Master's Thesis Topics for the academic year 2022-2023

1. Quantum algorithms for quantum games

Quantum algorithms will be developed to run quantum games on a quantum computer. Classical game theory will be studied, and a set of classical games will be quantized. Quantum games may include prisoner's dilemma, public goods games and Parrondo games. The players may be all quantum or quantum vs classical players. Applications of quantum games in real practical problems will be studied.

Master thesis examination committee.
Ioannis Karafyllidis (Supervisor)
Georgios Sirakoulis
Panagiotis Dimitrakis

2. Quantum algorithm for vehicle routing and traffic management based on quantum walks.

A simple city map will be mapped to a graph and a quantum walk on graphs algorithm will be developed to manage and optimize vehicle traffic and routing. Solid potential barrier will represent buildings and curbs and time-varying potentials will represent traffic lights. Finally, the quantum walk algorithms will be described as a quantum circuits and will be simulated using Qiskit.

Master thesis examination committee.
Ioannis Karafyllidis (Supervisor)
Georgios Sirakoulis
Pavlos Efraimidis

3. Quantum optimization algorithms based on the Ising model.

Quantum optimization algorithms based on the Ising chains model will be developed. Optimization parameters will be studied. The quantum algorithms will be executed on a quantum computer. Applications of quantum Ising optimization in real practical problems will be studied.

Master thesis examination committee.
Ioannis Karafyllidis (Supervisor)
Ioannis Boutalis
Pavlos Efraimidis

4. Quantum phase estimation algorithms for qubit string comparisons.

Comparing two qubit strings to find the number and location of differences is important in many applications. A quantum algorithm based on phase estimation will be developed and applied along with quantum Fourier transform to compare qubit strings.

Master thesis examination committee.
Ioannis Karafyllidis (Supervisor)
Pavlos Efraimidis
Raphael Sandaltzopoulos

5. Analysis of single-cell RNA-seq

Analysis of single-cell RNA-seq datasets from mouse or human samples. Alignment and downstream analysis in order to unveil the various populations and their respective transcriptomes and the differences between the populations.

Master thesis examination committee.
Petros Kolovos (Supervisor)
Raphael Sandaltzopoulos
Ioannis Karafyllidis

6. Application of quantum control methods for the efficient generation of entangled coupled spin states

This diploma thesis studies the problem of creation of an entangled state in a pair of coupled spins coupled by a specific interaction between them and driven by a pulsed magnetic field. Different quantum control methods will be used for the creation of the entangled state, namely resonant methods, adiabatic methods, shortcut to adiabaticity, optimal control, as well as machine learning techniques. In addition, the efficiency of the methods against the system parameters will be studied.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisios Stefanatos

7. Efficient generation of the exciton state in a semiconductor quantum dot – metal nanoparticle structure using specifically designed on-off pulses

To exploit the advantages offered by a coupled semiconductor quantum dot – metal nanoparticle system for quantum technology applications, a crucial problem is the efficient controlled population transfer from the ground state to the exciton state of the quantum dot, in the presence of the nanoparticle. This important problem has been explored in a series of studies, using different quantum control methods, with emphasis put on the effect of the interparticle distance. In this diploma thesis, the student will explore a new technique for the efficient generation of the exciton state, using specifically designed on-off electromagnetic pulses, which are created to give unity efficiency for the case of an ideal two-level quantum system without decay and dephasing effects in the absence of the plasmonic nanostructure. The efficiency of the studied scheme will be explored for different pulse sequences and for different interparticle distances between the quantum dot and the metal nanoparticle.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisios Stefanatos

8. Quantum control of a transmon qubit with different methods

Transmon qubits are of the utmost importance in quantum computing and quantum technology. In this diploma thesis, existing quantum control methods are applied in a transmon qubit theoretically and computationally and their efficiency in different system parameters for the creation of elementary quantum gates are explored. The student will also try to apply these quantum control methods experimentally in an existing transmon qubit and compare the experimentally obtained results with the theoretical and computational results.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisios Stefanatos

9. Efficient initialization of quantum dot spin states in the Voigt geometry: Optical pumping versus adiabatic preparation

Electron and hole spin states in semiconductor quantum dots are very important in quantum information technologies. Their manipulation can be efficiently achieved by the application of electromagnetic pulses. A particular system that has attracted significant attention in this research area is based on the spin states of a quantum dot in the Voigt geometry. An interesting problem for the quantum dot electron spin states in the Voigt geometry is the initialization, i.e., the preparation of one of the two electron spin states starting from an equal incoherent mixture, which is the natural initial state of the system. In this diploma thesis, the student will explore two different control methods for the initialization of the quantum, namely optical pumping and adiabatic preparation and compare the fidelity (efficiency of initialization) of the two methods for different parameters of the system.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisios Stefanatos

10. Exploring single-photon generation in an asymmetric quantum dot molecule

The generation of single photons is of major importance in several quantum technology applications. On demand single photon generation from semiconductor quantum dots has been shown with high efficiency in several cases and different quantum dot structures. This diploma thesis explores for the first-time single photon generation in an asymmetric quantum dot molecule consisting of two quantum dots coupled by tunnelling. The band structures of the quantum dots are different, while the rate at which the tunnelling effects occur is determined by the value of an applied voltage. The two-time intensity correlation function of the emitted photons is studied, focusing on the bunching–antibunching transition of the photons emitted in resonance fluorescence. The behaviour of the two-

time intensity correlation function is analysed for different parameters of the tunnelling coefficient, the intensity of the applied laser field and the detunings of the system.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisios Stefanatos

11. Nonlinear absorption and dispersion in an inhomogeneous collection of quantum dots

The nonlinear optical properties of quantum dots have been studied for several years and several potential applications in nanophotonics and quantum technology have been shown. In this diploma thesis, the optical properties of an inhomogeneous collection of quantum dots strongly driven by an external electromagnetic field are studied. The results for the nonlinear absorption coefficient and the nonlinear index of refraction are analysed under strong driving and saturation conditions. Also, the obtained results are compared with the case of weak driving and for the case of a homogeneous collection of quantum dots.

Master thesis examination committee
Emmanuel Paspalakis (supervisor)
Ioannis Thanopulos
Dionisios Stefanatos

12. Quantum algorithms in Artificial Neural Networks

Quantum algorithms will be implemented and tested to run various aspects of algorithms of ANN training and operation on a quantum computer. Classical ANN algorithms will be studied first, and a set of classical algorithms will be selected that could be quantized and benefited from the quantum implementation. Aspects of computational complexity, accuracy and generalization performance will be investigated in order to derive useful conclusions on the appropriateness of the quantized versions of the algorithms.

Master thesis examination committee
Ioannis Boutalis (supervisor)
Georgios Syrakoulis
Ioannis Karafyllidis

13. Controlling the quantum-light group velocity by cavity induced transparency: single-photon emission and interference effects

The propagation of a quantized probe field in a dense medium composed of three-level Λ-type quantum systems under conditions of electromagnetically induced transparency conditions is a topic which has attracted the interest of recent research activity due to its fundamental scientific importance as well as numerous potential applications in nanophotonics and quantum technologies.
In this diploma thesis, the group velocity of a probe pulse propagating under such conditions in a cavity is investigated in the weak and strong light-matter coupling regime. The possibility of photon-number selectivity on the group delay and the creation of single-photons on demand is studied. Also, the possibility of interference effects between different photon components in the probe pulse is addressed.

Master thesis examination committee
Ioannis Thanopulos (supervisor)
Emmanuel Paspalakis
Dionisios Stefanatos

14. Polychromatic adiabatic passage scheme for quantum information encoding

Polychromatic adiabatic passage schemes combine the high-selectivity between different target states achieved by coherent control methods with the effectively complete transfer of population under few-level adiabatic passage schemes. Such quantum control schemes have been in the center of the research on quantum control since its inception due to their evident potential for manipulating quantum systems and developing quantum technological applications. In this diploma thesis, the use of polychromatic adiabatic passage schemes for quantum encoding and decoding purposes is investigated on non-degenerate quantum systems. The dynamics of such processes are studied in the relevant quantum state subspace of dark states. The necessary parameters of the encoding laser fields required for achieving a target quantum information state by given a known initial state are determined. Also, the inverse process of developing a decoder for a given quantum information state is addressed.

Master thesis examination committee

Ioannis Thanopulos (supervisor)
Emmanuel Paspalakis
Dionisios Stefanatos

15. Quantum Machine Learning and Applications

Quantum machine learning combines concepts and algorithms of quantum computing with machine learning. The term encompasses quantum-enhanced machine learning, machine learning on data generated from quantum experiments, and the study of similarities between physical and learning systems. In the context of the MSc thesis, quantum machine learning will be studied, existing programming tools will be evaluated and indicative applications of quantum machine learning in the life sciences and other fields will be presented.

Master thesis examination committee.
Pavlos Efraimidis (Supervisor)
Ioannis Boutalis
Ioannis Karafyllidis

16. Dynamical decoupling methods for measuring the electron spin coherence time of atomic hydrogen

Encapsulated atomic hydrogen in polyhedral oligomeric silsesquioxane (POSS) cages is a potential molecular spin qubit that could be equally important to paramagnetic endohedral fullerenes. This thesis will investigate the electron spin coherence times of $H@T_8H_8$, where $T_8H_8 = Si_8O_{12}H_8$ is the smallest derivative of the POSS family. The student will focus on the implementation of the $(XY8)^N$ pulse sequence with resonant microwave (mw) pulses and will evaluate its performance upon selective mw excitation for the first time. This will allow discriminating between possible dephasing

mechanisms like nuclear spin diffusion and instantaneous diffusion. The latter mechanism will give insight into the local electron spin concentration, i.e., the local concentration of the encapsulated H atoms, which is expected to be an order of magnitude larger than the corresponding average value.

Master thesis examination committee
George Mitrikas (supervisor)
Yiannis Sanakis
Michael Pissas

17. Rabi oscillations and measurement of the rotating frame spin relaxation time $T_{1\rho}$ of atomic hydrogen

The longitudinal T_1 and transverse T_2 spin relaxation times cannot provide a complete description of the relaxation of dressed spins which are subject to resonant microwave (mw) irradiation. In the rotating frame (on-resonance), the quantization axis x of dressed spins is distinguished from y, therefore, relaxation along the two directions is expected to be different ($T_2/2<T_{1\rho}<T_1$). This thesis will study the $T_{1\rho}$ times of H@POSS (POSS: polyhedral oligomeric silsesquioxane) and will determine the spectral density $J(\omega_1)$ at the nutation frequency ω_1. The student will apply different pulse schemes comprising high turning angle (HTA) pulses and FID (free induction decay) or echo detection. The results will allow evaluating for the first time the spin relaxation properties of H@POSS under the application of quantum gates which are based on long resonant mw pulses.

Master thesis examination committee
George Mitrikas (supervisor)
Yiannis Sanakis
Michael Pissas

18. Magnetic characterization of a polynuclear transition cluster.

Polynuclear transition metal clusters (PTMC) have been proposed as possible candidates for the realization of qubits. In the present master thesis, the student will apply experimental methods in order to characterize the magnetic properties of a PTMC, based on transition metal and lanthanide ions. The characterization involves application of variable temperature, variable magnetic field static and dynamic magnetic susceptibility measurements, variable temperature Mössbauer Spectroscopy and variable temperature Continuous wave Electron Paramagnetic Resonance EPR spectroscopy. These studies will provide information about the nature of the spin value of the ground state, the exchange coupling scheme between the ions, the contribution of non-isotropic exchange terms, the composition of the eigenstates, and the temperature dependence of the spin relaxation time.

Master thesis examination committee
Yiannis Sanakis (supervisor)
George Mitrikas
Michael Pissas

19. Multivalued boundary and initial value problems and applications

The differential equations of multiple-order are studied, such as the two-dimensional wave equation, Laplace, Poison equations, the three-dimensional wave equation, the two-dimensional and three-dimensional heat equation, the Burgers equation, the Schrodinger equation and the corresponding boundary and initial value problem are detailed approached. A reference of the applications of the above problems in mathematical physics, electromagnetism, communication and other engineering scientific fields are mentioned. Relative software will be developed regarding to the solutions of these problems.

Master thesis examination committee.
Christos Schinas (Supervisor)
Ioannis Boutalis
Kyriakos Zoiros

20. Memristive accelerator for quantum computing simulators – the memory bottleneck

Memristive grids have been proposed as new nanoscale and low-power hardware accelerators for time-consuming operations such as matrix-vector multiplication and tensor products. The unique properties of memristive grids can be utilized to implement circuit-level quantum computations, simulate quantum computers, and serve as interfaces and accelerators in mixed classical-quantum computing systems since all quantum computations can be mapped to quantum circuits. Quantum computing simulation is constrained by the exponential increase in execution time and memory requirements as the number of qubits increases. The objective of this thesis is to design a memristive circuit capable of performing quantum computation that can reduce or even eliminate this issue by exploiting O(1) vector-matrix multiplication, Kronecker product, quantum algorithm compression and sparse matrices.

Master thesis examination committee.
Georgios Ch. Sirakoulis (Supervisor)
Ioannis Karafyllidis
Panagiotis Dimitrakis

21. Design and simulation of two-qubit quantum gates

Qubits are the fundamental elements for quantum computing. Superconducting qubits currently are more mature than any other technology proposed to realize qubits. Especially, transmon qubits have been studied and used extensively by many quantum processor manufacturers. However, the design and fabrication of transmon qubit has many parameters (structural, material, fabrication etc.) which could be optimized in terms of minimization of parasitics and qubit-to-qubit variability. The candidate will use the design tool Qiskit-Metal in conjunction with HFSS to solve and calculate the qubit operation characteristics and properties. Next, the design of a two-qubit gate will be implemented, and its functionality will be tested. The candidate should have very good knowledge of programming in python and transmon qubit theory.

Master thesis examination committee.
Panagiotis Dimitrakis (Supervisor)
Ioannis Karafyllidis
Georgios Ch. Sirakoulis

22. **Superconducting qubits based on transmon qubit**

The aim of the thesis is the graduate student to write a critical review/study of recent and current developments on superconducting qubits based on transmon qubit.

Master thesis examination committee.
Michael Pissas (Supervisor)
P. Dimitrakis,
I. Sanakis,

23. Use of the qiskit platform to design superconducting qubit

The graduate student will describe the design tools contained in the https://qiskit.org/documentation/metal/ platform. She/He will use these tools to design superconducting qubit.

Qiskit Metal is an open-source framework (and library) for designing superconducting quantum chips and devices (https://qiskit.org/documentation/metal/).

Master thesis examination committee.
Michael Pissas (Supervisor)
P. Dimitrakis,
G. Mitrikas