Complex Dynamical Networks

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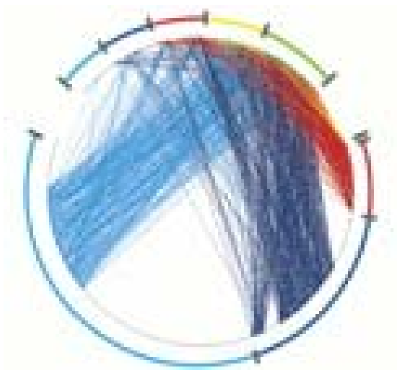
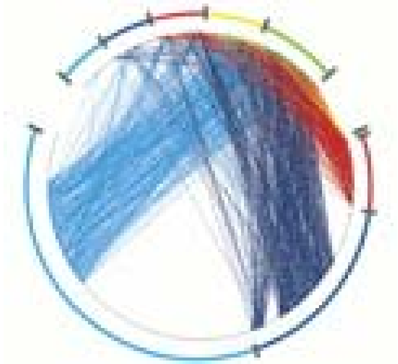


Lecture 1: Introduction



Course overview

- The course goal
  - To read some recent and interesting papers on information networks
  - Understand the underlying techniques
  - Think about interesting problems
- Prerequisites:
  - Mathematical background on discrete math, graph theory, probabilities, linear algebra
  - Programming skills, e.g. MatLab
- Style
  - Both slides and whiteboard

Evaluation

- Homeworks
  - About 6 series of homeworks (**Important!** no large delay is accepted; all reports should be hand-written)
  - **Extra points** for those actively participate in the exercise sessions
  - **40%** of the final grade (tentative)
- Quiz:
  - About 6 prearranged
  - **25%** of the final grade (tentative)
- Midterm written exam
  - **20%** of the final grade (tentative)
- Final written exam
  - **20%** of the final grade (tentative)
- (optional) Mini-projects and class participation (should be done by the end of the course)
  - **Extra points**

Topics

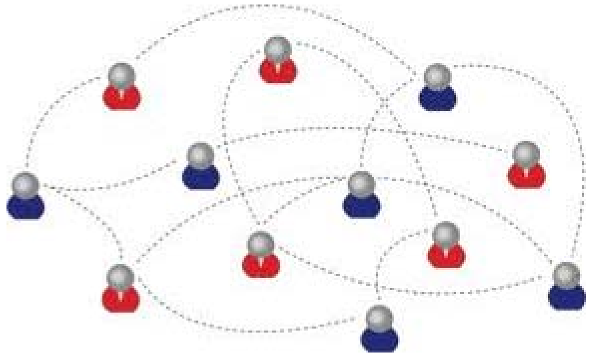
- Introduction on “why modeling networks?”
- Measuring Real Networks
- Models for networks
- ...

Topics

- What is a network?
- Many examples ...
- Many questions ...

What is a network?

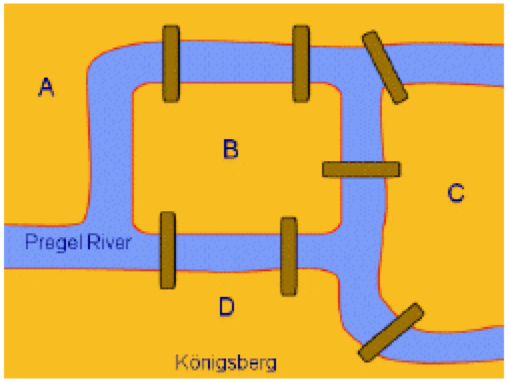
1. A collection of **nodes (vertices)**
2. A collection of **edges (links) connecting nodes**

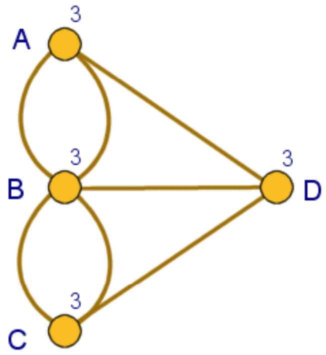


- A network model treats all nodes and links the same
- In a picture of a network, the spatial location of nodes is arbitrary
- Networks are abstractions of connection and relation
- Networks have been used to model a vast array of phenomena

Graphs

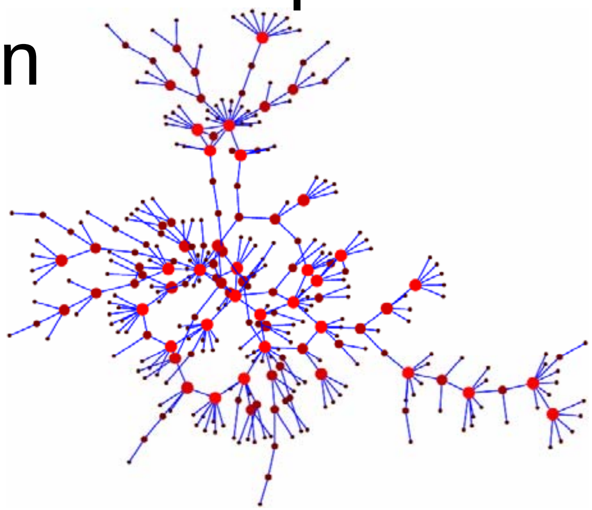
- In mathematics, networks are called graphs, the entities are nodes, and the links are edges
- Graph theory starts in the 18th century, with Leonhard Euler
  - The problem of Königsberg bridges
  - Since then graphs have been studied extensively.





Networks in the past

- Graphs have been used in the past to model existing networks (e.g., networks of highways, social networks)
  - usually these networks were small
  - network can be studied and visual inspection can reveal a lot of information



Networks now

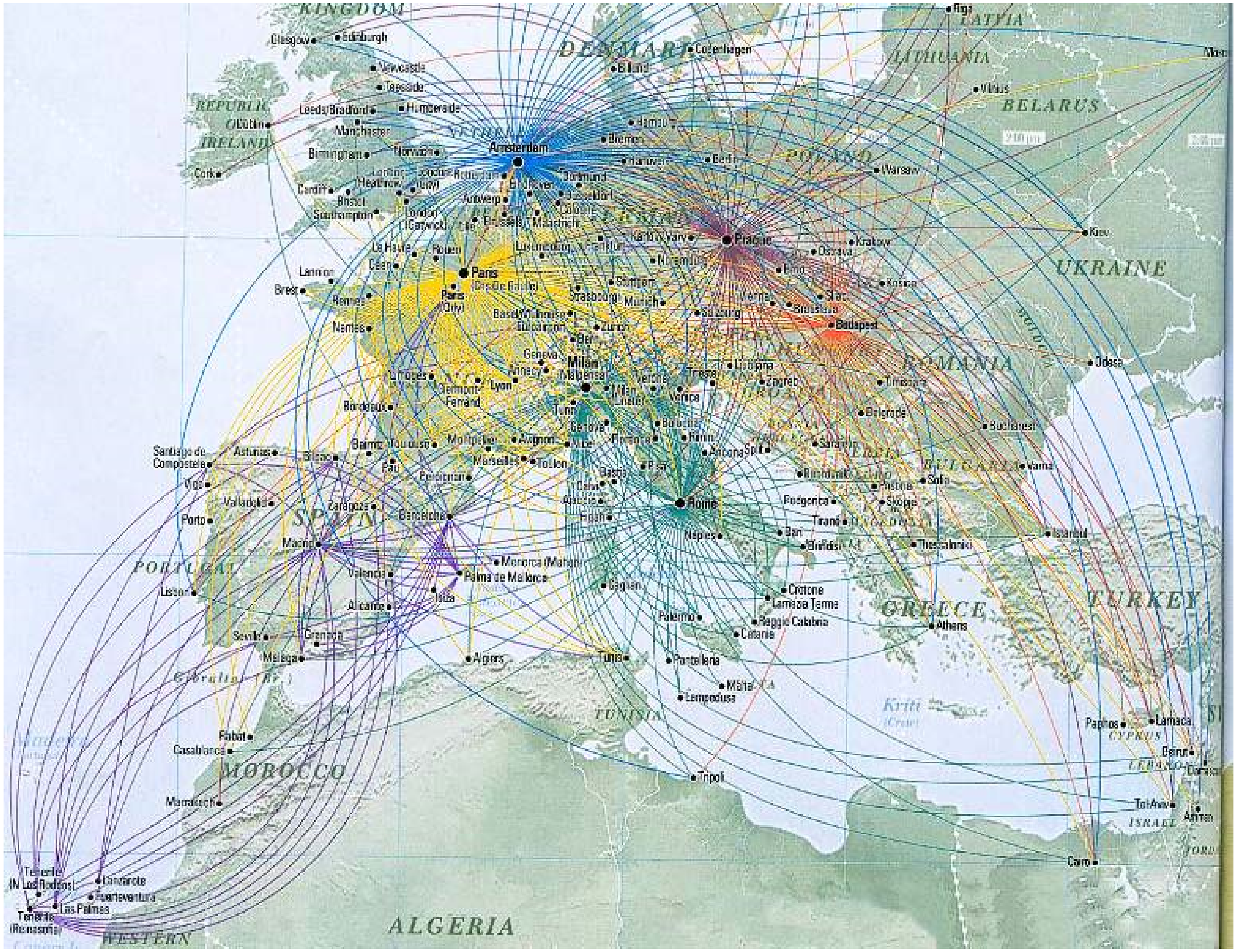
- More and larger networks appear
  - Products of technological advancement
    - e.g., Internet, Web
  - Result of our ability to collect more, better, and more complex data
    - e.g., gene regulatory networks
- Networks of thousands, millions, or billions of nodes
  - impossible to visualize

Many examples of networks

- The internet map
- Airlines networks
- Brain networks
- Protein-protein interaction
- Gene regulatory
- Social networks
- and .....

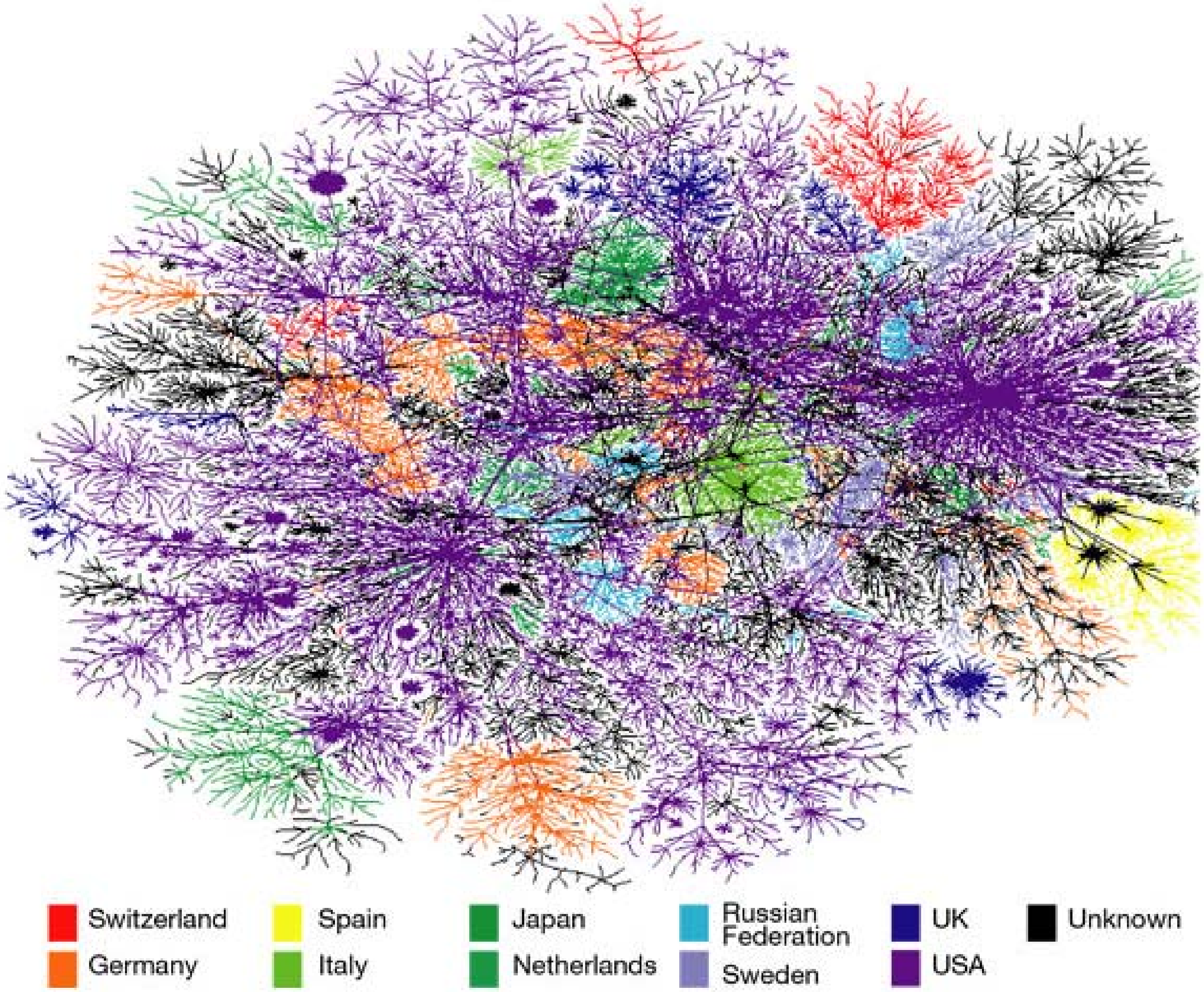
Technological

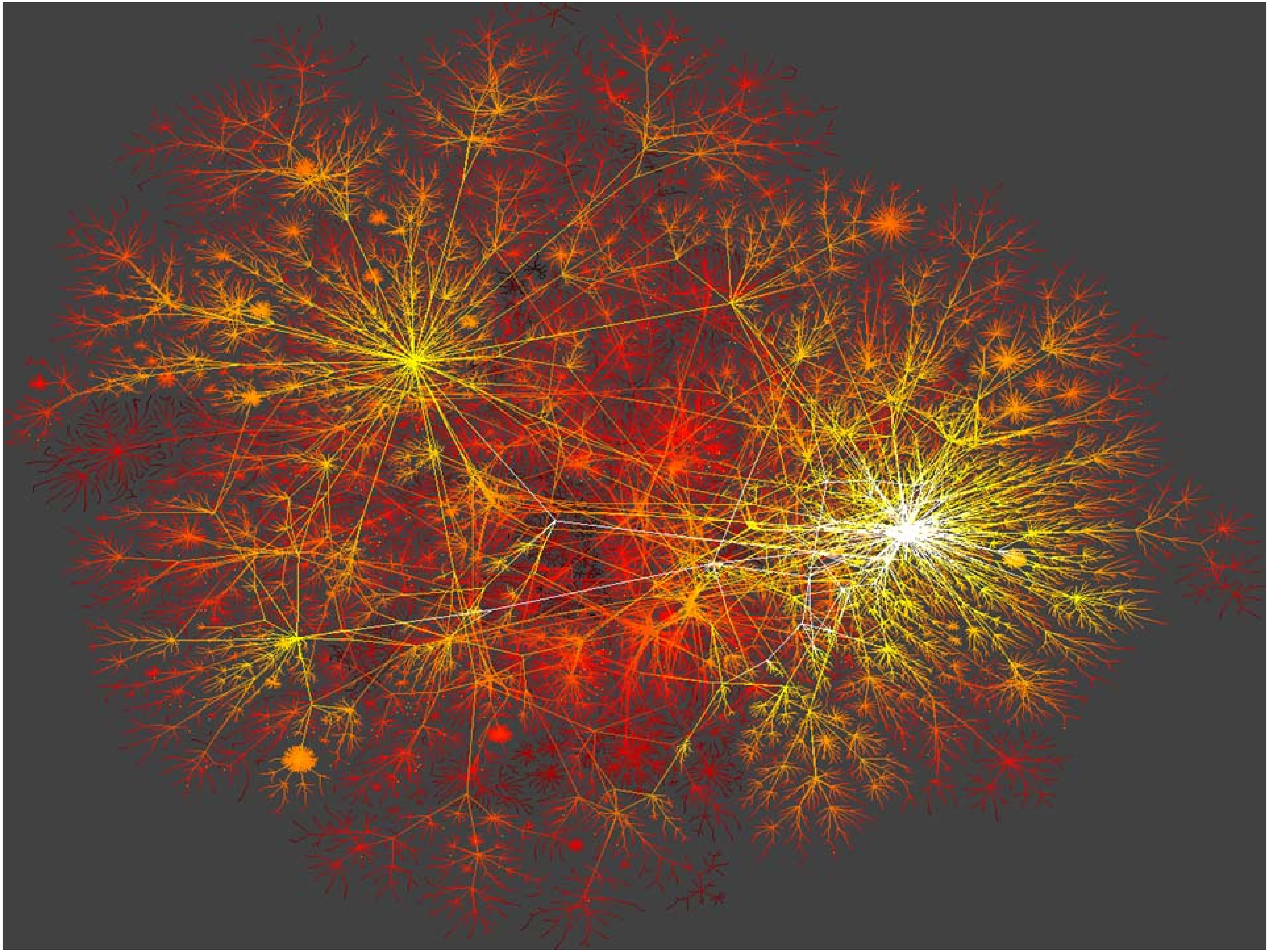
The airline networks



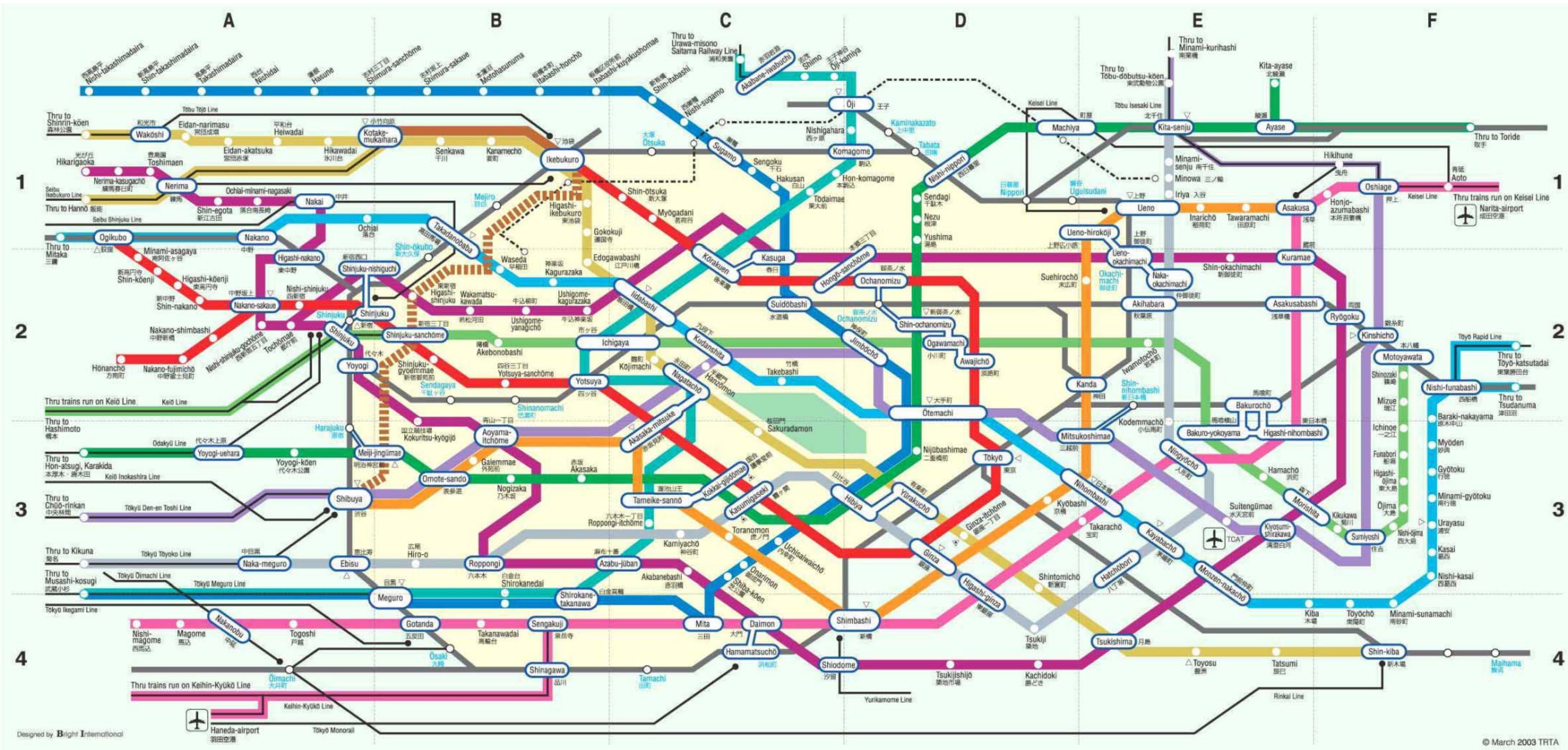
Source: Northwest Airlines WorldTraveler Magazine

The internet map





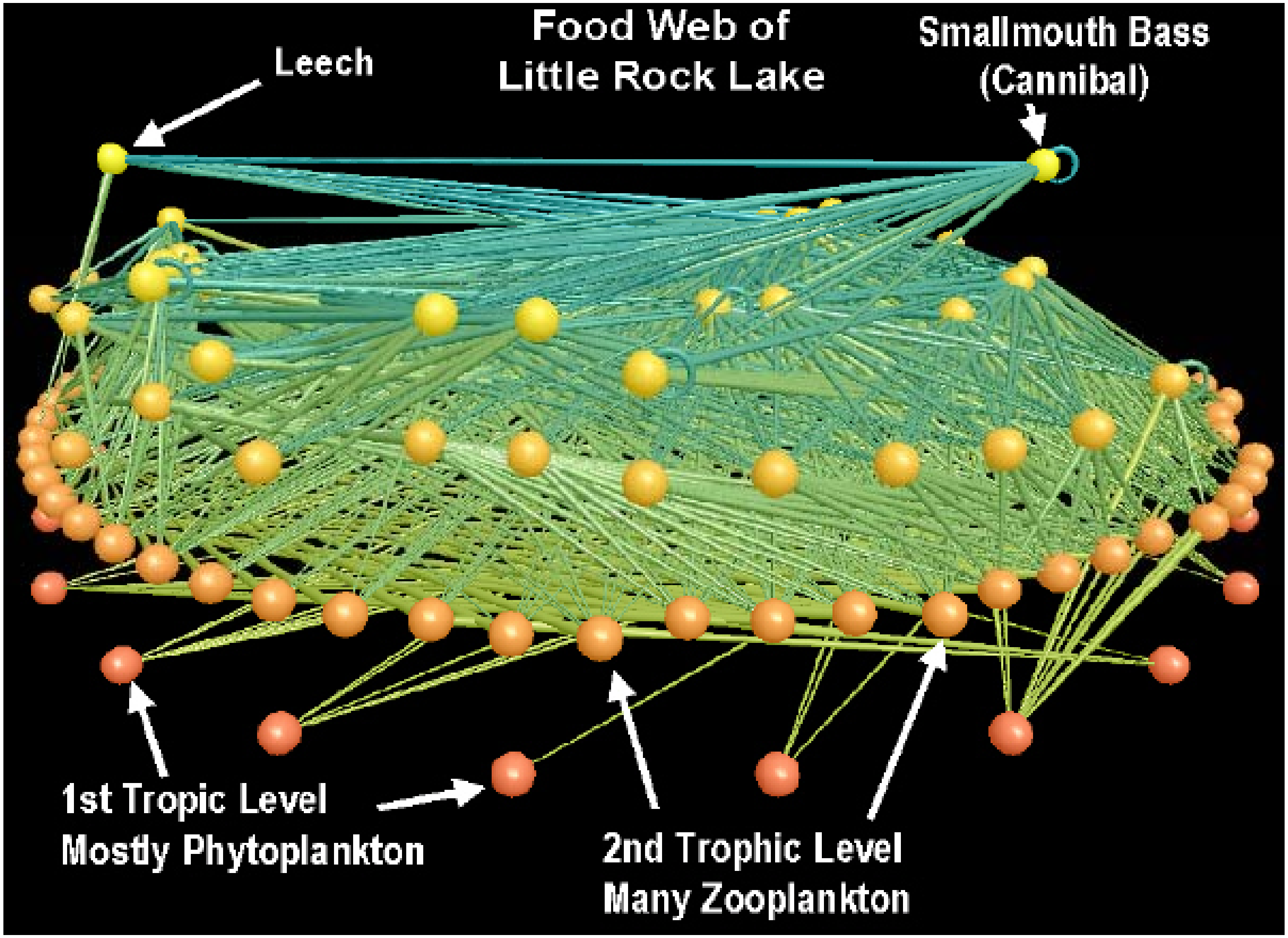
Railway networks



Source: TRTA, March 2003 - Tokyo rail map

Ecology

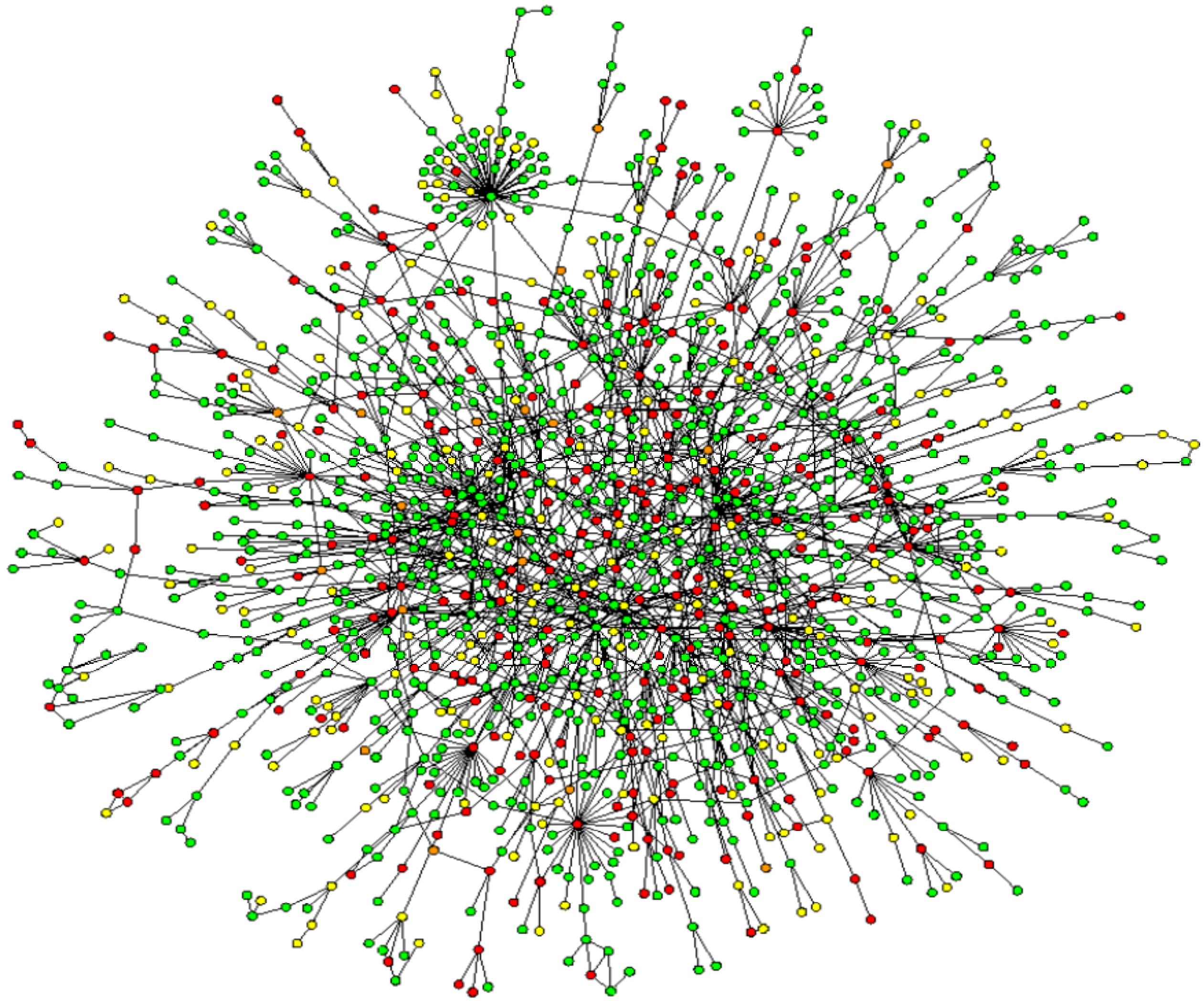
Food webs



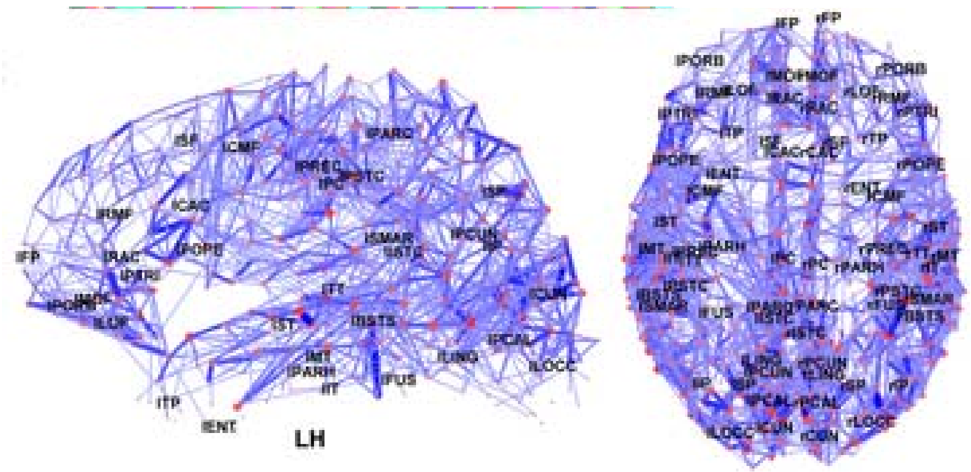
Leech
Food Web of
Little Rock Lake
Smallmouth Bass
(Cannibal)
1st Tropic Level
Mostly Phytoplankton
2nd Trophic Level
Many Zooplankton

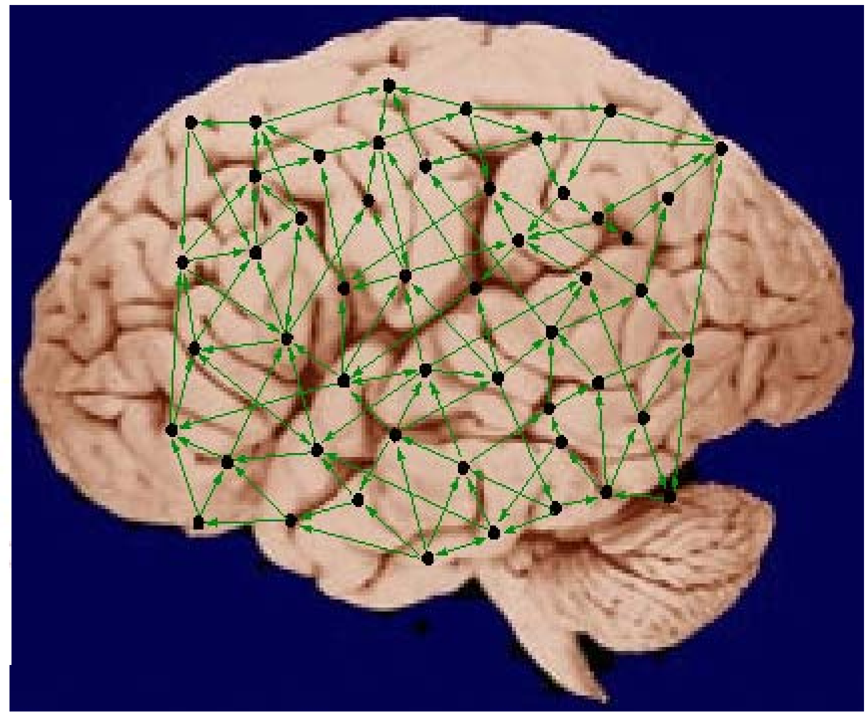
Biological

Protein-protein interaction



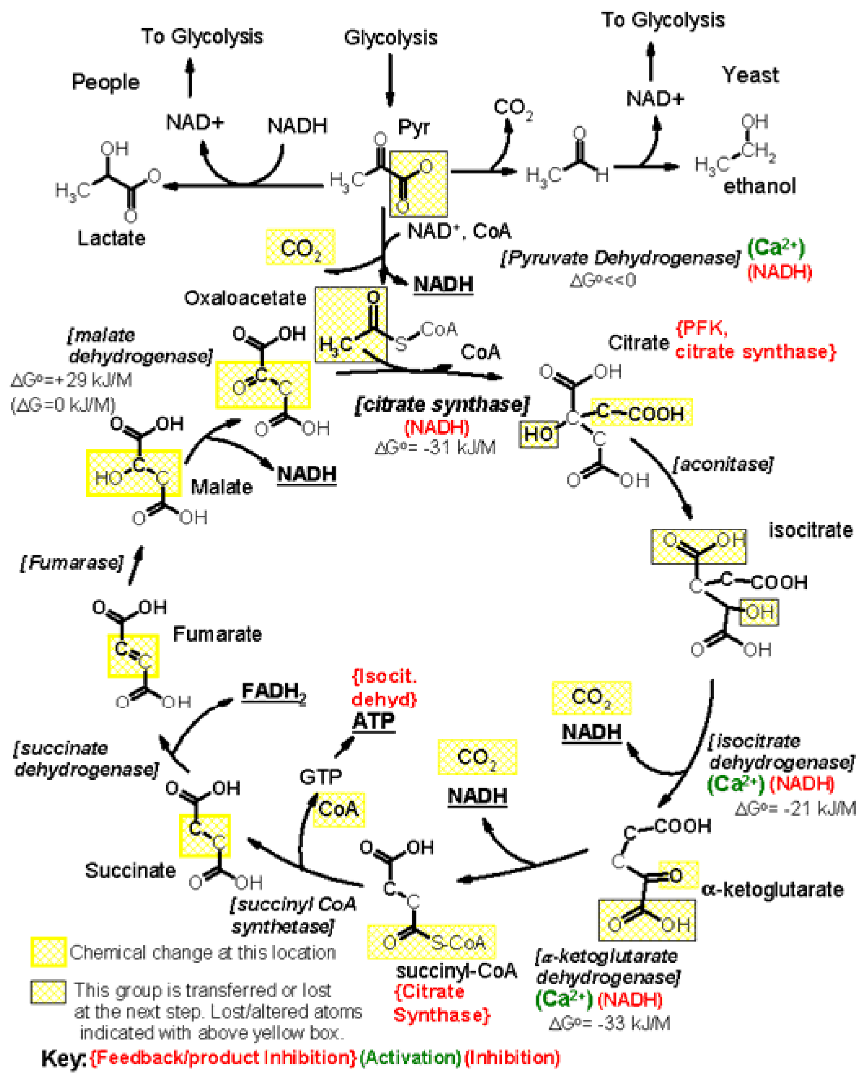
Brain networks





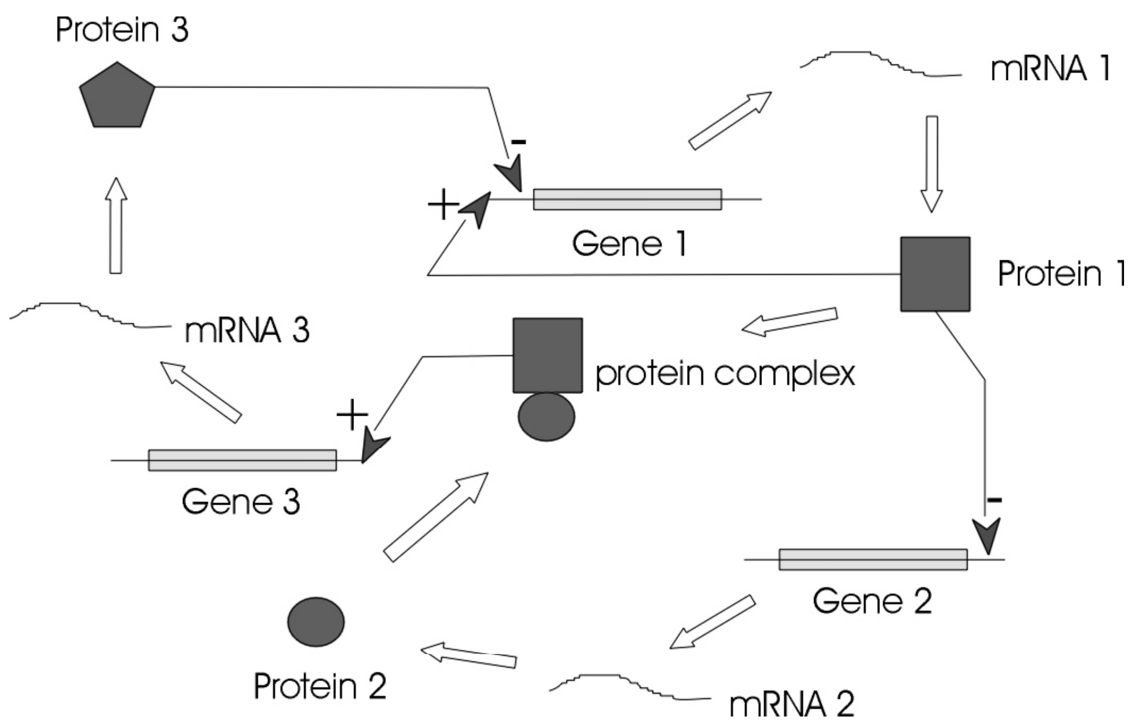
Metabolic networks

- Citric acid cycle
- Metabolites participate in chemical reactions



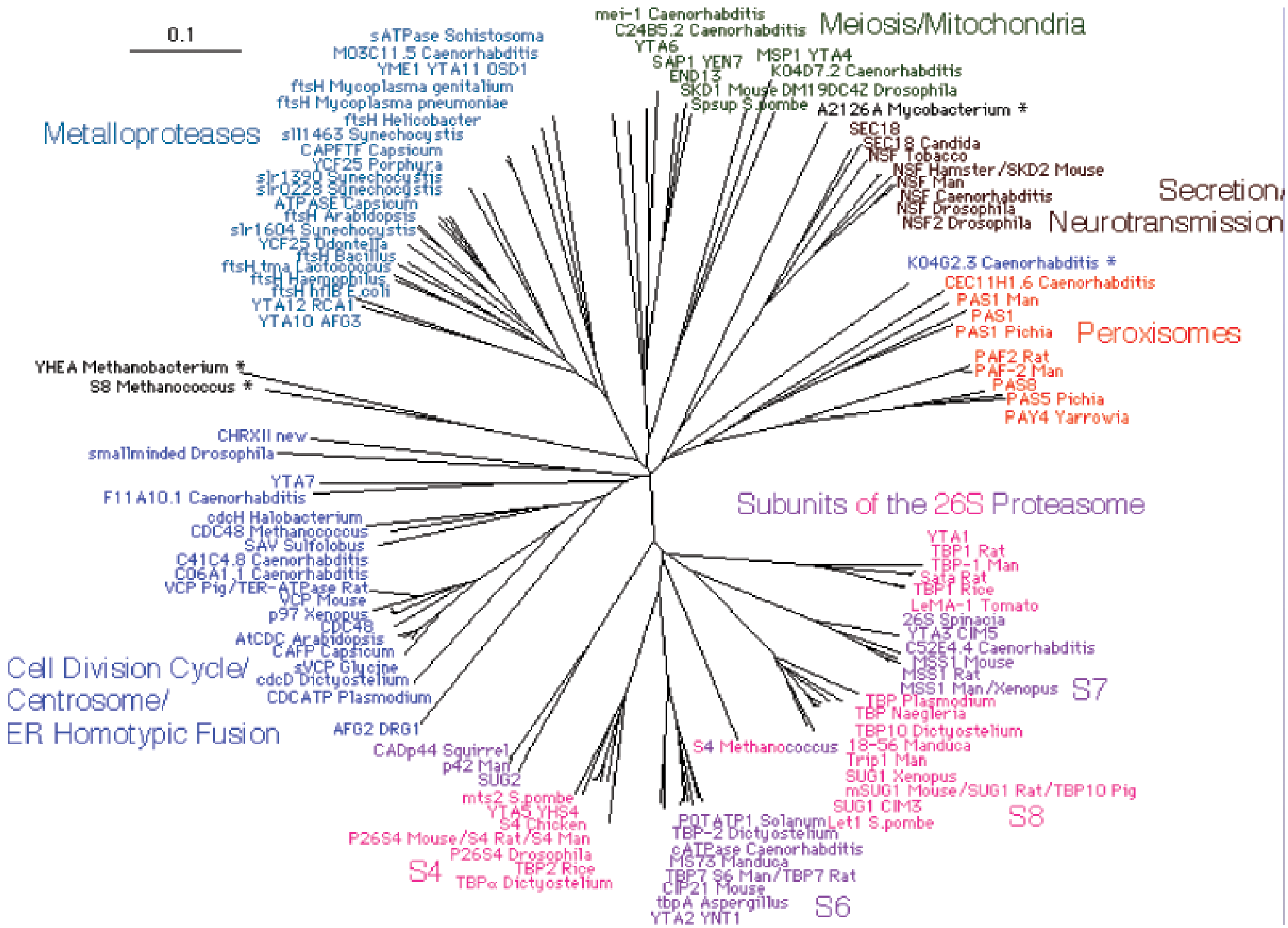
Gene regulatory network

- humans have only 30,000 genes, 98% shared with chimps
- the complexity is in the interaction of genes
- can we predict what result of the inhibition of one gene will be?

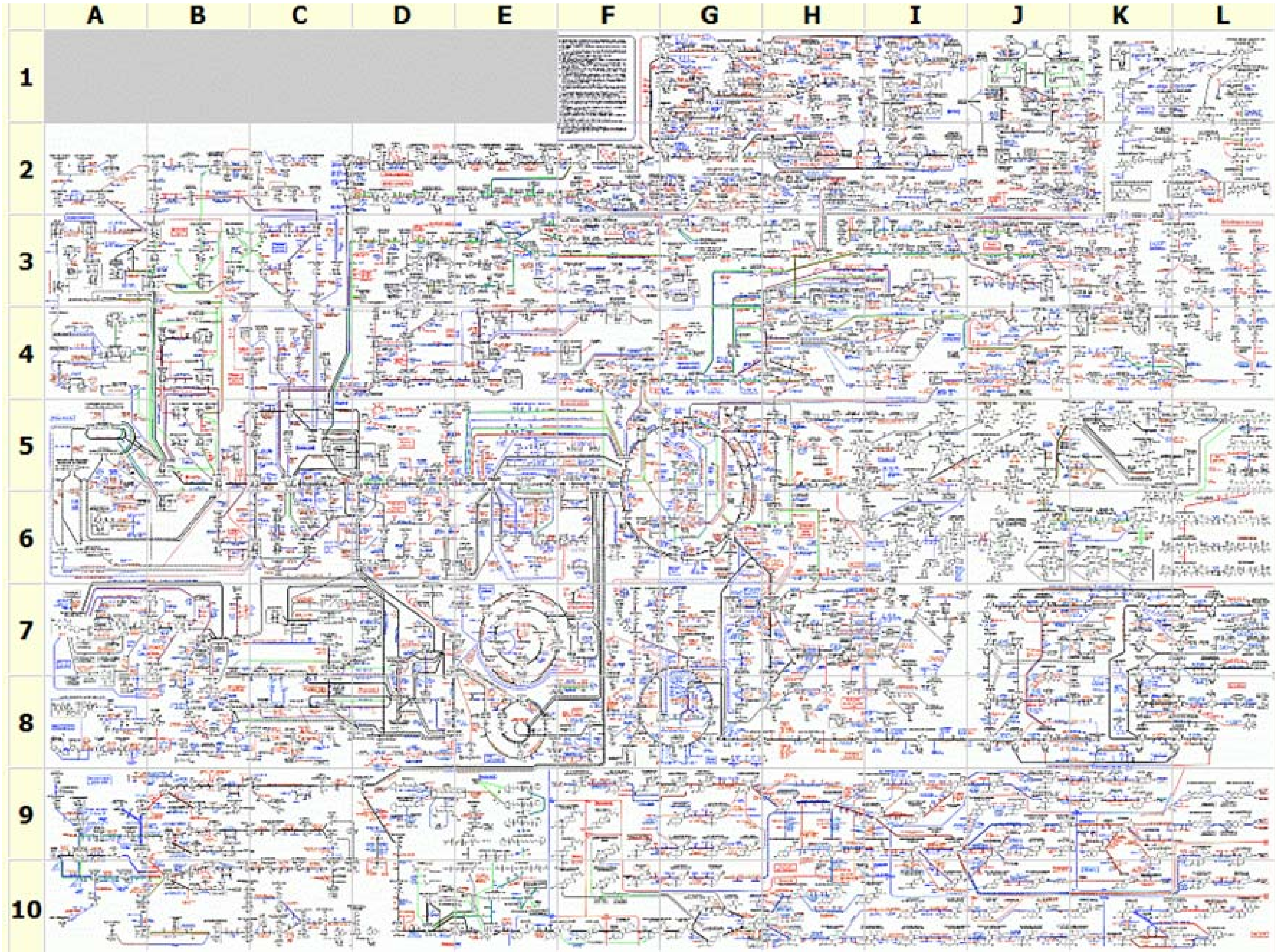


Source: http://www.zaik.uni-koeln.de/bioinformatik/regulatorynets.html.en

Phylogenetic trees

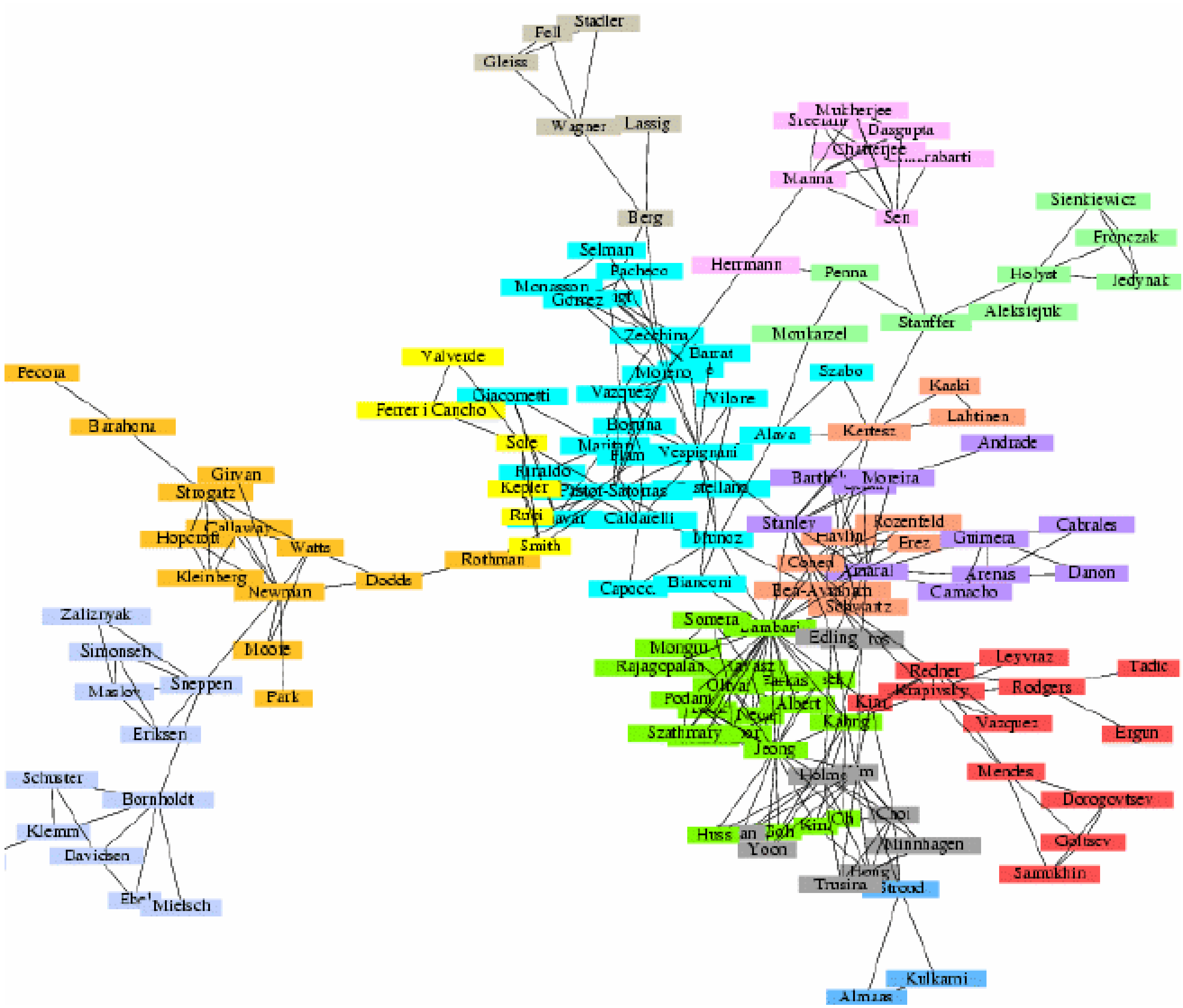


Metabolic pathways



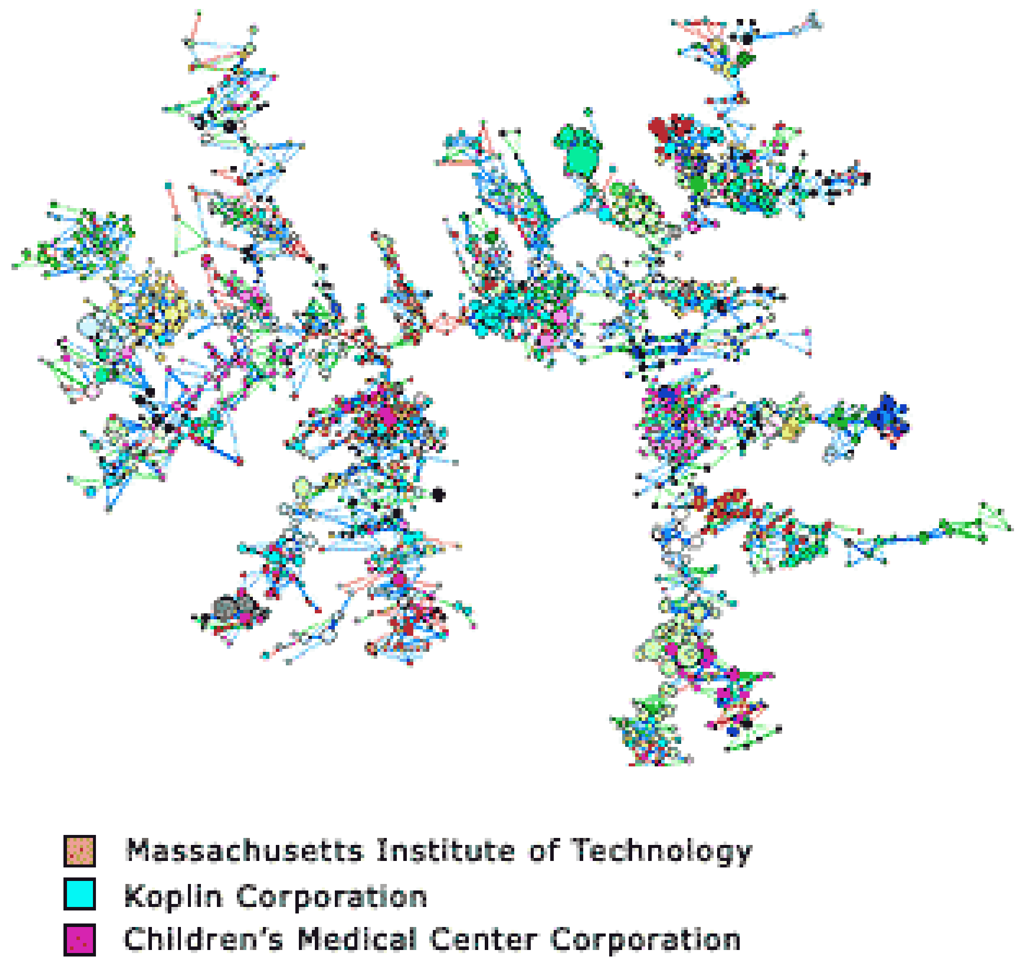
Social

Coauthorship network

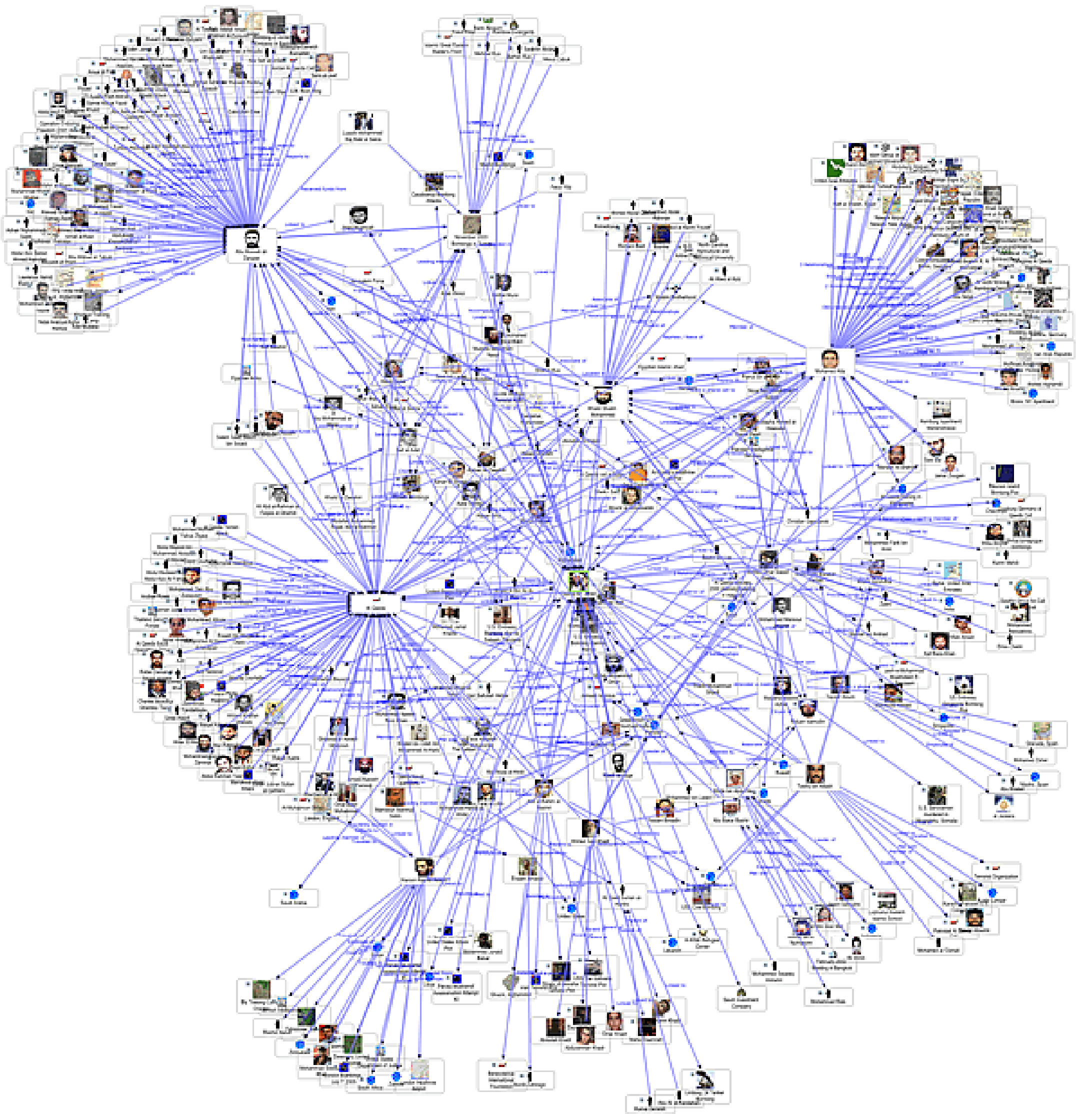


Another scientific networks

The largest connected component of patented Boston inventors in the mid-1990s. Each of the nodes illustrates an inventor. The colour corresponds to the inventor's organization and the size of the node corresponds to the importance of the inventions. A tie corresponds to co-authorship of a patent. Red ties are old, blue ties are recent, and green ties are most recent. The close-up illustrates the centrality of MIT in the Boston networks.

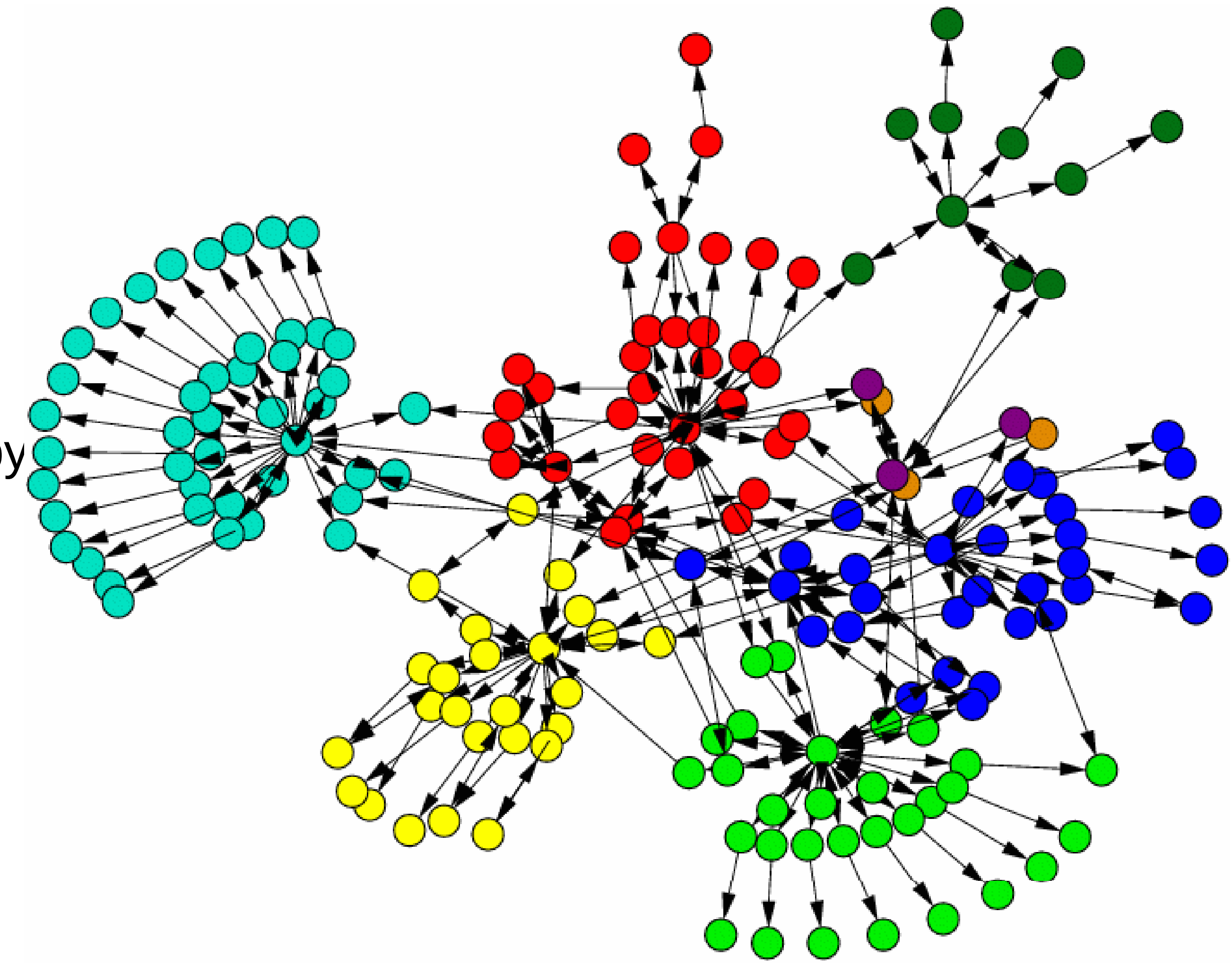


Social networks



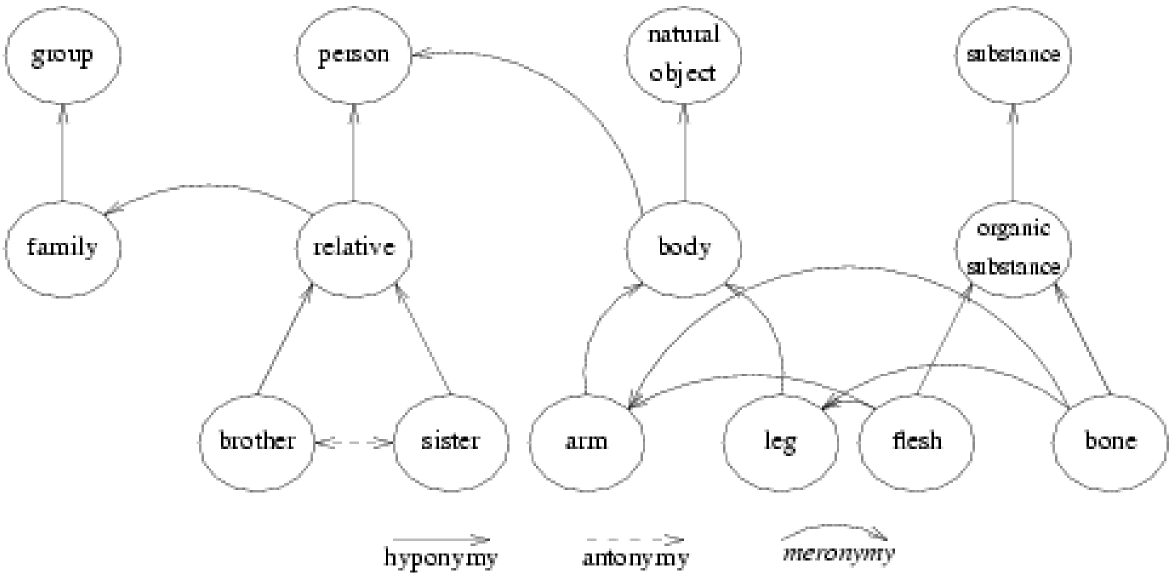
Webgages

Webpages connected by hyperlinks on the AT&T website circa 1996



Others

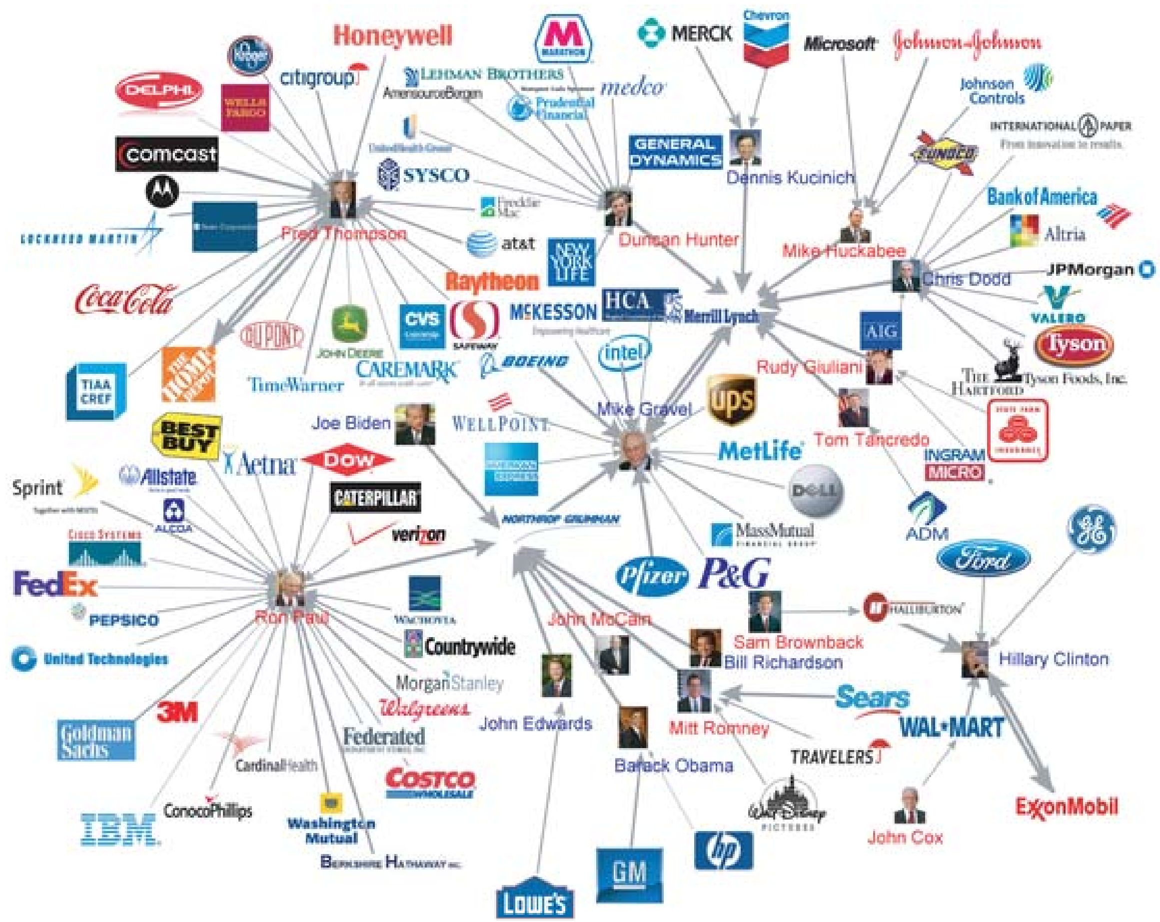
Words network



Source: http://wordnet.princeton.edu/man/wnlicens.7WN

US presidential candidates and ...

bipartite network of the US presidential candidates and the 100 corporations:
The Democratic candidates' names are colored as blue, the Republican candidates' names as Red, and the corporations as their logos. Normalized Google correlation values are used.



http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0011233

Network questions

- Structural
- Communities
- Dynamics of
- Dynamics on
- Algorithms
- outlook

Network questions: structural

Given a network, there are a number of structural questions we may ask:

1. How many connections does the average node have?
2. Are some nodes more connected than others?
3. Is the entire network connected?
4. On average, how many links are there between nodes?
5. Are there clusters or groupings within which the connections are particularly strong?
6. Is there any hierarchal structure?
7. What is the best way to characterize a complex network?
8. How can we tell if two networks are “different”?
9. Are there useful ways of classifying or categorizing networks?
10. What are the important nodes and links?

Network questions: communities

1. Are there clusters or groupings within which the connections are particularly strong?
2. What is the best way to discover communities, especially in large networks?
3. How can we tell if these communities are statistically significant?
4. What do these clusters tell us in specific applications?
5. How we can optimize the number of communities?
6. Is there any method applicable to large networks composed on millions of nodes and edges?
7. Is there a way to discover overlapping communities?

Network questions: dynamics of

1. How can we model the growth of networks?
2. What are the important features of networks that our models should capture?
3. Are there “universal” models of network growth? What details matter and what details don’t?
4. To what extent are these models appropriate null models for statistical inference?
5. What’s the deal with power laws, anyway?
6. How is the time-evolution of a network?
7. How the network properties affected by its dynamical evolution?

Network questions: dynamics on

1. How do diseases, computer viruses, innovations, rumors, revolutions, and opinions propagate on networks?
2. What properties of networks are relevant to the answer of the above question?
3. If you wanted to prevent (or encourage) spread of something on a network, what should you do?
4. What types of networks are robust to random attack or failure?
5. What types of networks are robust to intentional and cascading attack?
6. How collective behaviour such as synchronization emerges from interaction of dynamical systems over networks?
7. Does a social game such as Prisoner’s Dilemma survive on a network?
8. How are “dynamics of networks” and “dynamics on networks” coupled?

Network questions: algorithms

1. What types of networks are searchable or navigable?
2. What are good ways to visualize complex networks?
3. What are the optimal algorithms for computing network metrics?
4. How does google page rank work?
5. If the internet were to double in size, would it still work?

There are also many domain-specific questions:

1. Are networks a sensible way to think about gene regulation or protein interactions or food webs?
2. What can social networks tell us about how people interact and form communities and make friends and enemies?
3. Lots and lots of other theoretical and methodological questions …
4. What else can be viewed as a network? Many applications await …

Network questions: outlook

1. Advances in available data, computing speed, and algorithms have made it possible to apply network analysis to a vast and growing number of phenomena such as online social networks.
2. This means that there is lots of exciting, novel work being done.
3. This work is a mixture of awesome, exploratory, misleading, irrelevant, relevant, fascinating, ground-breaking, important, and just plain wrong.
4. It is relatively easy to fool oneself into seeing thing that aren’t there when analyzing networks. (This is the case with almost anything, not just networks.)
5. For networks, how can we be more careful and scientific, and not just descriptive and empirical?