《量子信息技术及实践》课程教学大纲

<table>
<tr><td colspan="6">课程基本信息（Course Information）</td></tr>
<tr><td>课程代码（Course Code）</td><td>MS331+MS333</td><td>*学时（Credit Hours）</td><td>64</td><td>*学分（Credits）</td><td>4</td></tr>
<tr><td rowspan="2">*课程名称（Course Name）</td><td colspan="5">量子信息技术及实践</td></tr>
<tr><td colspan="5">Quantum Information Technologies and a Practical Module</td></tr>
<tr><td>课程性质 (Course Type)</td><td colspan="5">本科生核心课程</td></tr>
<tr><td>授课对象（Audience）</td><td colspan="5">致远学院本科生、交◦通全球课堂本科生</td></tr>
<tr><td>授课语言 (Language of Instruction)</td><td colspan="5">全英文授课</td></tr>
<tr><td>*开课院系（School）</td><td colspan="5">致远学院、物理与天文学院</td></tr>
<tr><td>先修课程（Prerequisite）</td><td colspan="5">线性代数、量子力学</td></tr>
<tr><td>授课教师（Instructor）</td><td colspan="2">唐豪、金贤敏</td><td>课程网址 (Course Webpage)</td><td colspan="2">https://global.sjtu.edu.cn/en/page/sub/215</td></tr>
<tr><td>*课程简介（Description）</td><td colspan="5">本课程包含 3 学分的教学课程和 1 学分的实践课程。3 学分教学课中将讲授量子信息和量子计算的基本原理、算法介绍和前沿动态，强调实战化演练和面向应用场景的量子算法展现，使学生掌握扎实的量子信息实战技术。通过本课程的学习，学生将理解计算复杂度基本概念及量子计算与经典计算的实质区别；了解光子、超导体、离子阱等不同量子计算物理体系的特点和区别；学习量子逻辑门的物理实现和矩阵表示，掌握各种量子逻辑门的相互推导转换；掌握 Deutsche 算法、Grover 算法、Shor 算法、量子傅利叶转换等基础算法的量子线路构建，并结合在线量子云平台操作展示；理解玻色采样、量子行走等专用量子算法，学习专用光量子计算、伊辛模型机、量子退火模拟器等常见专用量子计算途径的原理和物理实现； 掌握目前中等有噪声量子时代常用的 VQE、QAOA 等量子-经典混合变分量子计算；学习量子机器学习、量子优化、量子化学等面向应用场景的新兴交叉方向的量子信息原理和量子算法设计。
1 学分实践模块基于课程对量子计算基本原理及量子算法的量子逻辑线路构建等知识，进一步锻炼学生运用量子云平台构建演示量子算法的实践能力。学生将自主实战操作量子云平台，面向图像分类、飞行机设计、蛋白质折叠、金融投资优化等特定的应用场景需求，灵活选择合适的量子计算途径和算法，通过构建量子线路实现算法，并对计算结果进行分析，理解量子算法对于解决特定优化问题的应用以及量子算法的加速优势。</td></tr>
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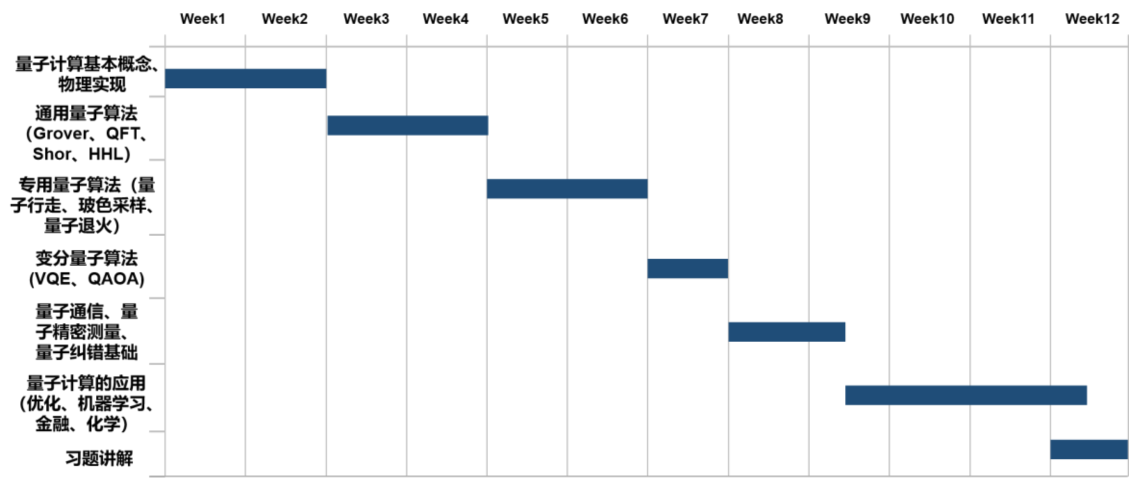
*课程简介 （Description）	This course would cover the fundamental principles, algorithm designs and frontier progresses on quantum information and quantum computing, with an emphasis on the practical skills and visions for application-oriented quantum information technologies. Through this course, the students are expected to: ✓ Understand fundamental concepts for computational complexity, and the essential difference between classical and quantum computing; ✓ Learn different physical platforms for quantum computing including photonics, superconductors, ion traps, etc; Understand the physical realization and matrix expressions for qubits and quantum gates. ✓ Master common universal quantum algorithms including Deutsche's algorithm, Grover's algorithm, Shor's algorithm, Quantum Fourier transform, and know how to implement quantum circuits on the online quantum cloud platform to demonstrate these algorithms. ✓ Learn analog quantum algorithms such as boson sampling and quantum walks, and understand the common analog quantum computing approaches including analog photonic quantum computing, Ising machine, and quantum annealer, etc. ✓ Know the hybrid quantum-classical algorithms such as VQE and QAOA that are being widely investigated as the Noisy Intermediate-Scale Quantum technologies. ✓ Learn the frontier progresses for the emerging field including quantum machine learning, quantum optimization, quantum chemistry and quantum finance, and how to design suitable quantum algorithms to address different applications. The practical module follows up the course *Quantum Information Technologies,* and would further train the practical skills of using quantum computing cloud platforms to apply quantum algorithms for real-life cases. Students are expected to use platforms such as IBM quantum experience, D-Wave Ocean or Amazon Braket to form the quantum circuits for solving real problems such as pattern classification, protein folding and financial portfolio optimization, etc. The students can flexibly choose a suitable quantum algorithm and implement it in a suitable quantum computing cloud platform. By analyzing the quantum implementation and the computational results, the students are expected to gain deeper understanding of quantum algorithms for optimization applications and the speed-up advantages brought up by quantum algorithms.
课程教学大纲（Course Syllabus）	
*学习目标 (Learning Outcomes)	1．了解量子计算与经典计算的实质区别以及在不同量子物理体系的实验实现； 2. 实战灵活运用不同量子逻辑门构建量子线路，实现特定用算法， 掌握扎实的物理知识与工科技能；从而了解并认识工程与科学的关系(A3) 3. 对常用专用量子算法、专用量子计算途径、以及量子加速优势等常见量子信息重点关注问题，对量子信息技术形成更全面的认识，培养良好的科研全局观。 4. 学习量子机器学习、量子优化、量子化学等面向应用场景的新兴交叉方向的量子信息原理和量子算法设计，培养多学科交叉的研究思维。

*教学内容、进度安排及要求 (Class Schedule & Requirements)

第 1-12 周内容安排：

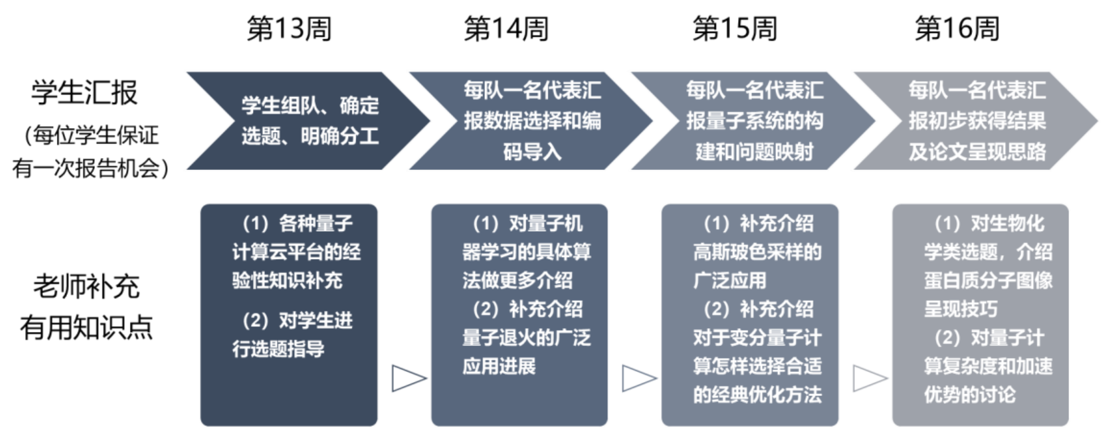


日期	*周次*	*教学内容*	*学时*	*教学形式*	*作业及要求*	*基本要求*	*考查方式*	*对应课程目标*
	1	*Some fundamental introduction* *1.1 An introduction to the course* *1.2 Brief history of computers* *1.3 Concepts for computational complexity,* *1.4 Basics for qubit. Essential difference between classical and quantum computing; Reviewing related quantum mechanics* *1.5 Realizing Qubits in different physical systems and their research progresses*	*4*	*课堂教学*	*文献阅读*	*阅读教程并理解概念*	*课堂提问*	*课程目标 1*
	2	*Quantum gates and quantum circuits (I)* *3.1 The bloch sphere* *3.2 Single qubit quantum gates* *3.3 Two-qubit and multi-qubit quantum gates* *3.4 Convert between CNOT and CZ gates* *3.5 Quantum gates in different physical systems*	*4*	*课堂教学*	*习题*	*掌握推导方法*	*课堂提问*	*课程目标 2*
	3	*Universal quantum algorithms and their circuit designs (I)* *3.1 Deutsch's algorithm*	*4*	*课堂教*	*习题*	*掌握公式推导*	*作业评分*	*课程目标 2*

		3.2 Grover's search algorithm for 1 out of 4 3.3 Grover search for general scenarios 3.4 Introduce IBM Quantum Experience, QPanda and HiQ online quantum processers		学		及平台操作		
	4	Universal quantum algorithms and their circuit designs(II) 4.1 Quantum Fourier Transform 4.2 The Shor's algorithm 4.3 Application to phase estimation	4	课堂教学	习题	掌握公式推导及平台操作	作业评分	课程目标 1 和 2
	5	Universal quantum algorithms and their circuit designs(III) (new algorithms based on QFT) 5.1 HHL algorithm 5.2 Quantum SVM 5.3 Quantum PCA 5.4 Exercise class on previous knowledge	4	课堂教学	习题及文献阅读	理解概念	作业评分	课程目标 1 和目标 2
	6	Analog quantum computing algorithms (I) 6.1 quantum walks and quantum stochastic walks 6.2 Boson sampling 6.3 Gaussian boson sampling	4	课堂教学	文献阅读	理解概念	课堂提问	课程目标 1
	7	Analog quantum computing algorithms (II) 7.1 Quantum annealing and adiabatic quantum computing 7.2 Superconducting annealer and photonic Ising machine 7.3 Map QUBO optimization problems in quantum annealing	4	课堂教学	文献阅读及分析	理解概念	课堂提问	课程目标 3 和目标 4
	8	Hybrid variational quantum computing 8.1 The NISQ era 8.2 VQE algorithm 8.3 QAOA algorithm 8.4 theoretical and experimental progress	4	课堂教学	习题及文献阅读	理解概念	作业评分	课程目标 1 和目标 2
	9	A brief introduction on quantum communication and quantum	4	课堂	文献	理解概念	报告评分	课程目标

		metrology 9.1 Fundamental concepts for quantum communication 9.2 Quantum communication network: from air to sea. 9.3 Fundamental concepts and applications for quantum communication		教学及示范操作	阅读及分析			3
	10	Quantum computing for optimization & machine learning 10.1 An overview of optimization of different types 10.2 Solve one optimization task using different quantum approaches such as Grover, quantum annealing, QAOA, etc. 10.3 An overview of quantum ML in different types: supervising, unsupervising and reinforcement learning 10.4 The gradient in quantum circuit and parameter shift rule 10.5 Feature maps in quantum circuits and case studies	4	课堂教学	文献阅读分析	理解概念	课堂提问	课程目标3
	11	Quantum computing for finance 11.1 An overview of quantitative finance and quantum involvement 11.2 QAE algorithm for financial derivative pricing 11.3 Quantum annealing for asset portfolio optimization 11.4 Exercise class for previous knowlege	4	课堂教学示范操作	文献阅读及分析	理解概念	报告评分	课程目标3
	12	Quantum computation for chemistry and biology 12.1 The mapping between fermions and qubits 12.2 Variational quantum eigensolver for solving molecular ground energy 12.3 Extensions and experimental implementations 12.4 Quantum annealing for protein folding	4	课堂教学及示范操作	文献阅读及分析	理解概念	报告评分	课程目标3

第 13-16 周内容安排：



日期	*周次*	*教学内容*	*学时*	*教学形式*	*作业及要求*	*基本要求*	*考查方式*	*对应课程目标*
	13	*Some fundamental introduction* *1.1 The practical tips for using the quantum cloud platform* *1.2 Tutorials on a few quantum machine learning algorithms e.g. QGAN, QAutoencoder, QCNN* *1.3 Set up teams, Q&A and discussion*	4	*课堂教学*	*文献阅读*	*阅读教程并理解概念*	*课堂提问*	*课程目标 1-4*
	14	*Practical training* *2.1 Each team reports on how to get the real data and how to load in quantum circuit* *2.2 Q&A and discussion (Teacher and TA help with practical issues)*	4	*实践操作*	*文献阅读*	*理解方法*	*课堂提问*	*课程目标 1-4*
	15	*Practical training* *3.1 Each team reports on Hamiltonian design for the task* *3.2 Q&A and discussion (Teacher and TA help with practical issues)*	4	*实践操作*	*文献阅读*	*理解方法*	*课堂提问*	*课程目标 1-4*
	16	*Analysis and Discussion* *4.1 Each team reports on the analysis of output results and how to present the work* *4.2 Discuss quantum advantages in quantum algorithms* *4.3 Q&A and discussion*	4	*课堂讨论及实践*	*文献阅读*	*理解方法*	*报告评分*	*课程目标 1-4*

*考核方式 (Grading)	（1）日常表现（30%）：课堂出勤、课堂回答问题及讨论分享等表现、课后作业。 Regular performance (30%): attendance, in-class performance and homework. （2）课上口头报告（20%）：在给定的题目中选择一个展开调研，做口头报告。 Oral talk (20%): Investigate a certain topic on quantum computing and make an oral talk on the topic in class. （3）期末试卷（25%）：根据课程知识点设计考卷答题，考核学生对于量子信息基本知识点和实用量子算法技术的理解。 Final exam paper (25%): The exam paper is designed according to the curriculum of the course, in order to assess students' understanding of the basic knowledge points of quantum information and practical quantum algorithm technology. （4）实践报告（25%）：针对特定的优化问题，基于量子云平台，运用所学知识演示尽可能高效优化的量子算法，分析量子线路和计算结果，并做书面报告。 Practical report (25%): The students are expected to demonstrate efficient quantum optimization algorithms for specific optimization problems using the quantum cloud platform. They would design quantum circuits, analyze the results, and write a formal report.
*教材或参考资料(Textbooks & Other Materials)	[1] Nielsen, M. A. and Chuang, I. L. *Quantum Computation and Quantum Information*. Cambridge University Press (2000). [2] Benenti, G., Giulio C., and Giuliano S. *Principles of quantum computation and information: Volume II: Basic Tools and Special Topics*. World Scientific Publishing Company (2007). [3] Wittek, P.. *Quantum machine learning: what quantum computing means to data mining*. Academic Press (2014). [4] IBM Quantum Experience Tutorial. Retrieved from: https://www.qiskit.org/documentation/index.html [5]Guo, G.P., Chen, Z. J., and Guo, G. C. *Introduction to Quantum Computing and Programming.* Science Press (2019).
其它（More）	
备注（Notes）	

备注说明：

1．带*内容为必填项。
2．课程简介字数为 300-500 字；课程大纲以表述清楚教学安排为宜，字数不限。