



NYU

TANDON SCHOOL
OF ENGINEERING

Course Syllabus

Computer Science and Engineering
CS-GY 6903-Applied Cryptography

Course Information

Course Prerequisites (Recommended)

(CS-UY 2134 or CS-UY 1134) and (CS-UY 2124 or CS-UY 1124).

- Some expertise in a programming language, like C, C++, Python, Java, etc.
- Some mathematical maturity, in terms of understanding and working with mathematical definitions, concepts, and proofs, and elementary notions of logic, set theory, number theory, probability and statistics; and
- Knowledge of basic algorithm analysis and complexity theory, as obtained from a graduate algorithms class.

Although relevant notions about logic, set theory, number theory, probability, statistics, algorithms, and complexity theory will be provided as part of the class lectures, students are still recommended to take this class after taking a graduate Algorithms class. If not possible, students are strongly encouraged to fill any relevant gaps using web links provided during class lectures as well as e-mail, online or in-person interactions with the instructor. A quick reading of the web content at whichever applicable among the following web links, is strongly recommended:

1. Propositional Logic: http://en.wikipedia.org/wiki/Propositional_calculus (only "Basic concepts" section), http://en.wikipedia.org/wiki/Truth_table, <http://en.wikipedia.org/wiki/Contraposition>
2. Set Theory: http://en.wikipedia.org/wiki/Algebra_of_sets
3. Probability: https://en.wikipedia.org/wiki/Probability#Mathematical_treatment
4. Algorithms: http://en.wikipedia.org/wiki/Analysis_of_algorithms, http://en.wikipedia.org/wiki/Big_O_notation
5. Complexity Theory: http://en.wikipedia.org/wiki/P_versus_NP_problem



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Course Description

The last 40+ years have witnessed a revolution in the area of Cryptography, bringing real-life security problems to the attention of a vast research community. This revolution created Modern Cryptography, where researchers started rigorously treating and solving several problems that only

a few years before were unknown or seemed impossible to solve or only had heuristic solutions. Today Modern Cryptography is a well-established mathematical discipline, with strong connections to several older disciplines such as Complexity Theory, Information Theory, Combinatorics, Number Theory, and Coding Theory, and several applications to real-life problems. This Applied Cryptography class offers a comprehensive introduction to Modern Cryptography, and, specifically, its main problems, formalisms, solutions, and open questions, with a heavy focus on application aspects, including case studies for real-life uses of Modern Cryptography solutions.

Upon completion of this course you will have acquired the following knowledge:

- Learn the main areas of Modern Cryptography, including their main problem statements and the rigorous mathematical approaches used to formalize them
- Learn and describe how various cryptographic algorithms and protocols work, pointing out the main techniques used in them, and proving/disproving most basic properties, such as correctness of decryption, digital signatures, authentication tags, and key agreement
- Evaluate functionality, security and performance properties of cryptography methods used as components of complex security solutions
- Analyze the impact of errors or different designs of cryptography algorithms and protocols 5. Describe the applications of cryptography algorithms and protocols to real-life problems and many implementation issues in developing these solutions.

At the end of the class the diligent student is also expected to be ready to initiate an advanced study or an applied research/development project on problems in the area, understand and use cryptographic software tools, and select known cryptographic solutions (e.g., algorithms, protocols, key lengths, etc.) for a desired cryptography application.



Course Structure

This course follows a “flipped-classroom” teaching model.

Except for textbooks, the course’s technical material, including lecture slides and explanation videos, is posted online and available so that students can read or listen to it whenever and as many times it is desired or needed. This material is divided into 12 weeks, and contains, for each of the 12 weeks:

- **Lecture Document:** i.e., a PDF file containing between 25 and 40 PowerPoint slides, with pointers to required or recommended textbooks, posted online by Monday of the appropriate week (usually, many weeks in advance)
- **Lecture Video:** i.e., one or more video recordings of an explanation of the lecture slides, posted together with the lecture document.

Grading Breakdown

- 5% Class participation (attendance and homework answer attempts)
- 10% Homework completion
- 15% Project 1
- 20% Project 2
- 25% Midterm
- 25% Final

Weights are tentative and might slightly change (for instance, slightly increasing the weight of the final is possible). Incomplete grades will not be given, unless under exceptional circumstances. Homework submitted later than the due date is eligible for partial credit that decreases with time. Submitting homework late will always be more convenient than submitting no homework but never more convenient than submitting homework before the due date. The instructor will not drop students’ lowest homework score.



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Weekly Structure

Lecture 1:

History of cryptography, some background in probability and algorithms, classical cryptography (shift cipher, monoalphabetic substitution cipher, polyalphabetic substitution cipher), encryption with perfect secrecy, one-time pad; implementation aspects: shared secret randomness vs perfect secrecy

Lecture 2:

Some background in algorithms and complexity theory, modern cryptography principles, one-way functions, trapdoor functions, hard-core bits, construction of a public-key cryptosystem based on general cryptographic primitives, implementation aspects: computational efficiency vs hardness

Lecture 3:

Algorithmic number theory, number theory and cryptographic assumptions, Reductions, proofs by reductions, number theory candidates for cryptographic primitives (e.g., factoring and related problems), public-key cryptosystems from number theory problems; brief discussion of quantum computing; implementation aspects: large integer arithmetic for implemented public-key cryptosystems

Lecture 4:

Randomness and pseudo-randomness, pseudo-random generators, functions and permutations. Symmetric encryption: introduction, security notions, symmetric encryption schemes based on pseudo-randomness primitives, security proofs, fundamental concepts; implementation aspects: generating and testing randomness

Lecture 5:

Symmetric encryption: block ciphers (e.g., DES, Triple-DES, AES), substitution/permutation networks, Feistel networks, modes of operations (e.g., ECB, CBC, OFB, Counter), cryptanalysis attacks (e.g., exhaustive, linear, differential, meet-in-the-middle attack), key lengths; implementation aspects: security-performance-features tradeoffs



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Lecture 6:

Message authentication: introduction, notion and schemes (e.g., CBC-MAC), collision resistant hashing (MD5, SHA-1, SHA-2, SHA-3, HMAC, Merkle-Hellman), CCA security for symmetric encryption, simultaneous message confidentiality and message integrity, the GCM mode, application case study 1: password-based secure computer access; implementation aspects: security performance-features tradeoffs

Lecture 7:

More number theory candidates for cryptographic primitives (e.g., discrete logarithms, brief discussion of related problems including elliptic curves). Asymmetric encryption: comparison with symmetric encryption, definitions, constructions (e.g., RSA variants, El Gamal), hybrid encryption; implementation aspects: security-performance-features tradeoffs

Lecture 8:

Asymmetric encryption: malleable and homomorphic encryption notion and schemes (e.g., Paillier, brief discussion of various schemes, including Gentry's), additional schemes achieving various security notions in various models (e.g., Cramer-Shoup), identity-based encryption; implementation aspects: security-performance-features-trust tradeoffs

Lecture 9:

Property-preserving public-key encryption, secure 2-party computation, secure multi party computation; application case study 2: sugar beet auction; implementation aspects of cryptographic protocols: transport layer, protocols over secure channels

Lecture 10:

Digital Signatures, hashing and signing, Hashed RSA, El Gamal and DSA signature schemes, public-key infrastructures, certificates, cryptography in TLS, IPSec and virtual private networks, NSA Suite B, application case study 3: secure online purchasing; implementation aspects: trust models, PKI implementation challenges



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Lecture 11:

Key protocols: key transport, key agreement, notions and schemes (e.g., Diffie-Hellman schemes); key management: concepts and lifecycle; code obfuscation, application case study 4: digital rights management; quantum computing, quantum-resistant cryptography; implementation aspects: creating correct and secure programs, quality of code, side-channel attacks, implementation flaws

Lecture 12:

Key lengths and recommendations, user authentication: password, challenge-response and zero-knowledge protocols; server authentication; application case study 5: secure online banking; digital cash, application case study 6: keeping/storing secrets, blockchain, application case study 7: cryptocurrencies; implementation aspects: weakest key, key modularity

Course Communication

Your weekly online meeting, instructor office hour and TA office hour are all reachable via NYU Classes.

Weekly Meeting

A **lecture summary review with focus on homework questions**. This meeting assumes the students have already listened to the lecture videos. It consists of a summary of the lecture slides, and includes discussions and elaborations on some key topics, possibly requested by students via email during the week, and an opportunity for students to solve homework questions. Attending these meetings is not mandatory but may improve your class grade; part of your class grade depends on attendance and number of hw questions answered (graded for effort and not answer correctness), and extra credit will be given to students with the highest number of correct answers.



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Office Hours with Instructor

In these office hours the instructor will address any questions on the lectures, homework, projects, extra credit, midterm and final; attending instructor office hours is not mandatory but students are strongly encouraged to attend and actively participate by posing their questions

Office Hours with TA (if any)

In these office hours the TA will address any questions on the lectures, homework, projects, extra credit, midterm and final; attending TA office hours is not mandatory but students are strongly encouraged to attend and actively participate by posing their questions.

The instructor will send a weekly email to remind students of their expected duties for the week, including any updates to class duties and/or schedule. Students are strongly encouraged to follow the recommended schedule of class duties.

Questions

Generally, students are very much encouraged to **email** their **technical and non-technical** questions (including class organization, etc.) to the **instructor**; questions can be sent at any time, and an answer would likely appear within 1 or 2 business days. For real-time answers, office hours are more appropriate. We will also have an online **forum** which can be more appropriate for questions among fellow students, live updates to course material or real-time communication from the instructor, etc. The instructor is also happy to make time for a limited number of one-on-one office hours outside of the designated times. The diligent student is expected to generate a weekly list of unclear technical issues to clarify with the instructor and/or the TA through the above channels.



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Course Materials

Required Reading Material

1. [KL] J. Katz and Y. Lindell, *Introduction to Modern Cryptography: Principles and Protocols*, Chapman & Hall/CRC Press, 2nd edition
<http://www.cs.umd.edu/~jkatz/imc.html>
2. [MOV] A. Menezes, P. Van Oorschot, S. Vanstone, *Handbook of Applied Cryptography*, CRC Press, August 2001
<http://www.cacr.math.uwaterloo.ca/hac/>

Note: text (1) contains about 85% of the class material; text (2) contains about 50% of the class material; past cs6903 students typically found it easier to study on lecture slides and to use (1) to strengthen understanding.

Recommended Texts

1. *One among the following two texts:*
 - a. [FSK] N. Ferguson, B. Schneier and T. Kohno, *Cryptography Engineering: Design, Principles and Practical Applications*, Wiley Publishing, Inc., 2010 (this book gives exposure to more cryptography engineering aspects and might be considered a modern follow-up of (1b), the first book that was written on the topic)
 - b. B. Schneier, *Applied Cryptography*, 2nd edition, J. Wiley and Sons.
 2. W. Stallings, *Cryptography and Network Security: Principles and Practice*, 2nd edition, Prentice Hall
 3. Books at <http://www.freetechbooks.com/information-security-f52.html>
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Assignments and Exams

Homework Assignments

Homework assignments are multiple-choice tests where you are presented a set of questions and are required to choose the correct answer among 4 possible ones. You will also be asked to provide a brief rationale for your



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answer to these questions. For $i=1,\dots,4$, homework $hw[i]$ typically refers to lectures $3i-2$, $3i-1$, $3i$ and is due by the end of the week dedicated to Lecture $3i$. During the weekly online meeting, the instructor will go over hw problem explanations, the students will have a chance to answer the questions, and the instructor will go over hw solutions (or, if there is no time, possibly made the answer available in a recorded video). Homeworks should be considered (the only) practice problems for your midterm and final exams. Homework is graded for effort (i.e., how many questions are answered with a rationale that shows that the student tried to answer the question) and not for correctness of answers. Of course, for more successful practice for midterm and final, the student should answer homework questions as if they were midterm or final questions.

Projects

The projects consist of solving practical problems (via software implementation) including: (1) the breaking or design of (variations of) a number of known cryptographic primitives (e.g., encryption schemes, authentication schemes, etc.); and (2) designing and implementing privacy and security solutions, based on the cryptography studied in class, as an improvement to a real-life system. In addition to implementation tasks, the projects will require a presentation document possibly including details on software documentation, cryptography design, cryptanalysis, performance analysis, etc. A project will have to be realized by a team of a number of students (to be decided during the class), and comes with a minimal assignment. Any additional work performed by the student(s) will be considered extra credit work. We will have a workshop day where each student will have a chance to present at least one of the projects. Students with the best projects will receive extra credit. Authorized sources: personal notes, required or recommended textbooks, and other web sources (only if they are properly quoted and not plagiarized). No collaboration is authorized with students beyond your team, or with parties external to the course. The following collaboration with instructor and TAs is authorized: you can ask via email or during office hours for clarifications on the project problem statement (or about any solutions, after grades have already been posted).

Midterm Exam

The midterm is based on lectures 1-6; you will be given a number of questions in some "enhanced multiple-choice format", for which the answers may require writing a brief rationale, as for homework questions, and you will



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be given a time limit (i.e., 3 hours) to write your answers. The midterm is a proctored test where you are allowed to inspect your textbook and lecture slides. For more detailed info on authorized (or not) sources, see info posted by the instructor. If the instructor is proctoring your exam, you can ask the instructor for clarifications on question statements. No collaboration is authorized with anyone else.

Final Exam

The final is based on lectures 7-12; you will be given between a number of in some "enhanced multiple-choice format", for which the answers may require writing a brief rationale, as for homework questions, and you will be given a time limit (i.e., 3 hours) to write your answers. The final is a proctored test where you are allowed to inspect your textbook and lecture slides. For more detailed info on authorized (or not) sources, see info posted by the instructor. If the instructor is proctoring your exam, you can ask the instructor for clarifications on question statements. No collaboration is authorized with anyone else.

Extra Credit

The following opportunities for extra credit (for which collaboration among students is allowed) will be offered:

1. Seminar attendance
2. Useful feedback provided to the instructor at the end of the semester
3. Highest numbers of correct answers on a weekly meeting
4. Best projects
5. Additional work on projects
6. Advanced topic surveys.

You can take opportunities 1,2,3,4 and no more than one among 5,6.

University Policies

Moses Center Statement of Disability

Academic accommodations are available for students with disabilities. Please contact the Moses Center for Students with Disabilities (212-998-4980 or



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mosescsd@nyu.edu) for further information. Students who are requesting academic accommodations are advised to reach out to the Moses Center as early as possible in the semester for assistance.

NYU Tandon School of Engineering Policies and Procedures on Academic Misconduct¹

- A. Introduction: The School of Engineering encourages academic excellence in an environment that promotes honesty, integrity, and fairness, and students at the School of Engineering are expected to exhibit those qualities in their academic work. It is through the process of submitting their own work and receiving honest feedback on that work that students may progress academically. Any act of academic dishonesty is seen as an attack upon the School and will not be tolerated. Furthermore, those who breach the School's rules on academic integrity will be sanctioned under this Policy. Students are responsible for familiarizing themselves with the School's Policy on Academic Misconduct.
- B. Definition: Academic dishonesty may include misrepresentation, deception, dishonesty, or any act of falsification committed by a student to influence a grade or other academic evaluation. Academic dishonesty also includes intentionally damaging the academic work of others or assisting other students in acts of dishonesty. Common examples of academically dishonest behavior include, but are not limited to, the following:
 - a. Cheating: intentionally using or attempting to use unauthorized notes, books, electronic media, or electronic communications in an exam; talking with fellow students or looking at another person's work during an exam; submitting work prepared in advance for an in-class examination; having someone take an exam for you or taking an exam for someone else; violating other rules governing the administration of examinations.
 - b. Fabrication: including but not limited to, falsifying experimental data and/or citations.
 - c. Plagiarism: intentionally or knowingly representing the words or ideas of another as one's own in any academic exercise; failure to attribute direct quotations, paraphrases, or borrowed facts or information.

¹ Excerpted from the [Tandon School of Engineering Student Code of Conduct](#)



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- d. Unauthorized collaboration: working together on work that was meant to be done individually.
- e. Duplicating work: presenting for grading the same work for more than one project or in more than one class, unless express and prior permission has been received from the course instructor(s) or research adviser involved.
- f. Forgery: altering any academic document, including, but not limited to, academic records, admissions materials, or medical excuses.

NYU School of Engineering Policies and Procedures on Excused Absences

- A. Introduction: An absence can be excused if you have missed no more than 10 days of school. If an illness or special circumstance has caused you to miss more than two weeks of school, please refer to the section labeled Medical Leave of Absence
- B. Students may request special accommodations for an absence to be excused in the following cases:
 - a. Medical reasons
 - b. Death in immediate family
 - c. Personal qualified emergencies (documentation must be provided)
 - d. Religious Expression or Practice