RESQ

IST–2001-37559

Resources For Quantum Information

Project funded by the European Community under the "Information Society Technologies" Programme (1998-2002)

Present

- Serge Massar (ULB): coordinator
- Nicolas Cerf (ULB): physicist
- Enrique Solano (MPQ): physicist
- Harry Buhrman (CWI): computer scientist
- Aram Harrow (UNIVBRIS): computer scientist

Plan

- The Project:
  - project structure and objectives
  - participants
- Administrative Issues during year 3
  - Second Amendement
  - RESQ meetings
  - Organization of international scientific events
- Review of Scientific Results of project RESQ (whole duration of project)
  - Physics (Serge Massar)
  - Information Theory (Andreas Winter)
  - Computer science (Harry Buhrman)
- Summary

Structure of the project:

Commission pointed out : "*the persisting cultural gap between computer scientists on the one hand and physicists and engineers on the other.*"

- This structured the project proposal.

  Remedying it is the essential Cultural objective of the project

- This was the basis for much of the work we carried out during the project

Project participants

- Partners from:
  - computer science
  - mathematics and statistics
  - physics

Part. Role	Participant Name	Short Name	Country	Computer Science	Mathematics	Physics
Co	Université Libre de Bruxelles	ULB	Belgium			●
P	CWI	CWI	Netherlands	●		
P	Université Paris-Sud / CNRS	LRI	France	●		
P	University of Bristol	UNIVBRIS	UK	●	●	●
P	Max Planck Institute for Quantum Optics	MPQ	Germany			●
P	University of Utrecht	UTRECHT	Netherlands		●	
P	MTA SZTAKI	MTA SZTAKI	Hungary	●		
P	University of Geneva	GAP	Switzerland			●
P	University of Cambridge	UCAM	United Kingdom			●
P	University of Gdansk	GDA	Poland			●
P	University of Waterloo	UW	Canada	●		●

Scientific Objectives

- Workpackage 1: Small Scale Applications
  - to understand how quantum information can be manipulated in small scale systems,
- Workpackage 2: Quantumness
  - to improve our understanding of the nature of quantum information, both at a fundamental level and from the pragmatic point of view of testing quantum systems,
- Workpackage 3: Networks
  - to understand how information can be processed in distributed quantum systems, both from the point of view of algorithms and from the point of view of security and cryptography,
- Workpackage 4: Quantum algorithms and algorithmical methods
  - to develop new quantum algorithms and to contribute towards building a toolkit for constructing quantum algorithms
- Workpackage 5: Management and Dissemination

Project Management

- **PROJECT COORDINATION COMMITTEE (PCC)**
  - **Assembly of all site leaders**
- **PROJECT COORDINATOR:**
  - **Serge Massar (ULB)**
  - **Assistant: Harry Buhrman (CWI)**
- **WP1:**
  - **Leader: Ignacio Cirac (MPQ)**
  - **Co-leader: Miklos Santha (LRI)**
- **WP 2:**
  - **Leader: Noah Linden (UNIVBRIS)**
  - **Co-leader: Richard Gill (Utrecht)**
- **WP3:**
  - **Leader: Harry Buhrman (CWI)**
  - **Co-leader: Nicolas Gisin (GAP)**
- **WP4:**
  - **Leader: Miklos Santha (LRI)**
  - **Co-leader: Gabor Ivanyos (MTA SZTAKI)**

Management in 2005

- Amendment :
  - No-cost extension until may 2006
- Organisation of 2½ day workshops:
  - Budapest (12-14 May 2005)
  - Paris (6-8 March 2006)
    - approximately 40 participants
    - Very informal
    - mix of tutorials and research presentations
    - invitation of external experts
    - invitation of members of other EU projects

RESQ meetings

RESQ meetings	**Location**	**Dates**
Preliminary meeting (not funded by RESQ)	Geneva	June 2002
RESQ kickoff meeting	Amsterdam	9-11 January 2003
Second RESQ meeting	Garching	12-14 May 2003
Third RESQ meeting	Barcelona	8-10 January 2004
Administrative meeting	Cambridge	10 September 2004
Fifth RESQ meeting	Budapest	12-14 May 2005
Sixth RESQ meeting	Paris	6-8 March 2006

Organisation of international scientific events

- **2004**

Newton Institute Program ***Quantum Information Sciences*** from 16/08/04 to 17/12/04. (Principal Organiser: UNIVBRIS) and associated workshops:

  - ***Quantum Information Theory: Present Status and Future Directions*** from 23-27 August (organised by partners ULB and UNIVBRIS);
  - ***Special Week on Quantum Cryptography*** from 6 to 10 September (organised by UCAM);
  - *Entanglement and Transfer of Quantum Information* from 26 to 30 September;
  - ***Quantum Statistics - Quantum Measurements, Estimation and Related Topics*** from 15-19 November (coorganiser: UNIVBRIS and UTRECHT)
  - ***Quantum Gravity and Quantum Information*** from 14-17 December (organiser UCAM).

- ***2005***

Semester on Quantum Information, Computation and Complexity at the Poincaré Institute (co-organiser LRI)and associated workshops

  - ***Ninth workshop on Quantum Information Processing****, 16-20 January* 2006 (organiser: LRI)
  - *QIPC Cluster Review and Conference 2006*, 13-15 February 2006.
  - *Quantum computation and coherence*, workshop, March 22-24 2006.

Scientific Results of RESQ (whole project)

- Publications
- Web of collaborations
- Overview of major scientific results

- High level of scientific output

Dissemination Activity	2003	2004	2005-2006
Published Articles and Letters in Scientific Journals (of which published in Phys. Rev. Lett., Nature)	37 (12)	70 (30)	74 (19)
Conference Proceedings	15	8	7
Total Publications	52	78	81
Accepted for publication, submitted, reports, manuscripts	68	90	78
Conference Presentations, seminars, posters	More than 95	More than 127	More than 170

Total PRL 51

Total Conf. 30

Total publications 211

Collaborations: On the Increase

- Collaborations published in 2003 : 5
- Collaborations published in 2004 : 7
- Collaborations published in 2005 : 22
- Collaborations submitted, in preparation 20

A web of collaborations

	# of collaborations
ULB	22
CWI	15
LRI	15
UNIVBRIS	19
MPQ	2
UTRECHT	2
MTA SZTAKI	6
GAP	14
UCAM	18
GDA	10
UW	9
TOTAL	**132**

See Table 1 of Peridic Progress Report for more details. Totals all collaborations of each partner (published in 2003, 2004, 2005, submitted and in preparation).

Major scientific results in 2004

WP1: Small Scale Applications

- New schemes for QIPC in specific systems:
  - Robust, fast 2 qubit gate in ion traps
  - Methods for entangling distant atoms
  - Method for generating a coherent superposition of the collective spin variable of atomic ensembles
  - Method for carrying out quantum computation in atomic lattices;
  - Error-free encoding of qubits in superconducting circuits;
  - Method for realizing a controlled phase gate for solid-state charge qubits;
  - carrying out optical quantum computing using photonic crystals;
  - carrying out quantum computing using spin chains;
  - producing entangled states of electrons and holes in solid state devices;
  - simulating statistical systems in ion traps.
  - deterministic generation of entangled multi-qubit states by the sequential coupling of an ancillary system to initially uncorrelated qubits
- These proposals will have a significant impact on experiments during the next years.

WP2: Quantumness (1)

- Quantum Non Locality:
  - Significant progress on using Bell inequalities as tests of quantumness
    - Statistical approach
    - Closing the Detection loophole
    - New loophole: « Coincidence time loophole »
    - Methods to carry out Bell tests in specific systems (continuous variables, cavity QED)

WP2: Quantumness (2)

- Study of correlations more non local than quantum correlations : maximally non local correlations (PR boxes)
  - What features of Quantum Mechanics are due to causality ?
    - No cloning
    - Uncertainty relations
    - Secure Key Distribution
  - What non local resources are required to simulate quantum correlations?
  - What features of nature break down when non local correlations stronger than quantum exist:
    - Communication complexity becomes trivial (Is Quantum Mechanics the bound ?)
    - (spin-off of this research : best upper bound for fault tolerant quantum computation)

WP2: Quantumness (3)

- Spin-Off to Solid State Physics: Improvements of Density Matrix Renormalisation Group method for classical simulation of quantum systems

WP2: Quantumness (4)

- Information Theory
  - First example of non-additivity of quantum channel capacity (multi-user case)
  - Locking of information in quantum states
    - Lockable measures: accessible information, entanglement cost, squashed entanglement, entanglement of purification
    - Spin-off: a new information-uncertainty relation
  - Resource calculus for QIT

WP2: Quantumness (5)

- Information Theory (cont'd)
  - Entanglement properties of generic states
    - Application: exotic entangled states
    - Application: statistical mechanics of pure states
  - State Merging *(Nature)*
    - Gives an operational meaning to quantum conditional entropy …and to negative information
    - Has a classical analogue

State Merging and Negative Information :

Bristol Evening Post

Friday, August 5, 2005

Scientist knows less than nothing

WP3: Networks (1)

- New protocols for quantum string flipping and quantum string commitment
  - New quantum commitment protocols outperforming classical ones
  - Applications to quantum information theory
  - Applications to classical string flipping protocols
- Quantum Key Distribution
  - QKD using continuous variables
  - QKD using higher dimensional systems
    - Error Filtration: method to reduce errors
  - QKD with bound entangled states
  - Key Distribution against an eavesdropper limited only by causality.

WP3: Networks (2)

- Analysis of strength and weaknesses of quantum simultaneous message passing model and quantum fingerprinting (STOC)
  - New fundamental bounds on classical versus quantum communication complexity
- Using quantum methods to obtain new results on classical “locally decodable error correcting codes” and “private information retreival schemes” (ICALP)

WP4 (1)
Quantum algorithms

- Algorithms for finding properties of graphs:

  ICALP 2004, pp. 481-493, 2004. (Best paper award of track A).
- Quantum algorithm for verifying matrix products (SODA'06)
- Strong time-space tradeoffs for fundamental problems (STOC'04 & '06)

WP4 (2)
Quantum Algorithms

- Progress on the hidden subgroup problem.
  - New instances were found where quantum mechanics allows fast solutions of the hidden subgroup problem were found.
  - Proved that certain quantum algorithms cannot help with the hidden subgroup problem when the group is the symmetric group.

WP4 (3)
Algorithmic methods

- Adiabatic quantum computing is equivalent to conventional computation model
  - translates the main open questions in quantum algorithms to the language of spectral gaps of sparse matrices
  - new vantage point from which to tackle the central issues in quantum computation (designing new quantum algorithms and constructing fault tolerant architectures)
- Finding the ground state energy of 2-Local Hamiltonian is QMA complete

WP4 (4)
Algorithmic methods

- (STOC04)Finding a local minimum for an integer valued function defined on the vertices of a graph. The complexity of the algorithm is measured by the number of evaluations of the function on some vertex.
  - This problem is the query analogue of PLS, an important complexity class between P and NP.
  - We show that for every graph, the classical and quantum query complexities of local search are polynomially related.
- New upper bounds on the noise threshold for fault tolerant quantum computation.

Summary (1)

RESQ is one of the main actors in the field of quantum information theory worldwide

- Large number of publications
- High quality of results
- Organisation of major scientific events
- Many internal collaborations

Summary (2)

- The results obtained in RESQ already have an important impact on Experiment and Theory of QIPC

- The web of collaborations will structure research on theory of QIPC in Europe over the next years.

- A significant part of RESQ continues in the integrated project QAP