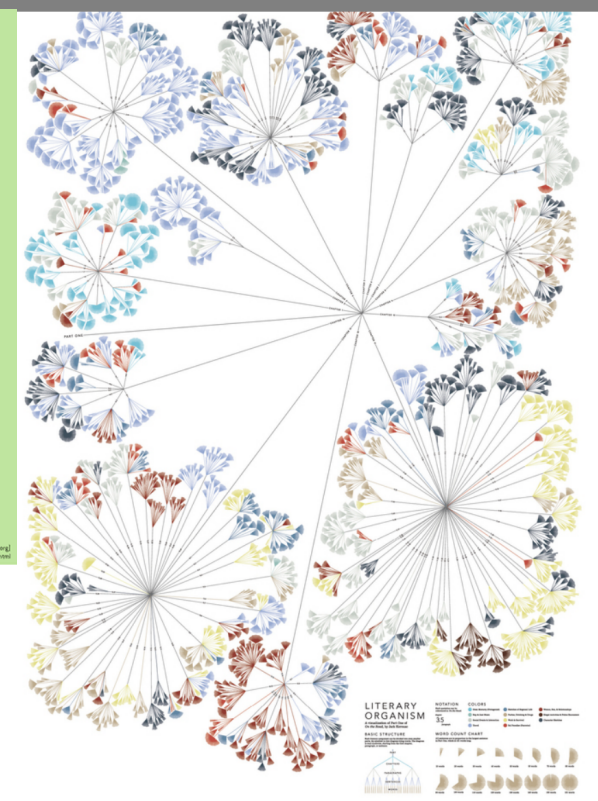
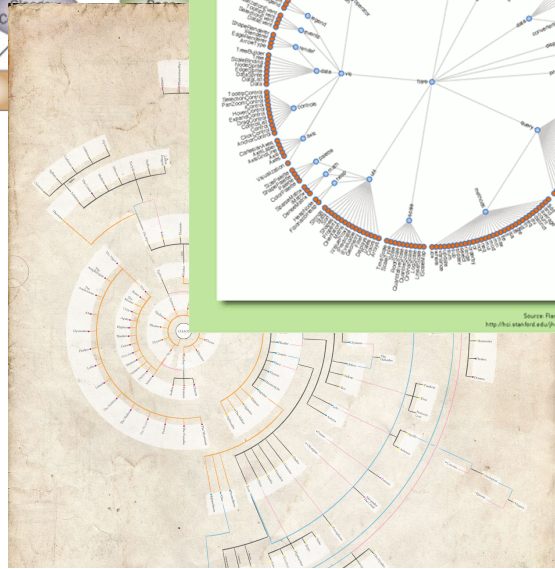
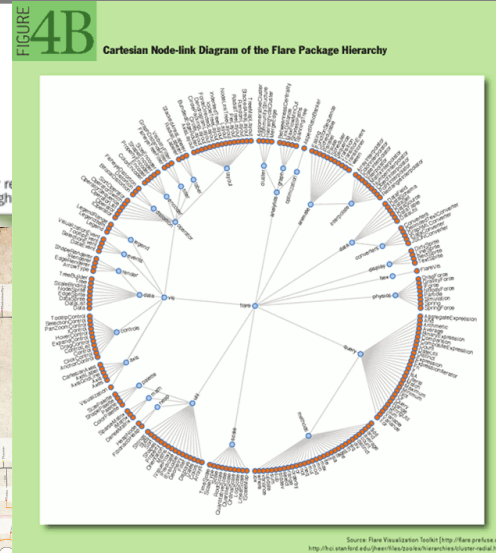
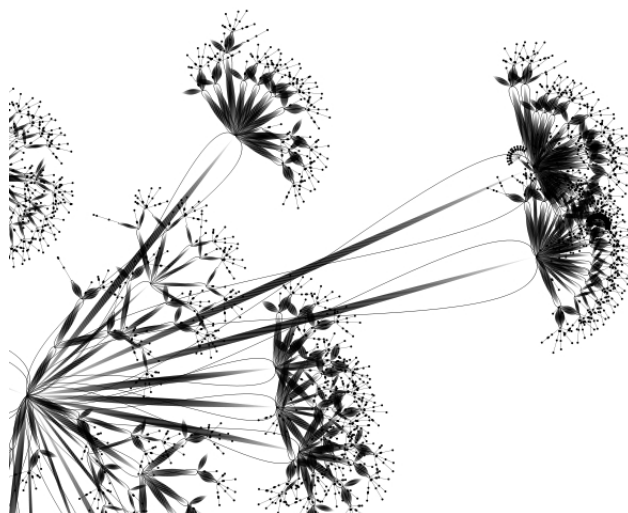
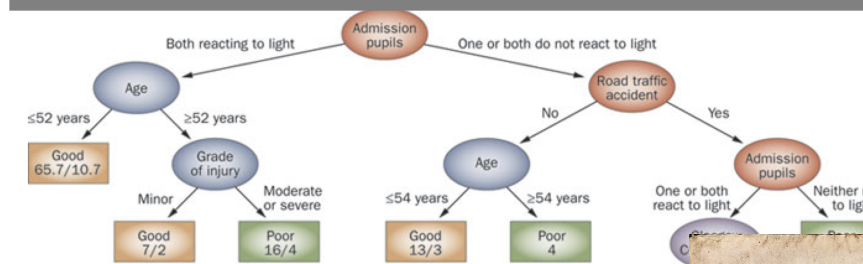


Introduction

Course : Data Visualization

Lecturer : Tamara Mchedlidze

Utrecht University, Dept. of Information and Computing Sciences



Lecture Overview

- **Why Data visualization?**
- **Data types and their models**
- **Networks and their visualizations (gallery)**
- **Let's draw some networks**
- **Basis for algorithm design: formalization of network visualization problem**
- **Evaluation of Network Visualization**
- **Types of algorithms (mind map)**
- **Some basic notions in Algorithm Complexity Theory**

Why Data Visualization?

We live in the era of data

Well-defined questions can be solved by purely computational methods (statistics, algorithms, machine learning)

Many problems are ill-specified – people do not know how to approach the problem, which questions to ask – > human in the loop

Vis tools are appropriate when we want to augment human capabilities

Visualization allows people to offload internal cognition and memory usage to the perceptual system (goes beyond classical data vis)

We need computer and algorithms to construct visualizations

Data Types

We collect and process tremendous amounts of complex data sets

To study data visualization systematically it helps to organize data by types

Data Types

We collect and process tremendous amounts of complex data sets

To study data visualization systematically it helps to organize data by types



Question: What data types do you know?

Data Types

We collect and process tremendous amounts of complex data sets

To study data visualization systematically it helps to organize data by types



Question: What data types do you know?

- High-dimensional data
- Relational data
- Spatial data

Data Types

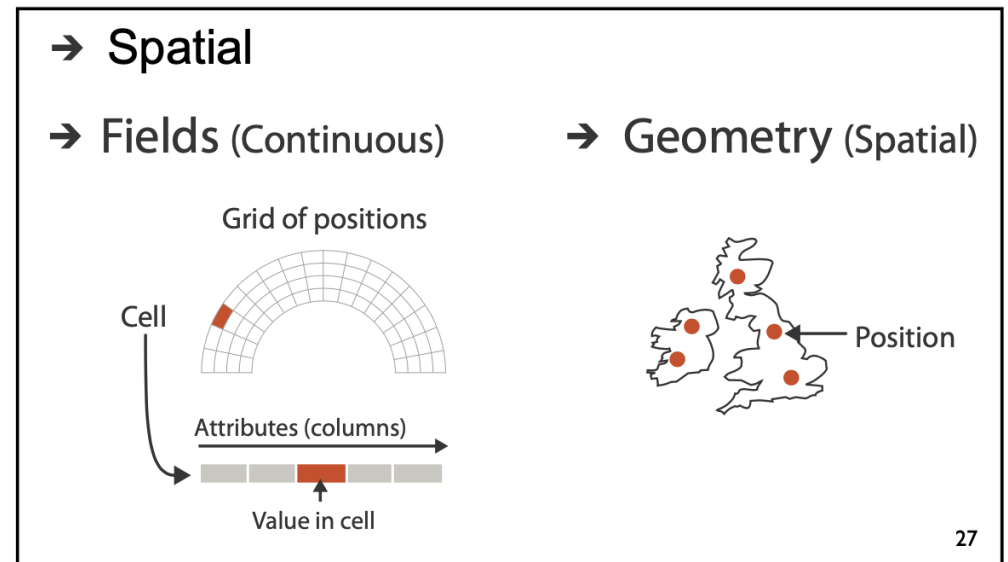
We collect and process tremendous amounts of complex data sets

To study data visualization systematically it helps to organize data by types



Question: What data types do you know?

- High-dimensional data
- Relational data
- Spatial data



from the book of T. Muzner

Data Types

We collect and process tremendous amounts of complex data sets

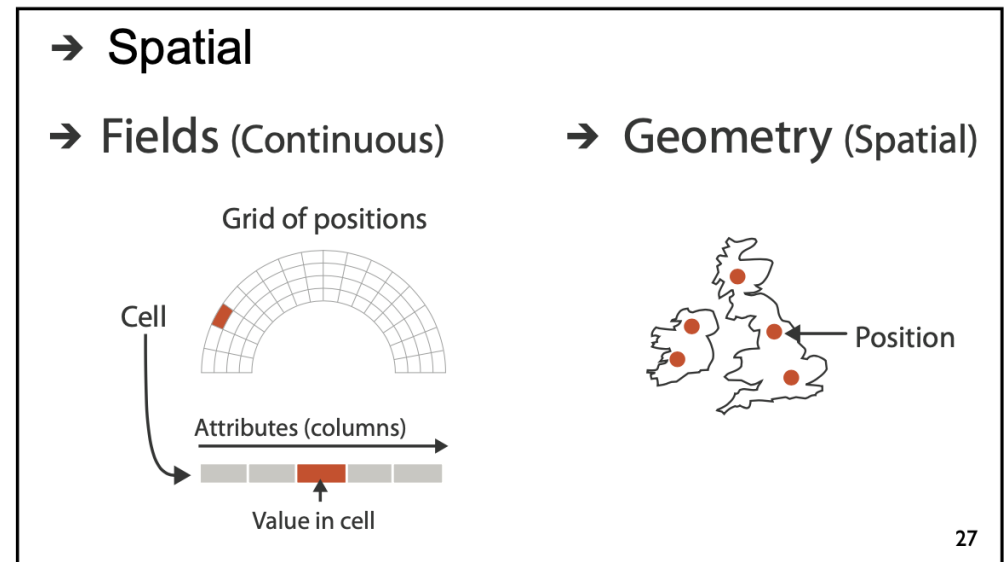
To study data visualization systematically it helps to organize data by types



Question: What data types do you know?

In this course

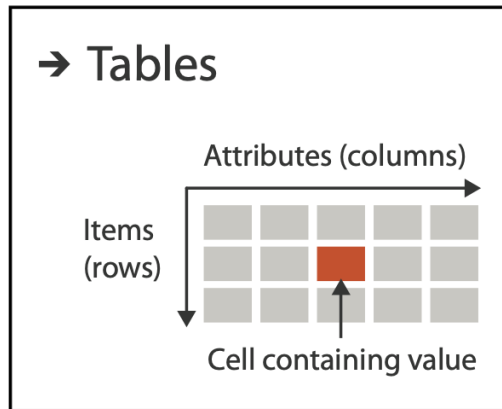
- High-dimensional data
- Relational data
- Spatial data



from the book of T. Muzner

High-dimensional data

High-dimensional data are modeled as tables

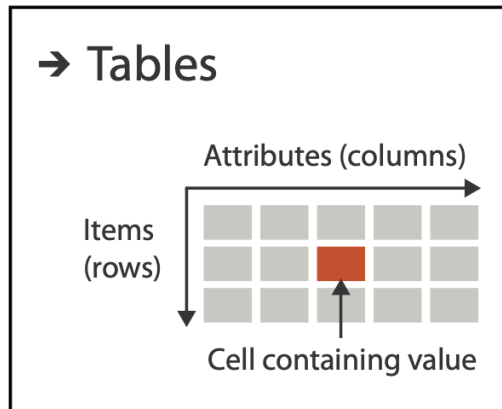


	Name	Age	Shirt Size	Favorite Fruit
	Amy	8	S	Apple
	Basil	7	S	Pear
	Clara	9	M	Durian
	Desmond	13	Cell	Elderberry
	Ernest	12	L	Peach
	Fanny	10	S	Lychee
	George	9	M	Orange
	Hector	8	L	Loquat
	Ida	10	M	Pear
Item	Amy	12	M	Orange

Column/attribute/dimension

High-dimensional data

High-dimensional data are modeled as tables



	Name	Age	Shirt Size	Favorite Fruit
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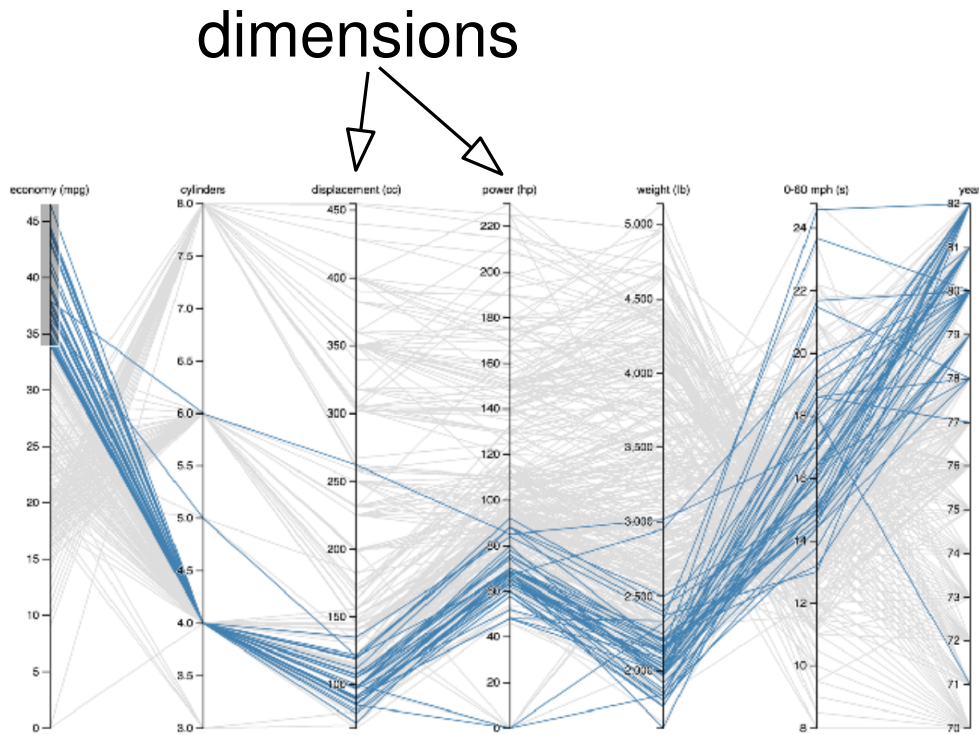
Column/attribute/dimension



Question: Examples of high-dimensional data?

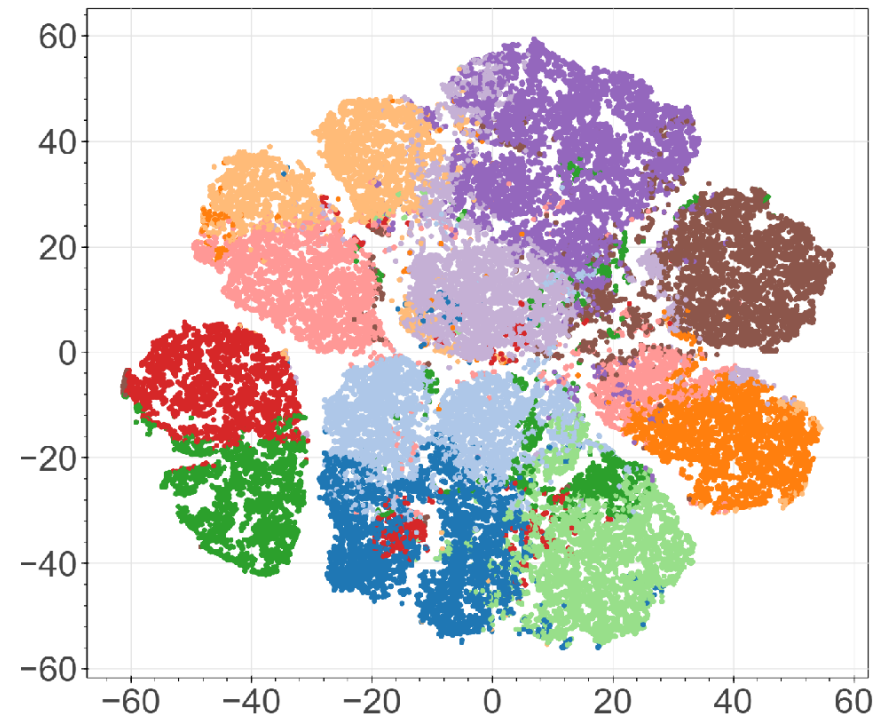
How to visualize high-dimensional data

explicit dimension representation



Parallel coordinates

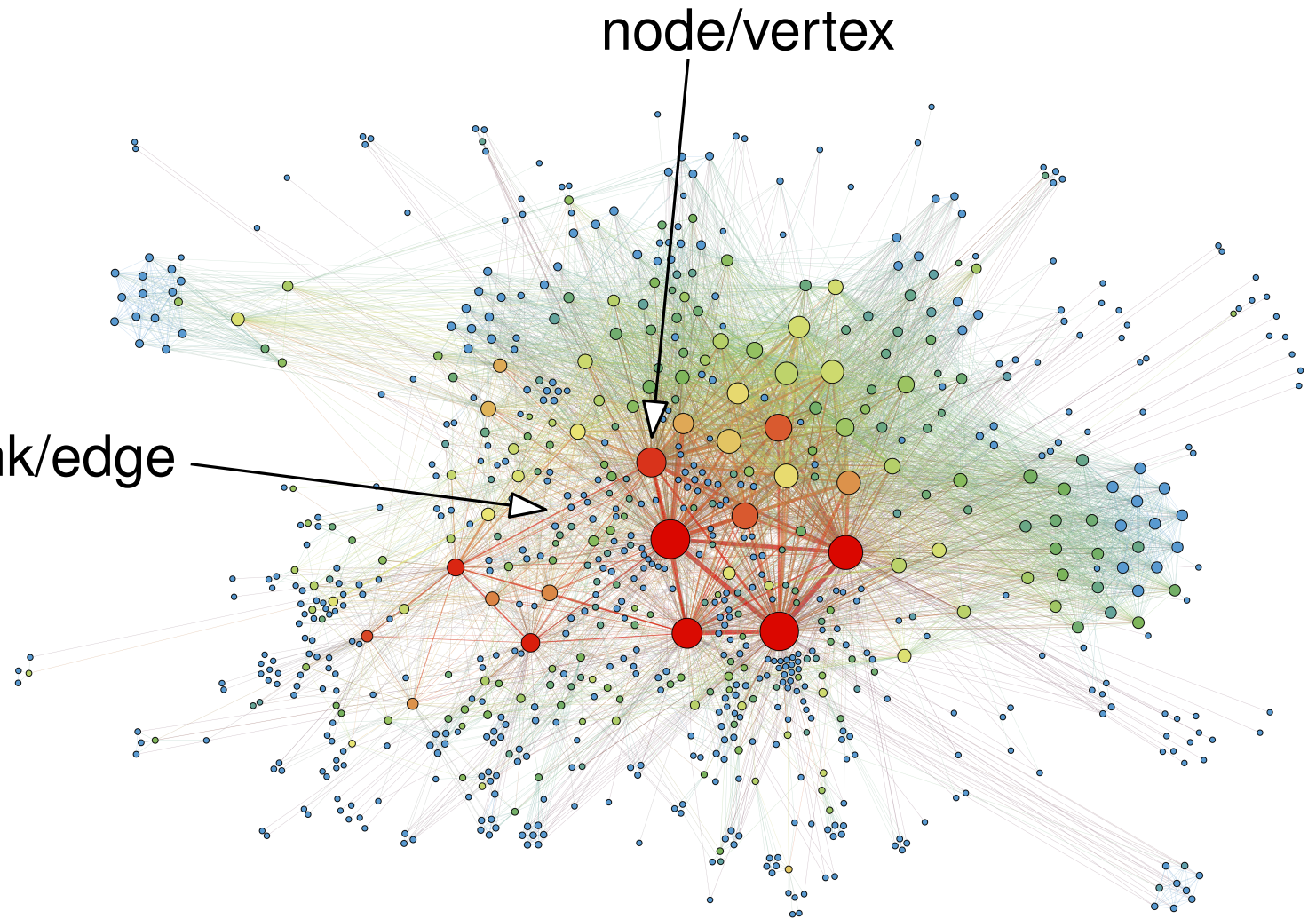
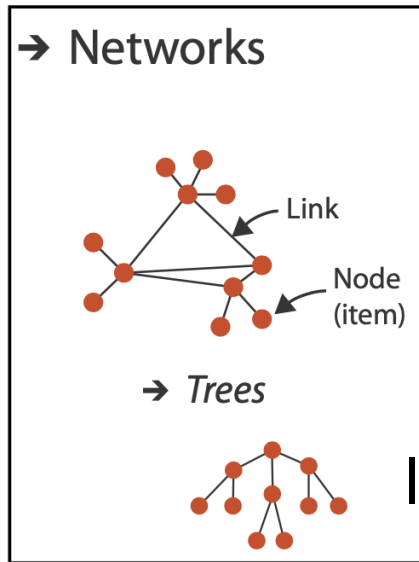
n initial dimensions are “squeezed” into two



Dimensionality reduction

Relational data

Relational data are modeled as networks

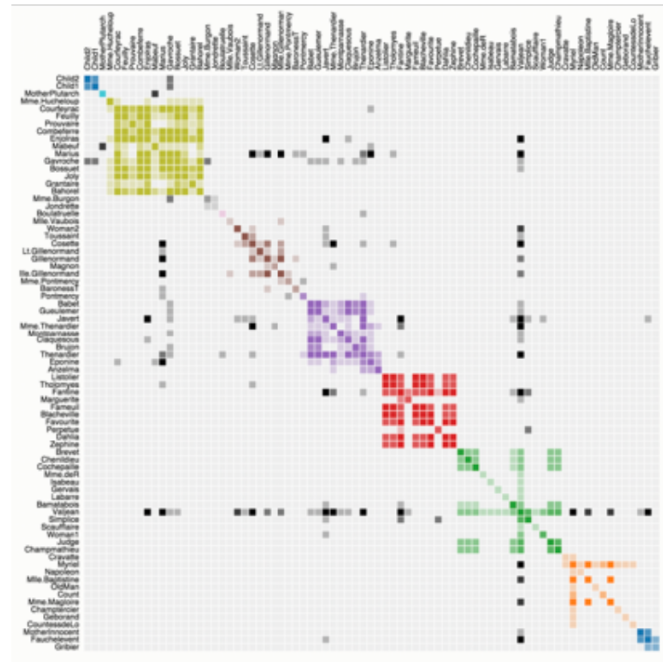


Question: Examples of relational data?

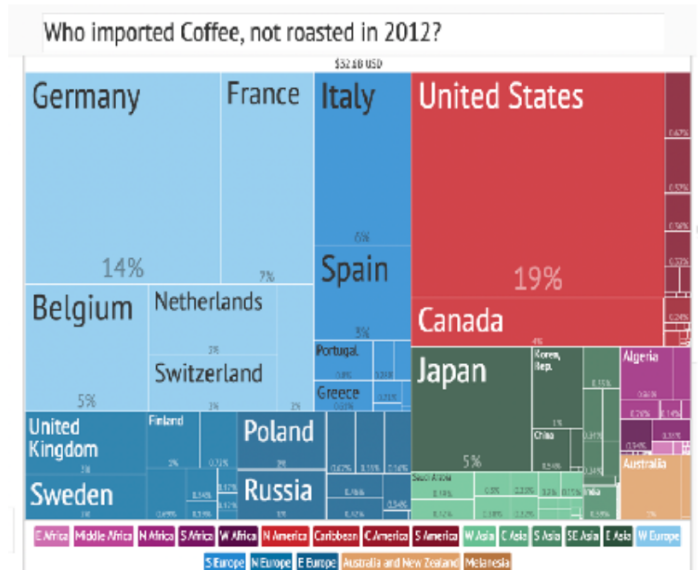
How to visualize relational data



Node-link diagram



Adjacency Matrix



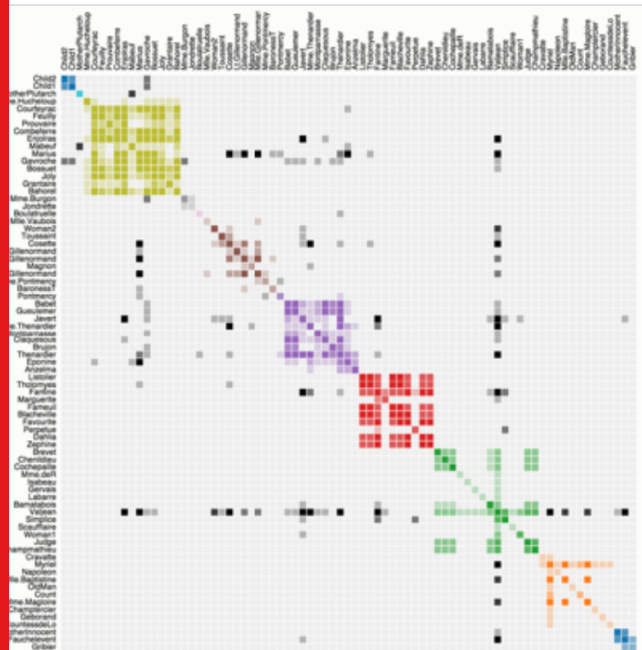
Treemaps

How to visualize relational data

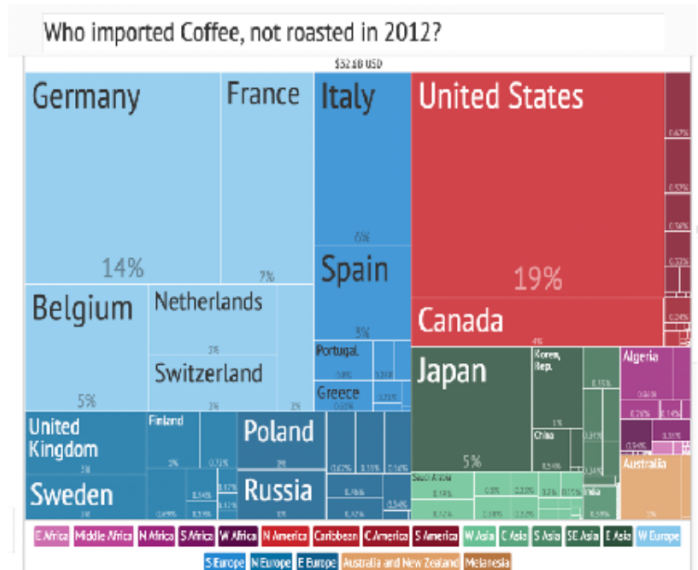
In this course



Node-link diagram

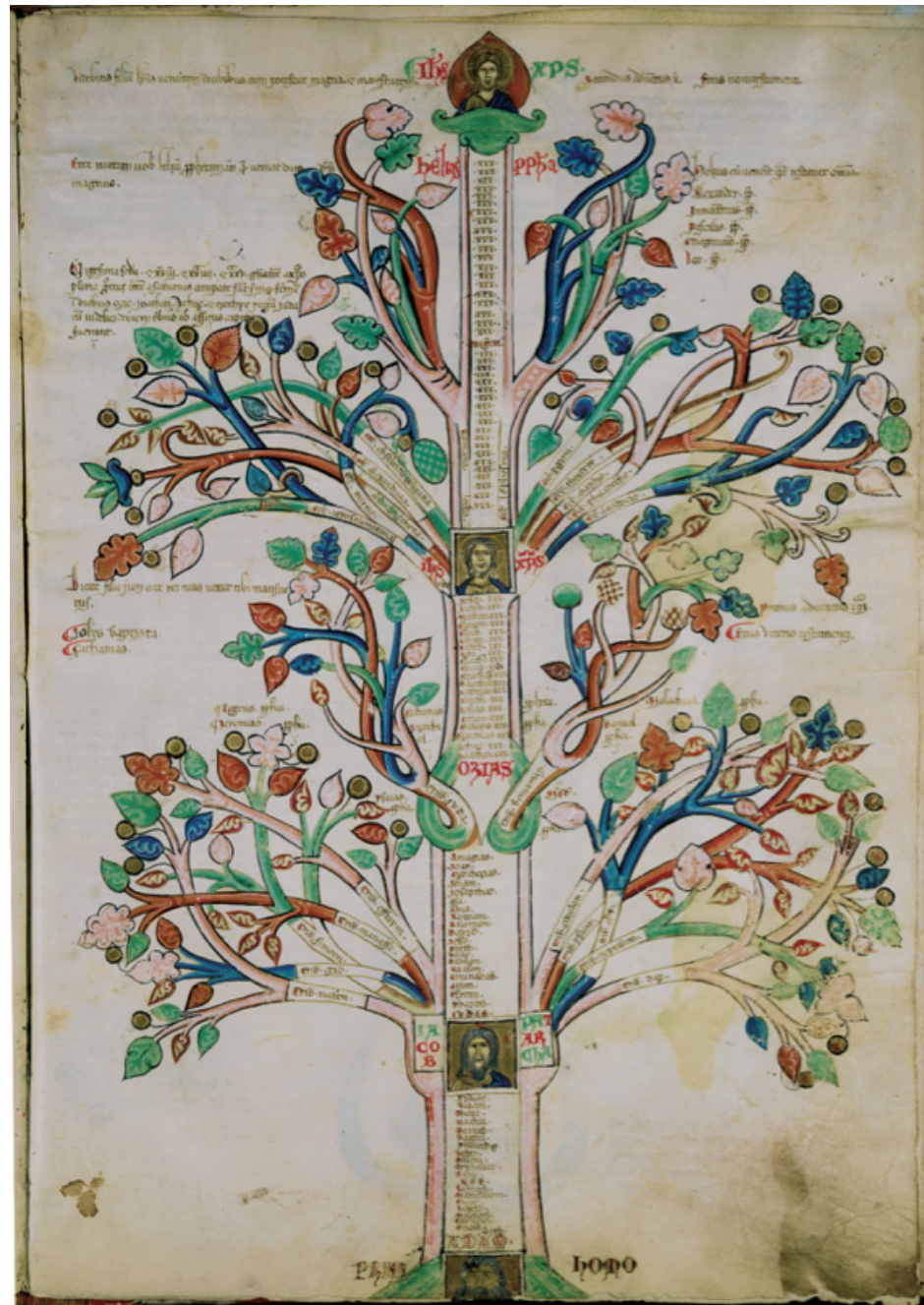


Adjacency Matrix



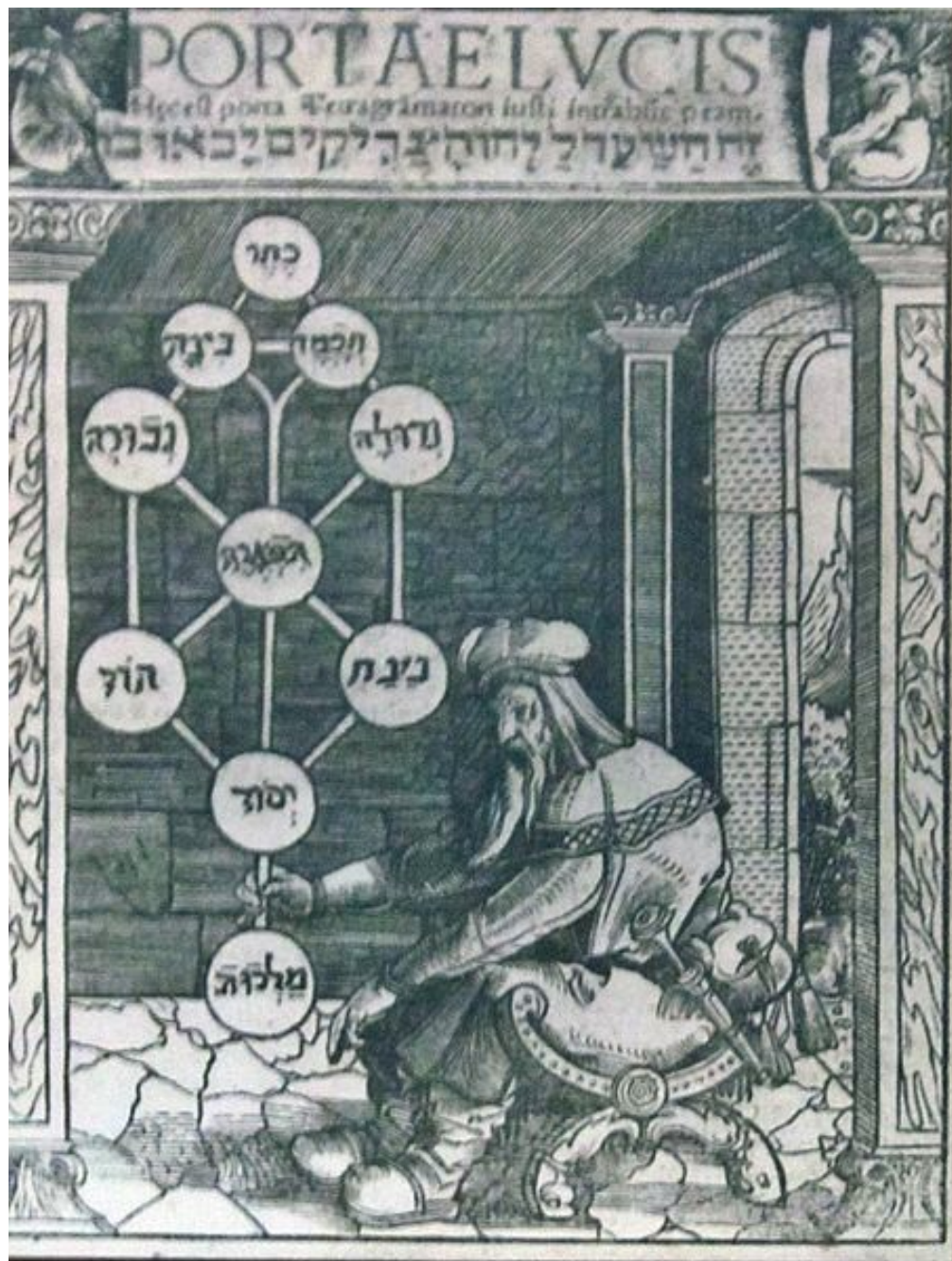
Treemaps

Biblical characters and events (1202)



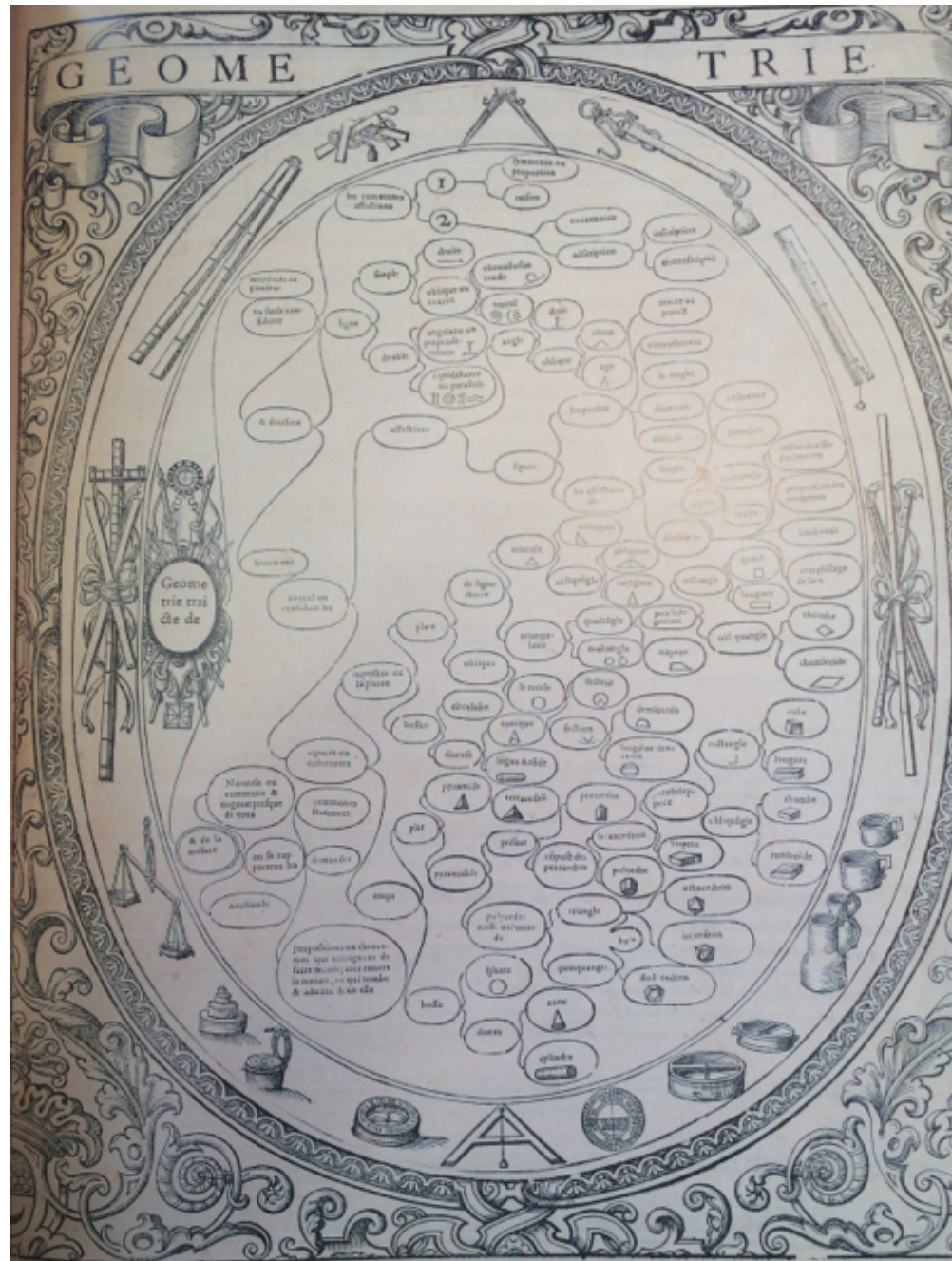
Source: Joachim de Fiore

"Tree of Life" (1516)



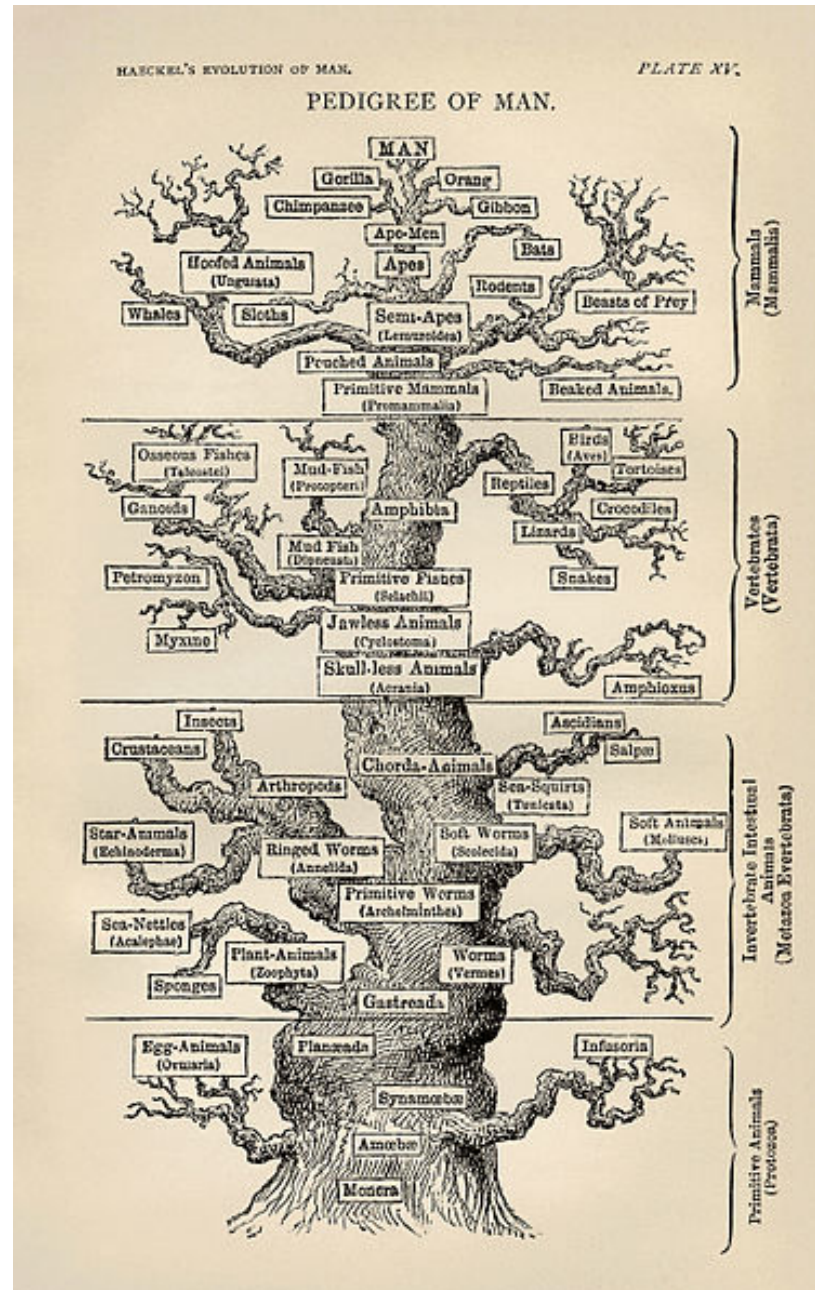
Source: Paul Riccius, Portae Lucis

Geometrical Concepts (1587)



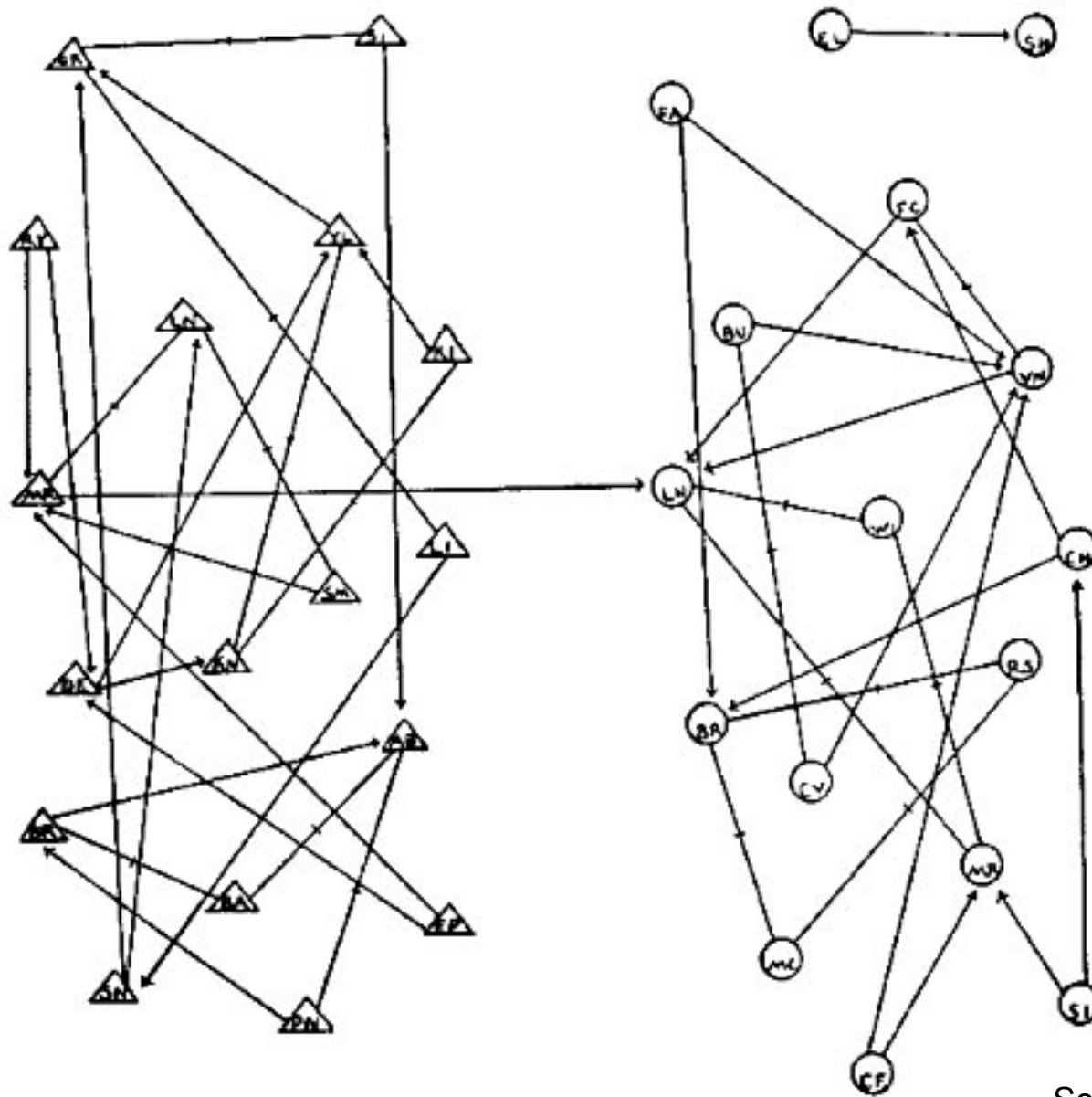
Source: Christophe de Savigny

Genealogical Tree (1879)



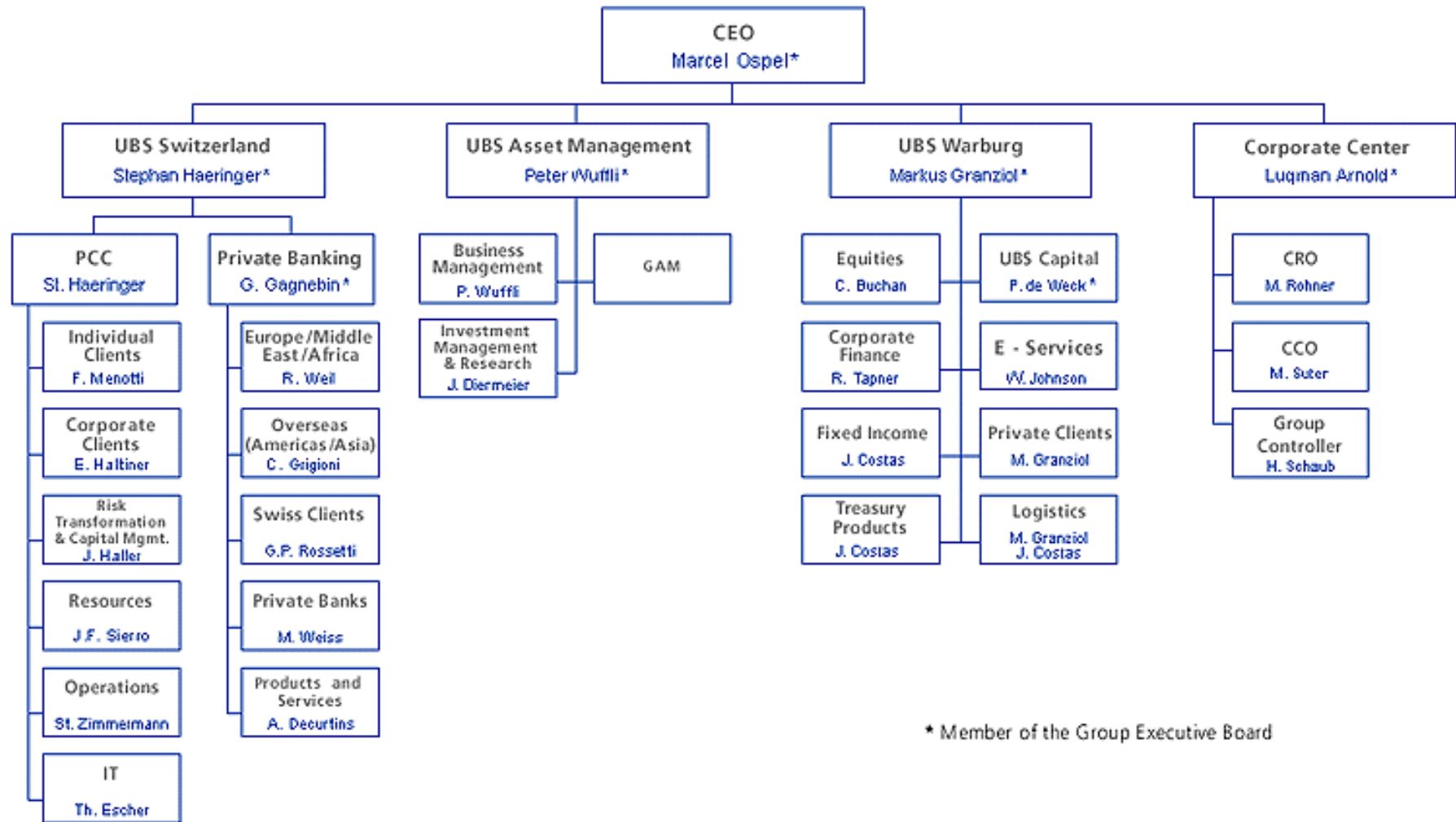
Source: Ernst Haeckel

Sociogramm (1933)



Source: Moreno, 1933

Social Network – Organization within UBS



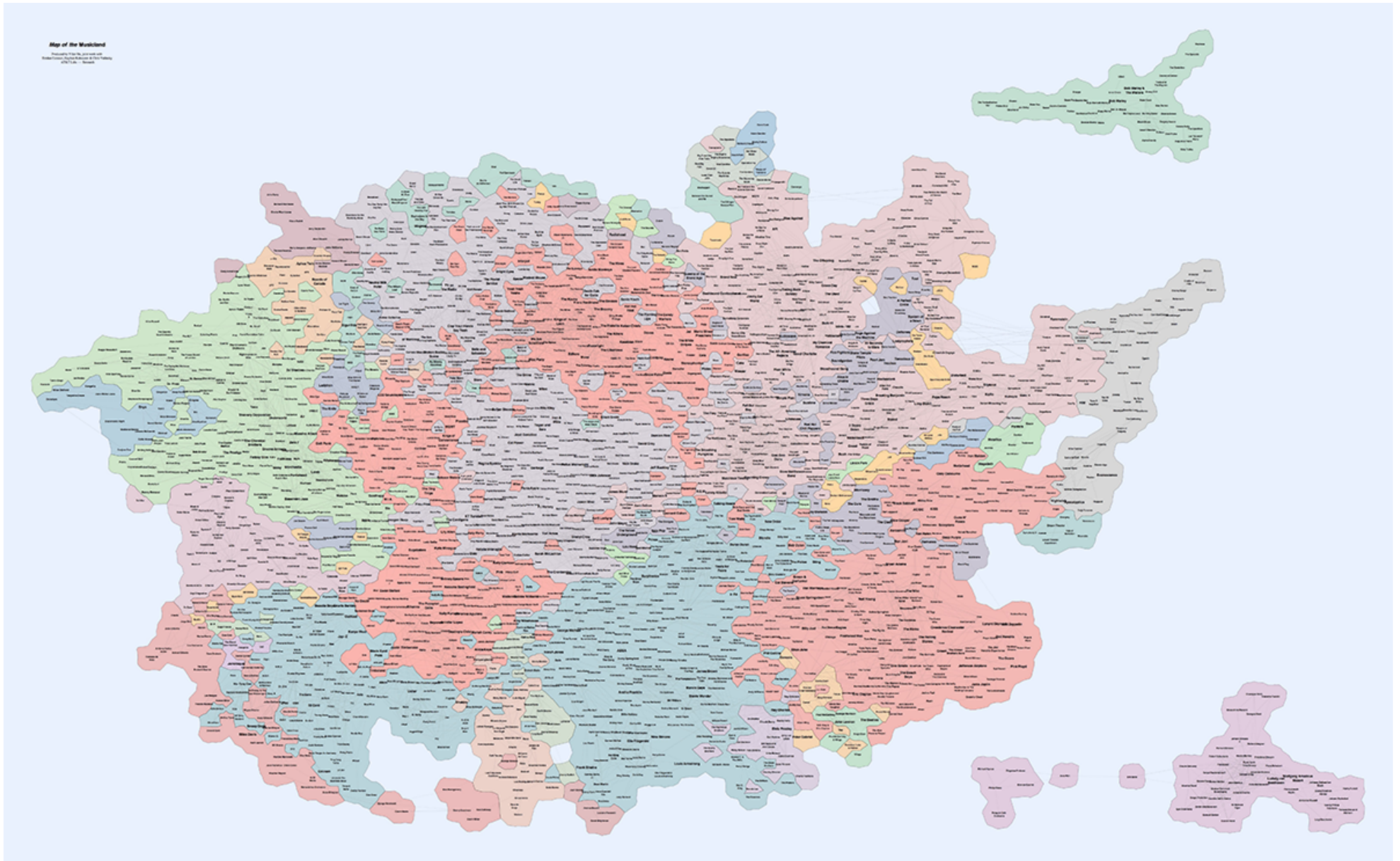
* Member of the Group Executive Board

CPAN Developer-Graph



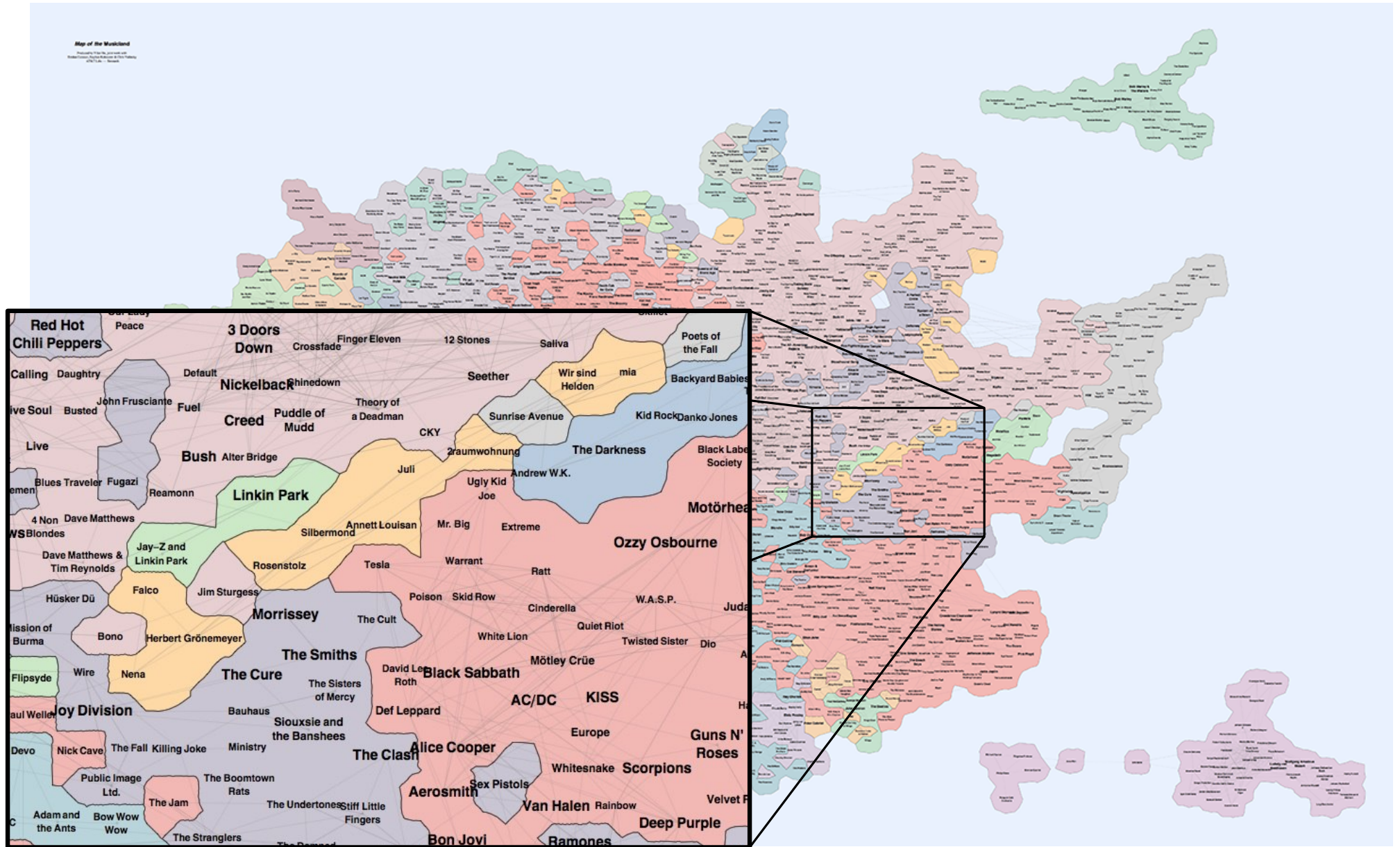
Source: cpan-explorer.org

last.fm Graph of musics as political map



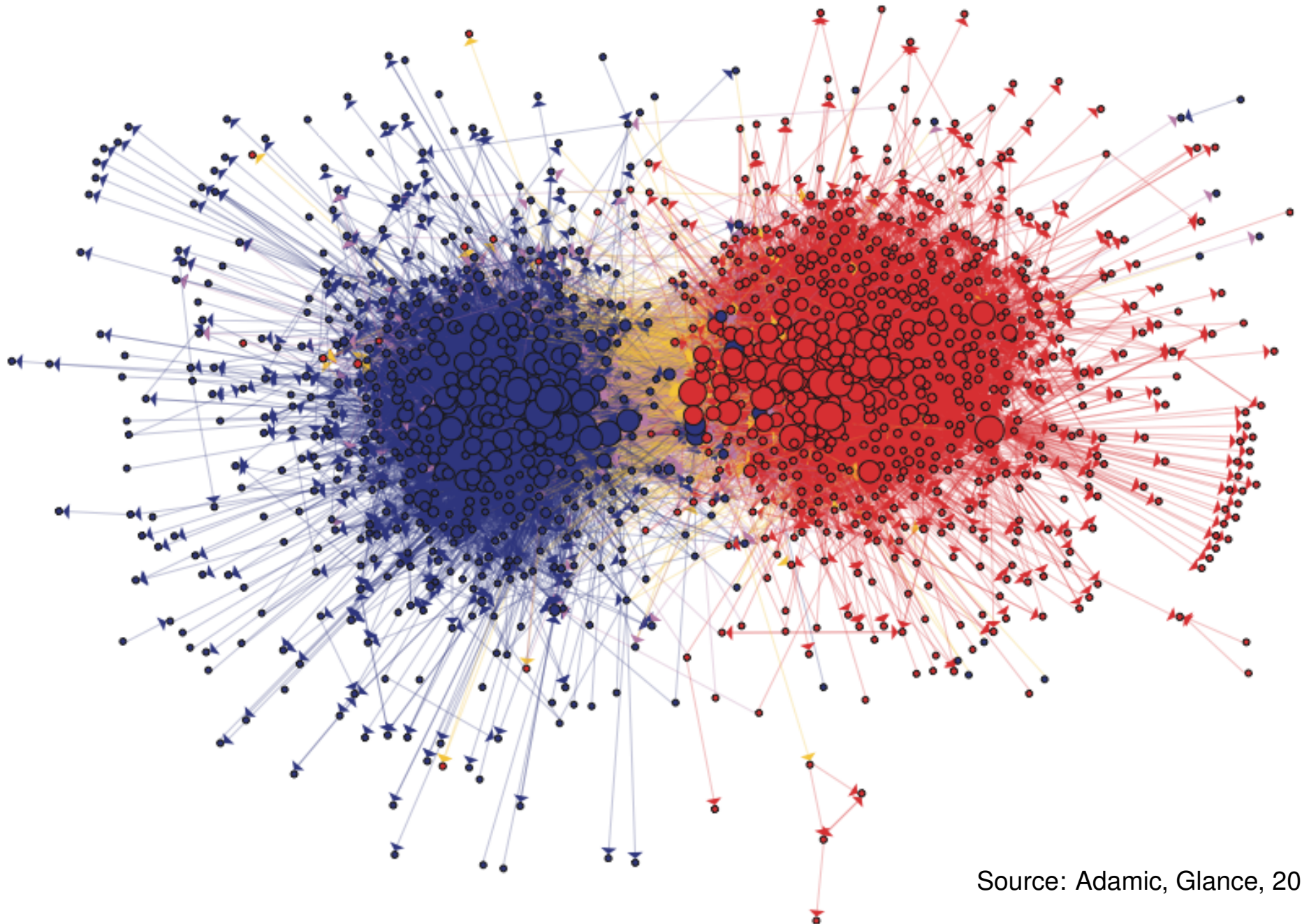
(Gansner, Hu, Kobourov: GMap, 2009)

last.fm Graph of musics as political map



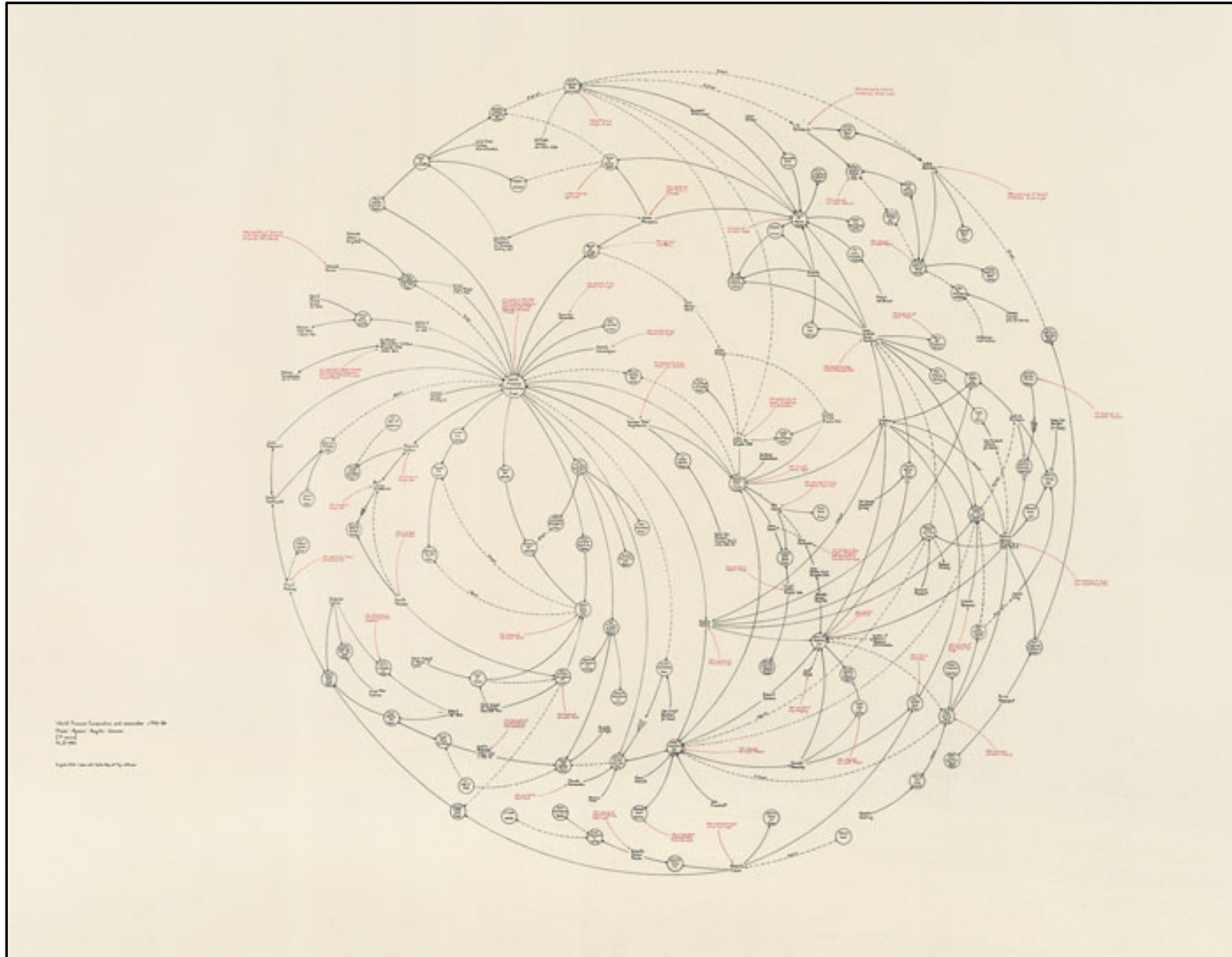
(Gansner, Hu, Kobourov: GMap, 2009)

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 Cayle in its stake sale to Mohandis, 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.

SARILIS GROUP
David Rubenstein, Co-founder and managing director

BRITAIN
STANDARD CHARTERED BANK
Peter Sands, Chief executive

BARCLAYS
John Varley, Chief executive

SWITZERLAND
UBS
Marcel Rohrab, Chief executive

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

Saudi Arabian Monetary Agency

Kuwait Investment Authority

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

HONGKONG INT. TERMINALS
Eric Si, Managing director

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

TEMASEK HOLDINGS
Ho Ching, Executive director and C.E.O.

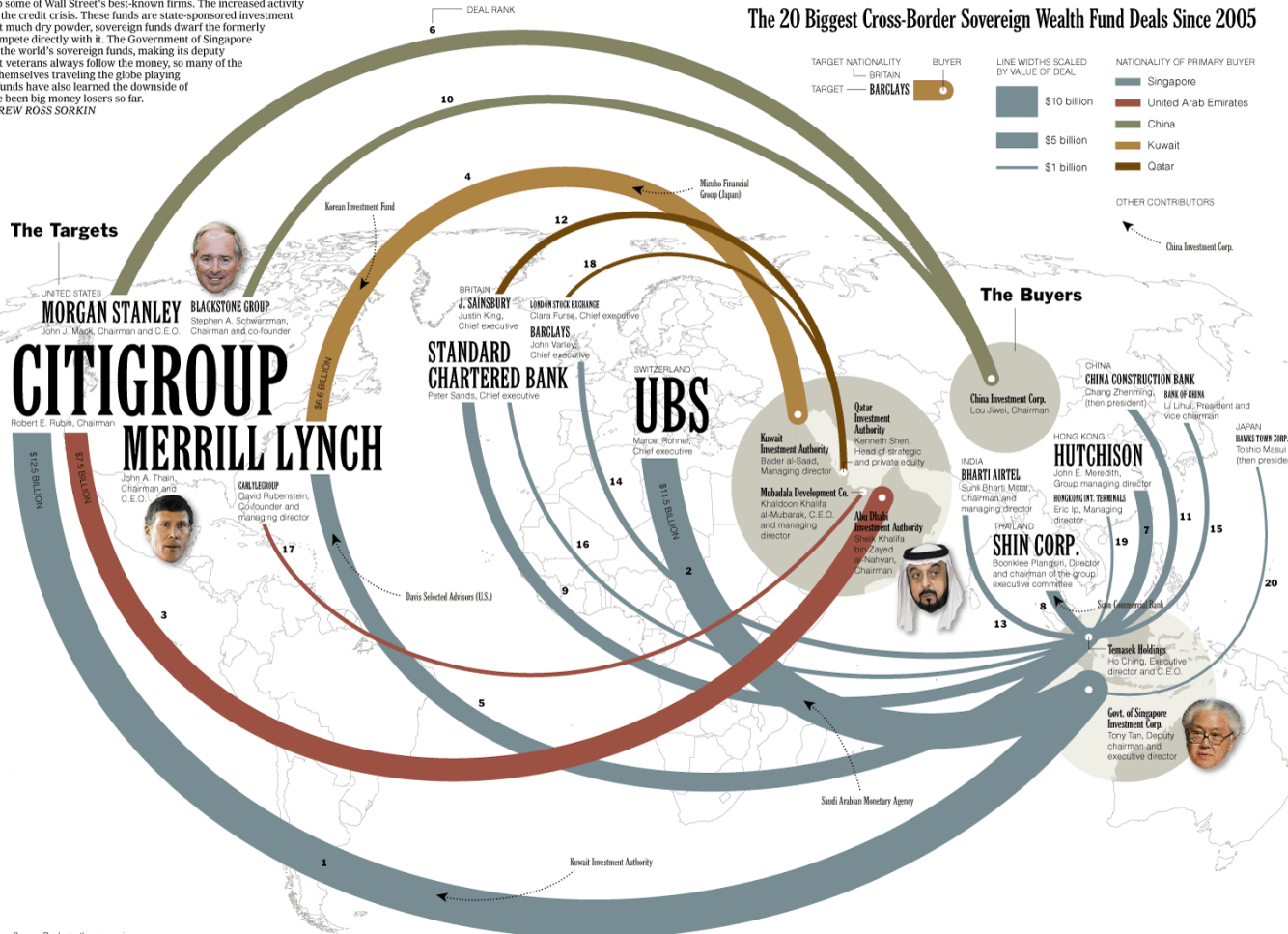
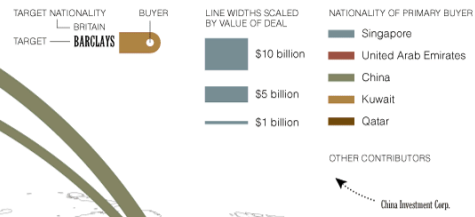
Govt of Singapore Investment Corp.
Tony Tan, Deputy chairman and executive director

JAPAN
DAIWA TOWERS CORP.
Toshio Masui, (then president)

INDIA
BHARTI AIRTEL
Sunil Bharti Mittal, Chairman and managing director

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

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



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. Quynn, 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

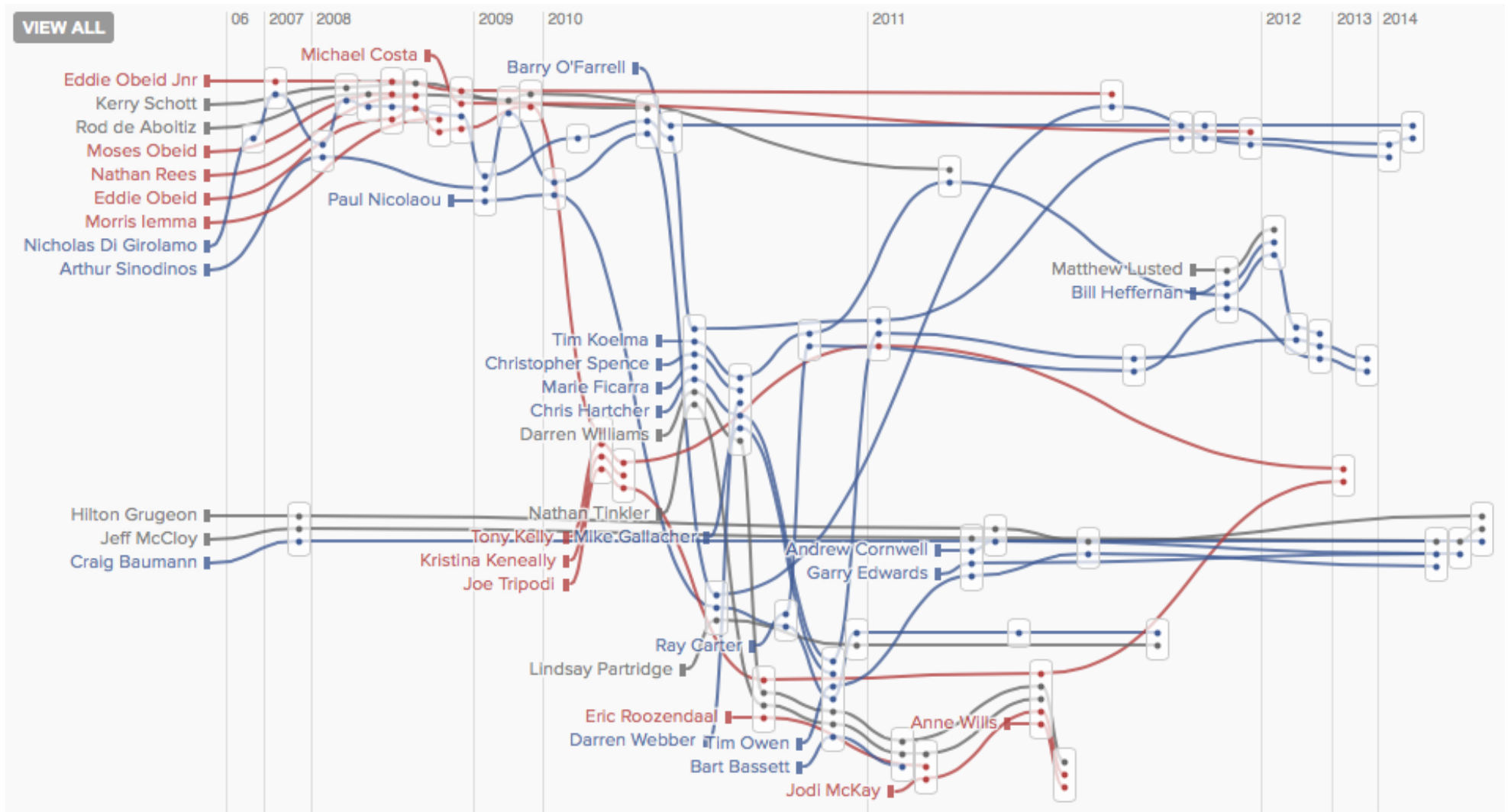


H. Rodgin Cohen, Chairman
The world's go-to lawyer for sovereign wealth investments in financial services firms. He worked on twice as many sovereign wealth related deals than any other individual.

Source: Dealogic, the companies

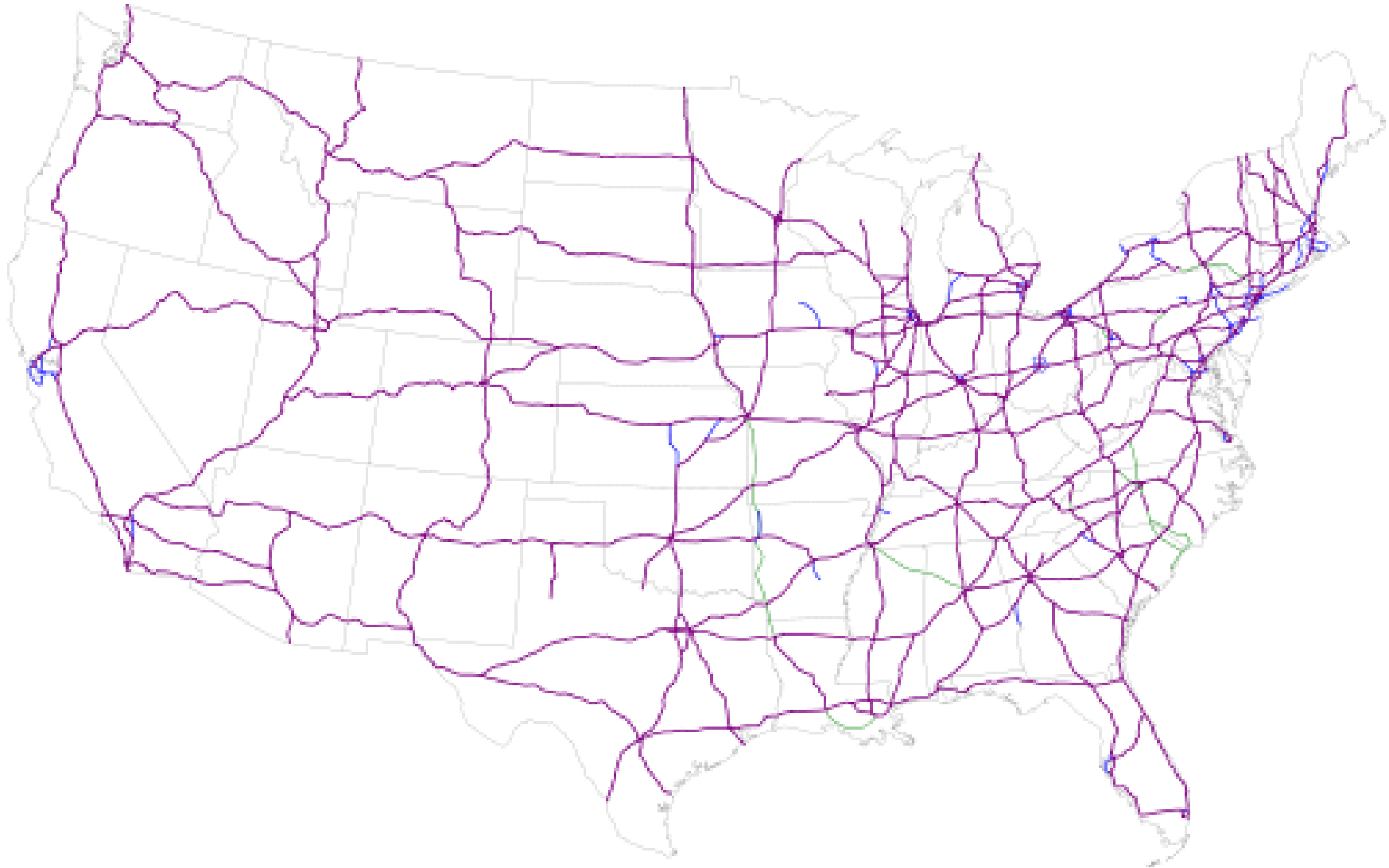
RESEARCH BY MICHAEL DE LA MERCEZ; GRAPHIC BY GILBERT GATES FOR THE NEW YORK TIMES

Temporal Graph Layout: Storylines

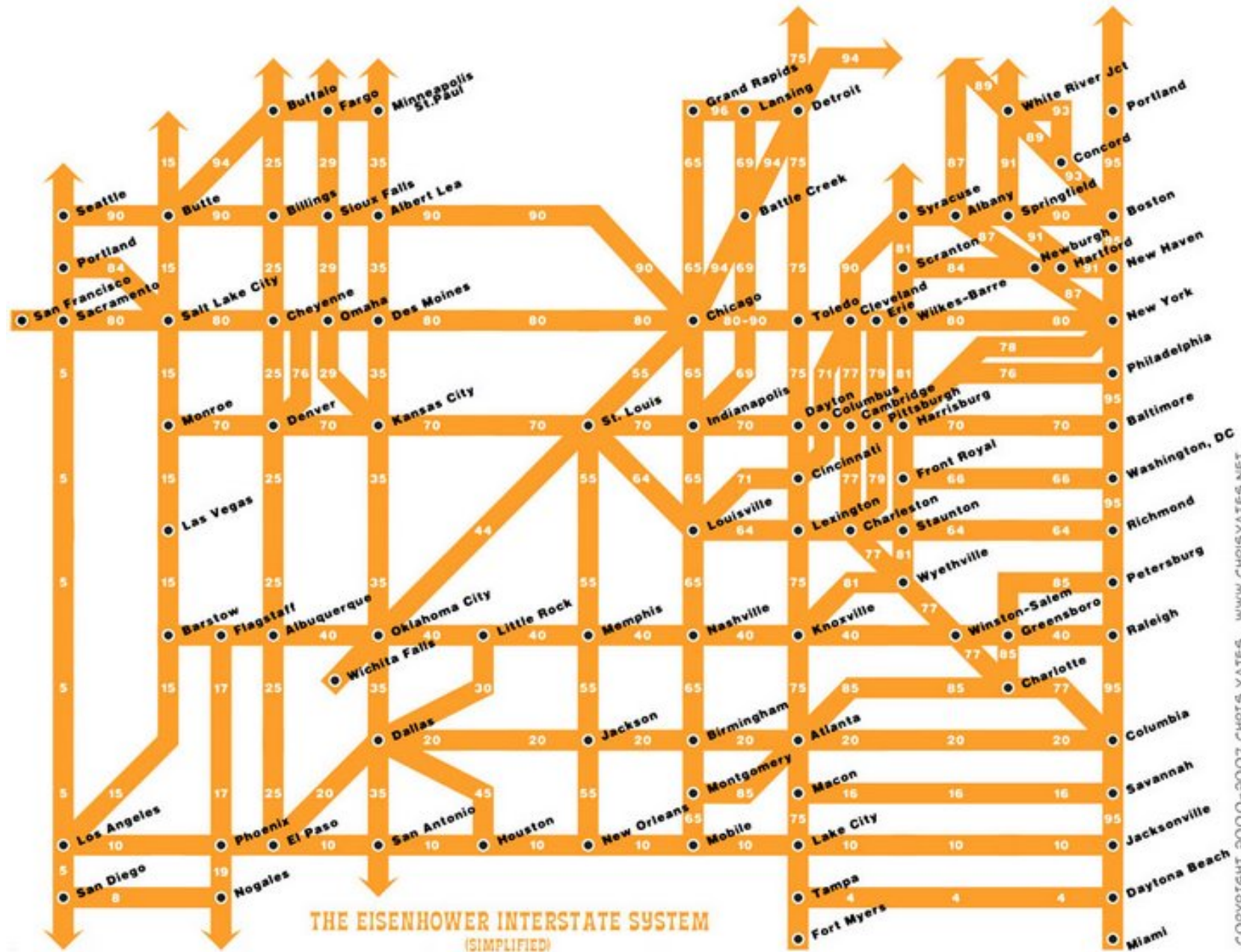


Source: ABC news, Australia

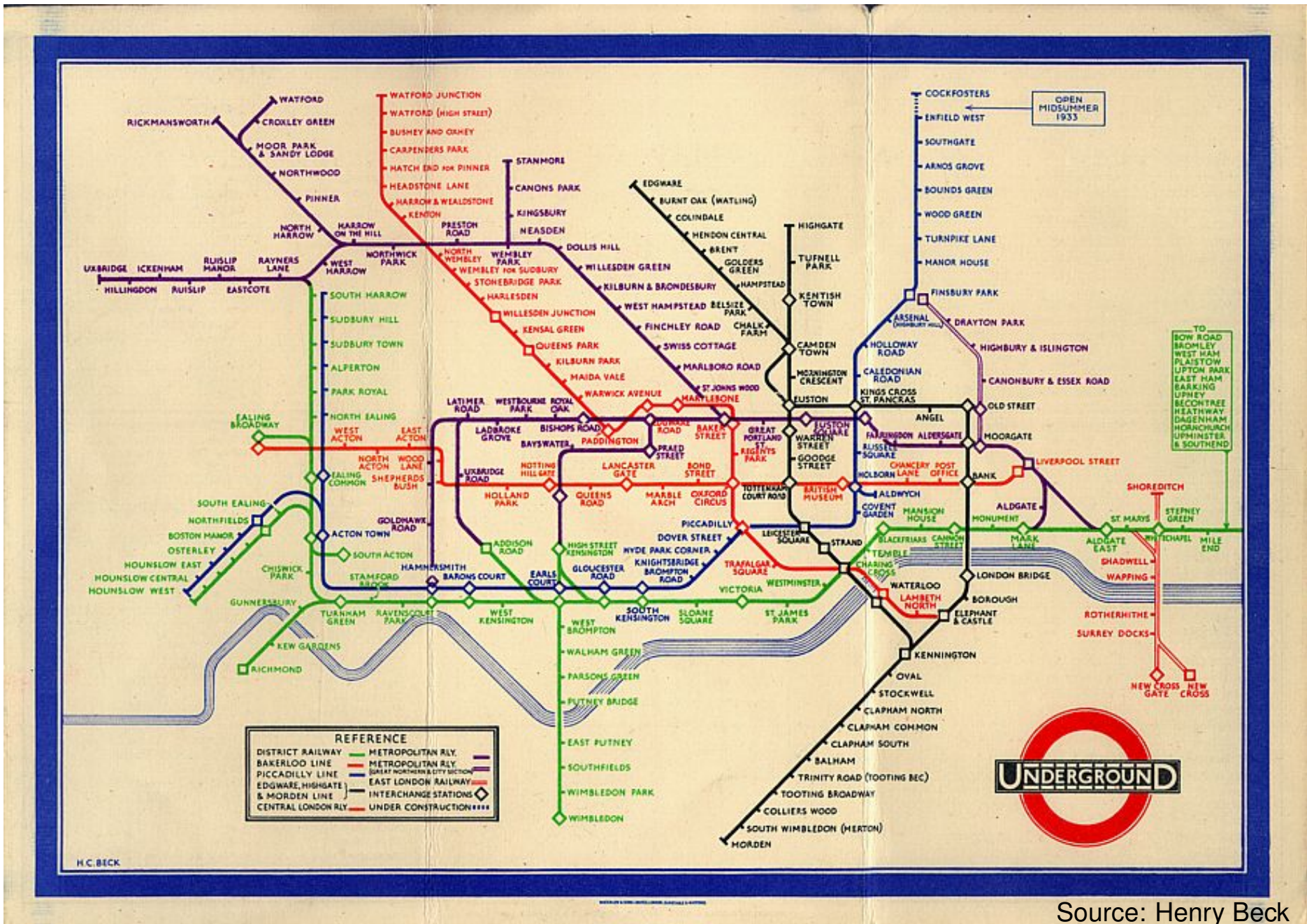
Traffic network – Highways USA



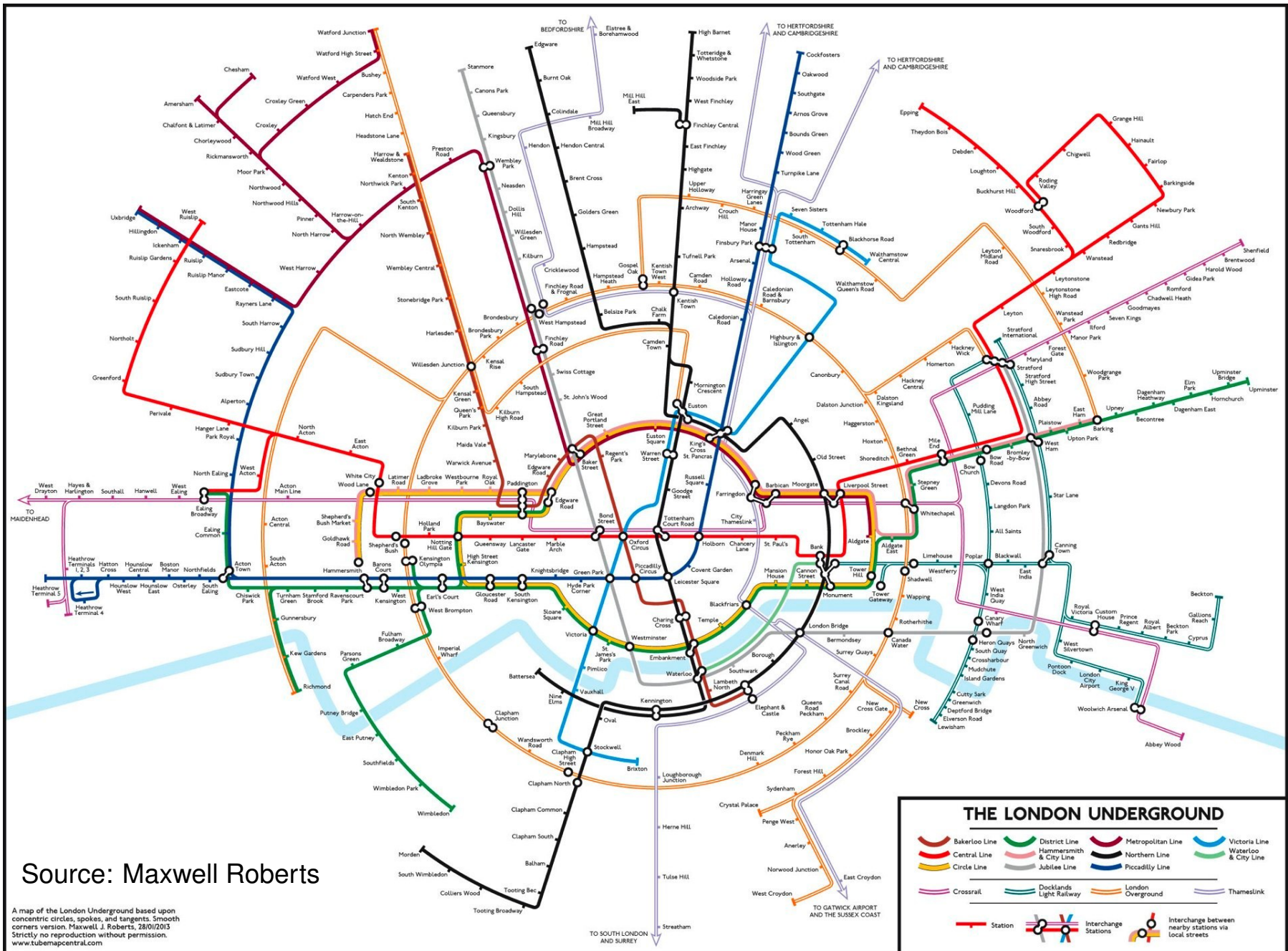
Traffic network – Highways USA



London Tube Map (1933)



Co-centric Tube Map



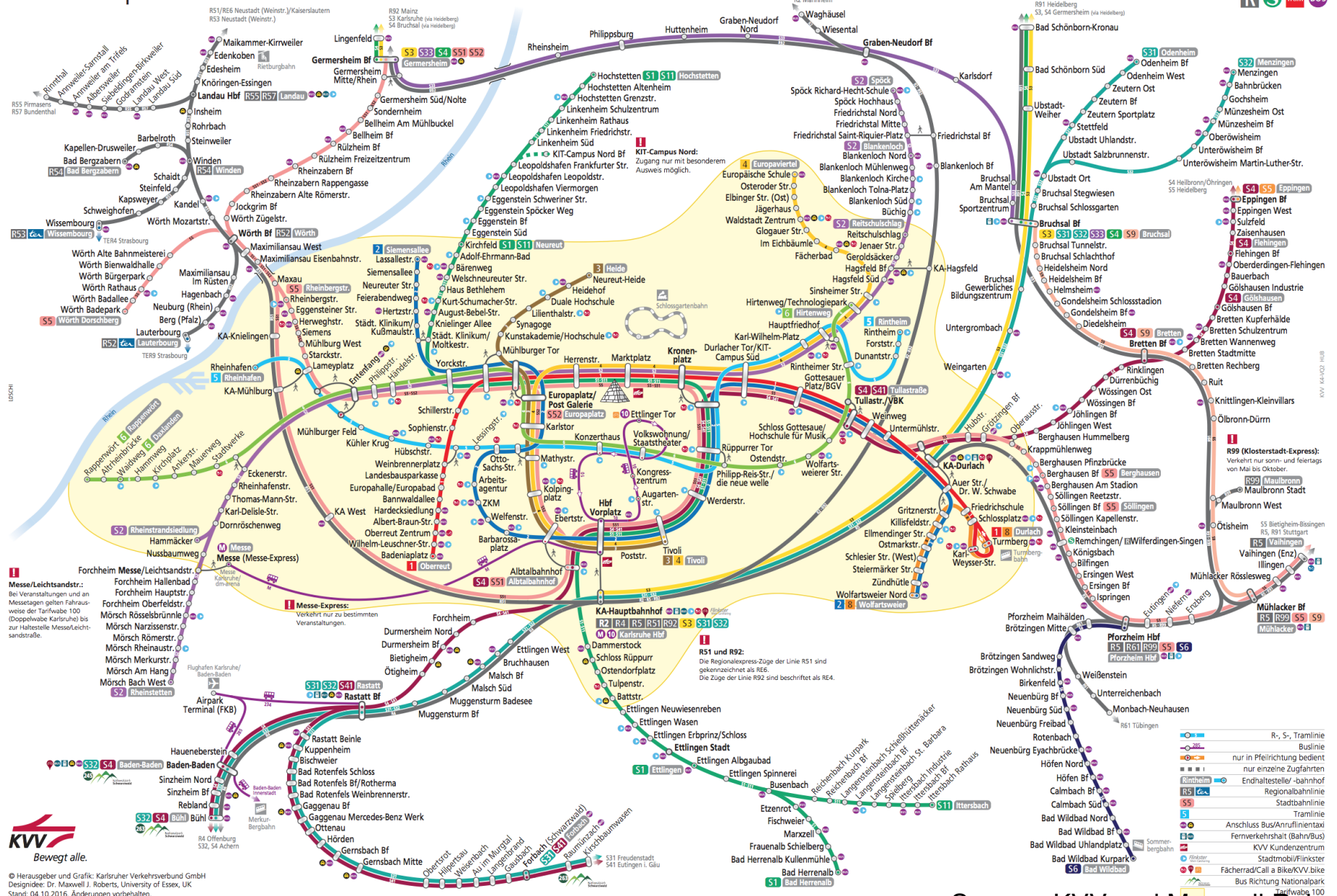
Source: Maxwell Roberts

A map of the London Underground based upon concentric circles, spokes, and tangents. Smooth corners version. Maxwell J. Roberts, 28/01/2013. Strictly no reproduction without permission. www.tubemapcentral.com

Curvilinear S/U-bahn map

Liniennetzplan

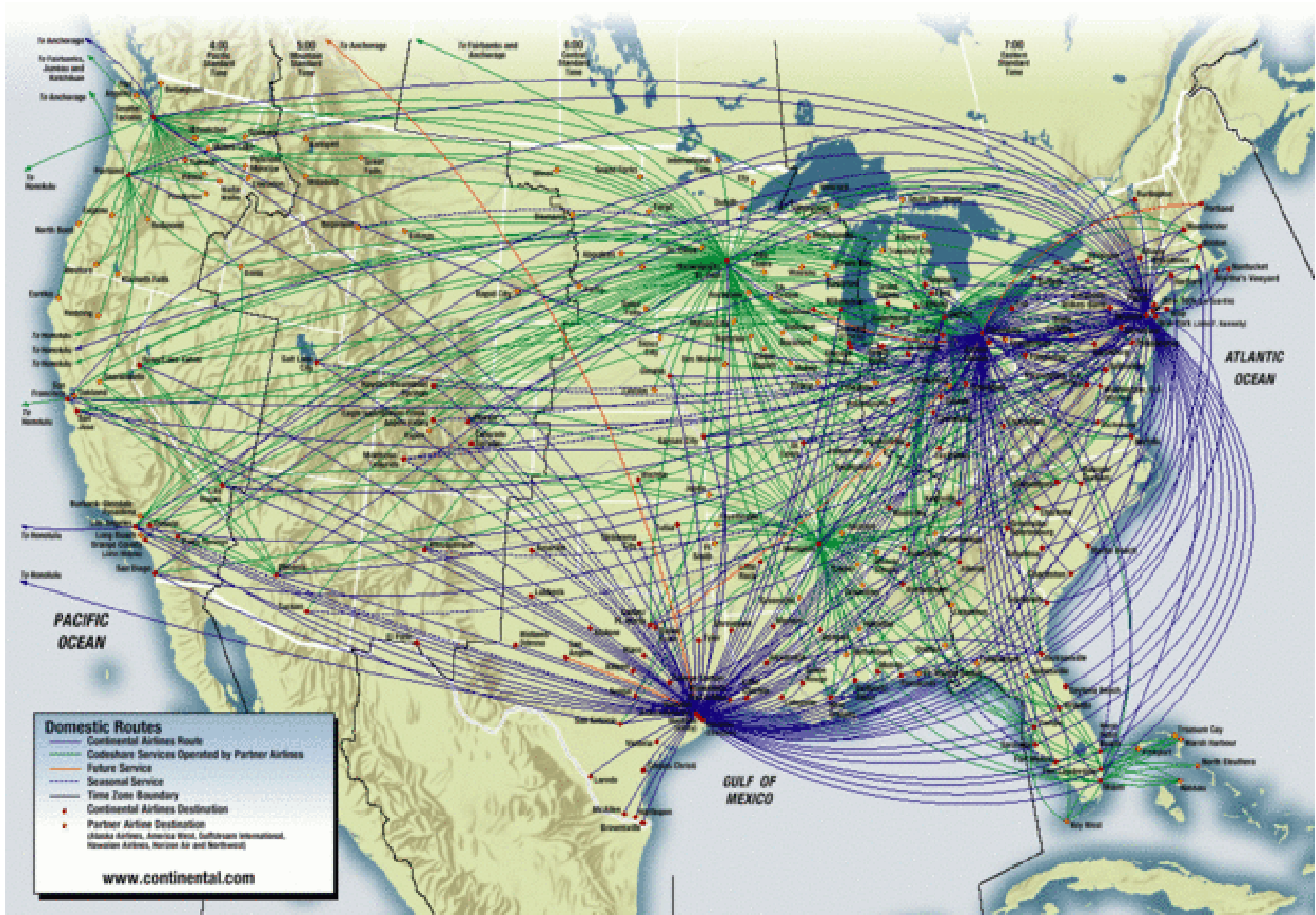
Gültig ab 13. Dezember 2015



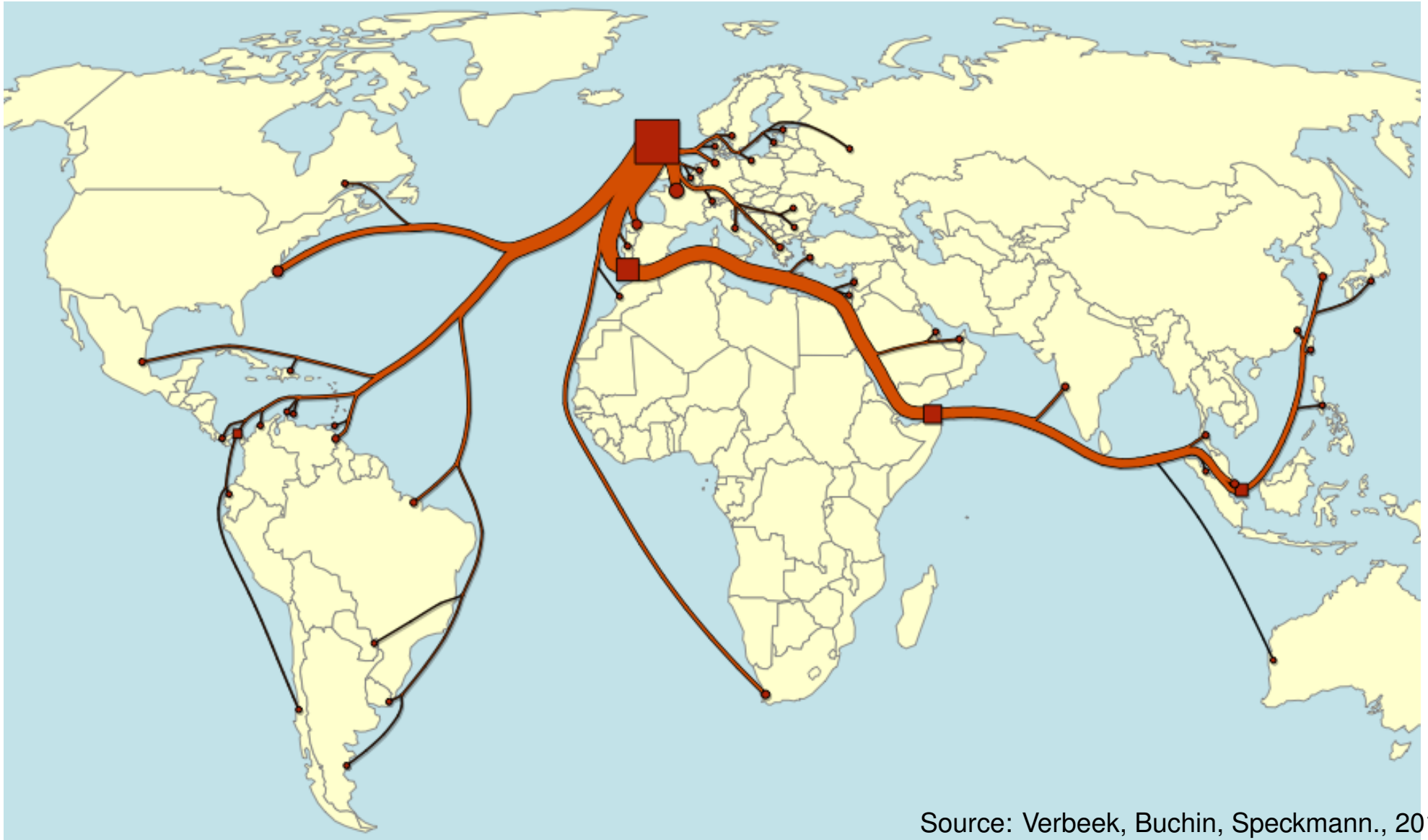
© Herausgeber und Grafik: Karlsruhe Verkehrsverbund GmbH
 Designidee: Dr. Maxwell J. Roberts, University of Essex, UK
 Stand: 04.10.2016, Änderungen vorbehalten.

Source: KVV and Maxwell Roberts

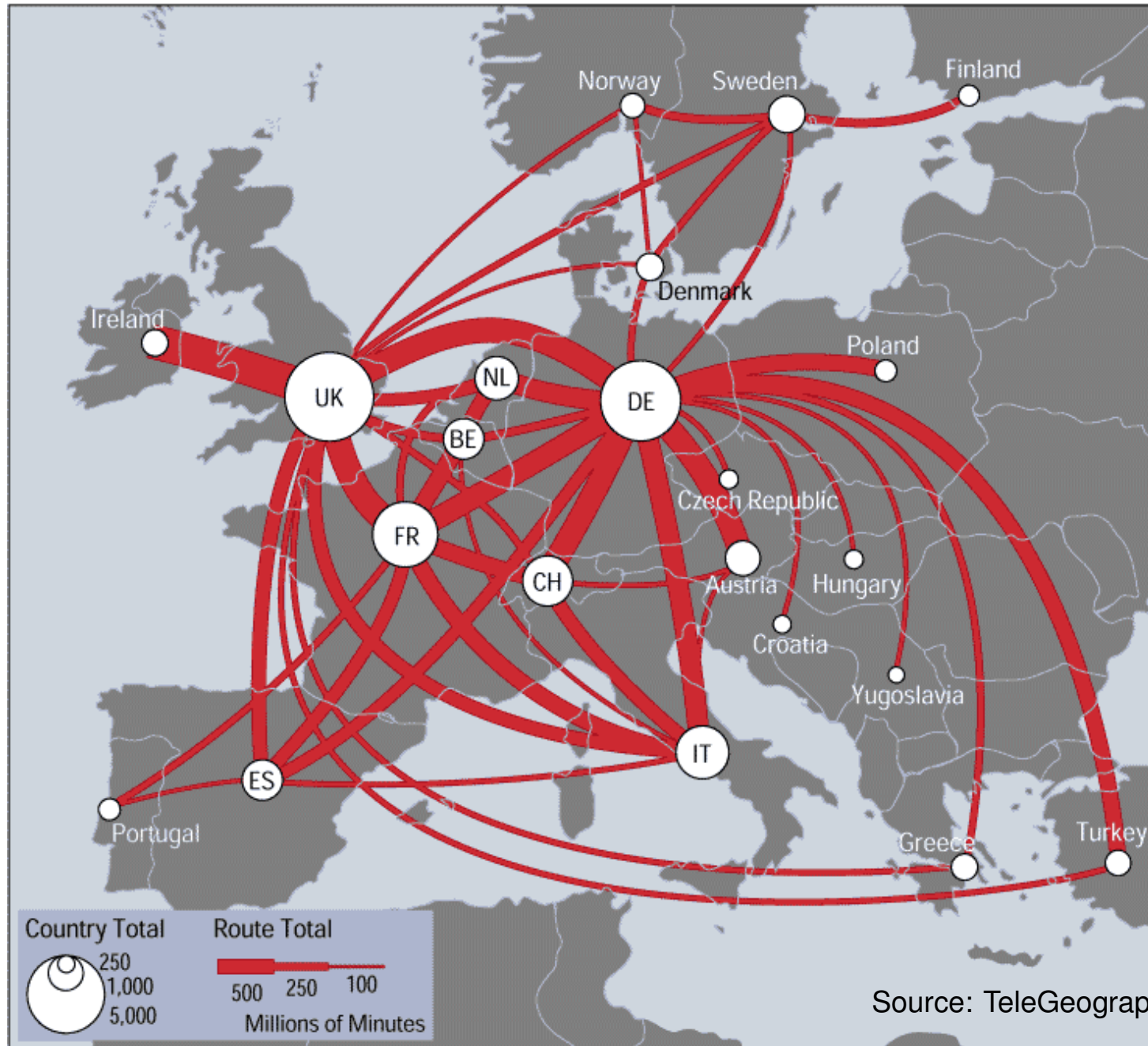
Flight Connections



Flow-Map: Whiskey Export



Telephony Map

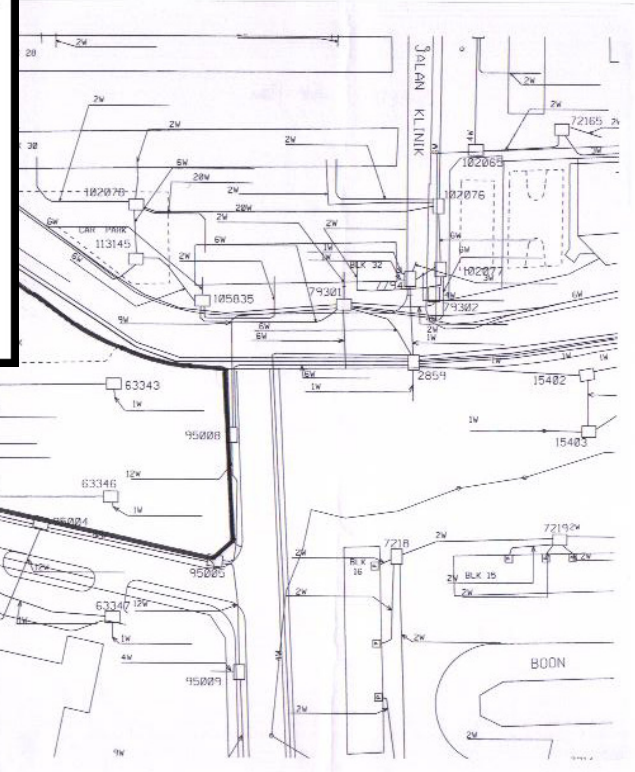
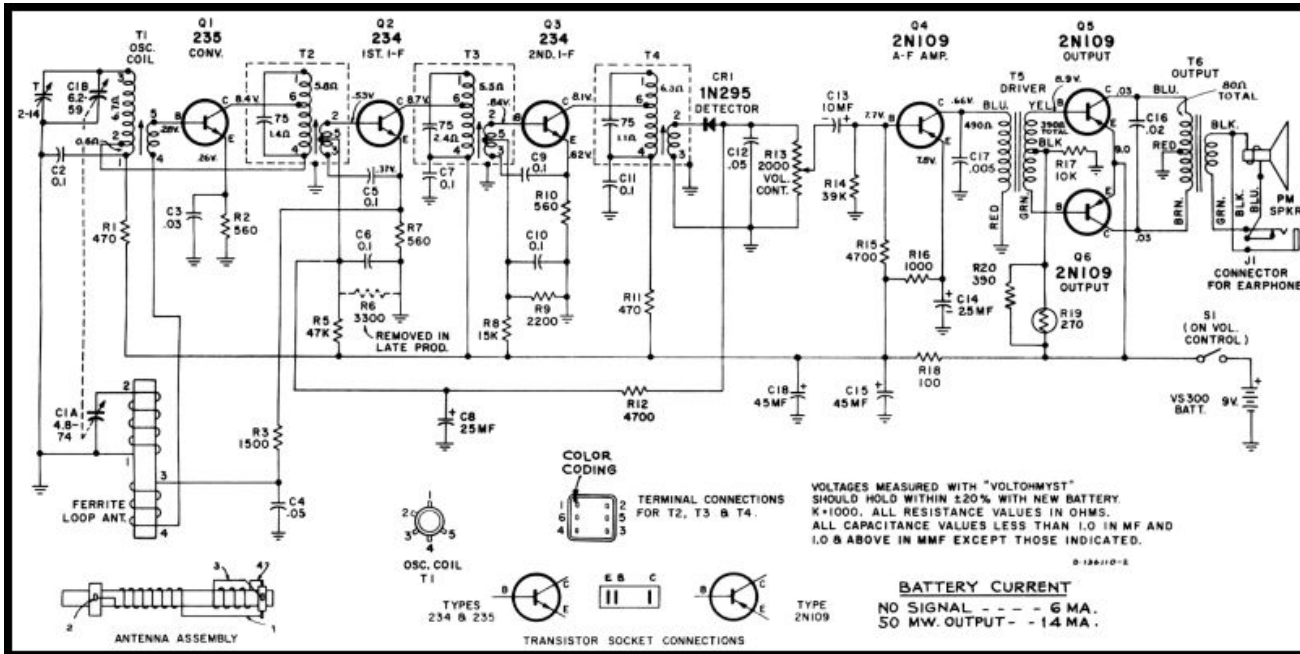


Monitoring of Energy Network

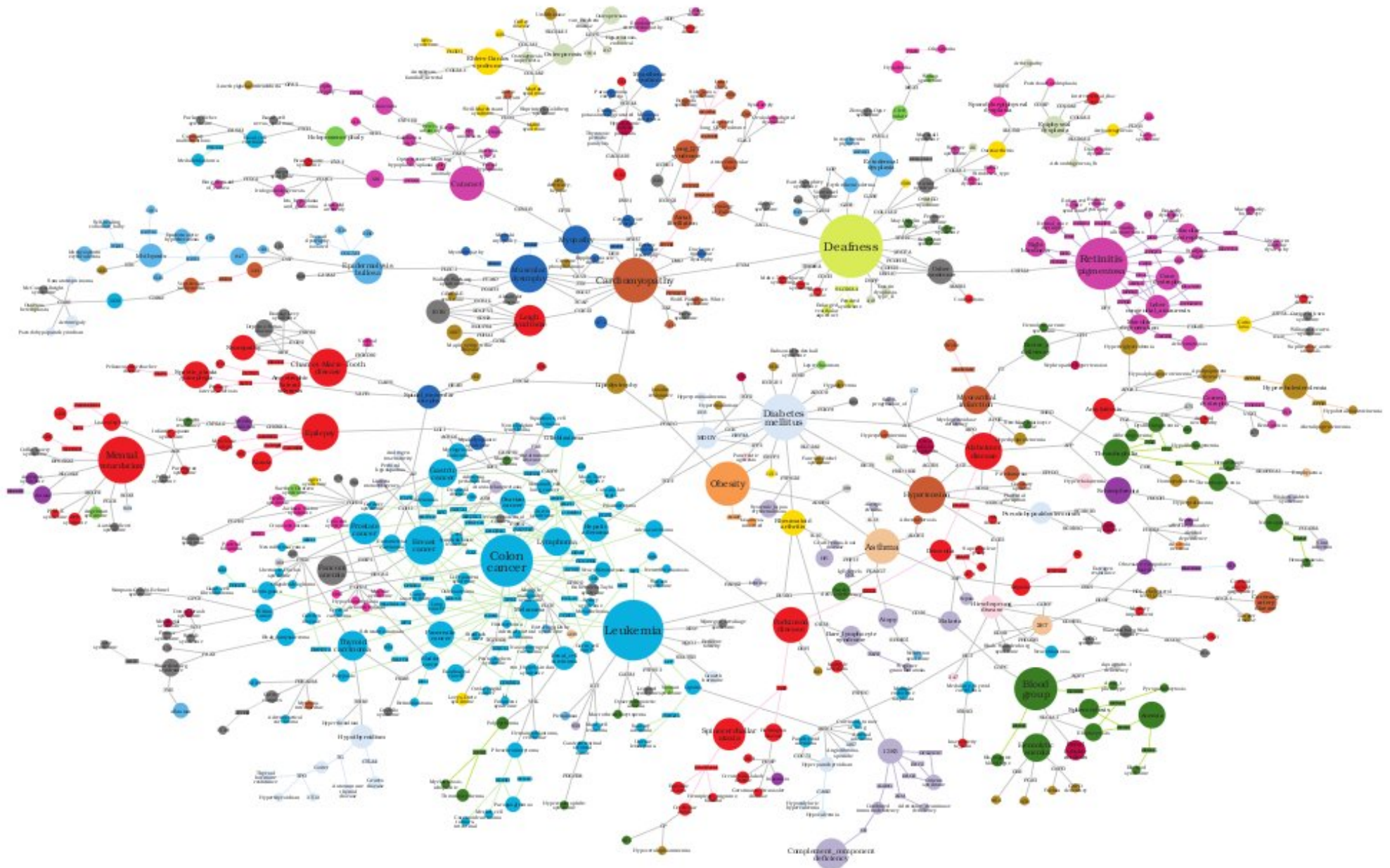


Source: Eir Grid, Ireland

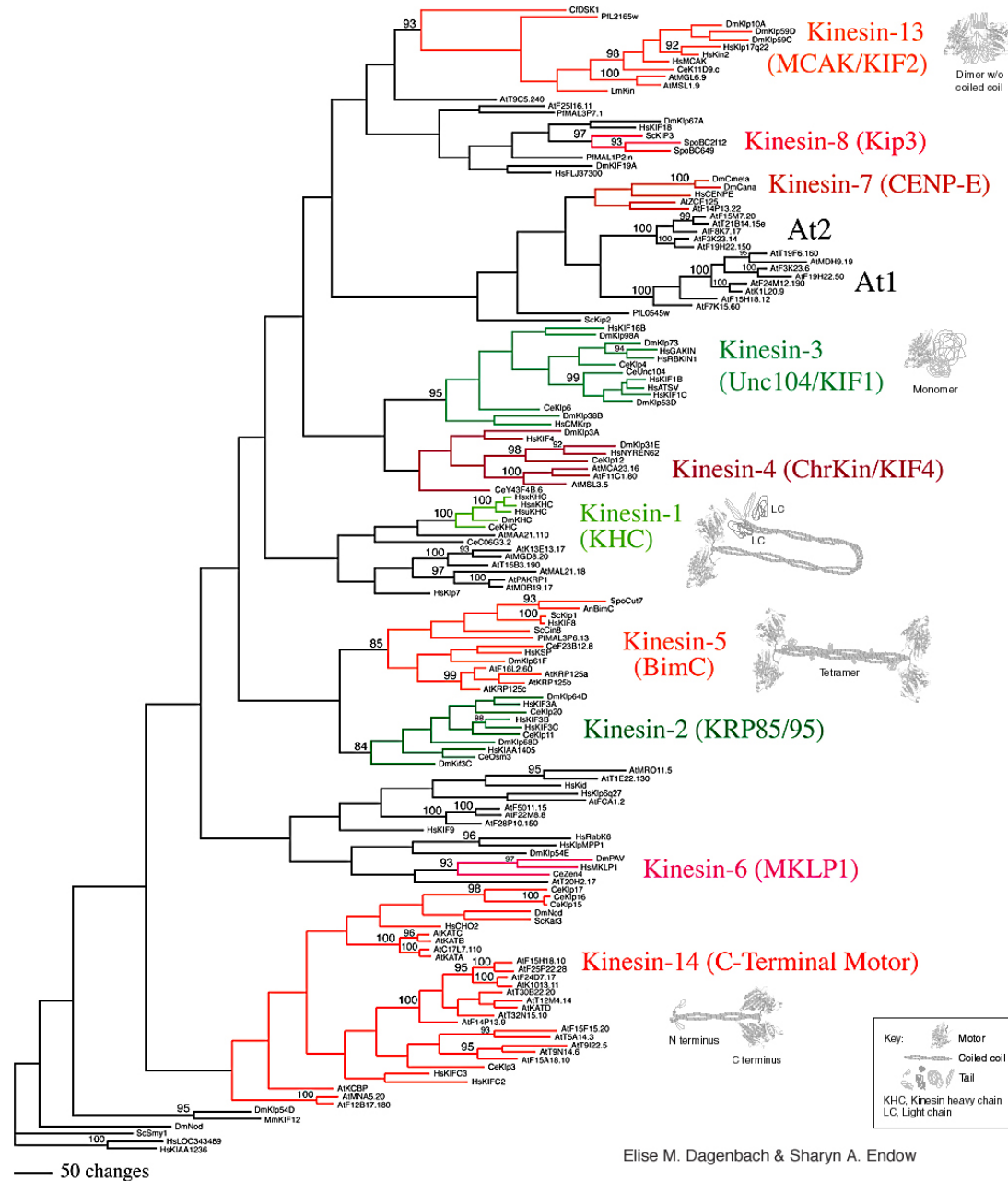
Wiring plan/ Cable plan



Medicine – Diseases

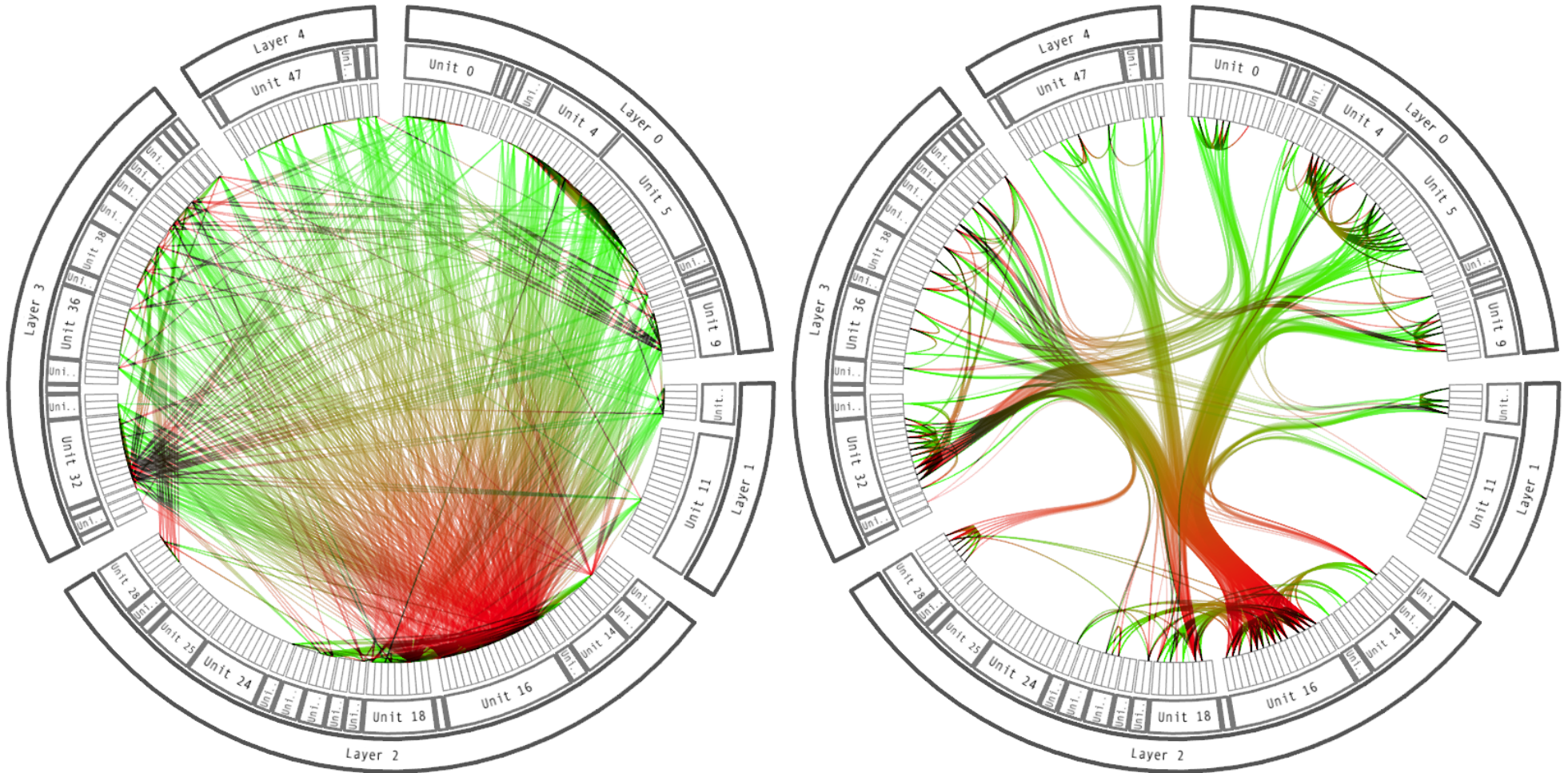


Medicine – phylogenetic Tree



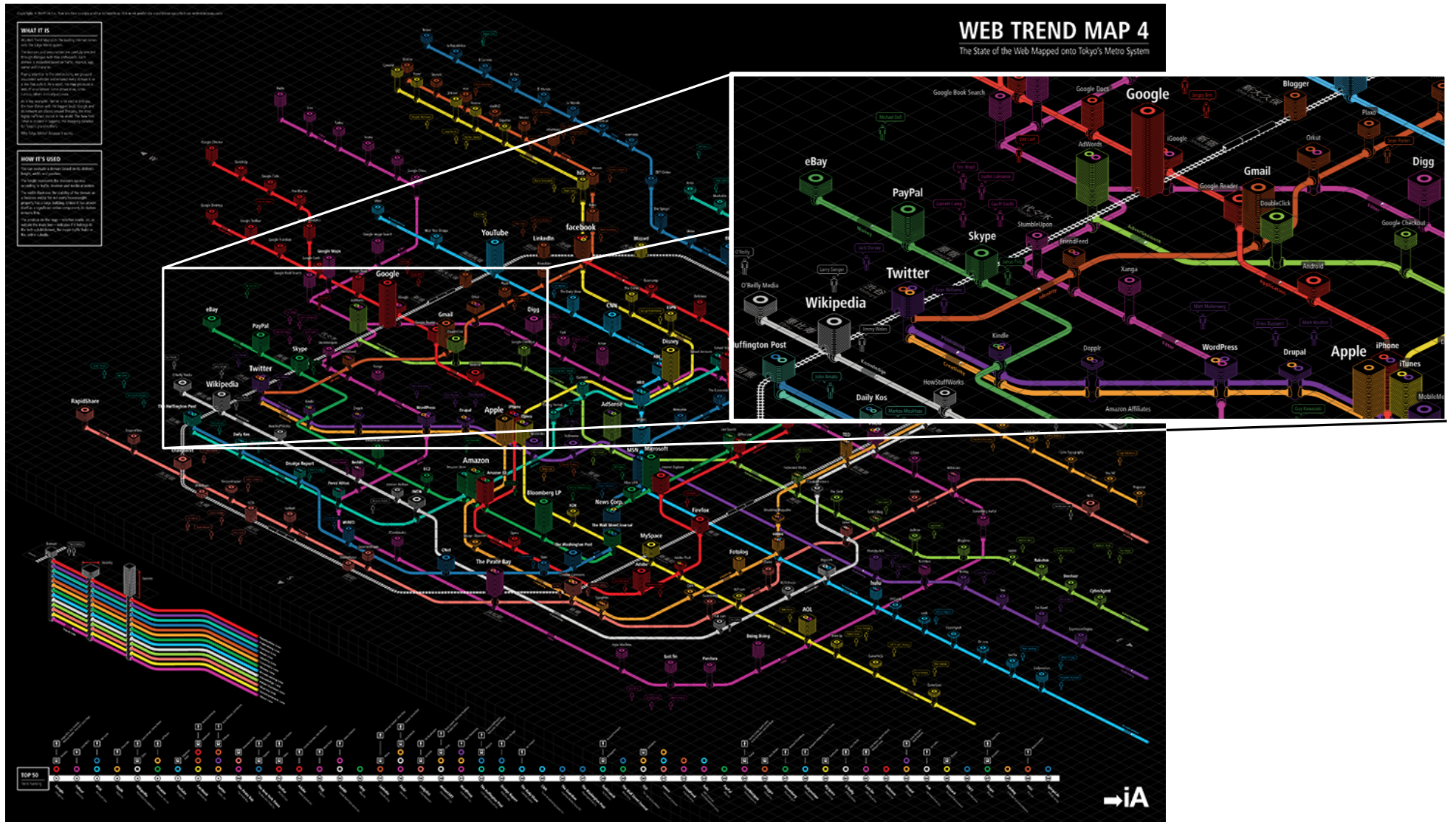
Elise M. Dagenbach & Sharyn A. Endow

Software Call-Graph with edge-bundling



Source: Danny Holten, 2011

Web Trend Map



Source: information Architects, 2009

Alternative Visualizations: Explorer vs Treemap

Name

- ▶ bin
- ▶ include
- ▶ lib
- ▶ libexec
- ▼ local
 - ▶ bin
 - ▼ etc
 - ▶ ImageMagick
 - ▼ include
 - ▶ CGAL
 - ▼ juniper
 - ▼ nc
 - 7.4.6
 - ▼ install
 - fwk_reference_tool
 - installer.common
 - ncinstallhelper
 - NCJarVerify.jar
 - uninstall_nc.sh
 - version

- ▼ lib
- ▼ CGAL
 - ▶ 2.6.2-to-2.8.1
 - CGAL_CheckCXXFileRuns.cmake
 - CGAL_Common.cmake
 - CGAL_CreateSingleSourceCGALProgram.cmake
 - CGAL_FindPackageHandleStandardArgs.cmake
 - CGAL_GeneratorSpecificSettings.cmake
 - CGAL_Locate_CGAL_TAUCS.cmake
 - CGAL_Macros.cmake

Alternative Visualizations: Explorer vs Treemap

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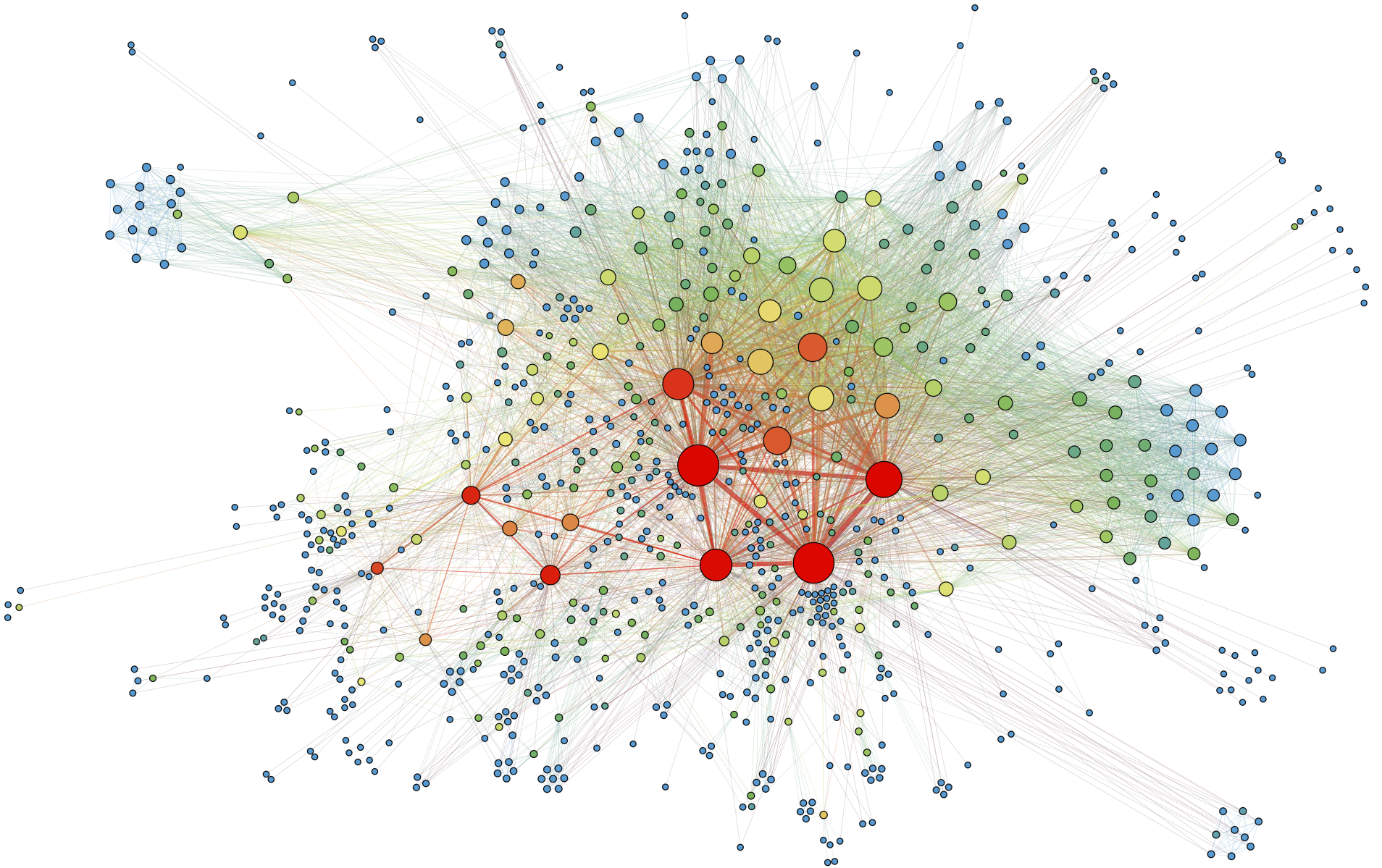
For more: <http://www.visualcomplexity.com/>

Graph and its Representation

What is a Network/Graph?

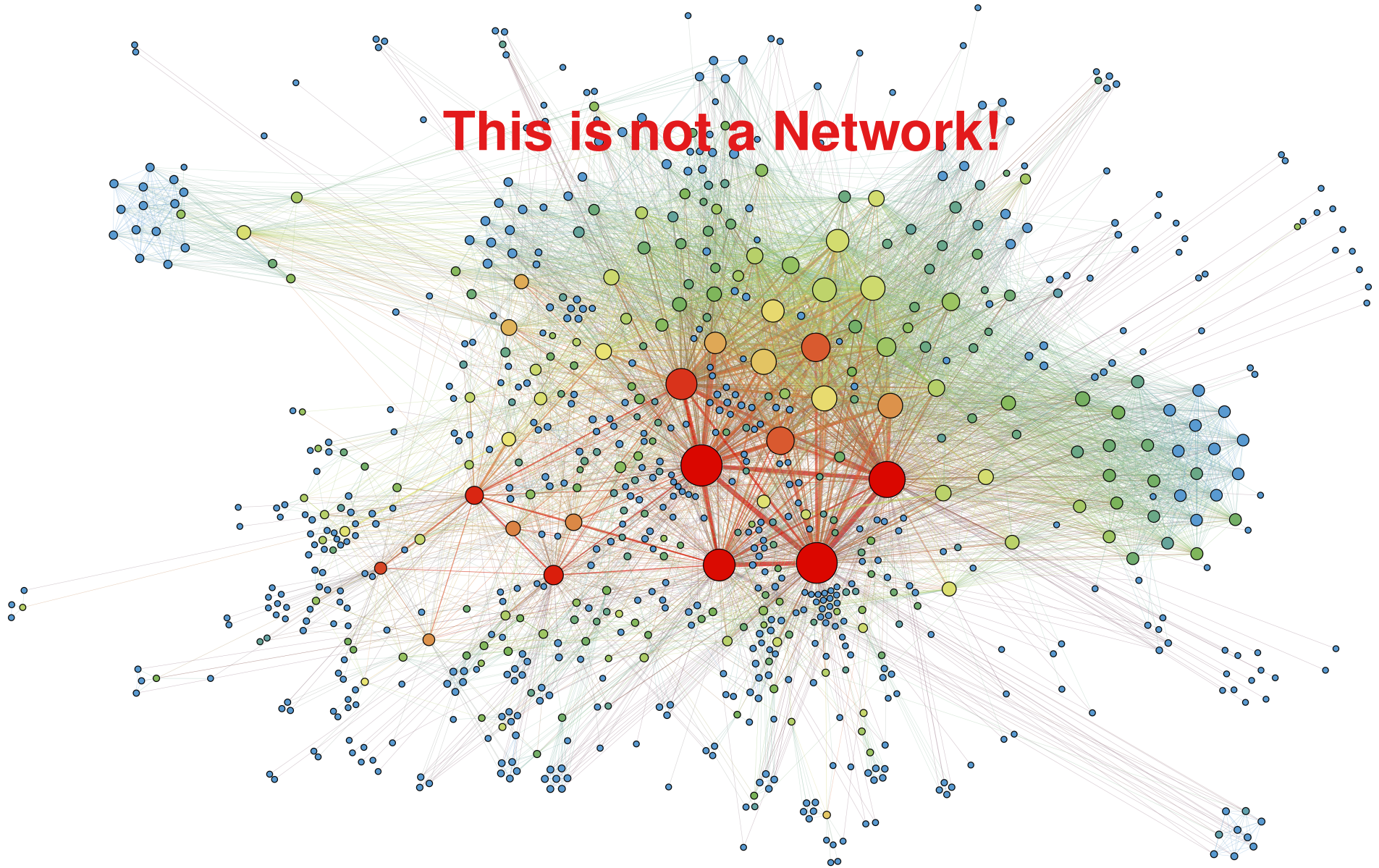
Graph and its Representation

What is a Network/Graph?



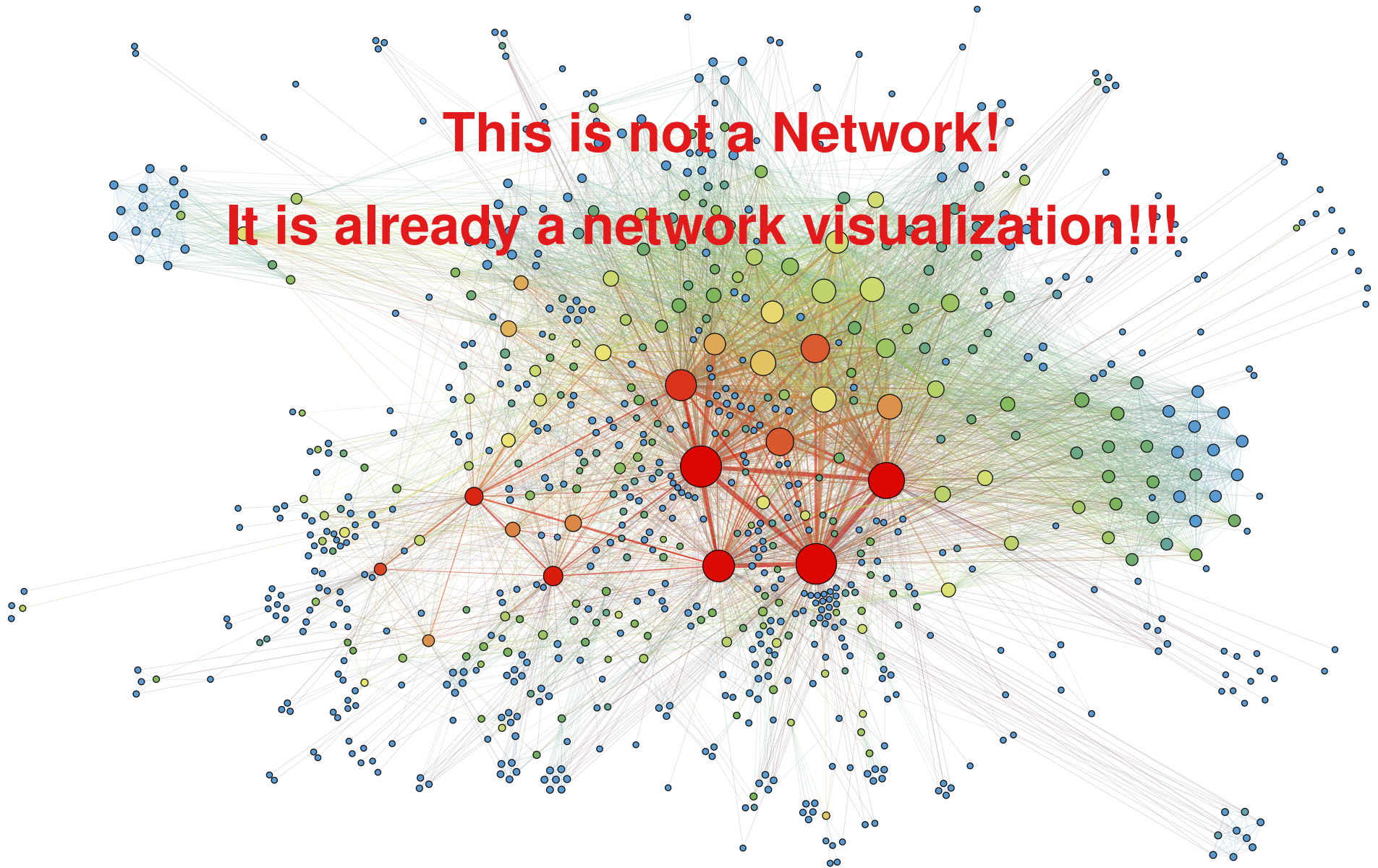
Graph and its Representation

What is a Network/Graph?



Graph and its Representation

What is a Network/Graph?



Graph and its Representation

What is a Network/Graph?

Tuple $G = (V, E)$

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

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

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

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Representations?

Graph and its Representation

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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

$V_1 : V_2, V_8$

$V_2 : V_1, V_3$

$V_3 : V_2, V_5, V_9, V_{10}$

$V_4 : V_5, V_6, V_9$

$V_5 : V_3, V_4, V_8$

$V_6 : V_4, V_8, V_9$

$V_7 : V_8, V_9$

$V_8 : V_1, V_5, V_6, V_7, V_9, V_{10}$

$V_9 : V_3, V_4, V_6, V_7, V_8, V_{10}$

$V_{10} : V_3, V_8, V_9$

Graph and its Representation

What is a Network/Graph?

Tuple $G = (V, E)$

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

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

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

Representations?

Set representation

Adjacency list

Adjacency matrix

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

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Representations?

We will use terms Graph and Network interchangeably, but commonly Network assumes a more complex data set, attributes on nodes and links, clusters, etc.

Let's draw some graphs



Work with your neighbour or in groups of three

15 min

- go to Teams/General/Class Materials/Graphs to draw
- graphs in form of adjacency matrix/list
- Use yEd:
<https://www.yworks.com/products/yed/download>
- draw one or more graphs as nice and as readable as possible
- export to PNG/PDF and upload to Teams/Network Visualization/Drawn Graphs
- keep the file name, add name of the team

We will show and discuss the results afterwards

Layout Problem

Graph visualization problem

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

find: **good** drawing Γ of G

- $\Gamma : V \rightarrow \mathbb{R}^2$, nodes $v \rightarrow$ point $\Gamma(v)$
- $\Gamma : E \rightarrow$ curves in \mathbb{R}^2 , edge $\{u, v\} \rightarrow$ 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

Graph visualization problem

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

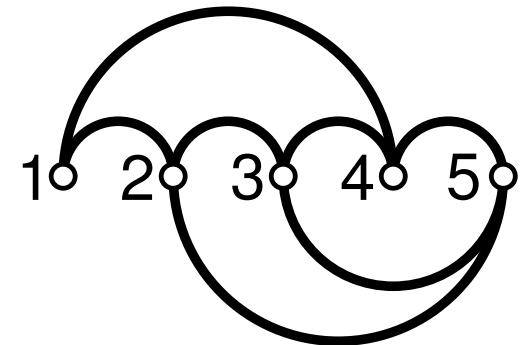
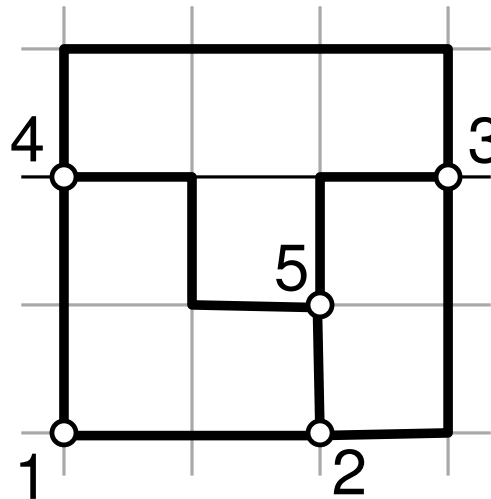
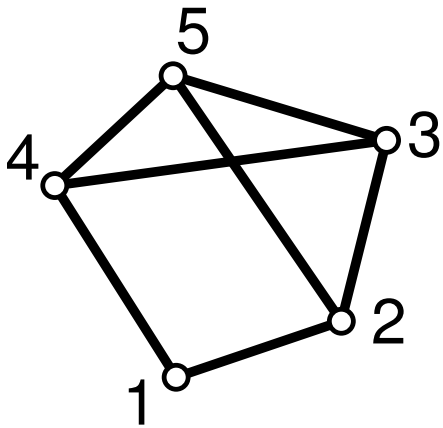
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Layout Problem

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

- straight-line edges
- orthogonal edges (polylines with 90° bends)
- drawing on a grid
- crossing-free

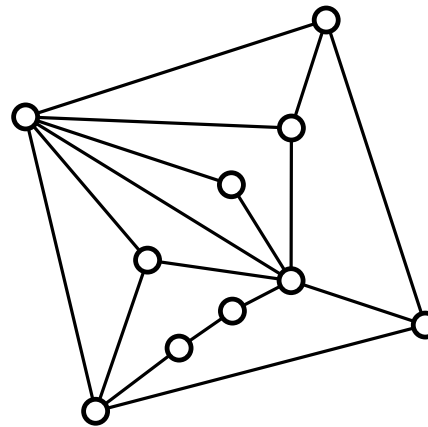


Layout Problem

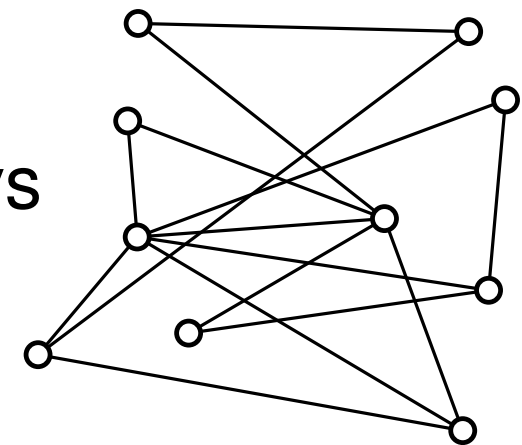
1) **Drawing conventions** : drawing rules that stem from applications

2) **Quality metrics** : criteria to be optimized that make drawing more readable*

- number of crossing
- number of bends
- area/length
- crossing resolution
- stress of layout



vs



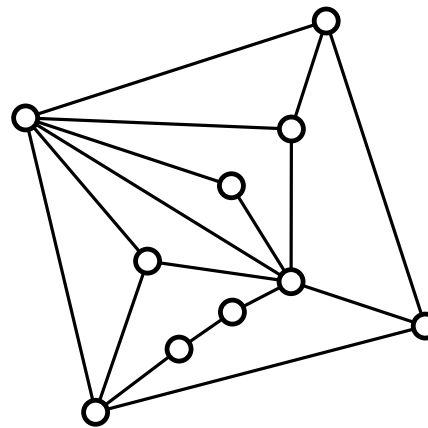
* insight from cognitive psychology

Layout Problem

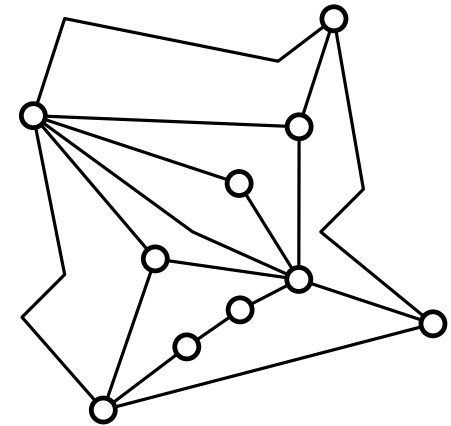
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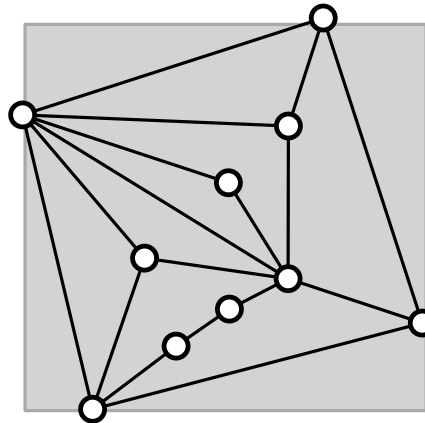
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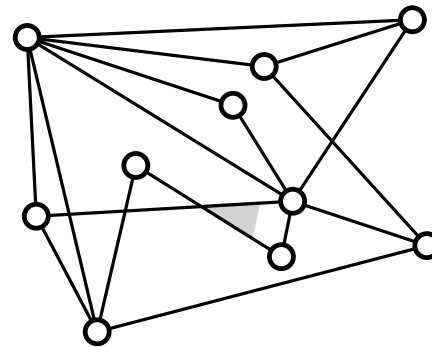
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the smallest angle formed by two crossing edges

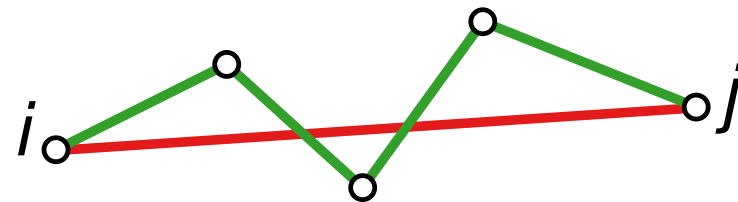
* insight from cognitive psychology

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$$\sum_{i < j} \frac{1}{d_{ij}^\alpha} (||X_i - X_j|| - d_{ij})^2$$

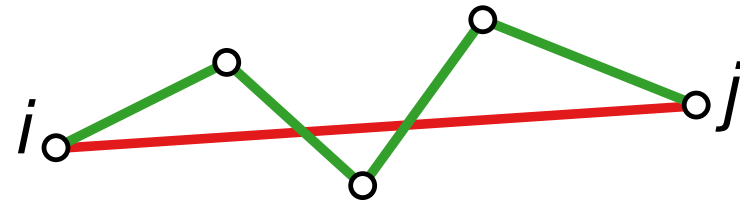
* insight from cognitive psychology

Layout Problem

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- stress of layout



$$\sum_{i < j} \frac{1}{d_{ij}^\alpha} (\| X_i - X_j \| - d_{ij})^2$$

3) **Partial constraints** : rules to be applied on a part of the drawing

★ insight from cognitive psychology

Layout Problem – Second Attempt

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

Layout Problem – Second Attempt

Graph visualization problem

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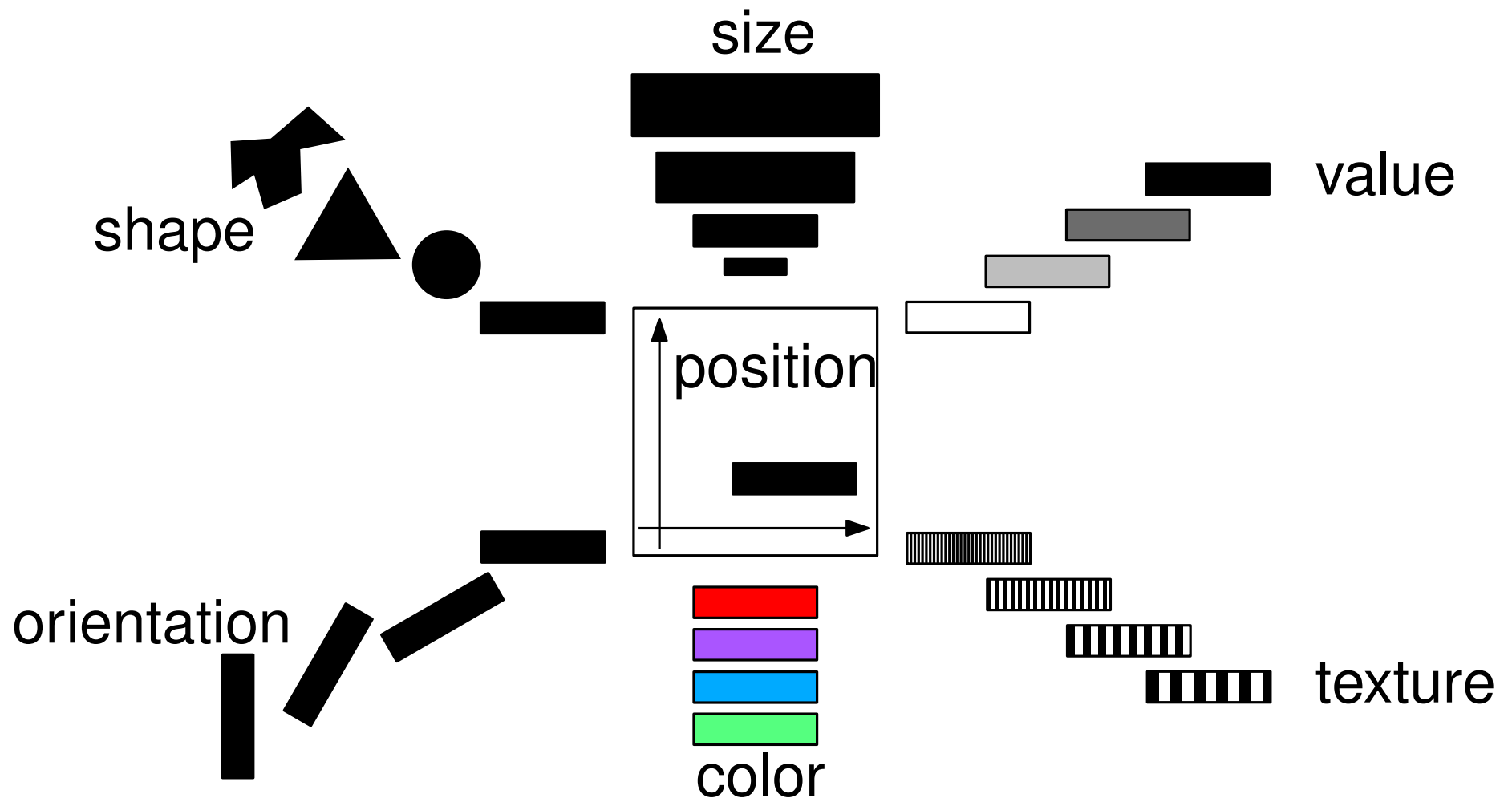
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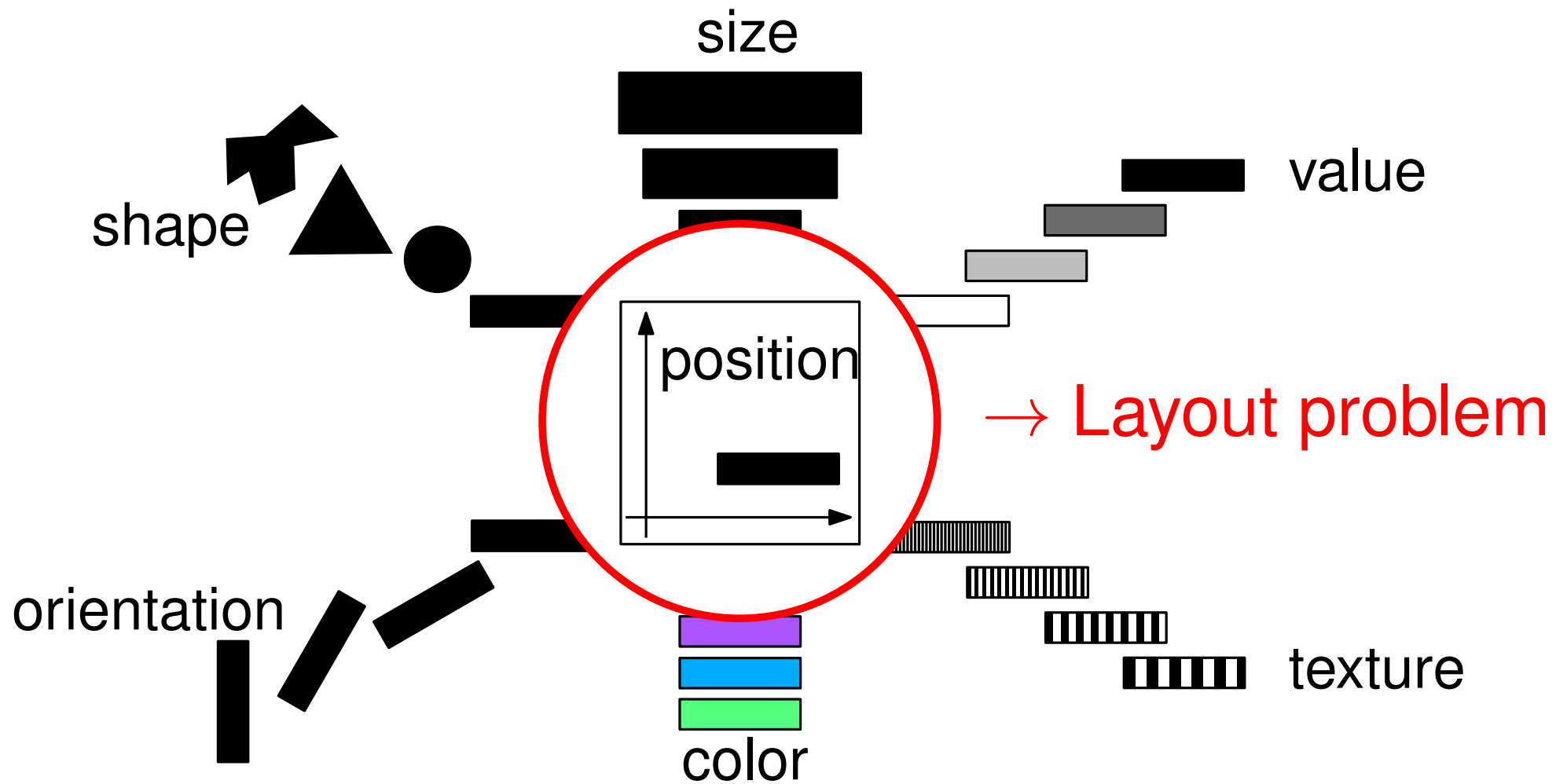
→ often lead to NP-hard optimization problems!

→ often several competing criteria: small area and number of crossings

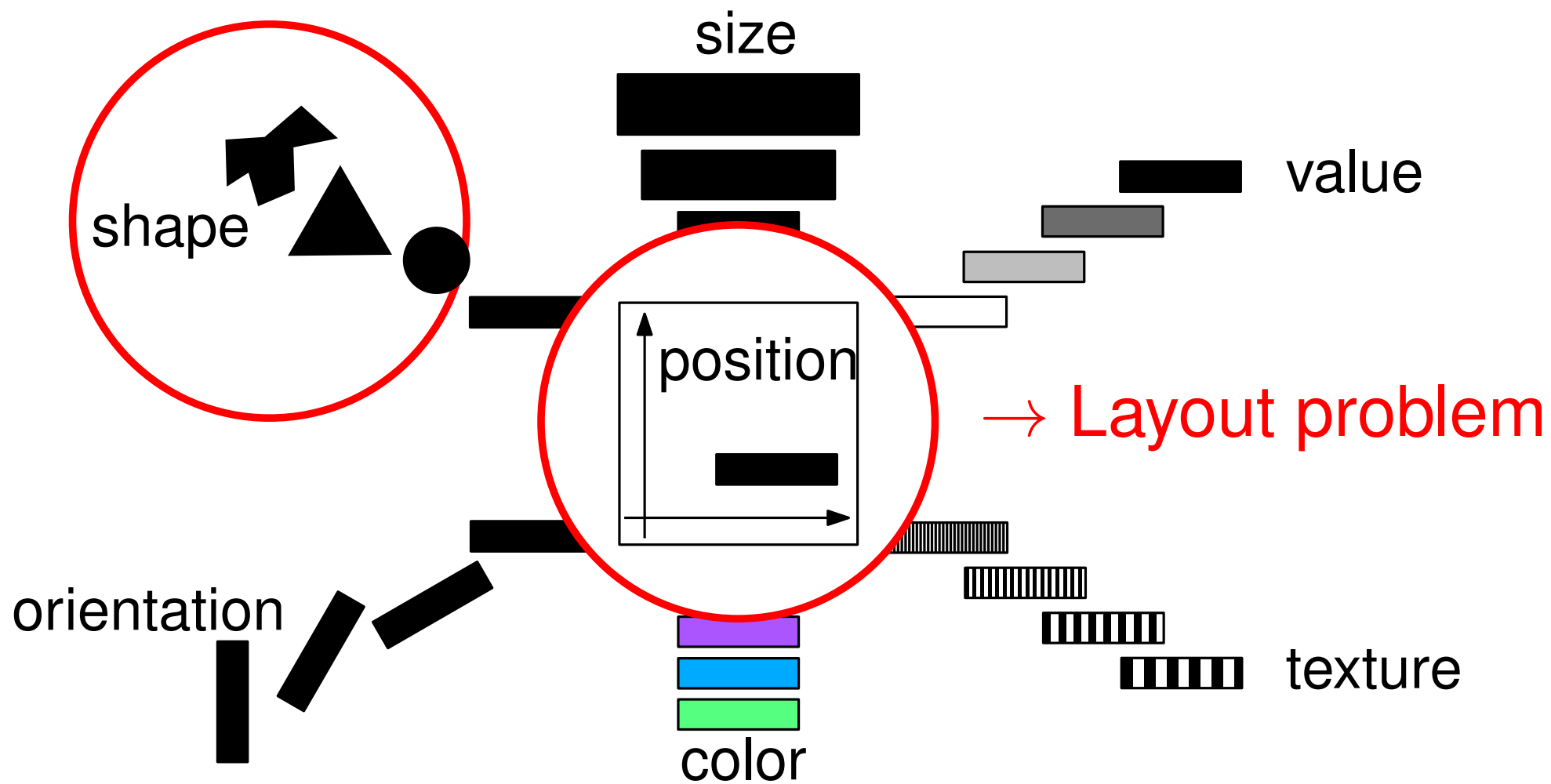
Visual Variables according to Bertin (1967)



Visual Variables according to Bertin (1967)



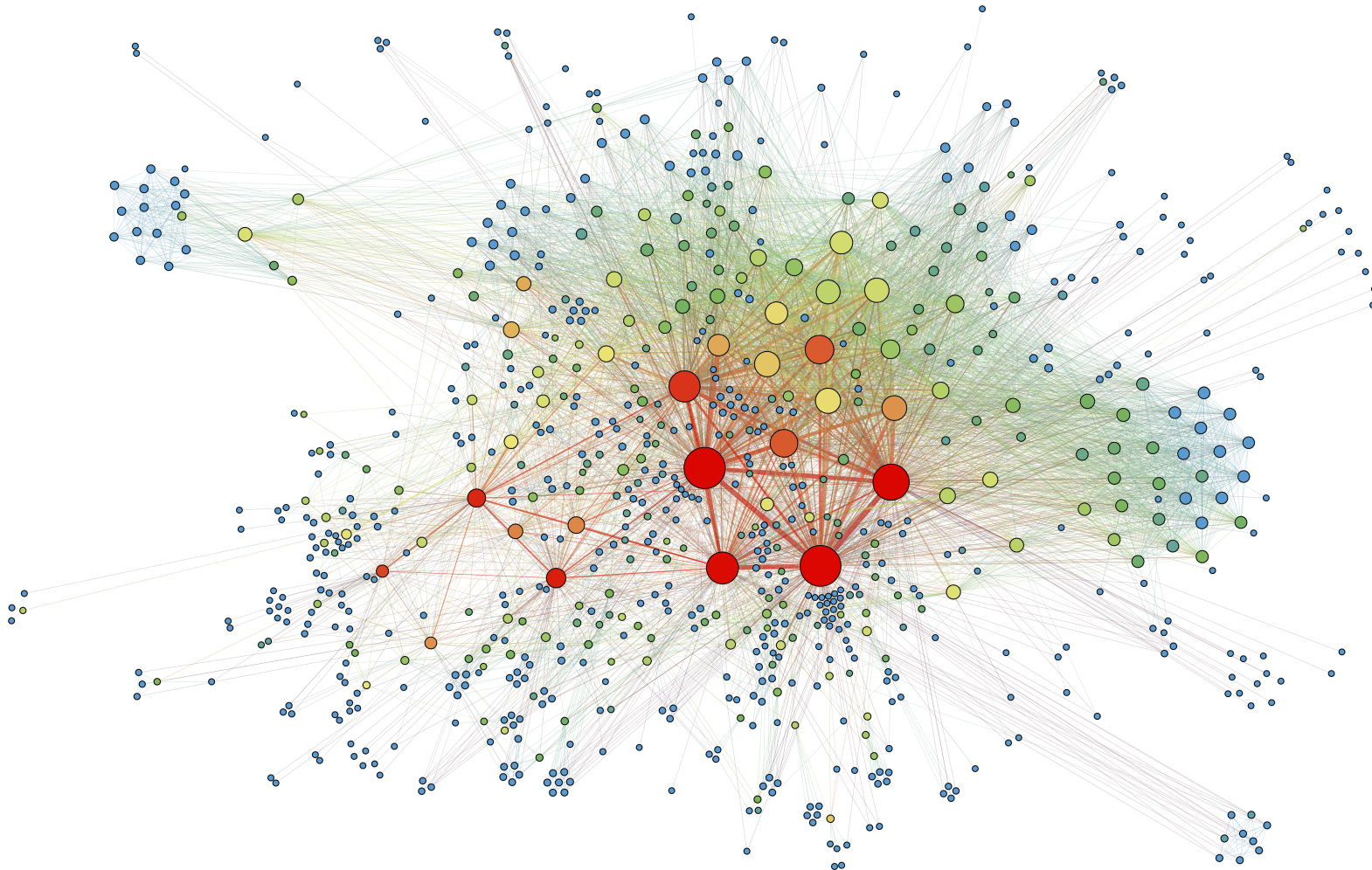
Visual Variables according to Bertin (1967)



Evaluation of Network Visualization

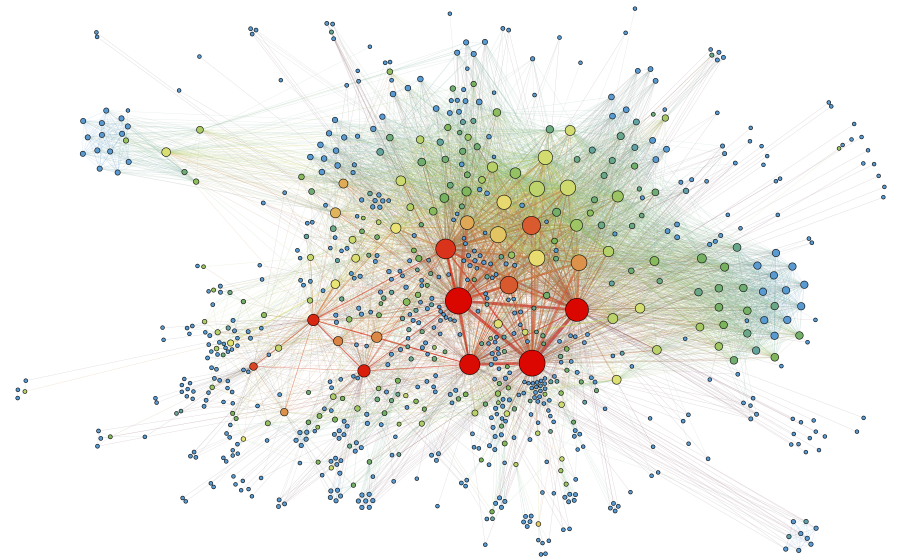


Question: How can we evaluate quality of a network visualization?



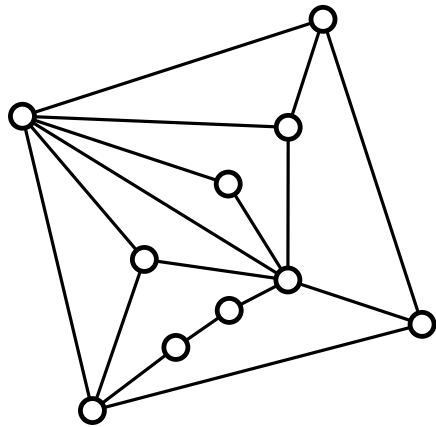
Evaluation of Network Visualization

Automatic methods – > use quality metrics, quantitative evaluation

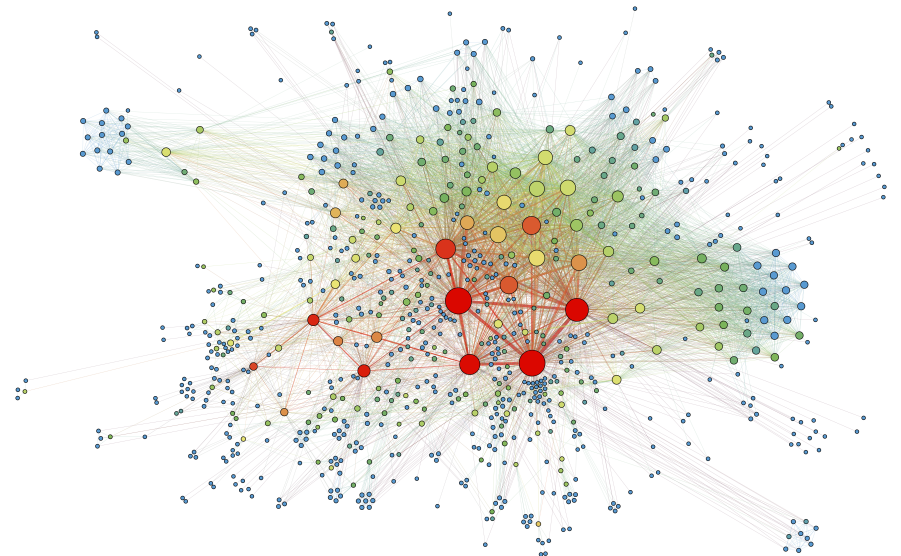
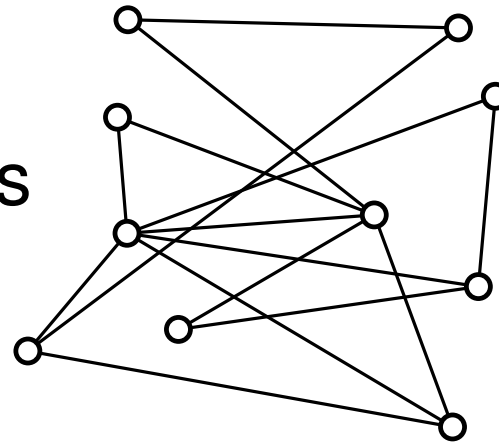


Evaluation of Network Visualization

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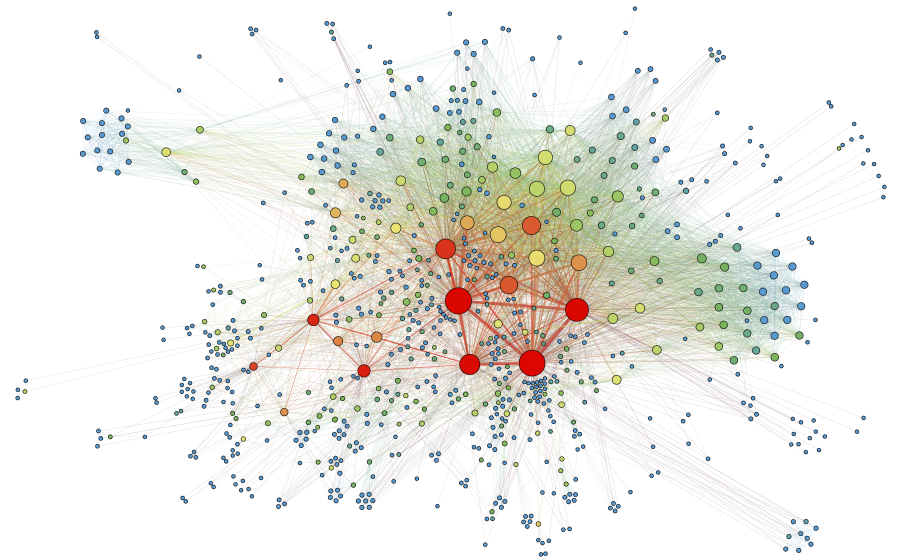
vs



Evaluation of Network Visualization

Automatic methods – > use quality metrics, quantitative evaluation

User studies – > both qualitative & quantitative evaluation

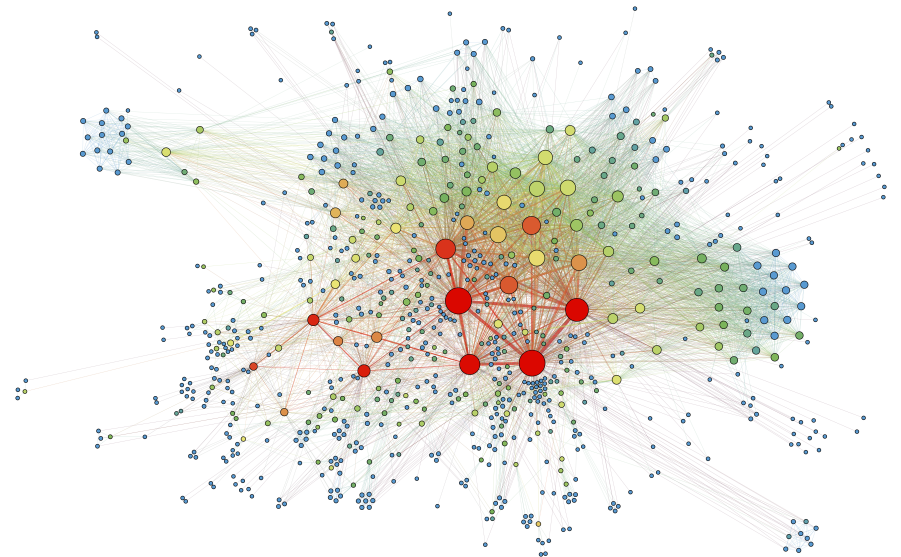


Evaluation of Network Visualization

Automatic methods – > use quality metrics, quantitative evaluation

User studies – > both qualitative & quantitative evaluation

Qualitative User Evaluation – > e.g. observe user interacting with a net.vis. and draw conclusion from this



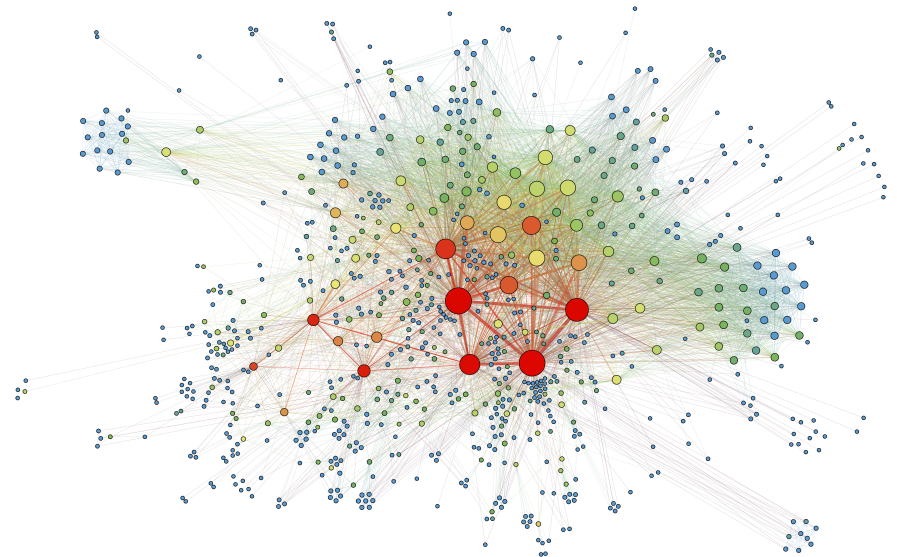
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Quantitative User Evaluation – > Tasks, subjective preference



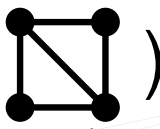
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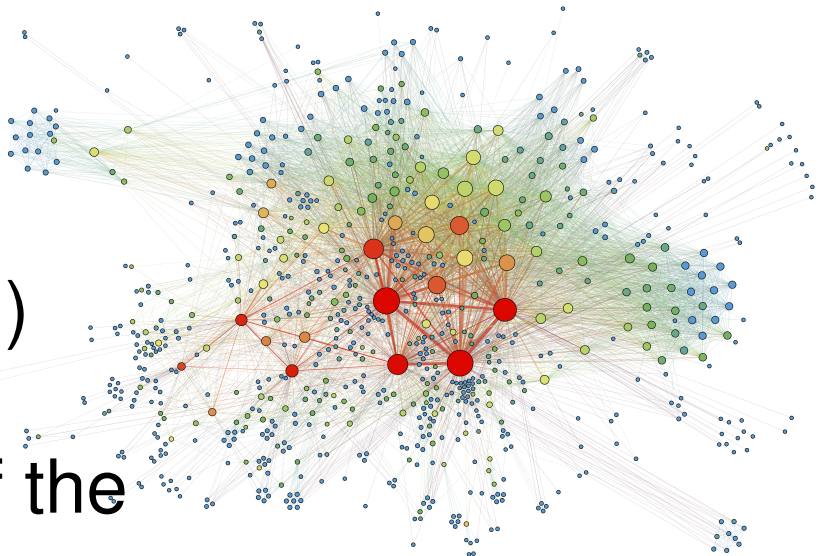
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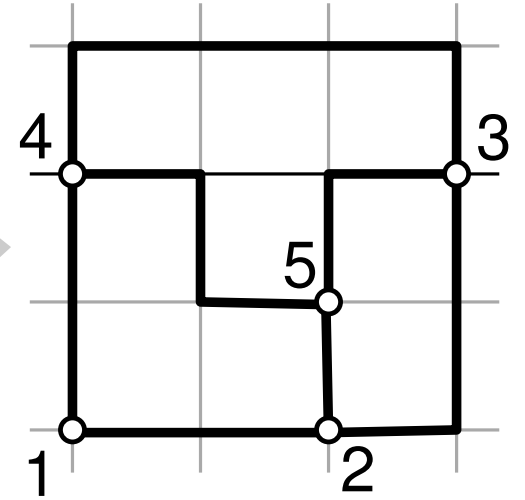
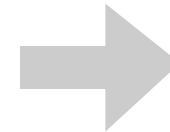
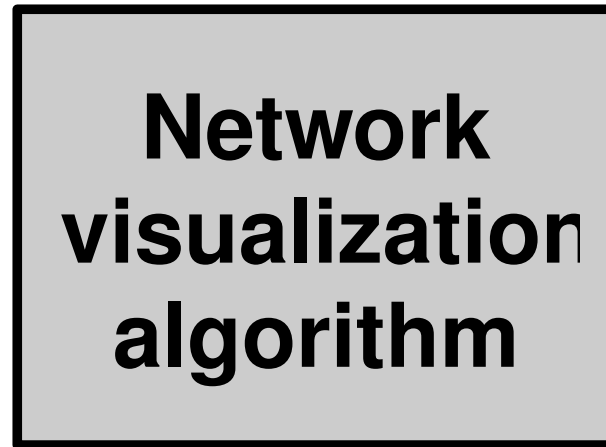
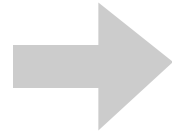
Quantitative User Evaluation – > Tasks, subjective preference

- What is the length of the shortest path between nodes A and B?
- What is the degree of a node A (number of incident edges)?
- Does certain structure (say ) appears as a subgraph?
- Subjective preference: which of the two layouts you prefer?



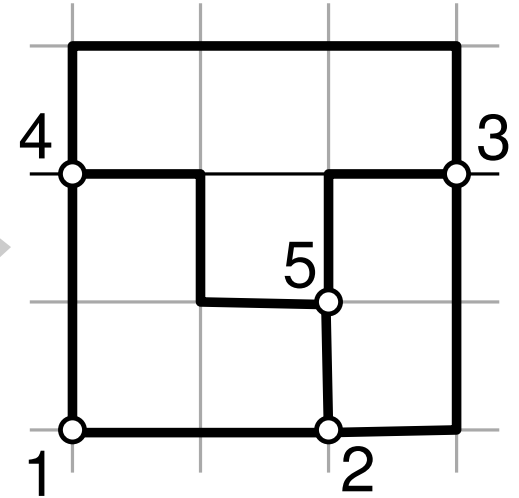
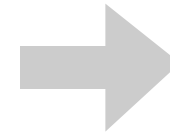
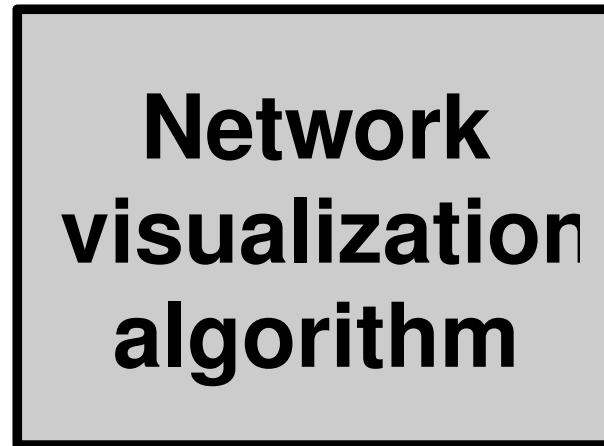
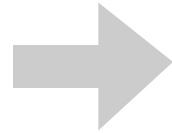
Types of Algorithms

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



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Quality metrics, drawing conventions
and constraints



Let's build the mental map: What types
of algorithms have you heard about?

Computational Complexity



How can we investigate how efficient is an algorithm?

Computational Complexity



How can we investigate how efficient is an algorithm?

Common measures: the quality of the layout and the running time

Computational Complexity



How can we investigate how efficient is an algorithm?

Common measures: the quality of the layout and the running time
Measure time running the algorithms for multiple inputs, compute e.g. average

Computational Complexity



How can we investigate how efficient is an algorithm?

Common measures: the quality of the layout and the running time
Measure time running the algorithms for multiple inputs, compute e.g. average
Or/and compute the worst-case computational complexity of the algorithm

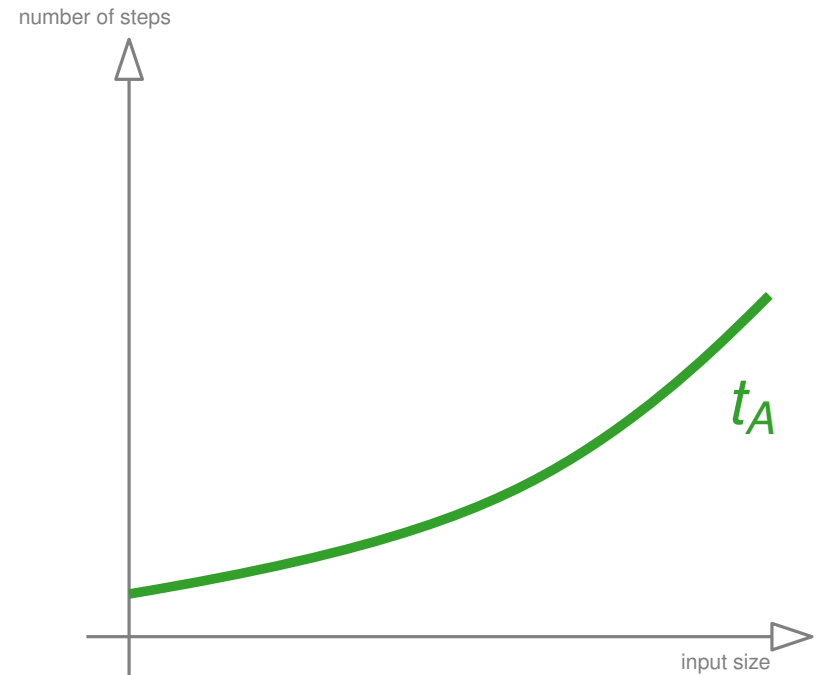
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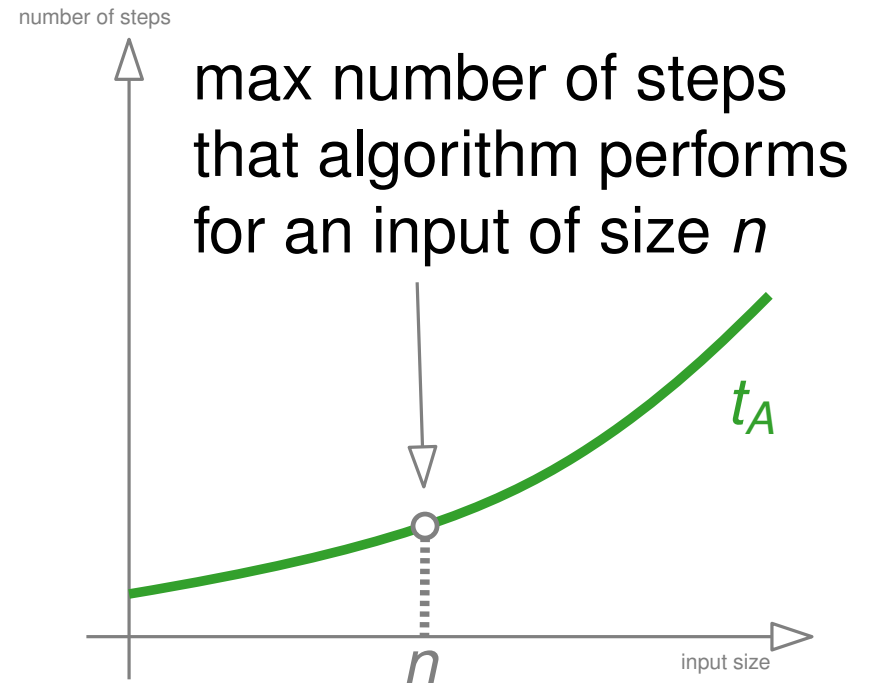
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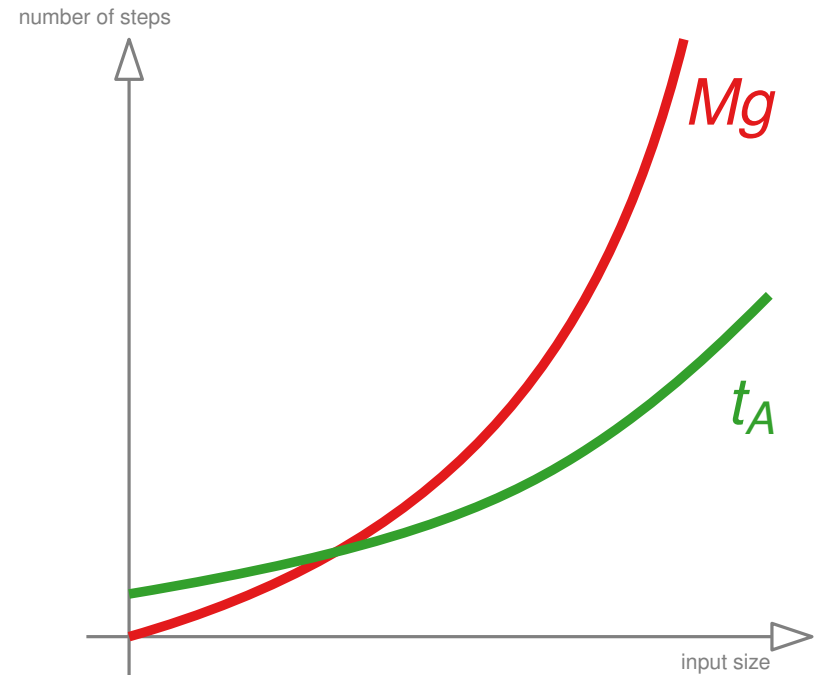
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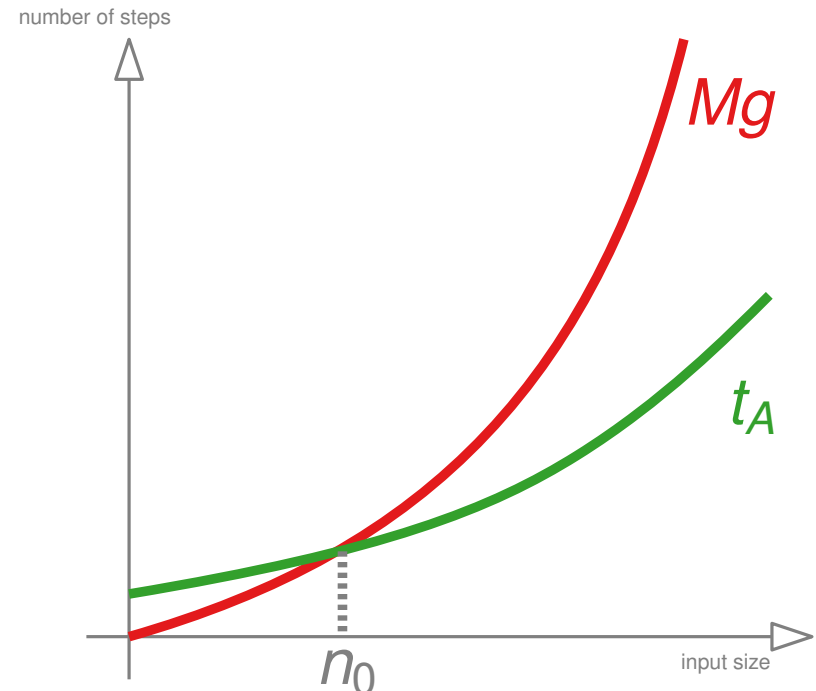
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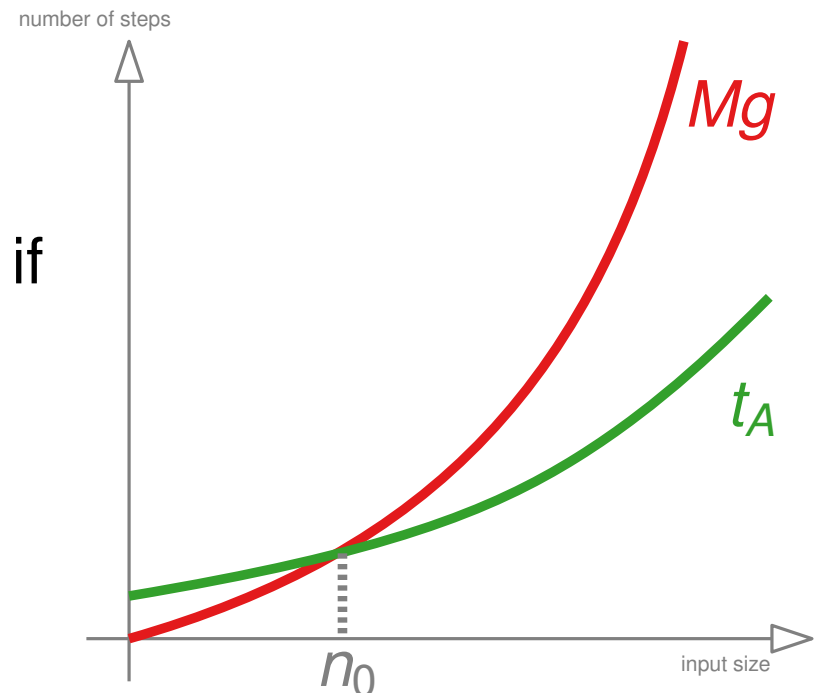


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We say that the worst-case computational complexity (or shortly **running time**) of an algorithm A is $g(n)$ if the number of steps that A performs for an input of size n (denote by $t_A(n)$) is upper bounded by $Mg(n)$, for some $n > n_0$ and constant M : $\exists M, \forall n > n_0$
 $t_A(n) < Mg(n)$



Lecture Overview

- **Why Data visualization?**
- **Data types and their models**
- **Networks and their visualizations (gallery)**
- **Let's draw some networks**
- **Basis for algorithm design: formalization of network visualization problem**
- **Evaluation of Network Visualization**
- **Types of algorithms (mind map)**
- **Some basic notions in Algorithm Complexity Theory**

Reading and Next



Recall

Types of algorithms

How to compute running time of algorithms

Reading and Next



Recall

Types of algorithms

How to compute running time of algorithms

Next

Tree drawing algorithms:

Layered layout, radial layout and bubble layout

