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ONLINE HACKATHON

Quantum code challenge

Innovative Quantum Algorithms for Smart Cities

22-25 OCTOBER 2024

THE EVENT IS ENDORSED BY

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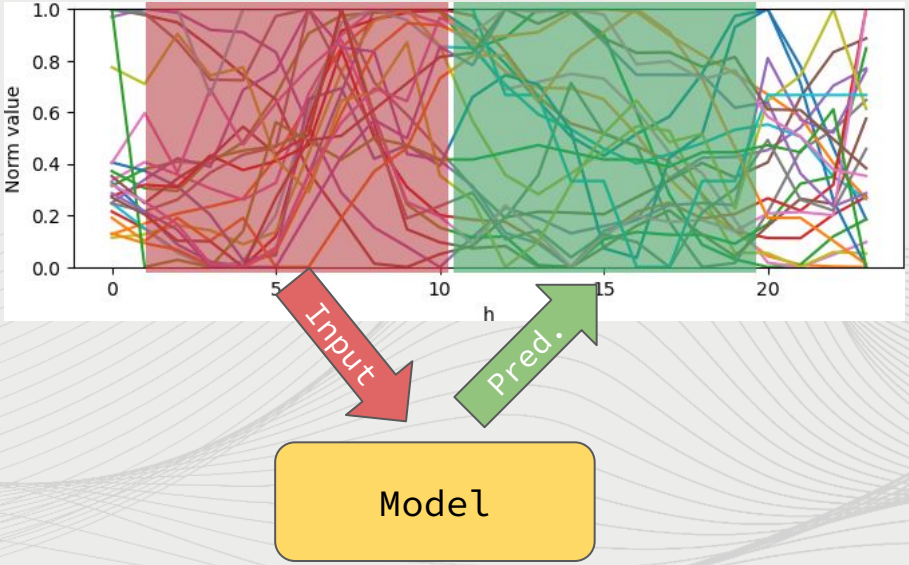
Motivation: Effects of Climate Change

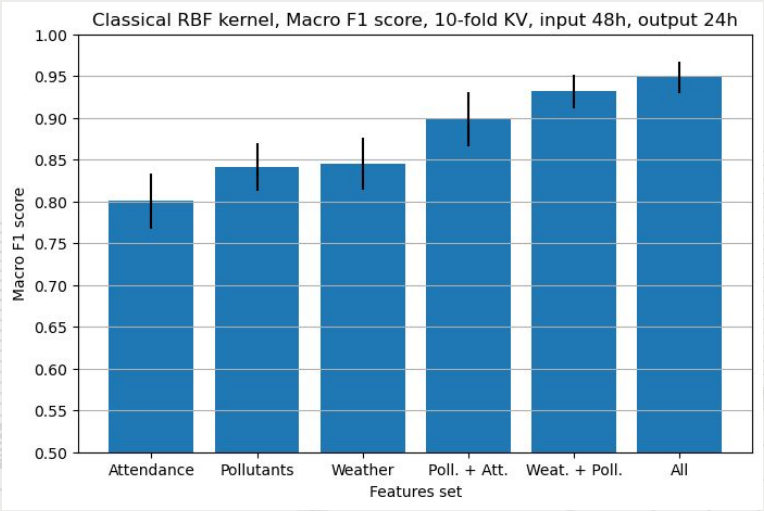
- "Climate change concerns the increase, in **intensity and frequency of extreme phenomena such as strong storms, floods, rising sea levels**,[...]" https://www.mase.gov.it/pagina/i-cambiamenti-climatici
- "Storms have become more intense and frequent in many geographic areas [...].**These storms are capable of destroying entire communities, causing enormous human and economic losses.**" https://unric.org/it/effetti-del-cambiamento-climatico
- "Other effects of climate change, **rising sea levels will increase the risk of flooding and erosion around coasts, with significant consequences for people, infrastructure, businesses and nature** in these areas.[...].

  Severe thunderstorms are expected to become more common and intense[...]" https://climate.ec.europa.eu

Task definition

- Predict if **rains** at least once within the **next N** hours based on sensor data from **previous M** hours
- Different set of features possible from all datasets
- Supervised binary classification task on sliding windows evaluated with **Macro F1 score**





Quantum Kernels

The main idea behind quantum kernel machine learning is to leverage quantum feature maps to perform the kernel trick[1]. In this case, the **quantum kernel** K is created by mapping a **classical feature vector** $\mathbf{x}_i$ to a Hilbert space using a **quantum feature map** $\phi(\mathbf{x}_i)$.

Mathematically:

$$K_{ij} = |< \phi(\mathbf{x}_i) | \phi(\mathbf{x}_j) >|^2$$

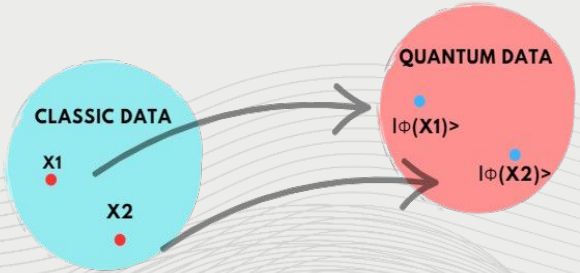


Figure: Encoding of classical data into quantum states.

[1] Schuld, Maria. "Supervised quantum machine learning models are kernel methods." arXiv e-prints (2021): arXiv-2101.

Quantum Support Vector Machines (QSVM)

- The **QSVM algorithm applies to problems** that require a feature map for **which computing the kernel is not efficient classically**[2].
- QSVM uses a **Quantum processor** to solve this problem by a direct estimation of the kernel in the feature space[3].
- The method used falls in the category of what is called **supervised learning**, consisting of a training phase and a test or classification phase where new data without labels is classified according to the solution found in the training phase[3].

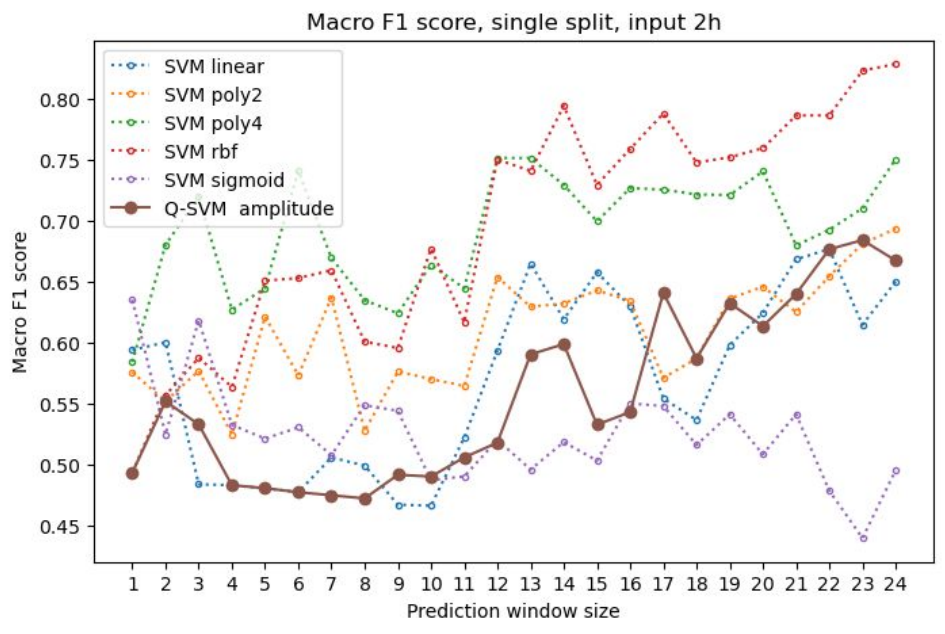
[2] Havlíček, V., Córcoles, A.D., Temme, K. et al. Supervised learning with quantum-enhanced feature spaces. Nature 567, 209-212 (2019).
[3] https://docs.quantum.ibm.com

Data preprocessing

- **27** sets of features from “**Particulate Matter**”, “**UniqueAttendance_15**” and “**Weather**”
- Sampled **hourly** from the 1st of August at 0:00 to the 8th October at 21:00
- **Missing** data approximated with forward filling strategy
- Label **rain** if “**cod_weather**” in “**Weather**” is **2xx**, **3xx** or **5xx**
- ~**1300** Unbalanced data samples (**1/4** rain over all windows with **N=24**, **1/25** with **N=2**)
- **Variable** input and prediction windows sizes (M and N)

Results with Q-SVM with amplitude embedding

- **Classical** SVM with different kernels.
- **Quantum** SVM with **amplitude** embedding quantum kernel.
- Simplified task to allow simulation of quantum kernels: input window of **2h**
- Amplitude embedding qubit **efficient** (logarithmic w.r.t. features space size)
- Quantum kernel is **comparable** with classical ones.
- **Simulated** with Pennylane for various prediction window sizes



Results with Q-SVM with angle embedding (best result)

- **Quantum** SVM with **angle embedding** quantum kernel.
- Simplified task to allow simulation with a linear number of qubits:
  - input window of **1h**
  - **compressed** features (total attendance, average particles and temperature)
- Quantum kernel is **better** than classical ones on the same split!
- **Simulated** with Pennylane

Model	Macro average F-1 score
Q-SVM angle embedding	**0.76**
Q-SVM amplitude embedding	0.61
SVM linear kernel	0.53
SVM poly 2 kernel	0.56
SVM poly 4 kernel	0.70
SVM RBF kernel	0.73
SVM sigmoid kernel	0.52