Department of Mathematics, University of Utah

**Analysis of Numerical Methods, II**
**Math 6620 – Section 001 – Spring 2024**
**Course Information and Syllabus**
Updated January 9, 2024

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| **Instructor:** | Akil Narayan |
| Email: | akil@sci.utah.edu |
| Phone: | 801-581-8984 |
| Office: | WEB 4666, LCB 116 |
| Office hours: | Wednesday 11am-12pm, LCB 116 |
| | Thursdays 1pm-2pm, WEB 4666 |


**Class type:** In Person

**Class time and location:** MWF, 12:55pm-1:45pm, HEB 2002
Virtual: Zoom, by request only, see Canvas for link

**Attendance policy:** Attendance during lectures is *not* a part of your grade. However, I strongly recommend that you attend the lectures; attendance is an essential ingredient for success in this course.

**Section webpage:** http://www.sci.utah.edu/~akil/math6620
**Note**: Scores for graded assignments will be posted on Canvas.

**Course Information:** This is a 3-credit course.

**Learning objectives:** The course will serve as a theoretical and computational overview for algorithms that approximate solutions to ordinary and partial differential equations (ODEs and PDEs). We will review basic functional analysis, linear algebra, and ODE+PDE theory. The bulk of the course will be devoted to finite difference methods, time-differencing methods, and spectral methods-based discretizations for PDEs. We will discuss theory behind stability and convergence of these methods along with computational and algorithmic considerations. Students will gain experience in implementation for these methods.

**Prerequisites:** Math 6610 or equivalent. This course requires graduate-level knowledge of numerical analysis (in particular, linear algebra and applied approximation theory) and some programming experience.

**Course description:** Second half of the course described under the listing for MATH 6610.

**Text**: There are no required textbooks, with class notes serving as the primary source of material. However, the following books are useful as supplementary texts as they are authoritative on certain topics:

- Finite difference methods
  - *Title: Finite Difference Methods for Ordinary and Partial Differential Equations: Steady-State and Time-Dependent Problems*, Randall J. LeVeque, SIAM, 2007, ISBN 978-0-89871-783-9.
  - *Finite Difference Computing with PDEs: A Modern Software Approach*, Hans Petter Langtangen & Svein Linge, Springer, 2017, ISBN 978-3-319-55456-3.
  - *Time-Dependent Problems and Difference Methods*, Heinz-Otto Kreiss, Joseph Oliger, & Bertil Gustafsson, John Wiley & Sons, 2013, ISBN 978-1-118-54852-3.
  - *Computer Methods for Ordinary Differential and Differential-Algebraic Equations*, Uri M. Ascher & Linda R. Petzold, SIAM, 1998, ISBN 978-1-61197-139-2.

- Spectral Methods
  - *Spectral Methods: Fundamentals in Single Domains*, Claudio Canuto, M. Youssuf Hussaini, Alfio Quarteroni, & Thomas A. Zang, Springer, 2011, ISBN 978-3-540-30725-9.
  - *Spectral Methods: Algorithms, Analysis and Applications*, Jie Shen, Tao Tang, & Li-Lian Wang, Springer Science and Business Media, 2011, ISBN 978-3-540-71041-7.
  - *Spectral Methods for Time-Dependent Problems*, Jan. S. Hesthaven, Sigal Gottlieb, & David Gottlieb, Cambridge University Press, 2007, ISBN 978-1-139-45952-5.

**Class meetings:** This class meets in person thrice per week. Class meetings will primarily be lecture-based, which will include a discussion of theory and practice examples. I encourage you to participate in class, in particular with questions and related discussions.

**Homework:** Problem sets will be announced in-class and subsequently posted on the course website. Homework will be assigned approximately every 2 weeks and collected online. Late homework assignments will be accepted, but with a 10% penalty per day late. This penalty will be enforced on Canvas, and can be waived if you submit to me documentation demonstrating extenuating circumstances.

Each homework assignment is worth equal weight and your lowest homework score over the semester will be dropped. You are welcome (and encouraged) to work on the homework assignment in groups, but each student must submit individual work.

**Exams:** This course will have 1 in-class midterm exam, and 1 in-class comprehensive final exam. The midterm exam will be held in class on February 28.

The final exam is a cumulative exam in the same format as the midterm exams. Per university policy, the final exam will be held on Tuesday, April 30 from 1:00-3:00pm.

Unless otherwise specified, **neither calculators or notes of any kind are allowed on either of the exams**. The homework assignment problems should be completed without resorting to a calculator, when possible. However, some assignment problems require programming.

**Grading:** Your course grade will be computed as follows.

- Homework ..... 45%
- Midterm exam ..... 25%
- Final exam ..... 30%

Final letter grades will be assigned based on the following scheme:

- 92% - 100% — A
- 90% - 91% — A−
- 88% - 89% — B+
- 82% - 87% — B
- 80% - 81% — B−
- 78% - 79% — C+
- 72% - 77% — C
- 70% - 71% — C−
- 68% - 69% — D+

- 62% - 67% — D
- 60% - 61% — D−
- 0% - 59% — E

**Qualifying exams**: (For mathematics graduate students only) To earn a "high-pass" in this class you need a A. To earn a "pass" you need a A- or B+. Earning a "pass" or "high-pass" in this class means you will earn that grade for the qualifying exam associated with this class (without having to take the qualifying exam). For more details, please see the graduate bulletin at `http://www.math.utah.edu/dept/gradbull.pdf`, which is the authoritative document on this matter.

**Important dates:**

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| **Jan 19** | | Last day to add, drop, elect CR/NC or audit classes |
| **Feb 28** | | Midterm 1 |
| **Mar 1** | | Last day to withdraw from classes |
| **Apr 19** | | Last day to reverse CR/NC option |
| **Apr 24** | | Reading Day |
| **Apr 30** | **1:00pm** | Final exam |

**Class communication:** An email list is set up with which I shall send out information not communicated during class. This email list will also be used to communicate class information in the case of unusual circumstances affecting the the logistics of the class. If you are not officially registered for the class but wish to be on the roster, please discuss it with me.

*If you are registered for the course, but do not receive the course email announcements to your University of Utah email address, please notify me immediately.* You can forward your Utah emails to other email addresses. (Navigate to `http://www.cis.utah.edu`, login, and change your UMail settings.)

The section website will be used to communicate more technical matter of the class (e.g. assignments, lecture summaries, etc.).

In the event of a major campus emergency, course requirements, deadlines and grading percentages are subject to change that may be necessitated by a revised semester calendar or other circumstances. The above two methods, in addition to the coursewide website, are reliable means of getting information about changes to the course.

**Communication with the instructor:** The most reliable and preferred means of contacting me is via email, and I typically respond in less than 24 hours. Communication through the messaging system in Canvas will also work, but possibly with a slightly longer response time. One-on-one meetings can also be set up with me outside of office hours; please set up such meetings with me via email.

**Student responsibilities and integrity:** All students are expected to maintain professional behavior in the classroom setting, according to the Student Code, spelled out in the Student Handbook. Students have specific rights in the classroom as detailed in Article III of the Code. The Code also specifies proscribed conduct (Article XI) that involves cheating on tests, plagiarism, and/or collusion, as well as fraud, theft, etc. Students should read the Code carefully and know they are responsible for the content. According to Faculty Rules and Regulations, it is the faculty responsibility to enforce responsible classroom behaviors, and I will do so, beginning with verbal warnings and progressing to dismissal from and class and a failing grade. Students

have the right to appeal such action to the Student Behavior Committee.
http://regulations.utah.edu/academics/6-400.php

**Inclusivity**: It is my intent that students from all diverse backgrounds and perspectives be well served by this course, that students' learning needs be addressed both in and out of class, and that the diversity that students bring to this class be viewed as a resource, strength and benefit. It is my intent to present materials and activities that are respectful of diversity: gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture. Your suggestions are encouraged and appreciated. Please let me know ways to improve the effectiveness of the course for you personally or for other students or student groups. In addition, if any of our class meetings conflict with your religious events, please let me know so that we can make arrangements for you.

**Discrimination and Harassment:** If you or someone you know has been harassed or assaulted, you are encouraged to report it to the Title IX Coordinator in the Office of Equal Opportunity and Affirmative Action, 135 Park Building, 801-581-8365, or Office of the Dean of Students, 270 Union Building, 801-581-7066. To report to the police, contact the Department of Public Safety, 801-585-2677(COPS). Please see Student Bill of Rights, section E http://regulations.utah.edu/academics/6-400.php. I will listen and believe you if someone is threatening you.

**Classroom Social Equity:** Canvas allows students to change the name that is displayed AND allows them to add their pronouns to their Canvas name. Class rosters are provided to the instructor with the student's legal name as well as "Preferred first name" (if previously entered by you in the Student Profile section of your CIS account, which managed can be managed at any time). While CIS refers to this as merely a preference, I will honor you by referring to you with the name and pronoun that feels best for you in class or on assignments. Please advise me of any name or pronoun changes so I can help create a learning environment in which you, your name, and your pronoun are respected. If you need any assistance or support, please reach out to the LGBT Resource Center: https://lgbt.utah.edu/campus/faculty_resources.php

**English Language Learners:** If you are an English language learner, please be aware of several resources on campus that will support you with your language and writing development. These resources include: the Writing Center (http://writingcenter.utah.edu/); the Writing Program (http://writing-program.utah.edu/); the English Language Institute (http://continue.utah.edu/eli/). Please let me know if there is any additional support you would like to discuss for this class.

**Undocumented Student Support**: Immigration is a complex phenomenon with broad impact—those who are directly affected by it, as well as those who are indirectly affected by their relationships with family members, friends, and loved ones. If your immigration status presents obstacles to engaging in specific activities or fulfilling specific course criteria, confidential arrangements may be requested from the Dream Center. Arrangements with the Dream Center will not jeopardize your student status, your financial aid, or any other part of your residence. The Dream Center offers a wide range of resources to support undocumented students (with and without DACA) as well as students from mixed-status families. To learn more, please contact the Dream Center at 801-213-3697 or visit dream.utah.edu.

**Veterans**: If you are a student veteran, the University of Utah has a Veterans Support Center located in Room 161 in the Olpin Union Building. Hours: M-F 8-5pm.Please visit their website for more information about what support they offer, a list of ongoing events and links to outside resources: http://veteranscenter.utah.edu/.

**The Americans with Disabilities Act**: The University of Utah seeks to provide equal access to its programs, services and activities for people with disabilities. If you will need accommodations in the class, reasonable prior notice needs to be given to the Center for Disability & Access, 162 Olpin Union Building, 801-581-5020, `https://disability.utah.edu`. CDA will work with you and the instructor to make arrangements for accommodations. All written information in this course can be made available in alternative format with prior notification to the Center for Disability & Access.

**Student wellness**: Personal concerns such as stress, anxiety, relationship difficulties,depression, cross-cultural differences, etc., can interfere with a student's ability to succeed and thrive at the University of Utah. For helpful resources contact the Center for Student Wellness at `www.wellness.utah.edu` or 801-581-7776.

**University Counseling Center (UCC)**: The UCC staff is committed to supporting the mental health needs of our campus community. Their phone number is 801-581-6826. Their hours are Monday-Friday, 8:00am-5:00pm. For after-hours emergencies, contact the 24/7 Crisis Line: 801-587-3000 . More information is at `https://counselingcenter.utah.edu/`. **Student Success Advocates:** The mission of Student Success Advocates is to support students in making the most of their University of Utah experience (ssa.utah.edu). They can assist with mentoring, resources, etc. Any student who faces challenges securing their food or housing and believes this may affect their performance in the course is urged to contact a Student Success Advocate for support (`https://asuu.utah.edu/displaced-students`).

**Addressing Sexual Misconduct**: Title IX makes it clear that violence and harassment based on sex and gender (which includes sexual orientation and gender identity/expression) is a Civil Rights offense subject to the same kinds of accountability and the same kinds of support applied to offenses against other protected categories such as race, national origin, color, religion, age, status as a person with a disability, veteran's status or genetic information. If you or someone you know has been harassed or assaulted on the basis of your sex, office for equal opportunity and affirmative action including sexual orientation or gender identity/expression, you are encouraged to report it to the University's Title IX Coordinator; Director, Office of Equal Opportunity and Affirmative Action, 135 Park Building, 801-581-8365, `https://oeo.utah.edu/contact-us/index.php` or to the Office of the Dean of Students, 270 Union Building, 801-581-7066, `https://deanofstudents.utah.edu`. For support and confidential consultation, contact the Center for Student Wellness, 426 SSB, 801-581-7776. To report to police, contact the Department of Public Safety, 801-585-2677(COPS), `https://police.utah.edu`.

**Campus Safety**: The University of Utah values the safety of all campus community members. To report suspicious activity or to request a courtesy escort, call campus police at 801-585-COPS (801-585-2677). You will receive important emergency alerts and safety messages regarding campus safety via text message. For more information regarding safety and to view available training resources, including helpful videos, visit `safeu.utah.edu`.

**Office of the Dean of Students**: The Office of the Dean of Students is dedicated to being a resource to students through support, advocacy, involvement, and accountability. It serves as a support for students facing challenges to their success as students, and assists with the interpretation of University policy and regulations. To contact the Office of the Dean of Students, please email `deanofstudents@utah.edu` or call 801-581-7066. There is more information at `https://deanofstudents.utah.edu`.

# Semester calendar

(Subject to change!)

| Day | Date | | Topic |
|---|---|---|---|
| Monday | January 8, 2024 | | Hello |
| Wednesday | January 10, 2024 | | Basic PDE concepts |
| Friday | January 12, 2024 | | Finite differences for 1D Poisson problems |
| Monday | January 15, 2024 | | No class: Margin Luther King Jr. Day |
| Wednesday | January 17, 2024 | | Finite differences for 1D Poisson problems |
| Friday | January 19, 2024 | | Finite differences for multidimensional Poisson problems |
| Monday | January 22, 2024 | | Finite differences for multidimensional Poisson problems |
| Wednesday | January 24, 2024 | | Initial value problems, I |
| Friday | January 26, 2024 | | Initial value problems, II |
| Monday | January 29, 2024 | | Initial value problems, III |
| Wednesday | January 31, 2024 | | Multi-stage methods, I |
| Friday | February 2, 2024 | | Multi-stage methods, II |
| Monday | February 5, 2024 | | Multi-step methods, I |
| Wednesday | February 7, 2024 | | Multi-step methods, II |
| Friday | February 9, 2024 | | Multi-step methods, III |
| Monday | February 12, 2024 | | Time-stepping miscellany |
| Wednesday | February 14, 2024 | | Stability + well-posedness for linear PDEs |
| Friday | February 16, 2024 | | Parabolic equations, I |
| Monday | February 19, 2024 | | No class: Presidents Day |
| Wednesday | February 21, 2024 | | Parabolic equations, II |
| Friday | February 23, 2024 | | Parabolic equations, III |
| Monday | February 26, 2024 | | Von Neumann stability |
| Wednesday | February 28, 2024 | | **Midterm Exam** |
| Friday | March 1, 2024 | | No class |
| Monday | March 4, 2024 | | No class: Spring break |
| Wednesday | March 6, 2024 | | No class: Spring break |
| Friday | March 8, 2024 | | No class: Spring break |
| Monday | March 11, 2024 | | Fourier series, I |
| Wednesday | March 13, 2024 | | Fourier series, II |
| Friday | March 15, 2024 | | Fourier interpolation |
| Monday | March 18, 2024 | | Non-smooth problems |
| Wednesday | March 20, 2024 | | Weak solutions |
| Friday | March 22, 2024 | | Weighted residual methods |
| Monday | March 25, 2024 | | Fourier Galerkin methods |
| Wednesday | March 27, 2024 | | Fourier collocation methods |
| Friday | March 29, 2024 | | Time-dependent Fourier spectral methods, I |
| Monday | April 1, 2024 | | Time-dependent Fourier spectral methods, II |
| Wednesday | April 3, 2024 | | Orthogonal polynomials, I |
| Friday | April 5, 2024 | | Orthogonal polynomials, II |
| Monday | April 8, 2024 | | Polynomial spectral methods, I |
| Wednesday | April 10, 2024 | | Polynomial spectral methods, II |
| Friday | April 12, 2024 | | Polynomial spectral methods, III |
| Monday | April 15, 2024 | | Buffer day |
| Wednesday | April 17, 2024 | | Buffer day |
| Friday | April 19, 2024 | | Buffer day |
| Monday | April 22, 2024 | | Review |
| Wednesday | April 24, 2024 | | Reading day |
| Tuesday | April 30, 2024 | 1:00pm-3:00pm | **FINAL EXAM** |