Computer simulations in physics: Exam questions

June 2, 2020

1. Random numbers
   (a) What is the difference between true and pseudo random numbers
   (b) Define the Multiplicative congruential algorithm
   (c) What is the Marsaglia effect
   (d) Define the method to obtain arbitrary random number distributions
   (e) Define the Monte Carlo integration
2. Differential equations
   (a) Define the finite differences
   (b) Define the Euler integration method
   (c) Define the implicit (backward) Euler method
   (d) Define the Verlet method
   (e) Define the velocity Verlet method
   (f) Examine the stability of the Euler and the implicit Euler method
   (g) Define the Laplacian for two dimensional square lattice both in normal and matrix formulation
   (h) What is random, random sequential and parallel update
3. Molecular dynamics
   (a) Define the distance calculation using periodic condition both for square and sheared boxes
   (b) Define the main parts of the molecular dynamics
   (c) What is the problem with frictional forces and describe the solution

(d) Describe the bucketing algorithm

(e) What is the Ewald summation

(f) Which integrators are time reversible, why is it important?

(g) Define the Nosé-Hoover thermostat

(h) Define the Event driven algorithm

(i) What is the inelastic collapse

(j) Define the Contact dynamics

(k) Describe how the forces are calculated in the contact dynamics

(l) Define the Kinetic Monte Carlo algorithm

4. Percolation, Fractals

   (a) Define the percolation model

   (b) What quantities scale in the percolation model, how the critical point is defined

   (c) Define the Hoshen-Kopelman algorithm

   (d) Define the fractals

   (e) What is the fractal dimension and how can be measured

5. Ising model

   (a) What is importance sampling

   (b) Define the Metropolis algorithm

   (c) What is a cluster algorithm, how do they work?

   (d) How can one simulate Microcanonical ensemble?

   (e) How can one simulate a system with conserved magnetization?

   (f) How can one calculate the Free energy in an Ising system?

   (g) Define the Finite size scaling

   (h) Define the voter model

   (i) Define the Schelling model

6. Parallelization, Optimization

   (a) What are the main methods of parallelization?

   (b) Which particles based models can be paralellized? Why?

   (c) Define steepest descent algorithm and the conjugate Gradient Method

(d) What is a rugged energy landscape?

(e) Linear regression: definition

(f) Simulated annealing: definition

(g) Maximum likelihood: definition

(h) Genetic algorithm: definition

(i) Genetic algorithm: algorithm

7. Complex networks

   (a) Define a general network (graph) and the adjacency matrix

   (b) What is the difference between a random and a scale free network?

   (c) Define the Dijkstra algorithm

   (d) What is the small world property?

   (e) Define the clustering coefficient

   (f) Define the Erdős-Rényi graph

   (g) Define the Watts-Strogratz model

   (h) Define the Barabási-Albert model

   (i) Define the Page rank algorithm

   (j) What is the difference between failure and attack on networks?

   (k) Describe the algorithm for finding connected components on a graph

8. Clustering, modularity, community detection

   (a) Difference between strict, overlapping, and hierarchical clustering

   (b) Modularity: definition

   (c) Modularity: algorithm

   (d) k-means clustering: defition

   (e) k-means clustering: algorithm

   (f) Hierarchical clustering: definition. What are complete- and single-linkage

   (g) Clique percolation: definition

   (h) Define the Huffman coding

   (i) Infomap: main idea coding principles

9. Algorithmically defined models

   (a) Self-Organized Criticality: definition

(b) Bak-Tang-Wiesenfeld: definition

(c) Bak-Sneppen model of evolution: definition

(d) Nagel–Schreckenberg model: definition

(e) Disease spreding, SIR model: definition

(f) Predator prey model: definition, main behaviour

(g) Deffuant model: definition

(h) Flocking model: definition

10. Neural networks

    (a) Deep learning: classification

    (b) Neural networks: feedforward network

    (c) Neural networks: activation function

    (d) Neural networks: Backpropagation

11. Game models

    (a) Game models: Nash equilibrium

    (b) Game models: Prisoner's dilemma, chicken game

    (c) Prisoner's dilemma: multiple agents: Strategies