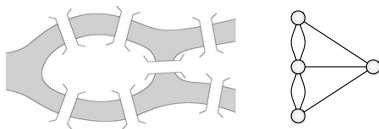# graph theory → *network science*

introduction to *network science in Python* (*NetPy*)

Lovro Šubelj
University of Ljubljana
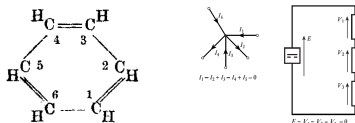14th Dec 2021

history *graph theory*

1736 seven *bridges of Königsberg* [Eul36] (Leonhard Euler)

1800s *travelling salesman* problem (William Hamilton)

1845 *electrical circuit* laws (Gustav Kirchhoff)

1857 *chemical structure* theory (August Kekulé)

1956 *shortest paths* (Edsger Dijkstra)

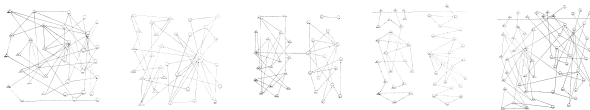1956 minimum *spanning tree* (Joseph Kruskal)

1956 maximum *flow*/minimum *cut* (Ford & Fulkerson)

1956 *signed graph* theory [CH56] (Cartwright & Harary)

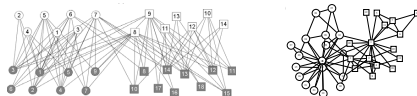1959 *random graph* theory [ER59] (Erdős & Rényi)

history *sociometry*

1934 children *sociograms* [Mor34] (Jacob Moreno)

1967 *small-world* experiment [Mil67] (Stanley Milgram)

1970 university *karate club* [Zac77] (Wayne Zachary)

1973 strength of *weak ties* [Gra73] (Mark Granovetter)

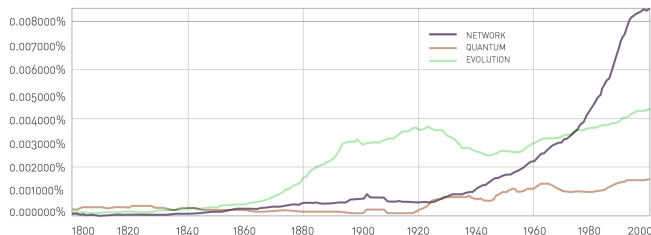1977 measures of *centrality* [Fre77] (Linton Freeman)

revolution *data*

< 2000 *small graphs* 10^2-10^3 nodes

≈ 2000 *communication networks* 10^5-10^8 nodes

≈ 2005 *online social networks* 10^8 nodes

today *Facebook graph* $> 10^9$ users

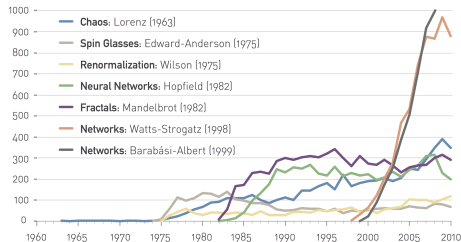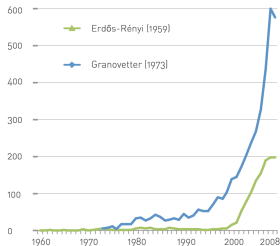today *Web graph* $> 10^{12}$ pages

revolution *models*

1959   *random graph* models [ER59]

1973   *valued graphs* models [Gra73]

1998   *small-world network* structure [WS98]

1999   *scale-free network* structure [BA99]

revolution *language*

> "A key discovery of network science is that the architecture of networks emerging in various domains of science, nature, and technology are similar to each other, a consequence of being governed by the same organizing principles. Consequently we can use a common set of tools to explore these systems."

Albert-László Barabási

> "Networks are ideal structures to describe problems of organized complexity."

César A. Hidalgo

> "I think the 21st century will be the century of complexity."

Stephen Hawking

network *science*

problem
understanding *real networks*

means
study of *network properties*
design of *mathematical models*
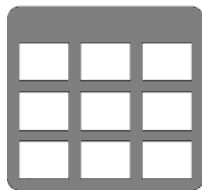*implementation* of *efficient algorithms*

goals
network *structure* and *evolution*
nodes, links, fragments, clusters, layers, network
network *dynamics* and *processes*
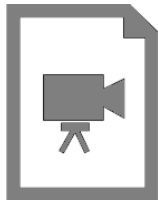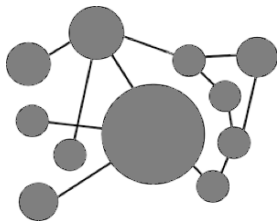spreading, diffusion, epidemics

network *analysis*

data *mining*   *text* *mining*   *computer* *vision*

network *analysis*

history *references*

A.-L. Barabási and R. Albert.
Emergence of scaling in random networks.
Science, 286(5439):509–512, 1999.

A.-L. Barabási.
Network Science.
Cambridge University Press, Cambridge, 2016.

Dorwin Cartwright and Frank Harary.
Structural balance: A generalization of Heider's theory.
Psychological Review, 63(5):277–293, 1956.

David Easley and Jon Kleinberg.
Networks, Crowds, and Markets: Reasoning About a Highly Connected World.
Cambridge University Press, Cambridge, 2010.

P. Erdős and A. Rényi.
On random graphs I.
Publ. Math. Debrecen, 6:290–297, 1959.

Leonhard Euler.
Solutio problematis ad geometriam situs pertinentis.
Comment. Academiae Sci. I. Petropolitanae, 8:128–140, 1736.

L. Freeman.
A set of measures of centrality based on betweenness.
Sociometry, 40(1):35–41, 1977.

Mark S. Granovetter.
The strength of weak ties.
Am. J. Sociol., 78(6):1360–1380, 1973.

history *references*

César A. Hidalgo.
Disconnected, fragmented, or united? A trans-disciplinary review of network science.
Appl. Netw. Sci., 1:6, 2016.

Stanley Milgram.
The small world problem.
Psychol. Today, 1(1):60–67, 1967.

J. L. Moreno.
Who Shall Survive?
Beacon House, Beacon, 1934.

Mark E. J. Newman.
Networks: An Introduction.
Oxford University Press, Oxford, 2010.

D. J. Watts and S. H. Strogatz.
Collective dynamics of 'small-world' networks.
Nature, 393(6684):440–442, 1998.

Wayne W. Zachary.
An information flow model for conflict and fission in small groups.
J. Anthropol. Res., 33(4):452–473, 1977.