qbsolv Documentation

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Contents

A decomposing solver that finds a minimum value of a large quadratic unconstrained binary optimization (QUBO) problem by splitting it into pieces. The pieces are solved using a classical solver running the tabu algorithm. qbsolv also enables configuring a D-Wave system as the solver.

Note: Access to a D-Wave system must be arranged separately.

CHAPTER 1

Example

```
from dwave_qbsolv import QBSolv
Q = {(0, 0): 1, (1, 1): 1, (0, 1): 1}
response = QBSolv().sample_qubo(Q)
print("samples=" + str(list(response.samples())))
print("energies=" + str(list(response.data_vectors['energy'])))
```

CHAPTER 2

Documentation

2.1 Introduction

Divide-and-conquer and dynamic programming algorithms have a rich history in computer science for problems with large numbers of variables. Many hard problems that can benefit from quantum computers are to large to map directly to a QPU. To solve a problem with more variables than the available number of qubits, we break the problem into subproblems, solve the subproblems, and then reconstruct an answer to the original problem from the subproblem solutions.

qbsolv is one such decomposing solver. It provides two interfaces:

- *Command Line Interface* (CLI)

  The tabu algorithm is executed on the problem which is divided into subproblems of several dozen variables each.

- *Python Interface*

  The Python interface provides a `QBSolv` class wrapper for the qbsolv C code. A *dimod* sampler can be substituted for the default tabu algorithm.

For a description of the algorithm and implementation, see `Partitioning Optimization Problems for Hybrid Classical/Quantum Execution`.

For a description of the tabu search algorithm, see Tabu search.

2.1.1 Example

This example sends 30-variable sub-problems of a 500-variable QUBO to the *dwave-neal* sampler to be incorporated into the tabu results run in the main loop of qbsolv.

```
>>> from dwave_qbsolv import QBSolv
>>> import neal
>>> import itertools
>>> import random
```

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```
...
>>> qubo_size = 500
>>> subqubo_size = 30
>>> Q = {t: random.uniform(-1, 1) for t in itertools.product(range(qubo_size),␣
↪repeat=2)}
>>> sampler = neal.SimulatedAnnealingSampler()
>>> response = QBSolv().sample_qubo(Q, solver=sampler, solver_limit=subqubo_size)
>>> print("energies=" + str(list(response.data_vectors['energy'])))    # doctest: +SKIP
energies=[-2800.794817495185]
```

2.2 Reference Documentation

2.2.1 Command Line Interface

Use the following command with its options to run qbsolv from a terminal.

```
qbsolv -i infile [-o outfile] [-m] [-T] [-n] [-S SubMatrix] [-w]
    [-h] [-a algorithm] [-v verbosityLevel] [-V] [-q] [-t seconds]
```

Description

qbsolv executes a quadratic unconstrained binary optimization (QUBO) problem represented in a file. It returns bit-vector results that minimizes—or optionally, maximizes—the value of the objective function represented by the QUBO. The problem is represented in QUBO(5) file format.

The QUBO input problem is not limited to the graph size or connectivity of a sampler, for example the D-Wave system.

Options are as follows:

```
-i infile
    Name of the file for the input QUBO. This option is mandatory.
-o outfile
    Optional output filename.
    Default is the standard output.
-a algorithm
    Optional selection for the outer loop algorithm.  Default is o.
    'o' for original qbsolv method. Submatrix based upon change in energy.
    'p' for path relinking.  Submatrix based upon differences of solutions
-m
    Optional selection of finding the maximum instead of the minimum.
-T target
    Optional argument target value of the objective function. Stops execution when␣
↪found.
-t timeout
    Optional timeout value. Stops execution when the elapsed CPU time equals or
    exceeds it. Timeout is only checked after completion of the main
    loop. Other halt values such as 'target' and 'repeats' halt before 'timeout'.
    Default value is 2592000.0.
-n repeats
    Optional number of times the main loop of the algorithm is repeated with
    no change in optimal value found before stopping.
    Default value is 50.
-S subproblemSize
```

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```
    Optional size of the sub-problems into which the QUBO is decomposed.
    If no "-S 0" or "-S" argument is present, uses the size specified in the
    embedding file found in the workspace set up by DW. If no DW environment is
    established, value defaults to 47 and uses the tabu solver on subproblems.
    If a value is specified, subproblems based on that size are solved with the
    tabu solver.
-w
    If present, the QUBO matrix and result are printed in .csv format.
-h
    If present, prints the help or usage message for qbsolv and exits without␣
↪execution.
-v verbosityLevel
    Optional setting of the verbosity of output. The default verbosityLevel of
    0 outputs the number of bits in the solution, the solution,
    and the energy of the solution.  A verbosityLevel of 1 outputs the same
    information for multiple solutions, if found. A verbosityLevel of 2
    also outputs more detailed information at each step of the algorithm. The
    information increases for verbosity levels of up to 4.
-V
    If present, prints the version number of the qbsolv program and exits without␣
↪execution.
-q
    If present, prints the format of the QUBO file.
-r seed
    Used to reset the seed for the random number generation.
```

2.2.2 Python Interface

Class

class QBSolv

Wraps the qbsolv C package for python.

Examples

This example uses the tabu search algorithm to solve a small Ising problem.

```
>>> h = {0: -1, 1: 1, 2: -1}
>>> J = {(0, 1): -1, (1, 2): -1}
>>> response = QBSolv().sample_ising(h, J)
>>> list(response.samples())
'[{0: 1, 1: 1, 2: 1}]'
>>> list(response.energies())
'[1.0]'
```

Methods

QBSolv.sample(bqm, **kwargs)	Sample low-energy states defined by a QUBO using qbsolv.

dwave_qbsolv.QBSolv.sample

QBSolv.**sample**(*bqm*, ***kwargs*)

Sample low-energy states defined by a QUBO using qbsolv.

Note: The qbsolv library being shared by all instances of this class is non-reentrant and not thread safe. The GIL should not be released by this method until that is resolved.

Note: The default build of this library doesn't have the dw library. To use solver='dw' this module must be built from source with that library.

The parameter *solver* given to this method has several valid forms:

- String 'tabu' (default): sub problems are called via an internal call to tabu.
- String 'dw': sub problems are given to the dw library.
- Instance of a dimod sampler. The *sample_qubo* method is invoked.
- Callable that has the signature (qubo: dict, current_best: dict) and returns a result list/dictionary with the new solution.

Parameters

- **Q** (*dict*) – A dictionary defining the QUBO. Should be of the form {(u, v): bias} where u, v are variables and bias is numeric.
- **num_repeats** (*int, optional*) – Determines the number of times to repeat the main loop in qbsolv after determining a better sample. Default 50.
- **seed** (*int, optional*) – Random seed. Default generated by random module.
- **algorithm** (*int, optional*) – Algorithm to use. Default is ENERGY_IMPACT. Algorithm numbers can be imported from the module under the names ENERGY_IMPACT and SOLUTION_DIVERSITY.
- **verbosity** (*int, optional*) – Prints more detail about qbsolv's internal process as this number increases.
- **timeout** (*float, optional*) – Number of seconds before routine halts. Default is 2592000.
- **solver** – Sampling method for qbsolv to use; see method description.
- **solver_limit** (*int, optional*) – Maximum number of variables in a sub problem.
- **target** (*float, optional*) – If given, qbsolv halts when a state with this energy value or better is discoverd. Default is None.
- **find_max** (*bool, optional*) – Switches from searching for minimization to maximization. Default is False (minimization).

Returns Response

Examples

This example uses the tabu search algorithm to solve a small QUBO.

```
>>> Q = {(0, 0): 1, (1, 1): 1, (0, 1): 1}
>>> response = QBSolv().sample_qubo(Q)
>>> list(response.samples())
'[{0: 0, 1: 0}]'
>>> list(response.energies())
'[0.0]'
```

2.2.3 qbsolv Input File Format

A .qubo file contains data that describes an unconstrained quadratic binary optimization problem. It is an ASCII file comprising four types of lines:

1. Comments defined by a "c" in column 1. Comments may appear anywhere in the file, and are ignored.
2. Program line defined by a "p" in the first column. A single program line must be the first non-comment line in the file. The program line has six required fields separated by space(s), as in this example:

```
p   qubo  topology   maxNodes   nNodes   nCouplers
```

   where:

```
p           Problem line sentinel.
qubo        File type identifier.
topology    String that identifies the topology of the problem and the␣
↪specific
            problem type. For an unconstrained problem, target is "0" or
            "unconstrained." In future implementations, valid strings
            might include "chimera128" or "chimera512" (among others).
maxNodes    Number of nodes in the topology.
nNodes      Number of nodes in the problem (nNodes <= maxNodes).
            Each node has a unique number and must take a value in the␣
↪range
            {0 - (maxNodes-1)}. A duplicate node number is an error. Node
            numbers need not be in order, and need not be contiguous.
nCouplers   Number of couplers in the problem. Each coupler is a unique␣
↪connection
            between two different nodes. The maximum number of couplers is␣
↪(nNodes)^2.
            A duplicate coupler is an error.
```

3. nNodes clauses. Each clause is made up of three numbers, separated by one or more blanks. The first two numbers must be integers and are the number for this node (repeated). The node number must be in range {0 , (maxNodes-1)}. The third value is the weight associated with the node. Weight may be an integer or float, and can take on any positive or negative value, or be set to zero.
4. nCouplers clauses. Each clause is made up of three numbers, separated by one or more blanks. The first two numbers, (i and j), are the node numbers for this coupler and must be different integers, where (i < j).Each number must be one of the nNodes valid node numbers (and thus in range {0, (maxNodes-1)}). The third value is the strength associated with the coupler. Strength may be an integer or float, and can take on any positive or negative value, but not zero. Every node must connect with at least one other node (thus must have at least one coupler connected to it).

Here is a simple QUBO file example for an unconstrained QUBO with 4 nodes and 6 couplers. This example is provided to illustrate the elements of a QUBO benchmark file, not to represent a real problem.

```
| <--- column 1
c
c  This is a sample .qubo file
c  with 4 nodes and 6 couplers
c
p  qubo  0  4  4  6
c ------------------
0  0   3.4
1  1   4.5
2  2   2.1
3  3   -2.4
c ------------------
0  1   2.2
0  2   3.4
1  2   4.5
0  3   -2
1  3   4.5678
2  3   -3.22
```

2.3 Installation

2.3.1 Python

A wheel might be available for your system on PyPI. Source distributions are provided as well.

```
pip install dwave-qbsolv
```

Alternatively, you can build the library with setuptools.

```
pip install -r python/requirements.txt
pip install cython==0.27
python setup.py install
```

2.3.2 C

To build the C library use cmake to generate a build command for your system. On Linux the commands would be something like this:

```
mkdir build; cd build
cmake ..
make
```

To build the command line interface turn the cmake option *QBSOLV_BUILD_CMD* on. The command line option for cmake to do this would be *-DQBSOLV_BUILD_CMD=ON*. To build the tests turn the cmake option *QBSOLV_BUILD_TESTS* on. The command line option for cmake to do this would be *-DQBSOLV_BUILD_TESTS=ON*.

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Version 2.0, January 2004

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2.5 Contributing to qbsolv

We, the qbsolv developers, expect a variety of contributions, from reporting of bugs or suggestions for examples or tutorials to development of improvements or alternatives to qbsolv's core algorithms. Here we describe how we plan to interact with contributors making such contributions, though that plan will of course change as those contributions occur.

2.5.1 Issues

Bugs or anomalies in the behavior of the tool, issues with its installation, requests for changes in documentation, design and development issues, and feature requests will be tracked via GitHub's Issues mechanism.

When reporting a bug, please provide the following info if appropriate:

- What are the steps to reproduce the bug? If possible, the simplest such set of steps is best.
- Does the bug still happen using the latest version?
- What qbsolv version and OS are you using?

2.5.2 Contributions

We believe that qbsolv will make the fastest progress to being a robust metaheuristic solver capable of quantum acceleration by being widely used both by end-users solving problems and by metaheuristic algorithm developers exploring new metaheuristic algorithms.

In general, you may want to think about starting your contributions gradually, using qbsolv and reporting any strengths and weaknesses (e.g., bugs, documentation improvements) you encounter. This will help you build relationships with the qbsolv developers. And don't forget that contributions can be other than just code or documentation; creating an example or a tutorial helps new users come up to speed and is often high value.

We expect to incorporate promising and proven algorithmic changes into the master code base. This wide use by algorithm developers requires a balance between accepting changes and maintaining a stable tool for end-users. Over time we expect to have processes for both building and regression testing (both correctness and performance) that we will expect new changes to pass before being considered for inclusion.

2.5.3 Submitting A Contribution

For now, we accept a contribution as a Pull Request (PR) on GitHub, though this may change. Please follow these steps:

- If your change is substantial, first create a feature request to start a discussion with the developers to ensure your intent aligns with qbsolv plans.

- A PR should have a clear purpose and do exactly one thing. This enables the rest of the process to be crisp.
- Each commit in PR should be an atomic change representing one step in development.
- As appropriate, please explain anything that is not obvious from the code; this could be in comments, commit messages, or the PR description.
- Sign your patch via the sign-off line, often created by git commit -s. Your sign-off certifies that you wrote the patch or otherwise have the right to pass it along as an open-source patch; see the full text of the certificate just below. Your sign-off line might look like Signed-off-by: Abby Smith <abby.smith@mail.com> Please use your real name, not a pseudonym. This project does not accept anonymous contributions.

2.5.4 License

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2.6 Indices and tables

- genindex
- modindex
- search
- Glossary

Python Module Index

d

Index