Recomended pass through the study plan

Name of the pass: Quantum Informatics

Faculty/Institute/Others:
Department:
Pass through the study plan: Quantum Informatics
Branch of study guranteed by the department: Welcome page
Guarantor of the study branch:
Program of study: Quantum Infromatics
Type of study: Follow-up master full-time
Note on the pass: Zbývající kredity do povinnosti 120 kreditů může student získat za kterýkoliv magisterský předmět.

Coding of roles of courses and groups of courses:
P - compulsory courses of the program, PO - compulsory courses of the branch, Z - compulsory courses, S - compulsory elective courses, PV - compulsory elective courses, F - elective specialized courses, V - elective courses, T - physical training courses

Coding of ways of completion of courses (KZ/Z/ZK) and coding of semesters (Z/L):
KZ - graded assesment, Z - assesment, ZK - examination, L - summer semester, Z - winter semester

Number of semester: 1

Code	Name of the course / Name of the group of courses *(in case of groups of courses the list of codes of their members)* *Tutors, **authors** and guarantors (gar.)*	Completion	Credits	Scope	Semester	Role
QNI-QC1	**Quantum Computation 1**	Z,ZK	6	2P+2C	Z	PP
QNI-LOM	**Linear Optimization and Methods**	Z,ZK	5	2P+1C	Z	PP
QNI-MQI	**Mathematics for Quantum Informatics**	Z,ZK	6	2P+2C	Z	PP
QNI-UKT	**Introduction to Quantum Theory**	Z,ZK	6	2P+2C	Z	PP
QNI-PV	**Povinně volitelné předměty programu QNI Kvantová informatika** *QNI-AVM,QNI-QEC,..... (see the list of groups below)*	Min. cours. 4 Max. cours. 12	Min/Max 20/63			PV

Number of semester: 2

Code	Name of the course / Name of the group of courses *(in case of groups of courses the list of codes of their members)* *Tutors, **authors** and guarantors (gar.)*	Completion	Credits	Scope	Semester	Role
QNI-KOS	**Quantum Optical Communications and Networks**	Z,ZK	6	2P+2C	L	PP
QNI-QC2	**Quantum Computing 2** *Aurél Gábor Gábris **Aurél Gábor Gábris** Aurél Gábor Gábris (Gar.)*	Z,ZK	6	2P+2C	L	PP
QNI-PPS	**Programming of parallel systems** *Pavel Tvrdík **Pavel Tvrdík** Pavel Tvrdík (Gar.)*	Z,ZK	6	2P+2C	L	PP
QNI-TIN	**Information Theory** *Pavel Hrabák **Pavel Hrabák** Pavel Hrabák (Gar.)*	Z,ZK	6	2P+2C	L	PP
QNI-PV	**Povinně volitelné předměty programu QNI Kvantová informatika** *QNI-AVM,QNI-QEC,..... (see the list of groups below)*	Min. cours. 4 Max. cours. 12	Min/Max 20/63			PV

Number of semester: 3

Code	Name of the course / Name of the group of courses *(in case of groups of courses the list of codes of their members)* *Tutors, **authors** and guarantors (gar.)*	Completion	Credits	Scope	Semester	Role
QNI-KKP	**Cryptology and Quantum Computing**	Z,ZK	6	2P+2C	Z	PP
QNI-MPR	**Master Project** *Zdeněk Muzikář **Zdeněk Muzikář** Zdeněk Muzikář (Gar.)*	Z	7		Z,L	PP

QNI-CPX	**Complexity Theory**	Z,ZK	6	3P+1C	Z	PP
QNI-PV	**Povinně volitelné předměty programu QNI Kvantová informatika** *QNI-AVM,QNI-QEC,..... (see the list of groups below)*	Min. cours. 4 Max. cours. 12	Min/Max 20/63			PV

Number of semester: 4

Code	**Name of the course / Name of the group of courses** ***(in case of groups of courses the list of codes of their members)*** *Tutors,* ***authors*** *and guarantors (gar.)*	Completion	Credits	Scope	Semester	Role
QNI-DIP	**Diploma Project** ***Zdeněk Muzikář*** *Zdeněk Muzikář (Gar.)*	Z	30	270ZP	L,Z	PP

List of groups of courses of this pass with the complete content of members of individual groups

Kód	Name of the group of courses and codes of members of this group (for specification see here or below the list of courses)	Completion	Credits	Scope	Semester	Role
QNI-PV	**Povinně volitelné předměty programu QNI Kvantová informatika**	**Min. cours. 4** **Max. cours. 12**	**Min/Max** 20/63			**PV**

QNI-AVM	Adiabatic computing and variatio ...	QNI-QEC	Quantum error correction	QNI-QOM	Quantum Optics, Metrology, Sensi ...
QNI-QML	Quantum machine learning	QNI-NMK	Numerical methods for quantum co ...	QNI-OQC	Optical quantum computing
QNI-OPM	Optical measurements	QNI-OVV	Optimization for Scientific Comp ...	QNI-PNM	Parallelization of numerical met ...
QNI-PJK	Programming languages for quantu ...	QNI-VOT	Fiber Optic Technology	QNI-PON	Selected Topics in Optimization ...

List of courses of this pass:

Code	Name of the course	Completion	Credits
QNI-AVM	Adiabatic computing and variational methods	Z,ZK	6
The course introduces adiabatic computing and variational quantum algorithms (VQA). We start with a broad introduction to variational methods in physical chemistry (e.g., for calculating ground state of small molecules) and a recapitulation of advances in theoretical computer science (computational complexity and problems such as MAXCUT). We will present the EQA Conjecture and the unique games conjecture. We will present the adiabatic theorem and quantum speedup by quantum annealing (QA). We will build up an understanding of variational quantum algorithms by introducing and analysing, in turn, Variational quantum eigensolver (VQE), Quantum Approximate Optimization Algorithm (QAOA), and their Warm-started variants. As applications, we will highlight variational solvers for systems of linear equations and variational solvers for Markowitz portfolio management, with some discussion of the challenges in benchmarking of VQA.			
QNI-CPX	Complexity Theory	Z,ZK	6
Students will learn about the fundamental classes of problems in the complexity theory and different models of algoritms and about implications of the theory concerning practical (in)tractability of difficult problems.			
QNI-DIP	Diploma Project	Z	30
Independent work of the student under the guidance of the thesis supervisor. Teaching is based on individual consultations with the thesis supervisor or other consultants. The scope of teaching 30 ECTS (i.e. about 900 hours) includes consultations, preparation of theoretical and practical parts of the thesis, writing, preparation for defence and defence of the thesis before the commission. The course supervisor guarantees the quality of the Masters thesis assignment and its compliance with the graduate profile.			
QNI-KKP	Cryptology and Quantum Computing	Z,ZK	6
The course covers methods and algorithms of cryptology and their relation to quantum computing. In the first introductory lectures, students will be introduced to the basic principles and algorithms of cryptography. Following these topics, students will be introduced to basic cryptanalytic methods. Then some cryptanalytic algorithms running on quantum computers will be presented. In this context, the problem of security of related cryptographic schemes will be discussed. The next lectures will be devoted to post-quantum algorithms. The last lectures deal with cryptosystems using quantum phenomena.			
QNI-KOS	Quantum Optical Communications and Networks	Z,ZK	6
The course focuses on the basic principles and technologies for building and using quantum networks. Students will learn about the key components of quantum networks, including quantum repeaters, routers and switches, and their role in creating a scalable quantum Internet. Emphasis will be placed on quantum cryptography systems. Students will also learn the fundamentals of optics, optical networks, and classical cryptography as they relate to quantum key distribution (QKD) and quantum networks. The course will cover types and architectures of QKD systems (including practical implementation of quantum protocols) according to international standards, key generation and distribution in these systems, and integration of QKD with classical communication systems. Students will also have the opportunity to explore satellite and FSO QKD systems and integrated quantum photonics and electronics.			
QNI-LOM	Linear Optimization and Methods	Z,ZK	5
Students learn the applications of optimization methods in computer science, economics, and industry. They are aware of practical importance of linear and integer programming. They are able to work with optimization software and are familiar with languages used in programming of that software. They get skills in formalization of optimization problems in computer			

science (such as scheduling of tasks to processors, analysis of network flows), distribution and allocation of resources (transportation problems, travelling salesman problems, etc.), issues from economics, and modelling of conflicts via the game theory. They get an overview of computational complexity of optimization problems. They get orientation in algorithms in linear programming.

QNI-MPR	Master Project	Z	7

1. At the beginning of the semester, a student reserves her/his final thesis topic and gets together with its supervisor. Together they decide on partial tasks that should be carried out during the semester. If the requirements they agreed upon are met, the supervisor awards the student an assessment for the course MI-MPR at the end of the semester. 2. The external supervisor enters the information on granting the credit using the form "Granting credit from the external supervisor of the final thesis" (http://fit.cvut.cz/student/studijni/formulare). The completed and signed form must be delivered in person or by email to the SZZ coordinator, who will arrange for the credit to be granted. 3. If the FT topic that the student has reserved is rather general, the immediate tasks the supervisor assigns to the student for the upcoming semester should aim at fine-tuning the FT topic so that the FTT will be complete and approvable at the end of the semester.

QNI-MQI	Mathematics for Quantum Informatics	Z,ZK	6

Linear algebra on finite dimensional spaces with scalar product, Hilbert spaces, Dirac's bra-ket formalism, normal, Hermitian and unitary operators, operator spectrum, orthonormalization, diagonalization, matrix exponential, tensor product of vector spaces and operators. Discrete Fourier transform and fast Fourier transform.

QNI-NMK	Numerical methods for quantum computation	Z,ZK	5

The course is devoted to numerical solution of boundary-value problems and intial-boundary-value problems for ordinary and partial differential equations. It explains finite-difference, finite-element and finite-volume methods for elliptic, parabolic and hyperbolic partial differential equations. Students are introduced to the recent advances in methods solving the mentioned problems.

QNI-OPM	Optical measurements	Z,ZK	6

The aim of this course is to acquaint students with optical measurement methods from the detection of microparticles, non-regulation and surface breaches, through the use of fiber optics in areas where it is not possible to use standard electronic sensors, or in places with increased risk of explosion and in hospitals, lidars used in intelligent transport infrastructures, to macroscopic sensing (remote sensing) of the Earth, atmosphere and space. The inclusion of these measurement methods requires in particular an understanding of the physical mechanisms on which they are based, as well as knowledge of measurement procedures and specifics in data processing and reconstruction.

QNI-OQC	Optical quantum computing	Z,ZK	5

The course covers the basic theoretical methods and concepts for optical quantum computing, complemented by on hands-on exercise and applications using quantum programming libraries, Strawberry Fields and Piquasso. Theoretical concepts include measurement-based quantum computation, Gaussian Boson Sampling, and quantum supremacy. Applications feasible on current and near-term hardware include recent generative and discriminative machine-learning algorithms, as well as molecular vibration simulations.

QNI-OVV	Optimization for Scientific Computing	Z,ZK	5

The content of the course is an explanation of numerical methods for solving nonlinear optimization, convex optimization, stochastic optimization, optimal control, applications for QC, genetic and evolutionary programming, machine learning, deep neural networks. Students are also introduced to modern trends in solving these problems.

QNI-PJK	Programming languages for quantum computing	Z,ZK	5

Computational models for quantum computing: quantum Turing machine, QRAM, lambda calculus with qubits. Higher programming languages for quantum computation: imperative languages (Silq), functional languages (QML, Quipper).). In the seminars the student will learn the basics of programming in the higher programming language Silq.

QNI-PNM	Parallelization of numerical methods	Z,ZK	5

The content of the course is an explanation of numerical methods for solving mathematical models with a focus on their parallelization and the use of these methods in QC. Students are also introduced to modern trends in the field of solving these problems.

QNI-PON	Selected Topics in Optimization and Numerical mathematics	Z,ZK	5

Students will be introduced to special optimization problems that arise in the field of machine learning and artificial intelligence and will extend the basic knowledge of continuous optimization acquired in previous studies. They will also learn about the details of implementing solutions to these problems on a computer and related mathematical concepts, especially from numerical linear algebra.

QNI-PPS	Programming of parallel systems	Z,ZK	6

Nowadays, multi-core processors and GPU accelerators have become common components of computing clusters and high-performance computing systems, so knowledge and skills related to parallel programming are essential for every computer scientist. The aim of this course is to introduce students to the architectures and programming methods of parallel computers with shared memory, GPU accelerators, or with distributed memory. To effectively use these modern computing systems, it is essential to combine parallelization techniques at all three levels. Students will gain knowledge of the relevant programming models, languages and environments. They will become familiar with fundamental parallel algorithms and be able to analyze the limitations, efficiency, and scalability of parallel solutions to selected problems on high-performance computing systems. In addition to the necessary theory in lectures, students will gain practical experience and skills in programming in OpenMP, CUDA and MPI environments.

QNI-QC1	Quantum Computation 1	Z,ZK	6

The course introduces the student to basic principles of quantum computation and shows the difference between classical and quantum mechanics. Quantum computation uses quantum circuits, which will be demonstrated in the Qiskit SDK. The course will gradually introduce the student to such concepts the state of a quantum system and its visualization, measurements, basic gates and their composition, and the so-called entanglement. The student will be introduced to the BB84 and E91 protocols as demonstrations of the properties of quantum states. The course will also cover quantum teleportation, quantum oracle queries, the Deutsch-Jozsa algorithm, the quantum Fourier transform, the phase estimation algorithm, and the Shor algorithm.

QNI-QC2	Quantum Computing 2	Z,ZK	6

Quantum Computing 2 focuses on advanced quantum algorithms and their implementations: the Grover algorithm and its applications, quantum algorithms solving linear algebra problems, HHL for solving systems of linear equations. In the course we also introduce students to variational methods and error correction.

QNI-QEC	Quantum error correction	Z,ZK	5

In this course, we will build a theory for the construction of quantum error-correcting codes. In the introductory part, necessary chapters from the classical theory will be summarized, atop of which we then present the quantum analogy. We will show how coherently stored quantum information can be made robust to loss and noise. We conclude the course by arriving at the principle of fault tolerance, based on which quantum computers are able to continuously correct errors arising at runtime and thus achieve correct results even with erroneous bits, gates or measurements.

QNI-QML	Quantum machine learning	Z,ZK	5

The aim of the course is to introduce students to quantum machine learning. Students will first learn theoretically and practically about the quantum representation of classical data. Next, they will explore kernel methods, the quantum SVM model, and the use of quantum variational methods in supervised learning scenarios. The course will also introduce quantum neural networks and quantum generative adversarial models in unsupervised learning scenarios. The primary focus of the course is quantum algorithms for classical data. The exercises will use the pandas and qiskit libraries for Python to work with data and models.

QNI-QOM	Quantum Optics, Metrology, Sensing and Imaging	Z,ZK	5

Students are given an introduction to the quantum theory of light and related fundamental principles with an emphasis on practical aspects. They acquire the theoretical and experimental foundations for the development of specifically quantum mechanical approaches to metrology and imaging in quantum computing and communications. Specific problems discussed include elementary processes with photons (absorption, emission, stimulated emission), interference, entanglement, non-classical phenomena with photons, methods of suppressing optical aberrations and dispersion. The various techniques are explained theoretically and also using experiments that demonstrate these principles in practice.

QNI-TIN	Information Theory	Z,ZK	6
The course focuses on the mathematical description of a random message source, its coding and transmission of the source through a noisy channel. The coding problem is addressed probabilistically, the relation of the mean length of the optimal code with the entropy and entropy rate of the random source is emphasized. In the case of the noisy channel we focus on the set of typical sequences and its appropriate coding by self-correcting codes. The course includes a reminder of necessary concepts such as conditional distributions, goodness-of-fit and independence tests, and an introduction to random chains.			
QNI-UKT	Introduction to Quantum Theory	Z,ZK	6
interpretation of quantum theory are explained using simple models mainly from finite-dimensional quantum mechanics. Emphasis is placed on further applications of quantum theory to information processing and communication. Possible physical realizations of a qubit, description of multipartite systems, quantum entanglement and its applications are discussed. The course concludes with a description of continuous quantum systems in infinite-dimensional Hilbert spaces, in particular the linear harmonic oscillator as a description of the mode of a quantized electromagnetic field.			
QNI-VOT	Fiber Optic Technology	Z,ZK	6
The aim of the course is to introduce the mechanisms of optical wave propagation in optical fibres and fibre components. Furthermore, the knowledge of optical measurement techniques and measurement methods for the characterisation of optical fibres. The content includes both methodologies for measuring design and transmission parameters for optical communication systems such as numerical aperture, attenuation, dispersion, as well as measurements of basic characteristics of active and passive elements of optical communication systems - connectors, couplers, coupling elements, refractive indices.			

For updated information see http://bilakniha.cvut.cz/en/FF.html
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