Inria Associate Teams programme

Intermediate report (Year 1 and 2)
(max 2 pages)

Associate Team acronym: QASAR (Quantum Architecture, Small And Reliable)

Period of activity: *Started in 2022.*

Principal investigator (Inria): Christophe Vuillot, MOCQUA Team, Inria Nancy.

Principal investigator (Partner Institution): Nikolas Breuckmann, lecturer at University of Bristol (since November 2022, at UCL before).

Other participants: Toby S. Cubbit, Associate Professor at UCL.

1. Future of the Associate Team
Would you like to pursue this Associate Team for one more year? ☒ Yes ☐ No

~~If the answer is No : *specify the reason(s) to end the Associate Team before the 3-year period*~~

2. Website of the Associate Team
https://team.inria.fr/qasar

3. List of participants
- **Nikolas Breuckmann (Bristol Lead), University of Bristol, junior researcher (Lecturer), permanent, started 2022, nikobreu.website**
- **Toby S. Cubitt (UCL Lead), UCL, senior researcher (Reader), started 2014,www.dr-qubit.org**
- **Alexandre Guernut, Inria, PhD student, started October 2021, end expected October 2024, members.loria.fr/Aguernut**
- **Timothée Goubault de Brugière, Quandela (startup), junior researcher, started 2022**
- **Oscar Higgott, PhD student, started 2019, end expected early 2024**
- **Emmanuel Jeandel, Université de Lorraine, senior researcher (Pr), permanent, started 2012, members.loria.fr/EJeandel**
- **Christophe Vuillot (Inria lead), Inria, junior researcher (CRCN), permanent, started 2021,members.loria.fr/CVuillot**

4. Achievements and Planned activities
The team made progress on the topic of efficiently performing logical operations on small quantum block codes.
The initial approach was to use 2D hyperbolic color codes as they posses a nice set of transversal gates. To augment them with addressable logical CNOT gates we numerically studied how to perform Dehn twists on them. This investigation revealed that for relatively small system sizes this approach was not practical, yielding low logical error rates. Even though it is guaranteed to work for sufficiently large sizes and since our goal is to target short and mid-term system with modest sizes we decided to switch to hyperbolic toric codes which are obtained from unfolding color codes.
A paper is currently being written with this set-up realizing the full Clifford group with a constant time-overhead using toric codes (Guernut and Vuillot).
This setup is a minimalistic one has the block of code host only two logical qubits. In parallel we have

started to identify the families of 2D hyperbolic and semi-hyperbolic codes to which we will extend the previous techniques (Breuckmann and Vuillot).
Another paper is also currently being written addressing the compilation side (Goubault de Brugière and Vuillot).
In parallel a result was obtained on how to robustly implement a family of quantum sampling experiments showing a quantum advantage over classical computers. The main innovation in this result is to define a specific quantum error correcting code with a particular set of transversal logical gates. This work was accepted at QIP24 (Vuillot and others).
Another result on modular architectures was obtained partially addressing our third objective (Breuckmann and others).
In 2024 we plan to meetup at the occasion of the workshop on "Advances in quantum coding theory" co-organized by Breuckmann at Simons Institute in the US, California, Berkeley (Breuckmann, Vuillot); organize a working session in Paris (Breuckmann, Goubault de Brugière, Guernut, Vuillot); and meetup again at the workshop on "Fault-Tolerant Quantum Technologies" co-organized by Vuillot and Breuckmann in Spain, Benasque (Breuckmann, Guernut, Vuillot).

5. Impact of covid-19 on the Associate Team's activity

No impact from covid.

6. Summary of the expenses

OM/BC	AGENT/FOURNISSEUR	DU	AU	OBJET	AMEX	GOELETT	FI	AGENT	TOTAL DEBIT	4 500,00 €
381008	HIGGOTT OSCAR	09/01/23	13/01/23	INVITE	261,00€	464,00 €	- €	105,00 €	830,00 €	3 670,00 €
381009	BREUCKMANN NIKOLAS	09/01/23	13/01/23	INVITE	133,00 €	426,90 €	- €	217,20 €	777,10 €	2 892,90 €
2023000829	API	09/01/23	13/01/23	10 REPAS INVITE	- €	- €	98,56 €	- €	98,56 €	2 794,34 €
MD C. VUILLOT	VUILLOT	11/01/23	11/01/23	REPAS	- €	- €	- €	145,10 €	145,10 €	2 649,24 €
387342	VUILLOT	10/04/23	16/04/23	BRISTOL	462,60 €	243,45 €	- €	310,28 €	1 016,33 €	1 632,91 €
									TOTAL DEPENSES	2600,64 €

We organized one working session in Nancy in January, one working session in Bristol in April and we initially intended to have one in Paris in the Fall which could not be organized due to conflicting schedules.

7. Budget requested for the coming year 2023

The requested budget for the coming year is 6000€.