

Mathematics of Information

APMA 2501 / ECE 2066

Time and Location:

TuTh 9:30PM - 10:45PM Olsson Hall 120 (APMA 2501/ECE 2066 lecture)

Tu 2:00PM - 2:50PM Mechanical Engr Bldg 213 (ECE 2066 laboratory)

Tu 5:00PM - 5:50PM Mechanical Engr Bldg 213 (ECE 2066 laboratory)

Instructor:

Daniel Weller, dweller@virginia.edu, Rice Hall 309

Instructor office hours:

Tuesdays, 3 – 4 PM, and Thursdays, 11 AM – noon, Rice Hall 309

If these time slots do not work for you, or you wish to meet individually, please email me in advance to make an appointment.

GTA:

Haris Jeelani

UGTAs:

Kaelyn Carroll, Karan Chawla

GTA office hours will be posted on Collab. UGTA's will be available during lectures and Tuesday lab sessions.

Course description and topics

This course surveys the mathematical topics that are needed to understand the fundamental principles that govern the storage, processing, and transmission of information on any device. We will study both the mathematical foundations and the engineering solutions enabled by these foundations. We will frequently use digital technologies such as the iPhone as examples to demonstrate them. For instance, how does the iPhone, which has mostly digital components, interact with an analog world? How does it store different types of data (music, video, apps) reliably, when the storage device itself (flash memory) is unreliable? What makes it possible to stream music over noisy wireless channels that sound so good (well, most of the time)?

Topics include: mathematical representation of information; spectral analysis and the sampling theorem; probability, uncertainty, and information; linear/abstract algebra and error correction; number theory and encryption; Boolean algebra and computation

Mathematical Area	Topics
Number and Set Theory	Cardinality, discrete v. continuous, countable vs. uncountable, number representation, quantization, divisibility, prime numbers and factorization, congruence, Euler's theorem, encryption

Mathematical Area	Topics
The Frequency Domain	Fourier transform, multiplication vs convolution, the sampling theorem, modulation, orthogonality in time and frequency domains
Applied Probability and Information Theory	Probability, counting, simple distributions, expected value, Bernoulli trials, conditional probability, entropy, compression and channel capacity
Applied Linear and Abstract Algebra	Matrices and matrix operations, matrix equations, correlation, finite fields, solving systems of equations over finite fields for error correction
Boolean Algebra	Number systems, binary arithmetic, logic operations, Boolean laws, truth tables, computation, reduction

Text

Course notes will be provided via Collab. This course does not have a required textbook, but a wide range of textbooks do provide useful background material on the topics covered in this course. These textbooks, many of which are available online through the UVA Library, include:

General references:

- *Engineering our Digital Future* by Geoffrey C. Orsak et al., Prentice Hall, 2004
- *Advanced Engineering Mathematics* by Erwin Kreyszig, Wiley, 1999 (<https://search.lib.virginia.edu/catalog/u2857982>)

About frequency domain:

- Various parts of *Engineering Signals and Systems* by Fawwaz T. Ulaby and Andrew E. Yagle, NTS Press, 2016 (<https://search.lib.virginia.edu/catalog/u7244724>)
- Various parts of *Signals & Systems* by Alan V. Oppenheim et al., Prentice Hall, 1997 (<https://search.lib.virginia.edu/catalog/u2645825>)
- Chapters 1 and 2 in *Digital Signal Processing: Fundamentals and Applications* by Li Tan, Academic Press, 2013 (<https://search.lib.virginia.edu/catalog/u6155075>)
- The websites for DSP First (<http://dspfirst.gatech.edu/>) and Signal Processing First (<https://www.rose-hulman.edu/DSPFirst/visible3/contents/index.htm>) contain online demos, lectures, and other materials.
- Various parts of *Introduction to Digital Communication Systems* by Krzysztof Wesolowski, Wiley, 2009 (<http://search.lib.virginia.edu/catalog/u6800090>)
- Chapters 1-4 of *Introduction to Communications Technologies: A Guide for Non-Engineers* by Stephan Jones et al., CRC Press, 2015 (<http://search.lib.virginia.edu/catalog/u7237226>)

About probability and information theory:

- Chapters 1, 3, 4 in *Probability and Stochastic Processes* by Roy D. Yates and David J. Goodman, Wiley, 2014 (<https://search.lib.virginia.edu/catalog/u6768392>) (excluding expected values, etc.)

- Chapters 2-4 in *Probability and Statistics for Engineering and the Sciences* by Jay L. Devore, Brooks/Cole, 2012 (<https://search.lib.virginia.edu/catalog/u6127720>)
- Chapters 1 and 2 in *Probability: an Introduction with Statistical Applications* by John Kinney, Wiley, 2015 (<https://search.lib.virginia.edu/catalog/u6700981>) (excluding details on expected values, hypergeometric distributions, and other advanced topics).
- Chapters 1-4, 7-9 in *Understanding Probability* by Henk Tijms, Cambridge, 2012 (<https://search.lib.virginia.edu/catalog/u6545649>)
- Chapters 1-3 in *Introduction to Probability* by Joseph Blitzstein, CRC Press, 2015 (<https://search.lib.virginia.edu/catalog/u6538225>) (excluding Bayes theorem, functions of random variables, etc.)
- Chapter 2 in *Information Theory and Rate Distortion Theory* by Jerry Gibson, Morgan & Claypool, 2014 (<http://search.lib.virginia.edu/catalog/u6568441>)
- Section 1.2 in *Information Theory and Coding by Example* by Mark Kelbert and Yuri Suhov, Cambridge, 2013 (<http://search.lib.virginia.edu/catalog/u6538091>)
- Sections 1.1-1.2 in the draft Part A of *Information, Physics, and Computation* by Marc Mezard and Andrea Montanari (<https://web.stanford.edu/~montanar/RESEARCH/BOOK/partA.pdf>)

About linear algebra:

- Various parts of *Linear Algebra with Applications* by Jeffrey Holt, W H Freeman, 2016
- Various parts of *Linear Algebra: Ideas and Applications* by Richard C. Penney, Wiley, 2016 (<https://search.lib.virginia.edu/catalog/u6971694>)

About Boolean algebra and computation:

- Various parts of *Digital Design with RTL Design, VHDL, and Verilog* by Frank Vahid, Wiley, 2010
- Chapters 1 and 2 of *Digital Logic Design* by Brian Holdsworth and Clive Woods, Newnes, 2002 (<https://search.lib.virginia.edu/catalog/u5107667>)
- Chapters 1-3 of *Fundamentals of Digital Logic with VHDL Design* by Stephen D. Brown and Zvonko G. Vranesic, McGraw-Hill, 2000 (<https://search.lib.virginia.edu/catalog/u3558046>)

Activities and assessment

Homework and Labs

Homework will be assigned throughout the semester (usually on a weekly basis) and will be collected at the beginning of class on the due date (usually due on Thursdays). Do not email your homework unless specifically requested by a TA or instructor. Homework will typically be due one week from when it is assigned. Some assignments will be lengthy and / or difficult. The goal of the homework is not necessarily to prepare you for the test. The goal of the homework is to challenge you, to allow you to learn, and to have some fun.

For ECE 2066 students: Students are expected to attend and complete the lab assignments during the assigned laboratory time. Laboratory assignments frequently will involve MATLAB, and some will require a stereo headset with standard 3mm plug (see below). These assignments will require reports submitted alongside the above weekly homework assignments.

For APMA 2501 students: In lieu of a formal laboratory section, the essential activities of the labs will be integrated with homework assignments throughout the semester, in parallel with the

laboratory activities assigned to the ECE 2066 students. These may also involve MATLAB, and some a stereo headset with standard 3mm plug. Separate laboratory reports will not be required.

Late Assignments: Please hand in assignments on time (at the beginning of the class on the due date). Assignments handed in the same day (up to 5PM) after the start of class will be subject to a 10% penalty. A TA will typically pick up the homework at the start of class (if it's hand-written) – after the TA leaves, any homework handed in will be late. Homework handed in before 5PM the next day (usually Thursday) will have a 20% late penalty. After that time, late homework will not be accepted (= 0 grade). Please submit your late homework to the head TA. Exemptions to this policy (e.g., due to illness or job interviews) may be granted only by Prof. Weller and only in advance of the deadline.

Exams

There will be two midterm exams and a comprehensive final examination. During the first midterm exam, a single 8 1/2" x 11" sheet of notes (single-sided) will be permitted. In the second exam, two sheets (single-sided) can be used. In the final, three such sheets (single-sided) may be used. Photocopying is not allowed on the note sheets. You will be required to submit your note sheet(s) with each exam. If you must miss an exam due to circumstances beyond your control, you must notify Prof. Weller (prior to the exam, if possible) so that arrangements can be made. Make-up exams will not be administered to accommodate a "busy" schedule. Neither exam will be rescheduled. If you miss an exam, you will be given a 0 grade for that exam. Any movement of the final exam must be scheduled ahead of the SEAS drop date (February 25).

Class Attendance

There will be no records taken of attendance. However, students are responsible for all material covered in class, even if the material is not in the notes. The expected workload is 6-9 hours outside of class each week. The instructor and TAs will not repeat lecture material in office hours. Note: given the lack of a textbook, class attendance and engagement is important for understanding the material and the emphases of the instructor.

Use of electronic devices

Please refrain from using electronic devices in class except for course-related activities like note-taking or demonstrations. Laptops, tablets, and phones can distract those sitting near or around you.

Grading disputes

Please communicate with the head TA regarding grading disputes. We are human and do make mistakes! In the event that the TAs and the student cannot resolve a dispute, Prof. Weller will resolve it.

In-class activities and software/hardware requirements

For some of the in-class activities, you will need a stereo headset with a standard (3mm) plug. Some will also use MATLAB, which can be obtained from UVA ITS (visit <https://data.library.virginia.edu/research-software/matlab-for-students/> for more information).

Evaluation and grading

Semester grades will be based on the overall class performance. The tentative weighting is as follows:

Midterm Exams	36%
Final Exam	24%
Assignments/Labs	40%

Other policies

Accessibility: The University of Virginia strives to provide accessibility to all students. If you require an accommodation to fully access this course, please contact the Student Disability Access Center (SDAC) at (434) 243-5180 or sdac@virginia.edu. If you are unsure if you require an accommodation, or to learn more about their services, you may contact the SDAC at the number above or by visiting their website at <https://www.studenthealth.virginia.edu/sdac>.

Preventing Violence and Assault: The University of Virginia is dedicated to providing a safe and equitable learning environment for all students. To that end, it is vital that you know two values that I and the University hold as critically important:

1. Power-based personal violence will not be tolerated.
2. Everyone has a responsibility to do their part to maintain a safe community on Grounds.

If you or someone you know has been affected by power-based personal violence, more information can be found on the UVA Sexual Violence website that describes reporting options and resources available – <http://www.virginia.edu/sexualviolence>.

As your professor and as a person, know that I care about you and your well-being and stand ready to provide support and resources as I can. As a faculty member, I am a responsible employee, which means that I am required by University policy and federal law to report what you tell me to the University's Title IX Coordinator. The Title IX Coordinator's job is to ensure that the reporting student receives the resources and support that they need, while also reviewing the information presented to determine whether further action is necessary to ensure survivor safety and the safety of the University community. If you would rather keep this information confidential, there are Confidential Employees you can talk to on Grounds (See <https://eocr.virginia.edu/chart-confidential-resources>). The worst possible situation would be for you or your friend to remain silent when so many here are willing and able to help.

Religious Accommodations: It is the University's long-standing policy and practice to reasonably accommodate students so that they do not experience an adverse academic consequence when sincerely held religious beliefs or observances conflict with academic requirements.

Students who wish to request academic accommodation for a religious observance should submit their request in writing directly to me by email as far in advance as possible. Students who have questions or concerns about academic accommodations for religious observance or religious beliefs may contact the University's Office for Equal Opportunity and Civil Rights (EOCR) at UVAEOCR@virginia.edu or 434-924-3200.

Accommodations do not relieve you of the responsibility for completion of any part of the coursework missed as the result of a religious observance.

Honor Code: I trust every student in this course to fully comply with all of the provisions of the University's Honor Code. By enrolling in this course, you have agreed to abide by and uphold the Honor System of the University of Virginia, as well as the following policies specific to this course.

- Students are permitted to work in groups on homework assignments, but must complete and turn in individual homework write-ups.
- Computer programs must be individually written.
- Use of and copying from homework solutions from previous semesters will be considered an Honor Violation.
- Be careful to cite references when necessary and to avoid plagiarism. Plagiarism includes copying written material and copying computer software.
- Examinations are pledged and are strictly individual work.

All suspected violations will be forwarded to the Honor Committee, and you may, at my discretion, receive an immediate zero on that assignment regardless of any action taken by the Honor Committee.

Please let me know if you have any questions regarding the course Honor policy. If you believe you may have committed an Honor Offense, you may wish to file a Conscientious Retraction by calling the Honor Offices at (434) 924-7602. For your retraction to be considered valid, it must, among other things, be filed with the Honor Committee before you are aware that the act in question has come under suspicion by anyone. More information can be found at <http://honor.virginia.edu/>. Your Honor representatives can be found at: <http://honor.virginia.edu/representatives>.