Classical-Quantum Crypto Gadgets

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informatics

Post Quantum Crypto

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There is **NO**

quantum danger or advantage

for classical cryptography **right now**

Quantum Danger

classical security against adversaries that exploit quantum effects

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classical security against adversaries that exploit quantum effects

Quantum algorithms breaking computational assumptions
Factoring and Discrete Logarithm [Shor 94] Principal ideal problem [Hallgren 02]

Quantum effects breaking Information-theoretical assumptions
commitment scheme becomes non-binding [Crepeau,Salvail,Simard,Tapp 06]

Classical proof techniques no longer apply
rewinding

Quantum NO Danger

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Learning with Error (LWE)

as hard as worst-case lattice problems, believed to be exponentially hard against QC

Regev, STOC 2005

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LWE-based Crypto Systems (FHE and etc)

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Regev, STOC 2005

LWE-based Crypto Systems (FHE and etc)

(classical) **mixed commitment schemes** (secure against quantum)

lifting classical security proof to the quantum setting, **coin flipping protocols**

Damgard and Lunemann, ASIACRYPT 2009
Damgard et.al. Crypto 2009
Lunemann, Ph.D. Thesis 2010
Lunemann and Nielsen, AFRICACRYPT 2011

Quantum NO Danger

Learning with Error (LWE)

as hard as worst-case lattice problems which are believed to be exponentially hard against QC

Regev, STOC 2005

LWE-based Crypto Systems (FHE and etc)

(classical) **Zero-Knowledge Proof-of-Knowledge** (secure against quantum)

lifting classical security proof to the quantum setting, **secure function evaluation**

Hallgren, Smith and Song, Crypto 11

Quantum Advantage

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qubits transmissions and classical post-processing

unconditional security based on physical laws

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Information gain vs. disturbance
No Cloning
Spooky actions at a distance

Examples

1970 - **quantum money** (Wiesner)

The first link between secrecy and quantum physics

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(conjugate coding)

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To distribute secret such that only the authorised partners could recover it

1997 - **bit commitment and oblivious transfer** (Lo and Chau, Mayers)
contrary to the case of QKD and secret sharing
quantum physics cannot guarantee unconditional security

Examples

2007 - **bounded-storage models** (Damgaard et al; Wehner, Schaffner, Terhal)

unconditionally secure OT and BC is possible

where honest parties need no quantum memory, whereas an adversarial must store

at least n/2 qubits to break the protocol, where n is the number of qubits

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2009 - **blind quantum computing** (Broadbent, Fitzsimons and Kashefi)

Unconditionally secure quantum delegated computing

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Efficiency and Real Implementation

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“what quantum mechanics takes away with one hand, it gives back with the other”

Nielsen and Chuang 2000

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Pre-Post Quantum Crypto

A **hybrid** network of classical protocols with quantum gadgets

boosting efficiency and security

of every task achievable against classical attackers against quantum attackers

Pre-Post Quantum Crypto - Examples

Pre-Post Quantum Crypto - Examples

Digital Signature

Coin Flipping

One Time Memory

Secure QMC

Delegated QC

Verification

Classically-controlled QC

Q Crypto: qubits transmissions and classical post-processing

Classically-controlled QC

Q Crypto: qubits transmissions and classical post-processing

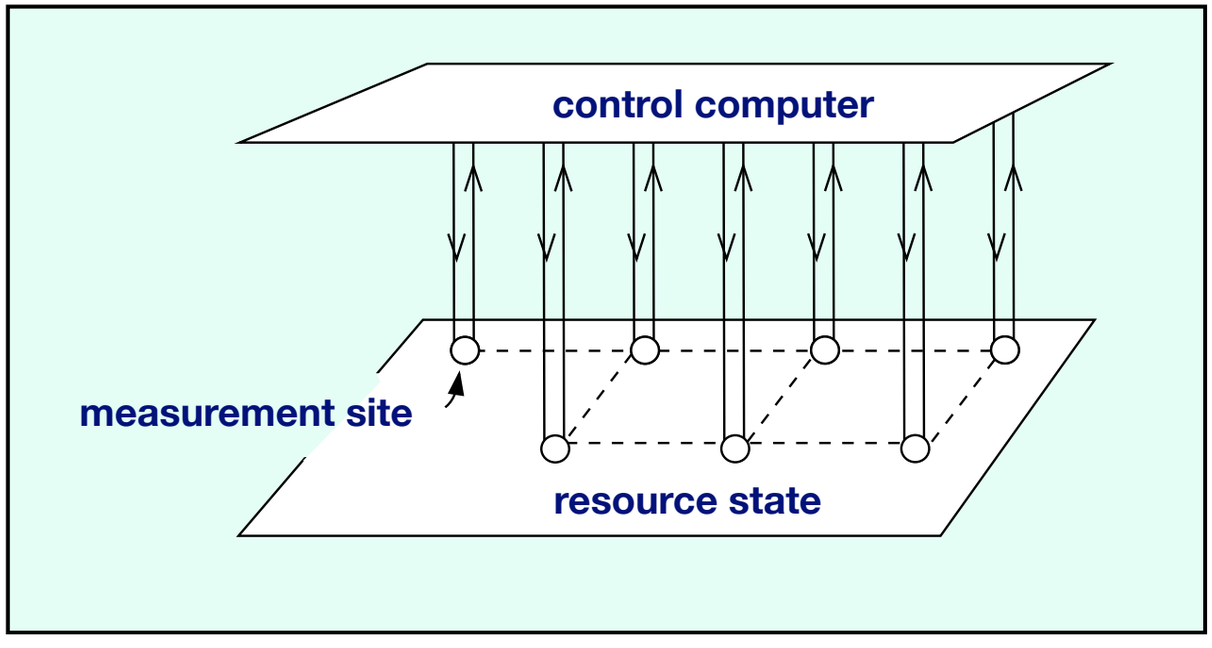
Teleportation Protocol

Classically-controlled QC

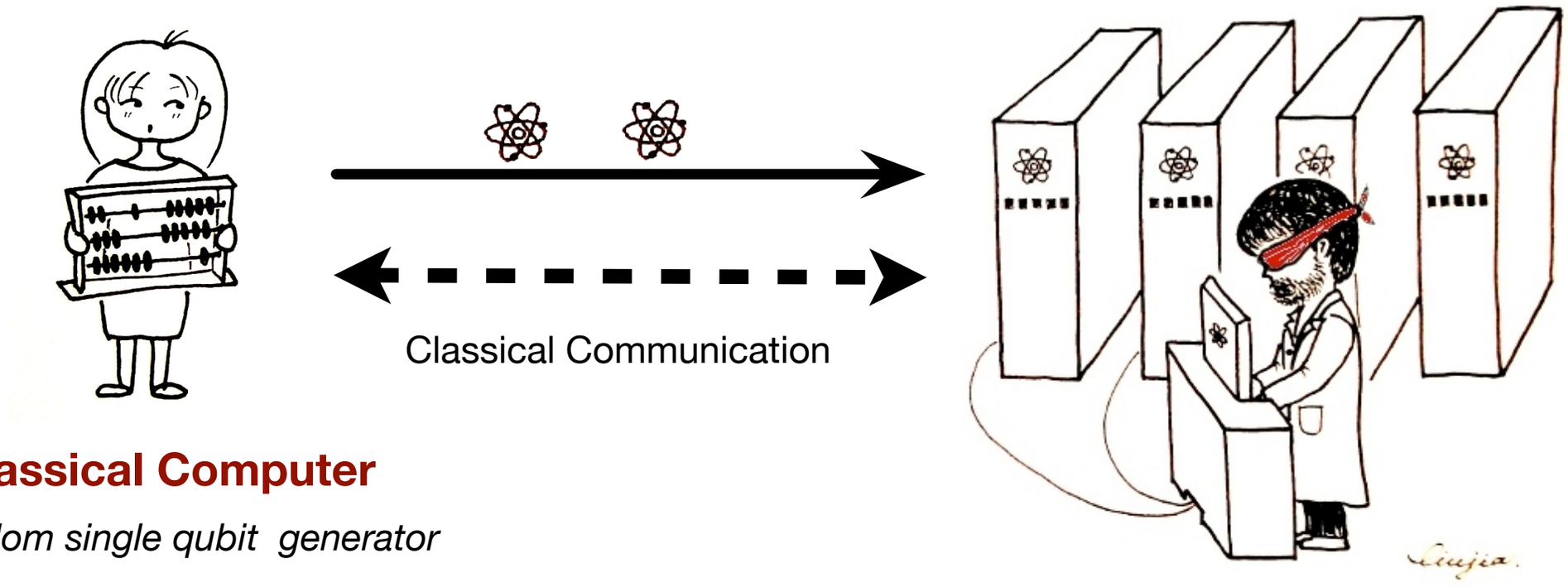
Q Crypto: qubits transmissions and classical post-processing

Teleportation Protocol

(universal) Q Comp: qubits transmissions and classical controlling



Q Crypt + Q Comp = Universal Blind QC



Classical Computer

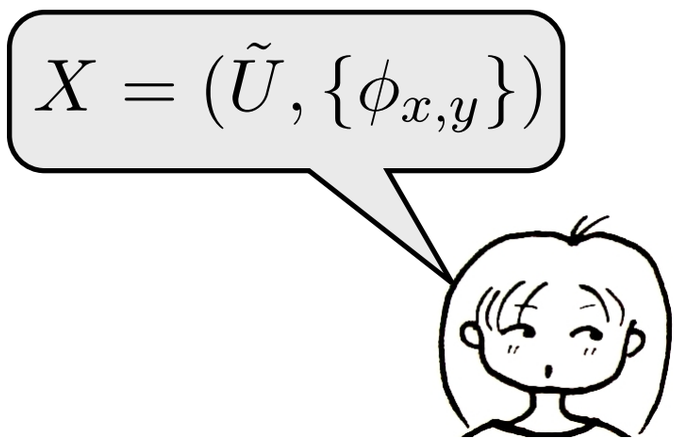
random single qubit generator

Unconditional Perfect Privacy

Server learns nothing about client's input/output/computation

Broadbent, Fitzsimons and Kashefi, FOCS 2009

UBQC Protocol



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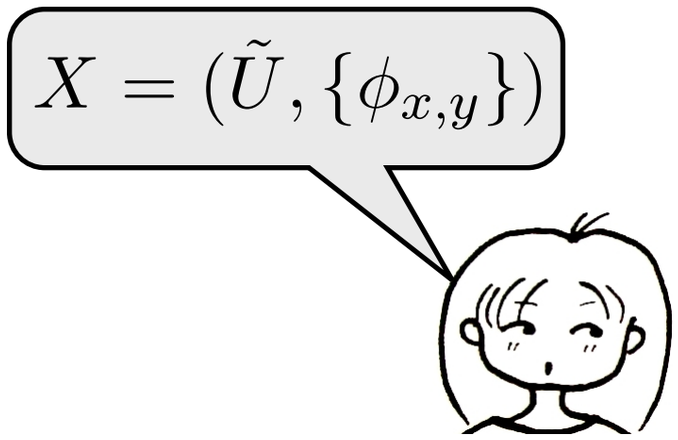

$|\psi_{x,y}\rangle \in_R \{|+_\theta\rangle\}$

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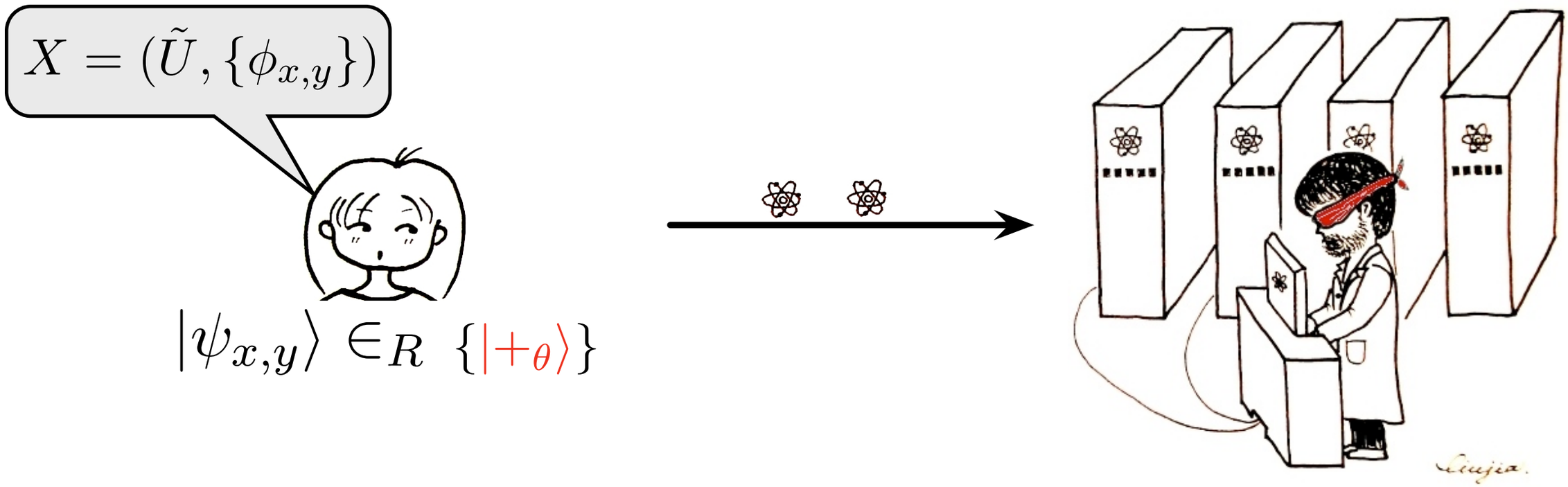

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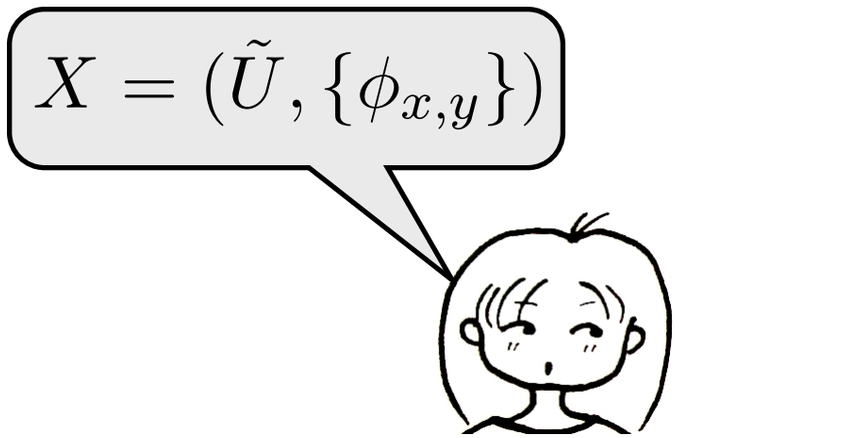

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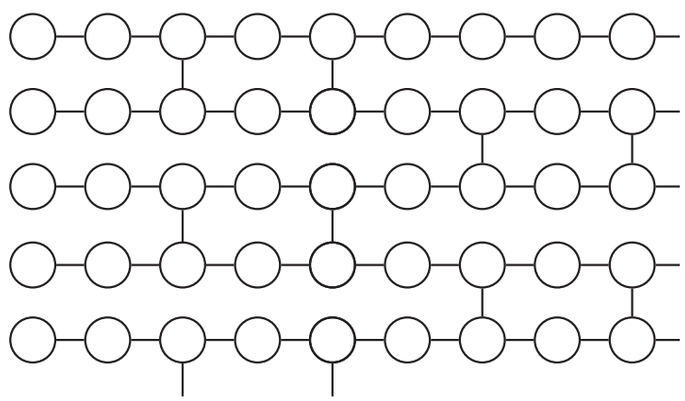

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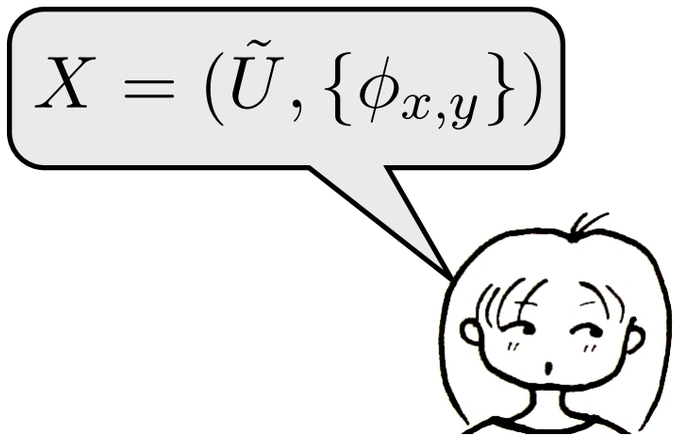

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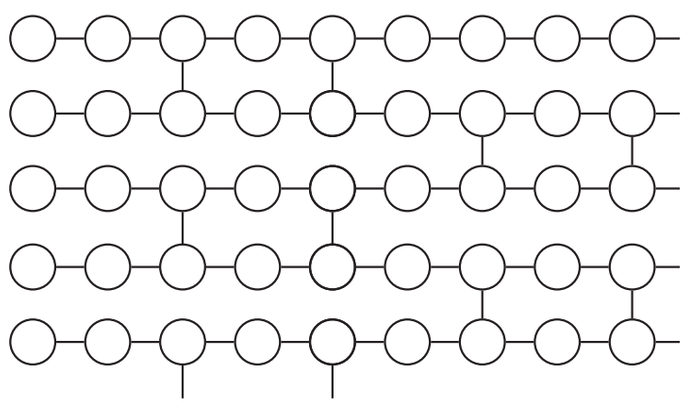

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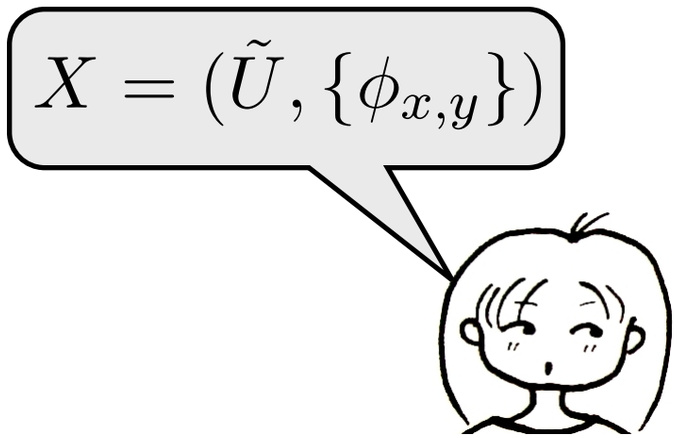

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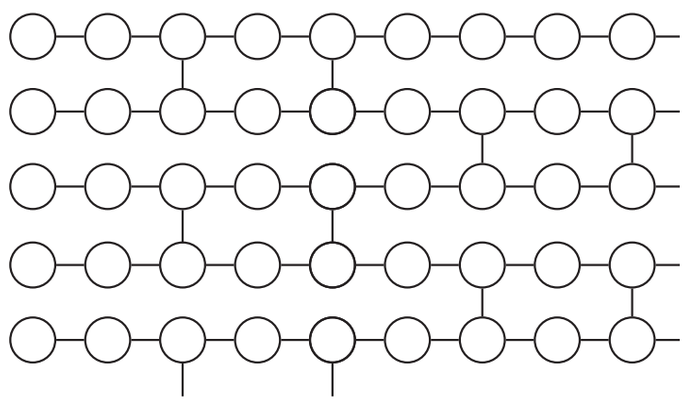

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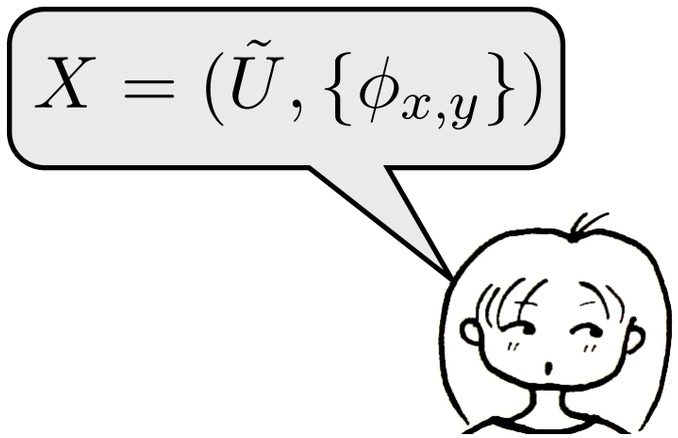

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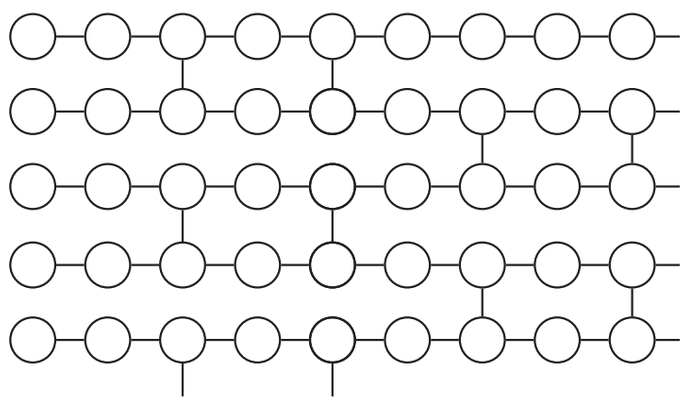

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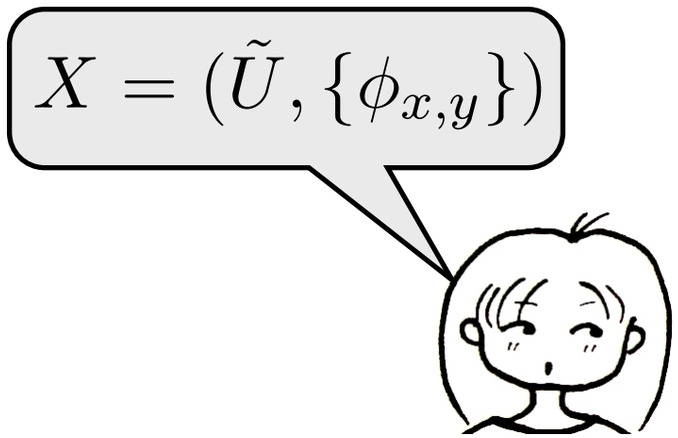

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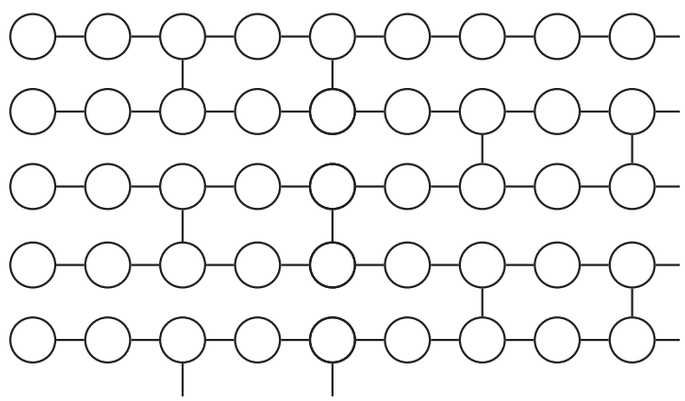

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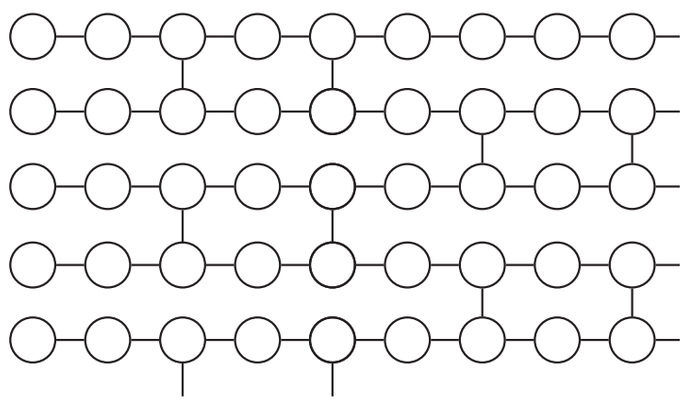

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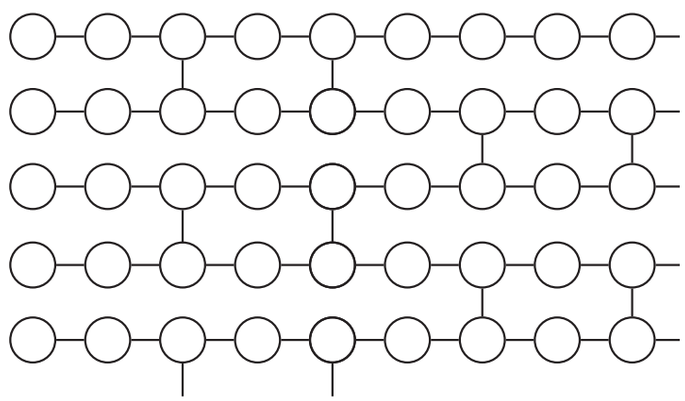

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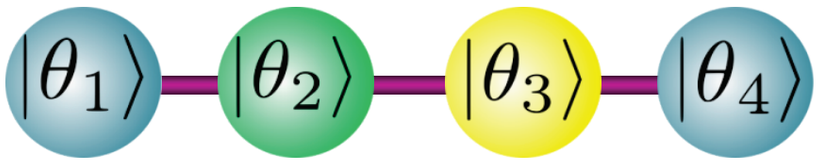
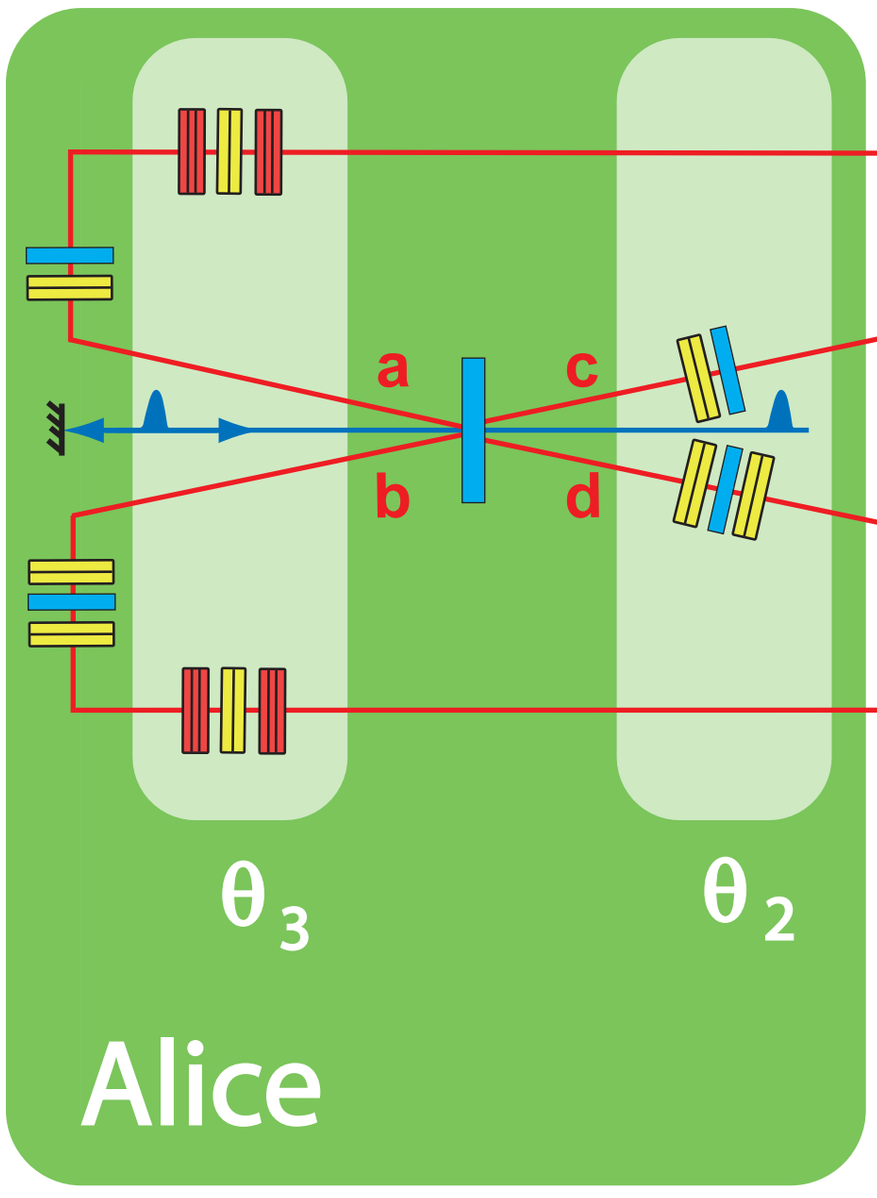
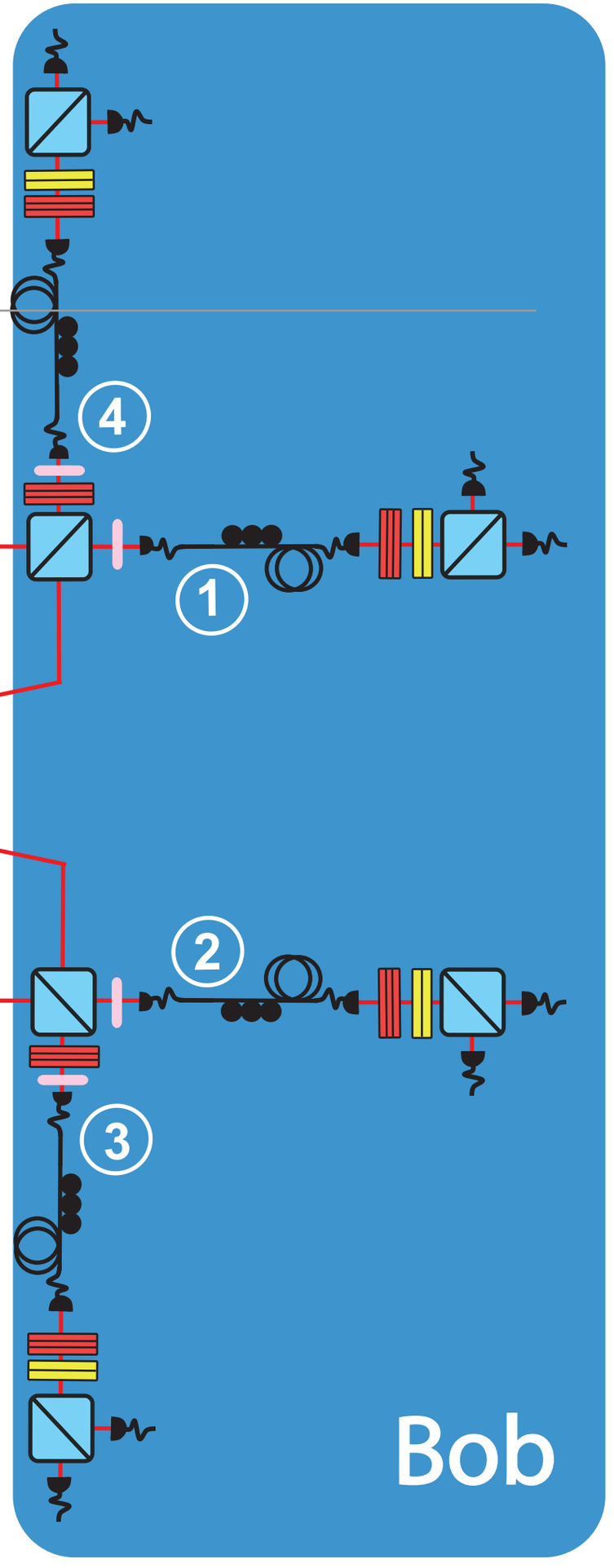
Experimental Implementation

S. Barz, E. Kashefi, A. Broadbent, J. Fitzsimons, A. Zeilinger, P. Walther, Science 2012







UBQC for other tasks

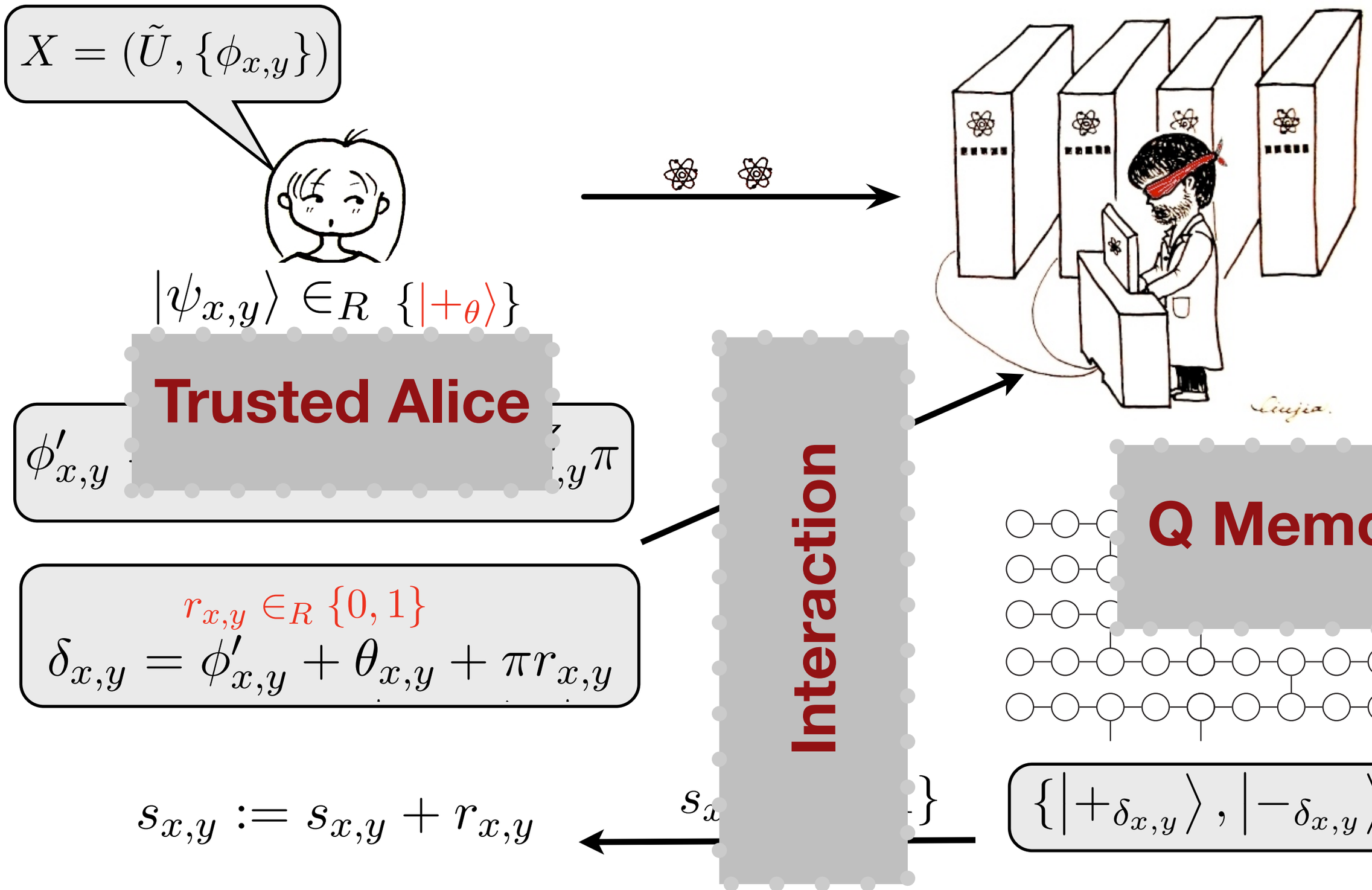
Yao Garbled Circuit

Fully Homomorphic Encryption

One-time program

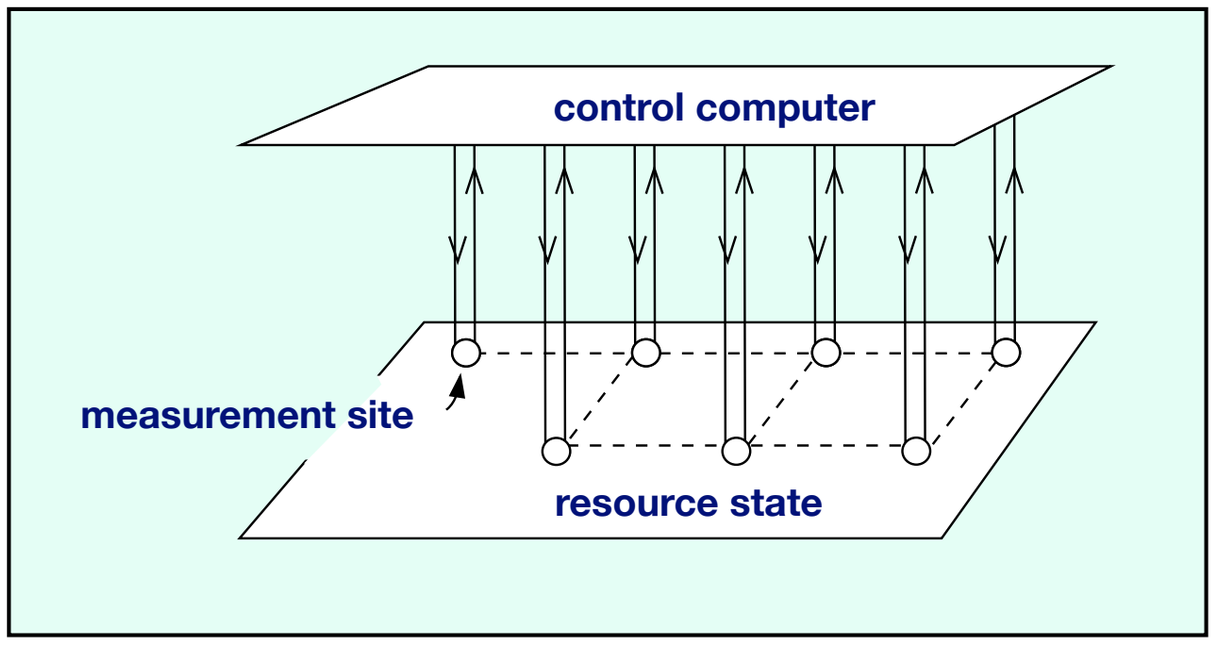
Secure Multi Party Computation

Issues about UBQC Protocol for other Crypto Tasks



Q Memory

UBQC for secure evaluation of classical function



Anders and Browne, PRL, 2009

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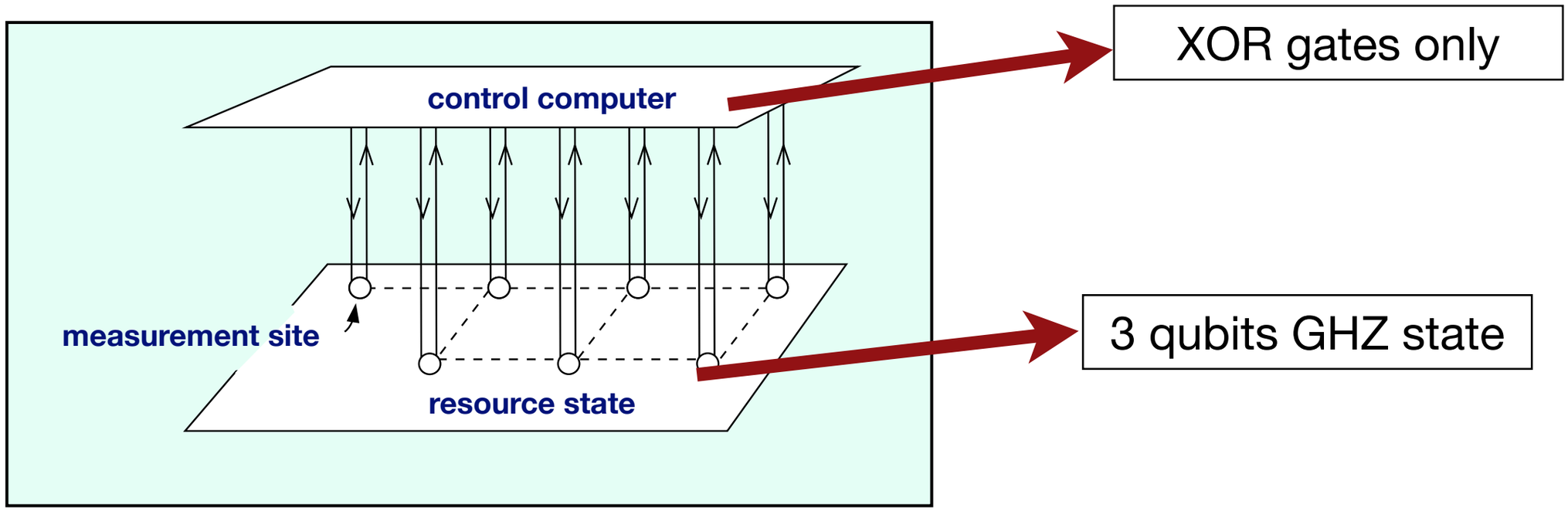

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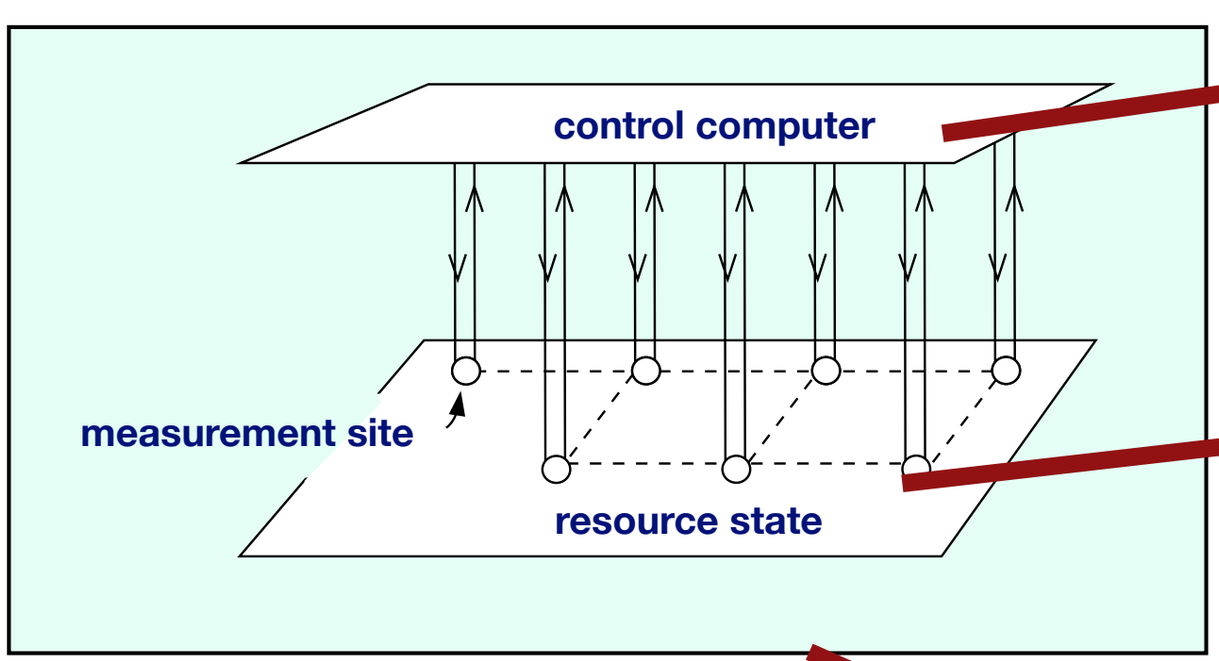


XOR gates only

3 qubits GHZ state

Universal Classical Computing

Anders and Browne, PRL, 2009

Restricted XOR Client

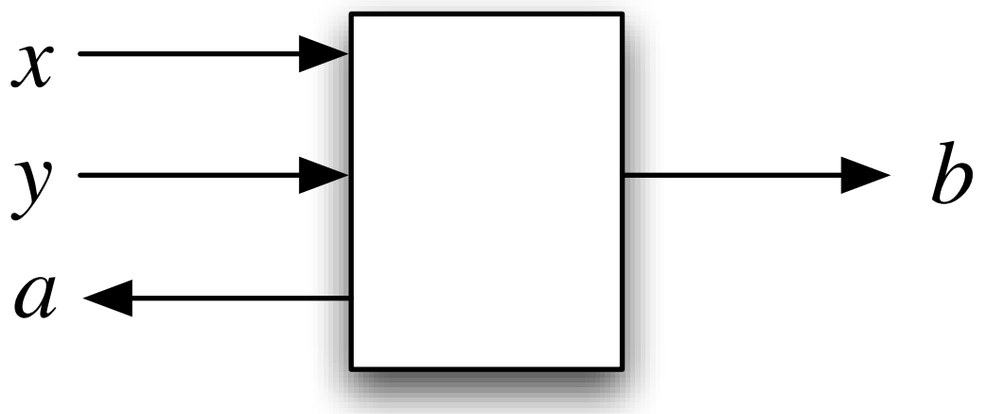
No classical protocol can delegate deterministically computation of NAND to a server while keeping the blindness

Dunjko and Kashefi, In preparation 2014

Restricted XOR Client

No classical protocol can delegate deterministically computation of NAND to a server while keeping the blindness

$$b = x.y + a$$



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Restricted XOR Client

No **quantum offline** protocol can delegate deterministically computation of NAND to a server while keeping the blindness

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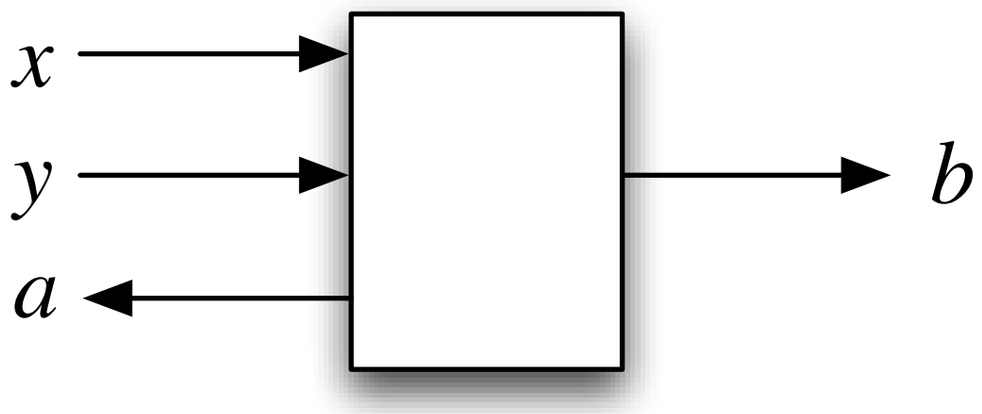
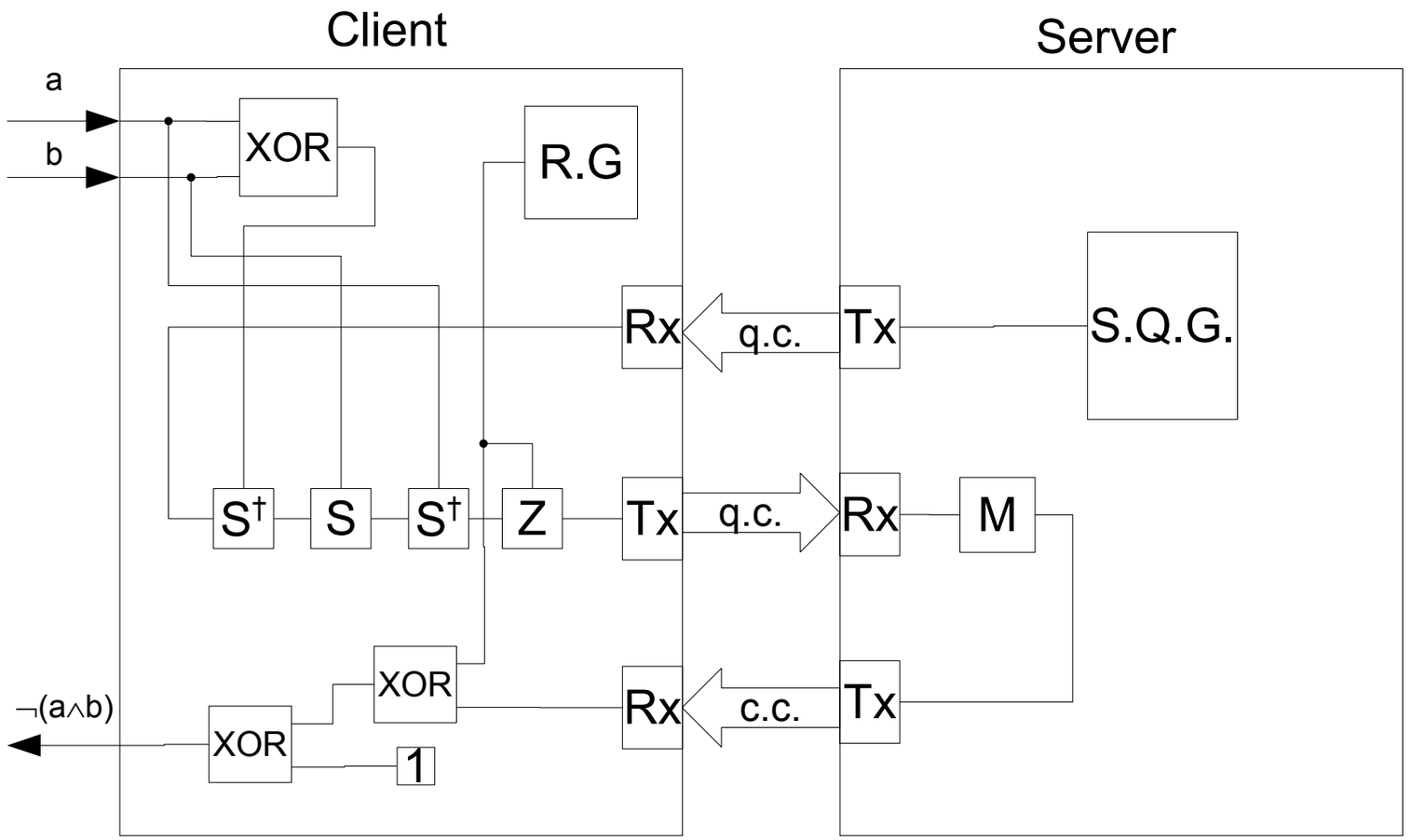


Quantum Communication

Quantum Communication



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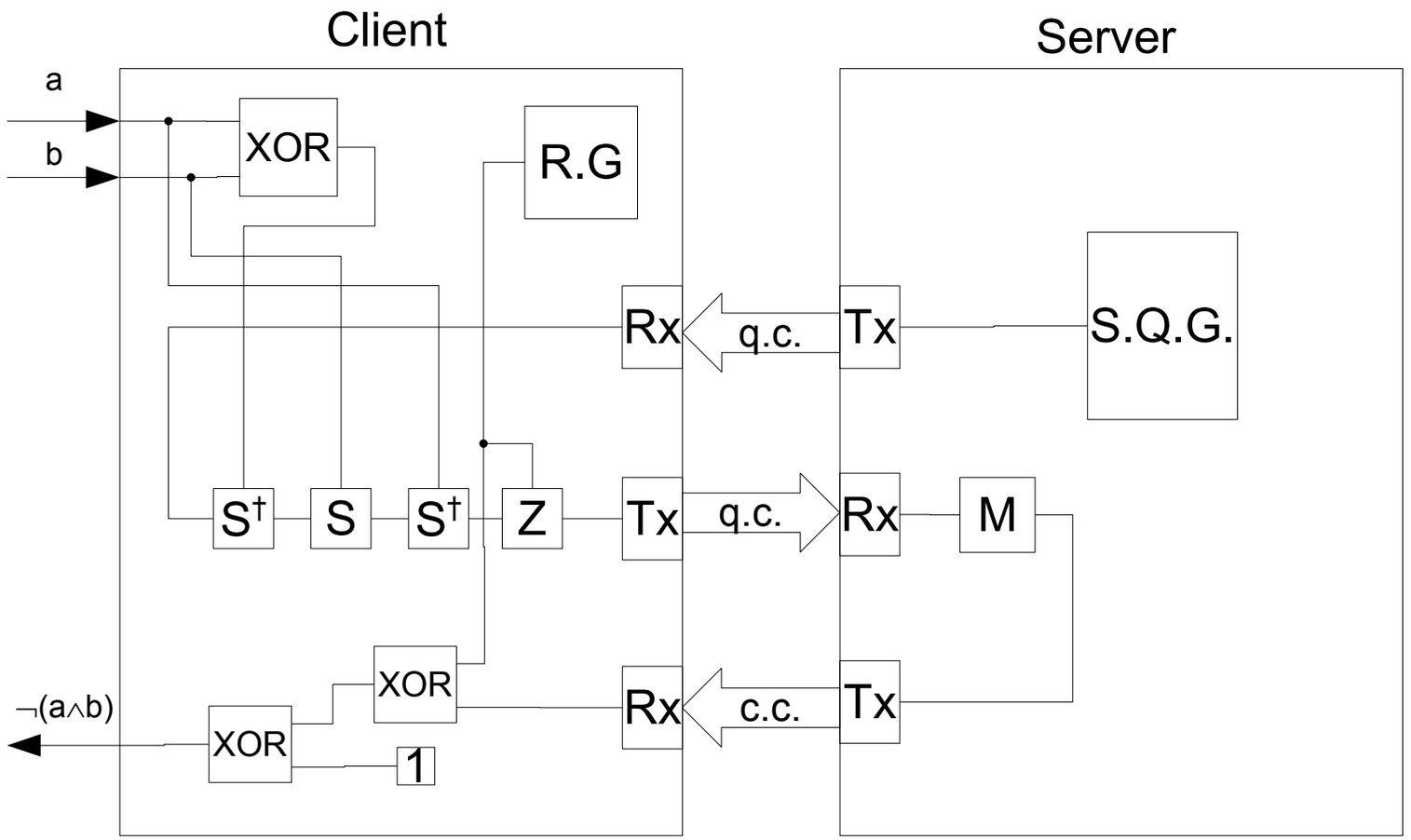
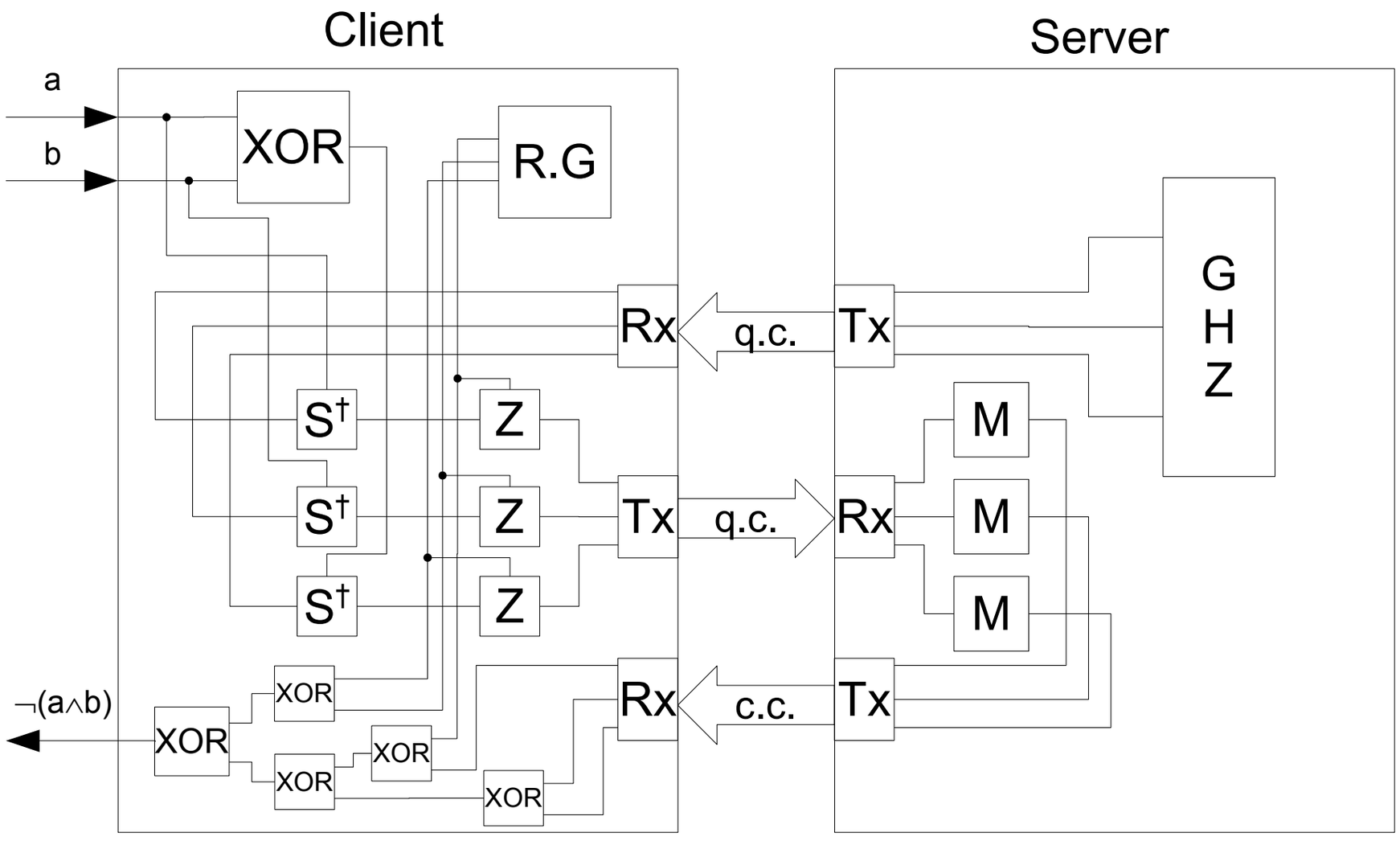


$$M^X\left(Z^a S^x S^y \left(S^\dagger\right)^{x\oplus y}|+\rangle\right)$$

measurement outcome $= x.y \oplus a \oplus 1$

Quantum Communication



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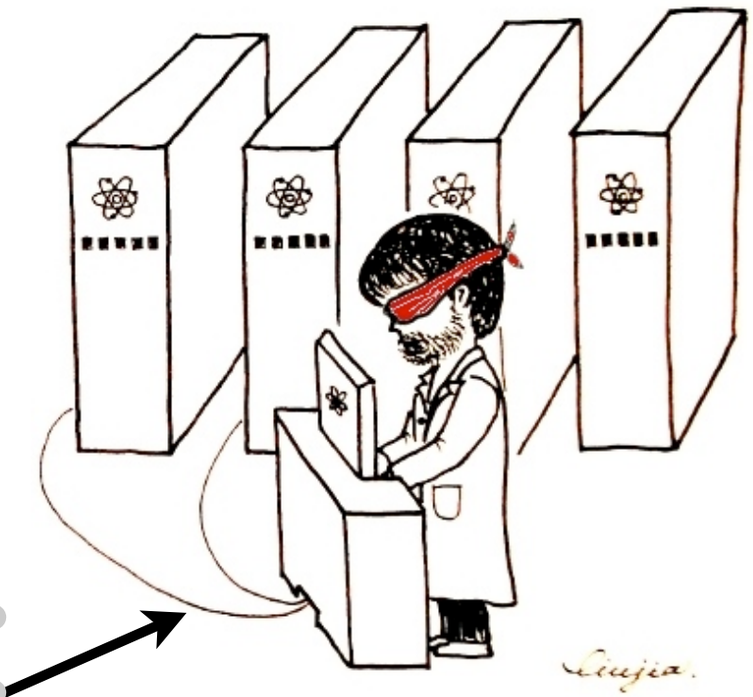

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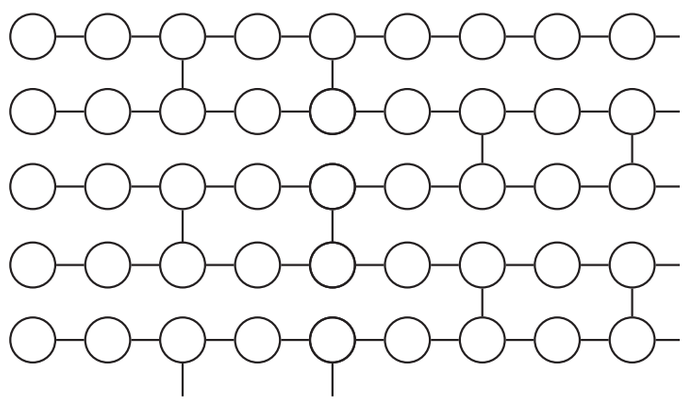
Interaction



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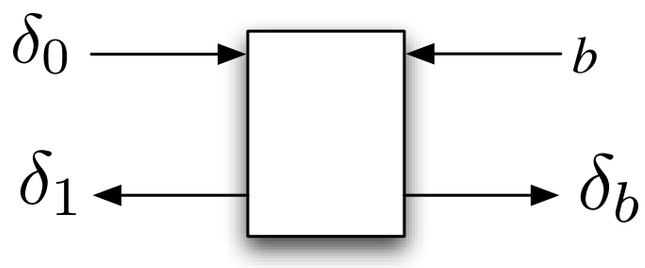
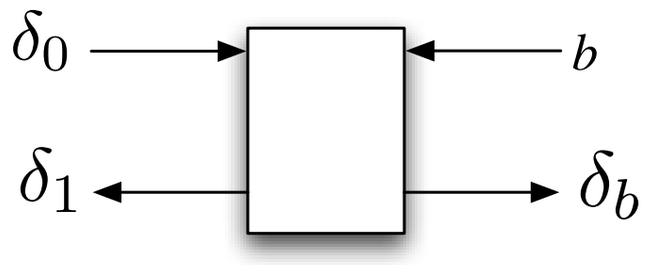
One-time Memory



Founding Cryptography on Tamper-Proof Hardware Tokens

Goldwasser, Kalai and Rothblum, Crypto, 2008
Goyal, Ishai, Sahai, Venkatesan, Wadai, TCC, 2010

One-time Memory



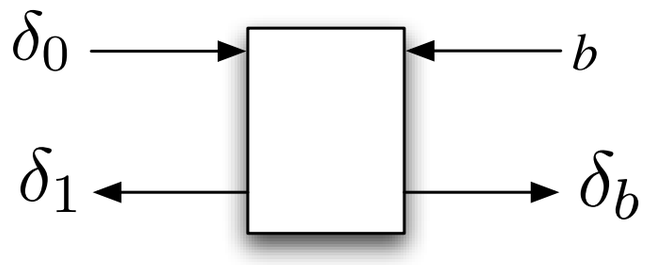
Founding Cryptography on Tamper-Proof Hardware Tokens

↓

Unconditional non-interactive secure computation

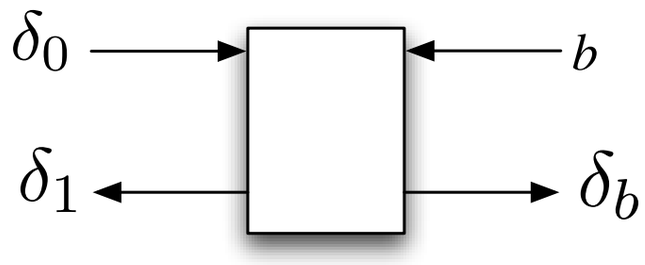
Goldwasser, Kalai and Rothblum, Crypto, 2008
Goyal, Ishai, Sahai, Venkatesan, Wadai, TCC, 2010

Non-interactive UBQC using OTM

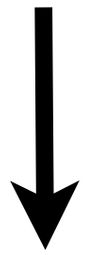


Kashefi, In preparation 2014

Non-interactive UBQC using OTM



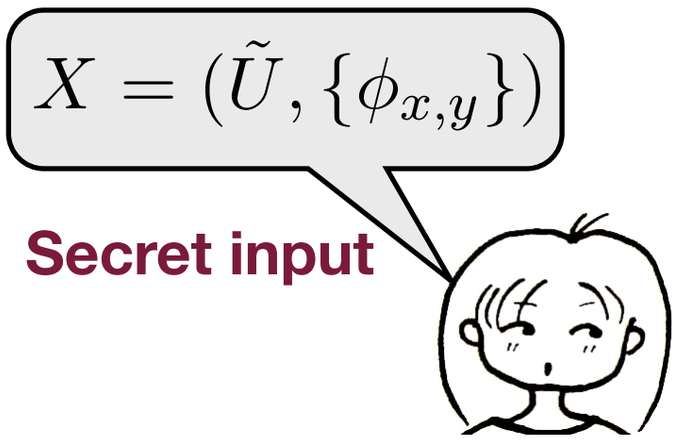
UBQC on a constant degree graph



Linear in the since of input circuit many OTM is required to make UBQC non-interactive

Kashefi, In preparation 2014

Somewhat QFHE



$$|\psi_{x,y}\rangle \in_R \{|+_\theta\rangle\}$$

$$r_{x,y} \in_R \{0,1\}$$

$$\delta_{x,y} = \phi'_{x,y} + \theta_{x,y} + \pi r_{x,y}$$

Encryption

Somewhat QFHE

$X = (\tilde{U}, \{\phi_{x,y}\})$

Secret input

Qubits and OTM

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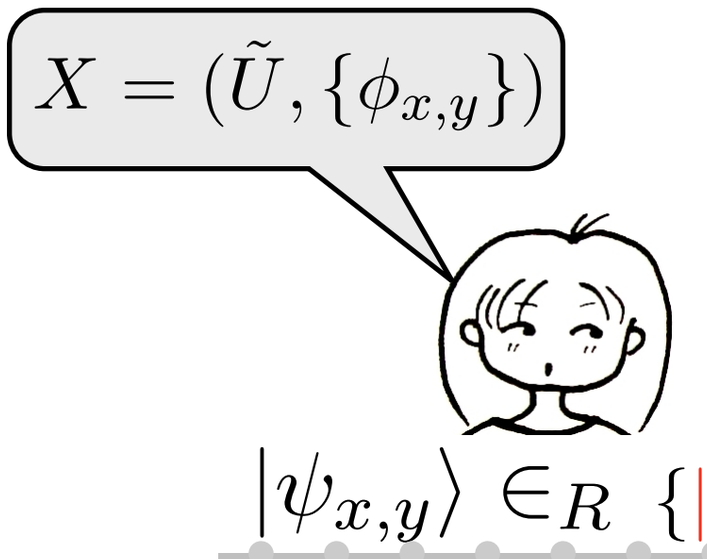
Encryption

Decryption

$$s_{x,y} := s_{x,y} + r_{x,y}$$

Verification



$|\psi_{x,y}\rangle \in_R \{|+_\theta\rangle\}$

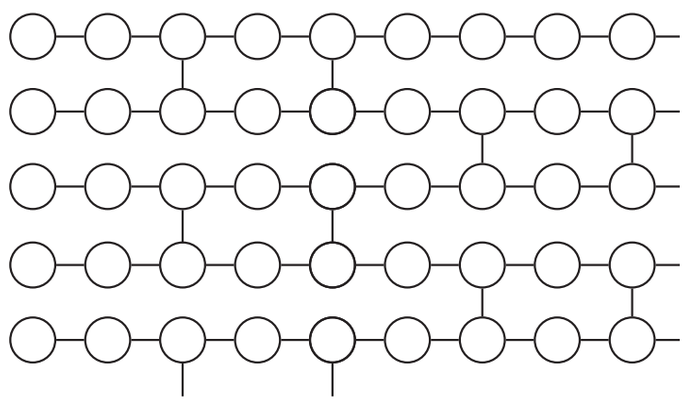
Trusted Alice

$\phi'_{x,y}$ ... $,y\pi$

$r_{x,y} \in_R \{0,1\}$

$\delta_{x,y} = \phi'_{x,y} + \theta_{x,y} + \pi r_{x,y}$

$\delta_{x,y}$



$\{|+_{\delta_{x,y}}\rangle, |-_{\delta_{x,y}}\rangle\}$

$s_{x,y} \in \{0,1\}$

$s_{x,y} := s_{x,y} + r_{x,y}$

Verification

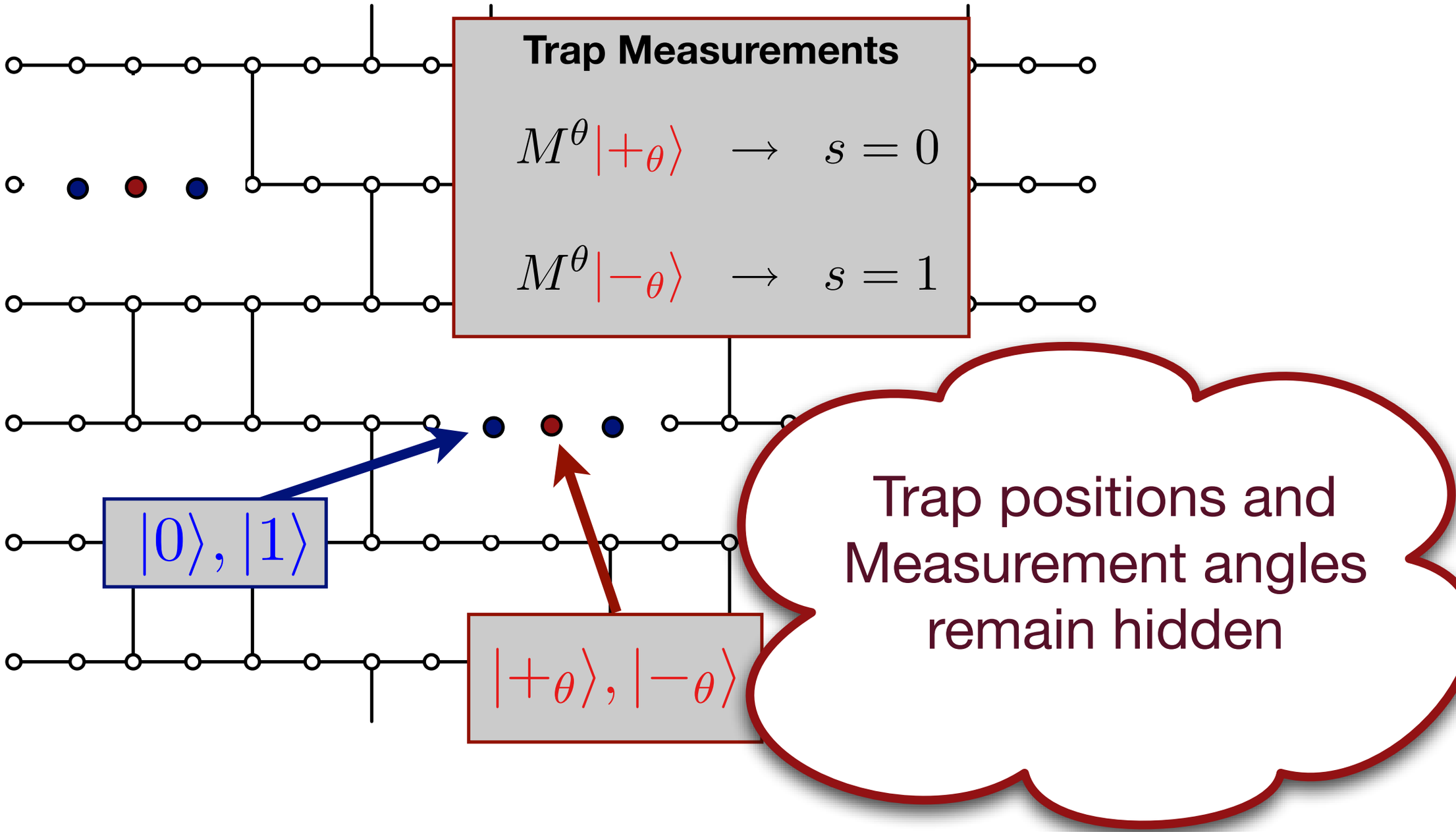
Verification

- Correctness: in the absence of any interference, client accepts and the output is correct

- Soundness: Client rejects an incorrect output, except with probability at most exponentially small in the security parameter

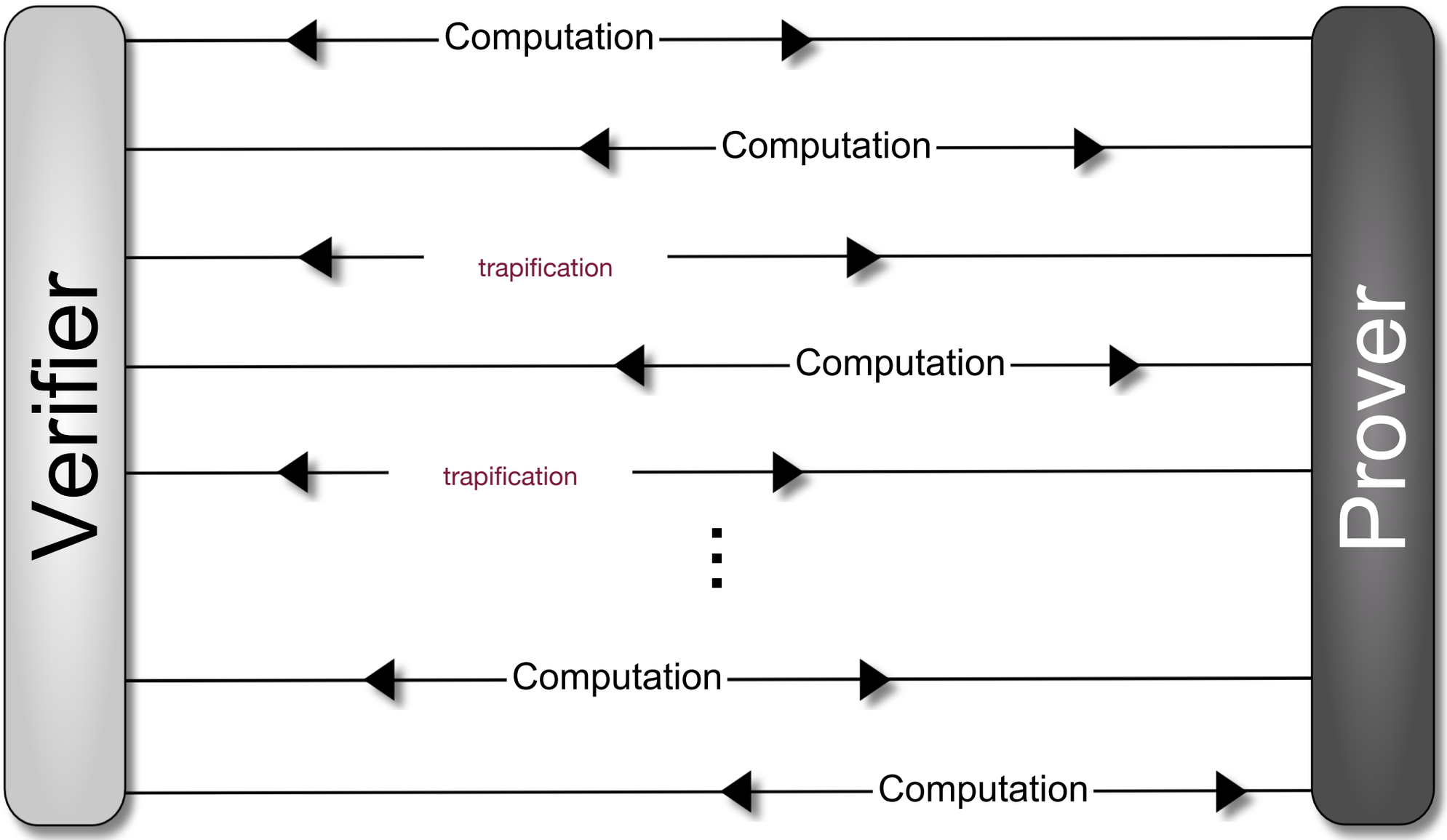
Fitzsimons and Kashefi, arXiv:1203.5217, 2012

Adding Traps - Verifying Bob only

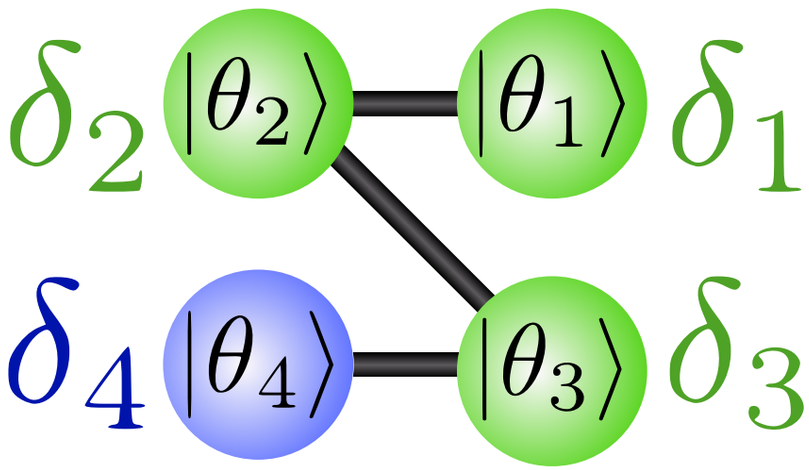


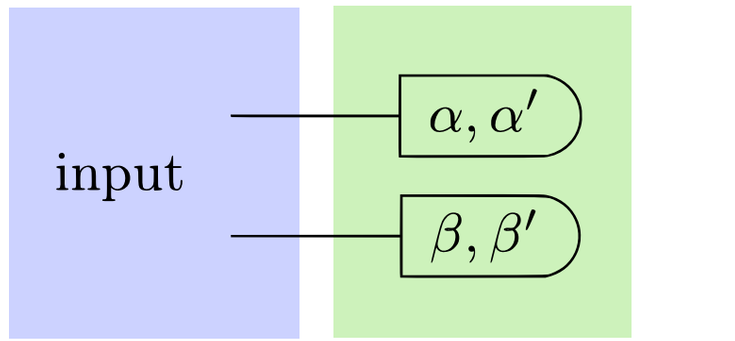
Verifying Bob

Verifying Bob



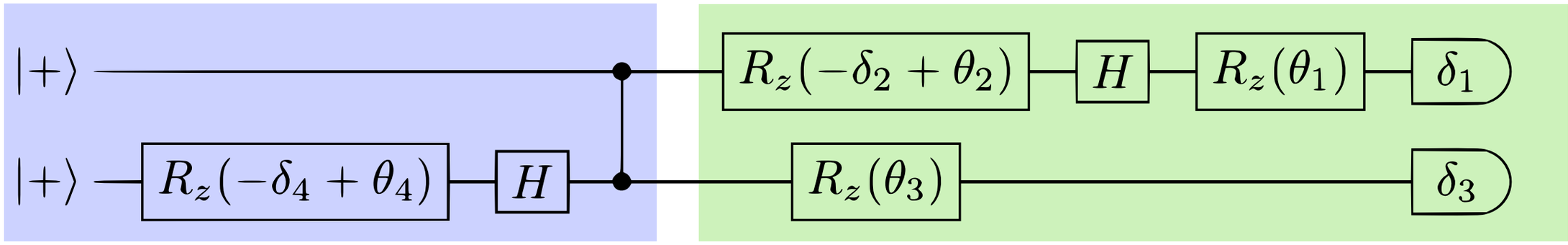
Blind Verification of Entanglement





State generation

Bell measurement



Blind state generation

Blind Bell test

Barz, Fitzsimons, Kashefi Walther. Nature Physcis 2013

Verifying Alice - Distributed UBQC - QSMC

Verifying Alice - Distributed UBQC - QSMC

$$X = (\tilde{U}, \{\phi_{x,y}\})$$

Common Secret of Clients

Fulop, Kapourniotis, Kashefi,
In preparation 2014

Verifying Alice - Distributed UBQC - QSMC

$|\psi_1 x,y\rangle \in_R \{|+_\theta\rangle\}$

Private Secret of Client

$|\psi_2 x,y\rangle \in_R \{|+_\theta\rangle\}$

Private Secret of Client

$$X = (\tilde{U}, \{\phi_{x,y}\})$$

Common Secret of Clients

Fulop, Kapourniotis, Kashefi,
In preparation 2014

Verifying Alice - Distributed UBQC - QSMC

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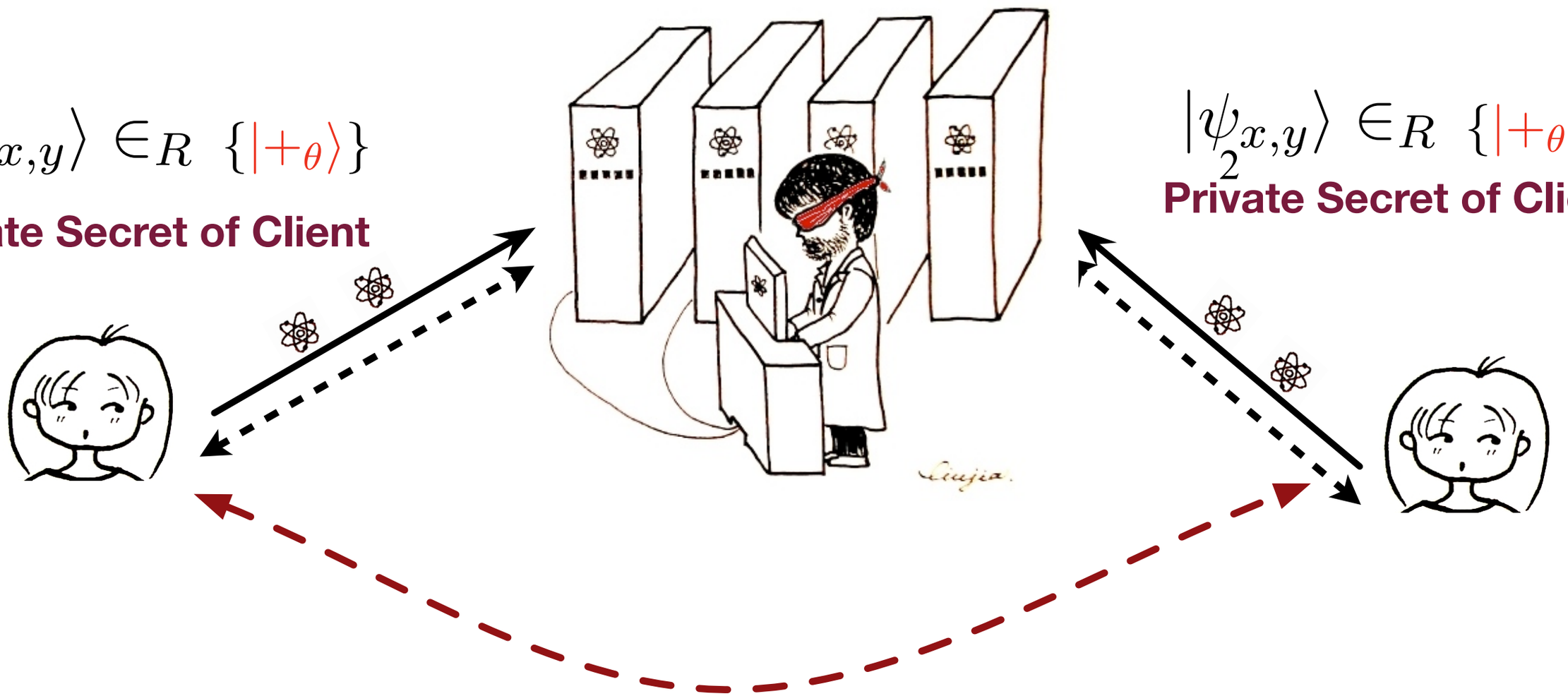
Private Secret of Client



$|\psi_2 x,y\rangle \in_R \{|+_\theta\rangle\}$

Private Secret of Client

Classical Secure Function Evaluation

$$X = (\tilde{U}, \{\phi_{x,y}\})$$

Common Secret of Clients

Fulop, Kapourniotis, Kashefi, In preparation 2014

Pre-Post Quantum Crypto

A hybrid network of **LWE-based FHE** with **UBQC gadgetds**

boosting efficiency and security

of classical delegated computing against quantum attackers