

TCS-UY.4504 Advanced Seminar: Physics and Information

Department of Technology, Culture and Society | NYU-Tandon

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Room
Mon/Weds 10am-11:50am
Spring 2027

I. Instructional Format: Instruction will be conducted in-class, unless circumstances require otherwise. Please be aware of the NYU policy on face masks at nyu.edu/life/safety-health-wellness/coronavirus-information/covid-related-guidance/protective-equipment.html. Masks are not required but welcome. As a reminder, if you are ill or are exhibiting symptoms of illness (coughing, sneezing, runny nose, etc.), you should stay home until you feel better and your symptoms are gone. It's ok to miss one or two lectures in this class: these can be easily made up by discussing any missed content with me. On the other hand, if you find yourself in a situation in which you will have to miss more than a week of lectures, please see Section VII.3.ii below. I will periodically remind the class of these policies over the course of the semester.

II. Description:

Does acquiring information increase your thermodynamic entropy? Is there more information in a quantum bit than in a classical bit? Does the information-processing power of a computer depend on the structure of spacetime? Is the fundamental nature of reality information-theoretic? In this seminar we will attempt to answer these and similar questions by using techniques from the field of history and philosophy of science to explore the many roles that the concept of *information* plays in physics: from its relation to entropy in thermodynamics and statistical mechanics, to its reconception as "quantum" information in quantum mechanics, to concepts of computability and how they relate to the physics of classical and relativistic spacetimes, and finally, to attempts to reconceive physics entirely in information-theoretic terms. We will be concerned throughout with the extent to which these different roles entail different notions of information: Is information-theoretic entropy the same as thermodynamic and statistical mechanical entropy? Is quantum information the same as classical information? How do physical constraints on the way information is processed inform our understanding of what information is? We will also be concerned with critically evaluating popularized accounts of information (as a measure of knowledge and/or surprise, as data, as bits, as binary digits, etc.): Are such accounts justified by the way the concept of information is actually used in physics? By the end of the seminar we should better appreciate the historical contingency of theoretical terms in physics, and how a single theoretical term can live many diverse non-overlapping lives.

This is a 4-credit course that meets over a 15 week semester. You should thus expect to devote 6.6 hours per week of supplemental time for this course. Supplemental time is time outside of classroom instruction that involves reading assignments, writing, exam preparation, homework assignments, and study time. For additional information on NYU policies related to this, please see: nyu.edu/academics/accreditation-authorization-assessment/resources-faqs/required-weekly-minutes.html

III. Objectives

HuSS (Humanities and Social Sciences) General Education Objectives

Think critically, creatively and independently; demonstrate information literacy; demonstrate skills in inquiry and analysis; demonstrate effective oral communication skills; demonstrate effective writing skills; bring the perspectives of HuSS to bear on technical discourse; demonstrate ethical reasoning.

STS (Science, Technology and Society) Cluster Objectives

- Demonstrate a basic understanding of the following:
 - How sci & tech shape society (in historical, philosophical, sociological, cultural, and technical ways).
 - How social processes frame sci and tech enterprises, including theory construction, invention, and innovation.
 - The relation between the content of sci/tech knowledge, and the social context in which it is created.
- Demonstrate technical proficiency in a field in the natural sciences or engineering.
- Demonstrate ability to critically analyze and communicate issues involving interactions among sci, tech, & society.

IV. Reading

A. Online via Bobst:

1. [Fr98] Friedan, R. (1998) *Physics from Fisher Information*, CUP (excerpts).
2. [ReFi17] Rex, A. & C. Finn (2017) *Finn's Thermal Physics*, Taylor & Francis (excerpts).
3. [RiPo11] Rieffel, E. & W. Polak (2011) *Quantum Computing*, MIT (excerpts).
4. [Sim23] Simon, S. (2023) *Topological Quantum*, OUP (excerpt: Chap 27).
5. [Tim13] Timpson, C. (2013) *Quantum Information Theory*, OUP (excerpt: Chap 2).

B. Online at course website:

1. [Bub01] Bub, J. (2001) "Maxwell's Demon & the Thermodynamics of Computation", *SHPMP* 32, p. 569-79.
2. [Bub04] Bub, J. (2004) "Why the Quantum?", *SHPMP* 35: 241-66.
3. [deM18] de Mol, L. (2018) "Turing Machines", *SEP*, E. Zalta (ed.), plato.stanford.edu/entries/turing-machine.
4. [EarNort98] Earman, J. & J. Norton (1998) "Exorcist XIV: The Wrath of Maxwell's Demon", *SHPMP* 29, p. 435-71.
5. [EarNort93] Earman, J. & J. Norton (1993) "Forever is a Day: Supertasks in Pitowski and Malament-Hogarth Spacetimes", *Phil. Sci.* 60: p. 22-42.
6. [FriWer19] Frigg, R. & C. Werndl (2019) "Statistical Mechanics: A Tale of Two Theories", *The Monist* 102, p. 424-438.
7. [Hog94] Hogarth, M. (1994) "Non-Turing Computers and Non-Turing Computability", in *PSA 1994*, D. Hull *et al.* (eds.), *PSA*, p. 126-38.
8. [Is25] Ismael, J. (2025) "Quantum Mechanics", *SEP*, E. Zalta (ed.), plato.stanford.edu/entries/qm.
9. [Ly17] Ly, A. *et al.* (2017) "A Tutorial on Fisher Information", arXiv:1705.01064v2.
10. [Shan48] Shannon, C. (1948) "A Mathematical Theory of Communication", *The Bell System Technical Journal* 27, pp. 379-423, 623-656 (excerpts).
11. [Wol19] Wolchover, N. (2019) 'How Space and Time Could be a Quantum Error-Correcting Code', *Quanta Magazine*, quantamagazine.org/how-space-and-time-could-be-a-quantum-error-correcting-code-20190103.

V. Requirements: This course has two websites: A Brightspace website, brightspace.nyu.edu, accessible to enrolled students, and a public website, research.engineering.nyu.edu/~jbain/tcs_seminar/index.html.

1. **Seven homework assignments.** These are posted in the Contents section in Brightspace. Please submit them by their due dates to links in the Brightspace Assignments folder. One optional extra credit assignment may also be submitted and will count towards your final homework grade.

Submission format: The preferred file type is .pdf. Please label the file you submit using the following format:

<assignment number>.<last name>_<first initial>.<file type>

Example: Albert Einstein's .pdf submission for homework #7 should be labeled:

07.Einstein_A.pdf

2. **One research paper.** Suggested themes and research questions are posted in the Contents section in Brightspace. Your research paper will be divided into 3 assignments:
 - (a) *Paper Assignment #1: Research Topic.* In this (ungraded) assignment, you will pick a theme and a research question and submit an abstract and a tentative list of references.
 - (b) *Paper Assignment #2: Initial Submission.* In this assignment, you will develop your research topic from Assignment #1 and submit a first draft of your research paper of no less than 10 pages and no more than 15 pages.
 - (c) *Paper Assignment #3: Revise and Resubmit.* In this assignment, you will response to comments on your first draft and submit a revision of no less than 15 pages and no more than 20 pages.

Due dates for (a)-(c) are in the Schedule of Topics below. The use of AI is permitted to formulate and organize ideas, but the text of your initial draft and revision should be your own, and not AI-generated.

Submission format: The preferred file type is .pdf. Please label the file you submit using the following format:

First_Draft_<last name>_<first initial>.<file type>

Revision_<last name>_<first initial>.<file type>

3. One in-class **midterm** and one in-class **final**. Each exam will consist of 8 short answer questions, of which you will be asked to pick 6; and 3 short essay questions, of which you will be asked to pick 2. A response to a short answer question should be no more than 1 paragraph (~3-4 sentences), and a response to a short essay question should be no more than 1 page (~3-4 paragraphs). Please see Section VII.3.ii below for the policy on makeup exams.

VI. Grade Distribution

Homework: 10% total Midterm: 15% Initial Draft: 30% Revision: 30% Final: 15%

VII. Reminders on University Policies

1. **Inclusion Statement.** NYU values an inclusive and equitable environment for all students. I hope to foster a sense of community in this class and consider it a place where individuals of all backgrounds, beliefs, ethnicities, national origins, gender identities, sexual orientations, religious and political affiliations, and abilities will be treated with respect. It is my intent that all 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. If this standard is not being upheld, please feel free to speak with me.
2. **Moses Statement.** If you would like to request accommodations, please contact the Moses Center for Students with Disabilities (CSD) at 212-998-4980, mosescsd@nyu.edu, nyu.edu/csd, 726 Broadway, 2nd Flr. You must be registered with CSD to receive accommodations.
3. **Standards and Procedures.** The NYU-Tandon Office of Student Affairs maintains a Community Standards and Procedures website at engineering.nyu.edu/life/student-affairs/community-standards-procedures. It contains information relevant to:

- (i) **Incompletes**. It is NYU-Tandon policy that incompletes can be given only in extenuating circumstances (medical emergencies, accidents, *etc.*). An incomplete cannot be given because of a heavy course load, job commitments, or because you've simply fallen behind. For this reason, you should attend every lecture and make sure you're aware of assignment deadlines and exam dates. If you find yourself falling behind during the semester, do not hesitate to contact me. If you think you qualify for an incomplete grade at the end of the semester, see the procedure in (ii) below.
- (ii) **Excuses due to illness or circumstances**. If you are experiencing an illness or any other situation, emotional or physical, that might affect your academic performance in a class (for instance, if you have to miss more than a week of lectures or an exam, or if you think you qualify for an incomplete grade at the end of the semester), please email or schedule a visit with Deanna Rayment, Coordinator of Student Advocacy, Compliance and Student Affairs, Dibner Hall Room LC 240C, eng.studentadvocate@nyu.edu. Deanna is your official advocate at NYU-Tandon. (No other NYU school offers a similar service to its students!) She can reach out to your professor on your behalf when warranted. She can also advise you on all issues related to Health and Wellness. For legal and privacy reasons, you should not directly contact your professor with requests and concerns of this nature.
- (iii) **University Honor System**. Please be aware of the university policy on cheating and plagiarism in the Student Code of Conduct. Cheating on an exam, or plagiarizing on an essay assignment, are sufficient reasons for receiving an F in the course. The Code of Conduct can be downloaded from the Office of Student Affairs website listed above.

4. **Grading Policy.** The following is NYU-Tandon's grading policy for undergrad classes:

A	Excellent (4.000)	S	Satisfactory
A-	Excellent (3.667)	U	Unsatisfactory Progress
B+	Good (3.333)	W	Withdrew Officially
B	Good (3.000)	I	Incomplete (converts to F after 180 days)
B-	Good (2.667)	AUD	Auditor Status
C+	Satisfactory (2.333)	NR	No record
C	Satisfactory (2.000)	P	Passing
C-	Satisfactory (1.667)		
D+	Minimum Passing Grade (1.333)		
D	Minimum Passing Grade (1.000)		
F	Failure (0.000)		

VIII. Class Schedule: Readings serve as background and sources for a given lecture topic, and should be completed by the date on which they appear. For multiple readings on a given day, try to read through at least one. This schedule may need to be modified over the course of the semester.

1		Weds 1/20. <i>Lecture 1: Introduction</i>
2	Mon 1/25. Part I: Info in Classical Info Theory and Statistics. <i>Lec 2: Shannon Information</i> [Shan48: Intro & Section 6]	1/27. Lec 2, cont. [Tim13: Chap 2] Sample research topics; hw1 due
3	2/1. Lec 3: Fisher Information [Ly17: Section 1]; [Fr98: 1.1-1.7]	2/3. Part II: Info in Thermodyn and Stat Mech <i>Lec 4: TD Entropy and Info.</i> [ReFi17: 3.1, 3.2] Sources.
4	2/8. Lec 4, cont. [ReFi: 4.1-4.4]	2/10. Lec 5: Statistical Mech Entropy and Info [FriWer19] Paper guidelines; hw2 due
5	2/16 (Tues). <i>Lecture 5, cont.</i>	2/17. Lec 5, cont. How to construct an abstract
6	2/22. Lec 6: Maxwell's Demon and Info [EarNort98]	2/24. Lec 6, cont. [Bub01] Citation methods; hw3 due
7	3/1. Part III. Info in Quantum Mech <i>Lec 7a: QM Basics.</i> [Is25]; Research topic due	3/3. Lec 7b, QM Basics. II [RiPo11: 3.1, 3.2, 10.1]
8	3/8. Lec 8: QIT Basics [RiPo11: 5.1, 5.2, 7.1]	3/10 Midterm
9	3/15 Spring Break	3/17 Spring Break
10	3/22. Lec 8, cont.	3/24. Lec 9: Quantum Information: Transmission [RiPo11: 5.3] hw4 due
11	2/29. Lec 10: Quantum Information: Protection [RiPo11: 11.1, 11.2]	3/31. Part IV. Info in Spacetime Physics <i>Lec 11: Turing Computability.</i> [deM18] First draft due
12	4/5. Lecture 11, cont.	4/7. Lec 12a: Classical and Relativistic Spacetimes hw5 due
13	4/12. Lec 12b: Relativistic Spacetimes and Computability. [EarNort93]	4/14. Lec 12b, cont. [Hog94]
14	4/19. Lec 13: Topology and QEC [Sim23]	4/21. Part V. Info-Theoretic Physics? <i>Lec 14: Spacetime as a QEC?</i> [Wol19]; hw6 due
15	4/26. Lec 15: Physics from Quantum Info? [Bub04]	4/28. Lec 15, cont. Revision due
16	5/3. Lec 16: Physics from Fisher Info? [Fr98: 3.1-3.4]; hw7 due; extra cred due; Final date announced by registrar	