CQC

Composing Quantum Channels

Michael Wolf – Technical University of Munich (TUM)
Matthias Christandl – ETH Zurich (ETH)
David Perez-Garcia – Universidad Complutense de Madrid (UCM)

Presenter: David Reeb, postdoc in TUM group

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: $\rho \longrightarrow \boxed{T} \longrightarrow \rho' = T(\rho)$

  - 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 1meter
    -> input = **A**lice, output = **B**ob

  - classical analogue of *T*: stochastic matrix *M*
    -> Markov chains, Shannon information theory, …

Project Content: CQC

- Quantum channel: $\rho \longrightarrow \boxed{T} \longrightarrow \rho' = T(\rho)$

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

$$\rho \longrightarrow \underbrace{\boxed{T} \longrightarrow \rho' \longrightarrow \boxed{T} \longrightarrow \rho'' \longrightarrow \quad \dots \quad \longrightarrow \boxed{T}}_{T^t} \longrightarrow T^t(\rho)$$

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

- Parallel repetition: e.g. communication resources

$$\rho_{(n)} \longrightarrow \underbrace{\begin{matrix} \boxed{T} \\ \boxed{T} \\ \vdots \\ \boxed{T} \end{matrix}}_{T^{\otimes n}} \longrightarrow T^{\otimes n}(\rho_{(n)})$$

  - 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

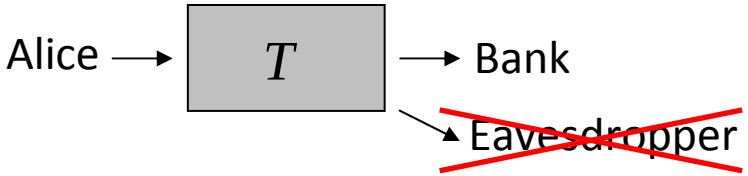
  e.g. quantum repeaters for communication (BMBF Förderschwerpunkt)

- 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:



  - quantum algorithms: complexity questions, etc.

Goals

O1: theory/tools
O2: implications
O3: dissemination (WP5)

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, …

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)

Project Status – organization

TUM, Munich
Prof. Michael Wolf

ETH, Zurich
Prof. Matthias Christandl

UCM, Madrid
Prof. David Perez-Garcia

PT-DLR

Bundesministerium für Bildung und Forschung

FNSNF Swiss National Science Foundation

Ministerio de Ciencia e Innovación

small consortium:

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

-> simple Consortium Agreement

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)

Project Status – scientific work II

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

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)

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

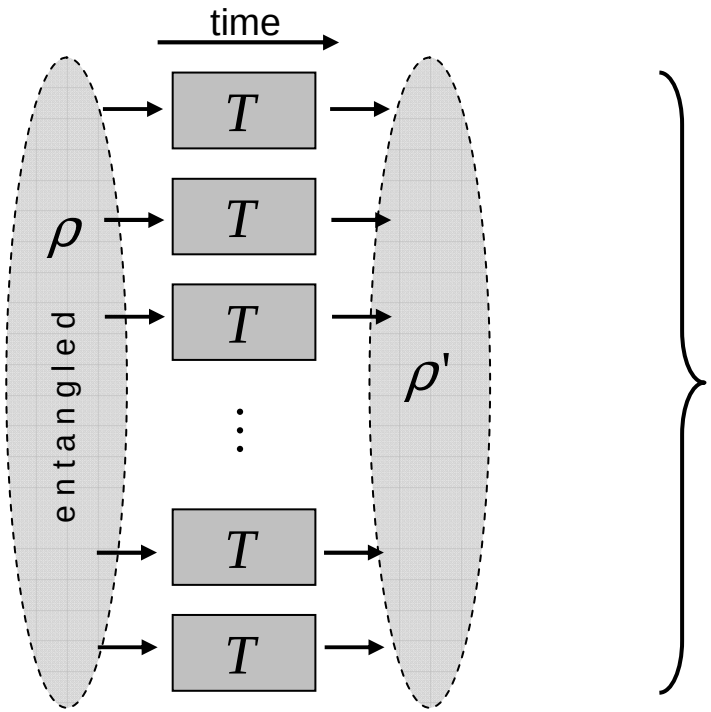
Time-window would allow
- to synchronize the start date of all 3 partners
- while still being able to find postdocs to start on the project
- if no flexbile time-window: need close cooperation between funding agencies

4. Scientific Part

„Cutoff Phenomenon“ for Quantum Channels, arXiv:1111.2123
M.J. Kastoryano, D. Reeb, M. Wolf

4. „Cutoff phenomenon“ for quantum channels

Scenario: q-memory or q-state-preparation

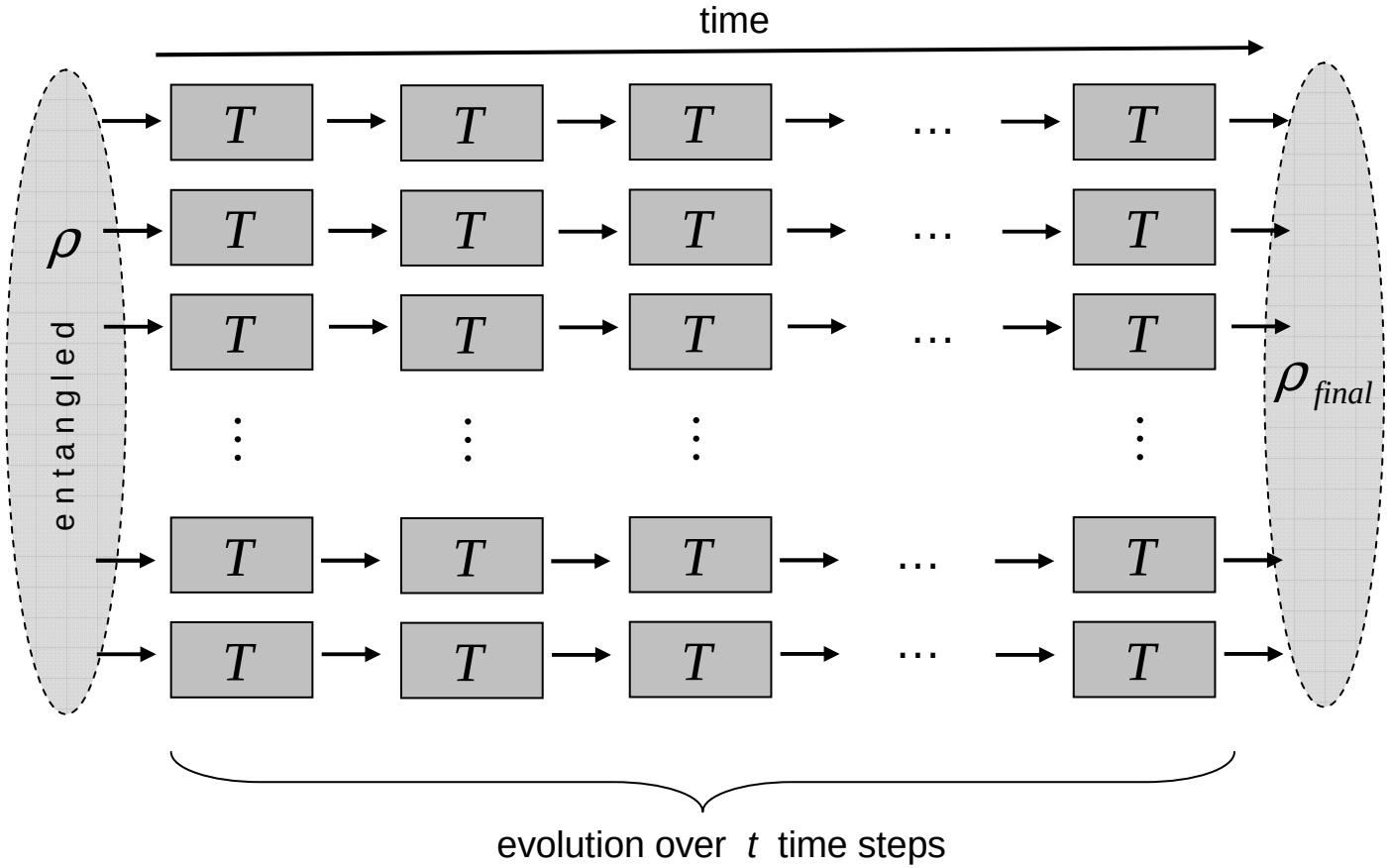


n memory cells
or: *n* quantum particles

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 $t \to \infty$

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

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

-> how long preserve info in q-memory ?

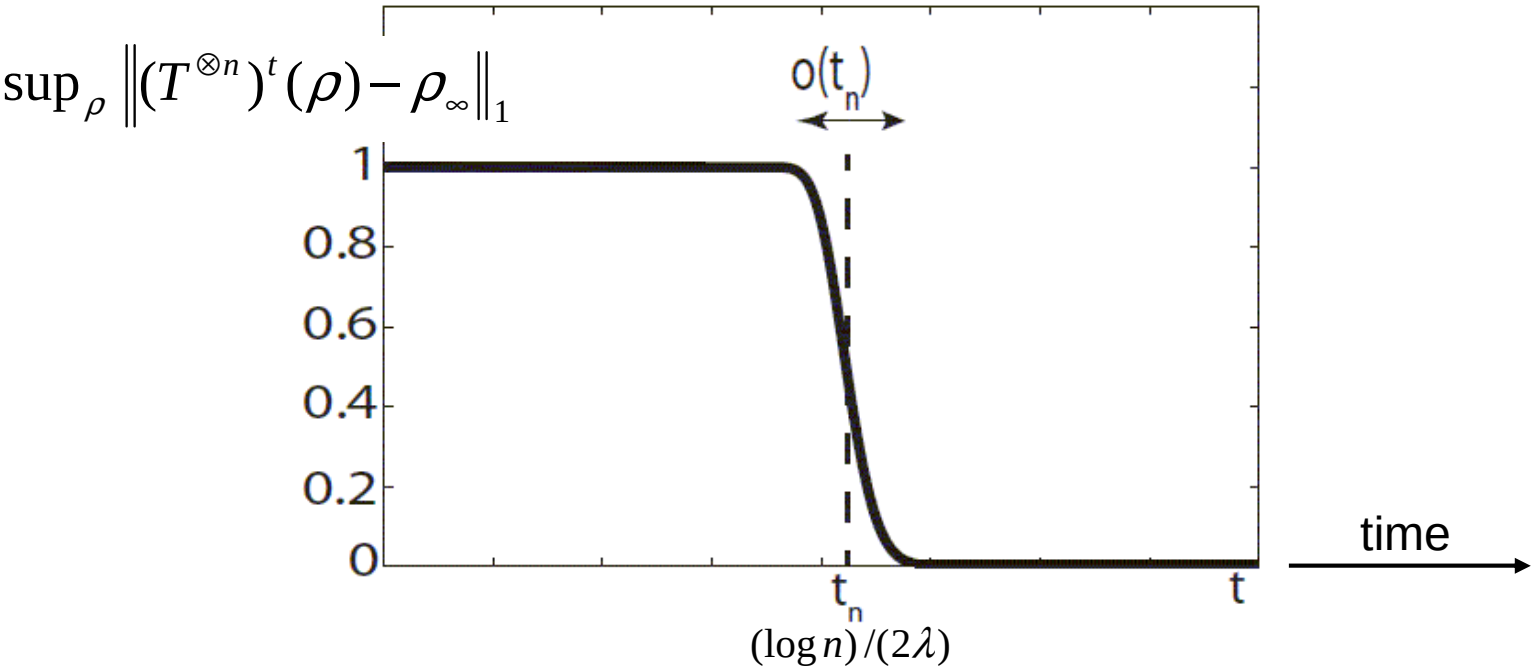
-> how long to prepare steady state ?

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:



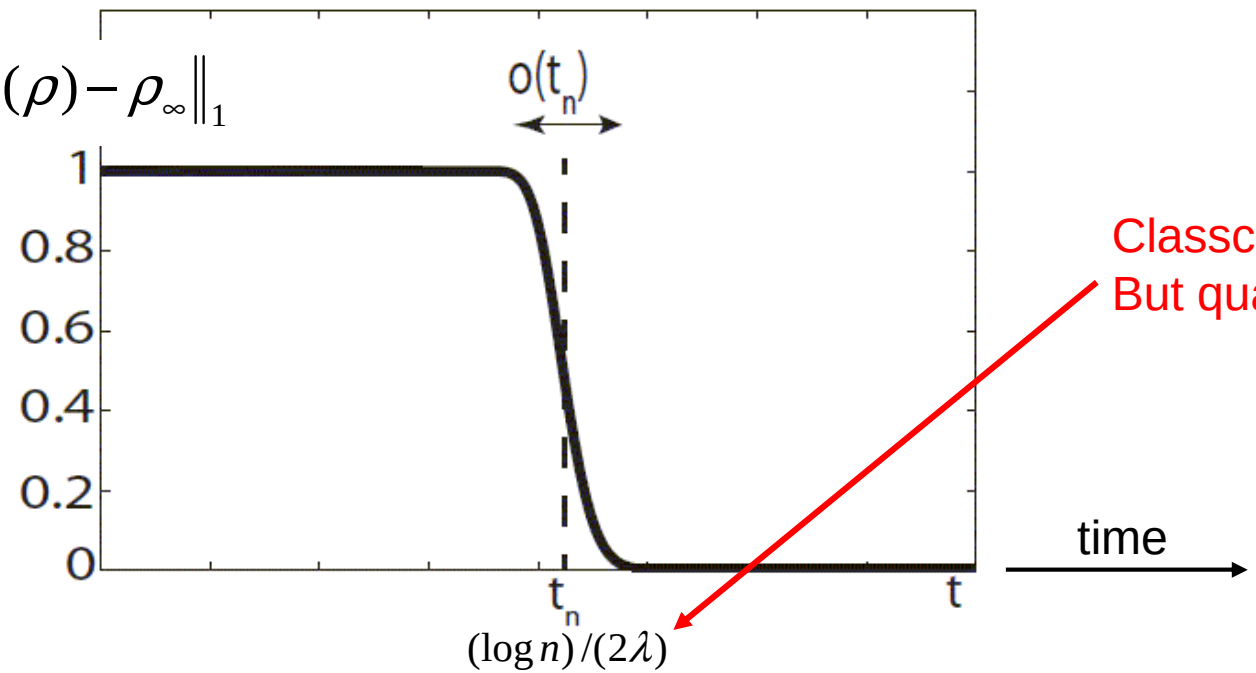
1) Quantum memory: info preserved | info lost

2) State engineering: random state | state successfully prepared

4. „Cutoff phenomenon“ for quantum channels

for large number *n* of cells/particles:

$$\sup_{\rho} \left\| (T^{\otimes n})^{t}(\rho) - \rho_{\infty} \right\|_{1}$$



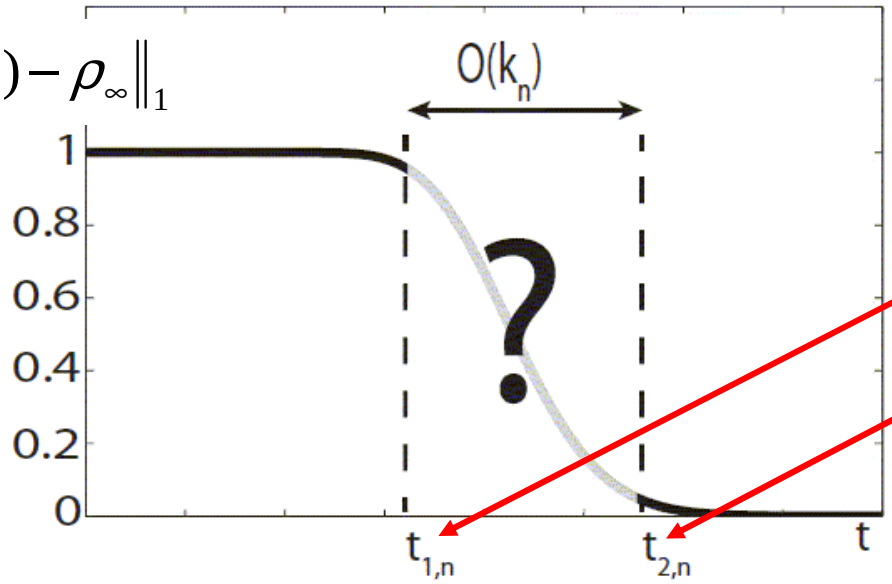
Classcially!
But quantum?

1) Quantum memory:	info preserved	info lost
2) State engineering:	random state	state successfully prepared

4. „Cutoff phenomenon“ for quantum channels

Quantum case:

$$\sup_{\rho} \left\| (T^{\otimes n})^{t}(\rho) - \rho_{\infty} \right\|_{1}$$



„ Pre-Cutoff “

$$t_{1,n} = (\log n)/(2\lambda)$$

$$t_{2,n} = (\log n)/\lambda$$

due to entangelement in the initial state

info preserved	info lost
random state	state successfully prepared

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 $\sim (\log n)/2\lambda$, 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?

5. Questions & Feedback

Your questions ?

Your feedback ?

Thank you!