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, initially postdoc at UCL now lecturer at University of Bristol (since November 2022)

Other participants: Toby S. Cubbit (Associate Professor, UCL), Alexandre Guernut (PhD, Inria), Timothée Goubault de Brugière (researcher, Quandela startup), Oscar Higgott (PhD, UCL), Emmanuel Jeandel (Pr, Université de Lorraine)

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
- <u>Nikolas Breuckmann (Partner Lead)</u>, University of Bristol, junior researcher (Lecturer), permanent, started 2022, nikobreu.website
- Toby S. Cubitt, 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 2023
- Emmanuel Jeandel, Université de Lorraine, senior researcher (Pr), permanent, started 2012, members.loria.fr/EJeandel
- <u>Christophe Vuillot (Inria lead)</u>, Inria, junior researcher (CRCN), permanent, started 2021, members.loria.fr/CVuillot

4. Achievements and Planned activities
The first objective of the associate team is to develop efficient techniques to perform logical operations on small quantum block codes.

We are first focusing on quantum color codes, which already have some interesting transversal gates. We are adapting to them a technique known to work for surface code called dehn twists. This allows to implement some Clifford operations to supplement the existing transversal operations. Applying this to 2D hyperbolic color codes can yield interesting gate sets. We are currently numerically evaluating the possible performance of the color code dehn twists on a simple torus first and then will try small 2D hyperbolic surfaces. This is mainly pursued by Guernut, Jeandel and Vuillot.

In parallel we started investigating the problem of compiling quantum circuits for gate sets obtained from quantum error correction architecture similar to the one above (hyperbolic color code in 2D or 3D). Typically one will have access to a global diagonal phase gate (as a transversal gate) and CNOT gates (obtained through dehn twists or measurement techniques). We obtained some preliminary results in the Clifford case (2D color code setup) in the form of a theorem of existence (depending on the structure of the phase gate) and some algorithms to compile in practice. We are now investigating the case beyond Clifford which is the most interesting setting. This is mainly pursued by Goubault de Brugière and Vuillot.

The third effort concerns 3D hyperbolic color codes and their possible generalization, quantum pin codes. Extending the effort above to 3D color code will be needed to reach universality of the logical gate set. This is a joint effort between London and Nancy which was set back due to personal circumstances: Christophe Vuillot had a child born prematurely in May (originally due end of June) which canceled and delayed the first planned visit between London and Nancy from May to August. The visit in August permitted to set everyone on the same track and the next planned visit is in January.

5. Impact of covid-19 on the Associate Team's activity
No impact from covid.

6. Summary of the expenses

EQUIPE ASSOCIE QASAR - C.VUILLOT
A retrouver sur EPIBUD en 5433
05/05RE1109-S/DRI-012233/0/210/62562/B541/0/BMI F

ANNEE	OM / BC	AGENT/FOURNISSEUR	du	au	LIEU	Désignation	Débit	SOLDE 8500	TOTAL MISSION
2022	371642	GUERNUT	22/08/22	22/08/22	LONDRES	AMEX	243	8257	
	371642					RYDOO	731	7526	
	371642					AGENT	357,01	7168,99	1331,01
	371171	VUILLOT	06/08/22	28/08/22	LONDRES	AMEX	587	6581,99	
	371171					AGENT	1561,02	5020,97	2148,02
	A venir	2 invités from London	decembre	1 semaine	Nancy	estimatif	0	5020,97	REPORTE JANVIER
	381008	HIGGOTT OSCAR	09/01/2023	13/01/2023	Nancy	AMEX	263	4757,97	
	381009	BREUCKMANN NIKOLAS	09/01/2023	13/01/2023	Nancy	AMEX	135	4622,97	
						TOTAL DEPENSES	3877,03		

A NOTER : EN PREVISON DE DEPENSES SUR LE BUDGET 2022, LES VISITES DE M.HIGGOTT ET M.BREUCKMANN ETAIENT ESTIMEES A 3200€.
MISSIONS REPORTEES EN 2023.
CERTAINES DEPENSES (BILLETS DE TRAIN VIA AGENCE DE VOYAGE) SONT PRIS SUR LE BUDGET 2022.
LES FRAIS DE SEJOUR (HEBERGEMENT, REPAS) ET LES DEPENSES AVANCEES PAR LES INVITES SONT PRIS SUR LE BUDGET 2023.
LES MONTANTS INSCRITS DANS LE BUDGET 2023 SONT A TITRE INDICATIF ET APPROXIMATIF.

ANNEE	OM / BC	AGENT/FOURNISSEUR	du	au	LIEU	Désignation	Débit	SOLDE 4500	TOTAL MISSION
2023	381008	HIGGOTT OSCAR	09/01/23	13/01/23	NANCY	AMEX	0	4500	
						RYDOO	464	4036	
						AGENT	145	3891	609
	381009	BREUCKMANN NIKOLAS	09/01/23	13/01/23	NANCY	AMEX	0	3891	
						RYDOO	464	3427	
						AGENT	225	3202	689
	BC API	API	09/01/2023	13/01/2023	NANCY	10 REPAS	130	3072	130
						TOTAL DEPENSES	1428		1428

7. Budget requested for the coming year 2023
The team is slowly growing, the requested budget for the coming year is 9000€.
There may be opportunities with the new partners institutions (UCL, University of Bristol, Quandela) to request additional funding.