Syllabus for Astronomy 8824:
Numerical and Statistical Methods in Astrophysics

Autumn Semester 2019

Lectures: TTh, 8:50-10:20am, 4054 McPherson Lab

Professor: Paul Martini

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Course Web Page:

http://www.astronomy.ohio-state.edu/~martini/Astro8824/

Course Objectives

Astronomy 8824 is intended to provide an overview of numerical and statistical methods in modern astrophysics. The numerical topics we will cover include integration, differentiation, root finding and fast Fourier transforms. The statistical topics will include Bayesian statistics, errors, likelihood analysis, Fisher matrix forecasts, and hypothesis testing. Throughout the course, we will emphasize how these topics arise in astrophysics research. By the end of the course, you should have a basic understanding of these topics when you encounter them in the research literature, when listening to talks and AstroCoffee discussions, and know enough about these topics that you can make informed decisions on their use in your research.

We will use the python programming language throughout the course because python has become the computational lingua franca of modern astrophysics, and therefore a basic skill you should have. Nevertheless, this is not a course on how to program in python. If you do not already have some familiarity with python, there are several resources on the course web site, many many more online, and I will be happy to provide extra help outside of class time. I will also provide many code examples throughout the course.

Written Material

This course was developed by David Weinberg and taught by him for many years. As this is the first time I will teach this course, I will closely follow the lectures from when he last taught the course in 2017. These notes are all available on his website, which is a great resource:

http://www.astronomy.ohio-state.edu/~dhw/A8824/

In addition I recommend these two books:

1. *Numerical Recipes* by Press, Teukolsky, Vetterling, and Flannery

This book is a good introduction to many numerical methods, and is available for a number of programming languages (although unfortunately not python). It should be more useful for descriptions of numerical methods than for the routines. The 3rd edition has more information than the previous ones, although the other editions have the essentials.

2. *Statistics, Data Mining, and Machine Learning in Astronomy* by Ivezic, Connolly, VanderPlas, and Gray

We will mostly cover the first five chapters, which are the chapters that focus on statistics. This book uses python, and so is a good way to improve your knowledge of that language.

If you are not already conversant in python, I recommend that you also obtain an introduction to the python programming language. One geared toward scientific programming is likely to be most relevant. David Weinberg has recommended this one to past classes, and I think it is really good too:

Effective Computation in Physics: Field Guide to Research with Python by Scopatz and Huff.

Evaluation

The course grade will be based on problem sets (70%), and class participation & presentations (30%). There will not be a final exam.

Problem Sets

There will be seven problem sets, due approximately every other week. The problem sets will be primarily computational assignments that implement the methods we discuss in class. These assignments will be a major part of the practical application of numerical and statistical methods, and therefore the assignments (and eventual solution sets) may be the most useful part of the class. I strongly encourage you to review and understand the solution sets.

Each problem set should take on order 10 hours to complete. In order to ensure you have time for research and your other responsibilities, you should not spend more than 10 hours on any assignment. Once you have spent 8-9 hours on a given assignment, you should focus on writing up what you have accomplished. Part of the rationale for this limit is that people with different backgrounds, or different luck with programming bugs, will get to different distances, and this is okay.

You may use any resource you wish to complete the assignment except a person not in the class (you may work together or ask me, but not solicit outside help). I encourage you to work in groups, although note who you worked with and write up your own solution.

All late assignments will lose 10% credit per day, starting with after class time on the due date.

Class Participation and Presentations

I expect you will show up to every class on time unless you have another commitment, such as a conference or observing trip, or some unforeseen situation arises such as an illness or a family emergency. In those cases, you should inform me as far in advance as practical and talk to a classmate or me about any material you may have missed. I also expect that you will have reviewed the recommended reading for that day's class prior to class time.

During the course you should plan to give two 10-15 minute presentations on topics related to the course. I expect most of these presentations will be discussions of papers that use one of the numerical or statistical methods we will cover. These should be in the style of presentations at AstroCoffee. You are also welcome to present an introduction to a method that we will not cover, or talk about a more computational topic, such as provide an introduction to a particular python programming technique, or a python package. I encourage you to think about this and discuss it with me.

Course Topics and Schedule

This is a 2-credit course, rather than a 3-credit course. Our nominal cadence will consequently be that we meet on Tuesday and Thursday every other week. In practice, I have a fairly busy travel schedule this fall, and so our schedule will be more irregular. I will attempt to keep the class website up to date with when we will have class about a month in advance. Nevertheless, please do not make commitments for any Tuesdays and Thursdays this semester during class time, as the schedule could change.

Below is the list of topics we will cover this semester. The class website will list when we will cover each topic, along with the readings for those topics.

Numerical Topics

- Numerical integration
- Numerical solution of differential equations
- Root finding and minimization
- Fourier Transforms

Statistical Topics:

- Bayesian parameter estimation
- Correlated errors, likelihood, and Markov Chain Monte Carlo
- Fisher matrix forecasts
- Hypothesis testing
- Error estimation