PHY313A/SE320A: Physics of Information Processing

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***Prerequisites**: While there is no official prerequisite, previous exposure to PHY102A, PHY204A, and PHY210A (or their equivalents) will be useful.*

Objective: Information is processed everywhere in nature. But information, in itself, is a very ambiguous term. In this course, we shall try to understand the formal meaning of information and see how it naturally appears in various topics of physics. We shall witness how the concepts of the information theory renders a unique viewpoint of physical phenomena around us. Furthermore, we shall showcase how the information-theoretic ideas can be put to use in understanding the data extracted and processed in various physical experiments.

S. no.	Broad Topics	Detailed Topics	No. of Lectures
1	*Uncertainty and Probability*	Different interpretations of probability, frequentist versus Bayesian.	6
		Reviewing basic tools in probability theory: probability distribution/mass function, moments, law of large numbers, central limit theorem, etc.	
		Concept of stochastic process and Markov chain.	
2	*Basics of Information Theory*	Shannon entropy, mutual information, relative entropy, differential entropy, maximum entropy distribution, Fisher information, asymptotic equipartition property, inequalities in information theory, other entropies (Kolmogorov–Sinai, Rényi, Tsallis, etc.).	9
3	*Applications in Statistical Physics and Chaos Theory*	Determinism versus non-determinism, metric entropy and Lyapunov exponent to define chaos, strange chaotic attractors and information dimension, predictability in chaotic systems: ε-entropy and finite size Lyapunov indicator.	10
		Reviewing connection between chaos, statistical mechanics, and thermodynamics.	
		Second law of thermodynamics and information theory, Maxwell's demon, Gibb's paradox, coarse-graining and irreversibility, Jaynes's formalism of statistical mechanics.	
4	*Applications in Measurement Theory*	Parameter estimation, Cramer–Rao bound, maximum likelihood, method of moments and Bayesian estimate. (Test case: Measuring interferometric phases/fine structure constant.)	15
		Precision and sensitivity in measurements, noise vs. signal measurements. (Test case: LIGO data.)	
		Quantum states and operators, quantum enhanced precision measurements. (Test case: Ramsey interferometry.)	
		Total number of lectures:	**40**

Course material will be an eclectic collection from the following references:

1) N. Gershenfeld, *Physics of information Technology,* Cambridge University Press (2011).
2) T. M. Cover and J. A. Thomas, *Elements of Information Theory,* Wiley-Interscience (2006).
3) M. Cencini, F. Cecconi, and A. Vulpiani, *Chaos: From Simple Models to Complex systems,* World Scientific (2009).
4) P. Bevington and D. K. Robinson, *Data Reduction and Error Analysis,* McGraw-Hill Education (2002).
5) V. B. Braginsky and F. A. Khalili, *Quantum Measurement,* Cambridge University Press (1992).
6) C. E. Shannon, *A Mathematical Theory of Communication,* Bell System Technical Journal **27**, 379 (1948).
7) E. T. Jaynes, *Information Theory and Statistical Mechanics,* Physical Review **106**, 620 (1957).
8) T. J. Loredo, *Promise of Bayesian Inference for Astrophysics* (in Feigelson E.D., Babu G.J. (eds.) Statistical Challenges in Modern Astronomy), Springer (1992).
9) F. A. Bais and J. D. Farmer, *The Physics of Information,* arXiv:0708.2837v2 (2007).