community structure

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

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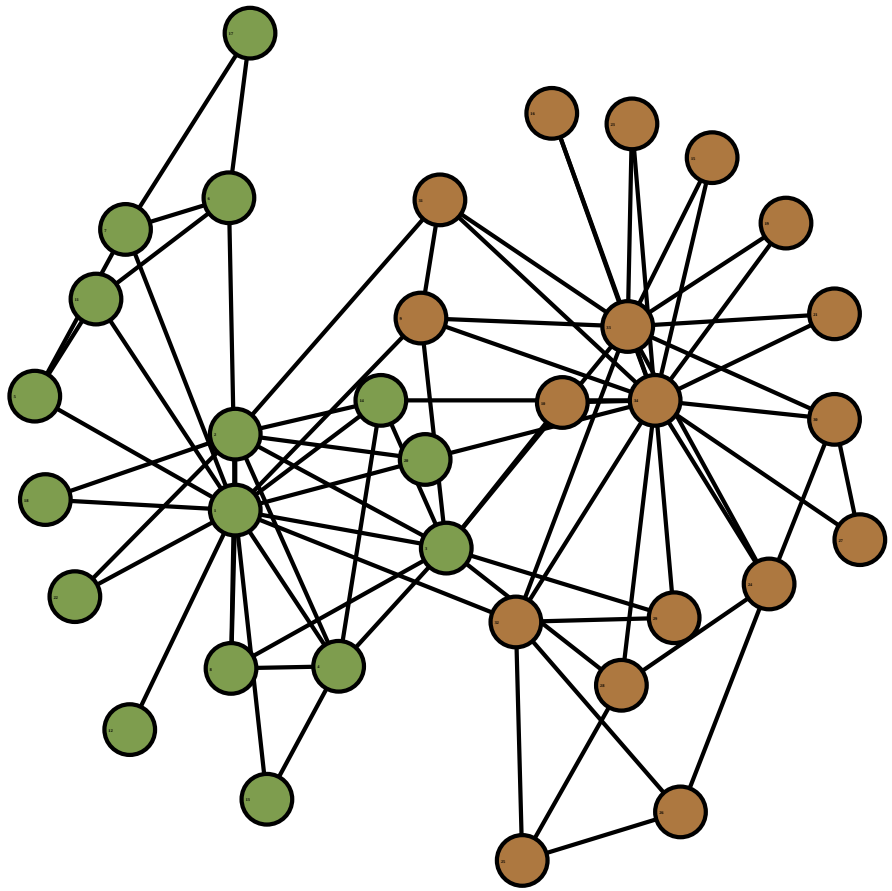
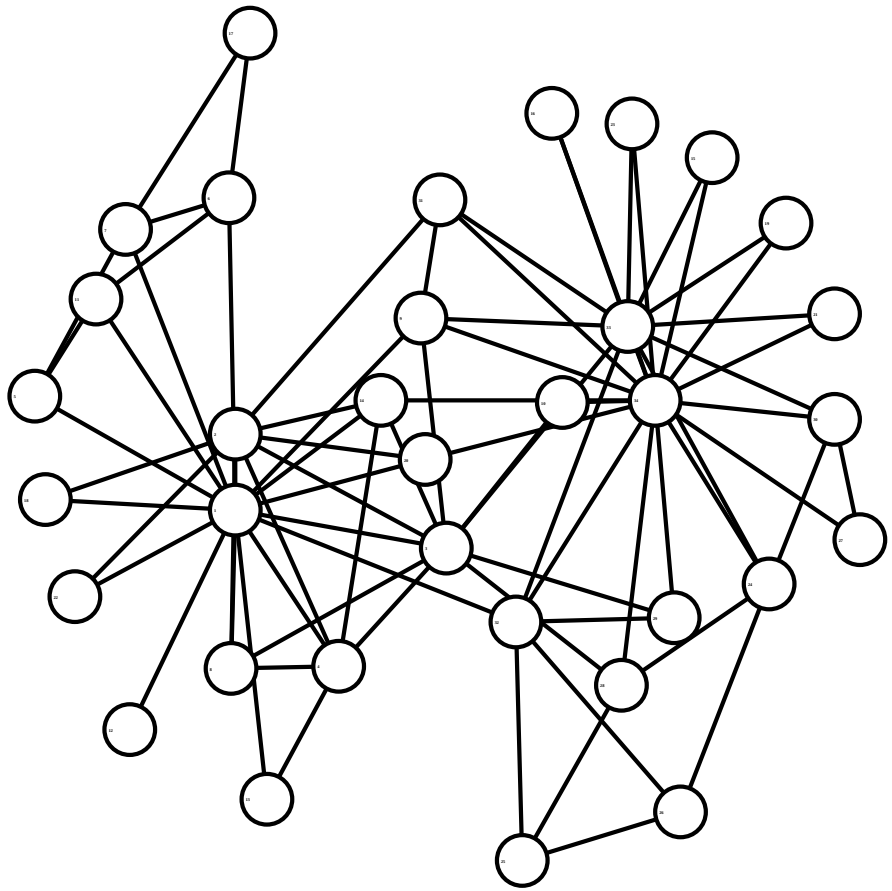
community *structure*

karate club *network split* [Zac77]



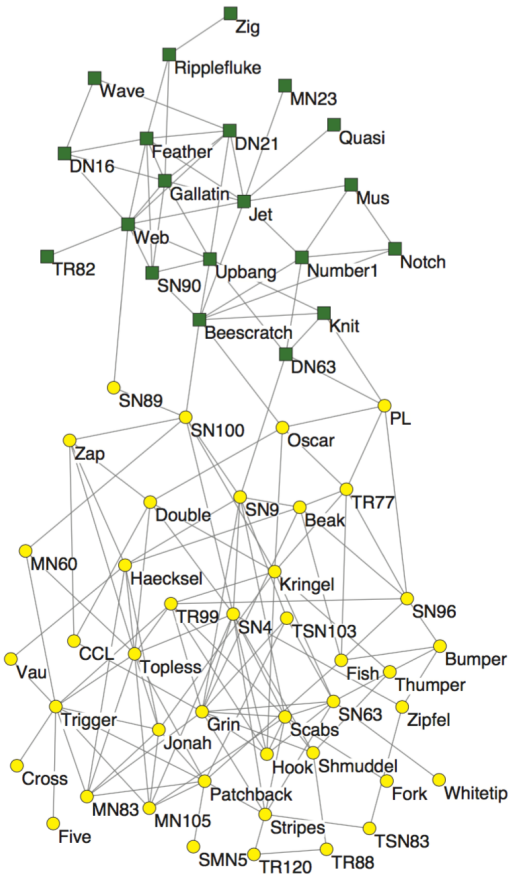
community *detection*

karate club *split detection* [RAK07]

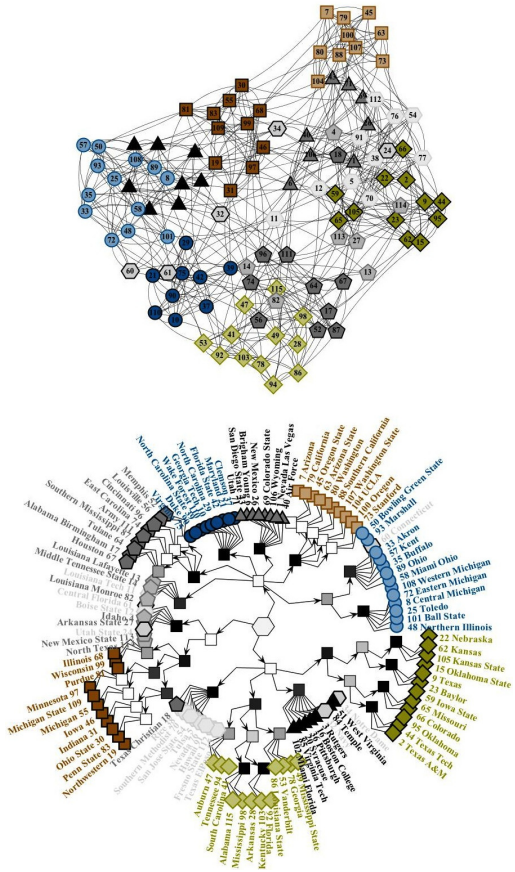


community *examples*

most social networks contain *communities* [GN02]



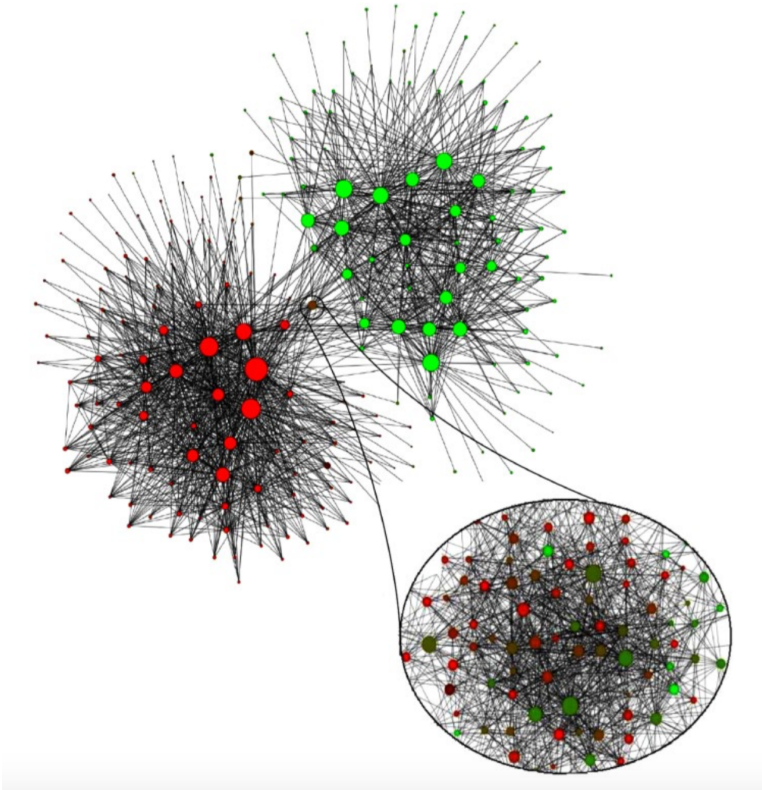
bottlenose dolphins [LSB+03]



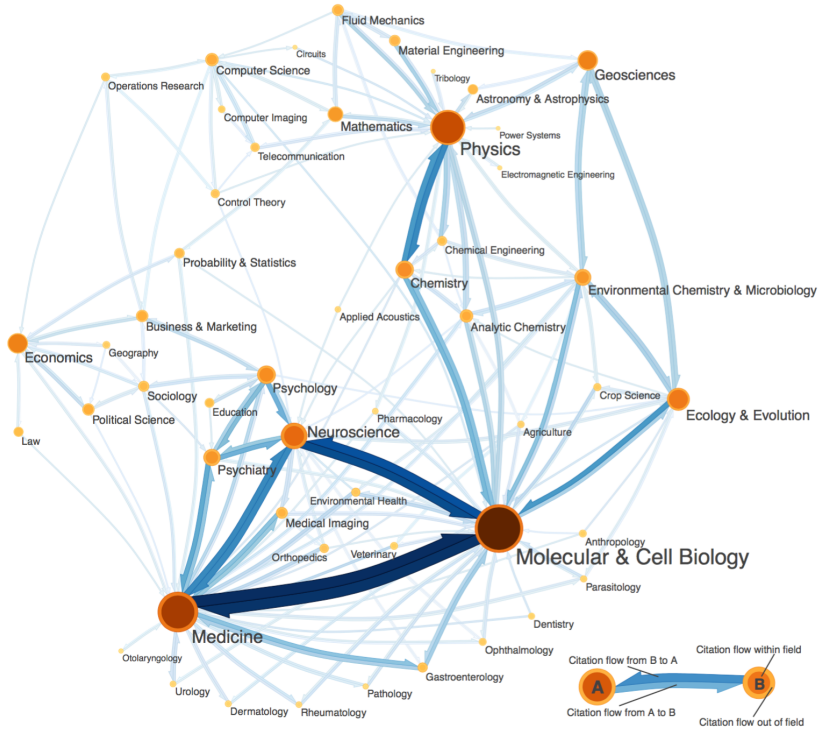
college football [GN02]

community *examples*

many information networks contain *communities* [FLG00]



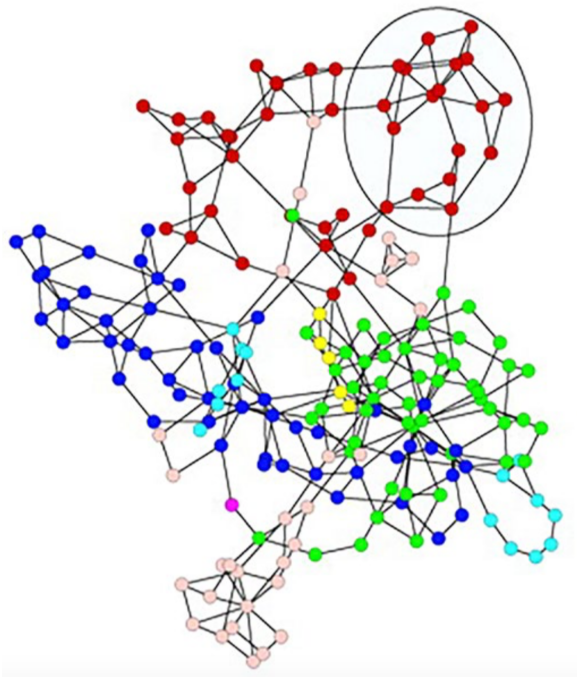
mobile communications [BGLL08]



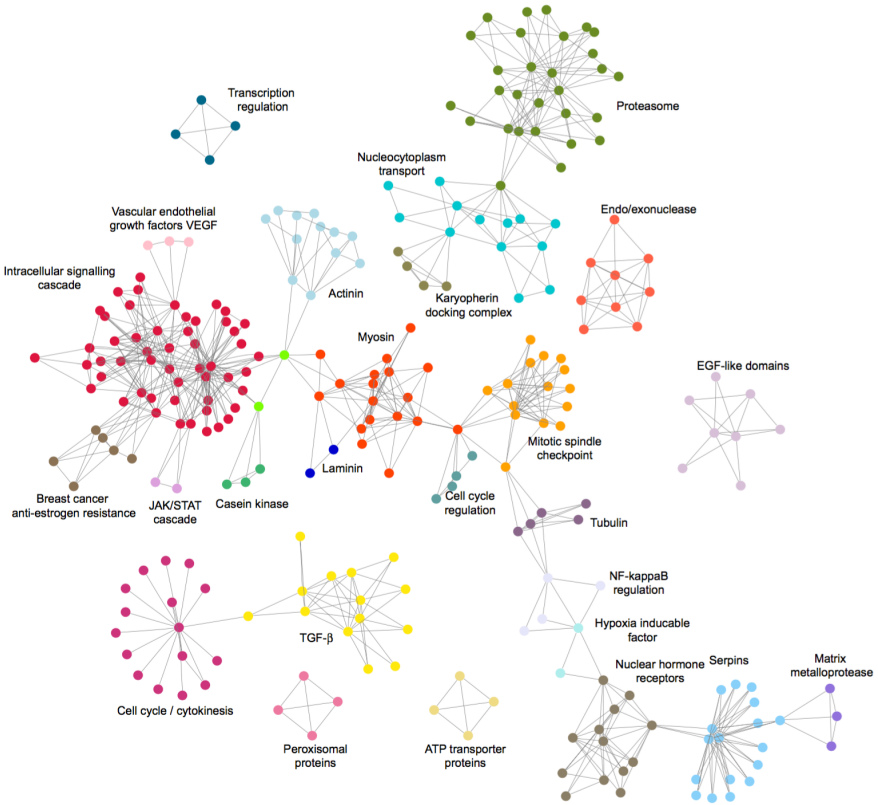
journal citations [RB08]

community *examples*

many biological networks contain *communities* [RSM+02]



E. coli metabolism [RSM+02]



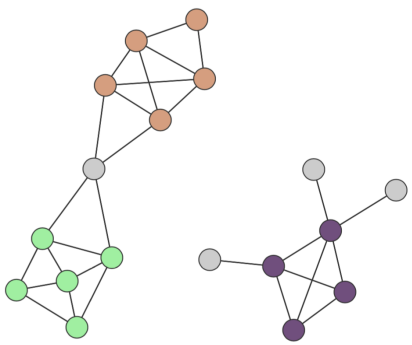
protein interactions [JCZB06]

community *definition*

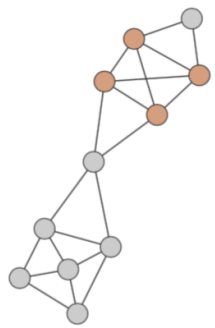
- *clique* is *complete subgraph of* some *graph*
- *community* is *dense subgraph of sparse network* [GN02]
- *strong* and *weak community* C [FLG00, RCC+04] defined as
  - k_i^{int} and k_i^{ext} are *internal* and *external degree* of i

$$\forall i \in C : k_i^{int} > k_i^{ext} \qquad \sum_{i \in C} k_i^{int} > \sum_{i \in C} k_i^{ext}$$

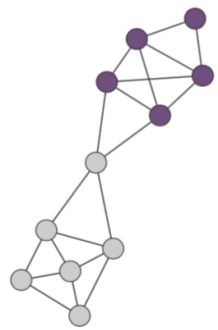
- *community detection* is $\gg$ *graph partitioning* [For10]



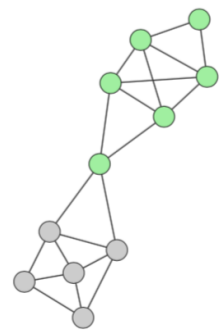
connected communities



maximum clique



strong community



weak community

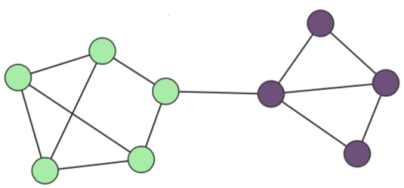
community *modularity*

— *random graphs* should *lack community structure*

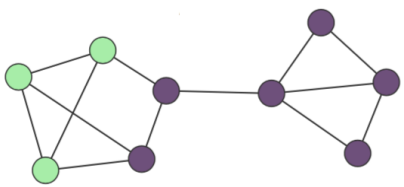
— *modularity* Q [GN02] of *communities* $\{C\}$ defined as

$$Q = \frac{1}{2m} \sum_{ij} \left(A_{ij} - \frac{k_i k_j}{2m} \right) \delta_{c_i c_j}$$

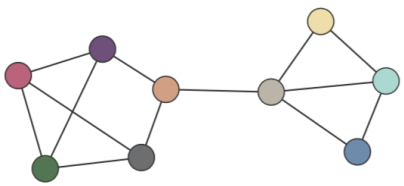
— *modularity* Q popular *quality*/*optimization function* [For10]



optimal $Q = 0.41$



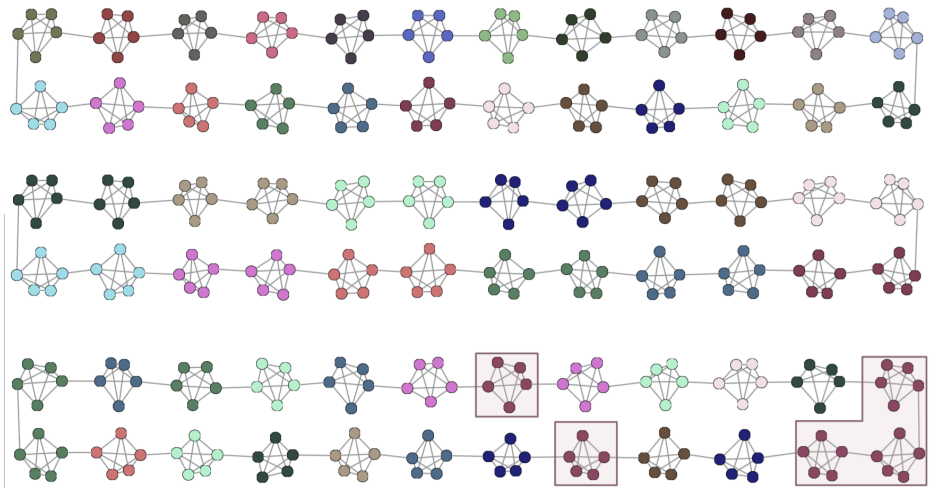
suboptimal $Q = 0.22$



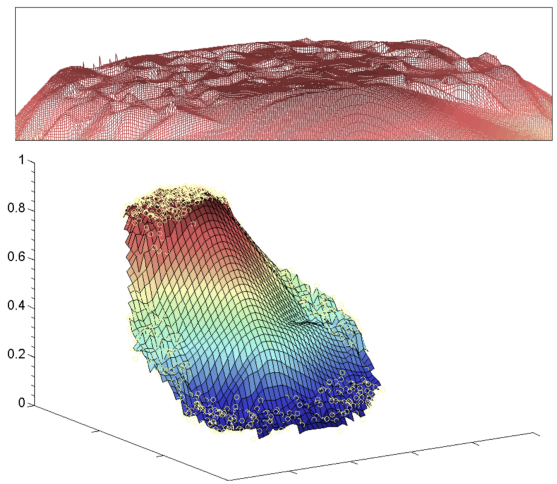
isolates $Q = -0.12$

community ¬*modularity*

- *modularity* $Q \gg 0$ also in *random graphs* [GSPA04]
- *modularity* Q has *resolution limit* at $k_c \leq \sqrt{2m}$ [FB07]
- *modularity* Q *lacks clear optimum* in real networks [GdMC10]

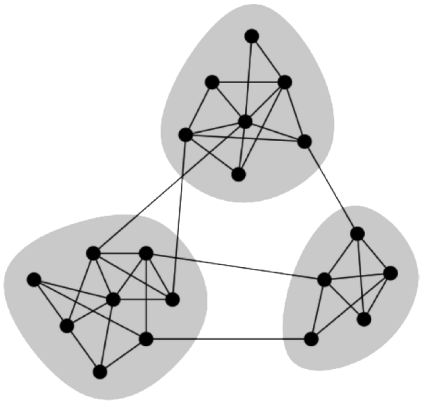


intuitive $Q = 0.867$, *optimal* $Q = 0.871$ and random $Q = 0.8$

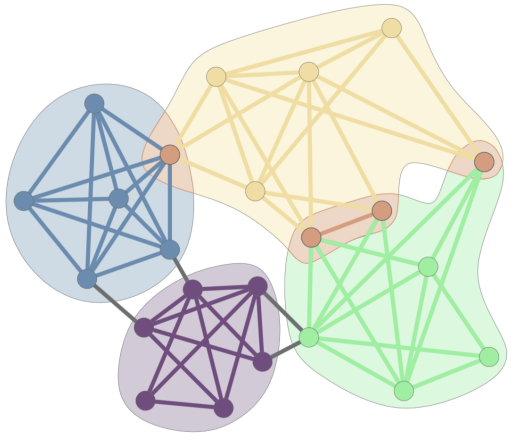


Q *plateau* and maxima

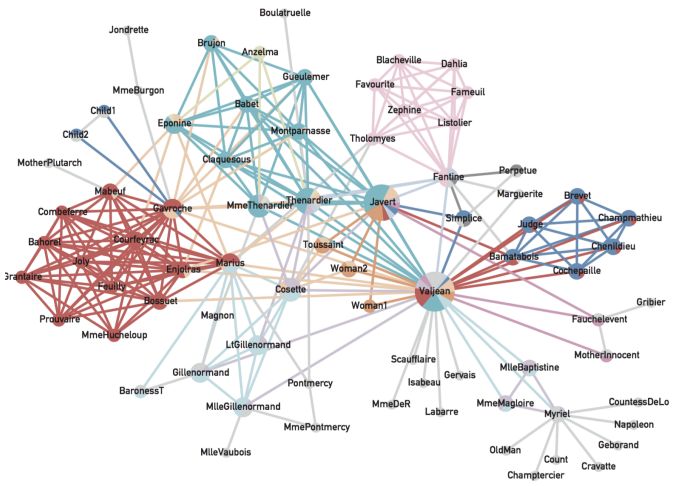
community *overview*



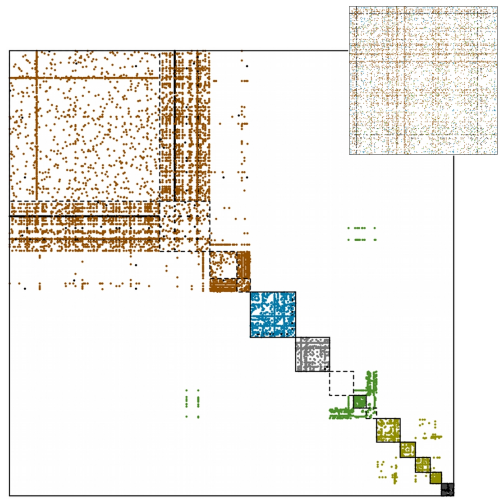
communities [GN02]



overlapping communities [PDFV05]



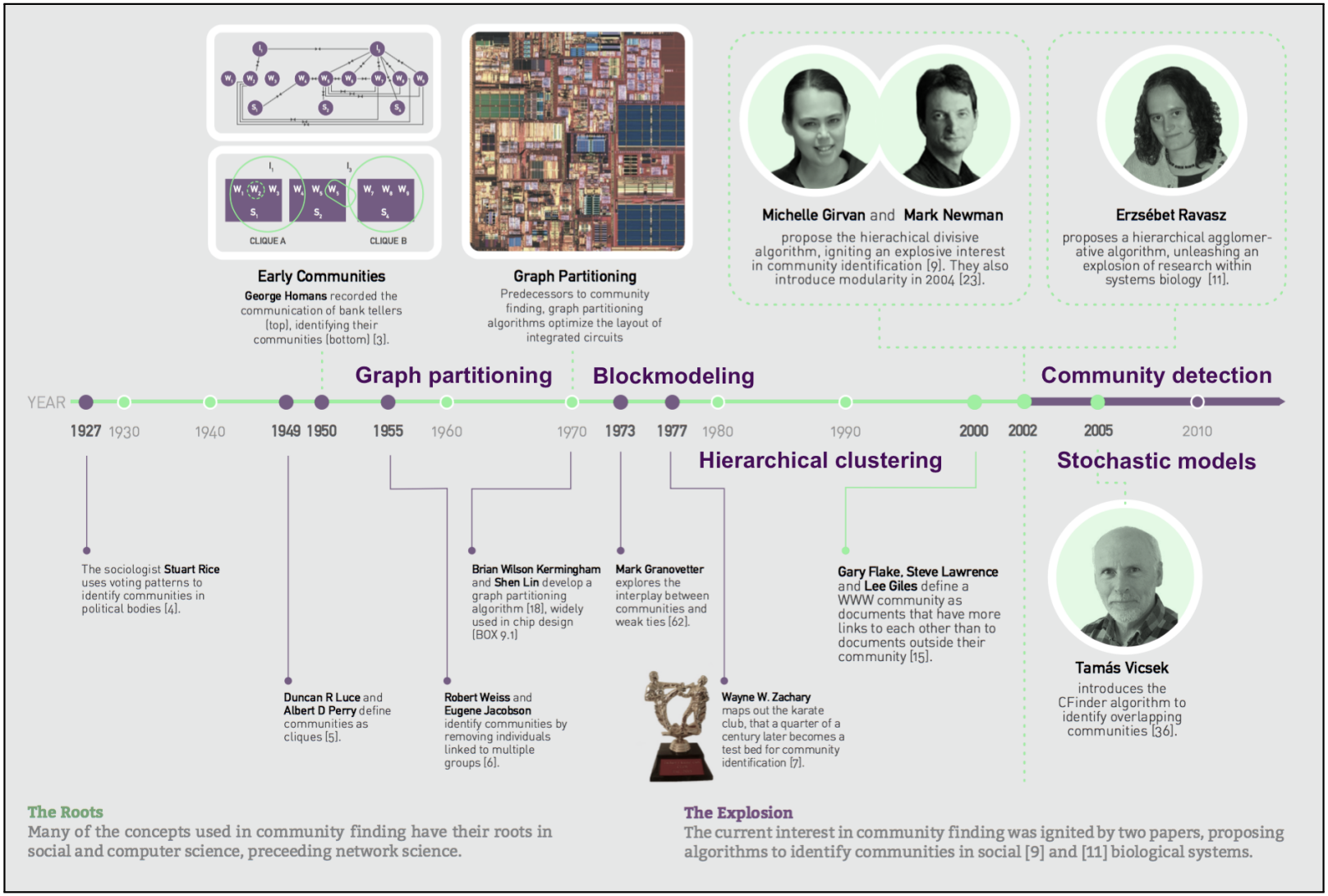
link communities [EL09, ABL10]



block models, *blockmodeling* etc.

`javax.swing`, `javax.management`, `javax.xml`, `javax.print`, `javax.naming`, `javax.lang`

community *history*



community *references*

Yong-Yeol Ahn, James P. Bagrow, and Sune Lehmann.
Link communities reveal multiscale complexity in networks.
Nature, 466(7307):761–764, 2010.

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

V. D. Blondel, J.-L. Guillaume, R. Lambiotte, and E. Lefebvre.
Fast unfolding of communities in large networks.
J. Stat. Mech., P10008, 2008.

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

Ernesto Estrada and Philip A. Knight.
A First Course in Network Theory.
Oxford University Press, 2015.

T. S. Evans and R. Lambiotte.
Line graphs, link partitions and overlapping communities.
Phys. Rev. E, 80(1):016105, 2009.

Santo Fortunato and Marc Barthelemy.
Resolution limit in community detection.
P. Natl. Acad. Sci. USA, 104(1):36–41, 2007.

community *references*

Gary William Flake, Steve Lawrence, and C. Lee Giles.

Efficient identification of web communities.
In *Proceedings of the ACM SIGKDD International Conference on Knowledge Discovery and Data Mining*, pages 150–160, Boston, MA, USA, 2000.

Santo Fortunato.

Community detection in graphs.
Phys. Rep., 486(3-5):75–174, 2010.

Benjamin H. Good, Yves Alexandre de Montjoye, and Aaron Clauset.

Performance of modularity maximization in practical contexts.
Phys. Rev. E, 81(4):046106, 2010.

M. Girvan and M. E. J Newman.

Community structure in social and biological networks.
P. Natl. Acad. Sci. USA, 99(12):7821–7826, 2002.

Roger Guimerà, Marta Sales-Pardo, and Luís A. Nunes Amaral.

Modularity from fluctuations in random graphs and complex networks.
Phys. Rev. E, 70(2):025101, 2004.

Pall F. Jonsson, Tamara Cavanna, Daniel Zicha, and Paul A. Bates.

Cluster analysis of networks generated through homology: Automatic identification of important protein communities involved in cancer metastasis.
BMC Bioinformatics, 7:2, 2006.

D. Lusseau, K. Schneider, O. J. Boisseau, P. Haase, E. Slooten, and S. M. Dawson.

The bottlenose dolphin community of Doubtful Sound features a large proportion of long-lasting associations. Can geographic isolation explain this unique trait?
Behav. Ecol. Sociobiol., 54(4):396–405, 2003.

community *references*

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

Gergely Palla, Imre Derényi, Illes Farkas, and Tamas Vicsek.
Uncovering the overlapping community structure of complex networks in nature and society.
Nature, 435(7043):814–818, 2005.

Usha Nandini Raghavan, Reka Albert, and Soundar Kumara.
Near linear time algorithm to detect community structures in large-scale networks.
Phys. Rev. E, 76(3):036106, 2007.

M. Rosvall and C. T. Bergstrom.
Maps of random walks on complex networks reveal community structure.
P. Natl. Acad. Sci. USA, 105(4):1118–1123, 2008.

Filippo Radicchi, Claudio Castellano, Federico Cecconi, Vittorio Loreto, and Domenico Parisi.
Defining and identifying communities in networks.
P. Natl. Acad. Sci. USA, 101(9):2658–2663, 2004.

E. Ravasz, A. L. Somera, D. A. Mongru, Z. N. Oltvai, and Albert László Barabási.
Hierarchical organization of modularity in metabolic networks.
Science, 297(5586):1551–1555, 2002.

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