



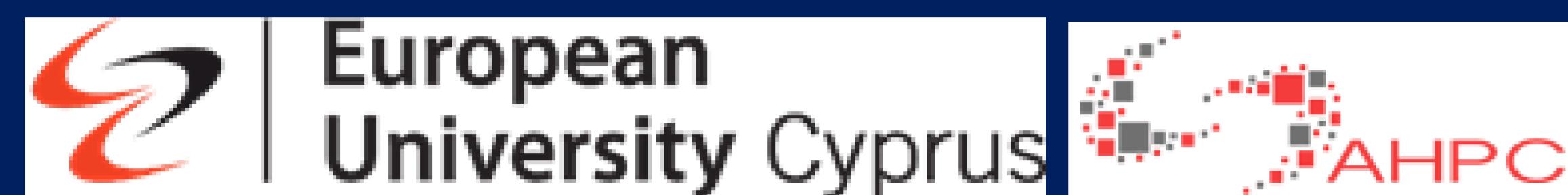
# GRATOS (Graph Theoretical Tools for Sciences)

Excellence Hub - EXCELLENCE/1216/0207

<http://gratos.euc.ac.cy/>



## Astrophysics and High Performance Computing Research Group <http://ahpc.euc.ac.cy>



### GRATOS BASIC Info

GRATOS (Graph Theoretical Tools for Sciences) – EXCELLENCE/1216/0207 is a project funded by the Cyprus Research Promotion Foundation, under the program EXCELLENCE HUBS, Programmes for Research, Technological Development And Innovation, "RESTART 2016 – 2020".

### GRATOS Aim:

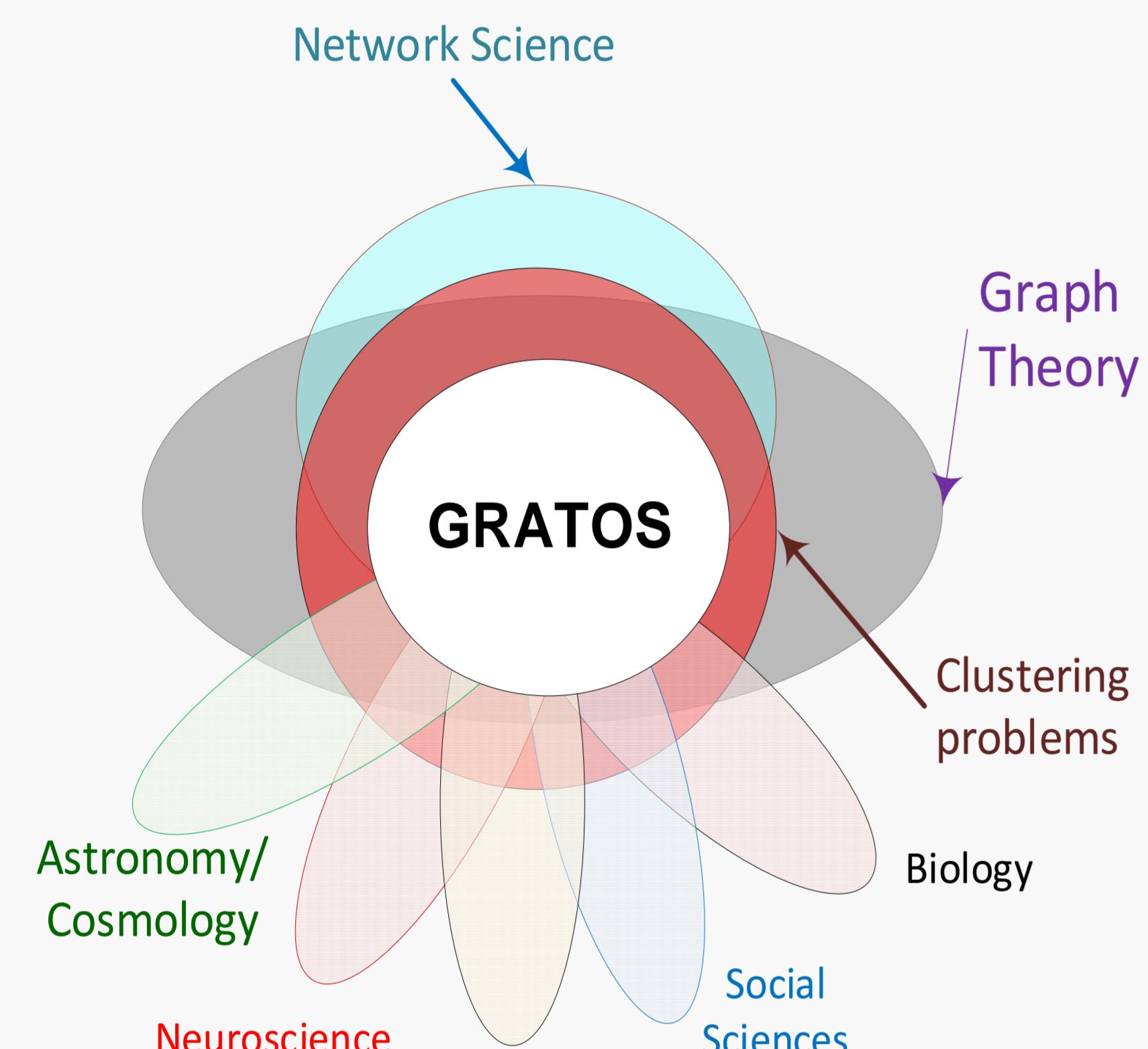
Target the important, multidisciplinary task of **clustering** focusing on **Astrophysics** and **Neuroscience** applications.

### Approach/tools

- ✓ Graph Theory
- ✓ Network Science
- ✓ Applications (**Astrophysics** and **Neuroscience**) Knowledge

### Goal:

A common scientific framework of **efficient solutions** for clustering problems in diverse Sciences.



The multi-disciplinary nature of the GRATOS project.

### GRATOS Partners:

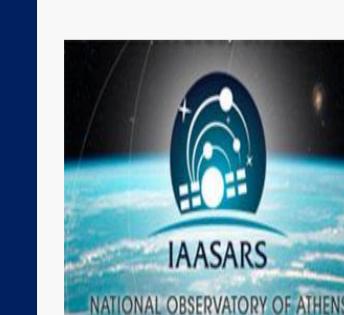
European University Cyprus > European University Cyprus (EUC-Leader).



➤ **AAI Scientific Cultural Services Ltd (AAISCS)**: is a private company with research intensive profile focusing on basic and applied research primarily in cognitive neuroscience (<http://aaics.com/>)



➤ **Institute of Communication and Computer Systems at National Technical University of Athens (ICCS/NTUA)**: is a leading R&D Institute in Greece. It is associated with the School of Electrical and Computer Engineering (ECE) of the National Technical University of Athens (NTUA) (<https://www.iccs.gr/>).

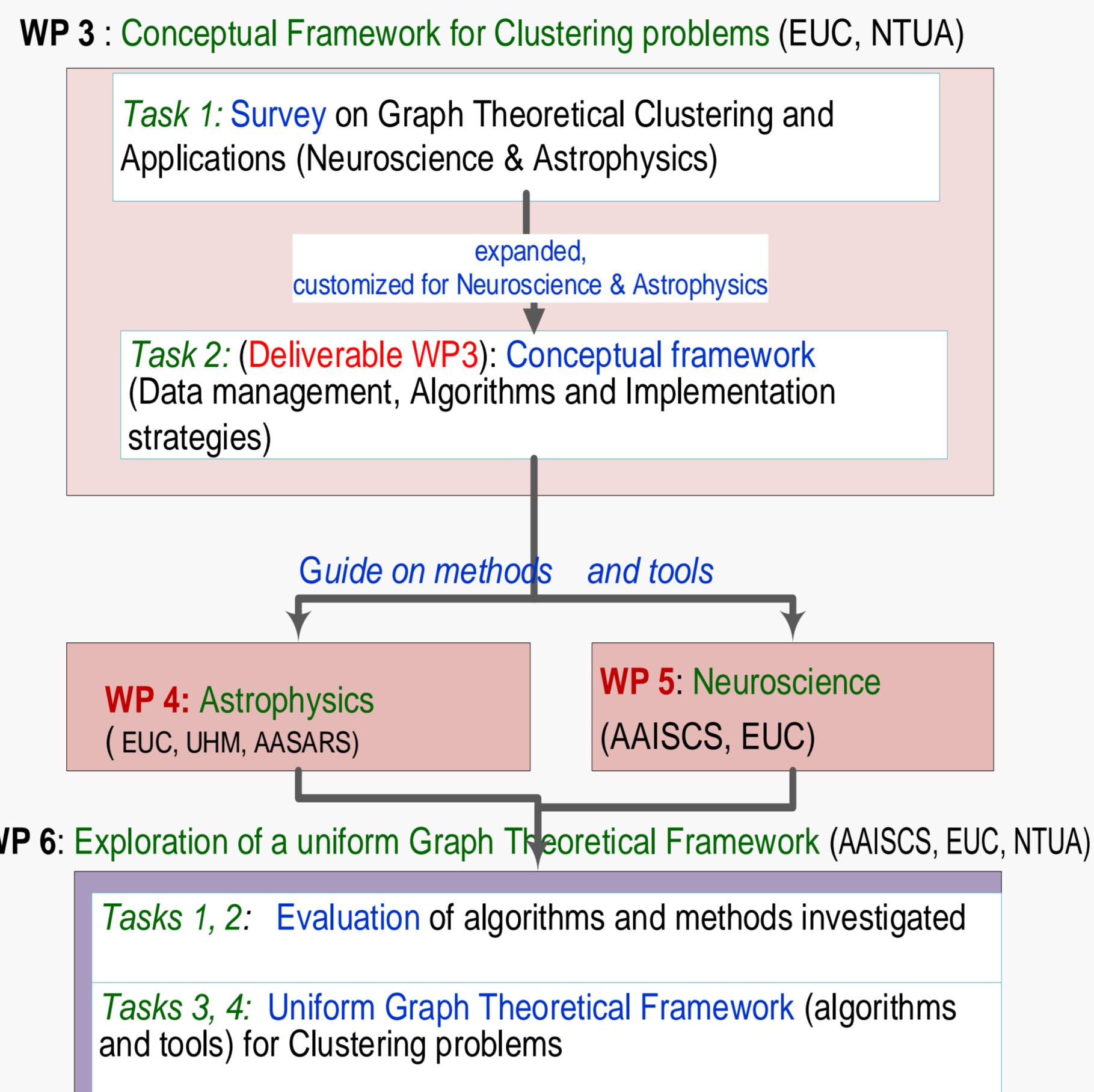


➤ **Institute for Astronomy, Astrophysics, Space Applications and Remote Sensing (IAASARS)**: is one of the three institutes of the National Observatory of Athens, the oldest research institution in Greece (<https://www.astro.noa.gr/en/main/>).



➤ **University of Hawaii at Manoa (UHM)**: is a public co-educational research university as well as the flagship campus of the University of Hawaii system. The school is located in Manoa, an affluent neighborhood of Honolulu, Honolulu County, Hawaii, United States (<https://manoa.hawaii.edu/>)

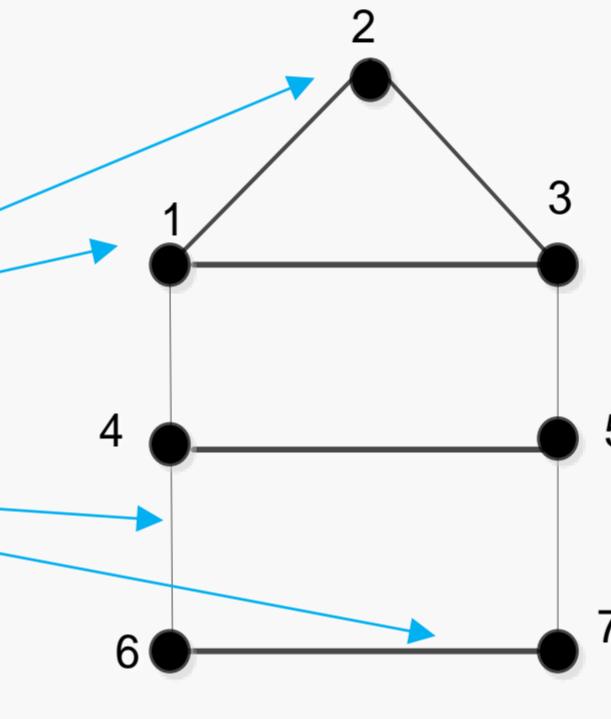
### GRATOS Implementation Plan



### Background- Graph Theory

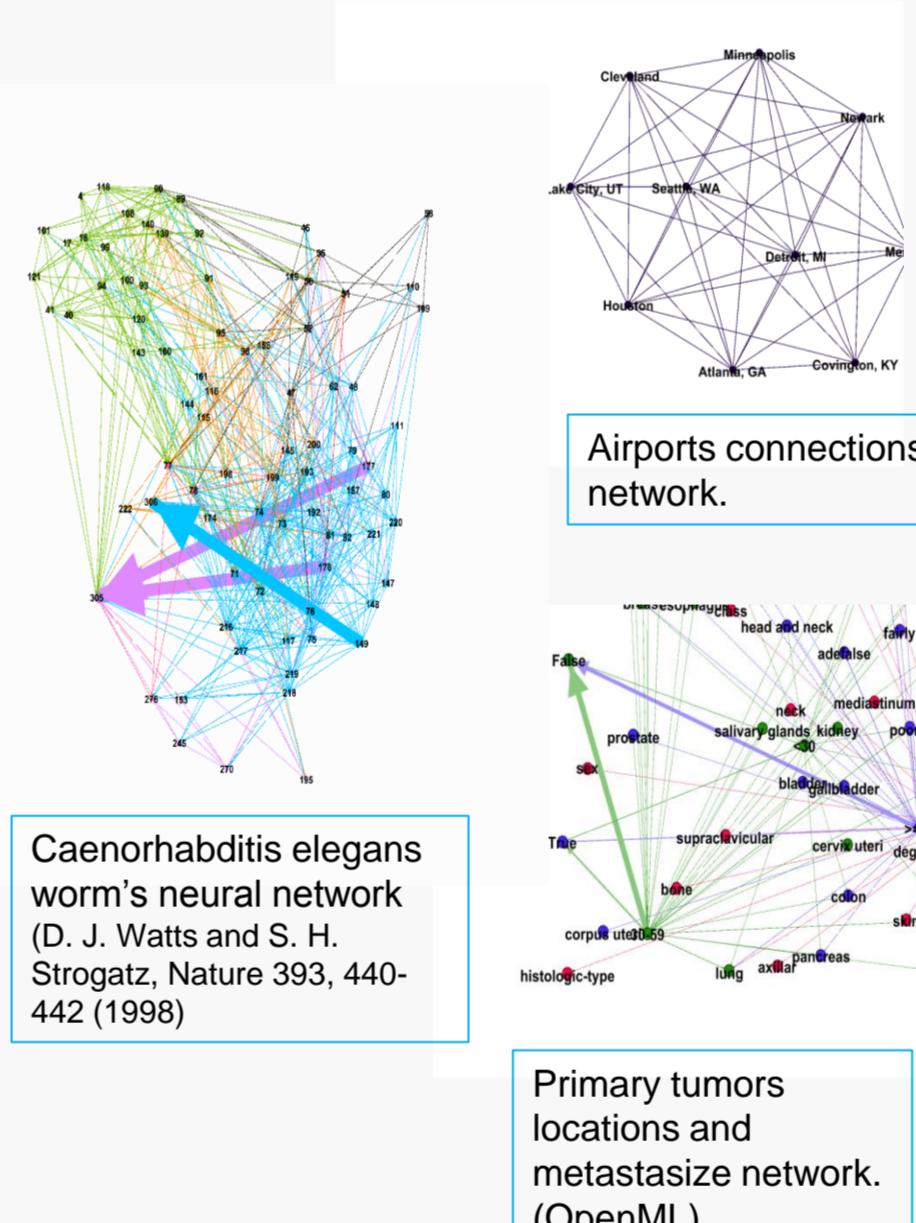
#### Definition:

- A graph  $G(V, E)$  consists of a :
  - a set  $V$  of **vertices**, **nodes**, or **points** which may be **related-connected** to each other
  - a set  $E$  of **edges**, **arcs**, or **lines**, i.e.
$$E = \{ (v, u) \mid v, u \in V \}$$



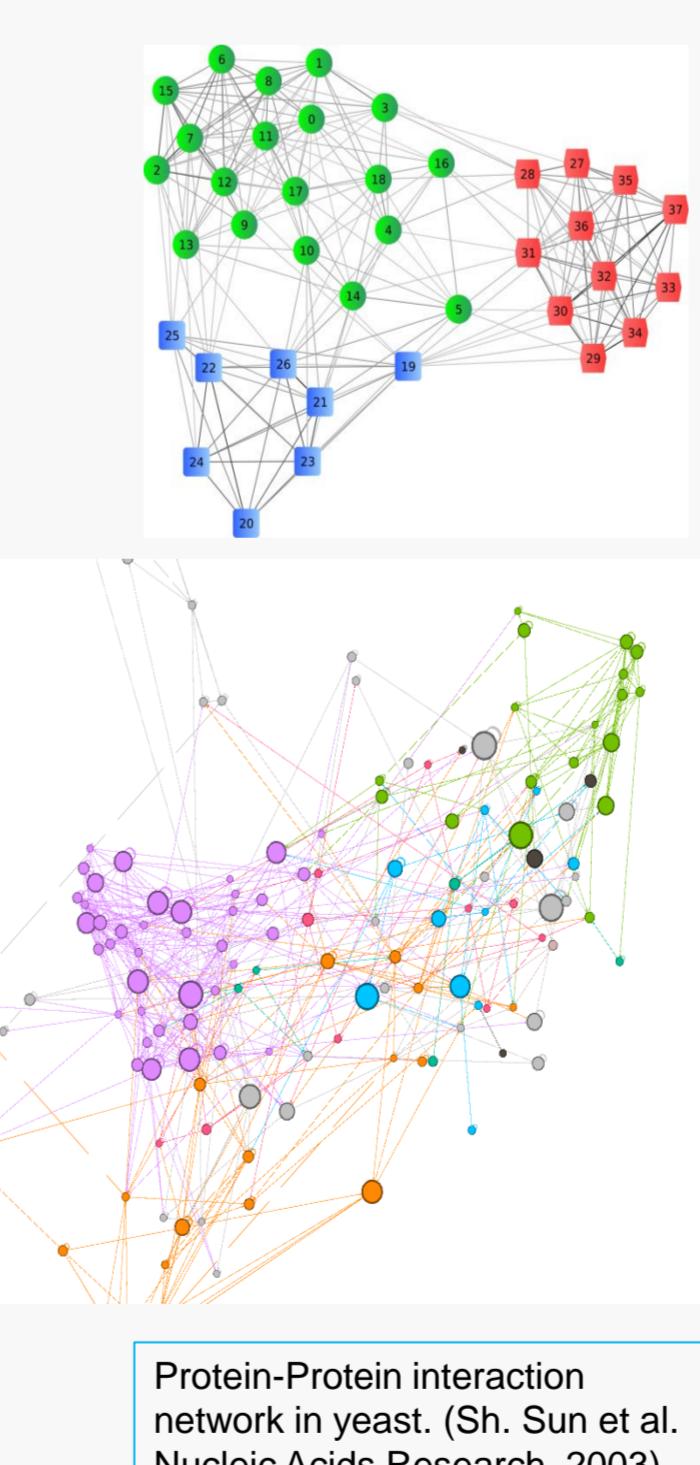
### Graphs as models

- models **system** of a set  $S$  of **entities** (nodes) that may be related via **pairwise relations** (set  $E$ ).
  - If an entity  $x \in V$  is **related** to  $y \in V \Rightarrow (x, y) \in E$
  - **Nodes** can be **non-homogeneous**
  - Edges declare/measure for a pair of nodes:
    - Dependencies, conflicts, relationships,
- Similarity** between nodes:
- Numerical measure of **how alike** two nodes are.
  - Higher when objects are more alike.

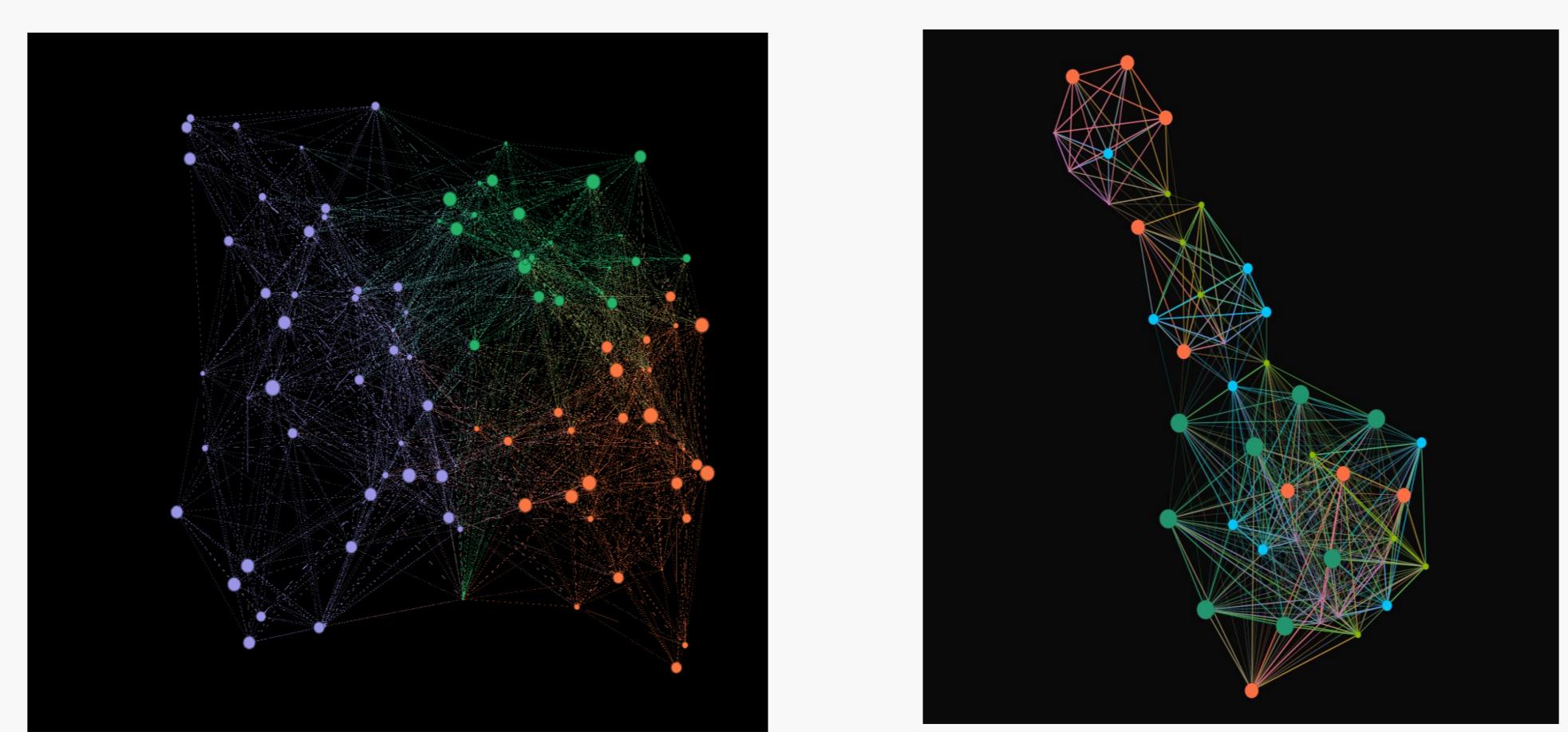


### The Graph Cluster problem

- No universal Definition!
- **Clustering** (*intuitive* definition):
  - grouping of **similar** objects
  - according to some **similarity** function
- **Clustering** (*Graph theoretic* definition):
  - the task of detecting group (**clusters**) of the vertices such a way that:
    - there should be **many edges inside** each cluster and
    - relatively **few edges between** the clusters.



### Selected Clusters investigated in GRATOS



Clustering of simulated galaxies. Nodes' sizes are proportional to their stellar mass.

Human's subjects response times to visual stimuli.

## AAI Scientific Cultural Services Ltd Laboratory for Human Brain Dynamics (LHBD) <http://aaics.com/LHBD/>



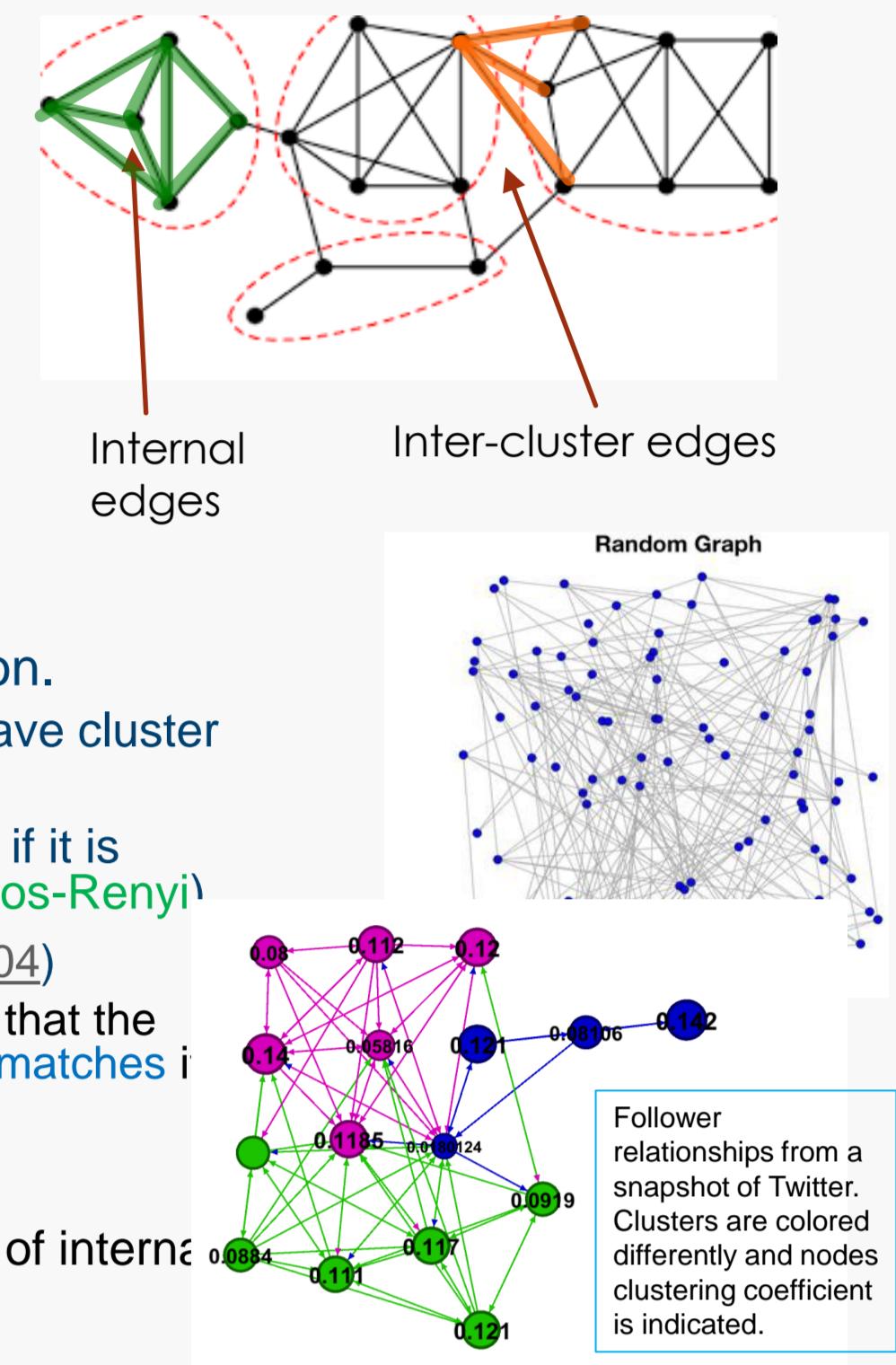
### Clusters/Communities Measurements

- **Intra-Cluster density** of a cluster  $C$   

$$\equiv \frac{(\# \text{ internal edges of } C)}{(\text{total possible internal edges})}$$
- **Inter-clustering density**  

$$\equiv \frac{(\# \text{ inter-cluster edges of } C)}{(\text{total possible inter-cluster edges})}$$
- **Connectedness** of cluster  $C$   

$$\equiv (\exists \text{ path between nodes of } C, \text{ using only nodes of } C)$$

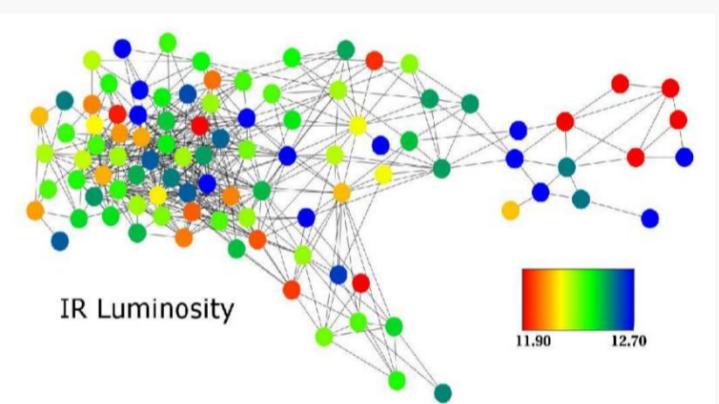


### Modularity

- Frequently used Quality Function.
- A random graph **not** expected to have cluster structure
- A graph **has** a cluster (community) if it is **different** from a random graph (Erdos-Renyi)
- **Null model** (Newman and Girvan 2004)
  - Edges are **rewired at random** so that the **expected degree** of each vertex **matches** its **degree** in the **original graph**
- **Modularity** of a cluster  $C$ 
  - $(\# \text{ of internal edges of } C) - (\# \text{ of internal edges of } C \text{ in the null model})$
  - Range: [-1,1]

### GRATOS Clustering Problems targeted in Cosmology and Astrophysics

► In the domain of Cosmology, we will use Graph Theoretical tools to study the clustering of galaxies which as is well known contains important constraints to cosmological models and parameters (e.g. [White & Frenk 1991]. As shown by [Hong et al 2016] an analysis of the clustering of galaxies using graph theory can be much more informative about the topology of the galaxy distribution compared with more traditional methods like the two-point correlation function.



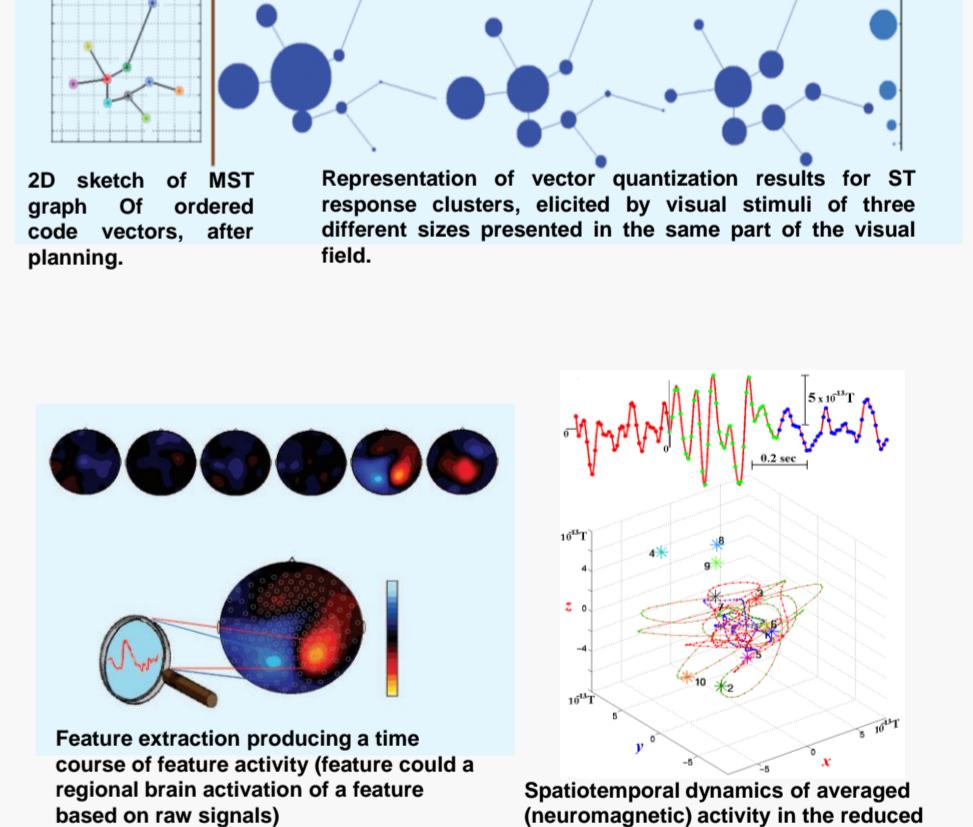
► In the domain of Astrophysics, we aim to explore Graph Theoretical tools combined with Bayesian inference for studying the evolution of galaxies. [Farrah et al. 2009] used bayesian inference and graph theory to analyse the SEDs of a sample of 102 low redshift infrared galaxies for which such high quality data are available.



Farrah et al succeeded using this approach to develop an evolutionary paradigm for low redshift infrared galaxies. We plan to use a similar approach to study the evolution of high redshift dusty star forming galaxies (e.g. [Blain et al. 2002, Casey et al. 2014]).

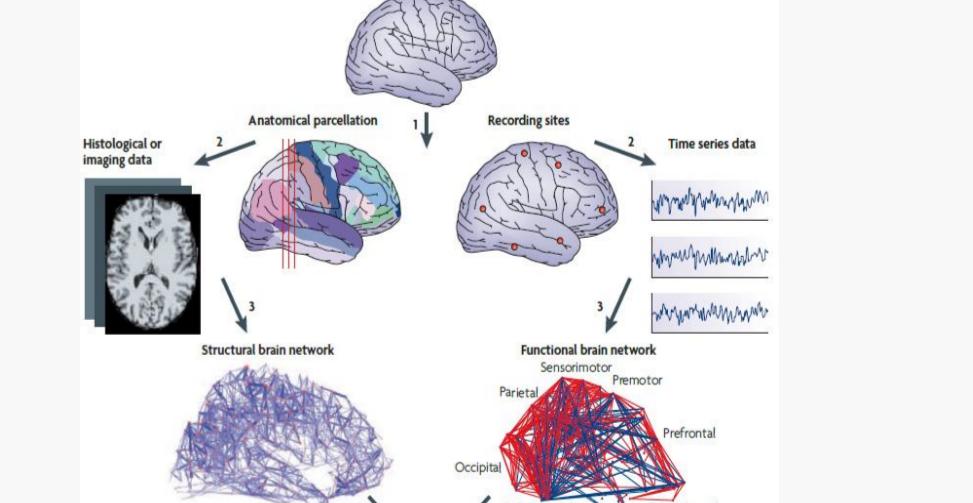
### GRATOS Clustering Problems targeted in Neuroscience

In neuroscience we have first used minimal spanning tree to obtain an "efficient" planar representation of single response manifold of single trial (ST) responses for clustering purposes (top figure). We were also the first to combine such structural description of response manifold with the dynamical description of ST responses (bottom right) using as input features of regional activations (bottom left) (Laskaris and Ioannides 2002; Laskaris, Fotopoulos and Ioannides 2004).



In GRATOS we will extend these methods and use new ones to:

- Analyze a set of tests producing results for response (selection) accuracy designed to cluster children according to educational needs and/or talents.
- Based on responses to questionnaires and features extracted from EEG data for smokers as they were trying to quit smoking using different methods.
- Analyze sensor based features and features derived from the tomographic analysis of the raw EEG data of sleep to produce an objective classification of sleep stages and other periods before and during characteristic graph elements.



The use of Graph Theory for studying structural and functional brain networks.  
(E. Bullmore and Olaf Sporns  
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