Lecture

Quantum Systems for Information Technology

spring term 2012

Lecturer:
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Exercise classes by:
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What is this lecture about?

Quantum Mechanics and its Applications in Information Processing

Questions:

- How can one use quantum physics to process information or to communicate?
- What kind of problems can be solved more efficiently using the ideas of quantum information processing?
- How does one build systems to process information quantum mechanically?

Tell us about yourself!

Who are you?

- What is your name? Where are you from?
- Which degree program are you in?
- Have you attended Quantum Physics (Exp/Theo) or Quantum Information (Exp/Theo) classes before?

Present your thoughts on:

How could quantum physics potentially be useful in information technology?

Lecture goals

understand how quantum mechanics is used for

quantum information processing (QIP) &
quantum communication (QC)

be proficient in basic concepts of QIP & QC

qubits, their manipulation and read-out

know basic examples of quantum communication

efficient information transfer (quantum dense coding),
transfer of quantum information (teleportation),
secure communication (quantum cryptography)

know basic examples of quantum algorithms

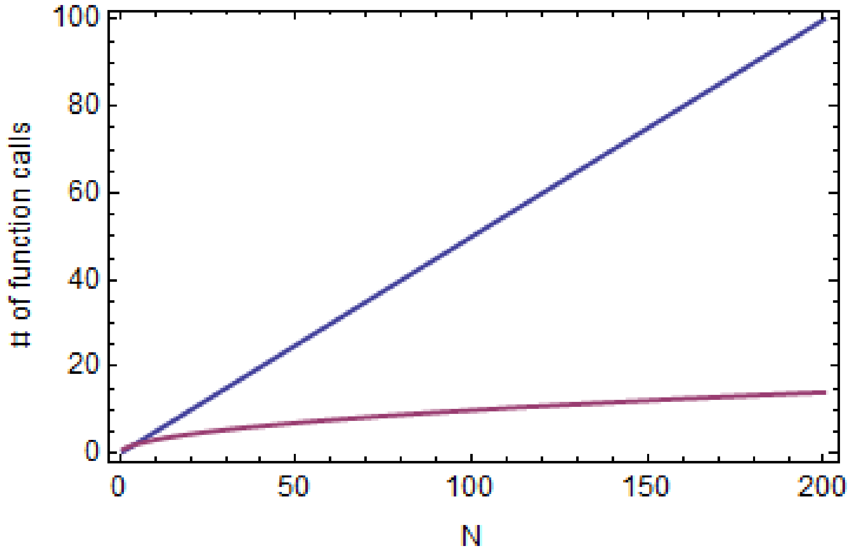
prime number factorization (Shor)
searching in a database (Grover)
simulating quantum systems (Feynman)

Grover search algorithm – A short introduction…

Question: Given a set of N cards in random order, how many guesses do you need (on average) to pick the right one?

Answer: You need O(N) guesses (function calls). On average that's N/2.

Using quantum mechanics, you can do better. Only $\sqrt{N}$ function calls are needed when using Grover's search algorithm.



Lecture goals

be knowledgeable about physical systems used for QIP

e.g. spins, atoms, solid state quantum systems,
their characteristic energy scales and operating conditions,
criteria to evaluate for QIP

know basic experimental techniques used to realize and characterize quantum systems

fabrication of quantum devices,
experimental setups,
general measurement and characterization techniques

Skills and competencies to be developed

You

- are able to explore the **use of quantum mechanics in different physical contexts:** atomic physics, solid state physics, optical physics, nuclear physics
- know basics concepts of **how quantum information experiments are performed** in different physical systems
- can use your knowledge of QIP concepts to **understand research** in areas not discussed in the lecture
- are able to **judge the state of the art** and relative progress in different technologies for quantum information processing
- are able to **critically evaluate prospects** of practical use of quantum mechanics for information processing and other quantum technologies
- acquire a basis to **decide if you want to work** in this field of research
- come up with your **own idea** of how to do an interesting QIP project

Basic Structure of the course

Part I: Introduction to Quantum Information Processing (QIP)

- basic concepts
- qubits, qubit control, measurement, gate operations
- circuit model of quantum computation
- examples of quantum algorithms

Part II: Superconducting Quantum Electronic Circuits for QIP

- qubit realizations, characterization, coherence
- physical realization of qubit control, qubit/qubit interactions and read-out
- interfacing qubits and photons (cavity quantum electrodynamics)

Part III: QIP Implementations (Lectures and Student Presentations)

- electrons and spins in semiconductor quantum dots
- trapped ions
- photons and linear optics
- spins (nuclear spin in NMR, electronic spin in NV defect centers)

Student Presentations

- **Topics**: Implementations of quantum information processing
- **Goal**: present key features of implementation
- **Material**: research paper + review articles
- **Preparation**: teams of 2 students, advice and support by TA (Arkady Fedorov)
- **Duration**: presentation + discussion (30 min talk +15 discussion)
- **Presentation**: PowerPoint, blackboard, transparencies
- compose a short, concise **abstract** of your presentation
- **feedback** on both content and presentation of your talk

Skills and competencies to be developed

You

- can **interpret current research results** in quantum information science
- know how to **extract relevant information** from scientific papers, possibly neglecting details
- can **communicate your understanding** of a scientific topic in an aural presentation
- are able to **summarize the scientific content** of a paper in short written form (abstract)

Exercise Classes

Part I & II (week 2-9)

- teaching assistant: Farrukh Abdumalikov– abdumalikov@phys.ethz.ch
- discuss and practice topics of lecture
- questions on the topics of lecture

Part III (week 10-13)

- teaching assistant Arkady Fedorov – fedoroar@phys.ethz.ch
- discuss and practice topics of lecture
- student presentations

Guest Lectures

topic:

- Ion Trap Quantum Computing (Jonathan Home, ETHZ)
- Quantum computing with spins (NMR, NV-Centers) (Christian Degen, ETHZ)

Literature:

- Quantum computation and quantum information (*the bible)*
  M. A. Nielsen & Isaac L. Chuang
  Cambridge University Press, 2000

- Preskill lecture notes
  (http://www.theory.caltech.edu/people/preskill/ph219/#lecture)

- Review papers
  (http://www.qudev.ethz.ch/content/courses/QSIT12/studentpres.html)

Credit (Testat) Requirements

- active contribution to lectures and exercises
- successfully prepare and present a talk on one the physical implementations of quantum information processing

Exam & Credits

- aural exam (20mins) during summer or winter exam session
- exam dates as required by your program of study
- 8 credit points (KP) can be earned successfully completing this class
- content of exam:
  - see goals of lecture
  - good presentation and active contribution to lecture will be a bonus

Time & Place

- **lecture**: Thursday (9-11), 8:45 – 10:30, HIT F 13
- **exercise class**: Friday (14-16), 13:45—15:30, HIT F13
- are there timing conflicts? potential alternative time slots?

Registration & Contact information

your registration and contact information

- please register online for the class – in this way we can contact you

our contact information

- qsit-lecture@phys.ethz.ch; filipp@phys.ethz.ch
- http://www.qudev.ethz.ch/content/courses/QSIT12/QSITlectureST12.html

The Bizarre World of Quantum Computing

YouTube video from engineering.com:

http://www.youtube.com/watch?v=e8c8_vO-dy8&feature=related

Let‘s get started…

"Actually I started out in quantum mechanics, but somewhere along the way I took a wrong turn."