Introduction to Computational Topology (Spring 2018)

Course Number  Math 574 (Topics Course)
Time  Tue-Thu 16:15–17:30 pm
Location  VECS 120, Sprk 333; via AMS
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Text  Class notes and handouts

Description of the Course

Topology studies how a shape or object is connected. In the past few years, there has been an increased interest in the development and use of topological methods for solving various problems in science and engineering. This new line of study is called Computational Topology or Applied Algebraic Topology. Computational topology combines topological results with efficient algorithms to analyze data and solve problems in many fields, including computer graphics and image analysis, sensor networks, clustering, robotics, genetics, protein biochemistry, geography, and others.

This course will present an introductory, self-contained overview of computational topology. There are no prerequisites, but mathematical sophistication at the senior undergraduate level and some familiarity with the use of computer packages (e.g., Matlab, Python, etc.) are expected. We will cover basic concepts from a number of areas of mathematics, such as abstract algebra, algebraic topology, and optimization. We will also look at algorithms and data structures, and efficient software for analyzing the topology of point sets and shapes – termed topological data analysis, or TDA. The grade will be based on a several homework assignments and a project, which will involve either an implementation of a method on your own, or recreation of results from recent research paper(s) using existing software tools.

Individuals with backgrounds in mathematics, engineering, or life sciences, all with some computational background, will find this class of interest.

Organization and Grading

There will be around eight homework assignments, and a project. The assignments will include mathematical problems as well as ones involving some use of software packages. The project will involve either the implementation and testing of a particular computational topology method, or summarizing at a low level the results of 2–3 related papers. The total score for the course will be calculated using the following weights: homework - 65%, projects - 35%.
Software

We will introduce and use several packages for computational topology (e.g., JavaPlex, Kepler-Mapper). Python or Matlab interfaces are available for many of them, while some of them come with fairly independent standalone implementations (i.e., one would not have to do much coding). The student would be expected to do a limited amount of basic scripting and/or coding (in Python, Octave, Matlab, C/C++, or another language/package). For optimization, we will use packages such as AMPL and Cplex.

Topics covered

The following is a rough plan. Based on student interests and course progress, new topics may be included and/or some of the ones listed here may be deleted.

1. Overview, results from topology - 3 lectures
   surfaces, Euler characteristic, homeomorphisms, groups;

2. simplicial complexes - 4 lectures
   Delaunay triangulation, Vietoris-Rips complex, alpha shapes, point clouds, simplicial complexes from data;

3. homology - 6 lectures
   homology groups, simplicial homology, relative homology, computing homology;

4. optimization - 3 lectures
   linear and integer programming, total unimodularity, optimality in homology;

5. topological persistence - 7 lectures
   matrix algorithms, stability, persistence diagram/barcodes, zigzag persistence;

6. Mapper - 5 lectures
   compact representations of data, hypothesis extraction

7. applications - 2 lectures
   biomedical data, CAD, geometric measure theory, etc.

Academic Integrity: Discussion of homework problems with others is allowed, and is also encouraged. But each person should hand in his or her own written solutions. Plagiarism or cheating will not be tolerated. Such behavior will result in a zero grade for a graded item and possibly a failing grade for the entire course.

Students with Disabilities: Reasonable accommodations are available for students with a documented disability through the Access center in Pullman. All accommodations MUST be approved through the Access Center (Pullman, Washington Building, Room 217). Please stop by or call 509-335-3417 for the Access Advisor.

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