Google Summer of Code 2020

QuTiP Project: Improve Quantum Circuits Efficiency and Portability

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Overview

Quantum Computing has widely become an outstanding field catching the attention of many scientists. QuTiP understood some time ago the relevance of this emerging field and the needs of its community, that is why although QuTiP is well-known by its simulations of the dynamics of open quantum systems, it also developed a Quantum Information Processing (QIP) module.

The high demands of QuTiP users for new features in the QIP module led to the GSoC 2019 project. This year, the GSoC 2020 project would allow the QIP module to achieve one of its greatest developments by integrating to its code the quantum libraries Cirq (Google) and Qiskit (IBM), two of the most developed companies around the world in this field that lead the quantum computing race. The project would also enhance quantum circuits in terms of speed to compete with other available solutions. Finally, the project would build a way to make possible communication between different implementations of quantum instructions, and it would further develop the GSoC 2019 code.

Deliverables

First Milestone: Faster Quantum Circuits (1st June - 28th June)

1.1. A method under the qutip.QuantumCircuit module that makes the time measure possible. (1st June - 7th June)

1.2. A Jupyter Notebook in GitHub using libraries of other solutions to measure times for different scenarios. (1st June - 14th June)

1.2.1. Define test scenarios for time measures.

1.2.2. Run each scenario using all the solutions (QuTiP, Qiskit, Cirq, Yao) and measure its respective time. (Task before GSoC starts: it requires to understand *how to use* the other solutions)

1.3. Functions to enhance the code in QuTiP taking actions to gradually reach the measures of other available solutions for quantum circuits. (8th June - 28th June)

1.3.1. Study of the matrix multiplication algorithm in QuTiP in terms of algorithm complexity.

1.3.2. Find key points *where the algorithm* could be improved such as avoiding unnecessary calculations, coding recursive instead of iterative functions, using different data structures, etc.

1.3.3. Find key points *where the execution of the algorithm* could be improved such as doing parallel computing within the PC processors, creating a C code to execute calculations, etc.

1.3.4. Explore other ideas (e.g. use of matrix mathematical properties) that may arise up while working in the increase of the quantum circuit speed.

1.4. A Jupyter Notebook in GitHub reporting the new speed capabilities of the QIP module after each modification. (22nd June - 28th June)

Second Milestone: Import/export of quantum circuits to a standard format and other libraries (29th June - 26th July)

2.1. Functions to export objects of the qutip.QuantumCircuit module in different formats such as JSON, HTML, JavaScript, XML or QASM to make them compatible with other implementations (e.g. Cirq, Qiskit, Yao, etc.) (29th June - 12th July)

2.1.1. Identify the format of Quantum Circuit objects for different solutions. (Task before GSoC starts: set up environments to use other solutions)

2.1.2. Create a function for each of the formats that QuTiP will export.

2.2. Functions that read Quantum Assembly Language (QASM) to create an intermediate representation for quantum instructions (6th July - 19th July).

2.2.1. Develop partial measurement objects in QuTiP.

2.2.2. Develop classical control objects in QuTiP.

2.2.3. Function to read a QASM v1 file to create its QuTiP representation. (currently, pull request #1140 ignores many parts of the QASM file since there are not modules for 2.2.1. and 2.2.2.)

2.3. Function to export/import circuits from Qiskit (IBM quantum circuit library) using its API. (It's important to notice that IBM's API is an API REST) (13th July - 26th July)

2.4. Function to export/import circuits from Cirq (Google quantum circuit library) using its API. (It's important to notice that Google's API is a traditional API) (13th July - 26th July)

Third Milestone: Test and documentation (27th July - 9th August)

3.1. Following the guidelines of QuTiP contributors, each section of the new code must have its documentation and a Jupyter Notebook testing the added features or capabilities of the previous milestones. (27th July - 9th August)

3.2. A public blog with an entry each week of the work done and the experience of doing it. (3rd August - 9th August)

Optional: Further development and extension of QuTiP (10th August - 16th August)

4.1. A function to include stochastic dynamics to the quantum information noise simulation module developed in GSoC 2019. (10th August - 16th August)

Background, skills and motivation

I have completed my bachelor's degree in Physics and I'm currently pursuing my second undergraduate degree in Computing and Systems Engineering. Due to these two fields of study, my background is related to computational physics which provides me with the knowledge to understand concepts as quantum circuits formalism, quantum information processing, and quantum computing; and which also provides me with the skills to work in the back-end and the front-end of a project, to code scientific-Python scripts and to work in open-source projects through GitHub.

I have scientific programming skills in python, java and, C. I have experience working with libraries such as Scikit-Learn, Tensorflow and, Keras for Machine Learning and Artificial Intelligence. For data treatment, I use Numpy, Pandas, and Scipy. In data visualization, Matplotlib and Seaborn. Regarding the engineering programming skills, I know how to develop software in the back-end (Maven, Jenkins, GlassFish, Postman) and front-end (Bootstrap, Angular, TypeScript) using Java, CSS, HTML.

I joined the quantum optics research group at my college because I like applied quantum mechanics, and I started my double degree because I like computation and algorithms. However, I was still missing the common topic between those fields. Then I found quantum computing, and in a fraction of time, I knew it would be what I want to do for the rest of my life. I'd like to join this specific project because it's my passion, I enjoy each of the tasks related to this topic. But I also want to join this project because it would let me interact with people that are already doing what I want to do in my life: their experience is priceless.

Previous projects

Each project has its link:

1. *Computational Search of The Lowest Bound of Phase Information for Plausible Digital Image Reconstruction*. I implemented artificial neural networks (using TensorFlow) to study the physics behind a digital image. The main purpose of the project was to know where was the critical information of an image for a reconstruction process.

2. *Natural Language Recognition to enhance the processes of medical services in Colombia*. I developed a code (using Tesseract) to recognize words relevant to medical services such as private and public hospitals, clinics, etc. This process was decisive for a patient when authorization for an immediate medical process was needed.

3. *Data Science applied to the industry: insights from purchases*. Given a set of data I was asked to find some useful insights for the company about the purchases of a product.

Time availability

My classes end on 4th of June, and the next academic semester I will not have a heavy burden since I will take just two lectures. Given that academic activities would not interfere with my GSoC project, having the time availability, the motivation and a week-by-week program would allow me to accomplish each of the goals of this project. Moreover, I can keep working after the GSoC project as an open-source contributor to QuTiP.

Chronogram

Tasks before the official coding time

- ***Communication with the mentors of the project***: this task was completed on the 15th march with an email to Nathan Shammah, Eric Giguère and Alex Pitchford. Since that day we've shared emails and comments on GitHub until nowadays.
- ***Communication with the community:*** this task was completed on the 15th and 23rd march. On the 15th, I wrote an email to Boxi Li (QuTiP graduate GSoC 2019) who kindly gave me helpful suggestions and provide me with his proposal as a guide. On the 23rd, I started helping a user in the QuTiP Help group.
- ***Open a pull request in QuTiP:*** this task was completed on the 20th of March. The first pull request #1209 was made to solve issue #1208 asking to add more single-qubit gates to the QubitCircuit module. The second pull request #106 was the documentation testing the new features added under issue #1208.
- ***Learning the QuTiP structure of the code:*** this task was made to make the pull request. However, this task would eventually come up again along with the entire project.
- ***Setting up the tools to code and to manage the project:*** download the QuTiP library and setting up a conda environment to be able to develop code as a contributor were tasks of this previous-stage of the project. This preliminary part of the project was managed using the tool TeamWork which allowed me to create tasks and milestones with defined dates.
- ***Study of other solutions and set up of environments:*** since this project would be related to other solutions such as Cirq and Qiskit, I'd need to understand better and practice more with those tools, so I will not waste time during the project in other solutions but coding in QuTiP.

Tasks during the official coding time

Deliverables	Task	Week												
		June				July				August				
		1st-7th	8th-14th	15th-21st	22nd-28th	29th-5th	6th-12th	13th-19th	20th-26th	27th-2nd	3rd-9th	10th-16th	17th-23rd	24th-31st
1	1.1	x											x	x
	1.2	x	x										x	x
	1.3		x	x	x								x	x
	1.4				x								x	x
					evaluation									
2	2.1					x	x						x	x
	2.2						x	x					x	x
	2.3							x	x				x	x
	2.4							x	x				x	x
									evaluation					
3	3.1									x	x		x	x
	3.2										x		x	x
Optional	4.1											x	x	x
													code submission	

Each *evaluation week* besides other activities, it is also intended to fix bugs and solve setbacks to complete the milestone of each month.

Code submission weeks are intended to prepare the commit that will be merged into the project, and that is the reason why it checks all the code. It is also an additional time in case there were delays in the previous months.

To access a repository with all the application files for the GSoC 2020, please see here.