture
- physical networks appear embedded in geography – are virtual networks embedded in some space as well?
- numbers of edges are variable, but often higher in virtual graphs, but is connectivity higher?
- often hard to consider one network in isolation
  - other similar connecting networks
  - competing networks
  - overlays and underlays

Network Science has been about looking for universality in network models, but I am more interested in finding useful models.

Further reading I


D. G. Albertson and J. N. Thomson, *The pharynx of caenorhabditis elegans*, Phil. Trans. R. Soc. London B **275** (1976), 299–325.


Renfrey B. Potts and Robert M. Oliver, *Flows in transportation networks*, Academic Press, 1972.


J. E. Sulston and H. R. Horvitz, *Post-embryonic cell lineages of the nematode Caenorhabditis elegans*, Developmental Biology **56** (1977), 110–156.


J. E. Sulston, E. Schierenberg, J. G. White, and J. N. Thomson, *The embryonic cell lineage of the nematode Caenorhabditis elegans*, Developmental Biology **100** (1983), 64–119.


J. G. White, E. Southgate, Thomson J. N., and S. Brenner, *The structure of the nervous system of the nematode Caenorhabditis elegans*, Phil. Trans. R. Soc. London B **314** (1986), 1–340.