# comparison of methods for clustering citation networks

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# study overview

## problem

grouping publications into clusters based on citation relations

## means

graph partitioning/community detection methods on citation networks

## goals

clusters of topically related publications or research areas

## wishes

experts should recognize cluster topics

small differences in cluster sizes

limited number of tiny clusters

robustness to small perturbations

reasonable computational complexity

# citation networks

## data

in-house version of Web of Science database of CWTS

## networks

citation networks represented as simple undirected graphs

| field | period | # publications | # nodes | # links |
|---|---|---|---|---|
| Scientometrics | 2009-2013 | 2,402 | 1,998 | 5,496 |
| L&IS | 1996-2013 | 43,741 | 32,628 | 131,989 |
| Physics | 2004-2013 | 1,314,458 | 1,233,542 | 9,838,008 |
| WoS | 2004-2013 | 11,780,132 | 11,063,916 | 122,148,955 |

Scientometrics — journals Journal of Informetrics, Scientometrics and JASIST

L&IS — Information Science & Library Science journal subject category

Physics — eight Physics journal subject categories and Astronomy & Astrophysics

WoS — all journal subject categories in Web of Science

# methods

## 30 basic/derived graph partitioning/community detection methods

| class | method | description |
|---|---|---|
| Spectral analysis | Graclus(S\|L) | *k*-means clustering iteration |
| | METIS(S\|L) | multi-level *k*-way partitioning |
| Map equation | Infomap | information flows compression |
| | Hiermap | hierarchical flows compression |
| Modularity optimization | Louvain | greedy hierarchical optimization |
| | Mouvain | multi-level hierarchical optimization |
| | SLM | smart local moving optimization |
| Statistical methods | OSLOM | order statistics local optimization method |
| Label propagation | LPA | label propagation algorithm |
| | BPA | balanced propagation algorithm |
| | DPA | diffusion-propagation algorithm |
| | HPA | hierarchical propagation algorithm |
| | COPRA | community overlap propagation algorithm |
| Random walks | Walktrap | random walks hierarchical clustering |
| Link clustering | Links(S\|L) | link similarity hierarchical clustering |
| Graph models | BigClam(S\|L) | cluster affiliation matrix factorization |
| | CoDA(S\|L) | communities through directed affiliations |
| Ego-networks | DEMON | democratic estimate of modular organization |
| Cliques | SCP | sequential clique percolation |
| | GCE | greedy clique expansion |
| 2-step methods | Metilus | METIS+Graclus |
| | Gracmap | Graclus+Infomap |
| | Metimap | METIS+Infomap |
| | Louvmap | Louvain+Infomap |
| | Labmap | LPA+Infomap |

2-step — second method applied to clusters obtained by first method

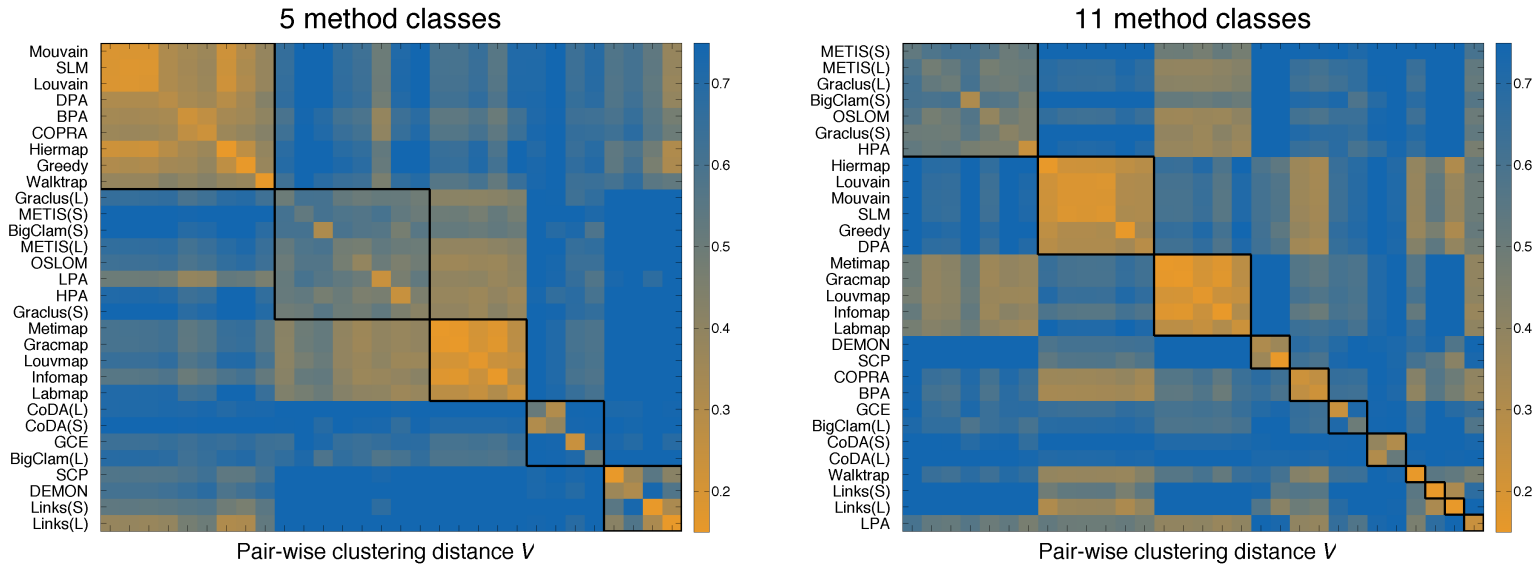
S|L — small|large clusters

# clustering distances

## clusterings

distances between clusterings by considered methods

10/15 selected representative methods



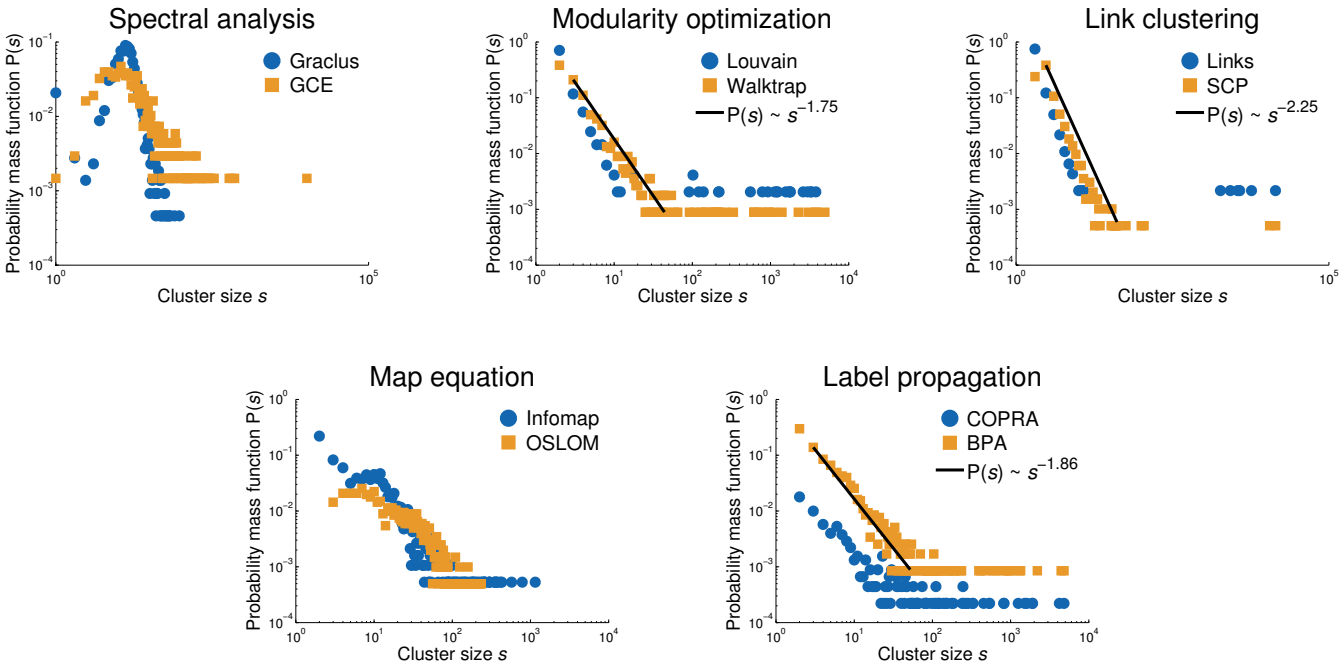

distance — normalized variation of information of clusterings

# clustering distributions

## sizes

size distributions of clusterings by representative methods

from homogeneous to inhomogeneous distributions

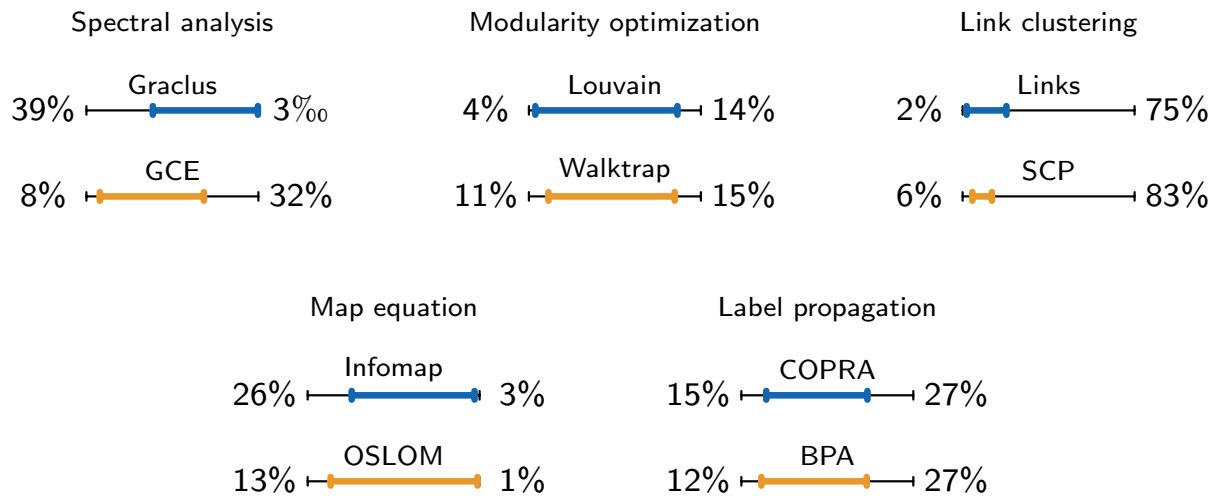


# clustering degeneracy

## ranges

degeneracy diagrams of clusterings by representative methods

narrowing effective ranges from left to right




left-hand side — % nodes in tiny clusters $< 15$ nodes

right-hand side — % nodes in largest cluster

## metrics

standard metrics of clusterings by representative methods

≈ 1500 clusters and decreasing Flake score from top/bottom

| method | # clusters | degree | expansion | Flake | modularity |
|---|---|---|---|---|---|
| Graclus | 2175 | 2.4 | 5.8 | 52% | 0.29 |
| OSLOM | 1914 | 3.8 | 4.4 | 37% | 0.45 |
| Infomap | 1871 | 5.0 | 3.2 | 19% | 0.60 |
| Louvain | 488 | 6.8 | 1.2 | 3% | 0.73 |
| Walktrap | 1127 | 6.5 | 1.6 | 7% | 0.69 |
| BPA | 1002 | 7.0 | 1.0 | 3% | 0.66 |
| COPRA | 3826 | 6.8 | 1.2 | 15% | 0.65 |
| Links | 2933 | 6.4 | 1.8 | 20% | 0.09 |
| SCP | 1969 | 4.9 | 3.2 | 37% | 0.22 |
| GCE | 682 | 4.1 | 4.0 | 29% | 0.43 |

degree — average node intra-cluster or internal degree

expansion — average node inter-cluster or external degree

Flake — % nodes with larger external than internal degree

# bibmetrics

bibliometric metrics of clusterings by representative methods

orders $\gg 1$ and increasing coverage from top/bottom

| method | size | orders | diameter | coverage | uncertainty |
|---|---|---|---|---|---|
| Graclus | 15.0 | 1.1 | 3.4 | 29% | 0.42 |
| OSLOM | 16.0 | 2.6 | 4.8 | 46% | 0.36 |
| Infomap | 17.3 | 2.7 | 4.3 | 62% | 0.13 |
| Louvain | 66.7 | 3.3 | 9.1 | 85% | 0.19 |
| Walktrap | 29.0 | 3.4 | 7.8 | 80% | 0.00 |
| BPA | 32.0 | 3.6 | 7.3 | 86% | 0.21 |
| COPRA | 8.8 | 4.0 | 6.9 | 85% | 0.22 |
| Links | 10.1 | 4.3 | 11.1 | 78% | 0.05 |
| SCP | 16.6 | 4.2 | 23.1 | 61% | 0.02 |
| GCE | 47.8 | 3.3 | 12.0 | 50% | 0.24 |

orders — orders of magnitude spanned by cluster sizes

diameter — average within cluster effective diameter

uncertainty — variation of information of clusterings

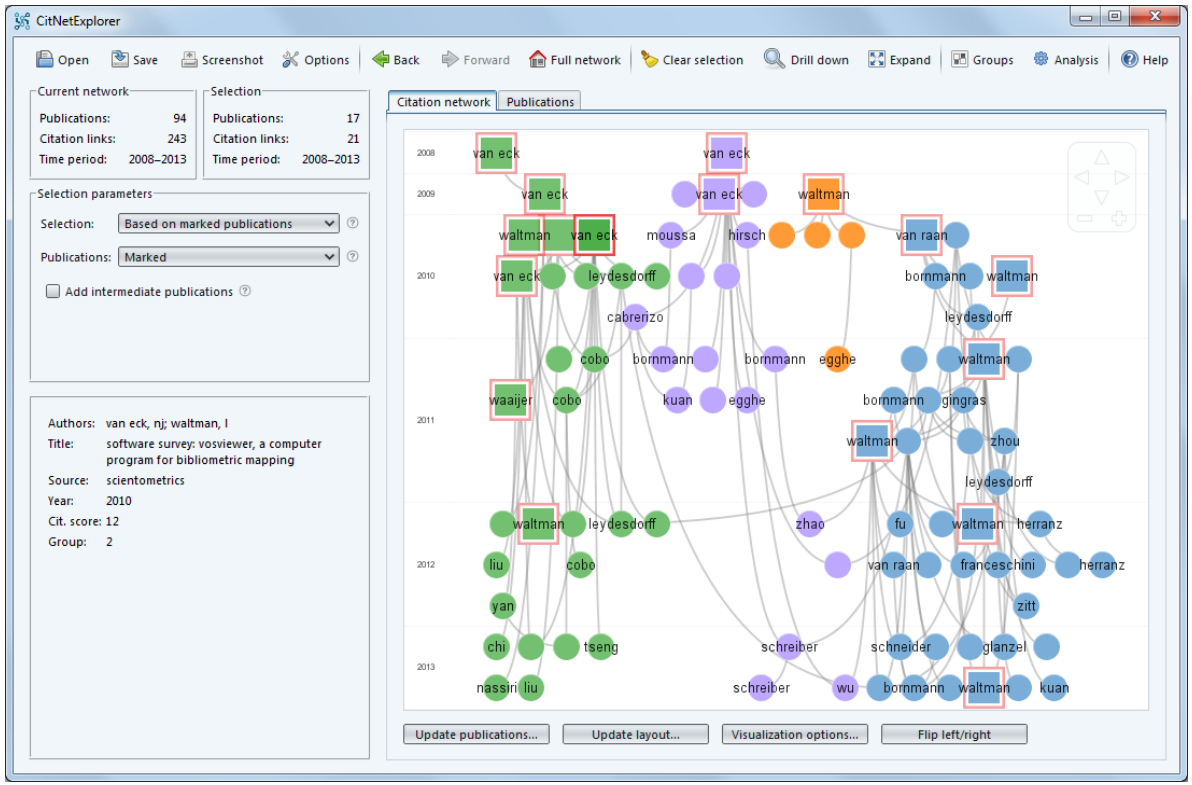
coverage — % links covered by clusters

# clustering tool

## assessment tool

CitNetExplorer for analyzing citation networks

freely available at www.citnetexplorer.nl



# clustering resolution

clusterings for L&IS by representative methods

hands-on expert assessment for scientometrics using CitNetExplorer

## low resolution

Walktrap and BPA

BPA returns one cluster covering scientometrics

## high resolution

Graclus(S|L) and METIS(S|L)

Graclus returns four clusters covering h-index

## topics resolution

OSLOM, Louvain, Metimap and Infomap

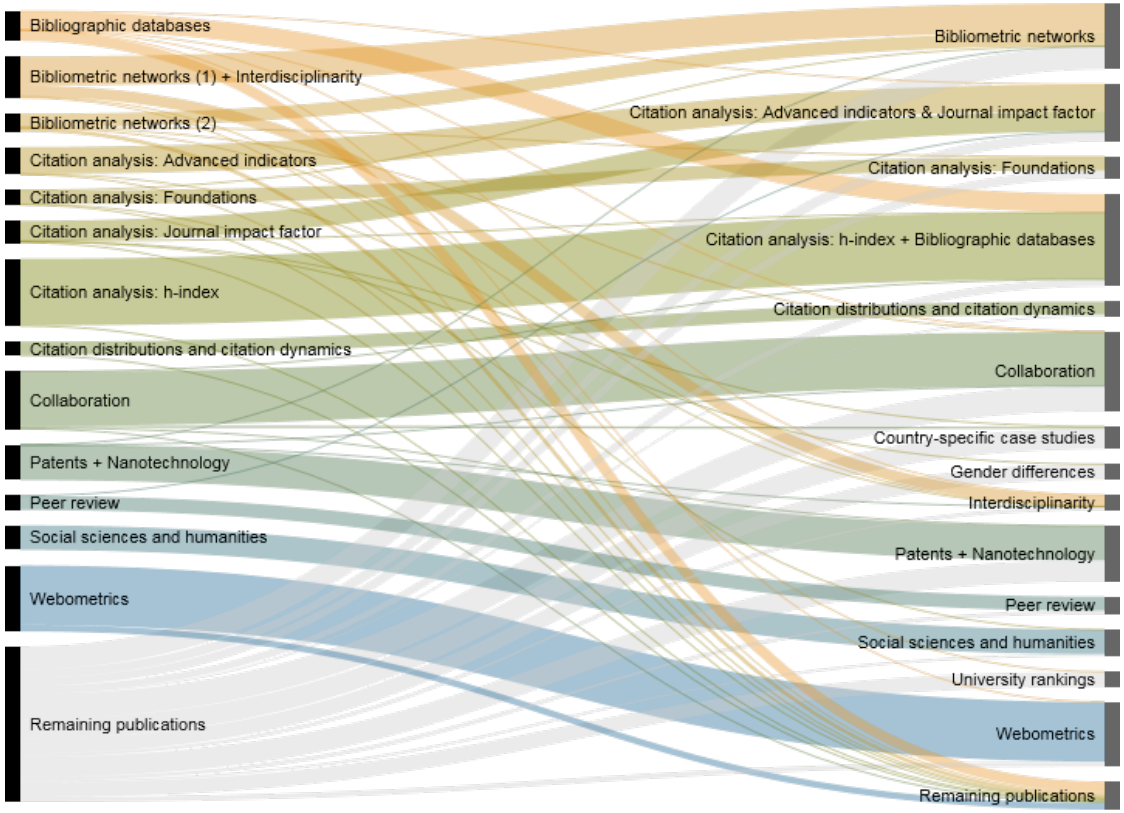
OSLOM, Louvain return ambigous/heterogeneous clusters

# clustering assessment

## expert assessment

largest scientometrics clusters by Metimap and Infomap methods

identified research topics of clusters covering ≈ 75% publications



# clustering WoS

## clustering metrics for WoS by fastest methods

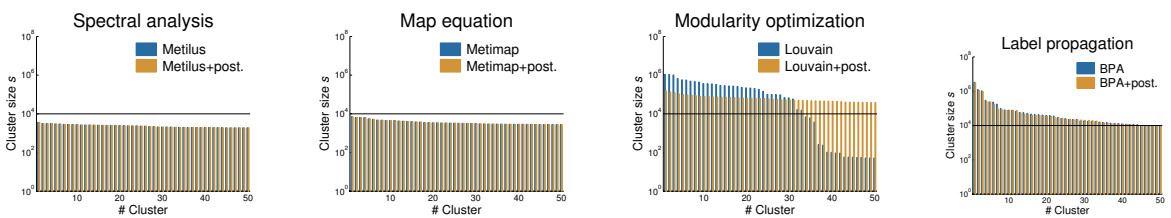
| method | size | orders | degree | coverage | Flake | complexity |
|---|---|---|---|---|---|---|
| Metilus | 50.0 | 2.3 | 5.9 | 27% | 69% | 30 min |
| Metimap | 33.2 | 3.6 | 10.3 | 47% | 45% | 94 min |
| Louvain | 334.4 | 5.7 | 18.5 | 84% | 5% | 52 min |
| BPA | 105.4 | 6.2 | 18.5 | 84% | 7% | 66 min |

# post-processing

## tiny clusters $< 15$ nodes merged by maximizing likelihood

| method | size | orders | degree | coverage | Flake | complexity |
|---|---|---|---|---|---|---|
| Metilus+post. | 51.5 | 2.2 | 5.9 | 27% | 69% | 34 min |
| Metimap+post. | 58.9 | 3.6 | 10.3 | 47% | 45% | 99 min |
| Louvain+post. | 320.9 | 4.9 | 15.2 | 69% | 17% | 79 min |
| BPA+post. | 167.1 | 6.2 | 18.0 | 82% | 9% | 114 min |

## giant clusters $> 10^4$ nodes repartitioned by same method



# study summary

## conclusions

methods return substantially different clusterings

no method performs satisfactory by all criteria

straightforward post-processing performs poorly

map equation methods provide good trade-off

## limitations

limitations of expert assessment of clusterings

limited number of methods with default parameters

no directed, overlapping, multi-resolution, principled methods

no equivalence clusters or co-citation and bibliographic coupling

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