Report QUDEDIS Exchange Grant 467

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1 Introduction

From December 13th 2004 to February 18th 2005, Armand Niederberger worked at the Institut für Theoretische Physik of Hannover University. The primary objective of this collaboration with Professor Lewenstein's Hannover Group was for him to study techniques for numerical simulations of dilute quantum systems. A recently proposed algorithm put forward by Guifré Vidal [1, 2] was in the main focus of this collaboration that is now continued between Armand Niederberger's home institution ICFO (Institut de Cienciès Fotòniques) in Barcelona and the host institution at Hannover University. Due to administrative constraints, Armand Niederberger had to be in Barcelona from March 1st 2005, which is why the exchange was ended two weeks earlier than scheduled.

2 Description of work carried out

During this visit, Armand Niederberger studied recent publications on new algorithms and protocols for studies of slightly entangled dilute quantum systems [1, 2, 3, 4, 5]. These algorithms are based on concepts developed in the context of Quantum Information Theory (QIT) that were then transferred to the study of cold gases.

On the whole, this exchange could be subdivided into two phases. In the first phase, the main goal was to get an overview of the latest articles on the subject as well a solid understanding of QIT–based approaches. The second phase then consisted of the actual implementation of these algorithms. In order to do so, fundamentals of scientific programming in C/C++ were learned. In this process, particular attention was payed to the choice of specific programming libraries, developed for numerical solution of linear algebra problems. Furthermore, fast allocation of computer memory and efficient programming structures were investigated. On top of that, possibilities of parallel computing and different ways of implementing complex numbers were explored.

3 Results

The main result of this collaboration is a computer programme, that contains an implementation of the numerical techniques for numerical studies of quantum dilute degenerate systems mentioned above. The present version is designed primarily for one–dimensional systems of spin–chains. Due to the inherent structure of the algorithm, it is most adapted to one particle interactions as well as to two particle next neighbours interactions. At this point, the programme is in the process of final testing and validation. We expect it to be fully operational already within the next couple of weeks.

4 Future collaboration

At ICFO, Armand Niederberger is currently finishing the programme. The remaining tasks are to implement imaginary and real time evolution routines as well as to validate the results. This last phase of development is subject to an ongoing close collaboration with a master's thesis student of Professor Lewenstein's Group who is working on a similar project. Because of this, mutual verification of results and discussions of different programming approaches are possible. Furthermore, the collaboration is continuing through the use of Hannover computer infrastructure not yet available at ICFO. Ultimately, our goal is to go beyond one dimensional systems by implementing similar algorithms for multi-dimensional systems [3]. The knowledge acquired during this exchange as well as the contacts with Hannover scientists are shared in the scope of ICFO quantum optics projects.

5 Projected publications

Up to now, numerical studies of general two-dimensional systems was very difficult with existing algorithms. The algorithms that we are considering being better adapted to these systems, we are very confident that we will be able to study two-dimensional lattice gases. In particular, we are currently considering triangular, square and hexagonal lattices with next neighbor interactions. The results of these studies are, of course, projected to be published as soon as the simulations are completed and evaluated.

6 Comments

Professor Lewenstein's Group for Theoretical Quantum Optics hosts very experienced researchers in the field of Numerical Quantum Optics. Being able to speak with these scientists directly accelerated not only the implementation these algorithms but also the understanding of efficient approaches to scientific programming as a whole. Recommendations and explanations of

specific libraries and access to computational resources not yet available at ICFO facilitated advances considerably.

On top of all that, this exchange tightened relations between researchers from Barcelona and from Hannover. Knowing about individual competencies will certainly prove to be very valuable for advances in our projects. For all these reasons we are grateful that we were given the possibility of pursuing this study in Hannover and confident about positive long term effects of this collaboration.

References

[1] G. Vidal. Efficient classical simulation of slightly entangled quantum computations. *Physical Review Letters*, 91(14):147902, October 2003.

[2] G. Vidal. Efficient simulation of one-dimensional quantum many-body systems. *Physical Review Letters*, 93(4):040502, July 2004.

[3] F. Verstraete and J. I. Cirac. Renormalization algorithms for quantum-many body systems in two and higher dimensions. cond-mat/0407066, July 2004.

[4] F. Verstraete, D. Porras, and J. I. Cirac. DMRG and periodic boundary conditions: a quantum information perspective. cond-mat/0404706, April 2004.

[5] E. Jané, G. Vidal, W. Dür, P. Zoller, and J. I. Cirac. Simulation of quantum dynamics with quantum optical systems. quant-ph/0207011, July 2002.