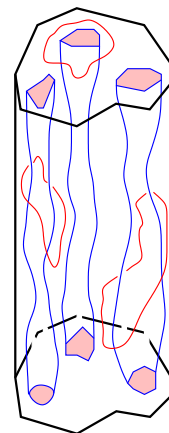


Math 529: Computational Topology (Spring 2022)

# Credits	3
Time	Tue-Thu 10:35–11:50 am
Location	TERR 106 (Pullman), VECS 125 (Vancouver), Zoom
Instructor	Bala Krishnamoorthy
Office	VUB 347, Zoom
Check-in Hours	Tue, Wed 2–3 PM
Email	kbala@wsu.edu
Web page	www.math.wsu.edu/faculty/bkrishna/Math529.html
Text	Class notes and handouts
References	Edelsbrunner and Harer: <i>Computational Topology</i> ISBN:0821-84925-5 (Preprint)

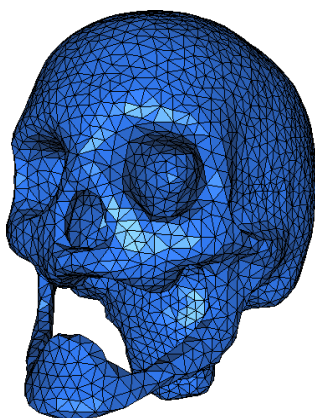


Required and Recommended Reading Materials

Required:	Class notes and handouts (posted on course web page)
Recommended:	Relevant sections from <i>Computational Topology: An Introduction</i> by Edelsbrunner and Harer.
Additional Materials/fees:	Not applicable.

Description of the Course

Topology studies how a shape or object is connected. In the past several 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 biomedicine, phenomics, machine learning, computer graphics and image analysis, sensor networks, robotics, geography, and several others.



Prerequisites: 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.

Expected Student Learning Outcomes (SLOs)

Quantitative skills: After completing this course, the student should be able to employ standard TDA computational tools (i.e., software packages) along with basic coding skills to perform persistent homology and mapper structural analysis of large scale data sets. They should also gain a working knowledge of basic concepts from computational algebraic topology—see the Tentative Schedule for a list of relevant concepts covered. They should demonstrate this knowledge through responses to problems—both proof-type as well as computational ones involving the use of software packages or coding—in the homework assignments as well as in the project.

Written communication skills: The student should be able to explain and communicate basic concepts of computational topology clearly in the homework assignments. They should be able to elucidate logical mathematical arguments as part of the proof-based exercises. They should also be able to write a cohesive yet brief (5–7 pages long) report for the project in the form of a short research paper.

Assessment: Required Assignments and Grading

Homework assignments: The course will have **six** homework assignments, which will include mathematical problems (including a few proof-based exercises) as well as ones involving use of software packages. The Tentative Schedule specifies the due dates for each homework assignment. The student will be scored based on their level of command over basic concepts demonstrated in proof-type problems as well as their command over the use of computational tools. **These assignments will evaluate the student's quantitative skills and written communication skills.** Grades for the homework assignments will be assigned using the following guidelines. *A*: logic is consistent, computing steps are accurate, work is explained in a clear manner, only minor mistakes such as typos; *B*: some logical inconsistency is present, or explanations are not clear and well justified, but underlying understanding of material as well as basic command over computing tools is demonstrated; *C*: a lack of understanding of some underlying conceptual material and/or difficulty in using computing tools is evident; and *D* or *F*: a lack of understanding of much of the underlying concepts and/or inability to use basic computing tools and/or a lack of meeting submission deadlines.

Project: Each student will also be required to work on a course project, which will involve either the implementation and testing of a particular computational topology method on a real life data set, or summarizing at a low level the results of 2–3 related papers. **The student will be evaluated on their understanding of underlying concepts, command over use of computational tools (quantitative skills), as well as their ability to present their results concisely in a 5–7 page long project report (written communication skills).** A sample project description is available here: <http://www.math.wsu.edu/faculty/bkrishna/FilesMath529/S20/Homeworks/Project.pdf>.

Late submissions will receive zero credit. The student should contact the instructor well before the deadline to request an extension if valid and unavoidable circumstances arise.

Grading Policy: The *total score* for the course will be computed using the following **weights**: homework: 65%, project: 35%. The total score will be *rounded up* at the first decimal place, e.g., 87.42 \rightarrow 87.5, and 79.91 \rightarrow 80. The **overall grade for the course** will be determined by the total score, based on the following scale: 93–100: A, 90–92.9: A–, 87–89.9: B+, 83–86.9: B, 80–82.9: B–, 77–79.9: C+, 73–76.9: C, 70–72.9: C–, 67–69.9: D+, 60–66.9: D, 0–59.9: F.

Attendance Policy: While student attendance will not be tracked on a regular basis, attending each lecture is critical to understand all concepts, and performing well in the course. The student is encouraged not to miss any lectures.

Software

We will introduce and use several packages for computational topology (e.g., Ripser, KeplerMapper). 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 Octave, Python, C/C++, or another language/package).

Expectation for Student Effort

Course Expectation: Academic credit is a measure of the time commitment required of a typical student in a specific course. For the WSU semester system, one semester credit is assigned for a minimum of 45 hours. The anticipated time commitment for this course is 3 hours of work per week for each credit hour (a minimum of 9 hours per week). **For each hour of lecture equivalent, students should expect to have a minimum of two hours of work outside class.** A tentative weekly time commitment for the student in this class is listed below:

class time (lectures)	2.5 hours/week
reading class materials	1.5 hours/week
completion of assignments (homework, project)	5.0 hours/week
Total	9.0 hours/week

Tentative Schedule and Topics Covered

Week	Lec #	Date	Details
1	1	Tue, Jan 11	topology and connectivity, motivating applications
	2	Thu, Jan 13	definitions from topology, homeomorphism
2	3	Tue, Jan 18	manifolds, orientability
	4	Thu, Jan 20	simplices and simplicial complexes [HW 1 Due]
3	5	Tue, Jan 25	abstract simplicial complexes (ASCs), geometric realization
	6	Thu, Jan 27	Euler characteristic, classification of manifolds
4	7	Tue, Feb 1	star and link, retractions, nerves
	8	Thu, Feb 3	nerve theorem, Čech and Vietoris-Rips complexes [HW 2 Due]
5	9	Tue, Feb 8	Voronoi diagram, Delaunay complex, filtration, alpha complex
	10	Thu, Feb 10	witness complexes, max-min selection
6	11	Tue, Feb 15	chains, boundary, chain complex
	12	Thu, Feb 17	fundamental lemma of homology, homology groups [HW 3 Due]
7	13	Tue, Feb 22	betti numbers (β_i s), examples of homology groups
	14	Thu, Feb 24	Euler-Poincaré theorem, boundary matrix
8	15	Tue, Mar 1	Smith Normal Form (SNF), algo for SNF, reduced homology
	16	Thu, Mar 3	relative homology, topological persistence
9	17	Tue, Mar 8	incremental algo for β_i s, pairing for persistence
	18	Thu, Mar 10	UNION-FIND data structure, persistence algorithm [HW 4 Due]
		Tue, Mar 15	<i>Spring break</i>
		Thu, Mar 17	<i>Spring break</i>
10	19	Tue, Mar 22	persistence diagram, fundamental lemma of persistent homology
	20	Thu, Mar 24	matrix algorithm for persistence
11	21	Tue, Mar 29	Reeb graph, pullback cover, mapper algorithm
	22	Thu, Mar 31	details of mapper: computational details [HW 5 Due]
12	23	Tue, Apr 5	homology over \mathbb{Z} , optimal homology problems
	24	Thu, Apr 7	boundary matrix $[\partial]$ and total unimodularity (TU)
13	25	Tue, Apr 12	linear and integer programming and TU
	26	Thu, Apr 14	conditions for $[\partial]$ being TU [HW 6 Due]
14	27	Tue, Apr 19	geometric measure theory (GMT) applications
	28	Thu, Apr 21	currents, flat norm, and TU of $[\partial]$
15	29	Tue, Apr 26	area minimizing surfaces, optimal bounding chains
	30	Thu, Apr 28	simplicial median shapes
16		Fri, May 6	Project due by 5:00 PM

WSU Systemwide Policies and Statements

Reasonable Accommodation

Students with Disabilities: Reasonable accommodations are available for students with documented disabilities or chronic medical or psychological conditions. If you have such a condition and need accommodations to fully participate in this class, please visit your campus' Access Center/Services website to follow published procedures to request accommodations. Students may also contact their campus offices to schedule an appointment with a Disability Specialist. All disability related accommodations are to be approved through the Access Center/Services on your campus. It is a university expectation that students connect with instructors (via email, Zoom, or in person) to discuss logistics within two weeks after they have officially requested their accommodations.

For more information, contact a Disability Specialist on your home campus:

- Pullman, WSU Global Campus, Everett, Bremerton, and Puyallup: 509-335-3417 Access Center (<https://www.accesscenter.wsu.edu>) or email at access.center@wsu.edu
- Vancouver: 360-546-9739 Access Center (<https://studentaffairs.vancouver.wsu.edu/access-center>) or email van.access.center@wsu.edu.

Academic Integrity

All members of the university community share responsibility for maintaining and promoting the principles of integrity in all activities, including academic integrity and honest scholarship. Students are responsible for understanding the full Academic Integrity Statement. Students who violate WSU's Academic Integrity Policy (identified in [WAC 504-26-010\(3\) and -404](#)) will receive a failing grade for the assignment or for the whole course, will not have the option to withdraw from the course pending an appeal, and will be reported to the Center for Community Standards. If you have any questions about what is and is not allowed in this course, ask your course instructor.

COVID-19

Students are expected to abide by all current COVID-19 related university policies and public health directives at <https://wsu.edu/covid-19/>. Students who do not comply with these directives may be required to leave the classroom; in egregious or repetitive cases, students may be referred to the Center for Community Standards for university disciplinary action.

Discrimination and Harassment

Discrimination, including discriminatory harassment, sexual harassment, and sexual misconduct (including stalking, intimate partner violence, and sexual violence) is prohibited at WSU (See [WSU Policy Prohibiting Discrimination and Harassment](#) (Executive Policy 15) and [WSU Standards of Conduct for Students](#)). If you feel you have experienced or have witnessed discriminatory conduct, you can contact the WSU Compliance & Civil Rights (CCR) and/or the [WSU Title IX Coordinator](#) at 509-335-8288 to discuss resources, including confidential resources, and reporting options. (Visit ccr.wsu.edu for more information). Most WSU employees, including faculty, who have information regarding sexual harassment or sexual misconduct are required to report the information to CCR or a designated Title IX Coordinator or Liaison. (Visit ccr.wsu.edu/reporting-requirements for more info).

Accommodation for Religious Observances or Activities

Washington State University reasonably accommodates absences allowing for students to take holidays for reasons of faith or conscience or organized activities conducted under the auspices of a religious denomination, church, or religious organization. Reasonable accommodation requires the student to coordinate with the instructor on scheduling examinations or other activities necessary for course completion. Students requesting accommodation must provide written notification within the first two weeks of the beginning of the course and include specific dates for absences. Approved accommodations for absences will not adversely impact student grades. Absence from classes or examinations for religious reasons does not relieve students from responsibility for any part of the course work required during the period of absence. Students who feel they have been treated unfairly in terms of this accommodation may refer to Academic Regulation 104 – Academic Complaint Procedures.

Classroom Safety

Classroom and campus safety are of paramount importance at Washington State University, and are the shared responsibility of the entire campus population. WSU urges students to follow the “Alert, Assess, Act,” protocol for all types of emergencies and the “[Run, Hide, Fight](#)” response for an active shooter incident. Remain ALERT (through direct observation or emergency notification), ASSESS your specific situation, and ACT in the most appropriate way to assure your own safety (and the safety of others if you are able).

Please sign up for emergency alerts on your account at MyWSU. For more information on this subject, campus safety, and related topics, please view the FBI’s [Run, Hide, Fight video](#) and visit the [WSU safety portal](#).

Full details can be found at <https://provost.wsu.edu/classroom-safety/>.

Severe Weather

For severe weather alerts, see <http://alert.wsu.edu/> and <https://oem.wsu.edu/emergency-procedures/severe-weather/>. In the event of severe weather affecting university operations, guidance will be issued through the alert system.

WSU Vancouver Statement: In the event that an adverse weather event (e.g., snow or ice) or natural hazard that poses a safety risk occurs, you should take personal safety into account when deciding whether you can travel safely to and from campus, taking local conditions into account. If campus remains open and your instructor decides to cancel the face-to-face meeting and substitute an alternative learning activity, you will be notified by your instructor via email or through Blackboard within a reasonable time after the decision to open or close campus has been made. Instructions regarding any alternative learning options or assignments will be communicated in a timely manner. If travel to campus is not possible due to adverse regional conditions, allowances to course attendance policy and scheduled assignments, including exams and quizzes, will be made. Students who attempt to gain advantage through abuse of this policy (e.g., by providing an instructor with false information) may be referred to the Center for Community Standards for disciplinary action. If a student encounters an issue with an instructor, the student should first talk with the instructor. If the issue cannot be resolved, the student should follow the reporting violations of policies outlined on the student affairs website.

Resources for Students

In Pullman

- Student Care Network: studentcare.wsu.edu
- Cougar Transit: 978 267-7233
- WSU Counseling and Psychological Services (CAPS): 509 335-2159
- Suicide Prevention Hotline: 800 273-8255
- Crisis Text Line: Text HOME to 741741
- WSU Pullman Police: 509 335-8548
- Pullman Police (Non-Emergency): 509 332-2521
- WSU Office of Civil Rights Compliance & Investigation: 509 335-8288
- Alternatives to Violence on the Palouse: 877 334-2887
- Pullman 24-Hour Crisis Line: 509 334-1133

In Vancouver

- Students may apply for grant assistance to cover technology or COVID-19 related educational costs through the Student Emergency Funding request form: <https://studentaffairs.vancouver.wsu.edu/financial-aid>
- The Laptop Loaner Program will continue in Spring 2022. To apply, students should visit: <https://www.vancouver.wsu.edu/information-technology/new-student-tech-guide>
- Tech Help for Students: <http://wsuvtech4students.org/>
- Access Campus Software Remotely with AppStream: <https://www.vancouver.wsu.edu/information-technology/access-campus-software-remotely-appstream>
- Cougar Food Pantry: We know that it can be hard for students to make ends meet when paying for college and living on a tight budget. The Cougar Food Pantry can help. The pantry provides free, nonperishable food items for WSU Vancouver students in need. The process is simple, anonymous and judgement-free. Learn more and request food at <https://studentaffairs.vancouver.wsu.edu/cougar-food-pantry>.