CQC
Composing Quantum Channels

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Outline

1. Content, motivation, goals

2. Status of the project
   - timeline
   - resources committed & work progress
   - plan for the near future

3. Comments on application process & setup of project

4. Scientific part: Cutoff-phenomenon for quantum channels

5. Questions & Feedback
Project Content

• Quantum channel: $\rho \rightarrow T \rightarrow \rho' = T(\rho)$

• input-output-relation: black box, separate state from physical carrier

• time-evolution: unitary (closed system), e.g. Schrödinger eqn.
  dissipative (disregard environment), e.g. Lindblad eqn.
  -> one cell in q-memory for 1sec
  -> one step in (dissipative) q-algorithm

• (noisy) transmission of q-system/q-information
  -> e.g. optical fiber of 1 meter
  -> input = Alice, output = Bob

• classical analogue of $T$: stochastic matrix $M$
  -> Markov chains, Shannon information theory, …
Project Content: **CQC**

- Quantum channel: \( \rho \rightarrow T \rightarrow \rho' = T(\rho) \)

- Sequential repetition: e.g. continued time-evolution

\[
\rho \rightarrow T \rightarrow \rho' \rightarrow T \rightarrow \rho'' \rightarrow \ldots \rightarrow T \rightarrow T^t(\rho)
\]

- q-memory storage process, possibly controlled
- dissipative q-algorithm

- Parallel repetition: e.g. communication resources

\[
\rho_{(n)} \rightarrow T \rightarrow T \rightarrow \ldots \rightarrow T \rightarrow T^\otimes n(\rho_{(n)})
\]

- repeated use of optical fiber
- many (identical) memory cells
- complexity theory: resource framework
Motivation

• technological progress through information theory
  e.g. error correction (hard disk, …)
  coding theory (mobile networks, …)
  -> bring to quantum level: sophisticated classical protocols

• experimental control of quantum systems
  e.g. quantum repeaters for communication (BMBF Förderschwerpunkt)

• ultimate limits to communication, cryptography, computation, etc: QUANTUM
  - quantum Shannon theory: $Q(T_1 \otimes T_2) \geq Q(T_1) + Q(T_2)$
    quantify! give explicit codes!
  - unconditional security: $\text{Alice} \longrightarrow T \longrightarrow \text{Bank}$
    Eavesdropper
  - quantum algorithms: complexity questions, etc.
Goals

WP1: single q-channels
  (preparatory) perturbation theory, bosonic channels, ...

WP2: sequential composition with applications:
  Propp-Wilson, dynamic information theory, ...

WP3: parallel composition
  channel capacities, tensor stability. Applications:
  parallel repetition protocols, ...

WP4: complexity theory
  computational complexity, descriptive complexity,
  (un-)decidability

Application to
  - equilibration
  - spin chains

WP5: dissemination
  q-channel textbook/database, workshop, publications, ...

O1: theory/tools
O2: implications
O3: dissemination (WP5)
2. Project Status

timeline, organization

scientific work progress

plan for the near future
Project Status – timeline

Deadline CHIST-ERA call (QIFT): 5. November 2010
   -> project recommended for funding (duration: 3 years)

National application: 30. April 2011 (BMBF/DLR, Germany)

Project granted: July 2011 (Germany, TUM Munich). Grant start: August 2011
   July 2011 (Switzerland, ETH Zurich)
   September 2011 (Spain, UCM Madrid)

Postdoc hiring:
   • TUM: Jukka Kiukas (starting 06/2012) – bosonic systems, beam models
     Ion Nechita (07-09/2012) – channel capacities, random matrices
   • ETH: 1 postdoc (starting 07/2012)
   • UCM: 1 postdoc (starting 07 or 08/2012)
2. Project status, resources involved

Project Status – organization

TUM, Munich
Prof. Michael Wolf

ETH, Zurich
Prof. Matthias Christandl

UCM, Madrid
Prof. David Perez-Garcia

small consortium:
• not a very hierarchical structure
• formally: 1 coordinator (TUM)
• de facto: decisions taken together

-> simple Consortium Agreement
2. Project status, resources involved

**Project Status – scientific work I**

TUM:  master student (Feb-Sept 2012): tensor stability, q-capacity bounds (WP3)
      master student (Apr-Oct 2012): (un-)decidability questions (WP4)
      DAAD summer student (May-July 2012): q-capacity bounds, additivity (WP3)

      -> supervision/collaboration: Prof. Wolf & D. Reeb

UCM:  1 postdoc working with Prof. Perez-Garcia in parts of the workpackages
      progress on task T2.6 (random channels, equilibration): arXiv:1201.6324

Meetings/visits:  Wolf – Perez-Garica (Sept 2011, at UCM)
                  Christandl – Wolf (Feb 2012, at TUM)
Cooperation with BMBF quantum repeater project through H. Boche (TUM), coordinator of IQuRe project (theory aspects) and M. Wolf (TUM), coordinator of CQC

-> thematic links: e.g. realistic communications channel models
-> currently: joint seminars (memory channel models, correlated noise)

Workshop on Operator Structures in Quantum Information Theory
M. Christandl (ETH), Banff, Feb 2012

-> operator space techniques (e.g. tensor power stability)
-> CQC goals very well received
-> may result in new collaborations
Plan for the near future (1st-2nd year)

TUM: 1 permanent researcher (Prof. M. Wolf)
   2 postdocs
   2 master students
   1 DAAD summer student

ETH: 1 permanent researcher (Prof. M. Christandl)
   1 postdoc
   1 master student

UCM: 1 permanent researcher (Prof. D. Perez-Garcia)
   1 postdoc

summer/fall 2012: CQC internal meeting (after start of postdocs)
during 2nd year: small international workshop, with external experts
3. Comments on
   - application process
   - project setup
3. Application process & project setup

Comments: application process I

- from German side:
  • very good and pleasant contact with PT-DLR (German contact point/partner)
  • prompt responses to inquiries
  • very helpful in writing the grant application

- equally good experiences with the Swiss contact point
Comments: application process II

2 applications: European and national

-> possible to simplify application process?

  e.g. allow application for BMBF in English language
  (motivation and some WP's are the same)
3. Application process & project setup

Comments: granting stage

Starting Date of grant:
- more flexible starting date possible?
- maybe: time-window of 1 year, e.g. after finding postdocs to start working

Our situation:
- not hard to find good people
- but hard to find good people who can start immediately (TUM: July -> Aug)
- can start serious recruiting only after grant secured
- took us 9-12 months

Time-window would allow
- to synchronize the start date of all 3 partners
- while still being able to find postdocs to start on the project
- if no flexible time-window: need close cooperation between funding agencies
4. Scientific Part

M.J. Kastoryano, D. Reeb, M. Wolf
4. „Cutoff phenomenon“ for quantum channels

Scenario: q-memory or q-state-preparation

- $\rho$ and $\rho'$ are entangled over 1 time-interval
- $T$ stands for transformation over time
- $n$ memory cells or $n$ quantum particles over 1 time-interval
4. „Cutoff phenomenon“ for quantum channels

Scenario: q-memory or q-state-preparation evolving over time

Questions:
1) How long information preserved? (q-memory)
2) How long to prepare steady state? (q-computing)
4. „Cutoff phenomenon“ for quantum channels

Our question:

Know asymptotics of time sequence of one memory cell: $T^t$ for $t \to \infty$

$$L e^{-\lambda t} \leq \| T^t (\rho) - \rho_\infty \|_1 \leq R e^{-\nu t}$$

-> What about behavior of large number $n$ of cells/particles?

-> how long preserve info in q-memory ?

-> how long to prepare steady state ?

Want: convergence behavior of $(T^\otimes n)^t$ for $t \geq 0$.

-> exhibits „Cutoff Phenomenon“
4. „Cutoff phenomenon“ for quantum channels

for large number $n$ of cells/particles:

$$\sup_{\rho} \left\| (T^{\otimes n})^t (\rho) - \rho_\infty \right\|_1$$

1) Quantum memory: info preserved, info lost

2) State engineering: random state, state successfully prepared
4. „Cutoff phenomenon“ for quantum channels

for large number $n$ of cells/particles:

$$\sup_{\rho} \left\| (T^\otimes n)^t (\rho) - \rho_\infty \right\|_1$$

Classically! But quantum?

1) Quantum memory: info preserved  info lost

2) State engineering: random state  state successfully prepared
4. „Cutoff phenomenon“ for quantum channels

Quantum case:

\[
\sup_\rho \left\| (T^{\otimes n})^t (\rho) - \rho_\infty \right\|_1
\]

due to entanglement in the initial state

\[
t_{1,n} = \frac{\log n}{2\lambda}
\]
\[
t_{2,n} = \frac{\log n}{\lambda}
\]

info preserved
random state
state successfully prepared

info lost
4. „Cutoff phenomenon“ for quantum channels

Applications:

1) Preparation of Graph States (stabilizers) in time \((\log n) / \gamma\)
   - not constant, but still efficient

2) Can store 1 classical bit for time \(\sim (\log n) / 2\lambda\), where \(\lambda = \text{spectral gap}\)
4. „Cutoff phenomenon“ for quantum channels

Applications:

1) Preparation of Graph States (stabilizers) in time \((\log n) / \gamma\)  
   -> not constant, but still efficient

   Questions for CQC:  
   - shrinking of transition window?  
   - what about „overlapping“ channels?

2) Can store 1 classical bit for time \(~ (\log n) / 2\lambda\) , where \(\lambda = \text{spectral gap}\)

   Questions for CQC:  
   - storing quantum information?  
   - channel capacities? as functions of time?  
   - error protection in-between: „dynamical“ information theory  
   - what about correlated noise?
Your questions?

Your feedback?
Thank you!