PHY665A: Uncertainty, Information, and Classical Dynamics

Instructor-in-charge: Sagar Chakraborty

Credits: 9 (3-0-0-0) [Weekly Lectures on Monday and Wednesday, 1715hrs–1830hrs]

Prerequisite: PHY412A

Objective and course content: Information is everywhere in nature which is very uncertain and unpredictable. But information, in itself, is a very ambiguous term. In this course, we shall understand a formal meaning of information by quantifying uncertainty and see how it naturally appears in two core topics of classical physics—classical mechanics and statistical mechanics. We shall witness how the concepts of the information theory render a unique viewpoint in physics. The course outline is as follows:

S. no.	Broad Topics	Detailed Topics	No. of Lectures
1	*Quantifying Uncertainty: Probability*	Different interpretations of probability, frequentist versus Bayesian, Bayes theorem, reviewing probability theory and random variables, basic concepts of Markov chain and ergodicity.	7
2	*Quantifying Uncertainty: Entropy*	Shannon entropy and its different interpretations, asymptotic equipartition property, generalized entropies (Rényi, Tsallis, etc.), mutual information, relative entropy, differential entropy, entropy rate or source entropy, maximum entropy distribution, minimum relative entropy distribution, Fisher information, data processing inequality.	8
3	*Uncertainty in Deterministic Chaos*	Lyapunov exponents, invariant density, strange chaotic attractors and fractal dimension (capacity dimension), information dimension, Rényi dimensions, information loss, topological entropy, Kolmogorov–Sinai (KS) entropy, fluctuations around KS entropy and generalized entropies, Rényi entropies and generalized Lyapunov exponents, ε-entropy and finite size Lyapunov indicator.	11
4	*Uncertainty in Statistical Mechanics*	Reviewing connection between chaos, statistical mechanics, and thermodynamics; second law of thermodynamics and relative entropy, Boltzmann entropy and Gibbs entropy and their connections with Shannon entropy, Landauer's principle, Maxwell's demon, coarse-graining and irreversibility, Jaynes' formalism of statistical mechanics, information geometry (e.g., in vapour-liquid equilibrium).	11
5	*Estimating Uncertain Parameters*	Cramer–Rao bound, frequentist versus Bayesian estimations.	3
		Total number of lectures:	**40**

Course material will be an eclectic collection from the following references (among others):

1. C. E. Shannon and W. Weaver, The *Mathematical Theory of Communication,* University of Illinois Press (1962).
2. A. I. Khinchin, *Mathematical Foundations of Information Theory,* Dover Publications (1957).
3. T. M. Cover and J. A. Thomas, *Elements of Information Theory,* Wiley-Interscience (2006).
4. A. Papoulis and S. U. Pillai, *Probability, Random Variables and Stochastic Processes,* McGraw Hill Education (2002).
5. M. Cencini, F. Cecconi, and A. Vulpiani, *Chaos: From Simple Models to Complex systems,* World Scientific (2009).
6. H. G. Schuster, Deterministic Chaos: An Introduction, Wiley VCH (1995).
7. C. Beck and F. Schlögl, *Thermodynamics of Chaotic Systems: An Introduction,* Cambridge University Press (1995).
8. E. T. Jaynes, Probability Theory: The Logic of Science, Cambridge University Press (2003).
9. R.D. Rosenkrantz (Ed.), *E. T. Jaynes: Papers on Probability, Statistics and Statistical Physics,* Springer Netherlands (1989).
10. P. Adriaan and J. van Benthem (Eds.), *Philosophy of Information (Handbook of the Philosophy of Science),* North Holland (2008).
11. A. Hájek, *Interpretations of Probability,* Stanford Encyclopedia of Philosophy (2002).
12. D. C. Brody and D. W, Hook, *Information Geometry in Vapour-Liquid Equilibrium,* Journal of Physics A: Mathematical and Theoretical 42, 023001 (2009).