Abubakr Muhammad

Postdoctoral Research Fellow, jointly with
Quantum Information Processing Group, and
Center for Intelligent Machines

School of Computer Science, McGill University, Montreal, Canada

Up

Computational Topology in Science & Engineering

Reading Group, Winter 2008

Organizer: Abubakr Muhammad

Time: Wednesdays at 4:15 pm

Venue: McConnell Bldg. Room 321 (SOCS Lounge)

What is Computational Topology?

In recent years, there has been an enormous interest among researchers in various disciplines to develop and use topological methods for solving various problems in science and engineering. These algorithmic methods provide *robust* measures for global qualitative features of geometric and combinatorial objects that are relatively insensitive to local details. This makes topological abstractions into useful models for understanding *qualitative* geometric and combinatorial questions in several settings. The abstract machinery of *algebraic topology* has been used in various contexts related to data analysis, object recognition, discrete & computational geometry and distributed computing.

Summary of Objectives & Activities

The aim of this reading group is to communicate some of these recent developments to the participants with a *minimal* background in algebraic topology. Our focus will be on applications, although the proper appreciation of this research will require the understanding of some sophisticated mathematical methods.

Since it is expected that the attendees will come from diverse backgrounds in science, mathematics and engineering; the organizer will provide tutorials on the required background in topology. Moreover, the organizer will demonstrate how to use various computational topology software tools. The majority of meetings will be dedicated to discussing various research articles written by the leading experts in the field. Hopefully, these activities will enable the participants to generate new mathematics as well as new applications.

Topics

Mathematics: Homology, homotopy, Morse theory, Conley index theory, configuration spaces

Computational Methods: Cech-, Rips-, witness- and alpha-complexes, persistent homology of filtrations, harmonic methods for computing homology, software tools

Applications: Coordination, navigation and reconfiguration in robotics, coverage and routing in sensor networks, visualization and qualitative analysis of high-dimensional data sets, analysis of nonlinear dynamical systems, structural biology, image classification, distributed algorithms

Who should attend?

- Mathematicians with interest in topology, geometry and dynamical systems

- Computer scientists investigating computational geometry, machine learning, visualization & data analysis
- Engineers interested in algorithmic aspects of robotics, networked sensing and control theory
- Life scientists dealing with large data sets in molecular biology, neuroscience, systems biology

Tentative Schedule

DATE	TOPICS	FRONTIERS	SUGGESTED READING
Background			
Jan 16	Overview of computational topology	.	Barcodes: The persistent topology of data by Robert Ghrist.
Jan 23	Simplicial & cubical complexes; homotopy	Math	Notes on homology theory by Abubakr Muhammad. Also check Afra Zomorodian's course notes.
Feb06	Homotopy; simplicial homology	Math, CS	Same as last week.
Feb 13	Filtrations & persistent homology	Math, CS	Computing Persistent Homology by Zomorodian and Carlsson.
Feb 20	Hands-on training: Plex software package	CS	
Data Analysis, Learning & Visualization			
March 05	Manifold Learning from point cloud data sets (PCD)	Math, CS, Bio	Finding the homology of submanifolds with high confidence from random samples by Niyogi, Smale and Weinberger
March 12	Persistence and its Stability in PCDs	Math, CS, Bio	Persistent Homology - a Survey by Herbert Edelsbrunner and John Harer.
April 02	Natural Image Classification	EE, CS, Bio	A Topological Analysis of the Space of Natural Images Gunnar Carlsson and Tigran Ishkhanov.
April 09	Homology computation using harmonic analysis	CS, Math	Computing Betti numbers via Combinatorial Laplacians by Joel Friedman
Networks and Sensing			
	Coverage problems in sensor networks –I	EE, CS	Homological sensor networks by deSilva and Ghrist (survey). Blind swarms for coverage in 2D by Ghrist, deSilva, Muhammad
	Coverage problems in sensor networks –II	EE, CS	Coordinate-free coverage in sensor networks with controlled boundaries via homology by deSilva and Ghrist.
	Landmarks, routing and homology feature size in sensor networks	EE, CS	Geodesic Delaunay Triangulation and Witness Complex in the Plane by Gao, Guibas, Oudot, and Wang.
Robotics and Coordination			
	Morse theory – continuous,		

	discrete & combinatorial	Math	
	Navigation in robotics	EE, ME, CS	
	Configuration spaces – I: Distributed coordination	Math, ME, EE	
	Configuration spaces – II: Reconfigurable systems	Math, ME, EE	
Dynamical Systems			
	Conley index theory	Math	
	Computer assisted proofs in dynamical systems	Math, Phys, Bio	
	Hands-on training: CHomP software package	Math, CS	
Miscellaneous Topics			
	Topology of random data and random fields	Math, CS	
	Protein docking and structural biology	Bio, CS	

Resources in Computational Algebriac Topology

(If you find someone missing in these lists, please email me!)

Workshops/Programs

- 2006 MSRI Workshop on Application of Topology in Science and Engineering
- 2004 IMA Short Course Computational Topology
- Topological Methods in Scientific Computing, Statistics and Computer Science, Stanford University
- Computational Homology Project, CHomP
- DARPA-DSO program in fundamental mathematics: Sensor Topology for Minimal Planning
- DARPA-DSO program in fundamental mathematics: Topological Data Analysis
- 2007 TTI Workshop on Geometric and Topological Approaches to Data Analysis
- 2008 International Workshop on Algorithmic Topology, Bellairs-McGill
- Workshop on Topology learning, NIPS 2007

Courses

- Computational topology by Prof Edulsbrunner at Duke
- Computational topology and geometry by Prof Yap at NYU
- Introduction to computational topology by Prof Zomorodian at Dartmouth
- Computational dynamics and topology by Prof Day at William & Mary
- Topology for computing by Profs Cheong & Choi at KAIST
- Computational topology seminar, by Profs Giesen and Sagraloff, Max Planck Institute

Software

- Plex (Stanford)
- Computational Homology Project, CHomP

Books

- Tomasz Kaczynski, Konstantin Mischaikow, Marian Mrozek (2004), Computational Homology, Springer, ISBN 0-387-40853-3.
- Afra J. Zomorodian (2005). *Topology for Computing*, Cambridge, ISBN 0-521-83666-2.
- William Brasener (2006), Topology and its applications, John Wiley, ISBN: 978-0-471-68755-9.
- Allen Hatcher, Algebraic Topology.