Università degli Studi di Padova

STRUCTURAL ANALYSIS OF THE ZEBRAFISH CONNECTOME

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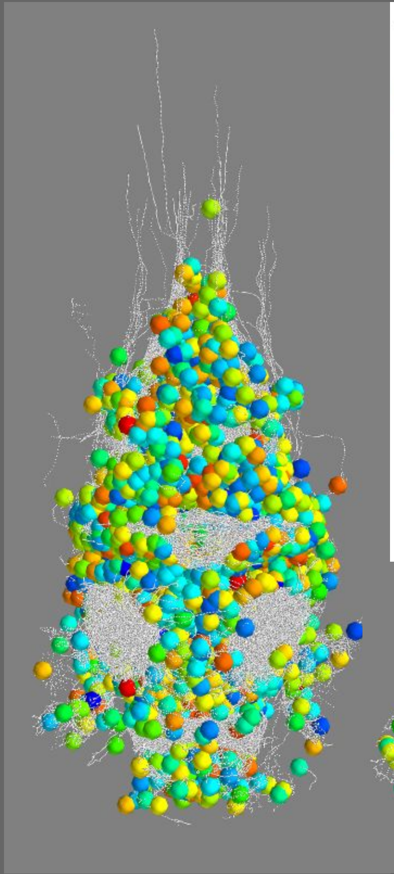
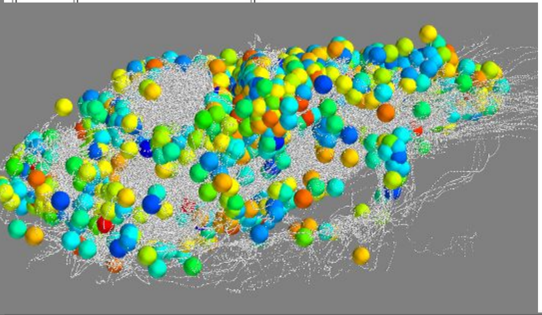
Dataset description

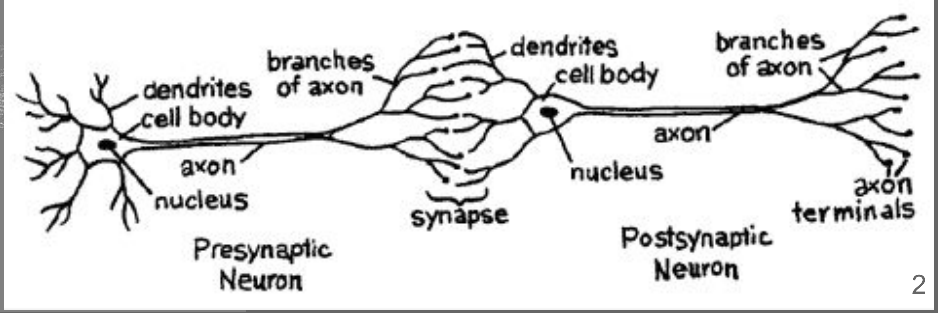
Spatial neural positions
(random colours)

SWC format

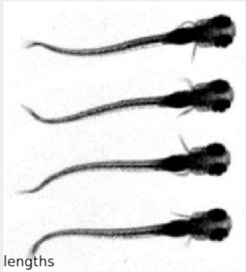
	1	2	4	5	6	7	8
data type	Sample number	Structure Identifier	x position	y position	z position	radius	parent sample
data value	integer value, generally continuous, starting from '1', though this is not required.	Standardized swc files (www.neuromorpho.org) - 0 - undefined 1 - soma 2 - axon 3 - (basal) dendrite 4 - apical dendrite 5+ - custom A lot of data does not conform exactly to this standard however e.g. CNIC data - 0 - undefined 1 - soma 2 - axon 3 - (basal) dendrite 4 - apical dendrite 5 - fork point 6 - end point 7 - custom	'x', 'y', 'z' are spatial co-ordinates, given in micrometers. 'radius' is half the dendrite thickness, also given in micrometers (note this is one of the few formats which use radius instead of diameter)				The sample number. Connectivity is expressed with this value. Parent samples should appear before any child samples.



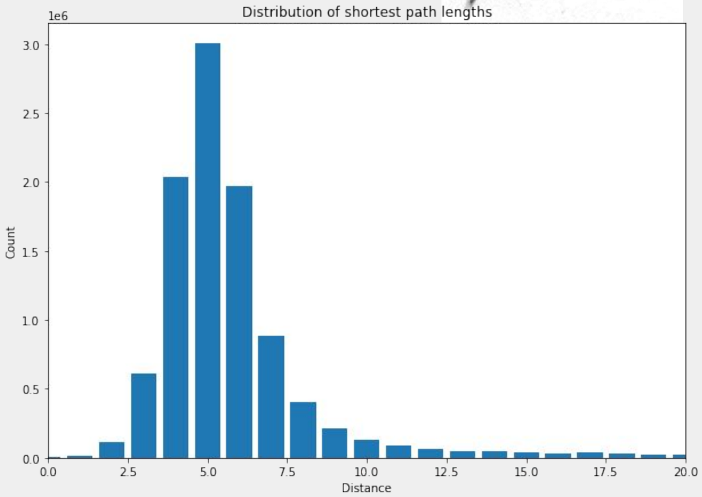




General network properties



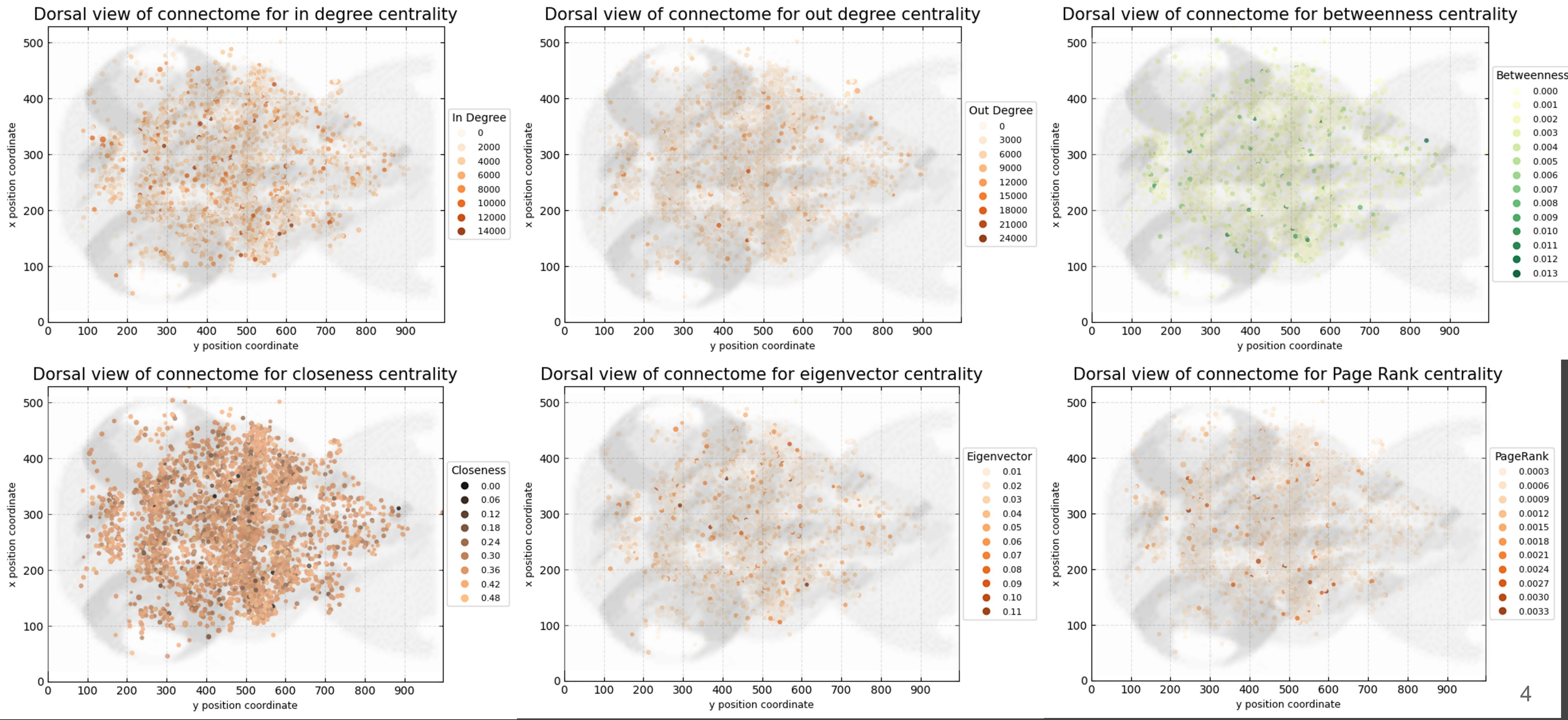
Network Property	Zebrafish	Cancer network*	Random network
Graph type	Directed	Undirected	Directed
Number of Nodes(Neurons)	3163	351	3163
Number of Edges	349194	1783	349948
N/W Density	0.03491	0.029	0.035
Diameter	10	7	11
Avg. Shortest path length	4.1595	*	2.03
Global Efficiency	0.4775	*	0.5349
Local Efficiency	0.7106	*	0.4818
Clustering coefficient	0.2947	0.261	0.035
Assortativity	*	0.12	*
In-Assortativity exponent	0.488	*	0.482
Out-Assortativity exponent	0.287	*	0.482
Giant Components (Number of Nodes)	3154	107	3163
Giant Components (Number of Edges)	349027	*	349948
Number of cliques	2264453	149677	1071503
Max clique size	81	15	6



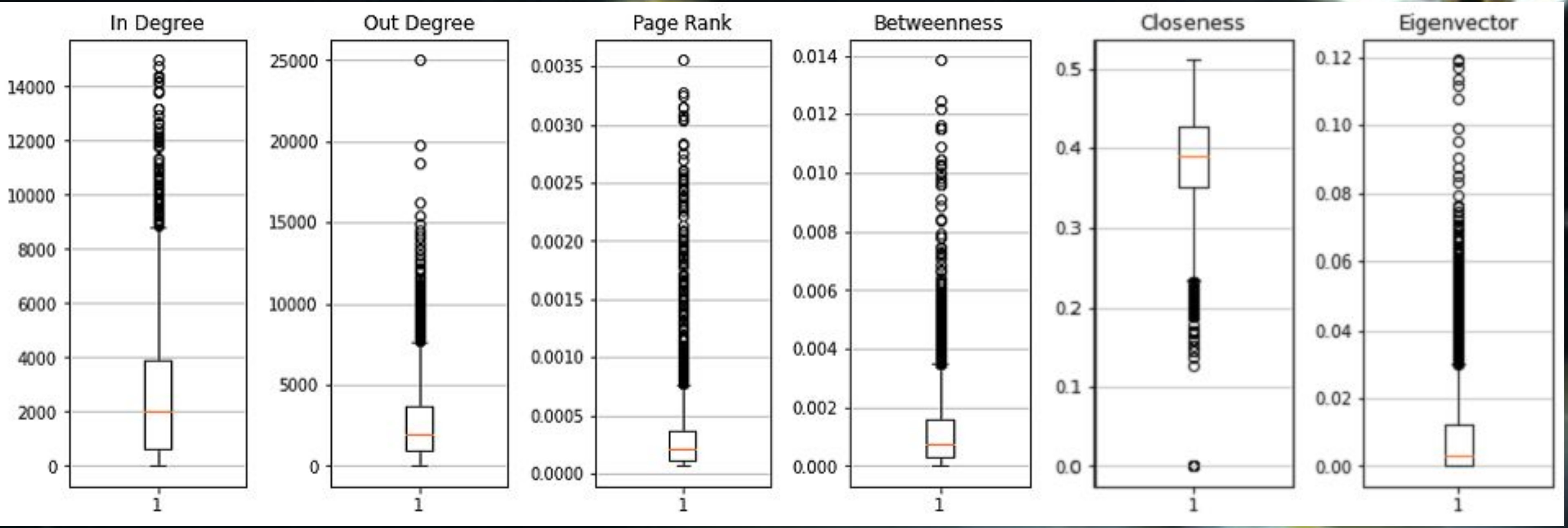
The value for average shortest path length is small, as anticipated for brain networks.

* Sahoo et al https://doi.org/10.1016/B978-0-12-804203-8.00017

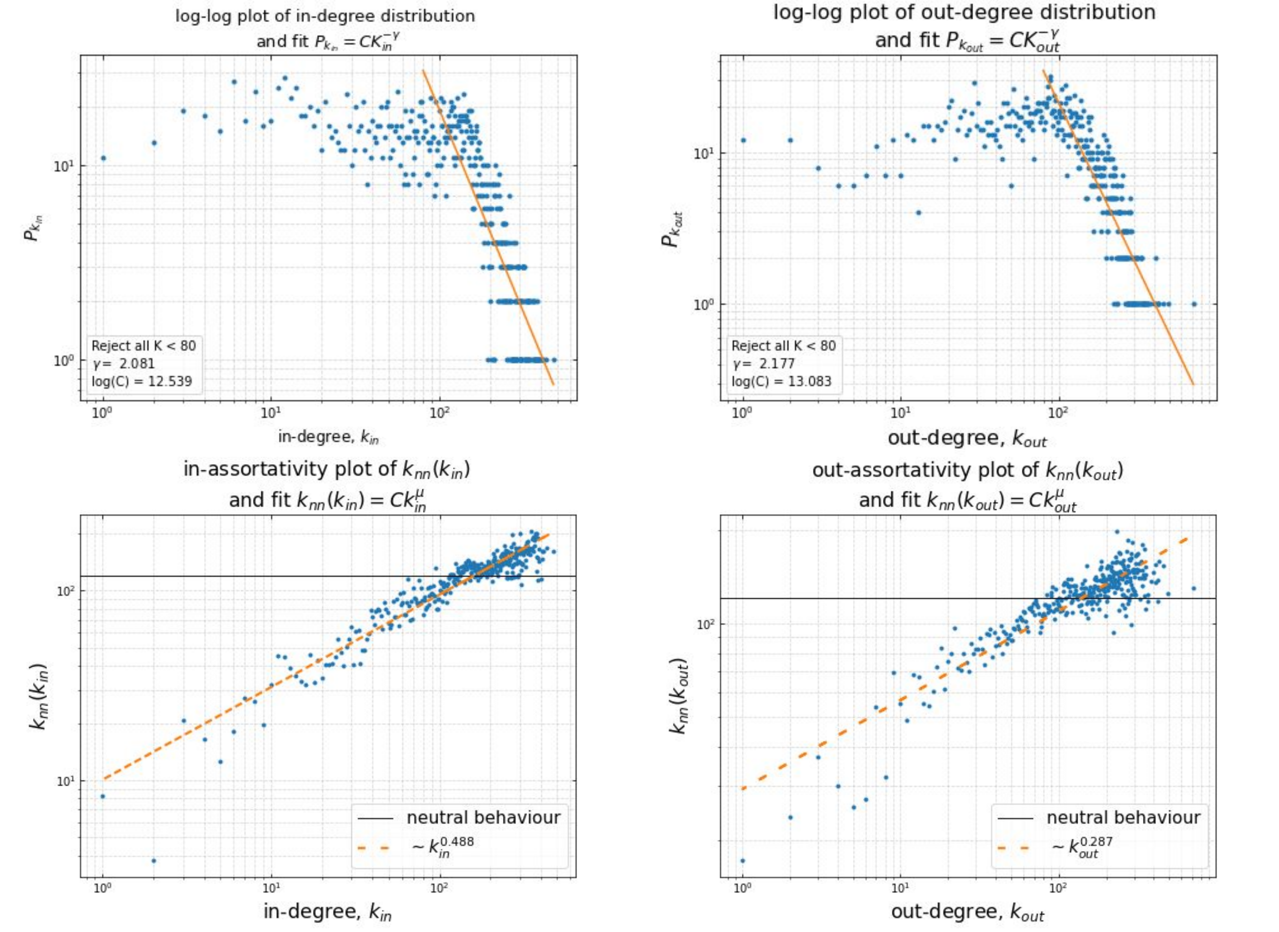
Network centralities



Box plots for various centrality measures



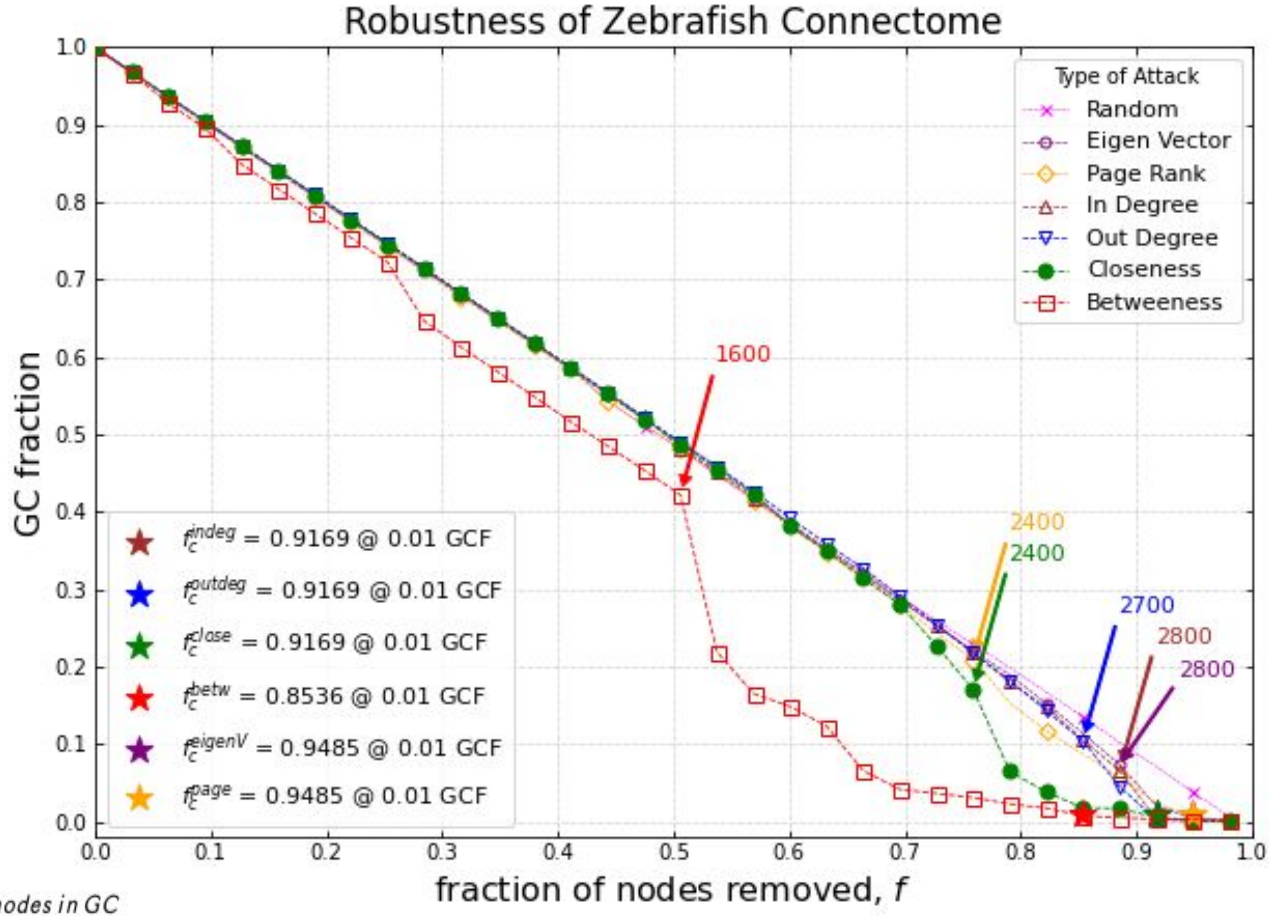
Degree distribution and assortativity



Since ɣ exponent is ~[2-3] for both in and out degree, we observe the scale free property

The network shows strong assortativity for both in-in and out-out degree

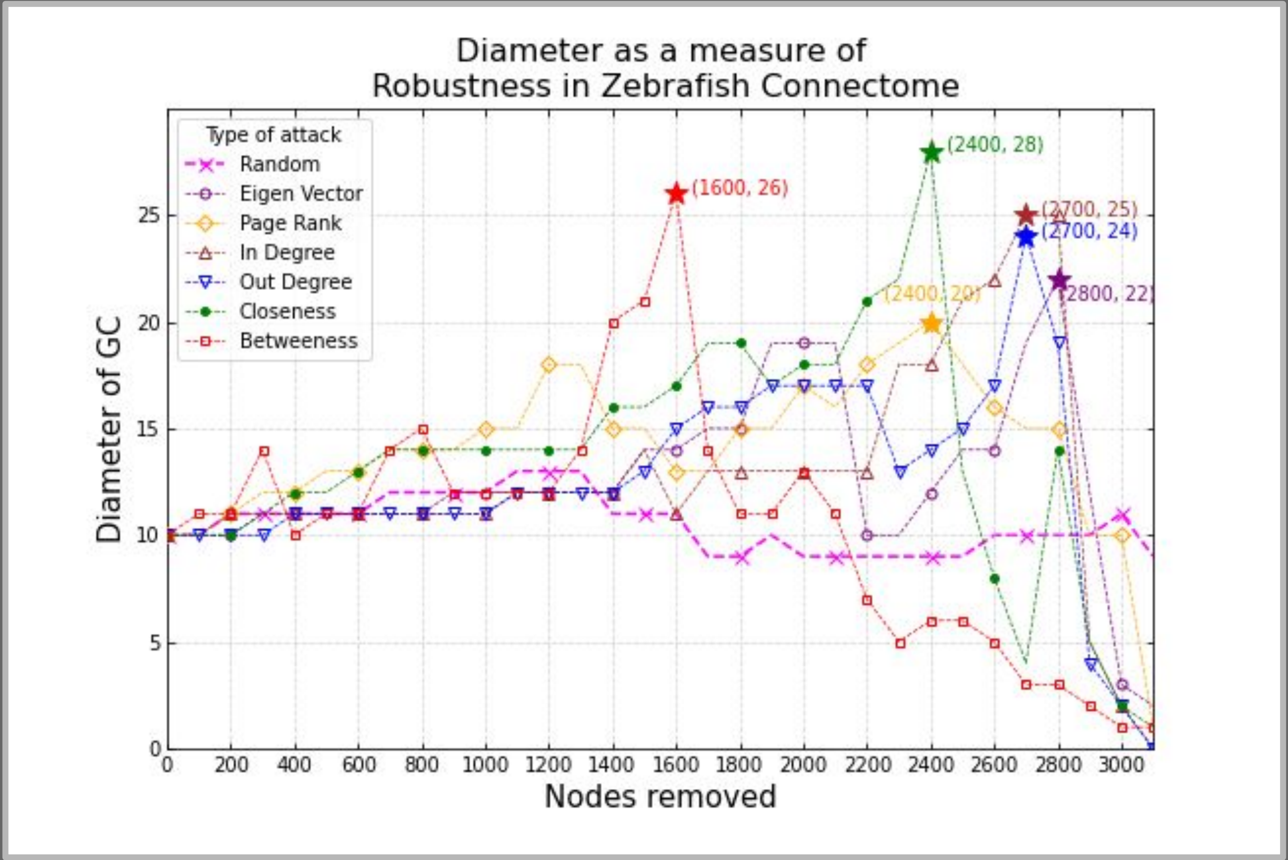
Robustness



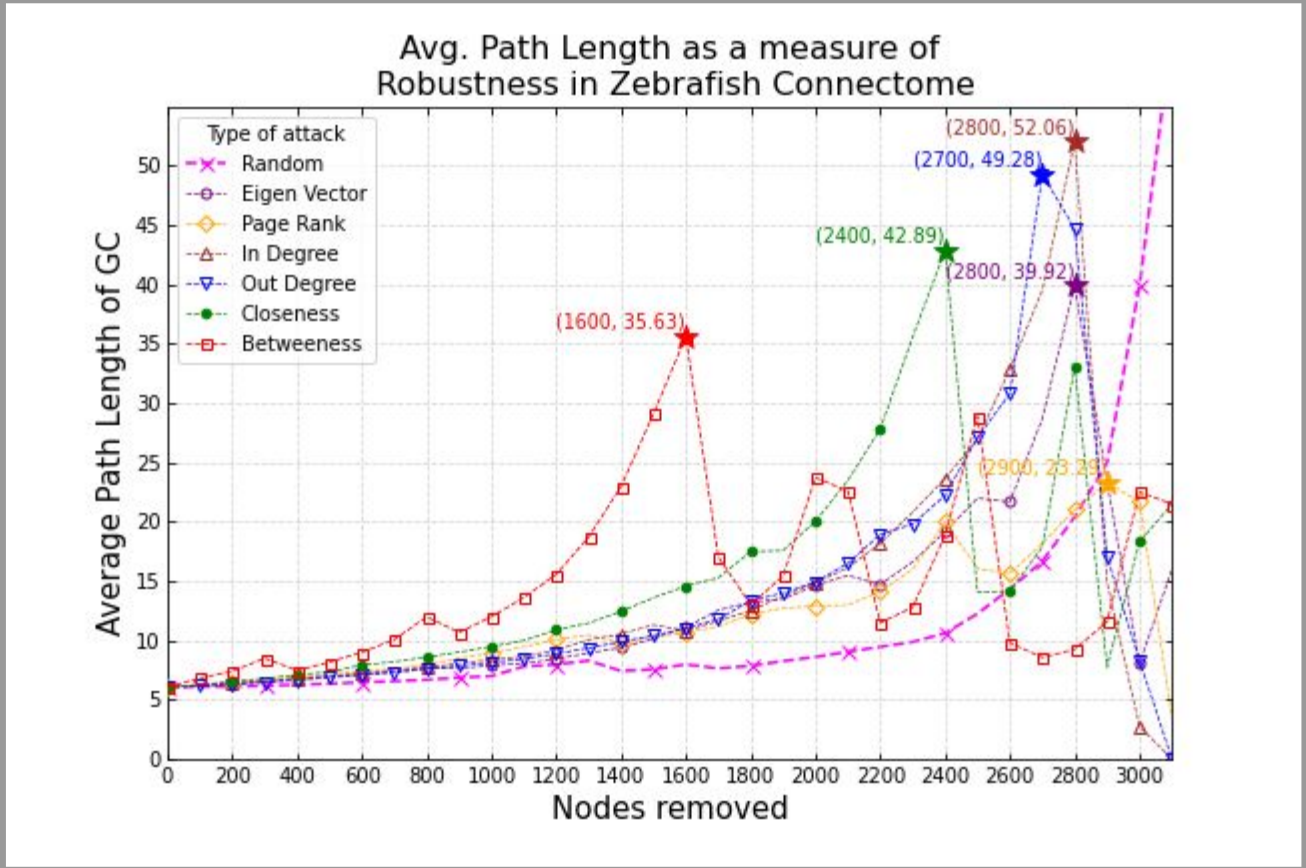
$$GC\,fraction = \frac{No.\ of\ nodes\ in\ GC}{Total\ no.\ of\ nodes\ in\ GC@f = 0}$$

$$frac.\ of\ nodes\ removed = \frac{Cumulative\ no. of\ nodes removed}{Total\ no.\ of\ nodes\ in\ G}$$

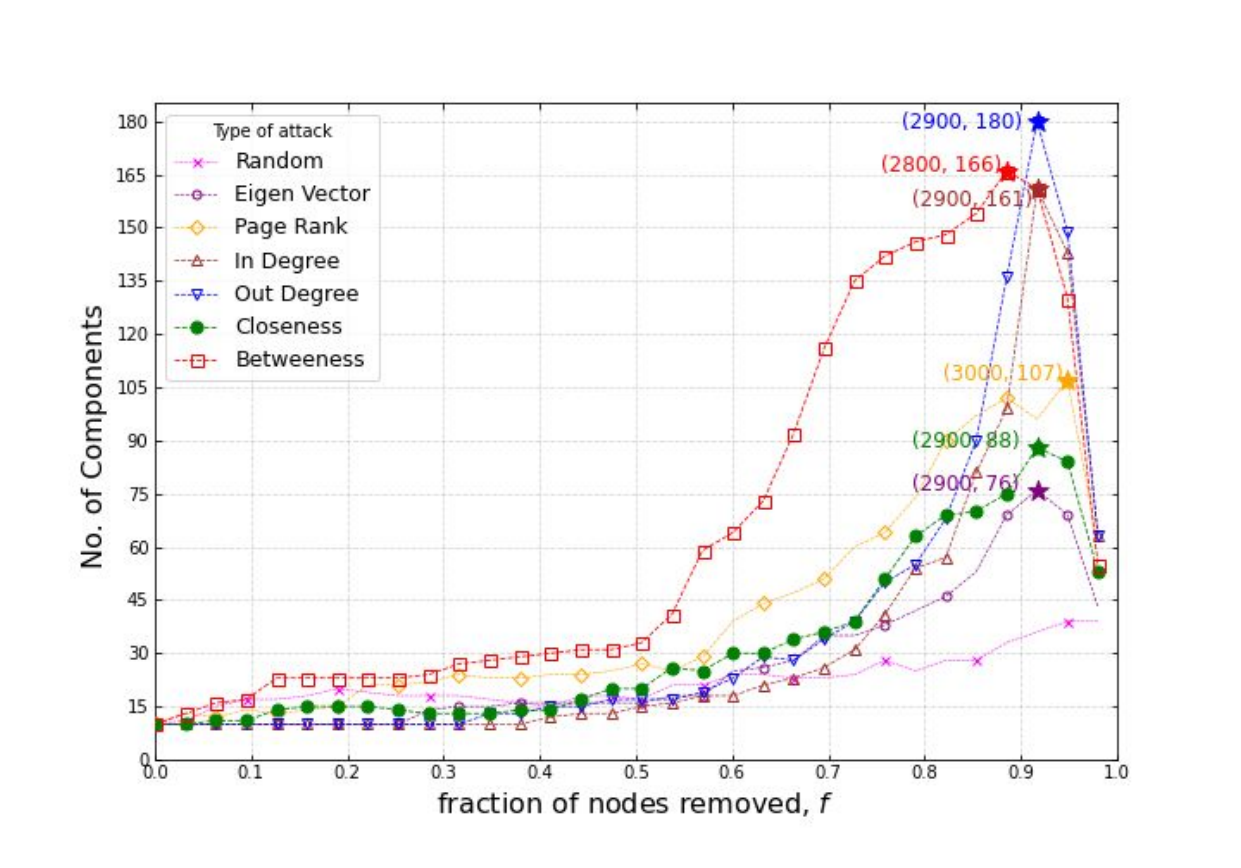
Robustness influence on diameter



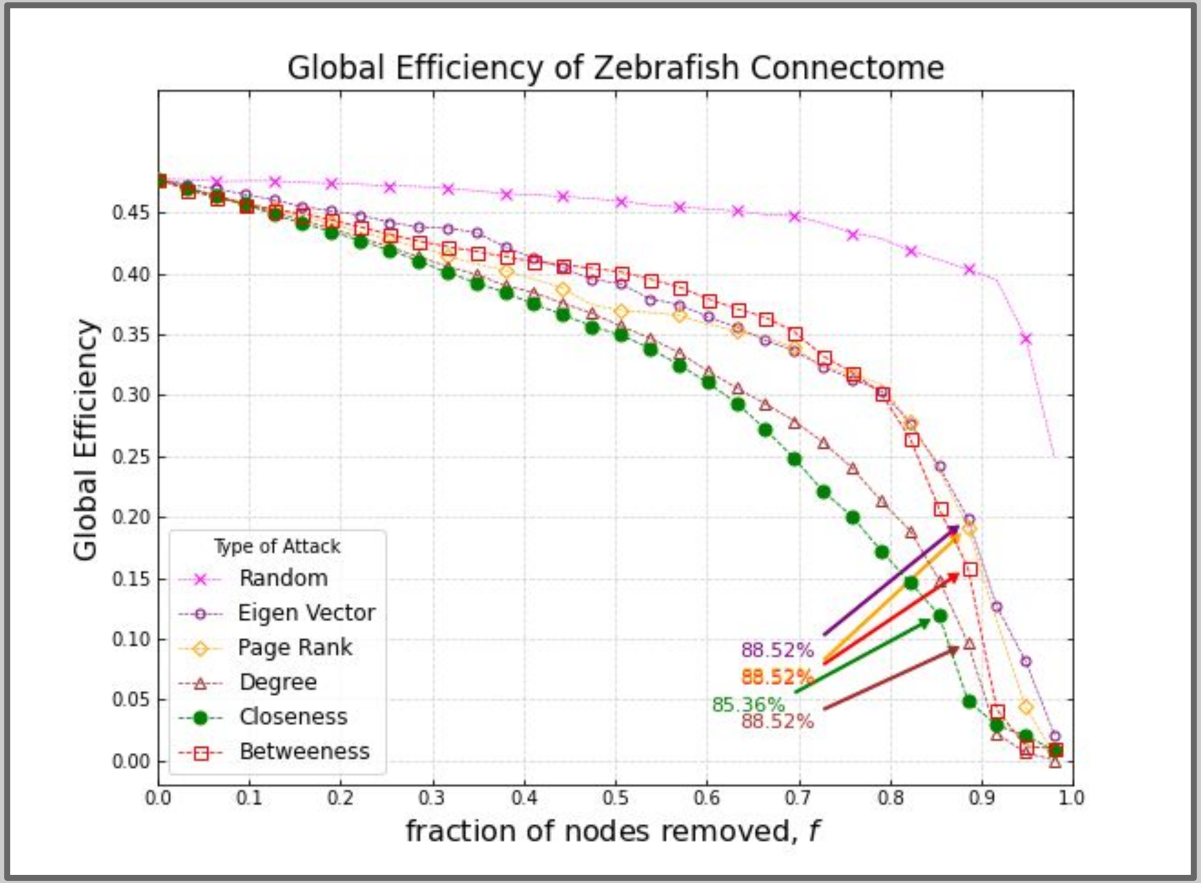
Robustness influence on avg. path length



No. of Connected Components at each node removals



Global efficiency by removal of nodes

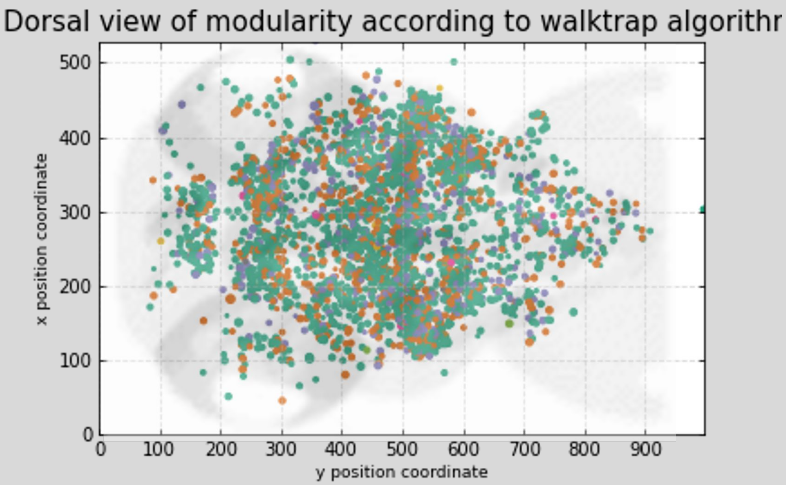


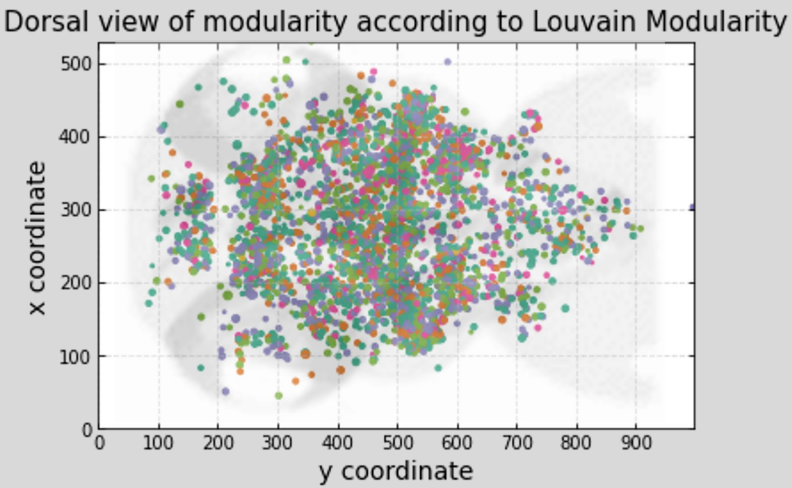
Community detection

Community algorithm	Number of Clusters	Modularity	Number of Cluster (GC)	Modularity (GC)
Walktrap	41	0.380	33	0.395
Infomap	47	0.351	34	0.399
Label Propagation	44	0.312	8	0.184
Louvain Modularity	12	0.460	9	0.463
Lovuain RBER	54	0.454	48	0.452
Louvain CPM	54	0.444	52	0.441
Louvain Significance	117	0.323	108	0.333
Louvain Surprise	147	0.305	135	0.324
Spinglass	*	*	17	0.468 ($T_f = 0$)

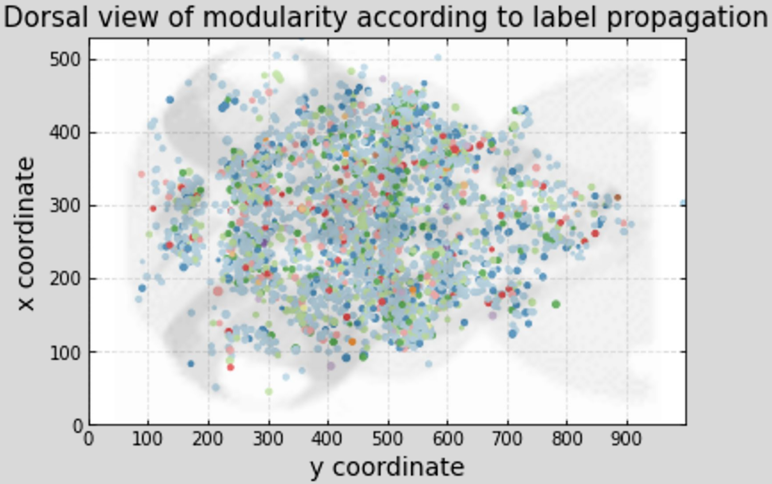
While the number of communities varies a lot between algorithms, all of them detect [~10 / ~20] communities with significant number of nodes.

Anatomical plots

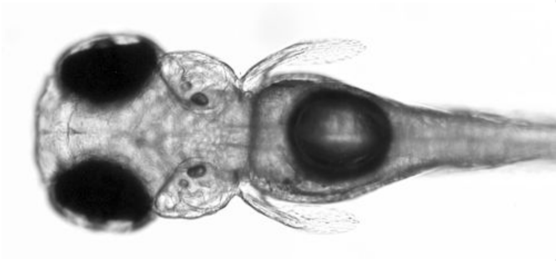


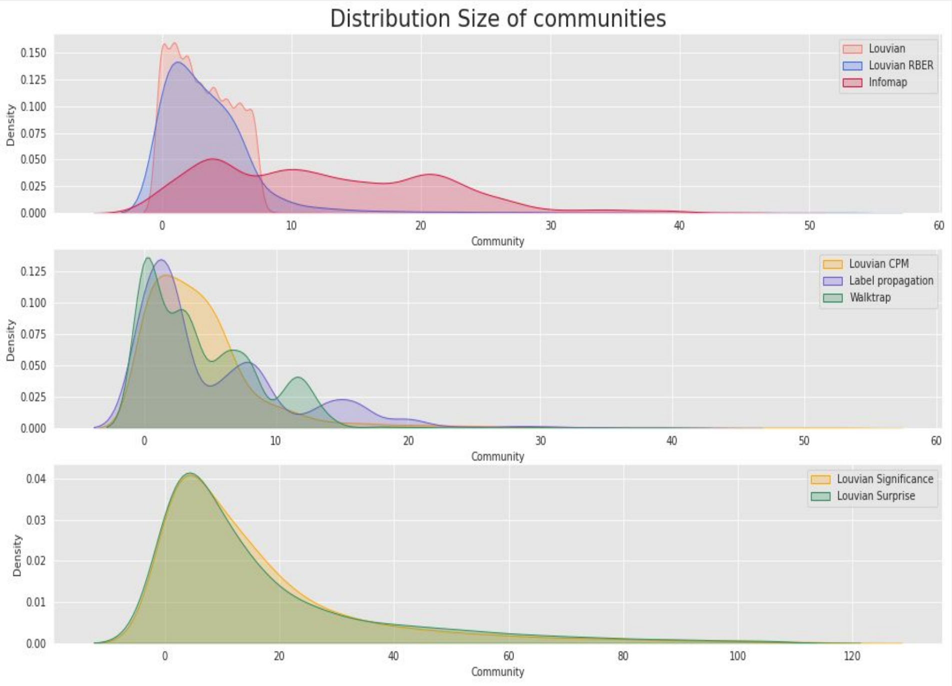


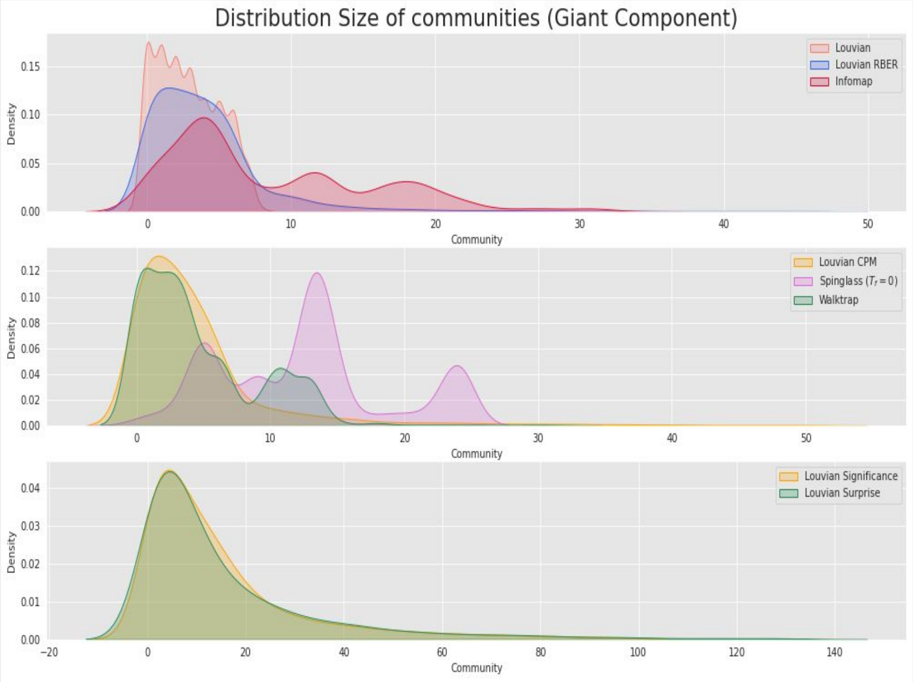
No distinguished anatomical regions have been detected with any of the algorithms. This is probably attributed to the non-uniform sampling of neurons during the dataset creation

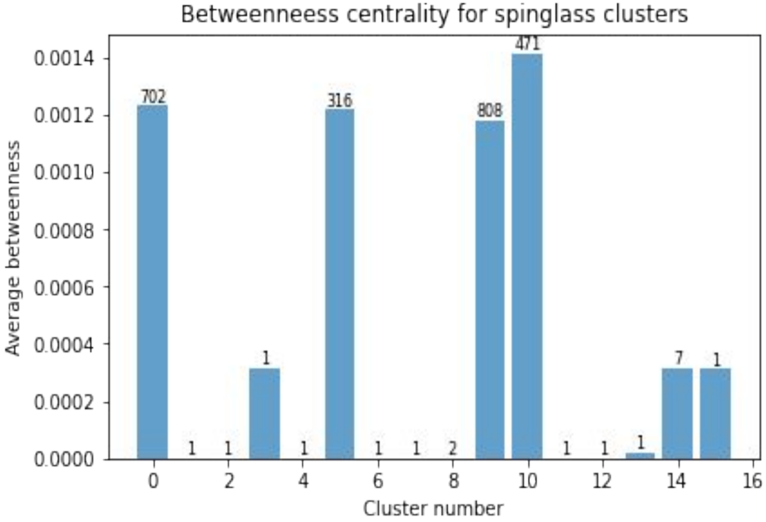


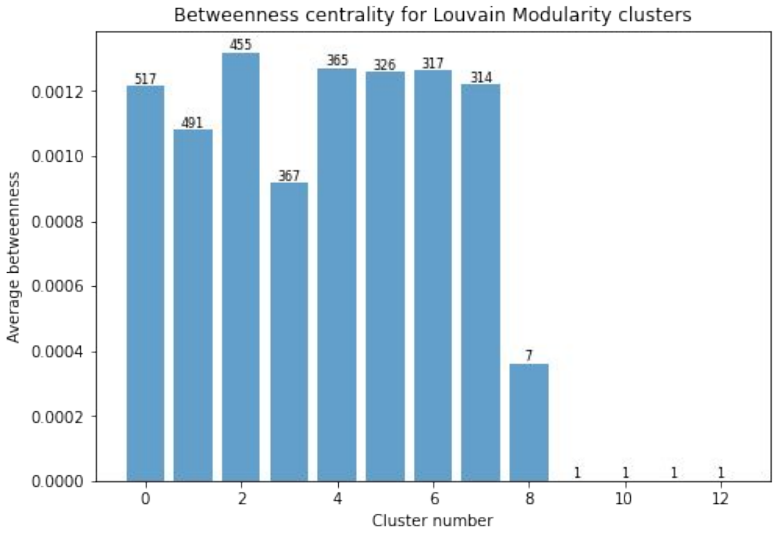
Comparison between algorithms: Distribution Size



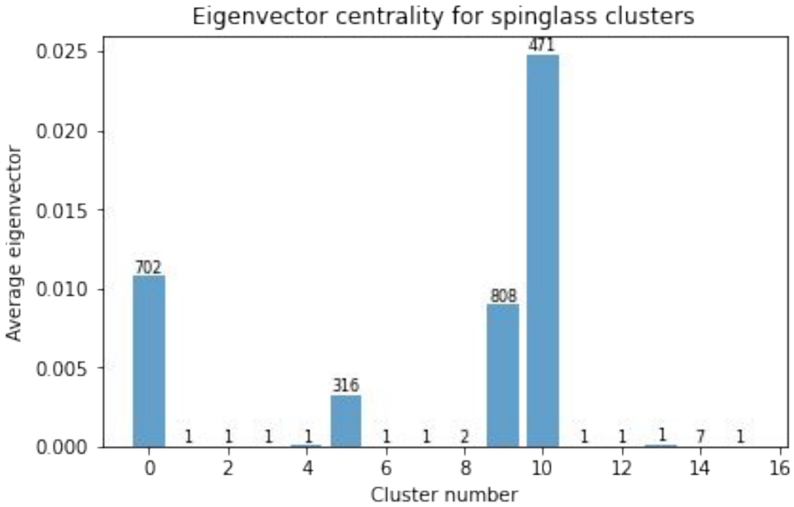


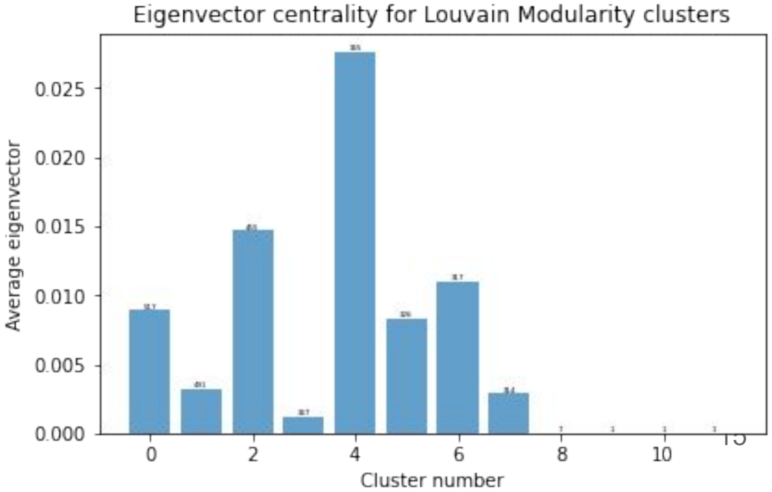




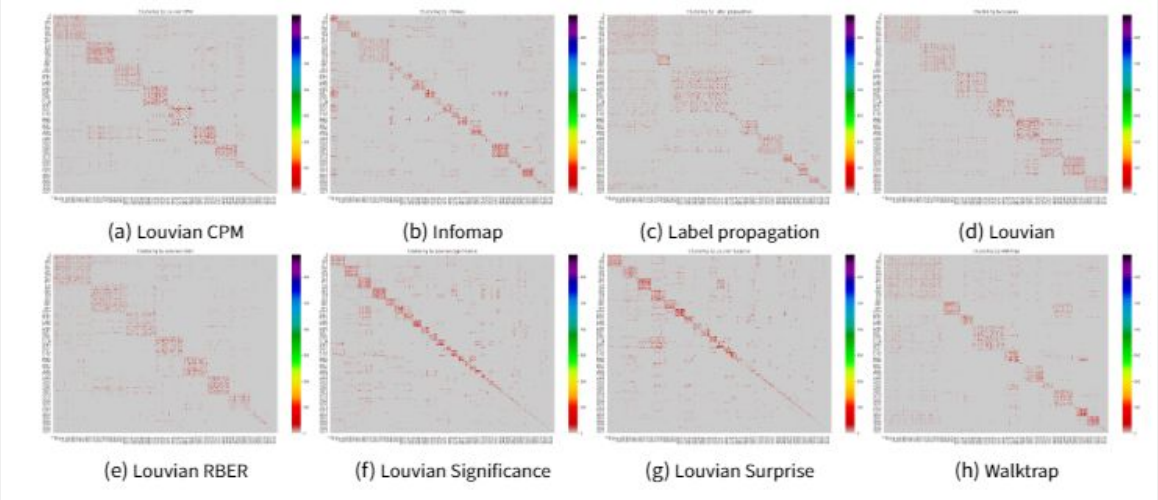


Comparison between algorithms: Betweenness centrality and eigenvector centrality

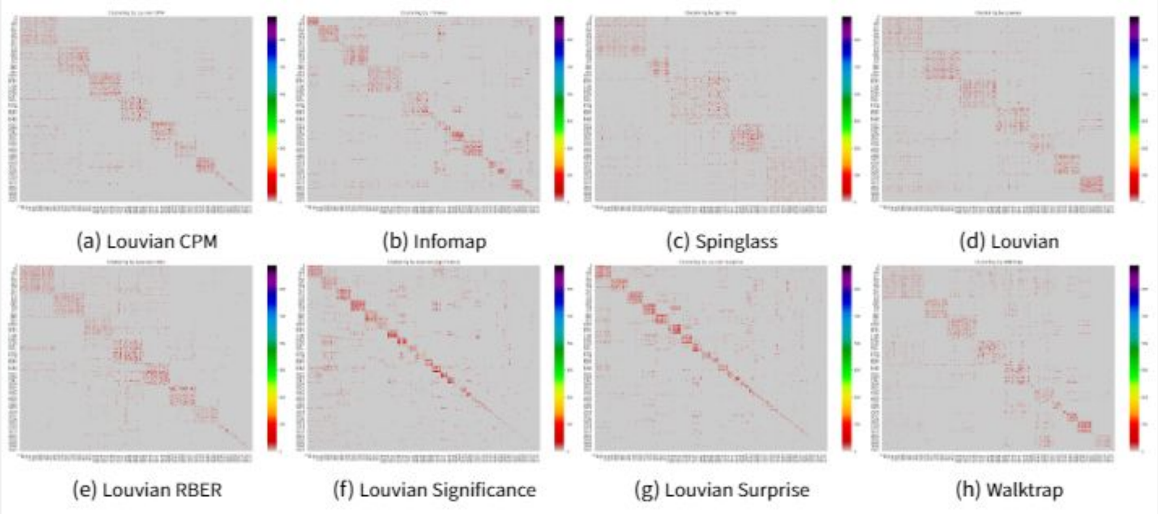




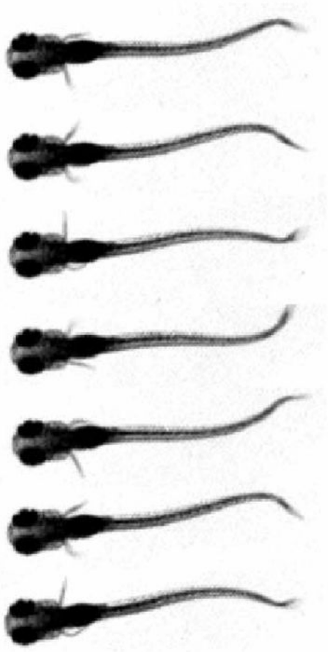
Comparison between algorithms



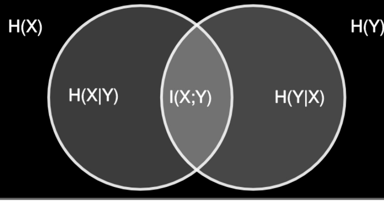
Whole Graph



Giant Component



Comparison between algorithms: VI



Giant Component

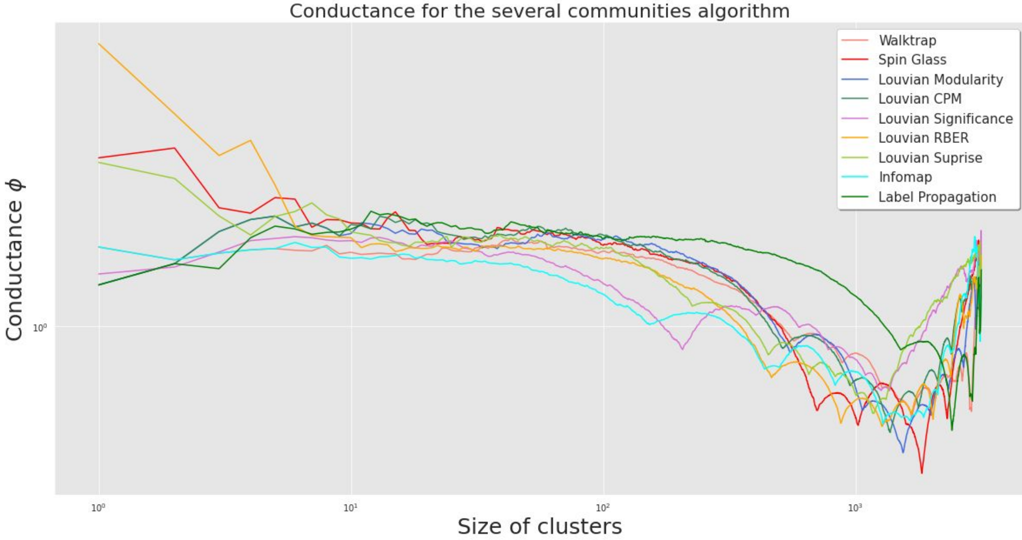
	Walktrap	Infomap	Label propagation	Louvian Modularity	Louvian RBER	Louvian CPM	Louvian Significance	Louvian Surprise	Spin Glass
Walktrap	0	1.7	2.1	1.6	1.6	1.7	2.2	2.3	1.7
Infomap	1.7	0	2.6	1.7	1.6	1.7	1.7	1.9	2
Label propagation	2.1	2.6	0	2	2.2	2.3	3.2	3.2	1.7
Louvian Modularity	1.6	1.7	2	0	0.94	1.1	2.4	2.2	1.4
Louvian RBER	1.6	1.6	2.2	0.94	0	0.63	2.1	1.9	1.6
Louvian CPM	1.7	1.7	2.3	1.1	0.63	0	2	1.9	1.7
Louvian Significance	2.2	1.7	3.2	2.4	2.1	2	0	1.6	2.7
Louvian Surprise	2.3	1.9	3.2	2.2	1.9	1.9	1.6	0	2.8
Spin Glass	1.7	2	1.7	1.4	1.6	1.7	2.7	2.8	0

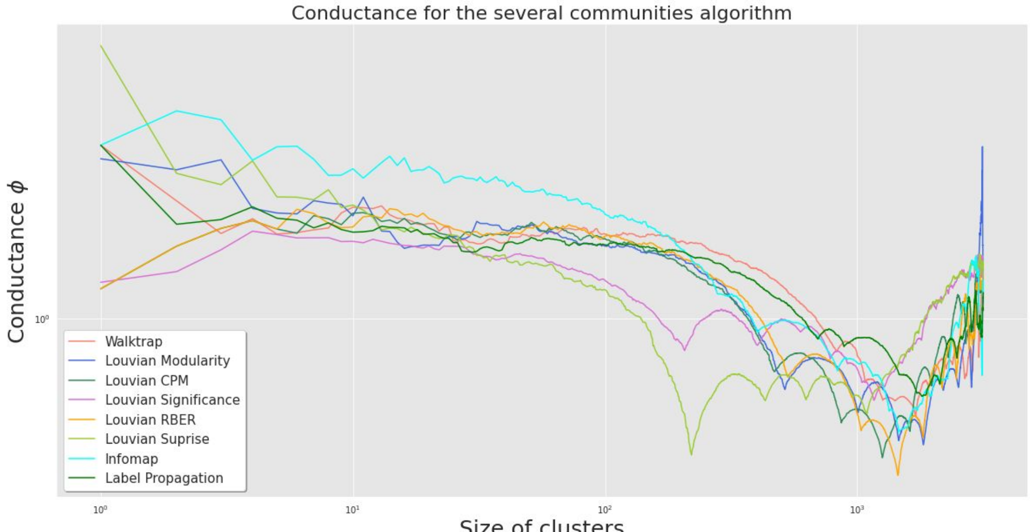
Whole Graph

Walktrap	Infomap	Label propagation	Louvian Modularity	Louvian RBER	Louvian CPM	Louvian Significance	Louvian Surprise
0	1.9	2.2	1.6	1.7	1.7	2.3	2.2
1.9	0	2.5	1.9	1.9	1.8	1.8	1.7
2.2	2.5	0	2.3	2.2	2.3	2.6	2.6
1.6	1.9	2.3	0	1	1.2	2.4	2.2
1.7	1.9	2.2	1	0	0.85	2.1	2
1.7	1.8	2.3	1.2	0.85	0	2	1.8
2.3	1.8	2.6	2.4	2.1	2	0	1.5
2.2	1.7	2.6	2.2	2	1.8	1.5	0

Community algorithm	Optimal size	Min conductance	Optimal size (GC)	Min conductance (GC)
Walktrap	1703	0.467	1668	0.511
Infomap	1461	0.412	1284	0.487
Label Propagation	1801	0.545	2411	0.464
Louvian Modularity	1828	0.374	1543	0.394
Lovuain RBER	1449	0.295	1272	0.478
Louvian CPM	1257	0.338	1371	0.457
Louvian Significance	1163	0.528	1360	0.621
Louvain Surprise	219	0.345	1179	0.526
Spin Glass	-	-	1832	0.338

Whole Graph





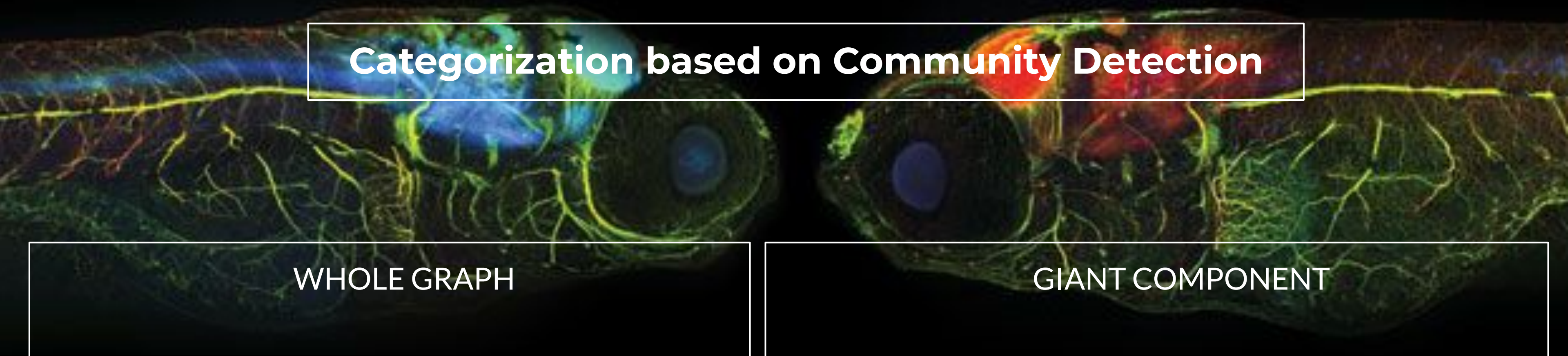
Giant Component

Conductance

$$\phi(S) = \frac{\mathrm{cut}(S)}{\min(\mathrm{vol}(S), \mathrm{vol}(\bar{S}))}$$

(edges leaving the set)

(total edges in the set)



Categorization based on Community Detection

WHOLE GRAPH

Large Brain Regions:

- Louvian Modularity
- Louvian RBER
- Louvian CPM

Large and small Brain Region:

- Walktrap
- Label propagation

Specific Brain Region:

- Louvian Significance
- Louvian Surprise
- Infomap

GIANT COMPONENT

Large Brain Region:

1. **With uniform cluster size:**
    - Louvian Modularity
    - Louvian RBER
    - Louvian CPM
2. **A mixture:**
    - Walktrap
3. **Irregular cluster sizes:**
    - Infomap
    - Spin Glass

Specific Brain Region:

- Louvian Significance
- Louvian Surprise

$\gamma \sim [2, 3] \rightarrow$ **Scale free**

$d \approx \ln(\ln N)/\ln(\gamma - 2)$

Unusual robustness → Threshold near one

→ more susceptible to the attack based on betweenness centrality

- Notable efficiency → more susceptible to the attack based on Closeness centrality

- **Positive assortativity** for in-Degree and out-Degree
- Many nodes act as **authorities** and few nodes act as **hubs**.

Conclusion

- Classification according to **brain size** of communities
- Around 10-20 number of **meaningful** communities
- Louvian modularity exhibit biggest value for the whole graph whereas Spin Glass for the GC
- Spin Glass may be the best one to capture the “real” regions of the brain.
- Most of the clusters have almost equal value for average betweenness.
- Robustness attack by communities ordered by betweenness centrality does not decrease the GC fraction any faster than the random attack.

Thank you for your attention