DRS Exam Preparation

Kolektiv decentralizovaných studentů

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Question 1: Recount briefly the history of man-made networks.

19th Century: Physical Infrastructure and Early Telecommunications
- Railroads (1830s)
- Telegraphs (1840s)
- Power Grids (1880s)

Early 20th Century: Wireless and Electronics
- Marconi (1900s)
- Radio (1920s)
- Television (1940s)

Late 20th Century to Present: The Information Age
- Computer Networks (1960s)
- Internet (1960s)

Question 2: Describe the general structure of a network.

- Fundamental components: nodes and edges
- Directionality
- Weighted vs unweighted
- Self-loops
- Multi-edges = multigraph
- Mathematical representation:
  - Graph: (V, E)
  - V: set of nodes
  - E: set of edges
  - Adjacency matrix: A
  - Degree matrix: D
  - Laplacian matrix: $L = D - A$

Question 3: Name a few examples of physical, biological, social and information networks.

- Physical: Power grid, transportation network
- Biological: Protein interaction network, food web, sexual contact network

- Social: Social network, citation network
- Information: World wide web, citation network

Question 4: Describe how the structure of various networks is revealed empirically.

Question 5: Define a binary relation and establish a connection with its graph.

Question 6: Tell the difference between a graph and a hyper-graph. Depict a given hyper-graph by a bipartite network.

Question 7: Explain the difference between a multi-graph and a simple graph.

Question 8: Define the graph adjacency matrix.

Question 9: Compare the co-citation and bibliographic coupling.

Question 10: Explain the two one-mode projections of a bipartite network.

Question 11: Define planar networks and state the 'four color' theorem.

Question 12: Explain the difference between a sparse and a dense network.

Question 13: Define a path and explain the difference between an Eulerian and a Hamiltonian path.

Question 14: State the min-cut max-flow theorem.

Question 15: Define the graph Laplacian matrix and its relation to diffusion processes on graphs.

Question 16: State the Geršgorin disc theorem and explain how it is applied to the graph Laplacian.

Question 17: Define the Fiedler eigenvalue and explain its significance for the graph topology.

Question 18: Define the Frobenius form of the graph Laplacian and explain how it reveals the graph topology.

Question 19: Define the Metzler matrix.

Question 20: Define the M-matrix.

Question 21: Explain how the geometric multiplicity of eigenvalues differ from the algebraic one.

Question 22: Explain the meaning of the geometric multiplicity of a zero eigenvalue for graph Laplacians.

Question 23: Define the left zero eigenvector.

Question 24: Define a balanced graph.

Question 25: Define a strongly connected graph.

Question 26: Define the degree centrality.

Question 27: Motivate the eigenvector centrality.

Question 28: Explain the difference between the eigenvector centrality and the Katz centrality.

Question 29: Define PageRank and modified PageRank.

Question 30: Explain hubs and authorities and their relation to co-citation and bibliographic coupling.

Question 31: Define closeness centrality and discuss different variants thereof.

Question 32: Define betweenness centrality.

Question 33: Explain the difference between cliques, plexes and cores.

Question 34: Define k-components and compare them with connected components.

Question 35: Define transitivity of a network in any of equivalent ways.

Question 36: Define local clustering.

Question 37: Explain the concept of reciprocity and how it relates to loops of length two.

Question 38: Define structural balance for networks with signed edges. Show that structurally balanced network is certainly clusterable (Harrary's theorem).

Question 39: Show by counterexample that a clusterable network need not be structurally balanced.

Question 40: Explain vertex similarity.

Question 41: Define structural and regular equivalence and explain the differences of them.

Question 42: Define homophily and assortative mixing in networks.

Question 43: Define assortative mixing with respect to scalar characteristics. Explain how does it differ from that for enumerative characteristics.

Question 44: Define the modularity matrix for undirected networks.

Question 45: Explain assortative mixing with respect to the degree. Discuss what are its implications on the network topology.

Question 46: Define the power law distributions, explain how to calculate their moments.

Question 47: Explain the effect of top heavy distribution of vertex degrees for the networks.

Question 48: Explain the importance of the small world effect for the functionality of computer networks.

Question 49: Explain the concept of algorithm complexity. Define the O notation.

Question 50: Explain how the network topology is represented in computer memory. Compare the adjacency matrix and the adjacency list.

Question 51: Define the tree data structure. What is a balanced tree and what is the worst case complexity of finding an element in it?

Question 52: Explain how trees are used to represent networks.

Question 53: Define a binary heap. Why would one use such a structure in network algorithms?

Question 54: Describe the breadth-first search algorithm.

Question 55: Explain the computational complexity of the naive implementation of the breadth-first search.

Question 56: Explain the computational complexity of the more sophisticated implementation of the breadth-first search using a buffer.

Question 57: Describe how to find the actual shortest paths. Assume first single shortest paths, then generalize to possible multiple shortest paths.

Question 58: Describe Dijkstra's algorithm, explain why it works and analyze its computational complexity.

Question 59: Explain how to apply Dijkstra's algorithm to find the actual least weight path tree for a given starting vertex.

Question 60: Explain how to find the betweenness centrality of a given vertex using either the breadth-first search or Dijkstra's algorithm.

Question 61: Describe the augmenting path algorithm (Ford-Fulkerson algorithm).

Question 62: Describe the power method for finding leading eigenvalues and eigenvectors. What is the importance of choosing the initial seed?

Question 63: Explain how to efficiently find all eigenvalues and eigenvectors of a given matrix. Specify which algorithms are used for matrix transformation and efficient solution of the transformed eigen-problem, given different starting matrices (symmetric/asymmetric, sparse/dense).

Question 64: Why to use heuristic algorithms in general, even if no proof of correctness is available?

Question 65: What is the difference between the graph partitioning and the community detection problems?

Question 66: Describe the Kernighan-Lin algorithm for graph partitioning. What is its computational complexity? What is roughly the size of the network for which it can be reasonably expected to work?

Question 67: Describe the spectral partitioning algorithm. Explain the importance of the graph Laplacian matrix and its Fiedler eigenvalue. What is its computational complexity? What is roughly the size of a network for which it can be reasonably expected to work?

Question 68: Describe the variant Kernighan-Lin algorithm for community detection. What is its complexity? How does it compare to the original Kernighan-Lin algorithm for graph partitioning?

Question 69: Describe the spectral modularity maximization method of community detection. Explain the importance of the modularity matrix and its leading eigenvector.

Question 70: How does repeated bisection work for modularity maximization? Compare it with the same approach in graph partitioning.

Question 71: Briefly describe simulated annealing, genetic algorithm and greedy algorithm for modularity maximization.

Question 72: Describe the algorithm using betweenness centrality for community detection. How does the Radicci algorithm differ from it?

Question 73: Explain how the agglomerative algorithms proceed in community detection.

Question 74: Define hierarchical clustering. What is a dendrogram? Explain the similarity-based hierarchical clustering with single-, complete- and average-linkage clustering.

Question 75: Comment on which of the algorithms detect a fixed number vs. an unspecified number of communities.

Question 76: Explain the difference between site and bond percolation.

Question 77: Describe uniform and non-uniform vertex removal. Comment on the robustness of power law networks to vertex removal.

Question 78: Describe a few examples of fully mixed epidemics models, e.g. SI, SIR, SIS, SEIR.

Question 79: Explain how to model epidemics on networks. What is the role of vertices and vertex variables?

Question 80: Describe the Lotka-Volterra predator-prey model. Explain various ways how it extends to the network setting.

Question 81: Enumerate the stages of the traditional (offline) web search. Explain how the algorithms used in modern web search engines such as Google differ from the traditional web search.

Question 82: Explain the web crawling procedure. Give examples of advanced techniques that facilitate the web crawling process.

Question 83: Describe the process of indexing in web search, both the simple version and its possible extensions.

Question 84: Describe simple search in distributed databases. What is its complexity if the file is present only on a single computer in the network? How does the complexity change if the file exists on a fixed fraction of computers in the network?

Question 85: Explain how supernodes improve the search in distributed networks.

Question 86: Describe the two models of message passing, i.e., the Kleinberg's model and the hierarchical model, and enumerate their limitations (assumptions). What is the complexity of message passing in these models?

Question 87: Elaborate on the constraints that have to be imposed on networks as the main conclusion of message passing analysis using models.

Question 88: Define the consensus/synchronization problem in states and outputs. Explain the difference between homogeneous and heterogeneous agents.

Question 89: Write the single-integrator leaderless consensus dynamics in continuous time. How to include a leader?

Question 90: Write the single-integrator leaderless consensus dynamics in discrete time. How to include a leader?

Question 91: Set up the dynamical equations for continuous-time homogeneous LTI agents using local neighborhood error signal for state synchronization.

Question 92: Show how to use complex matrix pencils for investigating state synchronization of homogeneous agents.

Question 93: Show that with the distributed feedback gain designed from the single-agent Algebraic Riccati Equation the resulting synchronizing region is an unbounded left-hand half-plane in the complex plane.

Question 94: What are the necessary topological conditions on the communication graph for consensus or synchronization? Explain the dynamical role of the Fiedler eigenvalue in continuous time single integrator consensus.