Algorithms for Geospatial Computing
CMSC498Q/ GEOG 498I/788I
(Spring 2021)

Instructor: Professor Leila De Floriani
E-mail: deflo@umd.edu
Office hours: 2:00pm-3:00pm Tuesday online, or by appointment

Schedule of Classes: Tuesdays and Thursdays: 12:30pm – 1:45pm, offered online

Course Description

Geospatial data science deals with representation, and analysis of data in which the spatial component plays a key role. The aim of the course is to familiarize the student with the fundamental algorithms in geospatial data science and their implementation in geographical information systems and in geospatial data analysis software tools. The course provides an introduction to fundamental geometric primitives and algorithms, which are the basic building blocks for spatio-temporal data processing and analysis. It will focus on algorithms and data structures for managing point clouds, including unsupervised learning algorithms, which are at the basis for geospatial data exploration and analysis, and apply them to processing and analysis of LiDAR (Light Detection And Ranging) data in the context of terrain reconstruction, urban modeling, forest management and coastal data management and analysis. Emphasis will be placed on surface and scalar field modeling, such as terrains, discussing both raster and vector models as well as algorithms for building, querying and performing morphological and visibility computations on them. Algorithms for road network analysis and reconstruction will be studied in connection with real-world applications.

Prerequisites. Some programming background in Python or C++ is required for this course.

Course Learning Objectives

Upon a successful completion of the course the students will be able to:

- Acquire in-depth knowledge of fundamentals of algorithms for geospatial data science.
- Learn techniques for efficiently encoding, manipulating and querying geospatial data.
- Gain substantial understanding of how geospatial data are actually processed in modern geographical information systems.
- Learn how to design, use and implement algorithms dealing with geospatial data, with emphasis on point data processing and analysis, on terrain modeling and on road network analysis.
- Apply algorithms for discrete and continuous geospatial data to LiDAR data processing and analysis, and algorithms for road network routing and reconstruction to real-world data sets
- Learn how to use open-source software to solve geospatial data analysis problems.

Required Resources and Corse Communication

The main course communication will be carried out through Canvas within the University of Maryland Enterprise Learning Management System (ELMS; https://elms.umd.edu). All students enrolled in the course have access to the system. Canvas will also be used by the instructor to post course slides, and
Course material consists of course notes in the form of slides posted on Canvas. This is the list of recommended books:

- M. Goodrich, R. Tamassia, M.H. Goldwasser, *Data Structures and Algorithms in Python*, 2013, Wiley and Sons. (from the same authors also similar books in C++ and Java).

**Course Structure**

The course consists of a series of lectures, homework assignments and a project. The topics which will be covered in class are:

- **Fundamental geospatial concepts** (objects (points, lines, regions), maps, fields (terrains), networks) and **geospatial data models** (raster, vector, Triangulated Irregular Networks (TINs), graphs)
- **Basic geometric algorithms**: point-in-polygon, line segment intersections, polygon centroid, polygon overlay, etc.
- **Processing and analysis of point data**:
  - Uniform grids; hierarchical spatial indexes: quadtrees, kd-trees, R-trees; spatial subdivisions (Voronoi diagrams): algorithms for nearest neighbor, and range searching
  - *Unsupervised learning algorithms*: clustering, hierarchical nearest neighbor, k-means, density-based clustering
  - *Application*: tree mapping and reconstruction from LiDAR (Light Detection And Ranging) data in forest management for carbon emission and visualization
- **Surface and field modeling (terrain models)**:
  - Triangulated Irregular Networks (TINs): data structures, Delaunay triangulation
  - Raster models: regular grids, gridding and deterministic interpolation algorithms
  - Computing terrain morphology: slope, aspect, curvature, critical points and watershed segmentation on grids and TINs
  - Visibility on terrains: algorithms for viewshed analysis and horizon computation
  - *Applications*: terrain reconstruction from LiDAR point clouds, rooftop reconstruction from LiDAR point clouds in urban environments; bathymetry and coastline reconstruction for coastal data processing and analysis
- **Road network computation and reconstruction**:
  - Networks: definitions, basic data structures, hierarchical networks
  - Algorithms for route computations in road networks; hierarchical approaches
  - Road network reconstruction from GPS and satellite data; clustering algorithms and morphological approaches.

In 2021, due to the pandemic, the course will be taught online. The online nature of this class will push students to take an active role in the learning process, by engaging and collaborating with other students and the instructor on a regular basis in live sessions.

**Major Assignments**
**Homework Assignments.** There will be two kinds of homework assignment, a reading assignment and a programming assignment. A reading assignment will consist of answering questions about material in a specified recommended book or presented in class. The purpose is to help the student to elaborate on the various notions and algorithms discussed in class. A programming assignment will consist of studying and implementing simple algorithms seen in class, for a geospatial applications. The development will be in Python (or C++), with the use of existing open-source libraries for spatial data. The purpose is to make the students familiar to basic programming tools that will then be used in the development of the project.

**Project.** The project will consist of designing and implementing algorithms for processing and analyzing geospatial data in the context of some specific application problem discussed in class. Examples are: developing a tool for segmenting LiDAR point clouds, or raster images in an urban environment, reconstructing trees in a city or in a forest from sets of LiDAR points, computing morphological information from bathymetric data for precision navigation near the coast, reconstructing a road network from satellite data, etc. The project will be developed in Python (C++), with support by libraries implementing specific techniques. The project for graduate students will be defined by an individual consultation with the instructor.

**Final Exam.** The exam will present a combination of questions requiring the definition of specific representations or the description of some techniques all seen in class and described in the course notes.

**Research paper (only for graduate students).** Graduate students will also be required to prepare a research paper with a review of the literature in the specific topic, and present it in class, replacing one or two homework assignments.

**Grading Structure and Policies**

- **Homework** – 42% (for graduate students: possibly replacing one/two homework assignments with a research paper)
- **Project**– 30% (for graduate students: individual project plus presentation in class)
- **Final exam** – 28%

Please plan to have any work submitted well before the scheduled deadline. I am happy to discuss any of your grades with you, and if I have made a mistake I will immediately correct it. Any formal grade disputes must be submitted in writing and within one week of receiving the grade. Final letter grades are assigned based on the percentage of total assessment points earned, as specified in the table below.

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**Course Outline (tentative)**
• **Week 1:** Course introduction; fundamental geospatial concepts (objects (points, lines, regions), maps, fields (terrains), networks); an algorithm for point-in-polygon.

• **Week 2:** Clustering points in space: convex hull; a simple algorithm for detecting the vertices of the convex hull; Graham’s algorithm for computing the convex hull.

• **Week 3:** Hierarchical data representations: binary and quaternary trees; algorithms for tree traversals.

• **Week 4:** Operations on point data; representations for point data: uniform grid; PR-quadtrees; kD trees., R-trees

• **Week 5:** Algorithms for building and querying PR-quadtrees and kD-trees.

• **Week 6:** Unsupervised learning algorithms: clustering, hierarchical nearest neighbor, k-means, density-based clustering.

• **Week 7:** Reading class reviewing the material of the first part of the course.

• **Week 8:** LiDAR (Light Detection And Ranging) data fundamentals and related computational problems. Presentation of the project.

• **Week 9:** Geospatial data models (raster, vector, Triangulated Irregular Networks (TINs), graphs); raster models: regular grids, gridding and deterministic interpolation algorithms.

• **Week 10:** Triangulated Irregular Networks (TINs): data structures, Delaunay triangulation. Voronoi diagram and spatial subdivisions.

• **Week 11** Computing terrain morphology: slope, aspect, curvature, critical points and watershed segmentation on grids and TINs. Applications to terrain reconstruction from LiDAR point clouds, rooftop reconstruction from LiDAR point clouds in urban environments, bathymetric data processing and analysis.

• **Week 12:** Discussion class on the project. Road network computation and reconstruction; networks: definitions, basic data structures, hierarchical networks. **Week 13:** Road network computation and reconstruction: algorithms for route computations in road networks; hierarchical approaches; road network reconstruction from GPS and satellite data; clustering algorithms and morphological approaches. **Project due at the end of week 13.**

• **Week 14:** Presentation of the research projects by the graduate students, reading class in preparation for the final exam.

• **Final exam**

**Note.** This is a tentative schedule, and subject to change as necessary – monitor the course ELMS page for current deadlines. In the unlikely event of a prolonged university closing, or an extended absence from the university, adjustments to the course schedule, deadlines, and assignments will be made based on the duration of the closing and the specific dates missed.

**Course Guidelines**

**Class attendance.** Requirements for this course include attendance and participation in the lectures, completion of programming assignments and/ or a research paper, a midterm exam, and a final exam. Course readings will come from a comprehensive set of slides posted by the instructor, which will form the course notes. Lectures will also include information not present in the posted notes, or in the recommended books. The exams will be based on all material presented in the lectures and on any required reading.

**Communications with the instructor.** Please contact me by email at deflo@umd.edu. Please do not
email me with questions that are easily found in the syllabus or on ELMS (i.e. When is this assignment due? How much is it worth? etc.) but please do reach out about personal, academic, and intellectual concerns/questions. Important announcements will be sent via ELMS messaging. You need to make sure that your email & announcement notifications (including changes in assignments and/or due dates) are enabled in ELMS so you do not miss any messages. You are responsible for checking your email and Canvas/ELMS inbox with regular frequency.

Communications with peers. With a diversity of perspectives and experience, we may find ourselves in disagreement and/or debate with one another. As such, it is important that we agree to conduct ourselves in a professional manner and that we work together to foster and preserve a virtual classroom environment in which we can respectfully discuss and deliberate controversial questions. I will make every reasonable attempt to create an atmosphere in which each student feels comfortable voicing their argument without fear of being personally attacked, mocked, demeaned, or devalued. Any behavior (including harassment, sexual harassment, and racially and/or culturally derogatory language) that threatens this atmosphere will not be tolerated. Please alert me immediately if you feel threatened, dismissed, or silenced at any point during our semester together and/or if your engagement in discussion has been in some way hindered by the learning environment.

Campus Policies

It is our shared responsibility to know and abide by the University of Maryland’s policies that relate to all courses, which include topics like:

- Academic integrity
- Student and instructor conduct
- Accessibility and accommodations
- Attendance and excused absences
- Grades and appeals
- Copyright and intellectual property

Please visit [www.ugst.umd.edu/courserelatedpolicies.html](http://www.ugst.umd.edu/courserelatedpolicies.html) for the Office of Undergraduate Studies’ full list of campus-wide policies and follow up with me if you have questions.

Academic Integrity

The University's Code of Academic Integrity is designed to ensure that the principles of academic honesty and integrity are upheld. In accordance with this code, the Smith School does not tolerate academic dishonesty. Please ensure that you fully understand this code and its implications because all acts of academic dishonesty will be dealt with in accordance with the provisions of this code. All students are expected to adhere to this Code. It is your responsibility to read it and know what it says, so you can start your professional life on the right path.

It is important to note that course assistance websites, such as CourseHero, are not permitted sources, unless the instructor explicitly gives permission for you to use one of these sites. Material taken or copied from these sites can be deemed unauthorized material and a violation of academic integrity. These sites
offer information that might not be accurate and that shortcut the learning process, particularly the critical thinking steps necessary for college-level assignments.

Additionally, it is understandable that students may use a variety of online or virtual forums for course-wide discussion (e.g., GroupME or WeChat). Collaboration in this way regarding concepts discussed in this course is permissible. However, collaboration on graded assignments is strictly prohibited unless otherwise stated. Examples of prohibited collaboration include: asking classmates for answers on quizzes or exams, asking for access codes to clicker polls, etc. Finally, on each exam or assignment you must write out and sign the following pledge:

"I pledge on my honor that I have not given or received any unauthorized assistance on this exam/assignment."

Please visit the Office of Undergraduate Studies’ full list of campus-wide policies and follow up with me if you have questions.

If a student ever feel pressured to comply with someone else’s academic integrity violation, please reach out to the instructor straight away. Also, if a student is ever unclear about acceptable levels of collaboration, please ask.

**Resources and Accommodations**

**Accessibility and Disability Services.** The University of Maryland is committed to creating and maintaining a welcoming and inclusive educational, working, and living environment for people of all abilities. The University of Maryland is also committed to the principle that no qualified individual with a disability shall, on the basis of disability, be excluded from participation in or be denied the benefits of the services, programs, or activities of the University, or be subjected to discrimination. The **Accessibility & Disability Service (ADS)** provides reasonable accommodations to qualified individuals to provide equal access to services, programs and activities. ADS cannot assist retroactively, so it is generally best to request accommodations several weeks before the semester begins or as soon as a disability becomes known. Any student who needs accommodations should contact me as soon as possible so that I have sufficient time to make arrangements. For assistance in obtaining an accommodation, contact Accessibility and Disability Service at 301-314-7682, or email them at adsfrontdesk@umd.edu. Information about **sharing your accommodations with instructors, note taking assistance** and more is available from the **Counseling Center.** Every effort will be made to accommodate students who are registered with the Disability Support Service (DSS) Office and who provide the instructor with a University of Maryland DSS Accommodation form. This form must be presented to the instructor at the beginning of classes. The instructor will not be able to accommodate students who are not registered with DSS or who provide the instructor with documentation which has not been reviewed and approved by UM’s DSS Office.

**Student Resources and Services.** Taking personal responsibility for your own learning means acknowledging when your performance does not match your goals and doing something about it. I hope you will come talk to me so that I can help you find the right approach to success in this course, and I encourage you to visit UMD’s Student Academic Support Services website to learn more about the wide range of campus resources available to you. In particular, everyone can use some help sharpening their communication skills (and improving their grade) by visiting UMD’s Writing Center and schedule an appointment with the campus Writing Center. You should also know there are a wide range of resources to support you with whatever you might need (UMD’s Student Resources and Services website may help). If you feel it would be helpful to have someone to talk to, visit UMD’s Counseling Center or one of the many other mental health resources on campus.
Basic Needs Security. If you have difficulty affording groceries or accessing sufficient food to eat every day, or lack a safe and stable place to live, please visit UMD’s Division of Student Affairs website for information about resources the campus offers you and let me know if I can help in any way.

Technology Policy. Please refrain from using cellphones, laptops, and other electronic devices during class sessions unless we have designated such use as part of a class exercise.

Netiquette Policy. Netiquette is the social code of online classes. Students share a responsibility for the course’s learning environment. Creating a cohesive online learning community requires learners to support and assist each other. To craft an open and interactive online learning environment, communication has to be conducted in a professional and courteous manner at all times, guided by common sense, collegiality and basic rules of etiquette.

Participation. Attendance will be crucial to note-taking and thus your performance in this class. Attendance is particularly important also because class discussion will be a critical component for your learning, and thus it is expected for every session. Students with a legitimate reason to miss a live session should communicate in advance with the instructor, except in the case of an emergency. Students who miss a live session are responsible for learning what they miss from that session. Additionally, students must complete all readings and assignments in a timely manner in order to fully participate in class.

Course Evaluation. Please submit a course evaluation through CourseEvalUM in order to help faculty and administrators improve teaching and learning at Maryland. All information submitted to CourseEvalUM is confidential. Campus will notify you when CourseEvalUM is open for you to complete your evaluations for fall semester courses. Please go directly to the Course Eval UM website to complete your evaluations. By completing all of your evaluations each semester, you will have the privilege of accessing through Testudo, the evaluation reports for the thousands of courses for which 70% or more students submitted their evaluations.

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