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VATTAMALAIPALAYAM, N.G.G.O. COLONY POST, COIMBATORE – 641 022.

Crop Schedule Management using Quantum Optimization Techniques

Team Number : 15

Guide

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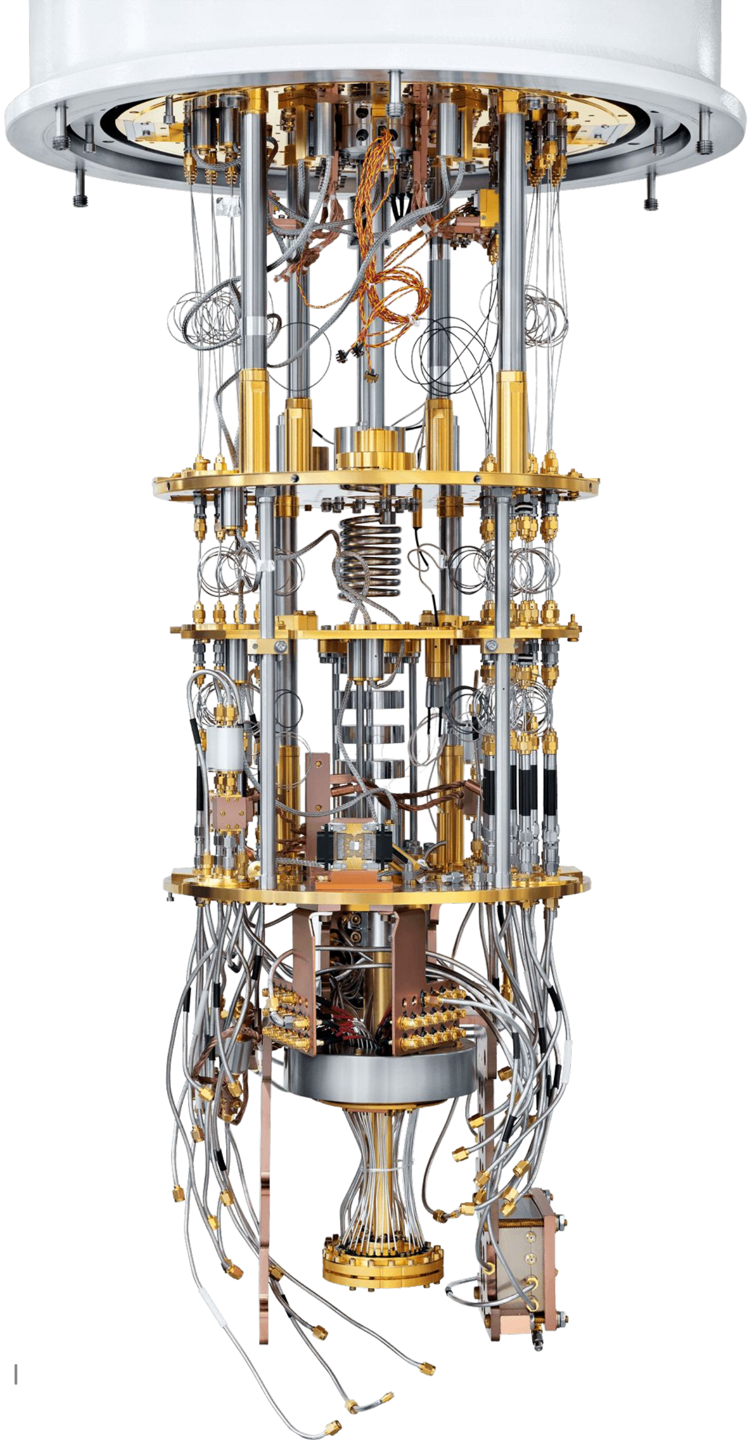
Introduction

Problem Statement & Understanding

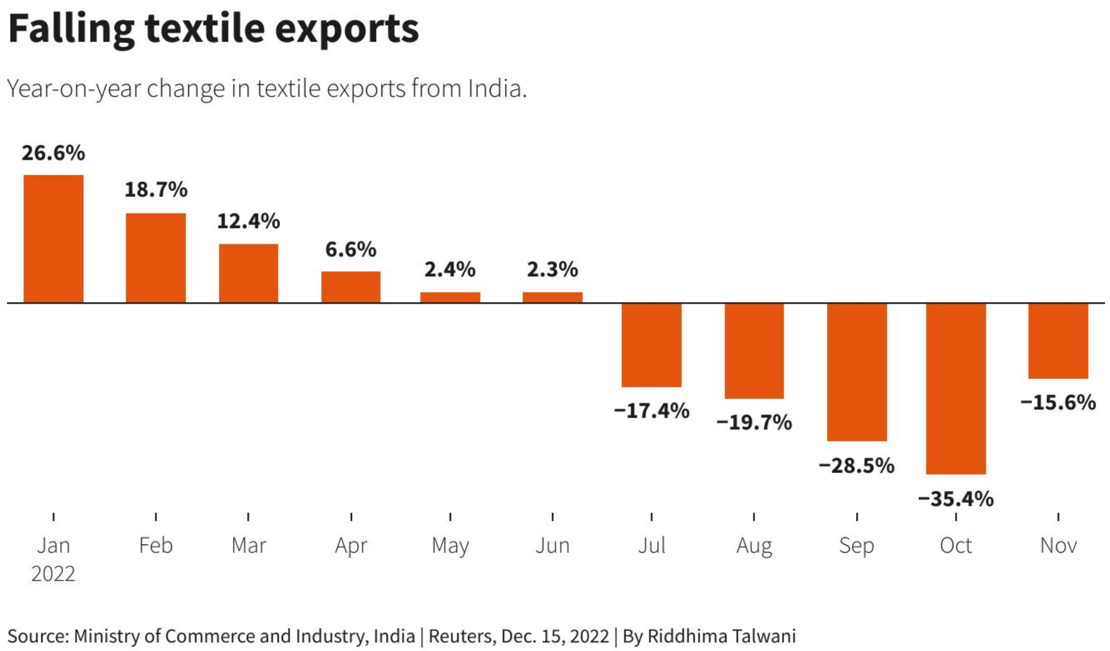
Introduction
Domain

- Quantum Computing – a break-through in computational method
  - Enables high performance computing, reduces computational time exponentially.
    - Utilizes the principles of quantum mechanics.
      - Superposition
      - Quantum Entanglement
      - Quantum Inference, gates, etc.
    - Deploys Qubits (for computing).



Introduction
Problem Background

- **Agricultural Optimization Challenges:**
  - Yield disparities
    - Crucial crops – Uneven distribution
    - Noticeable decline in overall crop yields
    - Threat to food security & marginalized farm income.
  - Lack of optimal resource utilization.
    - Resources: Land, Water, Nutrients, Microbe ecosystem.
  - Involves complex agricultural systems with multiples variables.
    - Throttles classical systems for computation.
    - Exponential time complexity.
- **Case Study: Dwindling textile industry in India**
  - Sparse cotton yield
    - Demand – Supply mismatch
    - Reduced yield per hectare
    - Exploitation of resources – with no improvement in productivity.
  - Low Raw Material input = Low production = Low utilization = Low profit = No capex cycle
  - Decreased fiscal prudence and thus, poor Balance Sheet (for consecutive Financial Years)
  - *Similar situation is prominent in over-all agriculture sector* (World Bank).



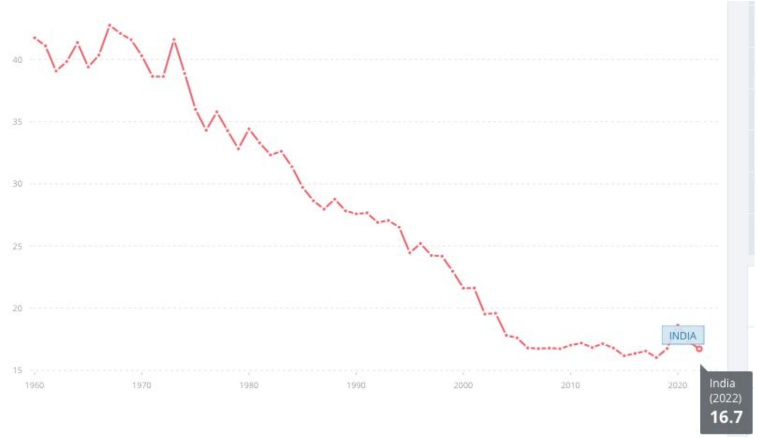


FIG: Agriculture (% of GDP) - India
Source: World Bank

Introduction
Problem Objective

- To introduce Quantum inspired - novel agricultural approach.
  - To formulate ‘Quadratic Model’ - crop optimization problem.
  - To encode QM for Problem with dynamic inputs.
    - Considerations: Set of Plots, Crop Options, Growth time, Utilization rate.
  - To solve the quadratic model effectively using a real Quantum computer.
    - To Create: Quantum Optimizer model.
    - To Create effective methods and functions – Quantum programming.
    - Submit the jobs to QC, use quantum annealing to solve.
    - Retrieve computed results from quantum computer.
  - To present the results – data visualization
    - Expect: Crop schedule – for crop rotation

Background Research

Literature Review & Findings

RESEARCH PAPER – 01

[1] K.Barati. et. al., *"Cropping Pattern Optimization Using System Dynamics Approach and Multi−Objective Mathematical Programming"*, J.Agr.Sci.Tech., vol.22 , no.5 , pp.1397−1412, 2020.

S.No	**Use - Case**	Paper Title	Year	Task	Method	Result	Disadvantages
1	**OPTIMIZE CROP PATTERN**	*Crop Pattern Optimization Using System Dynamics Approach and Multi-Objective Mathematical Programming*	2020	• Optimize cropping pattern using dynamic modelling • Forecasting parameters using mathematical programming	• By developing a dynamic model in Vensim PRO x32 software • Stochastic simulation of time series data.	• Ratio of benefit to water extraction improved in all scenarios • Low error rate	• Reduction in cultivation of secondary crops.

RESEARCH PAPER – 02

[2] C. Maraveas et al., *"Harnessing Quantum Computing for Smart Agriculture: Empowering Sustainable Crop Management and Yield Optimization",* Computers and Electronics in Agriculture, vol. 218, p. 1-23, 2024.

S.No	**Use - Case**	Paper Title	Year	Task	Method	Result	Disadvantages
2	**Quantum Computing – Smart Agriculture**	*Harnessing Quantum Computing for Smart Agriculture: Empowering Sustainable Crop Management and Yield Optimization*	2024	• Focuses on quantum computing applications in smart agriculture • Discusses quantum sensors, digital twin, quantum machine learning.	• Open-ended research method with labor-intensive recording and categorization.	• Enhanced precision in monitoring crop farming and agricultural productivity, using quantum computing. • Regulated farming practices	• Limited expertise in quantum computing in agriculture industry • Sparse implementation.

RESEARCH PAPER – 03

[3] K. Jun, "*QUBO Formulations for a System of Linear Equations*", Results in Control and Optimization, vol. 14, p. 1-12, 2024

S.No	Use - Case	Paper Title	Year	Task	Method	Result	Disadvantages
3	**QUBO MODEL – ALGORITHM FOR LINEAR SYSTEM**	*QUBO Formulations for a System of Linear Equations*	2024	• Formulating Quadratic Unconstrained Binary Optimization – (BQM) mathematical model for problems.	• By solving linear systems efficiently on quantum computers. • Involves cost function for n-dimensional binary vector.	• QPU solves problems efficiently using QUBO model.	• Less robust comparatively to DQM models.

RESEARCH PAPER – 04

[4] L. M. R. dos Santos et al., *"Crop rotation scheduling with adjacency constraints*", *Annals of Operations Research*, vol.190, pp. 165-180,2021.

S.No	Use - Case	Paper Title	Year	Task	Method	Result	Disadvantages
4	**CROP ROTATION**	*Crop rotation scheduling with adjacency constraints*	2021	• Focuses on crop rotation on crop scheduling in cropping areas • Presents a linear optimization model.	• Uses column generation method. • Heuristic procedure based on the columns • Greedy plot-to-plot heuristics for rapid good results.	• Heuristic HCGH outperformed CPLEX in solving crop rotation problems	• Novice implementation observed.

Proposed System

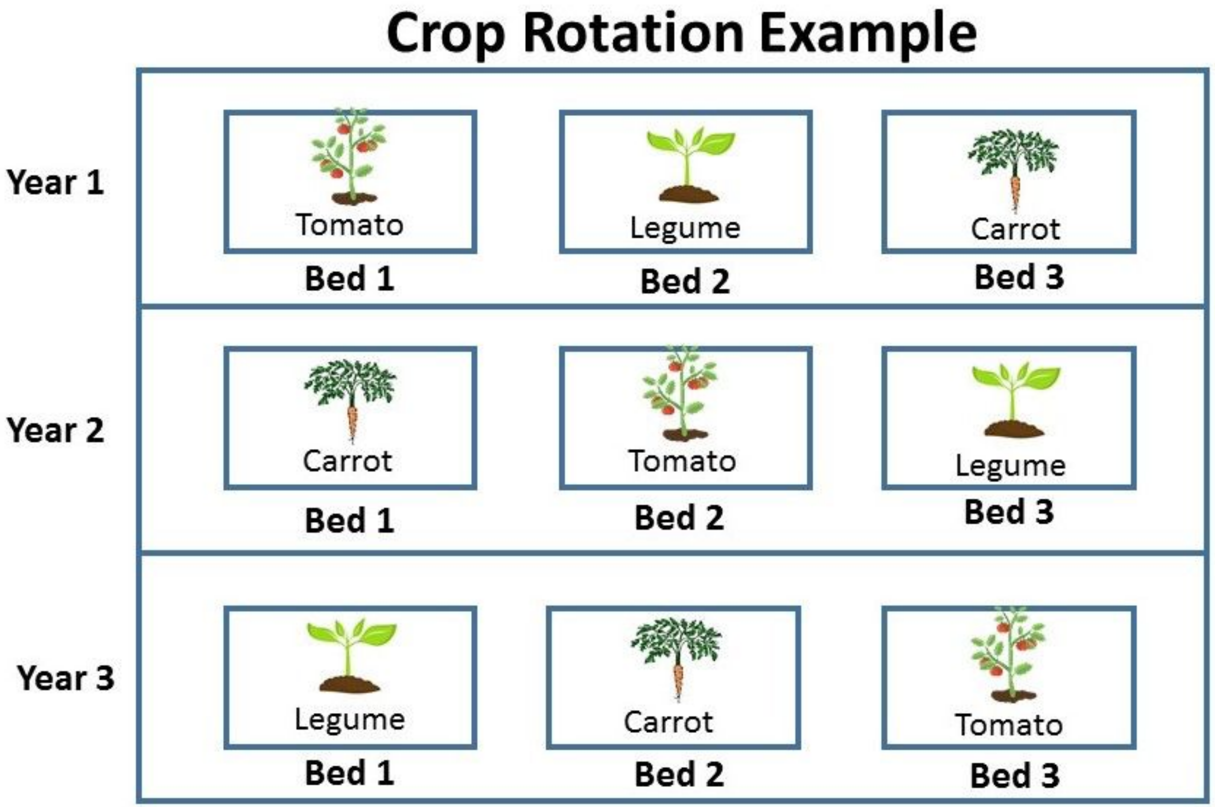
Architecture, Findings, etc.

PROPOSED SYSTEM

01. Farming Method

•Crop-Rotation

- Crop rotation is a **sustainable agricultural technique** that involves switching between cover crops and cash crops to avoid the adverse effects of intensive farming.
- Crop rotation is a method for crop production **diversification** and soil **fertility** improvement
- Enhancing accuracy in mapping crop rotation patterns for better **agro-ecosystem management.**
- Diversified crop rotation (**DCR**) enhances soil health, productivity, and sustainability by incorporating a variety of crops, reducing risks, and improving ecological balance in farming systems.



PROPOSED SYSTEM

02. *Quadratic model*

- Objective function:

$$min \sum_{k=1}^{L} \sum_{j=1}^{M} \sum_{i=1}^{N} - t_i . x_{i,j,k}$$

  - Where,
    - M = The duration of a complete crop rotation, measured in time units.
    - L = The total number of available plots for planting crops.
    - N = The count of distinct crop types.
    - $x_{i,j,k}$ represents whether crop *i* is planted on farm *k* in period *j*, where *i* ranges from 1 to the total number of distinct crops, *j* ranges from 1 to the total number of available farms, and *k* ranges from 1 to the total number of time units.

PROPOSED SYSTEM

02. *Quadratic model*

- Constraints : Using '*Crop Rotation*' Farming method.

1. Each period, atmost one crop can be planted on each farm.

$$\sum_{i=1}^{N}\sum_{r=0}^{t_i-1} x_{i,j-r,k} \leq 1, j=1,\ldots,M, k=1,\ldots,L$$

2. Crop rotation constraints to avoid consecutive planting of certain crops.

   I. Same crop ***'Species'*** should not be placed adjacent.

$$\sum_{i\in F_p}\sum_{r=0}^{t_i-1}\left[x_{i,j-r,u}+x_{i,j-r,v}\right]\leq 1\ ,\ p=1,\ldots,N_f,\ j=1,\ldots,M,\ (u,v)\in S$$

   II. Same ***'Family'*** crops should not be placed adjacent.

$$\sum_{i\in F_p}\sum_{r=0}^{t_i} x_{i,j-r,k\leq 11,\ p=1,\ldots,N_f\ ,\ j=1,\ldots,M\ ,\ k=1,\ldots,L}$$

3. Utilization rate of the fields in ***Total time period*** must be less than 95%

$$\sum_{k=1}^{L}\sum_{j=1}^{M}\sum_{i=1}^{N} x_{i,j,k} \leq \text{max\_utilization\_percentage} \times L \times M$$

PROPOSED SYSTEM

02. *Quadratic model*
Sample Calculations

- Inputs:
  - crops:
    - Aa: family: Aaaa , grow_time: 1, planting: [1,3]
    - Bb: family: Bbbb , grow_time: 1, planting: [1,4]
  - plot_adjacency: (1,2)
  - time_units: 4

- Quantum Solution:
- {'1,1': 'Aa', '2,1': 'Bb', '1,2': 'Bb', '2,2': 'Aa', '1,3': 'Aa', '2,3': 'Bb', '1,4': 'Bb', '2,4': None}

- Objective Function:

$$\text{Objective Function} = \sum_{i,j,k} x_{i,j,k} \times \text{grow\_time}[i]$$

  - Objective Function = (1 × 1) + (1 × 1) + (1 × 1) + (1 × 1) + (1 × 1) + (1 × 1) + (0 × 1) + (1 × 1)
  - Objective Function = 7

PROPOSED SYSTEM

02. *Quadratic model*
Sample Calculations

- Constraints:
  - Atmost one crop only:

$$x_{\mathrm{Aa},1,1} + x_{\mathrm{Bb},1,1} = 0 + 1 = 1$$

$$x_{\mathrm{Aa},1,2} + x_{\mathrm{Bb},1,2} = 1 + 0 = 1$$

$$x_{\mathrm{Aa},1,3} + x_{\mathrm{Bb},1,3} = 0 + 1 = 1$$

$$x_{\mathrm{Aa},1,4} + x_{\mathrm{Bb},1,4} = 0 + 1 = 1$$

$$x_{\mathrm{Aa},2,1} + x_{\mathrm{Bb},2,1} = 1 + 0 = 1$$

$$x_{\mathrm{Aa},2,2} + x_{\mathrm{Bb},2,2} = 0 + 1 = 1$$

$$x_{\mathrm{Aa},2,3} + x_{\mathrm{Bb},2,3} = 1 + 0 = 1$$

$$x_{\mathrm{Aa},2,4} + x_{\mathrm{Bb},2,4} = 0 + 1 = 1$$

PROPOSED SYSTEM

02. *Quadratic model*
Sample Calculations

- Constraints:
  - 2. Same ***'Family'*** crops should not be placed adjacent.

$$x_{\mathrm{Aa},1,1} + x_{\mathrm{Aa},2,1} = 1 + 0 = 1$$

$$x_{\mathrm{Aa},1,2} + x_{\mathrm{Aa},2,2} = 1 + 0 = 1$$

$$x_{\mathrm{Aa},1,3} + x_{\mathrm{Aa},2,3} = 0 + 1 = 1$$

$$x_{\mathrm{Aa},1,4} + x_{\mathrm{Aa},2,4} = 0 + 1 = 1$$

$$x_{\mathrm{Bb},1,1} + x_{\mathrm{Bb},2,1} = 0 + 1 = 1$$

$$x_{\mathrm{Bb},1,2} + x_{\mathrm{Bb},2,2} = 0 + 1 = 1$$

$$x_{\mathrm{Bb},1,3} + x_{\mathrm{Bb},2,3} = 1 + 0 = 1$$

$$x_{\mathrm{Bb},1,4} + x_{\mathrm{Bb},2,4} = 0 + 1 = 1$$

PROPOSED SYSTEM

02. *Quadratic model*
Sample Calculations

- Constraints:
  - Family count:

$$\sum_{j,k} x_{\mathrm{Aa},j,k} = 3$$

$$\sum_{j,k} x_{\mathrm{Bb},j,k} = 4$$

$$\mathrm{xAa,1,1+xAa,2,1+xAa,1,2+xAa,2,2+xAa,1,3+xAa,2,3+xAa,1,4+xAa,2,4} = 0+1+1+0+1+0+0+0 = 3$$

$$\mathrm{xBb,1,1+xBb,2,1+xBb,1,2+xBb,2,2+xBb,1,3+xBb,2,3+xBb,1,4+xBb,2,4} = 1+0+0+1+1+0+0+1 = 4$$

  - Maximum utilization rate: (95%)
    - Plot utilization = (7/8) = 0.875
    - 0.875 < 0.95

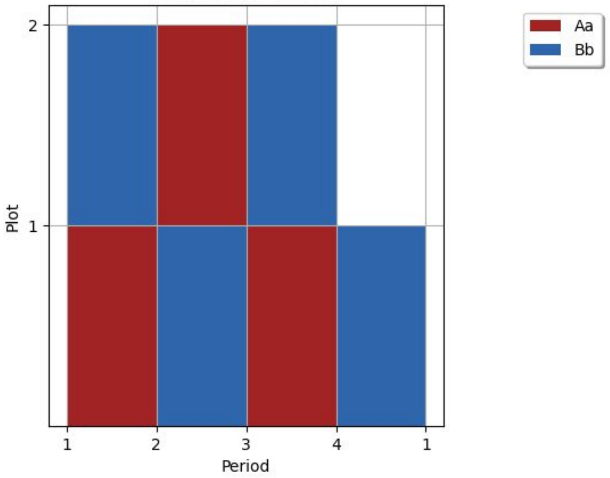
- <u>NOTE:</u>
- These are sample calculations only, for the output obtained (1 combination).
- But, to obtain output, all these <u>calculation must be done to all the combinations!!</u>

PROPOSED SYSTEM

02. *Quadratic model*
Sample Calculations

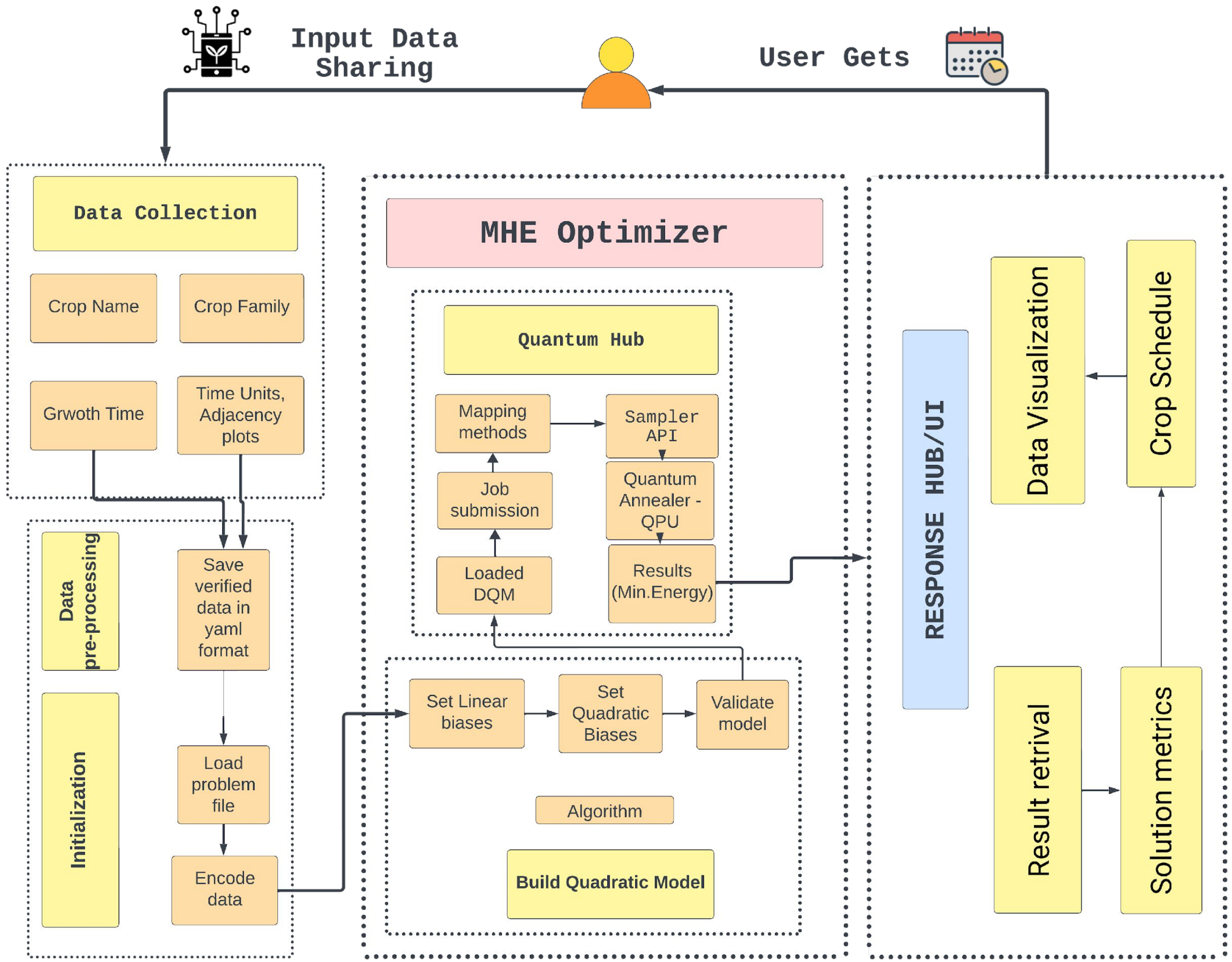
- But, to obtain output, all these calculation must be done to all the combinations!!

```
DQM num. variables: 8
DQM num. variable interactions: 12 (42.9 % of max)
DQM num. cases: 22
DQM num. case interactions: 19 (9.0 % of max)
Solution: {'1,1': 'Aa', '2,1': 'Bb', '1,2': 'Bb', '2,2': 'Aa', '1,3': 'Aa', '2,3': 'Bb', '1,4': 'Bb'}
Solution energy: -7.0
Plot utilization: 87.5 %
{'1,1': 'Aa', '2,1': 'Bb', '1,2': 'Bb', '2,2': 'Aa', '1,3': 'Aa', '2,3': 'Bb', '1,4': 'Bb', '2,4': None}
```



PROPOSED SYSTEM

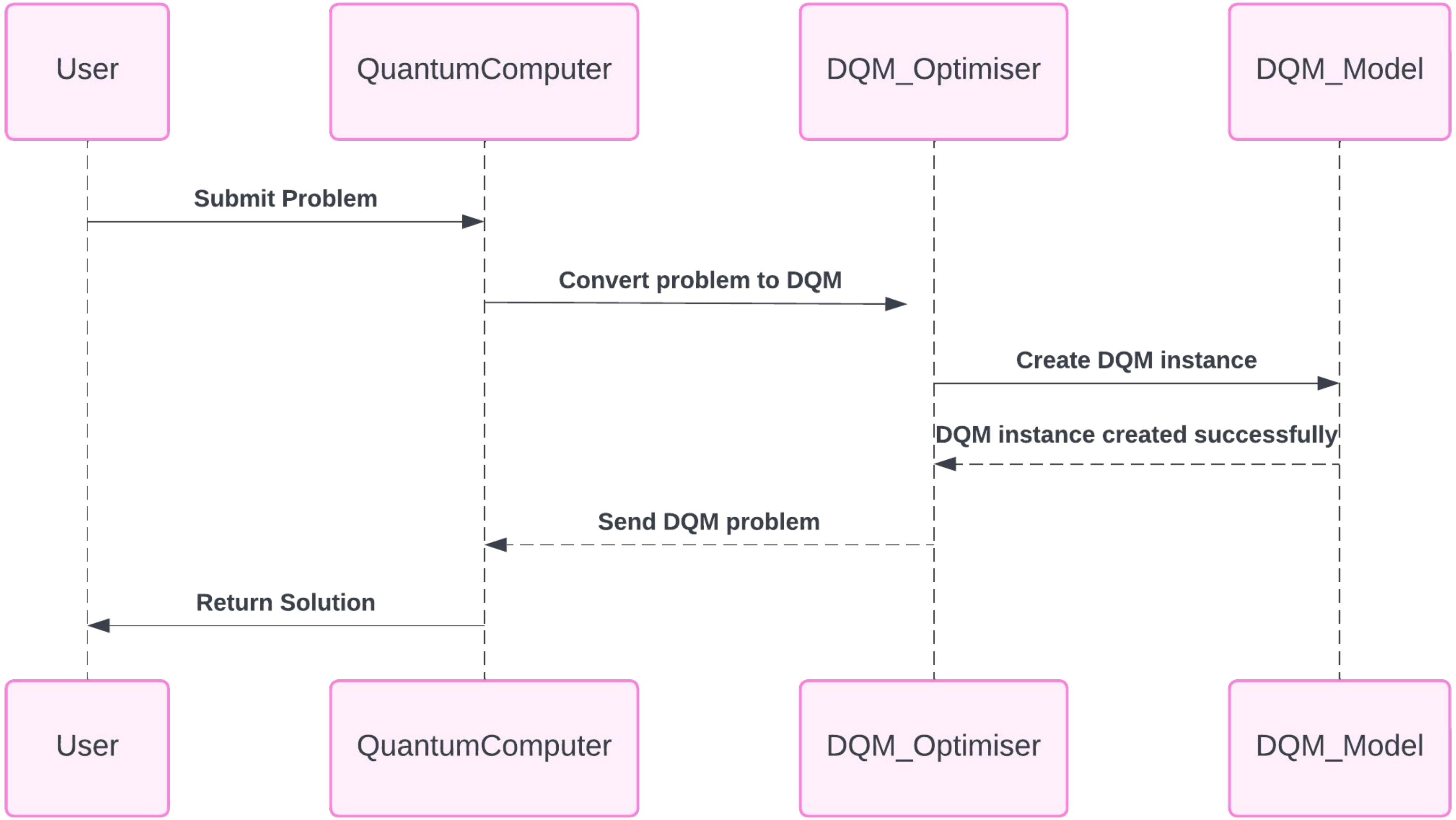
03. *Architecture*



- Overall, this system uses a **cloud-based quantum computer** to optimize crop planting schedules.
- The system takes agricultural data, translates it into a form a quantum computer can understand (**DQM**).
- Uses the **quantum annealing** to find the optimal planting schedule.
- Translates the **results** back into a usable form, and presents the results to the user.

PROPOSED SYSTEM

03. *Architecture*



- The Simplified diagram depicts a system that leverages a **quantum annealer** to solve an optimization problem.

Proposed System
Findings

Sample problem input

time_units: 20

plot_adjacency:
1: [2]
2: [3]
3: [4]
4: [5]
5: [6]
6: [7]
7: [8]
8: [9]
9: []

crops:
Cotton:
family: Mallows
planting: [2, 3]
grow_time: 6

Sunflower:
family: Aster
planting: [10, 12]
grow_time: 7

Peas:
family: Legume
planting: [6, 7]
grow_time: 3

Beans:
family: Legume
planting: [11, 12]
grow_time: 6

Tomato:
family: Solanum
planting: [11, 12]
grow_time: 4

Potato:
family: Solanum
planting: [9, 10]
grow_time: 6

Turnip:
family: Cole
planting: [2, 14]
grow_time: 4

Carrot:
family: Apium
planting: [7, 8]
grow_time: 4

Onion:
family: Alium
planting: [5, 7]
grow_time: 5

Garlic:
family: Alium
planting: [2, 2]
grow_time: 10

Spinach:
family: Chenopodium
planting: [6, 7]
grow_time: 3

Proposed System
Findings

- Sample DQM

```
 ================ DQM ====================

DQM num. variables: 180
DQM num. variable interactions: 1087 (6.7 % of max)
DQM num. cases: 486
DQM num. case interactions: 3568 (3.0 % of max)

    1,1 2,1 3,1 4,1 5,1 6,1 7,1 8,1 9,1 1,2 2,2 3,2 4,2 ... 9,20 energy num_
6     0   0   0   0   0   0   0   0   0   1   2   3   1 ...    0 -149.0    1
7     0   0   0   0   0   0   0   0   0   1   2   1   3 ...    0 -149.0    1
8     0   0   0   0   0   0   0   0   0   1   3   1   3 ...    0 -149.0    1
11    0   0   0   0   0   0   0   0   0   1   3   1   2 ...    0 -149.0    1
12    0   0   0   0   0   0   0   0   0   3   2   3   1 ...    0 -149.0    1
18    0   0   0   0   0   0   0   0   0   3   2   3   1 ...    0 -149.0    1
19    0   0   0   0   0   0   0   0   0   3   2   3   1 ...    0 -149.0    1
23    0   0   0   0   0   0   0   0   0   3   2   3   1 ...    0 -149.0    1
26    0   0   0   0   0   0   0   0   0   1   3   1   3 ...    0 -149.0    1
32    0   0   0   0   0   0   0   0   0   3   2   3   1 ...    0 -149.0    1
...
['INTEGER', 96 rows, 96 samples, 180 variables]
```

Problem Parameters | Solution | Timing

ID
702a422c-af96-41ae-98e9-6d3584f56e62

LABEL Copy Value
MMHE

SOLVER
hybrid_discrete_quadratic_model_version1

TYPE
dqm

SUBMITTED_ON
2024-05-09T00:07:41.581558Z

SOLVED_ON
2024-05-09T00:07:48.430677Z

STATUS
COMPLETED

SUBMITTED_BY
DEV-616af4426...

TIME_LIMIT
5

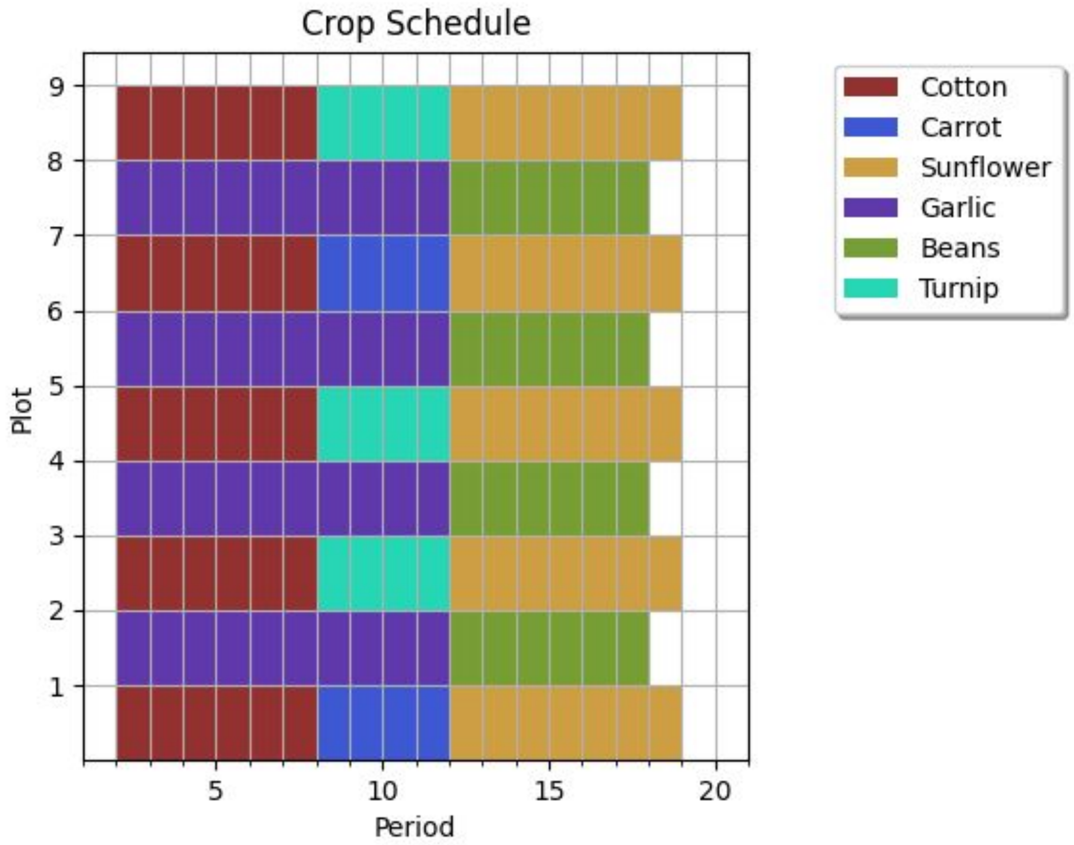
Problem Parameters Documentation

Proposed System Findings

- Built DQM:

```
DQM num. variables: 180
DQM num. variable interactions: 1105 (6.9 % of max)
DQM num. cases: 486
DQM num. case interactions: 3649 (3.1 % of max)
```

- Solution:
  - Solution: {'1,2': 'Cotton', '2,2': 'Garlic', '3,2': 'Cotton', '4,2': 'Garlic', '5,2': 'Cotton', '6,2': 'Garlic', '7,2': 'Cotton', '8,2': 'Garlic', '9,2': 'Cotton', '1,8': 'Carrot', '3,8': 'Turnip', '5,8': 'Turnip', '7,8': 'Carrot', '9,8': 'Turnip', '1,12': 'Sunflower', '2,12': 'Beans', '3,12': 'Sunflower', '4,12': 'Beans', '5,12': 'Sunflower', '6,12': 'Beans', '7,12': 'Sunflower', '8,12': 'Beans', '9,12': 'Sunflower’}
  - Solution energy: -149.0
  - Plot utilization: 82.8 %



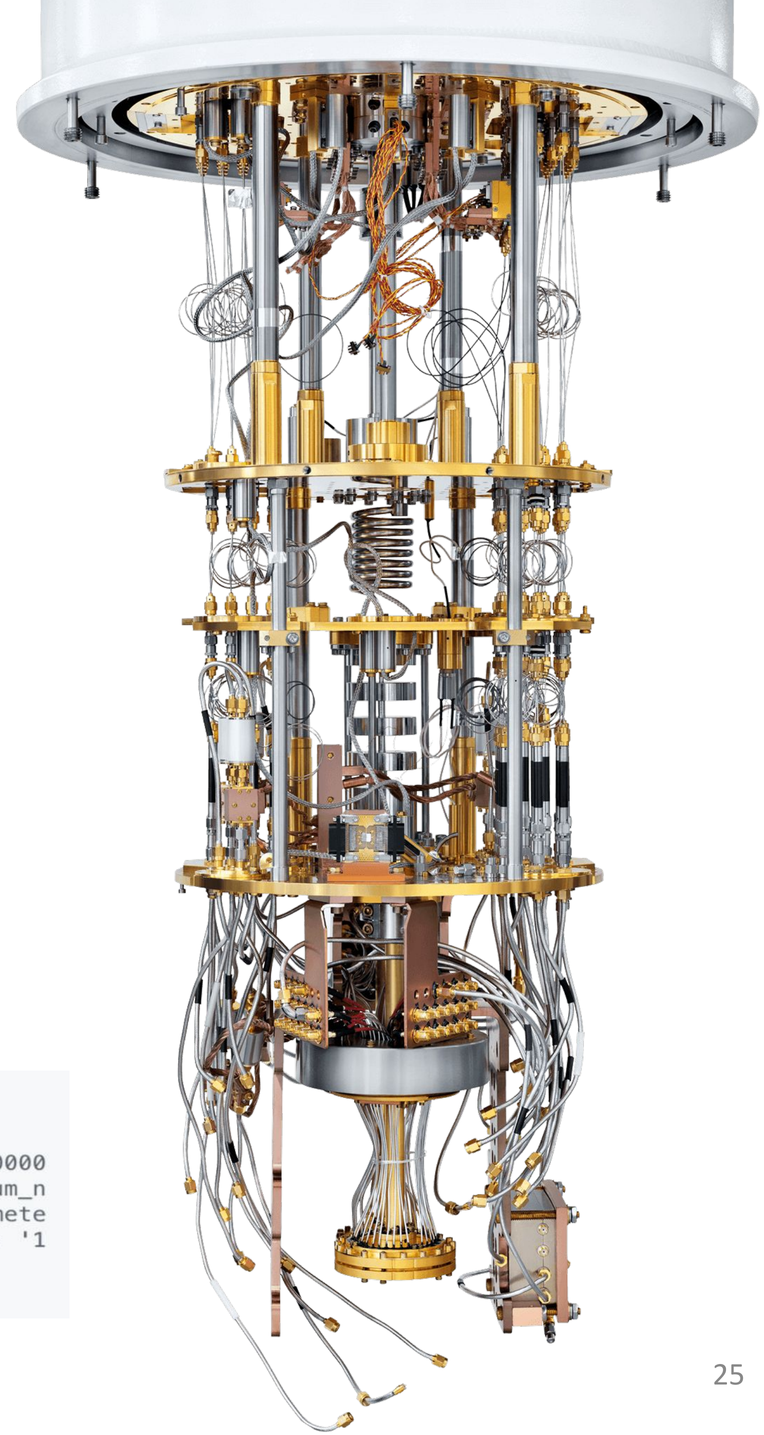
Proposed System
Findings

Accessing QPU

```
qc/ $ dwave ping
Using endpoint: https://cloud.dwavesys.com/sapi/
Using region: na-west-1
Using solver: Advantage_system4.1
Submitted problem ID: a140471a-433e-411a-aafc-4d783cfb70d8

Wall clock time:
 * Solver definition fetch: 2814.352 ms
 * Problem submit and results fetch: 2542.404 ms
 * Total: 5356.756 ms

QPU timing:
 * post_processing_overhead_time = 1.0 us
 * qpu_access_overhead_time = 0.0 us
 * qpu_access_time = 15857.35 us
 * qpu_anneal_time_per_sample = 20.0 us
 * qpu_delay_time_per_sample = 20.58 us
 * qpu_programming_time = 15780.37 us
 * qpu_readout_time_per_sample = 36.4 us
 * qpu_sampling_time = 76.98 us
 * total_post_processing_time = 1.0 us
qc/ $
```

Quantum Annealer : Sampler

```
================ SAMPLER PROPERTIES ====================

{'minimum_time_limit': [[20000, 5.0], [100000, 6.0], [200000, 13.0], [500000, 34.0], [1000000, 71.0], [2000000
, 152.0], [5000000, 250.0], [20000000, 400.0], [250000000, 1200.0]], 'maximum_time_limit_hrs': 24.0, 'maximum_n
umber_of_variables': 5000, 'maximum_number_of_biases': 5000000000, 'maximum_number_of_cases': 500000, 'paramete
rs': {'time_limit': 'Maximum requested runtime in seconds.'}, 'supported_problem_types': ['dqm'], 'version': '1
.12', 'category': 'hybrid', 'quota_conversion_rate': 20}
```

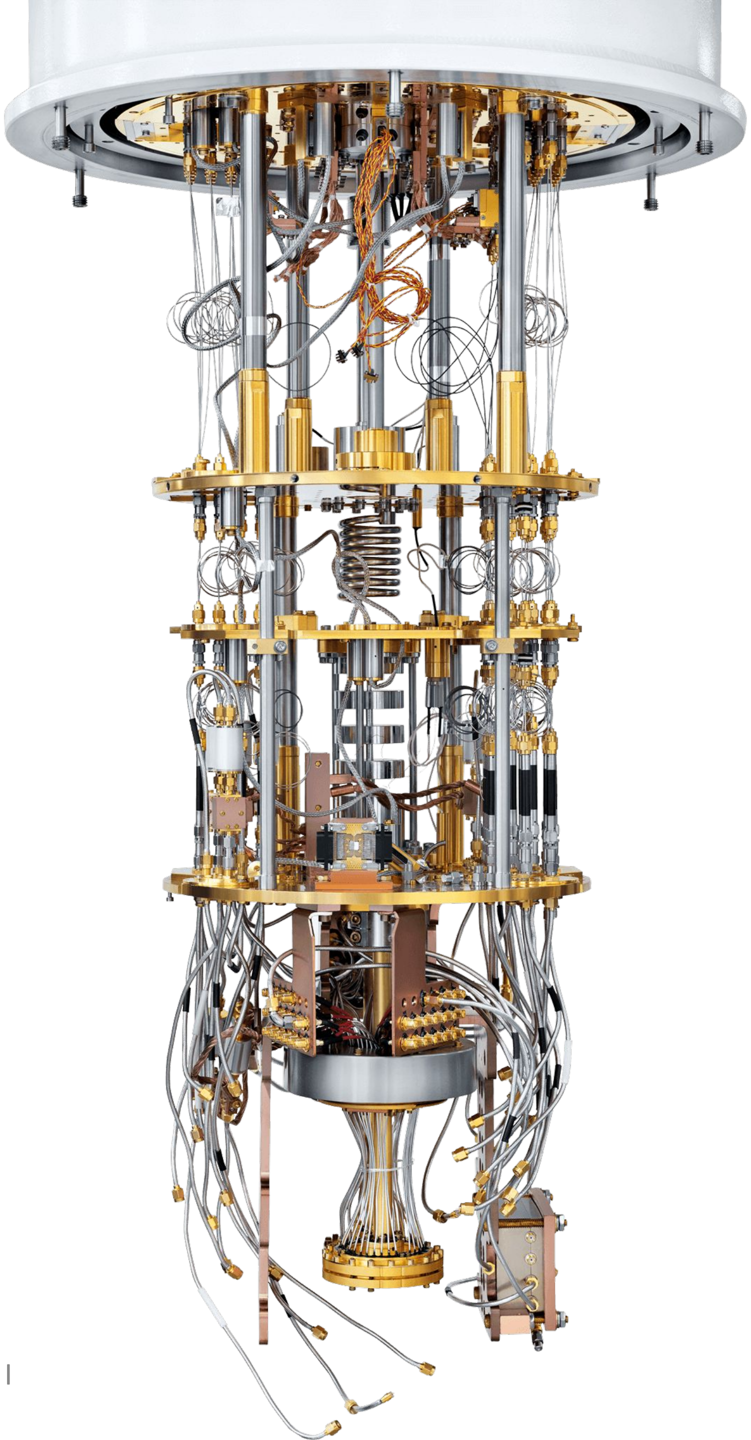


Conclusion

Result & Future Scope

Conclusion

- Achieved all the blocks in ‘Implementation Modules’, successfully **meet the objectives** by quantum annealing.
- Solves the computational limitation posed by classical computing, thus, **solves massive problem instances effectively**.
- Successfully demonstrated the **Quantum Advantage** for complex optimization problems with constraints.
- Observed **robustness** across multiple problem scenarios.
- Hence, Quantum computing’s potential in **revolutionizing** optimization tasks



Future Scope

- **Sustainable Tech**
  - Investigate quantum algorithms for sustainable agriculture practices **to reduce carbon footprint.**
- **Quantum Hardware Advancements**
  - Need practical Quantum sensors.
  - Explore advancements in quantum hardware technologies:
    - Increased qubit counts
    - Improved coherence and error rates
    - Availability of fault-tolerant quantum processors
- **Algorithmic Enhancements**
  - Develop and optimize quantum algorithms specifically tailored for optimization tasks:
    - Enhanced QAOA
    - Novel variational quantum algorithms
    - Quantum annealing approaches
- **Quantum Software Development**
  - Focus on developing user-friendly quantum software tools and libraries:
    - Quantum programming languages and frameworks
    - Simulation and optimization software for quantum computing
    - Quantum machine learning libraries

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- [1] L. M. R. dos Santos et al., *"Crop rotation scheduling with adjacency constraints,"* *Annals of Operations Research*, vol. 190, pp. 165-180, 2021.
- [2] K.Barati. et. al., *"Cropping Pattern Optimization Using System Dynamics Approach and Multi−Objective Mathematical Programming"*, J.Agr.Sci.Tech., vol.22 , no.5 , pp.1397−1412, 2020.
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THANK YOU!!!