University of Nevada, Reno

Lecture 01: Introduction

Perry Williams, PhD

NRES 779

Bayesian Hierarchical Modeling in Natural Resources

What is this course about?

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Gaining new insight about (ecological) processes using models and observations in the Bayesian framework.

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Data Model :	
$[y_i \| z_i, \boldsymbol{\theta}_d]$	A model of the data that arise from the process
Process Model :	
$[z_i \| \boldsymbol{\theta}_p]$	A model of the process
Parameter Model :	
$[\boldsymbol{\theta}_d][\boldsymbol{\theta}_p]$	Models of the parameters

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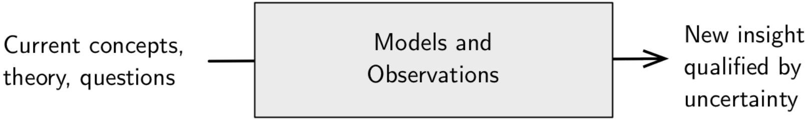

Why this course?

KEY TO STATISTICAL METHODS

	Design or Purpose	Measurement Variables	Ranked Variables	Attributes
1 variable 1 sample	Examination of a single sample	Procedure for grouping a frequency distribution, Box 2.1; stem-and-leaf display, Section 2.5; testing for outliers, Section 13.4 Computing median of frequency distribution, Box 4.1 Computing arithmetic mean: unordered sample, Box 4.2; frequency distribution, Box 4.3 Computing standard deviation: unordered sample, Box 4.2; frequency distribution, Box 4.3 Setting confidence limits: mean, Box 7.2; variance, Box 7.3 Computing g_1 and g_2, Box 6.2		Confidence limits for a percentage, Section 17.1 Runs test for randomness in dichotomized data, Box 18.3
	Comparison of a single sample with an expected frequency distribution	Normal expected frequencies, Box 6.1 Goodness of fit tests: parameters from an extrinsic hypothesis, Box 17.1; from an intrinsic hypothesis, Box 17.2 Kolmogorov–Smirnov test of goodness of fit, Box 17.3 Graphic "tests" for normality: large sample sizes, Box 6.3; small sample sizes (rankit test), Box 6.4 Test of sample statistic against expected value, Box 7.4		Binomial expected frequencies, Box 5.1 Poisson expected frequencies, Box 5.2 Goodness of fit tests: parameters from an extrinsic hypothesis, Box 17.1; from an intrinsic hypothesis, Box 17.2
1 ariable ≥2 amples	Single classification	Single classification anova: unequal sample sizes, Box 9.1; equal sample sizes, Box 9.4 Planned comparison of means in anova, Box 9.8; single degree of freedom comparisons of means, Box 14.10 Unplanned comparison of means: T-method, equal sample sizes, Box 9.9; T′, GT2, and Tukey–Kramer, unequal sample sizes, Box 9.10; Welsch step-up, Box 9.11; STP test, Section 9.7; contrasts using Scheffé, T, and GT2, Box 9.12; multiple confidence limits, Section 14.10 Estimate variance components: unequal sample sizes, Box 9.2; equal sample sizes, Box 9.3 Setting confidence limits to a variance component, Box 9.3 Tests of homogeneity of variances, Box 13.1 Tests of equality of means when variances are heterogeneous, Box 13.2	Kruskal–Wallis test, Box 13.5 Unplanned comparison of means by a nonparametric STP, Box 17.5	*G*-test for homogeneity of percentages, Boxes 17.5 and 17.8 Comparison of several samples with an expected frequency distribution, Box 17.4; unplanned analysis of replicated tests of goodness of fit, Box 17.5
	Nested classification	Two-level nested anova: equal sample sizes, Box 10.1; unequal sample sizes, Box 10.4 Three-level nested anova: equal sample sizes, Box 10.3; unequal sample sizes, Box 10.5		
	Two-way or multi-way classification	Two-way anova: with replication, Box 11.1; without replication, Box 11.2; unequal but proportional subclass sizes, Box 11.4; with a single missing observation, Box 11.5 Three-way anova, Box 12.1 More-than-three-way classification, Section 12.3 and Box 12.2 Test for nonadditivity in a two-way anova, Box 13.4	Friedman's method for randomized blocks, Box 13.9	Three-way log-linear model, Box 17.9 Randomized blocks for frequency data (repeated testing of the same individuals), Box 17.11

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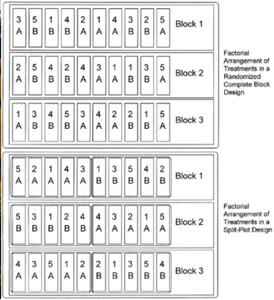


Why this course?

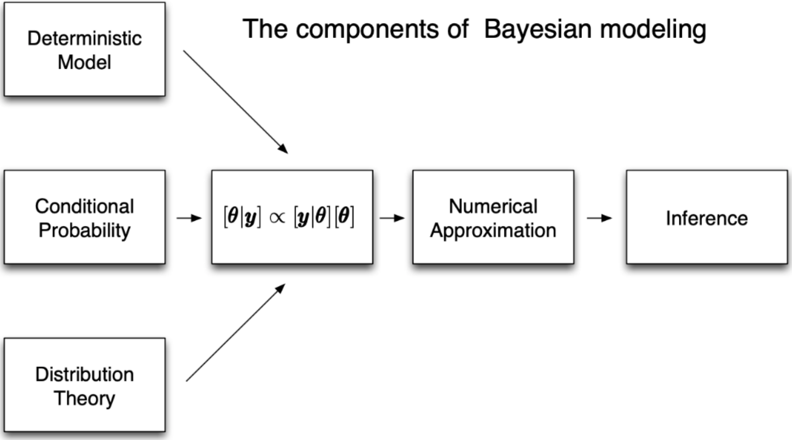
Problems poorly suited to traditional approaches

- Multiple sources of data
- Multiple sources of uncertainty
- Inference across scales
- Unobservable quantities
- Missing data
- Derived quantities
- Forecasting and interpolation

Goals

- Provide *principles* based understanding
- Enhance intellectual satisfaction
- Foster collaboration
- Build a foundation for self-teaching

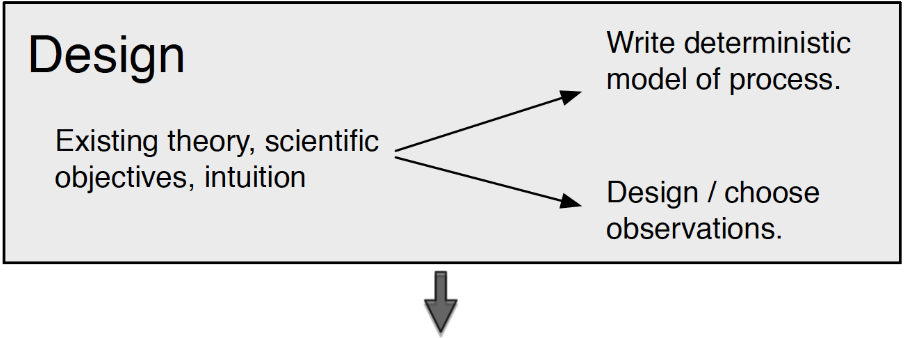
Learning Outcomes



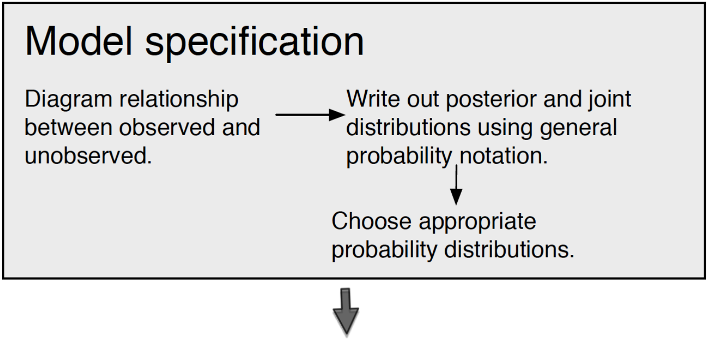
Learning Outcomes

1. Explain basic principles of Bayesian inference.
2. Diagram and write out mathematically correct posterior and joint distributions for Bayesian models.
3. Explain basics of the Markov chain Monte Carlo (MCMC) algorithm and be able to write an MCMC sampler.
4. Use software for implementing MCMC.
5. Develop and implement hierarchical models.
6. Evaluate model fit.
7. Appreciate possibilities for model selection.
8. Understand consequences of spatial and temporal autocorrelation.
9. Understand papers and proposals using Bayesian methods.

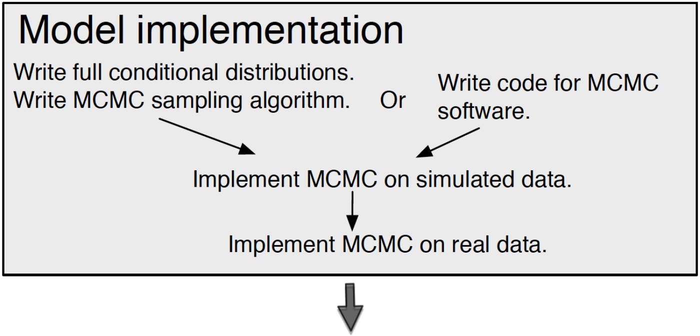
Learning Outcomes



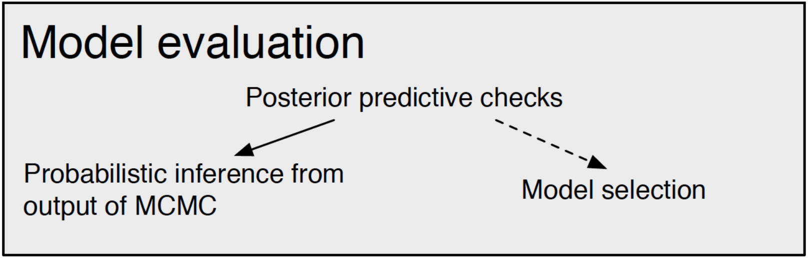
Learning Outcomes



Learning Outcomes



Learning Outcomes



Course Topics

Principles
- Laws of probability
- Distribution theory
- Moment matching
- Bayes' theorem
- Conjugacy

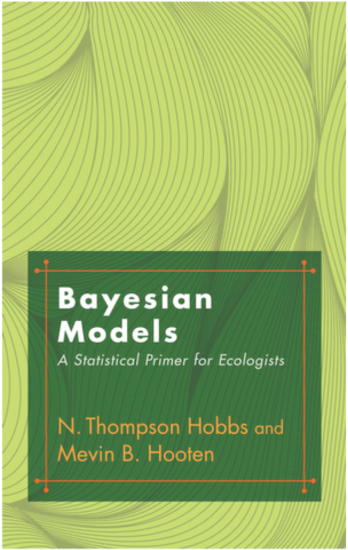
Implementation and inference
- MCMC
- JAGS
- Inference from single and multiple models
- Model checking

Hierarchical models
- Introduction
- Multi-level regression
- Mixture and occupancy
- State-space
- Spatial

Teaching Philosophy

- Principles are primary.
- Everyone learns, everyone teaches.
- Teaching trumps evaluation.
- The best learning comes from solving problems.

Text and Materials



Housekeeping

- Labs
    - Labs will be in groups of two
    - You will schedule time to work on labs with your partner.
    - We will introduce and review labs in class, as necessary.
- Lecture online Wednesdays and Fridays from 9-9:50

Housekeeping

- First laboratory available online
- Lecture notes: download morning of class (after 8:00)
- Some whiteboard work, so be prepared to take notes.

LaTeX

- Homework must be done in TeXenvironment.
  - LaTeX
  - Overleaf
  - Lyx
- I have a series of videos on getting started with LaTeX: YouTube Playlist

Evaluation

- About 8-12 laboratory exercises worth 50-100 points each (80% of grade)
- One of these may be a capstone problem done individually (20% of grade)
- You are graded relative to material, not relative to each other.
- Relax. You will get an A if you do the assignments carefully and thoughtfully.

Getting Help

- From me: Wednesdays and Fridays after class or by appointment.

Chores

- Have a working version of `R` and LaTeXon your machine.

First Assignment

- Read the syllabus
- Prepare a ≤ 2 minute presentation about yourself: background, what you are studying, who is your major professor, why you are taking the class.
- Prepare a 1-2 paragraph description of an important non-linear, static, deterministic model in your field. (Due Friday)
- Dust off your calculus book (or seek Google/Khan Academy). Review the definite integral and how it's derived.

Discussion Topic (if time permits)

- I am often referred to as “a modeler” (sometimes positively, sometimes negatively).
- Hobbs and Hooten (2015) state “all researchers are modelers”.
- Why do you suppose they say that?
- Describe your ideas about the relationships among observations, mathematical models, and statistical models in research.