Introduction

Lecture Graph Drawing Algorithms · 192.053

Martin Nöllenburg

13.03.2018

Lecturer and Dates

Lecturer

- Martin Nöllenburg
- noellenburg@ac.tuwien.ac.at
- Office: Favoritenstr. 9–11, room HC 04 11
- Office hours: by appointment

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Lecture schedule

- Tue 9:00 – 11:00, seminar room 186
- 12 units (pay attention to teach-free days)

Organization

Website

$\rightarrow$ visit TISS page for course 192.053 $\leftarrow$

- TUWEL course will go online this week
- up-to-date course information
- lecture slides
- exercise information
- additional literature and material
- registration for exercise groups and topic selection (mandatory for certificate, deadline March 23!)

Goals and Requirements

Objectives: At the end of the course you will be able to...

- explain concepts, structures, and problem definitions
- understand the discussed algorithms, explain them intuitively, analyze them formally and prove their properties
- use graph drawing tools and libraries to create your own visualizations
- select and adapt appropriate graph drawing algorithms
- analyze new graph drawing problems and build abstract models
- develop and analyze efficient algorithms in these models

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Prior Knowledge: graph algorithms and basic geometry, e.g.

- VU Algorithmen und Datenstrukturen (1+2) **required**
- VUs Algorithmics, Algorithmic Geometry, Visualization (1+2), InfoVis **optional**

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Course Time Breakdown: 3LP = 75h

- time in lectures and exercise sessions ca. 24h
- self-study of lecture material, exam preparation, and exam ca. 21h
- exercise (presentation or programming project) ca. 30h

Structure of the Lectures

Attendance:

- recommended (interaction, exercises), but not mandatory

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Media:

- slides & blackboard (take notes!)
- text books, original literature (mostly background reading)

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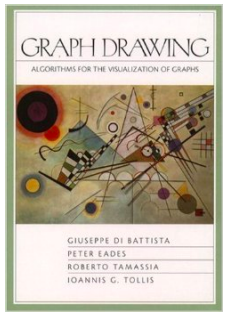
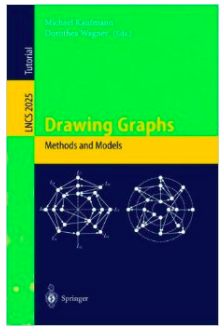
Content:

- aesthetic quality and optimization criteria, layout styles
- formal algorithmic perspective on graph visualization
- **not:** rendering or graphics
- algorithm types
  - divide & conquer / recursion
  - combinatorial optimization (network flow, ILP, ...)
  - incremental algorithms
  - iterative methods
  - algorithms for special graph classes

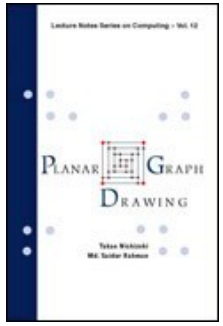
Literature (available in TU library)



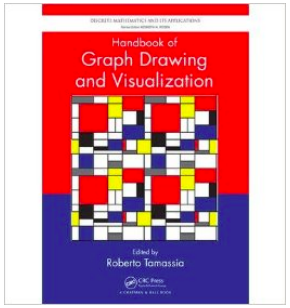
G. di Battista, P. Eades, R. Tamassia, I. Tollis:
Graph Drawing
Prentice Hall, 1998



M. Kaufmann, D. Wagner:
Drawing Graphs: Methods and Models
Springer, 2001
→ e-book via TU Wien



T. Nishizeki, Md. S. Rahman:
Planar Graph Drawing
World Scientific, 2004



R. Tamassia:
Handbook of Graph Drawing and Visualization
CRC Press, 2013 `http://cs.brown.edu/~rt/gdhandbook/`

What you should know

Basics graph theory:

- graph, vertices, edges
- vertex degree, neighborhood, adjacent, incident
- connectivity, tree, cycle, path
- planarity
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- network flow algorithms
- linear programming
- recursion
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general rule:
ask if s.th. is unclear

Exercises

Lecture is complemented by an exercise. You can choose between more theoretical or more practical exercises

- exercise will run in parallel to lecture throughout course
- presentation of your work at the end of semester (dates tba)
- regular meetings with Fabian to discuss progress
- exercises count for **30%** of the final grade

Lecture Assistant

- Fabian Klute
- `fklute@ac.tuwien.ac.at`
- Office: Favoritenstr. 9–11, room HA 04 06
- Office hours: by appointment

Graph Drawing – The GD Conference

Annual Symposium on Graph Drawing and Network Visualization

This year in Barcelona, usually iterates between EU and US

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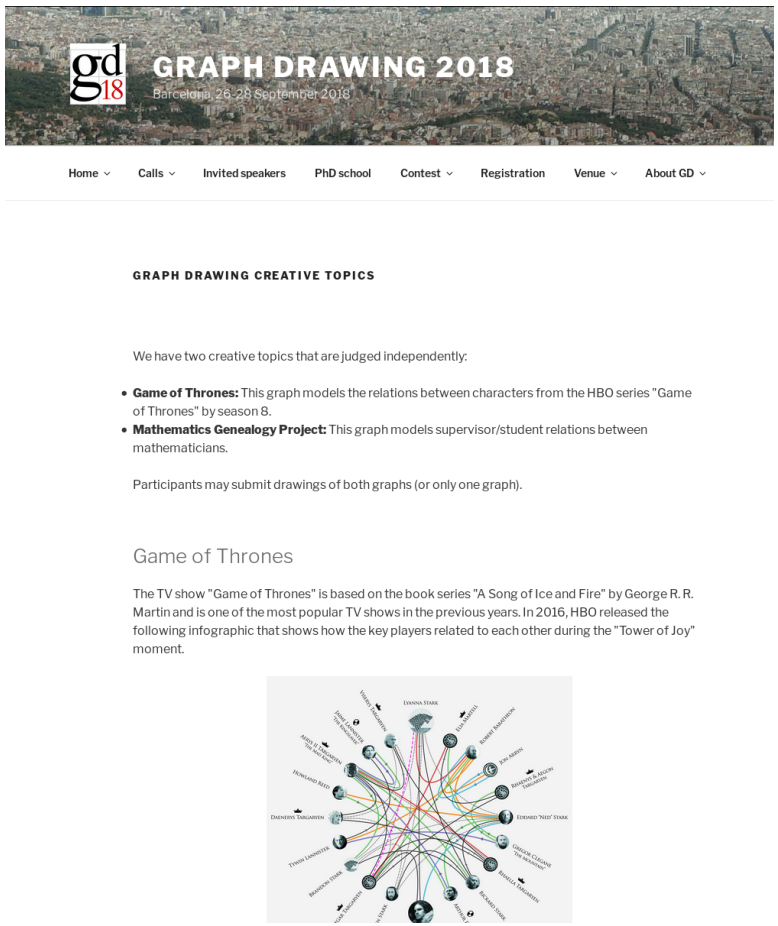

The practical exercises will be the contest topics of 2018!

Challenging topics!

Visual design and algorithmic tasks!

More details on the website!

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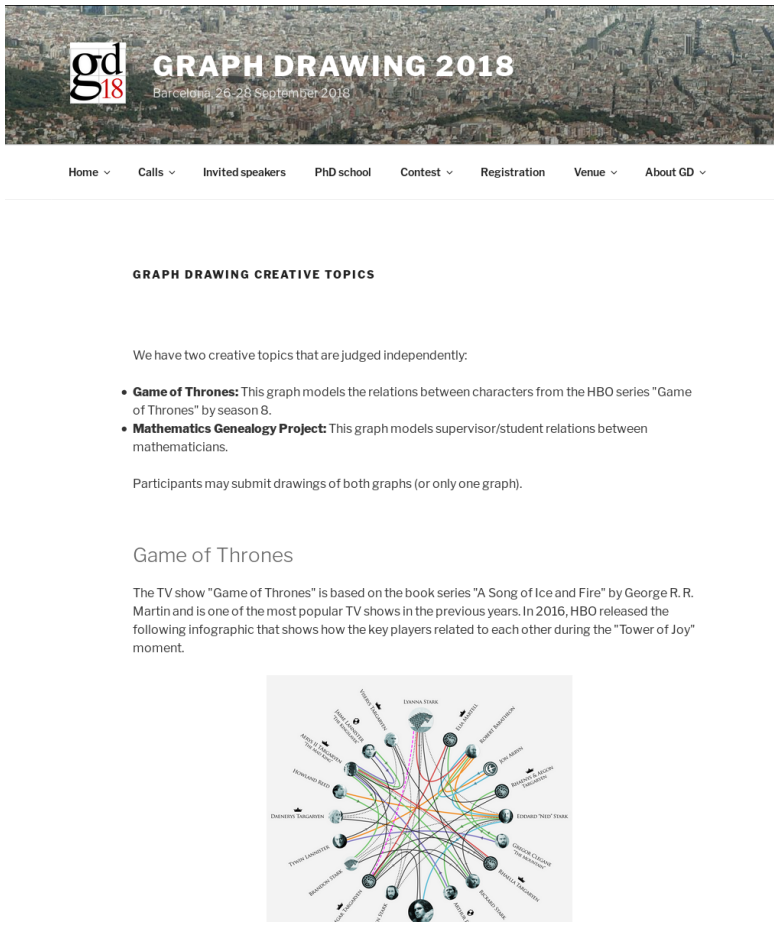

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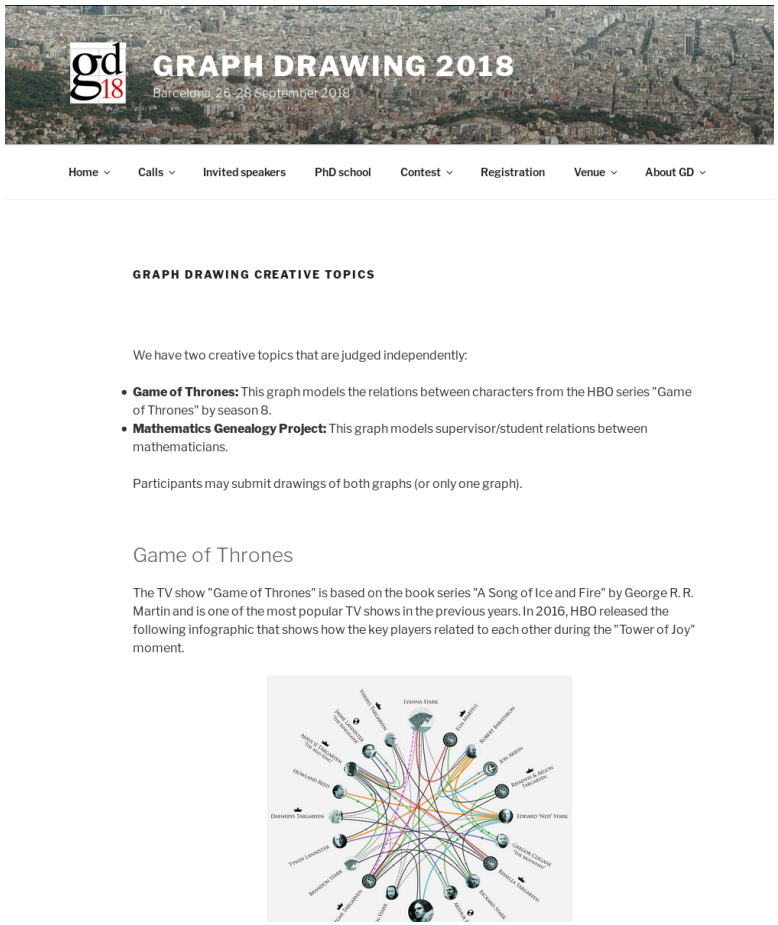

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- Theory paper!
- Read and understand
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Angle Optimization

- Create a drawing
- Straight lines
- Max min angles
- Your ideas needed!
- Short presentation

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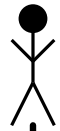

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GD contest!

Final Grading

Exam

- individual oral exams in July and September 2018
- each exam 15-20 minutes
- 70% of the final grade

Final grade

- 30% exercises + 70% oral exam

Requirements for positive grade

Successful participation in exercise part (incl. attendance of student presentations)

Introduction to Graph Drawing

Graphs and their Representations

What is a Graph?

Graphs and their Representations

What is a Graph?

Tuple $G = (V, E)$
Set of vertices $V = \{v_1, \ldots, v_n\}$
Set of edges $E = \{e_1, \ldots, e_m\}$,
$e_i = \{v_j, v_k\},\ 1 \leq i \leq m,\ 1 \leq j, k \leq n$

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Representations?

Set representation:

$$V = \{v_1, v_2, v_3, v_4, v_5, v_6, v_7, v_8, v_9, v_{10}\}$$
$$E = \{\{v_1, v_2\}, \{v_1, v_8\}, \{v_2, v_3\}, \{v_3, v_5\}, \{v_3, v_9\}, \{v_3, v_{10}\}, \{v_4, v_5\}, \{v_4, v_6\}, \{v_4, v_9\}, \{v_5, v_8\}, \{v_6, v_8\}, \{v_6, v_9\}, \{v_7, v_8\}, \{v_7, v_9\}, \{v_8, v_{10}\}, \{v_9, v_{10}\}\}$$

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Representations?

Set representation
Adjacency lists

$$
\begin{array}{ll}
v_1: & v_2, v_8 \\
v_2: & v_1, v_3 \\
v_3: & v_2, v_5, v_9, v_{10} \\
v_4: & v_5, v_6, v_9 \\
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Representations?

Set representation
Adjacency lists
Adjacency matrix

$$\begin{pmatrix}
0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\
1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \\
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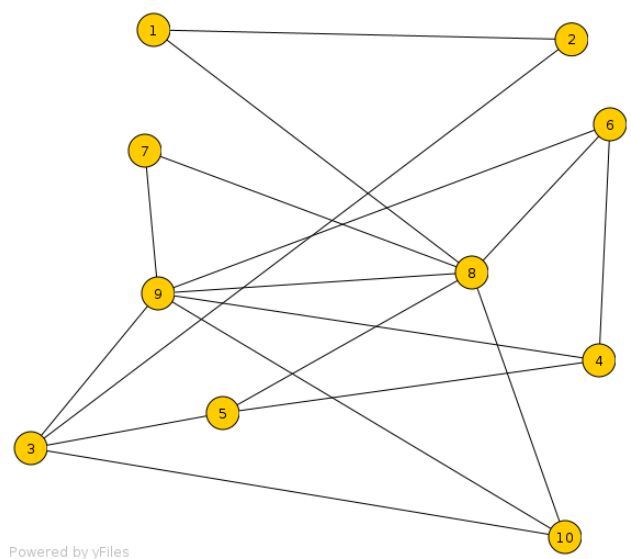
Adjacency matrix
Drawing



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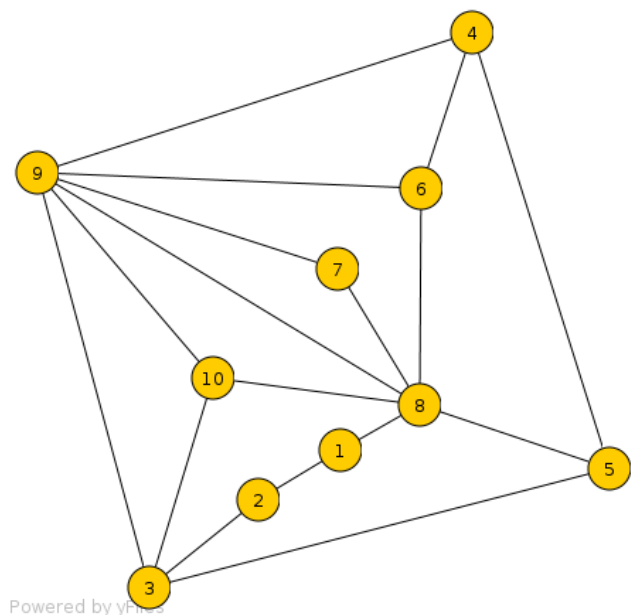

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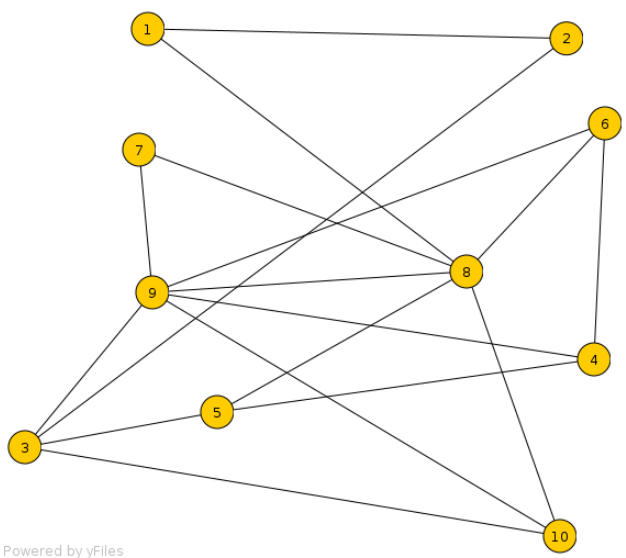

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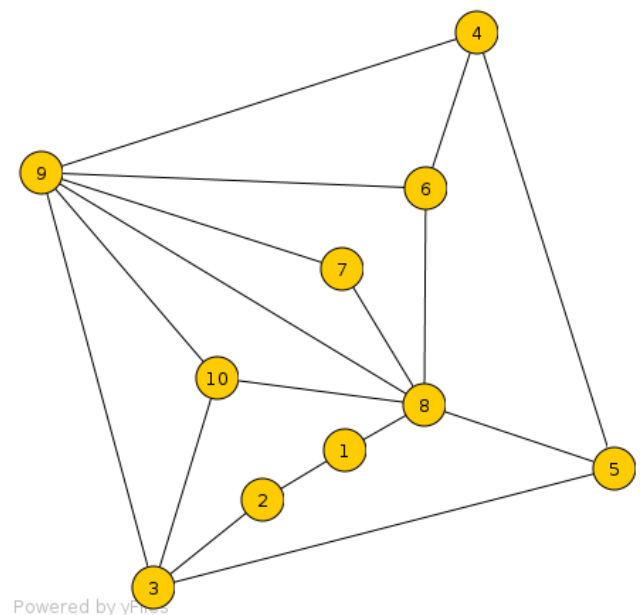


Why Draw Graphs?

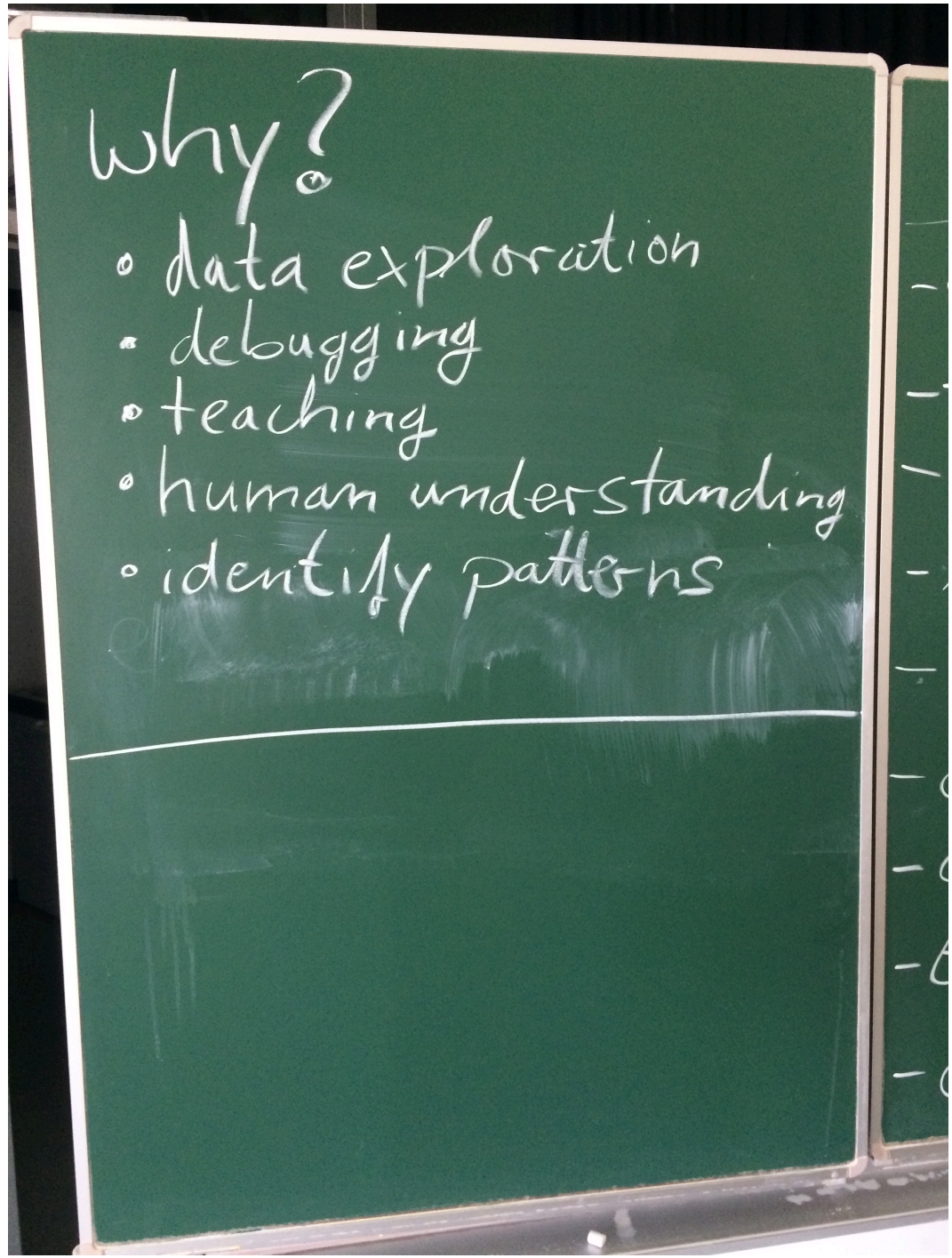
Why do we need graph/network visualizations?

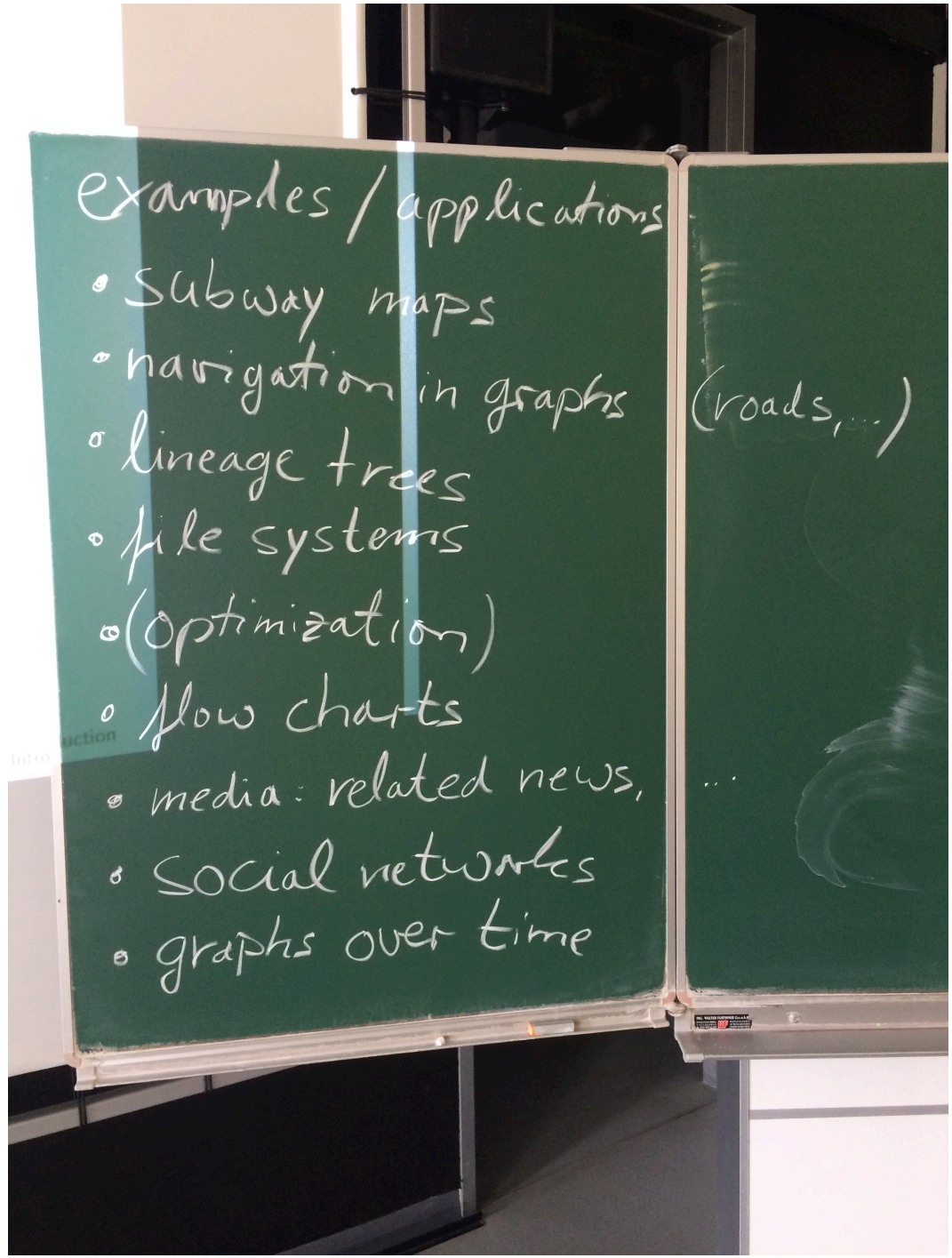
Which applications or examples do you know?

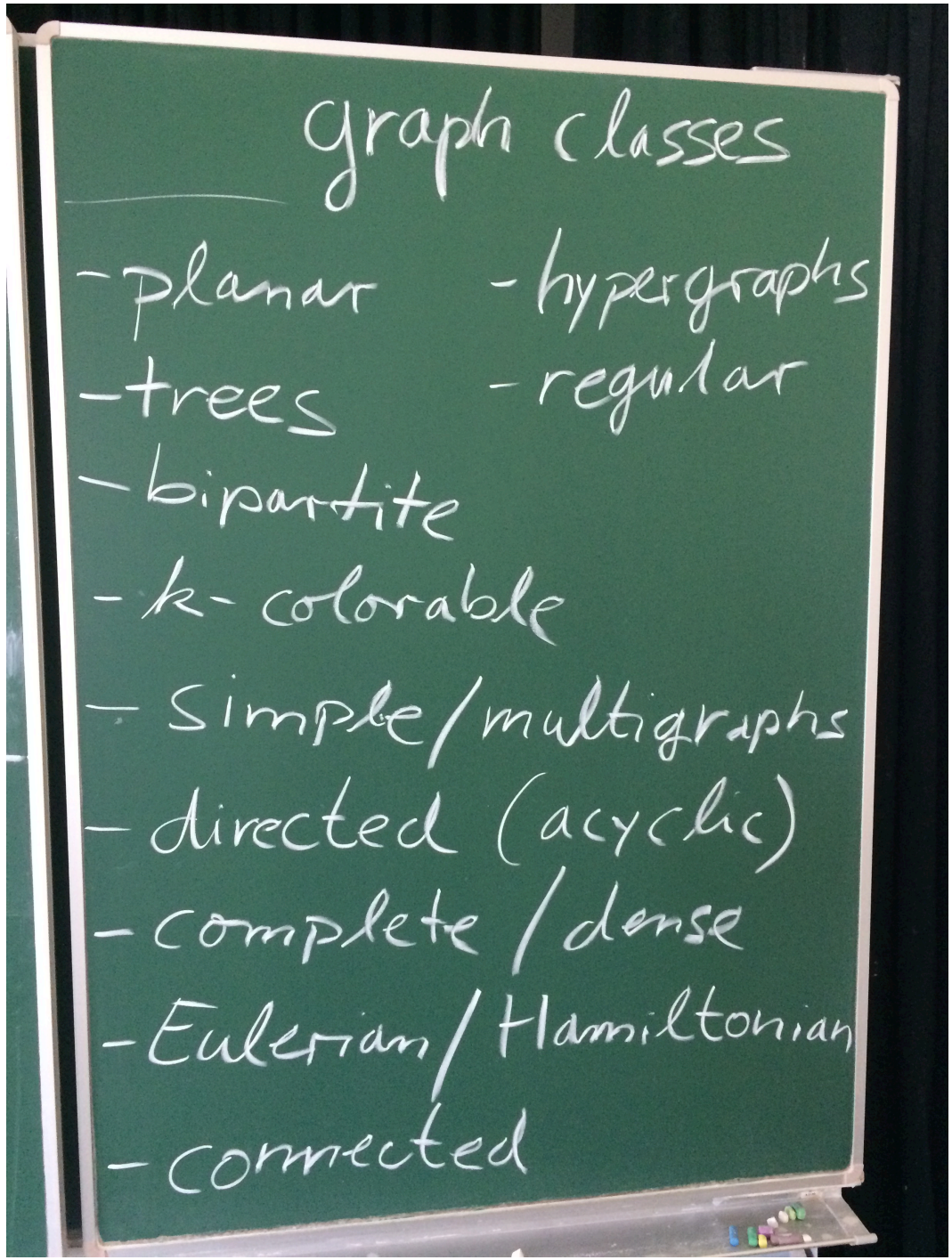
Which relevant graph classes do you know?

In groups of two or three: discuss and write down your answers

5 min


Why?
• data exploration
• debugging
• teaching
• human understanding
• identify patterns


examples / applications
• subway maps
• navigation in graphs (roads, ...)
• lineage trees
• file systems
• (optimization)
• flow charts
• media: related news, ...
• social networks
• graphs over time


graph classes
- planar
- trees
- bipartite
- k-colorable
- simple / multigraphs
- directed (acyclic)
- complete / dense
- Eulerian / Hamiltonian
- connected
- hypergraphs
- regular

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Graphs are mathematical models of real physical and abstract networks (social networks, metabolical networks, VLSI-network, UML-diagrams, citation networks, ...)

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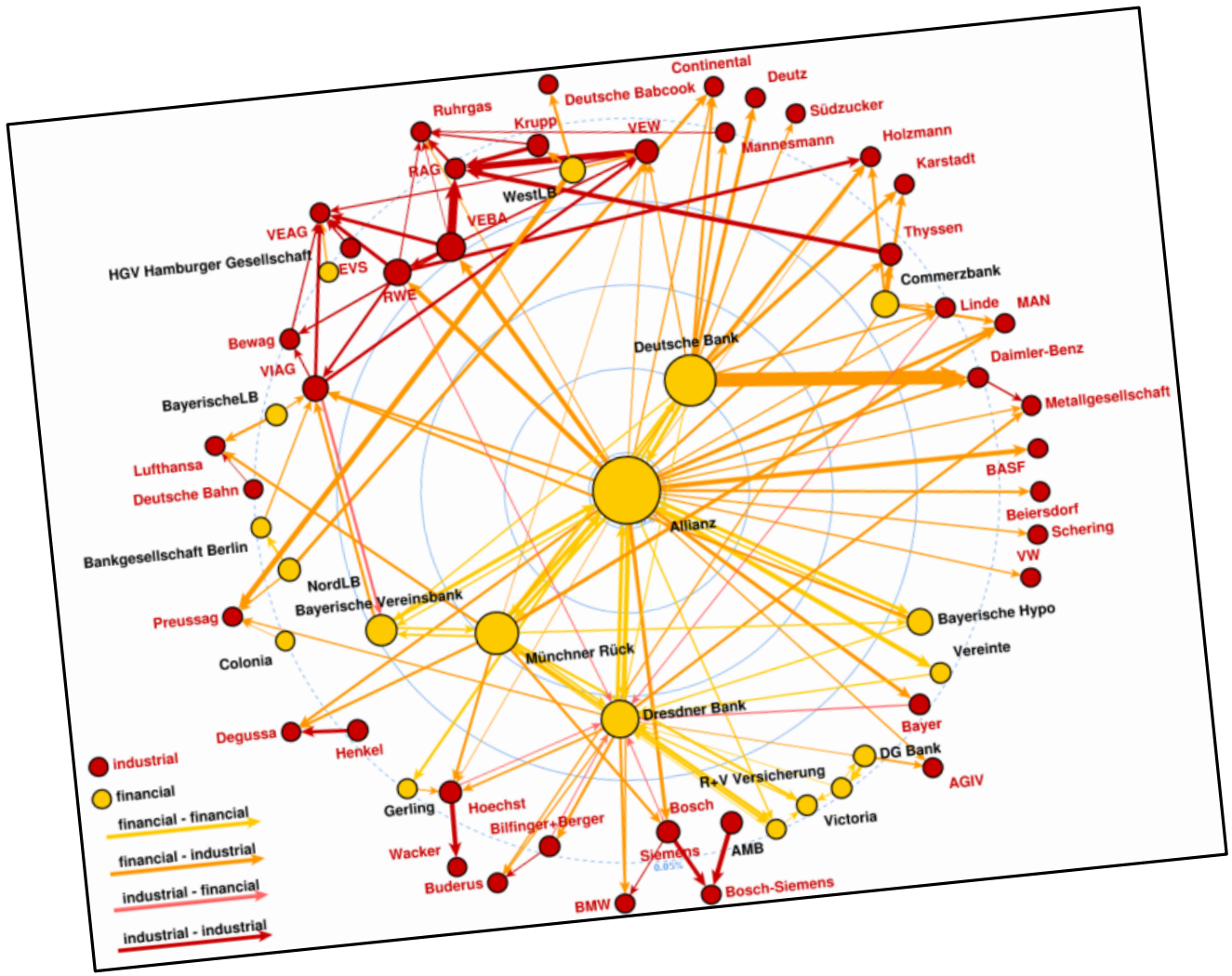

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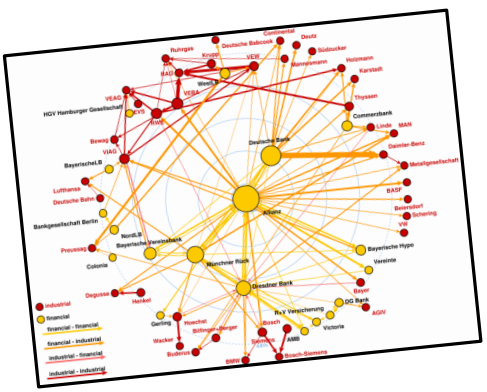

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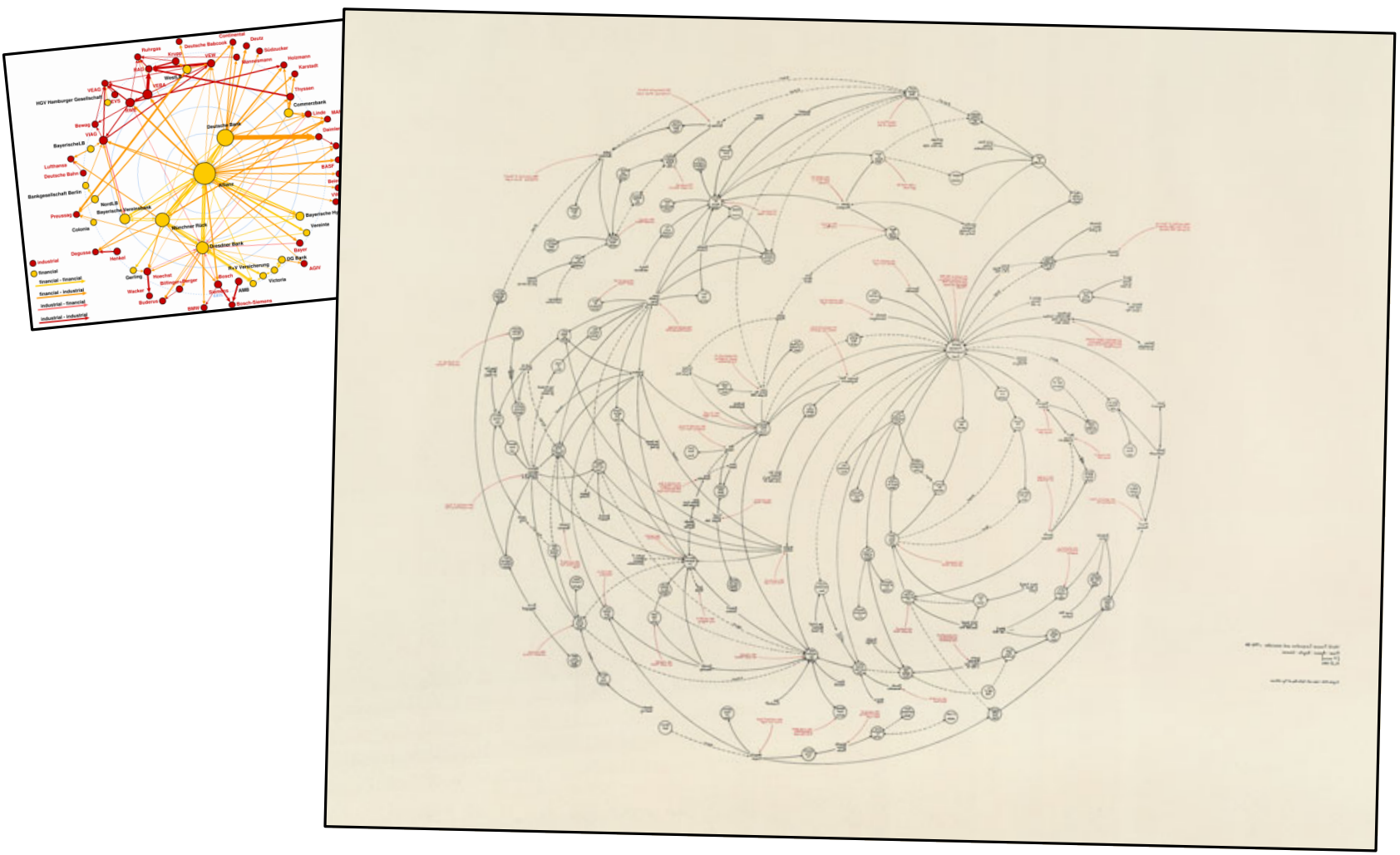

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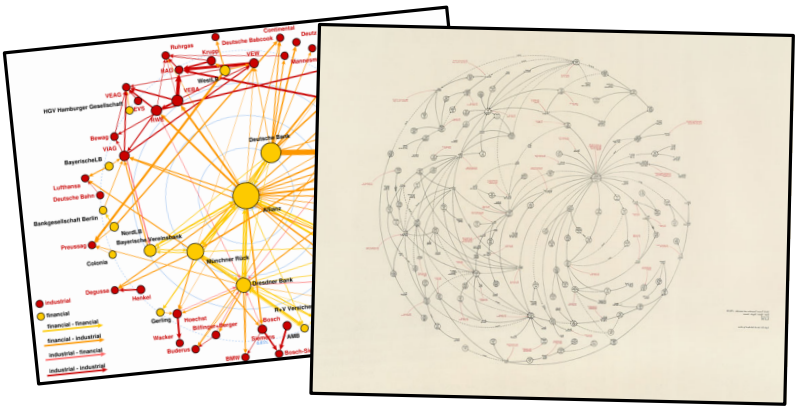

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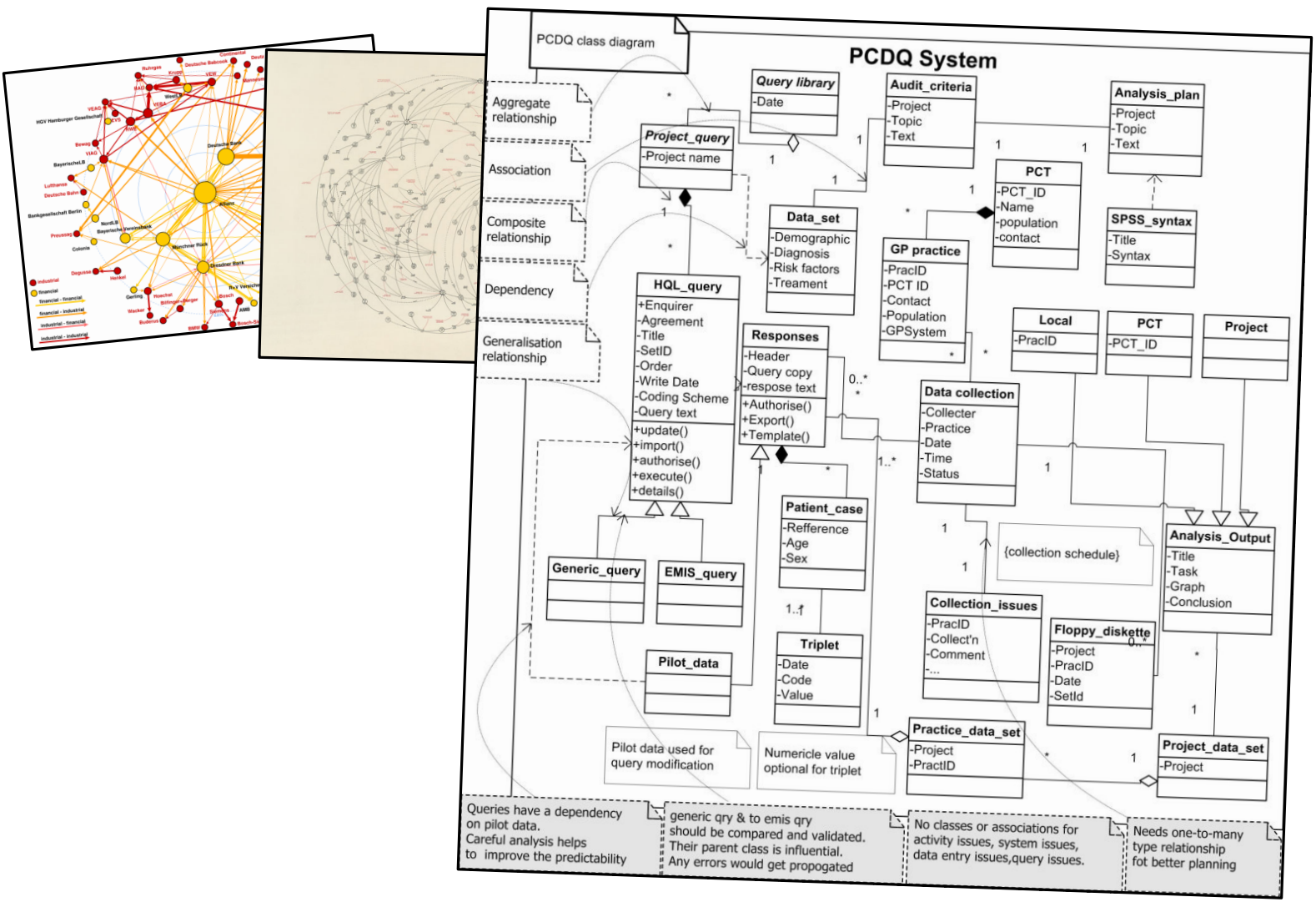

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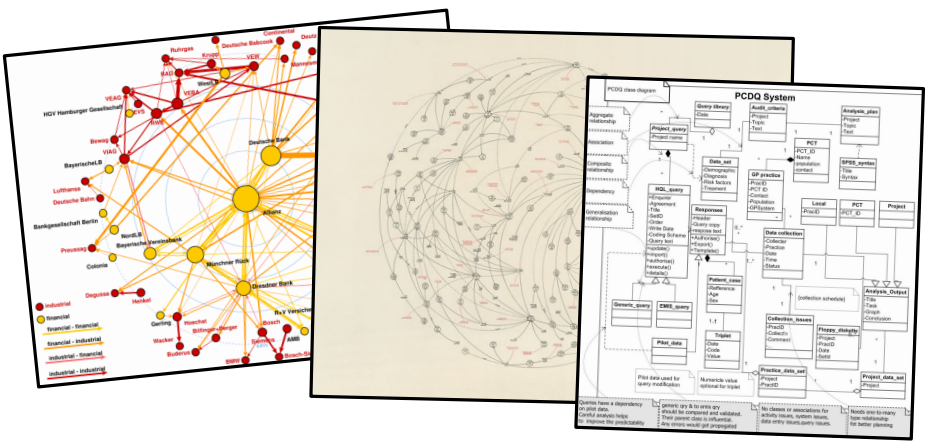

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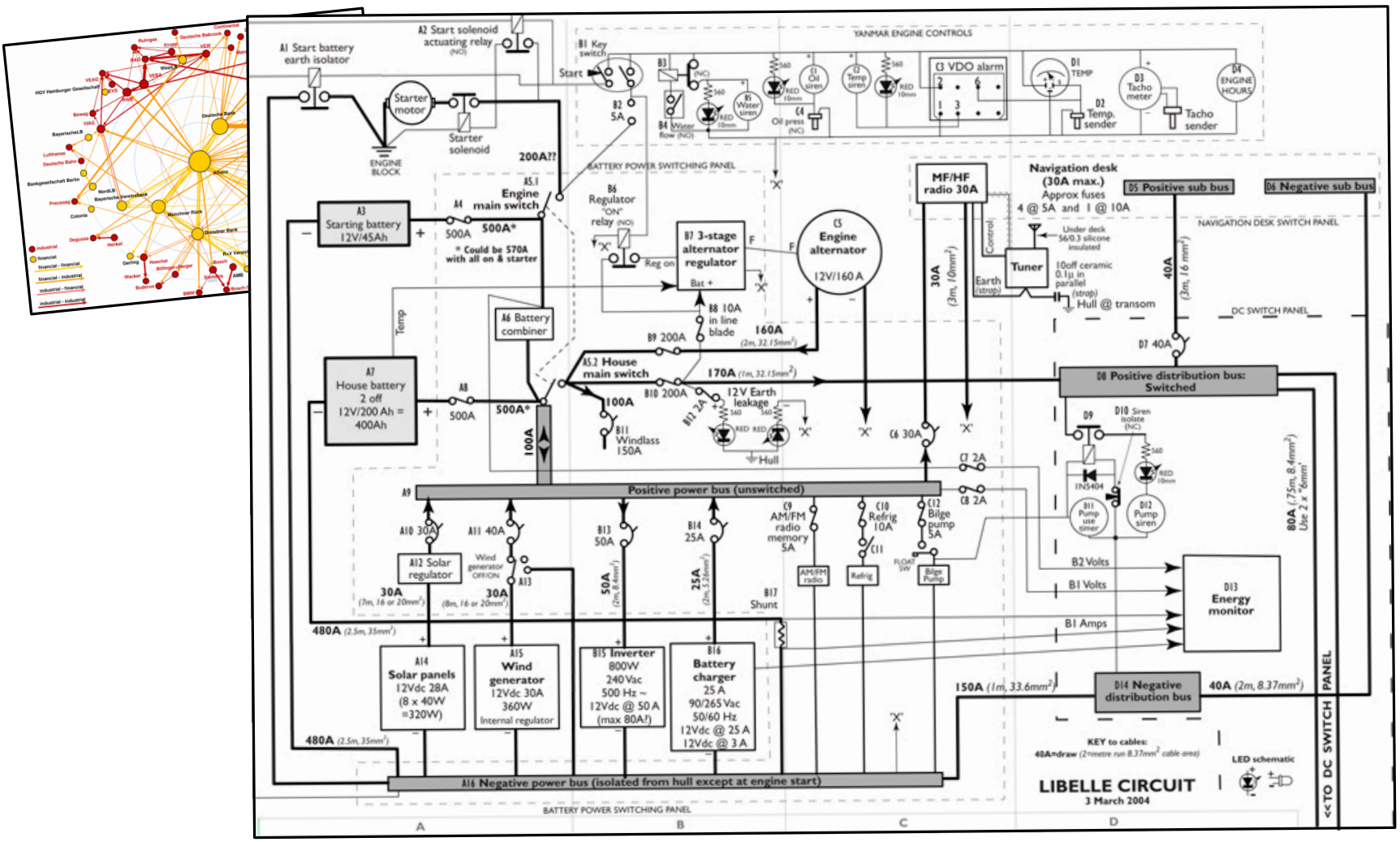

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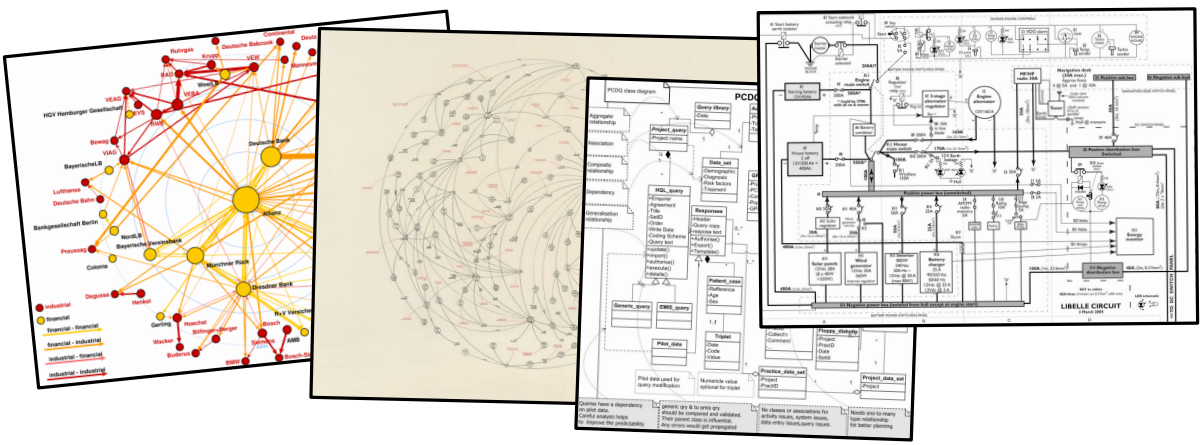

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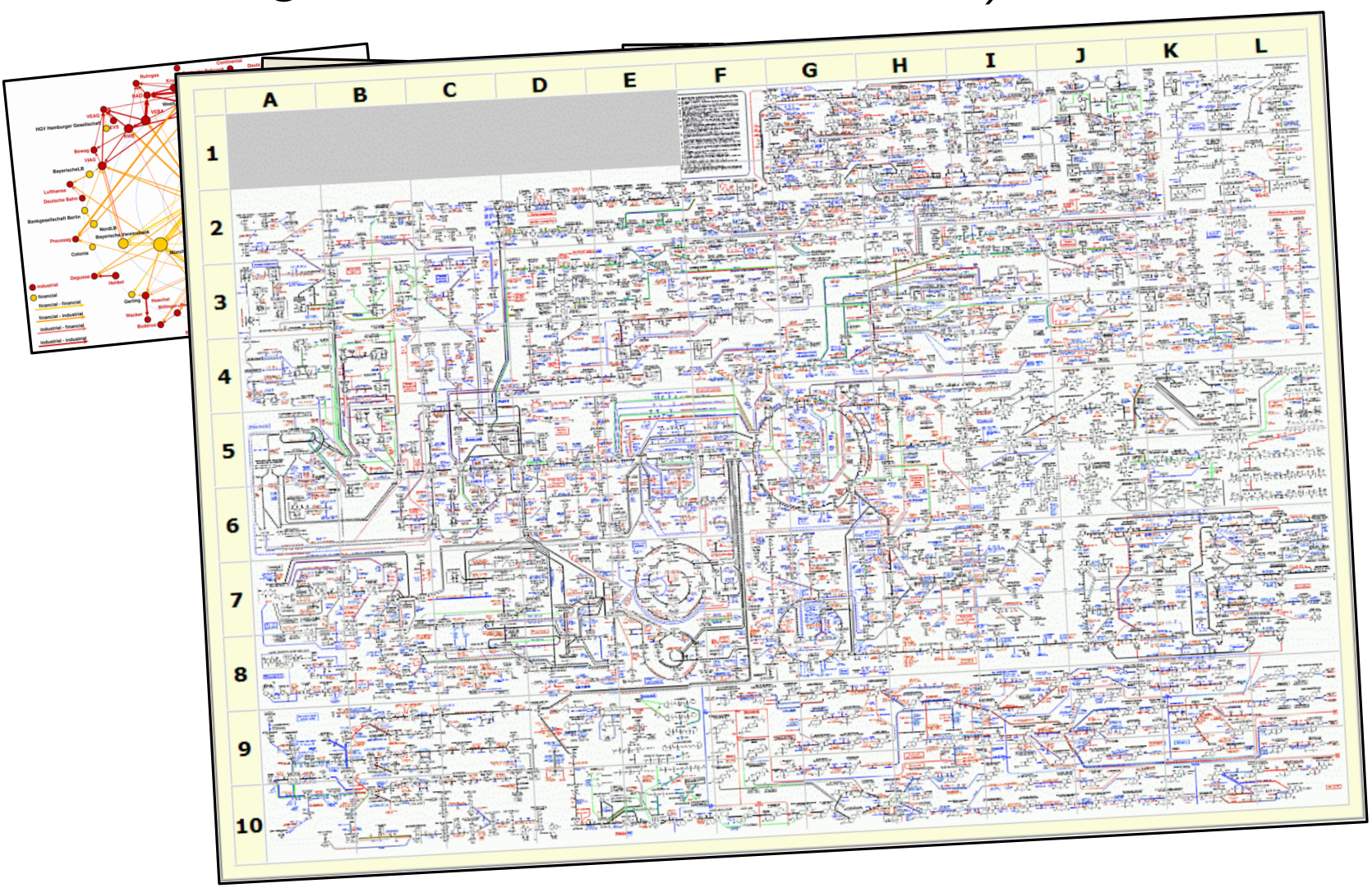

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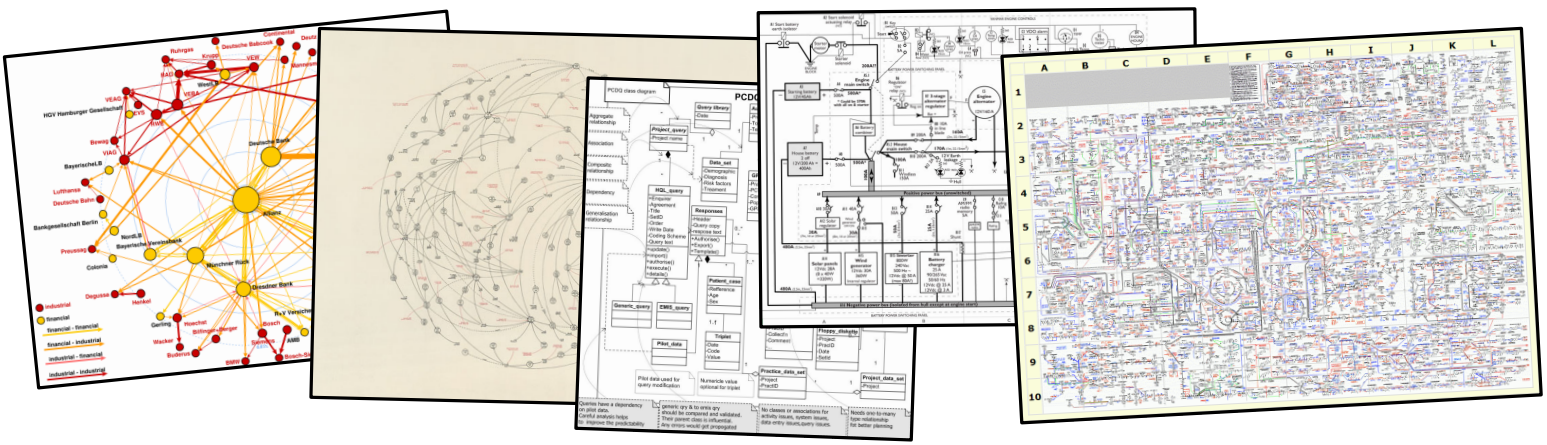

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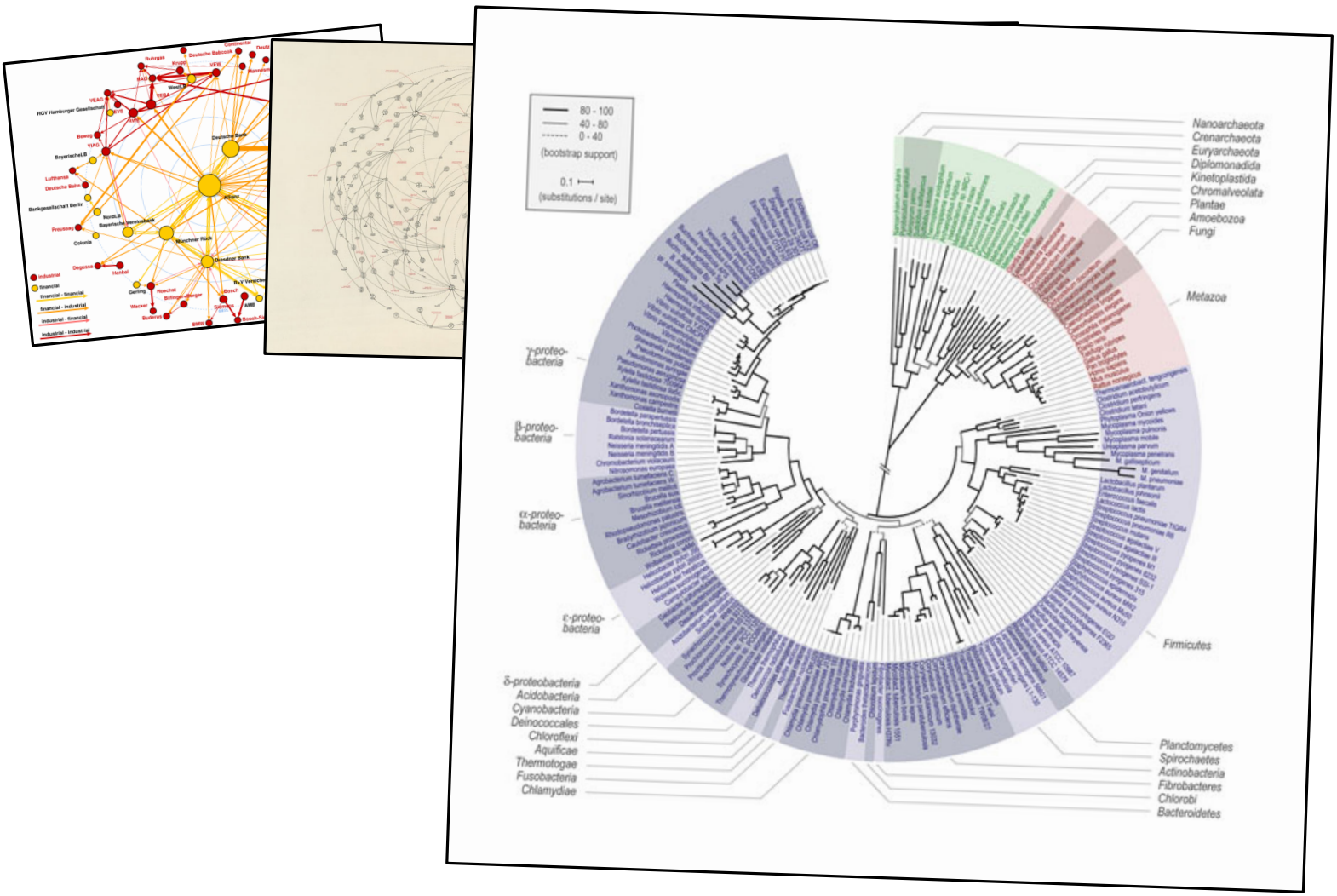

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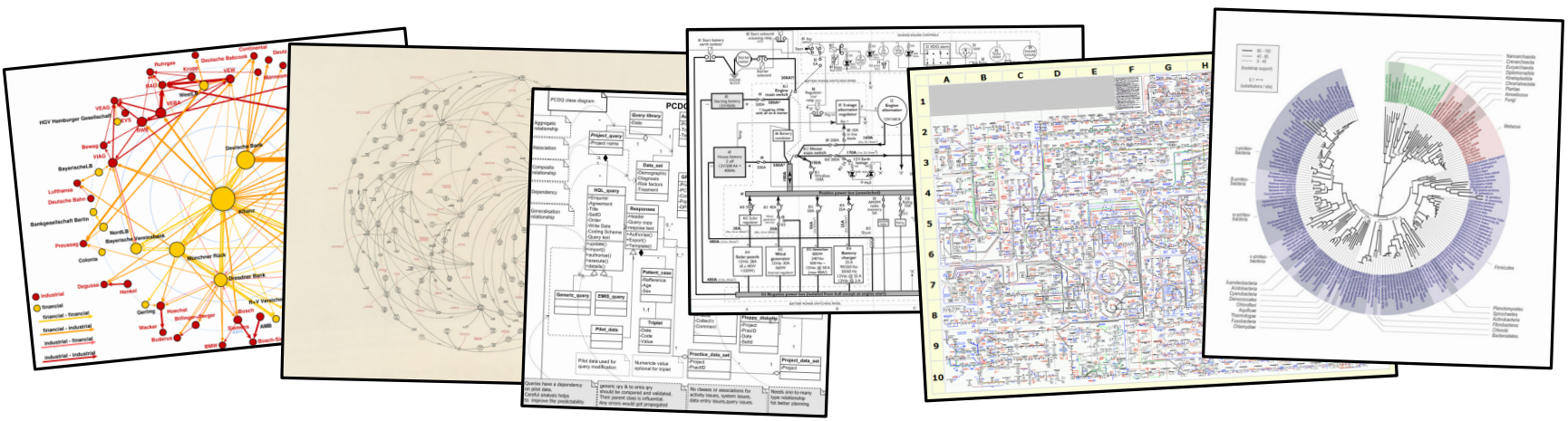

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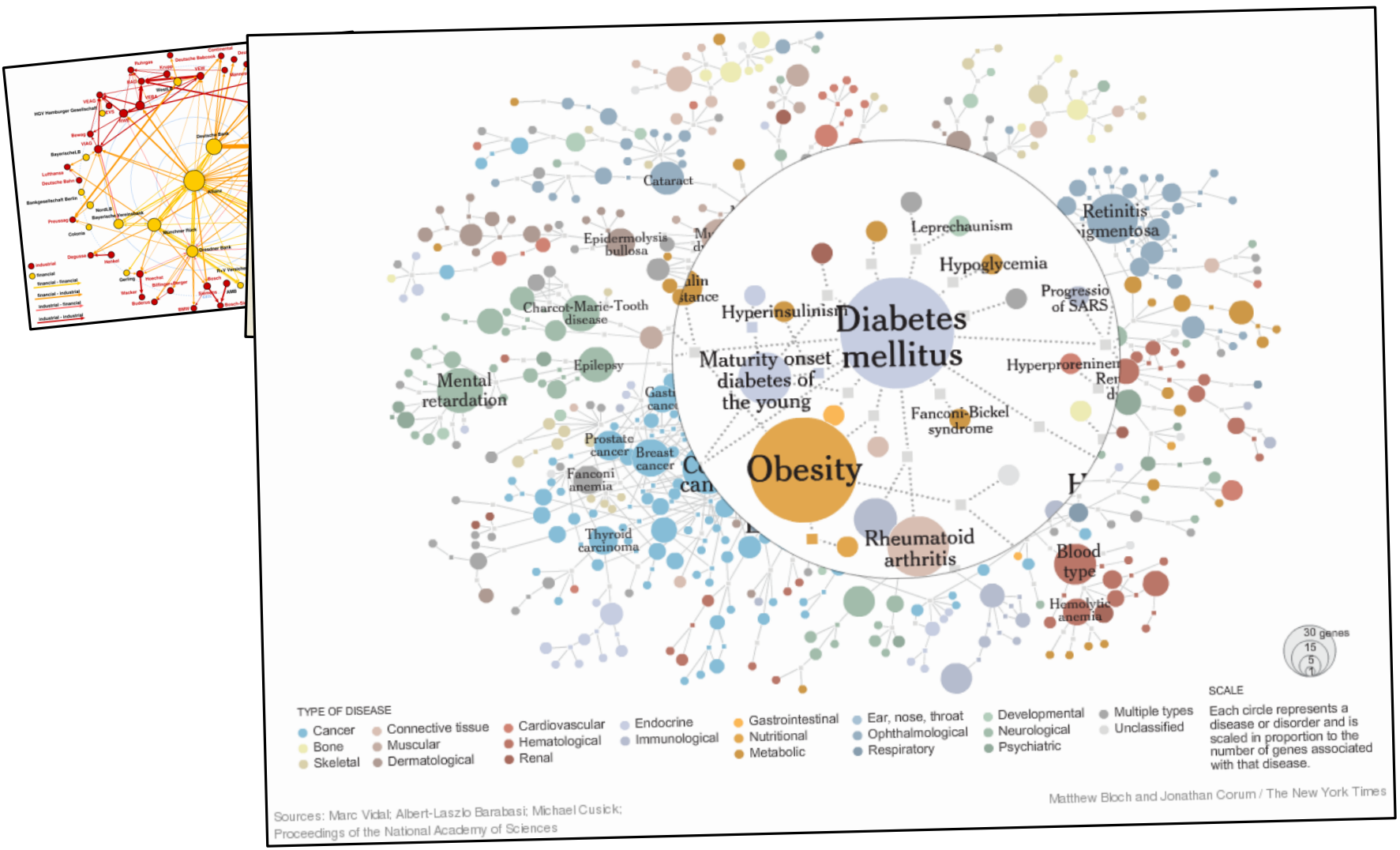

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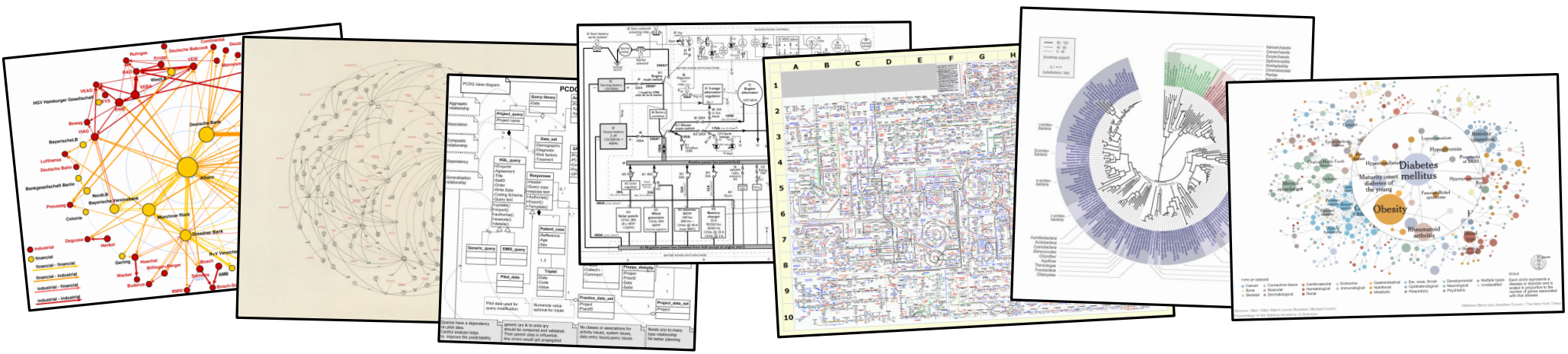

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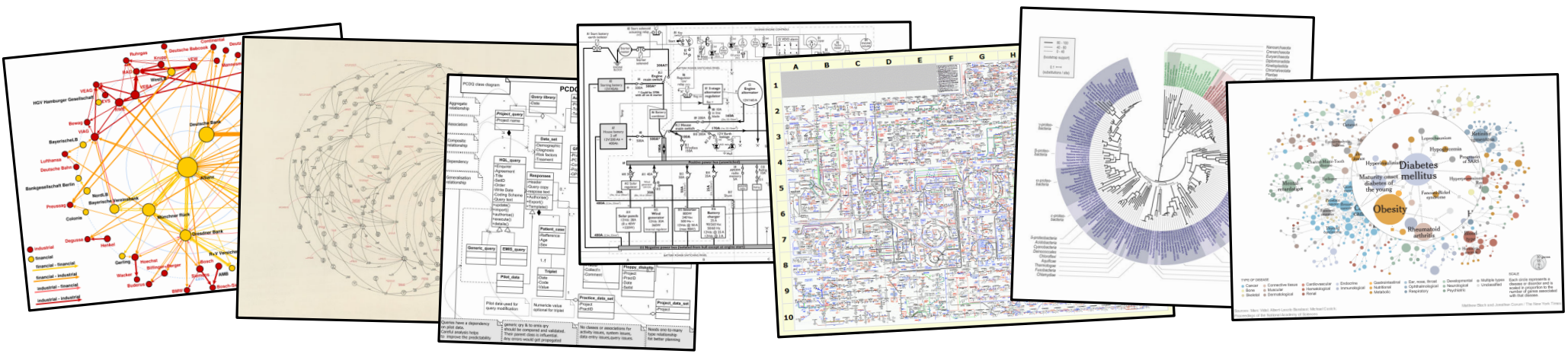
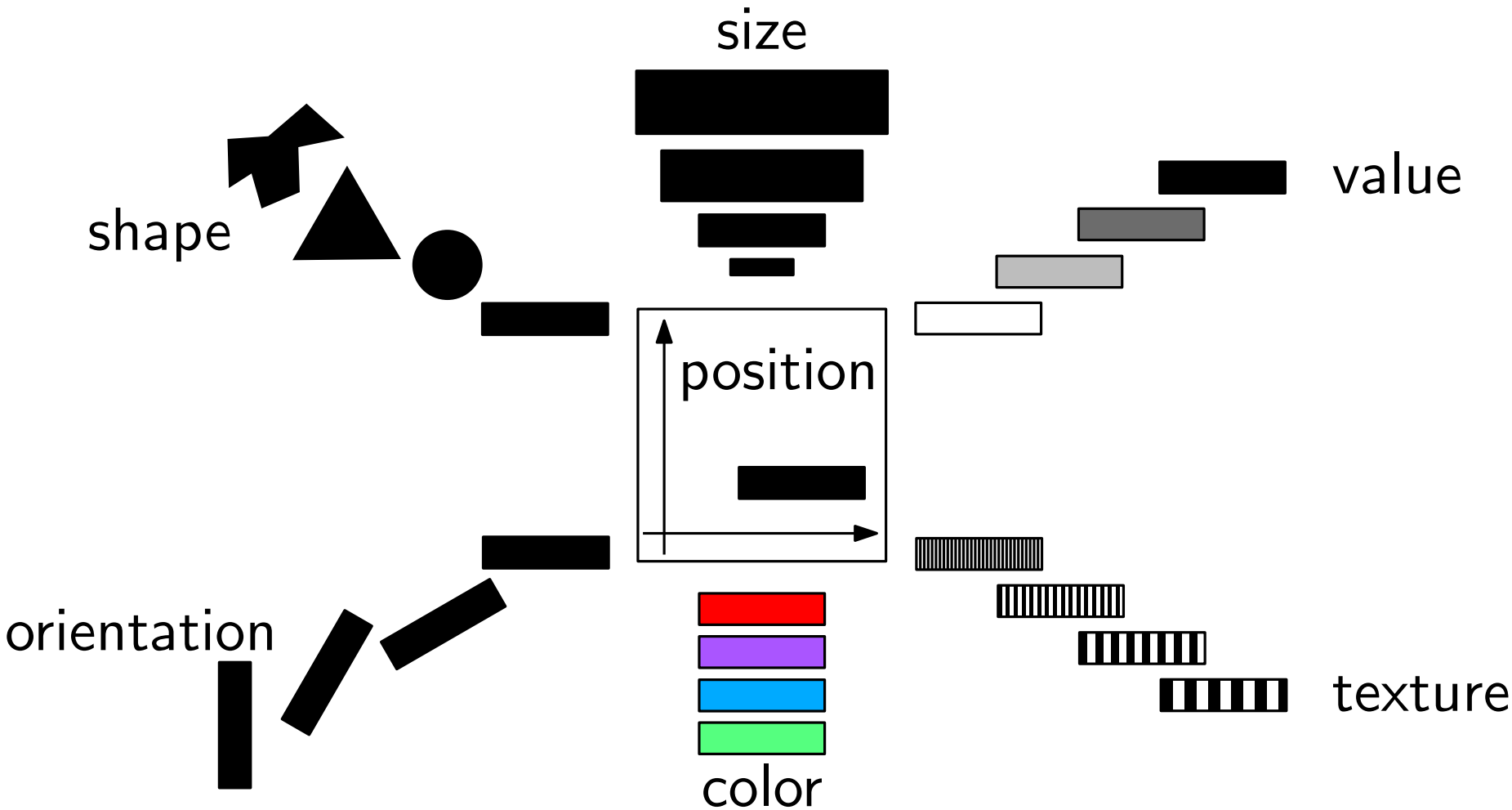


- **People think visually** – without a good visualization, complex graphs are not understandable to us
- A visualization helps to **communicate** and **explore** the graphs/networks
- We need **algorithms** to draw graphs, and make graphs and networks accessible to people

Visual Variables according to Bertin (1967)



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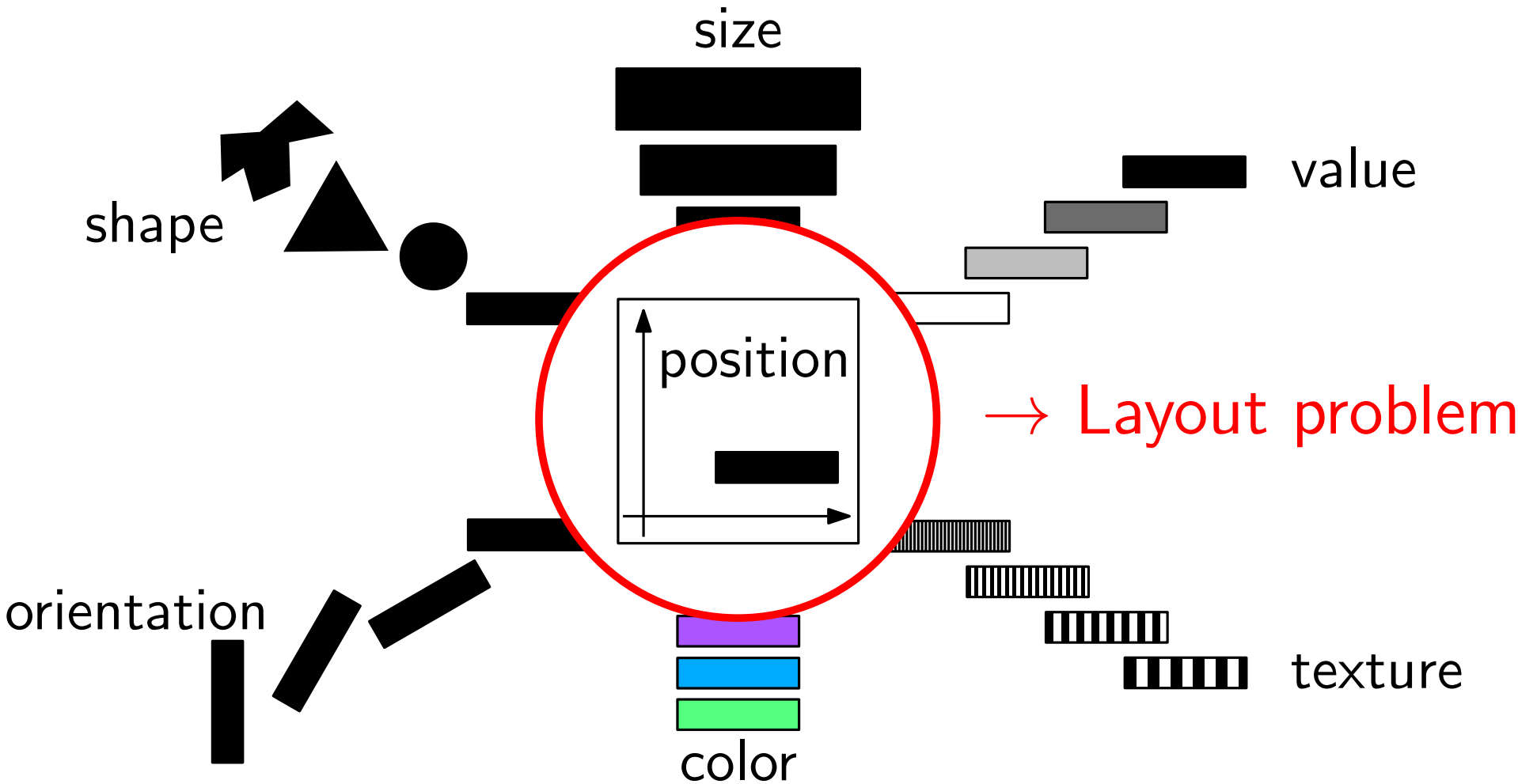
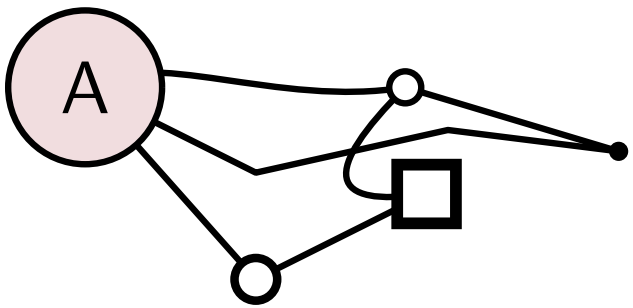


Layout Problem

Here: drawing is always meant to be in **standard representation** (aka node-link diagram)



Graph visualization problem

given: graph $G = (V, E)$
find: **good** drawing Γ of G

- $\Gamma : V \to \mathbb{R}^2$, vertex $v \mapsto$ point $\Gamma(v)$
- $\Gamma : E \to$ curves in $\mathbb{R}^2$, edge $\{u, v\} \mapsto$ simple open curve $c_{uv} : [0, 1] \to \mathbb{R}^2$ where $c_{uv}(0) = \Gamma(u)$ and $c_{uv}(1) = \Gamma(v)$

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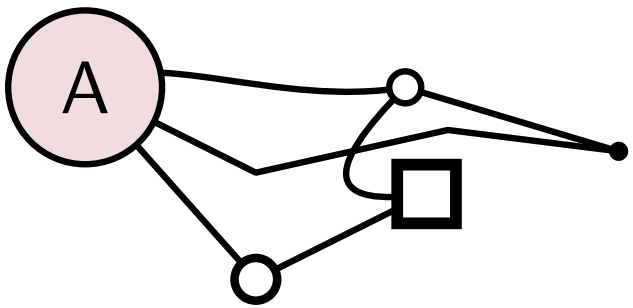

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But what is a **good** drawing?

Let's draw some graphs to find out

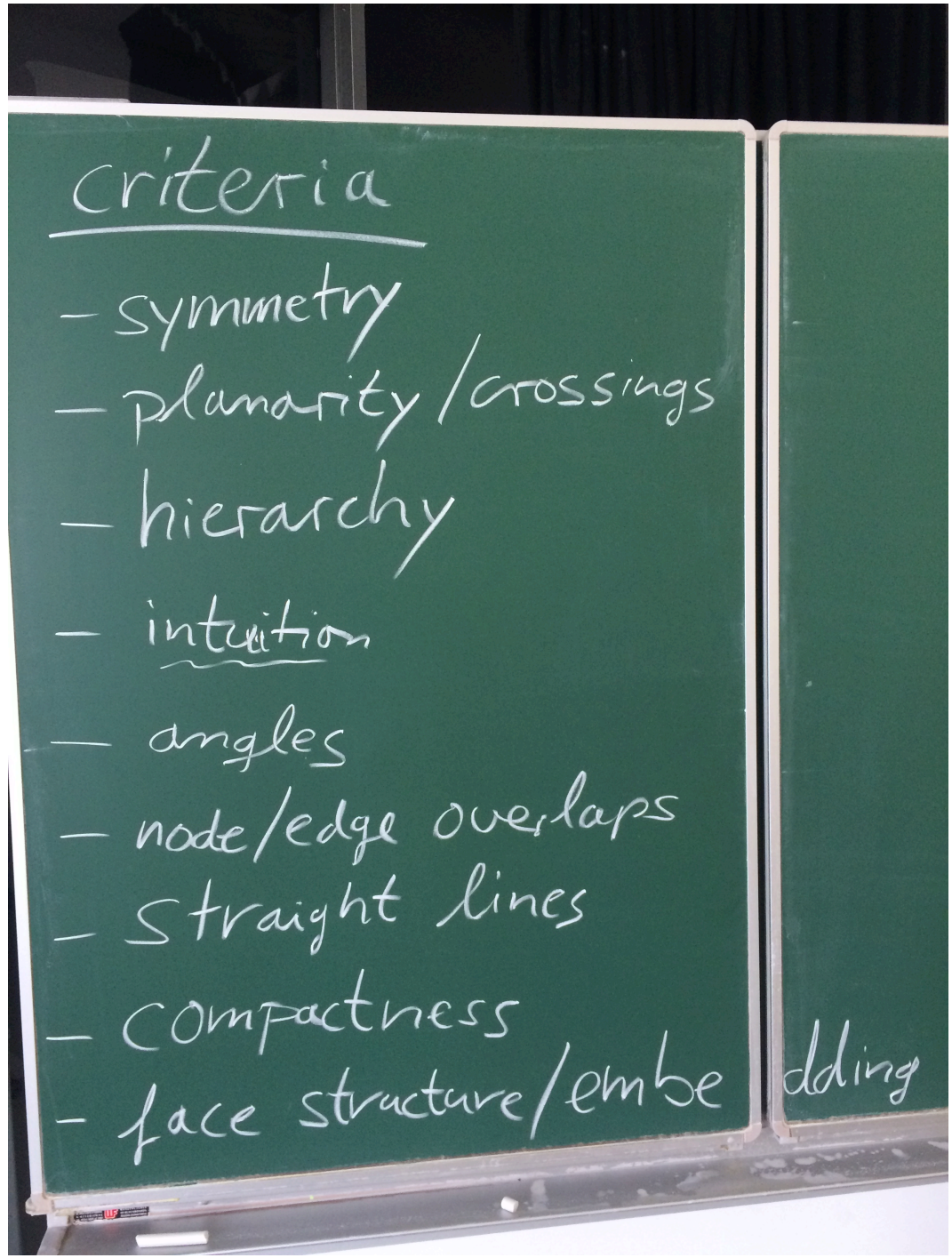
Central questions

- what makes a good drawing?
- what to avoid in a good drawing?
- are the criteria quantifiable?

Task:
Draw the graphs by hand as nicely as possible.

- work with your neighbor
- input is adjacency matrix or list

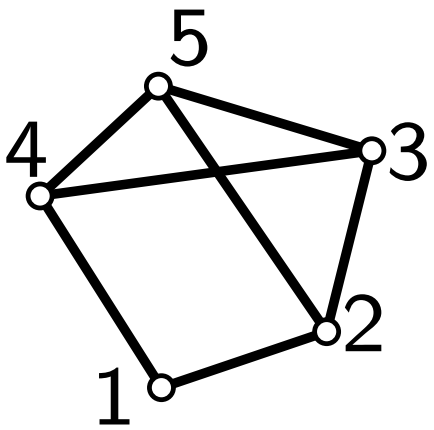
10 min

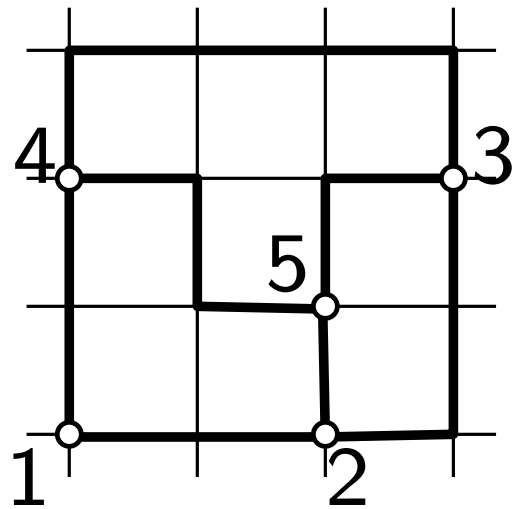

criteria
- symmetry
- planarity / crossings
- hierarchy
- intuition
- angles
- node/edge overlaps
- straight lines
- compactness
- face structure/embe
dding

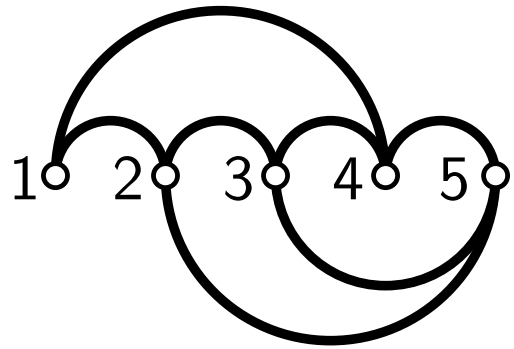
Quality Criteria for Graph Drawings

1) **Drawing conventions**, required properties, for example

- straight-line edges
- orthogonal edges (with 90° bends)
- grid drawings
- crossing-free
- ...





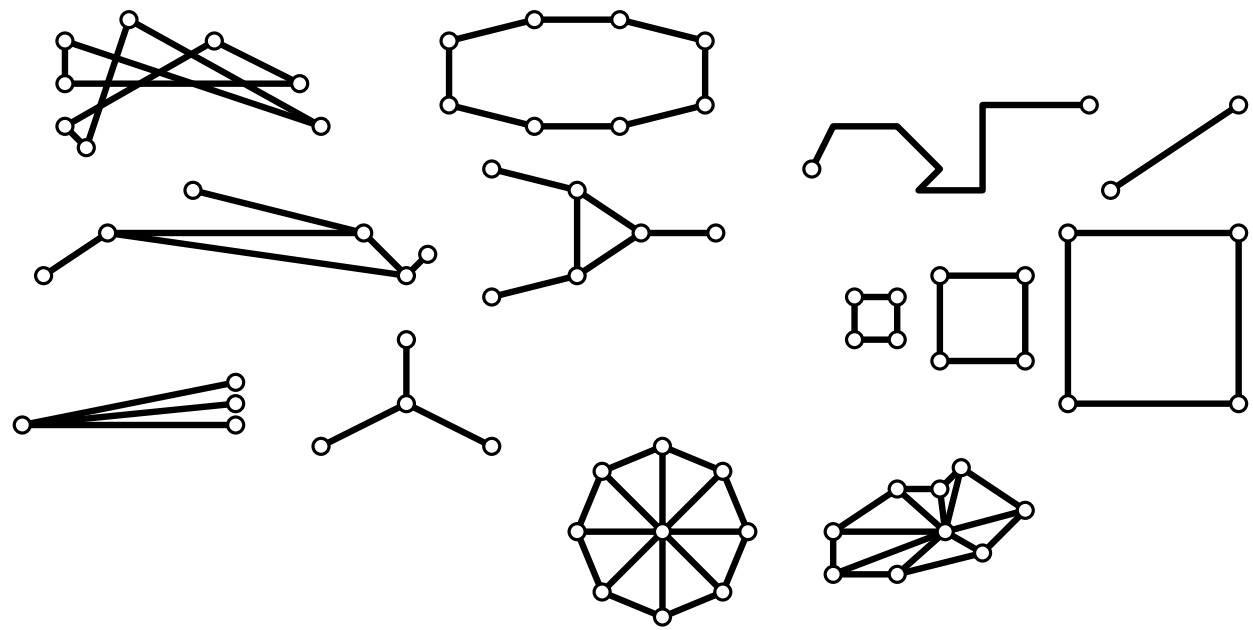


Quality Criteria for Graph Drawings

1) **Drawing conventions**, required properties

2) **Aesthetics** (to be optimized), for example:

- number of crossing
- number of bends
- uniform edge length
- area/length
- angular resolution
- symmetries
- ...



Quality Criteria for Graph Drawings

1) **Drawing conventions**, required properties

2) **Aesthetics** (to be optimized)

3) **Partial/local constraints**, for example:

- constraints on positions of some vertices
- constrained relative positions of vertices
- groups of vertices drawn close to each other

Layout Problem (2nd attempt)

Graph visualization problem

given: graph $G = (V, E)$
find: drawing Γ of G that

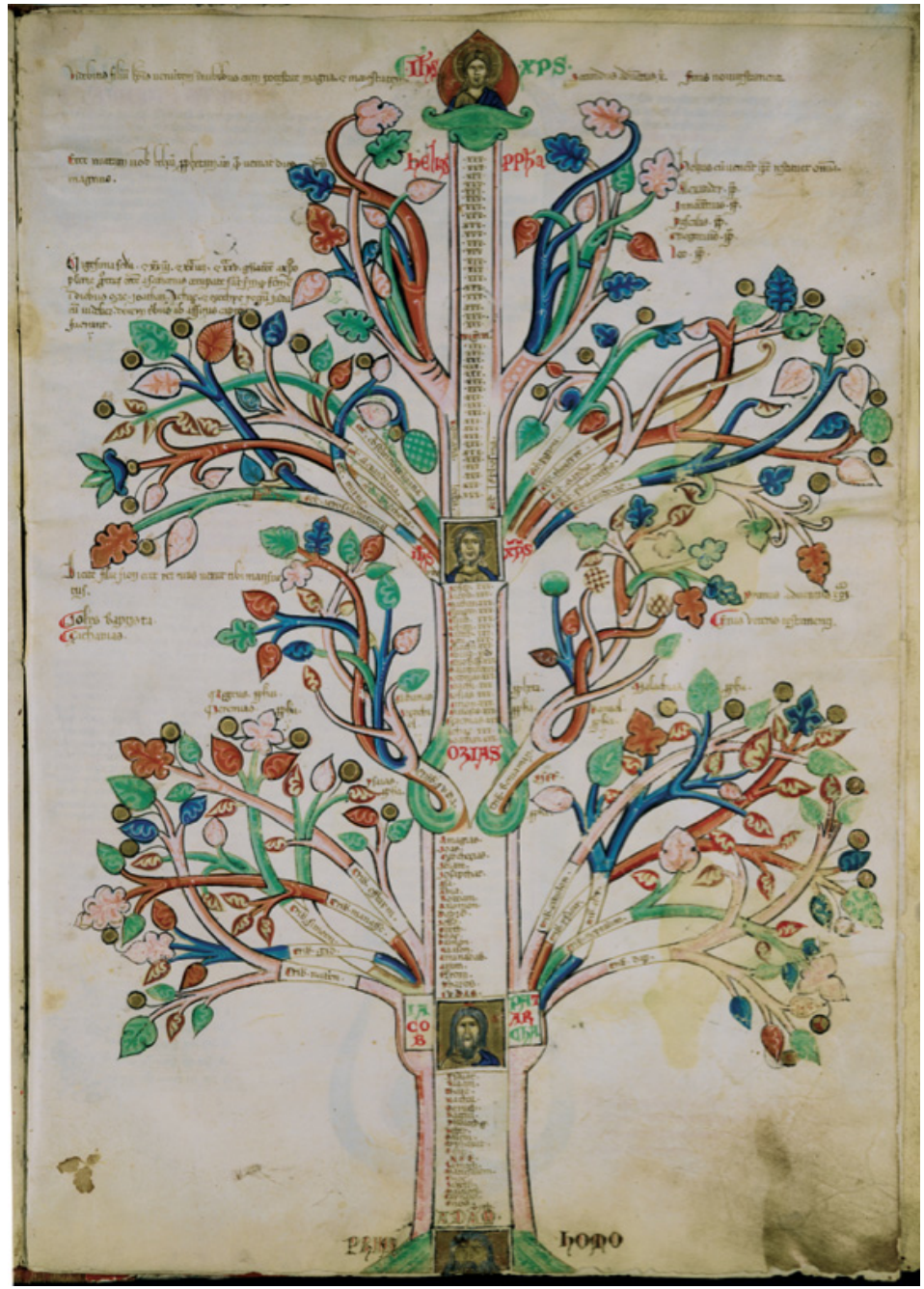
- complies with the given drawing conventions
- optimizes the given aesthetics
- satisfies the partial/local constraints

$\rightarrow$ often lead to NP-hard optimization problems!
$\rightarrow$ often several competing criteria

Example Gallery*

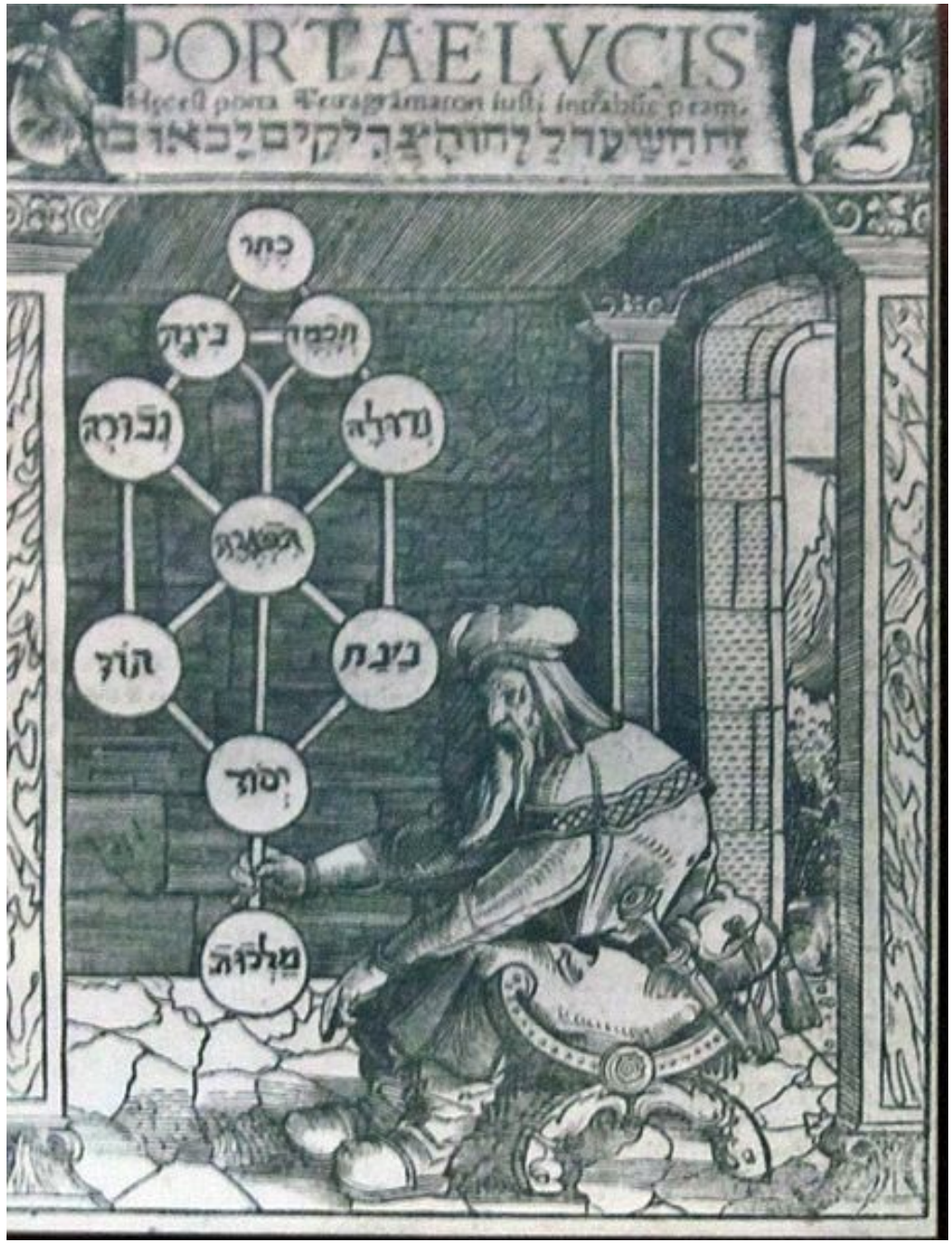
$\star$ for more examples see, e.g., collections like `www.visualcomplexity.com`

Biblical Characters and Events (1202)



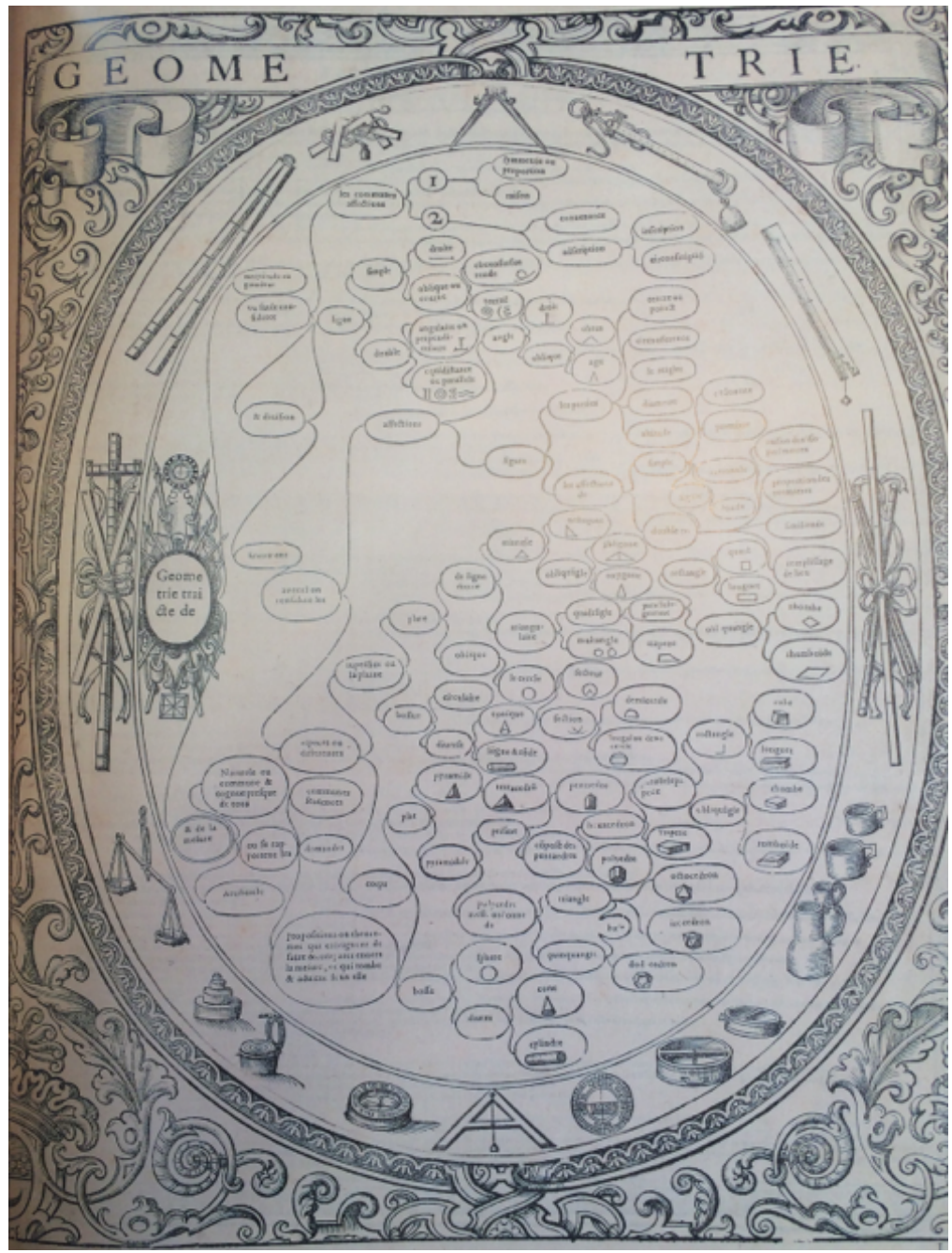
source: Joachim de Fiore

Tree of Life (1516)



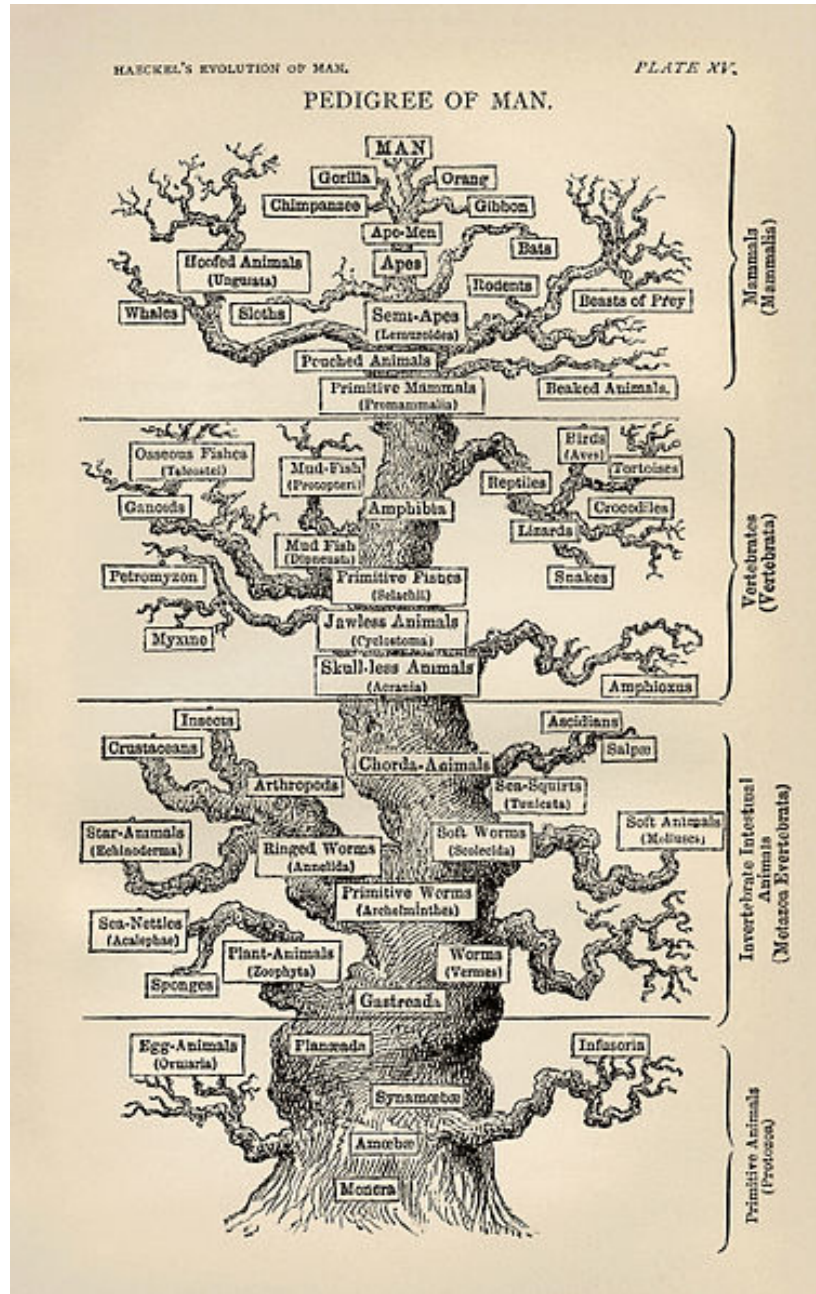
source: Paul Riccius, Portae Lucis

Geometrical Concepts (1587)



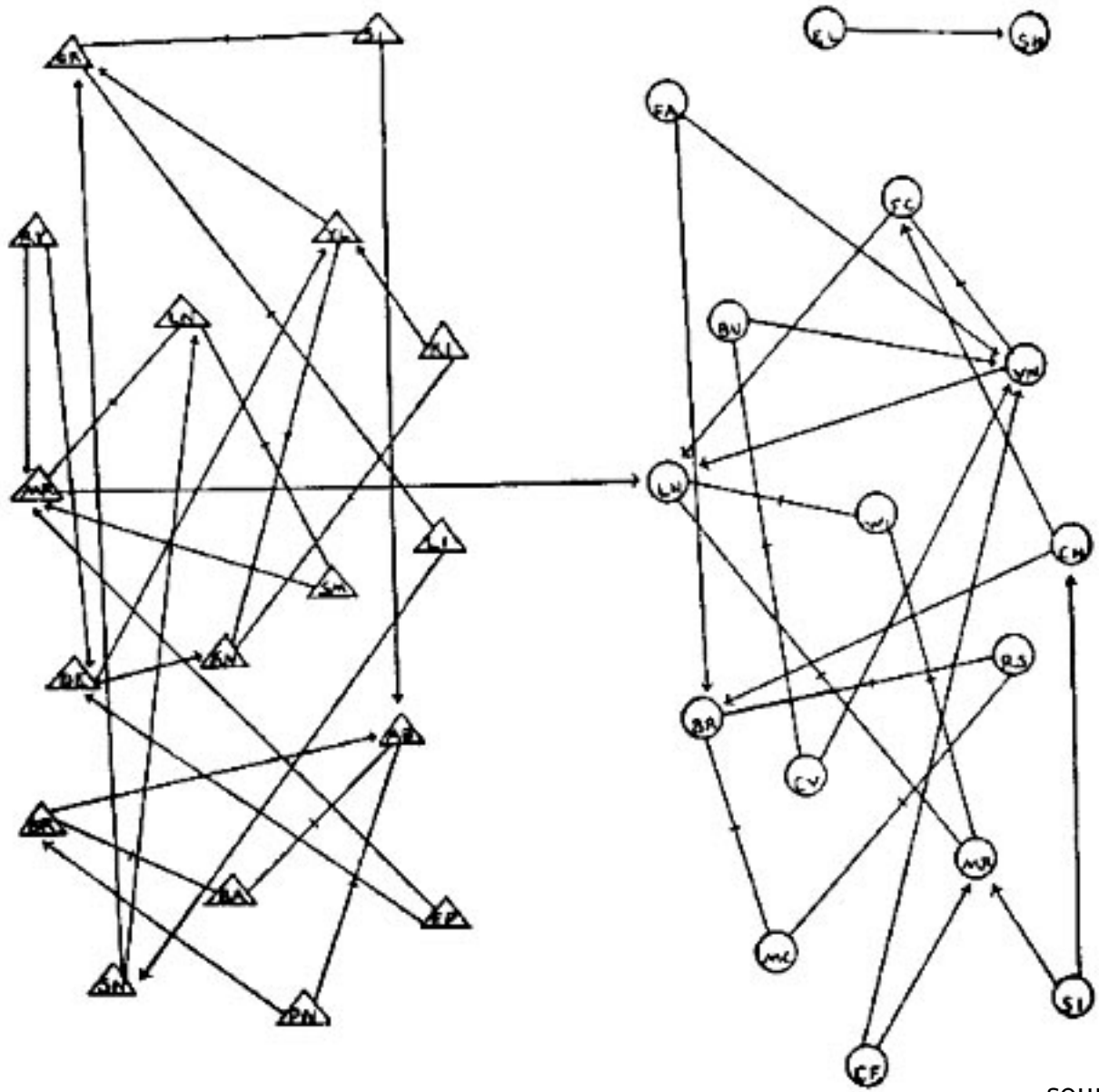
source: Christophe de Savigny

Evolutionary Tree (1879)



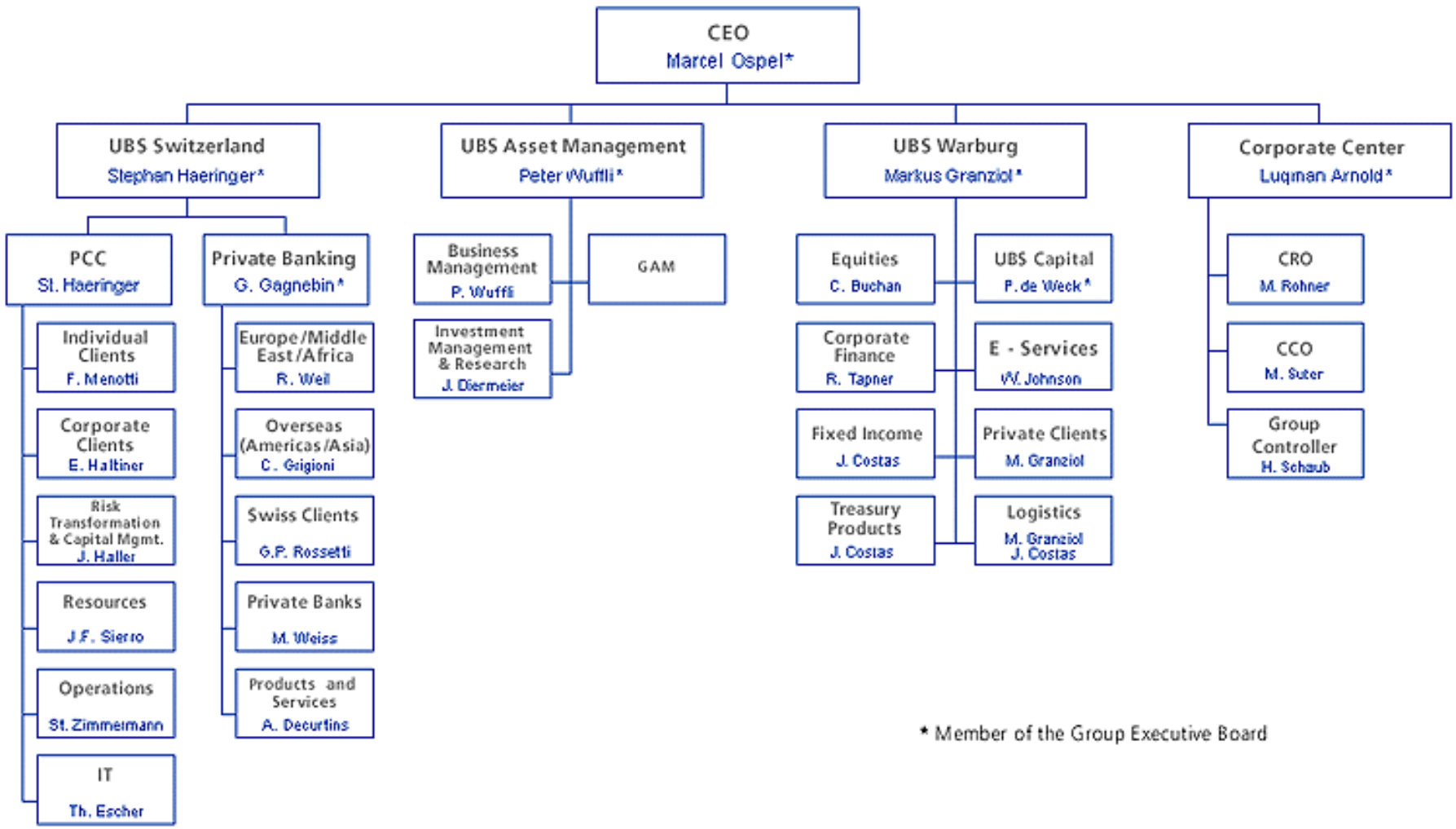
source: Ernst Haeckel

Sociogram (1933)



source: Moreno

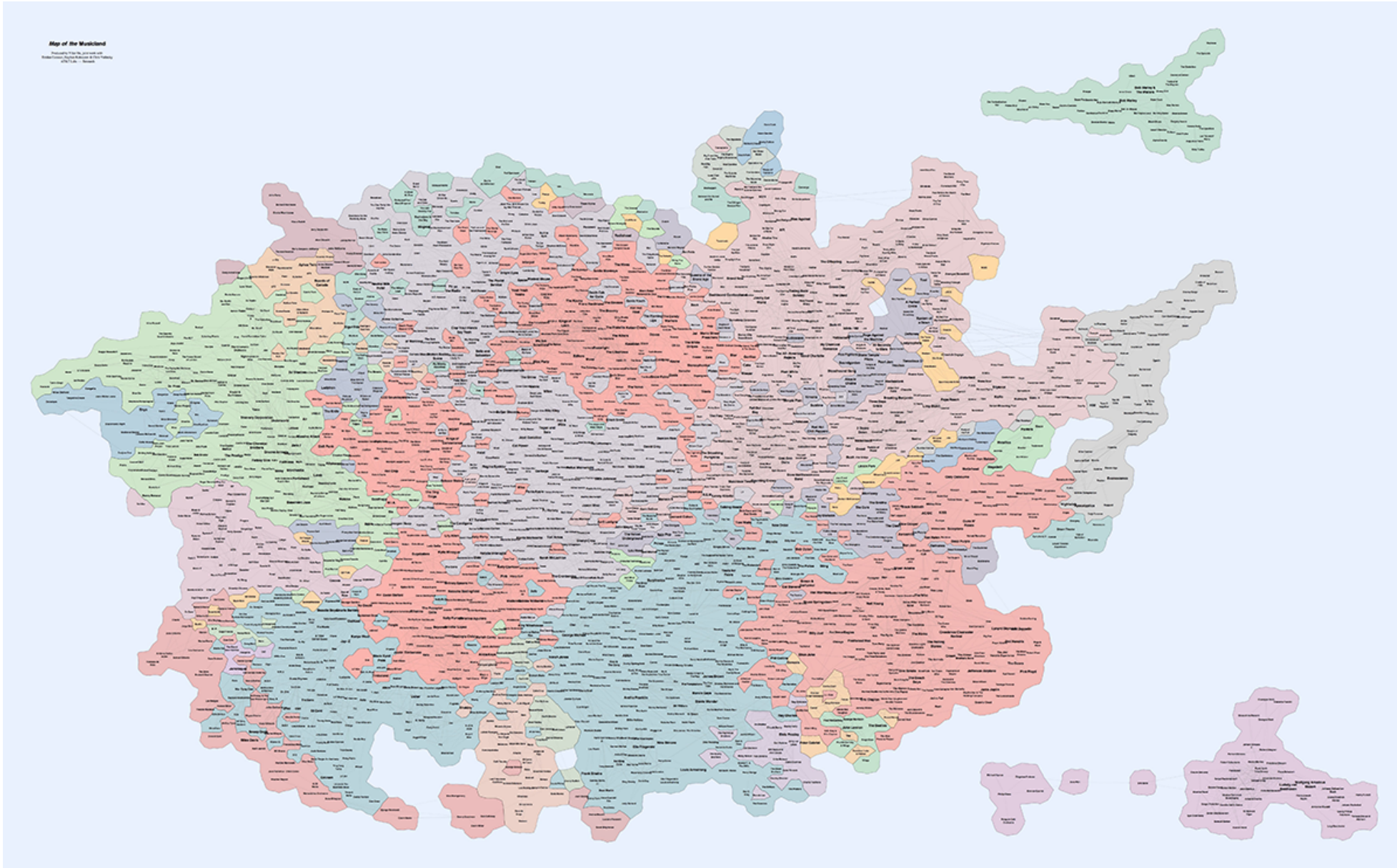
Social Network – Organigram UBS



CPAN Developer Graph

source: cpan-explorer.org

last.fm music graph as political map



(Gansner, Hu, Kobourov: GMap, 2009)

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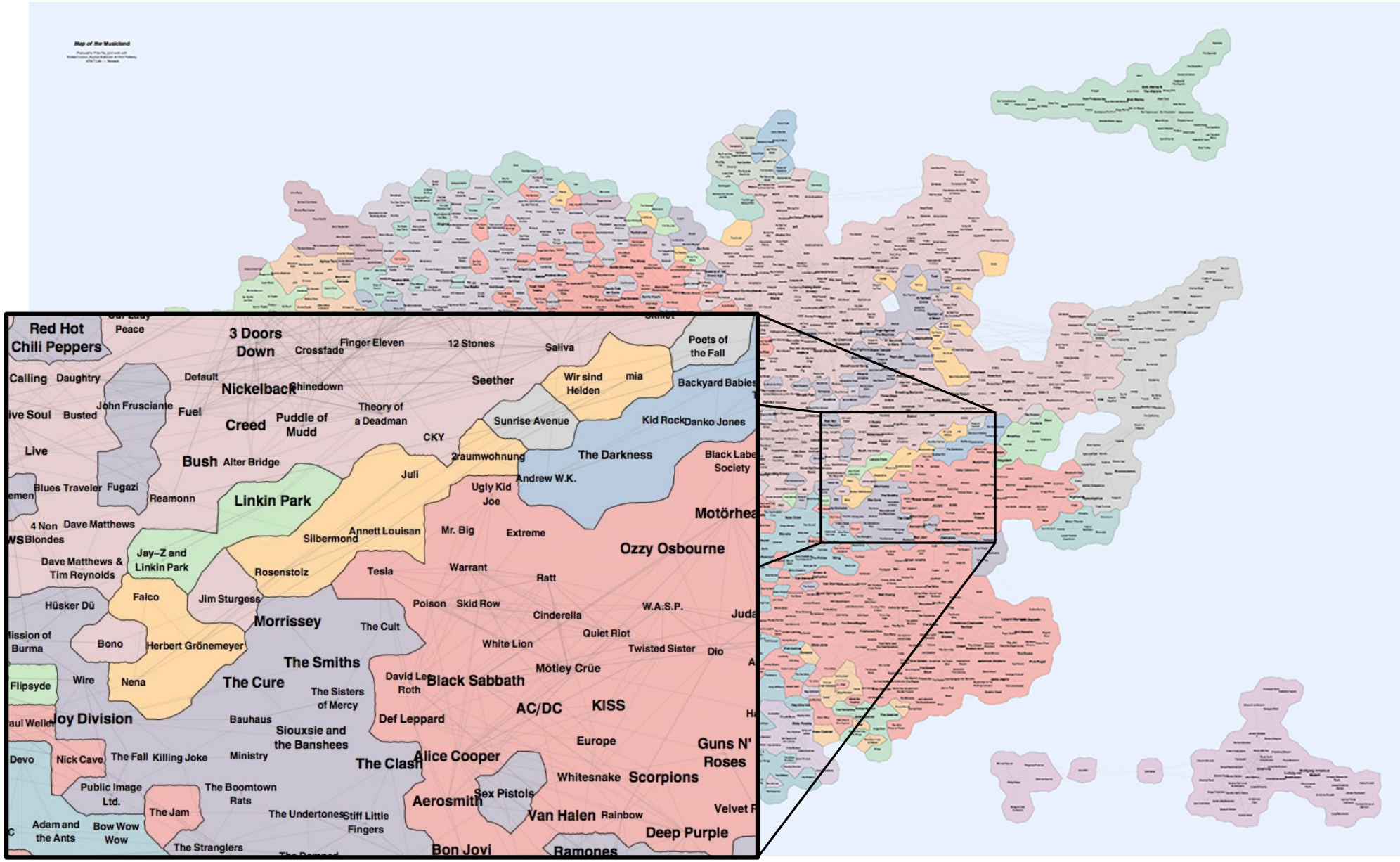
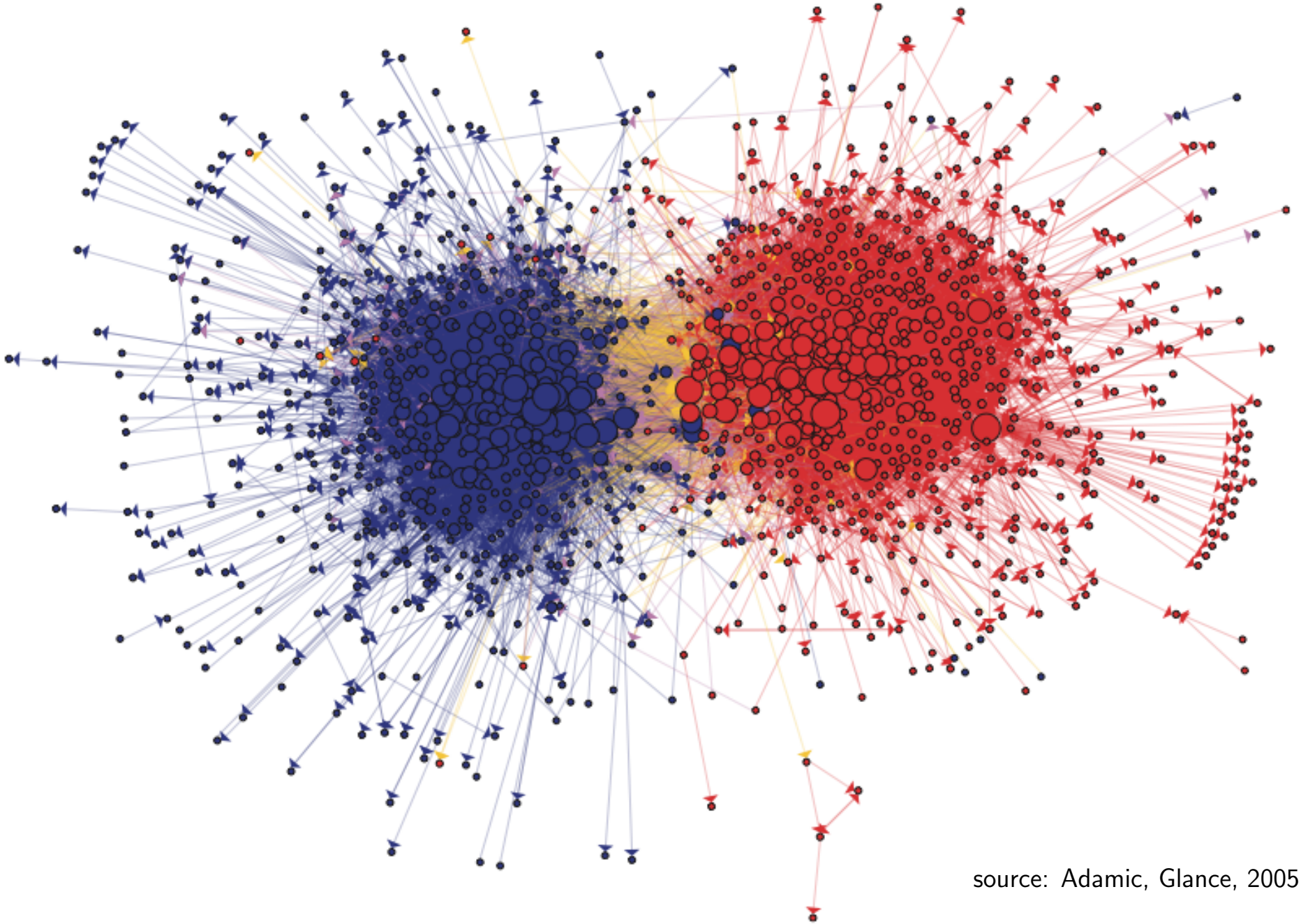


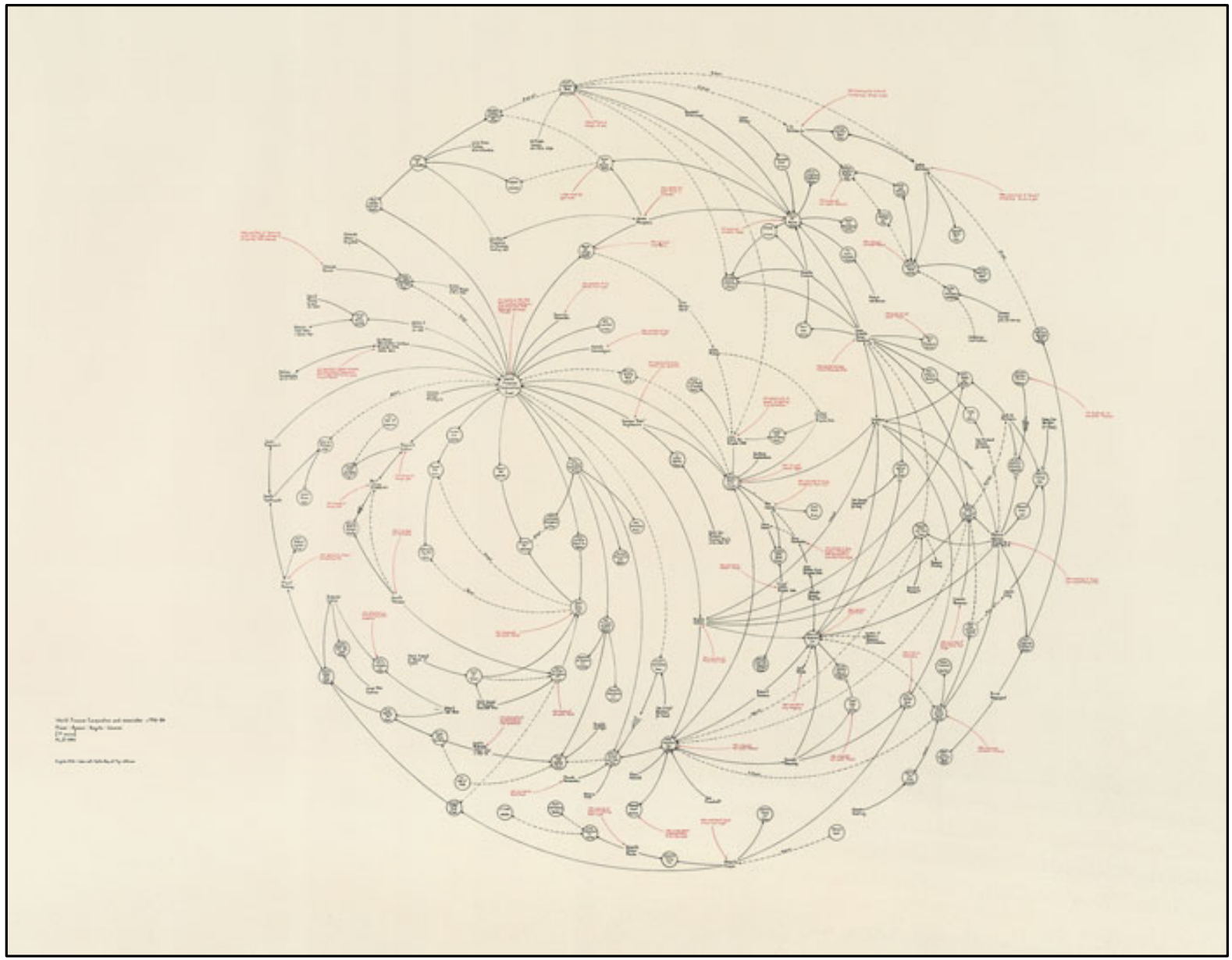
(Gansner, Hu, Kobourov: GMap, 2009)

Blogosphere 2004 Elections USA



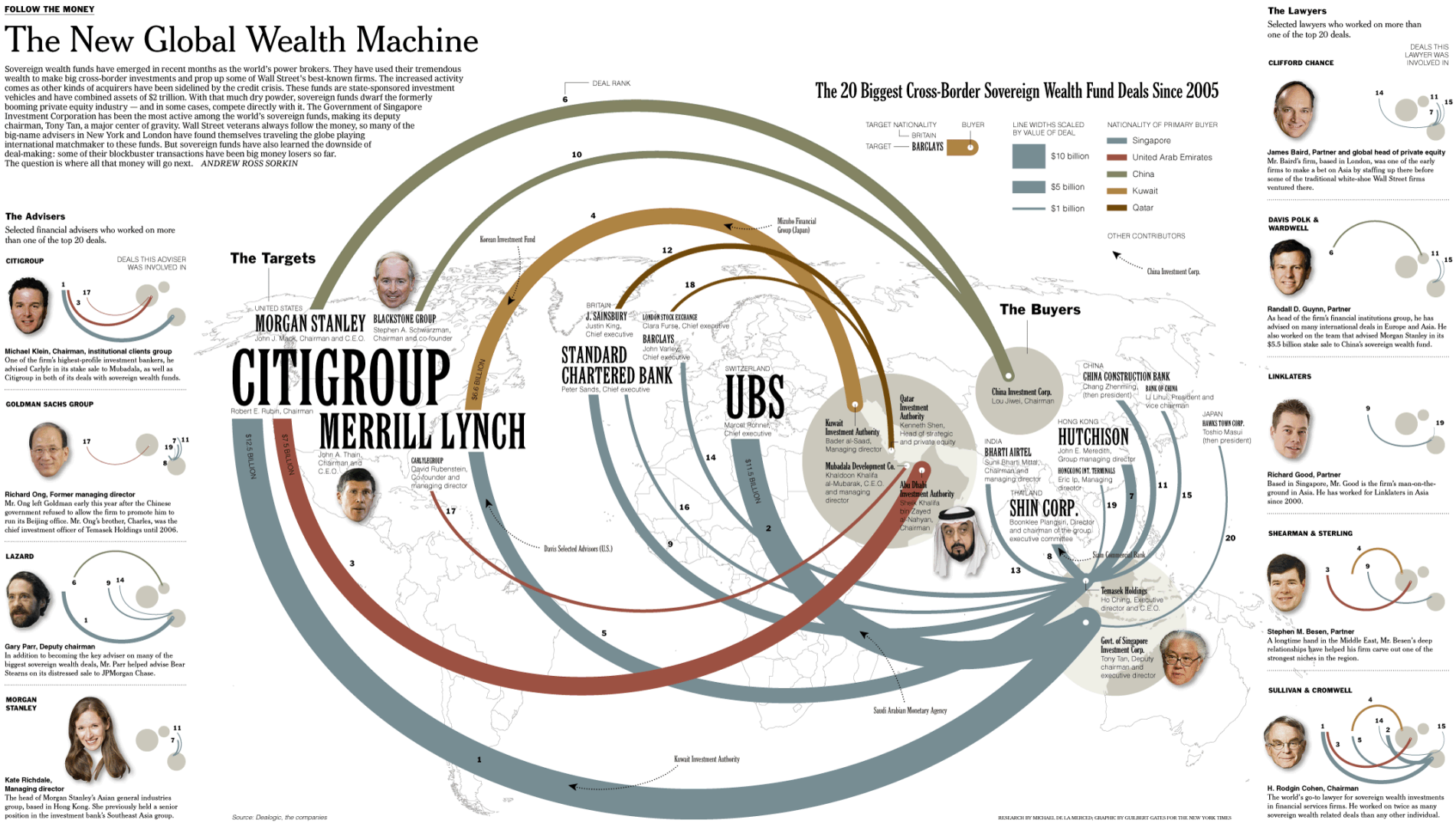
source: Adamic, Glance, 2005

Social Network – World Financial System

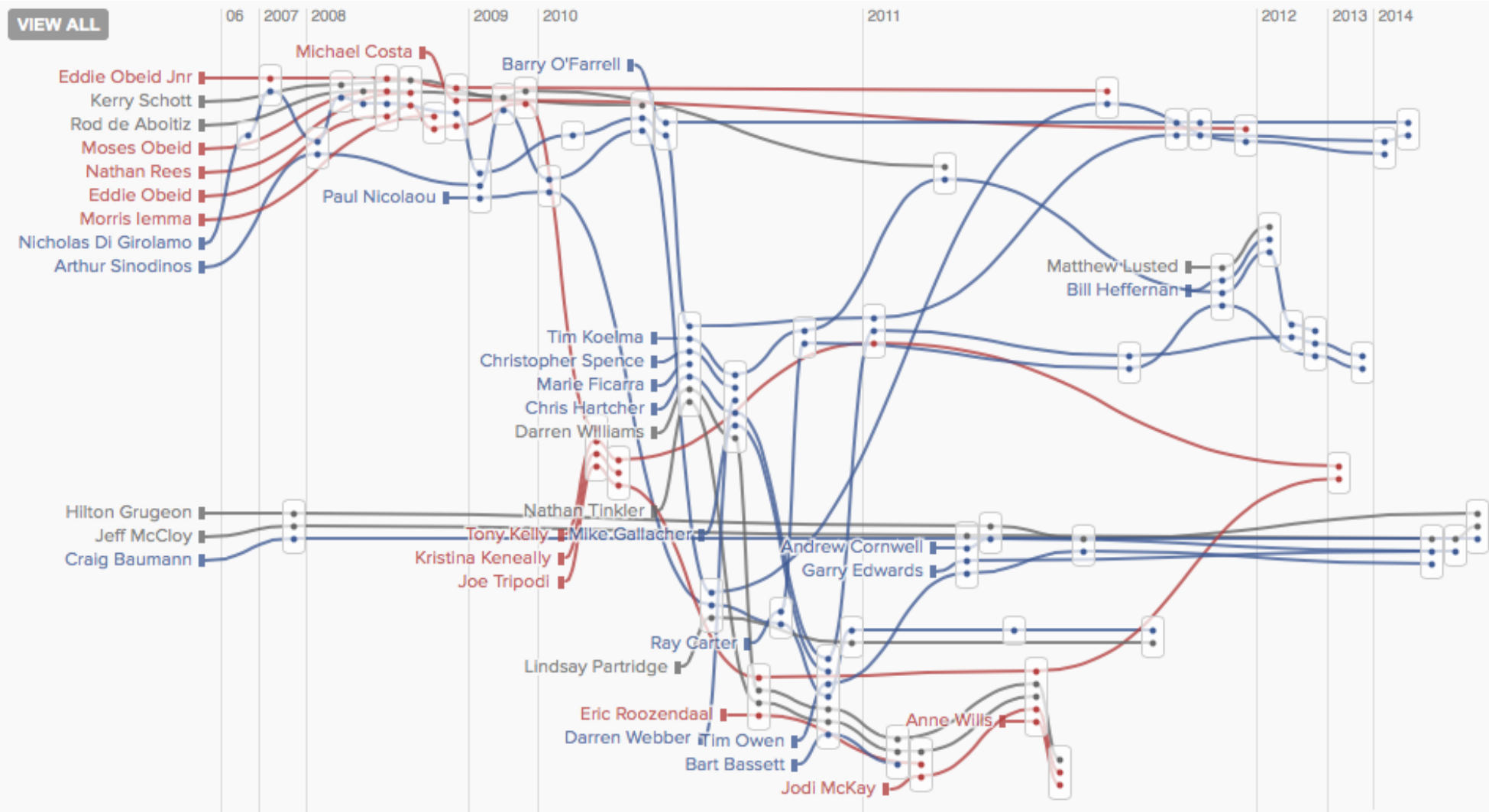


World Finance Corporation
© Mark Lombardi

Social Networks – State Funds

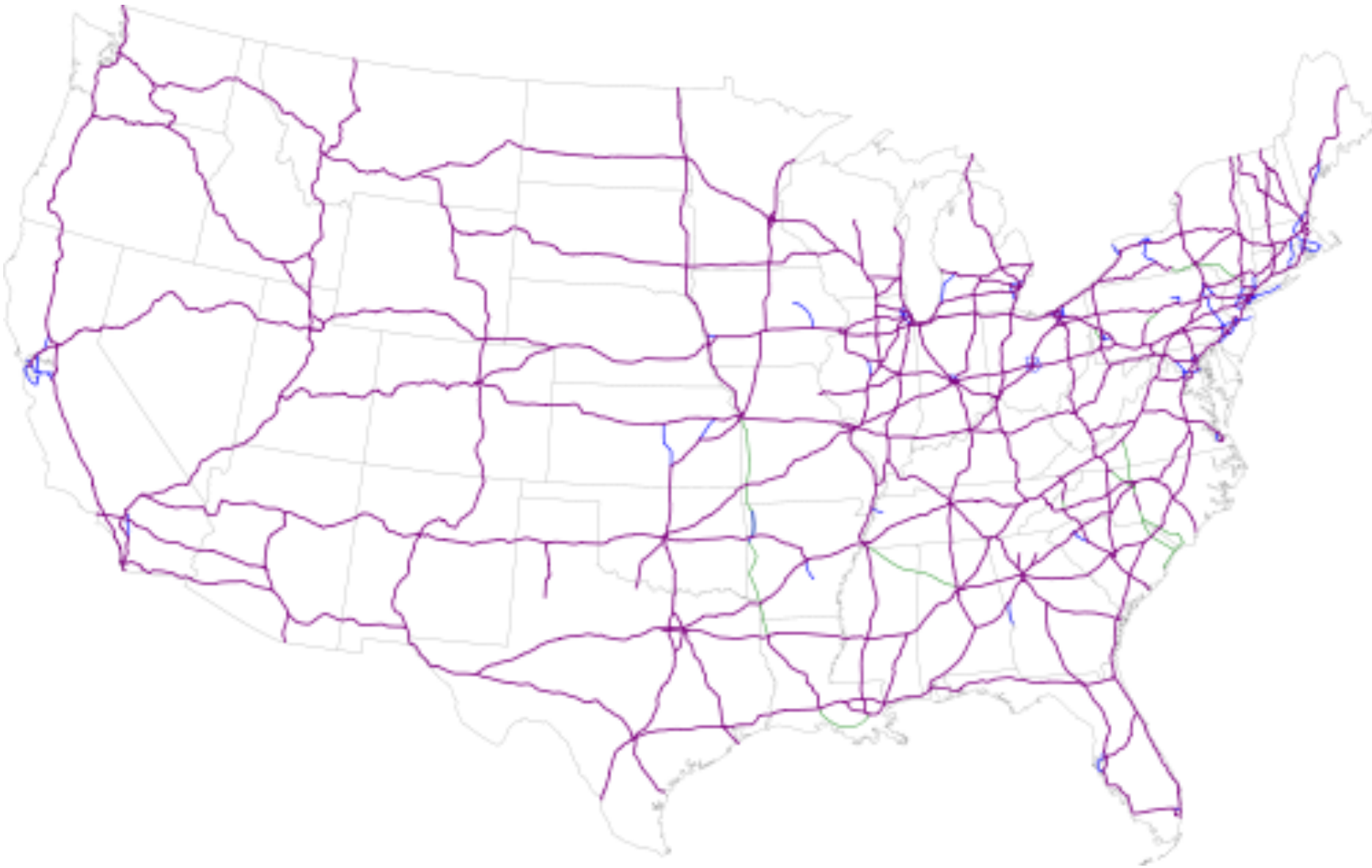


Temporal Graph Layout: Storylines



source: ABC news, Australia

Traffic Network – Highways USA



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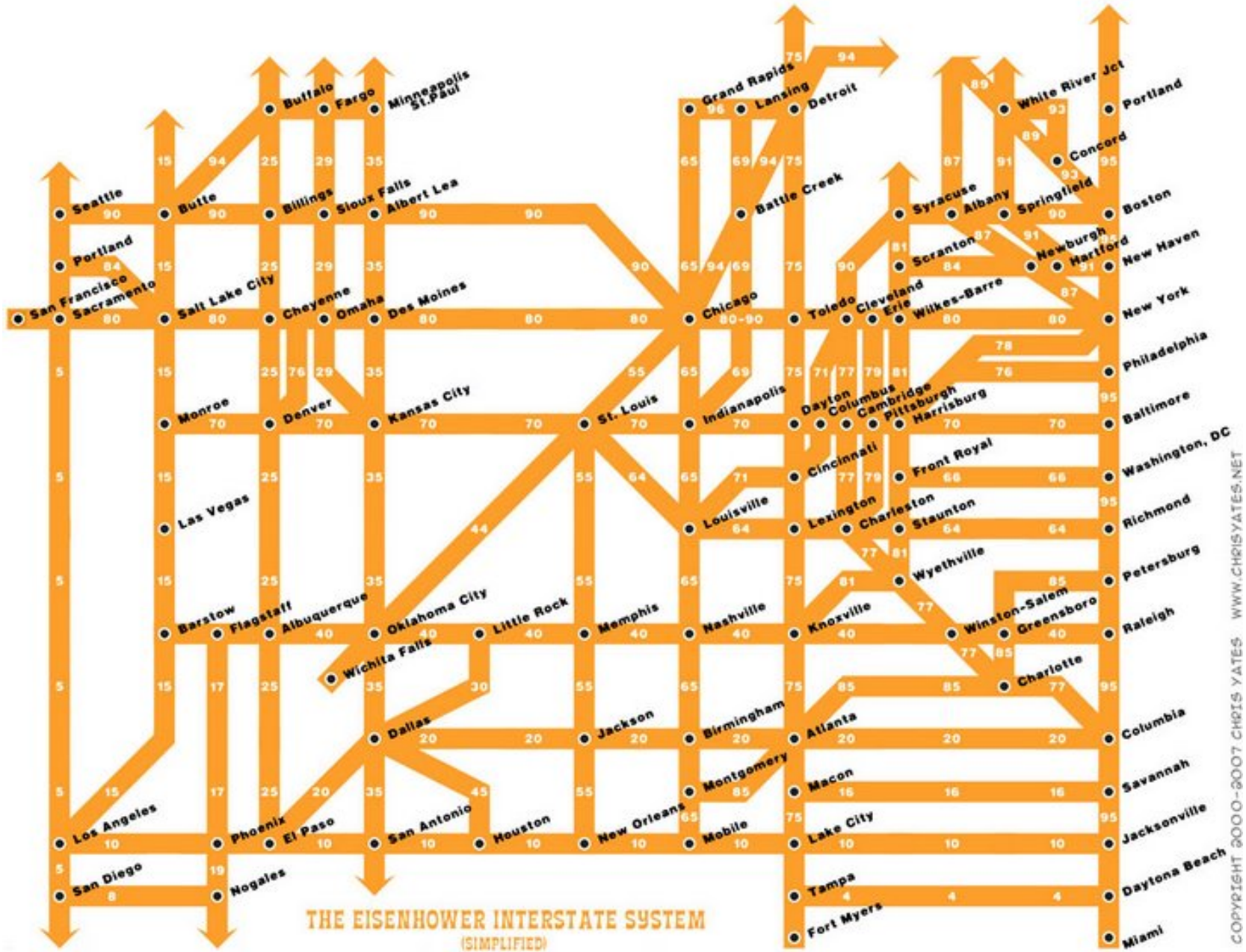
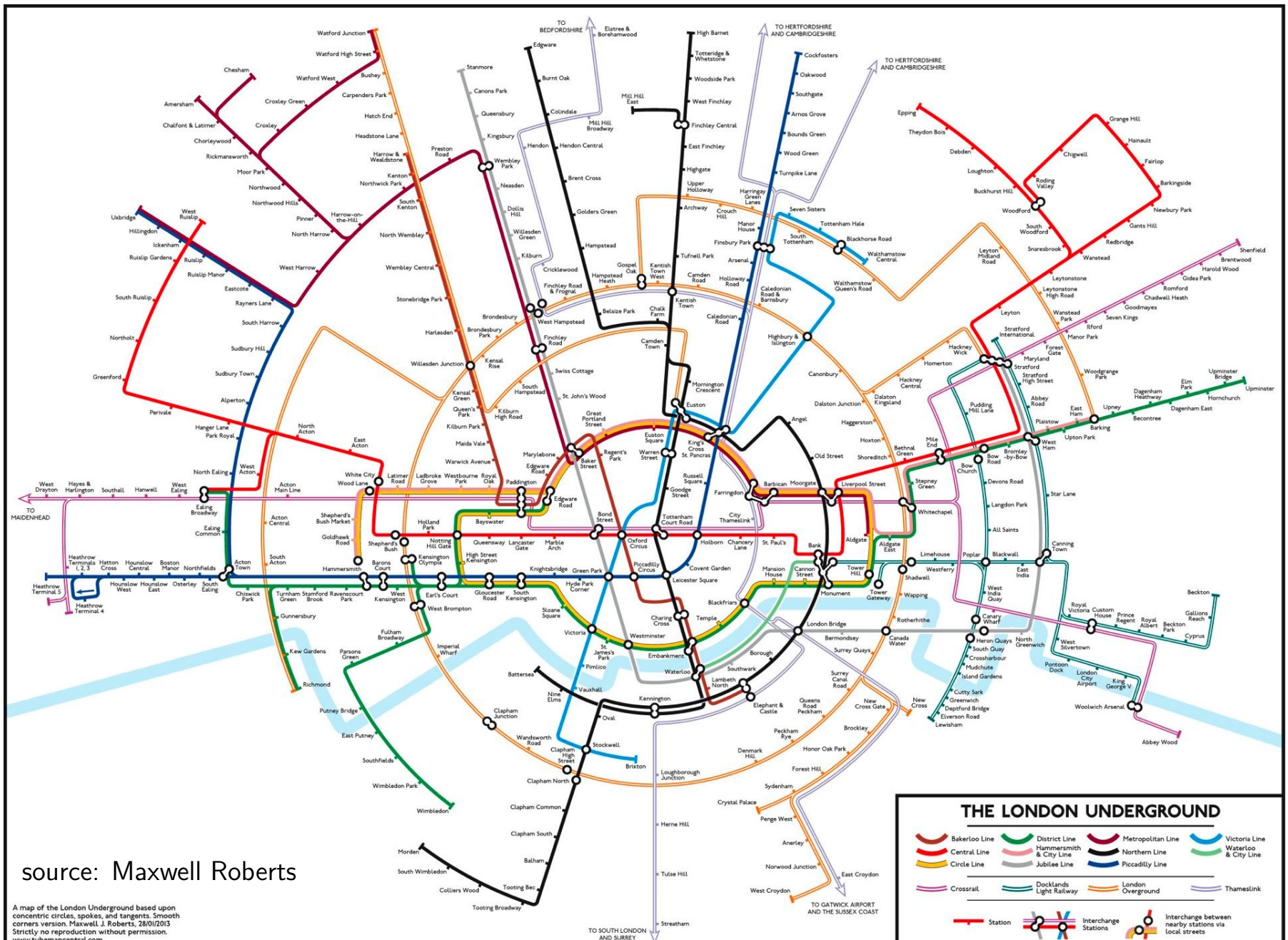


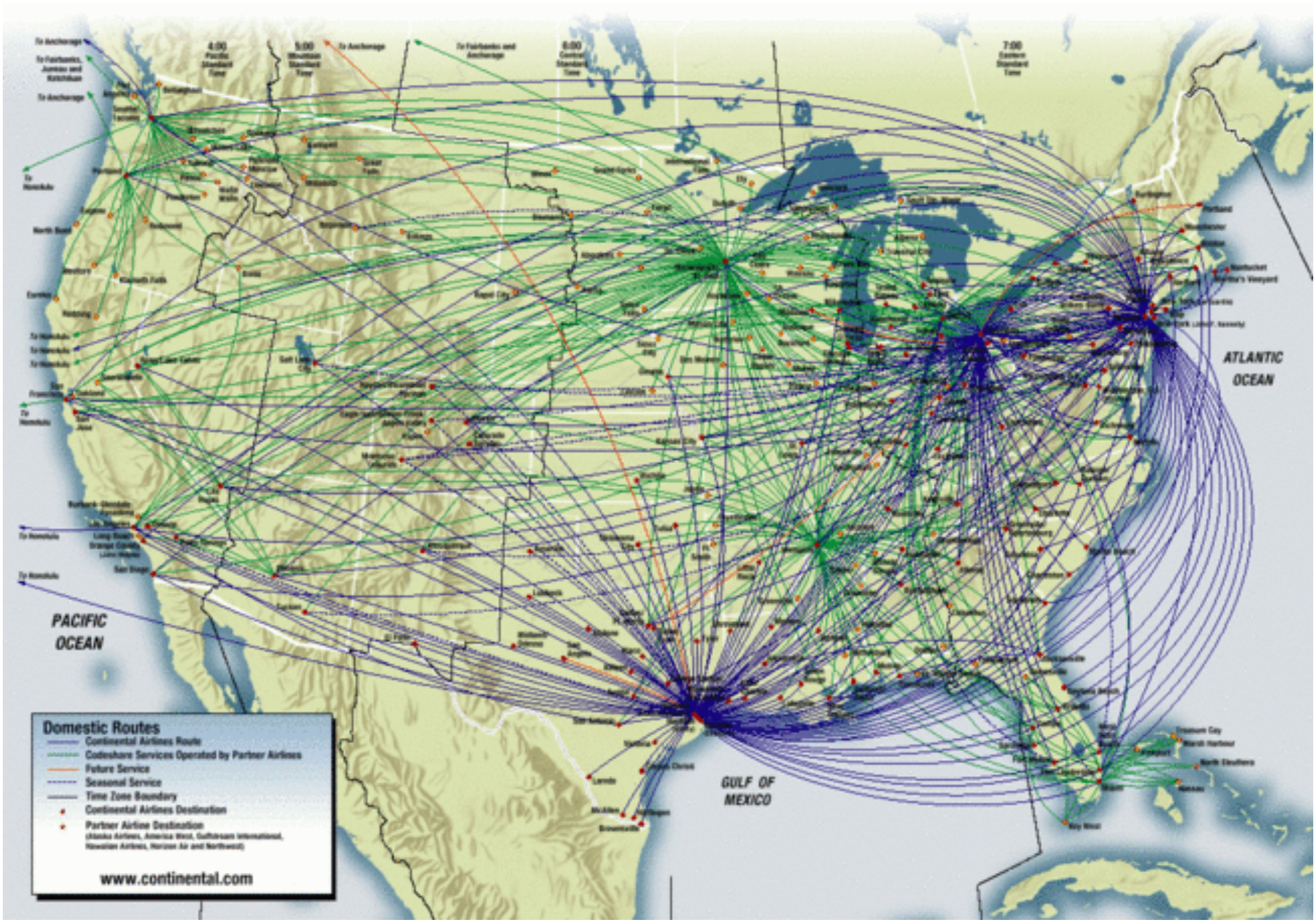
London Tube Map (1933)

source: Henry Beck

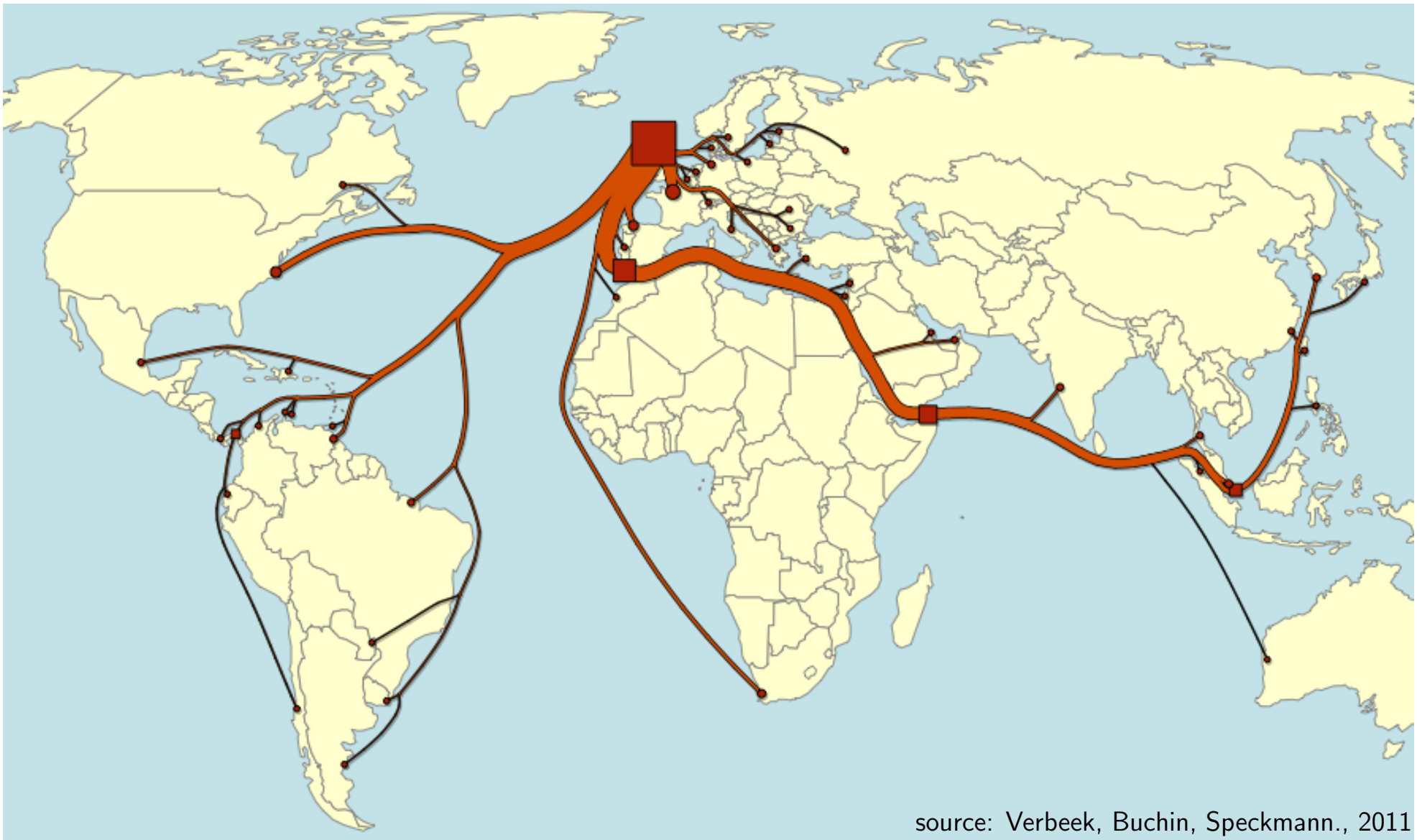
Concentric Tube Map



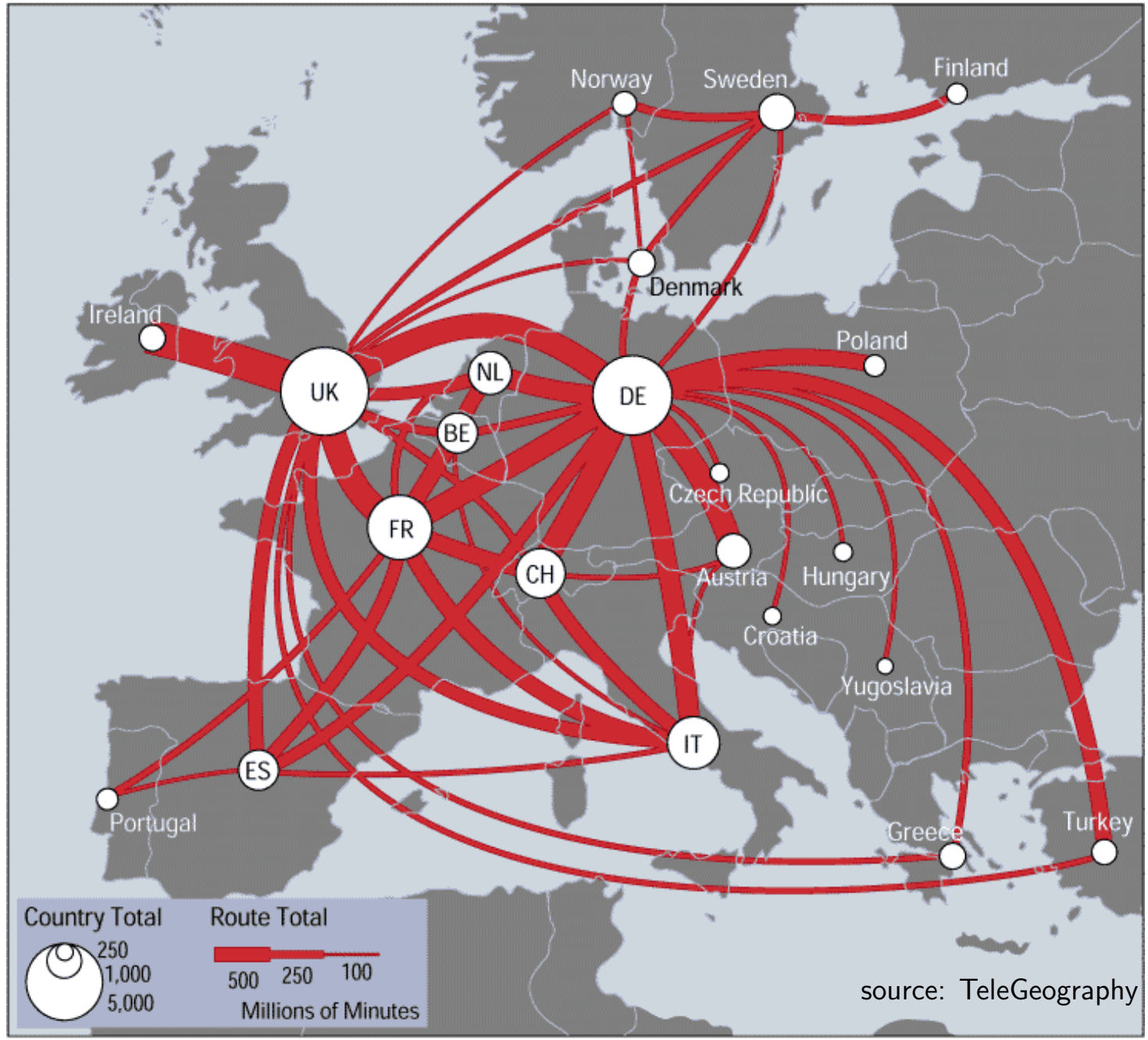
Traffic Network – Flight Destinations Continental



Flow-Map: Whiskey Exports



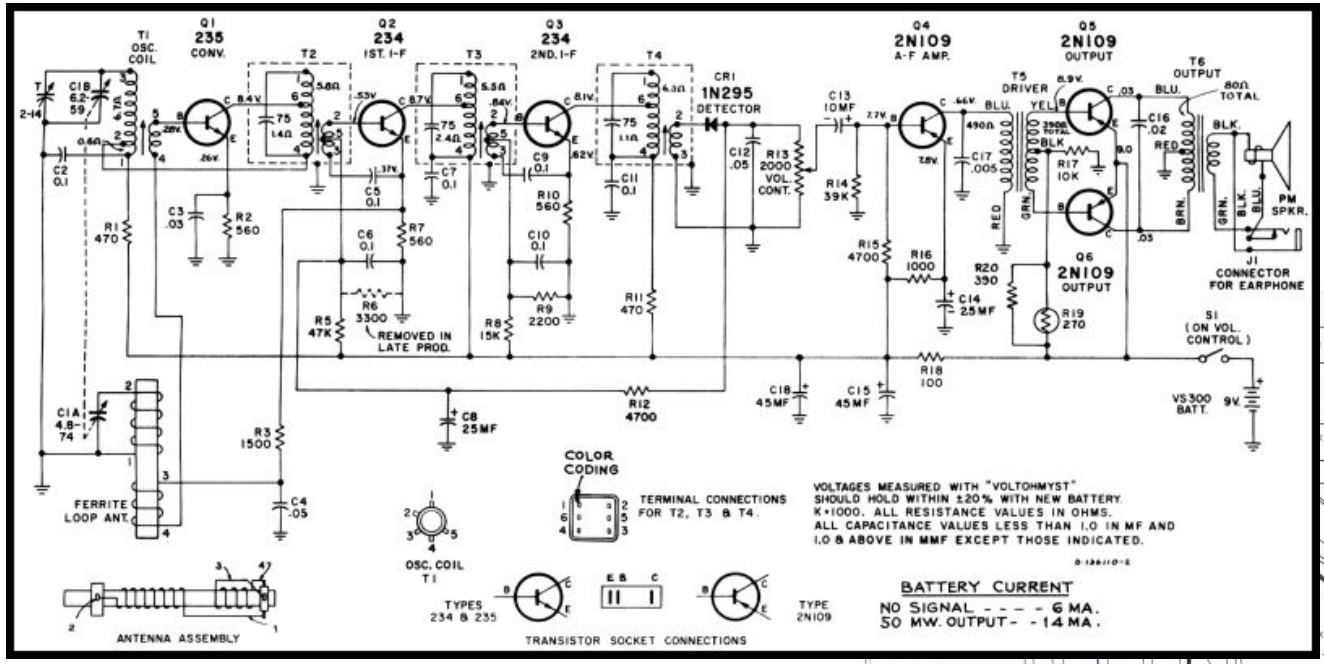
Phone Volume Map

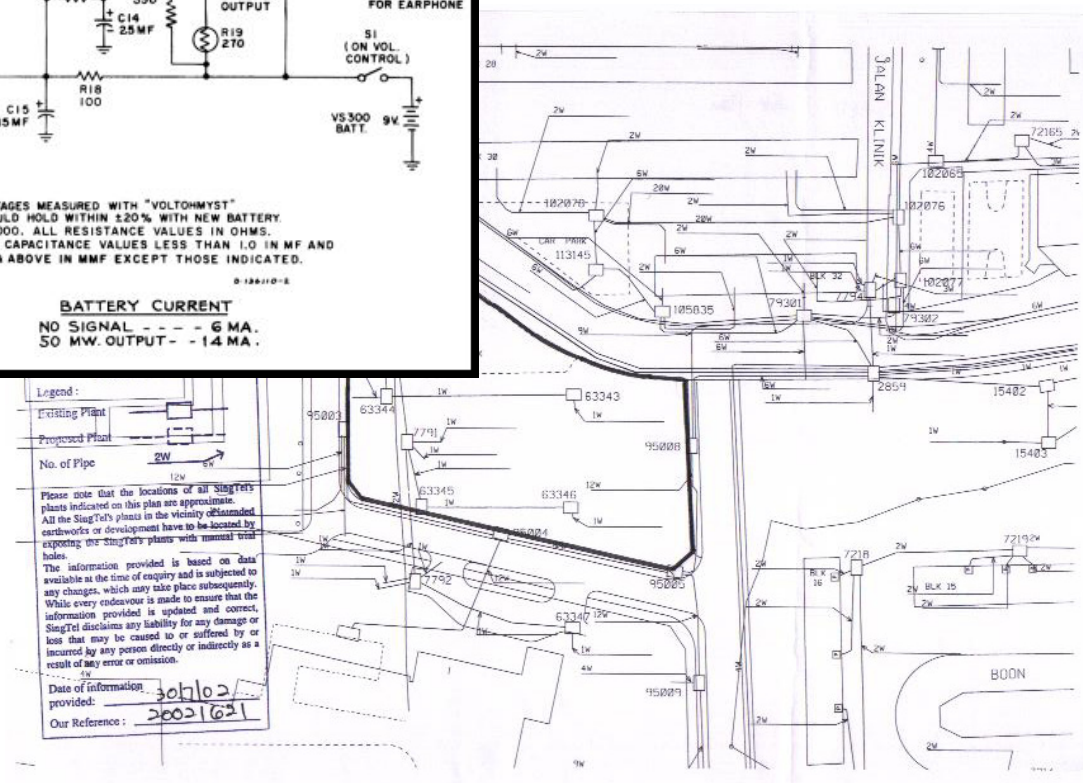


Monitoring Energy Networks

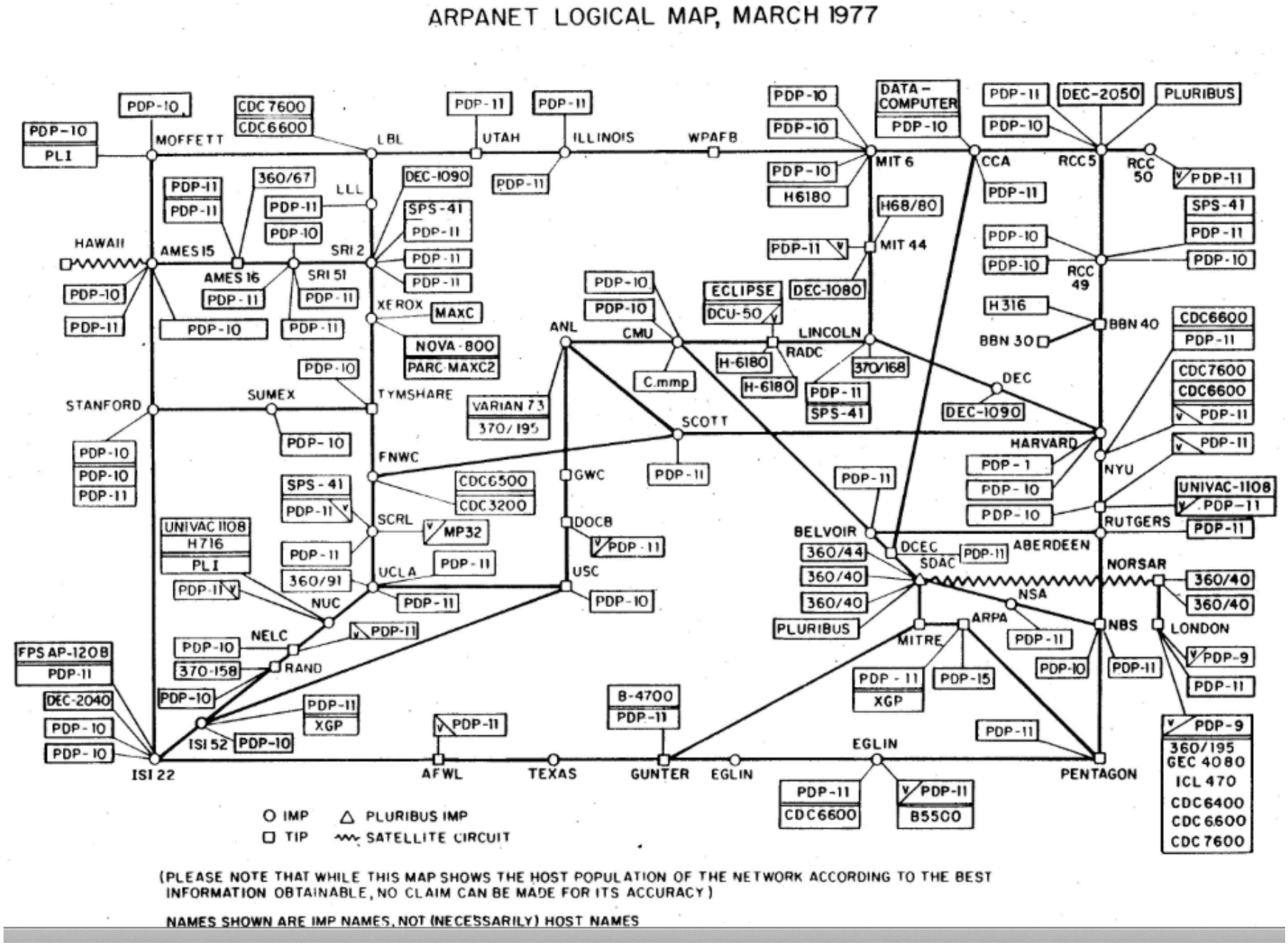
source: Eir Grid, Irland

Technical Networks – Circuit Diagram/Cable Plan

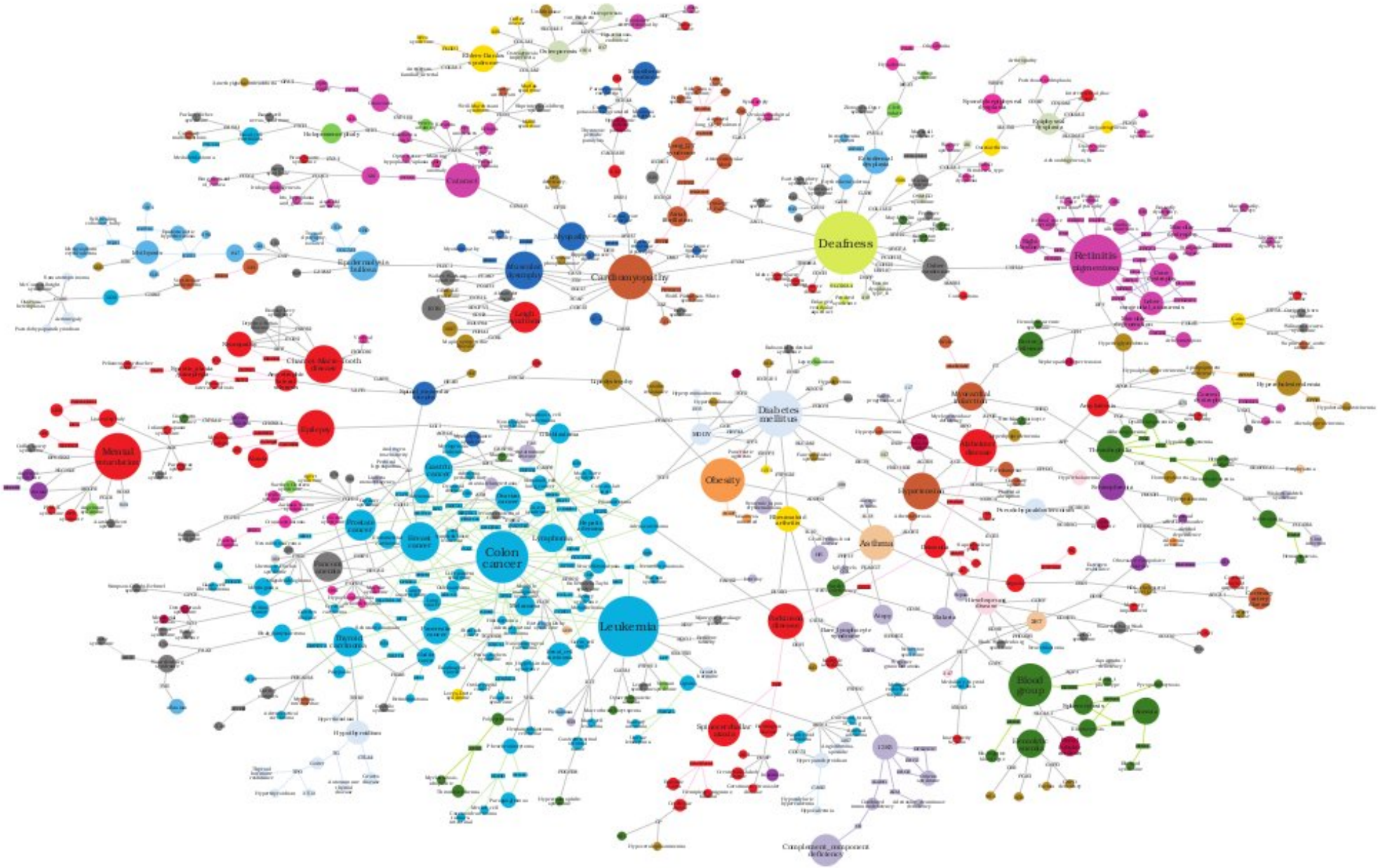




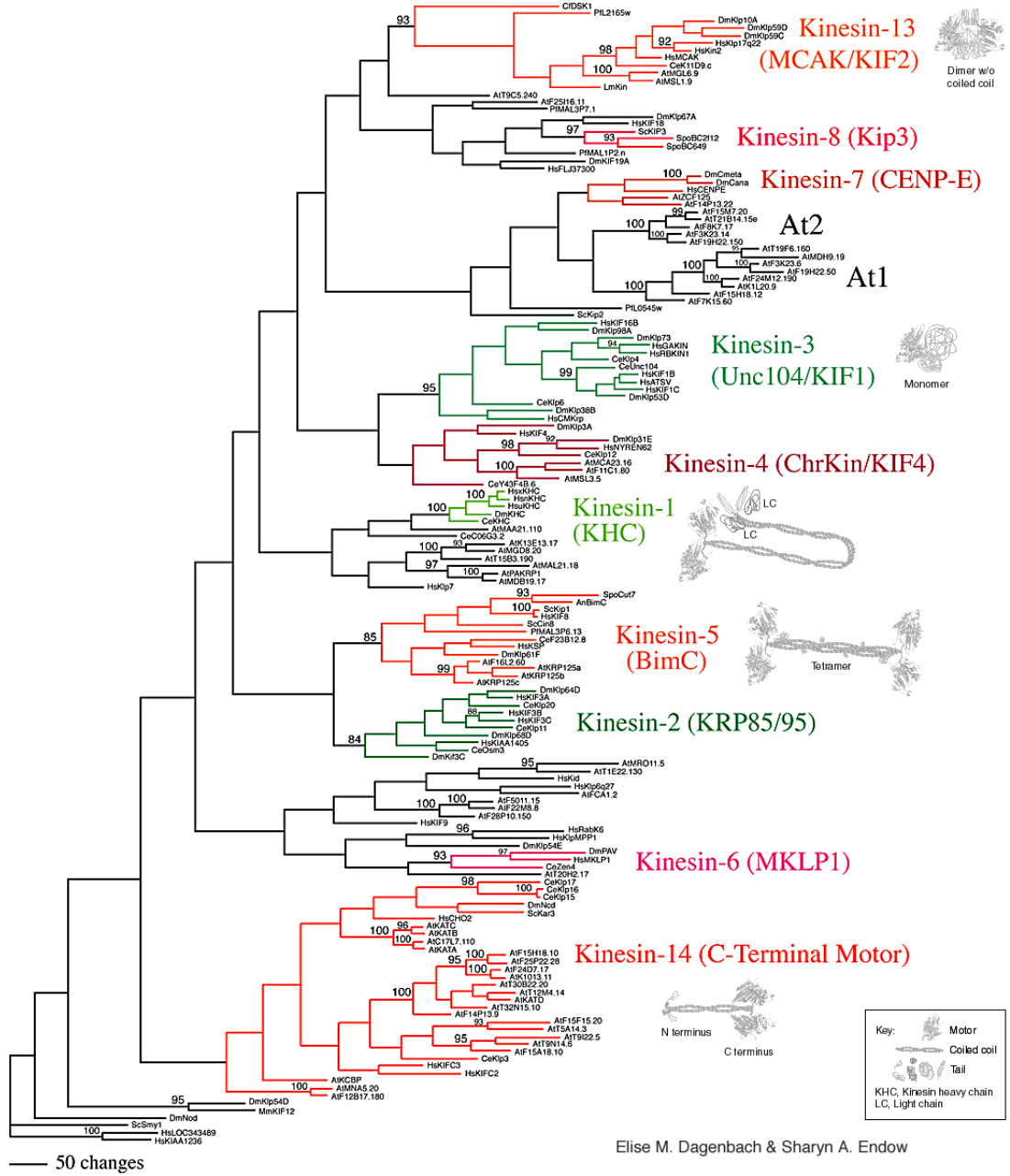
ARPANET Sketch (1977)



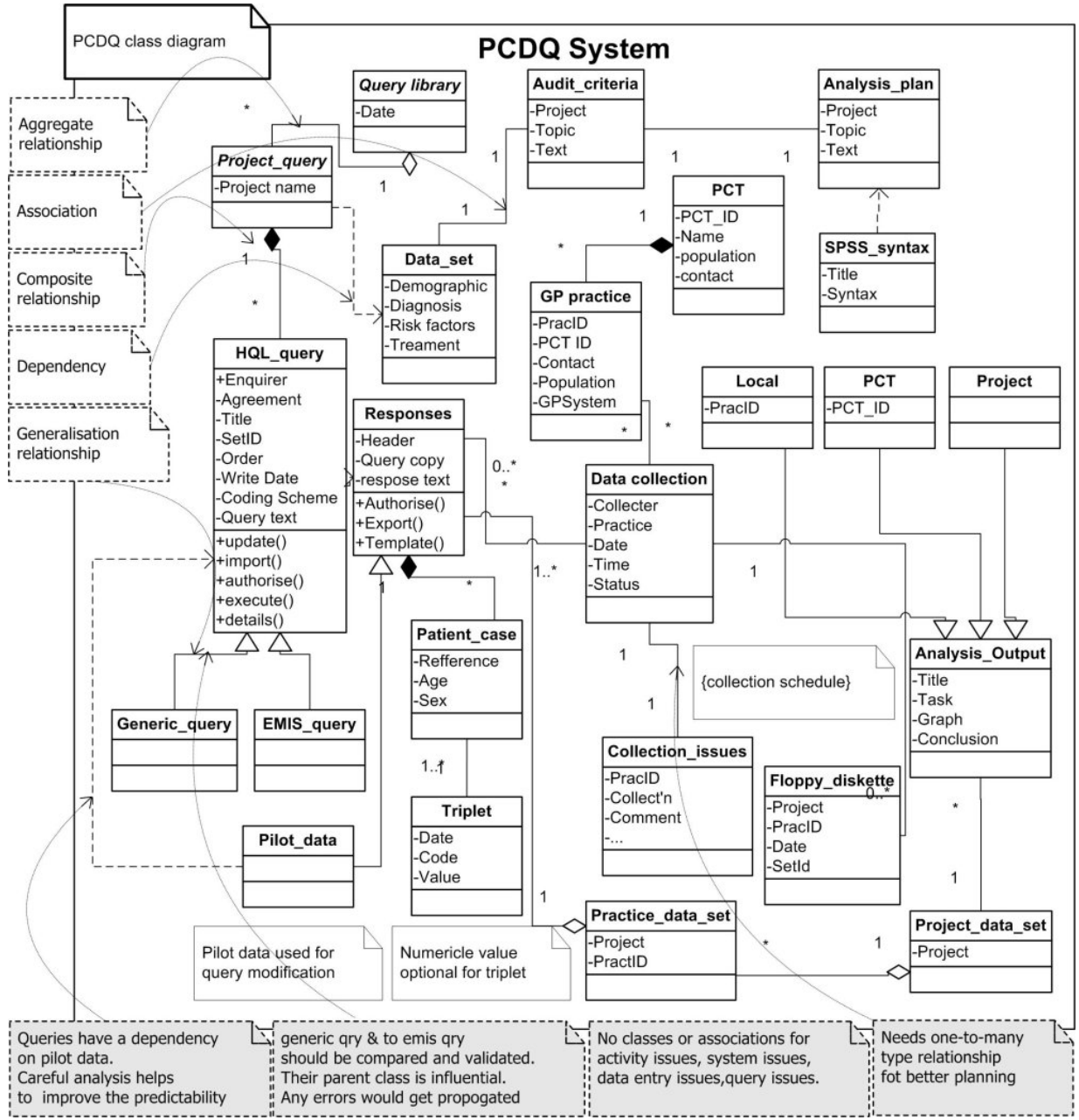
Biomedical Network – Diseasome



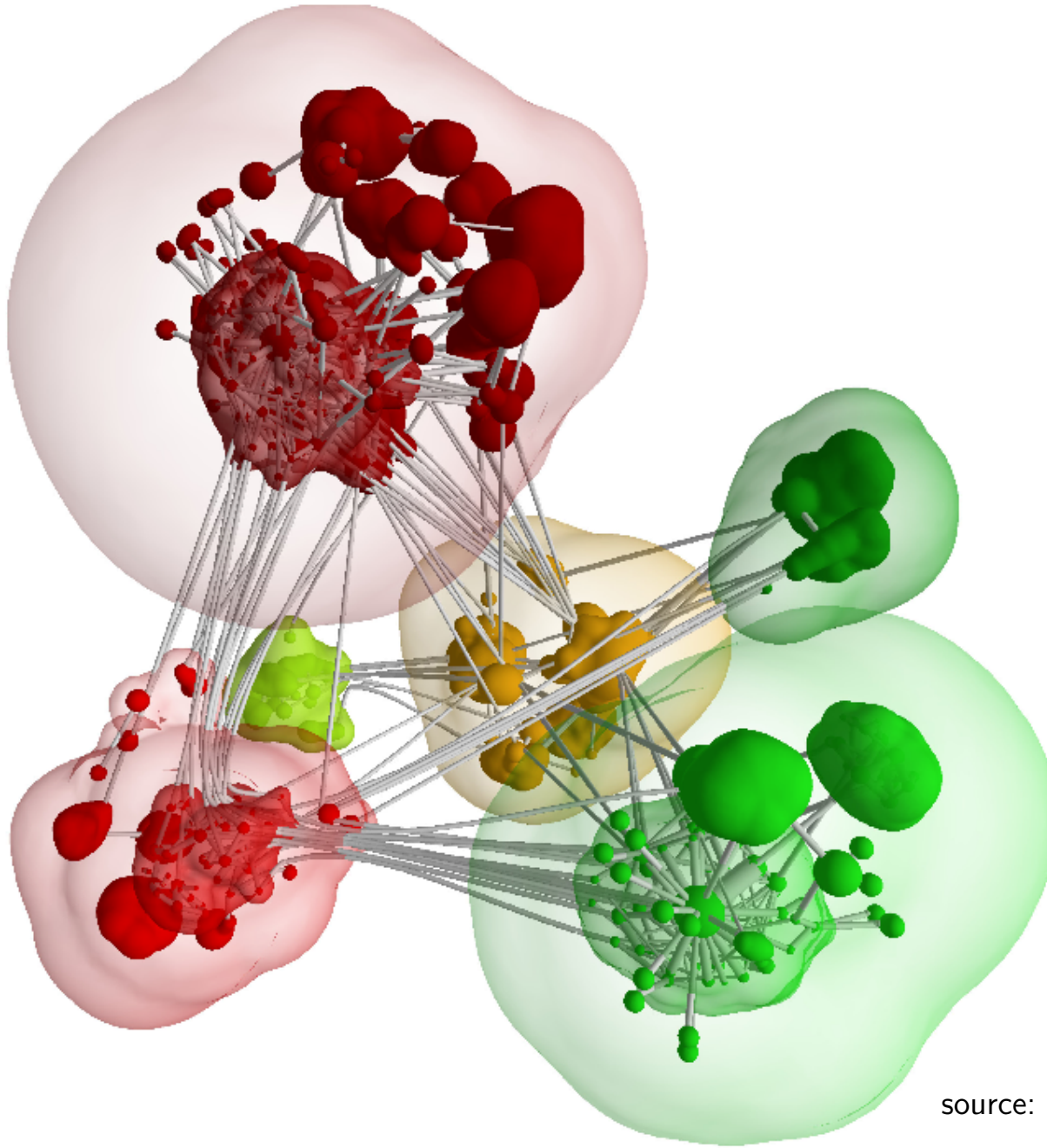
Biology – Phylogenetic Trees



Software Engineering – UML Diagrams

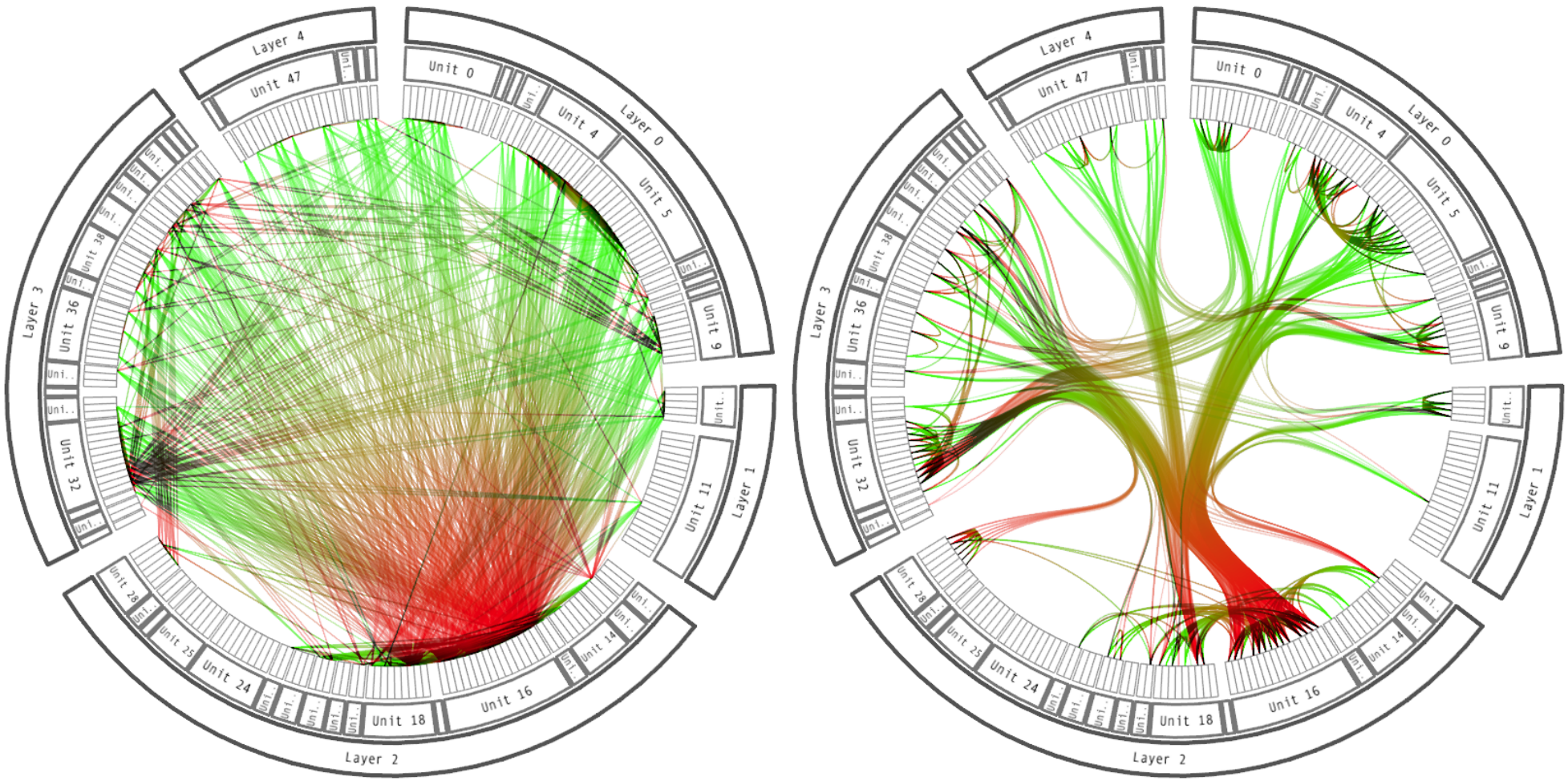


Clustered Software Graph in 3D



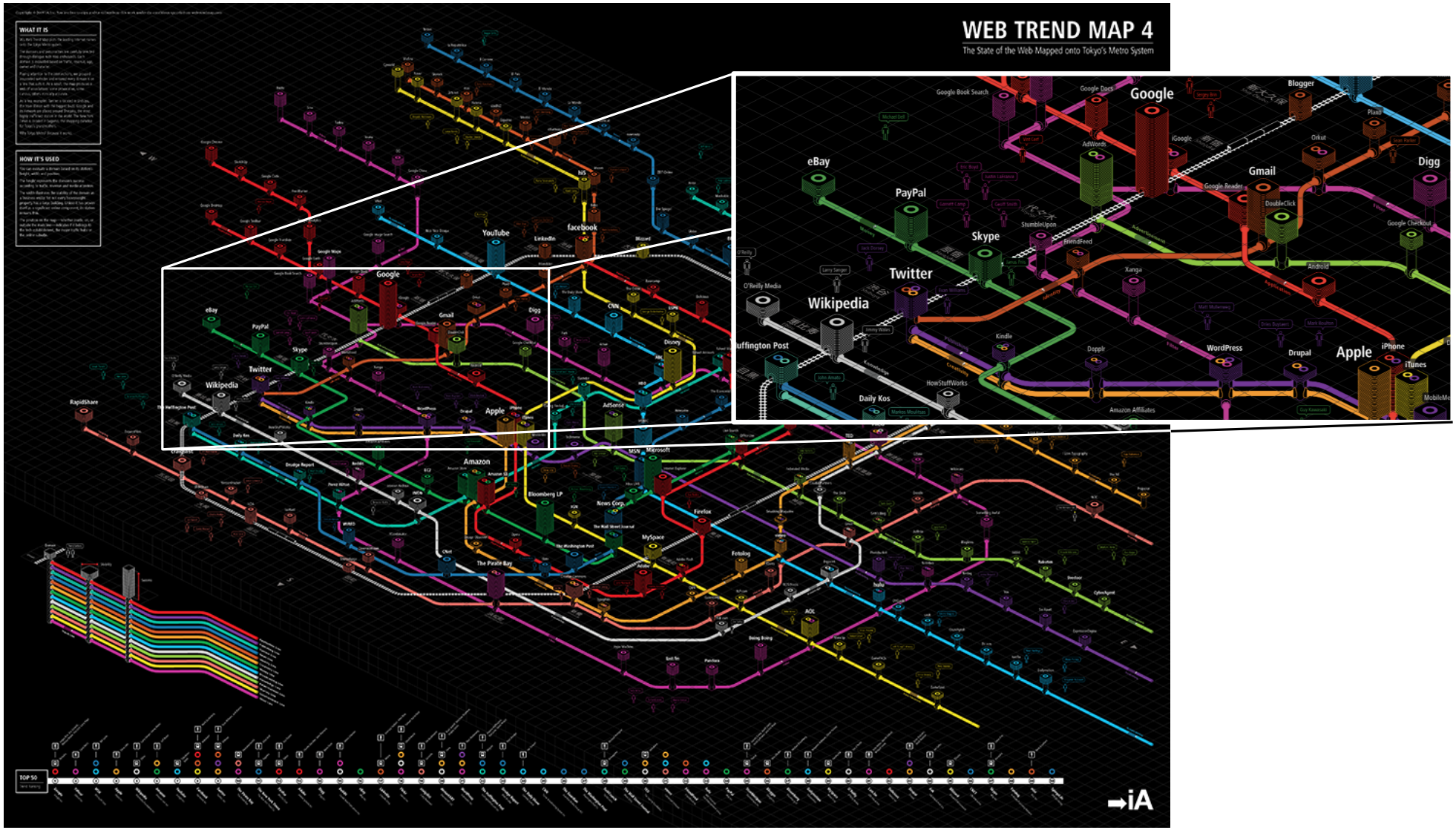
source: Balzer, Deussen, 2007

Software Call Graph with Edge Bundling



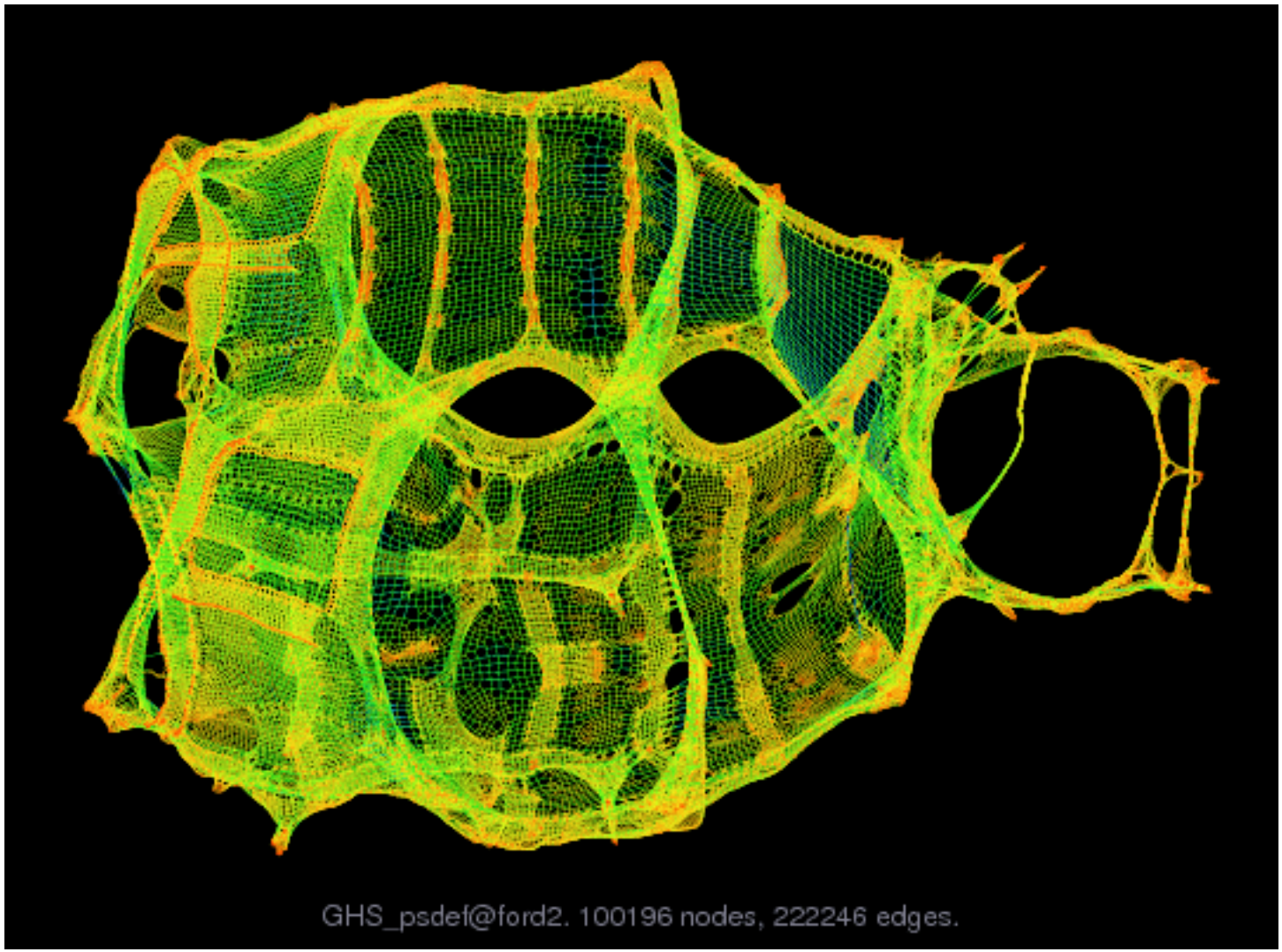
source: Danny Holten, 2011

Web Trend Map



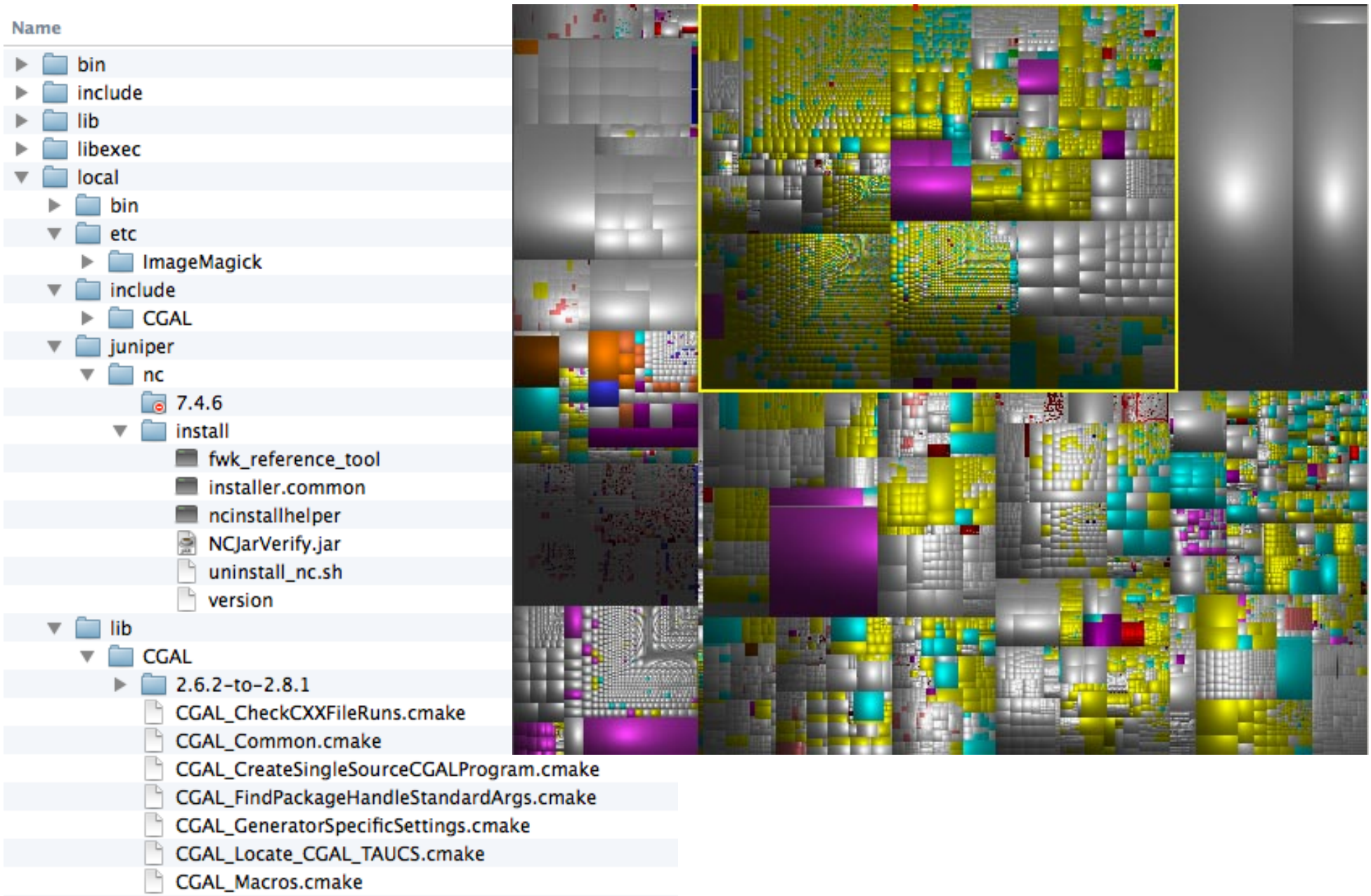
source: information Architects, 2009

Large Graphs – Component Mesh

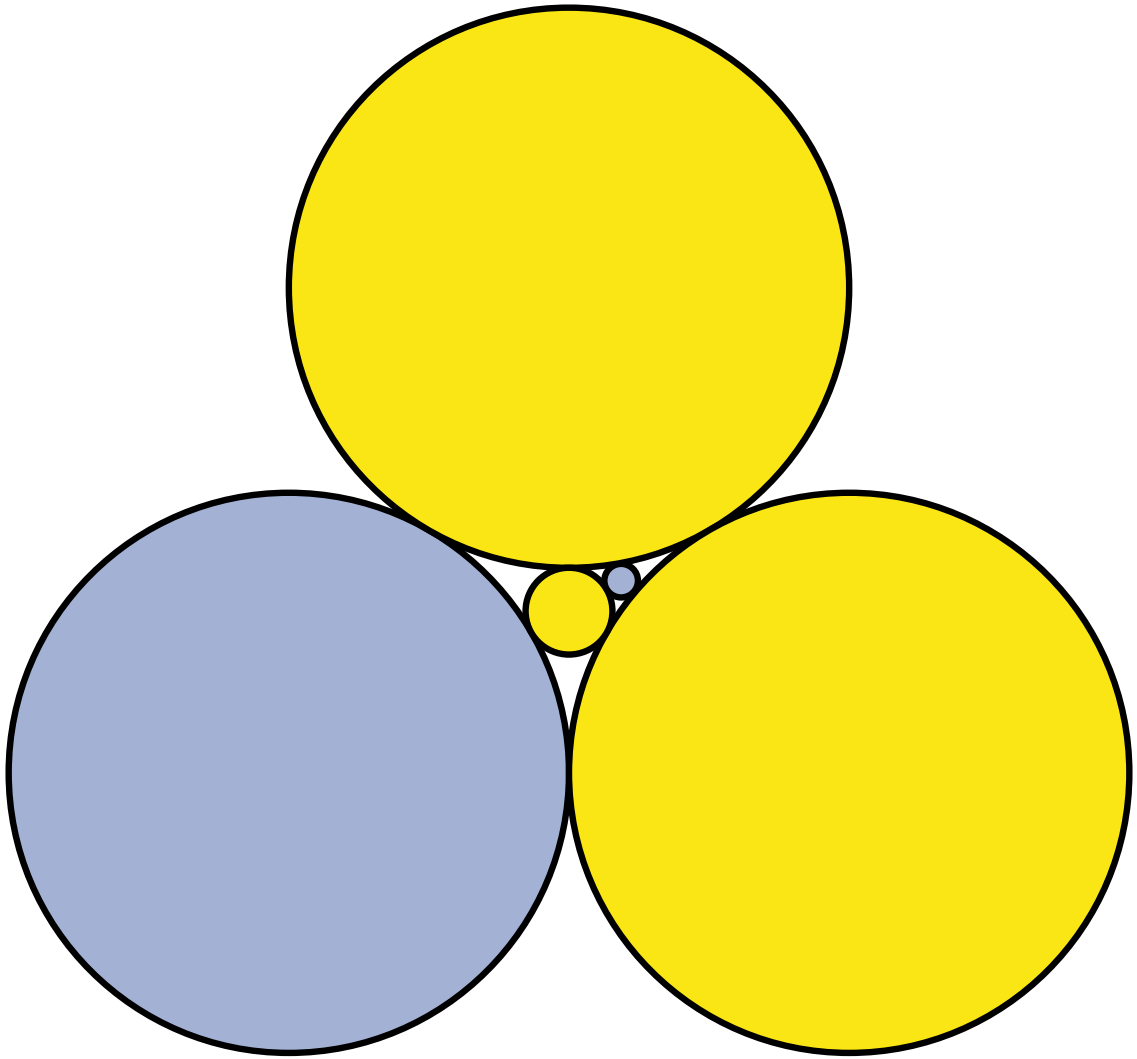


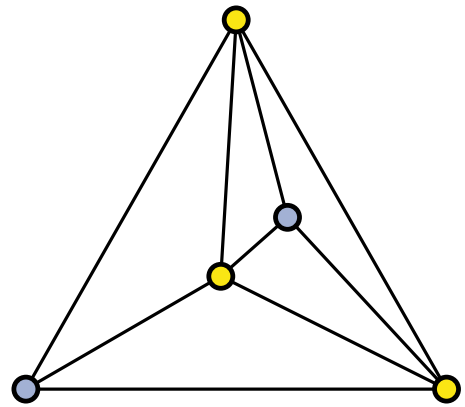
source: Yifan Hu

File System: Explorer vs Treemap



Alternative Representations – Contact Graph





Graph Drawing Software

Graph visualization libraries

- JUNG `jung.sourceforge.net` (Java)
- yFiles `www.yworks.com` (Java(FX), .NET, HTML)
- OGDF `www.ogdf.net` (C++)

Visualization tools

- visone `visone.info`
- graphviz `www.graphviz.org`
- yEd `www.yworks.com`
- Gephi `www.gephi.org`
- Tulip `tulip.labri.fr`
- Tom Sawyer Software `www.tomsawyer.com`

Topics

We will cover the following topics:

- basic definitions: layout problem, aesthetics (today)
- recursive algorithms: trees and related graph classes
- planar straight-line graph drawings
- force- and stress-based layouts
- hierarchical drawings of directed graphs
- orthogonal graph drawing
- ...
- (special drawing styles)

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- orthogonal graph drawing
- ...
- (special drawing styles)

Next week: tree layout algorithms

Homework:
Keep your eyes open for tree visualizations around you!
What do you see?