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Symmetry Invariant Encodings for Quantum Machine Learning

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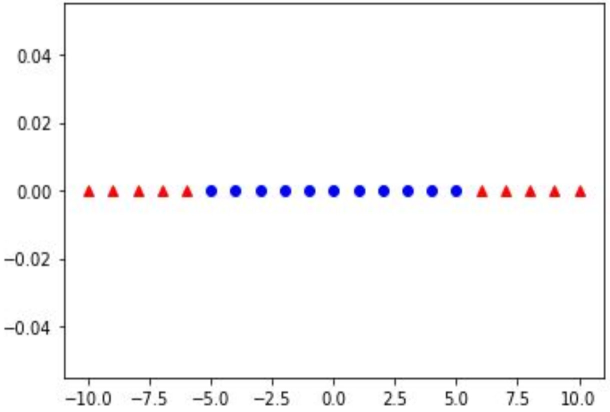
Classical Support Vector Machines

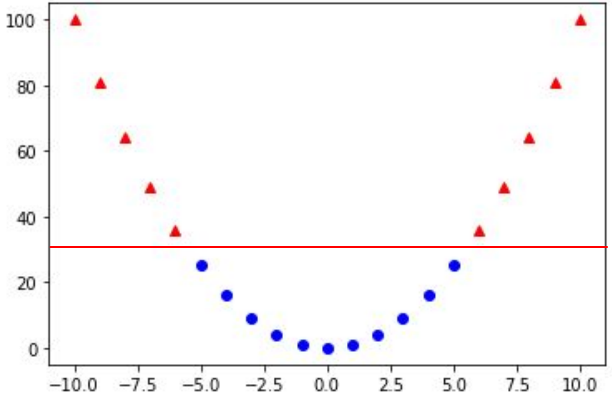
General Idea:

Encode to a higher dimensional space where the classification is easier.

Can’t separate in 1D



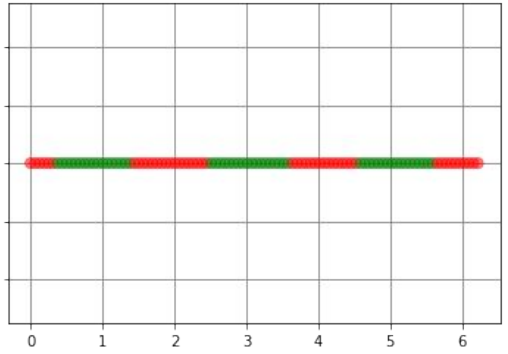
Separable in 2D

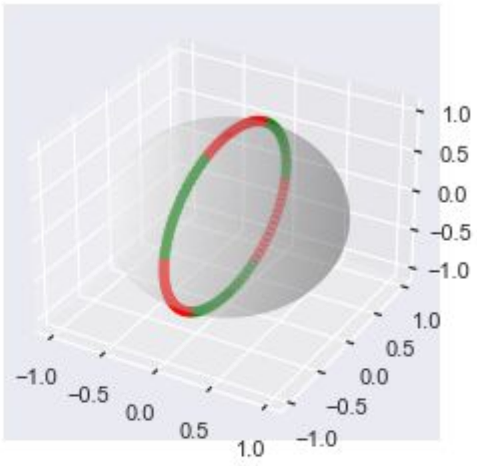


$y = x^2$

Single Qubit Encoding Example

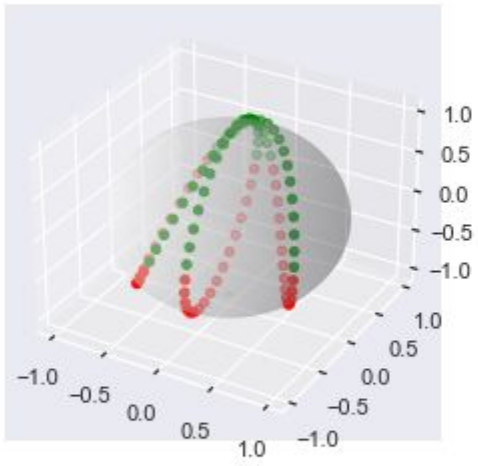
Classical 1 dimensional data





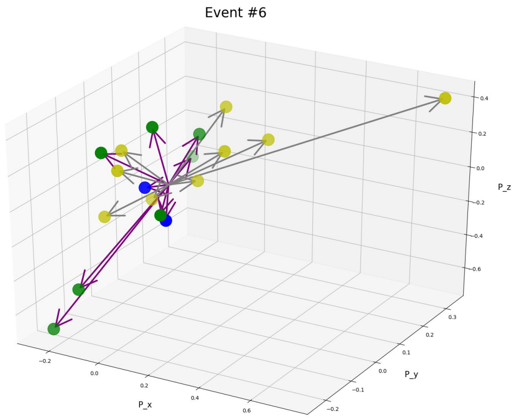
Encoding provided by a single x rotation gate on an initial 0 state

Encoding provided by circuit specific to the data

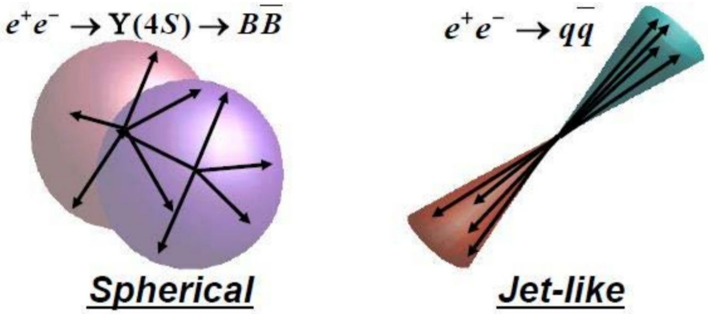


Pointcloud Data

Particle Decay Data



Particle Event Classification



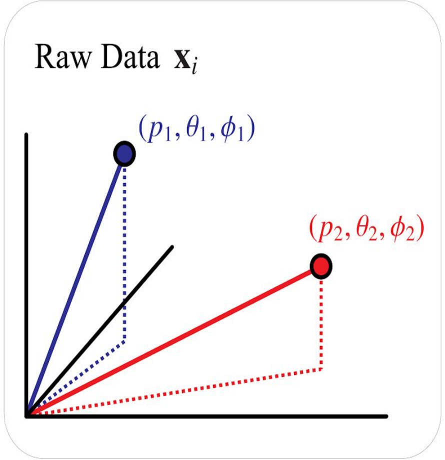
3D Object Classification

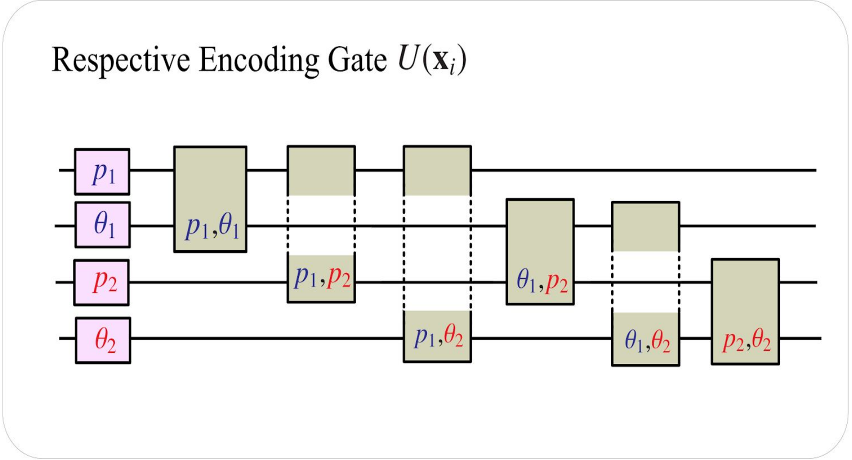
Encoding Step

$$|\Phi(z)\rangle = \mathcal{U}_{\Phi(z)}|0^n\rangle$$

Combinatorial Encoding

- Large number of gates
- Generic approach



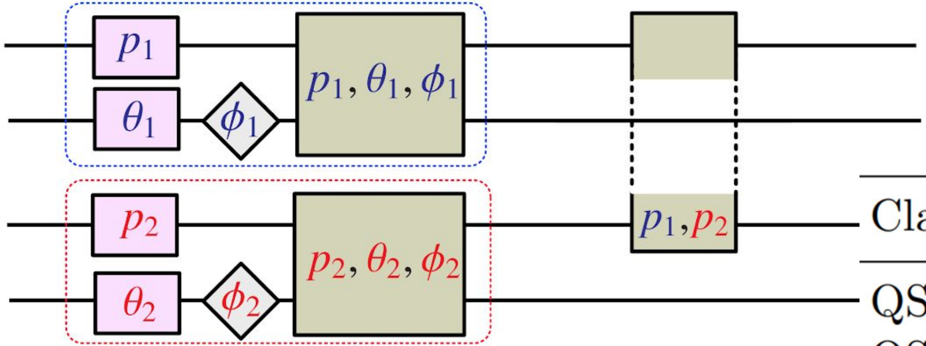


[1] Vojtech Havlicek, Antonio D. C´orcoles, Kristan Temme, Aram W. Harrow, Abhinav Kandala, Jerry M. Chow, and Jay M. Gambetta. Supervised learning with quantum enhanced feature spaces, Nature volume 567, 209–212 (2019)

Particle Physics Quantum Support Vector Machines

Particles entangled individually

Particles entangled with each other through their momenta



Classification Algorithm	AUC
QSVM - Combinatorial Encoding	0.827
QSVM - Bloch Sphere Encoding	0.861
QSVM - Separate Particle Encoding	**0.877**
Classical SVM - RBF Kernel	0.865
Classical FastBDT	0.821

[2] Heredge, Jamie & Hill, Charles & Hollenberg, Lloyd & Sevior, Martin. (2021). Quantum Support Vector Machines for Continuum Suppression in B Meson Decays. Computing and Software for Big Science. 5. 10.1007/s41781-021-00075-x.

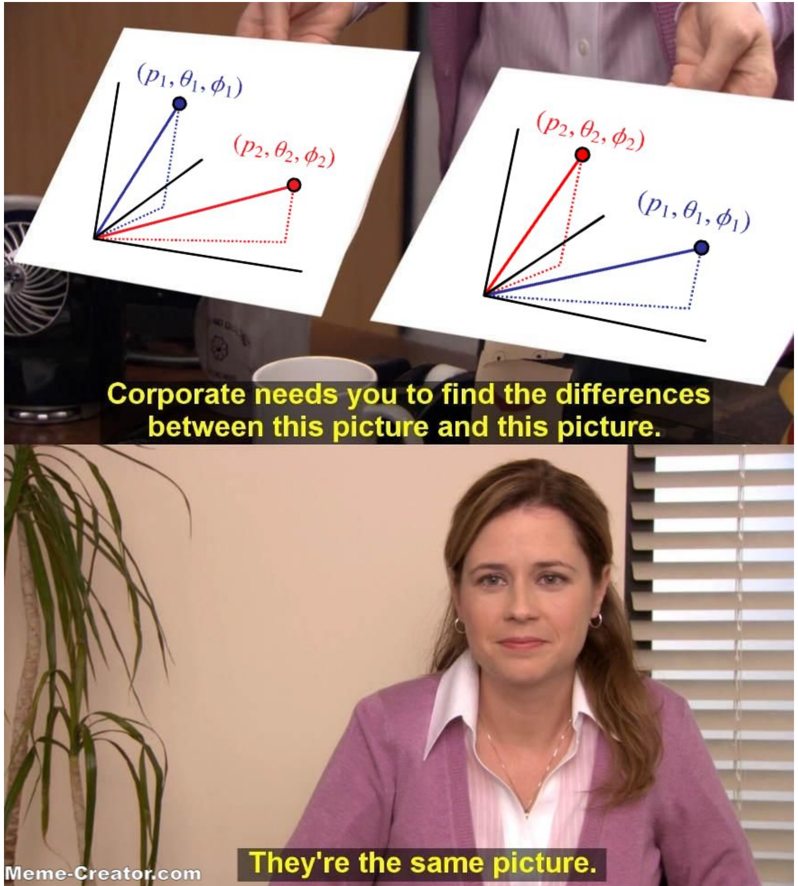
Point Order Permutation

Problem with QSVM is overfitting to training. Especially as dimension of space grows with more points.

We need a way to reduce expressibility

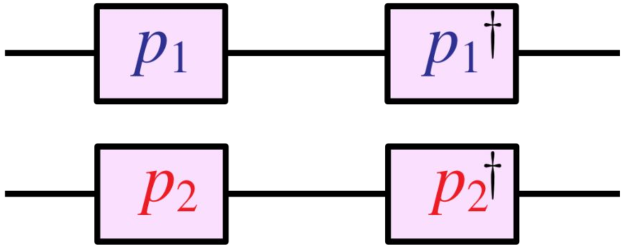
One way we can do this while still respecting properties of the underlying data is exploiting symmetries

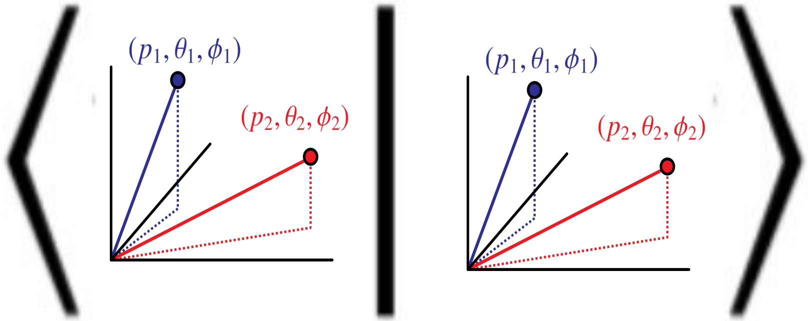
We focus on Point Re-ordering Permutation Symmetry.



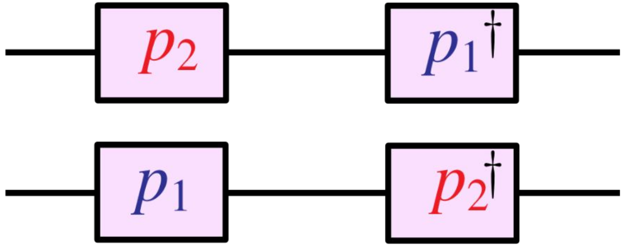
Different Results Under Point Order Permutation

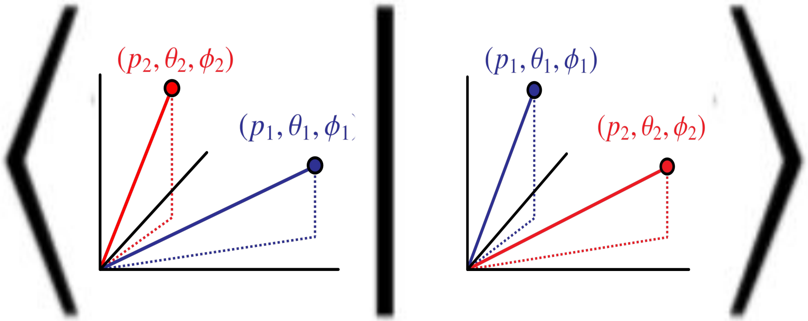
Always measure 0 state = Perfect overlap



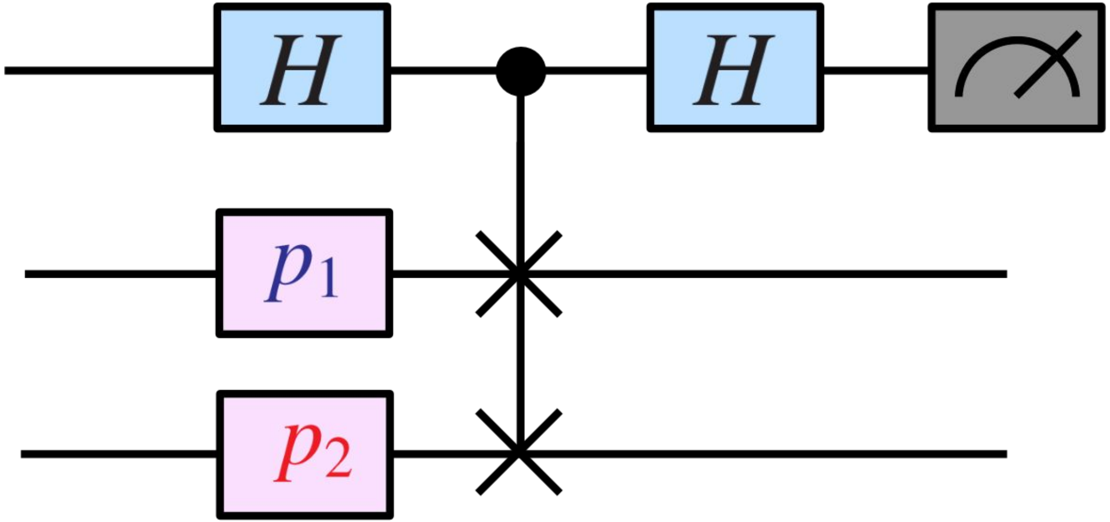


Non-perfect overlap = Data looks different!
But they are the same picture!





Symmetric State Preparation

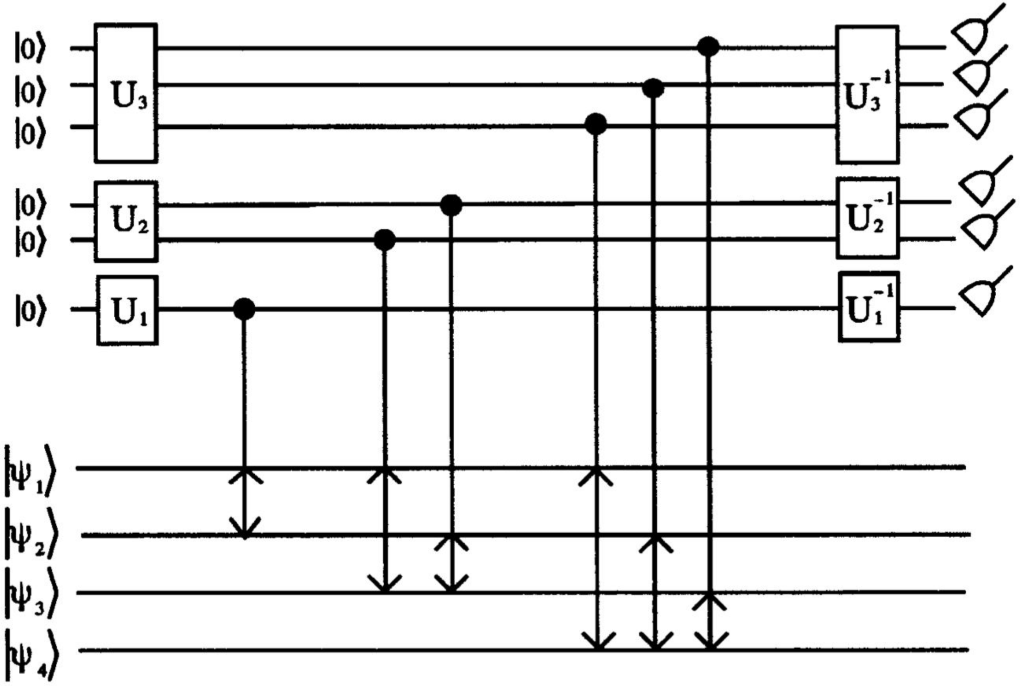


Measure 0 State = Symmetric

Measure 1 State = Anti-symmetric

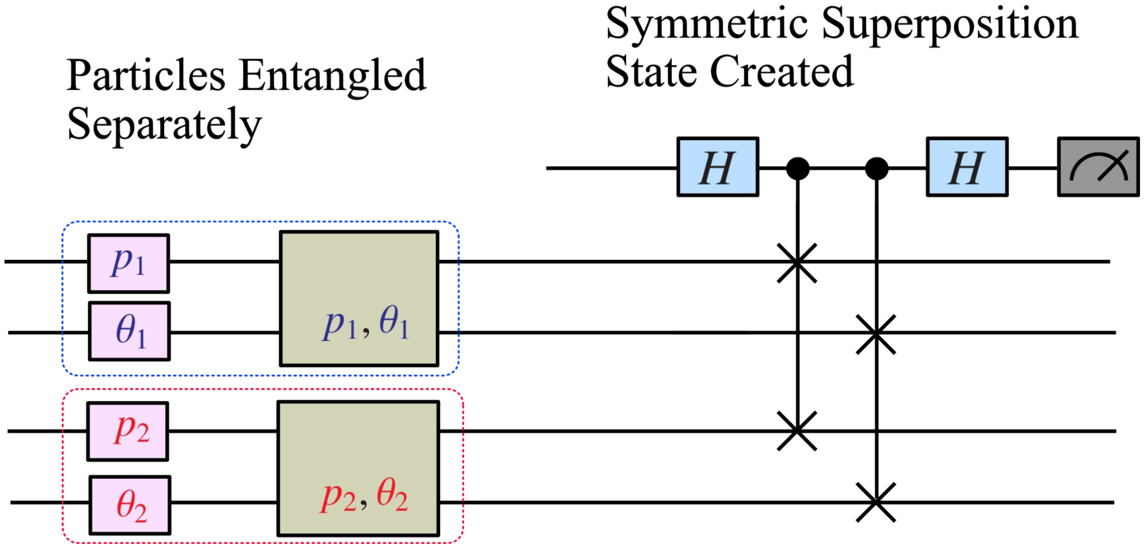
$$|\psi\rangle = \frac{1}{2}\left(|p_1\rangle|p_2\rangle + |p_2\rangle|p_1\rangle\right)|0\rangle + \frac{1}{2}\left(|p_1\rangle|p_2\rangle - |p_2\rangle|p_1\rangle\right)|1\rangle$$

Generalised Symmetrisation



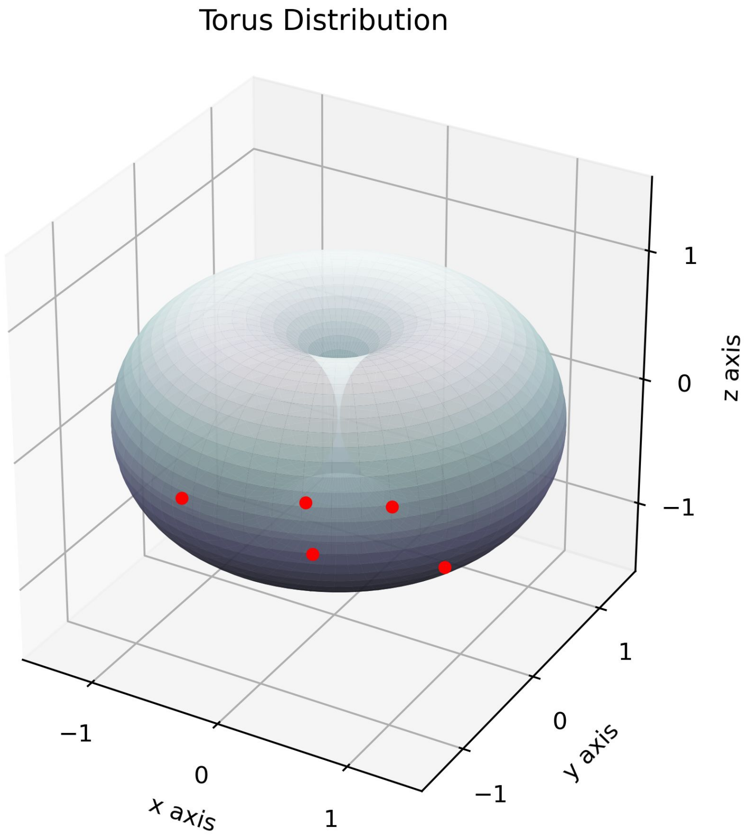
[2] Stabilisation of Quantum Computations by Symmetrisation, Adriano Barenco, Andre` Berthiaume, David Deutsch, Artur Ekert, Richard Jozsa, Chiara Macchiavello (1996)

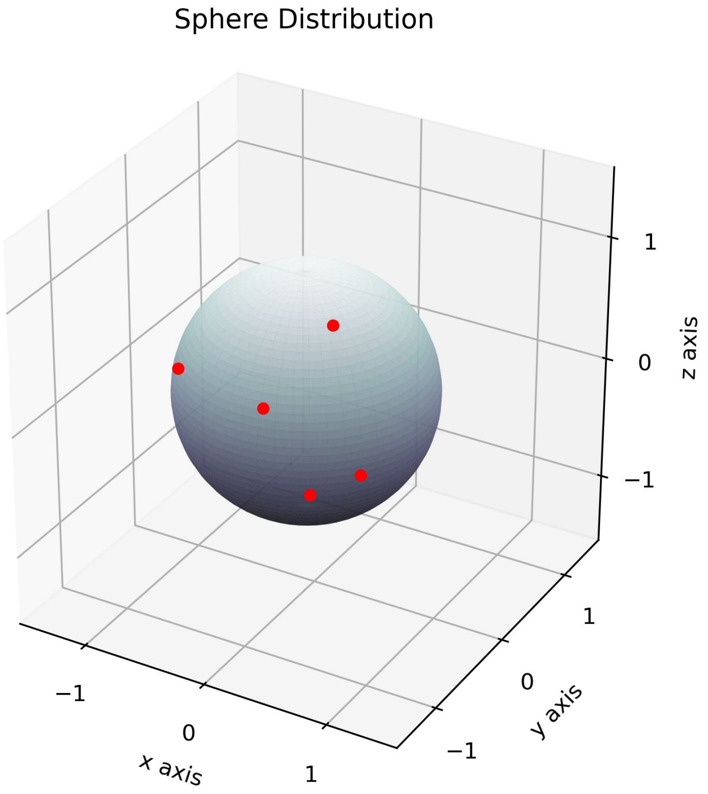
Symmetrised Encoding



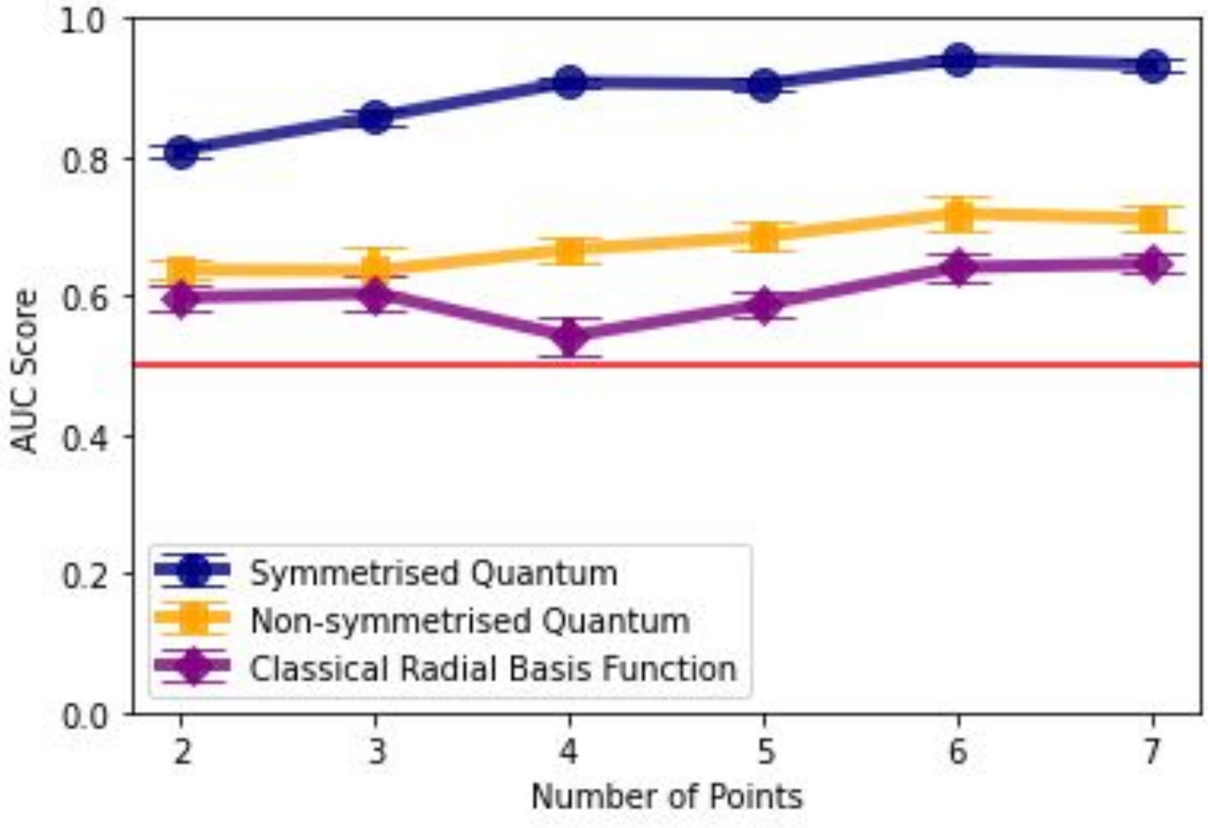
$$|\psi\rangle = \frac{1}{\sqrt{2}}\left(|p_1\rangle|p_2\rangle + |p_2\rangle|p_1\rangle\right)$$

Pointcloud Shape Classification Data





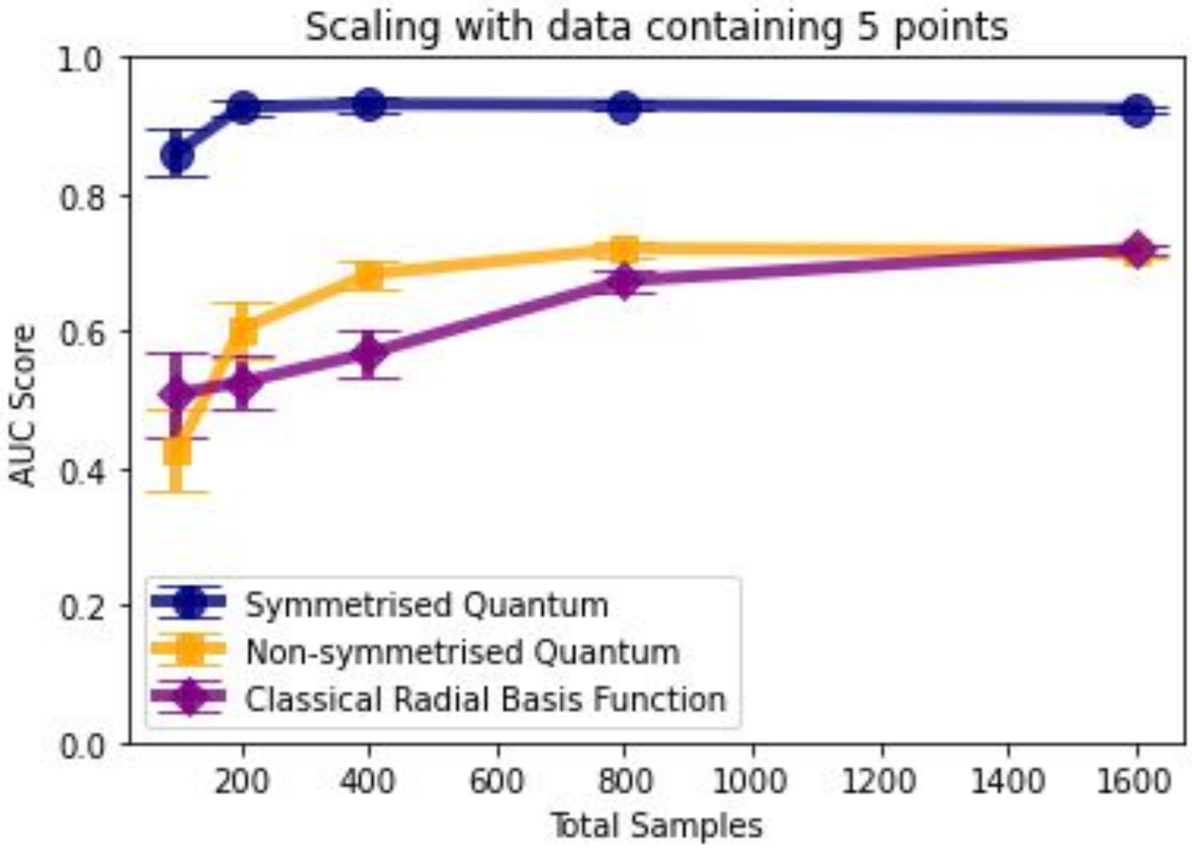
Scaling with Increased Points



Dataset size of 200

Average AUC over 10 randomised experiments

Scaling with Dataset Size



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Summary and Future Work

- Scaling in number on ancillary qubits is n^2
- Try improve the algorithm originally suggested (Have found a way for 3 points)
- Investigate whether anti-symmetrised data can still be useful
- Find approximately symmetrised methods through generic state preparation.

Encoding Circuit (3 point Pointclouds ,200 datasamples)	Average AUC Score (100 Experiments) (Error ± 0.01)
Symmetrised QSVM	0.856
Separate Particle QSVM	0.579
Combinatorial QSVM	0.451
Classical Pointnet (Symmetrised Classical)	0.750
Classical RBF SVM	0.684

References

[1] Vojtech Havlicek, Antonio D. C´orcoles, Kristan Temme, Aram W. Harrow, Abhinav Kandala, Jerry M. Chow, and Jay M. Gambetta. Supervised learning with quantum enhanced feature spaces, Nature volume 567, 209–212 (2019)

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