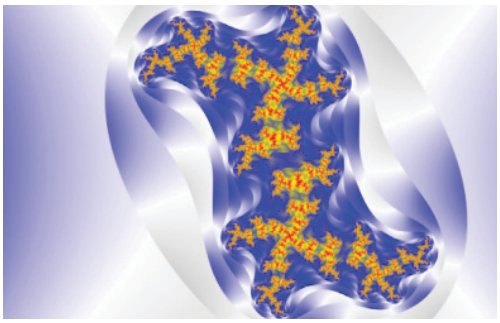
Pacific Institute *for the* Mathematical Sciences





Algebraic Topology: Methods, Computation and Science 6 (ATMCS6)

Conference Program

May 26-30, 2014

Pacific Institute for the Mathematical Sciences
Earth Sciences Building (ESB)
2207 Main Mall, Vancouver

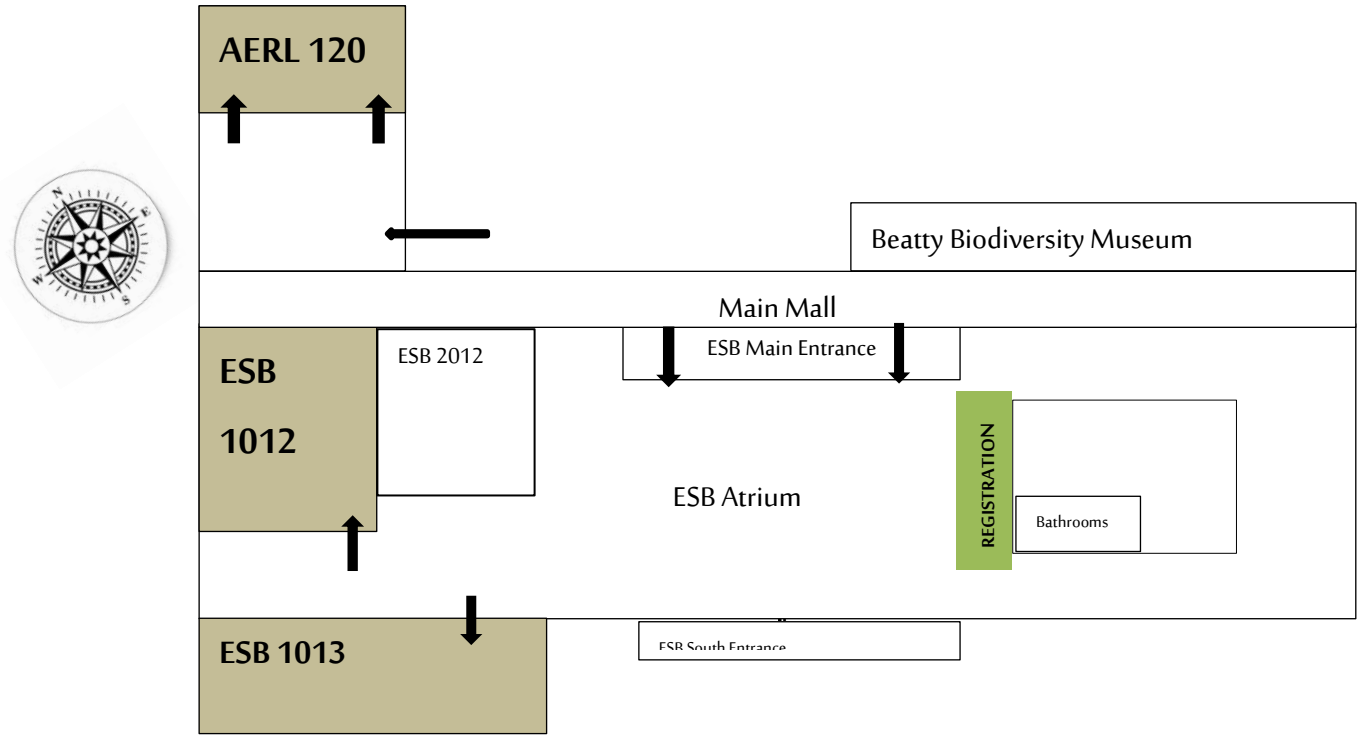
Pacific Institute *for the* Mathematical Sciences

IMA Institute for Mathematics and its Applications

Getting Started

- **Get connected:** Select the "ubcvisitor" wireless network on your wireless device. Open up a web browser, and you will be directed to the login page.
- **Event Evaluation Survey**: Please help PIMS to improve the quality of its events and plan for the future by filling out the survey at the end of the conference. It is located at http://goo.gl/JeoTod:
- **All Speaker Abstracts can be found beginning on page 6**

Conference Room Guide:



Mon May 26 :

- 8:35AM- 9:00AM: Registration & Check in: ESB Atrium
- 9:00AM- 4:30PM: ESB 1012

Tue May 27:

- 9:00AM- 12:30PM: AERL 120
- 12:30PM- 4:30PM: ESB 1013
- 4:30PM- 5:30PM: Poster Session ESB Atrium

Wed May 28:

- 9:00AM- 4:30PM: ESB1012

Thur May 29:

- 9:00AM- 4:30PM: AERL 120

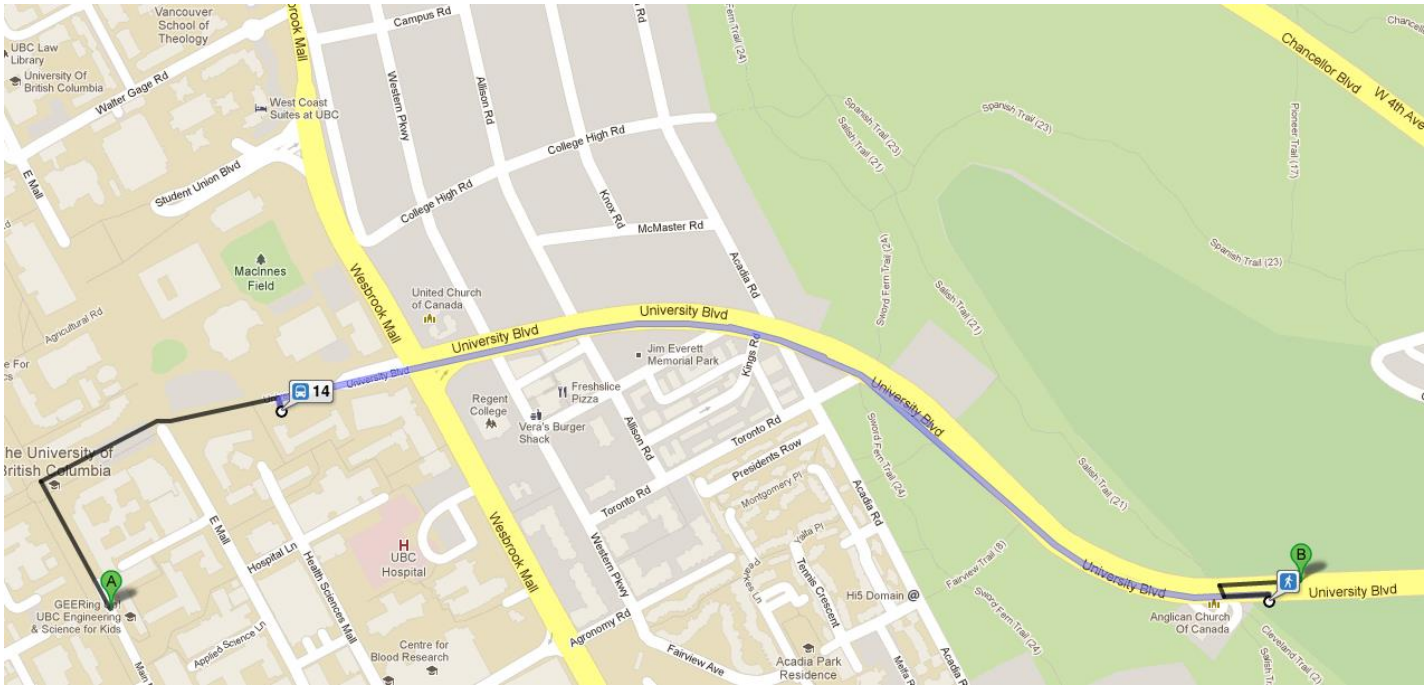
Fri May 30:

- 9:00AM- 4:30PM: ESB 1012

Dinner Venue and Directions:

Banquet Location Map: Wednesday May 28th, 2014. 6: 30pm

UBC Golf Club: 5185 University Blvd ,



A 2207 Main Mall, Vancouver:

Walk to UBC Trolley loop (about 6 minutes)**UBC Trolley Loop: Take either of these buses**

Bus **# 4,** or **# 14** - UBC/Downtown or Bus 9- Alma/ Commercial

Alight at EB University Blvd at **5100 Block,** Cross University Boulevard to enter Golf Club

B UBC Golf Club: 5185 University Blvd **Exact coin fare is needed $2.75 per trip, if using transit;**

This distance is walkable in 15- 20 minutes.

Monday May 26th

Earth Sciences Building: Room 1012

****Speaker Abstracts can be found on page 6**

9:00am - 9:30am Arrival and Registration (ESB Atrium)

9:30am- 10:30am **Vin de Silva** : *Lipschitz extensions and higher-order metric certificates*

10:30am- 11:00am **Coffee Break** (ESB 1012 lobby)

11:00am- 12:00pm **Amit Patel**: *The Quillen 2-Construction for Persistence*

12:00pm- 2:00pm **Lunch** (Self Catered: See attached list for campus dining options)

2:00pm- 3:00pm **Sarah Day:** *Symbolic Dynamics and Entropy via Conley Index Theory*

3:00pm- 3:30 pm **Coffee Break** (ESB1012 lobby)

3:30pm- 4:30pm: **Tamal Dey**: *Data sparsification in topology inference*

Tuesday May 27th

9:00 – 12:00pm Aquatic Ecosystems Research Lab (AERL) Room 120

9:30am- 10:30am **Gunnar Carlsson**: *Structures on bar code spaces and multidimensional persistence*

10:30am- 11:00am **Coffee Break** (AERL 120 lobby)

11:00am- 12:00pm **Vanessa Robbins**: *A persistent homology analysis of x-ray micro-CT images of granular materials.*

12:00pm- 2:00pm **Lunch** (Self Catered: See attached list for campus dining options)

Earth Sciences Building: Room 1013

2:00pm- 3:00pm **Radmila Sazdanovic:** *The Many Facets of Categorification*

3:00pm- 3:30 pm **Coffee Break** (ESB1013 lobby)

3:30pm- 4:30pm: **Omer Bobrowski**: *Topological Estimation for Super Level Sets*

4:35pm-6:00pm **Poster Session: ESB Atrium (See page 12 for poster abstracts)**

Wednesday May 28th

Earth Sciences Building: Room 1012

9:30am- 10:30am	**Jeff Erickson**: *Efficiently hex-meshing things with topology*
10:30am- 11:00am	**Coffee Break** (ESB 1012 lobby)
11:00am- 12:00pm	**Jose Perea**: *Obstructions to Compatible Extensions of Mappings*
12:00pm- 2:00pm	**Lunch** (Self Catered: See attached list for campus dining options)
2:00pm- 3:00pm	**Donald Sheehy:** *Nested Dissection and (Persistent) Homology*
3:00pm- 3:30 pm	**Coffee Break** (ESB1012 lobby)
3:30pm- 4:30pm:	**Shmuel Weinberger**: *Complex and Simple "Topological' invariants.*
6:30 pm	**Dinner at the University Golf Club (See page 2 for directions)**

Thursday May 29th

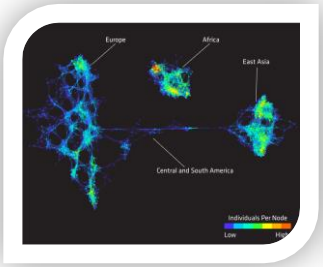
Aquatic Ecosystems Research Lab Room 120

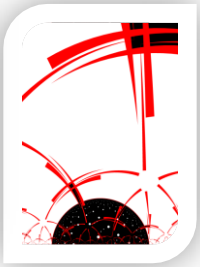
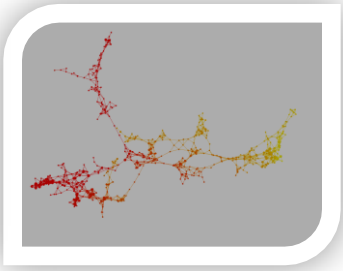
9:30am- 10:30am	**Sayan Mukherjee**: *Modeling surfaces and stratified spaces*
10:30am- 11:00am	**Coffee Break** (AERL 120 lobby)
11:00am- 12:00pm	**Elizabeth Munch**: *The Interleaving Distance for Reeb Graphs*
12:00pm- 2:00pm	**Lunch** (Self Catered: See attached list for campus dining options)
2:00pm- 3:00pm	**Peter Bubenik:** *Generalized persistence modules and stability*
3:00pm- 3:30 pm	**Coffee Break** (AERL 120 lobby)
3:30pm- 4:30pm:	**Yuliy Baryshnikov**: *Euler transforms and their inverses*

Friday May 30th

Earth Sciences Building: Room 1012

9:30am- 10:30am	**Christopher Hoffman**: *Recent progress in random topology*
10:30am- 11:00am	**Coffee Break** (AERL 120 lobby)
11:00am- 12:00pm	**Paul Villoutreix**: *Random triangulated surfaces with arbitrary degree distribution reveal embryonic epithelial organization*
12:00pm- 2:00pm	**Lunch** (Self Catered: See attached list for campus dining options)
2:00pm- 3:00pm	**Raul Rabadan** *The Topology of Evolution*
3:00pm- 3:30 pm	**Coffee Break** (AERL 120 lobby)
3:30pm- 4:30pm:	**Michael Robinson**: *Morphisms between logic circuits*



Speaker Abstracts

** In alphabetical order (Surname)

Yuliy Baryshnikov: *University of Illinois*

Euler transforms and their inverses

Integrals with respect to Euler characteristics engender exotic counterparts to the usual integral transforms of applied mathematics. Over the past few years, several proposals appeared pointing to potential usages of these Euler transforms in data analysis, sensing, computational geometry. I will survey some of the recent developments, focusing on the invertability of Euler integral transforms.

Omer Bobrowski: *Duke University*

Topological Estimation for Super Level Sets

The level sets of probability density functions are of a considerable interest in many areas of statistics, and TDA in particular. In this talk we focus on the problem of recovering the homology of the super level sets from a finite set of random samples. The main difficulty stems from the fact that even small perturbations to the estimated density function can generate a very large error in homology. In this talk we present an estimator that overcomes this difficulty and recovers the homology accurately (with a high probability). We discuss two possible applications of the proposed estimator. The first one is recovering the homology of a compact manifold from a (possibly very) noisy point cloud. The second application is recovering the persistent homology of the super level sets filtration. Finally, we show that similar methods can be used in the analysis of nonparametric regression models.

Peter Bubenik: *Cleveland State University*

Generalized persistence modules and stability

I will present an abstract formulation of persistence module that includes many of the versions of persistence previously studied. In order to make quantitative comparisons of generalized persistence modules we define an interleaving of such modules and make explicit what is needed to measure interleavings. In this framework, the stability of many generalized persistence modules is an immediate consequence of functoriality. For certain complicated persistence modules, I will also show that certain simpler persistence modules obtained from them are also automatically stable. This is joint work with Jonathan Scott and Vin de Silva.

G**unnar Carlsson**: *Stanford University*

Structures on bar code spaces and multidimensional persistence

We will discuss coordinatizations of bar code spaces, their properties, and propose some ways in which they can be used to obtain information from multidimensional persistence profiles.

Sarah Day: *College of William and Mary*

Symbolic Dynamics and Entropy via Conley Index Theory

Conley index theory, a generalization of Morse theory using algebraic topology, may be used in a computational framework to prove the existence of dynamics of various types. When searching for highly complicated dynamics, however, the Conley index may also become highly complicated and difficult to interpret. We present an automated approach to processing Conley index information for discrete-time dynamical systems. This approach produces a topologically semi-conjugate symbolic system whose entropy serves as a lower bound for the entropy of the system under study. Recent modifications of the original approach published in 2006 produce symbolic systems that capture more of the complexity encoded by the index, in some cases leading to substantial increases in computed lower bounds on system entropy. Sample results will be shown for the 2-dimensional Henon map, the three-dimensional LPA model, and the infinite-dimensional Kot-Schaffer map. This is joint work with Rafael Frongillo.

Tamal Dey *: Ohio State University*

Data sparsification in topology inference

In topological inference from data, one major goal is to limit the size of the complex built on top of the input data so that it remains amenable for further computations. We show two subsampling strategies to address this issue. In the first one, we build a sparsified complex called Graph Induced Complex (GIC) using a subsample from which we can infer the homology of the underlying sampled space. The inference is subject to a selection of two parameters, one guiding the connectivity of a graph built with the input points as vertices, and the other guiding the density of the subsample. In a second approach, we show that when the underlying space is a smooth manifold of known dimension embedded in an Euclidean space, a parameter-less sparsification of the data is possible without sacrificing the ability to infer the correct homology from the sparsified set. Preliminary experiments suggest that both strategies achieve effective sparsification in practice.

Jeff Erickson: *University of Illinois at Urbana-Champaign*

Efficiently hex-meshing things with topology

A topological quadrilateral mesh Q of a connected surface in $\mathbb{R}^3$ can be extended to a topological hexahedral mesh of the interior domain Ω if and only if Q has an even number of quadrilaterals and no odd cycle in Q bounds a surface inside Ω. Moreover, if such a mesh exists, the required number of hexahedra is within a constant factor of the minimum number of tetrahedra in a triangulation of Ω that respects Q. Finally, if Q is given as a polyhedron in $\mathbb{R}^3$ with quadrilateral facets, a topological hexahedral mesh of the polyhedron can be constructed in polynomial time if such a mesh exists. All our results extend to domains with disconnected boundaries. Our results naturally generalize results of Thurston, Mitchell, and Eppstein for genus-zero and bipartite meshes, for which the odd-cycle criterion is trivial.

Christopher Hoffman: *University of Washington*

Recent progress in random topology

The Erdos-Renyi model of random graphs is one of the most common in probabilistic combinatorics. Although it is not a common choice for modeling most graphs that appear in the real world it is useful for providing a baseline for the exploration of other graph models. Much of random topology considers higher dimensional generalizations of the Erdos-Renyi model. In this talk I will explain recent progress in random topology and its relationships with fields such as combinatorics, computer science, and geometric group theory.

Elizabeth Munch: *University of Minnesota*

The Interleaving Distance for Reeb Graphs

In order to understand the properties of a real-valued function on a topological space, we can study the Reeb graph of that function. The Reeb graph is a construction which summarizes the connectivity of the level sets. Since it is efficient to compute and is a useful descriptor for the function, it has found its place in many applications. As with many other constructions in computational topology, we are interested in how to deal with this construction in the context of noise. In particular, we would like a measure of similarity between Reeb graphs, as well as a method to "smooth out" the topology to get rid of, for example, small loops in the Reeb graph. In this talk, we will define a generalization of a Reeb graph as a functor. Using the added structure given by category theory, we can define interleavings on Reeb graphs which can be used to compare them. This also gives an immediate method for topological smoothing and we will discuss an algorithm for computing this smoothed Reeb graph. This is joint work with Vin de Silva and Amit Patel.

Sayan Mukerjhee : *Duke University*

Modeling surfaces and stratified spaces

We look at models for using geometry and topology for modeling surfaces and mixtures of subspaces of different dimension. We introduce a statistic, the persistent homology transform (PHT), to model surfaces in $\mathbb{R}^3$ and shapes in $\mathbb{R}^2$. This statistic is a collection of persistence diagrams -- multiscale topological summaries used extensively in topological data analysis. We use the PHT to represent shapes and execute operations such as computing distances between shapes or classifying shapes. We prove the map from the space of simplicial complexes in $\mathbb{R}^3$ into the space spanned by this statistic is injective. This implies that the statistic is a sufficient statistic for distributions on the space of "smooth" shapes. We also show that a variant of this statistic, the Euler Characteristic Transform (ECT), admits a simple exponential family formulation which is of use in providing likelihood based inference for shapes and surfaces. We illustrate the utility of this statistic on simulated and real data.
We introduce a Bayesian model for inferring mixtures of subspaces of different dimensions. The key challenge in such a model is specifying prior distributions over subspaces of different dimensions. We address this challenge by embedding subspaces or Grassmann manifolds into a sphere of relatively low dimension and specifying priors on the sphere. We provide an efficient sampling algorithm for the posterior distribution of the model parameters. We also prove posterior consistency of our procedure. The utility of this approach is demonstrated with applications to real and simulated data.

Amit Patel : *University of Minnesota*

The Quillen 2-Construction for Persistence

Given a simplicial sheaf, we introduce a persistent homology group P(U), for each open star U. This is the data that persists across the entire open set. It is our goal to organize this data as a sheaf. The first step is to define morphisms between persistent homology groups. Unfortunately, for two open stars V in U, there is not a linear map between P(V) and P(U). There is however a Quillen injection P(U) →P(V), which is a kind of multimap. For a triple of open stars W in V in U, the composition P(U) → P (V) → P (W) of the Quillen injections is not necessarily equal to the Quillen injection P(U) → P (W). Fortunately, there is a 2-morphism from the later to the former. We introduce the Quillen 2-category of vector spaces which is a 2-categorification of Quillen's Q-construction. Given a simplicial sheaf, we will show how its persistent homology groups organize into a simplicial 2-sheaf valued in the Quillen 2-category. This is joint work with Robert MacPherson.

Jose Perea : *Duke University*

Obstructions to Compatible Extensions of Mappings

Several classic invariants in algebraic topology can be phrased in terms of being able to extend, or lift, certain mappings. We will report in this talk ongoing efforts toward making these tools available in the world of topological data analysis. Joint work with John Harer.

Raul Rabadan: *Columbia University*

The Topology of Evolution

Phylogenies are popularly used to represent evolutionary relationships between organisms, species or other taxa. However, phylogenetic representations can be misleading when applied to genomic data, particularly during reticulate evolution mediated by non-vertical exchange of genetic material between different organisms. Such events can lead to different phylogenetic histories for each gene and even different sections within a single gene. In this talk I present a mathematical structure able to capture and represent large-scale properties of evolution. Persistent homology aims to extract global topological features from sequence data by reconstructing simplicial complexes, which at a particular scale of genetic distance represents the relation between different genomes. We show that there exist topological obstructions to the use of phylogeny for certain genomic datasets. In particular, we identify a set of topological equalities that, if unsatisfied, invalidates phylogenetic representations. In general, phylogenies represent a trivial zero-dimensional topology, while complex evolutionary patterns are captured by non-trivial higher dimensional homology. Persistent homology also informs us about the evolutionary scale at which phylogenetic inference could be accurate, the rate of nonvertical exchange of genomic information, and the history of complex reassortments involving more than two parental strains. To illustrate how persistent homology can be used to infer global evolutionary properties, we have selected a set of RNA viruses with distinct modes of exchanging genomic material: clonal evolution, reassortment and recombination. Our method detects widespread reassortment in avian influenza leading to a complex topology that cannot be accurately captured by any phylogenetic representation. Other viruses, such as HIV, present a high dimensional non-trivial topology reflecting pervasive recombination. In contrast to previous claims, we show that dengue does not show significant intra-serotype recombination. In addition, we

show how persistent homology is able to capture rates of exchange of genomic material and to provide a framework to extract patterns of genomic exchange. For instance, in avian influenza we estimate that there are at least 20 reassortments per year and that there are segments that are more likely to co-segregate (PB2-PB1-PA-NP).

Vanessa Robbins: *The Australian National University*

A persistent homology analysis of x-ray micro-CT images of granular materials

Our work with three-dimensional images of porous materials has required the development of topologically valid and efficient algorithms for studying and quantifying their intricate structure. This talk will describe our discrete Morse theory based image analysis algorithms for skeletonization and partitioning, and give a detailed analysis of what the persistent homology diagrams tell us about the micro-structure of various granular materials. This is work in progress with Adrian Sheppard and Olaf Delgado-Friedrichs in Applied Mathematics at the ANU.

Michael Robinson: *American University*

Morphisms between logic circuits

Designers of logic circuits usually work hierarchically: complex circuits are built of simpler ones, whose internal details have been abstracted away. For instance, two circuits whose truth tables are equivalent are often treated as having the same behavior. While this idea works in traditional synchronous systems, the temporal behavior of two implementations of the same boolean function may be quite different. These circuits can still be manipulated using a hierarchy of abstractions, but there is not a unified theory for their design. Recently, an intermediate family of algebraic logic circuit invariants has been discovered that arise from the theory of constructible sheaves on graphs. This talk will outline a way to analyze a circuit at different levels of detail, by describing sheaf morphisms between connection diagrams and their associated induced maps.

Radmila Sazdanovic : *North Carolina State University*

The Many Facets of Categorification

The goal of this talk is to introduce the notion of categorification and provide several examples in pure and applied mathematics. Examples include successful categorifications of polynomial invariants of knots and graphs, such as the Jones and chromatic polynomials. From a different point of view, categorification can also be viewed as a second linearization. As an illustration of this approach we describe diagrammatic categorification of the polynomial ring $\mathbb{Z}[x]$ and orthogonal polynomials such as Chebyshev and Hermite.

Donald Sheehy : *University of Connecticut*

Nested Dissection and (Persistent) Homology

Nested dissection is a way of solving systems of linear equations by divide and conquer. For many linear systems that occur naturally in many settings, nested dissection gives a guaranteed improvement over naive Gaussian elimination. These are the so-called beta-separable systems, where beta is a constant that governs how big the improvement will be. In this talk, I will give some historical background, going back to Strassen's fast matrix multiplication algorithm. Then, I will show how one

might apply nested dissection to computing persistent homology. Moreover, I will show that for a wide class of inputs that come up in persistent homology, the resulting systems are beta-separable, yielding an improvement in the asymptotic running time of the persistence algorithm. This is joint work with Primoz Skraba and Michael Kerber

Vin de Silva : *Pomona College*

Lipschitz extensions and higher-order metric certificates

The traditional TDA (topological data analysis) pipeline converts data to a filtered simplicial complex, and the filtered simplicial complexes to a persistence diagram (PD). The PD can then be studied for information about the input data. This process can be recursed: given lots of data sets, each can be turned into a PD, and this collection of PDs can be viewed as a data set in diagram space. One can then build Čech or Vietoris-Rips complexes from this data. Investigating the difference between Čech and Vietoris-Rips complexes in PD-space leads to interesting questions about Lipschitz extensions of maps between metric spaces. I will discuss some results on this, when the target is PD-space and also when the target is the space-class of metric spaces. This is joint work with Vidit Nanda and Peter Bubenik.

Paul Villoutreix : *Stanford University*

Random triangulated surfaces with arbitrary degree distribution reveal embryonic epithelial organization

Epithelial tissues are simple cellular structures found in developing embryo in different species. The organization of these tissues has been studied using local properties of the network of cellular contacts. However, accounting for global and spatial properties requires extending these approaches. Using persistent homology on the network of cellular contacts reveals global topological characteristics. To assess the significance of these characteristics, we provide a model of random triangulated surfaces with arbitrary degree distribution. These oriented surfaces are obtained by randomly gluing oriented polygons; this process results in planar graphs with appropriate degree distribution. We explore the topological characteristics of these surfaces and compare them to a set of empirical data. Differences between the null model and the data may provide insights for the understanding of underlying biological processes.

Shmuel Weinberger : *University of Chicago*

Complex and Simple "Topological" invariants

In topological data analysis one frequently discusses the problem of inferring the values of topological invariants. Typically, there are phase transitions in the (Kolmogorov, sample and/or logical) complexity of these problems. In response to this, one can inquire whether there are mechanisms why certain types of data sets are atypical, or whether one should concentrate on only certain "approximable" invariants. Motivated by ideas of testability, the "seven Samurai paper" (Abert, Bergeron et al, on lattices in high rank Lie groups) and the theory of quasicrystals, I will give some examples of invariants that PAC computable and some examples that I would like to know about.

Poster Presentation Abstracts

Ulrich Bauer: *IST Austria*

Induced Matchings of Barcodes and the Algebraic Stability of Persistence

We define a simple, explicit map sending a morphism $f: M \longrightarrow N$ of pointwise finite dimensional persistence modules to a matching between the barcodes of M and N. Our main result is that, in a precise sense, the quality of this matching is tightly controlled by the lengths of the longest intervals in the barcodes of ker f and coker f. As an immediate corollary, we obtain a new proof of the algebraic stability of persistence, a fundamental result in the theory of persistent homology. In contrast to previous proofs, ours shows explicitly how a δ-interleaving morphism between two persistence modules induces a δ-matching between the barcodes of the two modules. Our main result also specializes to a structure theorem for submodules and quotients

Ulrich Bauer: *IST Austria*

The Morse theory of Čech and Delaunay filtrations

Given a finite set of points in $\mathbb{R}^n$ and a positive radius, we consider the Čech, Delaunay-Čech, alpha, and wrap complexes as examples of a generalized discrete Morse theory. We prove that the latter three are simple-homotopy equivalent, and the same is true for their weighted versions. Our results have applications in topological data analysis and in the reconstruction of shapes from sampled data.

Magnus Bakke Botnan: *Norwegian University of Science and Technology*

The persistent homology of eukaryotic chromatin

The 3D architecture of eukaryotic chromatin plays an important role in processes such as gene regulation and cancer-driving gene fusions. By using contact data obtained from recent sequencing technologies, such as chromatin conformation capture assays (CCC), it has become possible to obtain high resolution 3D reconstructions of chromosome configurations. Such a 3D model can be generated by first transforming the CCC data into a distance matrix containing both inter- and intra-chromosomal distances between differing chromosomal loci, and then searching for an embedding in three-dimensional Euclidean space which approximates this distance matrix. However, it is not clear to what extent these models correctly capture chromatin geometry. To assess this we investigate if a weaker invariant, the persistent homology of the distance matrix, is preserved under a given 3D reconstruction. Our results show that the persistent topology is not preserved during reconstruction and therefore the geometry, as captured by the CCC data, cannot be either.

Yiqing Cai: *Institute for Mathematics and its Applications*

Periodic network system and cohomological waves

We use periodic protocol on sensor network to generate waves of waking sensors, in order to solve dynamic coverage problems. The topological degree of simplicial map from the flag complex of the network graph to the state space, is proved to be topological invariant, and can be used to classify the waves according to their cohomology classes. The self-organizing cyclic network automata is eventually periodic, therefore is a special case of periodic network system.

Barbara Di Fabio: *University of Bologna*

A stable combinatorial distance for Reeb graphs of surfaces

Reeb graphs provide a method to combinatorially describe the shape of a manifold endowed with a Morse function. One of the most important questions is whether Reeb graphs are robust against function perturbations that may occur because of noise and approximation errors in the data acquisition process. In this work we provide an editing distance between Reeb graphs of orientable surfaces in terms of the cost necessary to transform one graph into another by edit operations. Our main result is that changes in the functions, measured by the maximum norm, imply not greater changes in this distance, yielding the stability property under function perturbations. Moreover, we show that this editing distance is equal to the natural pseudo-distance, and hence results to be more discriminative than the bottleneck distance of persistent homology.

Daniela Egas Santander: *University of Bonn*

The homology of Sullivan diagrams using non-crossing partitions.

We show that Sullivan diagrams of the topological type of the disk with n punctures can be described in terms of weighted non-crossing partitions. We use this description to show that that the first and top homology groups of the chain complex of Sullivan diagrams of this type are trivial. Moreover, we compute the homology of the chain complex of Sullivan diagrams of the topological type of the disk with up to seven punctures, and we give explicit generators. We use these generators to give two infinite families of non trivial string topology operations following the ideas of Wahl and Westerland.

Kevin Emmett: *Columbia University*

Parametric Inference using Persistence Diagrams: A Case Study in Population Genetics

Persistent homology computes topological invariants from point cloud data. Recent work has focused on developing statistical methods for data analysis in this framework. We show that, in certain models, parametric inference can be performed using statistics defined on the computed invariants. We develop this idea with a model from population genetics, the coalescent with recombination. We apply our model to an influenza dataset, identifying two scales of topological structure which have a distinct biological interpretation.

Grzegorz Jablonski: *Jagiellonian University*

Group invariant adaptation of persistent homology

Persistent homology is a valuable tool in topological data analysis, allowing to deal with data expressed by $\mathbb{R}$-valued functions defined on a topological space X. The use of this mathematical theory has proved to be efficient and effective in applications requiring invariance with respect to the group Homeo(X) of all self-homeomorphisms of X. However, in many cases one would like to restrict the invariance group to a proper subgroup G of Homeo (X). In a previous paper (P. Frosini, G.Jablonski, *Combining persistent homology and invariance groups for shape comparison*) we have proved that this restricted invariance can be obtained by transforming the data via a suitable family of operators, before computing their persistent diagrams. These operators are required to be non-expansive and G-invariant. In our poster we recall the theoretical basis of this method and present the first experimental results that it has produced. In particular, we show the outcome of an experiment concerning the comparison of piecewise linear functions from $\mathbb{R}$ to $\mathbb{R}$ with respect to the group of affinities, the group of orientation-preserving affinities, the group of isometries, the group of translations and the identity group. We also show the preliminary results of an experiment concerning the comparison of some simple synthetic 2D grey-level images with respect to the group of isometries.

Sara Kalisnik: *Stanford University*

Alexander Duality for Parametrized Homology

An important problem with sensor networks is that they do not provide information about the regions that are not covered by their sensors. If the sensors in a network are static, then the Alexander Duality Theorem from classic algebraic topology is sufficient to determine the coverage of a network. However, in many networks the nodes change position with time. In the case of dynamic sensor networks, we consider the covered and uncovered regions as parametrized spaces with respect to time. Parametrized homology is a variant of zigzag persistent homology that measures how the homology of the levelsets of the space changes as we vary the parameter. We present a few theorems that extend different versions of classical Alexander Duality theorem to the setting of parametrized homology theories. This approach sheds light on the practical problem of 'wandering' loss of coverage within dynamic sensor networks.

Michael Lesnick: *Institute for Mathematics and its Applications*

Universality of the Homotopy Interleaving Distance

As part of an effort to establish homotopy-theoretic foundations for the well-known stability theory for persistent homology, we introduce and study "homotopy interleavings" between filtered spaces. These can be interpreted as "approximate weak equivalences," in the much same way that ordinary interleavings between filtered spaces can be interpreted as ``approximate isomorphisms." Homotopy interleavings induce an extended pseudometric d_{HI} on filtered spaces. Our main result is that d_{HI} is the universal pseudometric satisfying natural stability and homotopy invariance axioms. To motivate these axioms, we show that any pseudometric satisfying the axioms can be used lift several key TDA results from the algebraic (homological) level to the level of filtered spaces.

Florian Pausinger: *Institute of Science and Technology Austria*

Approximation and Convergence of Intrinsic Volumes

We introduce a modification of the classic notion of intrinsic volume using persistence moments of height functions. Evaluating the modified first intrinsic volume on digital approximations of a compact body with twice differentiable boundary in $\mathbb{R}^n$, we prove convergence to the first intrinsic volume of the body as the resolution of the approximation improves. We have weaker results for the other modified intrinsic volumes, proving they converge to the corresponding intrinsic volumes of the n dimensional unit ball. This is joint work with Herbert Edelsbrunner.

Joao Pita Costa: *Institute Jozef Stefan*

Towards a Topos for Persistence

A topos theoretic approach to set theory permits ideas like time variable sets and provides tools for unification of techniques for mathematics having had a great importance in the recent developments of Quantum Theory. Persistent homology is a central tool in topological data analysis, which examines the structure of data through topological structure. The basic technique is extended in many different directions, permuting the encoding of topological features by barcodes and correspondent persistence diagrams. The set of points of all such diagrams determines a complete Heyting algebra that can explain aspects of the relations between correspondent persistence bars and provide a global perspective over this approach. We are fundamentally interested in the algebraic foundations of applied and computational algebraic topology, in particular in a unifying theory for the various flavors of persistent homology that have emerged so far. In this poster we shall look at the topos of sheaves over such algebra, discuss its construction and potential for a generalized simplicial homology over it.

Gard Spreemann: *Norwegian University of Science and Technology*

Approximating persistent homology in Euclidean space through collapses

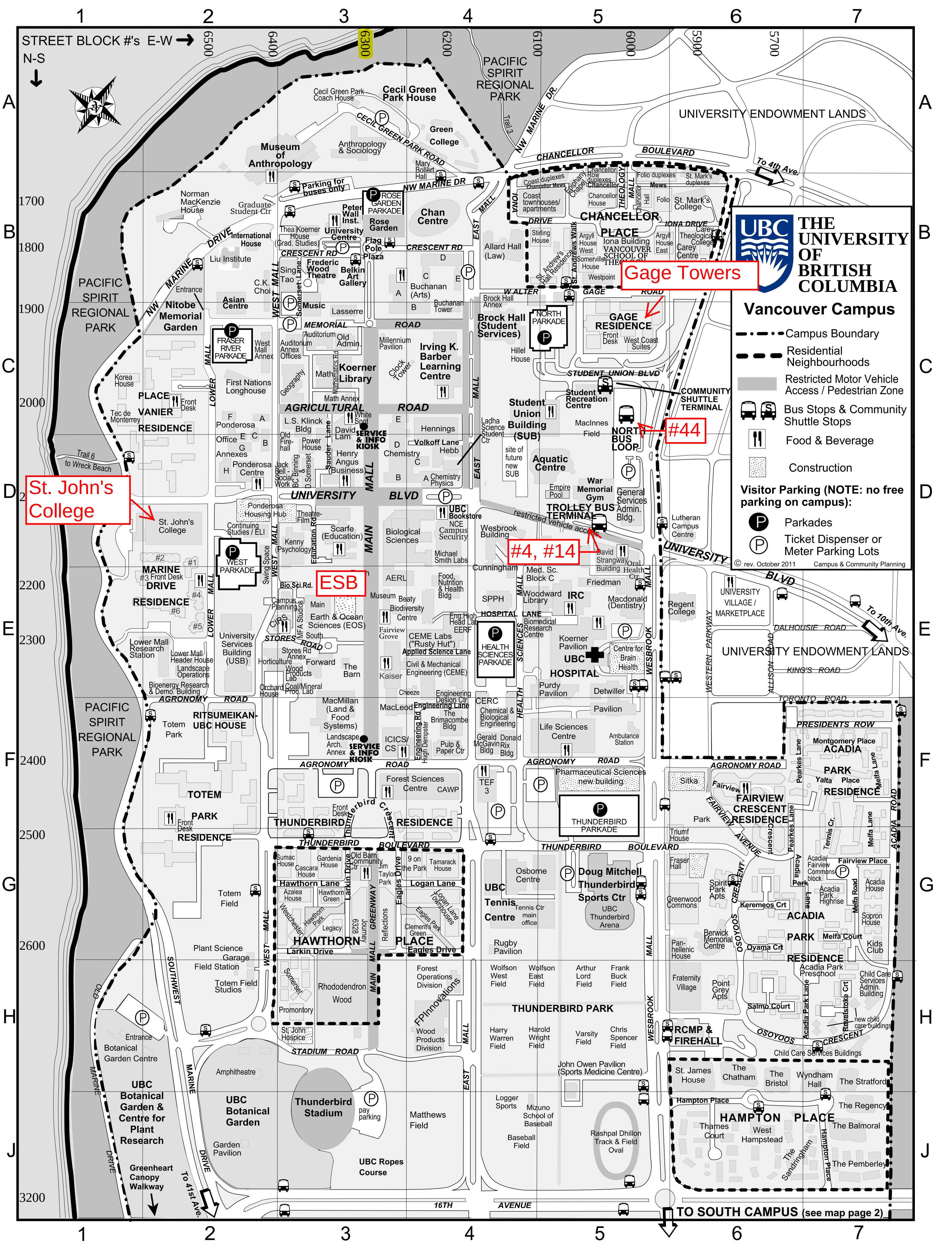
The Čech complex is one of the most widely used tools in applied algebraic topology. Unfortunately, due to the inclusive nature of the Čech filtration, the number of simplices grows exponentially in the number of input points. A practical consequence is that computations may have to terminate at smaller scales than what the application calls for. We propose two methods to approximate the Čech persistence module. Both constructions are built on the level of spaces, i.e. as sequences of simplicial complexes induced by nerves. We also show how the bottleneck distance between such persistence modules can be understood by how tightly they are sandwiched on the level of spaces. In turn, this implies the correctness of our approximation methods. Finally, we implement our methods and apply them to some example point clouds in Euclidean space. Join work with Magnus Bakke Botnan.

Matthew Wright: *Institute for Mathematics and its Applications*

Intrinsic Volumes of Random Cubical Complexes

The intrinsic volumes generalize both Euler characteristic and Lebesgue volume, quantifying the size of a set in various ways. A random cubical complex is a union of (possibly high-dimensional) unit cubes selected from a lattice according to a probability model. We analyze the intrinsic volumes of random cubical complexes, obtaining polynomial formulae for the expected value

and variance of these intrinsic volumes. We then prove an interleaving theorem about the roots of the expected intrinsic volumes -- that is, the values of the probability parameter at which an expected value is zero. Furthermore, we present a central limit theorem, showing that the distribution of each intrinsic volume tends toward a normal distribution as the size of the lattice increases towards infinity. This work is motivated by the study of noise in digital images, with applications in image processing, and is in collaboration with Michael Werman of The Hebrew University of Jerusalem.


STREET BLOCK #'s E-W
N-S
THE UNIVERSITY OF BRITISH COLUMBIA
Vancouver Campus
Campus Boundary
Residential Neighbourhoods
Restricted Motor Vehicle Access / Pedestrian Zone
Bus Stops & Community Shuttle Stops
Food & Beverage
Construction
Visitor Parking (NOTE: no free parking on campus):
Parkades
Ticket Dispenser or Meter Parking Lots
© rev. October 2011
Campus & Community Planning
Gage Towers
St. John's College
ESB
#44
#4, #14
PACIFIC SPIRIT REGIONAL PARK
UNIVERSITY ENDOWMENT LANDS
Museum of Anthropology
Cecil Green Park House
Green College
Chan Centre
CHANCELLOR PLACE
GAGE RESIDENCE
Nitobe Memorial Garden
Irving K. Barber Learning Centre
Koerner Library
Student Union Building (SUB)
Aquatic Centre
Brock Hall (Student Services)
NORTH BUS LOOP
COMMUNITY SHUTTLE TERMINAL
TROLLEY BUS TERMINAL
PLACE VANIER RESIDENCE
MARINE DRIVE RESIDENCE
UNIVERSITY VILLAGE / MARKETPLACE
Regent College
UBC HOSPITAL
RITSUMEIKAN-UBC HOUSE
TOTEM PARK RESIDENCE
THUNDERBIRD RESIDENCE
FAIRVIEW CRESCENT RESIDENCE
ACADIA PARK RESIDENCE
HAWTHORN PLACE
HAMPTON PLACE
Doug Mitchell Thunderbird Sports Ctr
UBC Tennis Centre
THUNDERBIRD PARK
RCMP & FIREHALL
UBC Botanical Garden & Centre for Plant Research
UBC Botanical Garden
Thunderbird Stadium
UBC Ropes Course
CHANCELLOR BOULEVARD
UNIVERSITY BLVD
AGRICULTURAL ROAD
MEMORIAL ROAD
AGRONOMY ROAD
THUNDERBIRD BOULEVARD
STADIUM ROAD
16TH AVENUE
To 4th Ave.
To 10th Ave.
To 41st Ave.
TO SOUTH CAMPUS (see map page 2)

Map Directory

Site or Building Name & Address	Grid
Abdul Ladha Science Student Ctr, 2055 East Mall	D4
Acadia/Fairview Commonsblock, 2707 Tennis Cres	G7
Acadia House, 2700-2720 Acadia Rd	G7
Acadia Park Residence	F/H-6/7
Acadia Park Highrise, 2725 Melfa Rd	G7
Acadia Park Preschool, 2750 Acadia Park Lane	H7
Allard Hall [Faculty of Law], 1822 East Mall	B4
Anthropology & Sociology Bldg, 6303 NW Marine Dr	A3
Aquatic Centre, 6121 University Blvd	D5
Aquatic Ecosystems Research Lab (AERL), 2202 Main Mall	E3
Asian Centre, 1871 West Mall	B2
Auditorium (a.k.a. "Old Auditorium"), 6344 Memorial Rd	C3
Auditorium Annex Offices, 1924 West Mall	C3
Barn (daycare), 2323 Main Mall	E3
B.C. Binning Studios (formerly Hut M-17), 6373 University Blvd	D3
Beaty Biodiversity Centre & Museum, 2212 Main Mall	E3/4
Belkin (Morris & Helen) Art Gallery, 1825 Main Mall	B3
Berwick Memorial Centre, 2765 Osoyoos Cres	G6
Bioenergy Research & Demonstration Bldg., 2337 Lower Mall	E2
Biological Sciences Bldg [Science Faculty office], 6270 University Blvd	D3
Biomedical Research Ctr, 2222 Health Sciences Mall	E4
Biotechnology Laboratory, 2125 East Mall	D4
Bollert (Mary) Hall, 6253 NW Marine Dr	A4
Bookstore, 6200 University Blvd	D4
Botanical Garden Centre/Gatehouse, 6804 SW Marine Dr	H1
Botanical Garden Pavilion (enter at Gatehouse, 6804 SW Marine Dr)	J2
Botan. Gard. Greenhses/ Workshops, 6088 S. Campus Rd	South Campus
Brimacombe Building, 2355 East Mall	F4
BROCK HALL: Student Services & Welcome Centre, 1874 East Mall	**C4**
Brock Hall Annex, 1874 East Mall	C4
Buchanan Building (Blocks A, B, C, D, & E) [Arts], 1866 Main Mall	B3/4
Buchanan Tower, 1873 East Mall	C4
C.K. Choi Building for the Institute of Asian Research, 1855 West Mall	B2
Campus & Community Planning, 2210 West Mall	E3
Campus Security, 2133 East Mall	D4
Carey Centre, 5920 Iona Drive	B6
Carey Theological College, 1815 Wesbrook Mall	B6
CAWP (Centre for Advanced Wood Processing), 2424 Main Mall	F4
Cecil Green Park Coach House, 6323 Cecil Green Park Rd	A3
Cecil Green Park House, 6251 Cecil Green Park Rd	A3
CEME — *see Civil & Mechanical Engineering Building*	
Centre for Comparative Medicine, 4145 Wesbrook Mall	South Campus
Centre for Interactive Research on Sustainability (CIRS), 2260 West Mall	E3
CERC (Clean Energy Research Ctr), 2360 East Mall	F4
Chan Centre for the Performing Arts, 6265 Crescent Rd	B4
Chancellor Place neighbourhood	B5
Chemical & Biological Engineering Bldg, 2360 East Mall	F4
Chemistry A Block - Chemistry Physics Building, 6221 University Blvd	D4
Chemistry B,C,D & E Blocks, 2036 Main Mall	D3
Child Care Services Administration Bldg, 2881 Acadia Rd	H7
Child Care Services Bldgs, Osoyoos Cresc and Revelstoke Crt	H7
CIRS — *see Centre for Interactive Research on Sustainability...*	
Civil & Mechanical Engineering Bldg (CEME), 6250 Applied Science Lane	E4
Civil & Mechanical Eng. Labs ("Rusty Hut"), 2275 East Mall	E4
Coal & Mineral Processing Lab, 2332 West Mall	E3
Continuing Studies Bldg [English Language Institute], 2121 West Mall	D2
Copp (D.H.) Building, 2146 Health Sciences Mall	D5
Cunningham (George) Building [Pharmaceutical Sc.], 2146 East Mall	E4
David Lam Learning Centre, 6326 Agricultural Rd	C3
David Lam Management Research Ctr, 2033 Main Mall	C3
Donald Rix Building, 2389 Health Sciences Mall	F4
Doug Mitchell Thunderbird Sports Centre, 6066 Thunderbird Blvd	G5
Dorothy Somerset Studios (formerly Hut M-18), 6361 University Blvd	D3
Earth Sciences Building (ESB) under construction, 2207 Main Mall	E3
Earth & Ocean Sciences (EOS) - Main and South, 6339 Stores Rd	E3
Earthquake Engineering Research Facility (EERF), 2235 East Mall	E4
Engineering High Head Room Lab, 2225 East Mall	E4
English Language Institute (E.L.I.) — *see Continuing Studies Building*	
Environmental Services Facility, 6025 Nurseries Rd	South Campus
Fairview Crescent Residence, 2600-2804 Fairview Cres	F6
Fire Department, 2992 Wesbrook Mall	H6
First Nations Longhouse, 1985 West Mall	C2
Flag Pole Plaza (Main Mall & Crescent Rd)	B3
Food, Nutrition and Health Bldg, 2205 East Mall	E4
Forest Sciences Centre [Faculty of Forestry], 2424 Main Mall	F4
Forward (Frank) Building, 6350 Stores Rd	E3
FPInnovations (Forest Operations & Wood Products), 2601/2665 E. Mall	H4
FPInnovations (Pulp & Paper Division), 3800 Wesbrook Mall	South Campus
Fraser Hall (public rental housing), 2550 Wesbrook Mall	G6
Fraternity Village, 2880 Wesbrook Mall	H6
Frederic Wood Theatre, 6354 Crescent Rd	B3
Friedman Bldg, 2177 Wesbrook Mall	E5
Gage Residence, 5959 Student Union Blvd	C5
General Services Administration Bldg (GSAB), 2075 Wesbrook Mall	D5
Geography Building, 1984 West Mall	C3
Gerald McGavin Building, 2386 East Mall	F4
Graduate Student Centre — *see Thea Koerner House*	
Green College, 6201 Cecil Green Park Rd	A4
Greenheart Canopy Walkway, Botanical Garden, 6804 SW Marine Dr	H1
Greenwood Commons (public rental housing), 2660 Wesbrook Mall	G6
Hampton Place neighbourhood	H/J-6/7
Hawthorn Place neighbourhood	G/H3
Hebb Building, 2045 East Mall	D4
Hennings Building, 6224 Agricultural Rd	C4
Henry Angus Building [Sauder School of Business], 2053 Main Mall	D3
Hillel House - The Diamond Foundation Centre for Jewish Campus Life, 6145 Student Union Blvd	C4
Horticulture Building/Greenhouse, 6394 Stores Rd	E2/3
Hugh Dempster Pavilion, 6245 Agronomy Rd	F4
ICICS/CS (Institute for Computing, Information & Cognitive Systems/Computer Science), 2366 Main Mall	F4
Instructional Resources Centre (IRC), 2194 Health Sciences Mall	E5
International House, 1783 West Mall	B2
In-Vessel Composting Facility, 6035 Nurseries Road	South Campus
Irving K. Barber Learning Centre, 1961 East Mall	C4
Jack Bell Building for the School of Social Work, 2080 West Mall	D3
John Owen Pavilion & Allan McGavin Sports Medicine Centre, 3055 Wesbrook Mall	H5
Kaiser (Fred) Building [Faculty of Applied Science], 2332 Main Mall	E3
Kenny (Douglas T) Building, 2136 West Mall	D3
Kids Club, 2855 Acadia Rd	G7
Klinck (Leonard S.) Bldg, 6356 Agricultural Rd	C3
Koerner (Walter C.) Library, 1958 Main Mall	C3
Landscape Architecture Annex, 2371 Main Mall	F3
Lasserre (Frederic) Building, 6333 Memorial Rd	C3
Law, Faculty of — *see Allard Hall*	
Leon and Thea Koerner University Centre, 6331 Crescent Rd	B3
Life Sciences Centre, 2350 Health Sciences Mall	F5
Liu Institute for Global Issues, 6476 NW Marine Dr	B2
Lower Mall Header House, 2269 Lower Mall	E2
Lower Mall Research Station, 2259 Lower Mall	E2
Macdonald (J.B.) Building [Dentistry], 2199 Wesbrook Mall	E5
MacLeod (Hector) Building, 2356 Main Mall	F3
MacMillan (H.R.) Bldg [Faculty of Land & Food Systems], 2357 Main Mall	F3
Marine Drive Residence (Front Desk in Bldg #3), 2205 Lower Mall	E2
Material Recovery Facility, 6055 Nurseries Rd	South Campus
Mathematics Annex, 1986 Mathematics Rd	C3
Mathematics Building, 1984 Mathematics Rd	C3
Medical Sciences Block C, 2176 Health Sc. Mall	E4
M.F.A. Studios (formerly B.C. Binning MFA Studios), 6363 Stores Rd	E3
Michael Smith Laboratories, 2185 East Mall	D4
Museum of Anthropology (MOA), 6393 NW Marine Dr	A2/3
Music Building, 6361 Memorial Rd	B/C3
Networks of Ctrs of Excellence (NCE), 2125 East Mall	D4
Nitobe Memorial Garden, 1895 Lower Mall	B/C2
Nobel Biocare Oral Heath Centre (David Strangway Bldg), 2151 Wesbrook Mall	E5
Norman MacKenzie House, 6565 NW Marine Dr	B2
NRC Institute for Fuel Cell Innovation, 4250 Wesbrook Mall	South Campus
Old Administration Building, 6328 Memorial Rd	C3
Old Auditorium — *see Auditorium*	
Old Barn Community Centre, 6308 Thunderbird Blvd	G3
Old Firehall, 2038 West Mall	D3
Orchard House, 2336 West Mall	E2
Osborne (Robert F.) Centre/Gym, 6108 Thunderbird Blvd	G4
Panhellenic House, 2770 Wesbrook Mall	G6
Peter Wall Institute for Advanced Studies, 6331 Crescent Rd	B3
Place Vanier Residence, 1935 Lower Mall	C/D2
Plant Ops Nursery/Greenhouses, 6029 Nurseries Rd	South Campus
Plant Science Field Station & Garage, 2613 West Mall	H2
Point Grey Apartments, 2875 Osoyoos Cresc	H6
Police (RCMP) & Fire Department, 2990/2992 Wesbrook Mall	H6
Ponderosa Centre, 2071 West Mall	D2
Ponderosa Office Annexes: A, B, & C, 2011-2029 West Mall	C/D2
Ponderosa Office Annexes: E to H, 2008-2074 Lower Mall	C/D2
Power House, 2040 West Mall	D3
Pulp and Paper Centre, 2385 East Mall	F4
Ritsumeikan-UBC House, 6460 Agronomy Rd	F2
Rose Garden	B3
Roy Barnett Recital Hall - in Music Building	
Rugby Pavilion, 2584 East Mall	G4
Scarfe (Neville) Building [Education], 2125 Main Mall	D3
School of Population & Public Health (SPPH), 2206 East Mall	E4
Simon K.Y. Lee HKU-UBC House — Bldg #1, Marine Drive Residence	E2
Sing Tao Building, 6388 Crescent Rd	B3
Sopron House, 2730 Acadia Rd	G7
South Campus Warehouse, 6116 Nurseries Rd	South Campus
Spirit Park Apartments, 2705-2725 Osoyoos Cresc	G8
St. Andrew's Hall/Residence, 6040 Iona Dr	B5
St. John's College, 2111 Lower Mall	D2
St. Mark's College, 5935 Iona Dr	B6
Staging Research Centre, 6045 Nurseries Rd	South Campus
Stores Road Annex, 6368 Stores Rd	E3
Student Recreation Ctr, 6000 Student Union Blvd	C5
Student Union Bldg (SUB), 6138 Student Union Blvd	C4
TEF3 (Technology Enterprise Facility 3), 6190 Agronomy Rd	F4
Thea Koerner House [Faculty of Graduate Studies], 6371 Crescent Rd	B3
Theatre-Film Production Bldg, 6358 University Blvd	D3
Thunderbird Residence, 6335 Thunderbird Cresc	F3/4
Thunderbird Stadium, 6288 Stadium Rd	J3
Thunderbird Winter Sports Ctr — *see Doug Mitchell Thunderbird Sports...*	
Totem Field Studios, 2613 West Mall	H2
Totem Park Residence, 2525 West Mall	F/G2
TRIUMF, 4004 Wesbrook Mall	South Campus
Triumf House (TRIUMF Visitor's Residence), 5835 Thunderbird Blvd	G6
UBC Bookstore, 6200 University Blvd	D4
UBC Farm, 6182 Wesbrook Mall	South Campus
UBC Hospital, 2211 Wesbrook Mall	E5
UBC Tennis Centre, 6160 Thunderbird Blvd	G4
UBC Thunderbird Arena (in Doug Mitchell Centre), 2555 Wesbrook Mall	G5
University Centre (Leon & Thea Koerner), 6331 Crescent Rd	B3
University Neighbourhoods Association, 5923 Berton Ave	South Campus
University Services Building (USB), 2329 West Mall	E2
Vancouver School of Theology, 6000 Iona Drive	B5
Walter H. Gage Residence, 5959 Student Union Blvd	C5
War Memorial Gymnasium, 6081 University Blvd	D5
Wayne & William White Engineering Design Ctr, 2345 East Mall	E4
Wesbrook Bldg, 6174 University Blvd	D4
Wesbrook Place neighbourhood	South Campus
Wesbrook Village shopping centre	South Campus
West Mall Annex, 1933 West Mall	C2
West Mall Swing Space Bldg, 2175 West Mall	D2
Wood Products Laboratory, 2324 West Mall	E3
Woodward IRC, 2194 Health Sciences Mall	E4/5
Woodward Library, 2198 Health Sciences Mall	E4/5

SOUTH CAMPUS MAP

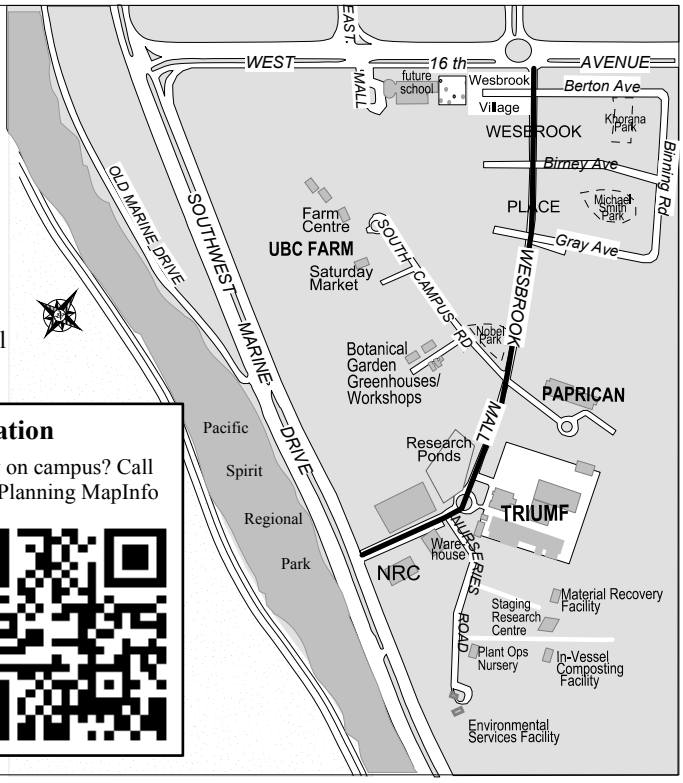
Campus & Community Planning
www.planning.ubc.ca

Note:
Local traffic only along Wesbrook Mall on South Campus

Map Information

Need help finding your way on campus? Call the Campus & Community Planning MapInfo Line at 604-827-5040, M-F, 8:30-4:30

Or use the online searchable colour map at www.maps.ubc.ca



Recreational Activities

at the University of British Columbia

Aquatic Centre
6121 University Boulevard
(604) 822- 4522 www.aquatics.ubc.ca

The UBC Aquatic Centre features a 50-metre indoor pool, seasonal 55-yard outdoor pool, whirlpool, fitness/weight room, sauna/steam rooms, seasonal patio area and diving boards from one to ten meters.

Summer Hours: Please call for swim times, lessons, etc.

Beaty Biodiversity Museum
2212 Main Mall
(604) 827- 4955 www.beatymuseum.ubc.ca

A new public museum dedicated to enhancing the public's understanding and appreciation of biodiversity. It is home to over 20,000 fossils from all over the world, including the largest blue whale exhibit in Canada

Summer Hours: Wed- Sun: 11:00am-5:00pm

Belkin Art Gallery
1825 Main Mall (beside Fredric Wood Theatre)
(604) 822- 2759 www.belkin.ubc.ca

The Morris and Helen Belkin Art Gallery's mandate is to research, exhibit, collect, publish, educate and develop programs in the field of contemporary art and in contemporary approaches to the practice of art history and criticism.

Summer Hours: Tues-Fri: 10:00am-5:00pm
Sat-Sun: 12:00pm-5:00pm

Botanical Garden
6804 Marine Drive
(604) 822- 9666 www.ubcbotanicalgarden.org

Established in 1916, the UBC Botanical Garden has an outstanding collection of temperate plants displayed according to their geographic areas. Exhibits of regional plants include the Native Garden and Alpine Garden.

Summer Hours: Daily 9:00am-5:00pm

Tennis Courts
2525 West Mall & 6010 Thunderbird Boulevard
(604) 822- 2505

All guests staying at the University of British Columbia are welcome to use the tennis courts located at Place Vanier and Totem Park Residences. There are additional courts at the UBC Coast Club located at 6160 Thunderbird Blvd. Please call for information on reservations, fees and special packages.

Please Note: Rates and Schedules are subject to change.

Museum of Anthropology
6393 NW Marine Drive
(604) 822- 5087 www.moa.ubc.ca

The Museum of Anthropology is one of North America's premier museums. School programs focusing on the Northwest Coast First Nations are available. All programs encourage discussion, observation and hands-on experience with touchable objects to learn about people and cultures. School programs must be arranged in advance.

Summer Hours: Daily 10:00am-5:00pm
Tues: 10:00an-9:00pm

Nitobe Memorial Garden
1903 Lower Mall
(604) 822- 9666 www.nitobe.org

Considered to be the best traditional, authentic Japenese Tea and Stroll garden in North America and among the top five Japanese gardens ouside Japan, the Nitobe Garden includes a rare authentic Tea Garden with a ceremonial Tea House. The exquisite work of art was created out of two=and-a-half acres (one hectare) of pristien forest by landscape architects and gardeners recommended by the government of Japan.

Summer Hours: Daily 10:00am-5:00pm

Pacific Spirit Regional Park
Park Office 4915 West 16th Avenue
(604) 224- 5739

The Pacific Spirit Regional Park encompasses 763 hectares of forest and foreshore surrounding UBC, and boasts 35 kilometres of walking trails. Experience a variety of landscapes, from estuary marshes, rock and cobble beaches, wooded ravines, ancient bog and upland forests. Regional Park Interpreters offer customized group programs on themes ranging between edible plants, birds, and bog ecology.

Student Recreation Centre
6000 Student Union Boulevard
(604) 822- 6000 www.rec.ubc.ca or www.birdcoop.ubc.ca

The SRC is one of Canada's premier University fitness facilities. It includes 1,800 square-feet of gym space, a full service fitness and weight room, a 2,300 square-foot dance studio, and a 1,600 square-foot traditional martial arts dojo.

Summer Hours: Mon-Thurs: 6:30am-9:00pm Saturday: 10:00am-6:00pm
Friday: 630am-7:00pm 12:00pm- 6:00pm

University Golf Course
5185 University Boulevard
(604) 224- 1818 www.universitygolf.com

Designed to satisfy players of every level, the course features low-mowed rough and few hazards of water to carry over. Still, it does present challenges even for the experienced golfer. Greens on Par 3's are well protected by sand and require stealth accuracy. Move back to the championship tees and put a little more distance between you and the pins. 18 holes, Par 72.

Summer Hours: First tee time: 6am Last tee time: 8pm

Please Note: Rates and Schedules are subject to change.

Campus Dining

at the University of British Columbia

From world-class catering to casual dining, coffee shops and internationally-inspired food outlets, UBC offers a delicious assortment of food services solutions. Here is an overview of food service providers certain to deliver a satisfying campus dining experience.

UBC Food Services

www.food.ubc.ca

Serving only locally-roasted fair trade organic shade-grown coffee at all UBC Food Services non-franchise locations

Wescadia Catering

Conference and special event catering

www.catering.ubc.ca

Sage Bistro at University Centre

Casual fine dining available for breakfast, lunch and special events

www.sage.ubc.ca

The Point Grill at Marine Drive Residence

New upscale casual dining restaurant open for brunch, lunch, and dinner. Open M-F

Triple O's at David Lam Research Centre

Casual dining in a family-friendly environment. Open daily

Residence Dining

Totem Park and Place Vanier Cafeterias

For information about group meal plans, please call 604-822-6204 or email rene.atkinson@ubc.ca

Pacific Spirit Place Cafeteria at the SUB

Student Union Building, 6138 Student Union Blvd

Pacific Spirit Place is open weekdays for breakfast and lunch. For information about group meal plans, please call 604-822-9310 or email fred.cheng@ubc.ca

- Bakeshop
- Pasta Bar
- Salad Bar
- Pizza Pizza
- A&W
- Koya Japan
- Manchu Wok
- Subway

Proudly Brewing Starbucks Coffee

- **Starbucks Coffee** at Student Union Building
- **The Barn** at Main Mall
- **Starbucks Coffee** at Fred Kaiser
- **Steamies Café** at the Bookstore
- **Pond Café** at Ponderosa Centre

More Great Locations…

- **Niche Café** at Beaty Biodivesity Museum
- **Caffé Perugia** at Life Sciences Centre
- **Café MOA** at Museum of Anthropology
- **Ike's Café** at Irving K. Barber Learning Centre
- **Tim Horton's** at Forest Sciences Centre

For guests, visitors, or groups visiting the UBC Campus, the UBC Food Services gift card is the easiest way for you and your group to dine at any of our locations.

Food Outlets

at the Student Union Building (SUB)

The SUB features a variety of food outlets all under one roof and conveniently located at the heart of campus. Get a delicious bagel or muffin to go, grab a slice of pizza at Pie R Squared, pick up some freshly made sushi or sit and enjoy a juicy beef burger at Pit Pub. The SUB has something for everyone!

Concourse and Sub-Level

Blue Chip Cookies

Proudly serving organic, fair trade coffees, cappuccinos and lattés. All our cookies and fabulous baked goods are made in-house and baked fresh daily.

Bernoulli's Bagels

Montreal-style bagels, sandwiches, and bagel melts using high-quality ingredients and freshly squeezed vegetable or citrus juice!

The Delly

Fresh sandwiches made to order. A wide selection of salads, wraps, curries, soups and pasta made daily.

The Moon Noodle House

Great wonton soup, daily specials, fresh steamed veggies, combos and hot & sour soup.

The Honour Roll

Maki rolls, nigiri, sushi, donburi rice bowls and bento boxes are made fresh throughout the day. Ask about party platters and catering.

The Patio BBQ

On the south side of the SUB, Monday to Friday (weather permitting) offering grilled 1/4 pound burgers, veggie burgers, smokies and drinks.

The Pit Burger Bar

Charbroiled hamburger specials, veggie burgers, hot wings, beer-battered fish & chips and more!

The Pendulum Restaurant

Delicious grilled sandwiches and panninis, and lots of vegetarian and vegan dishes!

The Pit Pub

Satellite big-screen sports, six high-definition TV's, great drink prices, and a great atmosphere!

Pie R Squared

Great house-made pizza slices, great prices, cold drinks. Now offering soft-serve ice cream and doughnuts.

www.catering.ubc.ca

NEED CATERING? *For catered events or meals on the go, Wescadia Catering offers a multitude of menu ideas to meet a range of dietary needs. We pride ourselves on our knowledgeable, friendly staff, professional service and quality ingredients.*

University Boulevard

Restaurants and Food Outlets

University Boulevard boasts a vibrant neighbourhood feel, and features dozens of places to enjoy a sit-down meal, people-watch over coffee, or grab a quick bite on the run. Visitors will feel right at home choosing from internationally-recognized franchises and unique offerings from local entrepreneurs.

The Boulevard Coffee Roasting Co.

at David Strang, 5870 University Blvd.
theboulevard.ca

Mahony & Sons Public House

at David Strang, 5990 University Blvd.
www.mahonyandsons.com

The Well Café

at Regent College, 5800 University Blvd.

University Village

5700 Block, University Blvd.

- Blenz — Coffee Shop
- Booster Juice — Juice & Snack Bar
- Mio Japan — Japanese Fast Food
- McDonald's — Breakfast – Late-Night Fast Food
- Pearl Fever — Tea House & Snack Bar
- Pita Pit — Lunch – Late-Night Take-Out & Delivery
- One More Sushi — Japanese Dining
- Only U Café — Deli & Diner
- Starbuck's — Coffee Shop
- University Pizza — Take-Out & Delivery
- Vera's Burger Shack — Diner
- Village Restaurant — Chinese Dining

International Food Fair

University Marketplace, Lower Level

- A-1 Vietnamese Food — Pho & Noodle House
- Curry Point — East Indian
- Donair Town — Persian, Mediterranean, Catering
- Leona Mediterranean Food — Lebanese
- Malaysian Cuisine — Malaysian, Thai
- Osaka Sushi — Japanese
- Timpo Mongolian BBQ — Stir-Fry
- Yi Kou Xiang — Chinese

ALSO RECOMMENDED… ***Westward Ho! PublicHouse & Grill Room*** *at the University Golf Club*
www.universitygolf.com/dine