Computational Complexity & Physics: Exam Standards

Models of computation

For good grade be comfortable with the notions: finite state machine, Turing machine (what kind of data is needed to specify it), languages, decision problems, Church-Turing-Thesis.

For excellent grade in addition: be able to explain limits to FSM model, be capable of writing TM program, be able to talk about CTT in relation to quantum computing.

Literature: Arora & Barak ([AB]).

Computability

Good: Turing number, UTM, Halting Problem

Excellent: Understand concepts of Gödel's Theorem

Not necessary: undecidable problems in QM.

Literature: [AB] sufficient, could look into *A Mathematical Introduction to Logic* by Enderton (but not required).

Ising model and graph theory concepts

OK: Understand Ising ground state problem, concept of frustration.

Ex.: have some intuition about "why" Ising suspected to be hard, understand the tree-case, have an idea of how reduction to graph problems like MAXCUT works (but not the actual proof).

Literature: Lecture notes probably sufficient. Could use `scholar.google.com` to locate a copy of *Finding a maximum cut of a planar graph in polynomial time* by Hadlock, but not required.

Time Complexity

OK: Def. of P, NP, PH; idea behind reductions, and completenes hardness; examples of NP-complete problems; SAT, k-SAT, basic ideas of Cook-Levin proof [AB], one example of Σ_2^p.

Ex.: Time hierarchy theorem; "why" we resort to reductions (rather than just prove things to be hard); use and limitations of "P" as model for "tractable"; a bit more details of Cook-Levin (though I certainly won't ask for the proof); FACT $\in$ NP$\cap$coNP and what that might mean; be comfortable with notion of "collapse" of PH; be comfortable with concept of post-selection (event though final lectures won't play a role).

Literature: AB. For post-selection: lecture notes or arXiv:1005.1407.

Circuits and probabilistic computations

OK: Circuits, randomized TM, BPP, PP. Basic idea of "amplification" (sheet 4).

Ex.: P $\neq$ P/poly, notion of "uniformity"; NP $\subset$ PP.

Not: BPP $\subset$ P/poly.

Literature: AB, Nielsen & Chuang [NC]

Randomness & Bell

OK: Idea of Bell, why would some people claim that it proves "true randomness is physical"?

Ex.: state Bell inequality precisely; be comfortable with various assumptions made in the argument.

Literature: The book *Quantum Mechanis: Concepts and Methods* by Asher Peres is a good source.

Quantum circuits

OK: Hamiltonians and unitaries; X, Z, H-gates and notion of "controlled gates"; read circuit diagrams; be able to analyze simple circuits.

Ex.: be comfortable with simple relations among X, Y, Z, H; Block sphere picure.

Not: memoryze *any* circuit!

Literature: NC.

Quantum complexity classes

OK BQP, evidence for BPP $\neq$ BQP.

Literature: NC.

Quantum algorithms

OK: Factoring and Order Finding problem statements (including simple modular arithmetic); QFT; QPE: what does it achieve? what are basic ingreadients; high-level view as found in "Summary of order finding" section in lecture notes.

Ex.: QPE for order finding: how to cope with fact that U^{2^j}-eigenvector depends on unknown quantity.

Not: details of c.f. expansion; reduction order finding $\rightarrow$ factoring; the *how* of Euclid's algorithm.

Literature: NC.

Number theory (one of two options)

Choose from either understanding the number theory of RSA at the level of sheet 6, or the "Physics of QC"-topic below.

Physics of quantum computation (one of two options)

Choose from either the “Number theory”-topic above, or: understand the ion trap computer to the level of sheet 9. That would include the basic architecture discussed in lecture: physics of trapping and laser cooling (phenomenologically); role of the bus; idea of rotating wave approximation (no details).

Not: the meansurement-based model

Literature: NC.