Engineering QUantum enabled Information Processing (EQUIP) – A journey so far!

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1. Introduction

2. Quantum Landscape and Strategy

3. Quantum Enabled Intelligence Research
   a) Stakeholder Workshop
   b) Phase 1 Results and Outcomes
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4. Conclusions and Looking Forward

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Quantum Landscape and Strategy

So what for Military? Unprecedented performance offered by Q coherence!

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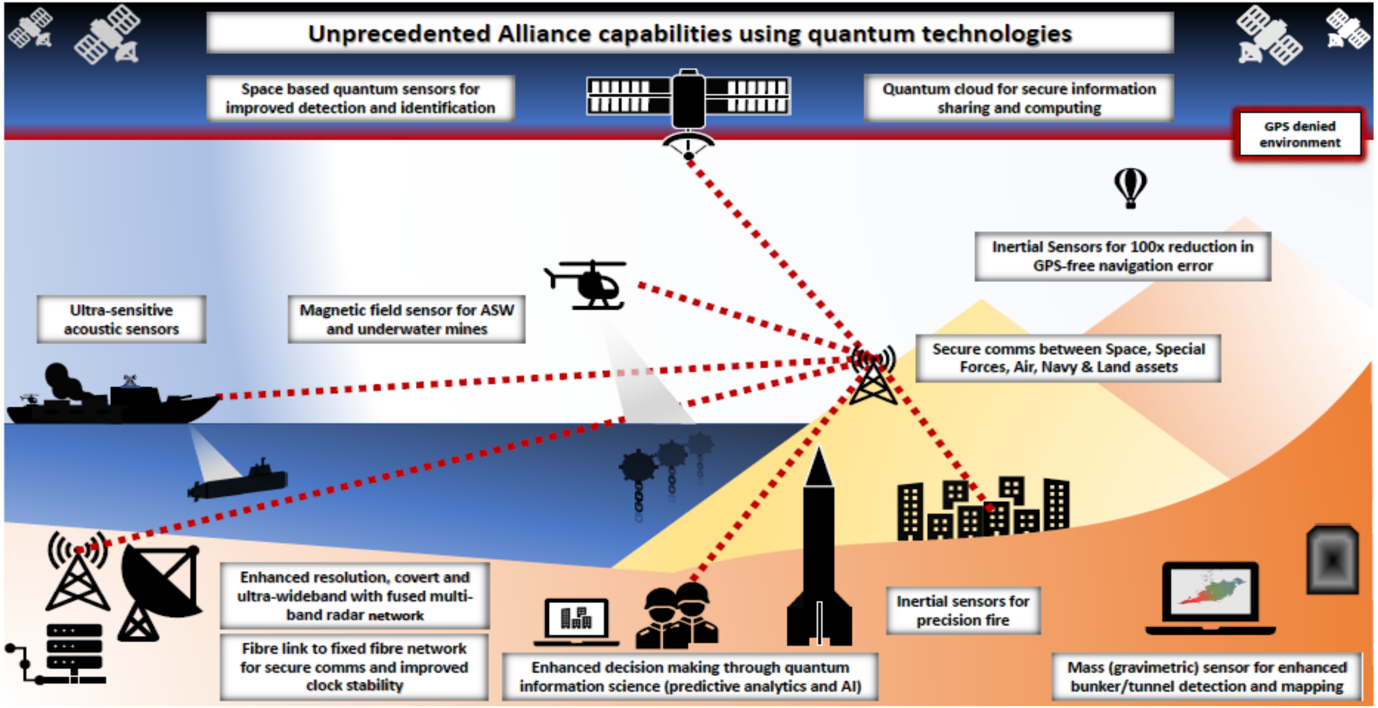
- Potential 'Game changer' with range of potential applications
  – Position, navigation and timing
  – Sensing, imaging and ranging
  – Data analytics and situational awareness from Q sensor data
- Opportunity & challenge for QC
- Growth of counters (e.g. Qsafe crpytos)



From: NATO S&T 190422-ST_Tech_Trends_Report_2020-2040

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UK National Quantum Technology Programme (NQTP)

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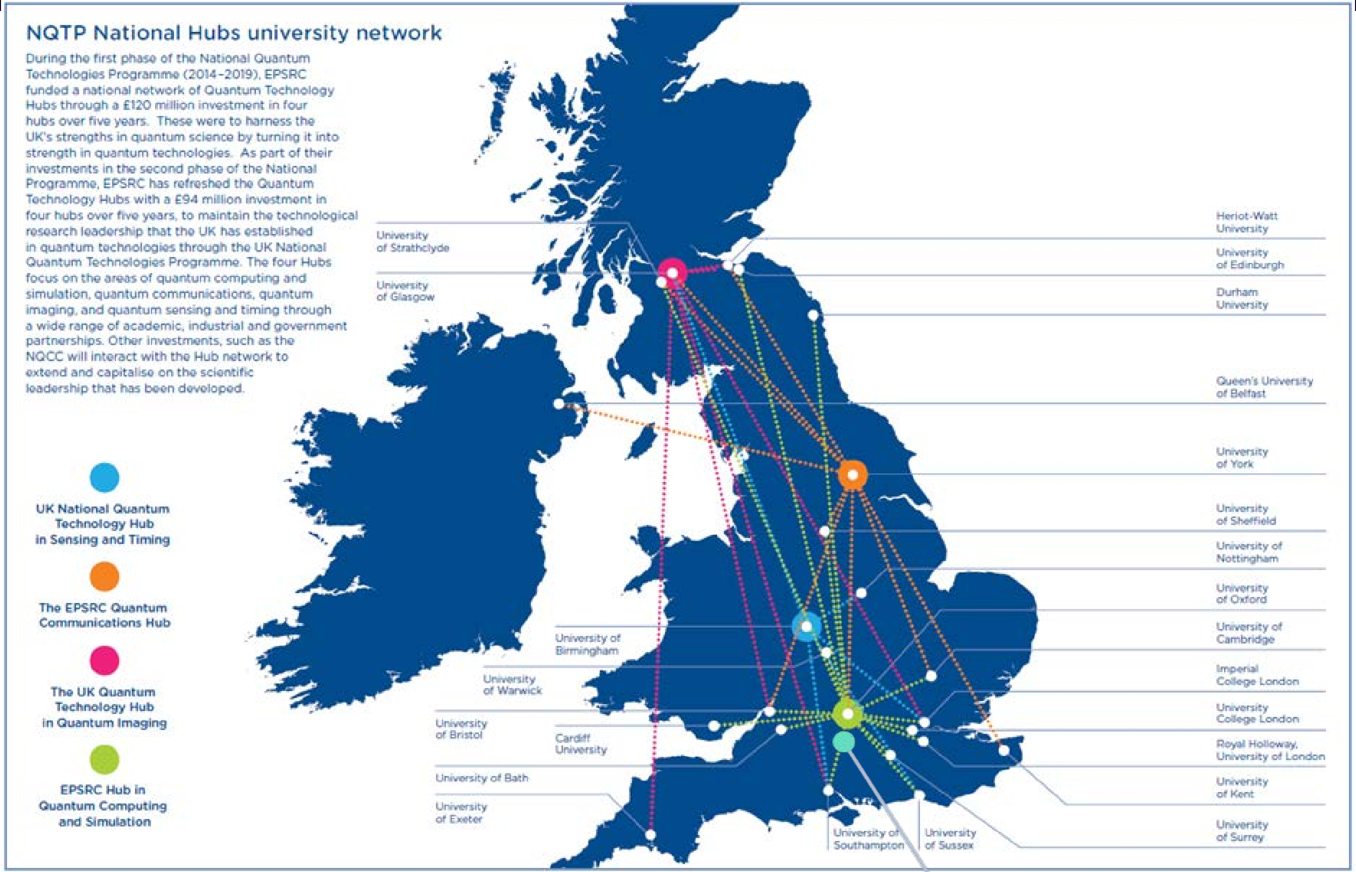

NQTP Strategic Intent: Nov 2020
Anchored In UK QT start-up Scene 2020

125 MSc candidates	**175** PhD candidates
300 Hub partners	**85** QT Apprenticeships
41 UK start-ups **370** employed	**> £135m** UK V/C funds raised
40 UK Quantum Suppliers	**£1bn** UK public/private investment

Source: McKinsey analysis

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Quantum Enabled Intelligence

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StratCom: Quantum Enabled Intelligence (QEI) projects

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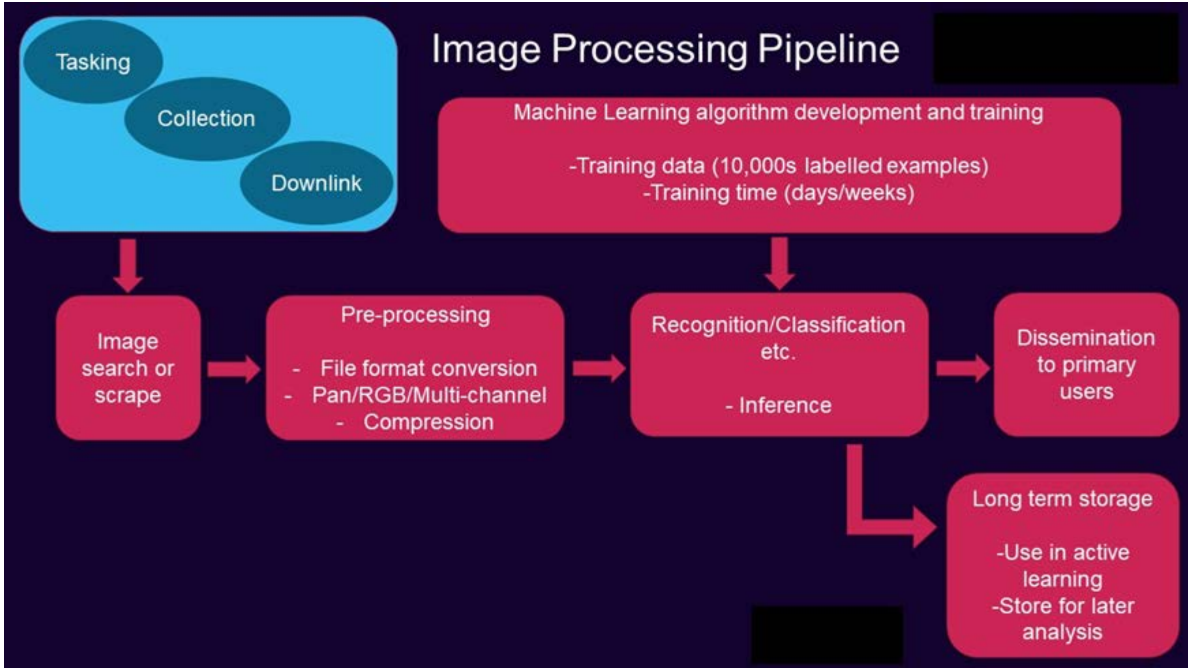
- **Objectives**

1. Benchmark D-Wave vs. ‘commodity’ processors
   - CPUs, GPUs & specialised chips (e.g. Intel Movidius NN chip);

2. Develop Operational Capability Demonstrator (OCD)
   - Hybrid system – digital front end + QC;



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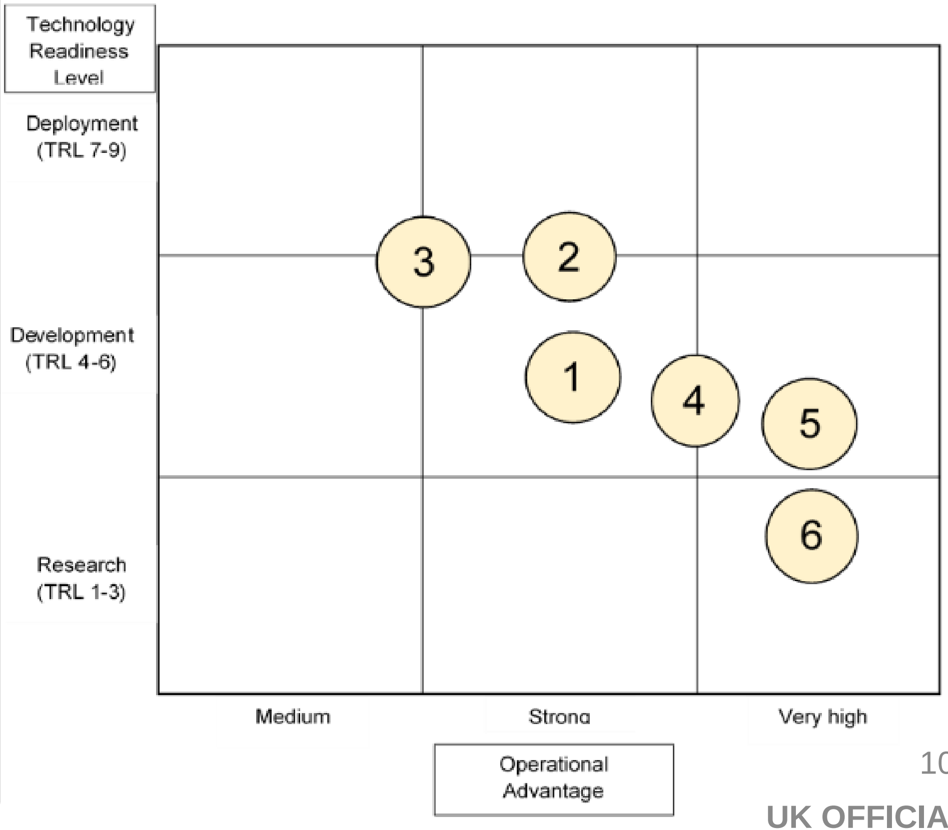
Stakeholder Workshop

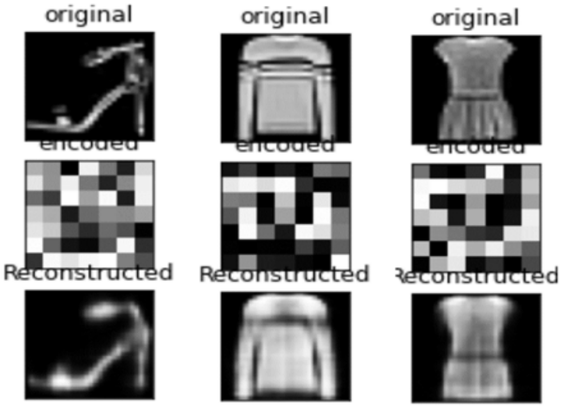
- Workshop with stakeholders
  - High level analysis of potential INT cycle areas for quantum acceleration
  - >30 use cases, 6 selected for possible development
- Exploring potential infrastructure needs
- Developing Roadmaps to in-service capability

Use Case	Operational advantages	Technology enablers
1. Automatically track moving targets ($\sim 10^{3/5}$) in cluttered environments	○ Permits military end users to track multiple targets simultaneously with high accuracy	○ Quantum enhanced particle filters ○ Model-based approaches to distributions/scenes ○ Bayesian inference
2. Imaging satellite constellation optimisation	○ Exploit full use of satellite duty cycles ○ Resource management to reduce latency in imagery tasking & collection ○ Combining data collection & processing	○ Capable of dealing with large parameters for optimisation ○ Quantum annealers for optimisation ○ Quantum sensors (hyperspectral) ○ Systems engineering methods for partitioning
3. Query large-scale imagery datasets, returning results in real-time	○ Reduced cost of querying large imagery datasets ○ Increased size of datasets queried when looking for targets ○ E.g. In how many cities have I seen the same target before?	○ Search algorithms could be run on NISQ processors ○ Requires appropriate metadata and encoding ○ Fast associative memories ○ Annealers for optimisation
4. Anomaly detection, e.g. unusual tracks (part of Tasking prioritisation and collection strategy	○ Reduced burden on human analysts	○ Unsupervised ML algorithms ○ Extreme value theory ○ Sophisticated correlation analysis (2+ events) ○ Empirical distribution characterisation
5. Recognising critical image changes as they happen across vast image libraries, (living memory management)	○ Help teams to collaborate when correlated activities are recognised across vast datasets	○ Quantum entangled images? ○ Neural nets to find more interesting patterns
6. Predicting intentions of enemy targets from its behaviours, (e.g. most threatening ones)	○ Better situational awareness, highlight enemy intentions and projected threatening activities in real-time ○ Support more complex wargaming	○ Quantum simulation, high most probable events ○ Reasoning over huge probability distributions



Part 1: Results and Outcomes

- Assessing the potential of QNNs for image data
- Developed auto-encoders for image pre-processing due to limited number of qubits
- Investigating how D-Wave can augment digital NNs
- Focus on sampling: rapidly find the ‘best’ QUBO solution
- Fewer epochs for training than in digital systems



Test Images	Model Input Size>	145	230	465
	Processor	Execution time µsecs		
10	QPU	1813.8	2014.4	2301.1
10	GPU (CPU)	272.5 (10.9)	251.8 (13.9)	231.7 (13.5)
100	GPU (CPU)	38.5 (15.2)	37.6 (15.8)	18.7 (17.2)
1000	GPU (CPU)	3 (38.5)	3 (37.6)	3 (18.7)

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Part 2: Results and Outcomes

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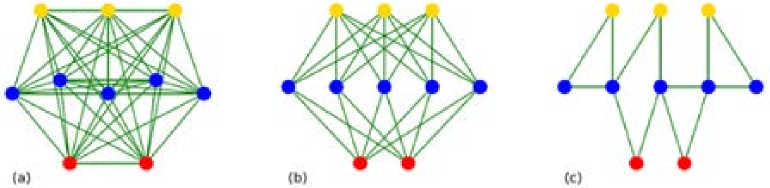
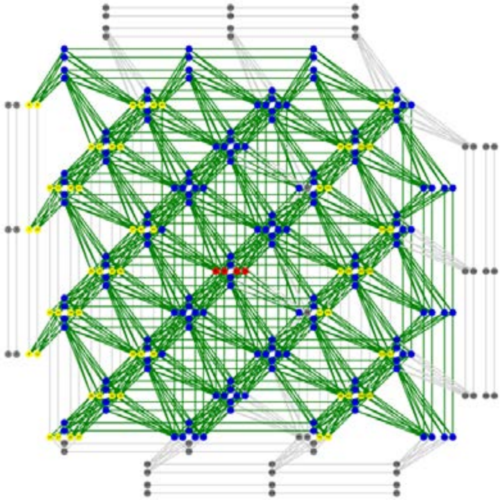
- Timing study on the use of sparse RBMs for image classification on both D-Wave QPU and CPU hardware
- Sparse RBMs were used to avoid embedding where there is limited connectivity on the device
- Reduced MNIST dataset (0,1,2,8) was used with one-hot encoding of label
- Discrete Cosine Transformation (DCT) was used to compress the images classically





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Part 2: Results and Outcomes

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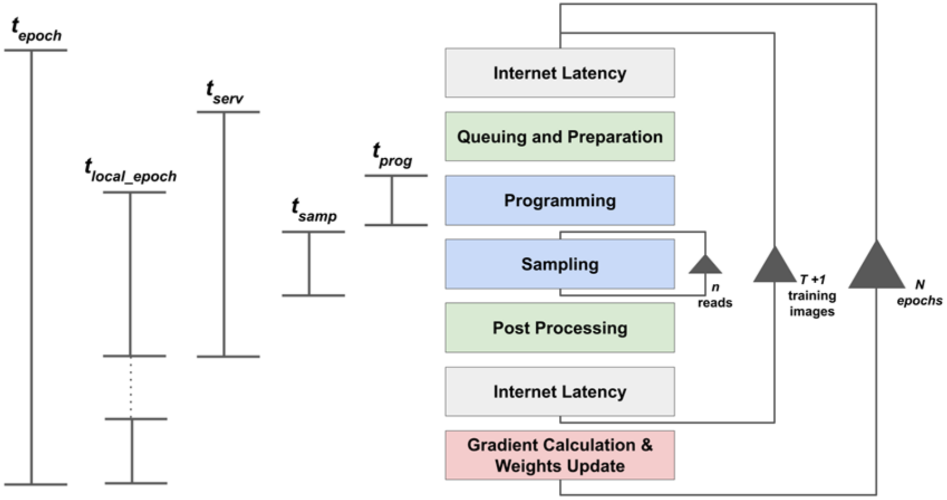

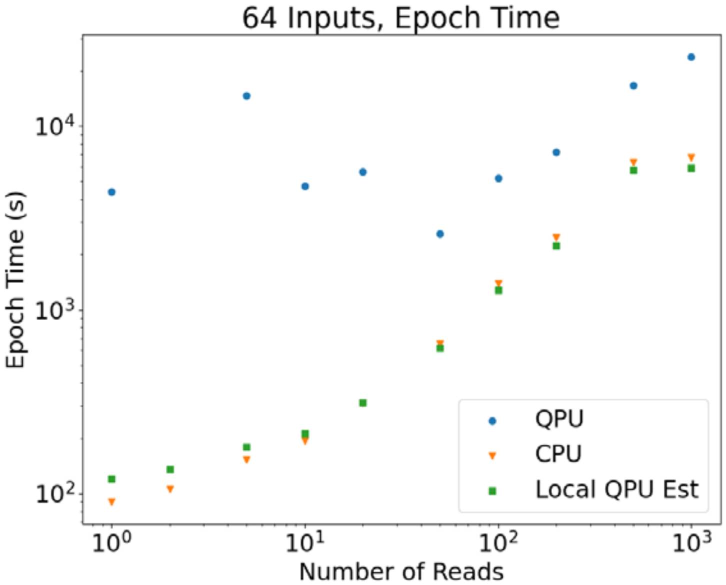

The main contributor to the epoch time on the D-Wave processor was the combination of internet latency, queuing and programming. This could be improved in theory by having a local QPU.

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Conclusions and Looking Forward

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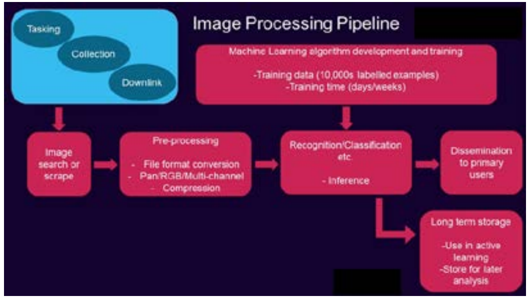
Recap

- The UK has a strong and growing quantum community made up of:
  - Government
  - Academia
  - Industry (including a number of start-ups)
- The Ministry of Defence plays a key role in steering, funding and executing the research and development in this field
- The image processing chain has been identified as a key area for potential quantum advantage
- The Quantum Enabled Intelligence Research Project has made a number of key strides forward in this area…



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Research Conclusions

The Quantum Enabled Intelligence Research Project has made a number of key strides forward in this area…

- Quantum annealers can be used advantageously for the Gibbs Sampling step in image classification using RBM implementations of neural networks
- Classical algorithms for pre- and post- processing have been developed with the aim of a hybrid image processing pipeline
- Phase 1 showed that the D-Wave annealer was capable of training with fewer epochs than the digital CPU but phase 2 showed that each epoch took more (wall-clock) time
- When latencies are stripped out, D-Wave performance exceeded CPU performance at all image sizes
- The low connectivity of the sparse RBMs are likely to have contributed to the poor classification results

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Looking Forward

- Hyper-parameter optimization for the D-Wave RBM will enable better classification performance
  - Quantum annealers are designed for optimization and therefore the default parameters are suited to this application and not RBM training
- Alternative classification algorithms that require less I/O such as reservoir computing models may present a better use of near-term quantum computers
- The National Quantum Strategy was released in March 2023 and lays out the UK's intention and strategy to become 'a leading quantum-enabled economy, recognising the importance of quantum technologies for the UK's prosperity and security.'

Source: https://www.gov.uk/government/publications/national-quantum-strategy

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Questions?

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