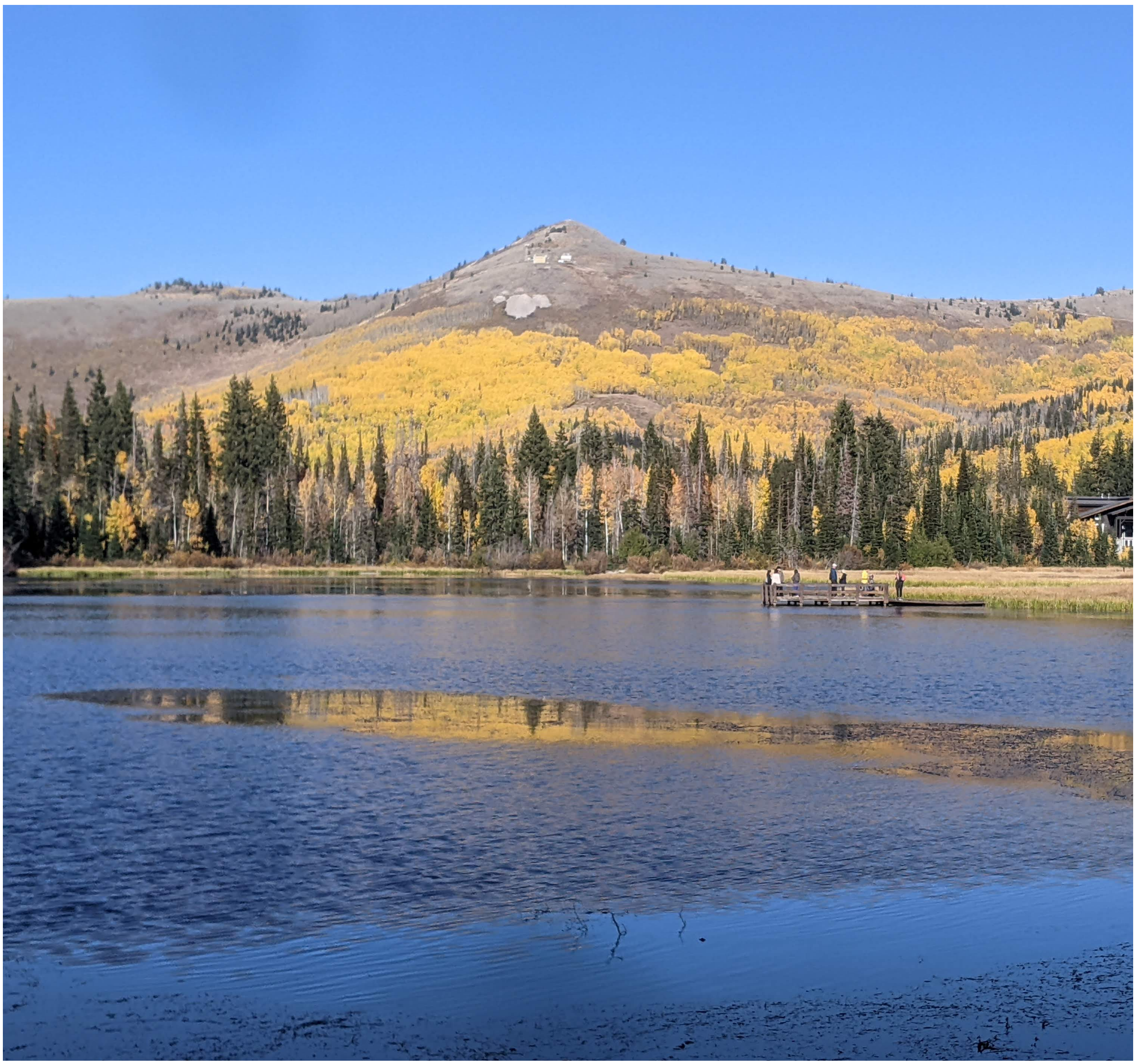
The University of Utah

Department of Mathematics

GRADUATE BULLETIN

2022–2023



About the cover

Westward moving pioneers arrived in the Salt Lake Valley of Utah Territory in July 1847. The hamlet of Brighton was established in 1871 at the top of Big Cottonwood Canyon, adjacent to Silver Lake in the photograph. The elevation of the lake is about 2,650 m (8,700 ft) above sea level. The canyon is home to two major ski resorts, Brighton and Solitude. Winter snowfall in Brighton averages about 13 m (42 ft).

A summer road can be followed from midway between the resorts, over Guardsman Pass (2,962 m, or 9,717 ft) in the background to the eastern slope of the Wasatch Mountains, where the road forks, one branch going to Heber City, and the other to Park City, home of three more ski resorts.

Fall colors in this region are predominantly yellow from aspen, and red from scrub oak.

GRADUATE MATHEMATICS
2022–2023

Department of Mathematics
University of Utah

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Cover: Spiral Jetty (Photo: Nelson H. F. Beebe)

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Contents

1 General information

This chapter briefly describes the Mathematics Department at the University of Utah, and the research facilities available to its members, within the department, elsewhere on campus, and at national computer laboratories.

1.1 A brief history

The University of Utah is a state tax-supported, coeducational institution. It was founded in 1850, and is the oldest state university west of the Missouri River. In recent years, the Graduate School has been awarding approximately 600 Ph.D. degrees per year. The University faculty consists of approximately 3100 members.

The Mathematics Department of the University of Utah now awards, on the average, about twelve Ph.D. degrees per year. Over 300 people have earned this degree since 1954. Most of them have positions in state and private universities, but some hold nonacademic positions. Six have been awarded Sloan Research Fellowships, 12 have been visiting members of the Institute for Advanced Study in Princeton, and five have been awarded National Science Foundation Postdoctoral Fellowships.

Our graduate faculty has more than 50 professors. Several members of the current faculty have received national awards including Sloan Fellowships and Presidential Young Investigator Awards. The University has also recognized members of our faculty with Distinguished Professor, University Distinguished Researcher, and Teaching Awards. A list of current members of the faculty is available at

http://www.math.utah.edu/people/faculty.html

The research interests of the faculty are the areas of specialization available for graduate studies. They include diverse areas in pure and applied mathematics such as algebraic geometry, commutative algebra, differential geometry, geometric group theory, geometric topology, materials and fluids, mathematical biology, mathematical cardiology, mathematical finance, mathematical physiology, number theory, numerical analysis, partial differential equations, probability and statistics, representation theory, scientific computing and imaging, and stochastic processes.

During the current year, approximately 30 members of the Mathematics faculty are associated with government-sponsored research contracts.

The University's total student enrollment is currently about 34,000. During 2021–2022, there were 74 men and 33 women Ph.D. students in Mathematics. Our graduate students come from many different areas of the United States, as well as from several foreign countries.

1.2 Departmental research facilities

The Marriott Library collection includes numerous books and journals of interest to mathematics researchers and scholars. Many of the journals, and journal databases, are also available electronically when accessed from *inside* the campus network.

The University of Utah was node four of the five founding members of the Arpanet in 1968, the precursor of the worldwide Internet today that drives world communications, commerce, entertainment, and much else. The University of Utah continues to play an important role in advanced networking research, and is a member of consortia that run the world's fastest long-distance networks.

From 2017, the University has a 40Gb/s network backbone, with multiple 10Gb/s links to the Internet through a large firewall that guards against many of the hostile attacks that negatively impact computing and networking worldwide. Almost all campus buildings have 10Gb/s uplinks to the network backbone. In addition, there is wide support throughout campus for both public, and access-controlled private, wireless networking.

There are extensive computing facilities available in the Department, including numerous multiprocessor multicore servers with 128GB of memory, and one with 1024GB of memory, all with a common filesystem for user login directories. Most users access those facilities from desktop thin-client workstations, or from remote computers via the secure-shell protocol that guarantees strong encryption of communications.

There is a huge installation of software, with almost 22,000 available programs, including numerous compilers for all major programming languages, and specialized mathematical, statistical, and scientific libraries and systems. There is also a large collection of virtual machines that provides an outstanding testbed for software portability to many different operating systems.

The main fileserver had a major upgrade in capacity and speed in Spring 2018. It uses ZFS (Zettabyte File System) to provide highly-reliable storage, flexible management and expansion, and user-accessible read-only filesystem snapshots, taken at least daily, and hourly in the active electronic-mail system and also in user home directories. There are generally three to four weeks of user-accessible online snapshots.

For reliability, the main filesystem has a live mirror in another campus building. There are nightly backups of all filesystems to holding disks that are copied to LTO-8 tapes in a 500-tape robot. Nightly ZFS snapshots are copied to a large-storage server in an off-campus datacenter for years-long retention.

A large battery backup power-conditioning system, and outside diesel generator, ensure uninterrupted computer operations, and immunity to electrical power bumps and outages.

Printing, copying, and scanning facilities are available on all building floors, and student computer labs have at least two printers each to reduce waiting times.

Online documentation about our computing environment is available at

`http://www.math.utah.edu/faq/`

Further details of machine particulars are available from systems staffers in offices LCB 103, 105, and 110. Computer-facility tours for departmental members are available on request, and systems staff are always happy to offer guidance in computer purchases, and to provide short tutorials on numerous aspects of computing.

1.3 Additional research facilities

The University of Utah's Center for High-Performance Computing (CHPC)

`http://www.chpc.utah.edu/`

is housed in the INSCC building adjacent to the Mathematics Department buildings.

The Center provides access to thousands of compute nodes in multiple distributed clusters with large parallel filesystem storage, as well as to advanced scientific software, through a quarterly application process that requires a brief description of the research to be performed, but, for modest computing needs, does not require payment.

Campus researchers with large computing needs, and sufficient financial resources from research grants, can also buy portions of the CHPC facilities to leverage economies of scale, and guarantee exclusive access when needed. Nodes that have been idle for some time normally move to a shared pool so that others can use them, avoiding resource waste.

CHPC is a gateway to several national computing facilities for extreme-scale computing, and hosted the National Supercomputer Conferences in Salt Lake City in 2012 and 2016. The University of Utah is a member of the Rocky Mountain Advanced Computing Consortium (RMACC) that encourages communication and collaboration among high-performance computing sites in the West.

1.4 Safety and wellness

Your safety is our top priority. In an emergency, dial 911 or seek a nearby emergency phone (throughout campus). Report any crimes or suspicious people to 801-585-COPS; that number will get you to a dispatch officer at the University of Utah *Department of Public Safety* (DPS; `https://dps.utah.edu`). If at any time, you would like to be escorted by a security officer to or from areas on campus, DPS will help — just give a call.

The University of Utah seeks to provide a safe and healthy experience for students, employees, and others who make use of campus facilities. In support of this goal, the University has established confidential resources and support services to assist students who may have been affected by harassment, abusive relationships, or sexual misconduct. A detailed listing of University resources for campus safety can be found at `https://registrar.utah.edu/handbook/campussafety.php`.

Your well-being is key to your personal safety. If you are in crisis, call 801-587-3000; help is close.

The university has additional excellent resources to promote emotional and physical wellness, including the *Counseling Center* (`https://counselingcenter.utah.edu`), the *Wellness Center* (`https://wellness.utah.edu`), and the *Women's Resource Center* (https://womenscenter.utah.edu). Counselors and advocates in these centers can help guide you to other resources to address a range of issues, including substance abuse and addiction.

2 Important dates

This chapter records links to documents recording critical dates for academic terms, thesis deadlines, training sessions, and the critical qualifying examinations.

2.1 University dates

For the most current list of dates, see:

Fall 2022
https://registrar.utah.edu/academic-calendars/fall2022.php

Spring 2023
https://registrar.utah.edu/academic-calendars/spring2023.php

Summer 2023
https://registrar.utah.edu/academic-calendars/summer2023.php

It is particularly important to pay attention to when classes begin and end, and the final days to add or remove classes.

2.2 Thesis related dates

Beyond the University dates listed above, there are also critical dates that one must not miss if writing a dissertation or thesis. See

http://gradschool.utah.edu/thesis/

for the specific dates.

2.3 Departmental dates

- Teaching Training Workshop, 10–12 and 17–18 August 2022.
- August Written Qualifying Exams, 17–19 August 2022.
- January Written Qualifying Exams, 4–6 January 2023 (tentatively).
- May Written Qualifying Exams, 17–18 May 2023 (tentatively).

3 Graduate study

This chapter describes the mechanical aspects of graduate work: advisors, committees, exams, and tuition.

3.1 Relevant groups and people in the Department

Before we discuss those, we list the individuals and organizations in the Department who can assist you.

3.1.1 Director of Graduate Studies

The Director of Graduate Studies, currently Fernando Guevara Vasquez, oversees the graduate program with the Graduate Committee. He also is a resource for questions about the program. Appeals or questions about any policy or departmental decision can generally be taken to him. You can also appeal any item further to the Department Chair or as specified in the Student Code.

3.1.2 Graduate Program Coordinator

The Graduate Program Coordinator, currently Paula Tooman, runs the graduate program on a day to day basis and helps with the necessary paperwork that must be done at various points in your degree. She is also a resource for questions about the program.

3.1.3 Graduate Committee

The Graduate Committee oversees the progress of all graduate students in the Department, and its decisions are carried out by the Director of Graduate Studies. The Graduate Committee reviews student progress annually and makes decisions about continuation of funding/continuation in the program: see Section 3.5.

The current composition of the Graduate Committee can be found at

`http://www.math.utah.edu/people/committees.html`

Subcommittees of this committee are also in charge of various other aspects of the program, such as Funded Graduate Student Travel.

3.1.4 Graduate Student Advisory Committee (GSAC)

The Graduate Student Advisory Committee exists for the following reasons:

- to advise new and continuing graduate students concerning curricula, requirements for degrees, and other aspects of the graduate program;
- to make recommendations to the Department about promotion, tenure, and retention of faculty members;
- to participate in the allocation of funds from the Associated Students of the University of Utah (ASUU) supplied to the College of Science Student Council;
- to make whatever recommendations it feels appropriate concerning the graduate program to the Department of Mathematics;
- to assist the Department in making its policies and requirements fully understood by graduate students.

More information about GSAC, and its current membership, is at

`http://www.math.utah.edu/gsac/`

3.2 Benefits and opportunities

This section highlights benefits and opportunities available to graduate students in the Mathematics Department at the University of Utah.

3.2.1 Tuition and tuition benefit

For the current tuition costs, see

`http://fbs.admin.utah.edu/income/tuition/general-graduate/`

However, most graduate students who work as a Teaching Assistant (TA), as a Research Assistant (RA), or are supported by a fellowship, are eligible for the University of Utah's tuition benefit program. For those students, there is no charge for tuition related to their program of study as long as it conforms to certain rules. Here are some key points about the program:

- You *must* register for between 9–12 credits (9–11 for most students who are not TAs). Students who are supported by RTG grants should register for different amounts that depend on regulations of the grant and the Graduate School.
- This is a merit based program. To be eligible you need to maintain a GPA of 3.0 or higher. This requirement does not apply to your first semester in the program.

- The tuition benefit comes with certain restrictions. One restriction is that the TB only covers graduate courses (i.e. 5000+ level classes). Another restriction is that the TB does not allow for repeated courses, with a few exceptions such as thesis research. For more details, see the Graduate School TB website linked below.
- Ph.D. students who entered with a Bachelor's degree have 10 semesters of tuition benefit. The benefit can be automatically extended for 2 additional semesters, if you have served as a TA for at least 4 semesters.
- Ph.D. students who entered with a Master's degree have at most 8 semesters of tuition benefit. The benefit cannot be automatically extended.
- Master's degree students receive at most 4 semesters of tuition benefit. The benefit cannot be automatically extended.
- Students who are out of tuition benefit can work with their advisor and the Director of Graduate Students to appeal for more from the Graduate School. These appeals depend on the individual case and frequently are not successful. Such graduate students can also request funding from the Graduate Committee or their advisor, or a combination thereof, to cover the cost of tuition if this appeal to the Graduate School is not successful.

For more details on the Tuition Benefit program, see

`http://gradschool.utah.edu/tbp/`

3.2.1.1 Differential tuition

Course fees and differential tuition are typically *not* covered by the tuition benefit program. However, if the course is part of your program of study and approved by your advisor, you can request that the Department contribute towards covering these additional costs (depending on availability of funds). your advisor then usually also contributes. The request, and supporting documentation from your advisor, must be made to the Director of Graduate Studies before the start of the semester. All requests are reviewed by the Department Chair and the Director of Graduate Studies.

For details, see

`https://fbs.admin.utah.edu/income/tuition`

3.2.2 Health insurance

The University of Utah sponsors a health-insurance plan at excellent rates for students, their spouses, and their dependent children under age 26. For details, see

`http://www.studenthealth.utah.edu/services/`

The Graduate School and the Department provide each funded graduate student with a premium subsidy that covers the full cost of group health insurance offered through United Healthcare; see

`http://gradschool.utah.edu/tbp/insurance-information/`

3.2.3 Parental leave

As of 1 July 2022, the University has adopted a graduate student Parental Leave policy benefiting all eligible University of Utah graduate students. The full *Policy 6-409 Graduate Student Parental Leave* can be found at

https://regulations.utah.edu/academics/6-409.php

Please consult the policy above for eligibility. During a parental leave of absence, the student has modified assigned duties. Typically, there is no teaching requirement during the period of absence. Students may still conduct research and take classes, including reading classes, but are not necessarily expected to work at the same pace for research projects. It is important that students take at least 3 credits during this semester to maintain their full-time status. If approved, the Graduate School provides 8 weeks of paid leave of absence. The Department completes this so that the student receives the normal TA stipend and insurance over a full semester. If the student does not use the tuition benefit, tuition costs for 3 credits are covered by the Department.

Requests for parental leave should be submitted to the Graduate Program Coordinator and are reviewed by the Chair, Associate Chair, and Director of Graduate Studies. The Director of Graduate Studies coordinates the submission of the parental leave request with the Graduate School. If applicable, the Director of Graduate Studies may consult the student's advisor to adjust research goals to the leave of absence. Requests for a parental leave of absence with modified duties should normally be made no fewer than *90 days* prior to the expected arrival of the child. It is necessary to make this request in advance so that the particular arrangements of the leave can be planned. The request should specify what duties and/or research the student is planning on performing.

If a student desires, the deadlines to meet various departmental requirements (such as passing qualifying exams) can be extended by one semester upon request.

Students who experience a medical condition associated with pregnancy, and need accommodations recommended by their medical provider, should contact the University's Title IX Coordinator, who then works with the student, cognizant faculty, and administration to determine what accommodations are reasonable and effective.

For more complicated situations, the Department tries to proceed in a way similar to the rules for parental leave with modified duties for faculty, as described at

http://regulations.utah.edu/academics/6-315.php

3.2.4 Funded travel for graduate students

A subcommittee of the Graduate Committee reviews requests by graduate students for funded travel. See

http://www.math.utah.edu/grad/TravelFunding.pdf

Additionally, such students should apply to the Graduate School Graduate Student Travel Assistance Program. For other ideas for sources of funding, see the following Graduate School website:

https://gradschool.utah.edu/diversity/conference-travel/

3.2.5 Other resources for students

The University of Utah offers many other resources for graduate students. We particularly draw attention to the Student Health Center,

http://studenthealth.utah.edu/

the University Counseling Center,

http://counselingcenter.utah.edu/

and the University Writing Center

https://writingcenter.utah.edu/

The Graduate School also maintains a list of resources that students can pursue:

http://gradschool.utah.edu/graduate-student-support-services/

3.3 Advisors and committees

In this section, we discuss advisors, Initial Academic Mentors, and Supervisory Committees.

3.3.1 Initial academic mentors

All Ph.D. students are assigned an Initial Academic Mentor before arrival at the University of Utah. This mentor should meet with the student at least once each semester to plan initial courses. A student may request a change of Initial Academic Mentor at any time by notifying the Director of Graduate Studies and Graduate Program Coordinator. The student works with this mentor in this way until a student selects an academic advisor.

3.3.2 Advisors

Master's degree students are assigned an Initial Academic Mentor upon entering the program and are expected to select an advisor before their second year. Once a Ph.D. student has chosen a research area, he or she should select an academic advisor. Typically, a student might do a reading course with a prospective advisor before deciding. To remain in good academic standing with the program, the Ph.D. student must select an advisor by January of the third year. It is strongly recommended, however, that the student choose an advisor much earlier, during the second year of study.

Once a student has an advisor, it is the student's responsibility to meet with the advisor and design a program of study. The student should meet with the chosen advisor at the beginning of each academic year to plan that year's work, and at least once a semester to discuss progress. Typically, this is done much more frequently. The responsibility for setting these meetings rests with the *student*. Advisors are requested by the Director of Graduate Studies to make brief comments on each student's progress each year.

A student may request a change of advisor at any time by notifying the Director of Graduate Studies and Graduate Program Coordinator. See also Section 3.5 on termination of the student–advisor relationship.

3.3.3 Committee composition

The following describes the members of a Master's degree or Ph.D. committee.

- The Committee Chair (advisor) is usually chosen to be a faculty member whose research area is the potential research area indicated by the student. If the student expresses a personal choice, and if the faculty member suggested is not already overworked with advising, the requested person is normally appointed.
- The Master's degree committee shall consist of *three* faculty members, the majority of whom must be regular faculty in the Department of Mathematics.
- The Ph.D. committee shall consist of *five* faculty members. At least *three* must be regular faculty in the Department of Mathematics, and at least *one* must be from another department. In some cases, faculty at other institutions can also fill the role of an outside committee member. To arrange this, a *curriculum vitae* of the outside member must be sent to the Graduate Program Coordinator who then requests approval from the Graduate School for this outside member.
- If the student's interests change, the committee makeup is modified appropriately by the Director of Graduate Studies, after consulting the student and committee.

3.3.4 When to form your committee

For Master's degree students, the Supervisory Committee should be formed during the first year of study. For Ph.D. students, the Supervisory Committee is typically formed after passing written qualifying exams but it can be done sooner. This committee must be formed prior to taking the oral exam. It is important that this committee is formed as soon as feasible and must be done by January of the *third year* in the program.

3.3.5 Role of the supervisory committee

The function of the advisor and the Supervisory Committee is to:

- Advise the student regarding a program of study.
- Evaluate the student's progress in the chosen program of study that is worked out with the committee shortly after the committee is formed.
- Set the ground rules and evaluate the preliminary and final oral examinations. This should be done in consultation with the student.
- Review any requests for changes or waivers in the usual requirements.

3.3.6 What is a program of study?

A program of study is the collection of courses and thesis work that makes up your academic record and that forms the basis of your graduation. You officially add courses to your program of study at certain points in your academic career.

3.3.7 Deviation from requirements

A majority of the student's committee is sufficient to approve (or disapprove) the program of study, or a petition for an exemption for some requirement. The student, or a dissenting member, can appeal any decision to the Director of Graduate Studies. Such an appeal is usually reviewed by the departmental Graduate Committee. Appeals or recommendations that explicitly or implicitly ask for a deviation from Graduate School policy must be reviewed by the Dean of the Graduate School.

3.4 Exams

Graduate students are required to take both written **and** oral exams, but some Master's degree programs require only written **or** oral exams.

3.4.1 Written preliminary and qualifying examinations

All Ph.D. students are required to pass at least *four* of the following written qualifying exams at a high-pass level. Additionally, they are required to pass at least *two* of the following exams. Thus Ph.D. students must pass *six* (4+2) exams in total.

Students in the Master's degree program may be required to pass up to 4 written exams, depending on the exact program that they are a part of.

For courses taken in Fall 2020 or later, the following applies. Earning an **A** in the corresponding course counts as a high pass. Earning a **B+** (or **A-**) in the corresponding course counts as a pass. It is possible for a student to pass out of all required exams via course performance.

Qualifying exams passed before August 2020 normally each count as *two high passes* for the purpose of these exams. See Subsection 3.4.4 for additional details.

The written Ph.D. preliminary examinations are the same as the Master's qualifying examinations.

All exams are offered in August, typically in the two weeks before the Fall semester. Additionally, each exam is offered approximately 4 weeks after the end of the corresponding course during the regular academic year. For courses offered in Fall semester, the corresponding exam will normally be held in early January. For courses offered in Spring semester, the corresponding exam will normally be held in May.

3.4.1.1 Exam topics

The written part of the Ph.D. preliminary examination in mathematics consists of tests based on the following courses. Grading of these courses is left to the discretion of the instructor. However, to maintain academic standards, it is required to offer a final exam, reviewed and graded by another faculty member (see Responsible Faculty) and whose questions are within the scope of the departmentally approved syllabus of the course. It is also required to evaluate the student's performance regularly by means such as homework, projects, quizzes, midterms, etc. These should be designed so that students who are not engaged or are struggling are identified well before the end of the semester.

6010 Linear Models

6040 Probability

6070 Mathematical Statistics

6210 Real Analysis

6220 Complex Analysis

6310 Algebra I

6320 Algebra II

6410 Ordinary Differential Equations

6420 Partial Differential Equations

6510 Differentiable Manifolds

6520 Algebraic Topology

6610 Analysis of Numerical Methods I

6620 Analysis of Numerical Methods II

6710 Applied Linear Operator and Spectral Methods

6720 Applied Complex Variables and Asymptotic Methods

Syllabi for these qualifying exams are available later in this document: see Chapter 5. Students must recognize that the tests are based on the material in the syllabus, *not* on the material in the preceding course on the subject. The student is responsible for preparing to be examined in all of the topics listed on the syllabus, whether or not all of the subjects were covered in a particular course on the subject.

Students should choose their tests in consultation with their advisor(s) or Initial Academic Mentor. One purpose of this consultation is to ensure sufficient breadth in the choice of tests. If the student wishes to take a written qualifying exam without having taken the associated class offered by our department, *the student needs express permission* from their Initial Academic Mentor, advisor(s) or Director of Graduate Studies before taking the exam.

As of Fall 2021, the Statistical Inference I and II qualifying exams based on Math 6824/6828 are discontinued. Students admitted before the Fall 2021 may request to take these written qualifying exams or have appropriate grades in these classes count towards their written qualifying exam requirements.

3.4.1.2 When to take exams

In order to pass the written qualifying examinations, a Ph.D. student must pass *four* tests at a high level (or earn **A**s in the corresponding courses if taken after August 2020) and must pass *two* additional tests (or earn **B+**s, **A-**'s, or higher in the corresponding courses if taken after August 2020). Starting in 2023, only high level passes are counted for August exams taken by entering students. See Subsection 3.4.4 for details for students starting before 2020.

A Master's student whose committee has selected the written qualifying exam option must pass *four* tests (or earn **B+**s or above in the corresponding courses if taken after August 2020). Master's degree students who have selected the written qualifying exam option should take the qualifying exams as soon as they have the necessary background.

Ph.D. students, without pre-arranged exceptions (which may, for example, be due to health or life emergencies), are expected to:

- Take 2–3 preliminary exam courses each semester in their first year if they did not pass out of those courses via exams they took when entering the program in August.
- Obtain 4 high passes by the end of January in their second year. Students who do not meet this target should expect to leave the program at the conclusion of year 2.
- Finish all written exams before their third year in the program.

Students who transfer to the Ph.D. program from the Master's program will normally have these deadlines set 1 year later with respect to when they started the graduate program, see Subsection 3.6.1.

Ph.D. students whose background is not sufficient to take courses and exams on this schedule may, in their first year in the program, request to be transferred to a Master's program with a goal of eventually completing the Ph.D. program. In that case, students can take the courses prerequisite to those written exam related courses described above. These students should be given a letter by the Director of Graduate Studies specifying exactly what they need to pass and by when in order to automatically be transferred to the Ph.D. program. Typically, students in this situation will be one year behind other students in terms of requirements for written preliminary and oral qualifying exams.

The Graduate Committee reviews students' progress towards completing their written exams in January of their second year. Each student's renewal-of-support letter for that year must include the date that the Graduate Committee expects the student to complete written exams if there is a pre-approved deviation from the schedule listed above. **Failure to pass by this specified date typically results in termination from the graduate program.**

3.4.1.3 Normal progress towards passing written exams

In order to make progress towards passing these exams, it is important for students to do well in their courses and to take exams promptly.

Ph.D. students meeting any of the following criteria:

- By the end of January of their first year, have *not* passed at least one exam at the high level and passed one additional exam.

- By May of their first year, have *not* passed at least three exams at the high level.
- By the start of their second year, have *not* passed at least three written preliminary exams at a high level and obtained at least one more pass.

should work with their advisor or initial academic mentor and the director of graduate studies or other members of the graduate committee, to develop a plan to remedy this situation. Such remedies may include regular tutoring by a faculty member, retaking a qualifying exam class, taking a different qualifying exam class, or dropping to a Masters program as described above (when appropriate).

Students who transfer to the Ph.D. program from the Master's program will normally have their deadlines set 1 year later with respect to when they started the graduate program, see Subsection 3.6.1.

3.4.1.4 Maximum exam attempts

There is no limit on maximum exam attempts.

3.4.1.5 Responsible faculty

The Department Chair appoints a member of the faculty (usually the Director of Graduate Studies) to make the arrangements for the written qualifying examinations of each academic year.

That person selects, for each exam, two members of the tenure line faculty to be in charge of the exams and the final exam for the corresponding course, which is required. One of those two members should be the faculty member who taught the corresponding course, if possible. Thus there are two responsible faculty.

(A) The faculty who taught the course.

(B) Another faculty member assigned to this duty.

The course instructor (A) has final responsibility for the final exam for their course but is expected to discuss the final exam for the course with the other responsible faculty member (B). Faculty member (B) has final responsibility for the exam given 4 weeks after the end of the course, but should likewise discuss the exam with the course instructor (A). These or other faculty members may also be asked to be involved in the August exam, in which case they should work together.

3.4.1.6 Nature of the examinations

The test in each area is a written test of two hours duration. The level of the test should be comparable to that of the corresponding first-year graduate course in the field. The faculty members responsible for a given test should check to see that the topics covered on the test are compatible with the Chapter 5. Copies of past examinations are available at

`http://math.utah.edu/graduate/qualifying_exams`

However, notice that starting in August 2020, the exams are broken up by semester. Thus, for example, there is a one exam on Real Analysis and a different exam on Complex Analysis. Before August 2020, most exams were based on two semesters, so for instance there was a combined exam on Real and Complex Analysis.
All examinations are proctored.

3.4.1.7 Grading of the tests

After all the tests in a given area have been graded, the two faculty members responsible for the test decide what is to be a passing score on the examination. *Student identities are not revealed to the graders.*

3.4.1.8 Announcement of results

Under normal circumstances, the student is informed within *one week* after the end of the examinations of the passing score on each test and is allowed to examine their tests.

3.4.1.9 Appeals

The Graduate Committee handles all appeals. In particular, grading of examinations may be disputed, and exceptions to these rules can be granted. A student wishing to make an appeal does so through his or her Initial Academic Mentor, advisor, Supervisory Committee or the Director of Graduate Studies. Those faculty members assist the student in taking the necessary actions. A student may also enlist the aid of the *Graduate Student Advisory Committee* (GSAC) to help in the process: see Subsection 3.1.4.

3.4.2 Oral qualifying examinations

Ph.D. students are required to take an oral qualifying examination, and some Master's degree students may also be required to take such an exam, depending on their program. Students who fail the oral qualifying examination may be given a second examination at the discretion of the student's Supervisory Committee. Oral examinations may only be repeated once.[1]

Responsibility for scheduling the examination rests jointly with the student and their advisor. The oral examination is not a test of specific subject-matter retention; rather it is designed to measure the student's overall mathematics maturity and breadth, and their skill at chalkboard exposition and verbal exchange. In general, the oral examination is concentrated on the area of specialization of the student and related areas. On the other hand, this oral examination is *not* a thesis defense, and should be conducted before much thesis research has been done.

The candidate initiates scheduling, with their Supervisory Committee's approval. The Supervisory Committee sets its own ground rules for Ph.D. oral qualifying exams. The student should arrange with the Committee the scope of questions, and how the exam is conducted.

[1]It is possible to appeal this, but such appeals must be granted by both the Graduate Committee and the Dean of the Graduate School.

To schedule the oral exam, the student should contact the Graduate Program Coordinator, Paula Tooman (`tooman@math.utah.edu`), at least one week before the exam and send her information about the date, time, and members of the Supervisory Committee. The student may request the oral exam to be advertised to the public or only to the members of the Supervisory Committee.

Most Mathematics oral qualifying exams have followed one of two plans:

Coursework: The student answers questions based on their graduate courses. Students taking this type of exam should, in consultation with their Supervisory Committee, prepare a written syllabus of the topics that are covered on the exam.

Research Proposal: The student makes a presentation of a background topic related to their proposed research or directly on their preliminary research. The student proposes the plan for the rest of the Ph.D. research and demonstrates they have the requisite background by answering questions related to the presentation/proposal/background topic.

Some supervisory committees might require a written research proposal and/or as with the coursework exam, a written syllabus of the topics covered on the exam. The Mathematical Biology Group has additional requirements for the written project proposal which accompanies their oral exam. See their website

http://www.math.utah.edu/research/mathbio/

for more details.

3.4.2.1 When to schedule oral qualifying exams

All Ph.D. students are required to:

- Have passed or scheduled their oral qualifying exam by January of their third year in the program. In particular, this means that students must have chosen their advisor and formed their committee by this time.
- Have passed their oral qualifying exam before their fourth year in the program.

The Director of Graduate Studies should be informed if there is a change to the date the exam is scheduled. Annual renewal-of-support letters include expectations of when students should pass their oral qualifying exam. Failure to meet the deadlines above, or other deadlines in the letter of support, which may supersede those deadlines, will typically lead to termination from the program.

Students who transfer to the Ph.D. program from the Master's program will normally have these deadlines set 1 year later with respect to when they started the graduate program, see Subsection 3.6.1.

3.4.3 Final oral examination

The final oral examination for Ph.D. students, and some Master's degree students, sometimes called the "Thesis Defense," is *distinct from* the oral qualifying examination. This examination consists of a *public* thesis defense. The Supervisory Committee meets *in private* after the defense to vote on final approval.

To schedule the thesis defense, the student should contact the Graduate Program Coordinator, Paula Tooman (`tooman@math.utah.edu`), at least two weeks before the examination and send her information about the title of the thesis, members of the Supervisory Committee, and date and time of the defense. The thesis defense is advertised to the public.

3.4.4 Students starting before May 2020.

Graduate students who started before May 2020 have the following rules.

- Students who have passed their written qualifying exams are still considered to have passed their qualifying exams.
- We expect that students will work in the following hybrid system below. However, if there are particular unforseen problems with doing this for a student (such as might disadvantage a student, particularly around the timing of the probability exam), the student should ask the Graduate Director to work with them to address their concerns. Any changes to the rules below will be reviewed by the graduate committee on a case by case basis.
  1. Any written preliminary exams passed before August 2020 count as 2 exams passed at a high level, this includes the Probability exam.
  2. Students take exams which are based upon one semester of study.
  3. They will need to pass 4 at a high level and pass 2 more exams.
- The deadline for passing written preliminary exams is set at 2.5 years. Note this is extended relative to the system of exams after August 2020.
- The deadline for passing the oral qualifying exam is whatever it is set to in the most recent letter of support. However, the expectation for students in pure mathematics is they pass this by January in their third year. Students in applied mathematics are normally expected to pass this by January in their fourth year. Note, this is a different schedule than what is expected for students who entered in August 2020 or later.

3.5 Evaluation and dismissal of graduate students

At the beginning of Spring Semester, all graduate students are evaluated by the Graduate Committee on the progress in their study toward a degree. The Graduate Committee also evaluates teaching performance at this time. There are two issues being decided:

- continuation in the program; and
- continued financial support in the form of a Teaching Assistantship and tuition benefit.

It is possible that a student may be allowed to continue progressing towards a degree without funding, for instance, without a Teaching or Research Assistantship. A student may also be responsible for his or her tuition costs, especially if the student has used up the tuition benefit: see Subsection 3.2.1.

Decisions to continue or award Teaching Assistantships, and to continue in the program, are based on both teaching performances and on academic performance. Notification of renewals or nonrenewals are distributed by April 15. These letters also contain individualized academic performance expectations for each student for future years.

3.5.1 Academic performance

The academic requirements, specified throughout the *Graduate Bulletin*, are considered by the Graduate Committee in Spring Semester for students in the graduate program. Below is a list of common conditions that cause a student to be academically deficient within the Ph.D. program. If a student satisfies any of the conditions below, then the student is academically deficient unless there is a previous written arrangement for deviation from the corresponding requirement. Failure to promptly address these issues or other issues will normally lead to termination from the program.

- Failure to have passed at least *four* written qualifying exams at a high level by January of their second year. See When to take exams.
- Failure to have passed all written qualifying exams before their third year. See When to take exams.
- Failure to have passed or scheduled, by January in the third year, the oral qualifying exam. While the exam does not have to be taken by this point, it must be scheduled in consultation with the student's advisor and Supervisory Committee. See When to schedule oral qualifying exams. Thus the student's advisor and committee must be in place by this point.
- Failure to have passed the oral qualifying examination before the fourth year of study.
- Failure to have passed oral or written qualifying exams by the time specified in the most-recent letter of support (or other most-recent letter from the Graduate Committee).
- Failure to graduate by the date specified in the most-recent letter of support (or other most-recent letter from the Graduate Committee).
- Failure to meet other individualized requirements specified in letters of support or other letters written by the Graduate Committee or Director of Graduate Studies.

- Failure to select an advisor by January of their third year: see Advisors.
- Failure to maintain a 3.0 grade point average (required by the Graduate School if the student is to continue to receive the tuition benefit).
- Failure to conduct research at a level needed to complete a Ph.D. See also the guidelines on the student/advisor relationship in Subsection 3.5.3.

Note, students who transfer to the Ph.D. program from the Master's program will normally have their deadlines set 1 year later than those deadlines outlined above, with respect to when they started the graduate program, see Subsection 3.6.1.

3.5.2 Appeals

Students who fall behind in any of these categories, or who fail to meet other requirements specified for their program, must promptly appeal to the Graduate Committee if they wish to continue in the program. Such deficiencies may be pointed out to the student in the annual letter of support, or in most cases, even earlier.

The content of the appeal should include a letter to the Graduate Committee explaining a plan to correct the deficiency. It should also include a letter from the student's advisor or academic mentor and may include additional evidence. Appeals are considered by the Graduate Committee on a case-by-case basis. The Graduate Committee may accept the plan to correct the deficits, accept the plan after revisions, decide to dismiss the student, or withdraw financial support. The student may also be put on a schedule with more-frequent evaluations by the Graduate Committee. A student who loses financial support in the form of a Teaching Assistantship may still be eligible for support in the form of a Research Assistantship, typically from his or her advisor. A student may also enlist the aid of the *Graduate Student Advisory Committee* (GSAC) to help in the process, see Subsection 3.1.4.

If a student is dismissed from the program in the middle of the academic year, the student is usually allowed to complete that academic year. In the case that the student is in the Ph.D. program, the student is usually allowed to obtain a Master's degree, if the program requirements have been met.

If a student is not satisfied with a decision made after an appeal to the Graduate Committee, the student may appeal to the decision to the Department Chair, and further as specified in Policy 6-400 of the Student Code.

3.5.3 Guidelines on the student/advisor relationship

A student or advisor may terminate the student/advisor relationship because of dissatisfaction. If a student wishes to terminate the student–advisor relationship, the student should notify the advisor, the Director of Graduate Studies, and the Graduate Program Coordinator. However, in most cases it is recommended that the student discusses the situation with the Director of Graduate Studies before making this decision. If a faculty advisor is dissatisfied with the research effort of a student, the faculty advisor should make every effort to communicate the concerns he or she may have at an early stage of the dissatisfaction. If deficiencies persist, the faculty member should identify to the student in writing the unsatisfactory aspects of the student's research performance and allow the student a reasonable time (typically at least 30 days) to correct the deficiencies. A copy of this letter should be sent to the Graduate Committee. If the deficiencies are corrected, the faculty advisor should notify the student in writing again with a copy of the letter sent to the Graduate Committee. If the deficiencies still persist, the student should expect that the student/advisor relationship is terminated. This may also lead to termination of financial support or termination from the program if the student is unable to find a new academic advisor.

3.5.4 Teaching Assistant performance

University Policy 6-309 regulates the procedure of hiring and firing of Teaching Assistants, among other academic staff, in cases of neglect of duties. The Course Coordinator and the Associate Chair are supervisors of Teaching Assistants as employees of the University. They periodically evaluate Teaching Assistants' job performance, notify them of any deficiencies, and monitor improvement in job fulfillment. The Graduate Committee decides continuation of Teaching Assistantships, or termination from the program, based on reported teaching performances. Notifications of renewals or nonrenewals are distributed by April 15. Appeals of termination decisions must be made first in writing to the Graduate Committee. Further appeals may be made as specified in University Policy 6-309.

3.6 Combining Master's and Ph.D. programs

There are two ways to combine the Ph.D. program and the various Master's programs available.

3.6.1 Continuing to the Ph.D. program from the Master's program

Some students in the Master's program are admitted with the expectation that they will continue to the Ph.D. program. They may have also started in the Ph.D. program and dropped to the masters program in order to take prerequisite courses.

The details of how to automatically transfer to the Ph.D. program will be included in their letter of admission to the graduate program, if the student falls into this case. One standard requirement for such students is that:

- They need at least two high passes and one pass by January in their second year to continue to the Ph.D. program.

Master's students not in the above category, but who wish to apply to the Ph.D. program in Mathematics must fill out an application form available from the Graduate Program Coordinator and do not need to reapply through Apply Yourself (AY) to the Graduate School. Applicants to the Ph.D. Program must arrange *three* letters of recommendation to support their applications. Acceptance and financial support for the Ph.D. program is awarded on the basis of a review of the application materials submitted, in a single competition among all applicants, irrespective of whether their previous degrees come from the University of Utah or other institutions.

Masters students who transfer to the Ph.D. program will typically be 1 year behind Ph.D. students who entered at the same time. Thus all deadlines for finishing written and oral exams will be 1 year later. For example, such students, after transferring to the Ph.D. program will need to:

- Pass at least 4 written exams at the high level by January of their third year in the *graduate program*.
- Complete all written exams before their fourth year in the *graduate program*.
- Have completed or scheduled their oral exam before their fifth year in the *graduate program*.

Compare with Subsubsection 3.4.1.2 and Subsubsection 3.4.2.1.

3.6.2 Earning a Master's degree while in the Ph.D. program

Students who have directly entered the Ph.D. Program can frequently earn a Master's degree along the way. See the Graduate Program Coordinator to arrange that required paperwork be sent to the Graduate School from the Department.

Course credits for the Master's degree and the Ph.D. degree *cannot* be double-counted. The coursework allotted for the Master's degree is reported in the student's Program of Study for the Master's Degree Form. Students should list the minimum number of course credits (30), in their M.S. programs of study forms. The course requirements for the Ph.D. must be satisfied by the remaining courses.

The *student is responsible* to make sure that tuition benefits cover the total semester hours needed for both the required Master's and Ph.D. coursework.

3.6.3 Entering the Ph.D. program with a Master's degree

Most students who enter the Ph.D. program do not have a previous Master's degree. However, if an entering student does have a Master's then typically that student will be promised 4 years of support upon entrance to the program, instead of 5. Such students do not have different timelines for passing their oral qualifying or written preliminary exams. Some details about their normal progress timeline changes though, see Subsection 3.7.2 for more details. One particularly important goal for such students is to identify an advisor as quickly as possible.

3.7 Timelines for normal academic progress

This section supplies brief timelines for normal academic progress for students in the Ph.D. and regular Master's programs.

3.7.1 Masters of Arts and Master of Science degrees

Financial support for the Master's program is limited to *two* years.

- **Year 1**
  - Meet with the Director of Graduate Studies to form a plan upon entering the program.
  - Find an advisor and form a three-person Supervisory Committee. *It is the responsibility of the student to suggest a committee to the Graduate Advisor, who is the Committee Chair.*
  - Discuss with your advisor your chosen area of study and Master's degree project if applicable.
- **Year 2 — Fall**
  - Make the final plan for your course work, submit your Program of Study through the Graduate Program Coordinator and have it approved by your entire Committee.
  - Talk with members of your Committee about plans for your comprehensive examination.
- **Year 2 — Spring**
  - File the Request for Supervisory Committee and Application for Admission to Candidacy for a Master's Degree forms for the Graduate School with the Mathematics Graduate Program Coordinator.
  - Schedule any final oral exams or thesis defenses. Students writing theses must pay particularly close attention to the deadlines available at

    http://gradschool.utah.edu/thesis/

3.7.2 Ph.D. degree

Below is a recommended timeline for students attempting to complete the Ph.D. degree and who did not previously earn a Master's degree in Mathematics at the University of Utah. Note this timeline has suggested dates earlier than the required dates for passing the qualifying exams listed for written exams and oral exams. Also see Continuing to Ph.D. program from Master's program for information about the timelines for students continuing from the Master's program to the Ph.D. program.

The number N of years of financial support that appears in a student's offer letter corresponds to the student's expected academic timeline. In some cases the financial support can be extended to year $N + 1$. In *extremely unusual* cases, it may be extended to year $N + 2$, although **at a reduced level**.

The timeline below does not depend on the type of support a student receives. Students are expected to graduate in 5 years (or 4, if they have a Master's degree) whether or not they are supported by the department as TA, whether they are supported by their advisor as an RA, or whether they are supported with a Fellowship.

- **Year 1**
  - Take 2–3 qualifying exam courses.
  - Pass at least 1 written preliminary exam at a high level (or obtain **A** in the course), and 1 more written preliminary exam (or obtain a **B+** or higher in the course) by January.
  - Pass at least 3 written preliminary exams at a high level and obtain at least 1 more pass by the August before your second year.
  - Think about choosing your advisor. If you have a previous Master's degree, choose your advisor if at all possible.
- **Year 2**
  - Choose your advisor!
  - Form your Supervisory Committee.
  - Pass at least 4 written qualifying exams at a high level, by January.
  - Pass remaining written qualifying exams by the August before your third year.
  - Take more advanced classes.
  - Start thinking about, and perhaps even pass, your oral qualifying exam.
  - Start working on/towards research.
- **Year 3**
  - Continue to work on research.
  - Form your Supervisory Committee if not already done. This must be done by January.
  - Schedule or pass your oral qualifying exam by January.
  - Pass your oral qualifying exam before August of your fourth year.
- **Year 4**
  - Continue to work on research.
  - Discuss with your advisor plans to graduate next year.
- **Year 5**
  - Continue to work on research.
  - During the Fall Semester, apply to graduate with the Graduate Program Coordinator.
  - Apply for jobs in the Fall Semester (if appropriate).
  - Start writing your thesis in the Fall Semester.
  - Schedule your thesis defense in the first two months of Spring Semester if you plan to graduate in Spring. Otherwise schedule your thesis defense in or before April if you plan to graduate in Summer.
  - Submit all your thesis material to the Thesis Office well in advance of *their* deadlines.

3.8 Outside employment

Graduate students supported by a TA, RA, or fellowship are expected to work full time on their duties and towards the completion of their degree. Supported students are not permitted to be employed while also working as a TA, RA, or under fellowship, unless prior approval is first obtained from the Graduate Committee.

3.9 Gaining other skills

All graduate students who have not had an appropriate course in computer programming are strongly encouraged to consult faculty about suitable classes in programming early in their programs. Familiarity with one or more computer-algebra systems, and the TeX and LaTeX typesetting systems, is expected of *all* graduating mathematicians, and many employers in engineering, mathematics, and science require job candidates to have good programming skills in numerical languages, such as C, C++, C#, Fortran, or Java. Graduates in statistics must have additional expertise in statistical software systems. Departmental computing staff are always happy to offer advice, guidance, and help in developing computer-programming experience.

3.9.1 Courses from other departments

In general, 5000-, respectively 6000-, level courses from other departments (e.g., courses in Biology, Chemistry, Computer Science, Economics, Physics & Astronomy, etc.) can be applied to fulfill the course requirements for the Master's, respectively Ph.D., program in Mathematics. Permission to include such courses must be obtained from the student's Committee. Some of these courses may charge differential tuition.

3.10 Applying to graduate study

Instructions for applying to graduate study in the Mathematics Department at the University of Utah, including information about GRE and TOEFL SCORES, are available at

`http://www.math.utah.edu/grad/GradApplicInst1.html`

3.11 Housing in Salt Lake City

The University accepts applications for on-campus residence hall and University student apartment housing.

Student residence halls provide a single room, with a shared bathroom and kitchen. For current information, visit
`https://housing.utah.edu/housing-options/graduate-housing`,
or contact Office of Housing and Residential Living, 5 Heritage Center, University of Utah, Salt Lake City, UT 84112-2036, (801) 587-2002.

Apartment housing for both married and single undergraduate and graduate students is available on campus. Visit `http://www.apartments.utah.edu/` for current information, or contact University Student Apartments, 1945 Sunnyside Avenue, Salt Lake City, UT 84108, (801) 581-8667.

Off-campus house and apartment listings can be found in the classified sections of

- the **Salt Lake Tribune** (`http://www.sltrib.com/`),
- the **Deseret News** (`http://www.desnews.com/`),
- the **Daily Utah Chronicle** (`http://www.dailyutahchronicle.com/`) student newspaper, and
- on radio and television station **KSL** (`http://www.ksl.com/`).

4 Degree requirements

This chapter lists the degree requirements for the Ph.D. degree, as well as the various Master's degrees offered.

4.1 Master of Arts and Master of Science degrees

4.1.1 Graduate School requirements

The Master of Arts degree requires standard proficiency in one foreign language — French, German, or Russian. The Master of Science degree does not have a language requirement. Otherwise, the degree requirements for the M.S. and M.A. degrees are identical. Visit

`http://gradschool.utah.edu/graduate-catalog/degree-requirements`

for information on the Ph.D. degree requirements.

A number of forms must be filed, and certain time limitations are to be observed. The student is responsible for submitting forms on time.

Each Master's candidate is assigned an Initial Academic Mentor upon entering the program but is expected to formally choose an advisor during their first year. This mentor or advisor has the primary responsibility of guiding and evaluating the candidate's progress through the Master's program: see Subsection 3.3.2 for more information. During the first year, the Master's candidate also forms a Supervisory Committee which assists with the same task: see Section 3.3.

A student can receive a Master's degree in either pure or applied mathematics.

4.1.2 Departmental requirements — pure mathematics

Requisites for the Master's degree in pure mathematics are listed in the following subsections.

4.1.2.1 Course requirements — pure mathematics

All coursework must be at the Master's level, courses numbered 5000 or above.

- Math 5210 (real analysis).
- Math 5310, 5320 (algebra).

- One 6000-level sequence consisting of two one-semester courses.
- Four additional one-semester courses at the 5000- or 6000-level.
- Thesis candidates must register for a minimum of six credit hours of thesis research (Math 6970), and at least one credit hour per semester, from the time of formal admission to the Graduate Program, until all requirements for the degree, including the final oral examination (thesis defense), are completed.

4.1.2.2 Graduation requirements — pure mathematics

There are four options to satisfy the graduation requirements for the Master's degree. The particular option utilized is decided by the student's Supervisory Committee.

1. *Qualifying Exam Option*. Pass four of the written qualifying exams (corresponding to 4 semesters of work)**and** take at least 30 semester hours of approved courses. The exams are comprehensive and serve as the required final exam. See Section 3.4 for more details on those exams.
   OR
2. *Research or Curriculum Project Option*. Write a Research or Curriculum Project and take at least 39 semester hours of approved courses. Students choosing this Non-Thesis Project Option may take up to 10 semester hours of Math 6960 Special Projects. The Non-Thesis Project is in every other way a Thesis but does not need approval from the Thesis Office. The required final examination for this option is the public oral Final Defense of the Project.
   OR
3. *Courses Project Option*. Take additional courses at the 6000- or 7000-level for a total of at least 39 semester hours of approved courses. The required final examination for this option is the oral Final Comprehensive Examination.
   OR
4. *Thesis Project Option*. Write a Master's Thesis and take at least 39 semester hours of approved courses. Students choosing this Thesis Option may take up to 10 semester hours of Math 6970, Master's Thesis Preparation. The required final examination for this option is the public oral Final Defense of the Thesis. The University Graduate School's Thesis Office must approve the thesis and a copy of the thesis is archived by the University Library. By arrangement with the Graduate School, students writing Master's theses may use credit hours in courses, numbered 6000 or above and in the general area of specialization of the thesis, to fulfill the 6–10 hours requirement of 6970 (Thesis Research).

The total number of semester hours required for the Master's degree in mathematics should fall in the range 30–39.

As specified by requirements of the Graduate School, a description of a nonthesis option, and the basis for its selection, shall be included with the student's proposed program. The statement, and the proposed program of study, must then have the approval of the departmental Director of Graduate Studies and be submitted to the Graduate Dean with the proposed program of study.

4.1.3 Departmental requirements — applied mathematics

Requisites for the Master's degree in applied mathematics are given in the following subsections.

4.1.3.1 Course requirements — applied mathematics

All coursework must be at the Master's level, courses numbered 5000 or above.

- Either two 6000-level sequences, or 5210 and three 6000-level one-semester courses, two of which must form a year-long sequence.
- Five additional one-semester courses at the 5000- or 6000-level.

4.1.3.2 Graduation requirements — applied mathematics

Same as those for the M.S. in pure mathematics.

4.1.4 Time limit

A period of *four* years is allowed to complete degree requirements for a Master's degree. Extensions beyond this four-year limit must be recommended by the Supervisory Committee and approved by the Dean of the Graduate School. The same time limit applies to M.S. and M.A. degrees. Supported students are entitled to tuition waivers for a total of *two* years or *four* semesters for Master's degrees.

4.1.5 Transfer credit

Upon the approval of the Master's Committee, at most *nine* hours of nonmatriculated credit from the University of Utah, or *six* hours of transfer credit from another university, are allowed in the graduate program toward a Master's degree.

4.2 Master of Statistics (Mathematics) program

An applicant selects Master of Statistics — Mathematics (MST) in the Graduate School application. A student is admitted to the program by the Departmental Statistics Committee and the Departmental Admissions Committee. The degree, Master of Statistics (Mathematics), is awarded by the Mathematics Department.

4.2.1 Prerequisites

- Either a Bachelor's degree in Mathematics, or the equivalent, e.g., two years of Calculus and two senior level mathematics sequences.[1]
- Math 3070, 3080, 3090, or equivalent.

4.2.2 Course requirements

The Master of Statistics (Mathematics) degree requires 31 credits of graduate level coursework, numbered 5000 or higher.

- Math 5010, 5080, 5090.[2]
- Math 6010, 6020.
- Math 6070.
- Electives approved by the Supervisory Committee, 12 credits.
- Math 6960 (Master's project), 1–6 hours.
- Oral examination on the Curriculum Project (Math 6960); this is a "Curriculum Project Defense."

For more information on the MSTAT program, see the MATHEMATICS INFORMATION SHEET available at

`http://mstat.utah.edu/degree-options/mathematics.php`

4.3 Master of Science in Mathematics Teaching

For information about the Master of Science in Mathematics Teaching, see the prerequisites and requirements at

`http://www.math.utah.edu/mathed/master_mt.html`

Students may also contact Paula Tooman (`mailto:tooman@math.utah.edu`) for administrative information, and Aaron Bertram (`mailto:bertram@math.utah.edu`) for academic program information.

[1] A "sequence" refers to a course that continues through an academic year.

[2] If Math 5010, 5080, 5090 were taken while the student was an undergraduate, they must be replaced by three courses approved by the Committee or the Director of Graduate Studies.

4.4 Professional Master of Science and Technology, Computational and Data Science Track

The mission of the Computational and Data Science Track of the PMST program is to prepare students for professional positions in business, industry, and government, because demand for computational and data-science specialists is rapidly increasing with the growth of large sets of data. For many businesses and industries, developing mathematical models, employing numerical methods, and using data visualization has become increasingly important for innovative scientific research.

The Computational and Data Science Track incorporates graduate coursework from different mathematical and computer-science disciplines to reflect the breadth of computational and mathematical tools employed to solve real-world problems.

The Computational and Data Science Track of the PMST Program is a professional interdisciplinary program that, together with graduate courses in mathematics and computing, includes courses in management and communication.

PMST students are required to complete an internship with a company, organization, or governmental agency. The business component serves to develop leadership and management skills that are highly valued by industry, and helps to prepare students for a career and professional development.

For more information, visit the PMST and CDS websites at

`http://pmst.utah.edu`
`http://pmst.utah.edu/computational-and-data-science-track/`

More details about the program, and examples of curricula within specific concentration areas, can be found at

`http://pmst.utah.edu/wp-content/uploads/2016/08/`
`Computational-and-Data-Science-Brochure.pdf`

Students with a background in mathematics, physics, computer science, or engineering are encouraged to apply.

4.5 Doctor of Philosophy degree

4.5.1 Graduate School requirements

Visit

`http://gradschool.utah.edu/graduate-catalog/degree-requirements`

for information on the Ph.D. degree requirements.

4.5.2 Departmental requirements

4.5.2.1 Advisors and Supervisory Committee

An Initial Academic Mentor is appointed for each prospective student prior to the first semester of graduate study.

During the first two years in the program, the student must select an advisor and form a Supervisory Committee. See Section 3.3 for more details on the composition and function of this committee.

4.5.2.2 Course requirements

- Course requirements for the Ph.D. degree consist of at least seven sequences numbered 6000 or above, or their equivalent, approved by the student's Supervisory Committee. The seven sequences required must include at least 14 credit hours of Math 7970, Thesis Research. The graduate student's Supervisory Committee, if it deems it appropriate, may require additional courses and/or require specific courses.

- Exceptions to the above regulations must be approved on an individual basis by the Graduate Committee upon recommendation by the student's Supervisory Committee.

4.5.2.3 Written preliminary examinations

The Written Ph.D. Preliminary Examinations are the same as the Master's Qualifying Examinations from Option #1. Ph.D. students must pass 4 written exams at a high level, by January of their second year and must pass at least two more exams before the third year. See Section 3.4 for more details on these exams, as well as more detailed timelines. Note that course performance can replace these exams.

4.5.2.4 Oral qualifying examination

Ph.D. students are required to take an oral qualifying examination. See Subsection 3.4.2 for more details.

4.5.2.5 Foreign language requirements

The Department of Mathematics does not have foreign language requirements for a Ph.D. degree.

4.5.2.6 Final oral examination

Ph.D. students must perform a final oral examination, sometimes called a "Thesis Defense". See Subsection 3.4.3.

4.5.2.7 Teaching requirements of Ph.D. candidate

The Department requires each graduate student who is studying toward a Ph.D. degree to teach a minimum of *two* courses, or equivalent tutorials, or laboratory supervisions to be carried out over a minimum of *one* year and a maximum of *six* years, whenever appropriate.

4.5.3 Time limit

The time limit for completion of degree requirements for the Ph.D. degree, as set by the Department, is *seven* years. The Graduate School limits the maximum number of years for which tuition waivers are granted to supported students. Currently, this is *five* years with a Bachelor's degree, or *four* years with a Master's degree. Entrants with a Bachelor's degree who have taught in our graduate program for *four* semesters (*two* years) can request another year of waiver. See Subsection 3.2.1 for more details.

4.5.4 Graduate School schedule of procedures for the Ph.D. degree

The Graduate School has prepared the Graduation Overview for Doctoral Candidates for students pursuing a graduate degree, available at

`https://gradschool.utah.edu/navigating-grad-school/graduation-overview/doctoral-candidates.php`

Thesis information may be found at

`http://gradschool.utah.edu/thesis/`

A Handbook for Theses and Dissertations is available at

`http://gradschool.utah.edu/thesis/handbook/`

5 Syllabi for qualifying examinations

This chapter discusses the material that is expected to be mastered for the written examinations that all graduate students must pass before completing their research programs.

5.1 Math 6010 – Linear Models

5.1.1 Topics

- Linear spaces, matrices, transformations, projections. Positive definite matrices, spectral theorem, metrics in linear spaces.
- Multivariate random variables, multivariate normal distribution, definition and properties.
- Quadratic forms, distributions derived from the multivariate normal.
- Linear regression, least squares, maximum likelihood. Estimation with linear regression, Lagrange method.
- Robust and nonparametric methods. Hypothesis testing in linear models.
- Confidence intervals, Bonferroni inequality.
- Confidence bands and surface.
- Straight line regression, splines and smoothing.
- Analysis of variance.
- Departures from assumptions.
- Model selection, shrinkage and Lasso.
- Models with large numberof parameters.

5.1.2 Texts

- A.F.G. Seber and A.J. Lee, *Linear regression analysis*, Second edition, Wiley (2003) [ISBN 0-471-41540-5, 978-0-471-41540-4].

5.2 Math 6040 – Probability

5.2.1 Topics

- Probability spaces, expectation, independence, Borel–Cantelli lemmas, Strong Law of Large Numbers.
- Weak convergence, characteristic functions, Central Limit Theorem.
- Conditional expectation, martingale convergence theorem, uniform integrability, optional stopping theorem.
- Countable Markov chains, recurrence, transience, stationarity, ergodicity.
- Brownian motion, sample path properties, Donsker's theorem.

5.2.2 Texts

- P. Billingsley, *Probability and Measure*, Third edition, Wiley (1995) [ISBN 0-471-00710-2, 978-0-471-00710-4].
- R. Durrett, *Probability: Theory and Examples*, Second edition, Duxbury Press (1996) [ISBN 0-534-24318-5, 978-0-534-24318-0].
- B. Fristedt and L. Gray, *A Modern Approach to Probability Theory*, Birkhäuser (1997) [ISBN 0-8176-3807-5 (Boston), 3-7643-3807-5 (Basel), 978-0-8176-3807-8 (Boston), 978-3-7643-3807-7 (Basel)].
- D. Khoshnevisan, *Probability, Graduate Studies in Mathematics 80*, American Mathematical Society (2007) [ISBN .] 0-8218-4215-3, 978-0-8218-4215-7.

5.3 Math 6070 – Mathematical Statistics

5.3.1 Topics

- Basic convergence concepts in probability, connection between them an their applications (convergence in probability, in distribution, almost sure, L^p). Borel-Cantelli lemma. Slutsky's lemma, weak and strong laws of large numbers, Glivenko-Cantelli theorem with proof.
- Convergence in distribution, Portmanteau theorem, the central limit theorem, Lyapunov's theorem, characteristic function, Lévy's theorem, multivariate central limit theorem, multivariate characteristic function, Cramér–Wold lemma, convergence of moments.
- Law of the iterated logarithm, stable distributions, domain of attraction of stable distributions, tail index.

- Pólya's theorem (with proof), rate of convergence in the central limit theorem, expansions in the central theorem
- Space of continuous functions, convergence in $\mathcal{C}[0,1]$, Skorokhod's space, Brownian motion and its properties, Brownian bridge, Gaussian processes, tightness and convergence in distribution, Donsker's theorem, Skorokhod's representation theorem.
- Order statistics, uniform order statistics, Rényi's representation of order statistics, uniform empirical and quantile process.
- Extreme, middle and central order statistics, the central limit theorem for central order statistics (with proof), Bahadur-Kiefer representation, three classes of extremes.
- Parametric estimation theory, the maximum likelihood estimator and its properties in the regular case (with proofs)
- U-statistics, projections, martingales, central limit theorem in the non generate, infinite order χ^2 estimates and their normality, concepts of efficiency, trimmed mean
- Hypothesis testing, basic concepts and optimality, power, size the likelihood ratio test, Lagrange's test and Rao's score test (with proofs)
- Alternatives, comparison of tests, Bahadur and Pitman efficiency
- Nonparametric methods, rank test, signed rank test, estimation of distribution functions, estimation of functionals of distribution functions
- Confidence bands for distribution and quantiles, Kolmogorov–Smirnov, Cramér–von Mises, Anderson–Darling statistics, rate of convergence.
- χ^2 test and the likelihood ratio test (with proof), two sample problems
- Resampling, jackknife, self-normalization.
- Estimation of distribution functions, bootstrap for confidence bands, bootstrap in hypothesis testing
- Density estimation
- Hypothesis testing using densities, densities with estimated parameters
- Test for exponentiality and normality
- Model fitting, penalty and information methods
- Multivariate methods, high dimensional data

5.3.2 Texts

- Anirban DasGupta, *Asymptotic Theory of Statistics and Probability*, First edition, Springer (2008) [ISBN 978-0-387-75971-5].

5.4 Math 6210 – Real Analysis

5.4.1 Topics

- **Measure theory**: Measure spaces, measurable functions and positive measures, integration, convergence, construction of Lebesgue measure, properties of Lebesgue measure. Riesz representation theorem. Jensen's Theorem, Hölder's inequality, Minkowski inequality, L^p spaces are complete. Fubini's Theorem. Complex measures, Radon–Nikodym theorem. Vitali covering theorem, Lebesgue density theorem and Lebesgue differentiation theorem. Fourier transform and properties, Inversion theorem, Parseval's theorem, Plancherel's Theorem.

- **Functional analysis**:
  Hilbert space, Cauchy–Schwartz, parallelogram law, continuous linear functionals. Banach–Steinhaus, Open mapping theorem, closed graph theorem, Hahn–Banach theorem. Linear functionals on L^p, $p < \infty$. Weak topology.

5.4.2 Texts

- H. Royden and P. Fitzpatrick, *Real Analysis*, Fourth edition, Prentice Hall (2010) [ISBN 0-13-511355-5, 978-0-13-511355-4].

- W. Rudin, *Real and Complex Analysis*, Third edition, McGraw–Hill (1987) [ISBN 0-07-054234-1, 978-0-07-054234-1].

- G. B. Folland, *Real Analysis: Modern Techniques and Their Applications*, Second edition, Wiley (2007) [ISBN 0-47-131716-0, 978-0-47-131716-6]

- F. Jones, *Lebesgue Integration on Euclidean Spaces*, Revised edition, Jones and Bartlett (2001) [ISBN 0-7637-1708-8, 978-0-7637-1708-7].

- C. C. Pugh, *Real Mathematical Analysis*, Second edition, Springer (2015) [ISBN 3-319-17770-2, 978-3-319-17770-0]. [Optional Supplement]

- J. B. Conway, *A Course in Functional Analysis*, Second edition, Springer (2010) [ISBN 1-4419-3092-2, 978-1-4419-3092-7]. [Optional Supplement]

- Y. Katznelson, *An Introduction to Harmonic Analysis*, Third edition, Cambridge University Press (2004) [ISBN 0-521-54359-2, 978-0-521-54359-0]. [Optional Supplement]

5.5 Math 6220 – Complex Analysis

5.5.1 Topics

- Holomorphic functions, Cauchy–Riemann equations, Cauchy's Theorem, Cauchy's integral formula, Maximum principle, Taylor series for holomorphic functions, Liouville's theorem, Runge's Theorem. Normal families, isolated singularities, Laurent series, residue theorem, applications to compute definite integrals. Rouche's Theorem, Maximum principle. Conformal mappings, examples, Schwartz lemma, isometries of the hyperbolic plane, Montel's theorem, Riemann mapping theorem. Infinite products, Weirstrass factorization theorem. Analytic continuation, monodromy. Elliptic functions. Picard's theorem.

5.5.2 Texts

- L. V. Ahlfors, *Complex Analysis*, Third edition, McGraw–Hill (1979) [ISBN 0-07-000657-1, 978-0-07-000657-7].
- J. B. Conway, *Functions of One Complex Variable*, Second edition, Springer (1978) [ISBN 0-38-790328-3, 978-0-38-790328-6]
- J. Noguchi, *Introduction to Complex Analysis*, American Mathematical Society (1997) [ISBN 0-821-80377-8, 978-0-82-180377-6]
- W. Rudin, *Real and Complex Analysis*, Third edition, McGraw–Hill (1987) [ISBN 0-07-054234-1, 978-0-07-054234-1].
- E. M. Stein and R. Shakarchi, *Complex Analysis*, Princeton University Press (2003) [ISBN 0-69-11385-8, 978-0-69-111385-2]

5.6 Math 6310 – Algebra I

- **Rings**: ideals, quotient rings, group rings, matrix rings, division rings, commutative rings, prime and maximal ideals, group of units, principal ideal domains, unique factorization domains, structure theorem for modules over a principal ideal domain and its applications to abelian groups and to linear algebra, rational and Jordan forms, eigenvectors, eigenvalues, minimal and characteristic polynomials, Cayley–Hamilton Theorem.
- **Module theory**: free modules, submodules, quotient modules, tensor, symmetric and exterior products of modules, projective and injective modules, exact sequences, complexes, homology, connecting homomorphisms, Tor and Ext functors.
- **Commutative ring theory**: polynomial rings, Gauss' Lemma, Eisenstein's criterion, localization and field of fractions, noetherian rings, Hilbert's Basis Theorem, integral extensions, algebraic sets, Hilbert's Nullstellensatz.

5.6.1 Texts

- N. Jacobson, *Basic Algebra I*, Second edition, Dover (2009) [ISBN 0-486-471896-X, 080-0-759-47189-8].
- N. Jacobson, *Basic Algebra II*, Second edition, Dover (2009) [ISBN 0-486-47187-X, 978-0-486-47187-7].

- D. S. Dummit and R. M. Foote, *Abstract Algebra*, Third edition, Wiley (2004) [ISBN 0-471-43334-9, 978-0-471-43334-7].
- S. Lang, *Algebra*, Third edition, Springer (2002) [ISBN 0-387-95385-X, 978-0-387-95385-4].
- J.-P. Serre, *Linear Representations of Finite Groups*, First edition, Springer (1977) [ISBN 0-387-90190-6, 978-0-387-90190-9]

5.7 Math 6320 – Algebra II

Problems on this exam will require usage of the topics from Algebra I.

- **Group theory**: subgroups, normal subgroups, quotient groups, homomorphisms, isomorphism theorems, groups acting on sets, orbits, stabilizers, orbit decomposition formula, Lagrange's Theorem, Cayley's Theorem, Sylow Theorems, permutation groups, symmetric and alternating groups, simple groups, classification of groups of small order, simplicity of the alternating group on at least 5 letters, direct products and semi-direct products of groups, exact and split exact sequences, commutator subgroups, solvable groups, nilpotent groups, solvability of p-groups, classical matrix groups, automorphism groups, Jordan–Holder theorem, free groups, presentations of groups.
- **Fields**: finite and algebraic extensions, degrees, roots, straight edge and compass constructions, splitting fields, algebraic closure, finite fields, derivatives of polynomials and multiple roots, separable and normal extensions, primitive elements, Galois groups, fundamental theorem of Galois theory, solvability by radicals, cyclotomic polynomials, constructible regular polygons, transcendental extensions.
- **Representation theory**: representations of finite groups and finite dimensional algebras, complete reducibility, Maschke's theorem, characters, orthogonality relations.

5.7.1 Texts

The texts for Algebra II are the same as for Algebra I, see Subsection 5.6.1.

5.8 Math 6410 – Ordinary differential equations

5.8.1 Topics

- **Initial value problems**: Fixed-point theorems; Basic existence and uniqueness; Dependence on initial conditions.
- **Linear equations**: The matrix exponential; Linear autonomous systems; General linear systems; Periodic linear systems and Floquet theory.

- **Boundary value problems**: Sturm–Liouville problems; Compact symmetric operators; Green's functions; Integral equations; Rayleigh–Ritz method.

- **Dynamical systems theory**: Flows, orbits and invariant sets; Definitions of stability; Planar dynamics and Poincaré–Bendixson; Hamiltonian mechanics; Stable and unstable manifolds; Hartman–Grobman theorem; Method of averaging.

- **Perturbation methods**: Regular perturbation theory, nonlinear oscillations; Poincaré–Linstedt; Singular perturbation theory, method of multiple scales; Boundary layers; WKB methods.

5.8.1.1 Texts

- G. Teschl, *Ordinary Differential Equations and Dynamical Systems*, AMS (2012) [ISBN 0-8218-8328-3, 978-0-8218-8328-0].

- J. David Logan, *Applied Mathematics*, Fourth edition, Wiley–Interscience (2013) [ISBN 0-471-74662-2, 978-0-471-74662-1].

- D. Jordan and P. Smith, *Nonlinear Ordinary Differential Equations: An Introduction for Scientists and Engineers*, Fourth edition, Oxford University Press (2007) [ISBN 0-199-20825-5, 978-0-199-20825-8].

- T. Sideris, *Ordinary Differential Equations and Dynamical Systems*, 2014 edition, Atlantis Press (2013) [ISBN 9-462-39020-7, 978-9-462-39020-1].

5.9 Math 6420 – Partial differential equations

5.9.1 Topics

- **Scalar conservation laws and first-order equations**: Linear transport equation and conservation laws; Traffic dynamics; Weak solutions and shock waves; Method of characteristics for quasilinear equations; General first-order equations.

- **Waves and vibrations**: General concepts, e.g., types of waves, group velocity, dispersion relations; One-dimensional wave equation, waves on a string; The D'Alembert formula and characteristics; Classification of second-order linear equations; Multi-dimensional wave equation, the Cauchy problem.

- **Diffusion**: The one-dimensional diffusion equation; Uniqueness: integral methods and maximum principles; Fundamental solution and the global Cauchy problem; Random walks; Global Cauchy problem, maximum principles; Some nonlinear problems: traveling waves.

- **The Laplace equation**: Harmonic functions, mean value theorems, maximum principles; Fundamental solution;Green's functions; Potential theory.

- **Variational formulation of elliptic problems**: Linear operators and duality; Lax–Milgram theorem and minimization of bilinear forms; Galerkin method; Variational formulation of Poisson's equation in 1D; Variational formulation of Poisson's equation in higher dimensions.

5.9.1.1 Texts

- S. Salsa, *Partial Differential Equations in Action: From Modelling to Theory*, Springer (2007) [ISBN 88-470-0751-8, 978-88-470-0751-2].

5.10 Math 6510 – Differentiable Manifolds

5.10.1 Topics

- Definition of a manifold via charts, submanifolds,
- Inverse function theorem (recalled from real analysis), immersions, submersions, (local) diffeomorphisms, local immersion and submersion theorems, regular values and transversality, preimage theorem, basic examples of manifolds: $\mathbb{R}^n$, S^n, T^n, $\mathbb{R}\mathrm{P}^n$, $\mathbb{C}\mathrm{P}^n$, Stiefel manifolds, Grassmannians, the notion of Lie groups and basic examples, e.g., $\mathrm{GL}_n(\mathbb{R})$, $\mathrm{SL}_n(\mathbb{R})$, $\mathrm{SO}(n)$, $\mathrm{SL}_n(\mathbb{C})$, $\mathrm{SO}(p,q)$, etc.
- Tangent space, vector bundles, tangent and normal bundle, stability of immersions, submersions, etc.
- Partitions of unity and applications: approximating continuous maps by smooth maps, existence of a Riemannian metric.
- Sard's theorem (proof not required), transversality theorem, Morse functions (existence, stability).
- Manifolds with boundary, classification of 1-manifolds (e.g., using Morse functions), Brouwer's fixed point theorem (also for continuous maps using approximations).
- Normal bundle, tubular neighborhood theorem, Whitney embedding theorem.
- Intersection theory $\bmod 2$, Jordan–Brouwer.
- Orientations, $\mathbb{R}\mathrm{P}^n$ orientable iff n odd, intersection theory, winding number, degree (e.g., degree and fixed points on spheres), Lefschetz fixed point theorem, vector fields, Poincaré–Hopf, Euler characteristic.
- Differential forms, exterior derivative, pullbacks, closed and exact forms, wedge product, integration, Stokes, Poincaré lemma, de Rham cohomology, degree formula, Gauss–Bonnet.
- Integral curves, flow, Lie bracket, Lie derivative, Lie algebra of a Lie group, exponential map on a Lie algebra (compute basic examples), foliations, examples of nonintegrable plane fields, Frobenius theorem and applications to Lie groups.

5.10.2 Texts

- V. Guillemin and A. Pollack, *Differential Topology*, Prentice–Hall (1974) [ISBN 0-13-212605-2, 978-0-13-212605-2].
- M. Spivak, *A Comprehensive Introduction to Differential Geometry*, Third edition, Publish or Perish (1999) [ISBN 0-914098-70-5, 978-0-914098-70-6].
- J. M. Lee, *Introduction to Smooth Manifolds*, Second edition, Springer (2013) [ISBN 1-4419-9981-7, 978-1-4419-9981-8].
- R. Bott and L. W. Tu, *Differential Forms in Algebraic Topology*, Springer (1995) [ISBN 0-387-90613-4, 978-0-387-90613-3]. [Sections 1–5, optional supplement]

5.11 Math 6520 – Algebraic Topology

5.11.1 Topics

Chapters and page numbers refer to Hatcher's book.

- Ch 0: Basic notions of homotopy, deformation retraction, adjunction spaces, cell complexes (see also appendix), cell complex structures on standard spaces: S^n, $\mathbb{C}\mathrm{P}^n$, $\mathbb{R}\mathrm{P}^n$, T^n, graphs, surfaces. $\mathrm{SL}_n(\mathbb{R})$ deformation retracts to $\mathrm{SO}(n)$.
- Ch 1: free products of groups and amalgams, fundamental group, van Kampen, computing π_1 of cell complexes and standard spaces, covering spaces, lifting properties, deck group, Galois correspondence, free properly discontinuous actions, Lie groups have abelian π_1, covering space of a Lie group is a Lie group, $\mathrm{SO}(2) = S^1$, $\mathrm{SO}(3) = \mathbb{R}\mathrm{P}^3$, $\mathrm{SL}_2(\mathbb{R})$.
- Ch 2: Δ and simplicial complexes, simplicial homology, singular homology, basic properties (homotopy invariance, long exact sequences, Mayer–Vietoris, excision), degree via homology, computation of homology for cell complexes, homology with coefficients, Euler characteristic, Brouwer's fixed point theorem, invariance of domain, $H_1(X) = \pi_1(X)_{\mathrm{ab}}$.
- Ch 3: Cohomology, universal coefficient theorem, cup and cap products, cohomology ring, computation for standard spaces, use to prove Borsuk–Ulam and e.g., to see that $S_2 \vee S_4$ and $\mathbb{C}\mathrm{P}^2$ are not homotopy equivalent, orientability, fundamental class and Poincaré duality statement. Lefschetz and Alexander duality.
- (p. 218–221) Method for showing two homology theories are equivalent. Illustrate on a subset of the following:
  - equivalence of singular and simplicial homology (p. 128–130);
  - de Rham theorem (this is in Lee's book);
  - Künneth formula (p. 218–221);
  - Poincaré duality in de Rham cohomology, i.e., $H_i(M) \otimes H_c^{n-i}(M) \to \mathbb{R}$, induced by $\omega \otimes \eta \mapsto \int_M \omega \wedge \eta$, say for M with finite good cover (see Spivak, Ch 11).

5.11.2 Texts

- A. Hatcher, *Algebraic Topology*, Cambridge University Press (2002) [ISBN 0-521-79160-X (hardcover), 0-521-79540-0 (paperback), 978-0-521-79160-1 (hardcover), 978-0-521-79540-1 (paperback)].

- R. Bott and L. W. Tu, *Differential Forms in Algebraic Topology*, Springer (1995) [ISBN 0-387-90613-4, 978-0-387-90613-3]. [Section 6, Optional Supplement]

5.12 Math 6610 – Analysis of Numerical Methods I

5.12.1 Topics

- **Numerical linear algebra**: Direct and iterative methods for linear system of equations; Error analysis; Methods for finding eigenvalues and eigenvectors; LU, QR, Cholesky, Singular value decomposition; Least squares.

- **Solution of nonlinear equations and optimization**: Contraction mapping principle; Newton's method, Quasi-Newton methods; Conjugate gradient method, Steepest descent method; Linear programming; Constrained optimization.

5.12.2 Texts

The texts for Math 6610 are the same as those for Math 6620, see Subsection 5.13.2.

5.13 Math 6620 – Analysis of Numerical Methods II

Note that many of the topics below require mastery of the material from Analysis of Numerical Methods I. Problems on this exam will frequently require extensive usage of the topics also covered on that exam.

5.13.1 Topics

- **Interpolation and approximation**: Polynomial, rational, Fourier series; Spline-based methods for interpolation and approximation; Quadrature; Orthogonal polynomials.

- **Numerical solutions of differential equations**: Runge–Kutta methods, Linear multi-step methods for initial value problems; Shooting methods for boundary value problems; Finite differences and finite elements for boundary value problems; Finite difference and finite element methods for simple PDEs.

5.13.2 Texts

- K. Atkinson, *An Introduction to Numerical Analysis*, Second edition, John Wiley & Sons (1989) [ISBN 0-4716-2489-6, 978-0-4716-2489-9].
- E. W. Cheney, *Introduction to Approximation Theory*, Second edition, McGraw–Hill (1998) [ISBN 0-8218-1374-9, 978-0-8218-1374-4].
- J. E. Dennis, Jr. and R. B. Schnabel, *Numerical Methods for Unconstrained Optimization and Nonlinear Equations*, Prentice–Hall (1983) [ISBN 0-13-627216-9, 978-0-13-627216-8].
- R. Fletcher, *Practical Methods of Optimization*, Wiley (1987) [ISBN 0-471-27711-8 (vol. 1), 0-471-27828-9 (vol. 2), 978-0-471-27711-8 (vol. 1), 978-0-471-27828-3 (vol. 2)].
- G. H. Golub and C. F. van Loan, *Matrix Computations*, Second edition, Johns Hopkins University Press (1989) [ISBN 0-8018-3772-3 (hardcover), 0-8018-3739-1 (paperback), 978-0-8018-3772-2 (hardcover), 978-0-8018-3739-5 (paperback)].
- D. R. Kincaid and E. W. Cheney, *Numerical Analysis: Mathematics of Scientific Computing*, Third edition, AMS (2009) [ISBN 0-8218-4788-0, 978-0-8218-4788-6].
- J. D. Lambert, *Computational Methods in Ordinary Differential Equations*, Wiley (1973) [ISBN 0-471-51194-3, 978-0-471-51194-6].
- R. J. LeVeque, *Finite Difference Methods for Ordinary and Partial Differential Equations: Steady-State and Time-Dependent Problems*, SIAM (2008) [ISBN 0-898-71629-2, 978-0-898-71629-0].
- A. R. Mitchell and D. F. Griffiths, *The Finite Difference Method in Partial Differential Equations*, Wiley (1980) [ISBN 0-471-27641-3, 978-0-471-27641-8].
- A. Quarteroni, R. Sacco, and F. Saleri, *Numerical Mathematics*, Springer (2000) [ISBN 0-387-98959-5, 978-0-387-98959-4].
- L. N. Trefethen and D. Bau, III, *Numerical Linear Algebra*, SIAM (1997) [ISBN 0-89871-361-7, 978-0-89871-361-9].
- L.N. Trefethen, *Approximation Theory and Approximation Practice*, SIAM (2013) [ISBN 1-61197-239-6, 978-161-197-2-39-9].

5.14 Math 6710 – Applied Linear Operator and Spectral Methods

5.14.1 Topics

- Introduction to function spaces: metric spaces: convergence, completeness; continuity of functions; separability; contraction mapping principle; vector spaces; Banach spaces; compactness; L^p spaces (without measure theory).

- Linear operators: linear operators; bounded linear operators; linear functionals; dual spaces; compact operators; Hahn–Banach Theorem and consequences; weak and weak* convergence; reflexive spaces; Fredholm alternative.
- Hilbert spaces: Inner product spaces; orthogonal projections; orthonormal sets; linear functionals and bilinear forms; Riesz representation theorem; Lax–Milgram theorem; adjoint operators; Fredholm alternative in Hilbert spaces.
- Spectral theory: resolvent and spectrum; basic results for bounded linear operators; spectral properties of compact operators; bounded self-adjoint operators; spectral theorem for compact self-adjoint operators; more general spectral representations.
- Distributions: spaces of test functions; definition of distributions; operations on distributions; Fourier transform and tempered distributions.

5.14.2 Texts

- E. Kreyszig, *Introductory Functional Analysis with Applications*, Wiley (1989) [ISBN 0-471-50459-9, 978-0-471-50459-7]. [Typically used for Math 6710.]
- F. G. Friedlander and M. S. Joshi, *Introduction to the Theory of Distributions*, Second edition, Cambridge (1998) [ISBN 0-521-64971-4, 978-0-521-64971-1]. [Optional supplement.]
- A. Bressan, *Lecture Notes on Functional Analysis: With Applications to Linear Partial Differential Equations*, American Mathematical Society (2012) [ISBN 0-821-88771-8, 978-0-821-88771-4]. [Optional supplement].
- H. Brezis, *Functional Analysis, Sobolev Spaces and Partial Differential Equations*, Springer (2010) [ISBN 0-387-70913-4, 978-0-387-70913-0]. [Optional supplement].
- J. P. Keener, *Principles of Applied Mathematics: Transformation and Approximation*, Addison–Wesley (1988) [ISBN 0-201-15674-1, 978-0-201-15674-4]. [Optional supplement].

5.15 Math 6720 – Applied Complex Variables and Asymptotic Methods

5.15.1 Topics

- Theory of complex variables: Analytic function theory, integral theorems, Taylor and Lauren series, singularities.
- Applications of complex variables: Contour integration, Conformal mapping, Fourier transform in complex domain, Argument principle.
- Asymptotic methods: Laplace's method, Watson's lemma, methods of stationary phase and steepest descent.

5.15.2 Texts

- M. J. Ablowitz and A. S. Fokas, *Complex Variables: Introduction and Applications*, Second edition, Cambridge University Press (2003) [ISBN 0-521-53429-1, 978-0-521-53429-1].
- J. P. Keener, *Principles of Applied Mathematics: Transformation and Approximation*, Addison–Wesley (1988) [ISBN 0-201-15674-1, 978-0-201-15674-4].

5.16 Math 6824 – Statistical Inference I

As of the Fall 2021, this class has been discontinued as a qualifying exam class. See Subsection 3.4.1.

- Maximum likelihood estimation and the method of moments. Unbiased estimation and the Cramér–Rao lower bound. Sufficiency, completeness, and the exponential class. Lehmann–Scheffe Theorem and the Rao–Blackwell Theorem.

5.16.1 Texts

- L. J. Bain and M. Engelhardt, *Introduction to Probability and Mathematical Statistics*, Second edition, PWS-KENT (1992) [ISBN 0-534-92930-3, 978-0-534-92930-5].
- P. J. Bickel and K. A. Doksum, *Mathematical Statistics: Basic Ideas and Selected Topics*, Second edition, Holden Day (Prentice–Hall) [ISBN 0-13-850363-X, 978-0-13-850363-5].

5.17 Math 6828 – Statistical Inference II

As of the Fall 2021, this class has been discontinued as a qualifying exam class. See Subsection 3.4.1.

- Confidence intervals, hypothesis testing, likelihood ratio tests. Chi-squared tests of simple and composite hypotheses. Nonparametric methods. Linear and multivariate statistics. Basic regression analysis.

5.17.1 Texts

The texts are the same as for Statistical Inference I, see Subsection 5.16.1.

6 Recent Ph.D. students

This chapter records our doctoral students of the past three decades to show their fields of study, graduate advisors, and the initial job positions that they moved to after graduation.

Ph.D. Graduate	Research Area	Advisor	Post-graduate position
2022			
Amanda Alexander	Numerical Analysis and Scientific Computing	Sean Lawley	Joint Postdoctoral position at the University of Houston and Rice University
Xuesong Bai	Numerical Analysis	Elena Cherkaev & Akil Narayan	Postdoctoral Associate at Brandeis University
Donald Chacon-Taylor		Sean Howe	
You-Cheng Chou	Algebraic Geometry	Yuan Pin Lee	Postdoc at Academia Sinica in Taiwan
Dihan Dai	Numerical Methods for Hyperbolic Systems	Yekaterina Epshteyn	Applied Scientist I at Amazon
Ryan Dickmann	Geometric Group Theory	Mladen Bestvina	Postdoc at Georgia Tech
George Domat	Geometric Group Theory	Mladen Bestvina	RTG Lovett Instructor at Rice University
Chengyu Du	Representation Theory	Peter Trapa	Postdoctoral position in China
Rebekah Eichberg	Dynamical Systems	Jon Chaika	Data Analyst at Capital Group
Kyle Gaffney	Mathematical Biology	Jim Keener	

Hannah Hoganson	Geometry/Topology	Ken Bromberg	Postdoctoral Fellow at the University of Maryland
Junpeng Jiao	Algebraic Geometry	Christopher Hacon	
Kristen Lee	Geometric Group Theory	Kevin Wortman	Data Scientist at Edge by Ascential
Zexin Liu	Numerical Analysis	Akil Narayan	Algorithm Engineer at Honor Global
Ryleigh Moore	Numerical Analysis	Akil Narayan	EDG Engineer at Mathworks in Boston
Thuong Hoai Nguyen	Numerical Analysis	Yekaterina Epshteyn	Posdoctoral Fellow at the UT Southwestern Medical Center
Vaibhav Pandey	Commutative Algebra	Anurag Singh	Visiting Assistant Professor at Purdue University
Marin Petkovic	Algebraic Geometry	Aaron Bertram	Seismic Imaging Analyst for CGG
Rebecca Terry	Mathematical Biology	Fred Adler	Teaching at St. Lawrence University
Yiming Xu	Numerical Analysis	Akil Narayan	Quantitative Analytic Specialist at Wells Fargo Bank
Nathan Willis	Applied Mathematics	Christel Hohenegger	Postdoctoral Position at the University of California-Merced
Ryeongkyung Yoon	Applied Mathematics	Braxton Osting	Joint Postdoctoral position at the University of Houston and Rice University
2021			
Yen-An Chen	Algebraic Geometry	Hacon	Postdoc Fellow at the National Center for Theoretical Sciences (NCTS)
Cody FitzGerald	Mathematical Biology	Keener	NSF-Simons Fellow at Northwestern University

Matthew Goroff	Geometric Group Theory	Wortman	Software Engineer at Palantir Technologies
Andrew Kassen	Mathematical Biology	Fogelson	
Christian Klevdal	Number Theory	Patrikis	UNIST (Ulsan National Institute of Science and Technology)
Jihao Liu	Algebraic Geometry	Hacon	Boas Assistant Professor at Northwestern University
China Mauck	Applied Mathematics	Guevara Vasquez	
Anna Nelson	Mathematical Biology	Fogelson	Duke University
Allechar Serrano Lopez	Number Theory	Patrikis	Harvard
Emily Smith	Dynamical Systems	Chaika	
Chee Han Tan	Applied Mathematics	Hohenegger & Osting	Postdoc at Bucknell University
Conor Tillinghast	Probability	Khoshnevisan	Data Scientist at Recursion
Andrew Watson	Mathematical Biology	Fogelson	
Daniel Zavitz	Mathematical Biology	Borisyuk	Postdoc at the Washington University School of Medicine
2020			
Matteo Altavilla	Algebraic Geometry	Bertram	
Hanna Astephan	Geometric Group Theory	Wortman	
Kevin Childers	Number Theory	Patrikis	Postdoc, University of Arizona
Huy Dinh	Applied Mathematics	Golden	Courant Institute, New York University
Pinches Dirnfeld	Commutative Algebra	Iyengar	

Priscilla Elizondo	Mathematical Biology	Fogelson	Biofire, Salt Lake City, UT
Gaoyang (Bridget) Fan	Mathematical Biology	Bressloff	University of Houston
Elizabeth Fedak	Mathematical Biology	Adler	Postdoc, University of Utah
Samantha Hill	Mathematical Biology	Adler	Biofire, Salt Lake City, UT
Hyunjoong Kim	Mathematical Biology	Bressloff	Simons Postdoctoral Fellow in the Center for Mathematical Biology, University of Pennsylvania
Sabine Lang	Representation Theory	Savin	Teaching Assistant Professor, University of Denver
Janina Letz	Commutative Algebra	Iyengar	Postdoc, University of Bielefeld, Germany
Erin Linebarger		Narayan	
Kathryn Link	Mathematical Biology	Fogelson	Postdoc, University of California, Davis
Dapeng Mu	Algebraic Geometry	Bertram	Postdoc, University of Campinas, San Paulo, Brazil
Patrick Murphy	Mathematical Biology	Bressloff	Postdoctoral Research Assistant, Rice University
Sergazy Nurbavliyev	Probability	Rassoul-Agha	Overstock
Marcus Robinson	Commutative Algebra	Schwede	Visiting Professor, Reed College, Oregon
Kiersten Utsey	Applied Mathematics	Keener	Research Associate II, Metrum Research Group
Ziwen Zhu	Algebraic Geometry	de Fernex	Boya Postdoctoral Fellow, Peking University

2019			
Adam Brown	Representation Theory	Trapa	Institute for Science and Technology (IST), Vienna, Austria
Huachen Chen	Algebraic Geometry	Bertram	Lecturer at UCSB
James Farre	Geometry/Topology	Bromberg	NSF Postdoctoral Research Fellow, Yale University
Stefano Filipazzi	Algebraic Geometry	Hacon	Hedrick Assistant Adjunct Professor, UCLA
Erjuan Fu	Algebraic Geometry	Lee & Clemens	Postdoc, Yau Mathematical Sciences Center, Tshinghua University, China
Greg Handy	Mathematical Biology	Borisyuk	Postdoctoral Associate, University of Pittsburgh
John Hull		Iyengar	Junior Data Engineer, Energy Ogre
Jenny Kenkel	Commutative Algebra	Singh	University of Kentucky
Sean McAfee	Representation Theory	Trapa	Postdoctoral Fellow, Northwestern University
Joaquin Moraga	Algebraic Geometry	Hacon	Instructor, Princeton
Franco Rota	Algebraic Geometry	Bertram	Hill Assistant Professor, Rutgers
Daniel Smolkin	Commutative Algebra	Schwede	Postdoctoral Fellow, University of Oklahoma
Weicong Su	Probability	Khoshnevisan	Data Scientist, Bayer Crop Science, St. Louis, MO
Ryan Viertel	Applied Mathematics	Osting	Senior Member of the Technical Staff, Sandia National Laboratories
Dawei Wang	Geometry/Topology	Bestvina	

Qing Xia	Numerical Analysis	Epshteyn	Postdoctoral Research Associate, Rensselar Polytechnic Institute
Hanlei Zhu	Statistics	Horváth	Strategist Associate, Goldman Sachs
		2018	
Leonard Carapezza	Dynamical Systems	Chaika	Utah International Charter School, Salt Lake City, UT
Sam Carroll	Mathematical Biology	Bressloff	University of Utah, Salt Lake City, UTp
Javier Carvajal-Rojas	Algebraic Geometry & Commutative Algebra	Schwede	EPFL, Lausanne, Switzerland
Katrina Johnson	Mathematical Biology	Adler	Brigham Young University, Idaho, Rexburg, ID
Ethan Levien	Biology/Natural Sciences	Bressloff	Harvard University, Cambridge, MA
Christopher Miles	Mathematical Biology	Keener	Courant Institute, New York University, New York, NY
Anna Miller	Biology/Natural Sciences	Adler	Moffitt Cancer Center, Tampa, FL
Anna Macquarie Romanova	Representation Theory	Milicic	University of Sydney, Sydney, NSW, Australia
Kyle Steffen	Numerical Analysis	Epshteyn & Golden	University of Texas at Austin, Austin, TX
Laura Strube	Mathematical Biology	Adler	Center for Systems Immunology, Polytechnic Institute and State University, Blacksburg, VA
Shiang Tang	Algebraic Number Theory	Patrikis	University of Illinois Urbana-Champaign, Champaign, IL
Chuanhao Wei	Algebraic Geometry	Hacon	Stony Brook University, Stony Brook, NY

Derrick Wigglesworth	Geometric Group Theory	Bestvina	University of Arkansas, Fayetteville, AR
Leif Zinn-Bjorkman	Mathematical Biology	Adler	University of California, Los Angeles, CA
Heather Zinn Brooks	Mathematical Biology	Bresslof	University of California, Los Angeles, CA
2017			
Andrew Bydlon	Algebraic Geometry & Commutative Algebra	Schwede	Williams College, Williamstown, MA
Parker Childs	Mathematical Biology	Keener	Biofire, Salt Lake City, UT
Sung Chan Choi	Probability	Ethier	University of Utah, UT
Joseph Eason	Mathematical Biology	Adler	University of Montana Western, Dillon, MT
Honglu Fan	Algebraic Geometry	Lee	ETH Zürich, Switzerland
Thomas Goller	Algebraic Geometry	Bertram	KIAS, Korea
Radhika Gupta	Geometric Group Theory	Bestvina	Technion University, Israel
Bhargav Karamched	Mathematical Biology	Bressloff	University of Houston, TX
Chung Ching Lau	Algebraic Geometry	de Fernex	University of Illinois at Chicago, IL
Shiu-Tang Li	Probability	Khoshnevsian	Verisk Analytics, UT
Jie Ma	Mathematical Biology	Keener	
Christian Sampson	Applied Mathematics	Golden	University of North Carolina, Chapel Hill, NC
Yuan Wang	Algebraic Geometry	Hacon	Northwestern University, Evanston, IL
Bin Xu	Mathematical Biology	Bressloff	University of Notre Dame, IN

Keyvan Yaghmayi	Algebraic Geometry	de Fernex	
2016			
Eric Jason Albright	Applied Mathematics	Epshteyn	Los Alamos National Laboratory, NM
Vira Babenko	Applied Mathematics	Alfeld	Ithaca College, Ithaca, NY
Patrick Bardsley	Applied Mathematics	Epshteyn & Guevara-Vasquez	University of Texas/Austin, TX
Andrew Basinski	Mathematical Biology	Adler	University of Idaho, Moscow, ID
Pavel Bezdek	Probability	Khoshnevisan	Wolverine Trading LLC, Chicago, IL
Morgan Cesa	Geometric Group Theory	Wortman	Data analyst
Paul Andrew Egbert	Algebraic Geometry	Hacon	mootipass.com
Drew Johnson	Algebraic Geometry	Bertram	University of Oregon, Eugene, OR
Brent Kerby	Statistics	Horváth	
Tony Lam	Probability	Rassoul-Agha	overstock.com
Haydee Lindo	Commutative Algebra	Iyengar	William's College, Williamstown, MA
Alan Marc Watson	Algebraic Geometry	Hacon	TransAmerica
2015			
Omprokash Das	Algebraic Geometry	Hacon	Tata Institute of Fundamental Research, Mumbai, India
Megan Gorringe Dixon	Mathematical Biology	Keener	University of Utah, Salt Lake City, UT
Kenneth (Jack) Jeffries	Commutative Algebra	Singh	University of Michigan, Ann Arbor, MI
Predrag Krtolica	Applied Mathematics	A. Cherkaev & Treibergs	University of Utah, Salt Lake City, UT
Cristian Martinez	Algebraic Geometry	Bertram	University of California/Santa Barbara, CA

Greg Rice	Statistics	Horváth	University of Waterloo, Waterloo, ON, Canada
Jia Wang	Statistics	Horváth	Goldman Sachs
Yohsuke Watanabe	Topology	Bromberg	University of Hawaii at Manoa, Honolulu, HI
2014			
Kei Yuen Chan	Representation Theory	Trapa	University of Amsterdam, The Netherlands
Chih-Chieh Chen	K Theory	Savin	
Sarah Cobb	Geometric Group Theory	Wortman	Midwestern State University, Wichita Falls, TX
Veronika Ertl	Algebraic Geometry	Nizioł and Savin	Universität Regensburg, Germany
Brendan Kelly	Geometric Group Theory	Wortman	Harvard University, Cambridge, MA
Michał Kordy	Applied Mathematics	E. Cherkaev	University of Utah, Salt Lake City, UT
Sonya Leibman	Geometric Group Theory	Bestvina	Online Image, Murray, UT
Ross Magi	Mathematical Biology	Keener	Walla Walla University, College Place, WA
Brian Mann	Geometric Group Theory	Bestvina	Amazon
James Moore	Mathematical Biology	Adler	Georgia Tech, Atlanta, GA
Feng Qu	Algebraic Geometry	Lee	Max-Planck-Institute für Mathematik, Bonn, Germany
Andrew Thaler	Applied Mathematics	Milton	The Institute for Mathematics and Its Applications (IMA), St. Paul, MN

Yuchen Zhang	Algebraic Geometry	Hacon	University of Michigan, Ann Arbor, MI
Dylan Zwick	Algebraic Geometry	Bertram	Overstock, Midvale, UT
	2013		
Geoffrey Hunter	Mathematical Biology	Keener	Ontario Institute for Cancer Research, Toronto, ON, Canada
Xiaodong Jiang	Algebraic Geometry	Hacon	Myriad Genetics, Salt Lake City, UT
Aaron Wood	Representation Theory	Savin	University of Missouri, Columbia, MO
	2012		
Brittany Bannish	Mathematical Biology	Fogelson	University of Central Oklahoma, Edmond, OK
Davide Fusi	Algebraic Geometry	de Fernex	The Ohio State University, Columbus, OH
Erica Graham	Mathematical Biology	Adler	University of North Carolina, Chapel Hill, NC
Adam Gully	Applied Mathematics	Golden	McMaster University, Hamilton, ON, Canada
Brian Knaeble	Statistics Education	Horváth	University of Wisconsin–Stout, Menomonie, WI
Christopher Kocs	Representation Theory	Savin	DOD Hill Air Force Base, Ogden, UT
Ching-Jui (Ray) Lai	Algebraic Geometry	Hacon & Lee	Purdue University, West Lafayette, IN
Erika Meucci	Geometric Group Theory	Bestvina	Paul H. Nitze School of Advanced International Studies, Bologna
Ben Murphy	Applied Mathematics	Golden	University of California/Irvine, CA

Ron Reeder	Statistics	Horváth	Watson Laboratories, Salt Lake City, UT
Christopher Remien	Mathematical Biology	Adler & Cerling	National Institute for Mathematical and Biological Synthesis, University of Tennessee, Knoxville, TN
Anna Schoening	Probability	Rassoul-Agha	University of Utah, Salt Lake City, UT
Stefano Urbinati	Algebraic Geometry	Hacon	University of Warsaw, Poland
Liang Zhang	Probability	Khoshnevisan	Michigan State University, East Lansing, MI
2011			
Julian Chan	Commutative Algebra	Singh	Weber State University, Ogden, UT
Matthew Housley	Representation Theory	Trapa	Brigham Young University, Provo, UT
Elisha Hughes	Statistics	Horváth	Myriad Genetics Inc., Salt Lake City, UT
Sean Laverty	Mathematical Biology	Adler	Swarthmore College, PA
Loc Nguyen	Differential Equations	Schmitt	École Normale Supérieure, Paris, France
Blerta Shtylla	Mathematical Biology	Keener	Mount Holyoke College, Hadley, MA
Ben Trahan	Representation Theory	Trapa	University of Utah, Salt Lake City, UT
Yuan Zhang	Applied Mathematics	A. Cherkaev	Universidad de Castilla-La Mancha, Cuidad Real, Spain
2010			
Yael Algom-Kfir	Geometric Group Theory	Bestvina	Yale University, New Haven, CT

Courtney Davis	Mathematical Biology	Adler	University of Maryland, College Park, MD
Trung Dinh	Commutative Algebra	Roberts	FPT University, Hanoi, Vietnam
Lindsay Erickson	Mathematical Biology	Fogelson	Sandia National Labs, Livermore, CA
Giao Huynh	Mathematical Biology	Adler	Oakland University, Oakland, CA
Casey Johnson	Representation Theory	Trapa	Department of Defense
Karim Khader	Probability	Khoshnevisan	Division of Epidemiology, University of Utah, Salt Lake City, UT
Zachary Kilpatrick	Mathematical Biology	Bressloff	University of Pittsburgh, PA
Sarah Kitchen	Representation Theory	Miličić	Albert-Ludwigs Universität, Freiburg, Germany
Hwan Yong Lee	Applied Mathematics	Dobson	Drexel University, Philadelphia, PA
Karin Leiderman	Mathematical Biology	Fogelson	Duke University, Durham, NC
Frank Lynch	Mathematical Biology	Keener	Occidental College, Los Angeles, CA
William Malone	Geometric Group Theory	Bestvina	C. H. Flowers High School, Springdale, MD
Jay Newby	Mathematical Biology	Bressloff	Oxford University, Oxford, UK
Michael Purcell	Probability	Khoshnevisan	Department of Defense
Russell Richins	Applied Mathematics	Dobson	Michigan State University, East Lansing, MI
Shang-Yuan Shiu	Probability	Khoshnevisan	Academia Sinica, Taipei, Taiwan
Josh Thompson	Geometric Group Theory	Bromberg	Colorado State University, Fort Collins, CO

2009			
Tommaso Centeleghe	Number Theory	Savin	Universität Duisburg-Essen, Essen, Germany
Scott Crofts	Representation Theory	Trapa	University of California, Santa Cruz, CA
Jason Preszler	Number Theory	Savin	University of Puget Sound, Tacoma, WA
Amber Smith	Mathematical Biology	Adler	Los Alamos National Laboratory, NM
Nessy Tania	Mathematical Biology	Keener	University of British Columbia, Vancouver, BC, Canada
2008			
Erin Chamberlain	Commutative Algebra	Roberts	Brigham Young University, Provo, UT
Elizabeth Doman Copene	Mathematical Biology	Keener	Idaho Technology Inc., Salt Lake City, UT
William Nesse	Mathematical Biology	Bressloff	University of Ottawa, Ottawa, ON, Canada
Gueorgui Todorov	Algebraic Geometry	Bertram	Princeton University, Princeton, NJ
Yoshihiro Iwao	Algebraic Geometry	Lee	
2007			
Berton Earnshaw	Mathematical Biology	Bressloff	University of Utah, and Michigan State University, East Lansing, MI
Domagoj Kovacevic	Number Theory	Savin	
Lars Louder	Geometric Group Theory	Bestvina	University of Michigan, Ann Arbor, MI
Meagan McNulty	Mathematical Biology	Adler	William & Mary College, Williamsburg, VA

Elijah Newren	Mathematical Biology	Fogelson	Sandia National Laboratory, Albuquerque, NM
Qiang Song	Commutative Algebra	Singh	MISYS, Beijing, China
Dali Zhang	Inverse Problems	E. Cherkaev	University of Calgary, Calgary, AB, Canada
John Zobitz	Mathematical Biology	Adler	Augsburg College, Minneapolis, MN
2006			
Nathan Albin	Applied Mathematics	A. Cherkaev	Universität Duisburg-Essen, Essen, Germany and California Institute of Technology, Pasadena, CA
Renate Caspers	Stochastic Processes	Mason	
Kenneth Chu	Complex Algebraic Geometry	Toledo	University of Texas at Austin, TX
Matthew Clay	Geometric Group Theory	Bestvina	University of Oklahoma, Norman, OK
Zrinka (Despotović) Keenan	Geometric Group Theory	Bestvina	Royal Bank of Scotland, Edinburgh
Young-Seon Lee	Math Physiology	Keener	Cornell University, Ithaca, NY
Andrew Oster	Mathematical Biology	Bressloff	The Ohio State University, Columbus, OH
Kazuma Shimomoto	Algebra	Roberts	University of Minnesota, Minneapolis, MN
2005			
Renzo Cavalieri	Algebraic Geometry	Bertram	University of Michigan, Ann Arbor, MI
Stefanos Folias	Mathematical Biology	Bressloff	Boston University, Boston, MA
An Hai Le	PDE	Schmitt	MSRI, Berkeley, CA

Fumitoshi Sato	Algebraic Geometry	Bertram	Korea Institute for Advanced Study, Seoul, Korea
	2004		
Robert Guy	Mathematical Biology	Fogelson	University of Utah, Salt Lake City, UT
Brynja Kohler	Mathematical Biology	Keener	Utah State University, Logan, UT
Eiko Koizumi	PDE	Schmitt	Ellis College, New York Institute of Technology online
Denis Lukic	Representation Theory	Miličić	Northwestern University, Evanston, IL
Greg Peipmeyer	Algebra	Roberts	University of Nebraska, Lincoln, NE
Thomas Robbins	Math Ecology	Lewis	University of Utah, Salt Lake City, UT
	2003		
Emina Alibegović	Geom Group Theory	Bestvina	University of Michigan, Ann Arbor, MI
Anca Mustata	Algebraic Geometry	Clemens	University of British Columbia, Vancouver, BC, Canada
Andrei Mustata	Algebraic Geometry	Bertram	University of British Columbia, Vancouver, BC, Canada
Bradford Peercy	Mathematical Biology	Keener	Rice University, Houston, TX
Matthew Rudd	PDE	Schmitt	University of Texas at Austin, TX
Inbo Sim	PDE	Schmitt	Utah State University, Logan, UT

2002			
Nicholas Cogan	Mathematical Biology	Keener	Tulane University, New Orleans, LA
Martin Deraux	Complex Geometry	Toledo	Purdue University, West Lafayette, IN
Sonjong Hwang	Topology	Kapovich	
Blake Thornton	Geometric Topology	Kleiner	Westminster College, Salt Lake City, UT
Sung Yil Yoon	Topology	Bestvina	Rensselaer Polytechnic Institute, Troy, NY
2001			
Eric Cytrynbaum	Math Physiology	Keener	Institute for Theoretical Dynamics, University of California/Davis, CA
Miguel Dumett	PDE	Keener	Lawrence Livermore National Laboratory, Livermore, CA
Michael Hohn	Numerical Analysis	Folias	Lawrence Berkeley National Laboratory, Berkeley, CA
Jian Kong	Algebraic Geometry	Bertram	The Johns Hopkins University, Baltimore, MD
İsmail Küçük	Applied Mathematics	E. Cherkaev	American University, Sharjah, and Sakarya University, Turkey
Chong Keat Arthur Lim	Rep Theory	Miličić	University of Minnesota, Minneapolis, MN
Xiangdong Xie	Geom Group Theory	Kleiner	Washington University, St. Louis, MO
Chung Seon Yi	Mathematical Biology	Fogelson	Virginia Polytechnic Institute and State University, Blacksburg, VA

2000			
Peter Brinkmann	Geom Group Theory	Gersten	University of Illinois/ Urbana–Champaign, IL
Chin-Yi Chan	Algebra	Roberts	Purdue University, West Lafayette, IN
Irina Grabovsky	Statistics	Horváth	National Board of Medical Examiners, Jacksonville, FL
Sean Sather-Wagstaff	Comm Algebra	Roberts	University of Illinois/ Urbana–Champaign, IL
Haoyu Yu	Mathematical Biology	Fogelson	University of Minnesota, Minneapolis, MN
1999			
Kristina Bogar	Applied Mathematics	Keener	University of Utah, Salt Lake City, UT
Charles Harris	Analysis	Tucker	University of Utah, Salt Lake City, UT
Jon Jacobsen	PDE	Schmitt	Pennsylvania State University, State College, PA
Elizabeth Jones	Comm Algebra	Roberts	University of Utah, Salt Lake City, UT
Nikolaos Tzolias	Algebraic Geometry	Kollár	Oklahoma State University, Stillwater, OK
Toshio Yoshikawa	Applied Mathematics	Balk	Utah State University, Logan, UT
1998			
Hsungrow Chan	Differential Geom	Treibergs	National Tsing Hua University, Hsinchu, Taiwan
Chi Kan Chen	Applied Mathematics	Fife	University of Utah, Post Doctoral
Jeffrey L. Fletcher	Geo Group Theory	Gersten	Louisiana State University, Alexandria, LA

Takayasu Kuwata	Algebraic Geometry	Kollár	Tokyo Denki University, Tokyo, Japan
Andrew L. Kuharsky	Mathematical Biology	Fogelson	Tulane University, New Orleans, LA
Timothy J. Lewis	Mathematical Biology	Keener	New York University, NYC, NY
Natasa Macura	Topology	Bestvina	University of Michigan, Ann Arbor, MI
Eric Marland	Mathematical Biology	Keener	University of California/Davis, CA
Igor Mineyev	Group Theory	Gersten	Max-Planck-Institute für Mathematik, Bonn, Germany
Min Xie	Applied Mathematics	Othmer	Intermountain Health Care, Salt Lake City, UT
1997			
Yongnam Lee	Algebraic Geometry	Clemens	Korea Institute for Advanced Study, Seoul, Korea
Richard Mayer	Algebraic Geometry	Carlson	University of Massachusetts, Amherst, MA
Laura Smithies	Rep Theory	Taylor	Kent State University, Kent, OH
Peter Spiro	Mathematical Biology	Othmer	Incyte Pharmaceuticals, Wilmington, DE
Nien-Tzu Wang	Applied Mathematics	Fogelson	
1996			
José Burillo	Group Theory	Gersten	Tufts University, Medford, MA
Shirnping Chen	Topology	Toledo	Triology Technologies Inc., Taiwan

Ionut Ciocan-Fontanine	Algebraic Geometry	Bertram	Mittag-Leffler Institut, Djursholm, Sweden
John Dallon	Applied Mathematics	Othmer	Warwick University, Warwick, England
Monika Serbinowska	Statistics	Horváth	University of California at San Diego, La Jolla, CA
1995			
Alberto Castro	Geometry	Toledo	Mt. Holyoke College, MA
Adam J. Chmaj	PDE	Fife	Brigham Young University, Provo, UT (Post Doctoral) and Utah State University, Logan, UT (Post Doctoral)
Ha Dang	Applied Mathematics	Fife	University of Utah, Salt Lake City, UT
Sándor Kovács	Algebraic Geometry	Kollár	MIT, Cambridge, MA
Vy Khoi Le	Nonlinear Analysis	Schmitt	University of Colorado, Boulder, CO
Lingyan Ma	Statistics	Horváth	University of Georgia, Athens, GA
Uwe Mayer	PDE	Korevaar	Brown University, Providence, RI
Pavle Pandžić	Lie Groups	Miličić	MIT, Cambridge, MA
Romuald Sawicz	Applied Mathematics	Golden	University of Minnesota, Minneapolis, MN
Tomasz Serbinowski	Differential Geom	Korevaar	University of California/Irvine, CA
Robert Van Kirk	Mathematical Biology	Lewis	Henry's Ford Foundation, Island Park, ID
1994			
Aldo Bernasconi	Group Theory	Gersten	Chile (not in academia)
John M. O'Reilly	Numerical Analysis	Stenger	

Robert Shalla	Lie Groups	Miličić	Bronx Community College, NYC, NY
1993			
Timothy Bratten	Lie Groups	Hecht	Argentina
Robert Dillon	Applied Mathematics	Othmer	Tulane University, New Orleans, LA
Azniv Kasparian	Algebraic Geometry	Carlson	University of Sofia, Bulgaria
Joo Kim Mok	Statistics	Mason	University of South Korea
Ming He	Probability	Ethier	Weber State University, Ogden, UT
Jeffrey McGough	Differential Equations	Schmitt	University of Nevada, Reno, NV
Endre Szabó	Algebraic Geometry	Kollár	Universität Bayreuth, Germany
Yuanhua Tang	Applied Mathematics	Othmer	Cornell University, Ithaca, NY
Randall Westhoff	Algebraic Geometry	Clemens	Bemidji State University, Bemidji, MN
1992			
Mario R. Candia	Real and Complex Geometry	Hecht	In industry, Chicago, IL
Gregory R. Conner	Algebra and Number Theory	Gersten	Brigham Young University, Provo, UT
Alessio Corti	Algebraic Geometry	Kollár	MSRI, Berkeley, CA
David J. Eyre	Applied Mathematics	Fife	University of Minnesota, Minneapolis, MN
Tina Ma	Statistics	Mason	Pharmaco LSR, Inc., Austin, TX
Denise White	Finite Groups	Gross	Westminster College, Salt Lake City, UT
Guangyan Yin	Applied Mathematics	Stenger	

1991			
Jorge Devoto	Topology	Braam	International Centre for Theoretical Physics (ICTP), Trieste, Italy
Kenneth Ferguson	Topology/Geometry	Stern	First Quadrant, Pasadena, CA
Christopher Grant	Applied Mathematics	Fife	Georgia Tech, Atlanta, GA
Elham Izadi	Algebraic Geometry	Clemens	Harvard University, Cambridge, MA
Michael Kinyon	Differential Equations	Tucker	Indiana University at Southbend, IN
Yonghao Ma	Algebra	Roberts	Southwest Texas State University, San Marcos, TX
Cameron Wickham	Ring Theory	Roberts	Southwestern Missouri State University, Springfield, MO
James Wiskin	Group Theory	Gross	University of Utah, Salt Lake City, UT
1990			
Gary DeYoung	Applied Mathematics	Othmer	University of California/Davis, CA
Ya Li	Differential Equations	Keener	Teikyo Westmar University, Le Mars, IA
Ronald Lundstrom	Probability	Tavaré	Cimarron Software, Salt Lake City, UT
Maritza Sirvent	Approximation Theory	Alfeld	Ohio State University, Columbus, OH
1989			
David M. Austin	Topology	Stern	Institute for Advanced Study, Princeton, NJ and Grand Valley State University, Allendale, MI

Luis Hernandez Lamoneda	Geometry	Toledo	University of Chicago, Chicago, IL
Jesus Jimenez Reyes	Complex Geometry	Clemens	University of California/Riverside, CA
Frederick Phelps	Applied Mathematics	Keener	Oxford University, Oxford, UK
	1988		
Mladen Božičević	Lie Groups	Miličić	Rutgers University, New Brunswick, NJ
Paul J. Joyce	Stochastic Processes	Tavaré	University of South California, Los Angeles, CA
Thomas Nordhaus	Applied Mathematics	Keener	
Marc Stromberg	Numerical Analysis	Stenger	Texas Tech University, Lubbock, TX
James D. Walker	Applied Mathematics	Folias	Southwest Research Institute, San Antonio, TX
Miljenko Zabčić	Lie Groups	Hecht	MIT, Cambridge, MA
Bertram Zinner	Applied Mathematics	Keener	Auburn University, Auburn, AL
	1987		
Paul R. Arner	CAGD	Barnhill	SDRC (Structural Dynamics Research Corporation), Cincinnati, OH
Phillip J. Barry	CAGD	Barnhill	University of Waterloo, Waterloo, ON, Canada
Bernard Bialecki	Numerical Analysis	Stenger	University of Kentucky, Lexington, KY
Roger Chen	Differential Geometry	Li	University of Toledo, Toledo, OH
J. Don Dockery	Applied Mathematics	Keener	Utah State University, Logan, UT

Greg A. Harris	Differential Equations	Schmitt	Auburn University, Auburn, AL
Nela Lakoš	Differential Equations	Schmitt	Ohio State University, Columbus, OH
Dennis Malm	Algebra	Goodearl	Northwest Missouri State University, Maryville, MO
Bruce R. Piper	CAGD	Barnhill	Rensselaer Polytechnic Institute, Troy, NY
Masaji Watanabe	Applied Mathematics	Othmer	Universität Stuttgart, Germany
Diana Woodward	Applied Mathematics	Hoppensteadt	Michigan State University, East Lansing, MI

7 Changes

For past versions of the bulletin, please contact the Director of Graduate Studies or the Graduate Coordinator, or visit the Web documents

`http://www.math.utah.edu/dept/gradbull-`*XXXX*`-`*YYYY*`.pdf`

for consecutive years, *XXXX* and *YYYY*, starting in 1996.

Here is a list of major changes to this Bulletin. This list of changes is only for indicative purposes. Please refer to the relevant section(s) in the main text for the details.

7.1 New in 2022–2023 Graduate Bulletin

- Added more about Tuition Benefit policy restrictions.
- Switched to new campus wide Parental Leave policy for Graduate Students.
- Added new policy on only counting High Passes for August exams taken by entering students.
- Started tracking changes.