Mphasis EON:
Quantum Computing Framework

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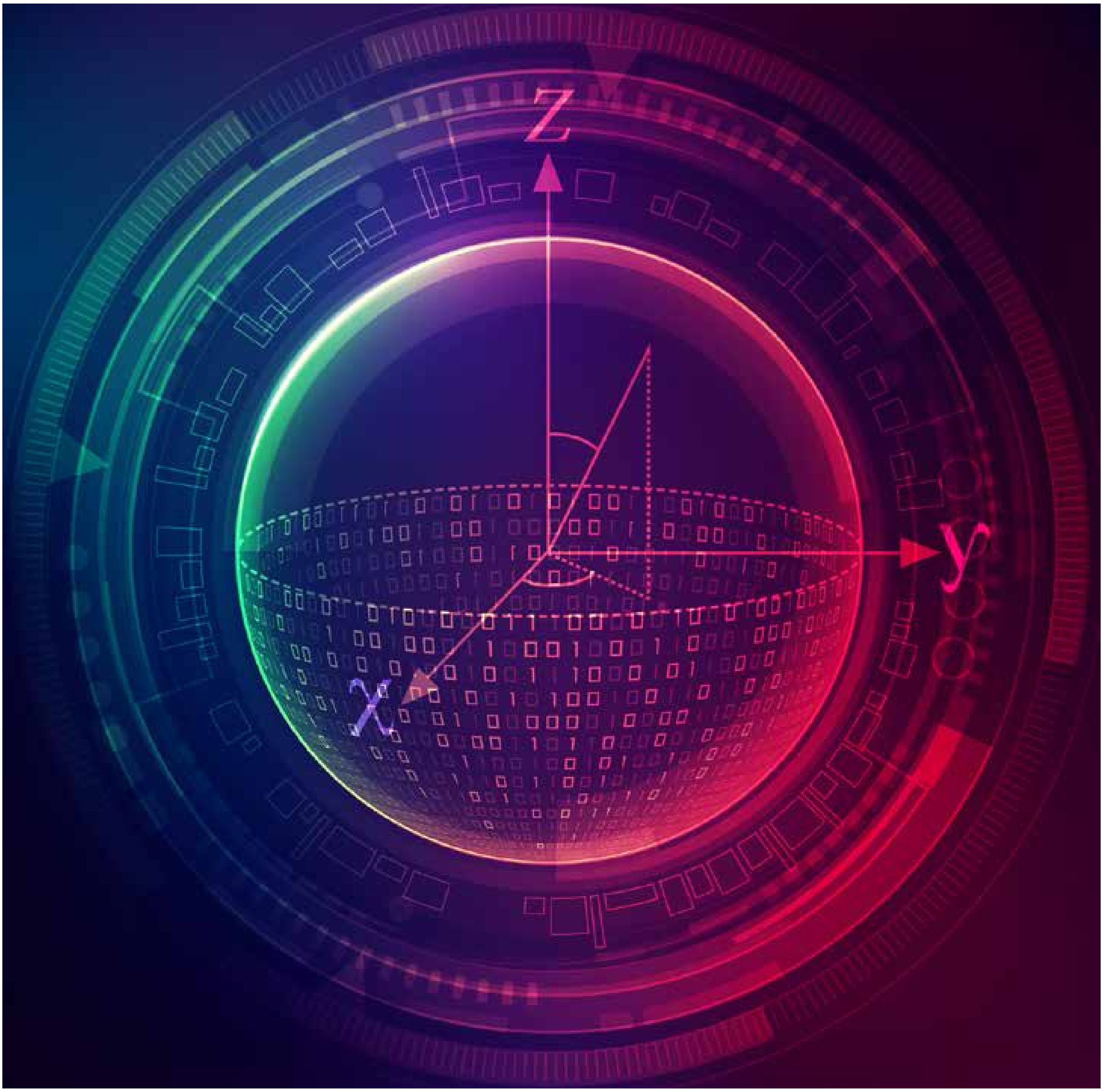

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1.
Introduction

Cognitive automation of decision processes has become a necessity for businesses, and with its capability to learn the patterns and rules from data, machine learning has emerged as an efficient way to automate. Data-driven models are more robust when compared to the traditional hard-coded rules as they can be retained or updated based on changing scenarios. Cognitive automation took a faster pace, especially after the wide-spread use of deep learning frameworks, as these models use contour-based learning which eventually can learn very complex patterns by using correct network architectural design.

Although deep learning has proved advantageous, productionizing machine learning is still a difficult task. Deep learning models have too many learnable parameters which require longer time to train and more computational resources. Due to the deterministic nature of the optimization process, reaching to global optimal parameters for non-convex learning problems is very difficult to achieve.

Quantum machine learning can help address the shortcomings of both the traditional approach and the deep learning approach. It utilizes the self-learning capability of machine learning models to learn quantum circuit parameters in a data-driven fashion. Quantum technologies promise computational efficiencies with their inherent nature of quickly converging to their low energy states. Properties such as quantum parallelism and tunneling accelerate the process of computational convergence to global optimal solution. Quantum circuits can represent non-convex relationships in classical data with fewer qubit parameters through better feature map representation. This helps quantum to explore kernels on higher order dimensions, directly making computations exponentially faster.

2.
Mphasis EON: Framework for Quantum Machine Learning

The current state of quantum computing has several limitations. The number of qubits available is not significant to leverage the advantages of quantum computing for machine learning. Another drawback is that quantum systems are not very good at handling the noise present in the data. Also, when using quantum devices, a protocol needs to be established to send data to the quantum device from a classical device. These protocols are not very clearly defined, and there is no established standard, to perform the handshake efficiently and effectively. Quantum algorithms do not perform very well when tried to force fit into certain constraints.

When using quantum computing, the data needs to be preprocessed so that it can be ingested by the quantum hardware. One of the popular preprocessing algorithms is amplitude embedding. However, these algorithms are not very well developed. Quantum state embedding can handle discrete values/variables very well. The number of qubits needed to encode these values is manageable but while embedding continuous values, the number of qubits required can overshoot the qubits currently supported on quantum hardware. Due to these limitations, quantum computing cannot directly replace the machine learning/deep learning algorithms.

To effectively handle the drawbacks in quantum machine learning, Mphasis has built the patent pending Energy Optimized Network (EON) framework that can handle data preprocessing and feature engineering before feeding the information to quantum state preparation. This reduces the feature dimensionality to suit the number of qubit requirement and ensures feature space transformation for extrapolating the information into a more expressible format so that it suits the quantum properties for information learning.

Due to the limitations of both quantum computing and deep learning, they are not very suitable for IT production systems. However, they complement each other to address certain business problems and use cases, which means the drawbacks of quantum can be covered by deep learning and vice versa. Hence, a quantum assisted deep learning architecture should be considered, where the deep learning part of the pipeline can handle the preprocessing or the data preparation step, while the quantum hardware can perform the task of parameter search. The efficiency of such a system is much higher than the efficiency of the two systems, when used individually.

Quantum machine learning works on the principle of superposition and entanglement. Preprocessing the data to suit the quantum properties for learning enhances the training performance of quantum circuit, resulting in better training accuracy. This brings us to the Classical-Quantum hybrid framework, which is divided into three sections: Mphasis EON, Quantum circuit and Deep neural network layers. Energy Optimized Network (EON) constitutes a deep neural network combined with feedback loop, dedicated to learning the incoming information and transforming the data into new feature space.

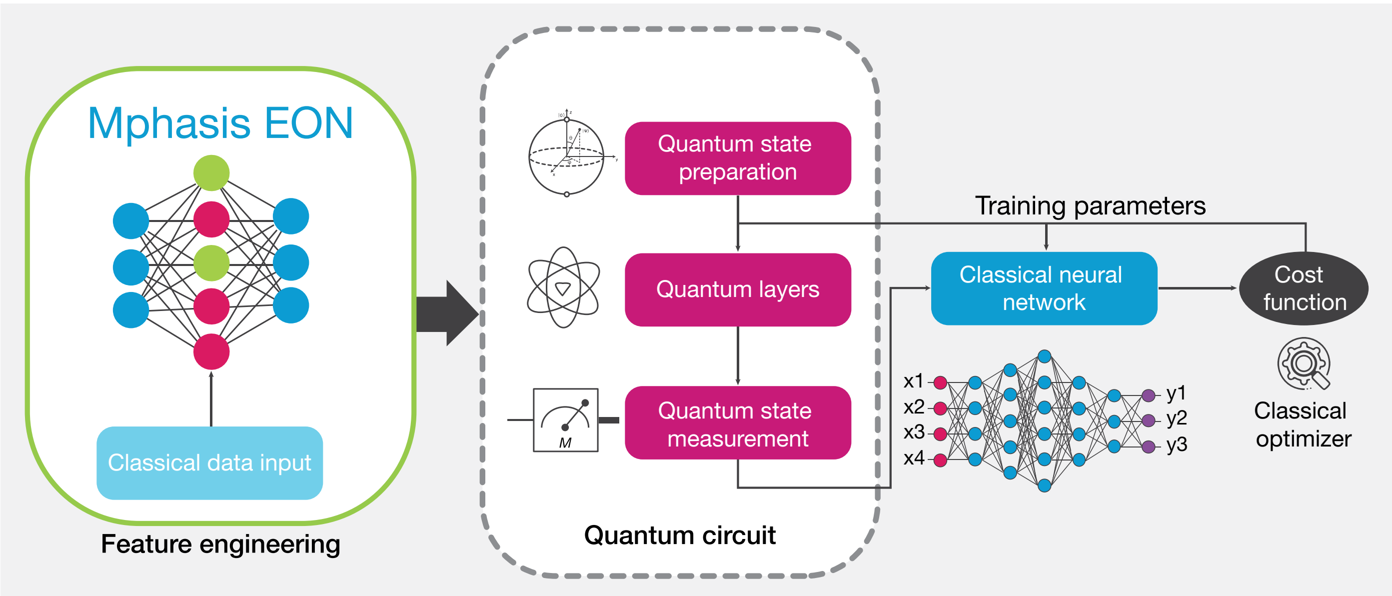

Fig 1: Mphasis EON Framework for Quantum assisted Machine Learning

The classical data is standardized to bring all the values in a range of [0,1], to reduce the big number effect on machine learning. After standardization, the input data is fed to Mphasis EON to prepare enhanced feature space that can better represent classical data on quantum systems for predictive tasks. The transformed feature space is mapped onto quantum systems using quantum state preparation such as angle embedding, amplitude embedding, etc. Quantum circuits perform a defined series of quantum operations on quantum data. Quantum measurement function is used to measure the quantum circuit state and feed it back to classical systems. The output from measurement functions becomes the input to deep neural network layers. The resultant cost function resides on the classical machine. The measured error is reduced by back propagation and different gradient descent methods.

Mphasis EON is an iterative process designed to select the best suited feature space transformation, by reducing the overall energy of the network, as well as capturing as much possible information spread. For classical data to input on quantum computational systems, data encoding is a necessary step. The strategy of how to represent classical data on quantum system influences the quantum circuit design and their efficiency. A better expression of data on quantum system for a given machine learning task leads to lower information loss, faster convergence, and better solution due to quantum efficient optimization as compared to their classical counter parts. Mphasis EON achieves the optimal information representation for quantum using feature space transformation and batch sampling.

Strategic batch sampling methods are adopted to feed the quantum circuit such that each batch incorporates the overall pattern of information spread. This continuous and adaptive strategy of Mphasis EON to enhance feature space preparation for Quantum predictive tasks makes it more performance centric, resulting in faster convergence with fewer qubit requirements.

Mphasis EON -

- Significantly **reduces the need for higher configuration** quantum systems due to increased data encoding efficiencies.
- Prepares the feature space specifically and adaptively for the quantum prediction, making the process more **outcome oriented** and suitable for quantum prediction tasks.
- **Learns data patterns as well as performs quantum predictive tasks** in an iterative mode,enabling quantum to manage the challenging task of handling the big data effectively.
- Helps in better representation of information by feature space transformation by exploiting hidden patterns in data. This results in better **learning of the complex patterns,** thereby improving the training accuracy.
- Generates more orthogonal features with **reduced intra-feature correlation,** making it more suitable for quantum mechanism of learning the information.
- Reduces **non-linear dimensionality** of the data, making quantum circuit training feasible in less available qubits.
- Generates batches that guides the quantum circuit to **strategically converge to optimal weights,** making training faster with better accuracy.

3.

Mphasis EON Applied to Quantum Machine Learning

Below mentioned are results of two use cases in the areas of classification and forecasting which highlight how Mphasis EON outperformed in comparison with the benchmark classical framework algorithms.

Defective Package Identification

- Goal was to classify images using quantum framework into two categories: defective and non-defective packages.
- Images of shipment are transformed into lower dimensionality feature space keeping the information content constant. Then a hybrid quantum deep learning model is used to learn the information.
- Frameworks compared: Mphasis EON & CNN deep learning
- Quantum system achieved the following over classical computing system
  - 12.34% improvement in test accuracy
  - 325% improvement in training time
  - 3.44% improvement in test time

Time Series Forecasting

- Goal was to implement time series forecasting using quantum machine learning principles.
- The time series data was first divided into orthogonal components, and each component was decomposed into trend and seasonality.
- The patterns in seasonality and trend were learnt using a quantum neural network and combined for a more accurate representation of the time series.
- Frameworks compared: Mphasis EON & ARIMA (with multiple seasonality detection)
- Quantum system achieved the following over classical computing system
  - 2% improved prediction percentage error achieved on 6-month future forecast

4.

Conclusion

The proposed framework is compatible with existing machine learning and deep learning frameworks. The quantum part of the framework serves as a black box, which takes in the unoptimized parameter values and returns the gradient of the parameters. These gradients then can be used through backpropagation to update the parameters. The quantum computation can be either performed on a hardware or a simulator. The EON Framework can self-learn parameters of the deep learning network, utilizing quantum capabilities of parallelism wherever necessary to get the best out of Quantum Computing systems.

Authors

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With 5+ years of experience in data science, Ashutosh Vyas is part of Mphasis NEXT Labs. He has built various solutions across domains including information retrieval from unstructured documents, simulation models for IT infrastructure machine failure prediction, FMCG price prediction and sales forecasting, customer sales pitch price optimization for advertisements in television and print media recommender system, among others.

His technical expertise spans generative machine learning, Bayesian statistics, generative deep learning, quantum hybrid modelling, deep learning, agent-based modelling, simulation designs and energy-based generative network design and modelling. Ashutosh holds a Master of Technology degree in Information Technology from IIIT-B and Bachelor of Engineering from SKIT Jaipur, Rajasthan Technical University.

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Dr. Udayaadithya Avadhanam has multiple granted patents and international publications to his credit. His research interests include quantum machine learning, complex systems, agent-based simulations and AI policy. Udayaadithya has a PhD from Indian Institute of Science (IISc, Bangalore) in artificial societies and complex systems.

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Dr. Jai Ganesh is Product and Service Innovation leader with extensive experience in inventing, conceptualizing, building and commercializing successful technology products and service innovations. Award winning digital transformation and innovation leader with expertise in lab-to-market product and service innovations. Under his leadership, NEXT Labs has created several global award-winning solutions, products and service offerings.

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Rohit Kumar Patel has over 11 years of experience in IT, with 5+ years of experience at Mphasis. His responsibilities include client engagement, pre-sales, process analysis for cognitive automation opportunity identification, AI-ML solution design, development and management. His current areas of work include process mining, quantum machine learning and optimization. He holds an MBA degree in Finance from Great Lakes Institute of Management, Chennai.

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Rajendrakumar Mishra's areas of expertise include machine learning, deep learning, natural language processing and image processing. His recent work at NEXT Labs involves research and development of several projects, transforming the way software development process was approached. He has built multiple Intellectual Properties at Mphasis and has been granted US patent for Autocode.AI. Rajendra has also worked in Smart Assistant and Chatbot domain, and automated Digital Content Generation. He holds an M.Tech in IT from International Institute of Information Technology, Bangalore.

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About Mphasis

Mphasis (BSE: 526299; NSE: MPHASIS) applies next-generation technology to help enterprises transform businesses globally. Customer centricity is foundational to Mphasis and is reflected in the Mphasis' Front2Back™ Transformation approach. Front2Back™ uses the exponential power of cloud and cognitive to provide hyper-personalized ($C = X2C^{2}_{TM} = 1$) digital experience to clients and their end customers. Mphasis' Service Transformation approach helps 'shrink the core' through the application of digital technologies across legacy environments within an enterprise, enabling businesses to stay ahead in a changing world. Mphasis' core reference architectures and tools, speed and innovation with domain expertise and specialization are key to building strong relationships with marquee clients. To know more, please visit www.mphasis.com

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