Introduction to Geostatistics

GEOL 5446
3 Credits
Spring, 2017

Dept. of Geology & Geophysics
University of Wyoming
Instructor: Ye Zhang

Grading: A-F
Location: ESB1006
Time: TTh (9:35 am~10:50 am),
Office hour: Th (4:00~6:00 pm), GE 220
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Course Objectives:
Geoscientists routinely face interpolation and estimation problems when analyzing data from the field. Geostatistics has emerged as a valuable tool to aid such analyses. It originated from the mining industries where it found acceptance through successful applications to problems where decisions concerning large-investment operations are based on interpretations of limited and sparse data. In characterizing and simulating subsurface reservoirs, geostatistics offers a means to quantify prediction uncertainty. In this class, both the principles of geostatistics and its applications will be presented. The main topics include variogram analysis, kriging, and stochastic simulations (unconditional and conditional).

The class is organized into seven Chapters:
1. Overview
2. Probability Theory Review
3. Spatial Analysis
4. Experimental Variogram
5. Variogram Modeling
6. Geostatistical Estimation (Kriging, CoKriging, Collocated Cokriging)
7. Geostatistical Simulation (Unconditional, Conditional);
8. Advanced Estimation (Cross Validation, Block Kriging, Indicator Kriging, Simple Kriging);
9. Advanced Simulation (SGS, SIS, SGS Collocated Cokriging, MPS, Reservoir Uncertainty Analysis)

**If we're short on time, some advanced topics may be dropped. Unless otherwise stated, most advanced topics will not be tested.*

Learning Outcome:
The students will learn the basic approach in conducting a variogram analysis, including the calculation of experimental variograms, directional analysis (Rose Diagram and variogram surface) and variogram modeling. They will also learn the mathematical and statistical principles behind Kriging, Co-kriging and stochastic simulations as well as how to apply these geostatistical methods in spatial interpolation based on a set of 2D sampled data. Though some exercises and homework are done by hand or small computer codes (mostly Matlab), throughout the class, Surfer, a commercial geostatistical package will be used to help students gain familiarity with the tools as well as learn to integrate the various components of a geostatistical analysis.

Prerequisite:
Calculus I & II;
Linear Algebra (Optional)
Probability & Statistics (Optional);
Matlab Programming language (required for this class)*;

*A quick start to help you learn Matlab (will take ~ 2-3 hours):
http://faculty.gg.uwyo.edu/yzhang/files/Matlab_Basics.pdf

Potential Audience:
Geologists, geological engineers, civil, agricultural and petroleum engineers, soil scientists.

Tools:
Tools for simple exercises include ruler, calculator and Excel spreadsheet. For programs of modest complexity, Matlab programming will be used. For more complex projects, we'll use software packages such as Surfer or Gslib.

Questions & Answers:
(1) during lecture; (2) office hour;

Course Web Page:
A course site will be used (via *Wyoweb*) where assignments and course notes will be regularly posted. The course notes are specifically written for this class. It is a good source for information since it contains a lot of explanations and in-depth discussions to complement the lectures. Often, a lot of materials are presented in a lecture, so reading the course notes afterwards is a good way to reinforce your new knowledge. However, the course notes do not contain derivations, nor solutions to homework/exercise/exam problems. So, lecture attendance is key for this class.

Course requirements:
Students are expected to attend the lectures, work out the exercises, chapter projects and presentations independently, as well as complete assigned literature readings. A midterm and final exam will be given to evaluate the students' performance.

Attendance Policy:
Each student is expected to attend the lectures to fulfill the academic requirements. For participation in a University-sponsored activity or for unusual circumstances (personal hardship), an authorized absence may be issued to the student by the Director of Student Life or the Director's authorized representative. If a student has been hospitalized, or if the student has been directed by the Student Health Service or the student's private physician to stay at the student's place of residence because of illness, the Health Service medical staff or the student's private physician must issue a statement to the student giving the dates of the student's confinement. If a student produces the proof of absence, a makeup session can be arranged with the instructor.
http://uwadmnweb.uwyo.edu/legal/Uniregs/ur713.htm

Grading Policy:
The final grade will be given based on the performance in homework, in-class exercises and chapter projects, presentations and exams. The approximate percentage is shown:

Homework	35.0%
Projects	25% -- 30%
Class Presentation (tentative)	5.0 -- 0%
Final Project	20.0%
Final Exam	20.0%

Note that each homework/exam has a standalone grade of 100 points. When determining the final grade, these will be normalized reflecting the percentage distribution above. The final letter grade is given based on the numerical grade:

A	B	C	D	F
90-100	80-89	70-79	60-69	< 60

Clearly, the grade is not determined based on a curve. The student's final grade reflects his/her overall absolute performance throughout the semester.

Concerning homework/lab/exams:

Four points must be emphasized: (1) For problems involving equations or derivations, if appropriate, provide a complete analysis rather than a single number/result. (2) Be professional in your presentations. If applicable, write down the unit for your results and round off the numbers to 2 decimal points. (3) You can discuss the problems with fellow students or the instructor, but complete your assignments by yourself. (4) Hand in the homework on time.

Policy on Late papers, make-up exams, grade of incomplete:
Policy for this class:

- Unless otherwise stated, homework is expected to be handed in to the instructor in the beginning of the class one week after the homework is assigned; If not handed in on time, each day it is delayed, 10 points will be taken out of the grade (100) of that particular homework until no points remain.

- Unless otherwise stated, projects should be handed in by the specified due date. If not handed in on time, each day it is delayed, 10 points will be taken out of the grade.

- If you cannot attend the class (you must produce valid proof of absence), you must independently finish the exercises/projects and present the evidence of your work to the instructor within a week.

- Exams are expected to be handed in at the end of the quiz/exam.

If a student can provide valid proofs of absence, the above rules do not apply. Within a reasonable time (1 week), the student is expected to hand in the late homework to the instructor, or, arrange with the instructor on a make-up exam (the usual time will be on weekends when the computer room is available). It is the student's responsibility to contact the instructor to make arrangement in a timely manner and in advance if at all possible, failing to do so will result in the forfeiture of the relevant points.

Grade of incomplete:
During the semester, if a student has suffered severe problems (e.g., serious physical or mental incapacitation) and cannot complete the course as a result, he/she may be issued an "I" (incomplete) grade. The UW regulation on how to make up for this grade is:
http://uwadmnweb.uwyo.edu/legal/Uniregs/ur720.htm

Academic dishonesty:

UW has a time-tested procedure to judge such cases, and serious penalties may be assessed. Please refer to UW Regulation 6-802 for details:
http://www.uwyo.edu/generalcounselsupport/clean%20uw%20regulations/UW%20Reg%206-802.pdf
So, do not cheat and do not help others cheat. In this class, if a student is caught cheating, he or she may be assigned a "F" for the course. Plagiarism is considered a form of cheating. Both students will lose the full points on the particular homework or lab assignments. However, when writing papers, a student may cite other's work, but proper attribution must be given.

Students with disability:
Please refer to the University Disability Support Service: http://uwadmnweb.uwyo.edu/UDSS/

Classroom decorum:
Turn off the cell phone. No smoking. Wear appropriate clothes. Do not bring food or drinks. Be respectful.

Tentative Schedule

Each homework generally consists of two related portions: (1) problem solving; (2) literature reading. The problem sets are typically described in the class Powerpoint files; the selected papers are posted on WyoWeb;.

Week 1 Jan 24 Jan 26	**Course Overview** *What is geostatistics? What kind of problems can geostatistics solve? Geostatistics versus simple interpolation. What is the overall approach in geostatistics? Are there problems and pitfalls to look out for? What is the characteristics of this class? What are expected from the students?* *Homework 1: Read 1.1~1.6 of Geostatistical Reservoir Simulation Textbook* **Mathematics & Statistics Review** *Summation; Vector; Matrix; Linear Algebra;*
Week 2 Jan 31 Feb 2	*Univariate Analysis; Bivariate Analysis; Multivariate Analysis; Gaussian Distribution (univariate);* *Homework 2: (1) see Powerpoint for problem descriptions; (2) Read 2.1~2.3 of Geostatistical Reservoir Simulation Textbook* ***Project One**: Univariate correlation among 2 data sets.*
Week 3 Feb 7 Feb 9	**Spatial Continuity Analysis** *Non-geostatistical Analysis (Posting, Contour, Symbol, Indicator, Moving Window); Spatial Continuity Analysis: Experimental Variogram;* *h-Scatterplot; Variogram versus Univariate Statistics; Higher Dimensions & Statistical Anisotropy;*
Week 4 Feb 14 Feb 16	**Spatial Continuity Analysis**: *Pure Nugget Variogram; Standard Deviation of Variogram Estimate;* *Homework 3: (1) see Powerpoint for problem descriptions; (2) Read Olea (1994).* *Irregular Data: Variogram Search Envelope; Exploring anisotropy;*
Week 5 Feb 21 Feb 23	**Spatial Continuity Analysis** (Continued): *Rose Diagram, Correlation Ellipse, Statistical Axis, Statistical Anisotropy, Variogram Surface* *Homework 4: Read Gringarten & Deutsch (1999)* *Issues; Outline of an Experimental Variogram Analysis;*
Week 6 Feb 28 March 2	**Spatial Continuity Analysis** (Continued): *Recommendations from both the Environmental and Petroleum fields.* *Homework 5: see Powerpoint for problem descriptions;* ***Project Two**: Experimental Variogram Analysis of 2 data sets using Surfer*
Week 7 March 7 March 9	**Variogram Modeling**: *Basic Permissible Models; Model Fitting "Rule of Thumb"; recommended workflow from petroleum reservoir modeling; invited lecture (Dr. Mohammad Koneshloo) on 'real world variogram modeling issues;* *Homework 6: (1) see Powerpoint for problem descriptions; (2) Read Chu et al. (1994).* ***Project Three**: Variogram Modeling of the 2 data sets analyzed in Project Two using Surfer.*

Week 8 March 14 March 16	**Spring Break** **No classes**
Week 9 March 21 March 23	**Estimation**: *Non-geostatistical Estimation; Geostatistical Estimation; Random Function Models; Ordinary Kriging (OK);*
Week 10 March 28 March 30	*Ordinary Kriging (continued); Kriging with a moving neighborhood;* *Homework 7 (1) see Powerpoint for problem descriptions;*
Week 11 April 4 April 6	*Co-Kriging; & Collocated CoKriging* ***Project Four**: Using OK to conduct spatial interpolation analysis based on the 2 data sets previously analyzed for the variograms;*
Week 12 April 11 April 13	*Finish up Cokriging topics; Cross Validation; Indicator Kriging; Simple Kriging;* *Homework 8 (1) collocated Co-Kriging (see class powerpoint); (2) Read 4.6 of Geostatistical Reservoir Simulation Textbook (creating cross variograms for the Co-Kriging analysis).*
Week 13 April 18 April 20	*Block Kriging; Unconditional Simulation (Cholesky Decomposition); Conditional Simulation;* ***Project Five (Optional)**:* *Using Conditional Simulation to generate images (a stochastic ensemble) based on the 2 data sets previously analyzed for the OK estimation. What are the difference between Kriging and Simulation?*
Week 14 April 25 April 27	*Sequential Gaussian Simulation (SGS); Sequential Indicator Simulation (SIS);* ***Term Project (4 alternatives):*** *(1) Instructor will assign a term project to the class;* *(2) For a set of 2D data (given by the instructor or the students' own choosing), conduct a full suite of geostatistical analysis including an exploratory univariate analysis, experimental variogram analysis, anisotropy analysis, variogram modeling, and OK interpolation (both Kriging estimate and variance of the Kriging error). Results must be presented with all relevant plots and a report discussing the findings found at each step.* *(3) Write a 1D Matlab code for Ordinary Kriging, unconditional, and conditional simulations.* *(4) A small research problem may be substituted (student must communicate the content and nature of this project to the instructor for prior approval);*
Week 15 May 2 May 4	*Collocated Co-Simulation; Multiple point geostatistics; Static/Dynamic data integration; Reservoir Uncertainty Analysis;* *Invited lecture on SGeMS (Mohammad Koneshloo)*
Week 16	***Final Exam, Location/Time TBA*** • *Please turn in the Term Project on the date of the Final Exam.* • *In the Final Exam, a bonus problem (10 points) will be given, involving full derivations of either an estimation or simulation problem.*