

Algorithms for Graph Visualization

Introduction

INSTITUT FÜR THEORETISCHE INFORMATIK · FAKULTÄT FÜR INFORMATIK

Tamara Mchedlidze, Benjamin Niedermann
17.10.2016



Lectures



- Tamara Mchedlidze
- `mched@iti.uka.de`
- Office 307
- Office hours: request by email

Exercises



- Benjamin Niedermann
- `benjamin.niedermann@kit.edu`
- Office 321
- Office hours: request by email

Lectures



- Tamara Mchedlidze
- `mched@iti.uka.de`
- Office 307
- Office hours: request by email

Exercises



- Benjamin Niedermann
- `benjamin.niedermann@kit.edu`
- Office 321
- Office hours: request by email

Meetings

- Monday 09:45 – 11:15 Uhr, Room 301
- Wednesday 9:45 – 11:15 Uhr, Room -119
- exact plan on the web-page

Webseite

`http://www.itl.kit.edu/teaching/winter2016/graphvis/`

- Latest news
- Lecture slides
- Exercise sheets
- Literature & Additional material
- Lecture notes (skript)

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Graph Visualization in Master's Studies

Bachelor

Algorithms 1 & 2
Basic Theory of Inf.
Algorithms for Planar Graphs

Master

Algorithms for
Graph
Visualization



Algorithms for Graph Visualization

Learning goals: At the end of the semester you:

- Know terms and problem definitions
- Know the introduced algorithms, understand how they work, can analyse them
- Can select appropriate algorithms and data structures
- Can analyse a new graph drawing problem and construct an efficient algorithm/prove hardness

Algorithms for Graph Visualization

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Prerequisites: Algorithms 1 & 2, Theoretical Basics of inf.

Helpful: Algorithms for Planar Graphs

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Suggested time requirements: 5LP = 150h

- Attending Lecture and Exercises: ca. 35h
- Preparation/post-processing ca. 35h
- Work on the exercises ca. 40h
- Preparation for the exam ca. 40h

Master Informatics

- Algorithms for Graph Visualization (IN4INALGVG)
- **new Module:** Graph visualization+ (more about this later)

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Examination procedure:

- In order to take an exam you need to participate actively in the exercise sessions
(e.g. present your own solutions on the board)
- oral exam(app. 20 Minutes)

Graph Visualization+

Background: International Symposium on Graph Drawing (GD) and Graph Drawing Challenge



24th International Symposium on
GRAPH DRAWING & NETWORK VISUALIZATION

gd16
19-21 SEPTEMBER
ATHENS GREECE

Logos of sponsors: National Technical University of Athens, Works, Microsoft, Springer.

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Maarten Löffler (chair)
Lev Nachmanson
Ignaz Rutter

INVITED SPEAKERS

Daniel Keim
Roger Wattenhofer

IMPORTANT DATES

Paper submission: June 12
Paper notification: July 24
Poster submission: Aug. 17
Poster notification: Aug. 28
Early registration: Aug. 30
Final versions due: Sept. 1
Contest submission: Sept. 11
PhD school: Sept. 22-23

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Task: develop software for a given graph visualization problem



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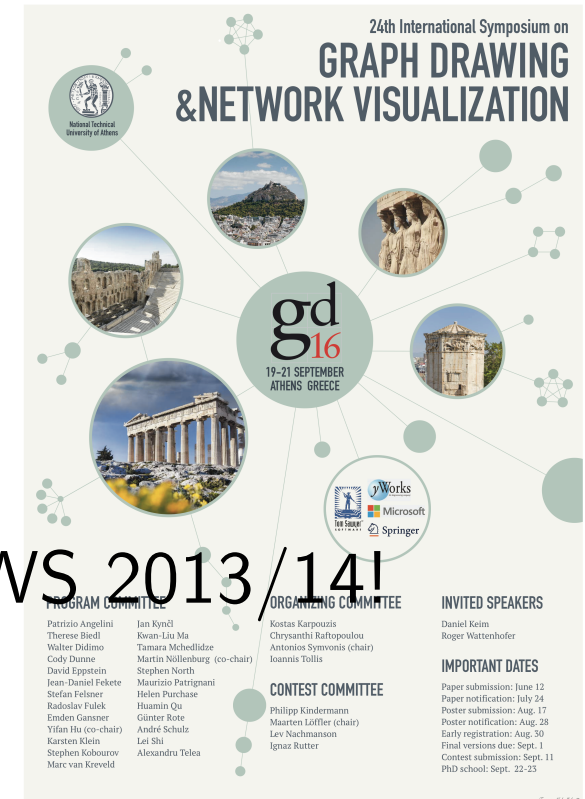
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Winner 2014: KIT-Team from the lecture WS 2013/14!



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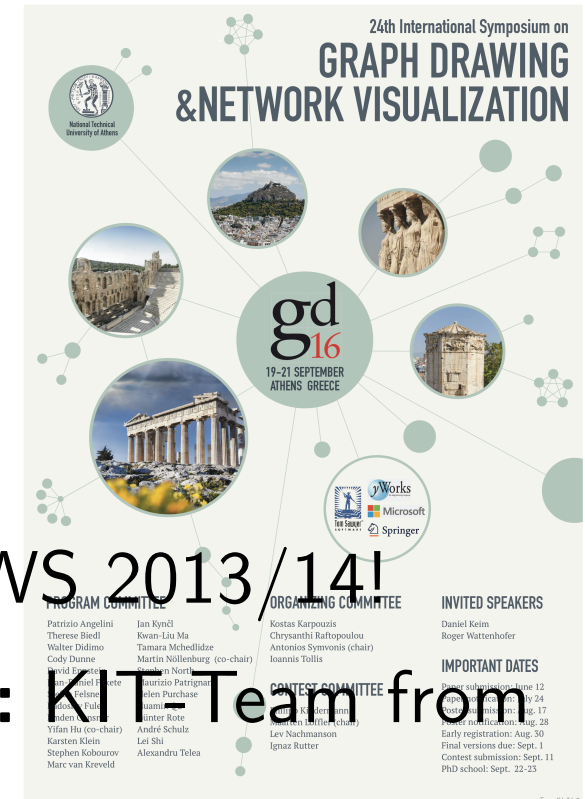
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Second place 2015: KIT-Team from the lecture SS 2015!

Best poster award 2016: One of the students who continued working on the 2015's topic!

Graph Visualization+

Background: International Symposium on Graph Drawing (GD) and Graph Drawing Challenge

Task: develop software for a given graph visualization problem

2013/14:

- Software development was part of the lecture
- Lots of fun but time-consuming

2015:

- as a practical course SS 2015
- combined modul with 10 LP
- time-wise worked very well
- **evaluation:** excellent practical course award



Structure of the Lecture

Media:

- **Slides & Blackboard**
- Exercise sheets are provided a week before the exercise session
- (incomplete) Lecture notes/Books
- Original literature (papers)

Structure of the Lecture

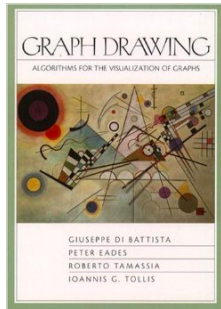
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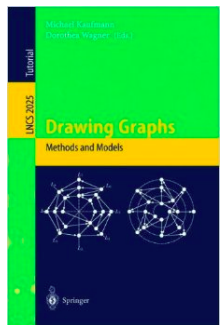
Content:

- We look at the **algorithmic core** of visualization problems
- **not:** graphical Rendering
- Modelling, Algorithms, formal Analysis
 - Divide & Conquer / Recursion
 - combinatorial optimization (ILP)
 - incremental algorithms
 - algorithms for special graph classes
 - drawing techniques using physical analogies

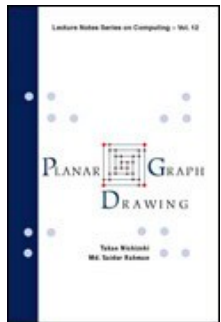
Literature (available in the library)



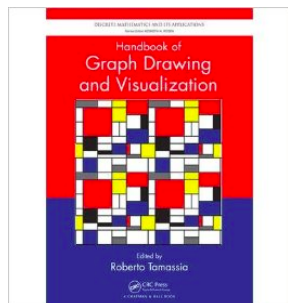
G. di Battista, P. Eades, R. Tamassia, I. Tollis:
Graph Drawing
Prentice Hall, 1998



M. Kaufmann, D. Wagner:
Drawing Graphs: Methods and Models
Springer, 2001



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/>

Usefull Knowledge

Basic knowledge of Graph Theory:

- Graph, Nodes/Vertices, Edges
- Node degree, Neighbourhood, Adjacent, Incident
- Connectivity, Tree, Cycle, Path
- ...

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Basic knowledge in Algorithms:

- Asymptotic running time, O -notation
- Complexity, NP-Hardness
- Network flow
- Linear Programming
- Recursion
- Divide & Conquer
- Approximation
- ...

Introduction to Graph Visualization

Graph and its Representation

What is a Graph?

Graph and its Representation

What is a Graph?

Tuple $G = (V, E)$

Set of nodes $V = \{v_1, \dots, v_n\}$

Set of edges $E = \{e_1, \dots, e_m\},$

$e_i = \{v_j, v_k\}, 1 \leq i \leq m, 1 \leq j, k \leq n$

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Representations?

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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 list

```
v1 : v2, v8
v2 : v1, v3
v3 : v2, v5, v9, v10
v4 : v5, v6, v9
v5 : v3, v4, v8
v6 : v4, v8, v9
v7 : v8, v9
v8 : v1, v5, v6, v7, v9, v10
v9 : v3, v4, v6, v7, v8, v10
v10 : v3, v8, v9
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Representations?

Set representation

Adjacency list

Adjacency matrix

$$\begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \end{pmatrix}$$

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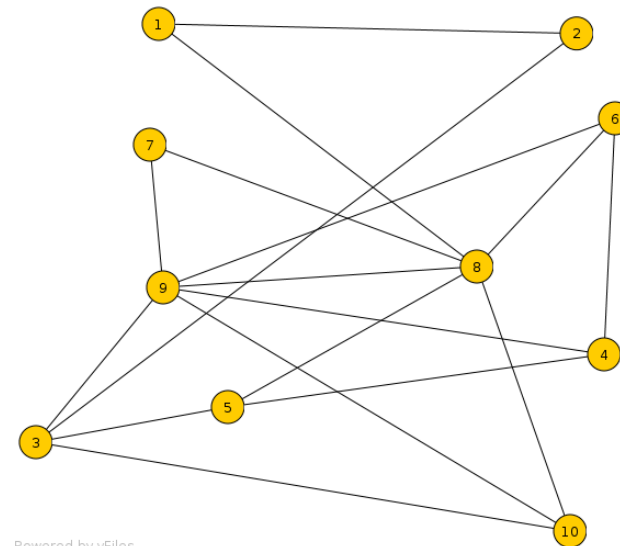
Representations?

Set representation

Adjacency list

Adjacency matrix

Drawing



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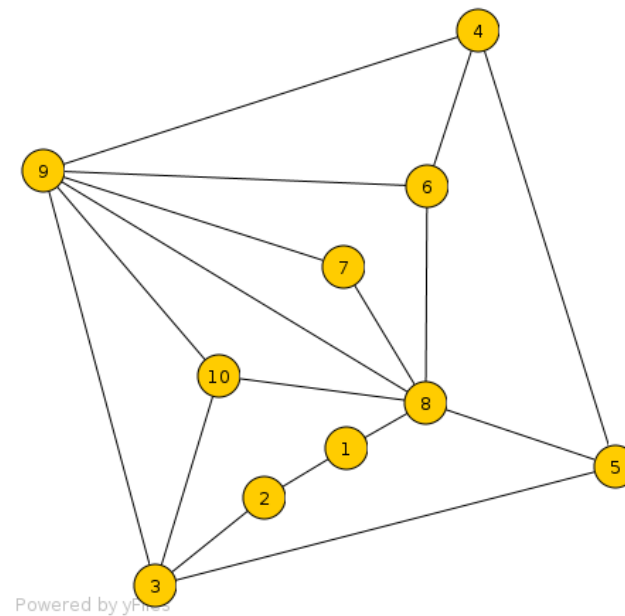
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Adjacency list

Adjacency matrix

Drawing

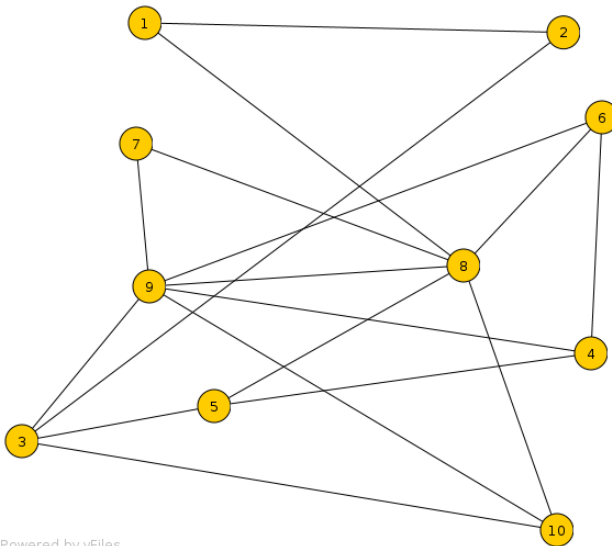


Graph and its Representation

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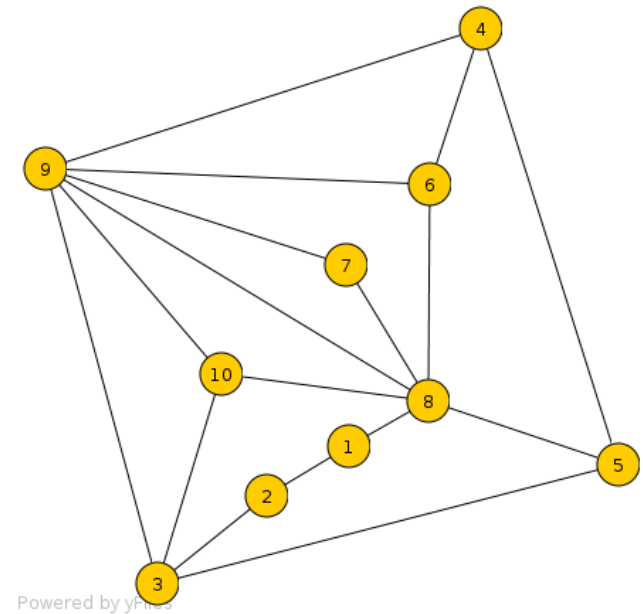
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 v_8 : $v_1, v_5, v_6, v_7, v_9, v_{10}$
 v_9 : $v_3, v_4, v_6, v_7, v_8, v_{10}$
 v_{10} : v_3, v_8, v_9



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$$\begin{pmatrix} 0 & 1 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \\ 1 & 0 & 0 & 0 & 1 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 1 & 1 & 0 \end{pmatrix}$$



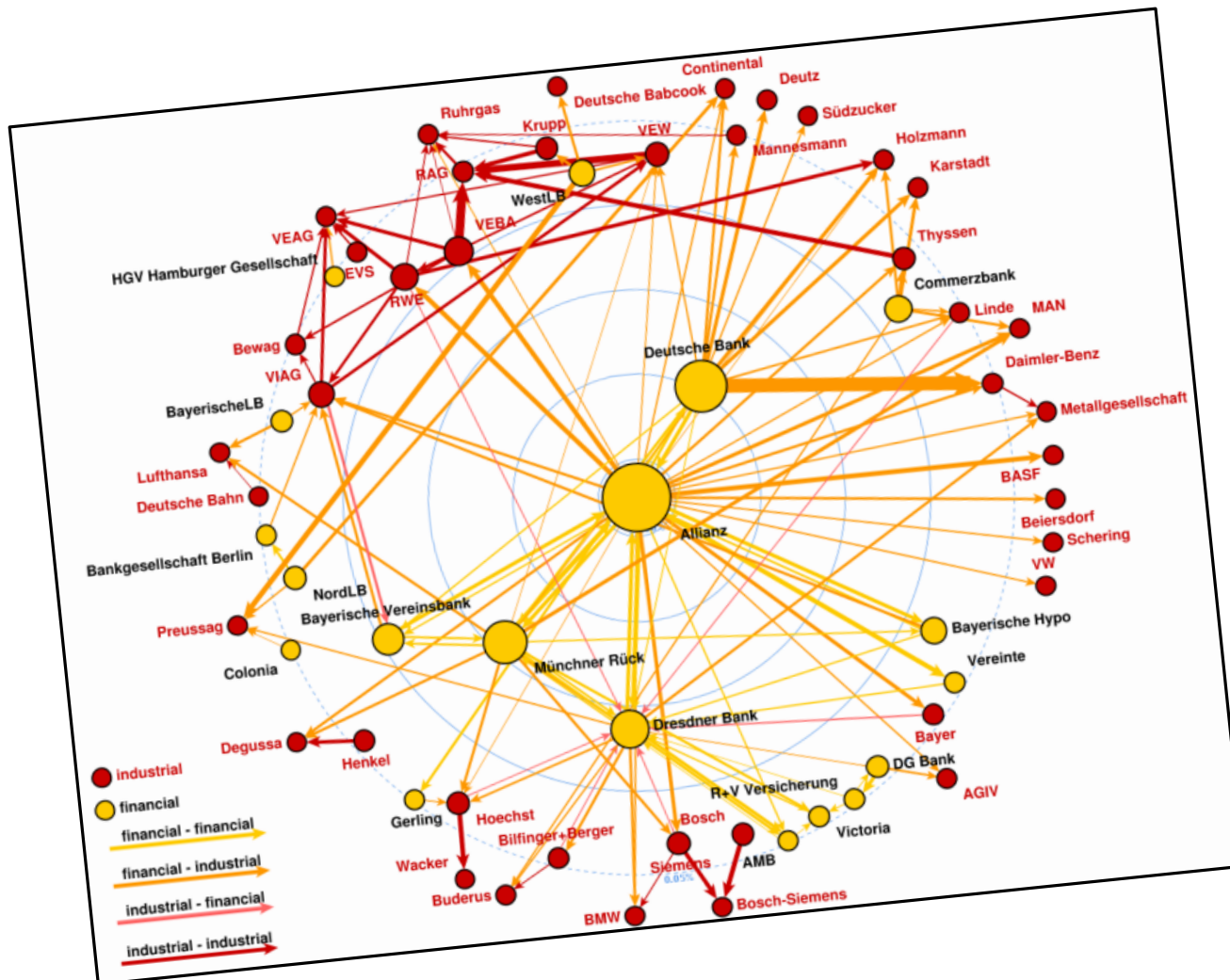
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Why to draw graphs?

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

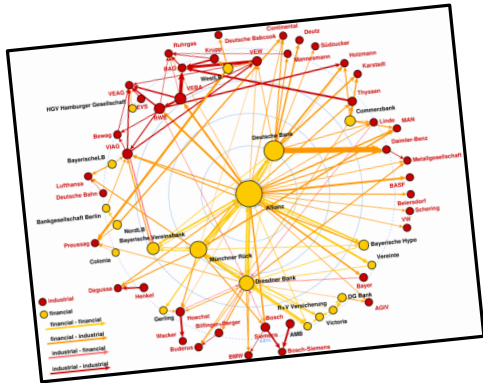
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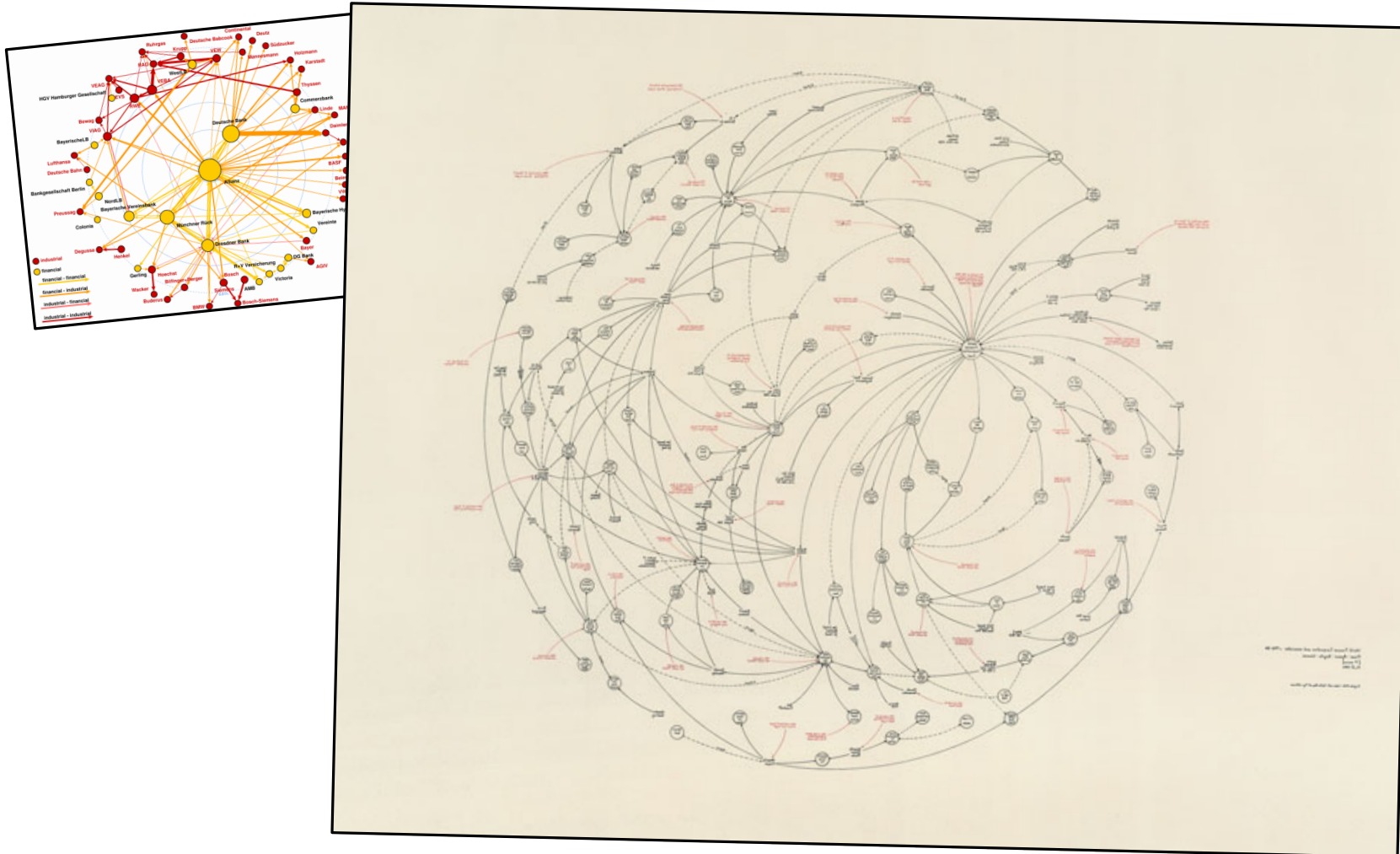
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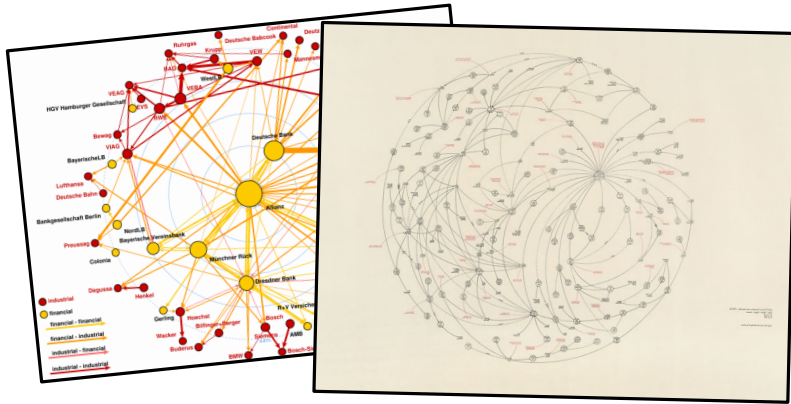
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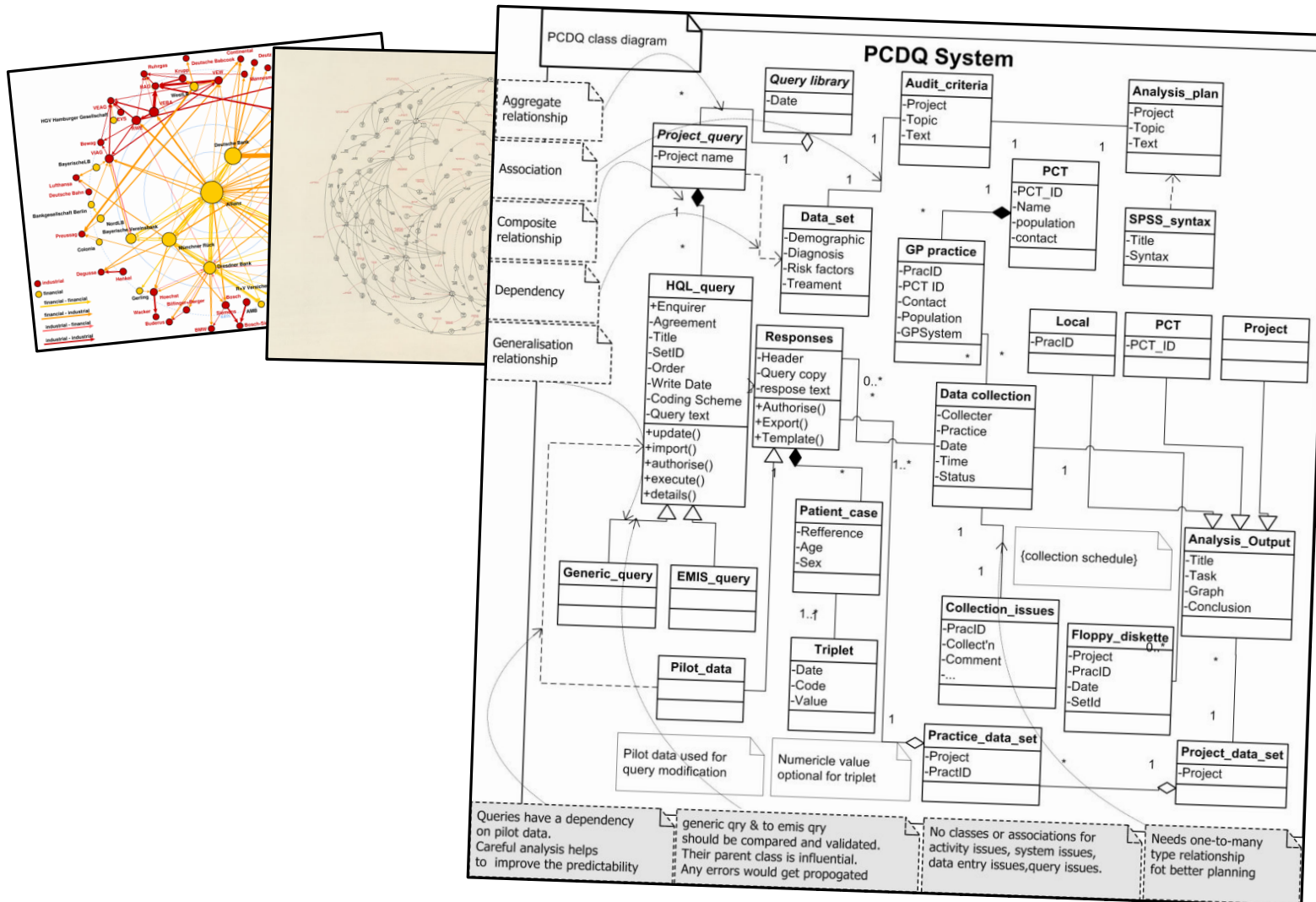
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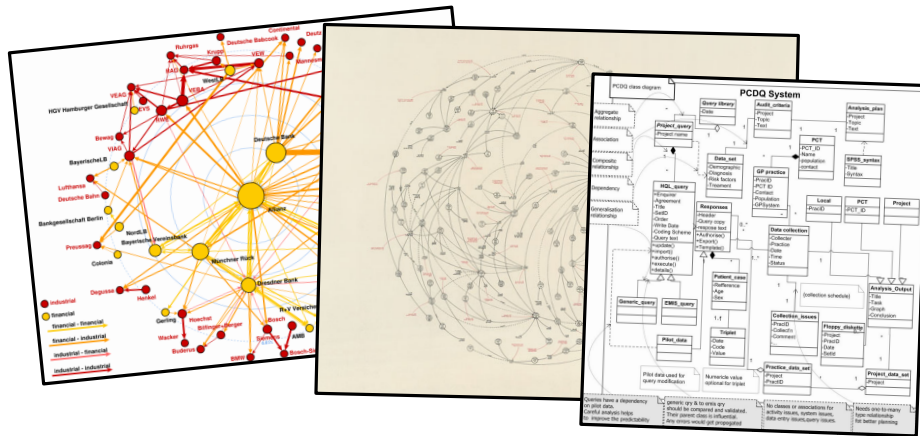
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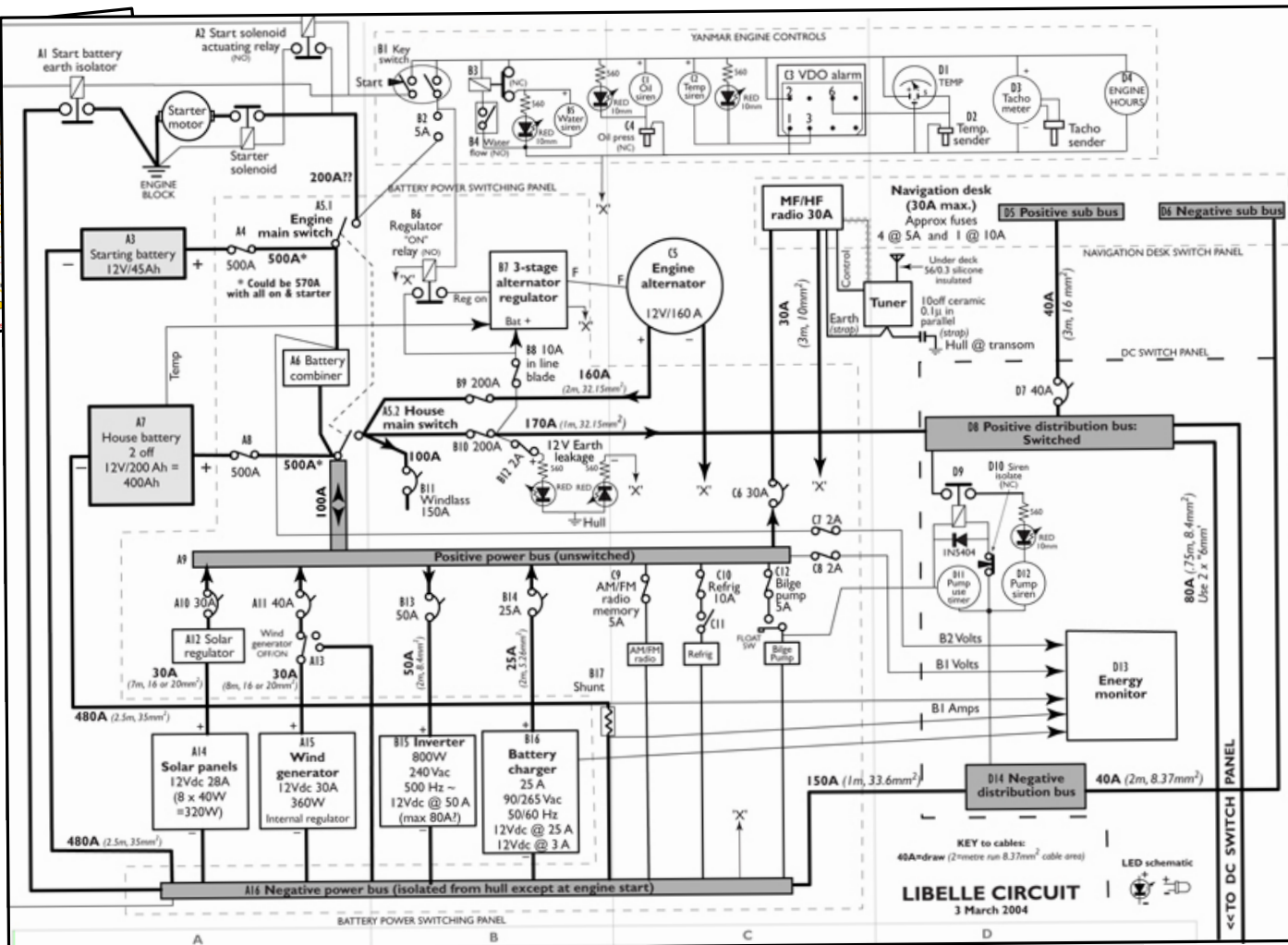
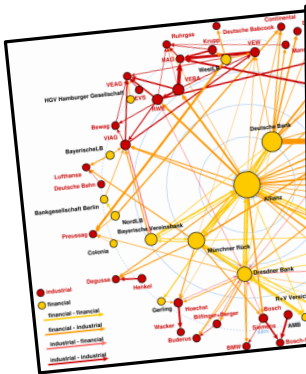
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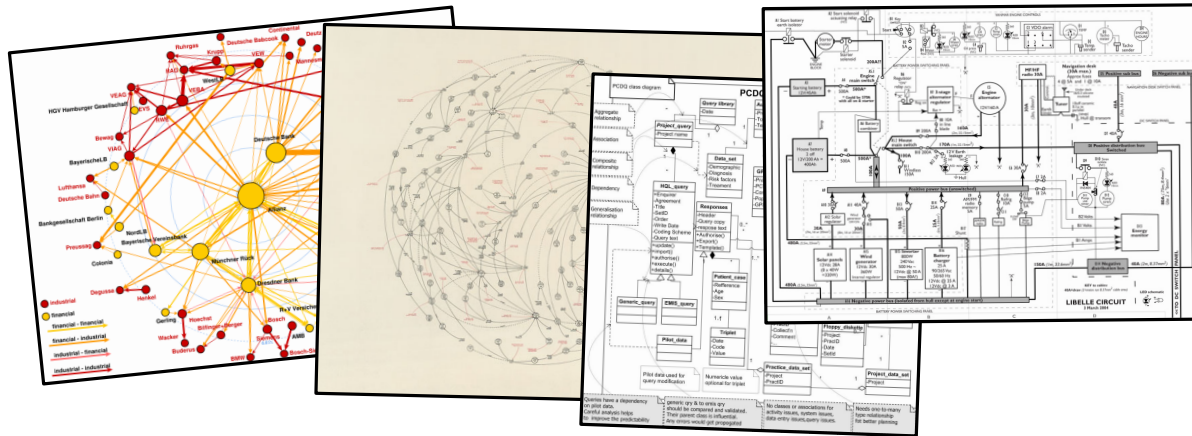
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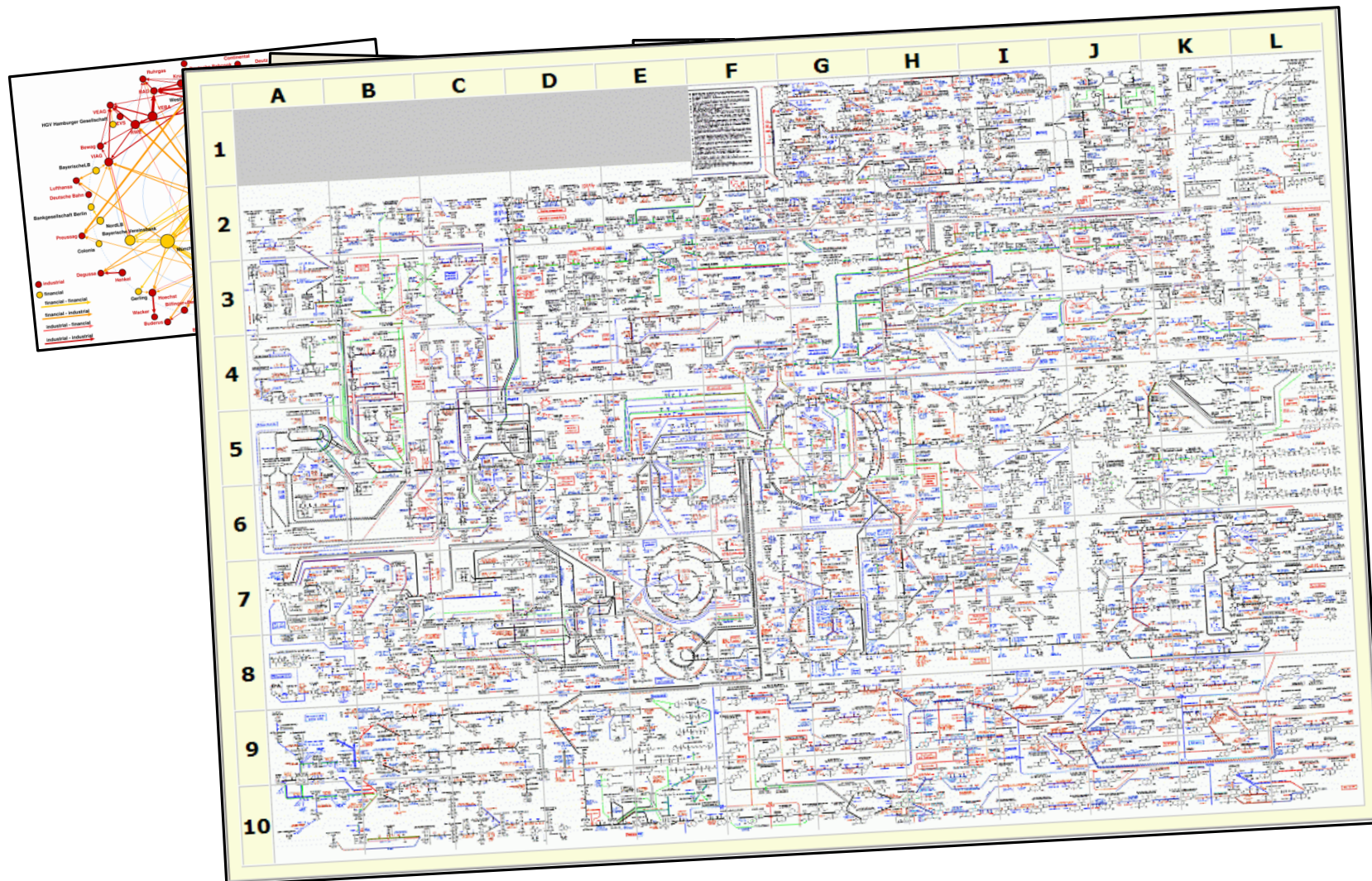
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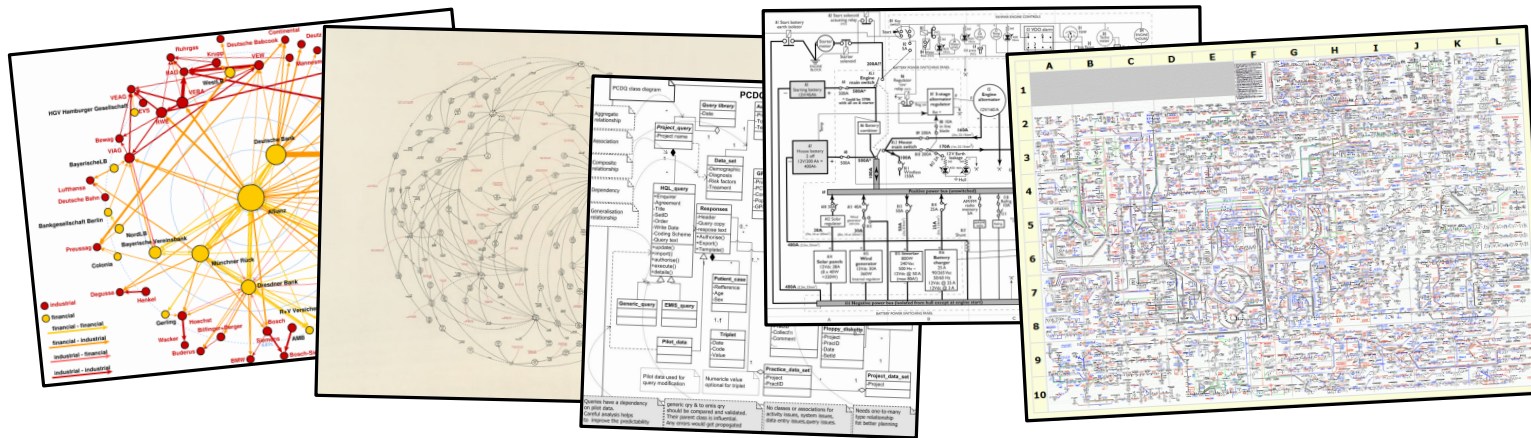
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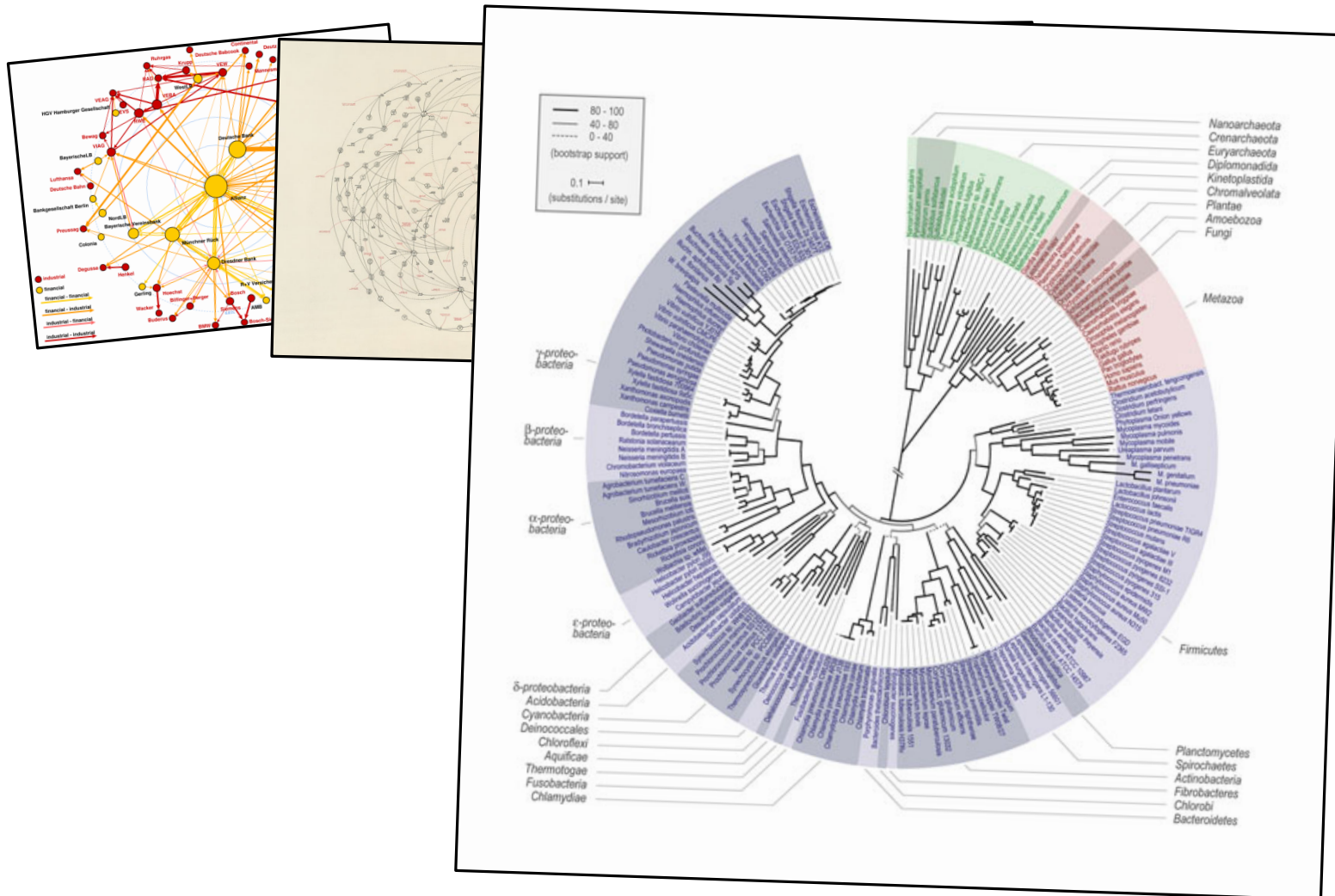
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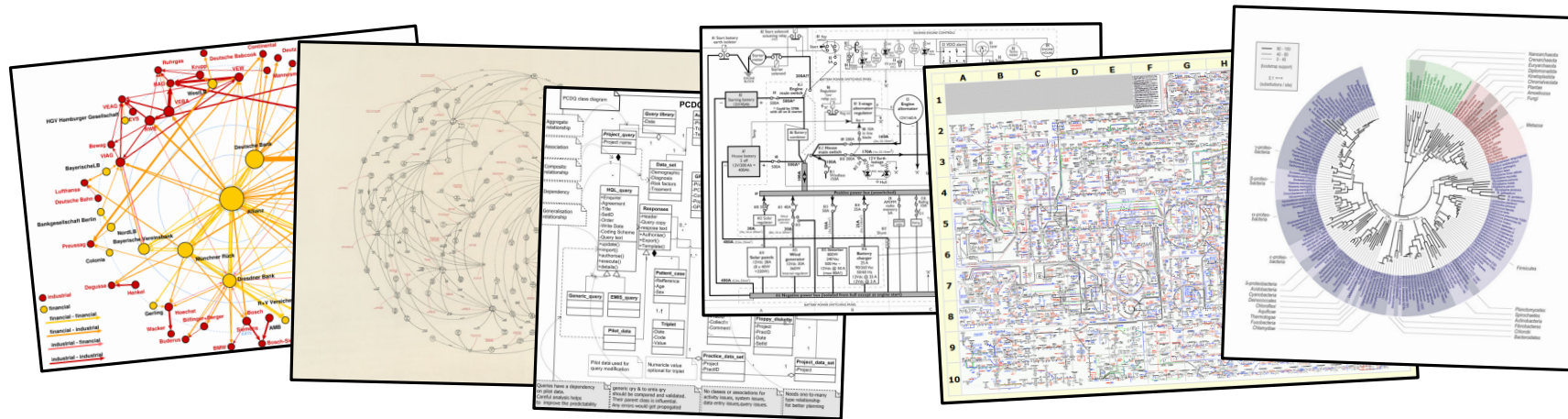
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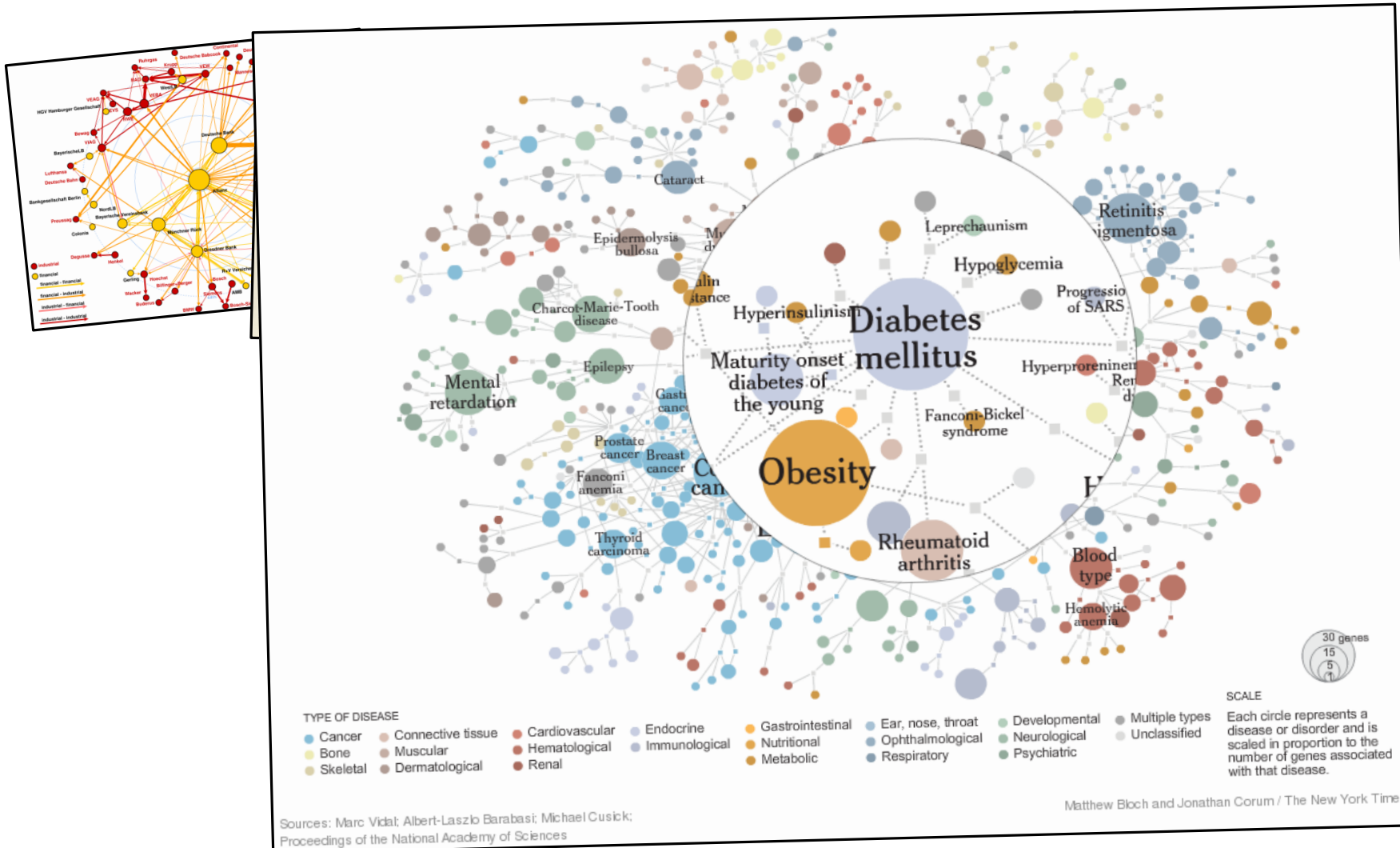
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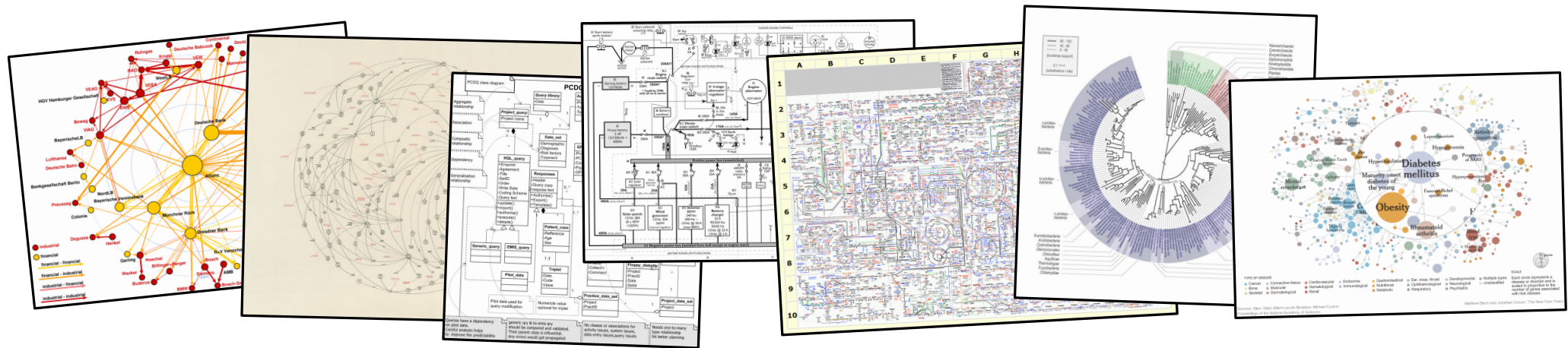
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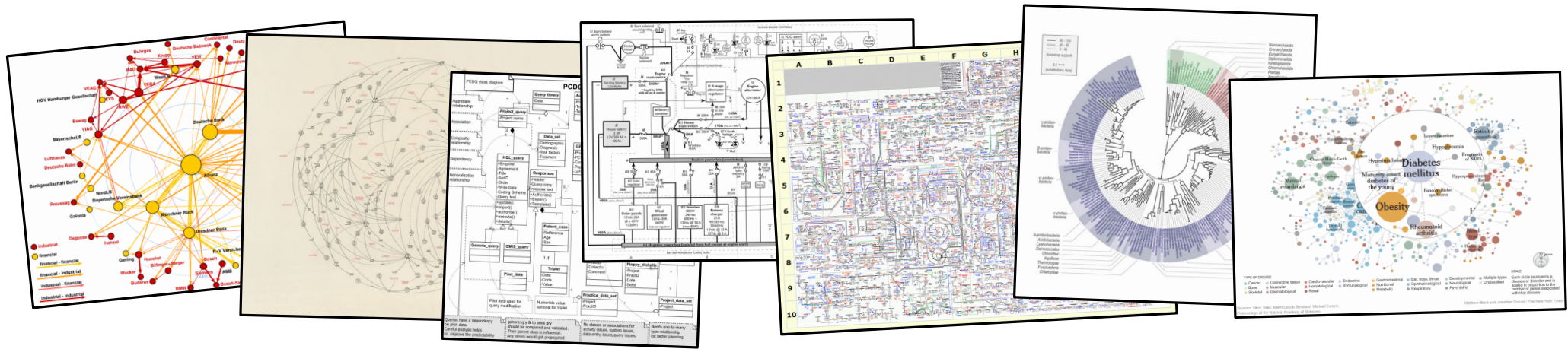
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- **People think visually** – without a good visualization, complex graphs are not understandable to us
- A visualization helps to **communicate** and **explore** the graphs/networks
- We need **algorithms** to draw graphs, and make graphs and networks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

How to draw graphs?

Guiding questions

- what makes a drawing good?
- what is a bad drawing?
- are there measures to quantify that?

How to draw graphs?

Guiding questions

- what makes a drawing good?
- what is a bad drawing?
- are there measures to quantify that?

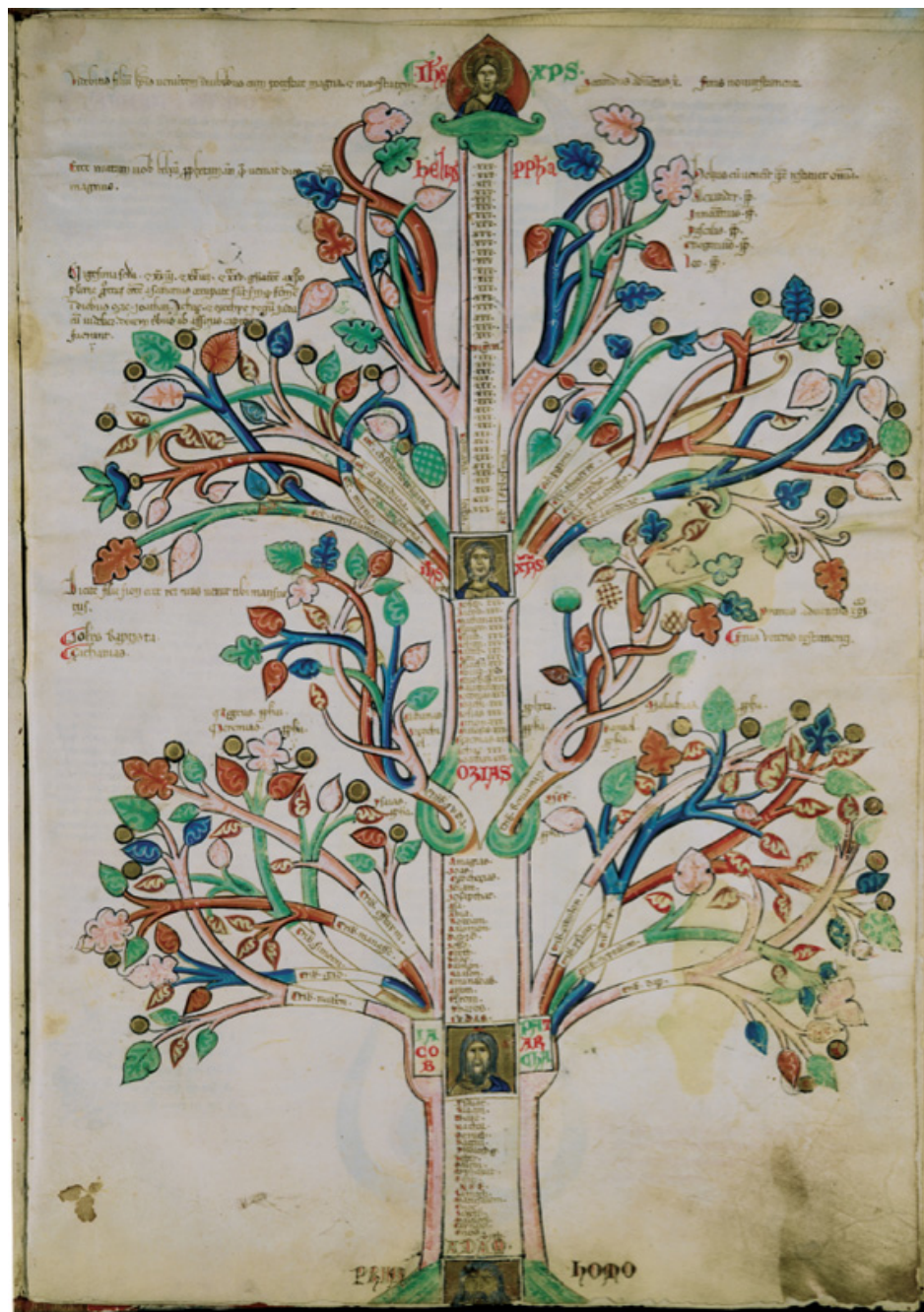
Warm-up WE WILL DRAW COUPLE OF GRAPHS

- Teams of two
- "tasks" in form of adjacency matrix/list
- Given time 15 minutes
- We will shortly discuss the results afterwards
- <https://www.yworks.com/downloads#yEd>

Network Visualizations

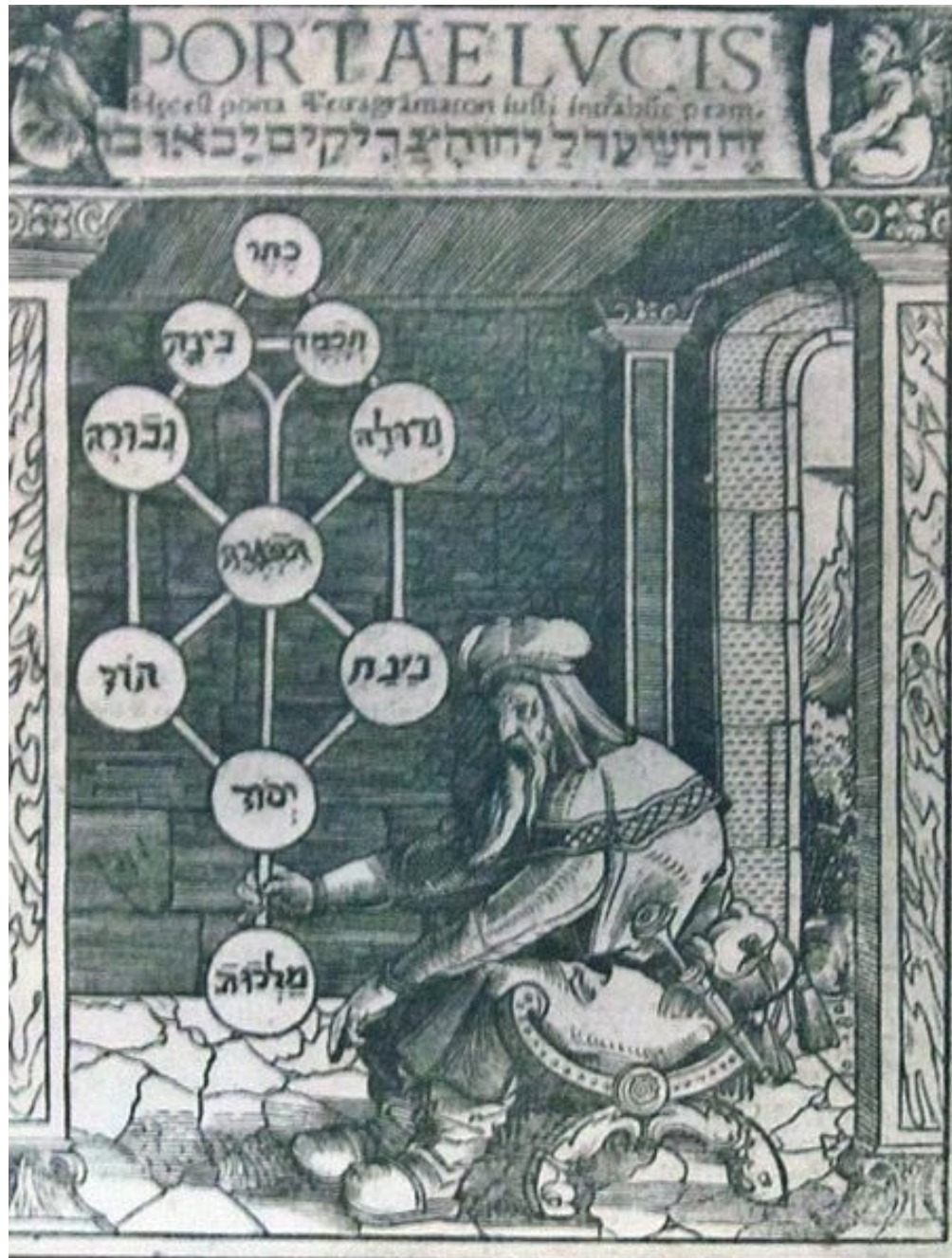
a small Film

Biblical characters and events (1202)



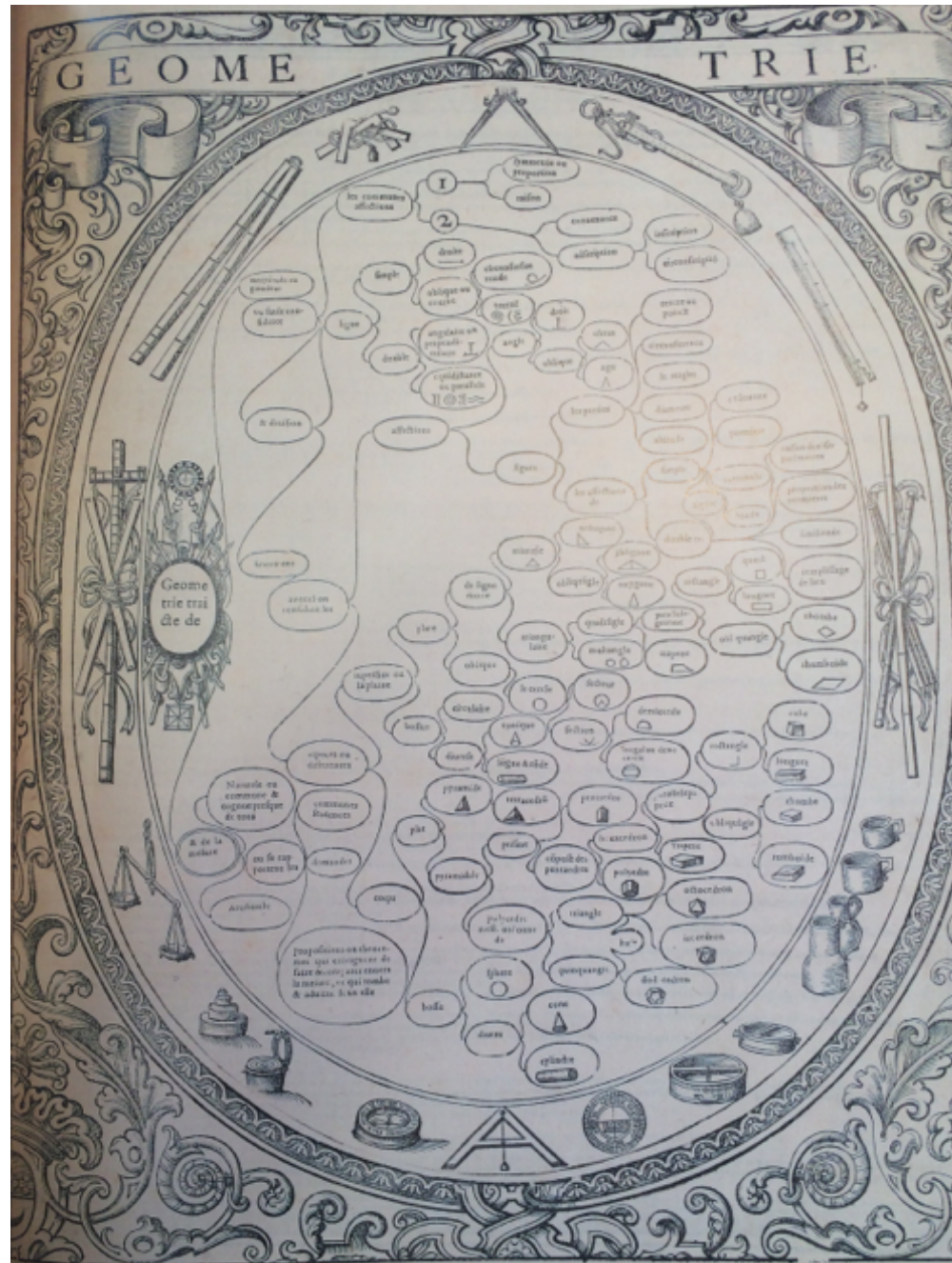
Source: Joachim de Fiore

"Tree of Life" (1516)



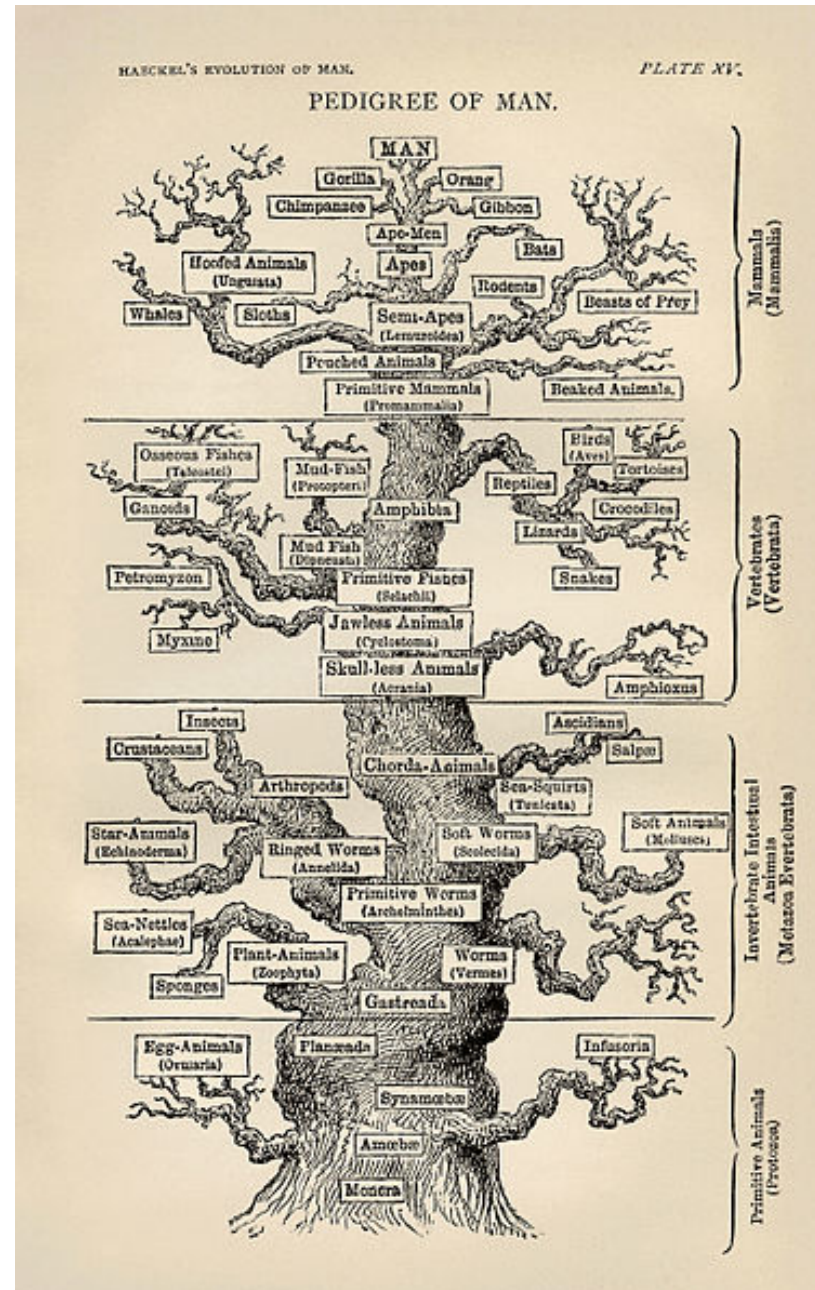
Source: Paul Riccius, Portae Lucis

Geometrical Concepts (1587)



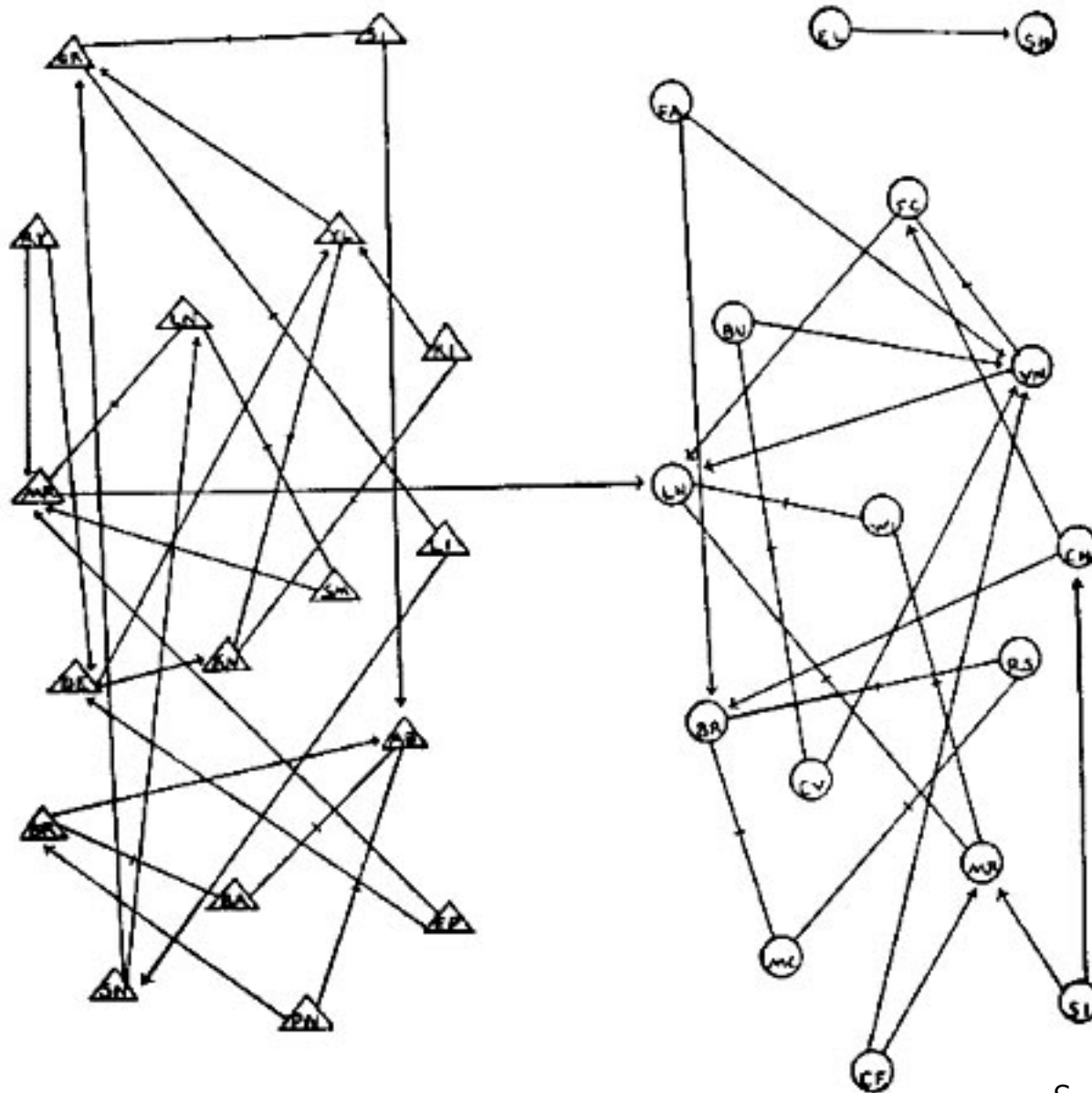
Source: Christophe de Savigny

Genealogical Tree (1879)



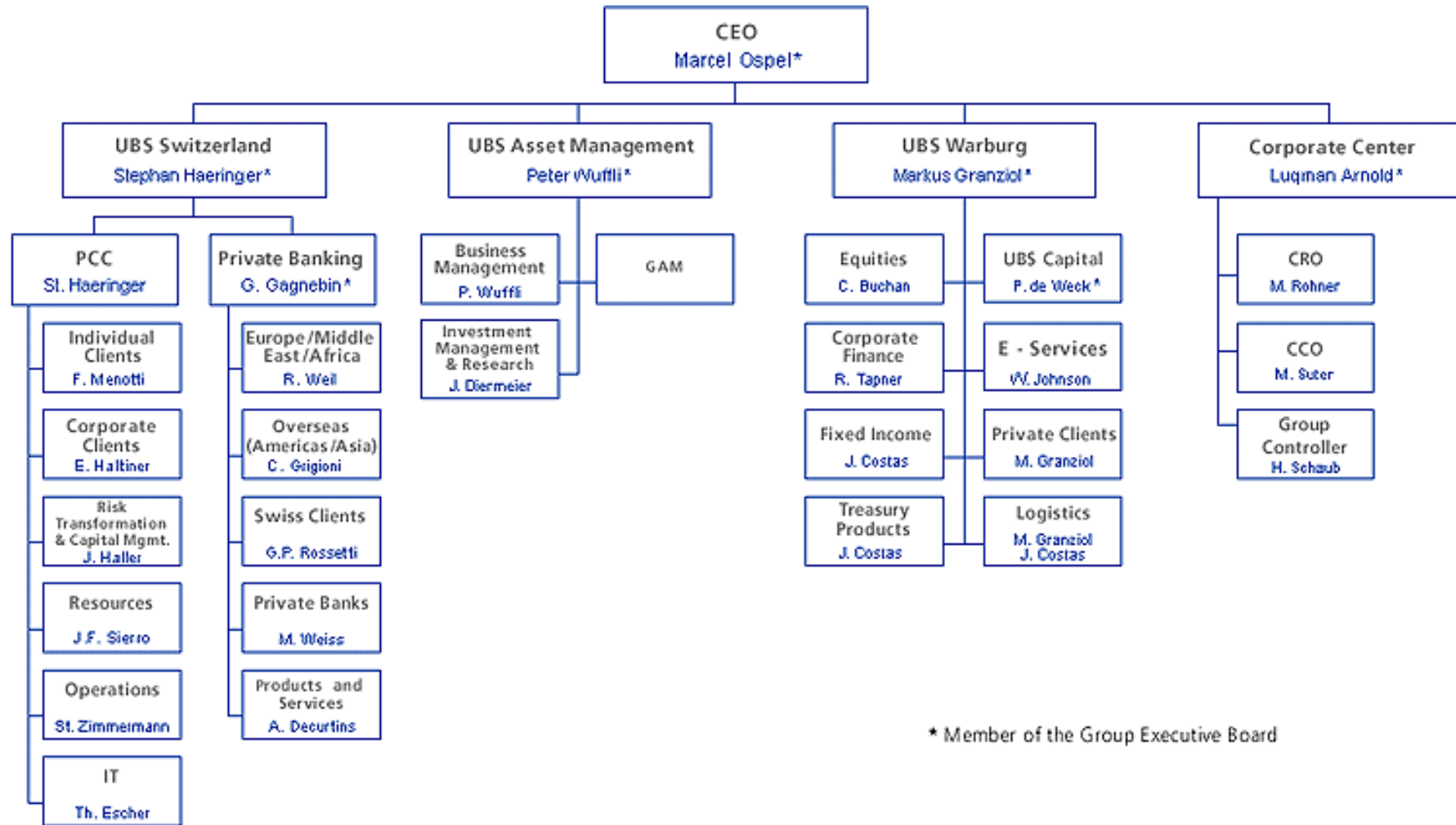
Source: Ernst Haeckel

Sociogram (1933)



Source: Moreno, 1933

Social Network – Organization within UBS



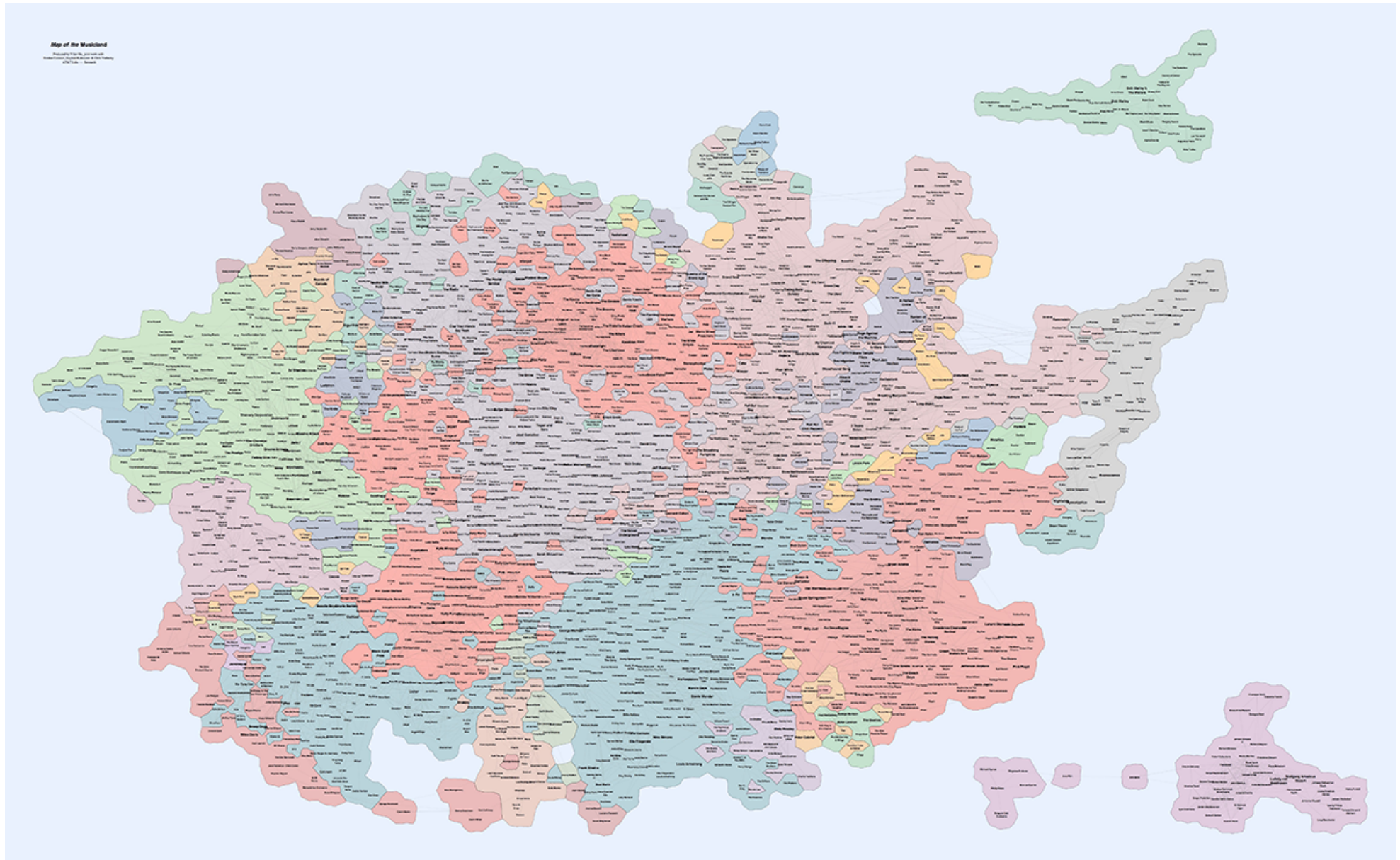
* Member of the Group Executive Board

CPAN Developer-Graph



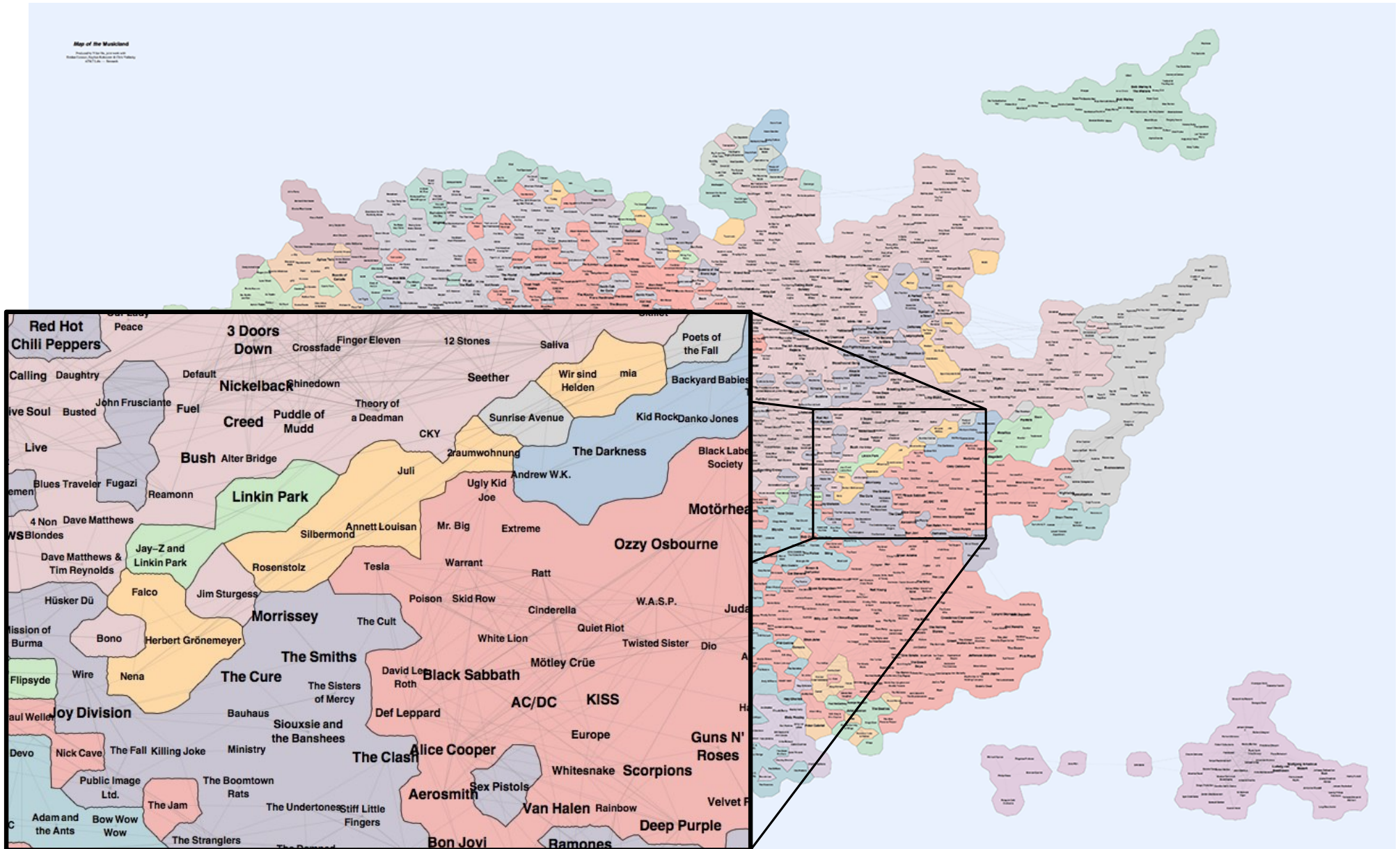
Source: cpan-explorer.org

last.fm Graph of musics as political map



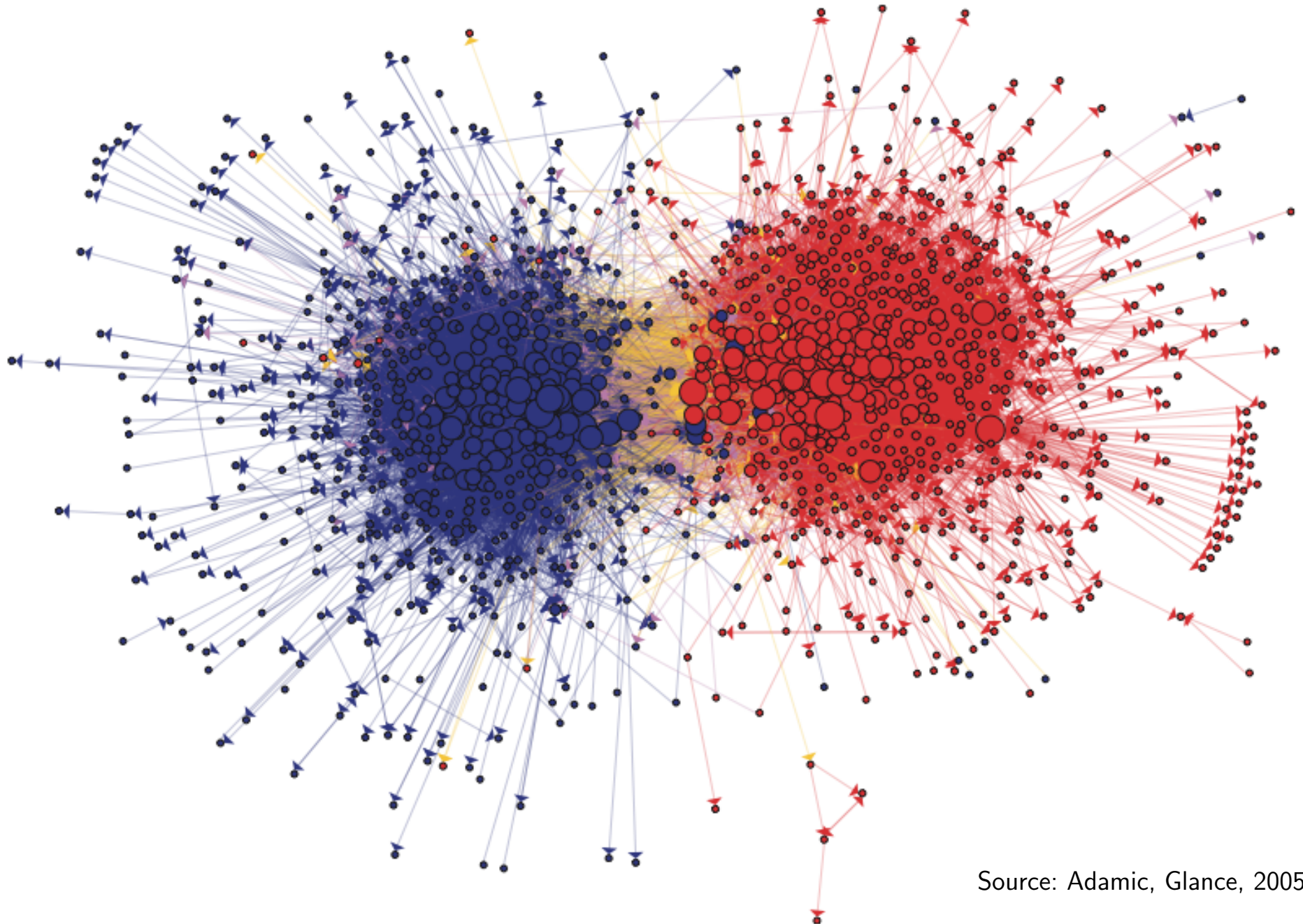
(Gansner, Hu, Kobourov: GMap, 2009)

last.fm Graph of musics as political map



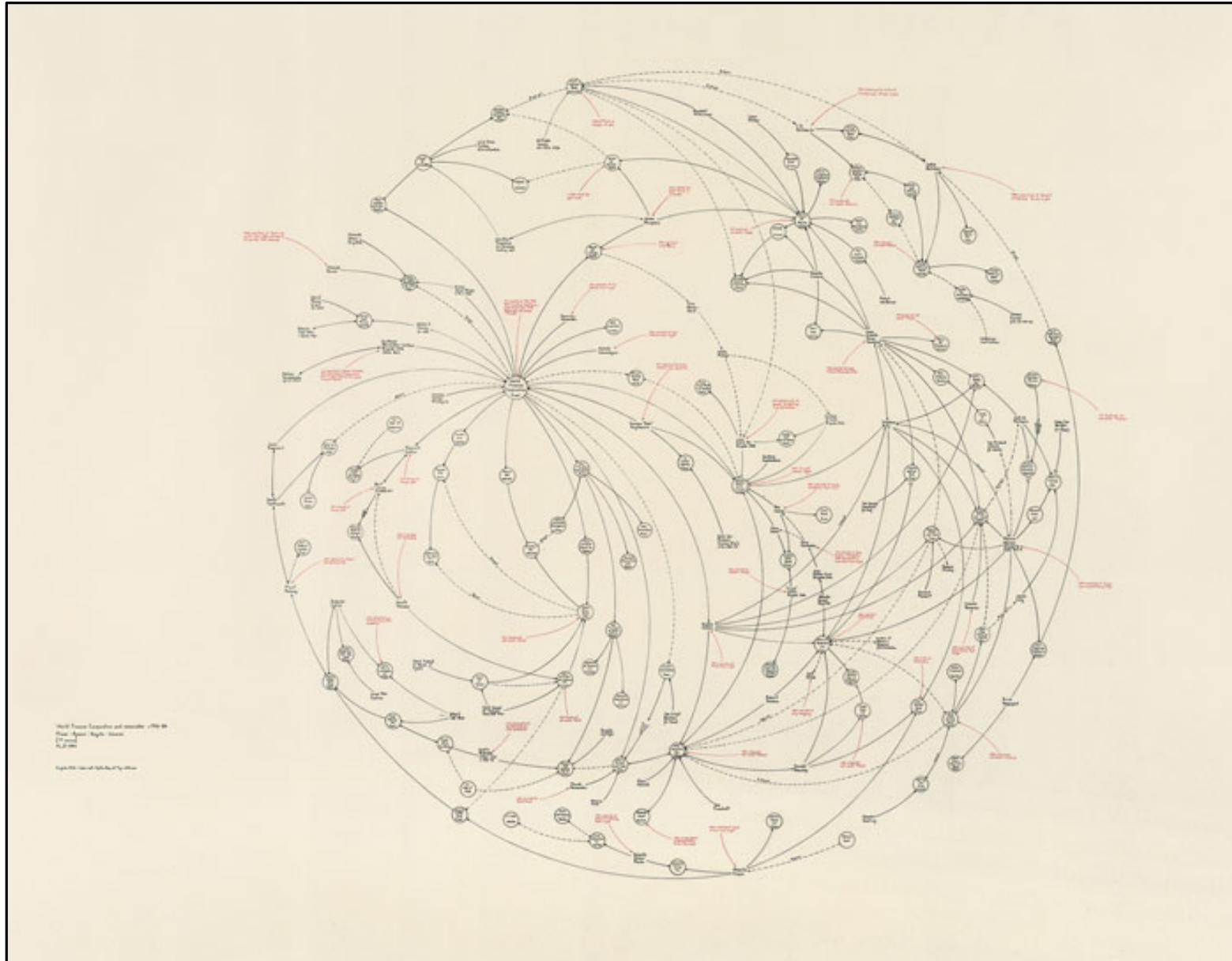
(Gansner, Hu, Kobourov: GMap, 2009)

Blogosphere 2004 Elections USA



Source: Adamic, Glance, 2005

Social Network – World Finance System



World Finance Corporation
© Mark Lombardi

Social Networks – State Funds

FOLLOW THE MONEY

The New Global Wealth Machine

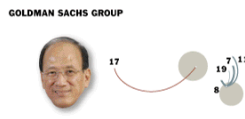
Sovereign wealth funds have emerged in recent months as the world's power brokers. They have used their tremendous wealth to make big cross-border investments and prop up some of Wall Street's best-known firms. The increased activity comes as other kinds of acquirers have been sidelined by the credit crisis. These funds are state-sponsored investment vehicles and have combined assets of \$2 trillion. With that much dry powder, sovereign funds dwarf the formerly booming private equity industry — and in some cases, compete directly with it. The Government of Singapore Investment Corporation has been the most active among the world's sovereign funds, making its deputy chairman, Tony Tan, a major center of gravity. Wall Street veterans always follow the money, so many of the big-name advisers in New York and London have found themselves traveling the globe playing international matchmaker to these funds. But sovereign funds have also learned the downside of deal-making: some of their blockbuster transactions have been big money losers so far. The question is where all that money will go next. **ANDREW ROSS SORKIN**

The Advisers

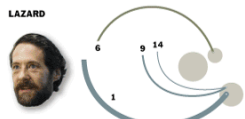
Selected financial advisers who worked on more than one of the top 20 deals.



Michael Klein, Chairman, institutional clients group
One of the firm's highest-profile investment bankers, he advised Citicorp in its stake sale to Mitsubishi, as well as Citigroup in both of its deals with sovereign wealth funds.



Richard Ong, Former managing director
Mr. Ong left Goldman early this year after the Chinese government refused to allow the firm to promote him to run its Beijing office. Mr. Ong's brother, Charles, was the chief investment officer of Temasek Holdings until 2006.



Gary Parr, Deputy chairman
In addition to becoming the key adviser on many of the biggest sovereign wealth deals, Mr. Parr helped advise Bear Stearns on its distressed sale to JP Morgan Chase.



Kate Richdale, Managing director
The head of Morgan Stanley's Asian general industries group, based in Hong Kong. She previously held a senior position in the investment bank's Southeast Asia group.

The Targets



MORGAN STANLEY
John J. Mack, Chairman and C.E.O.

BLACKSTONE GROUP
Stephen A. Schwarzman, Chairman and co-founder

CITIGROUP
Robert E. Rubin, Chairman

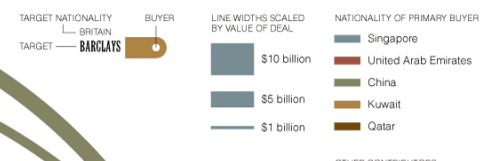
MERRILL LYNCH
John A. Trank, Chairman and C.E.O.

SALUS GROUP
David Rubenstein, Co-founder and managing director

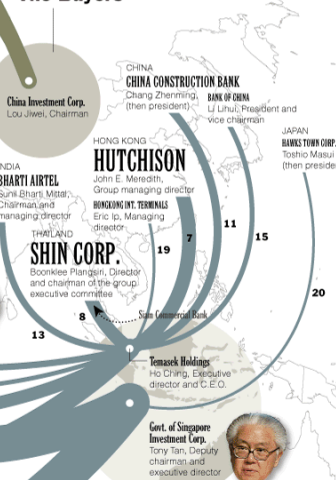
DEAL RANK

6
10
4
12
18

The 20 Biggest Cross-Border Sovereign Wealth Fund Deals Since 2005



The Buyers



CHINA INVESTMENT CORP.
Lou Jiwei, Chairman

CHINA CONSTRUCTION BANK
Chang Zhennong, (then president)

BANK OF CHINA
Li Lihua, President and vice chairman

HONG KONG
John E. Meredith, Group managing director

HUTCHISON
Eric S. Margolis, Managing director

BANKING INT'L TERMINALS
Eric S. Margolis, Managing director

SHIN CORP.
Boonkee Pangniri, Director and chairman of the group executive committee

Temasek Holdings
Ho Ching, Executive director and C.E.O.

Govt of Singapore Investment Corp.
Tony Tan, Deputy chairman and executive director

INDIA
BHARTI AIRTEL
Sunil Bharti Mittal, Chairman and managing director

Qatar Investment Authority
Kenneth Shen, Head of strategic and private equity

Mubadala Development Co.
Khalid bin Mubarak, C.E.O. and managing director

Abu Dhabi Investment Authority
Sheik Khalifa bin Zayed Al Nahyan, Chairman

Switzerland
UBS
Marcel Rohrabacher, Chief executive

Standard Chartered Bank
Peter Sands, Chief executive

Barclays
John Varley, Chief executive

London Stock Exchange
Clara Furse, Chief executive

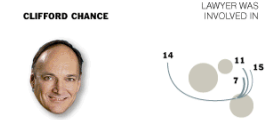
Japan
Mitsubishi Financial Group (Japan)

Korea
Korean Investment Fund

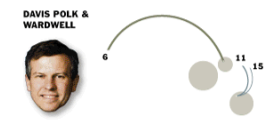
Other Contributors
China Investment Corp.

The Lawyers

Selected lawyers who worked on more than one of the top 20 deals.



James Baird, Partner and global head of private equity
Mr. Baird's firm, based in London, was one of the early firms to make a bet on Asia by staffing up there before some of the traditional white-shoe Wall Street firms ventured there.



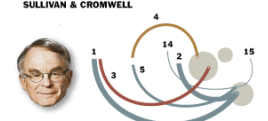
Randall D. Guynn, Partner
As head of the firm's financial institutions group, he has advised on many international deals in Europe and Asia. He also worked on the team that advised Morgan Stanley in its \$5.5 billion stake sale to China's sovereign wealth fund.



Richard Good, Partner
Based in Singapore, Mr. Good is the firm's man-on-the-ground in Asia. He has worked for Linklaters in Asia since 2000.



Stephen M. Besen, Partner
A longtime hand in the Middle East, Mr. Besen's deep relationships have helped his firm carve out one of the strongest niches in the region.

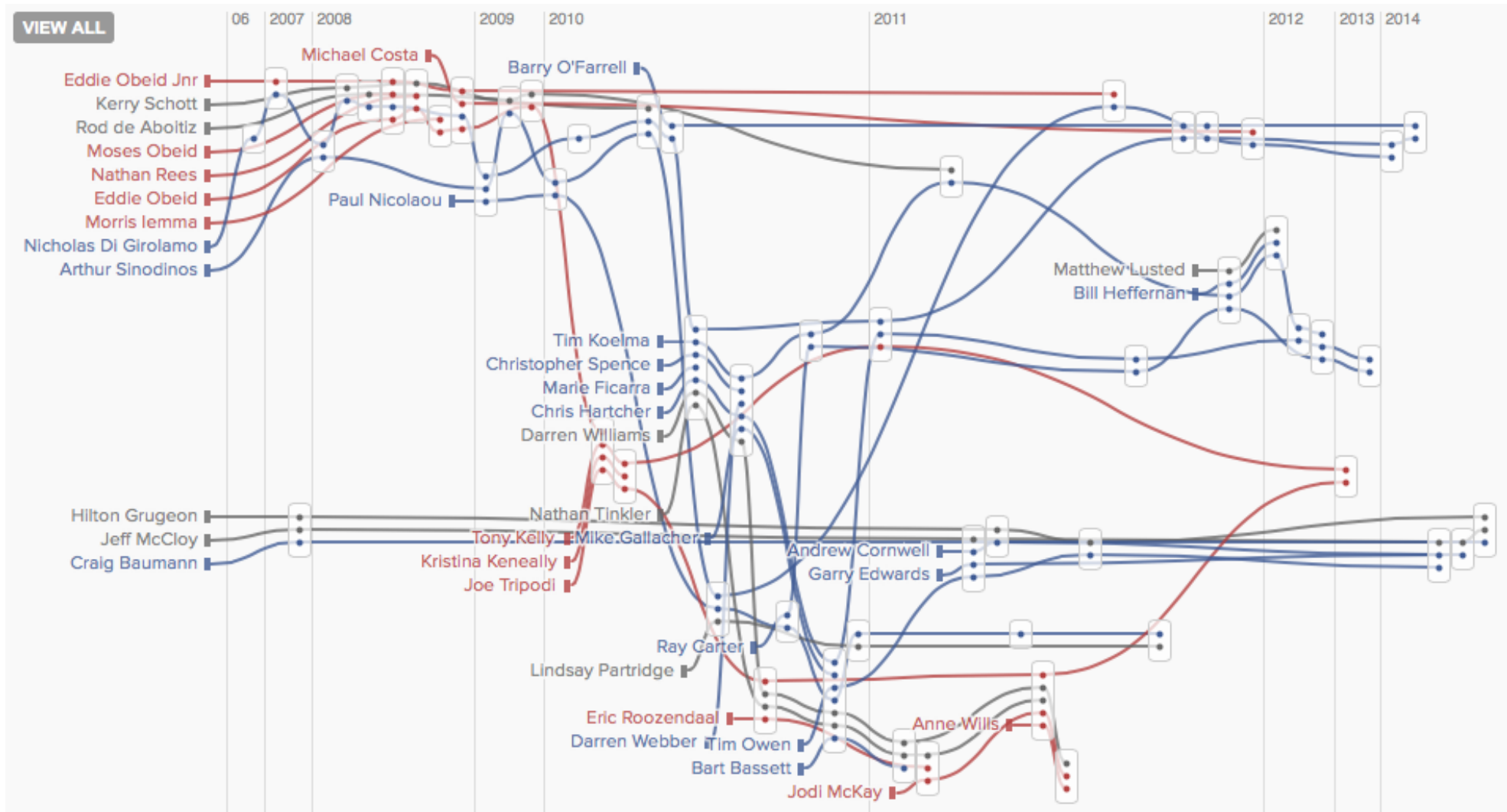


H. Rodgin Cohen, Chairman
The world's go-to lawyer for sovereign wealth investments in financial services firms. He worked on twice as many sovereign wealth related deals than any other individual.

Source: Dealogic, the companies

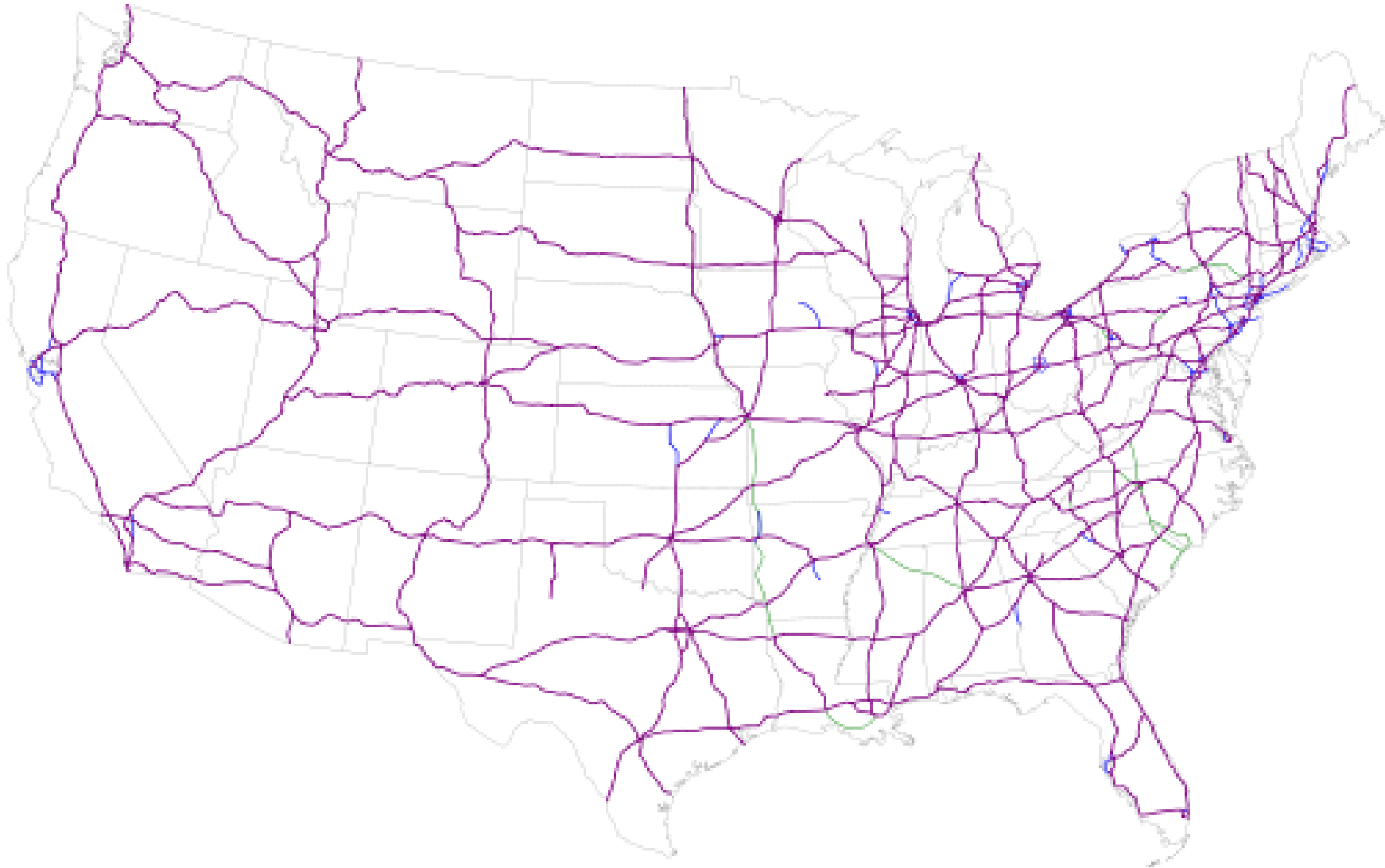
RESEARCH BY MICHAEL DE LA MERCEZ, GRAPHIC BY GILBERT GATES FOR THE NEW YORK TIMES

Temporal Graph Layout: Storylines

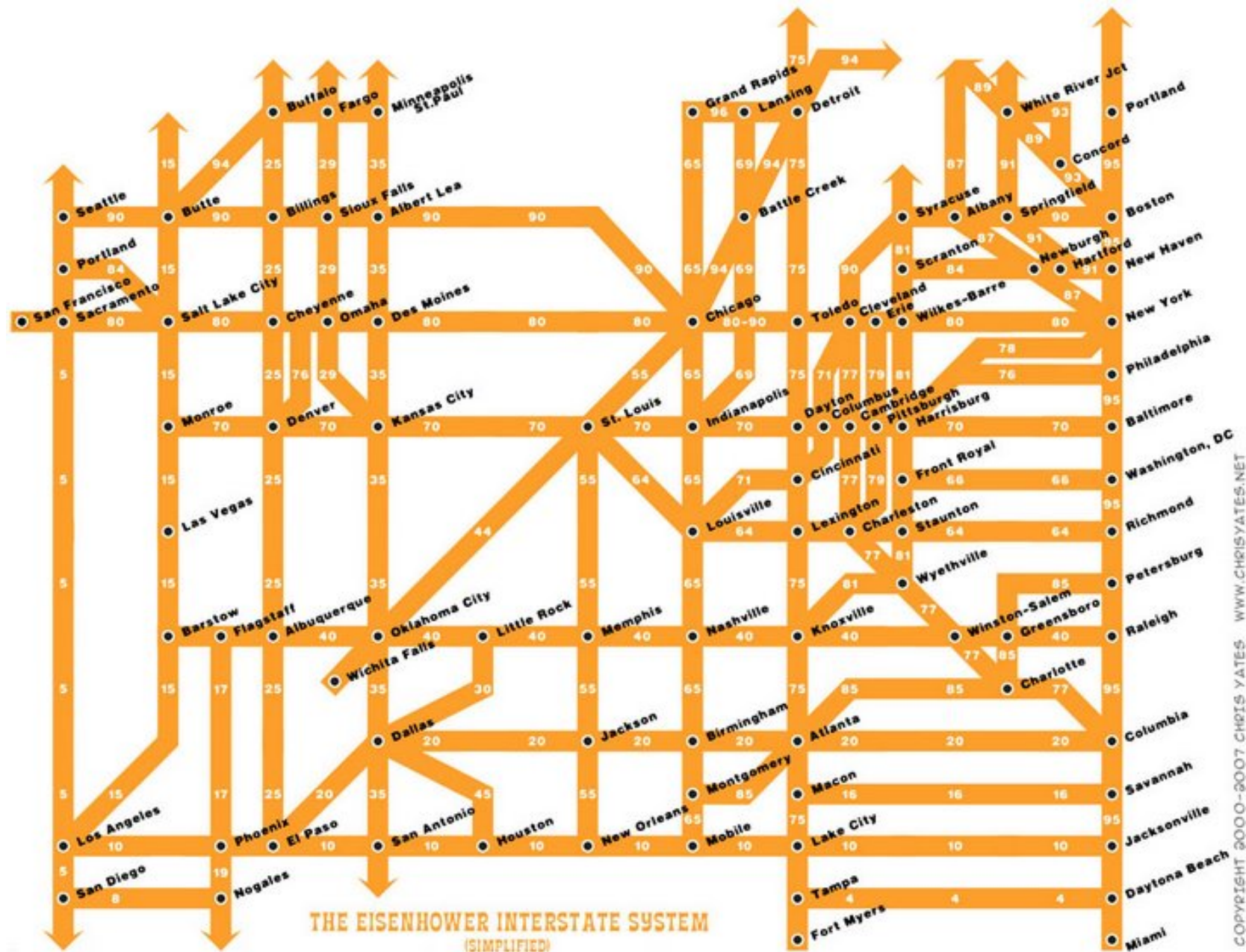


Source: ABC news, Australia

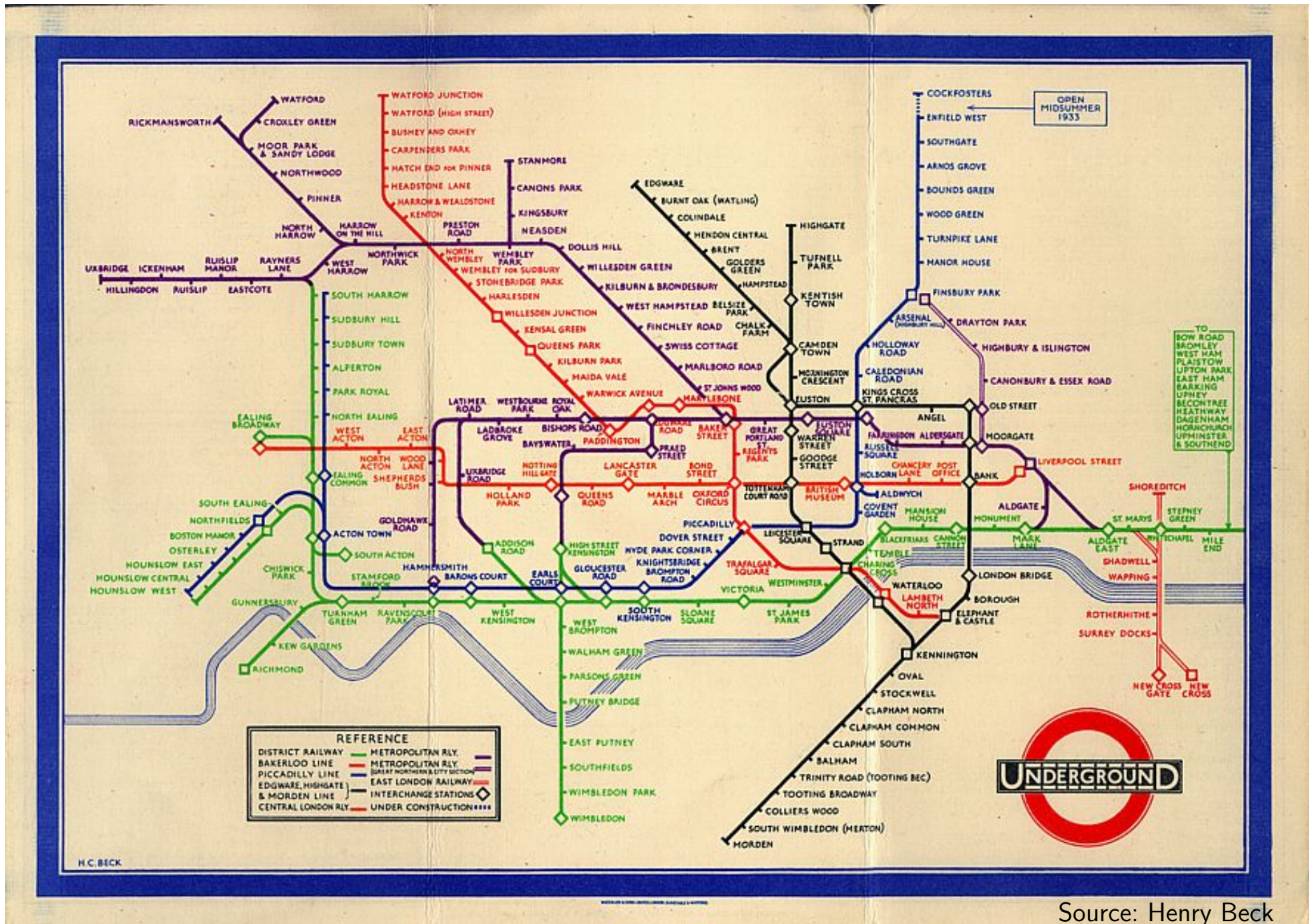
Traffic network – Highways USA



Traffic network – Highways USA

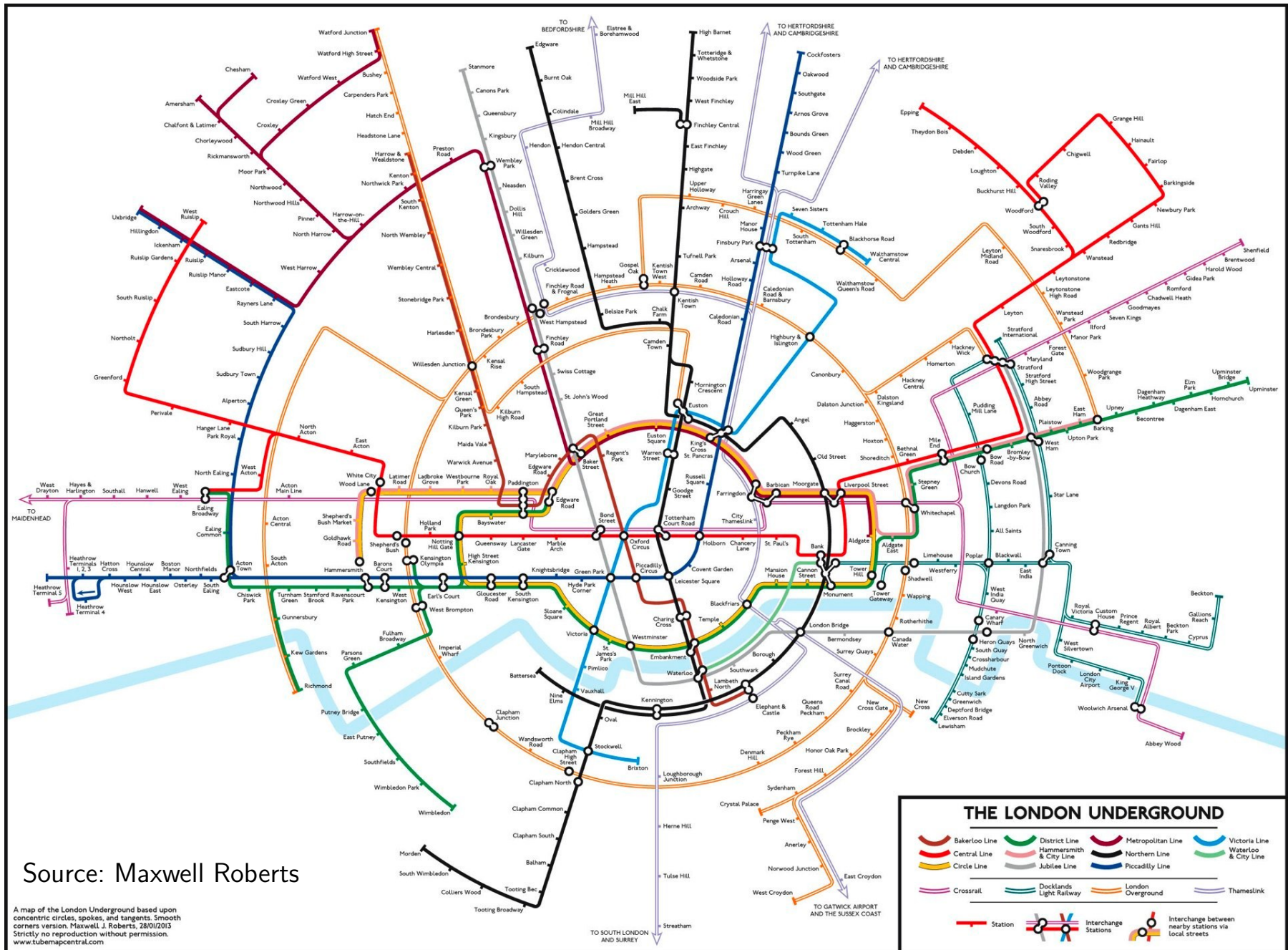


London Tube Map (1933)



Source: Henry Beck

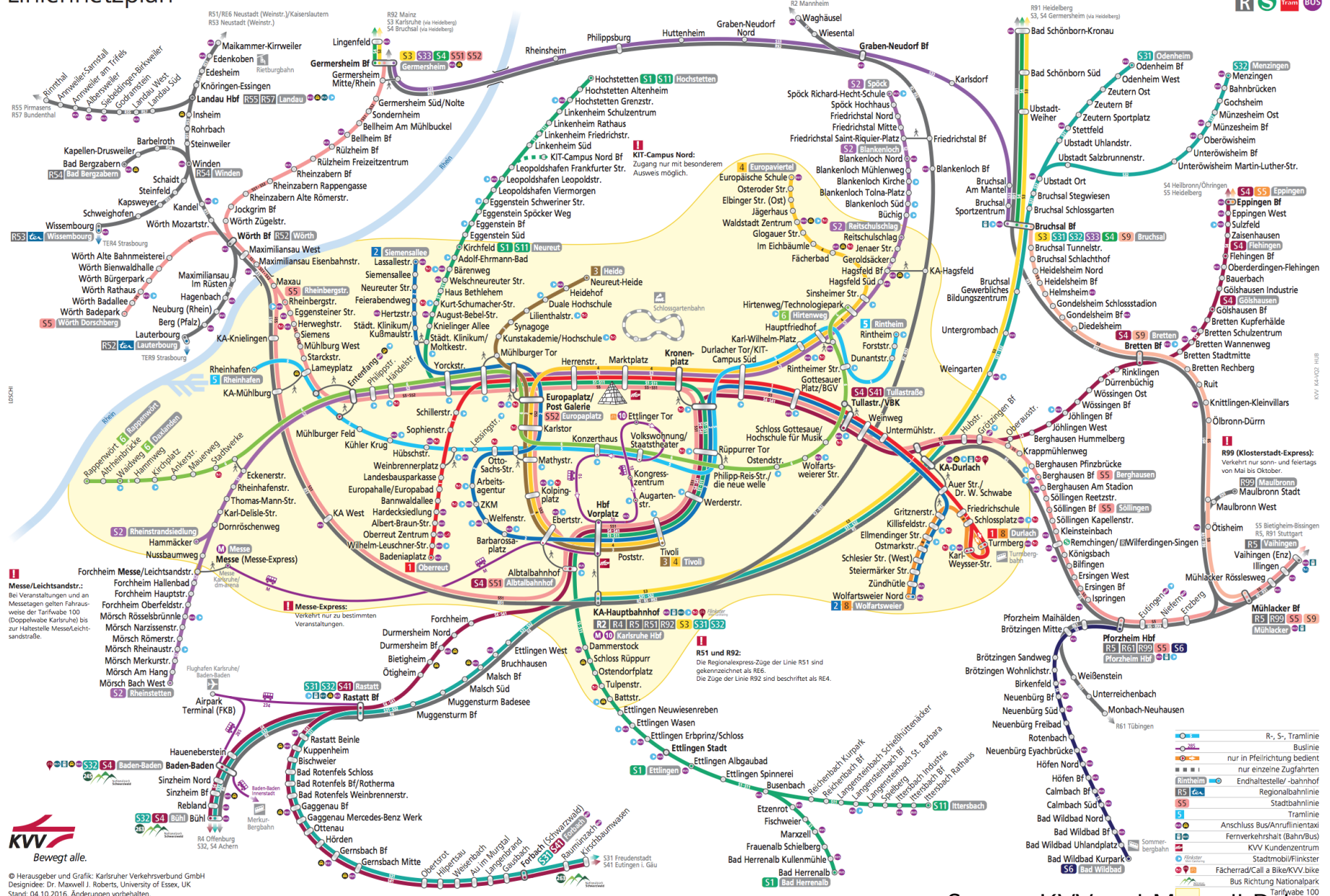
Co-centric Tube Map



Curvilinear S/U-bahn map

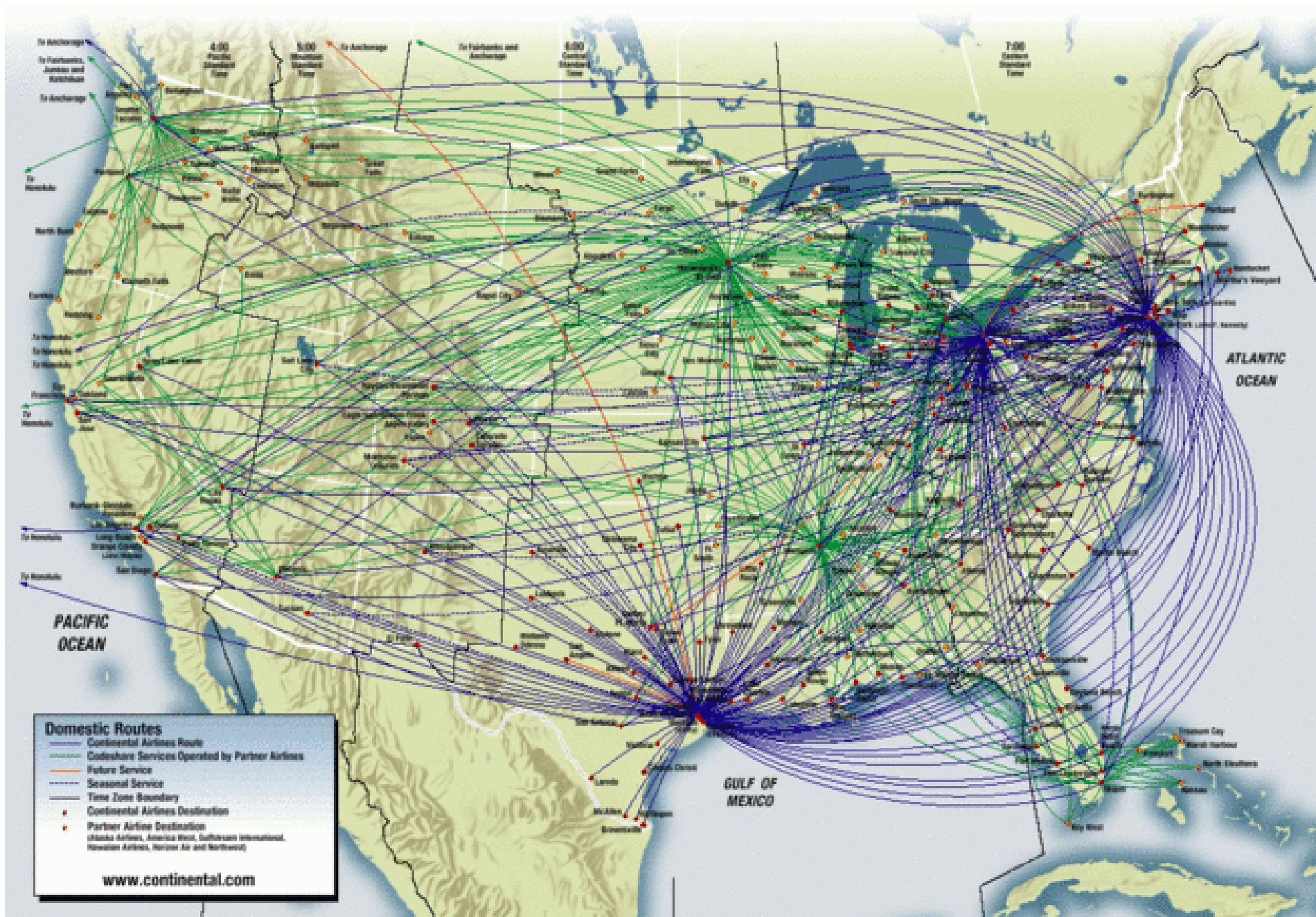
Liniennetzplan

Gültig ab 13. Dezember 2015

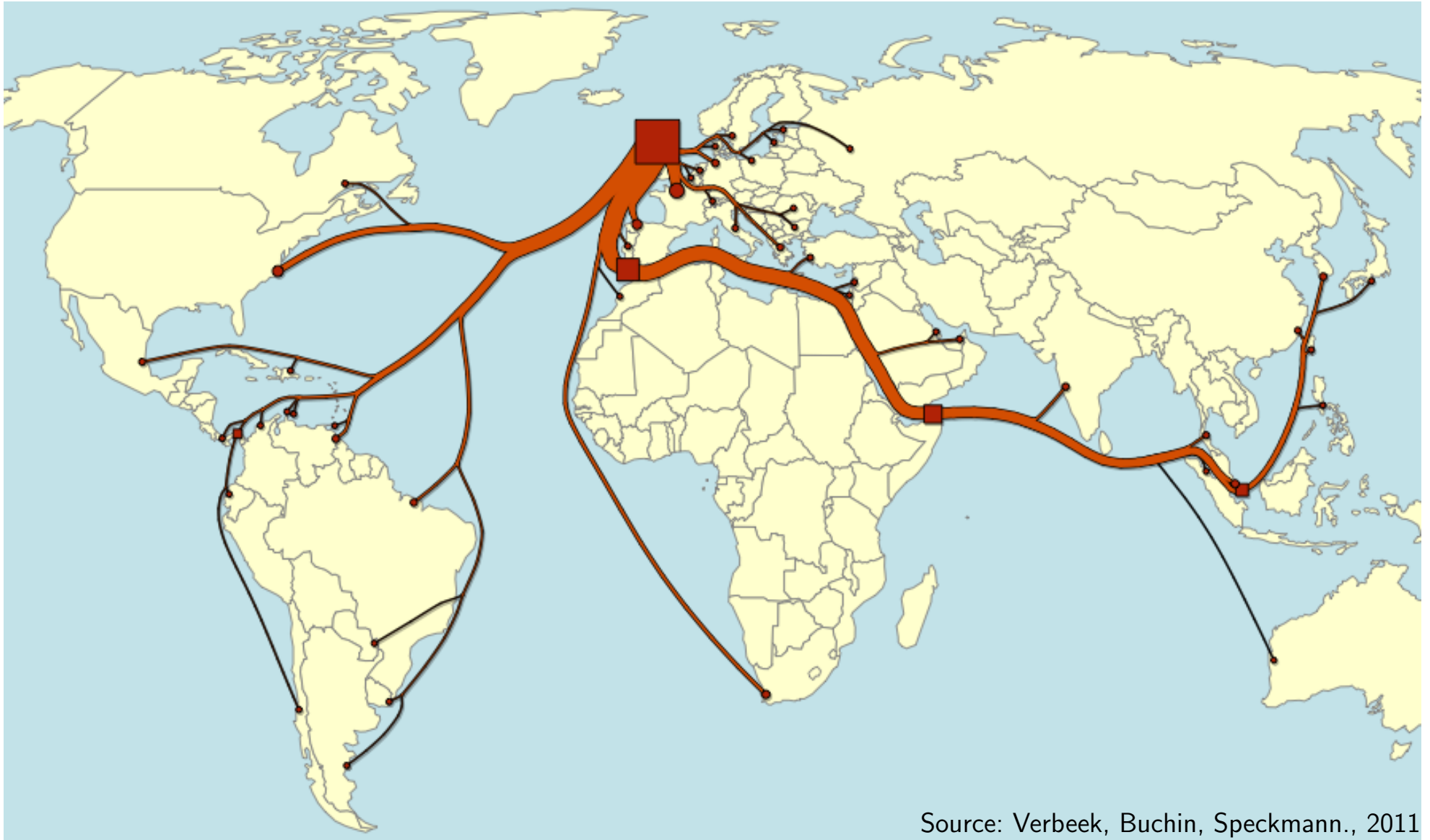


Source: KVV and Maxwell Roberts

Flight Connections

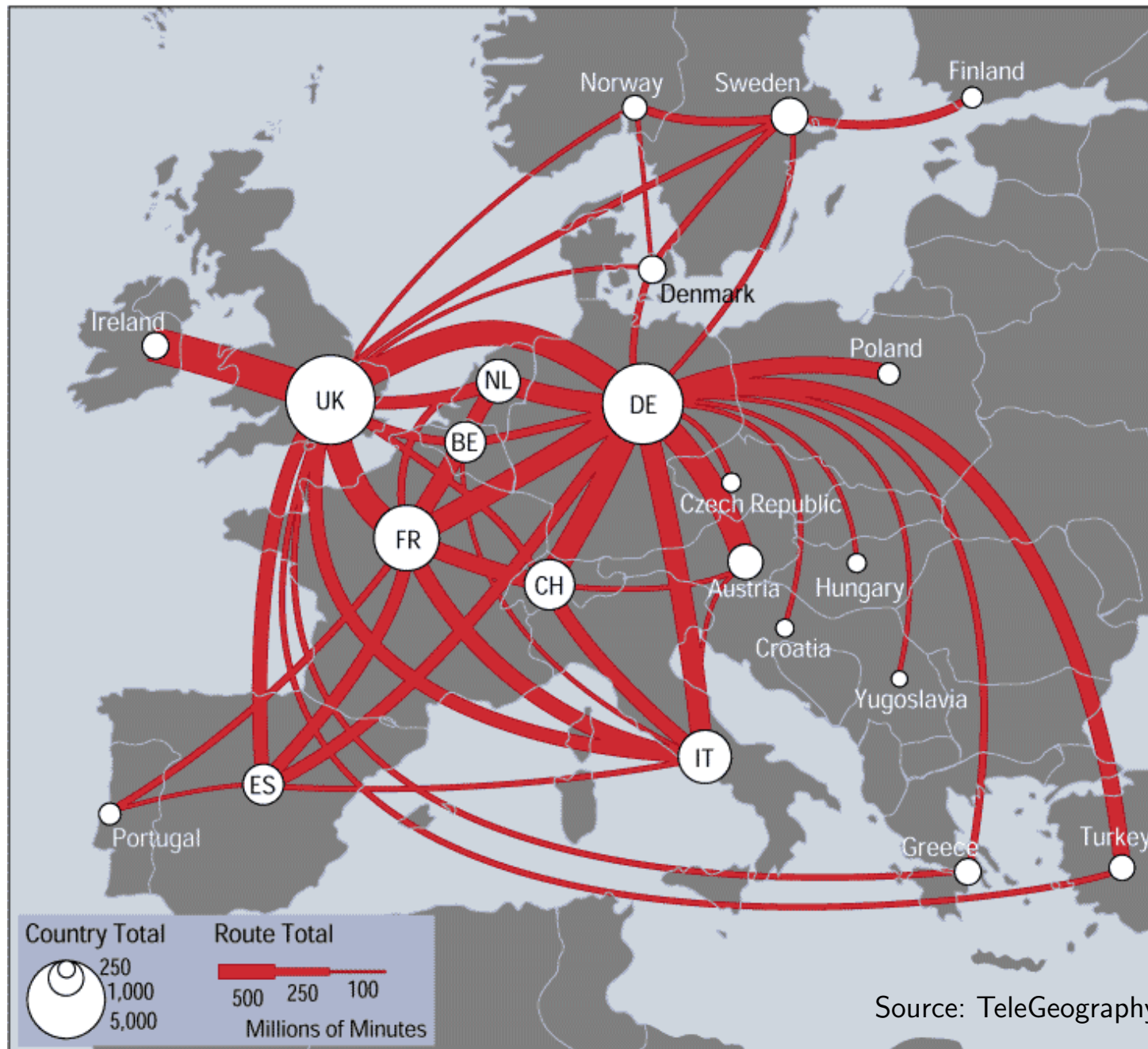


Flow-Map: Whiskey Export



Source: Verbeek, Buchin, Speckmann., 2011

Telephony Map

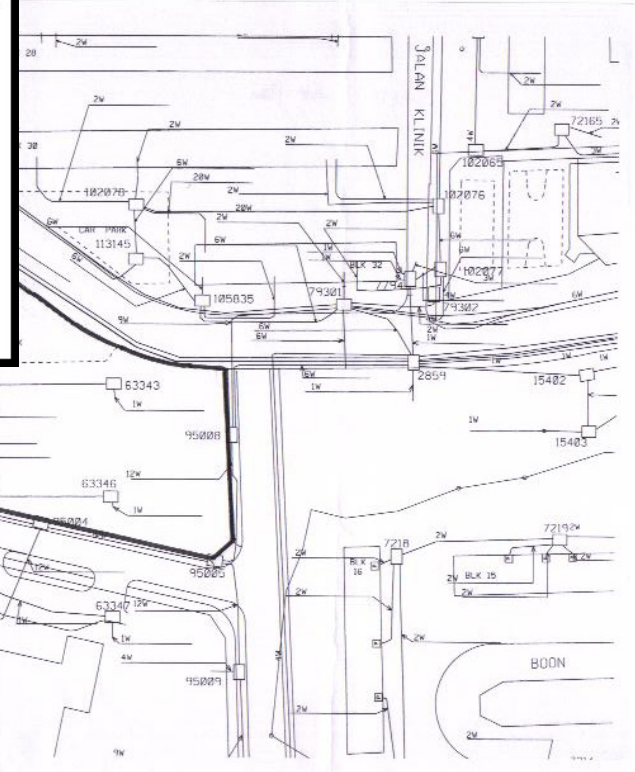
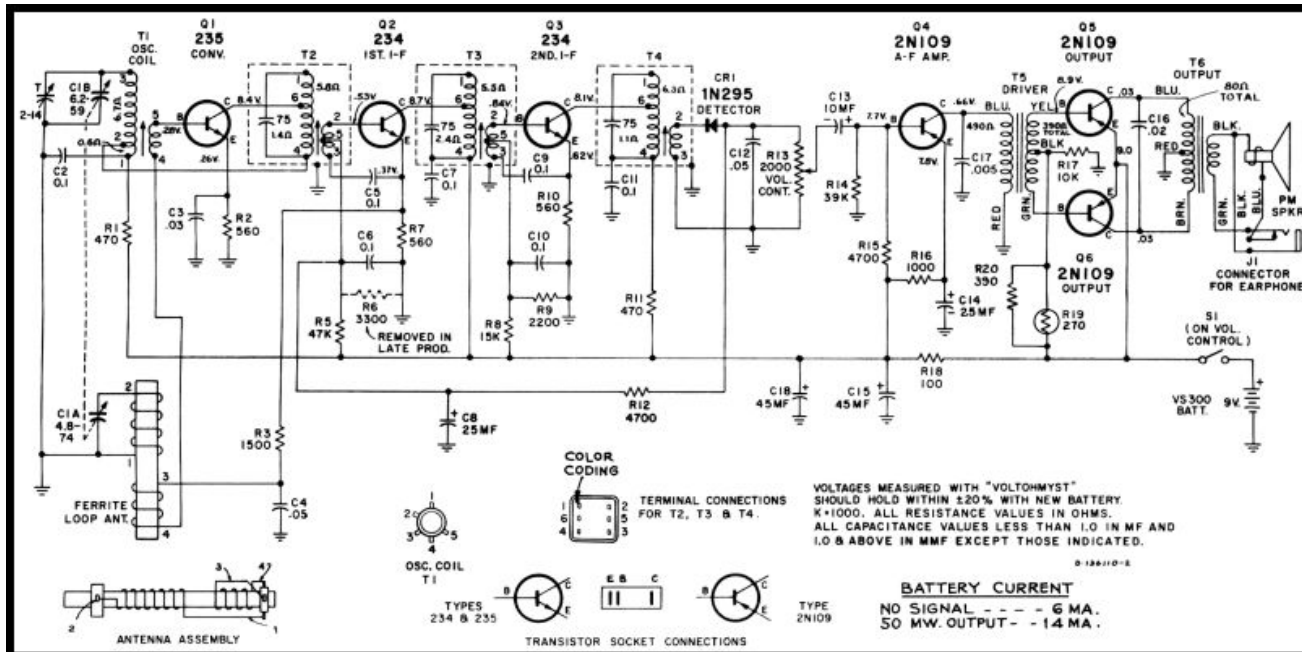


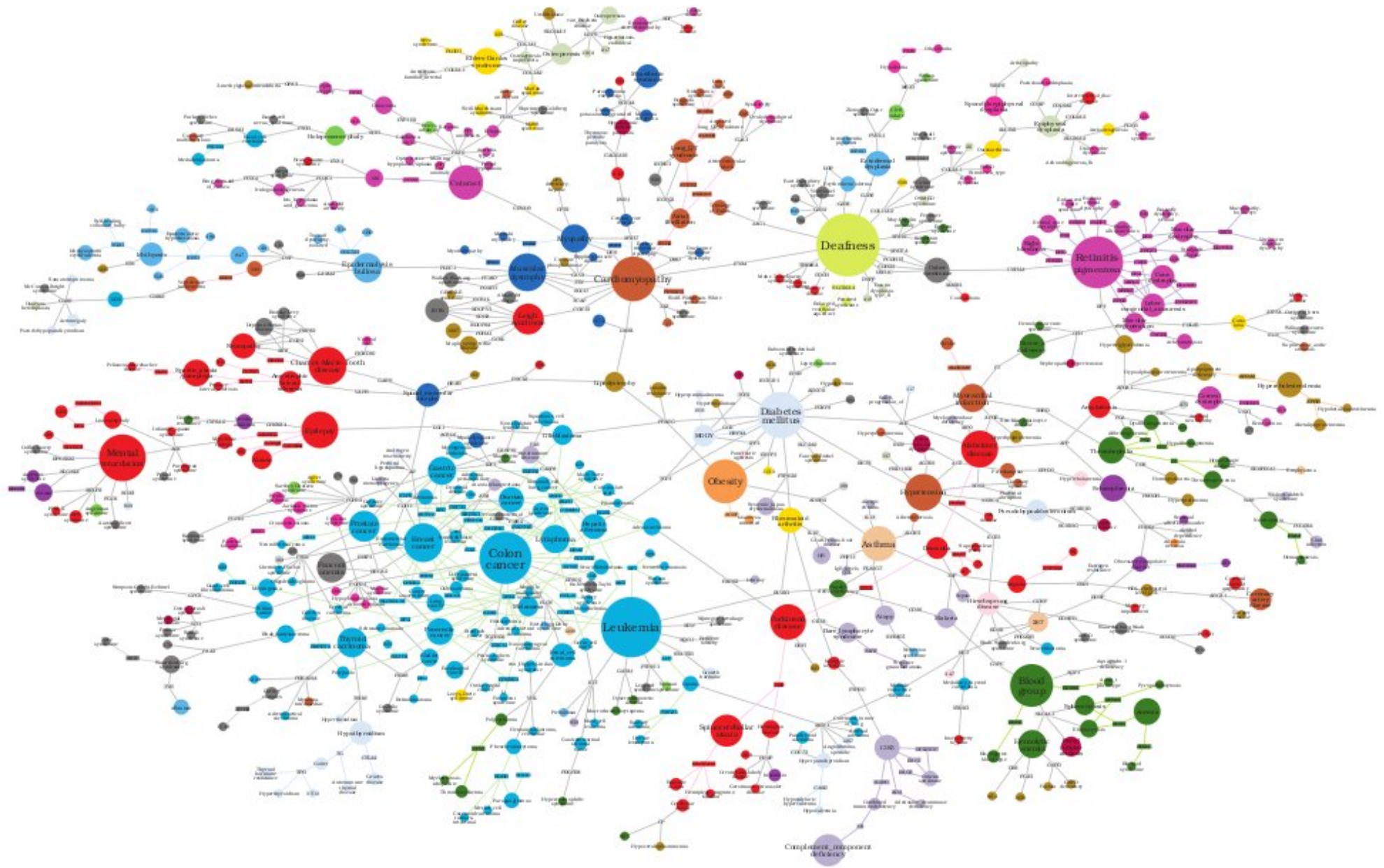
Monitoring of Energy Network



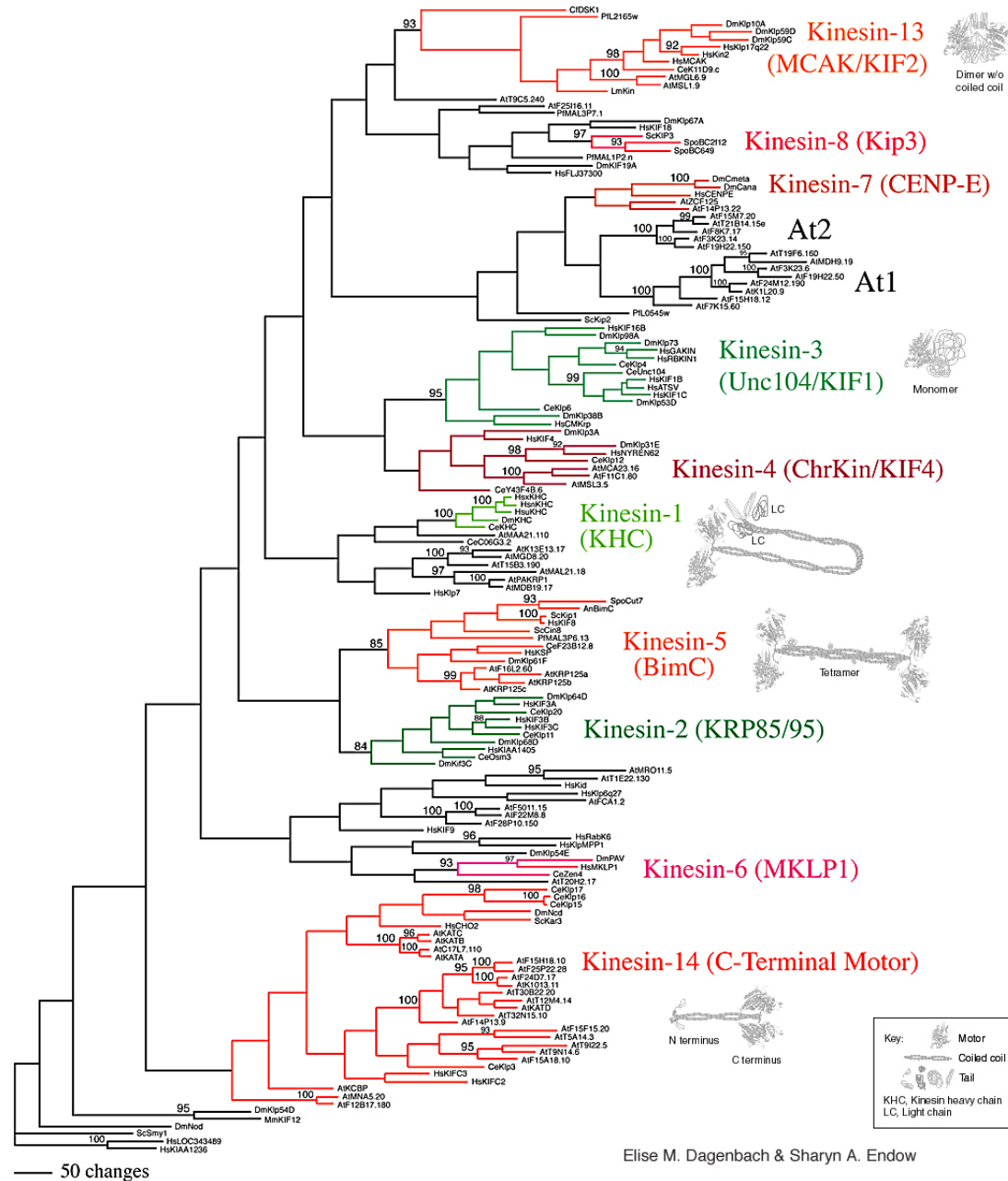
Source: Eir Grid, Ireland

Wiring plan/ Cable plan

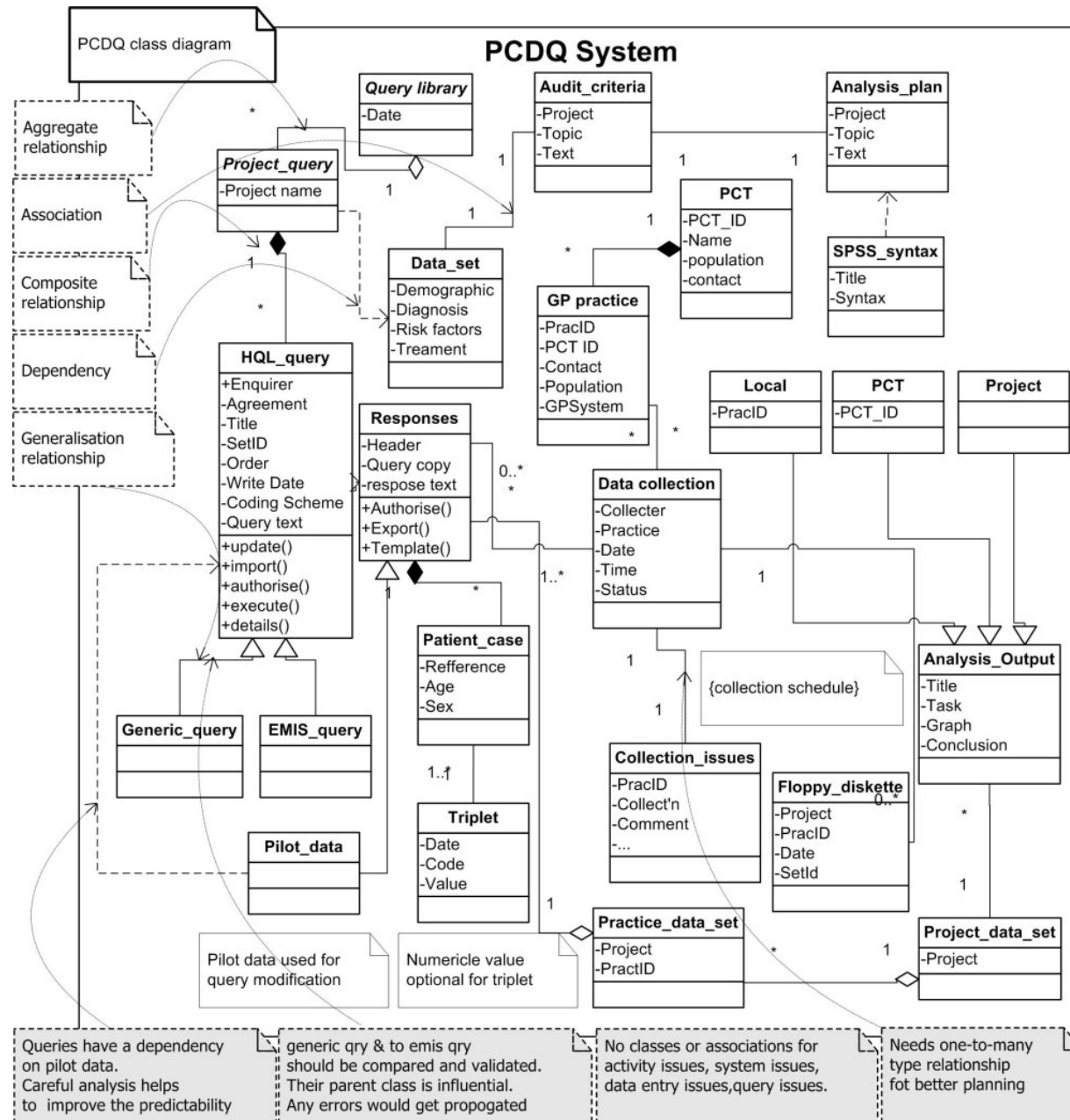




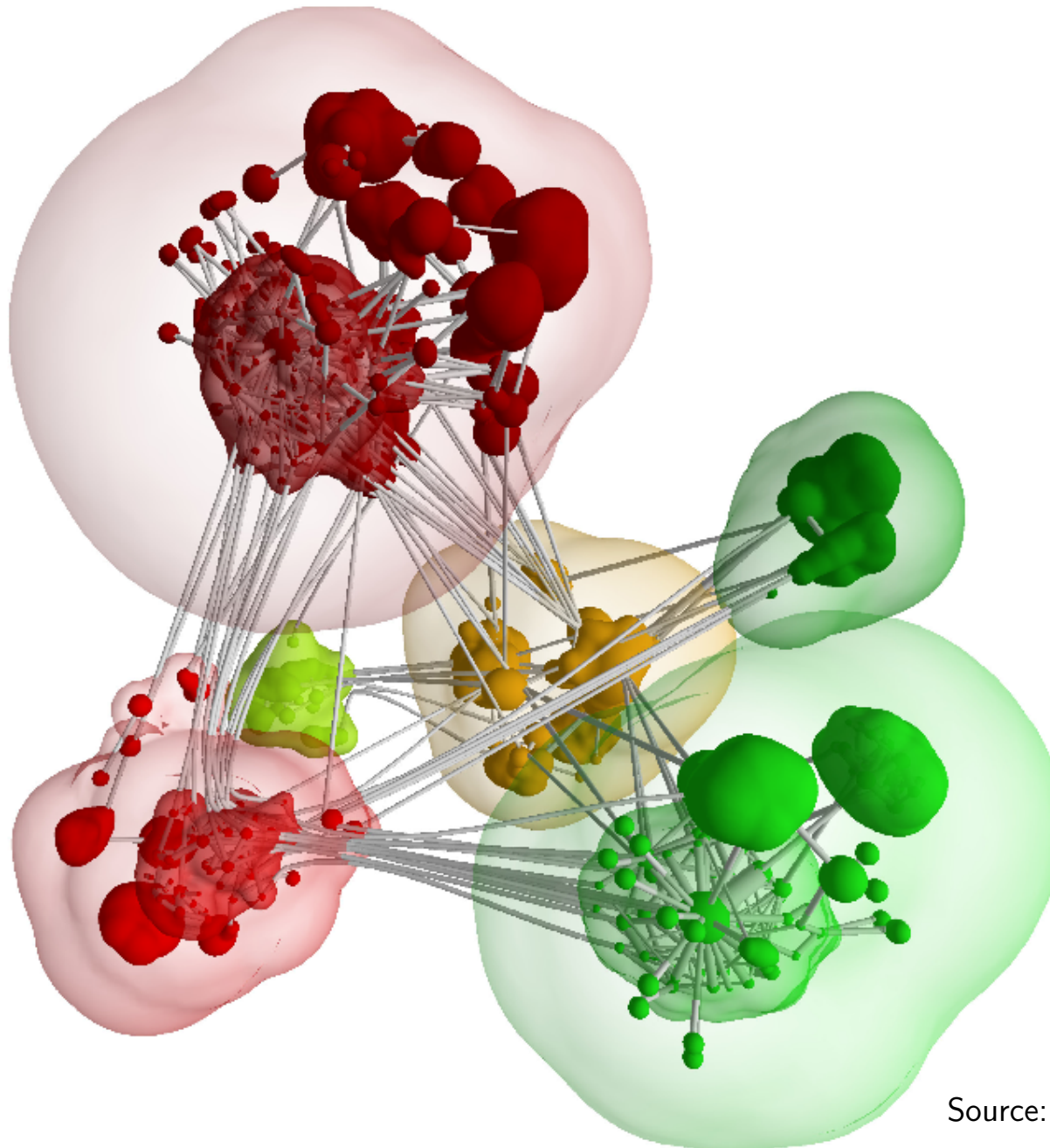
Medicine – phylogenetic Tree



Software-Network – UML Diagram

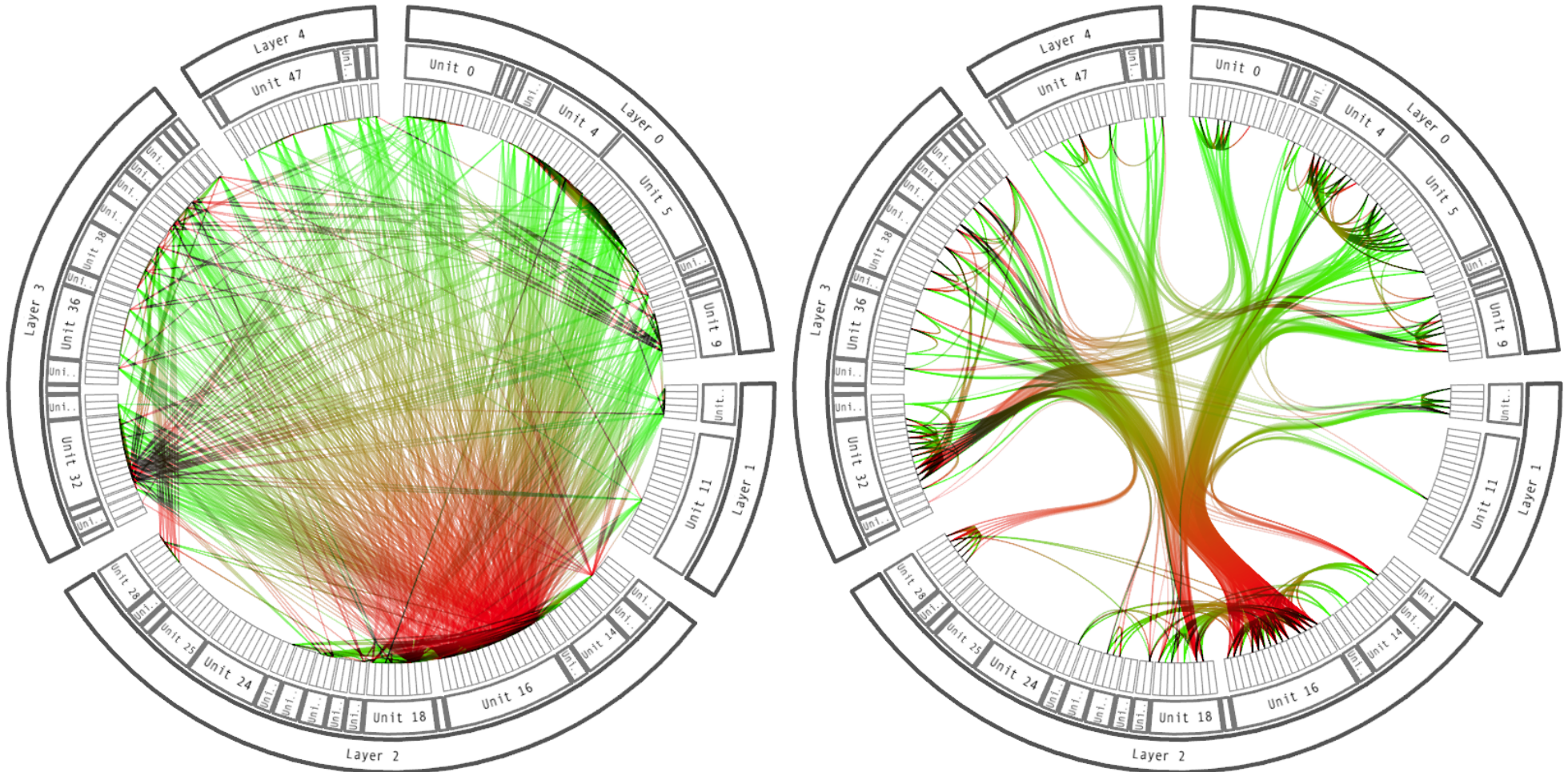


Clustered Software-Graph in 3D



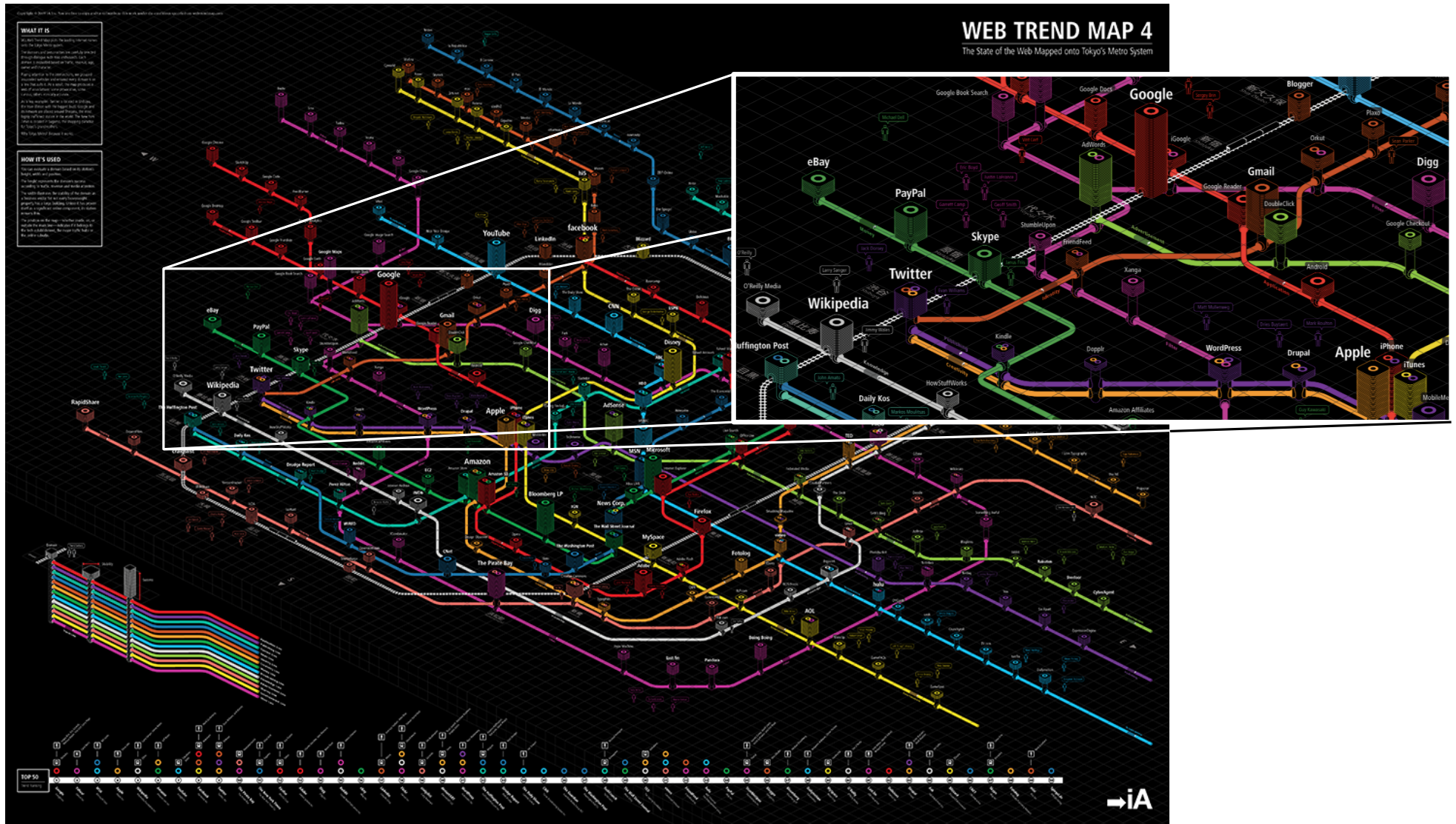
Source: Balzer, Deussen, 2007

Software Call-Graph with edge-bundling



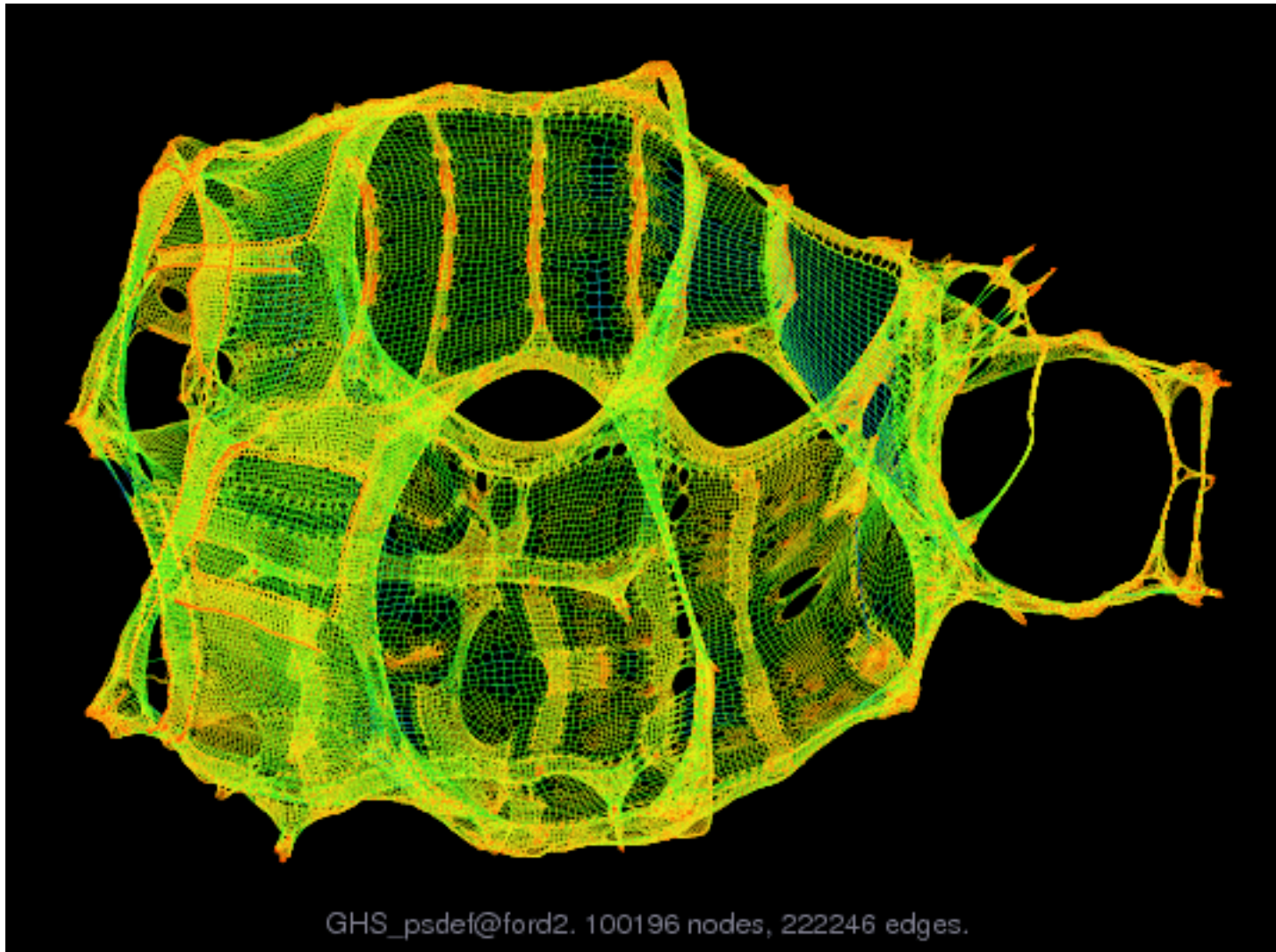
Source: Danny Holten, 2011

Web Trend Map



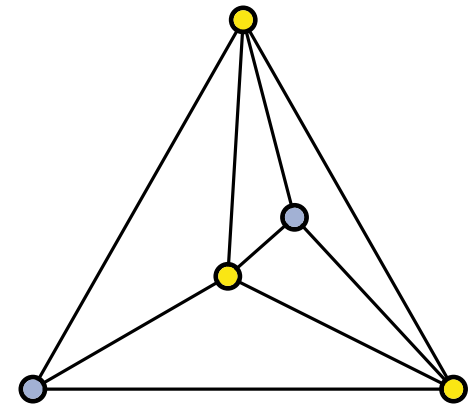
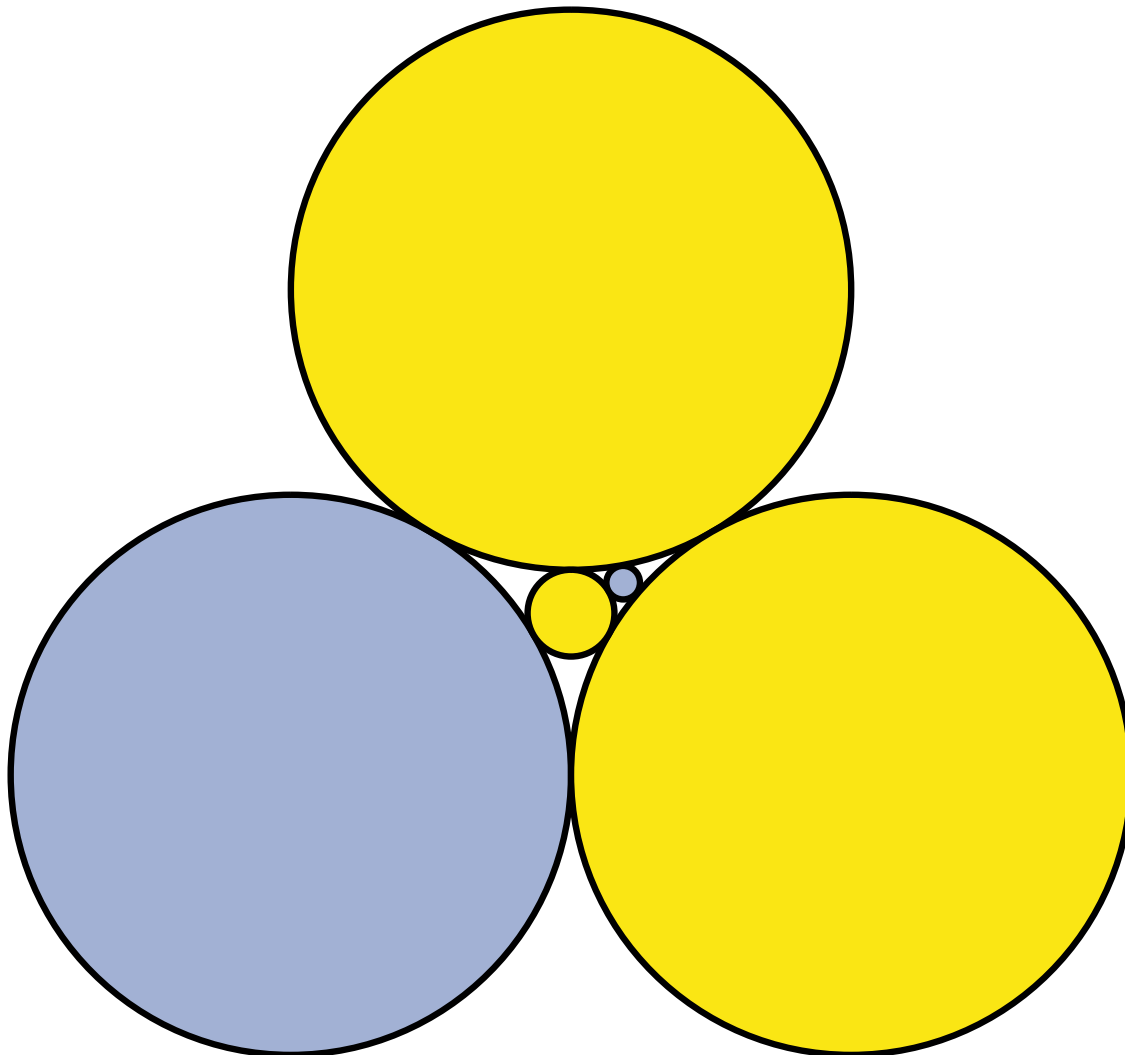
Source: information Architects, 2009

Large Graphs – Object Mesh



Source: Yifan Hu

Alternative Visualizations: Contact map



Libraries for graph visualization

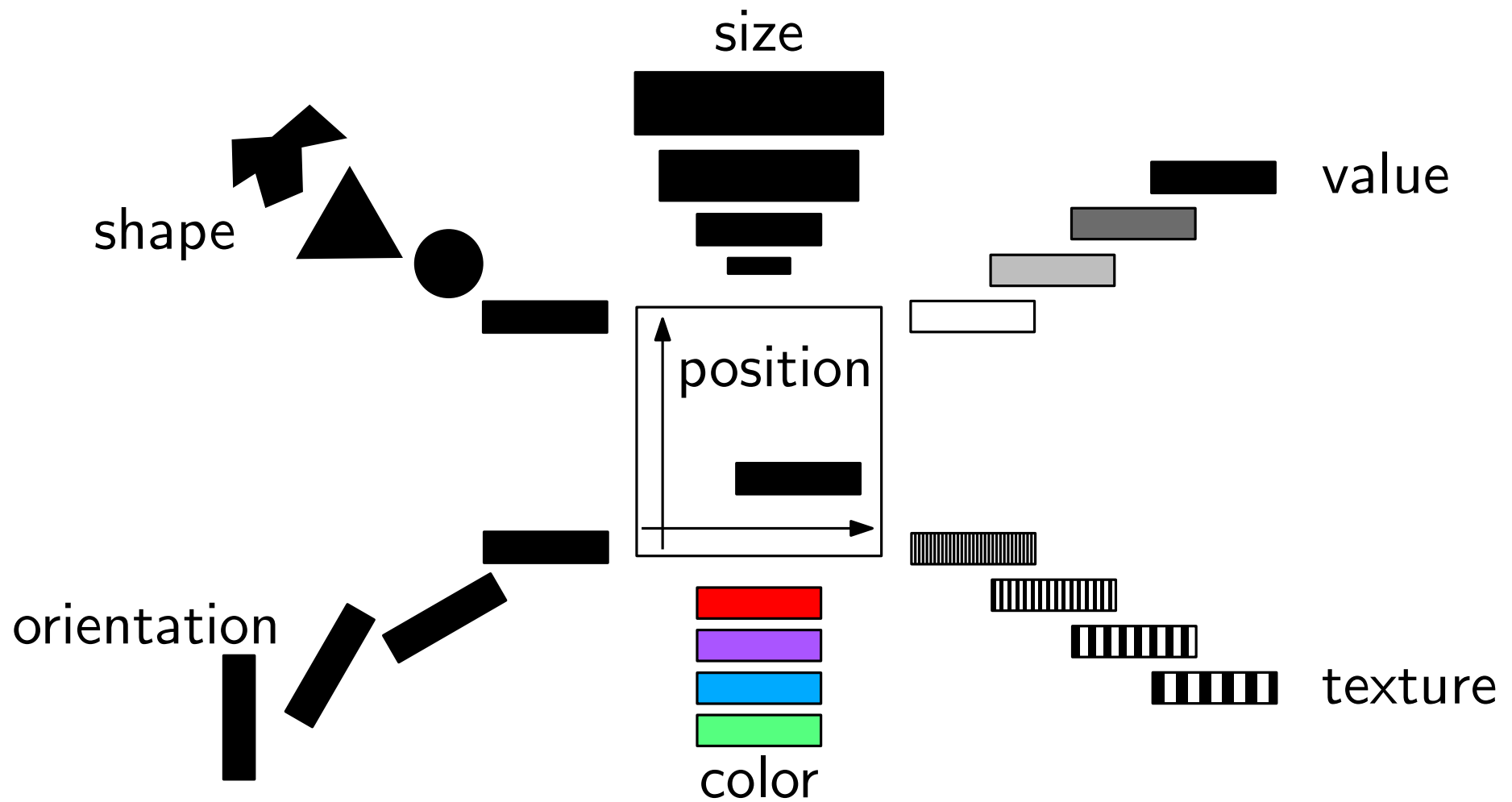
- JUNG jung.sourceforge.net (Java)
- OGDF www.ogdf.net (C++)

Visualization tools

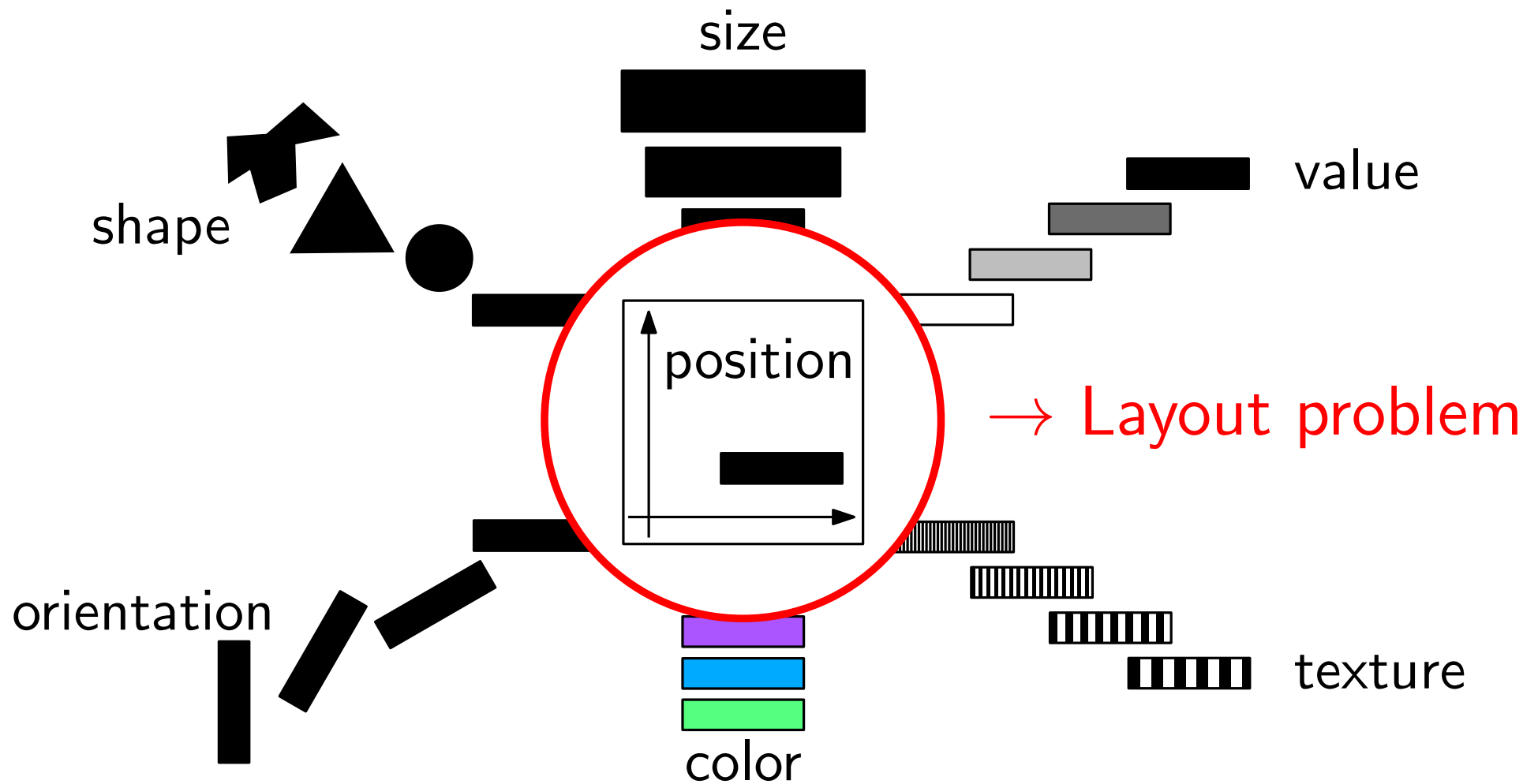
- visone visone.info
- graphviz www.graphviz.org
- yEd www.yworks.com
- Gephi www.gephi.org

Basic Definitions

Visual Variables according to Bertin (1967)



Visual Variables according to Bertin (1967)



Layout Problem

Restriction in the following: **drawing** is always meant to be in form of a node-link diagram

Graph visualization problem

given : Graph $G = (V, E)$

find: **good** drawing Γ of G

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

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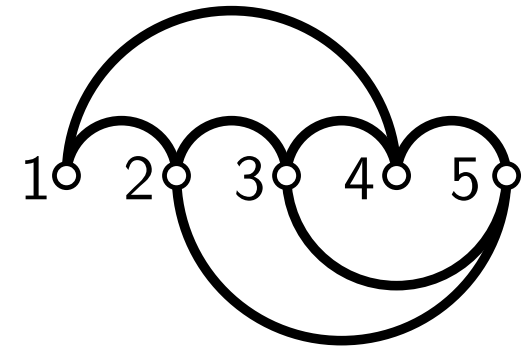
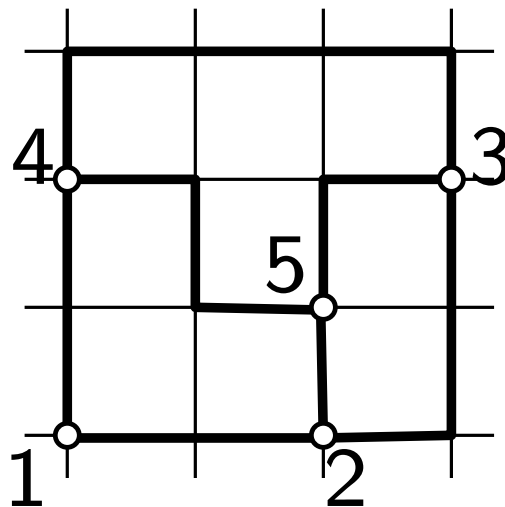
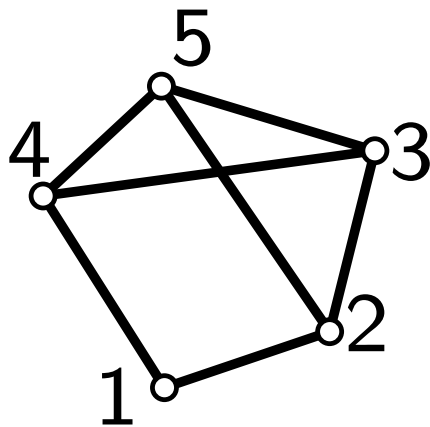
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But what is a **good** Drawing?

Requirement to the graph layout

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

- straight-line edges
- orthogonal edges (with bends 90 degrees)
- Drawing on a grid
- crossing-free
- ...



Requirement to the graph layout

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
- Symmetry
- ...

→ often lead to NP-hard optimization problems!

→ often several competing criteria

Requirement to the graph layout

- 1) **Drawing conventions**, required properties
- 2) **Aesthetics** (to be optimized)
- 3) **Partial/local constraints**, for example:
 - Positions of several vertices
 - Relative positions of vertices
 - Group of nodes drawn close to each other

Graph visualization problem

given: Graph $G = (V, E)$

find: good drawing Γ of G , that

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

Graph visualization problem

given: Graph $G = (V, E)$

find: good drawing Γ of G , that

- complies with drawing conventions
 - optimizes aesthetics
 - satisfies local/partial constraints
-
- this definition drives to interesting algorithmic problems

- **Drawings of Trees and other recursively defined graph classes**
- **straight-line drawings of planar graphs**
- incremental layouts
- orthogonal drawings
- contact representation of graphs
- hierarchical drawings of layered graphs
- force-based drawing algorithm
- . . .

Lecture topics

- **Drawings of Trees and other recursively defined graph classes**
- **straight-line drawings of planar graphs**
- incremental layouts
- orthogonal drawings
- contact representation of graphs
- hierarchical drawings of layered graphs
- force-based drawing algorithm
- ...

Next Meetings

Lecture on 24.10 9:45

Exercise on 26.10 9:45 → please bring your Laptops

→ install the Software yEd (www.yworks.com)