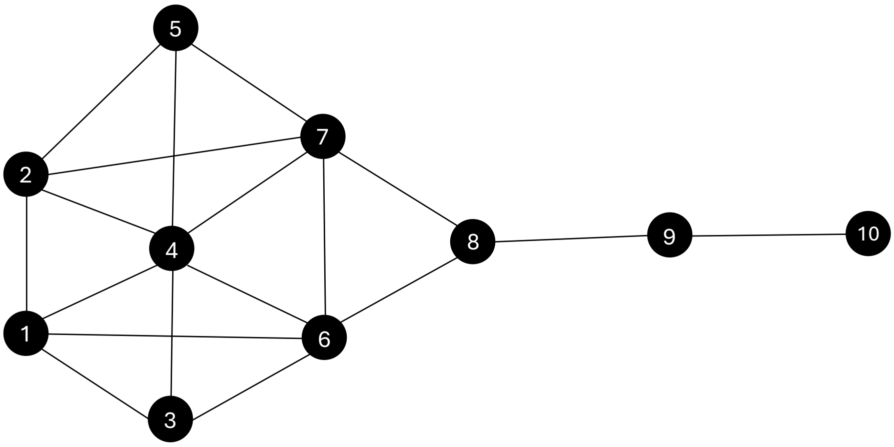
School of Architecture, Civil and Environmental Engineering, EPFL
CIVIL 534: Computational Systems Thinking for Sustainable Engineering
Spring 2025

EXAM 2 practice questions - solutions

Question 1

The following graph is a famous graph known as the “Krackhardt Kite Graph”

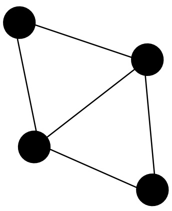


Circle the 3-core of this graph
Nodes 1-7 (not 8)

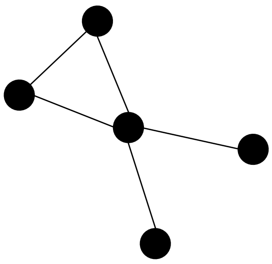
How many cliques of size 4 are there?
2 - (1,3,4,6) and (2,4,5,7)

How many occurrences of the following motifs appear in the graph?

Motif A



Motif B



Motif A: 9
Motif B: 0

Below are the occurrences for each motif from 10 randomly generated graphs with the same degree distribution. What is the z-score for each motif? Would you say these motifs are over or under represented in the original Krackhardt Kite Graph?

Motif A: [7, 5, 7, 6, 8, 5, 0, 7, 9, 7]

Motif B: [9, 8, 1, 6, 8, 13, 6, 8, 3, 9]

Motif A: $Z_i = \frac{\left(N_i^{\text{real}} - \overline{N_i^{\text{rand}}}\right)}{std\left(N_i^{\text{rand}}\right)} = \frac{9-6.10}{2.34} = 1.24$

Motif B: $Z_i = \frac{\left(N_i^{\text{real}} - \overline{N_i^{\text{rand}}}\right)}{std\left(N_i^{\text{rand}}\right)} = \frac{0-7.10}{3.18} = 2.24$

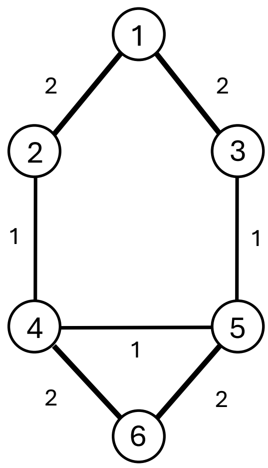
The z-score for motif B is above 2, indicating the observation is more than 2 standard deviations away from the mean, which implies this motif is significantly underrepresented in the kite network.

Motif A does not appear to be significantly overrepresented.

Question 2

EPFL is concerned about the increasing threat of cybersecurity and the risk of someone disrupting its district heating system, which uses an extensive network of pipes to carry heated water to condition the buildings on campus. In one critical part of the network, heat must get from node 1 to node 6 for highly sensitive and important nuclear physics experiments. There are electronically controlled devices that control the flow between the nodes and could be the target of cyber threats.

Since you did so well in CIVIL-534, EPFL has hired you to conduct a study of the resilience of this part of the network. In the network diagram, nodes represent pipe junctions (including the electronically controlled devices) and edges represent pipes (flow can go either direction).



Given the importance of getting heated water from 1 to 6, EPFL has decided that a minimum flow of 4 is required from 1 to 6. What edge would you add (including its capacity) to meet this new requirement? Justify your answer with the min-cut/max-flow theorem.

Many edges you can add:

- 1-6 (2)
- 2-6 (2)
- 2-5 (2)
- 3-4 (2)
- 1-5 (2)
- 1-4 (2)

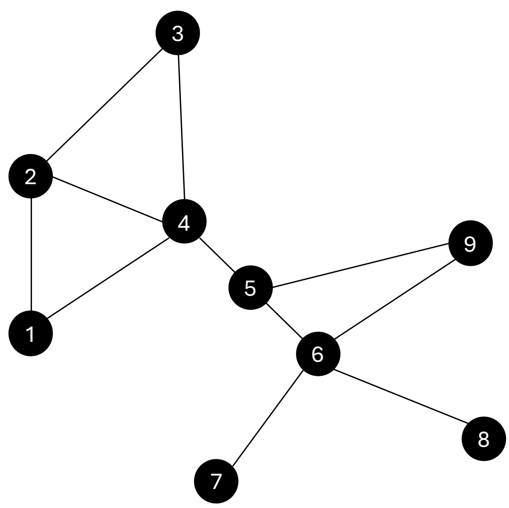
EPFL now wants to add extra layers of security to nodes that are the most critical in this problem setting. Using the new network with the added edge, use the local clustering coefficient to identify the critical node(s) in the network and explain what the local clustering coefficient indicates in this problem setting.
Note: you can assume the network is unweighted for the local clustering coefficient calculation

If we choose 2-5:
$c1 = 0$
$c2 = 1/3$
$c3 = 0$
$c4 = 2/3$
$c5 = 1/3$
$c6 = 1$

Since c1 and c3 have a small clustering coefficient, they control a lot of the flow and are critical nodes in the network.

Question 3

Consider the following network:



What type of network is this?
Undirected, unweighted

Which node(s) have the highest degree centrality?
4 and 6

Which node(s) have the highest betweenness centrality?
5 – it lies on the largest number of shortest paths between other nodes

Which type of random graph model would you have expected to produce this network?

a. Erdos-Renyi
b. Barabasi-Albert
c. Watts-Strogatz

b. is not correct because there does not appear to be one or more "hubs" with very high degree centrality (4 and 6 have higher centrality than the rest but not by much)

c. is not correct because there is no regular pattern that is "rewired"