Title: Self-guided quantum systems

Date: Sep 23, 2015 04:00 PM

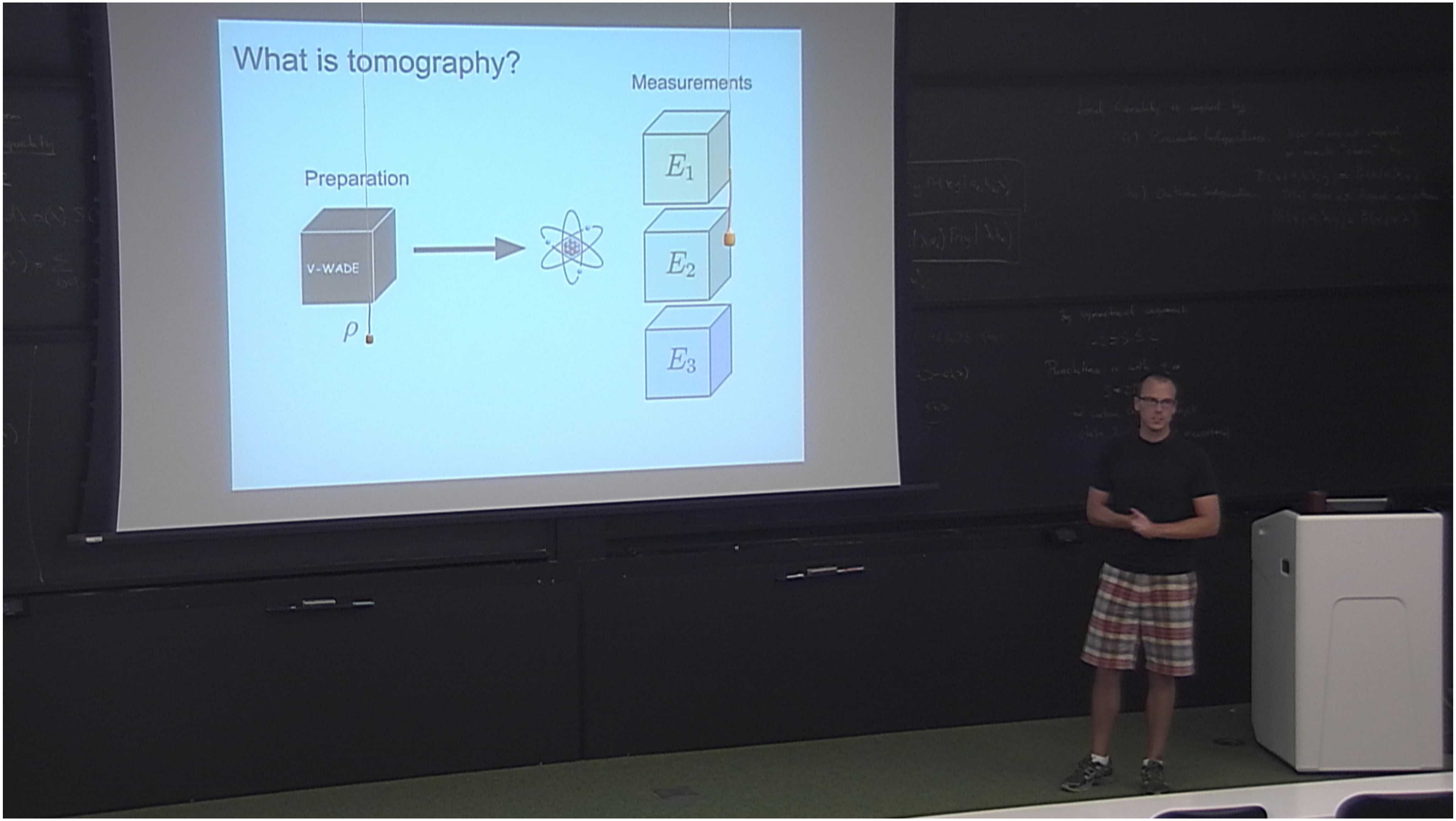
URL: http://pirsa.org/15090068

Abstract: <p>Iâ€™ll present new approaches to the problems of quantum control and quantum tomography wherein no classical simulation is required. The experiment itself performs the simulation (in situ) and, in a sense, guides itself to the correct solution. The algorithm is iterative and makes use of ideas from stochastic optimization theory.</p>

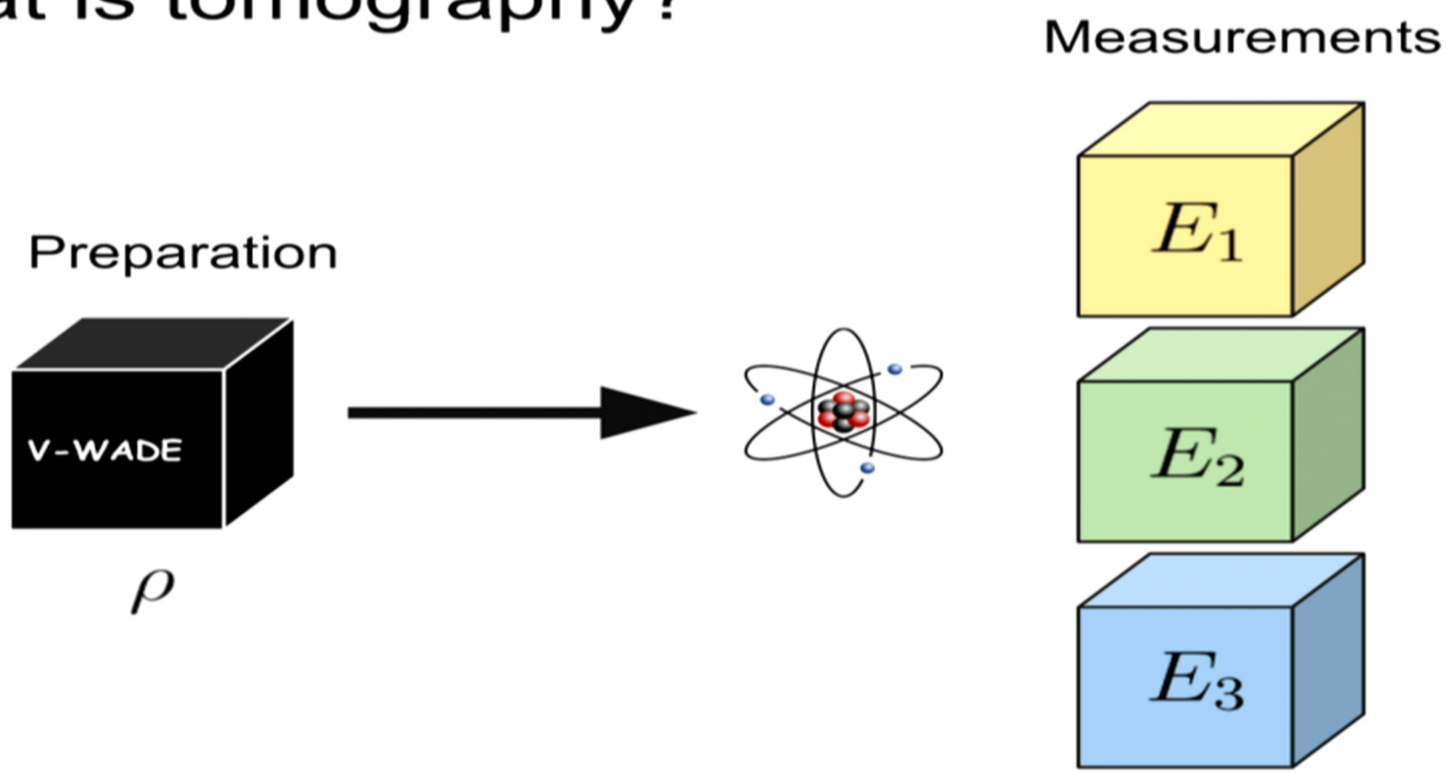
Self-guided quantum tomography

Chris Ferrie (University of Sydney)

arXiv:1406.4101
(also PRL)


What is tomography?
Measurements
Preparation
V-WADE
ρ
E_1
E_2
E_3

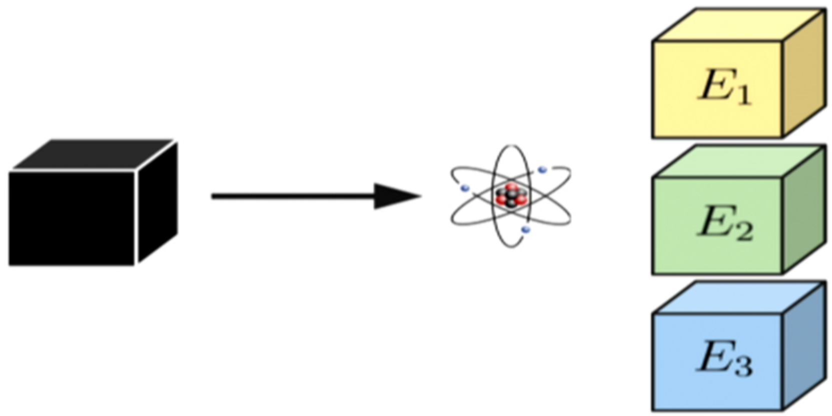
What is tomography?



What is tomography?

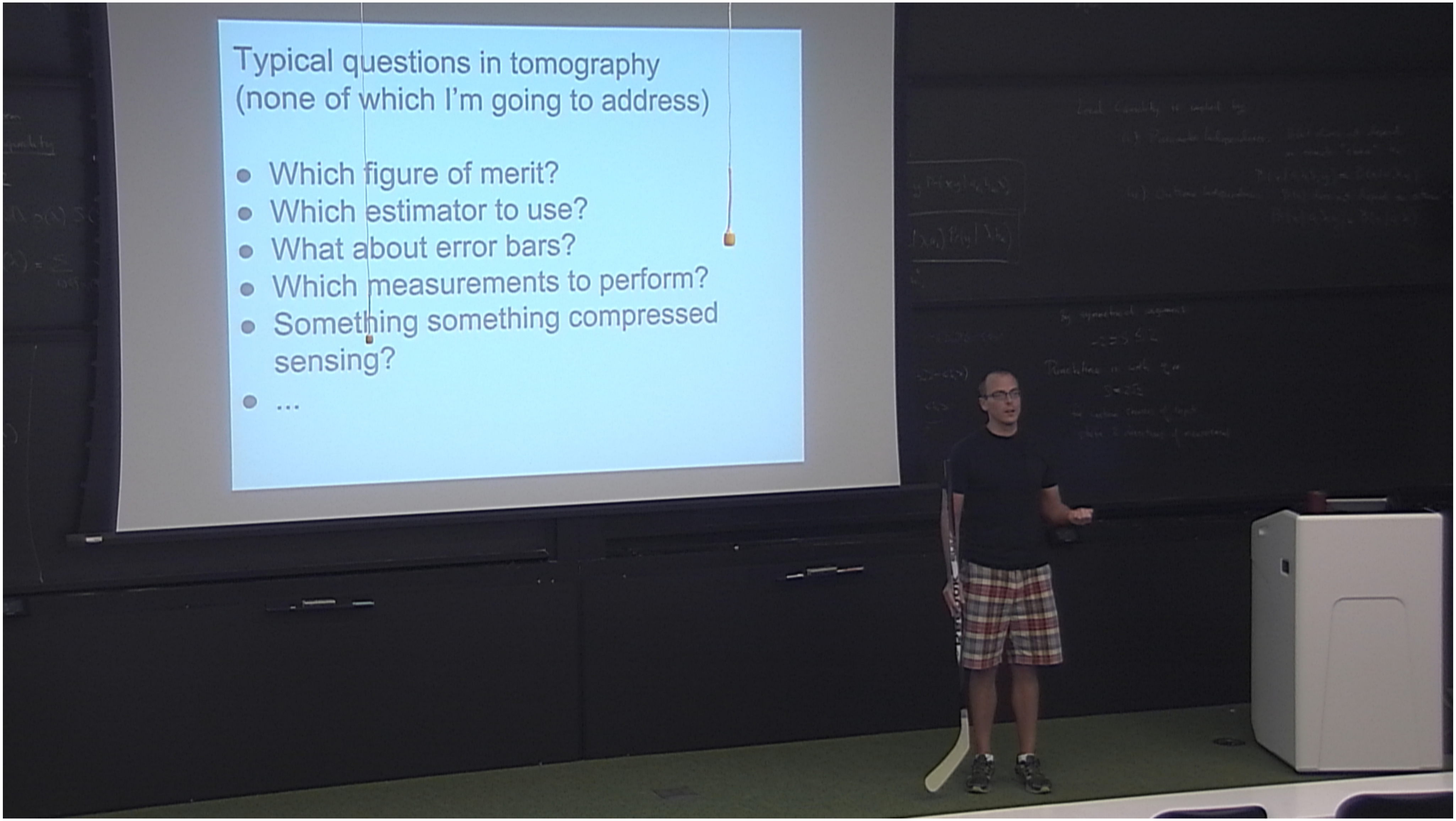
Deduction

$$\rho \longrightarrow \Pr(E_k|\rho) = \mathrm{Tr}(E_k\rho)$$



$$\rho \longleftarrow E_k$$

Induction


Typical questions in tomography
(none of which I'm going to address)
Which figure of merit?
Which estimator to use?
What about error bars?
Which measurements to perform?
Something something compressed sensing?
...

Punchline:

1. Can perform adaptive measurement tomography without reconstructing the state.

2. Trade-off between measurement complexity and computational complexity.

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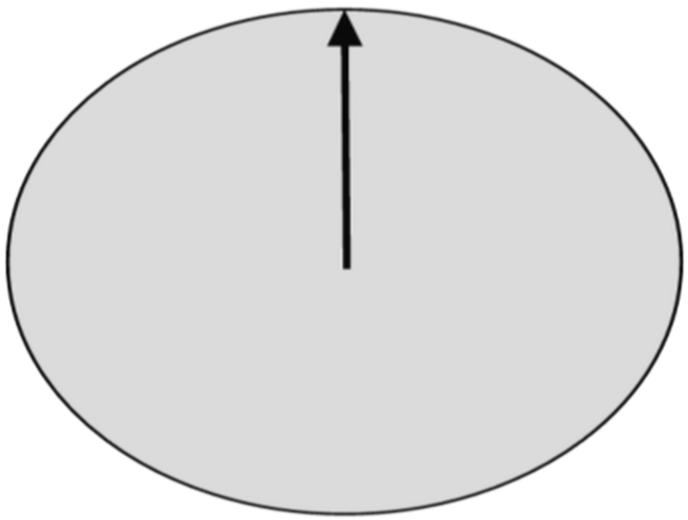

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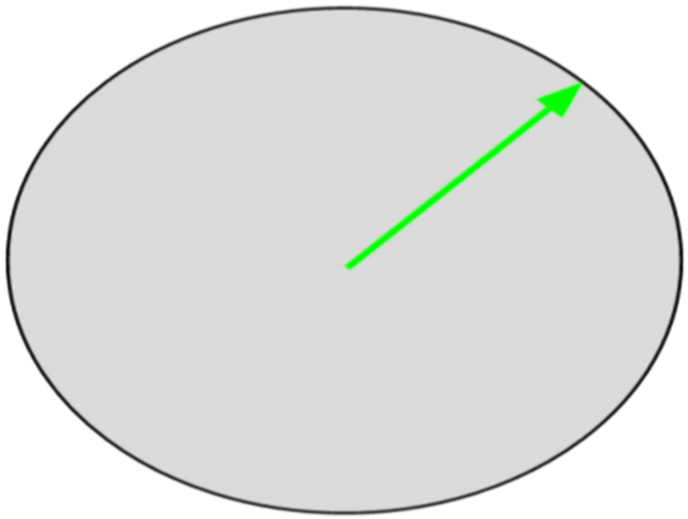

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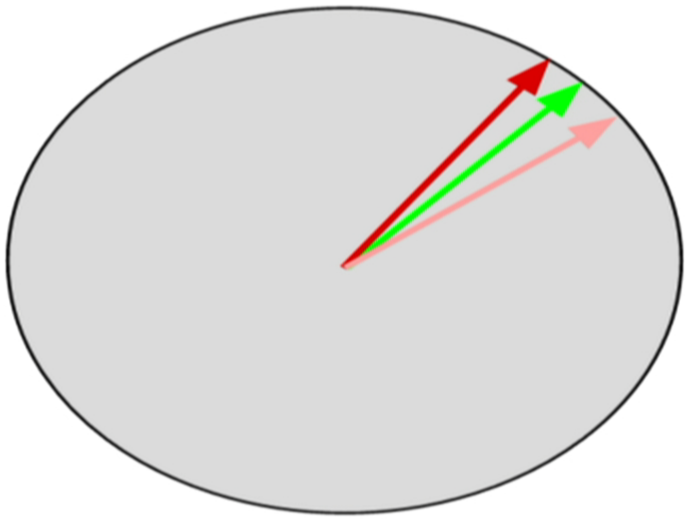

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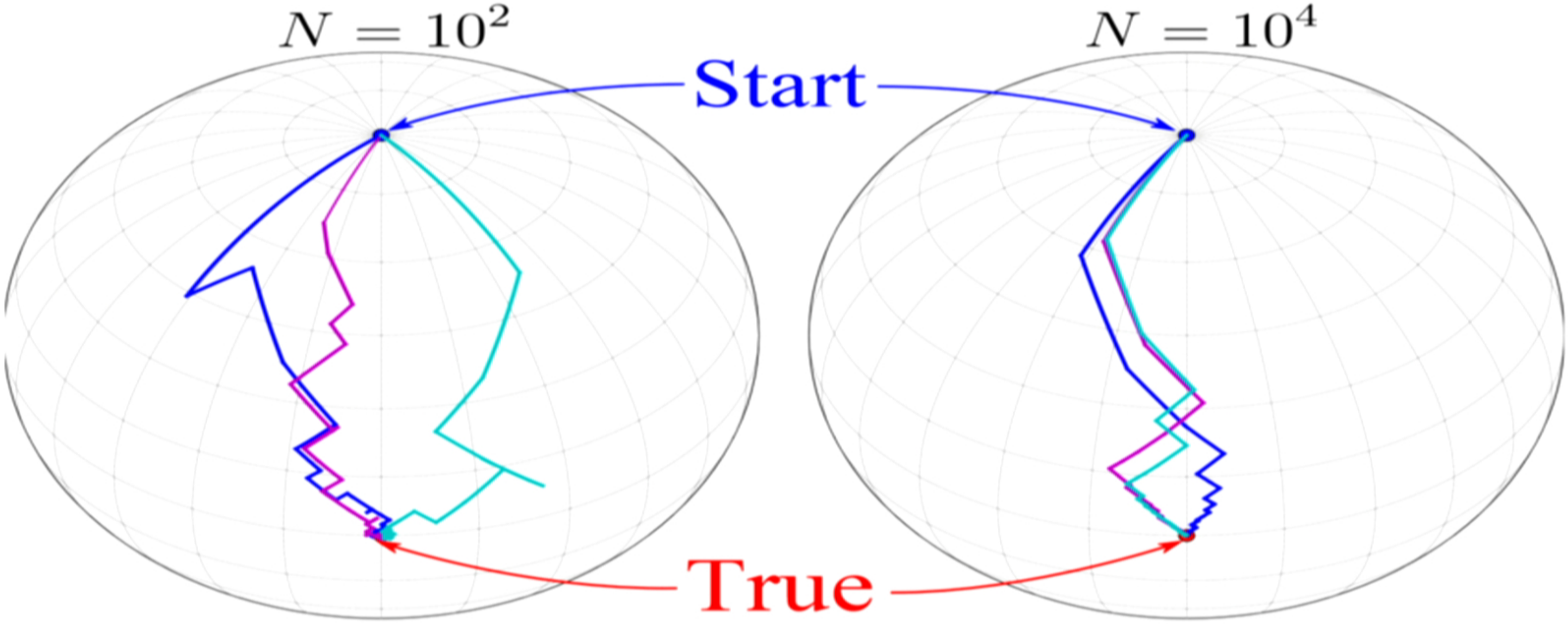

2. Trade-off between measurement complexity and computational complexity.

	Accuracy	Measurement Complexity	Space Complexity	Time Complexity
Standard Tomography	$O(d/N_{\mathrm{tot}})$	$O(d)$	$O(d^3)$	$O(d^3)$
Self-guided Tomography	$O(d^\eta/N_{\mathrm{tot}})$	$O(N_{\mathrm{tot}})$	$O(d)$	$O(d)$

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Self-guided quantum tomography = Adaptive direct fidelity estimation

Direct Fidelity Estimation from Few Pauli Measurements
(Steven T. Flammia, Yi-Kai Liu)
arXiv:1104.4695

Practical characterization of quantum devices without tomography
(Marcus P. da Silva, Olivier Landon-Cardinal, David Poulin)
arXiv:1104.3835

Immediate objections

You got a kangaroo loose in the top paddock!

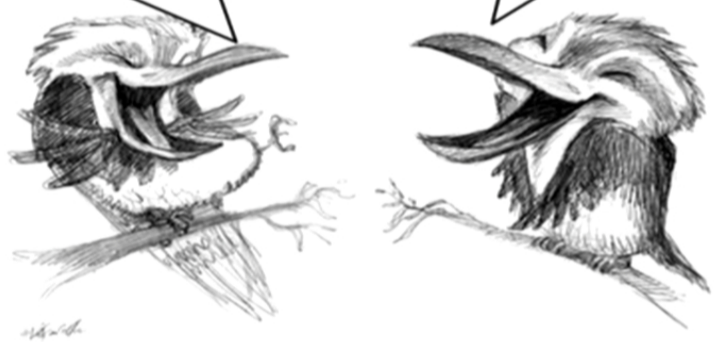
The number of fidelity estimates increases linearly with dimension (hence exponentially in the number of qubits)!

Besides, if you are going to estimate fidelity in every direction of state space, you might as well do standard tomography!

Have you hit the turps, mate?

Estimating fidelity is noisy and noisy gradients will steer you in the wrong direction.

Your method will never converge to the true state!



Simultaneous perturbation stochastic approximation

$$\sigma_{k+1} = \sigma_k + \underbrace{\alpha_k}_{\text{Gain}} \underbrace{\frac{f(\sigma_k + \gamma_k \triangle_k) - f(\sigma_k - \gamma_k \triangle_k)}{2\gamma_k}}_{\text{Magnitude}} \underbrace{\triangle_k}_{\text{Direction}}$$

Simultaneous perturbation: Do not estimate the gradient in all directions. Estimate instead in a single random direction. This reduces the number of fidelity estimates to 2, independent of dimension.

Simultaneous perturbation stochastic approximation

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Stochastic approximation: (almost) unbiased estimate of the gradient with a finite difference approximation. Convergence analysis reveals the necessary conditions on the sequence

$$\{\alpha_k, \gamma_k, \triangle_k\}$$

SPSA

$$\sigma_{k+1} = \sigma_k + \alpha_k \frac{f(\sigma_k + \gamma_k \triangle_k) - f(\sigma_k - \gamma_k \triangle_k)}{2\gamma_k} \triangle_k$$

$$\sum_k \alpha_k = \infty \qquad \alpha_k = \alpha_0 / k$$

$$\sum_k \frac{\alpha_k^2}{\gamma_k^2} < \infty \qquad \gamma_k = \gamma_0 / k^{\frac{1}{3}}$$

$(\triangle_k)_j$ independent, zero-mean, finite inverse first and second moments

Rademacher distribution (± 1 with probability ½)

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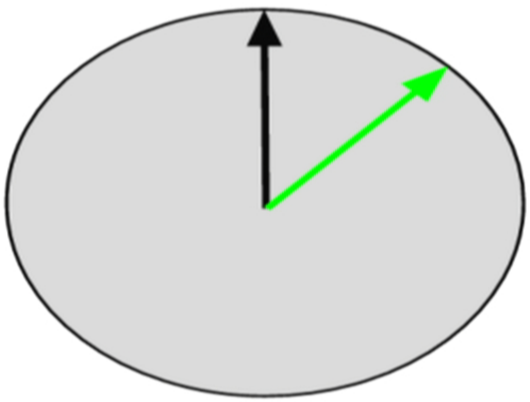
Applied to quantum state estimation

Recall, fidelity: $f(\sigma) = \mathrm{Tr}(\rho\sigma)$

Estimate using test: $\{\Pi_+, \Pi_-\} := \{\sigma, I - \sigma\}$

Via: $f(\sigma) = \mathbb{E}\left[\frac{n_+}{n_+ + n_-}\right]$



Finite size scaling analysis

k : number of iterations
M : number of fidelity estimates per iteration
N : number of measurements per fidelity estimate

$$N_{\text{tot}} = MNk = 2Nk$$

We will fit simulated measurement data to:

$$1 - F \sim k^{-\beta}$$

Fits will suggest: $1 - F \sim N_{\text{tot}}^{-1}$

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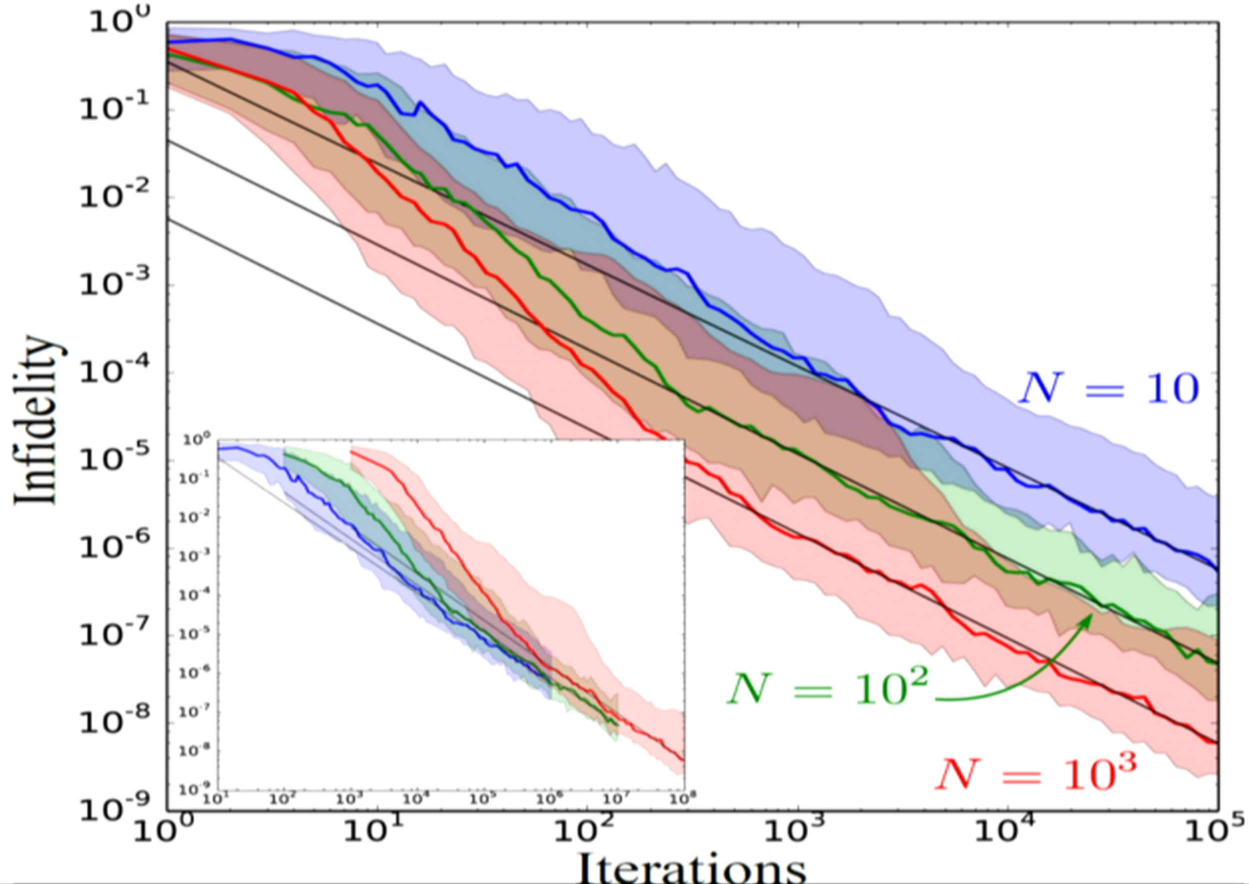
Single qubit (1-*F* vs *k*)



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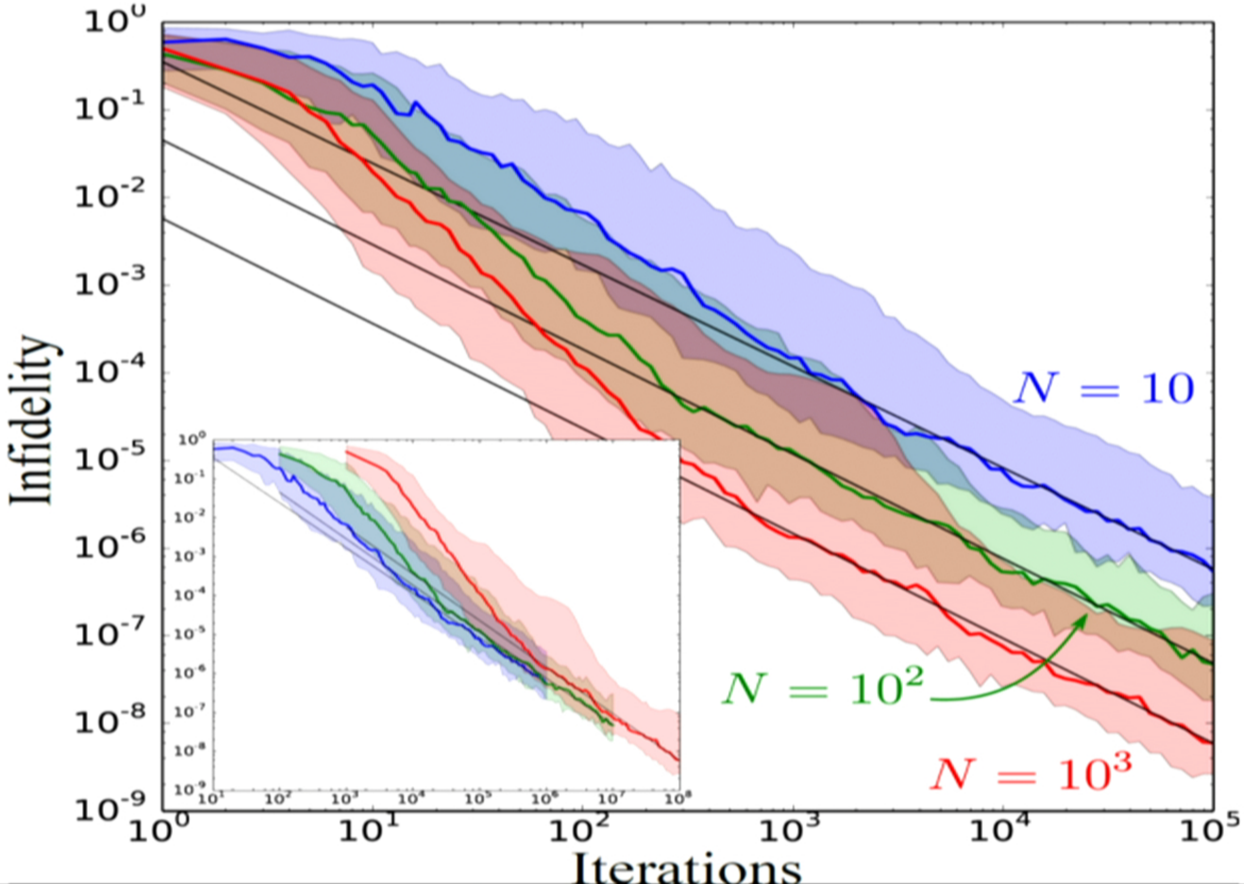
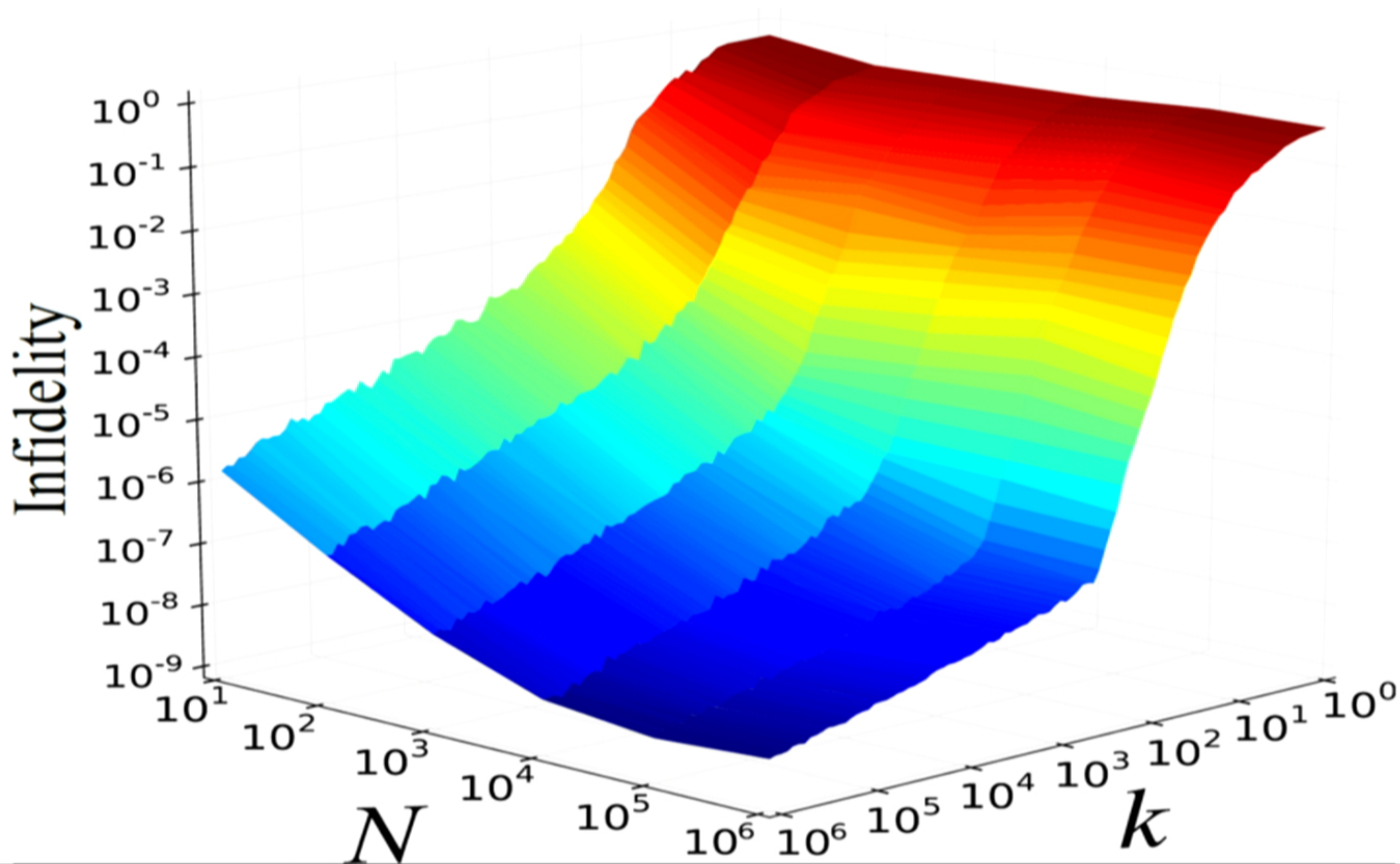
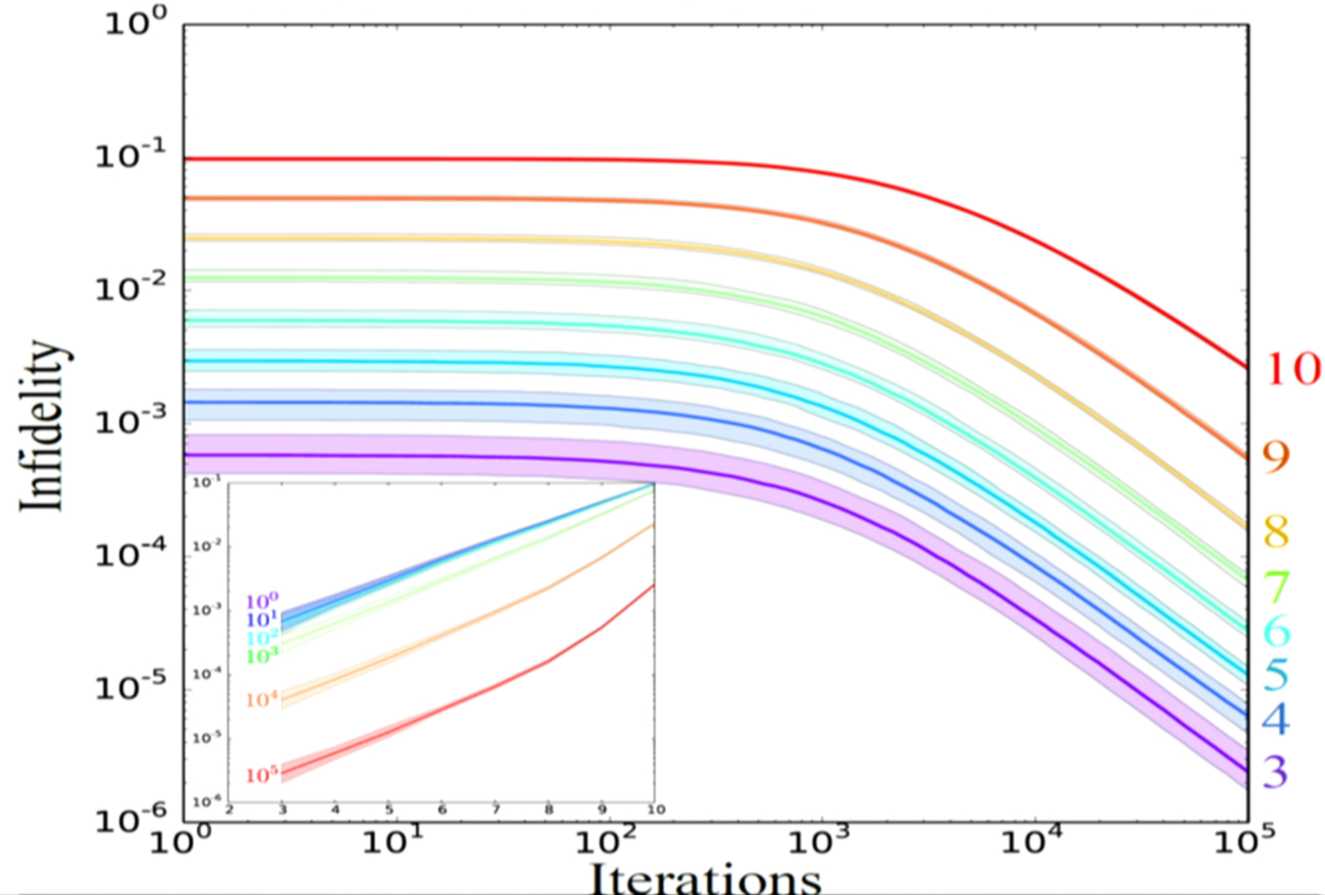
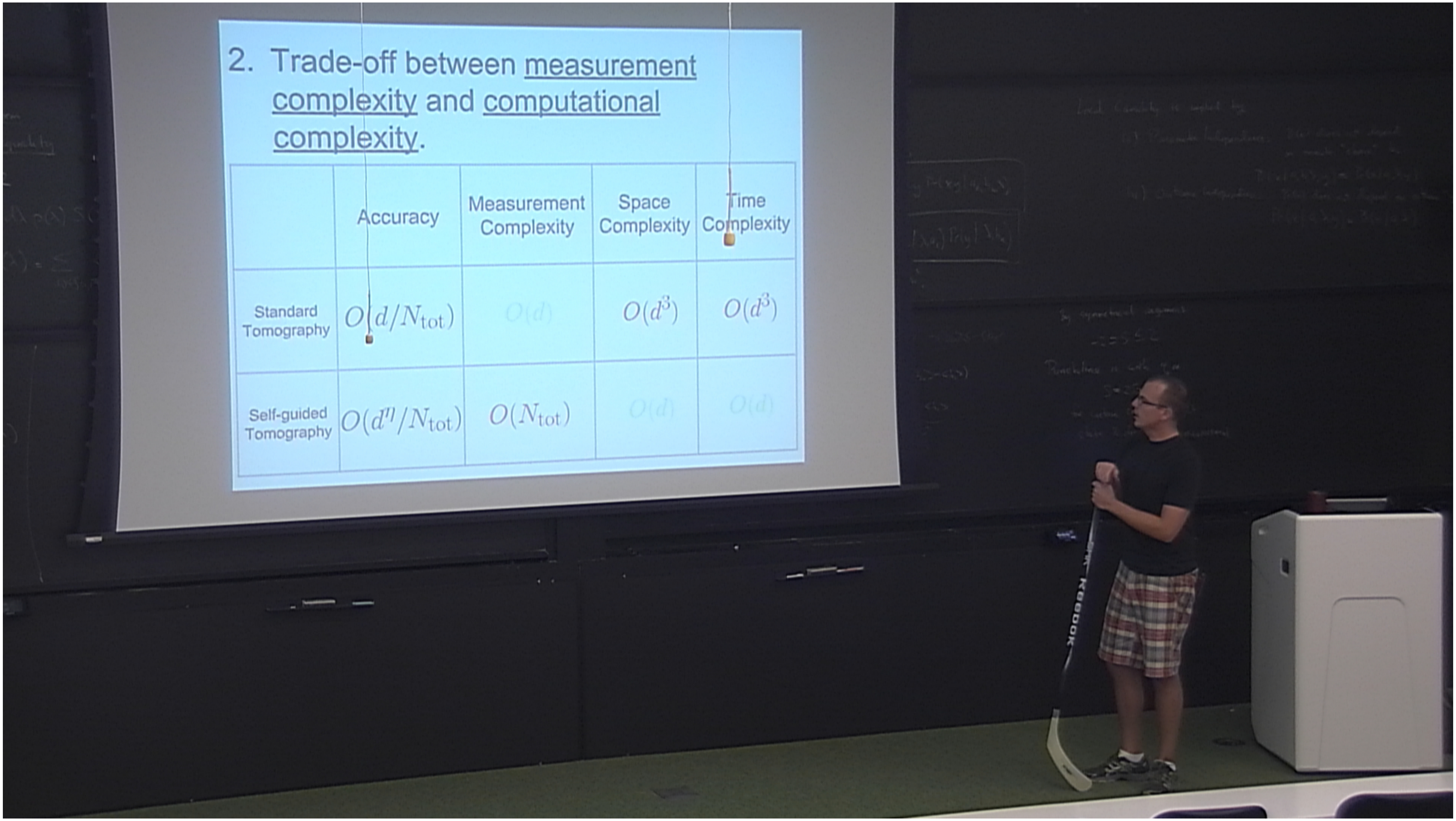


Single qubit (1-F vs k vs N)



Multi-qubit (1-F vs k)

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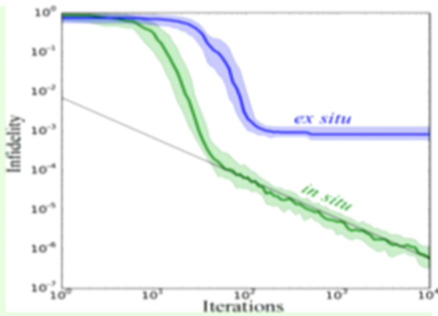
Where to from here?

ACRONYM
(w/ O. Moussa, 1409.3172)



MOQCA
(Granade, PhD Thesis)

Used as subroutine in genetic algorithm for quantum control

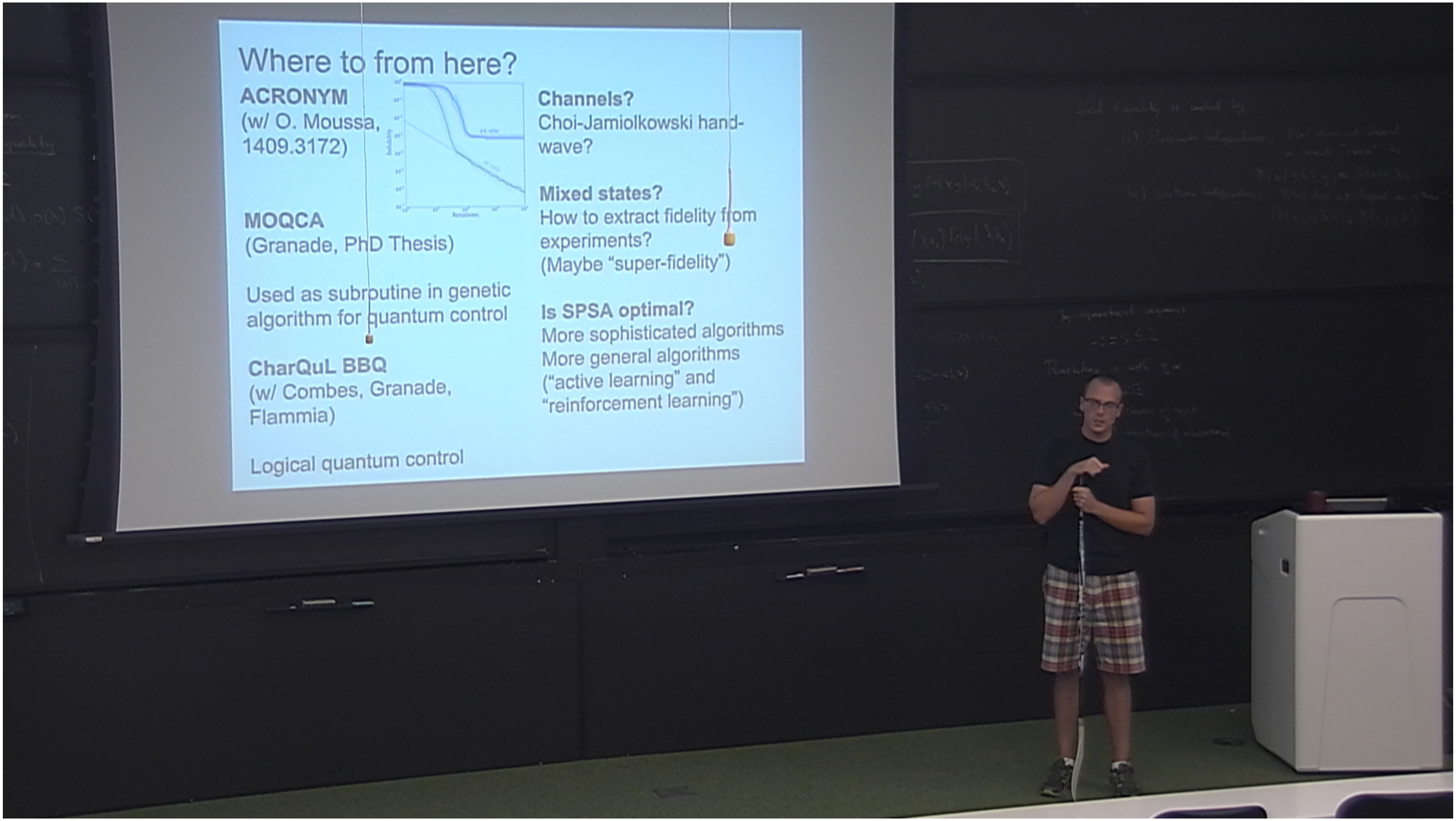
CharQuL BBQ
(w/ Combes, Granade, Flammia)

Logical quantum control

Channels?
Choi-Jamiolkowski hand-wave?

Mixed states?
How to extract fidelity from experiments?
(Maybe “super-fidelity”)

Is SPSA optimal?
More sophisticated algorithms
More general algorithms
(“active learning” and “reinforcement learning”)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