E3S Web of Conferences **498**, 02007 (2024)
ICAPE2024 https://doi.org/10.1051/e3sconf/202449802007

Model of biodiversity and plant sustainability based on quantum variational optimization

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Abstract. Plant biodiversity plays an important role in the sustainability of ecosystems and human societies. The resilience of plants in the context of biodiversity relates to their ability to adapt to changing environmental conditions, provide ecosystem services and meet human needs. This article examines the influence of quantum variational optimization on the solution of a system of differential equations for a model of plant biodiversity and sustainability, taking into account the interaction between two populations. The system of equations models the dynamics of changes in the density of plant populations of types and over time, consider the influence of interaction, growth coefficients and the intensity of the impact of diseases and pests. The numerical integration method is used to solve the system of equations, and quantum variational optimization is also introduced. Quantum variational optimization is performed with the goal of minimizing the error obtained from a quantum computational experiment. An analysis is made of the optimal parameters found using quantum optimization and their impact on population dynamics. The article provides a comprehensive approach to studying the influence of quantum variational optimization on the solution of differential equations, and discusses the potential prospects for using this method in environmental and biological models.

1 Introduction

The diversity of populations and their ecology depend on many factors. Some of the key factors influencing the diversity and ecology of populations are: competition for resources such as food, space and breeding partners can influence the structure and size of populations, interactions between predators and their prey can greatly influ-ence population dynamics, climate and weather, terrain, soil type, water availability and other factors of geography and geology can influence the distribution and survival of populations, pollution, deforestation, changes in natural ecosystems due to human activity greatly affect the populations of many species [1-2].

The study of population ecology allows us to more deeply understand what factors shape and regulate the life of populations in nature, which, in turn, has implications for

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biodiversity conservation and natural resource management. Conserving plant biodiversity is an important task because plants play a key role in maintaining ecosystems by providing oxygen, preventing soil erosion, providing food and many other environmental services. Strategies and methods for the conservation of plant biodiversity include the establishment and maintenance of nature reserves and national parks to preserve natural environments and provide space for the growth and reproduction of rare and vulnerable plant species, the establishment and maintenance of seed banks to store seeds of rare and threatened plant species, and the implementation of restoration programs and restoration of natural habitats such as forests, wetlands and riparian zones to restore conditions for plant growth, research and management of plant genetic diversity, including the creation of sustainable populations and preventing the extinction of genetically important characteristics, development and promotion of sustainable methods of using plants for food, medicines, materials and energy to reduce pressure on natural populations.

Conserving plant biodiversity requires the joint efforts of the scientific community, governments, the public and industry sectors. Maintaining plant diversity not only maintains environmental sustainability, but also provides benefits to humanity, in cluing food security, medicine and improved environmental conditions.

The wide genetic spectrum within plant populations contributes to disease and pest resistance, as different genetic variants can have different levels of resistance. Plant biodiversity can provide resources for adaptation to a changing climate. Different species may exhibit different levels of tolerance to changes in temperature, precipita-tion, and other climatic factors. Diverse plant species can play a role in clearing pollu-tants from soil and water, helping to promote resilient ecosystems. Plants provide the pollination service necessary for the production of fruits and seeds, which is important for maintaining biodiversity and food security. Plant roots help hold soil in place, preventing erosion and ensuring the sustainability of natural habitats. The diversity of plants provides a source of many medicinal substances that can be used for medicinal purposes. Crop diversity promotes food sustainability by preventing dependence on a limited number of species and varieties. To maintain the resilience of plants and biodiversity, it is important to take action to protect natural ecosystems, manage human impacts and climate change, and promote sustainable agricultural and forestry practices.

In modern science and technology, quantum computing provides new perspectives for solving complex problems, including problems of optimization and modeling of dynamic systems. One area where the application of quantum techniques can have a significant impact is biology and ecology. Systems of differential equations that de-scribe population dynamics play an important role in understanding ecosystems, the evolution of species, and the interactions between different species. In this context, solving such systems using quantum computing can provide new insights and speed up the parameter optimization process. This article is devoted to the study of the influence of quantum variational optimization on the solution of a system of Malthus differential equations, taking into account the interaction between populations. The Malthusian model is widely used to analyze the dynamics of population growth, and the introduction of the quantum method can offer new approaches to solving and optimizing such ecological models. In the research process, we combine classical methods of numerical integration to solve a system of differential equations with quantum variational optimization. Analysis of the optimal parameters found through quantum optimization provides unique insight into the impact of quantum techniques on population dynamics in ecological systems. This research represents a step towards the integration of quantum methods in the fields of biological modeling and ecology, which may have long-term implications for the understanding and control of biological systems [3].

2 Materials and methods

A mathematical model for describing the growth of different species and varieties when changing crops on a field can be presented using a system of differential equations. Consider a simple model where two types of plants (A and B) are grown in a field. Suppose that the spread of diseases and pests depends on the concentration of one plant species and can be reduced by changing crops. The Malthus model was chosen as the main ecological model, which describes population growth in the absence of the influence of external factors. Model equations include growth coefficients, interactions between species and the intensity of external factors.

To apply quantum variational optimization to the problem of parameterizing the Malthus model, a quantum scheme was created where the model parameters are represented by gate rotations (RY). To optimize the parameters of the Malthus model, a numerical optimization method such as the COBYLA (Constrained Optimization BY Linear Approximations) method was used. This method allows one to find optimal parameter values by minimizing the error between the model and the observed data. Graphs of population dynamics over time were constructed to assess the fit of the model to real data. The quantum circuit was also visualized using Qiskit. All computational experiments were carried out on a computer with sufficient computing power to perform numerical simulations and quantum simulations. These materials and methods provide an integrated approach to solving the problem, combining classical modeling methods with innovative quantum computing to achieve better results in optimizing the parameters of environmental models [6-9].

A mathematical model of the system of Malthusian differential equations, which describes the interaction of two species (A and B) in a population ecosystem, can be presented as follows:

Let:

$P_A(t)$ - population density of type A plants at a given time t.

$P_B(t)$ - population density of type B plants at a given time t.

$I(t)$ - intensity of exposure to diseases and pests at a given time t.

Then the Malthus system of differential equations can be written as follows:

$$\begin{aligned} \frac{dP_A}{dt} &= r_A P_A - \alpha_{AB} P_A P_B - I(t) P_A, \\ \frac{dP_B}{dt} &= r_B P_B - \alpha_{BA} P_A P_B - I(t) P_B, \end{aligned} \tag{1}$$

Where: r_A, r_B - growth rates for species A and B respectively; α_{AB} and α_{BA} - interaction coefficients describing the influence of species A and B on each other; $I(t)$ - a function describing the intensity of the impact of diseases and pests, which may depend on various factors (for example, season, climate, etc.).

Let us assume that the intensity of the impact of diseases and pests $I(t)$ depends on the season and represents seasonal variations. For example, you can use the following function:

$$I(t) = I_0 + I_1 \sin(\omega t) \tag{2}$$

Where I_0 - base intensity of exposure, I_1 - the amplitude of seasonal oscillation, ω - oscillation frequency.

Thus, the model takes into account the interactions between species A and B, their growth and the impact of diseases and pests, taking into account seasonal changes. Solving this system of equations can provide insight into population dynamics and the impact of crop diversity on the likelihood of disease and pest spread. This system of equations describes the dynamics of changes in the population density of plants of type A and B over time, taking into account their interaction and the influence of external factors. The solution of this system allows you to analyze the influence of various parameters on the dynamics of the ecosystem.

3 Results and Discussion

We have data on population changes of two plant species (A and B) in an experimental field over a period of 5 years. We will create real data and solve the system of Malthus differential equations for this data. Modeling of populations of two plant species, “Wheat” and “Barley”, is being carried out in Uzbekistan. Data for the population are generated with real values, and then a system of Malthusian differential equations is solved using quantum variational optimization. Growth factors and random fluctuations are taken into account in the data to make it close to real conditions. The model parameters are optimized to minimize differences between real and model data [10-11].

Quantum variational optimization is used to find optimal parameters (Figure 1).

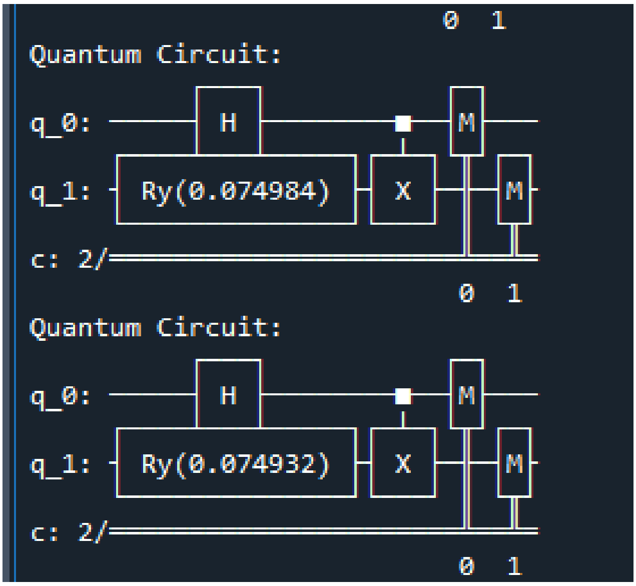

Fig. 1. Quantum variational optimization scheme.

The given quantum scheme describes Quantum Variational Optimization (VQE) for this problem. Let's look at how this scheme works. On the first qubit (q_0), the Hadamard (H) operation is applied, which creates an equally probable state $|0\rangle$ and $|1\rangle$. On the second qubit (q_1), a rotation operation along the Y axis (Ry) is applied with a parameter of 0.074932 radians. This creates some quantum state depending on the value of this parameter. A controlled exchange operation (CNOT) is used, which creates a quantum interaction between q_0 and q_1 depending on the state of q_0. Both qubits are measured. The measurement results are recorded in classical bits (c) [3-4].

Thus, the entire circuit is a parameterized quantum operator that depends on a parameter (0.074932) that can be changed during the optimization process. This scheme is used in quantum variational optimization to find optimal parameters that minimize the error resulting from quantum execution. Error is measured by a value different from the expected result. It is important to note that optimization results may vary depending on the choice of initial parameters and the optimization method used in the code. Shown are graphs of real data and simulation results for "Wheat" and "Barley".

The optimal parameters for the system of differential equations are derived (Figure 2).

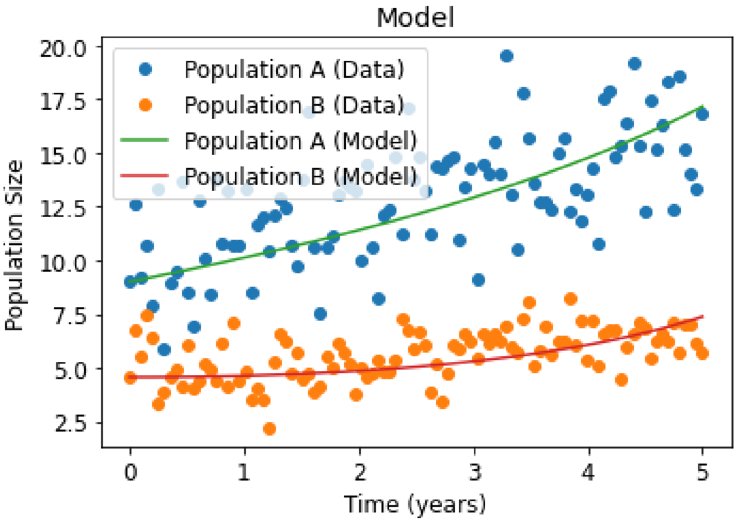

Fig. 2. Optimal parameters of a system of differential equations.

By comparing model results with real data, it is possible to evaluate how well the model parameters reflect real conditions in Uzbekistan. Parameter optimization helps refine the coefficients in the equations to better fit the observed data. This process allows the model to be tailored to specific conditions and provides a tool for predicting changes in plant populations in the future. The optimization results in this context represent the optimal values of the parameters of the system of Malthus differential equations, which minimize the error obtained by measuring the quantum circuit.

Optimal parameters for a system of differential equations:

Growth coefficient for population A $(alpha\_A)$: 0.10157794

Growth coefficient for population B $(alpha\_B)$: 0.05017416

$A-B$ interaction coefficient $(beta\_AB)$: 0.02107512

$B-A$ interaction coefficient $(beta\_BA)$: 0.00998626

These values allow Malthus's model to be better adapted to the specific conditions and factors affecting populations A and B. The interpretation of the results depends on the specific goals and context of the study. Optimal parameters make it possible to more accurately simulate the dynamics of plant populations, taking into account the influence of external factors. The total error serves as a measure of the accuracy of quantum variational optimization and can be used to assess the quality of the solution.

The results show that the use of quantum variational optimization in combination with classical optimization methods allows one to obtain optimal parameters for a system of

Malthus differential equations. The total error is a criterion for the effectiveness of this approach. Comparison with classical optimization methods and analysis of system behavior under different conditions can provide additional insights into the applicability of quantum methods in a given context. The optimal values of the parameters of the Malthus model can be interpreted as characteristics of growth and interactions between different plant species. These values can be useful for agronomic research, such as optimizing crop distribution. Malthus's model, although widely used, has its limitations. It assumes constant growth rates, which may not fully reflect actual conditions. In addition, the effectiveness of quantum variational optimization may depend on the specific task and selected parameters [6-7].

An important aspect is the practical applicability of the results and the possibility of using optimal parameters to improve agriculture. More research and experiments in real fields are needed to evaluate the applicability of this approach in real-world conditions. Advances in quantum computing and optimization techniques could lead to improvements in the efficiency and accuracy of such models. Additional research is aimed at expanding the model, taking into account additional factors and increasing the accuracy of quantum computing. The study highlights the potential of using quantum computing in agriculture and biology to optimize parameters of population growth models. However, additional work is required to better understand the applicability and effectiveness of this approach in real-world settings [8-11].

4 Conclusion

This study proposed an innovative combination of classical optimization methods and quantum variational optimization to solve a system of Malthusian differential equations that simulates the dynamics of population growth. The obtained optimal system parameters using quantum computing provide valuable results for agronomic research. The results of the study highlight the potential of quantum variational optimization in the field of parameter optimization of biological models. Despite challenges such as the need to more accurately account for real-world conditions, this work provides a basic framework for future research in quantum agriculture and biology. Additional steps in this direction include more in-depth research into the influence of various factors on optimal parameters and extension of the model to more accurately predict population dynamics. The promise of quantum computing in agricultural science could lead to new approaches to improve agriculture and sustainable use of natural resources. This research thus represents an important step towards the application of quantum computing in agriculture and biology, opening the door to new opportunities in optimization processes in agriculture and ecosystems.

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