Spring 2023

PHYS 114 - 002: Introduction to Data Reduction with Applications

Andrew Gerrard

New Jersey Institute of Technology- Spring 2023

PHYS 114 – INTRODUCTION TO DATA REDUCTION WITH APPLICATIONS (3-0-3)

Topics: An introduction to both the theory and application of data processing, error analysis, and data reduction methodologies, for use in scientific research. Topics include probability distribution functions, specifically the binomial distribution and its simplification to Gaussian and Poisson probability distribution functions, estimation of moments, and propagation of uncertainty. Forward modeling, including least-squares fitting of linear and polynomial functions are discussed. Topics in digital signal processing, including Fourier transforms, windowing, filtering, and power spectral density estimation is reviewed. The course enables students to apply the concepts of the data reduction and error analysis using a commonly available data analysis software suite to real data sets often found in the physical sciences.

Objectives: By the end of the course, students should
a) Be able to address the pros and cons of various methods of measurement
b) Be conversant with the data reduction and error analysis concepts mentioned above,
c) Be able to analyze 1D and 2D data sets to find computational estimates of PDFs, moments, and to address the appropriateness of various forward models,
d) Be familiar with various measurement techniques so as to best experimentally determine PDFs, moments, and the appropriateness of various forward models,
e) Be able to create figures that are journal-quality,
f) Be extremely familiar with the agreed upon software package so as to utilize it in subsequent classes and research endeavors.

Instructor: Andrew J. Gerrard, Ph.D., Professor
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Office Hours: TBD

Co-requisite: MATH 111

Course Materials: Bevington, P.R. and D. K. Robinson, *Data reduction and error analysis for the physical sciences, 3rd ed.*, McGraw-Hill, Boston, 2003.

Python, using the Anaconda package (https://www.anaconda.com)

Course Requirements and Grading Policy:

Homework: 30%

Homework is given every other week and is considered an important part of the class. The homework usually consists of reading the text, short answer questions, and mathematical calculations; often requiring Python. An assignment is given on the first lecture of the week [when theoretical material is covered] and may require measurements to be performed during that week either at the second lecture or outside of class. Students *are encouraged to work together* on the homework problems, though each student is responsible for handing in an *individual* homework set.

3 Exams (2 during the semester worth 15% each, and 1 final worth 25%): 55%

The purpose of the exams is to test the *individual* student's progress in the class. Exams are closed book/notes, but the student is allowed to bring in one 8.5x11 inch sheet of notes for each exam. Later exams can make use of previous note sheets (i.e., the note sheets are cumulative). Exams will be announced ahead of time.

Class participation 15%

Attendance at lecture is expected.

THE NJIT HONOR CODE WILL BE STRICTLY ENFORCED AND ANY VIOLATIONS WILL BE BROUGHT TO THE IMMEDIATE ATTENTION OF THE DEAN OF STUDENTS.

Week	Date	Topic
1	Jan 15	INTRODUCTION TO CLASS Data files, types, conversion, importance (e.g., *header*, *metadata*, *EOF*) Review of *Python*: reasons for use, range of capabilities, and alternatives APPLICATION: Writing a basic Python program
2	Jan 22	*Undergraduate Research 101* *Funding agencies and mission*, *proposals* (purpose, submission, review), *budgets*, *tasks* Things To Do and Things To Not Do: Strongly Encouraged Suggestions Basic Python operations for reading in data, analysis, and professional graphical output APPLICATION: Write a basic Python program to read in real data and make a plot
3	Jan 29	Uncertainties in Measurement: Chap 1 *Probability Distribution Functions (PDFs)* *Sample mean* + *sample standard deviation* *Percent error, SNR, dB/dBi* APPLICATION: Given a counting experiment [e.g., PMT] find various quantities
4	Feb 5	Explicitly defined *PDFs*: Chap 2 *Binomial* *Gaussian*, *Poisson*, Others [*Lorentzian*, *Cauchy*, etc.] *PDF Moments* and *Moment Generating Function*, focus on the *first and second moments* APPLICATION: Determine the PDF for 3-4 different random variables [temperature, PMT photon count from previous week]
5	Feb 12	**CATCH UP + REVIEW + EXAM 1**
6	Feb 19	An Aside: Uncertainty Analysis: Chap 3 *Statistical Uncertainty* and *Bias* *Propagation of Uncertainty* APPLICATION: Propagation of uncertainty in a "complex" measurement: Measurements from a CCD
7	Feb 26	*Estimators and Estimation Theory*: Chap 4 Best estimates of the moments: Mean, standard deviation of the mean, standard deviation of the standard deviation of the mean, etc. Variance, standard deviation of the variance, standard deviation of the standard … The *Forward Model* Concept APPLICATION: Expected photon counts from "*The Lidar Equation*"
8	Mar 5	*Curve Fitting*: Chap 6-8 Linear fits to data Least-squares fitting to a linear data set Polynomial forward model Least-squares fitting to a polynomial data set *Generalized Least-Squares Fitting*
9	Mar 12	**SPRING BREAK**
10	Mar 19	Testing the Fit: Chap 11 [and some Chap 5] *Correlation Analysis* *Chi-square* *Monte-Carlo Techniques/Methods*
11	Mar 26	**CATCH UP + REVIEW + EXAM 2**
12	Apr 2	*Generalized Random Variables and Stochastic Processes* Continuous realm to discrete realm Introduction to *Digital Signal Processing (DSP)* *Common DSP functions: delta, step, step down, top-hat (square), sinc, Gaussian*
13	Apr 9	Into the *Spectral Domain* Limitations and assumptions, *data windows* *FT vs. DFTs vs. FFTs* FTs of common functions
14	Apr 16	*Power Spectral Density (PSD)* estimation, from *periodograms* *DSP Filtering* concepts, *low-pass, high-pass, bandpass, and stopband filters* When all heck breaks loose: *Lomb-Scargle*, *parametric vs. non-parametric*, etc.
15	Apr 23	**LAST WEEK OF CLASSES + CATCH UP-REVIEW**