STS-UY.3264 Physics, Information, and Computation

Prof: Jonathan Bain | Office: LC124 | Office Hour: Tu/Th 12:30-1:30pm | Spring 2020 | Room: xxx
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I. Description: What is entropy and how does it relate to the concept of information? Does the computational power of a computer depend on the structure of spacetime? How would a quantum computer differ from a classical computer? Is the fundamental nature of reality information-theoretic? This course considers these and similar questions by investigating the concepts of *information* and *computation* from the point of view of physics. Part 1 considers the relation between thermodynamic entropy and classical information; Part 2 considers the relation between spacetime structure and physical concepts of computation; Part 3 considers the relation between quantum and classical information; and Part 4 considers recent attempts to reconceive physics entirely in information-theoretic terms.

II. 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 and 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 and intellectual 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 complex issues involving the interactions among sci, tech, and society.

III. Required Reading (All required reading can be downloaded from the course website):

1. [B04] Bub, Jeffrey (2004) "Why the Quantum?", *SHPMP 35*: 241-66.
2. [B01] Bub, Jeffrey (2001) "Maxwell's Demon and the Thermodynamics of Computation", *SHPMP 32*: 569-79.
3. [DM18] de Mol, Liesbeth. (2018) "Turing Machines", *The Stanford Encyclopedia of Philosophy*, E. Zalta (ed.), <http://plato.stanford.edu/entries/turing-machine/>.
4. [EN99] Earman, John and John Norton (1999) "Exorcist XIV: The Wrath of Maxwell's Demon. Part II. From Szilard to Landauer and Beyond", *SHPMP 30*:1-40.
5. [EN98] Earman, John and John Norton (1998) "Exocist XIV: The Wrath of Maxwell's Demon. Part I. From Maxwell to Szilard", *SHPMP 29*: 435-71.
6. [EN93] Earman, John and John Norton (1993) "Forever is a Day: Supertasks in Pitowski and Malament-Hogarth Spacetimes", *Philosophy of Science 60*: 22-42.
7. [F93] Finn, C. P. (1993) *Thermal Physics*, Chapman & Hall (excerpts).
8. [Fr99] Friedan, B. R. (1999) *Physics from Fisher Information*, Cambridge Univ. Press, (excerpts).
9. [G01] Goldsein, Sheldon (2001) "Boltzmann's Approach to Statistical Mechanics", in Bricmont, J. *et al*. (eds.) *Chance in Physics: Foundations and Perspectives, Lecture Notes in Physics 574*, Springer: 39-54.
10. [H94] Hogarth, Mark (1994) "Non-Turing Computers and Non-Turing Computability", in *PSA 1994*, D. Hull, M. Forbes & R. Burian (eds.), Philosophy of Science Association: 126-38.
11. [RP00] Rieffel, Eleanor and Wolfgang Polak (2000) "An Introduction to Quantum Computing for Non-Physicists", arXiv:quantu-ph/9809016v2.

12. [T08] Timpson, Chris (2008) "Philosophical Aspects of Quantum Information Theory", in D. Rickles (ed.) *The Ashgate Companion to the New Philosophy of Physics*, Ashgate.
13. [T04] Timpson, Chris (2004) *Quantum Information Theory and the Foundations of Quantum Mechanics*, PhD Dissertation, University of Oxford (excerpt).

IV. Requirements

1. **Two papers** of 5-7 pages. Suggested topics will be provided at least 2 weeks before due dates.
   (a) All papers must conform to writing guidelines that will be handed out in class.
   (b) *Late paper policy*: There are no extensions on due dates. Late papers will be accepted but will be given an initial penalty of 1/3 grade point, and a further penalty of 1/3 grade point for every period of 7 days after the due date. *Example*: An A paper turned in 1-7 days late will receive an A-; an A paper turned in 8-14 days late will receive a B+; an A paper turned in 15-21 days late will receive a B; *etc*. *Under no circumstances will late papers be accepted after the date of the final.*
2. **Seven take-home assignments** due every other week on the dates listed below. These assignments will involve primarily conceptual questions on the material covered in lecture. *Late assignments cannot be accepted*.
3. One **midterm** and one **final**. These will consist of short answer questions and short essay questions. Both will be closed-notes/closed-text/smart-phones off. Please be aware that rest-room breaks are prohibited during examinations.

V. Grade Distribution

Assignments: 20% total Midterm: 20% Papers: 40% total (2@20%) Final: 20%

VI. Reminders on University Policies

1. **Community Standards and Procedures**. Please familiarize yourself with the NYU-Tandon Office of Student Affairs "Community Standards and Procedures" website: http://engineering.nyu.edu/life/student-affairs/community-standards-procedures. This website contains information relevant to:
   (i) ***Incompletes***. It is university and TCS 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 must attend every lecture and make sure you're aware of assignment deadlines and exam dates. If for whatever reason you find yourself falling behind during the semester, do not hesitate to see the instructor as soon as possible. If you think you qualify for an incomplete grade at the end of the semester, see the procedure in (ii) below.
   (ii) ***Excused absences and missed exams***. If illness or an accident causes you to miss class or an exam, the Office of Student Affairs instructs you do to the following:
   - Notify your professor by email of your absence, the reason for it, and how long you think you may be away.
   - Obtain medical documentation and when you are back on campus see Judith Simonsen, Coordinator of Advocacy and Compliance in Dibner Hall Room LC 240C.
   - Do not provide anyone except her with a copy of your paperwork. If a professor requests a copy, refer them to Ms. Simonsen. This is to protect the confidentiality of your medical information

   (iii) ***University Honor System***. All students should 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.
2. **Moses Statement.** If you are student with a disability who is requesting accommodations, please contact the Moses Center for Students with Disabilities (CSD) at 212-998-4980, mosescsd@nyu.edu, nyu.edu/csd, 726 Broadway, 2nd Fr. You must be registered with CSD to receive accommodations.

VI. Schedule (Subject to change over the semester. The reading assignments should be completed by the date on which they appear.

1	Tues 1/28. ***Part I: Entropy and Information*** *Carnot and Heat Engines.* Background: [F93] Chap 3.	Thurs 1/30. *Formulations of the 2nd Law*. [F93] Chap 4.
2	2/4. *Thermodynamic Entropy*. [F93] Chap 5.	2/6. *Thermodynamic Entropy, cont.* hw1 due.
3	2/11. *Maxwell's Demon*. [EN98] pp. 435-464.	2/13. *Boltzmann Entropy*. [G01].
4	2/18. *Boltzmann Entropy, cont.*	2/20. *Shannon Information*. [T04]. hw2 due.
5	2/25. *Demons and Information.* [EN99] pp. 1-20.	2/27. *Thermodynamics of Computation*. [B01].
6	3/3. ***Part II: Computation and Spacetime*** *Turing Machines*. [DM18]. Paper 1 due.	3/5.*Turing Machines, cont.* hw3 due.
7	3/10. *Classical and Relativistic Spacetimes.*	3/12. Midterm
8	3/17. Spring Break	3/19. Spring Break
9	3/24. *Turing Machines in Curved Spacetimes*. [EN93].	3/26. *Turing Machines in Curved Spacetimes, cont.* [H94]. hw4 due.
10	3/31. ***Part III. Quantum Information*** *Quantum vs. Classical 2-State Systems.* [RP00] pp. 1-16.	4/2. *Qubits and No-Cloning.* [T08] pp. 1-7.
11	4/7. *Quantum Cryptography*. [T08] pp. 7-13.	4/9. *Dense Coding and Teleportation.* [T08] pp. 13-20; [RP00] pp. 17-19. hw5 due.
12	4/14. *Dense Coding and Teleportation, cont.*	4/16. *Quantum Computation*. [T08] pp. 20-22; [RP00] pp. 19-23.
13	4/21. ***Part 4: Information-Theoretic Physics*** *Physics from Quantum Info*. [T08] pp. 38-45; [B04].	4/23. *Physics from Quantum Information, cont.* hw6 due.
14	4/28. *Physics from Quantum Information, cont.*	4/30. *Physics from Fisher Information*. [Fr99]. Paper 2 due.
15	5/5. *Physics from Fisher Information, cont*.	5/7. *Overflow/Review.* hw7 due.
16	Final (date to be announced by Registrar)	