In [1]:
```
import igraph as ig
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
%matplotlib inline
from sklearn.linear_model import LinearRegression
from collections import Counter
import os
import umap
import pickle
import partition_igraph
import subprocess
from sklearn.metrics import adjusted_mutual_info_score as AMI
from itertools import combinations
import time
import warnings
warnings.filterwarnings('ignore')

## we used those for the book, but you can change to other colors
cls_edges = 'gainsboro'
cls = ['silver','dimgray','black']
```

In [2]:
```
datadir = '../Datasets/'
```

In [3]:
```
def run_clustering(z, n=None, exclude=[], verbose=False):
    cluster_map = {}
    if 'ecg' not in exclude:
        starting_time = time.time()
        cluster_map['ecg'] = z.community_ecg().membership
        if verbose: print('ecg:', time.time() - starting_time)
    if 'louvain' not in exclude:
        starting_time = time.time()
        cluster_map['louvain'] = z.community_multilevel().membership
        if verbose: print('louvain:', time.time() - starting_time)
    if 'infomap' not in exclude:
        starting_time = time.time()
        cluster_map['infomap'] = z.community_infomap().membership
        if verbose: print('infomap:', time.time() - starting_time)
    if 'label_prog' not in exclude:
        starting_time = time.time()
        cluster_map['label_prog'] = z.community_label_propagation().membership
        if verbose: print('label_prog:', time.time() - starting_time)
    if 'gn' not in exclude:
        starting_time = time.time()
        cluster_map['gn'] = z.community_edge_betweenness().as_clustering(n).membership #
        if verbose: print('gn:', time.time() - starting_time)
    if 'cnm' not in exclude:
        starting_time = time.time()
        cluster_map['cnm'] = z.community_fastgreedy().as_clustering(n).membership
        if verbose: print('cnm:', time.time() - starting_time)
    return cluster_map
```

Problem 1

In [4]:
```
z = ig.Graph.Famous('zachary')
z.vs['size'] = 12
z.vs['name'] = [str(i) for i in range(z.vcount())]
```

```
z.vs['label'] = [str(i) for i in range(z.vcount())]
z.vs['label_size'] = 8
z.es['color'] = cls_edges
z.vs['comm'] = [0,0,0,0,0,0,0,0,1,1,0,0,0,0,1,1,0,0,1,0,1,0,1,1,1,1,1,1,1,1,1,1,1]
z.vs['color'] = [cls[i] for i in z.vs['comm']]
#ig.plot(z, 'zachary_gt.eps', bbox=(0,0,300,200))
ig.plot(z, bbox=(0,0,350,250))
```

Out[4]:

b' \n'

In [5]:
```
print("---- AMI ----")
cluster_map = run_clustering(z, n=2)
ground_truth = z.vs['comm']
for cluster_method, cluster in cluster_map.items():
    ami = AMI(ground_truth, cluster)
    print(cluster_method, ':', round(ami, 4))
```

```
---- AMI ----
ecg : 0.6298
louvain : 0.5817
infomap : 0.6874
label_prog : 0.2015
gn : 0.8328
cnm : 0.8335
```

Problem 2

In [6]:
```
## read the GitHub edge list as tuples and build undirected graph
D = pd.read_csv(datadir+'GitHubDevelopers/musae_git_edges.csv')
tuples = [tuple(x) for x in D.values]
gh = ig.Graph.TupleList(tuples, directed = False)

## read node features
X = pd.read_csv(datadir+'GitHubDevelopers/musae_git_target.csv')

## map node names in edgelist to indices in the graph
idx = [int(i) for i in gh.vs['name']]
sorterIndex = dict(zip(idx,range(len(idx))))
X['Rank'] = X['id'].map(sorterIndex)
X.sort_values(['Rank'], ascending=[True],inplace=True)
X.dropna(inplace=True)
```

```
lbl = ['web','ml']     ## node labels
## there are 2 node types: ml or web
gh.vs['lbl'] = [lbl[i] for i in list(X['ml_target'])]
```

In [7]:
```
## build the subgraphs
gh_ml = gh.subgraph([v for v in gh.vs() if v['lbl']=='ml'])
gh_web = gh.subgraph([v for v in gh.vs() if v['lbl']=='web'])

## there are 9739 ml developers and 27961 web developers
print('GitHub nodes:',gh.vcount(),'; ml developers:',gh_ml.vcount(),'; web developers:',
```

```
GitHub nodes: 37700 ; ml developers: 9739 ; web developers: 27961
```

In [8]:
```
# running time
gh_ml_cluster_map = run_clustering(gh_ml, exclude=['gn'], verbose=True)
```

```
ecg: 1.5060999393463135
louvain: 0.06590485572814941
infomap: 10.23180103302002
label_prog: 0.05117392539978027
cnm: 0.22686290740966797
```

In [9]:
```
clustering_pairs = list(combinations(gh_ml_cluster_map.keys(), 2))
clustering_pairs_2_ami = {}
for pair in clustering_pairs:
    clutering_1 = gh_ml_cluster_map[pair[0]]
    clutering_2 = gh_ml_cluster_map[pair[1]]
    ami = round(AMI(clutering_1, clutering_2), 4)
    print(f'AMI of {pair[0]} and {pair[1]}:', ami)
    clustering_pairs_2_ami[pair] = ami
```

```
AMI of ecg and louvain: 0.6353
AMI of ecg and infomap: 0.5724
AMI of ecg and label_prog: 0.4941
AMI of ecg and cnm: 0.5478
AMI of louvain and infomap: 0.4996
AMI of louvain and label_prog: 0.5717
AMI of louvain and cnm: 0.5785
AMI of infomap and label_prog: 0.2973
AMI of infomap and cnm: 0.4686
AMI of label_prog and cnm: 0.5918
```

In [10]:
```
max_ami = max(clustering_pairs_2_ami, key=clustering_pairs_2_ami.get)
print(f'{max_ami[0]} and {max_ami[1]} produce the most similar result with ami = {cluste
```

```
ecg and louvain produce the most similar result with ami = 0.6353
```

Problem 5

In [9]:
```
## read graph and communities; plot
g = ig.Graph.Read_Ncol(datadir+'ABCD/abcd_1000.dat',directed=False)
c = np.loadtxt(datadir+'ABCD/abcd_1000_comms.dat',dtype='uint16',usecols=(1))
g.vs['comm'] = [c[int(x['name'])-1]-1 for x in g.vs]
gt = {k:(v-1) for k,v in enumerate(g.vs['comm'])}
# ## map between int(name) to key
# n2k = {int(v):k for k,v in enumerate(g.vs['name'])}
# g.vs['size'] = 7
# g.es['color'] = cls_edges
# g.vs['color'] = [cls[i] for i in g.vs['comm']]
# ig.plot(g, bbox=(0,0,300,200))
```

In [10]:
```
def compute_z_p(z):
    ## compute internal degrees
    n_comm = max(z.vs['comm'])
    in_deg_list = []
    for idx in range(n_comm+1):
        in_deg_i = z.subgraph_edges(
            [e for e in z.es if z.vs['comm'][e.tuple[0]]==idx and z.vs['comm'][e.tuple[1
            delete_vertices=False).degree()
        in_deg_list.append(in_deg_i)

    ## compute z (normalized within-module degree)
    vs_in_deg = []
    for i in range(z.vcount()):
        vs_in_deg.append(sum([in_deg_i[i] for in_deg_i in in_deg_list]))
    z.vs['in_deg'] = vs_in_deg

    mu = []
    sig = []
    for in_deg in in_deg_list:
        mean = np.mean([x for x in in_deg if x>0])
        mu.append(mean)

        std = np.std([x for x in in_deg if x>0], ddof=1)
        sig.append(std)

    z.vs['z'] = [(v['in_deg']-mu[v['comm']])/sig[v['comm']] for v in z.vs]

    ## computing p (participation coefficient)
    z.vs['deg'] = z.degree()
    z.vs['out_deg'] = [v['deg'] - v['in_deg'] for v in z.vs]
    z.vs['p'] = [1-(v['in_deg']/v['deg'])**2-(v['out_deg']/v['deg'])**2 for v in z.vs]
    D = pd.DataFrame(np.array([z.vs['z'],z.vs['p']]).transpose(),columns=['z','p']).sort
    return z, D
```

In [11]:
```
g, _ = compute_z_p(g)
```

In [12]:
```
## Zachary graph w.r.t. roles
# z.vs['color'] = 'black'
# z.vs['shape'] = 'circle'
families_count = {
    "non-hub": {
        "kinless": 0,
        "connector": 0,
        "peripheral": 0,
        "ultra-peripheral": 0
    },
    "hub": {
        "provincial": 0,
        "connector": 0,
        "kinless": 0
    }
}
for v in g.vs:
    if v['z'] <= 2.5: # non-hub
        if v['p'] >= .8: # kinless
            families_count["non-hub"]["kinless"] += 1
        elif v['p'] >= .62 and v['p'] < .8: # connector
            families_count["non-hub"]["connector"] += 1
        elif v['p'] < .62 and v['p'] >= .05: # peripheral
            families_count["non-hub"]["peripheral"] += 1
        elif v['p'] < .05: # ultra-peripheral
```

```
            families_count["non-hub"]["ultra-peripheral"] += 1
    elif v['z'] > 2.5: # hub
        if v['p'] < .3: # provincial
            families_count["hub"]["provincial"] += 1
        elif v['p'] >= .3 and v['p'] < 0.75: # connector
            families_count["hub"]["connector"] += 1
        elif v['p'] >= .75: # kinless
            families_count["hub"]["kinless"] += 1
#ig.plot(z, 'zachary_roles_1.eps', bbox=(0,0,350,250))
# ig.plot(z, bbox=(0,0,350,250))
families_count
```

Out[12]:
```
{'non-hub': {'kinless': 0,
  'connector': 0,
  'peripheral': 958,
  'ultra-peripheral': 0},
 'hub': {'provincial': 0, 'connector': 42, 'kinless': 0}}
```

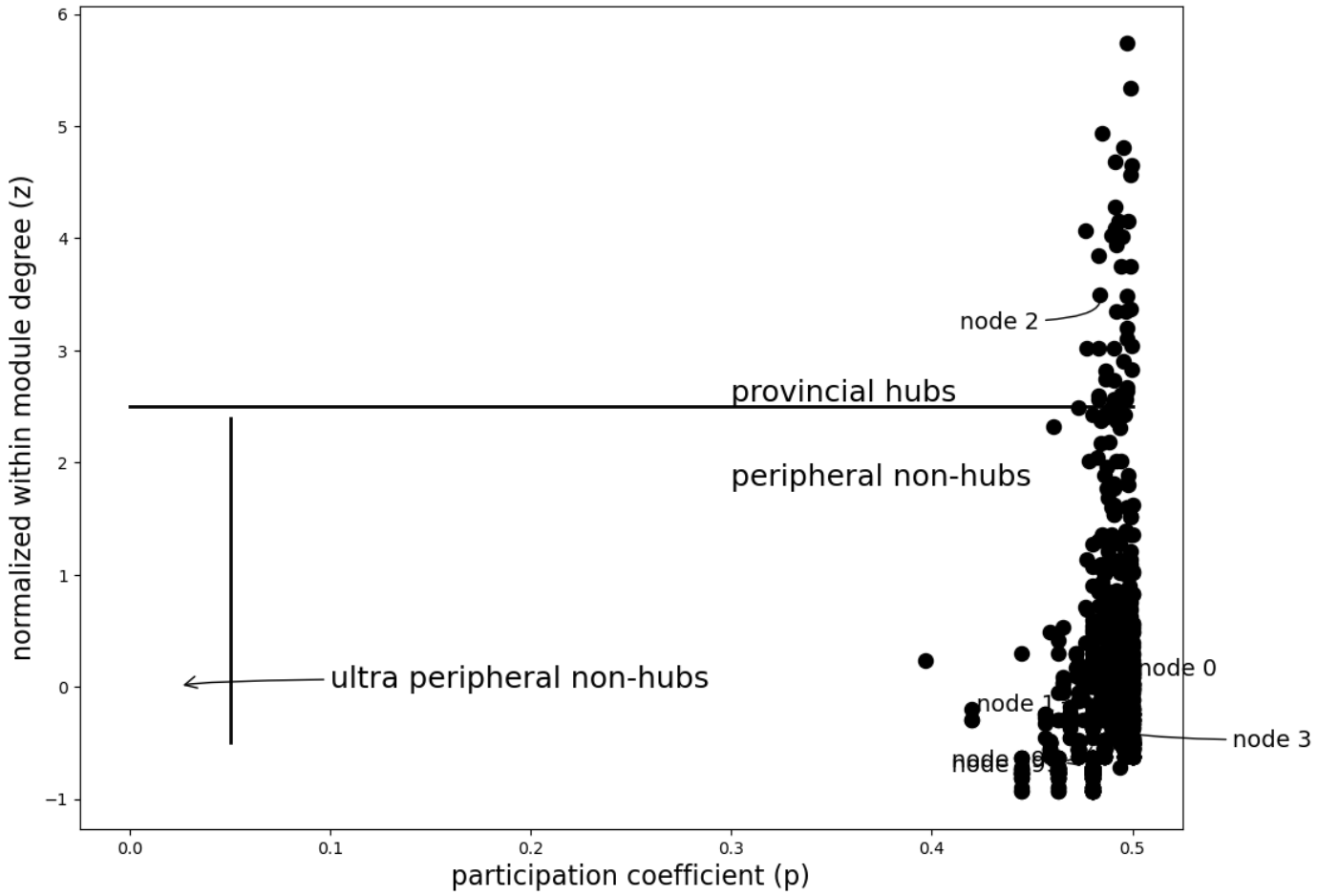
In [13]:
```
for hub_type in families_count.keys():
    for family in families_count[hub_type].keys():
        print(f'{hub_type}/{family} contains {families_count[hub_type][family]} nodes')
```

```
non-hub/kinless contains 0 nodes
non-hub/connector contains 0 nodes
non-hub/peripheral contains 958 nodes
non-hub/ultra-peripheral contains 0 nodes
hub/provincial contains 0 nodes
hub/connector contains 42 nodes
hub/kinless contains 0 nodes
```

In [14]:
```
def plot_family_z_p(z):
    max_v_idx = len(z.vs()) - 1

    ## Figure 5.3(b) -- comparing the roles
    fig, ax = plt.subplots(figsize=(12,9))
    ax.scatter(z.vs['p'],z.vs['z'],marker='o',s=75, color='k')

    plt.plot([0, .5], [2.5, 2.5], color='k', linestyle='-', linewidth=2)
    plt.plot([.05, .05], [-.5, 2.4], color='k', linestyle='-', linewidth=2)

    ax.annotate('node 0', (z.vs['p'][0],z.vs['z'][0]-.05), xytext=(z.vs['p'][0]+.01,z.vs
                fontsize=14,
                arrowprops = dict(  arrowstyle="-",connectionstyle="angle3,angleA=0,angl

    ax.annotate(f'node {max_v_idx}', (z.vs['p'][max_v_idx],z.vs['z'][max_v_idx]-.05), xy
                fontsize=14,
                arrowprops = dict(  arrowstyle="-",connectionstyle="angle3,angleA=0,angl

    ax.annotate(f'node {max_v_idx-1}', (z.vs['p'][max_v_idx-1]-.005,z.vs['z'][max_v_idx-
                fontsize=14,
                arrowprops = dict(  arrowstyle="-",connectionstyle="angle3,angleA=0,angl

    ax.annotate('node 1', (z.vs['p'][1],z.vs['z'][1]-.05), xytext=(z.vs['p'][1]-.07,z.vs
                fontsize=14,
                arrowprops = dict(  arrowstyle="-",connectionstyle="angle3,angleA=0,angl

    ax.annotate('node 3', (z.vs['p'][3],z.vs['z'][3]-.05), xytext=(z.vs['p'][3]+.07,z.vs
                fontsize=14,
                arrowprops = dict(  arrowstyle="-",connectionstyle="angle3,angleA=0,angl

    ax.annotate('node 2', (z.vs['p'][2],z.vs['z'][2]-.05), xytext=(z.vs['p'][2]-.07,z.vs
                fontsize=14,
```

```
                arrowprops = dict(  arrowstyle="-",connectionstyle="angle3,angleA=0,angl

    ax.annotate('provincial hubs',(.3,2.55), fontsize=18)
    ax.annotate('peripheral non-hubs',(.3,1.8), fontsize=18)
    ax.annotate('ultra peripheral non-hubs',(0.025,0.0),xytext=(.1,0), fontsize=18,
                arrowprops = dict( arrowstyle="->", connectionstyle="angle3,angleA=0,an

    plt.xlabel('participation coefficient (p)',fontsize=16)
    plt.ylabel('normalized within module degree (z)',fontsize=16);
    #plt.savefig('zachary_roles_2.eps')
```

In [15]:
```
plot_family_z_p(g)
```



Problem 6

In [6]:
```
abcd_path = '../Datasets/ABCDGraphGenerator.jl/utils/'
julia = '/Applications/Julia-1.8.app/Contents/Resources/julia/bin/julia'
```

In [26]:
```
L = {}   ## store results in a list
node_count_ls = [100, 200, 400, 800, 1600]
for node_count in node_count_ls:
    L[str(node_count)] = []

os.system(f"rm -r {' '.join([str(node_count) for node_count in node_count_ls])}")

REP = 1  ## number of graphs for each value of xi
# XIs = [x/100 for x in np.arange(10,81,5)] ## values for xi
XIs = [0.3]
print(f"XIs {XIs}")
for node_count in node_count_ls:
```

```
    print(f"============ node_count {node_count} ============")

    os.system(f"mkdir {str(node_count)}")

    for rep in range(REP):
        deg_path = f'{node_count}/deg.dat'
        cmd = f'{julia} {abcd_path}/deg_sampler.jl {deg_path} 2.5 10 50 {node_count} 100
        os.system(cmd)

        cs_path = f'{node_count}/cs.dat'
        cmd = f'{julia} {abcd_path}/com_sampler.jl {cs_path} 1.5 50 100 {node_count} 100
        os.system(cmd)

        for xi in XIs:
            print(f"------------ xi {xi} ------------")
            net_path = f'{node_count}/net.dat'
            comm_path = f'{node_count}/comm.dat'
            cmd = f'{julia} {abcd_path}/graph_sampler.jl {net_path} {comm_path} {deg_pat
            os.system(cmd)

            ## compute AMI for various clustering algorithms
            g = ig.Graph.Read_Ncol(net_path, directed=False)
            c = np.loadtxt(comm_path, dtype='uint16', usecols=(1))
            g.vs['comm'] = [c[int(x['name'])-1] for x in g.vs]
            n = max(g.vs['comm'])

            cluster_func_dict = {
                'ecg': g.community_ecg,
                'louvain': g.community_multilevel,
                'infomap': g.community_infomap,
                'label_prog': g.community_label_propagation,
                'gn': g.community_edge_betweenness,
                'cnm': g.community_fastgreedy,
            }
            for cluster_name, cluster_func in cluster_func_dict.items():
                start = time.time()
                if cluster_name in ['gn', 'cnm']:
                    _ = cluster_func().as_clustering(n)
                else:
                    _ = cluster_func()
                end = time.time()
                elapsed_time = end - start
                print(cluster_name, elapsed_time)
                L[str(node_count)].append(elapsed_time)
```

```
rm: 1600: No such file or directory
XIs [0.3]
============ node_count 100 ============
[ Info: Usage: julia deg_sampler.jl filename τ₁ d_min d_max n max_iter [seed]
[ Info: Example: julia deg_sampler.jl degrees.dat 3 5 50 10000 1000 42
[ Info: Expected value of degree: 17.59492981753638
[ Info: Usage: julia com_sampler.jl filename τ₂ c_min c_max n max_iter [seed] [nout]
[ Info: Example: julia com_sampler.jl community_sizes.dat 2 50 1000 10000 1000 42 100
[ Info: Expected value of community size: 70.53394879444838
------------ xi 0.3 ------------
[ Info: Usage: julia graph_sampler.jl networkfile communityfile degreefile communitysize
sfile mu|xi fraction isCL islocal [seed] [nout]
[ Info: Example: julia graph_sampler.jl network.dat community.dat degrees.dat community_
sizes.dat xi 0.2 true true 42 100
```

```
ecg 0.023712873458862305
louvain 0.0007081031799316406
infomap 0.007651805877685547
label_prog 0.0001862049102783203
gn 0.4130129814147949
cnm 0.0005700588226318359
============ node_count 200 ============
[ Info: Usage: julia deg_sampler.jl filename τ₁ d_min d_max n max_iter [seed]
[ Info: Example: julia deg_sampler.jl degrees.dat 3 5 50 10000 1000 42
[ Info: Expected value of degree: 17.59492981753638
[ Info: Usage: julia com_sampler.jl filename τ₂ c_min c_max n max_iter [seed] [nout]
[ Info: Example: julia com_sampler.jl community_sizes.dat 2 50 1000 10000 1000 42 100
[ Info: Expected value of community size: 70.53394879444838
------------- xi 0.3 -------------
[ Info: Usage: julia graph_sampler.jl networkfile communityfile degreefile communitysize
sfile mu|xi fraction isCL islocal [seed] [nout]
[ Info: Example: julia graph_sampler.jl network.dat community.dat degrees.dat community_
sizes.dat xi 0.2 true true 42 100
ecg 0.041539907455444336
louvain 0.0010361671447753906
infomap 0.017045021057128906
label_prog 0.0004470348358154297
gn 3.044651985168457
cnm 0.0018796920776367188
============ node_count 400 ============
[ Info: Usage: julia deg_sampler.jl filename τ₁ d_min d_max n max_iter [seed]
[ Info: Example: julia deg_sampler.jl degrees.dat 3 5 50 10000 1000 42
[ Info: Expected value of degree: 17.59492981753638
[ Info: Usage: julia com_sampler.jl filename τ₂ c_min c_max n max_iter [seed] [nout]
[ Info: Example: julia com_sampler.jl community_sizes.dat 2 50 1000 10000 1000 42 100
[ Info: Expected value of community size: 70.53394879444838
------------- xi 0.3 -------------
[ Info: Usage: julia graph_sampler.jl networkfile communityfile degreefile communitysize
sfile mu|xi fraction isCL islocal [seed] [nout]
[ Info: Example: julia graph_sampler.jl network.dat community.dat degrees.dat community_
sizes.dat xi 0.2 true true 42 100
ecg 0.08267903327941895
louvain 0.0026967525482177734
infomap 0.04370403289794922
label_prog 0.0011179447174072266
gn 21.39252996444702
cnm 0.004858255386352539
============ node_count 800 ============
[ Info: Usage: julia deg_sampler.jl filename τ₁ d_min d_max n max_iter [seed]
[ Info: Example: julia deg_sampler.jl degrees.dat 3 5 50 10000 1000 42
[ Info: Expected value of degree: 17.59492981753638
[ Info: Usage: julia com_sampler.jl filename τ₂ c_min c_max n max_iter [seed] [nout]
[ Info: Example: julia com_sampler.jl community_sizes.dat 2 50 1000 10000 1000 42 100
[ Info: Expected value of community size: 70.53394879444838
------------- xi 0.3 -------------
[ Info: Usage: julia graph_sampler.jl networkfile communityfile degreefile communitysize
sfile mu|xi fraction isCL islocal [seed] [nout]
[ Info: Example: julia graph_sampler.jl network.dat community.dat degrees.dat community_
sizes.dat xi 0.2 true true 42 100
```

```
ecg 0.1733090877532959
louvain 0.0036208629608154297
infomap 0.09715628623962402
label_prog 0.001580953598022461
gn 158.2232587337494
cnm 0.015326976776123047
============ node_count 1600 ============
[ Info: Usage: julia deg_sampler.jl filename τ1 d_min d_max n max_iter [seed]
[ Info: Example: julia deg_sampler.jl degrees.dat 3 5 50 10000 1000 42
[ Info: Expected value of degree: 17.59492981753638
[ Info: Usage: julia com_sampler.jl filename τ2 c_min c_max n max_iter [seed] [nout]
[ Info: Example: julia com_sampler.jl community_sizes.dat 2 50 1000 10000 1000 42 100
[ Info: Expected value of community size: 70.53394879444838
------------- xi 0.3 -------------
[ Info: Usage: julia graph_sampler.jl networkfile communityfile degreefile communitysize
sfile mu|xi fraction isCL islocal [seed] [nout]
[ Info: Example: julia graph_sampler.jl network.dat community.dat degrees.dat community_
sizes.dat xi 0.2 true true 42 100
ecg 0.3766138553619385
louvain 0.008880138397216797
infomap 0.21748709678649902
label_prog 0.003287076950073242
gn 1373.812355041504
cnm 0.05546379089355469
```

In [27]:
```
cluster_running_time = pd.DataFrame(data=L)
# cluster_running_time['cluster_method'] = cluster_func_dict.keys()
cluster_running_time = cluster_running_time.T
cluster_running_time.columns = cluster_func_dict.keys()
cluster_running_time
```

Out[27]:

	ecg	louvain	infomap	label_prog	gn	cnm
100	0.023713	0.000708	0.007652	0.000186	0.413013	0.000570
200	0.041540	0.001036	0.017045	0.000447	3.044652	0.001880
400	0.082679	0.002697	0.043704	0.001118	21.392530	0.004858
800	0.173309	0.003621	0.097156	0.001581	158.223259	0.015327
1600	0.376614	0.008880	0.217487	0.003287	1373.812355	0.055464

In [28]:
```
cluster_method_2_time = dict(cluster_running_time.mean())
```

In [29]:
```
fastest_method = min(cluster_method_2_time, key=cluster_method_2_time.get)
slowest_method = max(cluster_method_2_time, key=cluster_method_2_time.get)
print(f'{fastest_method} is fastest with {cluster_method_2_time[fastest_method]} seconds
print(f'{slowest_method} is slowest with {cluster_method_2_time[slowest_method]} seconds
```

```
label_prog is fastest with 0.001323843002319336 seconds
gn is slowest with 311.3771617412567 seconds
```

In [ ]: