Quantum Shannon Theory

Aram Harrow (MIT)

QIP 2016 tutorial
9-10 January, 2016

the prehistory of quantum information

ideas present in disconnected form

- 1927 Heisenberg uncertainty principle
- 1935 EPR paper / 1964 Bell's theorem
- 1932 von Neumann entropy
  subadditivity (Araki-Lieb 1970)
  strong subadditivity (Lieb-Ruskai 1973)
- measurement theory
  (Helstrom, Holevo, Uhlmann, etc., 1970s)

relativity: a close relative

- Before Einstein, Maxwell's equations were known to be incompatible with Galilean relativity.
- Lorentz proposed a mathematical fix, but without the right physical interpretation.
- Einstein's solution redefined space/time, mass/momentum/energy, etc.
- Space and time had solid mathematical foundations (Descartes, etc.), unlike information and computing.

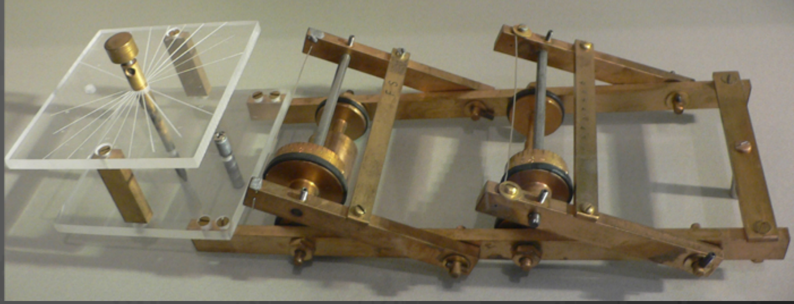
theory of information and computing

- 1948 Shannon created modern information theory (and to some extent cryptography) and justified entropy as a measure of information independent of physics. units of bits.
- Turing, Church, von Neumann, ..., Djikstra described a theory of computation, algorithms, complexity, etc.
- This made it possible to formulate questions such as:
  how do "quantum effects" change the capacity?
  (→ Holevo bound)

  what is the thermodynamic cost of computing?
  (Landauer principle, Bennett reversible computing)

  what is the computational complexity of simulating QM?
  (→ DMRG/QMC, and also Feynman)

some wacky ideas



Feynman '82: "Simulating Physics with Computers"

- Classical computers require exponential overhead to simulate quantum mechanics.
- But quantum systems obviously don't need exp overhead to simulate *themselves*.
- Therefore they are doing something more computationally powerful than our existing computers.
- (Implicitly requires the idea of a universal Turing machine, and the strong Church-Turing thesis.)

Wiesner '70: "Conjugate Coding"

- The uncertainty principle restricts possible measurements.
- In experiments, this is a disadvantage, but in crypto, limiting information is an advantage.
- (Requires crypto framework, notion of "adversary.")
- Paper initially rejected by IEEE Trans. Inf. Th. ca. 1970

towards modern QIT

- Deutsch, Jozsa, Bernstein, Vazirani, Simon, etc. – impractical speedups
  required oracle model, precursors to Shor's algorithm, following Feynman.
- quantum key distribution (BB84, B90, E91) – following Weisner.
- ca. 1995
  - Shor and Grover algorithms
  - quantum error-correcting codes
  - fault-tolerant quantum computing
  - teleportation, super-dense coding
  - Schumacher-Jozsa data compression
  - HSW coding theorem
  - resource theory of entanglement

modern QIT

semiclassical

- compression: $S(\rho) = -\mathrm{tr}\,[\rho \log(\rho)]$
- CQ or QC channels: $\chi(\{p_x, \rho_x\}) = S(\Sigma_x\, p_x \rho_x) - \Sigma_x p_x S(\rho_x)$
- hypothesis testing: $D(\rho \| \sigma) = \mathrm{tr}[\rho(\log(\rho) - \log(\sigma)]$

"fully quantum"

- complementary channel: $N(\rho) = \mathrm{tr}_2\, V \rho V^\dagger,\ N^c(\rho) := \mathrm{tr}_1\, V \rho V^\dagger$
- quantum capacity: $Q^{(1)}(N) = \max_\rho\, [S(N(\rho)) - S(N^c(\rho))]$
  $Q(N) = \lim_{n\to\infty} Q^{(1)}(N^{\otimes n})/n$
- tools: purifications (Stinespring), decoupling

recent

- one-shot: $S_\alpha(\rho) := \log(\mathrm{tr}\ \rho^\alpha)/(1-\alpha)$
- applications to optimization, condensed matter, stat mech.

Relevant talks

- Wed 9. Omar Fawzi and Renato Renner. Quantum conditional mutual information and approximate Markov chains.
- Wed 9:50. Omar Fawzi, Marius Junge, Renato Renner, David Sutter, Mark Wilde and Andreas Winter. Universal recoverability in quantum information theory.
- Thurs 11. David Sutter, Volkher Scholz, Andreas Winter and Renato Renner. Approximate degradable quantum channels
- Thurs 4:15. Mario Berta, Joseph M. Renes, Marco Tomamichel, Mark Wilde and Andreas Winter.
  Strong Converse and Finite Resource Tradeoffs for Quantum Channels.

semi-relevant talks

- Tues 11:50. Ryan O'Donnell and John Wright. Efficient quantum tomography merged with
  Jeongwan Haah, Aram Harrow, Zhengfeng Ji, Xiaodi Wu and Nengkun Yu. Sample-optimal tomography of quantum states
- Tues 3:35. Ke Li. Discriminating quantum states:the multiple Chernoff distance
- Thurs 10. Mark Braverman, Ankit Garg, Young Kun Ko, Jieming Mao and Dave Touchette. Near optimal bounds on bounded-round quantum communication complexity of disjointness
- Thurs 3:35. Fernando Brandao and Aram Harrow. Estimating operator norms using covering nets with applications to quantum information theory
- Thurs 4:15. Michael Beverland, Gorjan Alagic, Jeongwan Haah, Gretchen Campbell, Ana Maria Rey and Alexey Gorshkov. Implementing a quantum algorithm for spectrum estimation with alkaline earth atoms.

outline

- metrics
- compressing quantum ensembles (Schumacher coding)
- sending classical messages over q channels (HSW)
- remote state preparation (RSP)
- Schur duality
- RSP and the strong converse
- hypothesis testing
- merging
- quantum conditional mutual information and q Markov states

metrics

Trace distance $T(\rho,\sigma) := ½ \|\rho - \sigma\|_1$

- Is a metric.
- monotone: $T(\rho,\sigma) \geq T(N(\rho),N(\sigma))$
- and this is achieved by a measurement
  → T = max m'mt bias

Fidelity $F(\rho,\sigma) := \|\sqrt{\rho}\sqrt{\sigma}\|_1 = \mathrm{tr}\sqrt{\sqrt{\sigma}\rho\sqrt{\sigma}}$

- F=1 iff $\rho = \sigma$ and F=0 iff $\rho \perp \sigma$
- monotone $F(\rho,\sigma) \leq F(N(\rho),N(\sigma))$
- and this is achieved by a measurement!

Relation:
$1-F \leq T \leq (1-F^2)^{1/2}$

Pure states with angle θ:
$F = \cos(\theta)$ and $T = \sin(\theta)$.
(exercise: which m'mts saturate?)

the case for fidelity

Church of the Larger Hilbert Space

Uhlmann's theorem:

$F(\rho_A, \sigma_A) = \max_{\psi,\phi} F(\psi_{AB}, \phi_{AB})$ s.t.

$\psi = |\psi\rangle\langle\psi|$, $\phi = |\phi\rangle\langle\phi|$, $\psi_A = \rho_A$, $\phi_A = \sigma_A$.

Note:

1. $\geq$ from monotonicity.
   $=$ requires sweat
2. Can fix either ψ or ϕ and max over the other.
3. $F(\psi, \phi) = |\langle\psi|\phi\rangle|$. (Some use different convention.)
4. Implies that $(1-F)^{1/2}$ is a metric.

Also F is multiplicative.

Compression

$|\psi_x\rangle \in \mathbb{C}^d$ with prob p_x $\longrightarrow$ encoder $\xrightarrow[\text{dim } r < d]{}$ decoder $\longrightarrow$ $\approx |\psi_x\rangle$

Average fidelity:

$\Sigma_x\, p_x\, F(\psi_x, D(E(\psi_x))) \leq F(\rho, D(E(\rho)))$

Simplification: use ensemble density matrix

$\rho = \Sigma_x\, p_x\, \psi_x$ with eigenvalues $\lambda_1 \geq \lambda_2 \geq \ldots \geq \lambda_d \geq 0$

$\text{rank}(\sigma) = r \Rightarrow F(\rho, \sigma)^2 \leq \text{tr}\,[P_r \rho] = \lambda_1 + \ldots + \lambda_r$

P_r projects onto top r eigenvectors

$$\sigma = \frac{P_r \rho P_r}{\text{tr}[P_r \rho]}$$

Suggests optimal fidelity $= (\lambda_1 + \ldots + \lambda_r)^{1/2}$.

Too good to be true!

Ensemble density matrix: $\rho = \Sigma_x \, p_x \, \psi_x$

Yes compression depends only on ρ.

But reproducing ρ is not enough!

consider:

$E(\cdot)=|0\rangle\langle 0|$

$D(\cdot)=\rho$

Gets the average right but not the correlations.

Reference system

Average fidelity:
$\Sigma_x\, p_x\, F(\psi_x, E(D(\psi_x)))$
$\quad = F(\Sigma_x\, p_x\, |x\rangle\langle x| \otimes \psi_x, \Sigma_x\, p_x\, |x\rangle\langle x| \otimes E(D(\psi_x)))$

Not so easy to analyze.
Instead follow the Church of the Larger Hilbert Space.

$$|\varphi\rangle_{RQ} := \sum_x \sqrt{p_x}\, |x\rangle_R\, |\psi_x\rangle_Q$$

Avg fidelity $\geq F(\varphi, (id_R \otimes D \circ E_Q)(\varphi))$
(pf: monotonicity under map that measures R.)

Protocol: $E(\omega) = P_r\, \omega\, P_r$. $D = id$.
achieves $F = \langle\varphi|\, (I \otimes P_r)\, |\varphi\rangle = tr\, [\rho P_r] = \lambda_1 + \ldots + \lambda_r$

Optimality

Complication: E, D might be noisy.

Solution: purify!

1. Write $D(E(\omega)) = \mathrm{tr}_G V \omega V^\dagger$
where V is an isometry from Q -> $Q \otimes G$.

2. Uhlmann →
$F(\varphi, \mathrm{tr}_G V\varphi V^\dagger) = |\langle\varphi|_{RQ} \langle 0|_G V |\varphi\rangle_{RQ}|$

3. a little linear algebra →
$F \leq \mathrm{tr}[\rho P]$ for P rank-r and $||P|| \leq 1$
$\leq \lambda_1 + \ldots + \lambda_r$

compressing i.i.d. sources

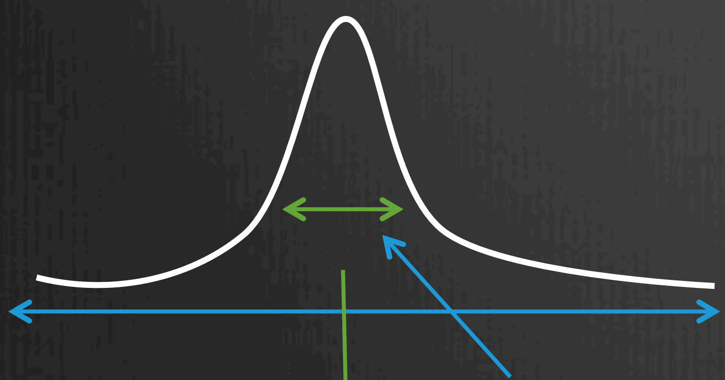
Quantum story ≈ classical story

$\rho^{\otimes n}$ has eigenvalues $\lambda_{x_1} \lambda_{x_2} \cdots \lambda_{x_n}$ for $X=(x_1,\ldots,x_n) \in [d]^n$.

Typically this is ≈ $\lambda_1^{n\lambda_1} \cdots \lambda_d^{n\lambda_d} = \exp(-nH(\lambda))$

$H(\lambda) = -\Sigma_x \lambda_x \log(\lambda_x) = S(\rho) = -\mathrm{tr}[\rho \log(\rho)]$

distribution of $-\log(\lambda_{x_1} \lambda_{x_2} \cdots \lambda_{x_n})$



$nH(\lambda)$ $\sigma\sqrt{n}$

$\sigma^2 = \Sigma_x \lambda_x (\log(1/\lambda_x) - H)^2$

qubits	fidelity
$nH(\lambda) + 2\sigma n^{1/2}$	0.98
$nH(\lambda) - 2\sigma n^{1/2}$	0.02
$n(H(\lambda)+\delta)$	$1-\exp(-n\delta^2/2\sigma^2)$
$n(H(\lambda)-\delta)$	$\exp(-n\delta^2/2\sigma^2)$

typicality

<u>Definitions:</u>

An eigenvector of $\rho^{\otimes n}$ is k-typical if its eigenvalue is in the range $\exp(-nS(\rho) \pm k\sigma n^{1/2})$.

Typical subspace V = span of typical eigenvectors
Typical projector P = projector onto V

<u>Structure theorem for iid states:</u> "asymptotic equipartition"

- $\mathrm{tr}\,[P\rho^{\otimes n}] \geq 1 - k^{-2}$
- $\exp(-nS(\rho) - k\sigma n^{1/2})\, P \leq P\rho^{\otimes n} P \leq \exp(-nS(\rho) + k\sigma n^{1/2})\, P$
- likewise $\mathrm{tr}[P] \approx \exp(nS(\rho) + k\sigma n^{1/2})$

Almost flat spectrum.
Plausible because of permutation symmetry.

Quantum Shannon Theory

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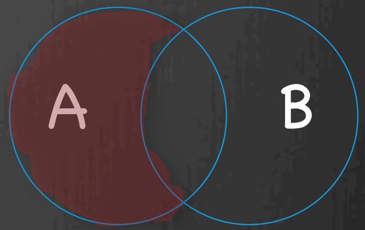
QIP 2016 tutorial day 2
10 January, 2016

entropy

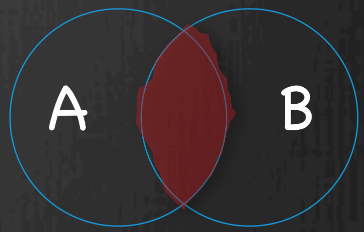
$S(\rho) = -\mathrm{tr}\,[\rho \log \rho]$

- range: $0 \leq S(\rho) \leq \log(d)$
- symmetry: $S(\rho) = S(U \rho U^\dagger)$
- multiplicative: $S(\rho \otimes \sigma) = S(\rho) + S(\sigma)$
- continuity (Fannes-Audenaert):
  $| S(\rho) - S(\sigma) | \leq \varepsilon \log(d) + H(\varepsilon, 1-\varepsilon)$
  $\varepsilon := \| \rho - \sigma \|_1 / 2$

S(A|B)



I(A:B)



- multipartite systems: ρ_{AB}
  $S(A) = S(\rho_A)$, $S(B) = S(\rho_B)$, etc.
- conditional entropy: $S(A|B) := S(AB) - S(B)$, can be < 0
- mutual information: $I(A:B) = S(A) + S(B) - S(AB)$
  $= S(A) - S(A|B) = S(B) - S(B|A) \geq 0$ "subadditivity"

CQ channel coding

CQ = Classical input, Quantum output

$$|x\rangle\langle x| \longrightarrow \boxed{N} \longrightarrow \rho_x = N(|x\rangle\langle x|)$$

Given n uses of N, how many bits can we send?

Allow error that $\rightarrow 0$ as $n \rightarrow \infty$.

HSW theorem: Capacity = max χ

$\chi(\{p_x, \rho_x\}) = S(\Sigma_x\, p_x \rho_x) - \Sigma_x p_x S(\rho_x)$

$\omega_{XQ} = \Sigma_x\, p_x\, |x\rangle\langle x| \otimes \rho_x$

$\chi = I(X;Q)_\omega = S(Q) - S(Q|X)$

HSW coding

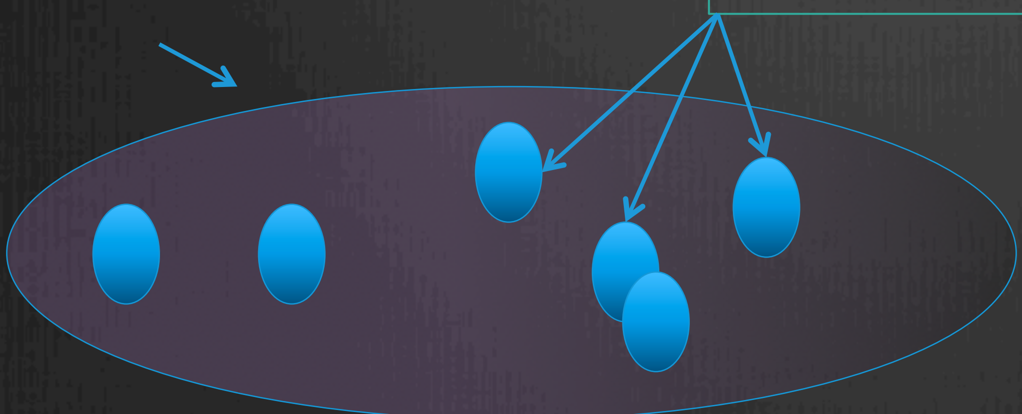
$$\rho = \Sigma_x p_x \rho_x$$
$$\chi = S(\rho) - \Sigma_x p_x S(\rho_x)$$
$$= S(Q) - S(Q|X)$$

total information

ambiguity in each message

typical subspace of $\rho^{\otimes n}$ has dim $\approx \exp(n S(\rho))$

If $x=(x_1,\ldots,x_n)$ is p-typical then $\rho_{x_1} \otimes \rho_{x_2} \otimes \ldots \otimes \rho_{x_n}$ has typical subspace of dim $\approx \exp(n\Sigma_x p_x S(\rho_x))$

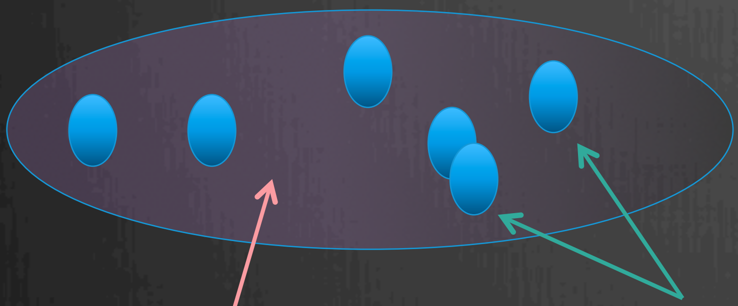


"Packing lemma"

Can fit $\approx\exp(n\chi)$ messages.

Packing lemma

Classically: random coding and maximum-likelihood decoding
Quantumly: messages do not commute with each other



Suppose $\sigma = \sum_x p_x \; \sigma_x$
and there exist Π, $\{\Pi_x\}$ s.t.

1. $\mathrm{tr}[\Pi\, \sigma_x] \geq 1 - \varepsilon$
2. $\mathrm{tr}[\Pi_x \sigma_x] \geq 1 - \varepsilon$
3. $\mathrm{tr}[\Pi_x] \leq d$
4. $\Pi\, \sigma\, \Pi \leq \Pi \;/\; D$

Packing lemma:
We can send M messages with error $O(\varepsilon^{1/2} + Md/D)$

For HSW:
$\sigma = \rho^{\otimes n}$ with typ proj Π. $D \approx \exp(n\, S(Q))$
$\sigma_x = \rho_{x_1} \otimes \ldots \otimes \rho_{x_n}$ with typ proj Π_x. $d \approx \exp(n\, S(Q|X))$.

Upper bound

$X \in \{X^1, \ldots, X^M\} \to \boxed{N^{\otimes n}} \xrightarrow[Q]{\rho_X = \rho_{x_1} \otimes \ldots \otimes \rho_{x_n}} \boxed{D} \to Y$

$\Sigma_Y D_Y = I$

$\Pr[Y|X] = tr[\rho_X D_Y]$

$\boxed{\text{proof: } n\chi \geq I(X;Q) \geq I(X;Y) \geq (1-O(\varepsilon)) \log(M)}$

additivity
Wed 10:50
Cross-Li-Smith.
also Shannon 1948

data-processing inequality

continuity

$Q \to \boxed{D} \to Y \quad \cong \quad Q \to \boxed{V_D} \to Y, Q'$

isometry

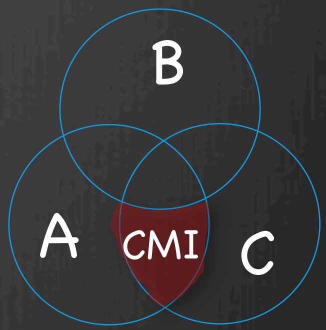
$I(X:Q) =$
$I(X:YQ') \geq$
$I(X:Y)$

conditional mutual information

Claim that $I(A:BC) - I(A:B) \geq 0$.

$=: I(A:C|B)$ conditional mutual information

$= S(A|B) + S(C|B) - S(AC|B)$
$= S(AB) + S(BC) - S(ABC) - S(B)$



If B is classical, $\rho = \sum_b p(b)\, |b\rangle\langle b| \otimes \sigma(b)_{AC}$
then $I(A:C|B) = \sum_b p(b)\, I(A:C)_{\sigma(b)} \geq 0$ from subadditivity

$I(A:C|B) \geq 0$ is strong subadditivity [Lieb-Ruskai '73].

$I(A:C|B) = 0$ for "quantum Markov states"
Wed morning you will hear $I(A:C|B) \geq$ "non-Markovianity"

capacity of QQ channels

Additional degree of freedom: channel inputs $|\psi_x\rangle$.

$C^{(1)}(N) = \max_{\{p_x, \psi_x\}} \chi(\{p_x, \psi_x\})$

NP-hard optimization problem [Beigi-Shor, H.-Montanaro]

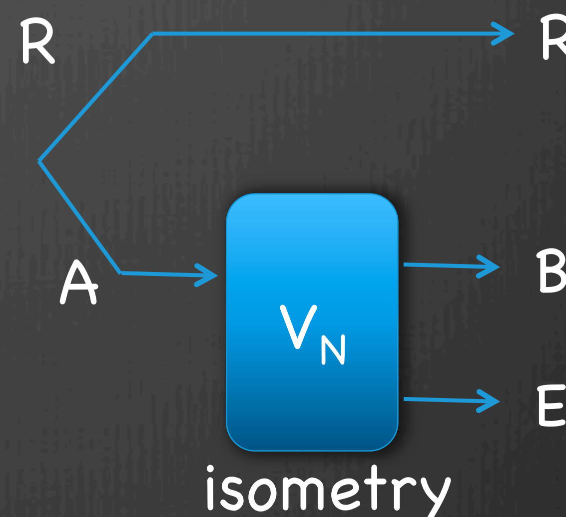
Worse: $C(N) = \lim_{n\to\infty} C^{(1)}(N^{\otimes n})/n$.
and $\exists$ channels where $C(N) > C^{(1)}(N)$.

Open questions: Non-trivial upper bounds on capacity.
Strong converse (p_{succ} -> 0 when sending $n(C+\delta)$ bits.)
(see Berta et al, Thurs 4:15pm).

quantum capacity

How many qubits can be sent through a noisy channel?

$\cong$



$$
\begin{aligned}
Q^{(1)}(N) &:= \max S(B) - S(E) \\
&= \max S(B) - S(RB) \\
&= \max -S(R|B)
\end{aligned}
$$

"coherent information"

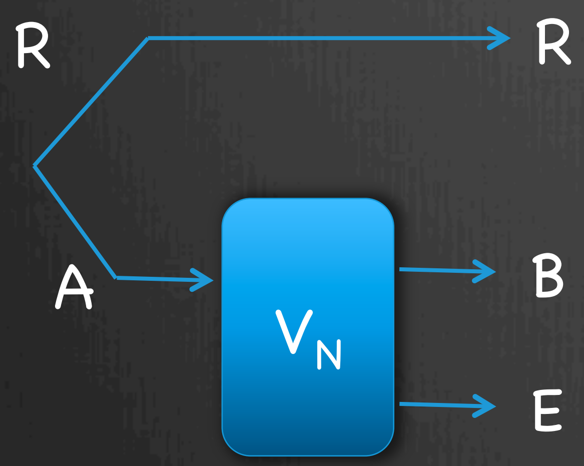
$$Q(N) = \lim_{n\to\infty} Q^{(1)}(N^{\otimes n})/n$$

not known when > 0.

sometimes $Q^{(1)}(N) = 0 < Q(N)$.

entanglement-assisted capacity

Alice and Bob share unlimited free EPR pairs.



$$C_E(N) = \max I(R:B)$$

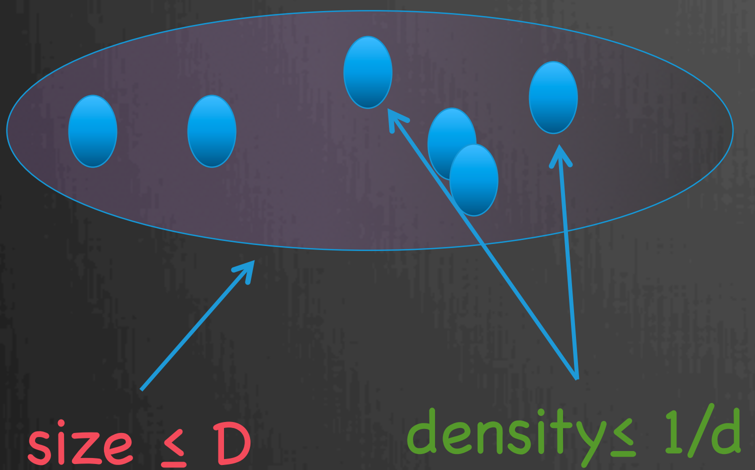
$$Q_E(N) = C_E(N)/2$$

Bennett
Shor
Smolin
Thapliyal
q-ph/0106052

1) additive
2) concave in input

→ efficiently computable

covering lemma



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1. $\mathrm{tr}[\Pi \, \sigma_x] \geq 1 - \varepsilon$
2. $\mathrm{tr}[\Pi_x \sigma_x] \geq 1 - \varepsilon$
3. $\mathrm{tr}[\Pi] \leq D$
4. $\Pi_x \sigma_x \Pi_x \leq \Pi_x \, / \, d$

Covering lemma:
If $x_1, \ldots, x_M$ are sampled randomly from p
and $M \gg (D/d) \log(D)/\varepsilon^3$ then with high probability

$$\sigma \approx_{O(\epsilon^{1/4})} \frac{\sigma_{x_1} + \cdots + \sigma_{x_M}}{M}$$

wiretap (CQQ) channel

$\rho^{x}_{BE} = N(|x\rangle\langle x|)$

<u>Thm</u>: Alice can send secret bits to Bob at rate $I(X:B) - I(X:E)$.

Proof: packing lemma -> coding $\approx nI(X:B)$ bits for Bob
covering lemma -> sacrifice $\approx nI(X:E)$ bits to decouple Eve

remote state preparation (RSP)

Q: Cost to transmit n qubits?

A: 2n cbits, n ebits using teleportation.

Cost is optimal given super-dense coding and entanglement distribution.

visible coding: What if the sender knows the state?

We want to simulate the map: "ψ" → $|\psi\rangle$.
Requires ≥n cbits, but above optimal arguments break.

RSP via covering

Consider the ensemble $\{U\psi U^\dagger\}$ for random U.
Average state is $I/2^n$.

Covering-type arguments [Aubrun arXiv:0805.2900] →
If we choose $U_1, \ldots, U_M$ randomly with $M \gg 2^n / \varepsilon^2$ then

with high probability, $\forall \psi$ $$\left\| \frac{1}{M} \sum_{i=1}^{M} U_i \psi U_i^\dagger - \frac{I}{2^n} \right\| \leq \frac{\epsilon}{2^n}$$

Set $E_i := \dfrac{2^n}{M(1+\epsilon)} U_i \psi U_i^\dagger$ Then $(1-\varepsilon)I \leq \sum_i E_i \leq I$

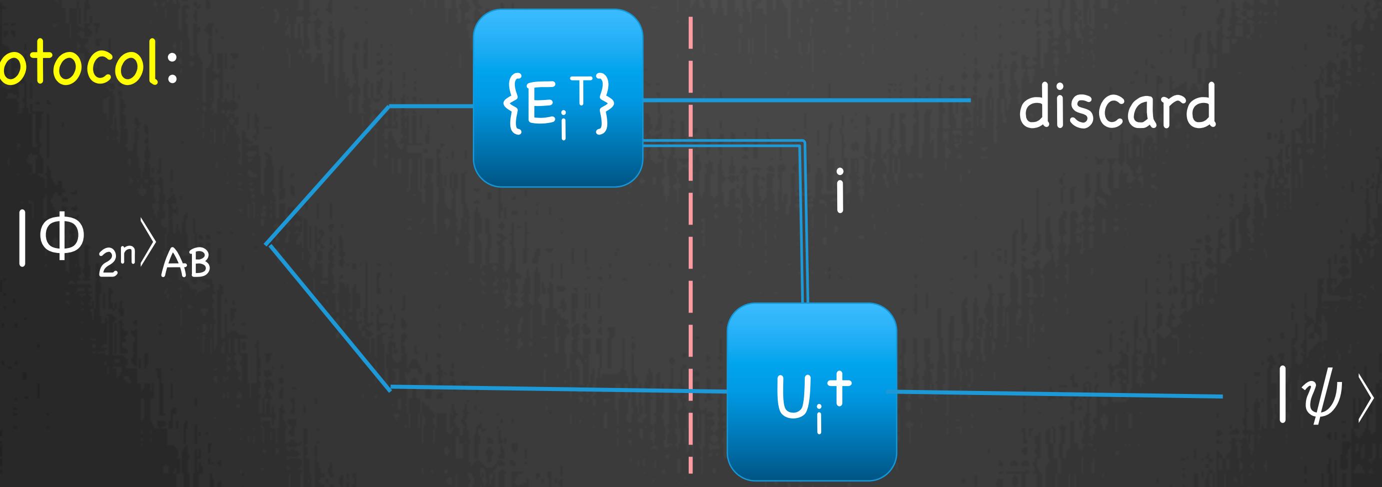
So $\{E_i\}$ is ≈ a valid measurement. So what?

RSP finally

$$|\Phi_d\rangle := \frac{1}{\sqrt{d}} \sum_{i=1}^{d} |i\rangle \otimes |i\rangle$$ recall $$E_i := \frac{2^n}{M(1+\epsilon)} U_i \psi U_i^\dagger$$

Lemma: $(A \otimes I)|\Phi_d\rangle = (I \otimes A^T)|\Phi_d\rangle$

Protocol:



$\propto E_i^T \otimes E_i \propto (U_i \psi U_i^\dagger)^T \otimes (U_i \psi U_i^\dagger)$

cost ≈ n cbits + n ebits.

RSP of ensembles

can simulate $x \to \rho_x$ with cost χ

$\approx n\chi$ cbits + some ebits $\geq N^{\otimes n} \geq \approx n\chi$ cbits

Lemma: Converting $n(C-\delta)$ cbits + ∞ ebits into nC cbits will have success probability $\leq \exp(-n\delta)$.

implies **strong converse**:
sending $n(\chi+\delta)$ bits through $N^{\otimes n}$
has $\exp(-n\delta')$ success prob

simulation and strong converses

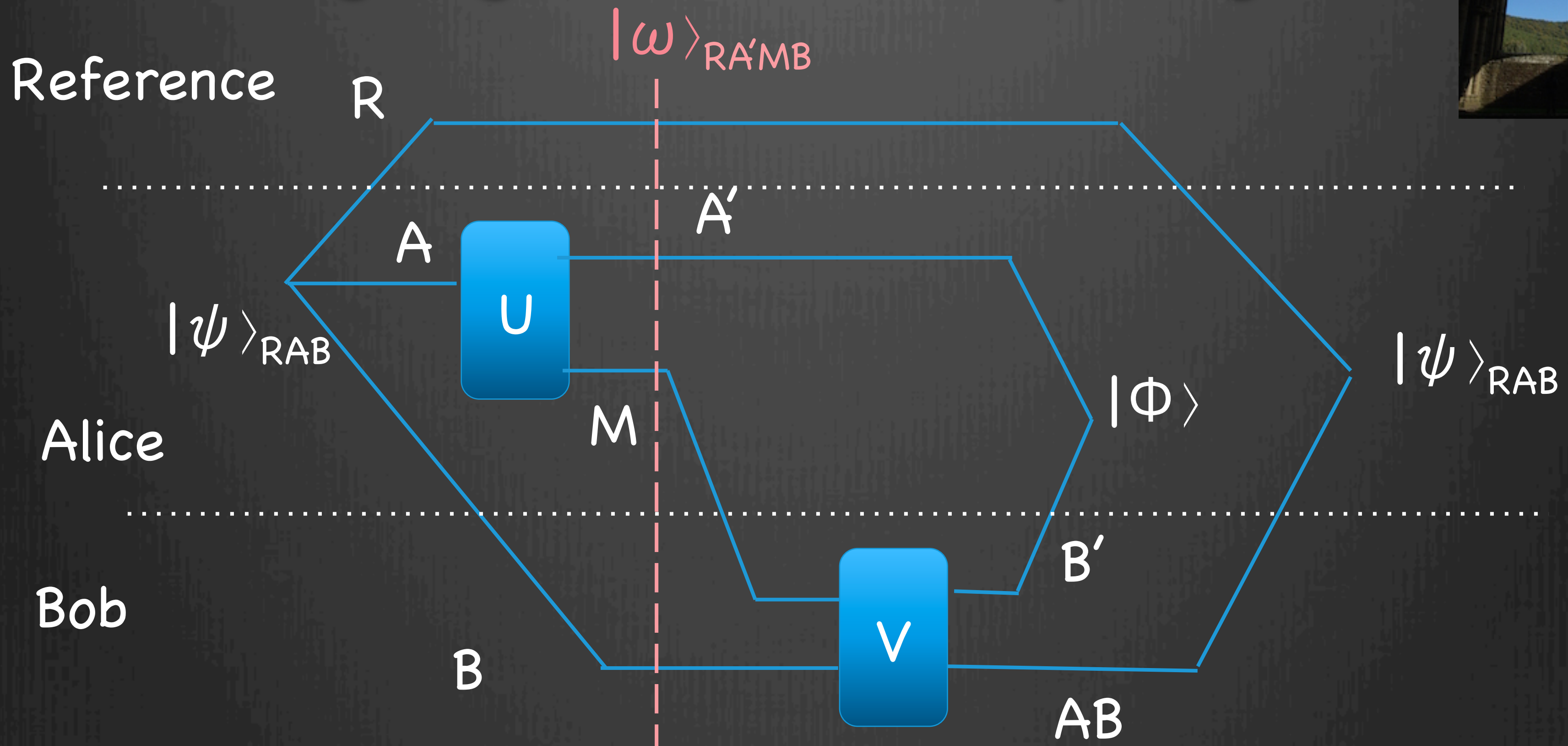
Let N be a general q channel.

Type of simulation	**cbit simulation cost**	**also needs**
visible product input	χ	EPR
visible arbitrary input	R	EPR
arbitrary quantum input	C_E	embezzling

R is "strong converse rate"; i.e. min s.t. sending $n(R+\delta)$ bits has success prob $\leq \exp(-n\delta')$

$$\chi \leq C \leq R \leq C_E$$

merging and decoupling



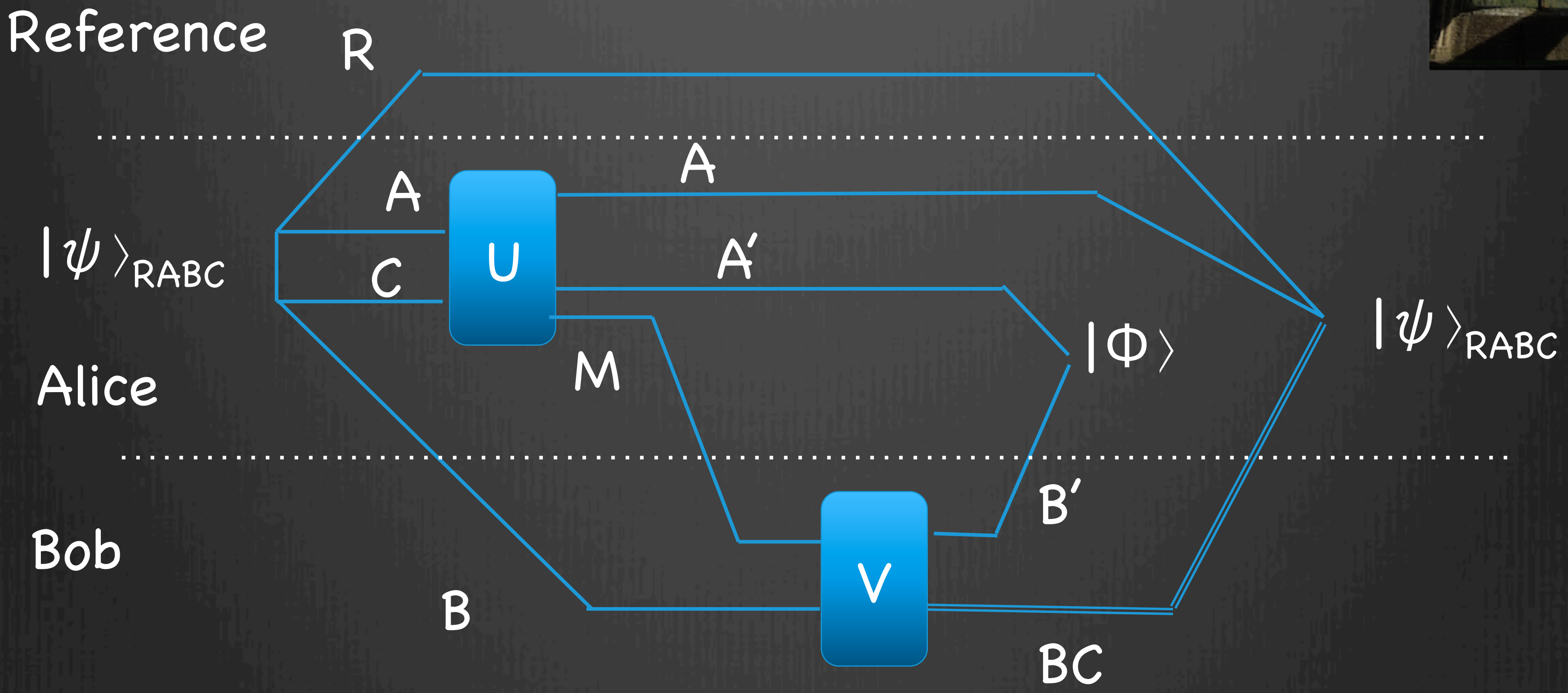
Let $|\omega\rangle = U|\psi\rangle$.

Claim: All we need is $\omega_{RA'} \approx \omega_R \otimes \omega_{A'}$.

Pf: The LHS is purified by $|\omega\rangle$ and the RHS by $|\psi\rangle_{RAB}|\Phi\rangle_{A'B'}$
Uhlmann's theorem says $\exists\, V{:}MB \rightarrow ABB'$ making these close.

state redistribution

[Luo-Devetak, Devetak-Yard]

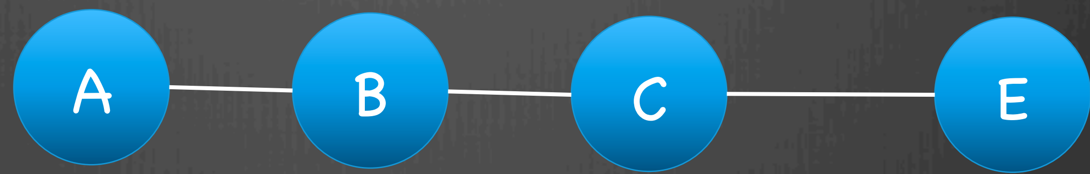


$|M| = \frac{1}{2} I(C{:}R|B) = \frac{1}{2} I(C{:}R|A)$ qubits communicated

entanglement consumed/created = $H(C|RB)$

quantum Markov states

relabel



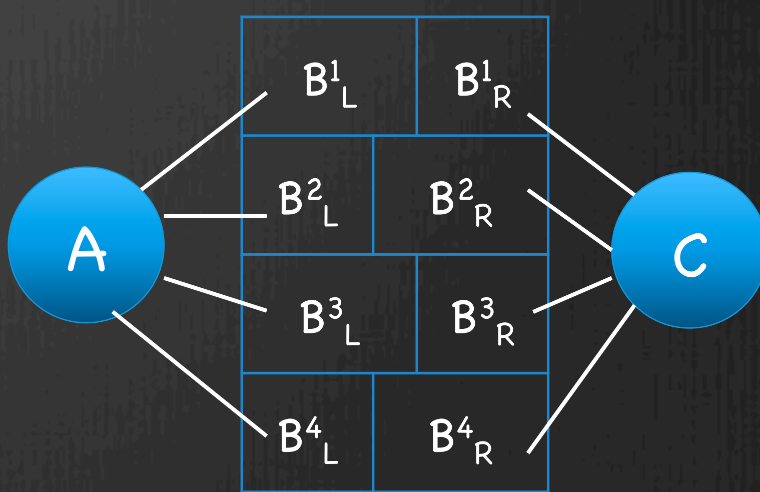
Bob can "redistribute" C to E with ½ I(A:C|B) qubits.
If I(A:C|B)=0 then this is reversible!

Implies recovery map R : B -> BC such that
$(\mathrm{id}_A \otimes R_{B\to BC})(\rho_{AB}) = \rho_{ABC}$

structure theorem: I(A:C|B)=0 iff

$$B = \bigoplus_i B_i^L \otimes B_i^R$$

$$\rho_{ABC} = \bigoplus_i p_i \rho^i_{AB_i^L} \otimes \rho^i_{B_i^R C}$$



approximate Markov states

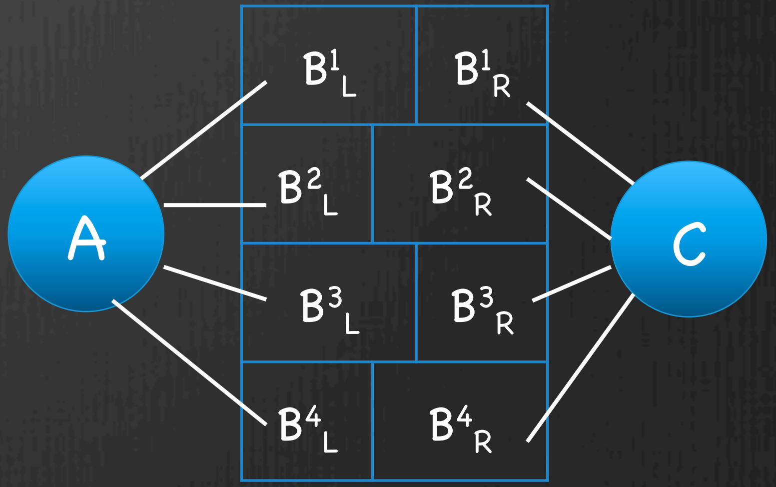
towards a structure thm: [Fawzi-Renner 1410.0664, others]
If I(A:C|B) ≈ 0 then ∃ approximate recovery map R, i.e.
$(\mathrm{id}_A \otimes R_{B\to BC})(\rho_{AB}) \approx \rho_{ABC}$

states with low CMI appear in condensed matter, optimization, communication complexity, ...

structure theorem: I(A:C|B)=0 iff

$$B = \bigoplus_i B_i^L \otimes B_i^R$$

$$\rho_{ABC} = \bigoplus_i p_i \rho^i_{AB_i^L} \otimes \rho^i_{B_i^R C}$$



Relevant talks

- Wed 9. Omar Fawzi and Renato Renner. Quantum conditional mutual information and approximate Markov chains.
- Wed 9:50. Omar Fawzi, Marius Junge, Renato Renner, David Sutter, Mark Wilde and Andreas Winter. Universal recoverability in quantum information theory.

QCMI

- Thurs 11. David Sutter, Volkher Scholz, Andreas Winter and Renato Renner. Approximate degradable quantum channels
- Thurs 4:15. Mario Berta, Joseph M. Renes, Marco Tomamichel, Mark Wilde and Andreas Winter. Strong Converse and Finite Resource Tradeoffs for Quantum Channels.

channel capacities

semi-relevant talks

- Tues 11:50. Ryan O'Donnell and John Wright. Efficient quantum tomography
merged with
Jeongwan Haah, Aram Harrow, Zhengfeng Ji, Xiaodi Wu and Nengkun Yu. Sample-optimal tomography of quantum states
- Tues 3:35. Ke Li. Discriminating quantum states:the multiple Chernoff distance

HSW metrics

- Thurs 10. Mark Braverman, Ankit Garg, Young Kun Ko, Jieming Mao and Dave Touchette. Near optimal bounds on bounded-round quantum communication complexity of disjointness

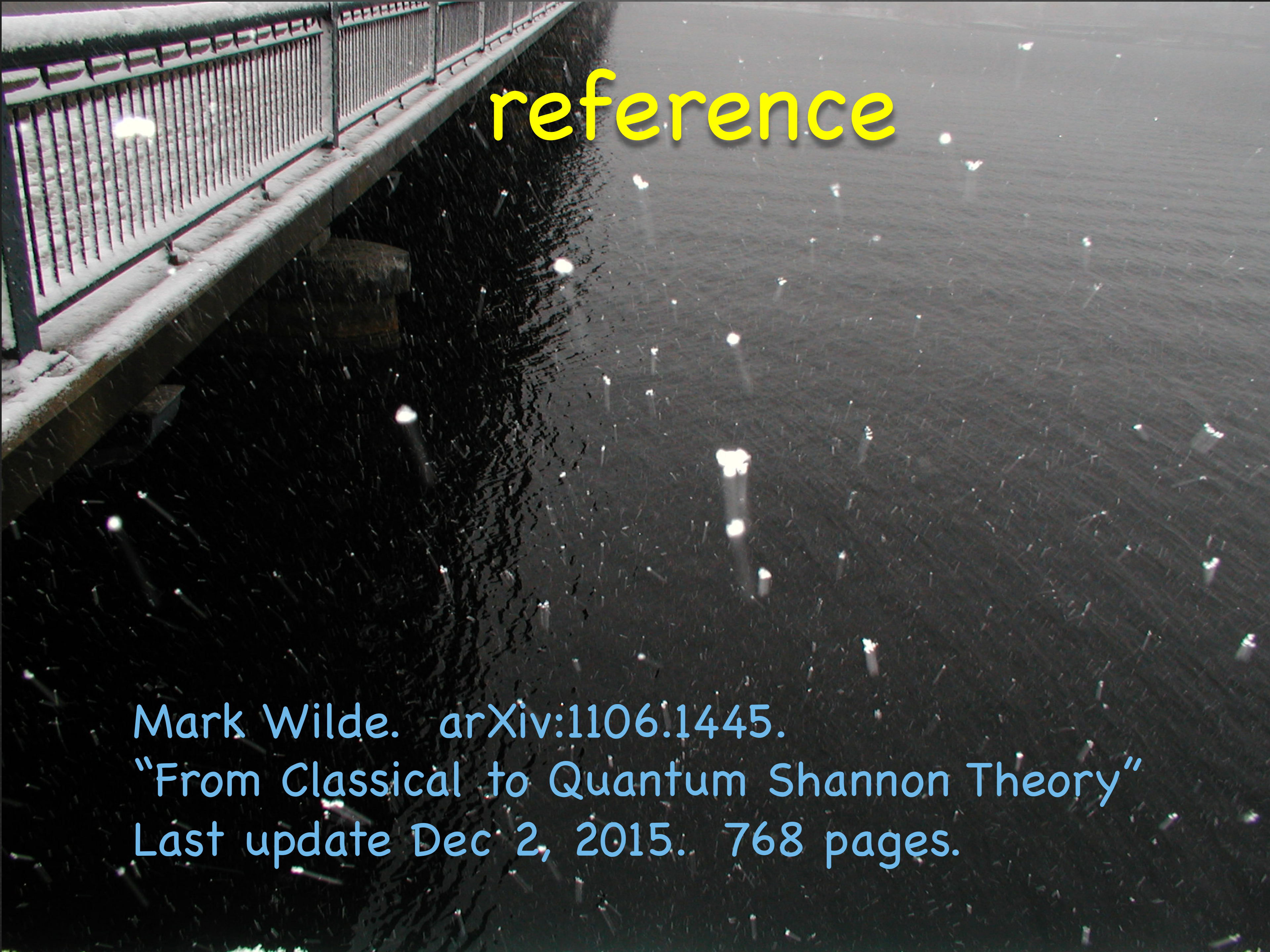
QCMI

- Thurs 3:35. Fernando Brandao and Aram Harrow. Estimating operator norms using covering nets with applications to quantum information theory

covering

- Thurs 4:15. Michael Beverland, Gorjan Alagic, Jeongwan Haah, Gretchen Campbell, Ana Maria Rey and Alexey Gorshkov. Implementing a quantum algorithm for spectrum estimation with alkaline earth atoms.

entropy


reference
Mark Wilde. arXiv:1106.1445.
"From Classical to Quantum Shannon Theory"
Last update Dec 2, 2015. 768 pages.