2024 Asia and Pacific Mathematical Contest in Modeling

Problem D

Exploring Frontiers in Quantum-Accelerated AI

Quantum computing holds tremendous potential for solving complex problems and processing large-scale datasets, far surpassing the capabilities of classical computers. When integrated with artificial intelligence (AI), quantum computing can bring revolutionary breakthroughs. Its parallel processing capabilities enable solving more intricate problems in shorter periods, which is of significant importance for optimizing and enhancing AI algorithms. This competition aims to assess participants' modeling and problem-solving skills in the field of quantum computing. Through challenging real-world scenarios, we explore the limitless possibilities that arise from the synergy of quantum computing and AI.

The competition consists of three parts, each involving a dataset and a task. Participants are required to formulate a corresponding QUBO (Quadratic Unconstrained Binary Optimization) model and solve it using the simulated annealing algorithm provided by the Kaiwu SDK. The QUBO model, suitable for CPQC (Coherent Photonic Quantum Computer), is expressed as:

$$\min x^{T}Qx, \quad x \in \{0,1\}^{n}$$

where Q is the coefficient matrix.

The competition focuses on AI-related scenarios, converting problems into QUBO form and solving them using the Kaiwu SDK, a specialized software development kit for solving QUBO models on CPQC. The SDK is accessible at this link (https://platform.qboson.com/).

Reference materials for QUBO modeling across different scenarios are provided in the attachments to help participants understand and apply these concepts.

Task 1: Resource Demand Prediction in Cloud Computing (20 points)

Background

Efficient operation of cloud computing platforms relies on precise resource scheduling, where demand prediction is a core component. By analyzing historical data to build predictive models, resource wastage can be minimized, and system efficiency and availability can be improved. Time series forecasting is commonly employed in such scenarios, but transforming these optimization problems into quantum computing-compatible forms remains a challenge.

Problem Description

You are tasked with developing a resource management system for a cloud computing platform to predict resource demand. The dataset is as follows:

Table 1. Computing resource demand from January to September.

Month	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept
Demand	9000	9400	9594	9859	9958	10043	10309	10512	10588

These data represents monthly computing resource demand from January to September. You decide to use an Autoregressive (AR) model for forecasting, represented as:

$$y_t = c + \sum_{i=1}^{p} \varphi_i y_{t-i} + \varepsilon_t ,$$

where c is a constant, p is the order of the AR model, and ε_t represents random noise with a mean of zero.

You are expected to:

1. Transform the above time series forecasting problem into a QUBO model, clearly defining the objective function and decision variables.

2. Use Kaiwu SDK's simulated annealing algorithm to solve the model and predict the demand for October.

Task 2: Classification Using Support Vector Machines (40 points)

Background

In machine learning, in addition to regression tasks like time series prediction problem

above, classification is another classical task. Classification aims to assign input samples to predefined categories based on their features, which is widely applicable in real-world scenarios, such as spam detection and image classification. Support Vector Machines (SVMs) are a popular supervised learning technique based on maximizing margins. SVM also excel in nonlinear classification through kernel tricks.

Integrating quantum computing introduces new perspectives to classification tasks. By converting the SVM optimization problem into QUBO form, quantum computing can accelerate the solution process.

Problem Description

The Iris dataset (https://archive.ics.uci.edu/dataset/53/iris) is a classical machine learning dataset containing 150 samples, each with four features and a class label (one of three categories). Your task is to classify this dataset using an SVM model and the Kaiwu SDK.

You are expected to:

1. Transform the optimization problem of training an SVM-based classification model into a QUBO model, clearly defining the objective function and decision variables.

2. Solve the QUBO problem using the simulated annealing algorithm in the Kaiwu SDK.

Task 3: Exploring the Integration of Quantum Computing and Deep Learning (40 points)

Background

Deep learning models, such as Convolutional Neural Networks (CNNs), demonstrate outstanding performance in complex tasks like image classification and recommendation systems. However, optimizing these models often requires significant computational resources. By leveraging quantum computing's optimization capabilities, more efficient training and inference methods can be developed for deep learning.

You are expected to:

Select a specific application scenario, such as image classification or recommendation systems, for which you need to design a suitable deep learning model and structure. Then, transform the related optimization problem (e.g., model training) into a QUBO model. Solve it using Kaiwu SDK's simulated annealing algorithm.

Submission Requirements:

1. Complete code files, including data preprocessing, model construction, QUBO model conversion, and solution processes.

2. A detailed result report containing:

a. The problem scenario and its background.

b. Description of the artificial intelligence model structure.

c. Specific QUBO model formulation.

d. Solution process and solving time of the QUBO model, together with results analysis.

f. Model performance evaluation and interpretation of results.

Please provide sources and explanations for any external datasets or reference materials used.

Note:

1. Kaiwu SDK is restricted to solve problem under 600 bits.

2. Only the latest version of Kaiwu SDK is supported.

3. For the Problem 1, participants may choose to submit their matrices to CPQC (https://platform.qboson.com/), which is **optional**. Each participant will receive a total of 5 quotas during the competition. No additional quotas will be granted once they are used up. Additionally, there may be delays in receiving results from CPQC.

4. If you have any questions about the tasks, please scan the QR code below to contact us.

5. You can view the Kaiwu SDK installation and usage guide via this link (https://b23.tv/IqKoPnv).