Imperial College London

Transfer Learning in Quantum Optimal Control

Jamie Leppard and Leonard Logaric

Group: QOLS
Supervisor: Florian Mintert

1. Introduction

Quantum Optimal Control (QOC)

- Find the optimal parameters to drive a quantum system from some initial state to a final state [1]
- Useful for technological innovations such as quantum computing based on trapped ions
- An example is to optimize ϕ as shown in Figure 1

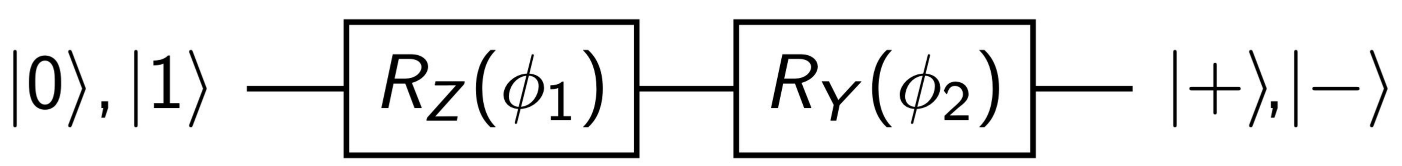

Figure 1: An example of a quantum circuit to produce a Hadamard gate.

Bayesian Optimisation & Transfer Learning

- Bayesian optimization (BO) is a technique for maximising expensive-to-evaluate black-box functions
- It has been demonstrated that Bayesian optimization performs well in QOC problems [2]
- We want to transfer information about a state optimization to the corresponding gate optimization

Aims

- Develop a framework for transfer learning with BO
- Apply the transfer learning method to a range of quantum optimal control tasks
- Benchmark the results against standard BO

2. Method

Our method for transfer learning consists of three steps:

1. Choose a gate preparation problem of interest
2. Perform standard BO on a related state preparation problem
3. Proceed with Bayesian optimization of the gate using the transfer acquisition function Equation 1

$$a_{transfer}(\vec{\phi}) = \mu_g(\vec{\phi}) + \mu_s(\vec{\phi}) - (\mu_s(\vec{\phi}) - \mu_g(\vec{\phi}))e^{-\kappa\sigma_g(\vec{\phi})}$$

Equation 1. The acquisition function targets parameters that performed well in the state optimization, but then ignores them if they do not perform well in the gate optimization.

3a. Results: One qubit warm-up

- Optimize parameters for the circuit in Figure 1
- The state and gate control landscapes are shown in Figure 2
- The state preparation finds two potential maxima regions
- The gate preparation shares one of these maxima
- How transfer learning maps the gate landscape is shown in Figure 3

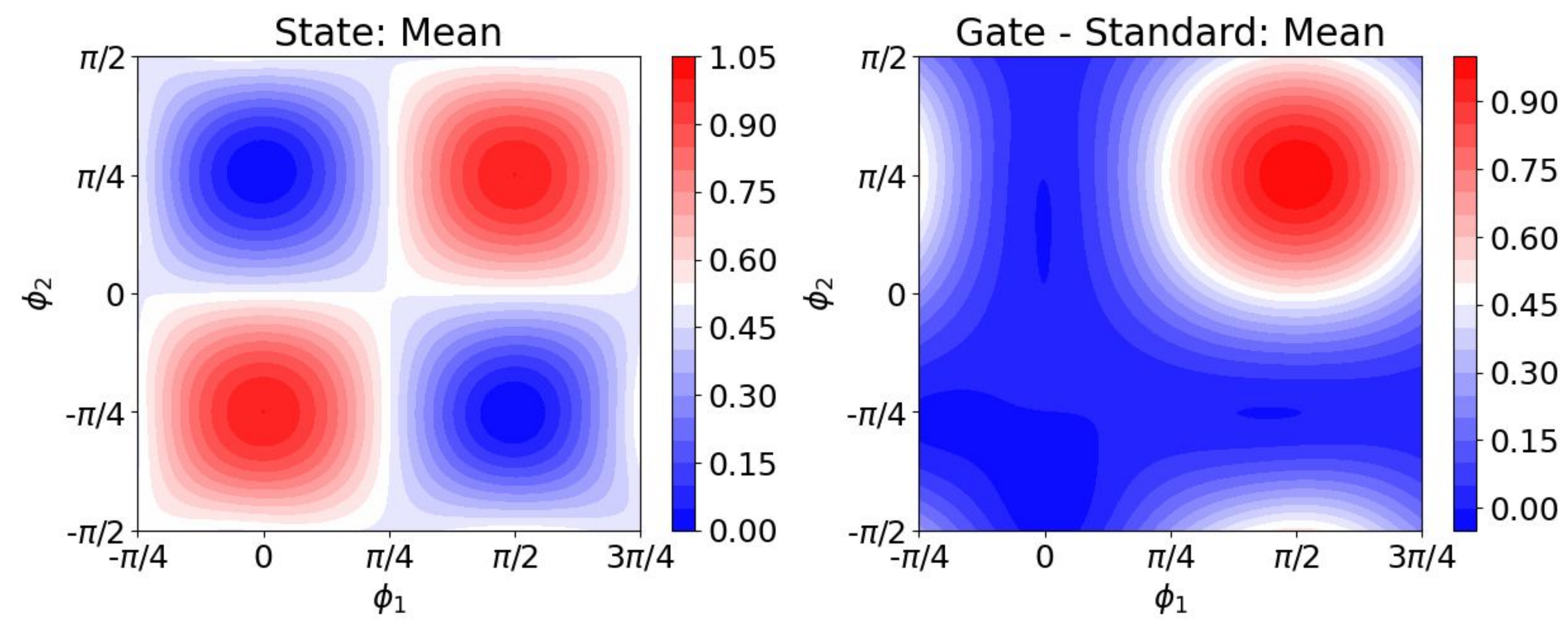

Figure 2: Optimization landscapes mapped with standard Bayesian optimization: A) State control, B) Gate control.

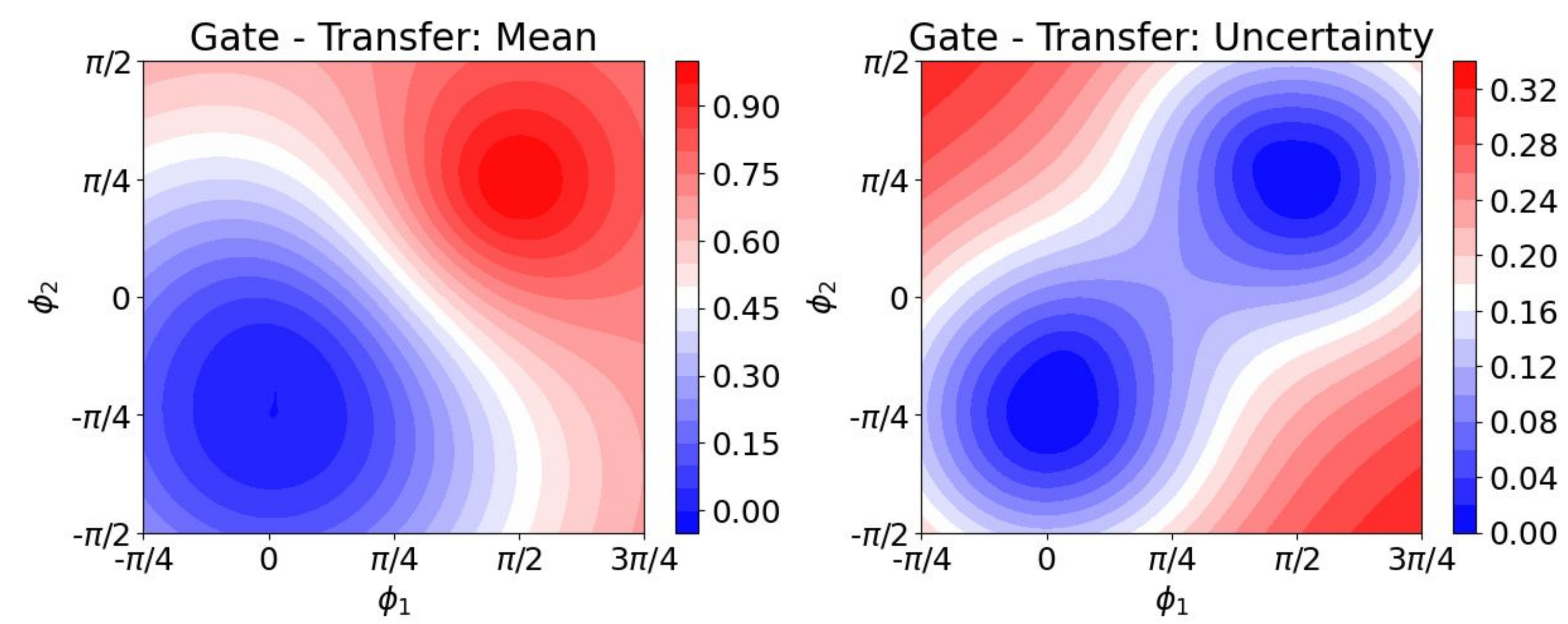

Figure 3: A) Gate landscape mapped with transfer learning. B) Uncertainty of landscape. Blue indicates regions sampled from.

3b. Results: Three Qubit problem

- Three qubit gate with six control parameters - circuit diagram in Figure 4
- Gate measurements cost 8 times state measurements, due to the Hilbert space dimensionality
- The transfer learning technique outperforms the standard BO - results shown in Figure 5

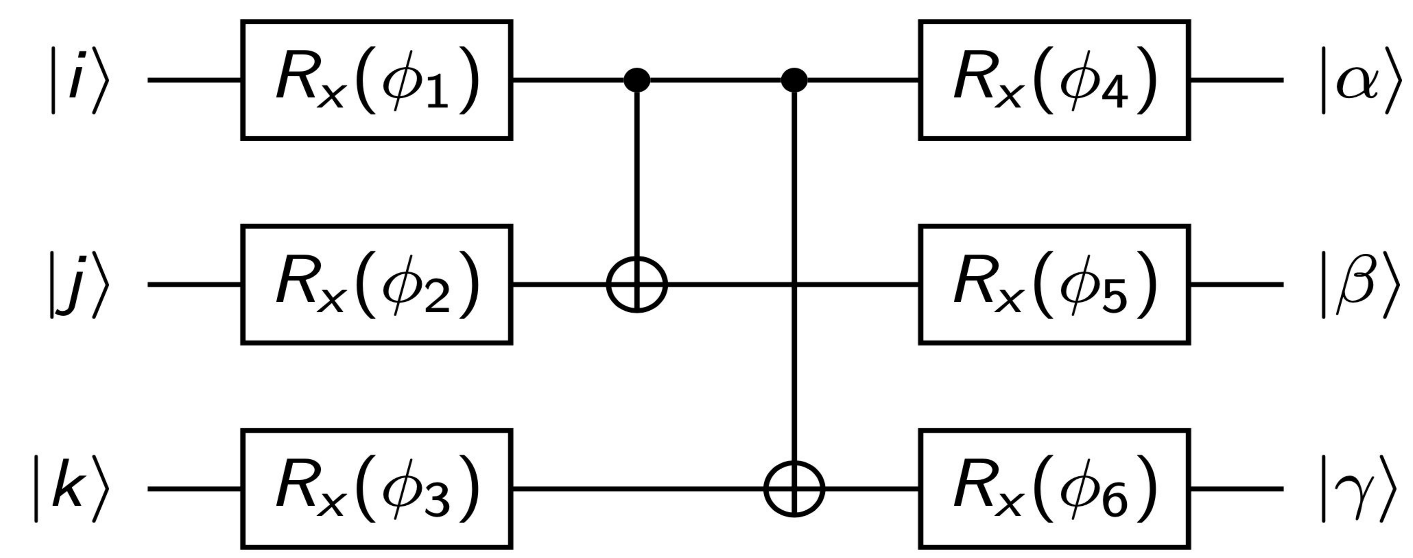

Figure 4: Circuit diagram for our chosen three qubit problem.

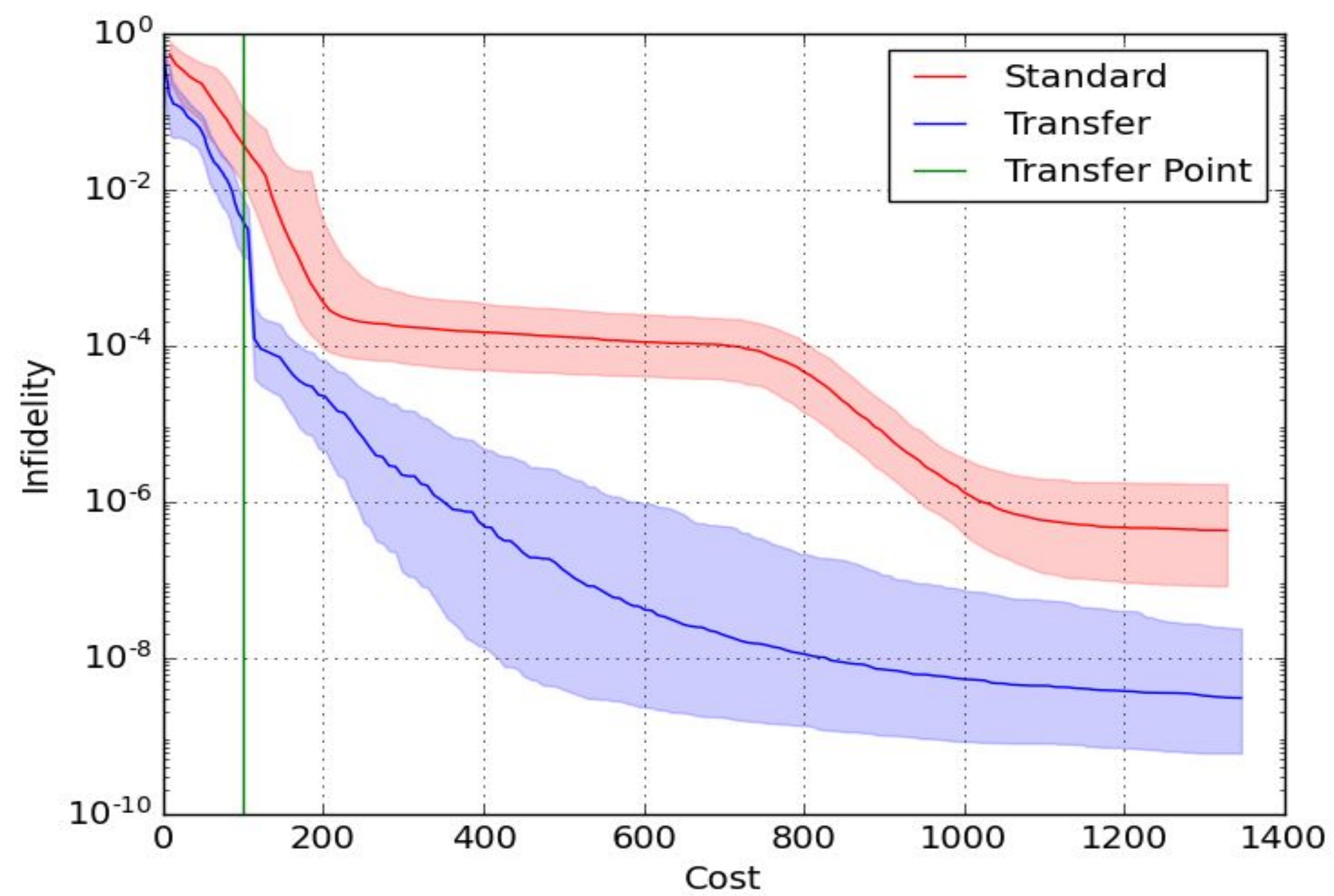

Figure 5: Comparison of standard BO and transfer learning based technique. Shaded regions indicate 80% of the data over 1000 optimizations.

4. Conclusion

- We have demonstrated that state preparation knowledge is useful for speeding up gate preparation
- The transfer learning method outperforms standard BO in a three qubit problem
- Future work - Investigate how multiple state preparations impact the optimization

References

1. D. d'Alessandro, Introduction to quantum control and dynamics. CRC press, 2007.
2. F. Sauvage, F. Mintert, "Optimal quantum control with poor statistics", PRX Quantum vol. 1, no. 2, p. 020 322, 2020.