NORTHERN ARIZONA UNIVERSITY

College of Engineering, Informatics, and Applied Sciences

INF626/626L Applied Bayesian Modeling[1]

School of Informatics, Computing, and Cyber Systems

Term: Fall 2019
Pre-requisite(s): Graduate student status.
Co-requisites(s): INF 626 & INF 626L
Co-convene(s):
Cross-listed course(s):
Mode of Instruction: face-to-face
Credit Hours: 4
Meeting Pattern: Lecture: TuTh 9:35-10:50am
Location: Lecture: SICCS (Bldg 90), Room 102
Meeting Pattern: Lab: Tu 4:00-6:30pm
Location: Engineering (Bldg 69), Room 314

Instructor: Dr. Joseph (Joe) Mihaljevic (joseph.mihaljevic@nau.edu)
Office: SICCS (Bldg 90), Room 213
Office Hours: TBD, SICCS (Bldg 90), Room 213

Course Purpose

This is an applied course in Bayesian data analysis and modeling. Some basic theory, essential to Bayesian data analysis, will be presented. The course will cover a range of statistical models that are typically encountered in data analysis, and it will show how these models can be accommodated within a Bayesian framework. The course will focus on generalized linear modeling approaches, but will cover more advanced topics such as forecasting and the estimation of parameters of ordinary differential equation models. The depth of coverage for each topic will depend on time availability and class interests.

Course Student Learning Outcomes

- **LO1**: Select, apply, and synthesize basic to advanced statistical analysis of data sets using Bayesian analytical methods and computational methods.
- **LO2**: Select and apply computational solutions, particularly using *R* and Stan, to estimate the parameters of statistical models.

[1]The instructor reserves the right to alter this syllabus. Students will be immediately notified of any changes.

- **LO3**: Synthesize model analysis and draw inferences on the meaning of these analyses, using written and oral formats.

Assignments / Assessments of Course Student Learning Outcomes

Learning outcomes are assessed through a variety of means:

Computer-based, laboratory assignments will reinforce the analytical problem-solving that will be developed in class lecture, supporting LO1 and LO2. Specifically, students will be confronted with problem sets that will require both analytical (i.e., hand-written mathematical analysis) and computational approaches to apply, synthesize, and interpret statistical analysis of various data sets. **Lab assignments will be due on Bblearn by Monday at 11:59pm the week after the associated lab period**. Students will receive prompt feedback on these assignments from the instructor, and some problems will be discussed in lecture to reinforce important topics.

The take-home, mid-semester exam will ask students to apply the knowledge gained in lecture and lab to a novel problem set, supporting LO1 and LO2.

The final project will consist of writing a grant proposal focused on understanding a problem of interest, and an associated data set. This project with require students to synthesize their understanding of statistical modeling and apply this understanding to a novel problem (LO3). **Depending on the size of the class, students may be required to work in groups. If groups are used, a detailed "Roles of PIs" document will be required, which is to be signed by both parties, so that the instructor understands how each member of the team participated. In this case, the instructor will assign a unique grade to each individual, based on the LOI and written final, the "Roles of PIs" document, and the individual performances on the collaborative oral presentation.**

Students will choose a data set and devise an appropriate statistical analysis. Mid-semester, students will turn in an NSF-style Letter of Intent (LOI) outlining their proposed project and identifying an appropriate data set. A rubric for this LOI will be provided, and students will receive prompt feedback on their planned project from the instructor. Students are required to consult with the instructor before the LOI is due. Note that the project can evolve from the submission of the LOI to the final product, but any significant deviations from the plan outlined in the LOI must be approved by the instructor.

By the end of the semester students will produce a grant proposal that describes the question of interest, the proposed structure of the statistical model, and at least three proof-of-concept analyses. Again, a rubric will be provided. Students will turn in their final project, including all associated computer code, on the last day of class. The last several days of class will be reserved for oral presentations of the grant proposals, with accompanying slides, in support of LO3.

Grading System

A weighted sum of assessment components is used to determine your final grade in the course.

Grade for Lecture:

Participation in class discussion and activities	15%
Take-home, mid-semester exam	40%
Final Project: - Letter of Intent - Final Written Presentation - Final Oral Presentation	 5% 20% 20%

Grade for Lab:

Participation and attendance	50%
Lab Assignments	50%

Final course grades (for lecture and lab) will be determined on a standard scale (90-100 = A, 80-89 = B, 70-79 = C, 60-69 = D, <60 = F). There is no "curve". Each students grade is based on their own assessments and not affected by the grades of other students. Mistakes in grading can happen, and students are encouraged to respectfully discuss such concerns with the instructor during office hours.

Course Materials

Readings

- These two books are highly encouraged, but optional:
- Andrew Gelman et al. *Bayesian Data Analysis*. Chapman & Hall/CRC, Boca Raton, FL, 2004 (2nd edition) or 2013 (3rd edition). **Note: this is referenced as AG in the schedule below, and chapters refer to the 2nd edition text.**
- John Kruschke. *Doing Bayesian Data Analysis*. Elsevier, Oxford, UK, 2011 (1st edition) or 2014 (2nd edition). **Note: this is referenced as JK in the schedule below, and chapters refer to 1st edition.**
- Other suggested readings are TBA and will be procured from the primary literature, provided on BBLearn. We may discuss specific readings during lecture, and the instructor will make this clear via an announcement on BBLearn.

Software

- Each student will need to bring a laptop to class on days that involve computer assignments. If this is a problem for any student, please inform the instructor.
- *R*, an open-source statistical programming language.
- *RStudio*, an integrated development environment (IDE) for *R*.
- *Stan*, a statistical programming language that interfaces with *R* via the package *rstan*.

Figure 1: Tentative Schedule

Week	Date	Type	Description	Readings
1	27-Aug	Lecture	Probability and Probability Distributions I	AG: Appendix A; JK: Ch 3
		Lab	Installations and Simulations	
	29-Aug	Lecture	Probability and Probability Distributions II	
2	3-Sep	Lecture	Bayes Rule	AG: Ch 1-3; JK: Ch 4-5
		Lab	Priors and Likelihoods	
	5-Sep	Lecture	Exact Posterior Calculations	
3	10-Sep	Lecture	Computational Methods I	AG: Ch 10-11,13; JK: Ch 7, 23.2
		Lab	Markov Chain Monte Carlo	
	12-Sep	Lecture	Computational Methods II	
4	17-Sep	Lecture	Simple Linear Regression (SLR)	AG: Ch 14; JK: Ch 16-17
		Lab	Simple Linear Regression	
	19-Sep	Lecture	SLR with Multiple Predictors	
5	24-Sep	Lecture	Heirarchical Modeling: Sparse Linear Regression	JK: Ch 17; AG: Ch 15 (skim); Vehtari et al. 2016;
		Lab	Sparse Linear Regression	
	26-Sep	Lecture	Methods of Model Comparison I	
6	1-Oct	Lecture	Methods of Model Comparison II	P & V et al. 2017; Conn et al. 2018;
		Lab	WAIC and LOO-IC in Action	
	3-Oct	Lecture	Heirarchical Modeling: SLR with Multiple Groups	
7	8-Oct	Lecture	Heirarchical Modeling: SLR with Random Effects I	AG: Ch 15; Harrison et al. 2018;
		Lab	Heirarchical SLRs	
	10-Oct	Lecture	Heirarchical Modeling: SLR with Random Effects II	
8	15-Oct	Lecture	Heirarchical Modeling: SLR with Nested Random Effects LETTER OF INTENT DUE	AG: Ch 16; JK: Ch 20
		Lab	Heirarchical SLRs with Random Effects	
	17-Oct	Lecture	Generalized Linear Modeling (GLM): Logistic Regression I	
9	22-Oct	Lecture	Generalized Linear Modeling (GLM): Logistic Regression II	AG: Ch 16
		Lab	Logistic Regression	
	24-Oct	Lecture	GLM: Poisson and Negative Binomial Regression	
10	29-Oct	Lecture	GLM: Zero Inflated Poisson Regression	Zeilis et al. 2008; Stan Users: 1.13
		Lab	Poisson Regression	
	31-Oct	Lecture	Advanced: Correlated Parameters I TAKE HOME EXAM DUE	
11	5-Nov	Lecture	Advanced: Correlated Parameters II	TBD literature
		Lab	Correlated Parameters	
	7-Nov	Lecture	Advanced: Combining data from different scales	
12	12-Nov	Lecture	Advanced: Near-term Iterative Forecasting	Dietze et al. 2018; TBD literature
		Lab	Updating priors and posteriors	
	14-Nov	Lecture	Advanced: Ordinary Differential Equation (ODE) Models I	
13	19-Nov	Lecture	Advanced: Ordinary Differential Equation (ODE) Models II	TBD literature; Mihaljevic et al. 2019
		Lab	ODE Parameter Estimaton	
	21-Nov	Lecture	In-class working time (Final Project)	
14	26-Nov	Lecture	In-class working time (Final Project)	
		Lab	In-class working time (Final Project)	
	28-Nov	Lecture	THANKSGIVING DAY - NO LECTURE	
15	3-Dec	Lecture	Presentations	
		Lab	Presentations	
	5-Dec	Lecture	Presentations	
16	10-Dec	Lecture	No Class	
		Lab	No Class	
	12-Dec	Lecture	FINAL WRITTEN PROJECTS DUE	

Course Policies

- Visiting the instructor during office hours is encouraged! I am happy to talk about the class, careers, research, and topics related (even loosely) to this course. If a student cannot attend regular office hours, an appointment may be made via email, with sufficient advanced notice. However, if the student has not spent the entire lab time attempting to complete the assignment, I will not make additional office hour appointments outside of lab time to discuss these assignments.
- The paramount policy of this course is that each student is required to demonstrate respect towards their peers and the instructor. The behavior of the instructor is held to the same standard. Students and instructors come from all walks of life, and may identify with a variety of ethnic, racial, religious, gender and sexual identities. Diversity of thought and perspective enhances our science. As such, discriminatory behaviors will not be tolerated in this course. See University Policies (below) that relate to this topic.
- Attendance is required and will be recorded in both lecture and lab. Excessive absences will reduce your overall grade: 2 unexcused absences leads to 10% course grade reduction, ..., 5 unexcused absences leads to 40% course grade reduction, and 6 unexcused absences leads to a failing grade in the course.
- Email addressed to the instructor must be respectful and professional. Please include a descriptive subject line that includes "INF626" at the start. The instructor will respond to emails promptly, within 2 business days, but the instructor will generally not respond to emails on weekends or late in the evenings. Please plan accordingly.
- The instructor will not provide course notes or make-up lab sessions to students who cannot attend class.
- No late work will be accepted (i.e., any late assignments, exams, or projects will receive zero points), no matter how close to the deadline these assignments are received.
- Cheating and plagiarism are strictly prohibited. All academic integrity violations are treated seriously. Academic integrity violations will result in penalties including, but not limited to, a zero on the assignment, a failing grade in the class, or expulsion from NAU. For group assignments, the "Roles of PIs" document must be of sufficient detail that the instructor can understand the intellectual contributions of all parties. For individual-based assignments, students are encouraged to discuss the intellectual aspects of assignments with other class participants. However, each student is responsible for formulating solutions on their own and in their own words.
- Electronic device usage must only support learning in the class, otherwise the instructor may ask the student to power down such devices or leave the class.
- Grades will be entered in BbLearn but your final grade will be calculated outside of BbLearn, using the grading system described above, and then entered in LOUIE. Your final course grade will not necessarily appear in BbLearn. Please check LOUIE for your final grade.

Appendix A. UNIVERSITY SYLLABUS POLICY STATEMENTS

ACADEMIC INTEGRITY

NAU expects every student to firmly adhere to a strong ethical code of academic integrity in all their scholarly pursuits. The primary attributes of academic integrity are honesty, trustworthiness, fairness, and responsibility. As a student, you are expected to submit original work while giving proper credit to other peoples ideas or contributions. Acting with academic integrity means completing your assignments independently while truthfully acknowledging all sources of information, or collaboration with others when appropriate. When you submit your work, you are implicitly declaring that the work is your own. Academic integrity is expected not only during formal coursework, but in all your relationships or interactions that are connected to the educational enterprise. All forms of academic deceit such as plagiarism, cheating, collusion, falsification or fabrication of results or records, permitting your work to be submitted by another, or inappropriately recycling your own work from one class to another, constitute academic misconduct that may result in serious disciplinary consequences. All students and faculty members are responsible for reporting suspected instances of academic misconduct. All students are encouraged to complete NAUs online academic integrity workshop available in the E-Learning Center and should review the full academic integrity policy available at https://policy.nau.edu/policy/policy.aspx?num=100601.

COURSE TIME COMMITMENT

Pursuant to Arizona Board of Regents guidance (Academic Credit Policy 2-224), for every unit of credit, a student should expect, on average, to do a minimum of three hours of work per week, including but not limited to class time, preparation, homework, and studying.

DISRUPTIVE BEHAVIOR

Membership in NAUs academic community entails a special obligation to maintain class environments that are conductive to learning, whether instruction is taking place in the classroom, a laboratory or clinical setting, during course-related fieldwork, or online. Students have the obligation to engage in the educational process in a manner that does not breach the peace, interfere with normal class activities, or violate the rights of others. Instructors have the authority and responsibility to address disruptive behavior that interferes with student learning, which can include the involuntary withdrawal of a student from a course with a grade of W. For additional information, see NAUs disruptive behavior policy at https://nau.edu/university-policy-library/disruptive-behavior.

NONDISCRIMINATION AND ANTI-HARASSMENT

NAU prohibits discrimination and harassment based on sex, gender, gender identity, race, color, age, national origin, religion, sexual orientation, disability, or veteran status. Due to potentially unethical consequences, certain consensual amorous or sexual relationships between faculty and students are also prohibited. The Equity and Access Office (EAO) responds to complaints regarding discrimination and harassment that fall under NAUs Safe

Working and Learning Environment (SWALE) policy. EAO also assists with religious accommodations. For additional information about SWALE or to file a complaint, contact EAO located in Old Main (building 10), Room 113, PO Box 4083, Flagstaff, AZ 86011, or by phone at 928-523-3312 (TTY: 928-523-1006), fax at 928-523-9977, email at equityandaccess@nau.edu, or via the EAO website at https://nau.edu/equity-and-access.

TITLE IX

Title IX is the primary federal law that prohibits discrimination on the basis of sex or gender in educational programs or activities. Sex discrimination for this purpose includes sexual harassment, sexual assault or relationship violence, and stalking (including cyberstalking). Title IX requires that universities appoint a Title IX Coordinator to monitor the institutions compliance with this important civil rights law. NAUs Title IX Coordinator is Pamela Heinonen, Director of the Equity and Access Office located in Old Main (building 10), Room 113, PO Box 4083, Flagstaff, AZ 86011. The Title IX Coordinator is available to meet with any student to discuss any Title IX issue or concern. You may contact the Title IX Coordinator by phone at 928-523-3312 (TTY: 928-523-1006), by fax at 928-523-9977, or by email at pamela.heinonen@nau.edu. In furtherance of its Title IX obligations, NAU will promptly investigate and equitably resolve all reports of sex or gender-based discrimination, harassment, or sexual misconduct and will eliminate any hostile environment as defined by law. Additional important information about Title IX and related student resources, including how to request immediate help or confidential support following an act of sexual violence, is available at http://nau.edu/equity-and-access/title-ix.

ACCESSIBILITY

Professional disability specialists are available at Disability Resources to facilitate a range of academic support services and accommodations for students with disabilities. If you have a documented disability, you can request assistance by contacting Disability Resources at 928-523-8773 (voice), 928-523-6906 (TTY), 928-523-8747 (fax), or dr@nau.edu (e-mail). Once eligibility has been determined, students register with Disability Resources every semester to activate their approved accommodations. Although a student may request an accommodation at any time, it is best to initiate the application process at least four weeks before a student wishes to receive an accommodation. Students may begin the accommodation process by submitting a self-identification form online at https://nau.edu/disability-resources/student-eligibility-process or by contacting Disability Resources. The Director of Disability Resources, Jamie Axelrod, serves as NAUs Americans with Disabilities Act Coordinator and Section 504 Compliance Officer. He can be reached at jamie.axelrod@nau.edu.

RESPONSIBLE CONDUCT OF RESEARCH

Students who engage in research at NAU must receive appropriate Responsible Conduct of Research (RCR) training. This instruction is designed to help ensure proper awareness and application of well-established professional norms and ethical principles related to the performance of all scientific research activities. More information regarding RCR training is available at https://nau.edu/research/compliance/research-integrity.

MISCONDUCT IN RESEARCH

As noted, NAU expects every student to firmly adhere to a strong code of academic integrity in all their scholarly pursuits. This includes avoiding fabrication, falsification, or plagiarism when conducting research or reporting research results. Engaging in research misconduct may result in serious disciplinary consequences. Students must also report any suspected or actual instances of research misconduct of which they become aware. Allegations of research misconduct should be reported to your instructor or the Universitys Research Integrity Officer, Dr. David Faguy, who can be reached at david.faguy@nau.edu or 928-523-6117. More information about Misconduct in Research is available at https://nau.edu/university-policy-library/misconduct-in-research.

SENSITIVE COURSE MATERIALS

University education aims to expand student understanding and awareness. Thus, it necessarily involves engagement with a wide range of information, ideas, and creative representations. In their college studies, students can expect to encounter and to critically appraise materials that may differ from and perhaps challenge familiar understandings, ideas, and beliefs. Students are encouraged to discuss these matters with faculty.