CAAM454 / 554
Iterative Methods for Systems of Equations and Unconstrained Optimization
Spring 2020

Course Title. The course title for CAAM454 / 554 used to be *Numerical Analysis II*, but was renamed *Iterative Methods for Systems of Equations and Unconstrained Optimization* in Spring 2020 to better reflect the course content. The overall content and structure of CAAM454 / 554 remained unchanged.

Course Content. Iterative methods for linear systems of equations including Krylov subspace methods; Newton and Newton-like methods for nonlinear systems of equations; Gradient and Newton-like methods for unconstrained optimization and nonlinear least squares problems; techniques for improving the global convergence of these algorithms; (if time permits) linear programming duality and primal-dual interior-point methods.

Prerequisites. You should be comfortable with Analysis (at the level of MATH 302 or MATH 321) and Linear Algebra (at the level of CAAM 334/335), and be able to write MATLAB or Python programs. CAAM 453 Numerical Analysis I (CAAM 550/553) is a recommended pre-requisite for CAAM 454 (CAAM554). You will benefit from the exposure to how Numerical Analysis is approached in CAAM 453/550/553, but CAAM 454/554 does not require specific methods/tools taught in these courses.

Course Web-Page. Check the course web-page `http://www.caam.rice.edu/~caam454` and the course CANVAS regularly for assignments, handouts, etc.

Time and Room. T/Th 2:30PM-3:45PM, Room: SEW 307

Instructor. Matthias Heinkenschloss
Office: Duncan Hall 3088
Phone: x5176
Office Hours: TBA
email: heinken@rice.edu

Office Hours. M 1:00PM-2:00PM, Duncan Hall 3088, or by appointment.

Course Objectives. Students should learn about the construction, analysis, implementation, and application of iterative methods for linear systems of equations including Krylov subspace methods, of Newton and Newton-like methods for nonlinear systems of equations, and of gradient and Newton-like methods for unconstrained optimization and nonlinear least squares problems.
For CAAM 454 students, the analysis of the iterative methods above will be limited to simpler cases and these iterative methods will be applied to simpler examples.
CAAM 554 students should learn how to carry out rigorous mathematical convergence analyses, and apply the iterative methods above in more advanced settings.

Outcomes. For both CAAM 454 and 554:

- Describe basic iterative methods, the conjugate gradient (CG) method, and GMRES for the solution of linear systems, and their convergence properties.
- Derive Newton's method and prove local convergence.

- Describe and apply line-search methods to globalize the convergence of gradient and of Newton-type methods.
- Develop Matlab programs of basic iterative methods, CG, GMRES, and Newton-type methods with line-search, and apply them to example problems.

Additional outcomes for CAAM 554:

- Carry out rigorous mathematical convergence analyses for basic iterative methods as well as for the Krylov subspace methods CG and GMRES.
- Carry out rigorous mathematical convergence analyses for line search globalizations.

CAAM454 or 554? CAAM 454 or 554 meet for the same T/Th lectures, but CAAM 554 will include more theoretical homework and exam problems, and potentially several supplemental lectures with additional theoretical material. CAAM PhD students must enroll in CAAM 554; other graduate students comfortable writing rigorous mathematical proofs may also consider this option. Students cannot take both CAAM 454 and 554 for credit.

Textbooks and References. Lecture notes will be made available through the course CANVAS page. The course lecture page contains recommended reading, primarily from the following books.

- J. E. Dennis, Jr., and R. B. Schnabel: *Numerical Methods for Unconstrained Optimization and Nonlinear Equations*, Prentice Hall 1983. Reprinted by SIAM, Philadelphia, 1996. https://doi.org/10.1137/1.9781611971200.
- P. E. Gill, W. Murray and M. H. Wright: *Practical optimization*, Academic Press, 1981. Reprinted by SIAM, Philadelphia, 2019. https://doi.org/10.1137/1.9781611975604.
- C. T. Kelley: *Iterative Methods for Linear and Nonlinear Equations*, SIAM, Philadelphia, 1995. A free PDF version of this book is is available at http://www.siam.org/books/textbooks/download.php.
- C. T. Kelley: *Iterative Methods for Optimization*, SIAM, Philadelphia, 1999. A free PDF version of this book is is available at http://www.siam.org/books/textbooks/download.php.
- J. Nocedal and S. J. Wright: *Numerical Optimization (second edition)*, Springer Verlag, 2006. https://doi.org/10.1007/978-0-387-40065-5. (Free download if you access the URL from within the Rice University network.)
- Y. Saad: *Iterative methods for sparse linear systems (2nd edition)*, SIAM, Philadelphia, 2003. A free PDF version of this book is is available at http://www-users.cs.umn.edu/~saad/books.html.
- L. N. Trefethen and D. Bau, III: *Numerical Linear Algebra*, SIAM, 1997. (A draft(?) of this book is available at https://people.maths.ox.ac.uk/trefethen/lafront.ps (accessed Jan. 8, 2020).)

Grading. Problem sets will be assigned roughly once a week. There will be two exams/pledged homework assignments. The final grade will be determined from unpledged problem sets (60%) and pledged problem sets/exams (40%).

On unpledged assignments you may collaborate, but your write-up must be your own independent work. Exams/pledged homework assignments may be timed and ‘closed book’, and you are not allowed to discuss exams/ pledged assignments with anyone but your instructor. Transcribed solutions are unacceptable; you may not consult solutions from previous sections of this class.

You may turn in two unpledged problem sets one class period late without penalty. Subsequent late assignments will be penalized 20% each. Homework will not be accepted more than one class period late without a written excuse. This implies that you may not use two 'lates' on one assignment. Pledged assignments/exams must be turned in on time.

Absence Policies. Regular and active class participation is expected.

Programming. Homework assignments will require some programming in Matlab or Python. Your solutions should adhere to good programming standards, and must not be copied from other students.

Rice Honor Code. In this course, all students will be held to the standards of the Rice Honor Code, a code that you pledged to honor when you matriculated at this institution. If you are unfamiliar with the details of this code and how it is administered, you should consult the Honor System Handbook at http://honor.rice.edu/honor-system-handbook/. This handbook outlines the University's expectations for the integrity of your academic work, the procedures for resolving alleged violations of those expectations, and the rights and responsibilities of students and faculty members throughout the process.

Disability Support Services. If you have a documented disability or other condition that may affect academic performance you should: 1) make sure this documentation is on file with Disability Support Services (Allen Center, Room 111 / adarice@rice.edu / x5841) to determine the accommodations you need; and 2) talk with me to discuss your accommodation needs.

Syllabus Change Policy. This syllabus is only a guide for the course and is subject to change with advanced notice.