COMPUTATIONAL PHYSICS FINAL PROJECT

Physics 3363

Components

Students are required to complete a Final Project, present their work in **poster** form, and submit **a short written report** (~8 pages plus appendix) for their project that includes the following components:

i. Statement of the investigation based upon a journal article;
ii. Formulation of an algorithm to solve the problem computationally;
iii. Development of a computer program to solve the problem;
iv. Results of the investigation;
v. Discussion of insights gained from the simulation;
vi. References

Report

The Final Report should be written typeset in LaTeX in the format of a scientific paper containing the following components:

1. Title, author information, and abstract.
2. Introduction containing statement of the investigation and importance of numerical solution of the problem.
3. Procedures section describing formulation of an algorithm and development of a computer program to solve the problem. List any equations used. Use figures and diagrams to illustrate procedures used. List the program output in an appendix of paper where the code is structure is presented.
4. Results section describing data and analysis of running your problem to solve the problem. Figures and sample plots should be included to illustrate a range of simulations for physically interesting domains of variables and parameters. The figures and plots need to contain a caption, labels of axes, and legend identifying different curves which may be present in some figures. When appropriate, a comparison of solution of the problem should be made with other known results with appropriate references being given.
5. Discussion and conclusion section describing outcomes of solution of the problem, insights gained into the phenomenon through the simulation, and effectiveness of the algorithm and computer program to solve the problem.

Poster

An ePoster containing summaries of the aforementioned sections will be created. A template will be provided for your use.

Timeline

NOVEMBER 15, 2019: Initial selection of topic reported.
NOVEMBER 22, 2019: Abstract due describing your proposed project.
DECEMBER 2-4, 2019: Presentation of preliminary results in an office meeting.
DECEMBER 11, 2018: Eight-page report due.
DECEMBER 17, 2019: 2 p.m. Poster presentation at final exam meeting.

Possible topics include the following. You are urged to use the Web for researching topics and you must select at least one scientific paper, read and digest it, and then develop a simulation based on it and examine your results and discuss your insights.

1. Chain Break: Simulate the dynamics of determining where a harmonic chain of beads will break.

   "Which part of a chain breaks?"
   Baek, S.K., *Am. J. Phys.*, **86**, 663 (2018)

2. Modeling a Flipped Water Bottle: Model the dynamics of the water bottle flipping challenge that consists of spinning a bottle partially filled with water and making it land upright.

   "Water bottle flipping physics"

   Dekker, P.J., et al., *Am. J. Phys.*, **86**, 733 (2018)

3. Monte Carlo Simulation of Electron Scattering: Scattering of electron in a thin metal film.

   "Monte Carlo Scattering of Nonrelativistic Electron Scattering", W. Williamson, G.C. Duncan, *Am. J. Physics*, 54:262, 1986.

4. Self-Organized Criticality (SOC): A simulation of avalanches in sand piles with applications to many areas.

   "Self-Organized Criticality," P.Bak. C. Tang. Kurt Wiesenfeld., Physical Review A, **38**, Number 1, July 1988.

5. 3D Percolation Clusters: Simulation of percolation clusters in three dimensions.

   An Introduction to Percolation Theory, D. Stauffer and A. Aharony, Taylor and Francis, London (1992).

6. Controlling Chaos: Controlling chaos in nonlinear systems applied to the Henon-Heiles strange attractor.

   "A simple method for controlling chaos," *Am. J. Phys.*, 66:730, 1998.

7. Closed Orbits about a Massive Oblate Spheroid: Simulation of closed orbits around a gravitational object such as an elliptical galaxy.

   “Closed orbits about a massive thing ring,” R Wesley Tobin, J. West, *Eur. J. Phys.* **27**, 215 (2006).

8. Synchronized Random Walks :

   Randomly place two walkers on a one-dimension lattice of m sites, so that both walkers are not in the same site. Two random walks can move on a one-dimensional line with m sites. In each step a direction, either left or right, is chosen randomly. Then both random walkers move in this direction. If one random walk hits the boundary, it is reflected, i.e. the random walk remains at its site on the left or on the right. As the other random walker is not affected, the *distance d* between both decreases by 1 at each reflection. Otherwise d remains constant. A trial end when both walkers are at the same site. Find mean time for two walkers to reach the same site. What is connection between the mean time and the number of sites m? The model is relevant to a method of doing cryptography using neural networks.

   Ruttor et al J. Phys. A: Math. Gen. 37 (2004) 8609-8618 4.

9. Particle Simulation of Lyapunov Exponents in One-Component Plasmas: Investigating the Lyapunov exponents for Coulomb many-body systems

   “Particle simulation of Lyapunov exponents in one-component strongly coupled plasmas”, Ueshima, Y., et al., *Phys. Rev. E*, **55**, 3439 (1997) .

10. Diffusion Limited Aggregates Based on the Margolus Neighborhood:

    Margolus, Norman H., and Toffoli, Tomasso**:** *"Cellular Automata Machines: A New Environment for Modelling"*, 1987.

11. Effect of the Solar Wind on Particles in the Solar System: An investigation of the Poynting-Robertson drag forces and the Yarkovsky effect.

    “Radiation forces on small particles in the solar system,” Joseph A.Burns, Philippe L.Lamy, StevenSoter, Icarus, Vol 40, 1 (1979).

12. <u>Lévy Flight and Animal Foraging</u>: Lévy flights are aspecial class of random walks whose step lengths are not constant byt rather are chosen from a probability distribution with a power-law tails. Realizations of Lévy flights in physical phenomena are very diverse and they are found in biological systems extensively.

  "Lévy flight search patterns of wandering albatrosses", Viswanathan, G.M., et al., *Nature*, **381**, 413 (1996).

  "Spatiotemporal Dynamics of Bumblebees Foraging under Predation Risk", Friedrich Lenz, Thomas C. Ings, Lars Chittka, Aleksei V. Chechkin, and Rainer Klages, *Phys. Rev. Lett.* **108**, 098103 (2012).

13. <u>Polymer physics</u>: A polymer consists of N repeat units (monomers) with N>>1. For example polypropylene can be represented as ... -CH2-CH2-CH2-... Random walk models can be used to study global properties of polymer formation. Polymers have an important physical feature, that is, two monomers cannot occupy the same spatial condition (the excluded volume condition). For random walk models it corresponds to the self-avoiding walk (SAW). This model consists of the set of all N-step walks starting from the origin subject to the global constrain that no lattice site can be visited more than once in each walk: this constrains accounts for the excluded volume condition.

  Consider a 2D square lattice and write a program and compute

  1. average number of monomers in this kind of 2D polymer
  2. the fraction of successful attempts f(N) at constructing polymer chains with N total monomers (plot a histogram)
  3. what is the maximum value of N that you can reasonably consider?
  4. plot an example for a polymer with an average number of monomers in your simulation.

14. <u>The classical helium atom</u>: Write a program to simulate motion of electrons in the 2D classical helium atom.

  1. Study the effect of interaction between electrons on their orbits.
  2. Are there total energy and angular momentum of two electrons conserved?
  3. Are the energy and angular momentum of electron 1 conserved?
  4. What if the force of electron-electron interaction was 100 times weaker?

  "Helium Atom as a Classical Three-Body Problem", T. Yamamoto and K. Kaneko Phys. Rev. Lett., vol. 70, 1928 (1993) 5 .

15. Random Walks on Percolation Clusters: Investigating random walkers on various percolation clusters.

> "Two Dimensional Random Walk on Percolation Clusters", George M Paily, Shivakumar Jolad, Sanghamitra Neogi.

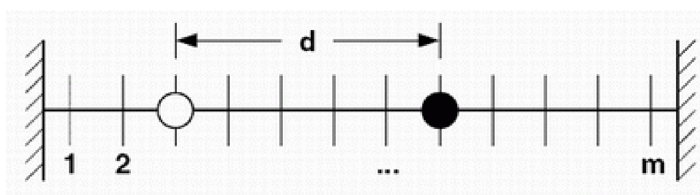
16. Self Organized Criticality in Digging Myopic Ant Model: Modeling the phenomenon of self organized criticality (SOC) in a simplerandom walk model described by a random walk of a myopic ant.

> "Self Organized Criticality in Digging Myopic Ant Model", Prashant M. Gade1 and M. P. Joy.

17. Dynamical Systems Modeling of Chaotic Stellar Oscillations: The Blazhko Effect

> Buchler, J.R., Ap&SS.210,9B (1999).
> Klapp, J., Goupil, M.J., Buchler, J.R., ApJ, 296, 514 (1985).
> Buchler, J.R., Koll´ath, Z., ApJ, 731, 24 (2011)

18. Synchronized Random Walks: Randomly place two walkers on a one-dimension lattice of *m* sites, so that both walkers are not in the same site. Two random walks can move on a one-dimensional line with m sites. In each step a direction, either left or right, is chosen randomly. Then both random walkers move in this direction. If one random walk hits the boundary, it is reflected, i.e. the random walk remains at its site on the left or on the right. As the other random walker is not affected, the distance d between both decreases by 1 at each reflection. Otherwise *d* remains constant. A trial end when both walkers are at the same site. Find mean time for two walkers to reach the same site. What is connection between the mean time and the number of sites m? The model is relevant to a method of doing cryptography using neural networks,



> Ruttor et al *J. Phys. A: Math. Gen.* 37 (2004) 8609-8618

19. The Toomres’ Model of Interacting Galaxies: Purely gravitational interactions in simulating colliding galaxies.

   “Galactic Bridges and Tails”, Toomre, A., J. Toomre, ApJ 178, p. 623, 1972

20. The Eccentric Kozai-Lidov Effect and Its Applications: Chaos in exoplanet orbits.

   “The eccentric Kozai-Lidov Effect and Its Applications”, Naoz, S., Annu. Rev. In Astronomy & Astrophysics, 2016, A.A:1-59

21. Stability of Circumbinary Orbits: Exploration of stability of exoplanets in circumbinary orbits.

   “On the stability of S and P type orbits”, De Cesare, G. and R. Capuzzo-Dolcetta, Exoplanet in Lunch (conference), 6^{th}-9^{th} May 2015.

   “Stability of planetary orbits in binary systems”, Musielak, Z.E., et al. A&A, 434,355-364 (2005).

   “The Stability and Habitability of S-Type Orbits in the Alpha Centauri System,” C. Tulban, H. Ambrose, M. Palese, University of Arizona report.

22. Neural Models: Eugene Izhikevich developed a simple, semiempirical, model of cortical neurons. The properties of each neuron are controlled by 4 parameters, plus a constant current input. His web site includes detailed descriptions of the cell model.

   “Simple Model of Spiking Neurons”, Izhikevich, E.M., IEEE Transactions on Neural Networks (2003) 14:1569- 1572

23. Coastal Erosion Using Cellular Automata Simulations: Coastal flooding and associated land erosion are important environmental issues that are difficult to model for large scale systems. Cellular automaton models are attractive as computational simple and inexpensive individual cell calculations can be scaled up to model relatively large area models.

   “Modelling Flood Incursion and Coastal Erosion Using Cellular Automata Simulations”, Hawick, K.A., Hull Technical Report CSI-0007 (2014)

24. Charges on an Ellipse: Determine how charges placed on an ellipsoid will distribute themselves by examining the electrostatic repulsion.

Notes

25. Protein Folding: Monte Carlo simulation of protein folding and resulting structures.

"Active-Walker Models: Growth and Form in Nonequilibrium Systems", Lam, L, and R. Pochy, *Computers in Physics* Vol. 7, p. 534 (1993).

Computational Physics by N. Giordano, Prentice Hall (1997)

26. Damped harmonic oscillator: linear or quadratic drag?: Investigate the drag effects on a harmonic oscillator and compare the model to experiments.

"Damped harmonic oscillator: Linear or quadratic drag force?"
Hauko. R, and R. Repnick, *Am. J. Phys.* **87**, 910 (2019)

27. The Rabbit Jump over Log Problem with Drag: Determine the starting point for a rabbit to clear a log with the minimum use of energy.

Notes

28. Stability of a Satellite in Elliptical Orbit: A look at non-linear stability of a dumbbell-shaped satellite in an elliptical orbit.

"Condition of non-linear stability of dumbbell satellite in elliptical orbit, Narayan, A. and Randey, M.D., *Int. J. Pure and Applied Mathematics*, **72**, 173 (2011).