

Algorithms for Graph Visualization

Introduction

INSTITUT FÜR THEORETISCHE INFORMATIK · FAKULTÄT FÜR INFORMATIK

Tamara Mchedlidze, Torsten Ueckerdt, Marcel Radermacher
16.10.2018



Lectures



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



- Torsten Ueckerdt
- `torsten.ueckerdt@kit.edu`
- Office 319
- Office hours: request by email

Exercises



- Marcel Radermacher
- `radermacher@kit.edu`
- Office 306
- Office hours: request by email

Lectures



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



- Torsten Ueckerdt
- `torsten.ueckerdt@kit.edu`
- Office 319
- Office hours: request by email

Exercises



- Marcel Radermacher
- `radermacher@kit.edu`
- Office 306
- Office hours: request by email

YOU: Name, Field of your Bachelor studies, why you are interested in this lecture

Mailing list

About this course

Repetition of the material. We build our Mind Map.

Drawing graphs “by hand”. Complete MindMap.

Formal definition of Layout Problem.

About this course: learning objectives.

Applications gallery.

About this course

Repetition of the material. We build our Mind Map.

Drawing graphs “by hand”. Complete MindMap.

Formal definition of Layout Problem.

About this course: learning objectives.

Applications gallery.

About this Course

- **Lecture:** Wednesday 14:00 – 15:30, Room 301
- **Exercise:** Tuesday 14:00 – 15:30, Room 236
- exact plan on the web-page*

Website

`i11www.itl.kit.edu/teaching/winter2019/graphvis/`

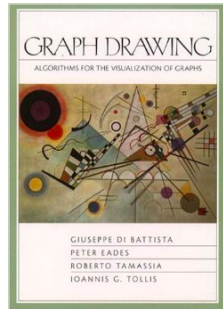
- Latest news
- Lecture slides
- Exercise sheets
- Literature & Additional material
- Lecture notes (skript)

About this Course

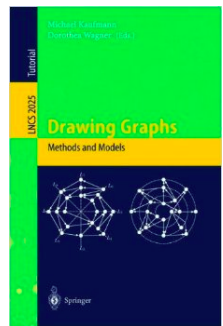
Media:

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

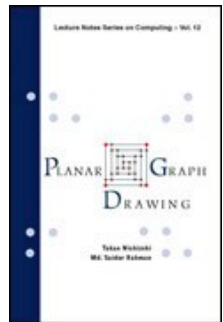
Books (available in the library)



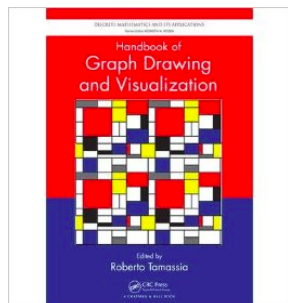
G. di Battista, P. Eades, R. Tamassia, I. Tollis:
Graph Drawing
Prentice Hall, 1998



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/>

About this Course

Master Informatics

- Module: General: M-INFO-102094
This year: T-INFO-104390

About this Course

Master Informatics

- Module: General: M-INFO-102094
This year: T-INFO-104390

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

About this Course

Master Informatics

- Module: General: M-INFO-102094
This year: T-INFO-104390

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

Exercises:

- We expect that you **participate actively** in the exercise sessions (e.g. present your own solutions on the board)

Examination procedure: Oral exam(app. 20 Minutes)

About this course

Repetition of the material. We build our Mind Map.

Drawing graphs “by hand”. Complete MindMap.

Formal definition of Layout Problem.

About this course: learning objectives.

Applications gallery.

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 $E = \{e_1, \dots, e_m\}$,

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

Graph and its Representation

What is a Graph?

Tuple $G = (V, E)$

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

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

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

Representations?

What is a Graph?

Tuple $G = (V, E)$

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

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

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

Representations?

Set representation:

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

Graph and its Representation

What is a Graph?

Tuple $G = (V, E)$

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

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

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

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
```

Graph and its Representation

What is a Graph?

Tuple $G = (V, E)$

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

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

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

Representations?

Set representation

Adjacency list

Adjacency matrix

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

Graph and its Representation

What is a Graph?

Tuple $G = (V, E)$

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

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

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

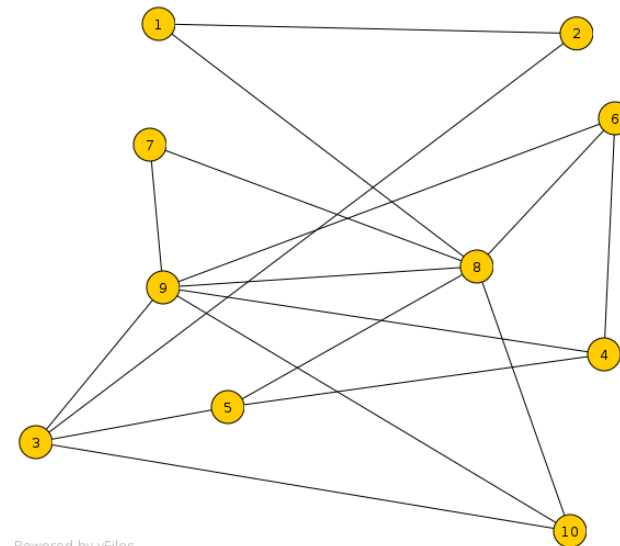
Representations?

Set representation

Adjacency list

Adjacency matrix

Drawing or Node-link diagram



Powered by yFiles

Graph and its Representation

What is a Graph?

Tuple $G = (V, E)$

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

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

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

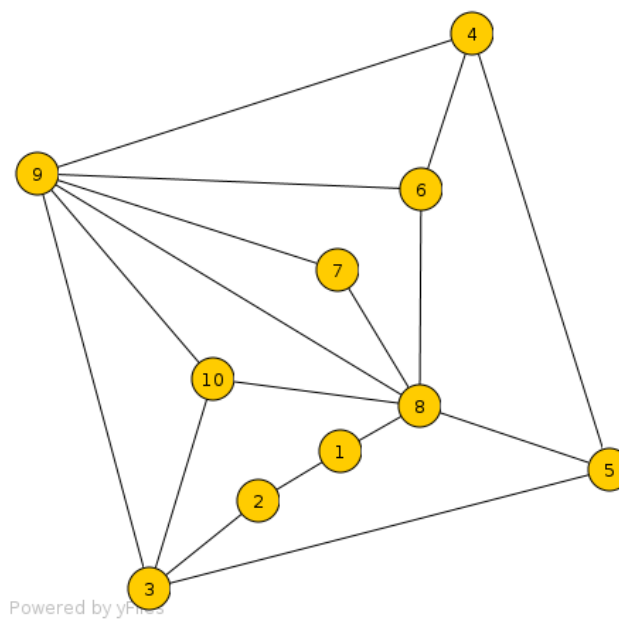
Representations?

Set representation

Adjacency list

Adjacency matrix

Drawing or Node-link diagram

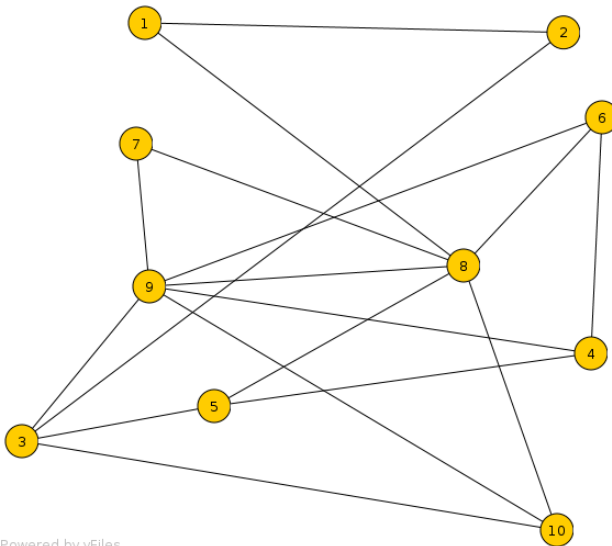


Graph and its Representation

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

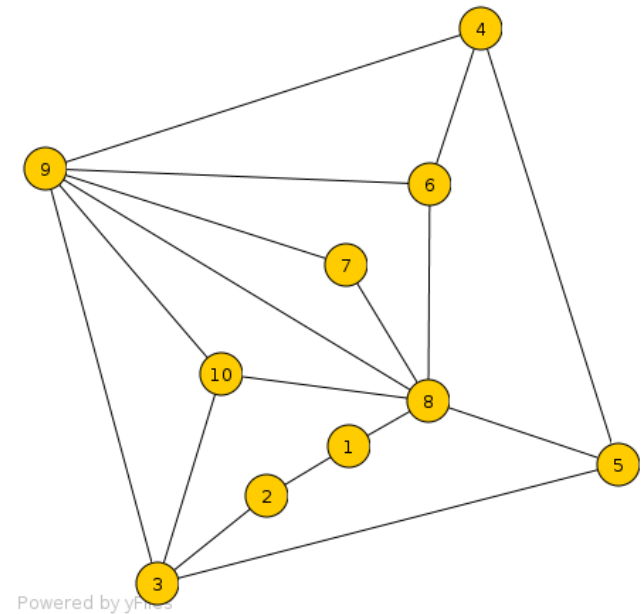
$$E = \{\{v_1, v_2\}, \{v_1, v_8\}, \{v_2, v_3\}, \{v_3, v_5\}, \{v_3, v_9\}, \{v_3, v_{10}\}, \{v_4, v_5\}, \{v_4, v_6\}, \{v_4, v_9\}, \{v_5, v_8\}, \{v_6, v_8\}, \{v_6, v_9\}, \{v_7, v_8\}, \{v_7, v_9\}, \{v_8, v_{10}\}, \{v_9, v_{10}\}\}$$

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
 v_5 : v_3, v_4, v_8
 v_6 : v_4, v_8, v_9
 v_7 : v_8, v_9
 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



Powered by yFiles

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



Powered by yFiles

Graph and its Representation



Think and write down

- **Why do need node-link diagrams?**

2 min

Let's Recall



Discuss with your neighbour or in groups of three and write down

10 min

Graph classes you know (planar etc.)

Algorithmic techniques you know (greedy etc.)

Applications of network visualization you have heard about

We will group your knowledge into a MIND MAP

Let's Recall



Discuss with your neighbour or in groups of three and write down

10 min

Graph classes you know (planar etc.)

Algorithmic techniques you know (greedy etc.)

Applications of network visualization you have heard about

We will group your knowledge into a MIND MAP

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

Helpful: Algorithms for Planar Graphs

Overview

About this course

Repetition of the material. We build our Mind Map.

Drawing graphs “by hand”. Complete MindMap.

Formal definition of Layout Problem.

About this course: learning objectives.

Applications gallery.

How to draw graphs?



Work with your neighbour or in groups of three

15 min

- graphs in form of adjacency matrix/list
- Use <https://www.yworks.com/downloads#yEd> or paper
- draw all or some graphs as nice and as readable as possible
- export to PNG or make a picture and send to mched@iti.uka.de

We will show and discuss the results afterwards and complete the MIND MAP

Overview

About this course

Repetition of the material. We build our Mind Map.

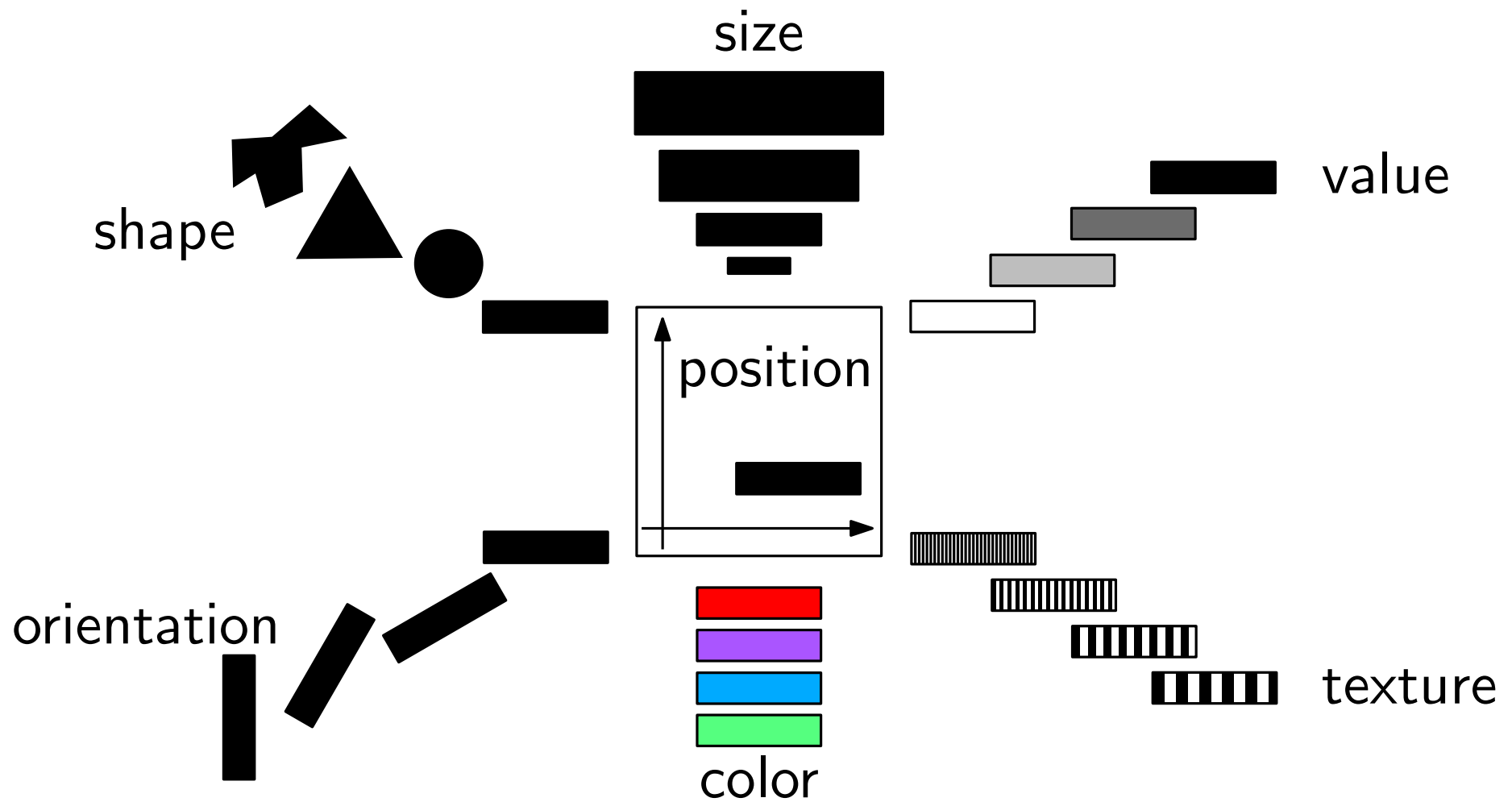
Drawing graphs “by hand”. Complete MindMap.

Formal definition of Layout Problem.

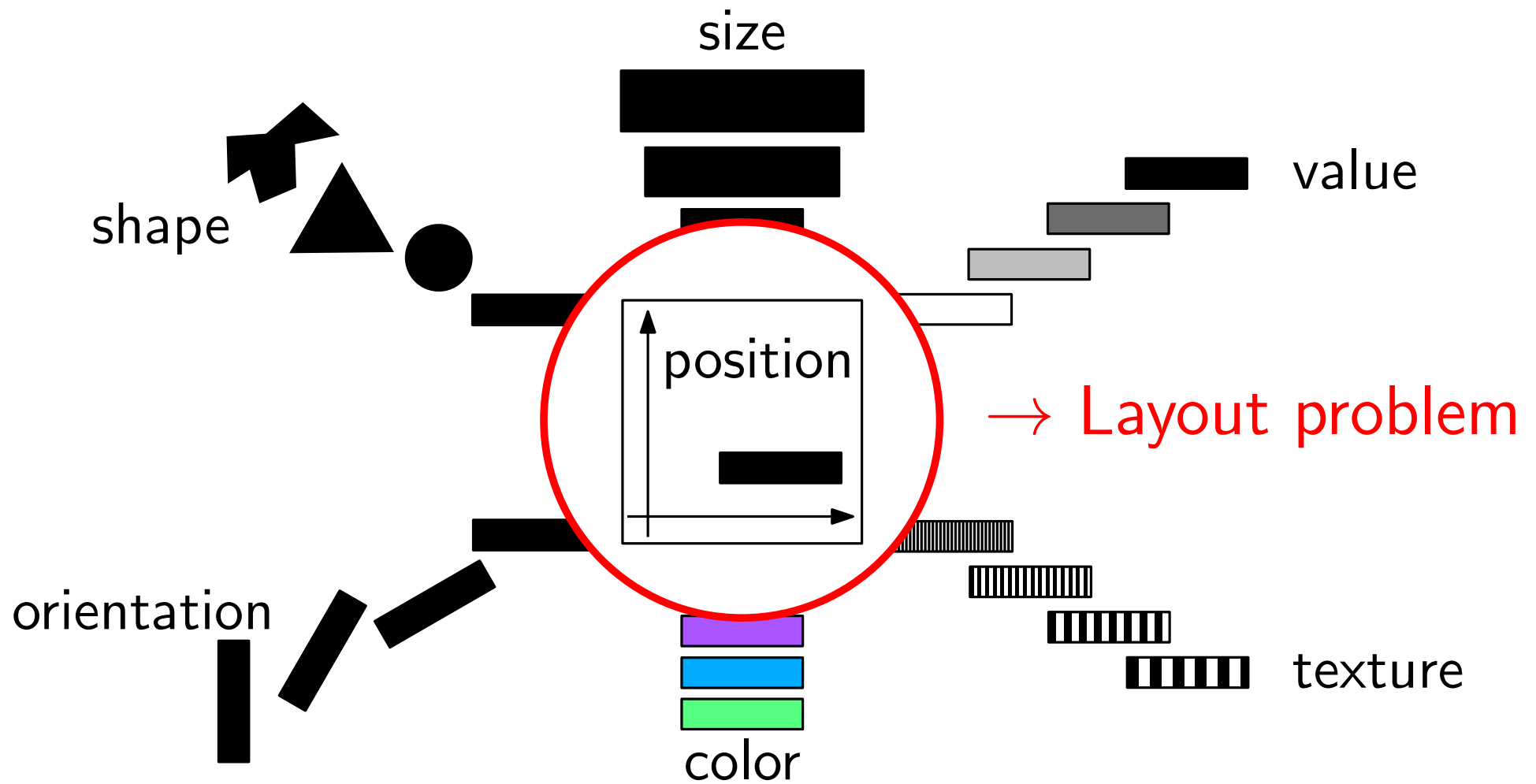
About this course: learning objectives.

Applications gallery.

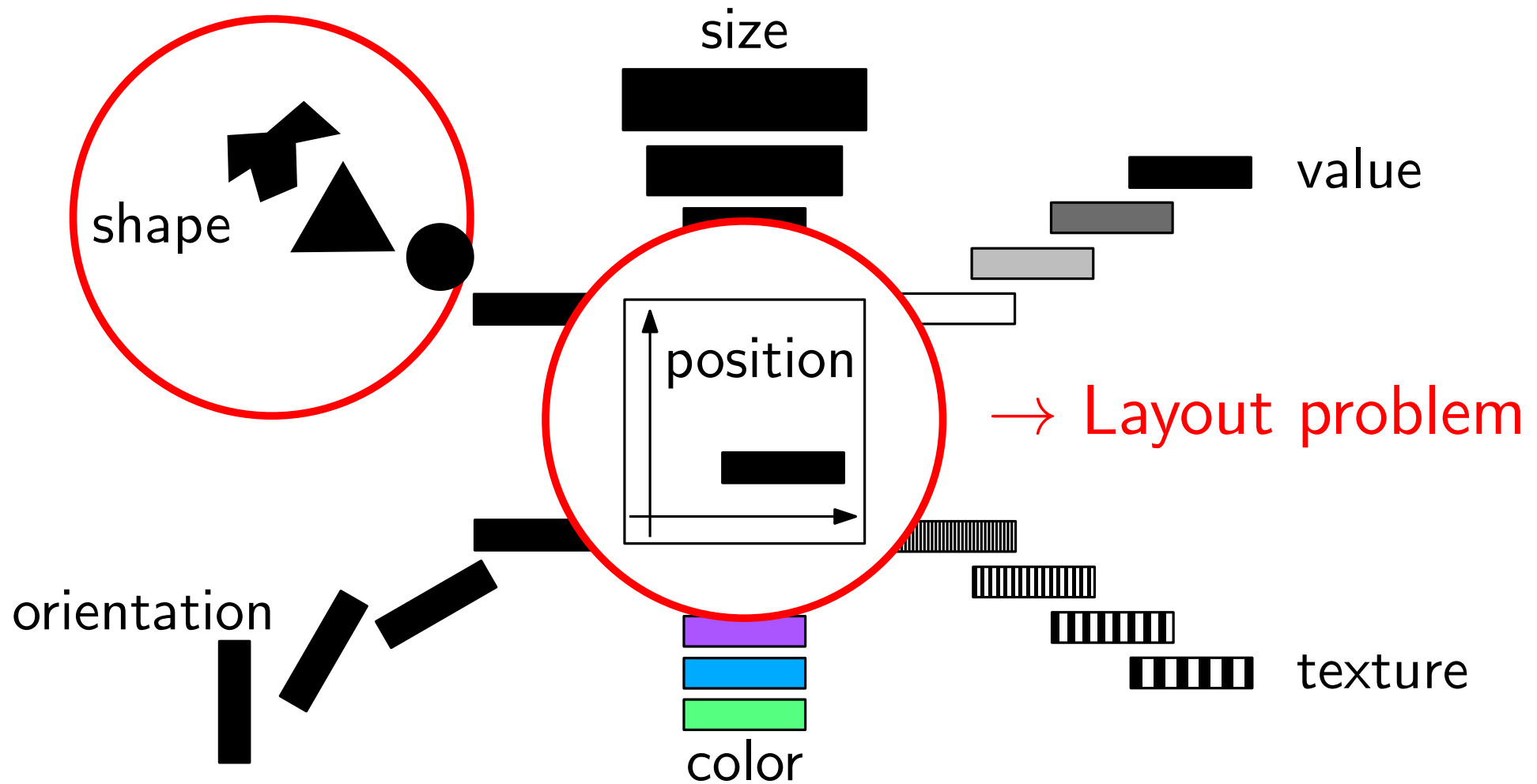
Visual Variables according to Bertin (1967)



Visual Variables according to Bertin (1967)



Visual Variables according to Bertin (1967)



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 $c_{uv}(1) = \Gamma(v)$

Graph visualization problem

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

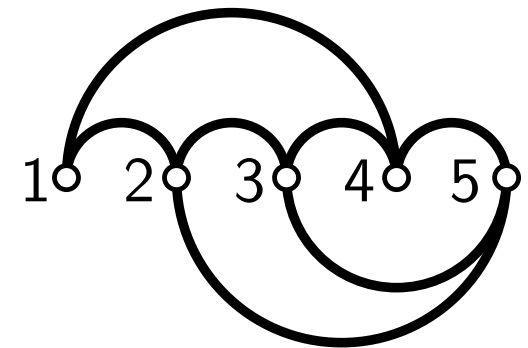
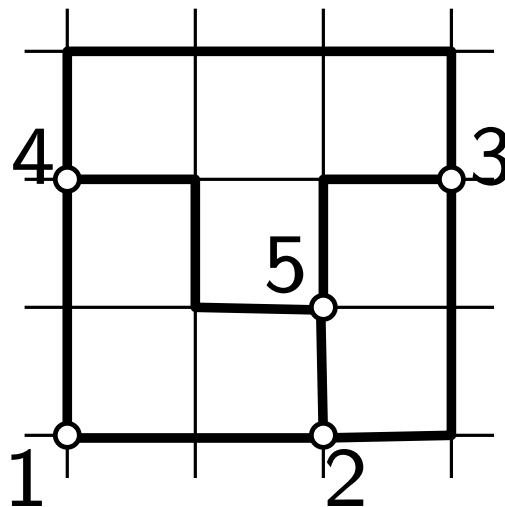
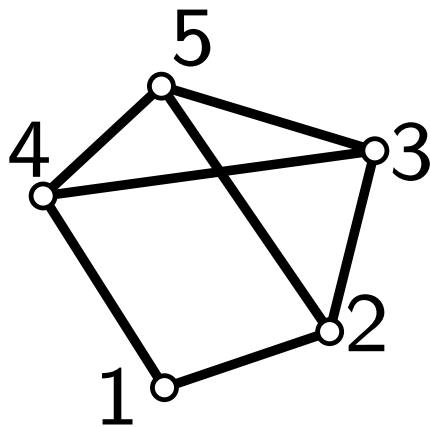
find: **good drawing** Γ of G

- $\Gamma : V \rightarrow \mathbb{R}^2$, 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 $c_{uv}(1) = \Gamma(v)$

Layout Problem

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

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



Layout Problem

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
-

Layout Problem

- 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: a drawing Γ of G , that

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

Graph visualization problem

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

find: a drawing Γ of G , that

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

→ often lead to NP-hard optimization problems!

→ often several competing criteria

Overview

About this course

Repetition of the material. We build our Mind Map.

Drawing graphs “by hand”. Complete MindMap.

Formal definition of Layout Problem.

About this course: learning objectives.

Applications gallery.

Learning Objectives

At the end of the semester you are able to:

At the end of the semester you are able to:

- List various network visualization styles
- Formally state a network visualization problem
- Describe several algorithms for network visualization in a intuitive way
- Describe formally several network visualization algorithms
- Identify the techniques behind the algorithms (greedy, iterative, dynamic programming, etc.)
- Analyze the time complexity of algorithms
- Proof correctness of the algorithms
- Solve new network visualization problems by selecting and adapting known approaches

At the end of the semester you are able to:

- List various network visualization styles
 - Formally state a network visualization problem
 - Describe several algorithms for network visualization in a intuitive way
 - Describe formally several network visualization algorithms
 - Identify the techniques behind the algorithms (greedy, iterative, dynamic programming, etc.)
 - Analyze the time complexity of algorithms
 - Proof correctness of the algorithms
- Recall Level**
- Solve new network visualization problems by selecting and adapting known approaches

Learning Objectives

At the end of the semester you are able to:

- List various network visualization styles
- Formally state a network visualization problem

Recall Level

- Describe several algorithms for network visualization in a intuitive way
- Describe formally several network visualization algorithms
- Identify the techniques behind the algorithms (greedy, iterative, dynamic programming, etc.)
- Analyze the time complexity of algorithms
- Proof correctness of the algorithms
- Solve new network visualization problems by selecting and adapting known approaches

Analyze, Apply, Generalize Level

Overview

About this course

Repetition of the material. We build our Mind Map.

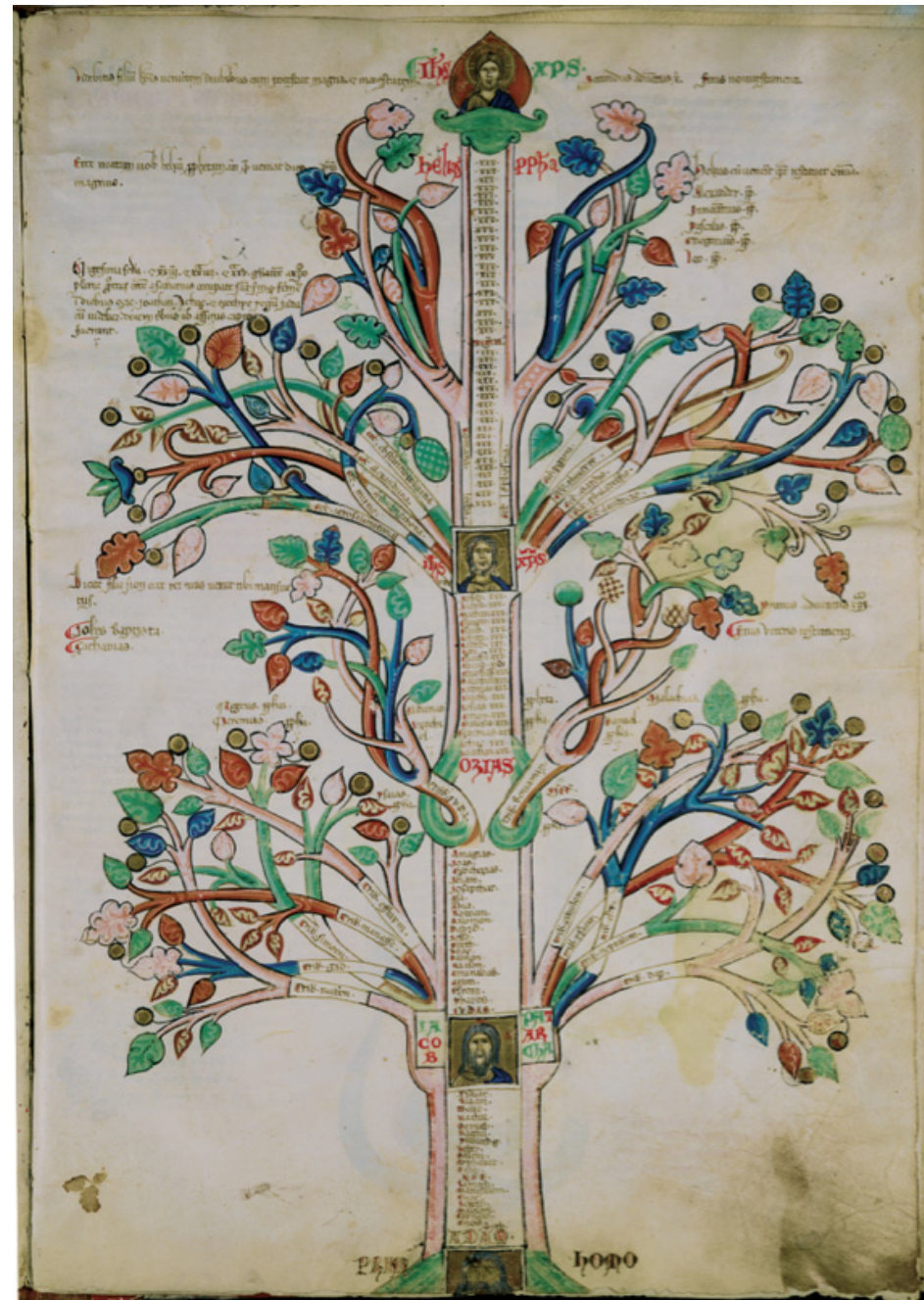
Drawing graphs “by hand”. Complete MindMap.

Formal definition of Layout Problem.

About this course: learning objectives.

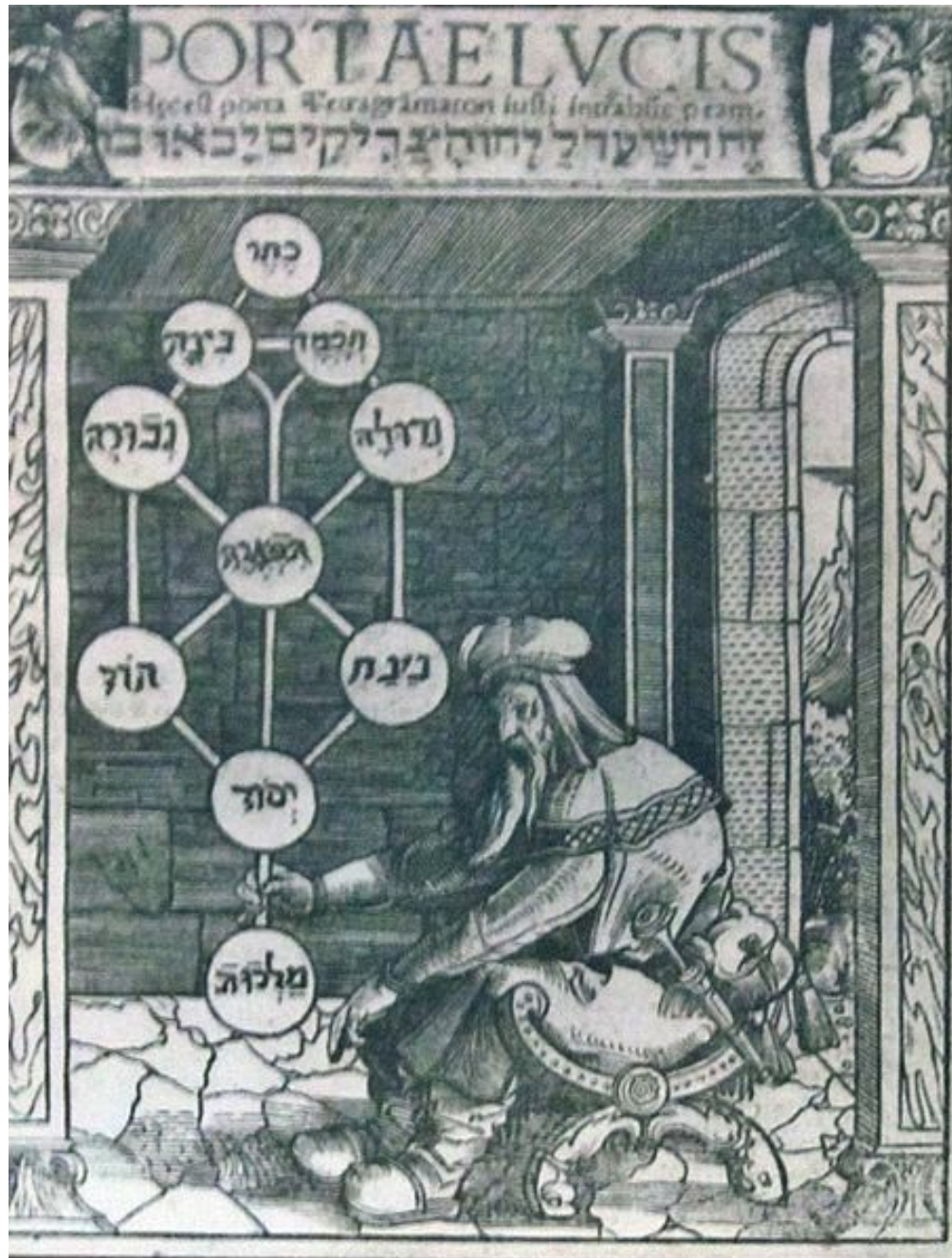
Applications gallery.

Biblical characters and events (1202)



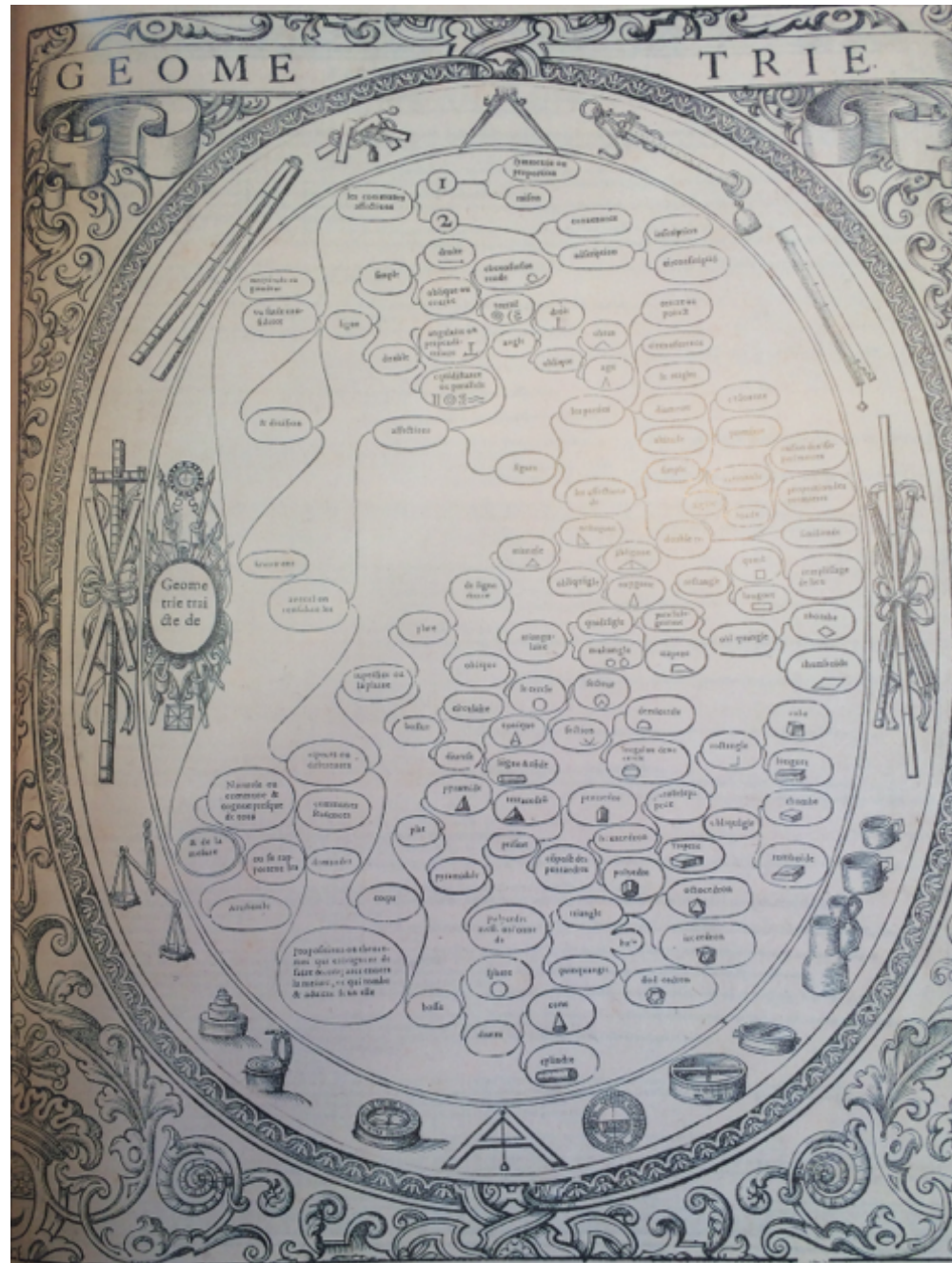
Source: Joachim de Fiore

"Tree of Life" (1516)



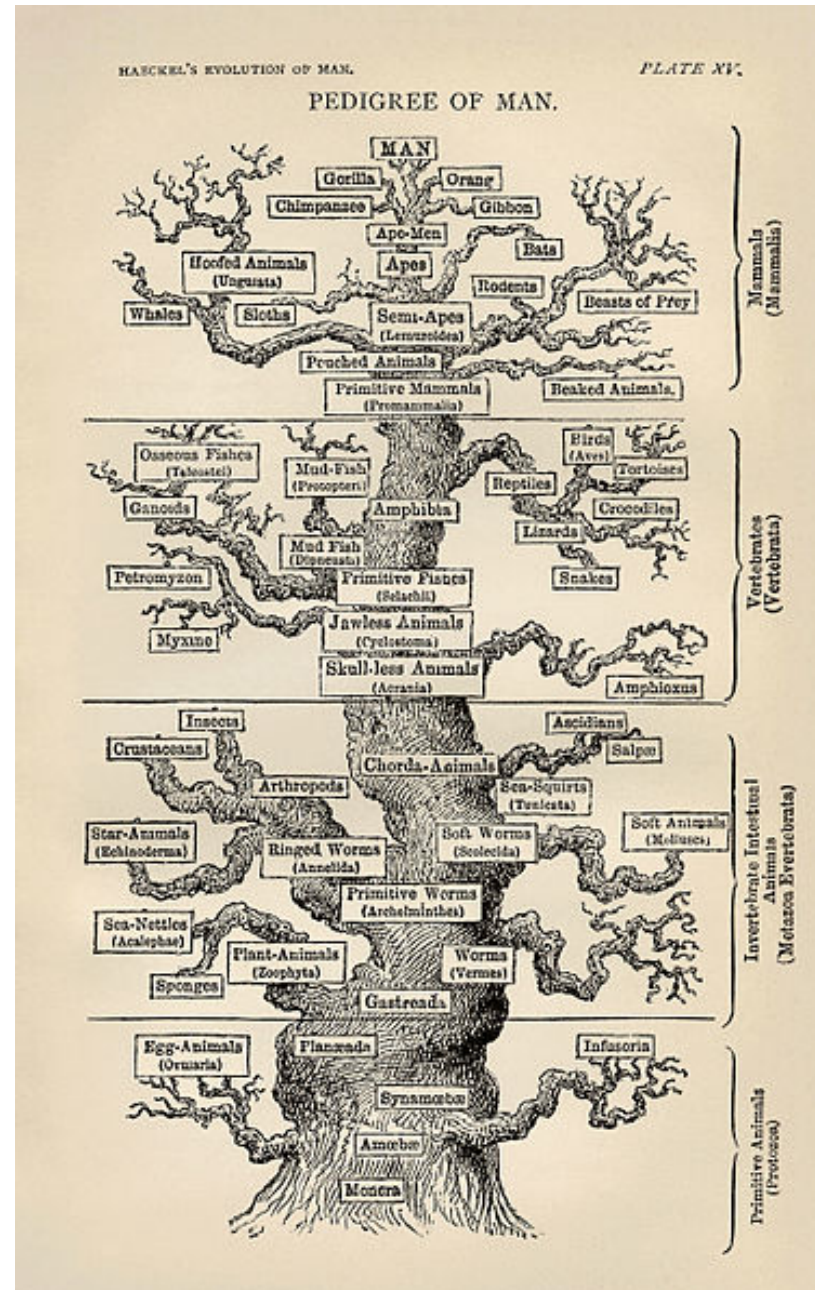
Source: Paul Riccius, Portae Lucis

Geometrical Concepts (1587)



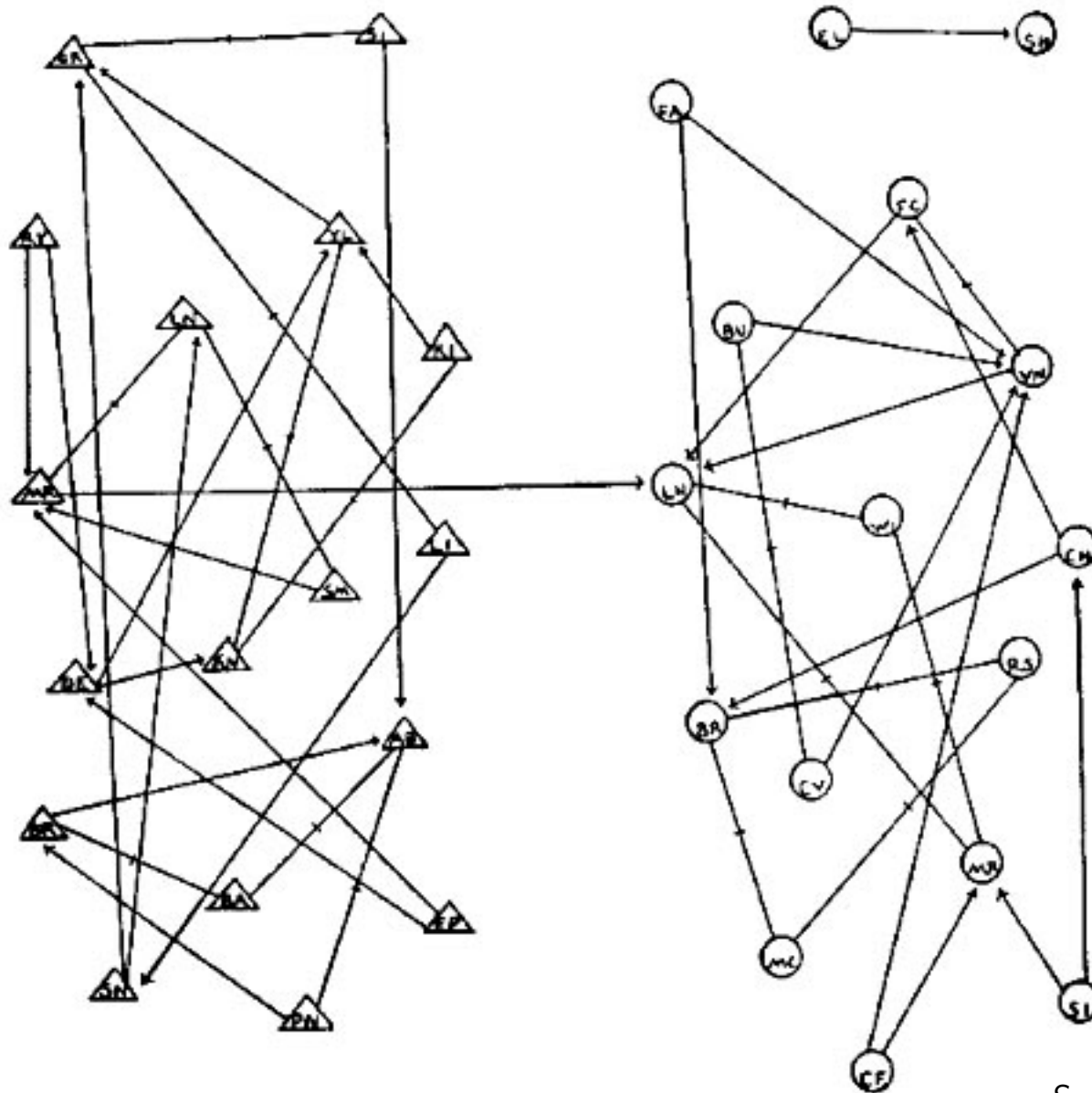
Source: Christophe de Savigny

Genealogical Tree (1879)



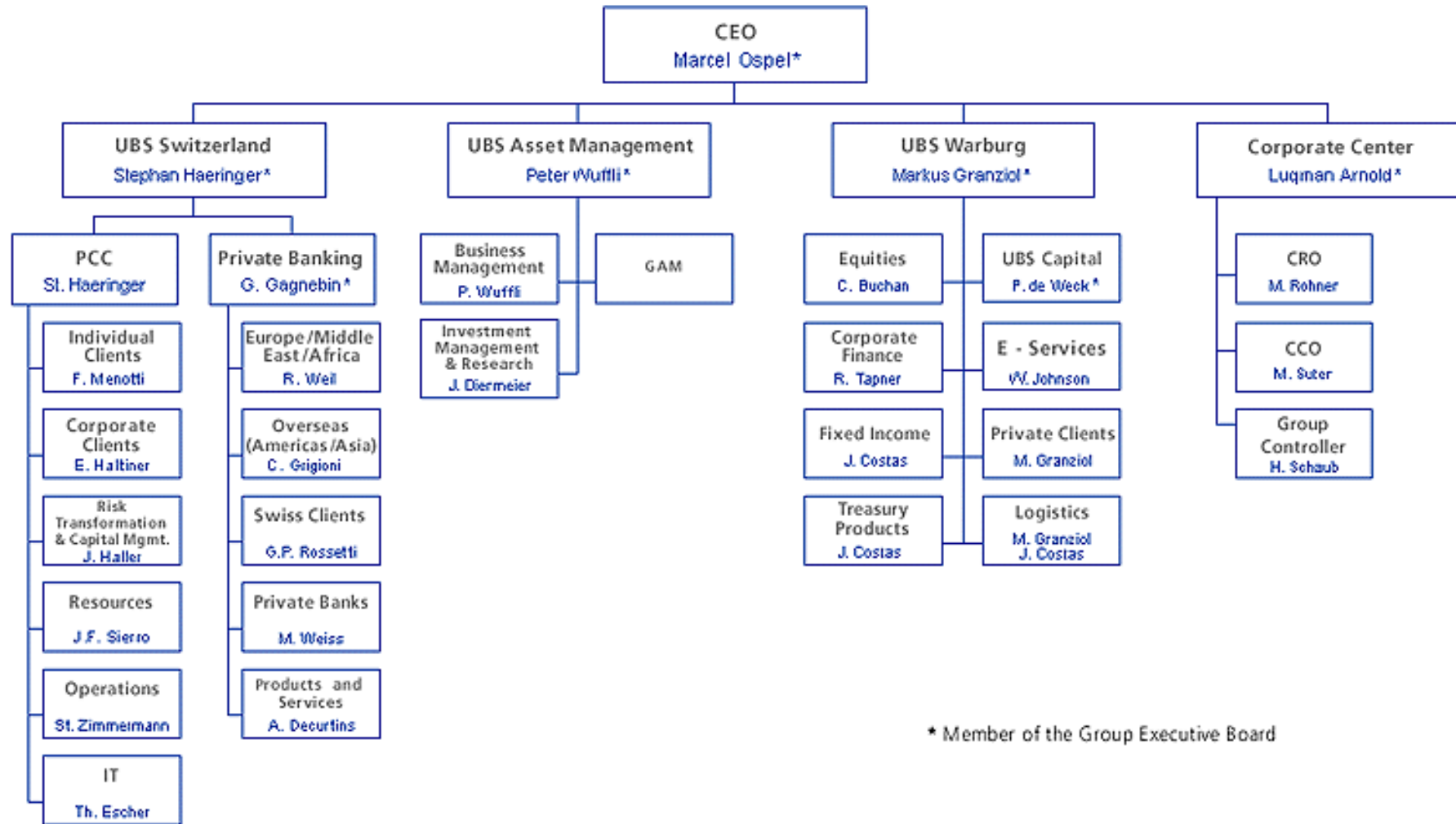
Source: Ernst Haeckel

Sociogram (1933)



Source: Moreno, 1933

Social Network – Organization within UBS



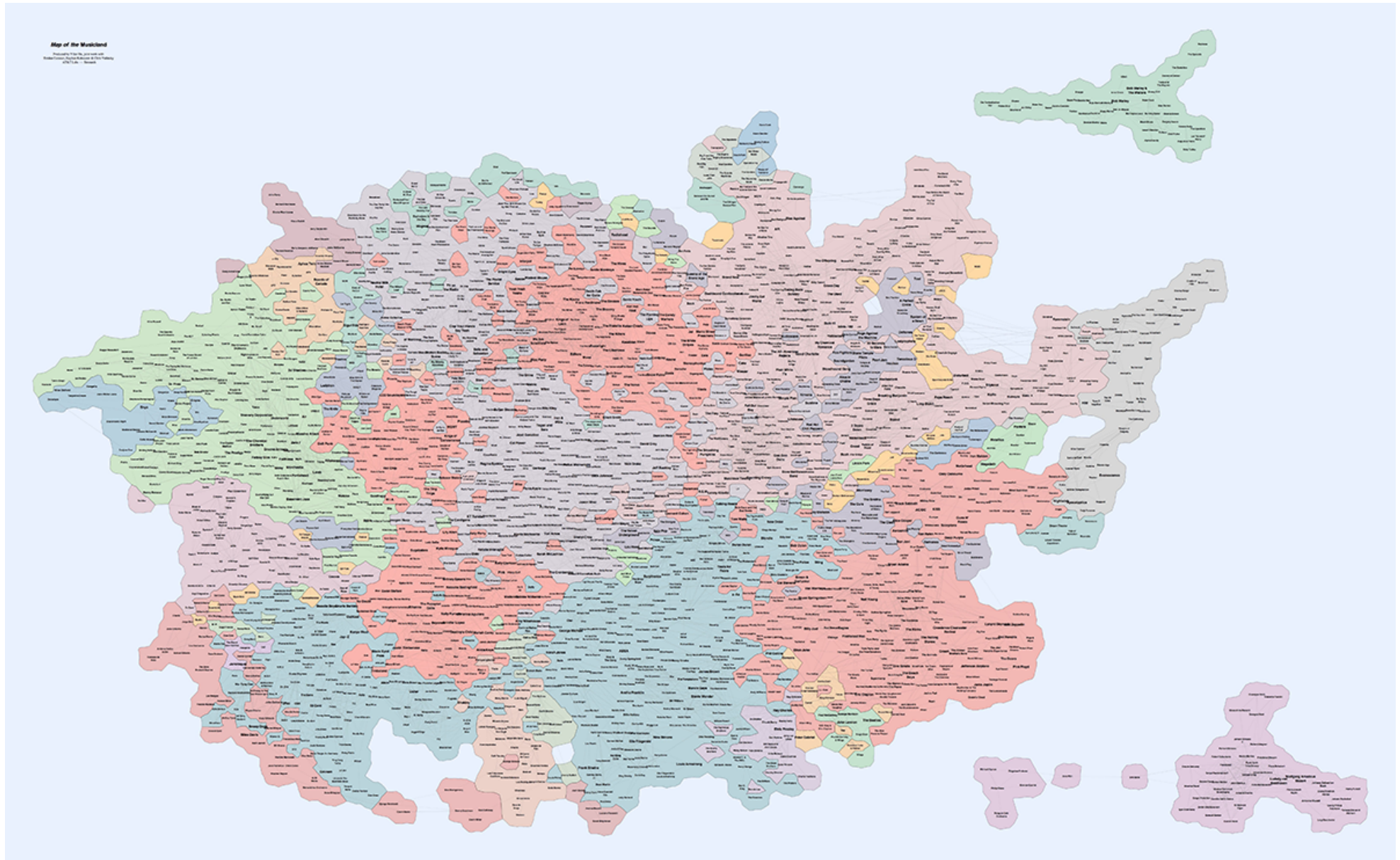
* Member of the Group Executive Board

CPAN Developer-Graph



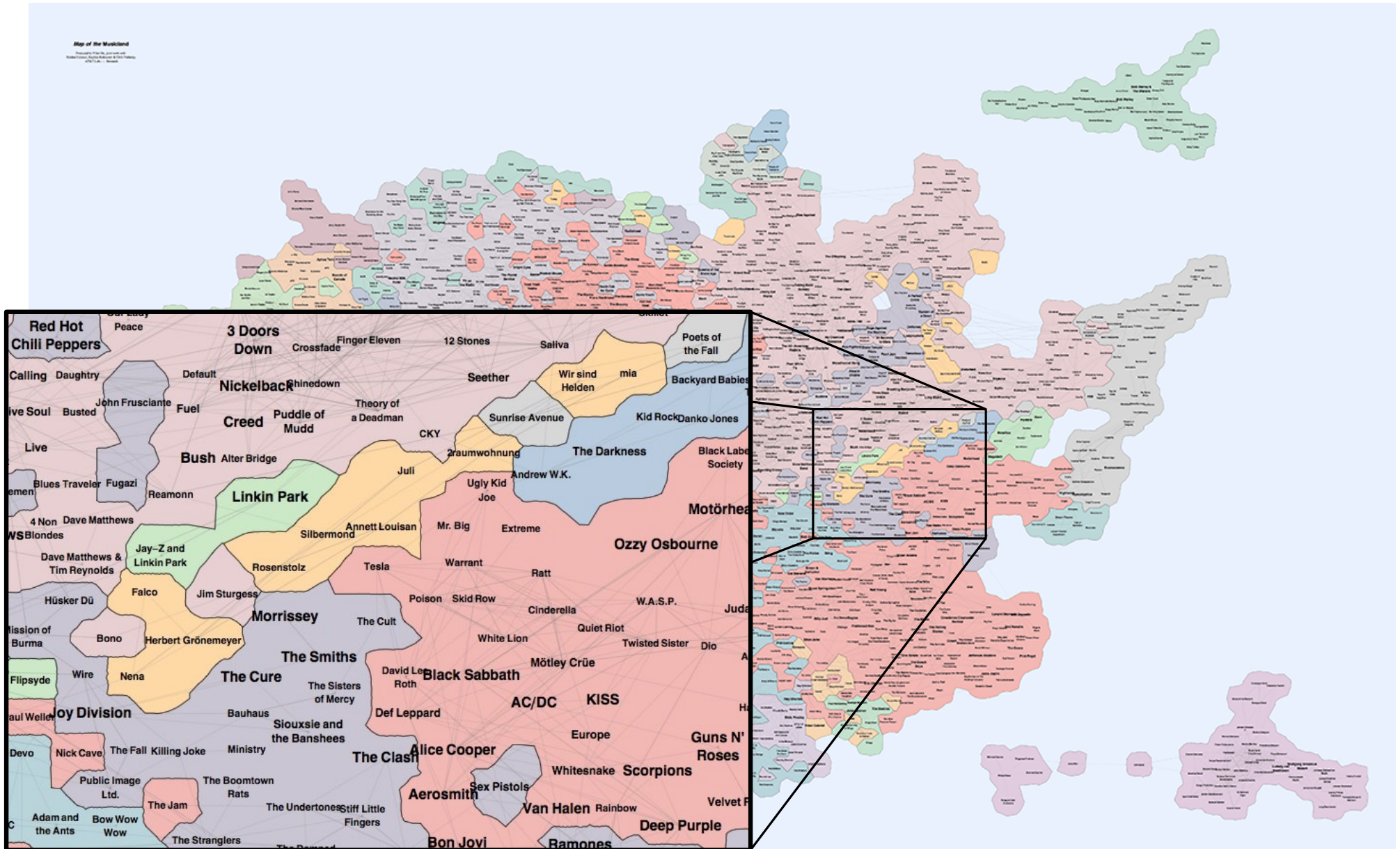
Source: cpan-explorer.org

last.fm Graph of musics as political map



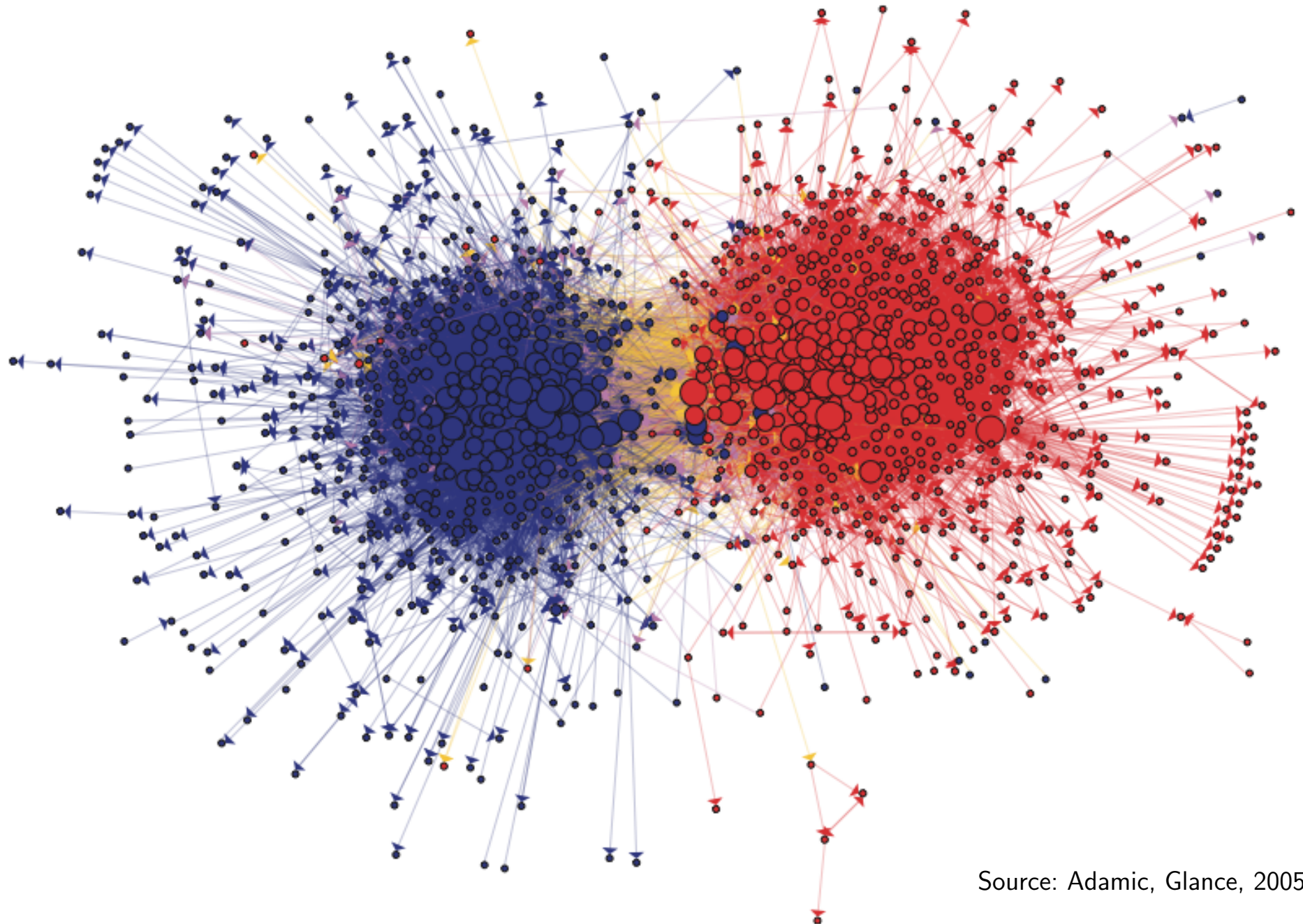
(Gansner, Hu, Kobourov: GMap, 2009)

last.fm Graph of musics as political map



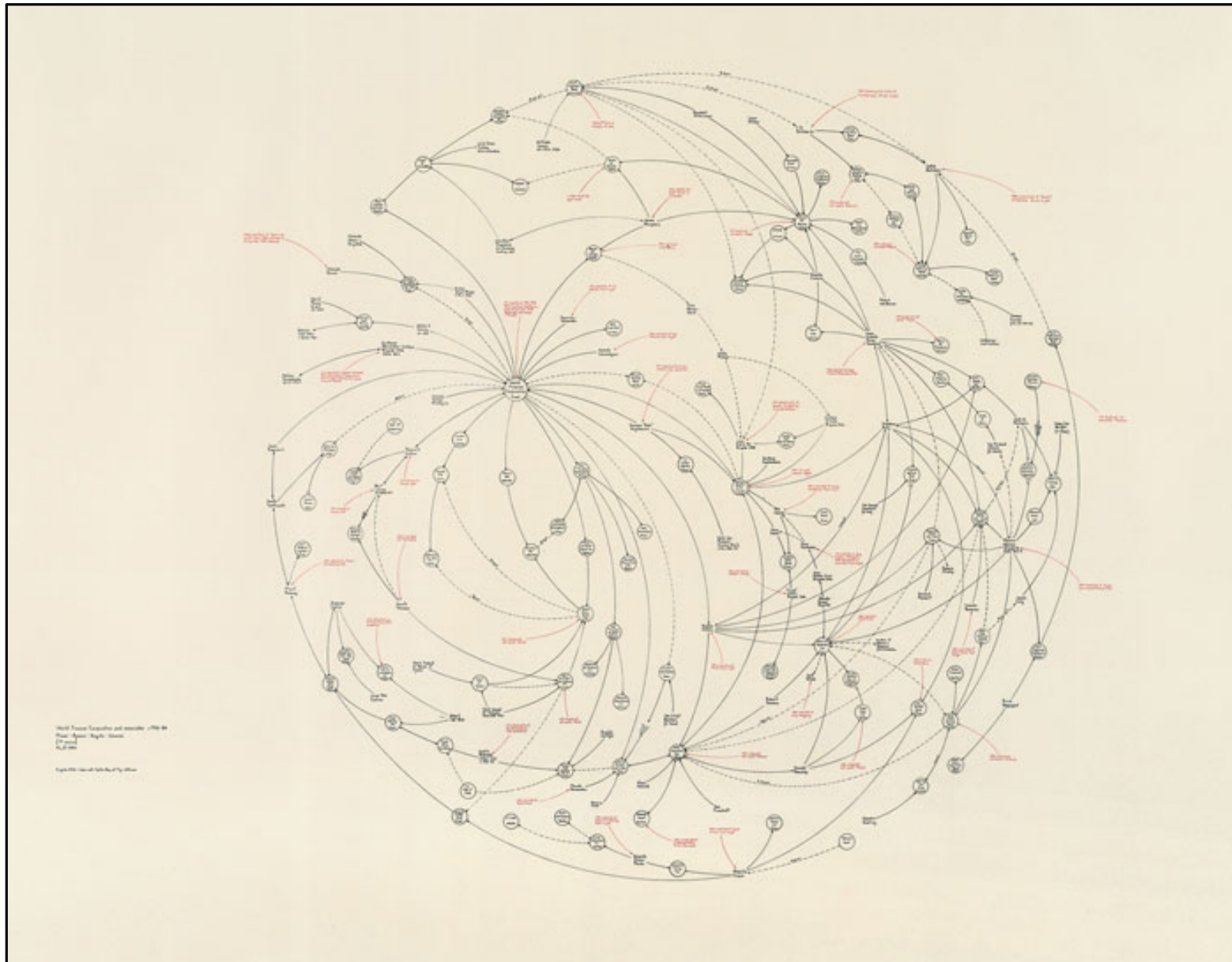
(Gansner, Hu, Kobourov: GMap, 2009)

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

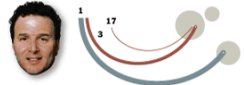
The New Global Wealth Machine

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.

CITIGROUP DEALS THIS ADVISER WAS INVOLVED IN



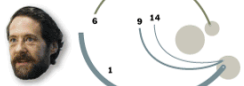
Michael Klein, Chairman, institutional clients group
One of the firm's highest-profile investment bankers, he advised Citicorp in its stake sale to Mitsubishi, as well as Citigroup in both of its deals with sovereign wealth funds.

GOLDMAN SACHS GROUP



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.

LAZARD



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.

MORGAN STANLEY



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.

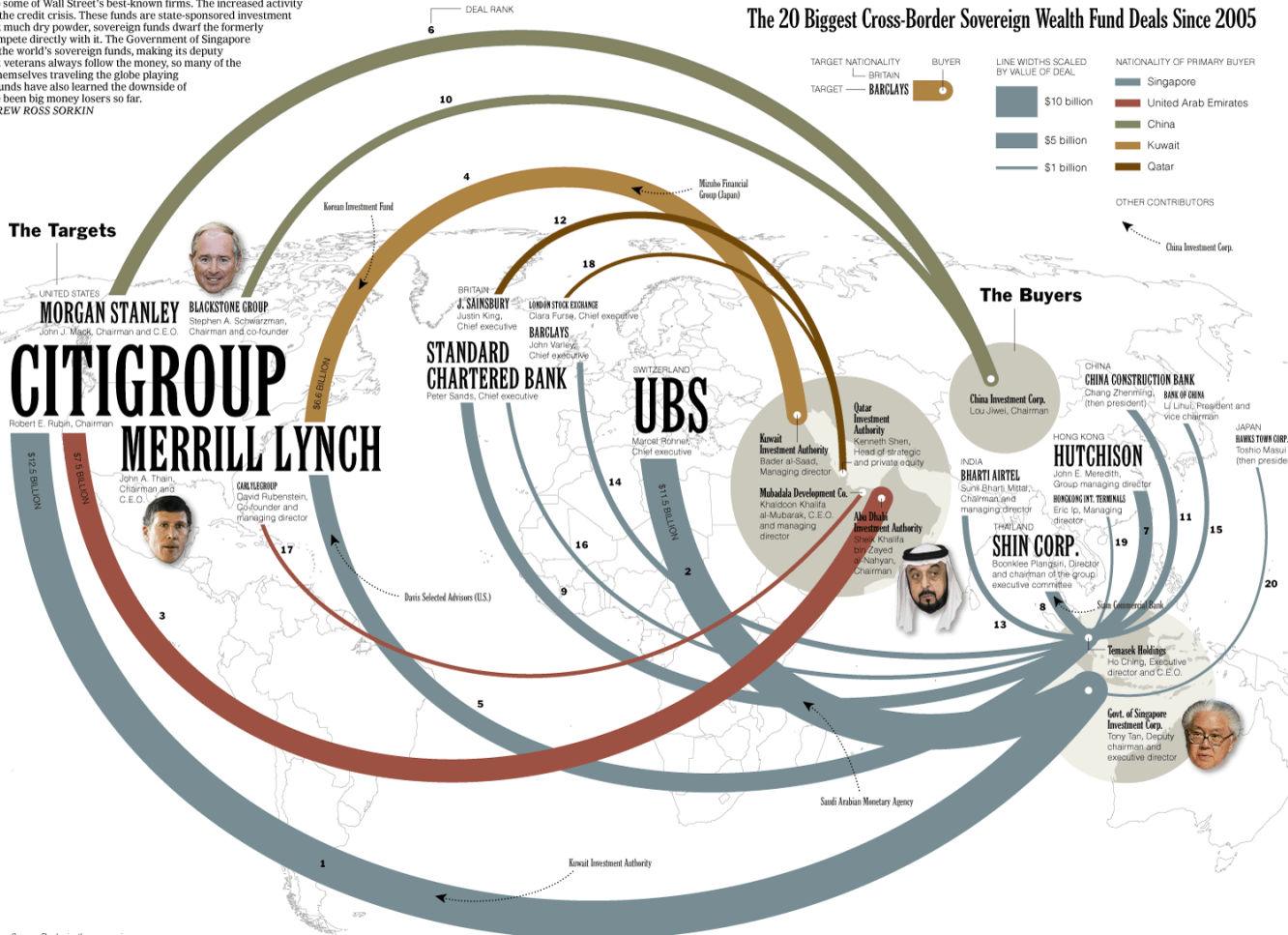
The Targets



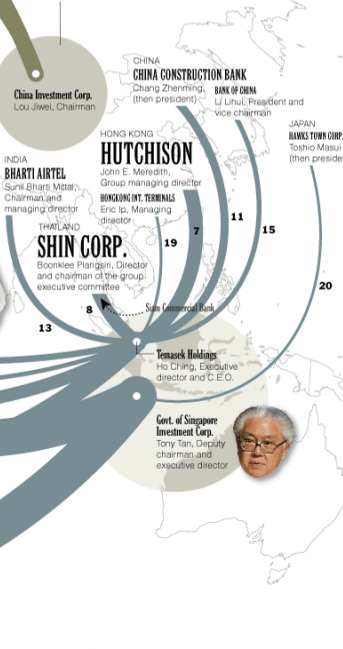
UNITED STATES
MORGAN STANLEY John J. Mack, Chairman and C.E.O.
BLACKSTONE GROUP Stephen A. Schwarzman, Chairman and co-founder
CITIGROUP Robert E. Rubin, Chairman
MERRILL LYNCH John A. Trank, Chairman and C.E.O.
BARCLAYS GROUP David Rubenstein, Co-founder and managing director

Source: Dealogic, the companies

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



The Buyers



CHINA
CHINA INVESTMENT CORP. Lou Jiwei, Chairman
CHINA CONSTRUCTION BANK Chang Zhennong, (then president)
BANK OF CHINA Li Lihu, President and vice chairman
HONG KONG
HUTCHISON John E. Meredith, Group managing director
BANKING INT'L TERMINALS Eric Si, Managing director
INDIA
BHARTI AIRTEL Sunil Bharti Mittal, Chairman and managing director
THAILAND
SHIN CORP. Boonkee Plangtari, Director and chairman of the group executive committee
SINGAPORE
Govt of Singapore Investment Corp. Ho Ching, Executive director and C.E.O.
QATAR
Qatar Investment Authority Kenneth Shen, Head of strategic and private equity
Mohadala Development Co. Khalid bin Mubarak, C.E.O. and managing director
Mohadala Investment Authority Ghafar bin Zayed bin Nahyan, Chairman
SAUDI ARABIA
Saudi Arabian Monetary Agency

The Lawyers

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

CLIFFORD CHANCE



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.

DAVIS POLK & WARDWELL



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.

LINKLATERS



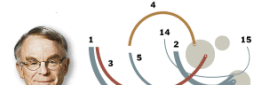
Richard Good, Partner
Based in Singapore, Mr. Good is the firm's man-on-the-ground in Asia. He has worked for Linklaters in Asia since 2000.

SHEARMAN & STERLING



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.

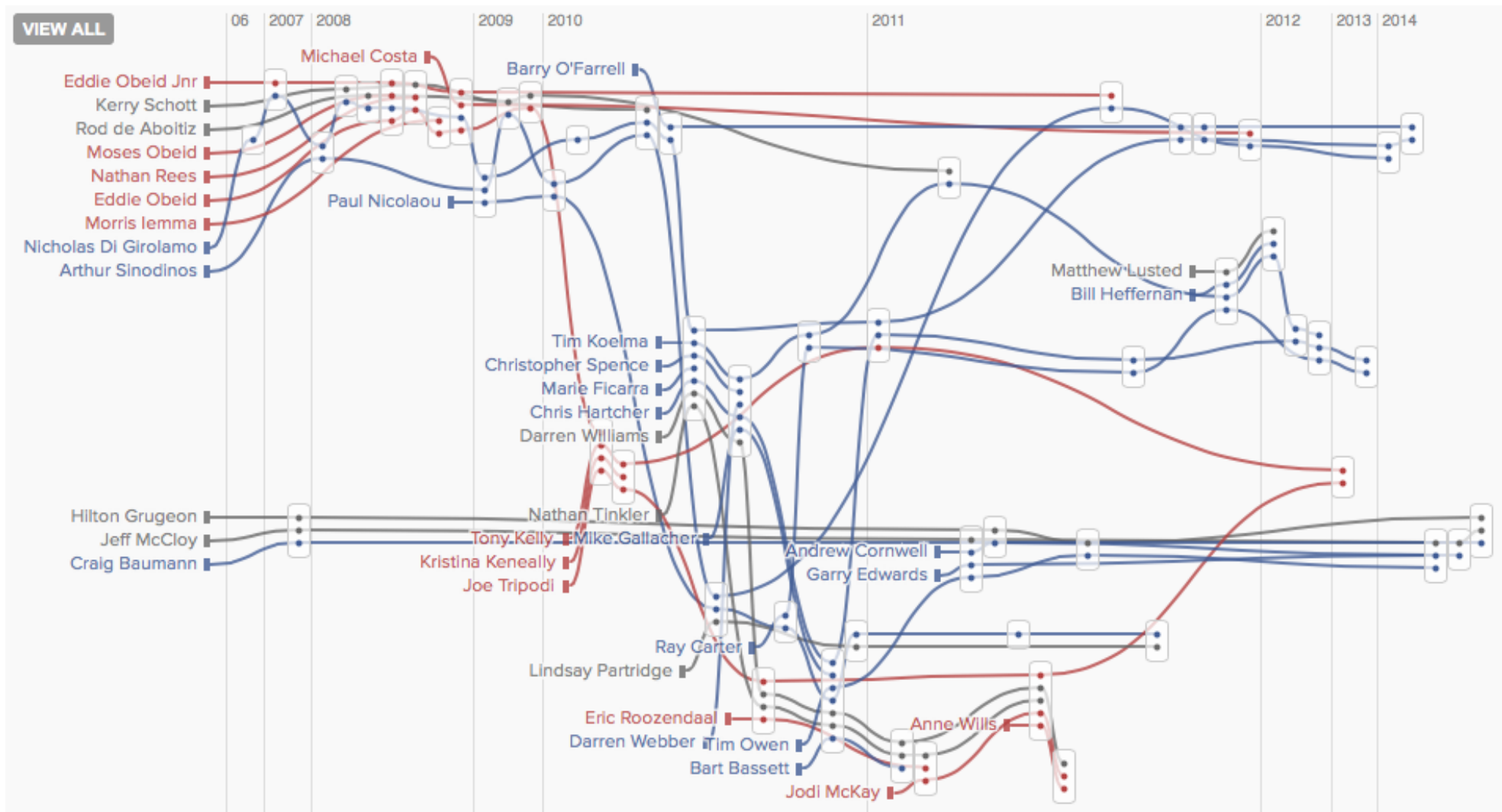
SULLIVAN & CROMWELL



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.

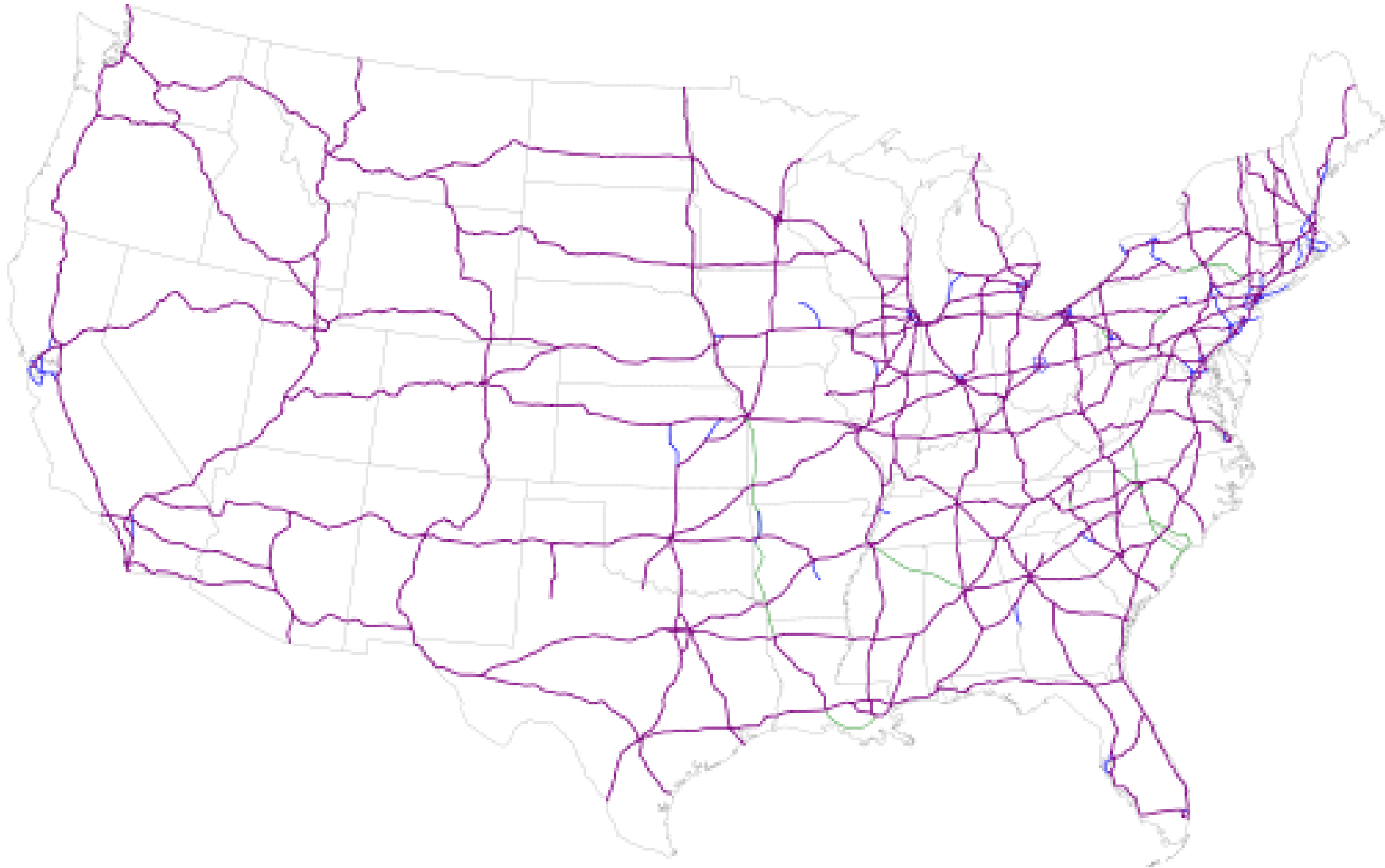
RESEARCH BY MICHAEL DE LA MERCEZ; GRAPHIC BY GILBERT GATES FOR THE NEW YORK TIMES

Temporal Graph Layout: Storylines

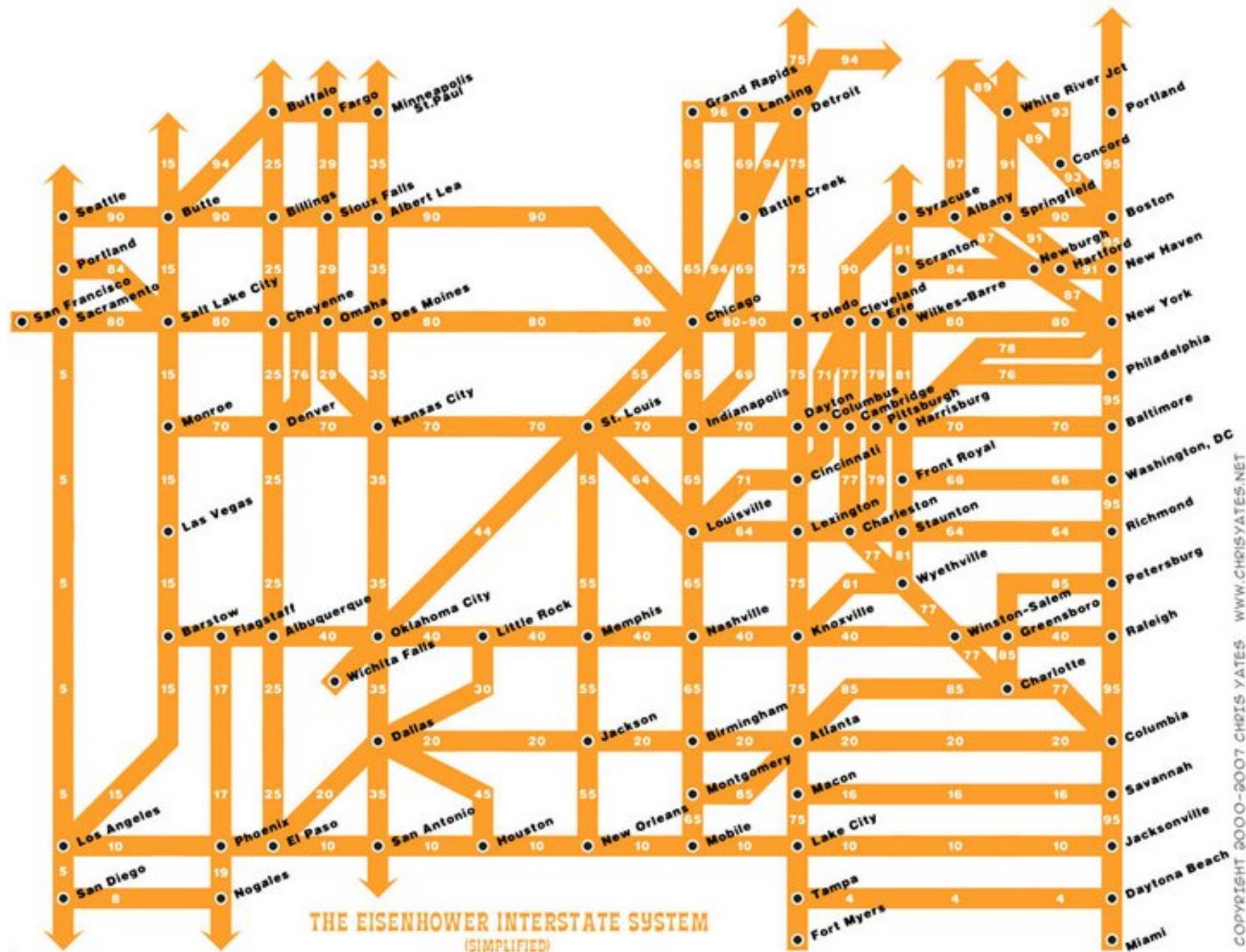


Source: ABC news, Australia

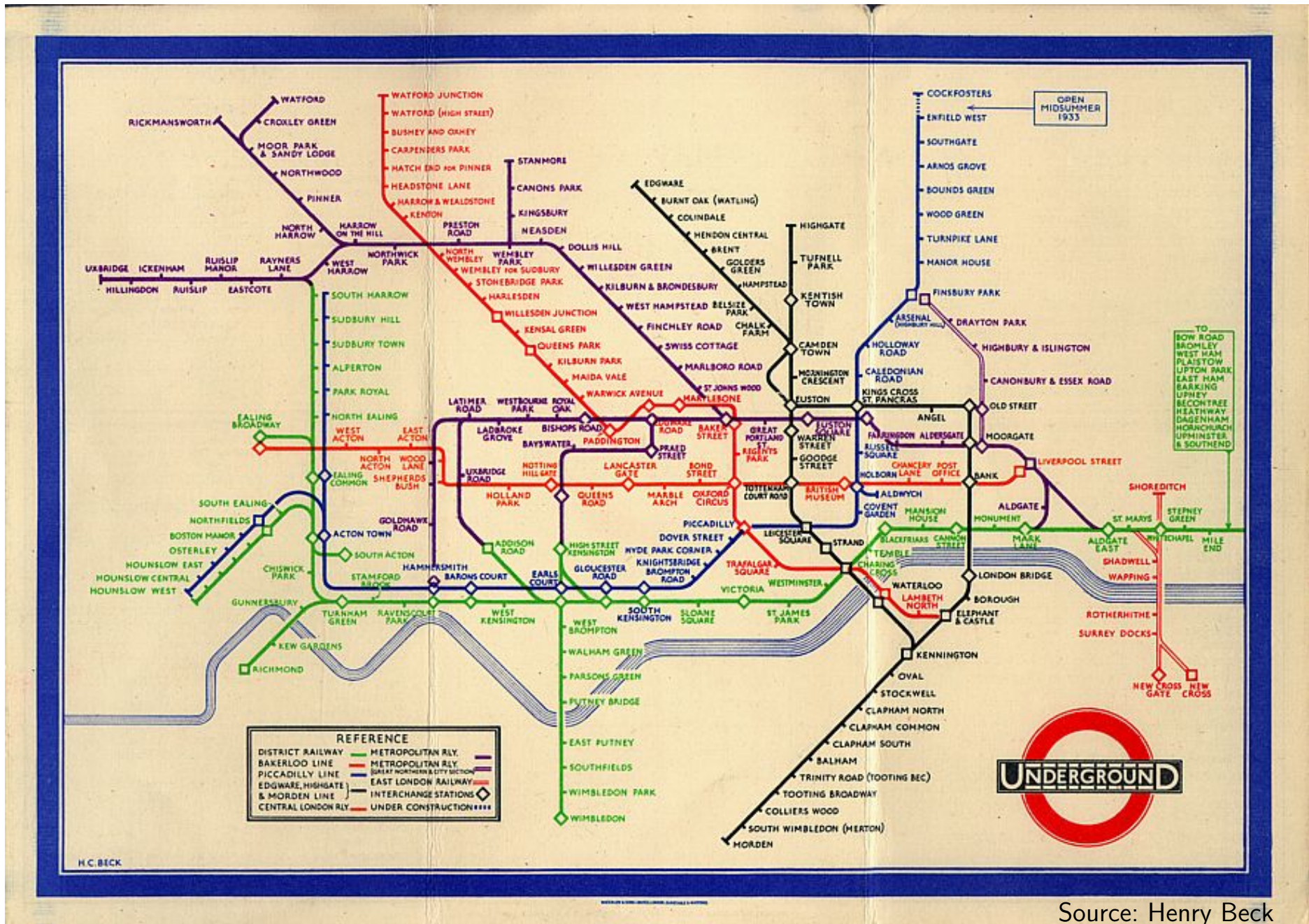
Traffic network – Highways USA



Traffic network – Highways USA

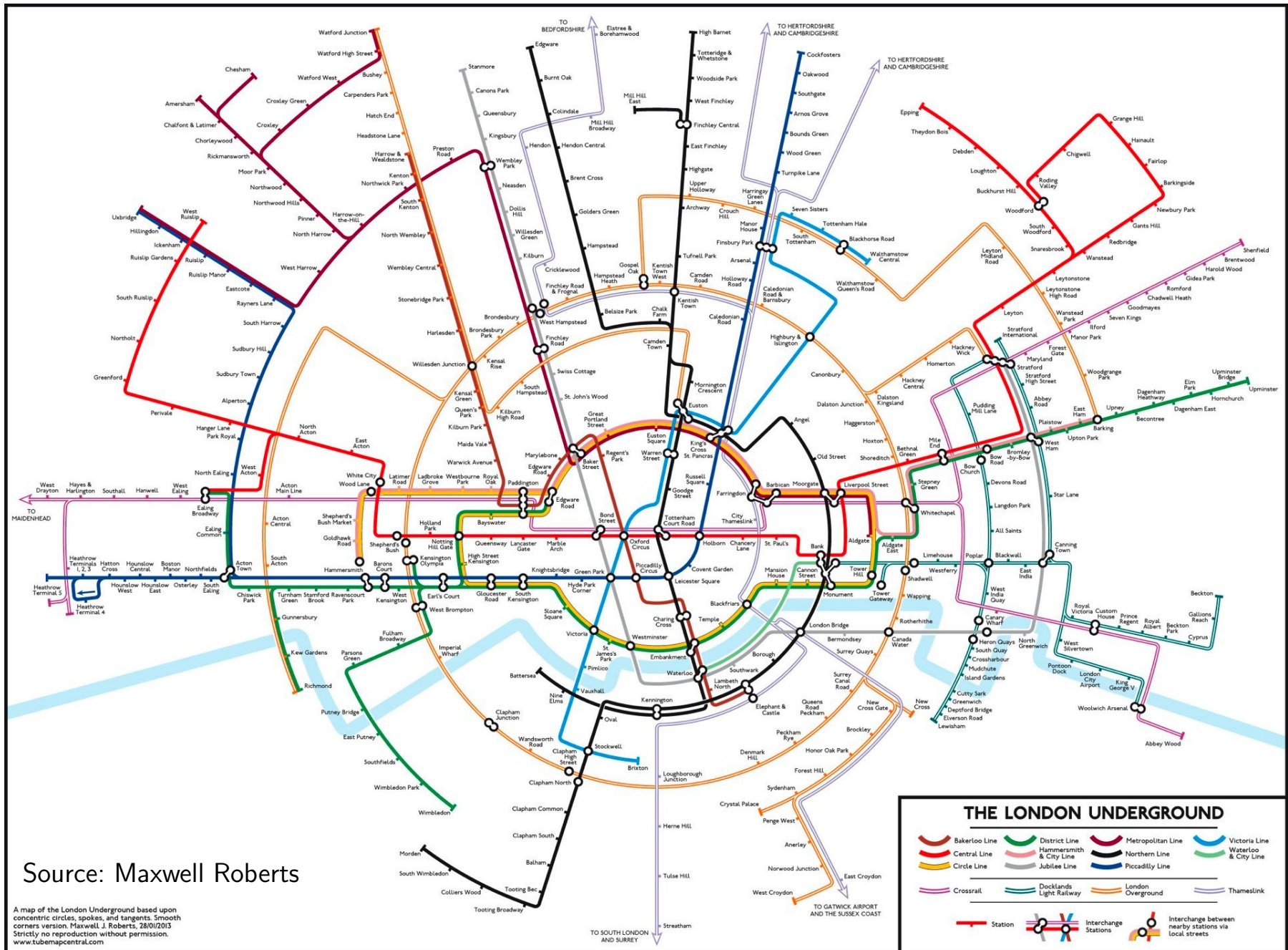


London Tube Map (1933)



Source: Henry Beck

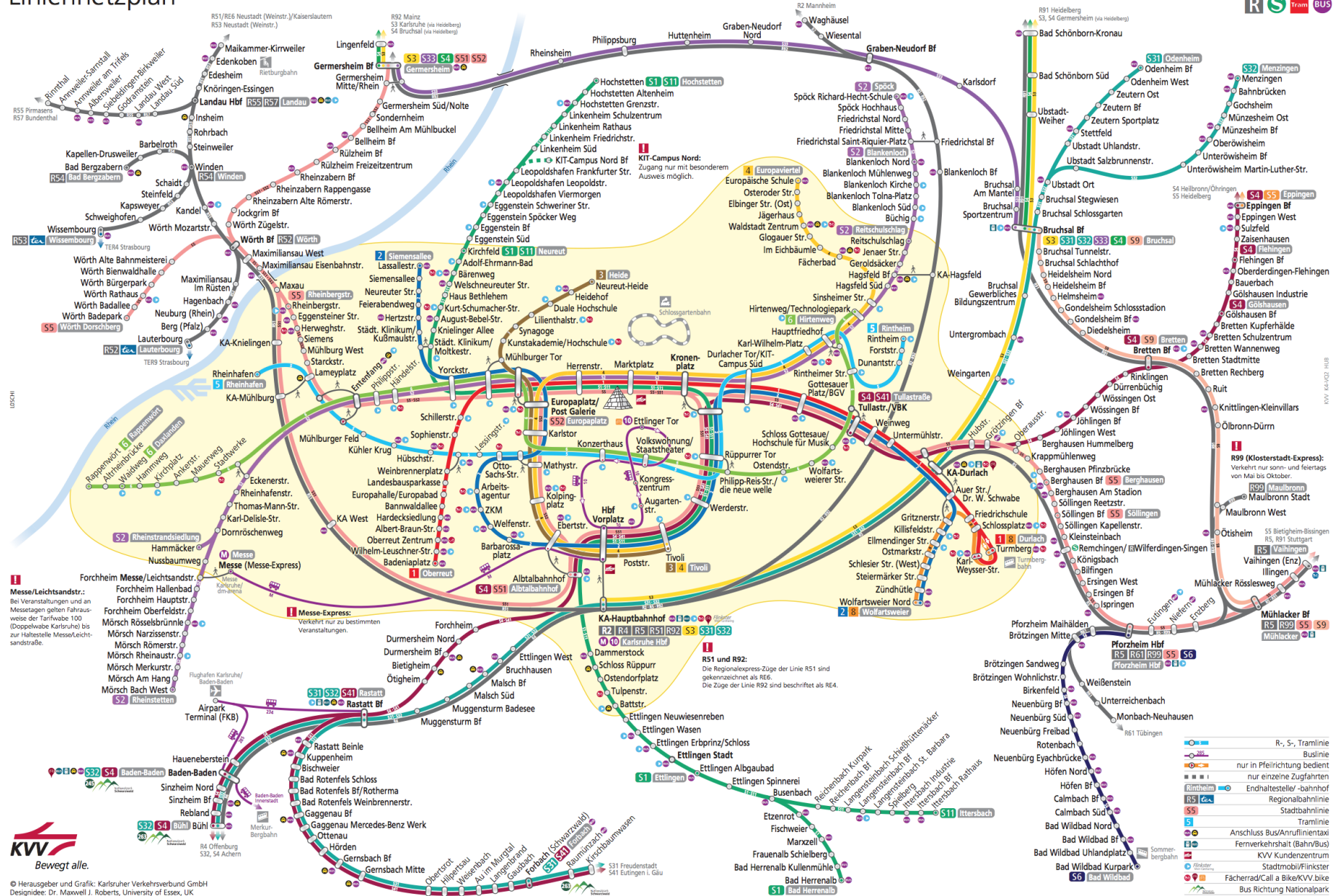
Co-centric Tube Map



Curvilinear S/U-bahn map

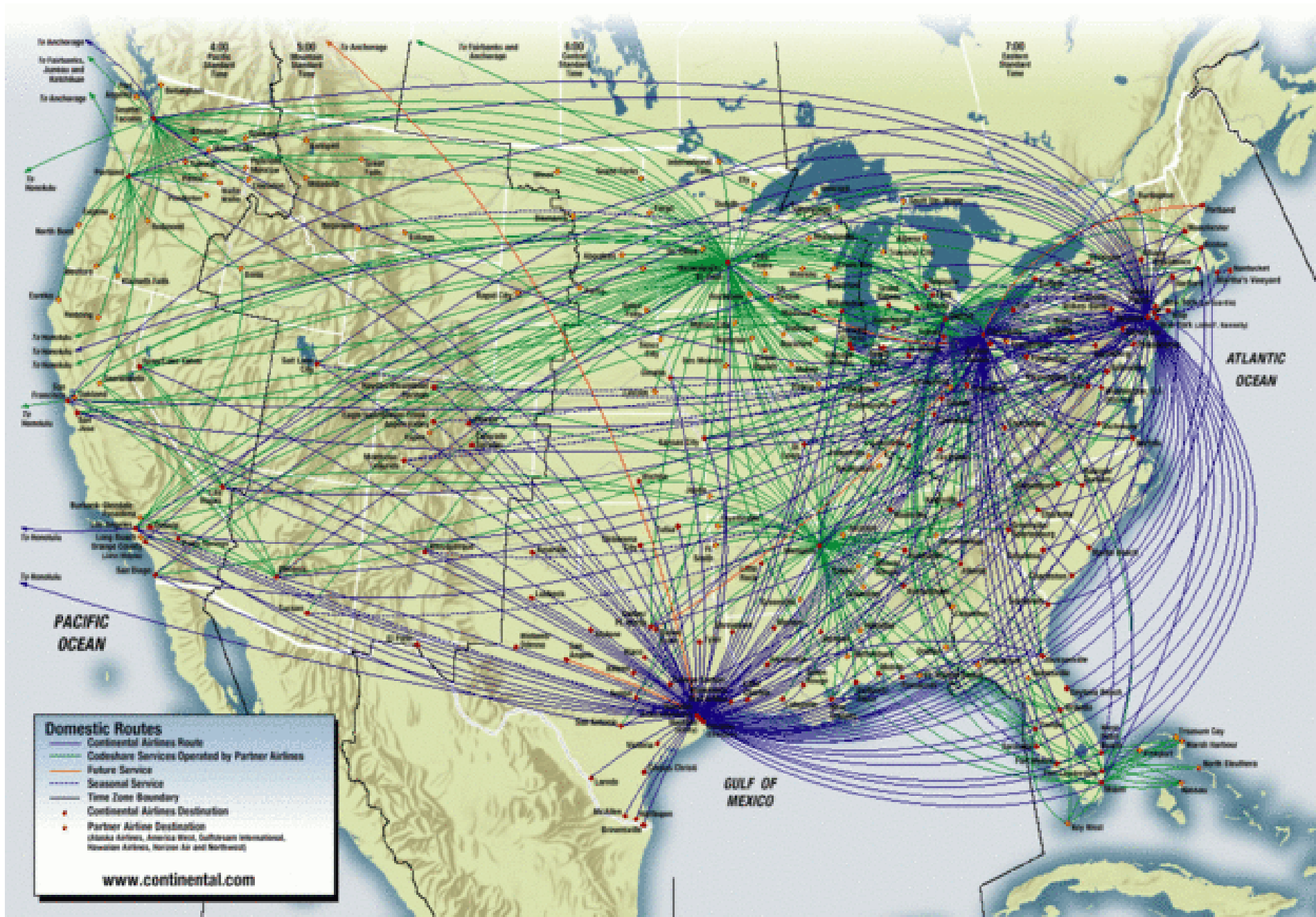
Liniennetzplan

Gültig ab 13. Dezember 2015

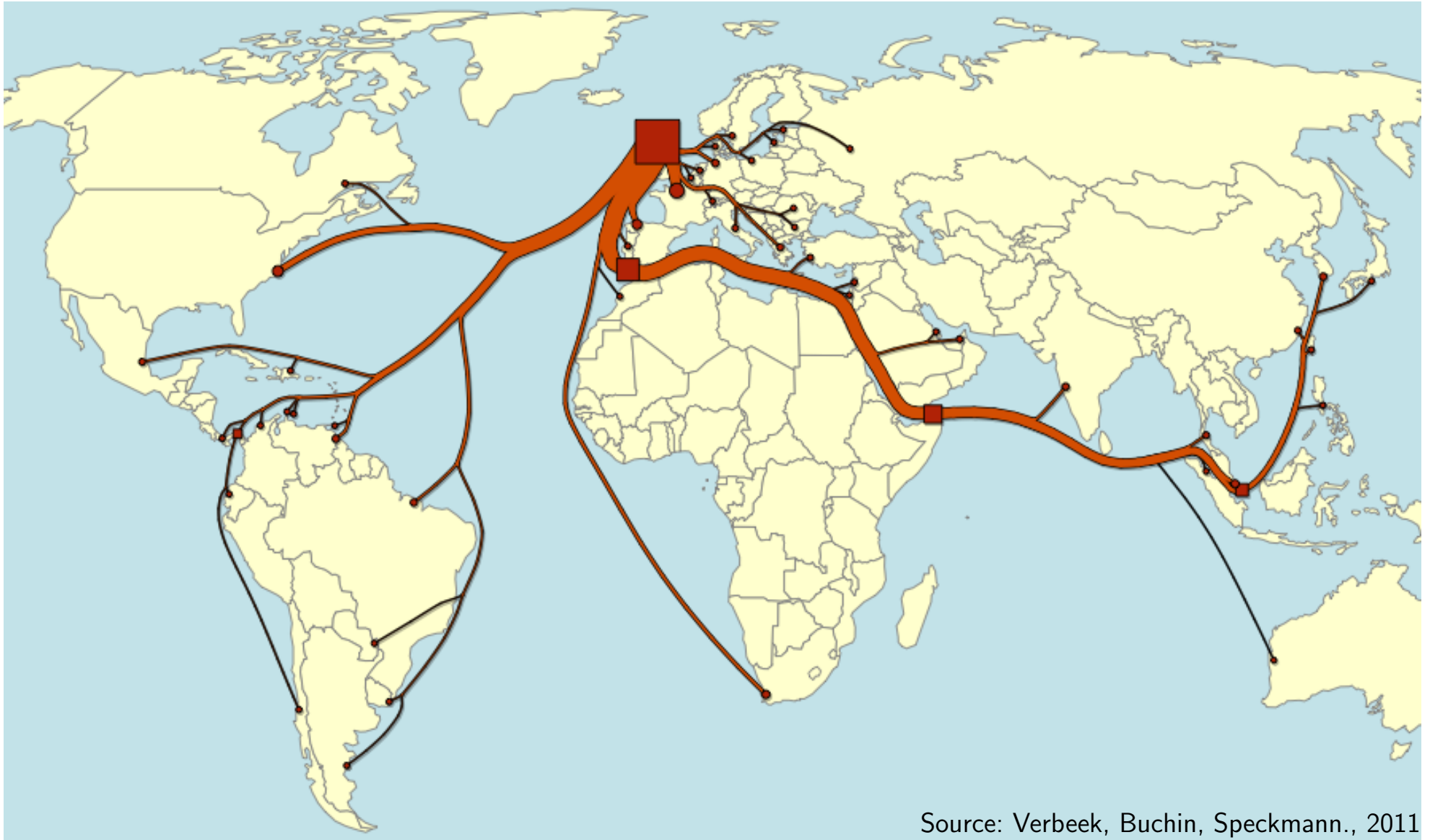


Source: KVV and Maxwell Roberts

Flight Connections

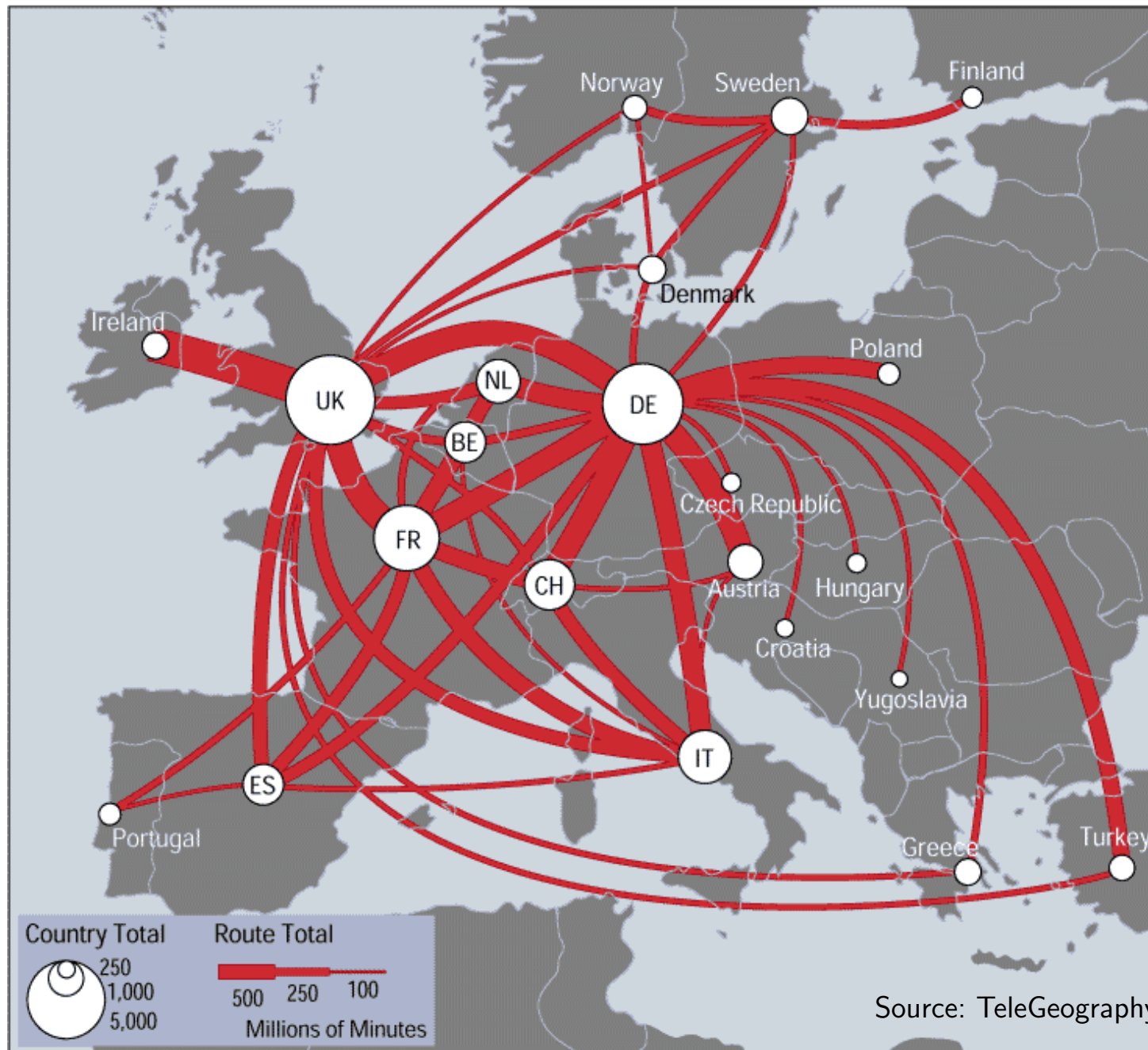


Flow-Map: Whiskey Export



Source: Verbeek, Buchin, Speckmann., 2011

Telephony Map

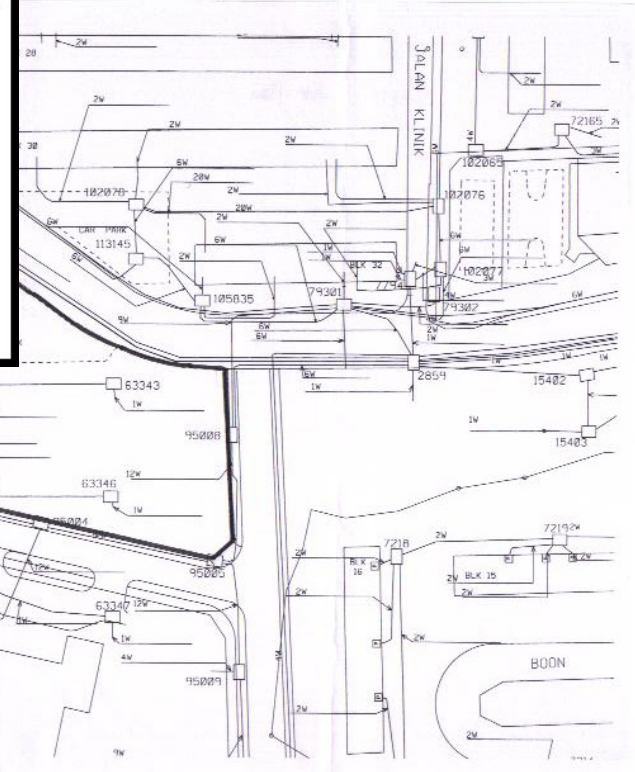
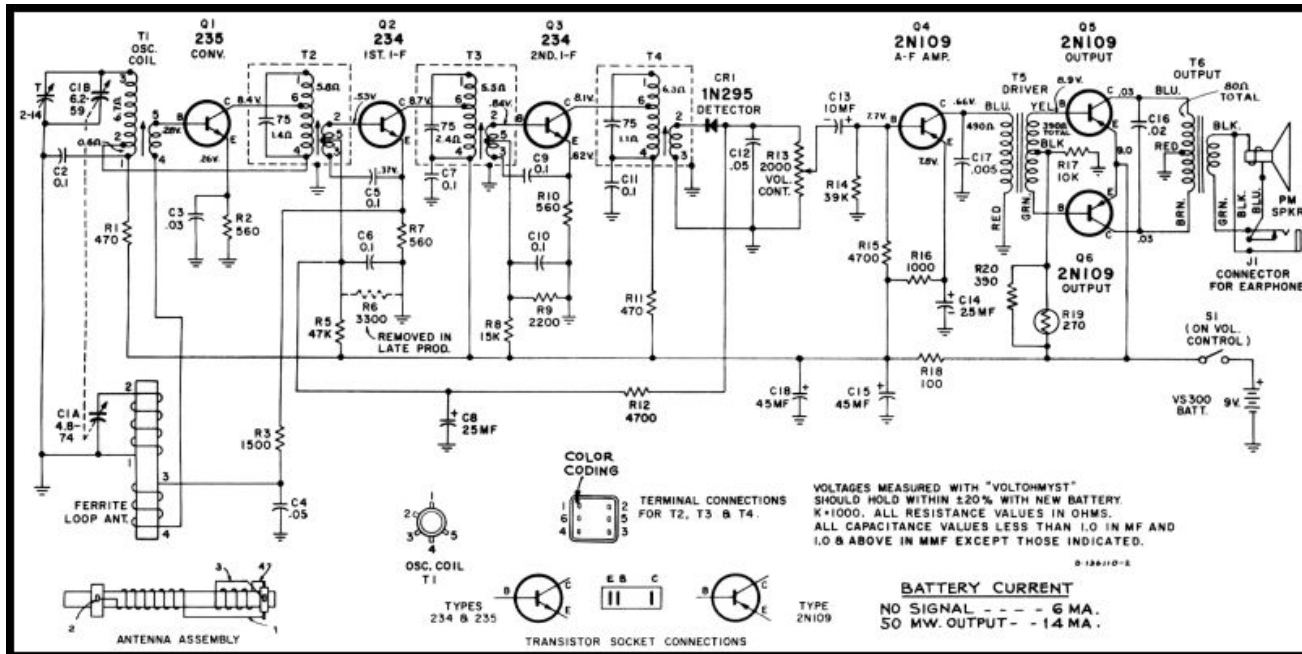


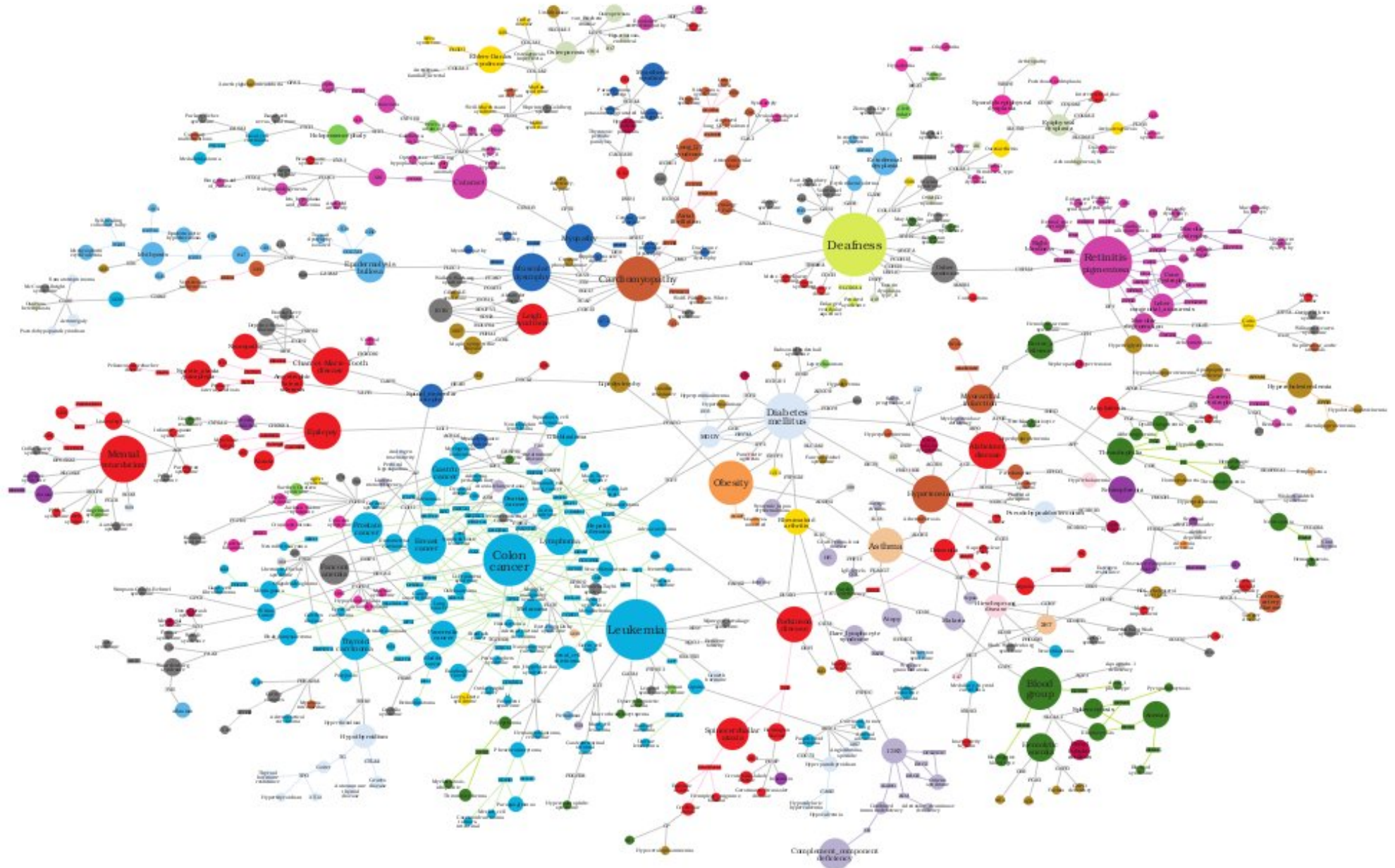
Monitoring of Energy Network



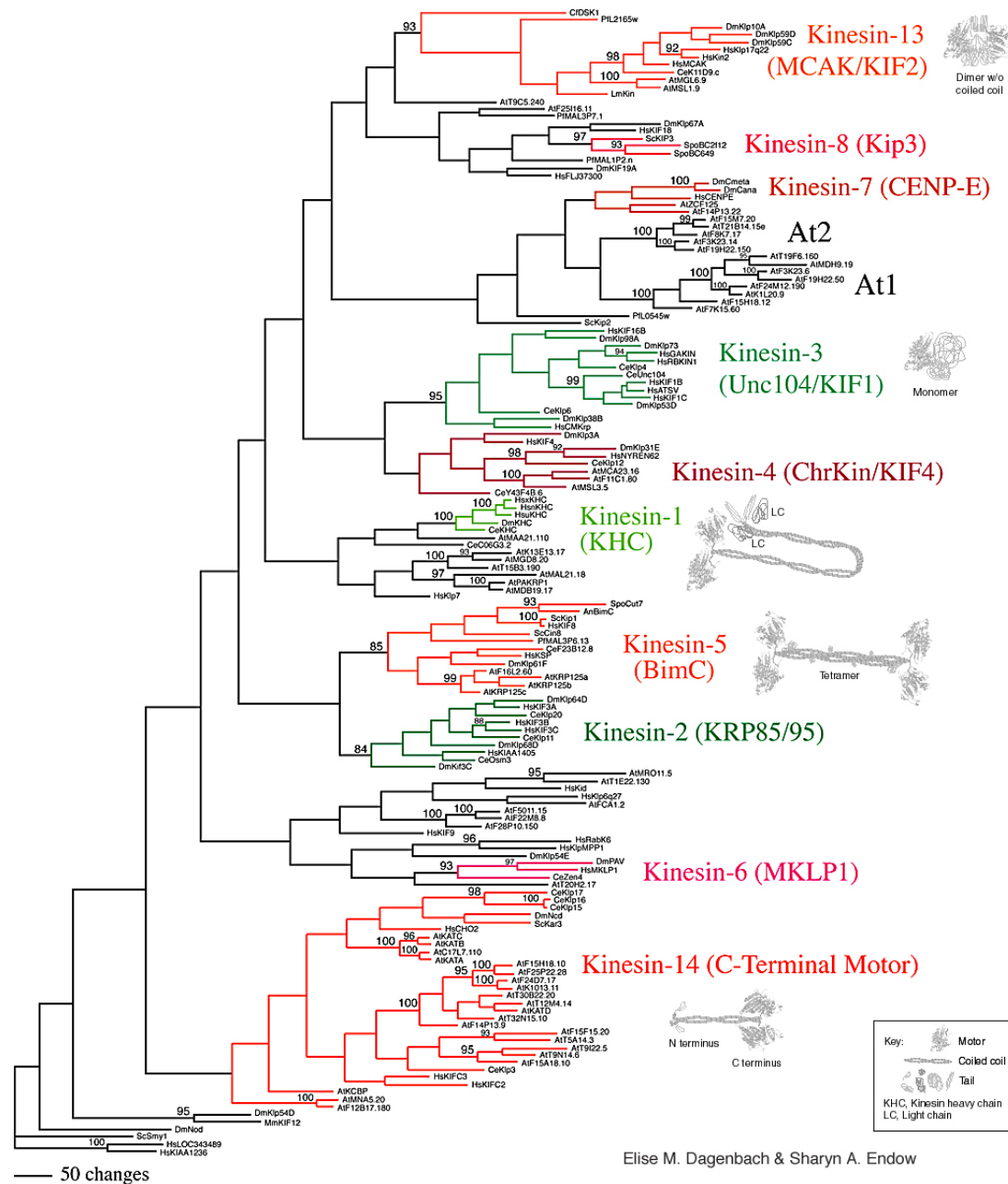
Source: Eir Grid, Ireland

Wiring plan/ Cable plan

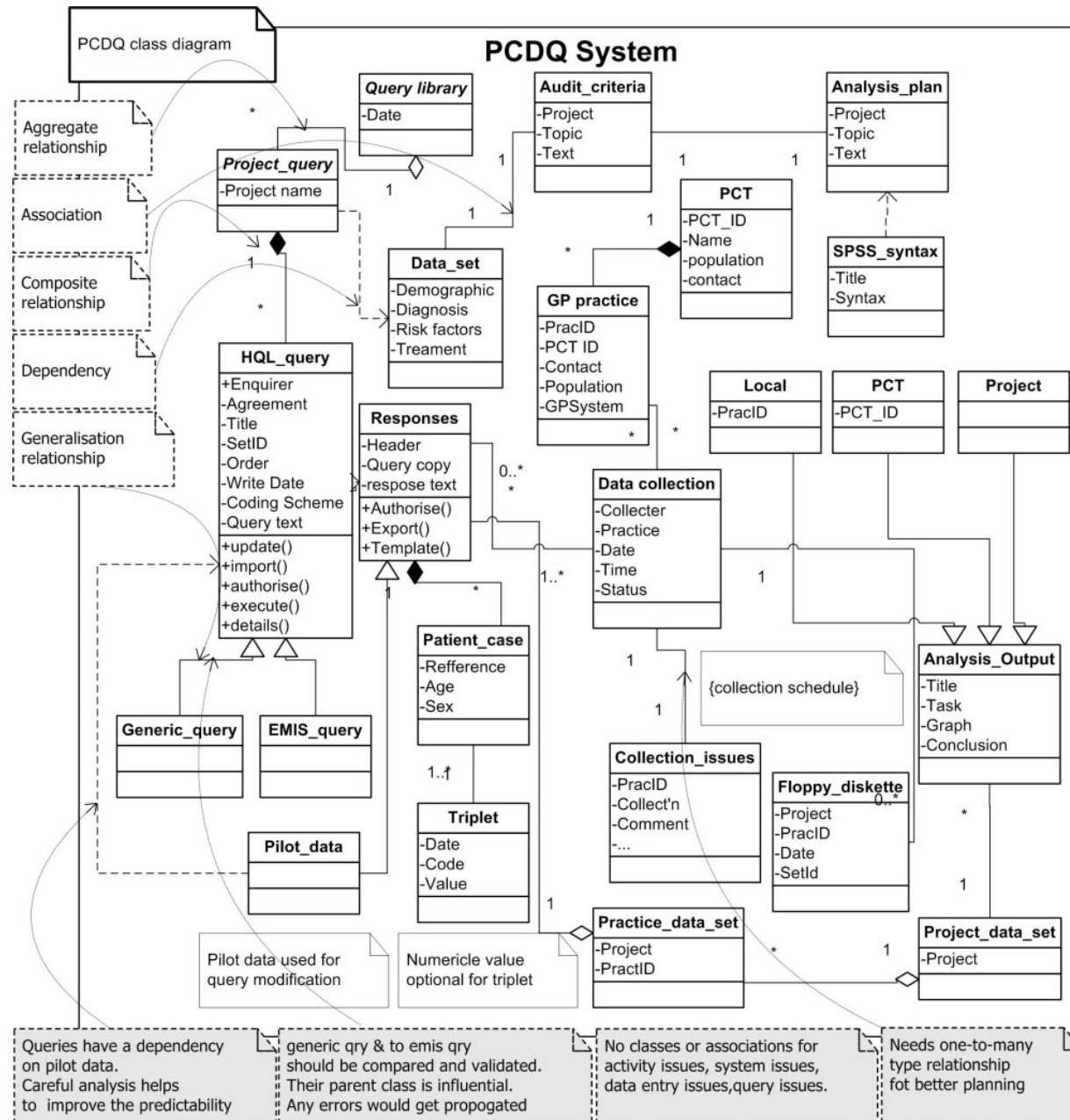




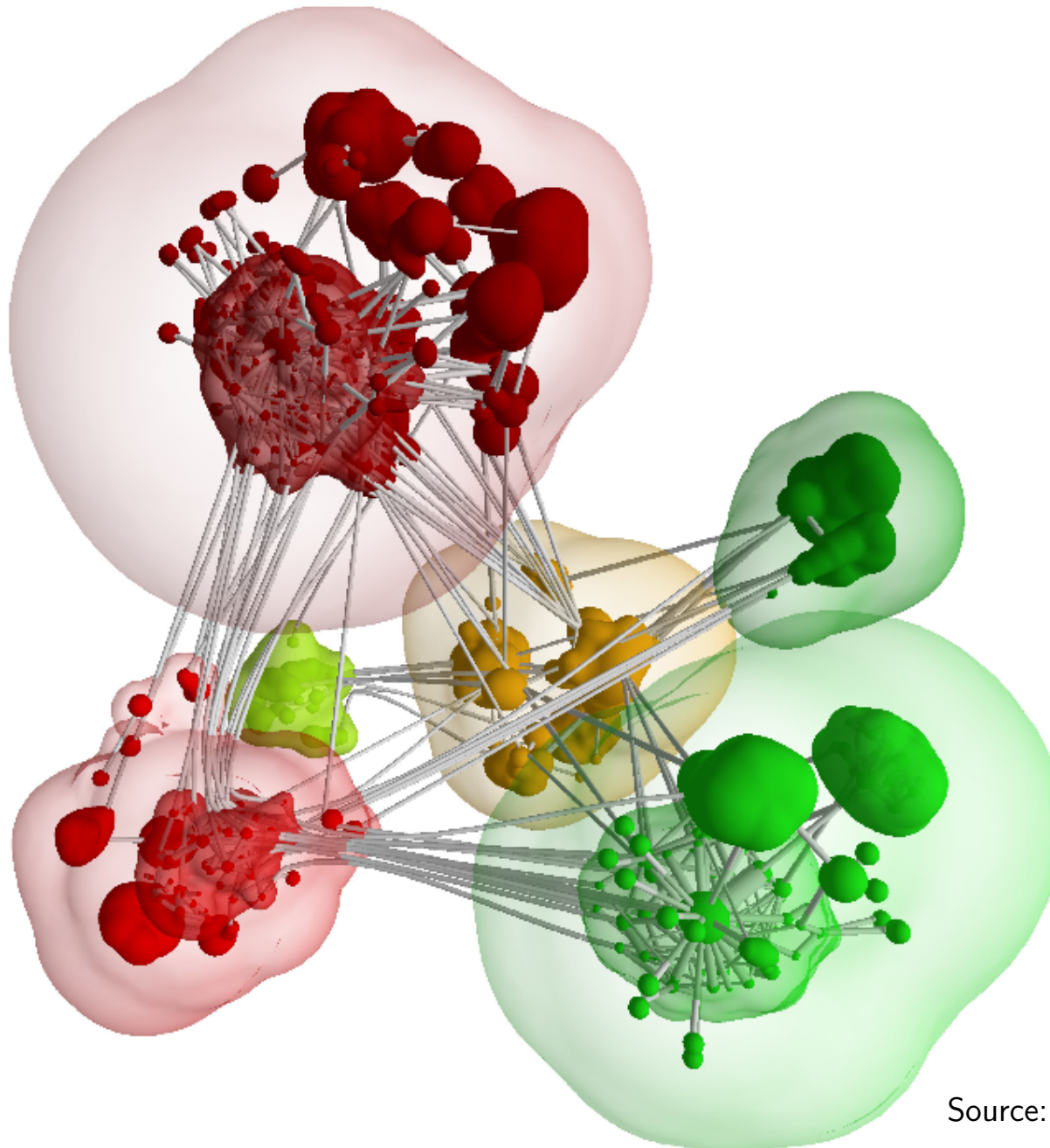
Medicine – phylogenetic Tree



Software-Network – UML Diagram

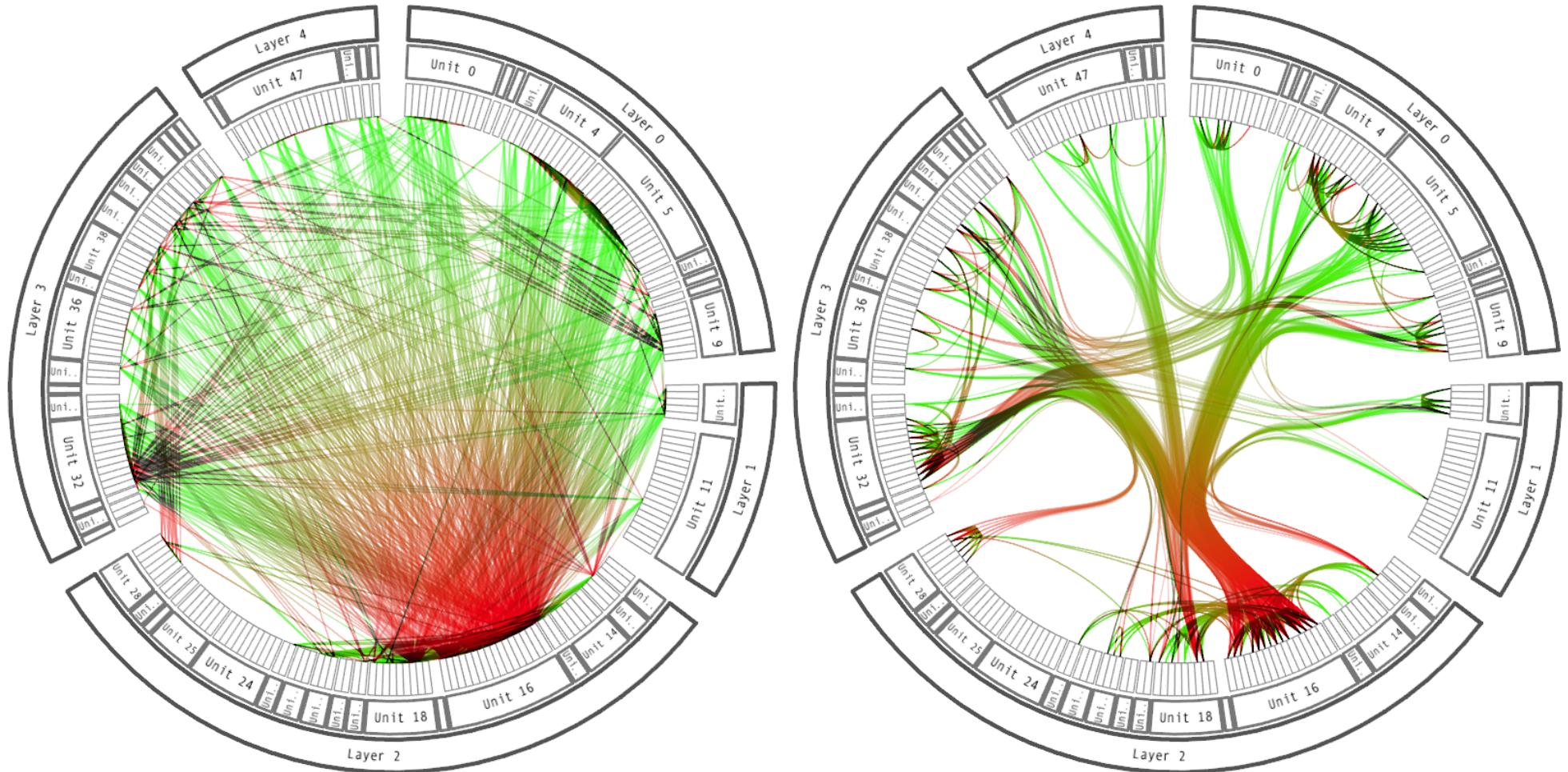


Clustered Software-Graph in 3D



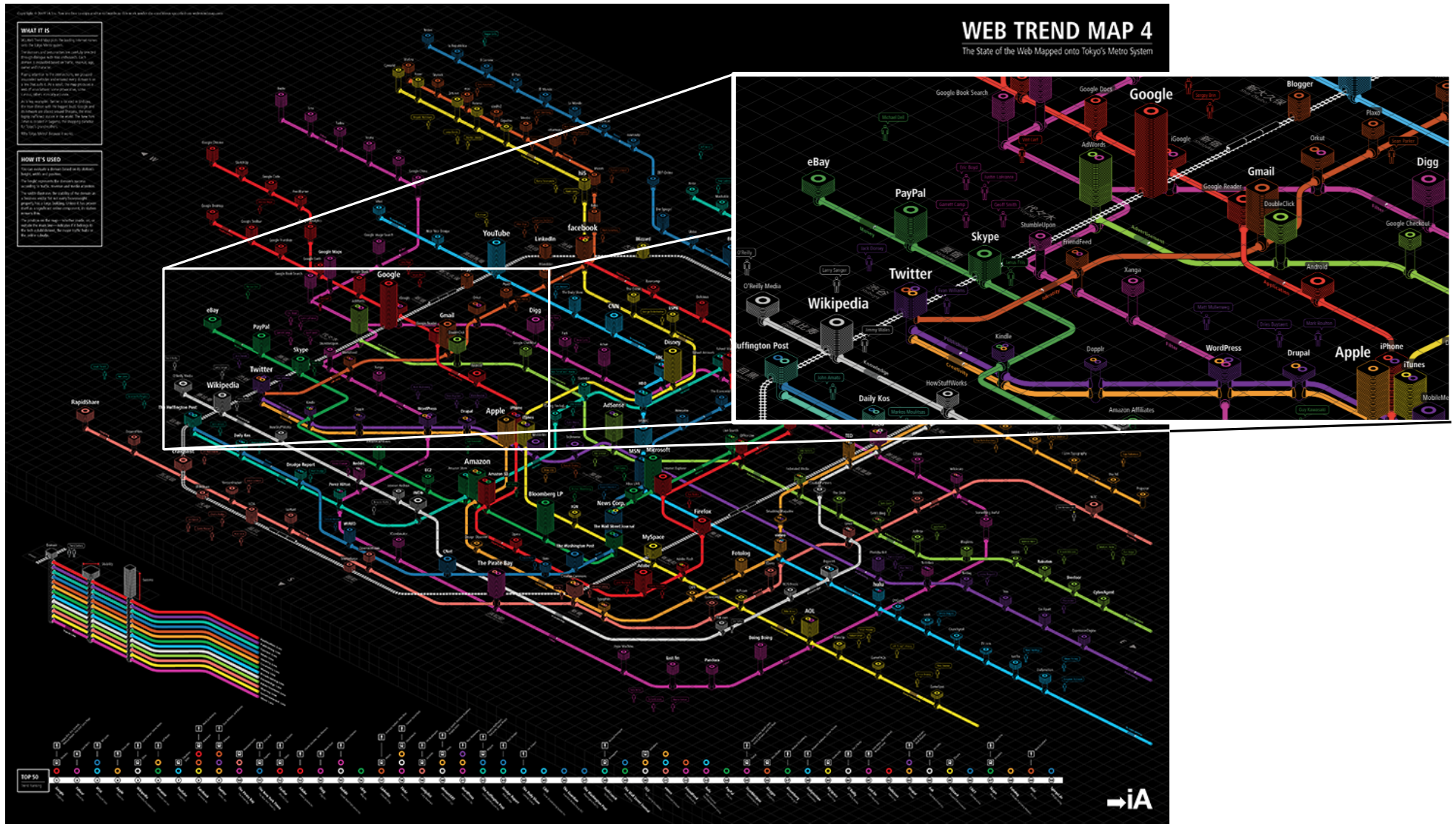
Source: Balzer, Deussen, 2007

Software Call-Graph with edge-bundling



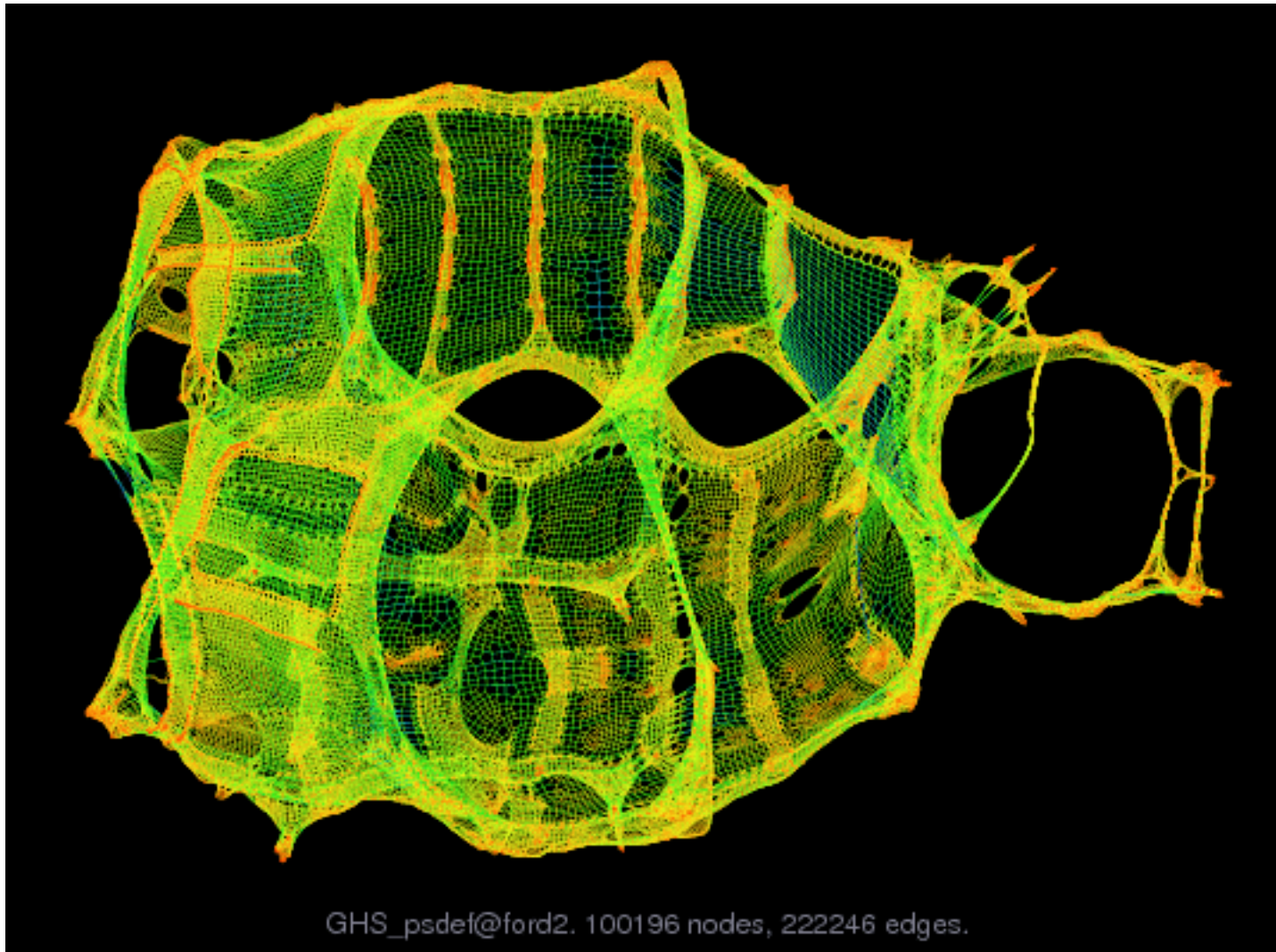
Source: Danny Holten, 2011

Web Trend Map



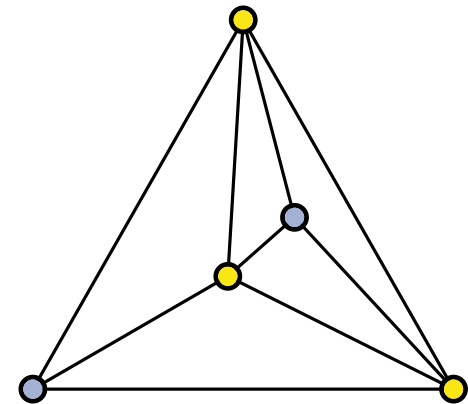
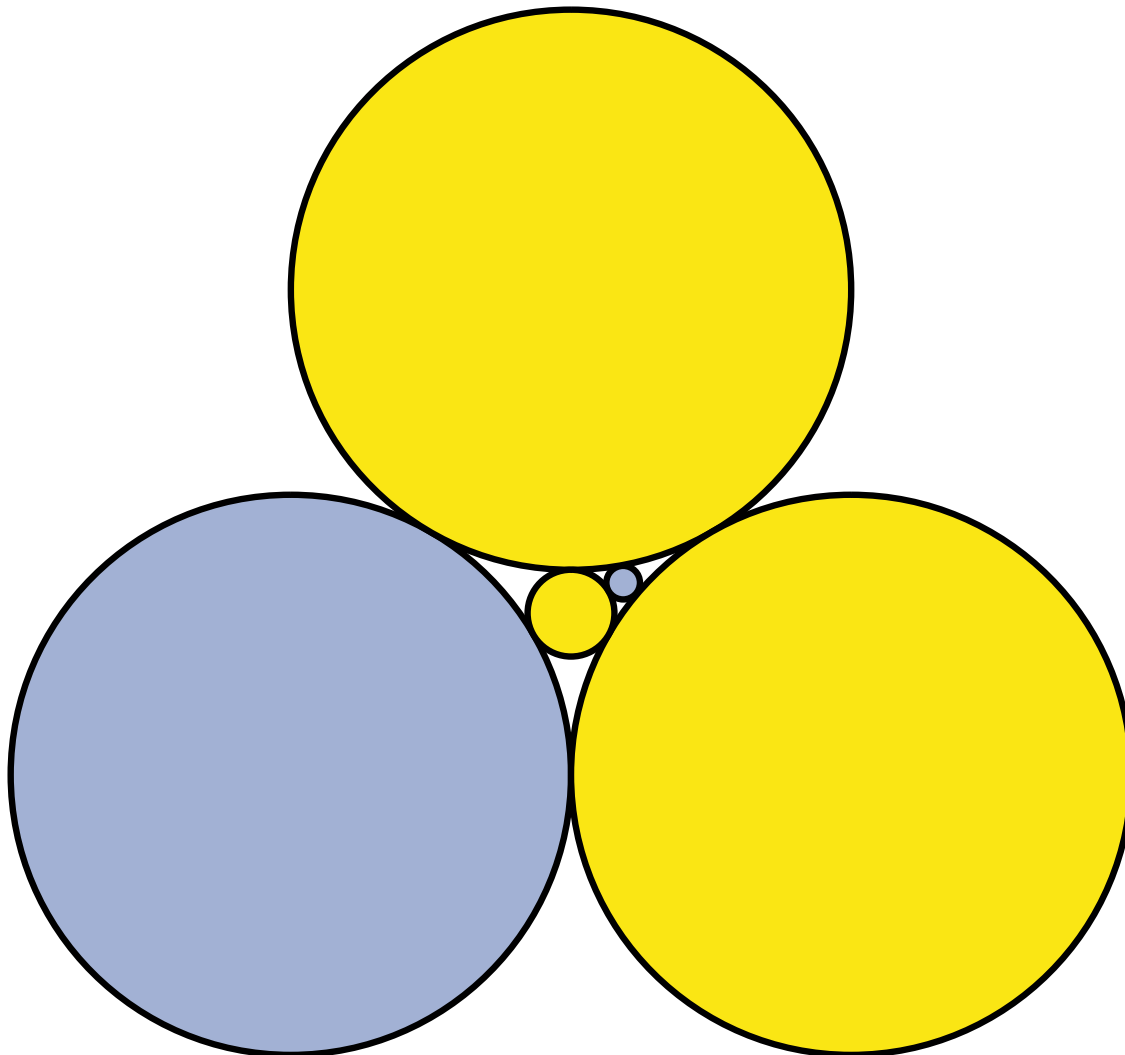
Source: information Architects, 2009

Large Graphs – Object Mesh

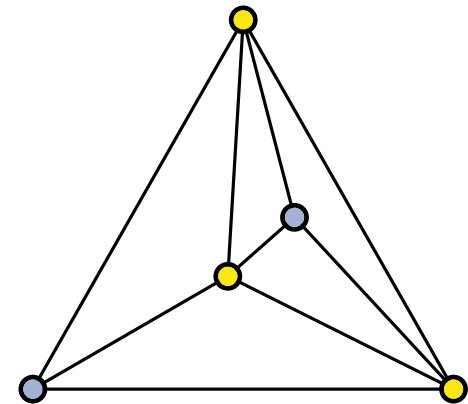
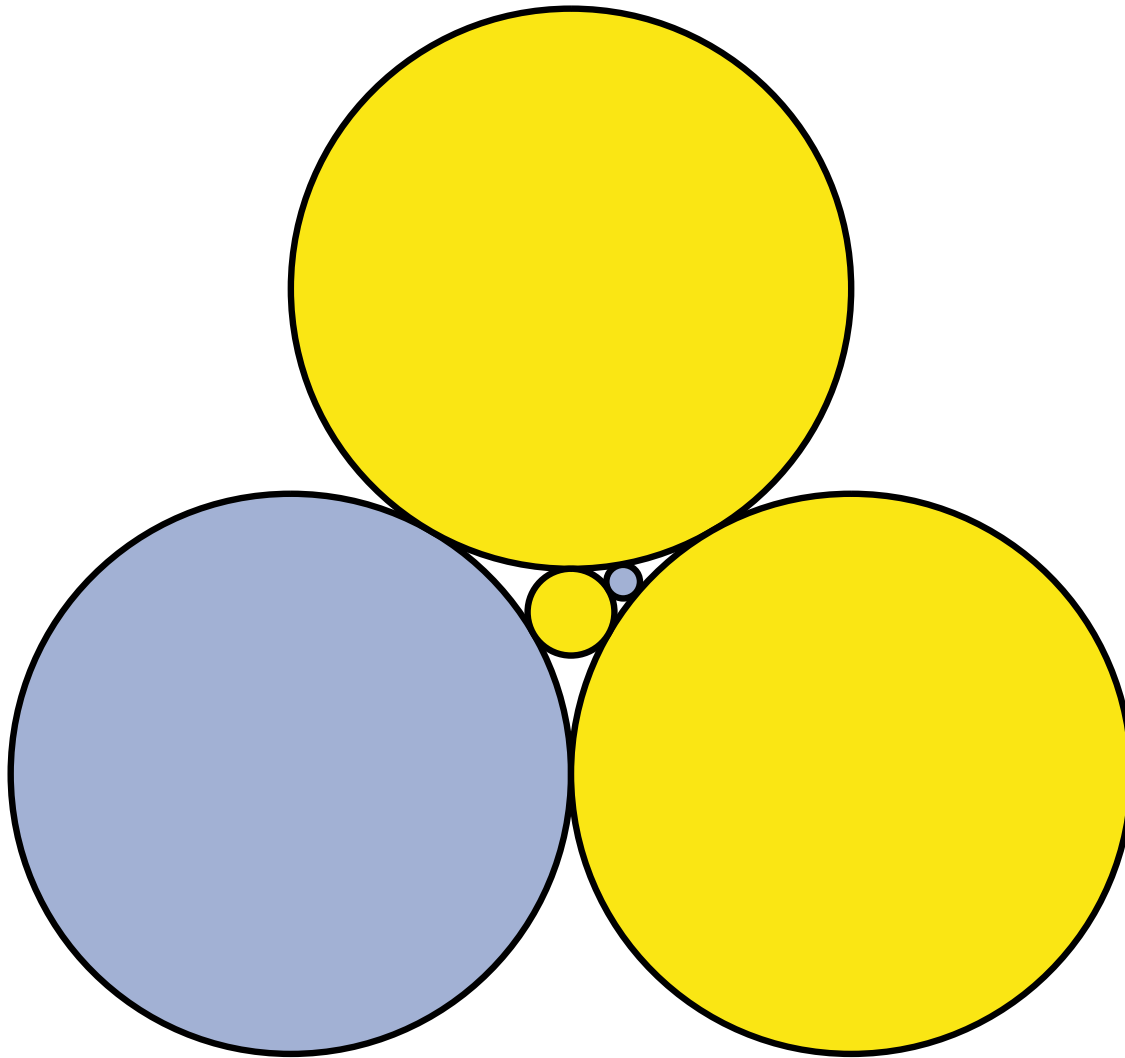


Source: Yifan Hu

Alternative Visualizations: Contact map



Alternative Visualizations: Contact map



For more: <http://www.visualcomplexity.com/>

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

Next Meeting

Lectures 16.10, 23.10 14:00

Exercise on 22.10 14:00

Next Meeting

Lectures 16.10, 23.10 14:00

Exercise on 22.10 14:00

Topic Tree Layouts

Home task In which applications we need to construct a tree layout?