

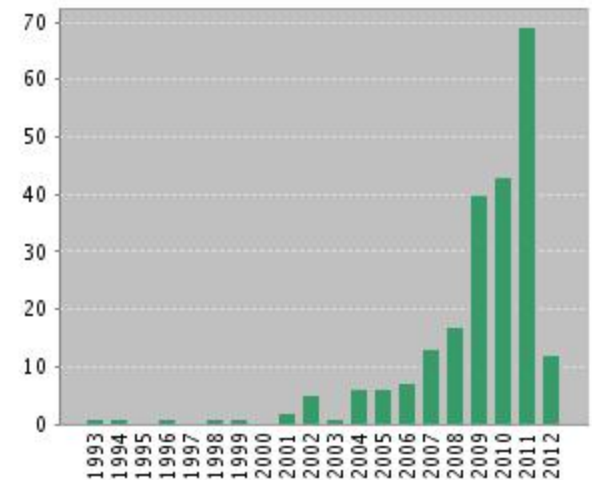
Brain Network Analysis with Pluto

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Laboratory of Neuro Imaging

Graph Theory and the Brain

- Made up of Nodes and Edges
 - Node: Brain Region (e.g. V5) or Single Voxel
 - Edge: Direct Connection between Nodes (e.g. Corpus Callosal Fiber)
- Mathematical Formalization of Connectivity
- Allows researchers to characterize communication
 - “small world networks”
 - Random networks
- Look for subtle patterns
 - Not visible at a glance
 - vs. easily visible effects such as lesions
- Pluto Tools makes these fast and easy



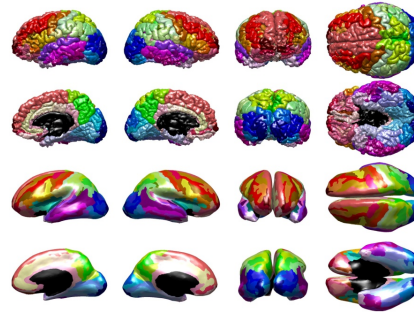
Published Papers
Featuring “Graph Theory”
and “Brain”

Overview

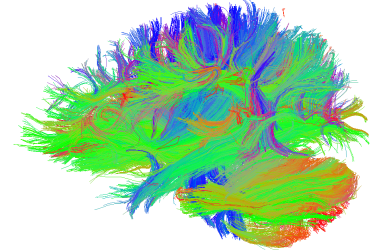
fMRI



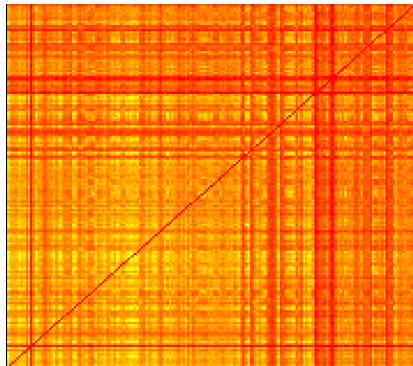
Cortical Parcellation Map



Diffusion Tractography



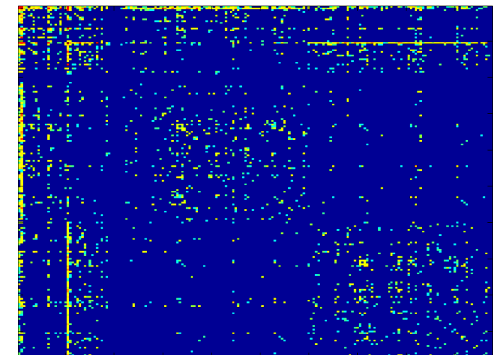
Voxel-Voxel Functional Connectivity



Regional Functional Connectivity

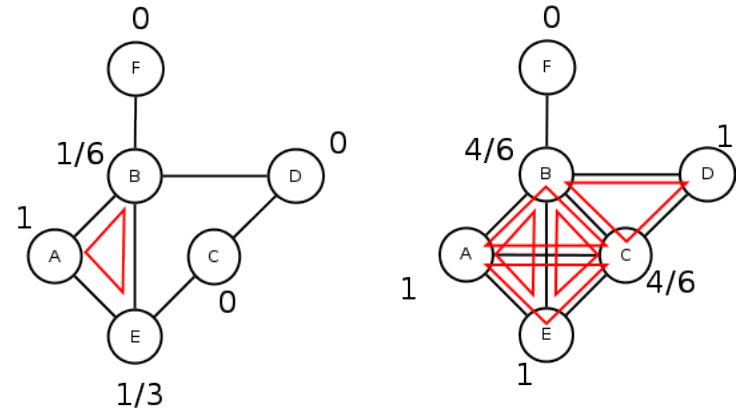


Regional Structural Connectivity

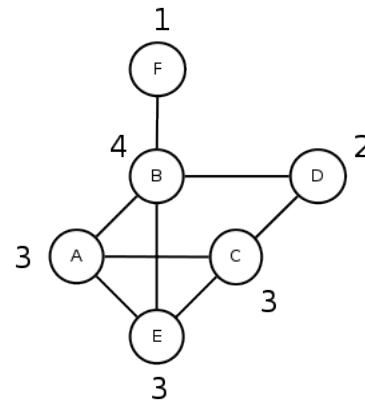


Node Statistics

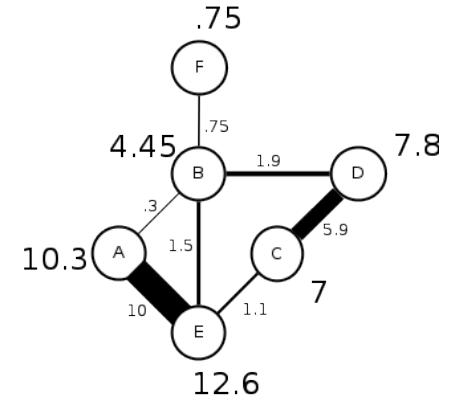
- Clustering Coefficient
 - Ratio of Realized vs. Potential Triangles
- Degree
 - Number of Edges
- Strength
 - Sum of Weights



Clustering Coefficient



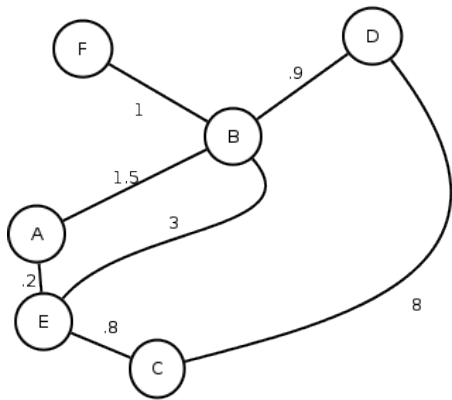
Degree



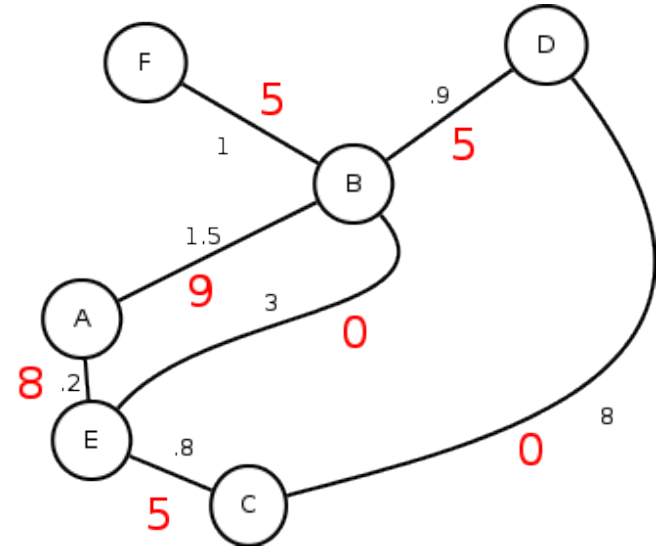
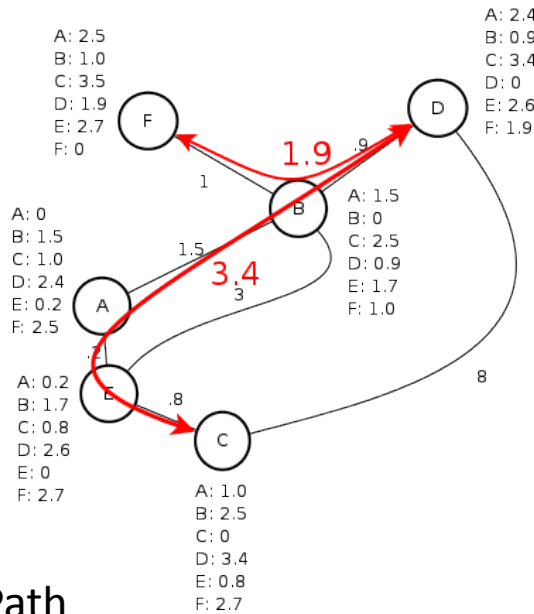
Strength

Distance Metrics

- All Shortest Paths
- Edge Betweenness
 - Number of Shortests Paths Traversing the edge



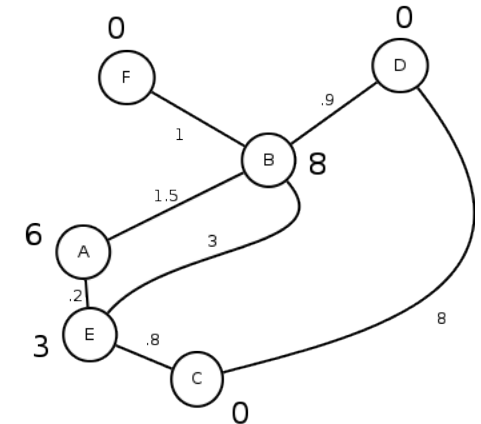
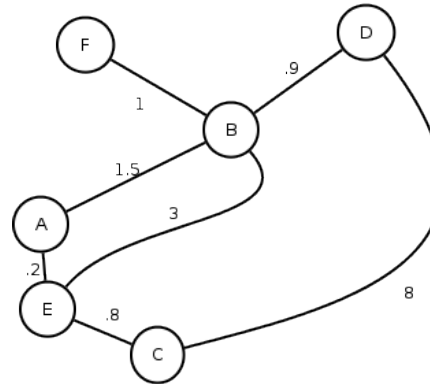
Shortest Path



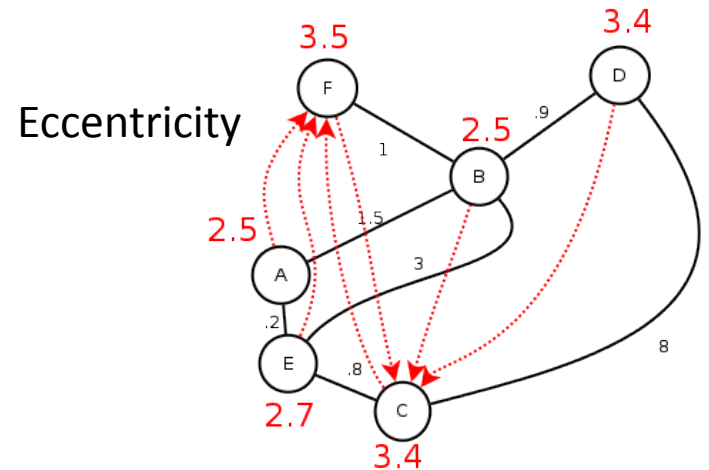
Edge Betweenness

Distance Metrics

- **Betweenness Centrality**
 - Number of Shortest Paths Containing the Vertex
- **Eccentricity**
 - Length of the longest shortest path for a vertex
- **Characteristic Path Length**
 - Average Shortest Path
- **Radius**
 - Minimum of Eccentricity
- **Diameter**
 - Maximum of Eccentricity



Betweenness Centrality



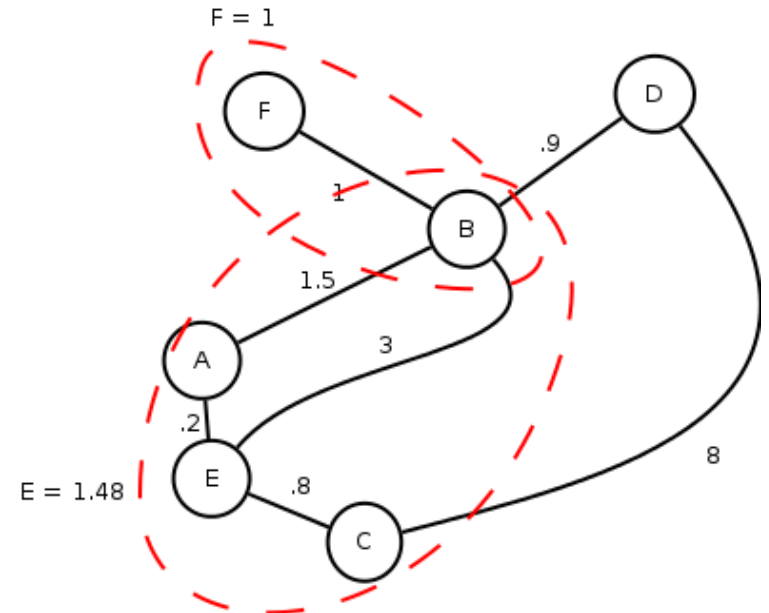
Eccentricity

Radius: 2.5
 Diameter: 3.5
 Characteristic Path Length: 1.8

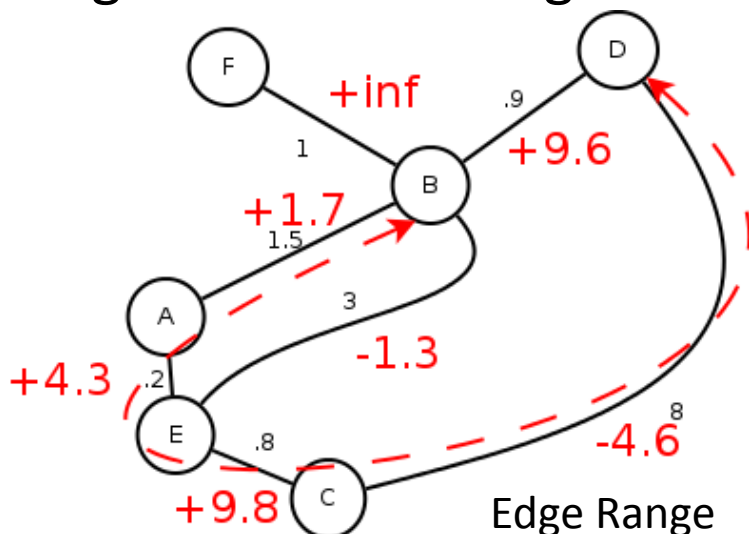
Distance Metrics

- Local Efficiency
 - Sum of Reciprocal Shortest Paths in subgraph

- Edge Range
 - “Shortcut” Paths – change in path length after removing a path



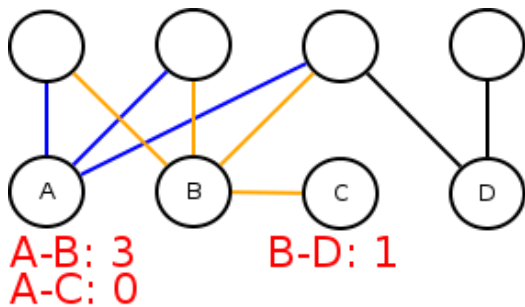
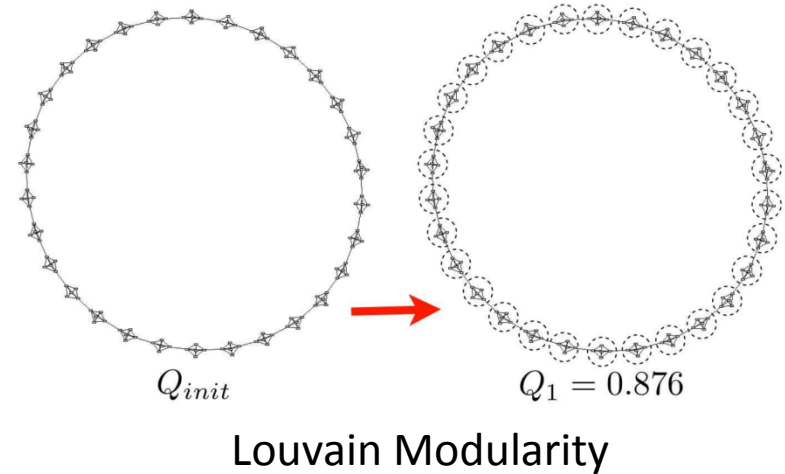
Local Efficiency



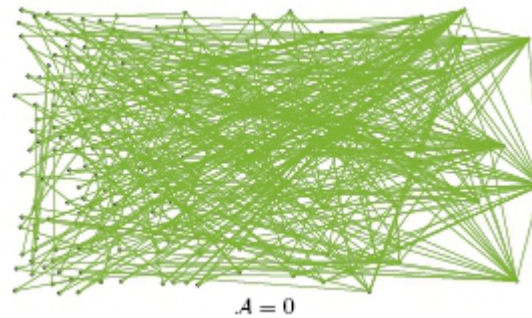
Edge Range

Other Metrics

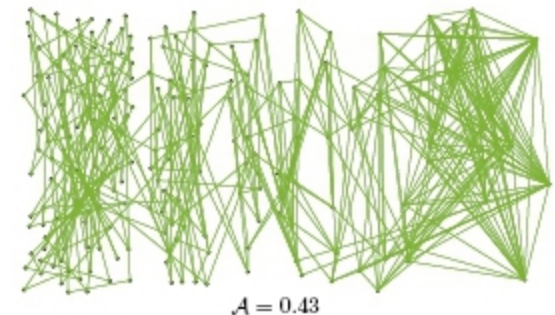
- Louvain Modularity
- Assortivity
 - Correlation of Degree Between Connected Vertices
- Matching Index



Matching Index



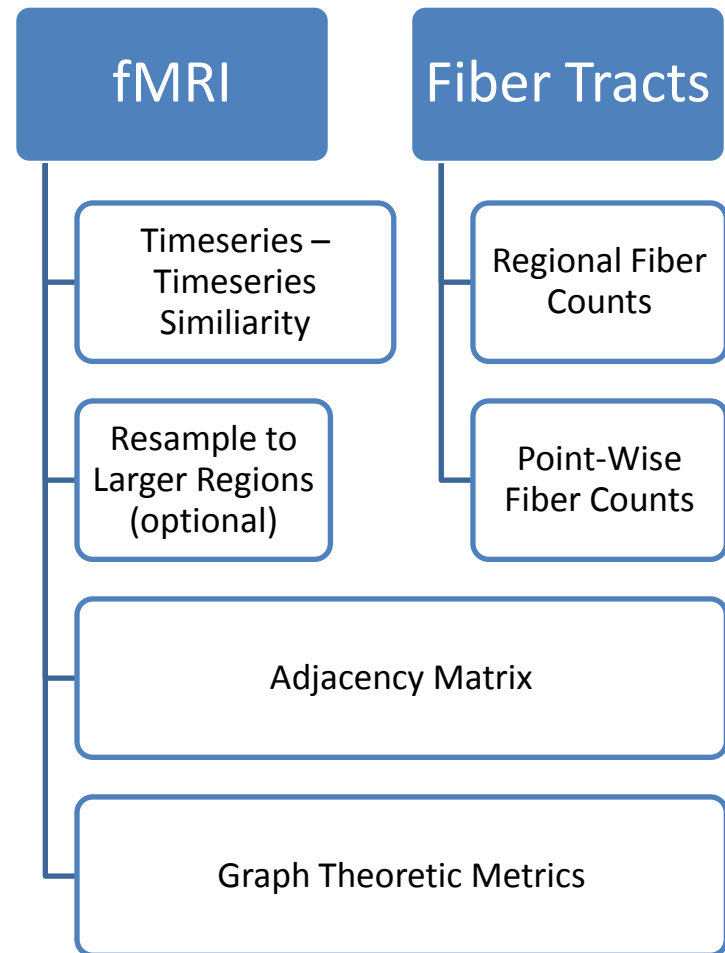
Low Assortivity



High Assortivity

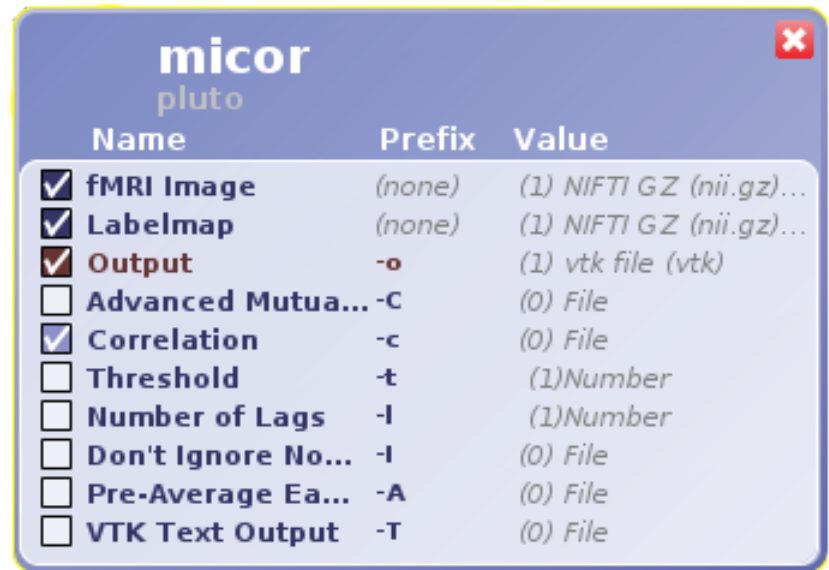
Pluto Tools Overview

- micor : timeseries similarity
 - Calculates voxel-voxel mutual information or correlation
- gCalcAdj : Fiber Counts
 - Count between regions or mesh-points
- gRed : Resampling
 - calculate regional averages of connectivity
- gRed : Graph Theory
 - Calculate Metrics using Graph Theory



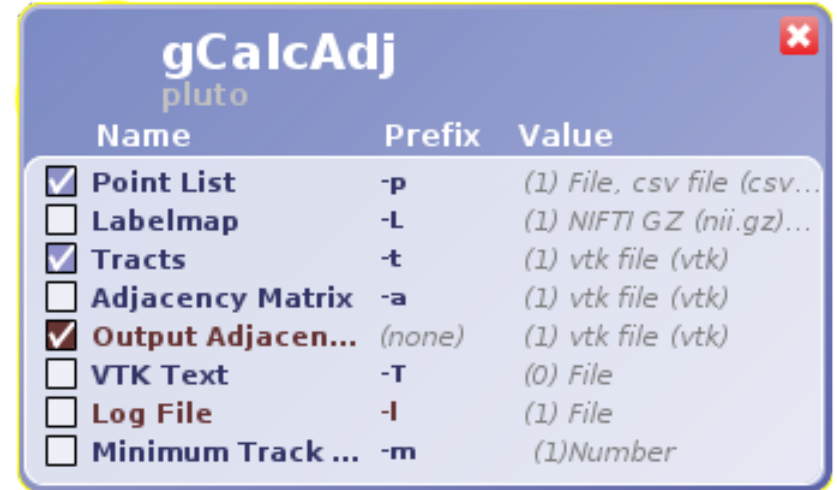
Functional Connectivity Calculation

- Required Input:
 - fMRI Image
 - Labelmap Image
 - Nearest N. Resampling Handled Internally
- Required Output:
 - Adjacency Matrix Stored in vtkImageData
- Lags: number of TR's to lag in search of maximal connectivity (2L+1)
- Metrics:
 - Correlation, “-c” (Recommended in Pipeline, < 1 hour runtime)
 - Mutual Information (Not Recommended in Pipeline, 10+ Hour runtime)
 - Mutual Information with Interpolation (Not Recommended in Pipeline, Day+ Runtime)
- Outside Pipeline: “-G” to use GPU



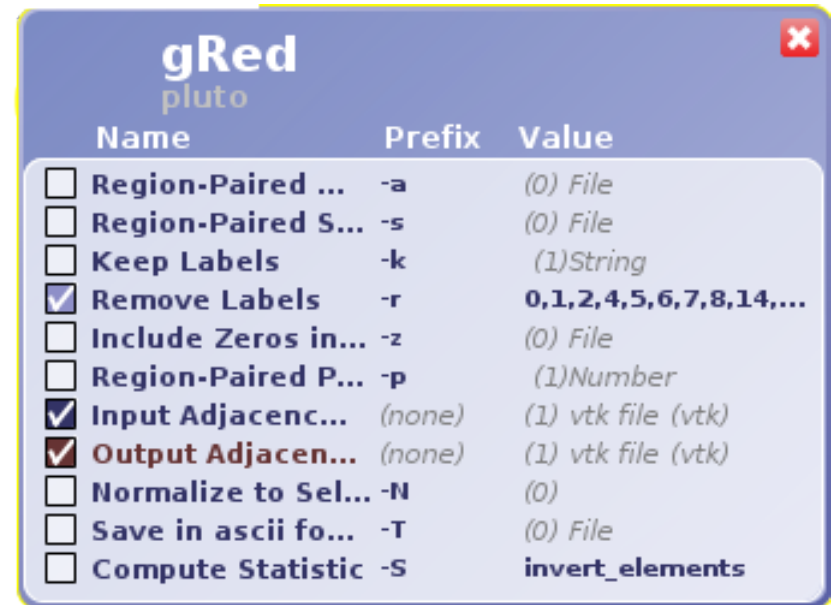
Structural Connectivity Calculation

- Required Input:
 - Vertices Either:
 - Point List “-p”
 - Label Map Image “-L”
 - Input Data Either:
 - Existing Adj. Matrix “-a”
 - Fiber Tracts “-t”
- Filter out short tracts with “-m <length>”
 - Very short tracts are often considered noise



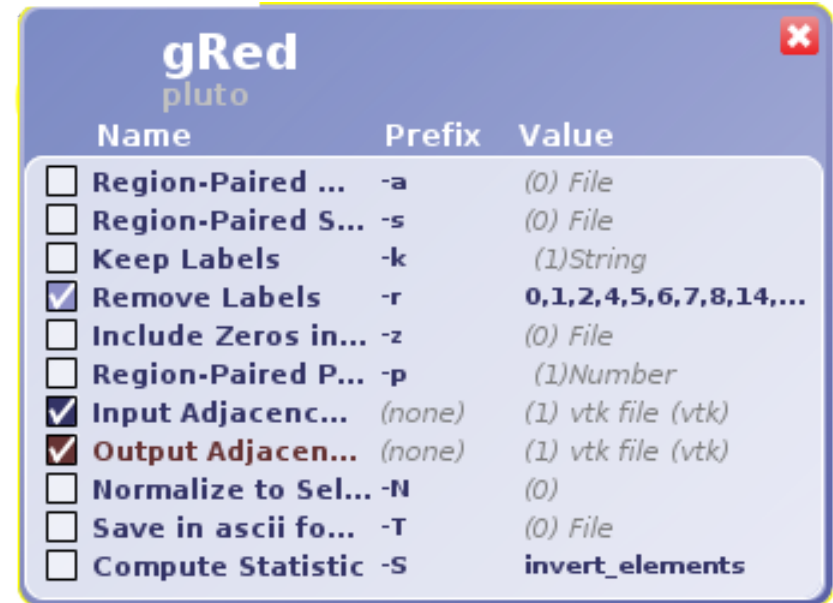
Graph Modification

- Keep Only List of Nodes
 - e.g. List of cortical Regions
- Remove List of Nodes
 - e.g. Ventricles
 - Extremely important when calculating shortest paths
- Graph Simplification:
 - Average Connectivity over Label-Pairs
 - Percentile over Label-Pairs
 - Optional Inclusion of Zeros in statistics



Graph Statistics “-S”

- Compute Statistic “-S”:
 - Betweenness Centrality
 - Clustering Coefficient
 - Degree
 - Strength
 - Eccentricity
 - Local Efficiency
 - Shortest Path
 - Edge Range
 - Edge Betweenness
 - Matching Index
 - Joint Degree
 - Assortivity
 - Characteristic Path Length
 - Diameter
 - Radius
 - Global Efficiency
 - Louvain Modularity
 - Invert Elements (for converting weight to distance)



Odds and Ends

- gTxtToVtk
 - Input: CSV Adjacency Matrix
 - Output: vtkImageData
- gVtkToTxt
 - Input: vtkImageData
 - Output: CSV Adjacency Matrix
- trkToVtk
 - Input: trackvis .trk file
 - Output: vtkPolyLines

gTxtToVtk

pluto

Name	Prefix	Value
<input checked="" type="checkbox"/> Input Adj.	(none)	(1) Text file (txt), c...
<input checked="" type="checkbox"/> Output Adj.	(none)	(1) vtk file (vtk)

gVtkToTxt

pluto

Name	Prefix	Value
<input checked="" type="checkbox"/> Input Adj.	(none)	(1) vtk file (vtk)
<input checked="" type="checkbox"/> Output Adj.	(none)	(1) Text file (txt), c...

trkToVtk

Name	Prefix	Value
<input checked="" type="checkbox"/> Input	(none)	(1) tract (.trk)
<input checked="" type="checkbox"/> Output	(none)	(1) vtk file (vtk)

Conclusions

- Native C++ Code
 - Source Available for Request
 - Compiled Versions at `/ifs/students/mchambers/pluto-0.5`
- Pipelines Available Now
 - Make interfacing with other tools far easier
- GPU Support for functional connectivity (outside pipeline)
 - More may be added for slower graph-metrics
- Designed For Neuro Imaging Applications
 - Wide Variety of Input Image Types (nifti preferred)
 - Easily Convertible VTK format, tools included
- Please Contact Me at:
 - micahcc@ucla.edu
 - Come talk to me at the Ice Cream Social