Echo Messaging Systems, Inc.
www.echomessaging.com
info@echomessaging.com
401-475-9642
December 7, 2021

ADIN Quantum Interfaces

This paper is an Executive Summary to the accompanying technical paper titled "Quantum Computing in Agent-Based Technologies" accepted for inclusion by the SAI Conference "Computing Conference 2022", to be held in July 2022 in London UK. The paper can be see here: https://echo.echoware.net/FullerDeaneComputingConf2022.pdf and is indexed worldwide for collaboration and research. Citations are accessible via scholar.google.com.

Introduction to ADIN Quantum processing

Classes of problems called 'Constraint Satisfaction Problems' are difficult to solve on today's computers, where the goal is to find the best solution that satisfies a number of constraints while minimizing an overall goal. The Traveling Salesman problem is a classic example of this type of problem, where the goal is to design a route such that the salesman visits every city one time and minimizes the overall distance traveled to save on energy costs. For small problem sets, a computer can determine the route by listing every possible route combination, add up the distances and pick the shortest one. As the problem gets larger, the time to solve gets exponentially larger to the point where this is no longer a viable approach, even with more sophisticated searching and sorting algorithms than 'picking the shortest of all possible routes'.

Quantum computers, like those made by DWave (www.dwavesys.com) are better at solving Constraint Satisfaction Problems (CSP) by first formulating the problem as a quadratic equation (see Eq. 1), such that it can be submitted to the quantum computer, followed by processing using a technique called quantum annealing.

$$Ax + By + Cxy$$

Equation 1. Quadratic equation example

Quantum annealing interacts with quantum gates in the hardware (known as qubits). Each qubit represents a term in quadratic equation that holds all possible variables settings of the CSP. At the beginning every qubit is both a 0 and a 1. This is fundamentally different from today's 'classical' computers where a binary gate is either a 0 or a 1. The quantum annealing process results in qubits eventually committing to either a 0 or a 1 as energy is minimized in the quadratic equation input, based on the variables (A, B, and C in the above equation). Each term is associated with a qubit, and through a process called 'embedding', is sent to the quantum hardware. Quantum annealing finds terms such that the result is the minimum energy of the quadratic equation, where 'energy' is a placeholder for the key thing being minimize (distance, money, time, etc).

Echo Messaging Systems, Inc.
www.echomessaging.com
info@echomessaging.com
401-475-9642
December 7, 2021

ADIN Interfaces

ADIN stands for Anomaly Detection and Intelligent Notification and is Echo's AI agent-based framework for applications. See 'Further Reading' section at the end of this document for more background information. ADIN Quantum Interface lets user setup Constraint Satisfaction Problems for scheduling, routing, and resource sharing. Your Constraint Satisfaction Problem is defined using ADIN Quantum interface forms using dropdown menus, and checkbox controls. This results in the CSP's global cost function and additional constraints expressed as a quadratic equation that is ready to be embedded on the DWave computer, if the number of variables do not exceed the limit, which is currently 5000.

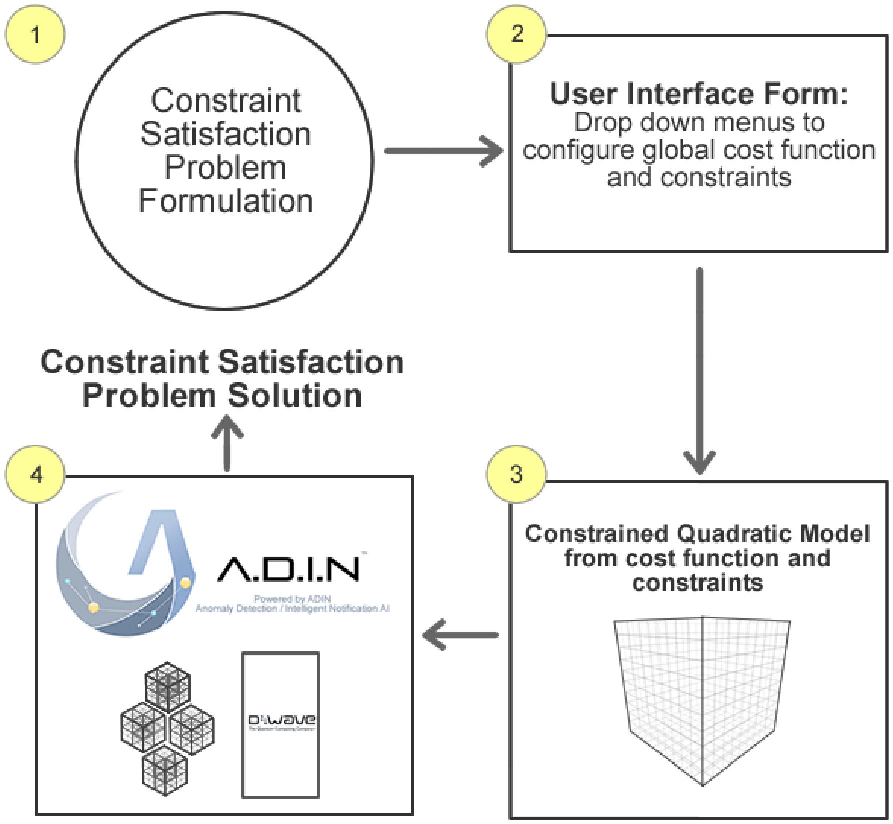


Figure 1. High Level Dataflow

Figure 1 shows the high-level data flow:

1) A Constraint Satisfaction Problem is defined. Problems like 'The Traveling Salesman' problem is a classic example of a constraint satisfaction problem. These types of problem seek to minimize (or maximize) a global cost function such as 'minimize gas used while visiting every city for a salesman' or 'minimize time while visiting every city for a salesman'. The global cost function is to minimize gas used or time spent, and constraints are to visit each city one time.

2) Using a user interface, the user selects from options that best describe their Constraint Satisfaction problem to minimize time on a schedule, distance in a route, or jobs completed

when shared resources are required.

3) The global cost function and constraints define a Constrained Quadratic Model expressed as a quadratic equation where each variable in the equation forms a cube called an ADIN Quantum Matrix. DWave quantum computer has a 5000 variable limit (current) for the quantum annealing process they perform over the variables. If more than 5000 variables are defined by the ADIN Quantum Matrix, the problem must be broken down into smaller pieces.

4) ADIN breaks down the Quantum Matrix into ADIN Quantum Cubes repeated until the component cubes have variables that fit the DWave limit, which is sent to the DWave quantum computer.

User Interfaces allow for inspection, debugging, experimentation, and insight into ADIN Quantum agents as shown in Figures 2 and 3, including:

1a) Select the type of Constraint Satisfaction problem you need to solve for to best schedule jobs in a calendar of teams, and/or equipment; to best route crews to jobs to complete jobs quicker; and to schedule use of shared tools / resources. This selection determines the global cost function that needs to be minimized as part of the Quantum annealing process the finds optimal solutions.

Echo Messaging Systems, Inc.
www.echomessaging.com
info@echomessaging.com
401-475-9642

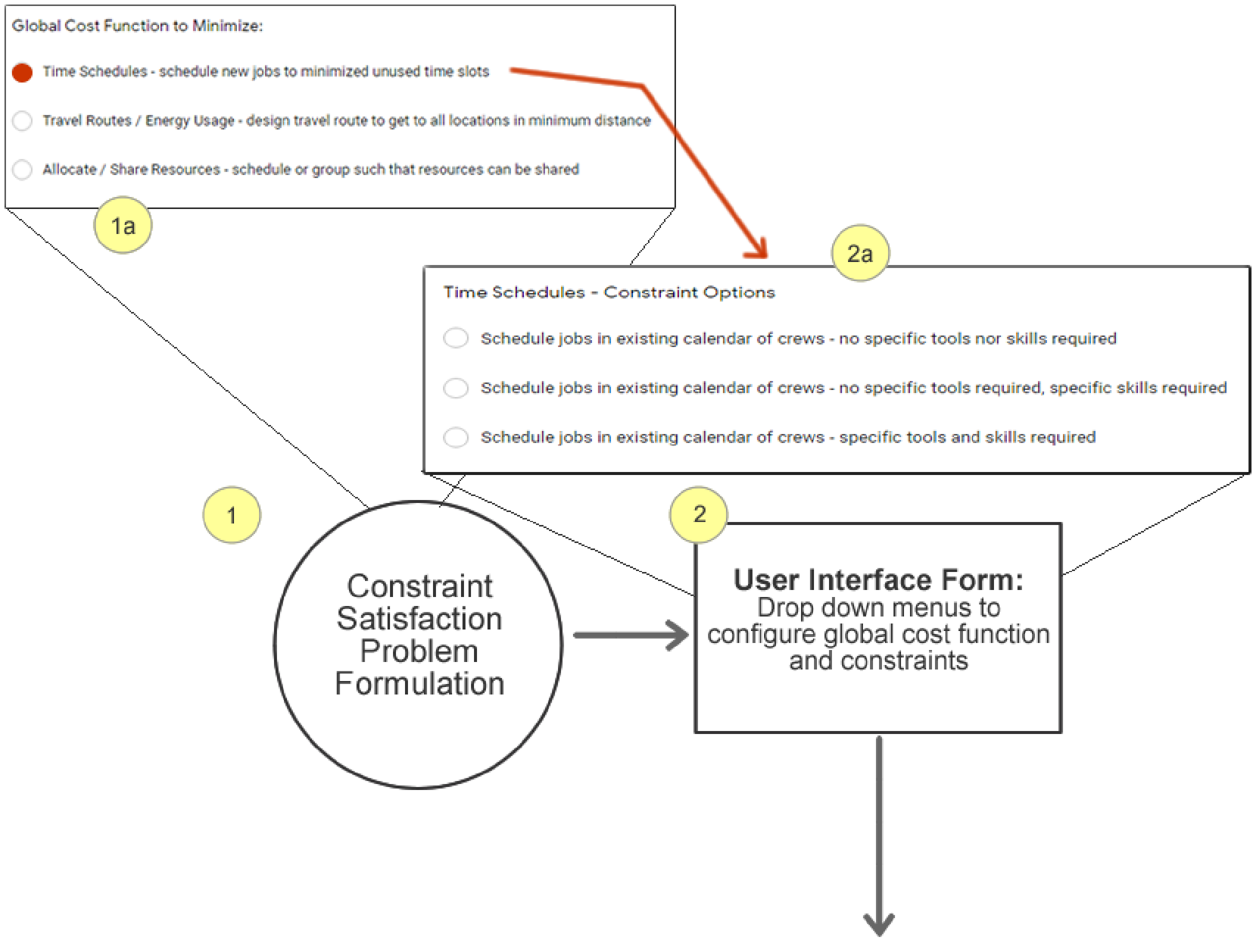


Figure 2. ADIN Interfaces

2a) Depending on the global cost function that is being minimized, various constraints are next specified that are particular to the cost function. For example, if jobs being best scheduled is the global cost function, additional constraint will further limit solutions, such as, when scheduling a certain type of job, requires a person certified with a particular skillset be on the assigned team. The next section goes into more detail.

3a) A Constrained Quadratic Model is created from the global cost function and constraints and is represented as a quadratic function. The variables form an ADIN Quantum Matrix and if the number of variables exceeds 5000, which is the current limit of DWave's quantum annealing computer, the Quantum Matrix will be decomposed using ADIN Quantum Agents. A UI allows users to experiment with different values before being submitted to DWave.

4a) UI tools to inspect partial results as they are returned from DWave to eliminate common 'black box' problems in AI. The user interface includes 'through-lines' that show how decomposed components contribute back into the final constraint satisfaction solution.

Echo Messaging Systems, Inc.
www.echomessaging.com
info@echomessaging.com
401-475-9642
December 7, 2021

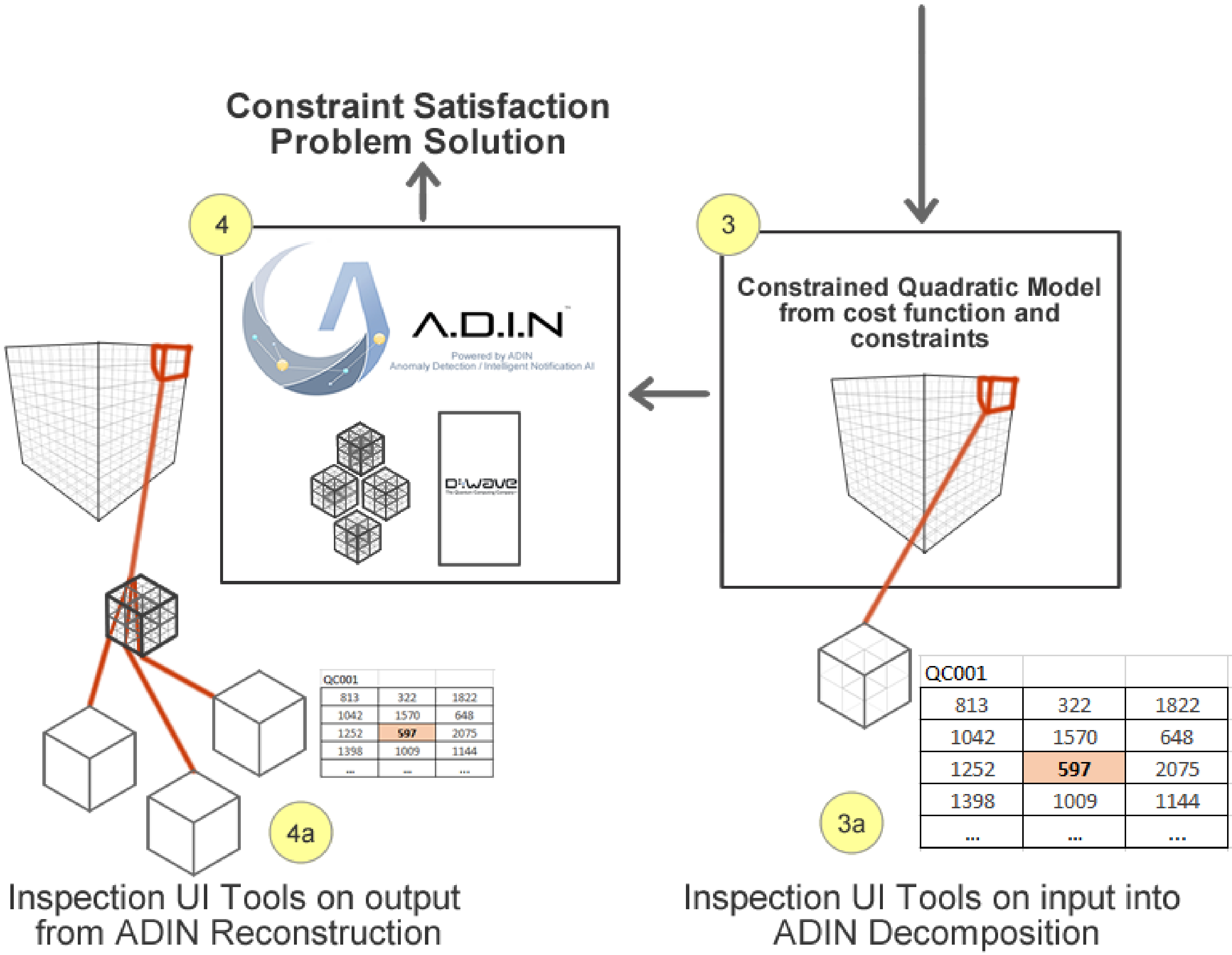


Figure 3. ADIN Interfaces

Constraint Satisfaction Problem Decomposition

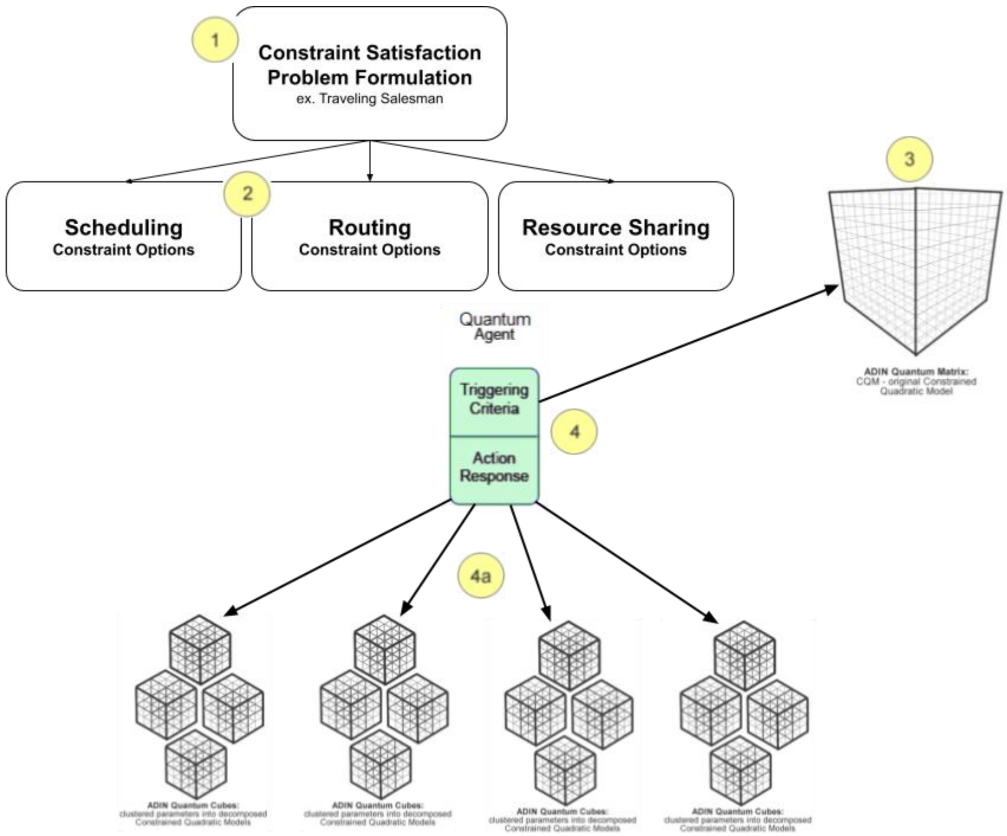


Figure 4. Decomposition

1) In the ADIN Quantum Interface, indicate the type of Constraint Satisfaction Problem you seek to solve, as Scheduling, Routing, or Resource Sharing. Select the Constraint Options based on the selection.
2) The ADIN Quantum Interface defines the global cost function that will be minimized by the DWave quantum computer using quantum annealing techniques to find minimum energy. The constraint options and global cost function form Constrained Quadratic Model (CQM) and the variables that define the equations. An ADIN Quantum Matrix is created from the CQM's variables. If the number of variables exceeds 5000, which is the current upper limit of DWave, the ADIN Quantum Matrix must be decomposed into ADIN Quantum Cubes until they are small enough to not exceed the DWave limit.
3) An ADIN Quantum Agent detects the new ADIN Quantum Matrix as its triggering criteria.
4) The ADIN Quantum Agent's action response is to automatically decompose the CQM along the constraint dimension, in order to keep the global cost function, the same for all decomposed components.

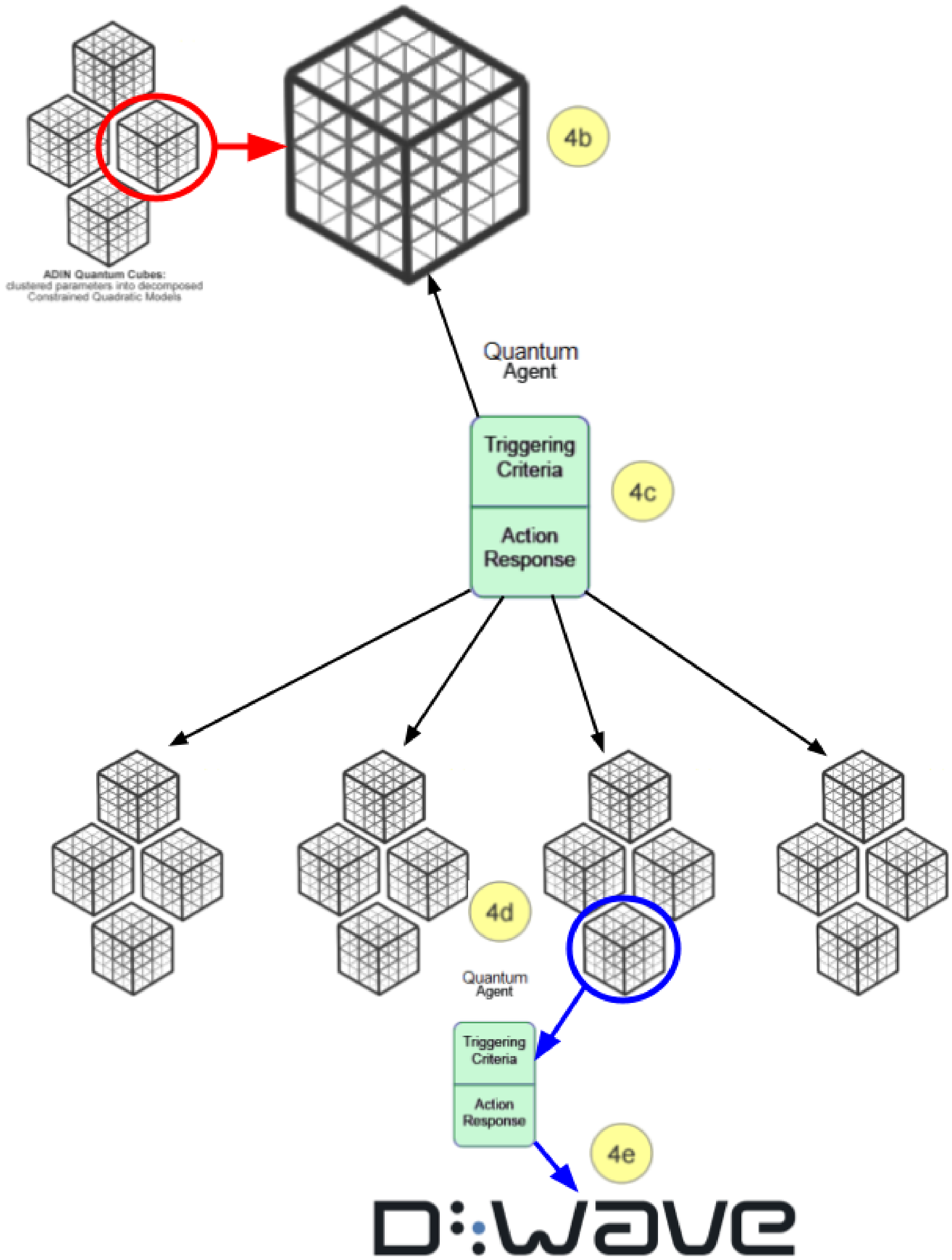


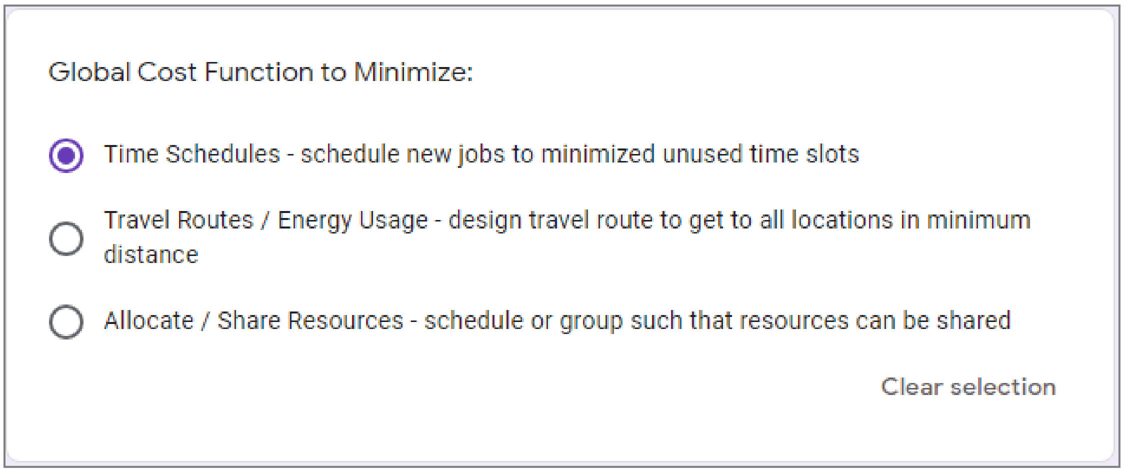
Figure 5. Decomposition and Embedding CQM in DWave quantum computer

4a) Each ADIN Quantum Cube created during the decomposition process becomes the triggering criteria for another set of ADIN Quantum Agents.
4b) The Action responses further decompose the CQM into smaller cubes until their number of variables are less than the DWave's size limit.

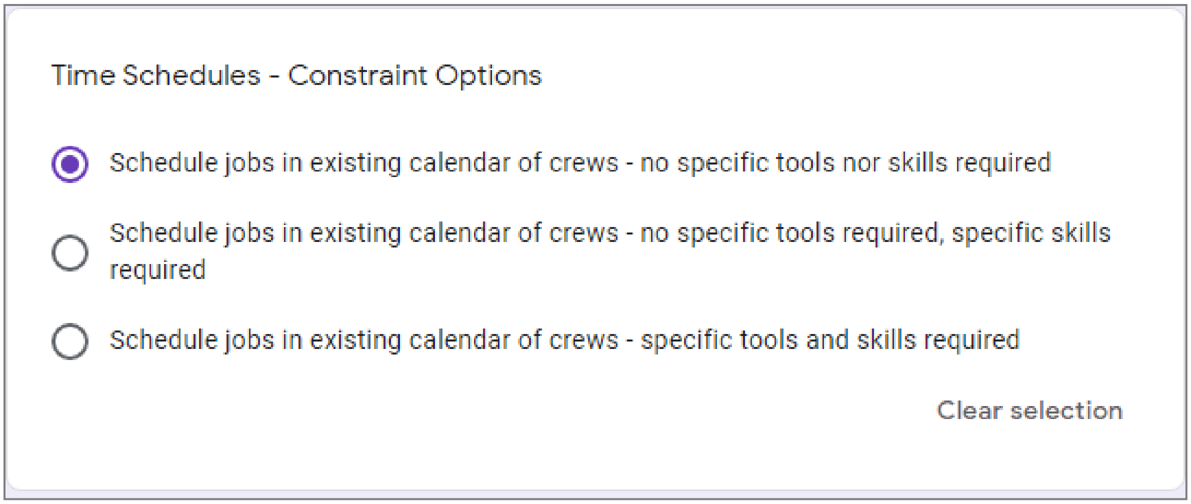
4c) An ADIN Quantum Agent's triggering criteria detects the smaller ADIN Quantum Cube that fits the DWave's size limits, and its action response submits the CQM to the DWave quantum annealing solver and gets the local minimum energy result. This process is performed until all Quantum Cube's CQM's are solved and a greedy sort selects the least energy among them.
4d) CQM is embedded in DWave hardware.
4e) DWave performs quantum annealing process on the embedded CQM.

Screen Samples

Step 1 - Global Cost Function to be minimized (or maximized):



Step 2a - Time Schedules to be Minimized:



Step 2b - Travel Routes to be Minimized:

Travel Routes - Constraint Options

- ◯ Develop route for truck and driver to deliver items to minimize overall distance
- ◉ Develop route for a crew, which is composed of people, tools and a truck riding together, to minimize overall distance
- ◯ Develop route for truck and driver to deliver items to minimize time lost due to real-time traffic information

Clear selection

Step 2c - Allocate / Share Resources to be Minimized:

Allocate / Share Resources - Constraint Options

- ◯ Schedule jobs requiring the same tool to minimize unused tool time slots
- ◯ Schedule jobs requiring two different tools where tool-1 is required before tool-2 to minimize unused time slots
- ◯ Distribute items into groups / containers by weight to evenly distribute weight and value
- ◉ Distribute items into groups / container by weight to maximize value without existing weight limits

Clear selection

Once the constraint is selected for the global cost function, datasets will be required for the specific modelling.

Quantum Agents

An ADIN Quantum Matrix is the starting ADIN Quantum Cube. ADIN agents configured to interact with quantum information are called Quantum Agents, and do the following:

- Quantum Agent Type 1:
  - Trigger: new Quantum Cube where # variables > limit
  - Action: decompose into Quantum Cubes based on the partitioned constraint dimension into evenly partitioned units, resulting in a set of new ADIN Quantum Cubes each with a unique ID and a link to its parent Quantum Cube.

- Quantum Agent Type 2:
  - Trigger: new Quantum Cube where # variables <= limit
  - Action: Define Constrained Quadratic Model based on global cost function, 1st constraint and partitioned 2nd constraint, connect to DWave, solve using Hybrid Solver, save result and associate it with its uniquely identified ID.

- Quantum Agent Type 3:
  - Trigger on new DWave Hybrid Solver result for a Quantum Cube, and answer is better than current answer (or is first answer) for the associated Quantum Cube parent
  - Action: Set this result at the best answer for the Quantum Cube Parent

There can be many Quantum Agents of the above types as this decomposition algorithm can run in parallel.

For every decomposition task from Quantum Agent Type 1, new Quantum Cubes are created, that in turn are detected by a Quantum Agent to further divide or submit to the DWave Hybrid Solver. Quantum Agents constantly monitor for either new Quantum Cubes or results from DWave.

As Quantum Agent Type 2 returns answers from the DWave Hybrid Solver and saves the answer, Quantum Agent Type 3 monitors for new results and selects it if the answer is better than the current (or is the first answer).

This forms a structured system that automatically decomposes the constraint satisfaction problem into smaller sub-problems, which are each solved by the DWave Hybrid solver. Best answers to sub-problems propagate up to parents where the best overall answer is returned to the ADIN Quantum Matrix.

Further Reading

Research Summary

Published Tech Papers:

- **https://echo.echoware.net/FullerDeaneIntelliSys2019.pdf**
- **https://echo.echoware.net/EchoFICC2018.pdf**
- **https://echo.echoware.net/FullerDeaneFTC2016.pdf**
- **https://echo.echoware.net/FullerDeaneSASO2015.pdf**
- **https://echo.echoware.net/FullerDeaneSasoMITposter_2015.pdf**

Articles, White Papers, Executive Summaries:

- **https://echo.echoware.net/EchoADIN_Cluster.pdf**
- **http://echo.echoware.net/ADIN_2_Turns_Containers_into_Intelligent_Agents.pdf**
- **http://echo.echoware.net/ADIN_2_Introduced_in_Singapore.pdf**
- **https://echo.echoware.net/EchoMessagingOnePager.pdf**
- **https://echo.echoware.net/EchoWareAgents.pdf**
- **https://echo.echoware.net/EchoWareIoTPlatform.pdf**
- **https://echo.echoware.net/EchoWarePushNotification.pdf**