

# OpenJij

An open-source project  
towards a unified annealing platform.

Jij Inc.

Yu Yamashiro,  
Kohji Nishimura

[j-ij.com](http://j-ij.com)

**Jij**



# Outline

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- About Jij Inc.
  - The process of developing "An application of annealing method"
  - New QA algorithms, other annealing devices.
  - Why we need unified annealing platform (OpenJij)
  - About OpenJij project
- Technical details of OpenJij

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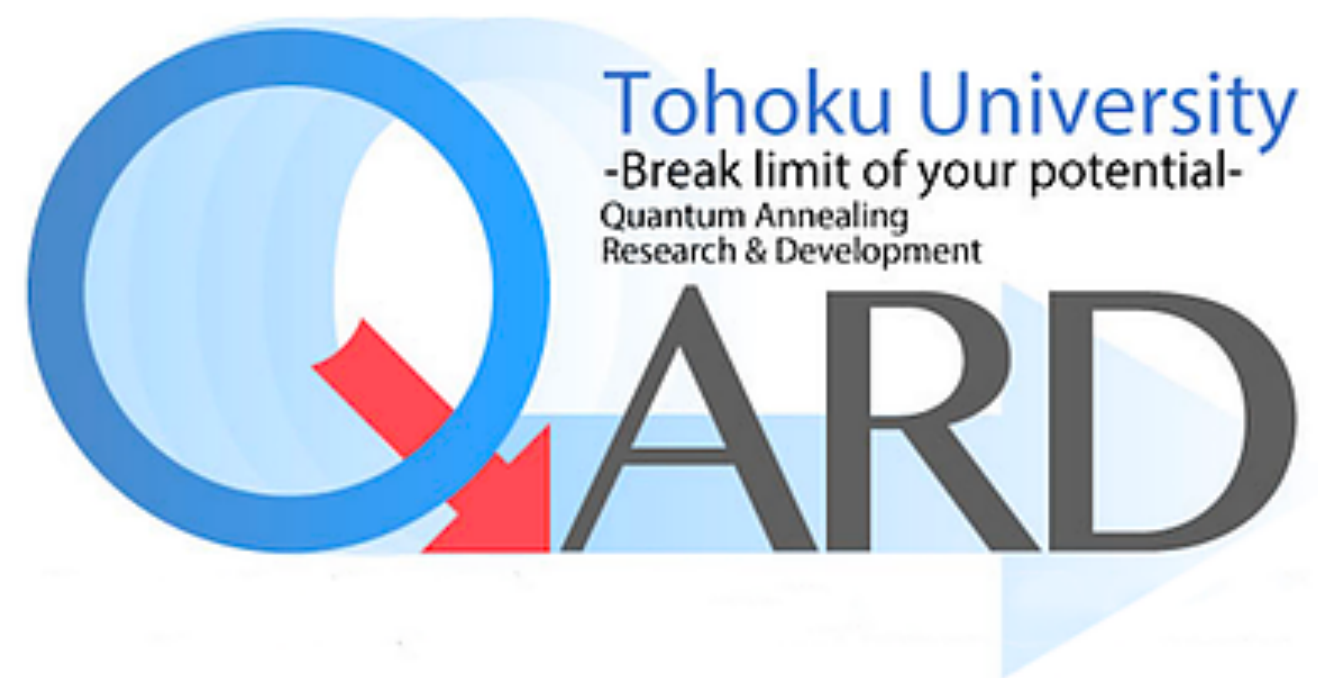


$$H = \sum_{i < j} J_{ij} \sigma_i \sigma_j + \sum_i h_i \sigma_i \quad \text{- Ising model -}$$



# Jij Inc.

We established with the support of  
“JST(Japan Science and Technology Agency)-START Ohzeki-project”

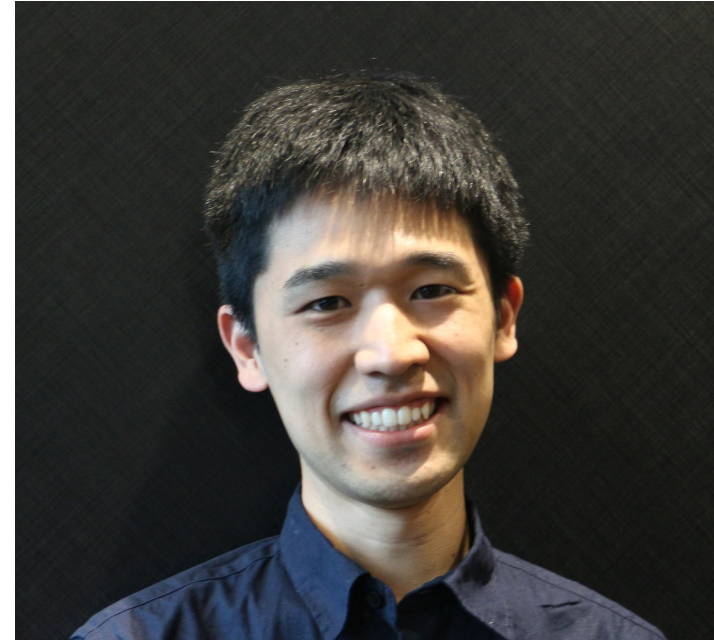


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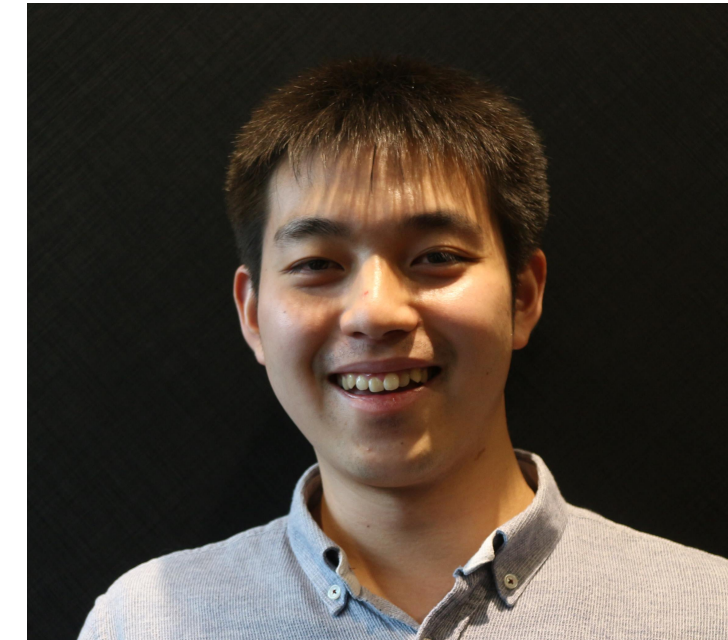


# Member

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**CEO : Yu Yamashiro**  
Tokyo Tech, Nishimori Lab.



**CTO : Kohji Nishimura**  
Tokyo Tech, Nishimori Lab.



**Advisor : Masayuki Ohzeki**  
Tohoku Univ, Tokyo Tech



**Advisor : Masamichi Miyama**  
Tohoku Univ

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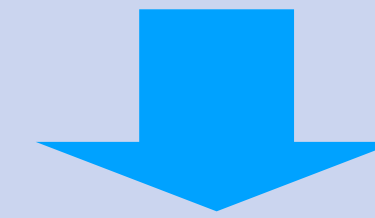


# Development using annealing devices

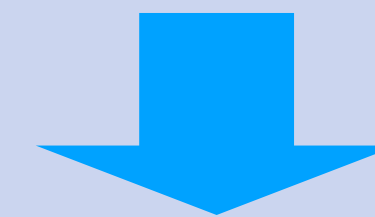
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We support the process from finding issues and QUBO formulation to an analysis of results.

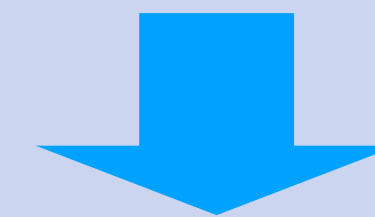
Optimization problem on businesses issues



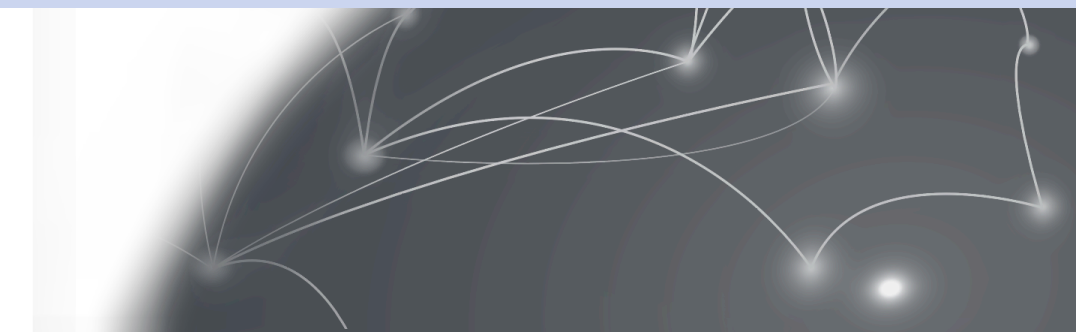
Formulation QUBO (or the Ising model)



Simulation and Experiment for benchmark  
(Conventional computer, D-Wave device, etc)



Analysis for future applications



# Quantum annealing

## Quantum annealing

A new algorithm for solving optimization problems using the dynamics of quantum mechanics.

$$\hat{H}(t) = A(t) \left( \sum_{i < j} \hat{\sigma}_i^z \hat{\sigma}_j^z + \sum_i \hat{\sigma}_i^z \right) + B(t) \sum_i \hat{\sigma}_i^x$$

D-Wave 2000Q

Quantum annealing processor

Methods

- Quantum annealing (optimization)
- Sampling (Machine learning, Quantum simulation)



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# Quantum annealing

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## Extended QA algorithms

- **Non-stoquastic Hamiltonian** [1,2,3]

For more quantum effects and universal computation

- **Inhomogeneous driving (anneal offsets)** [4,5]

Individually control transverse field per spin

- **Reverse quantum annealing** [6,7,8]

A new quantum algorithm

[1] Jacob D. Biamonte and Peter J. Love Phys. Rev. A **78**, 012352 (2008)

[2] Y. Seki and H. Nishimori. Phys. Rev. E, **85**, 051112 (2012).

[3] L. Hormozi, E. W. Brown, G. Carleo, and M. Troyer. Phys. Rev. B **95**, 184416 (2017)

[4] M. M. Rams, M. Mohseni, and A. del Campo, New J. Phys. **18**, 123034 (2016).

[5] Y. Susa, Y. Yamashiro, M. Yamamoto, I. Hen, D. A. Lidar, and H. Nishimori, Phys. Rev. A **98**, 042326 (2018).

[6] M. Ohkuwa, H. Nishimori, and D. A. Lidar. Phys Rev A **98**, 022314 (2018).

[7] D. Venturelli and A. Kondratyev. arXiv: 1810.08584 (2018).

[8] A. D. King. *et al.*, Nature **560**, 456-460 (2018).





# Annealing devices

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## Quantum devices

D-Wave : D-Wave 2000Q (QA)

## Classical devices

Fujitsu : Digital annealer (SA)

Hitachi : CMOS annealing machine (SA, SQA)

## Conventional computer

CPU, GPU (SA, SQA, Other algorithms)

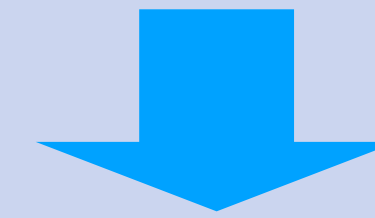


# Development using annealing devices

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We need benchmarks for various algorithms and hardware in simulations and experiments.

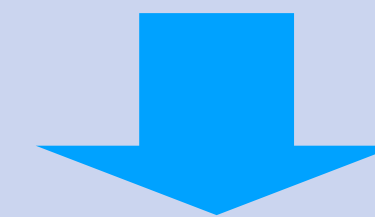
Optimization problem on businesses issues



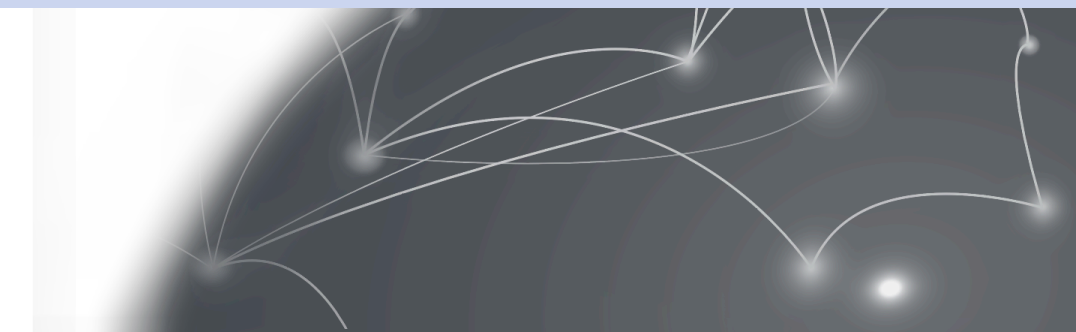
Formulation QUBO (or the Ising model)



**Simulation and Experiment for benchmark  
(Conventional computer, D-Wave device, etc)**



Analysis for future applications



# OpenJij

An open-source project  
towards a unified annealing platform.

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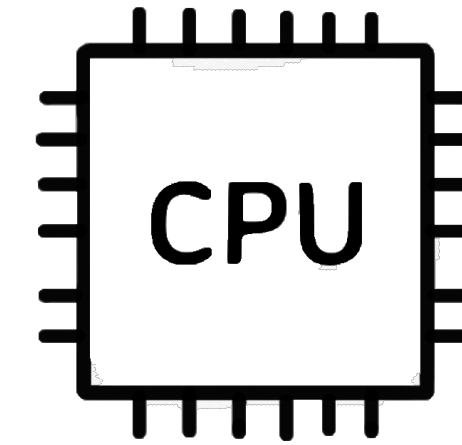


# What is OpenJij ?

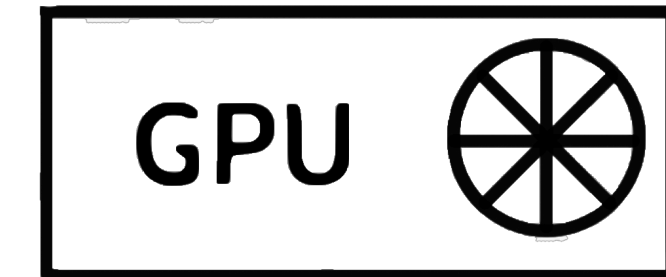
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SA, SQA, others



SA, SQA, others



QA, Inhomogeneous, RQA

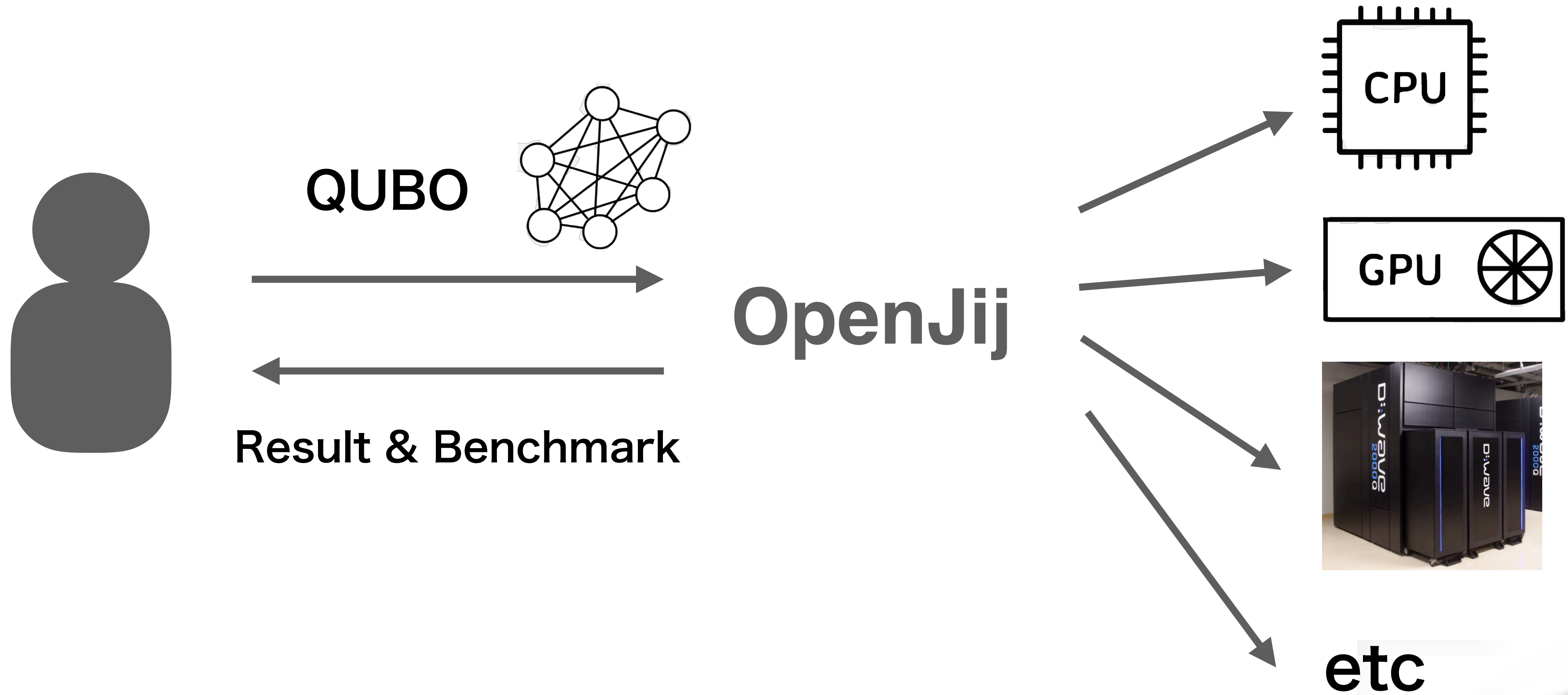


Other devices

**etc**



# What is OpenJij ?



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# OpenJij

Lead engineer : K. Nishimura

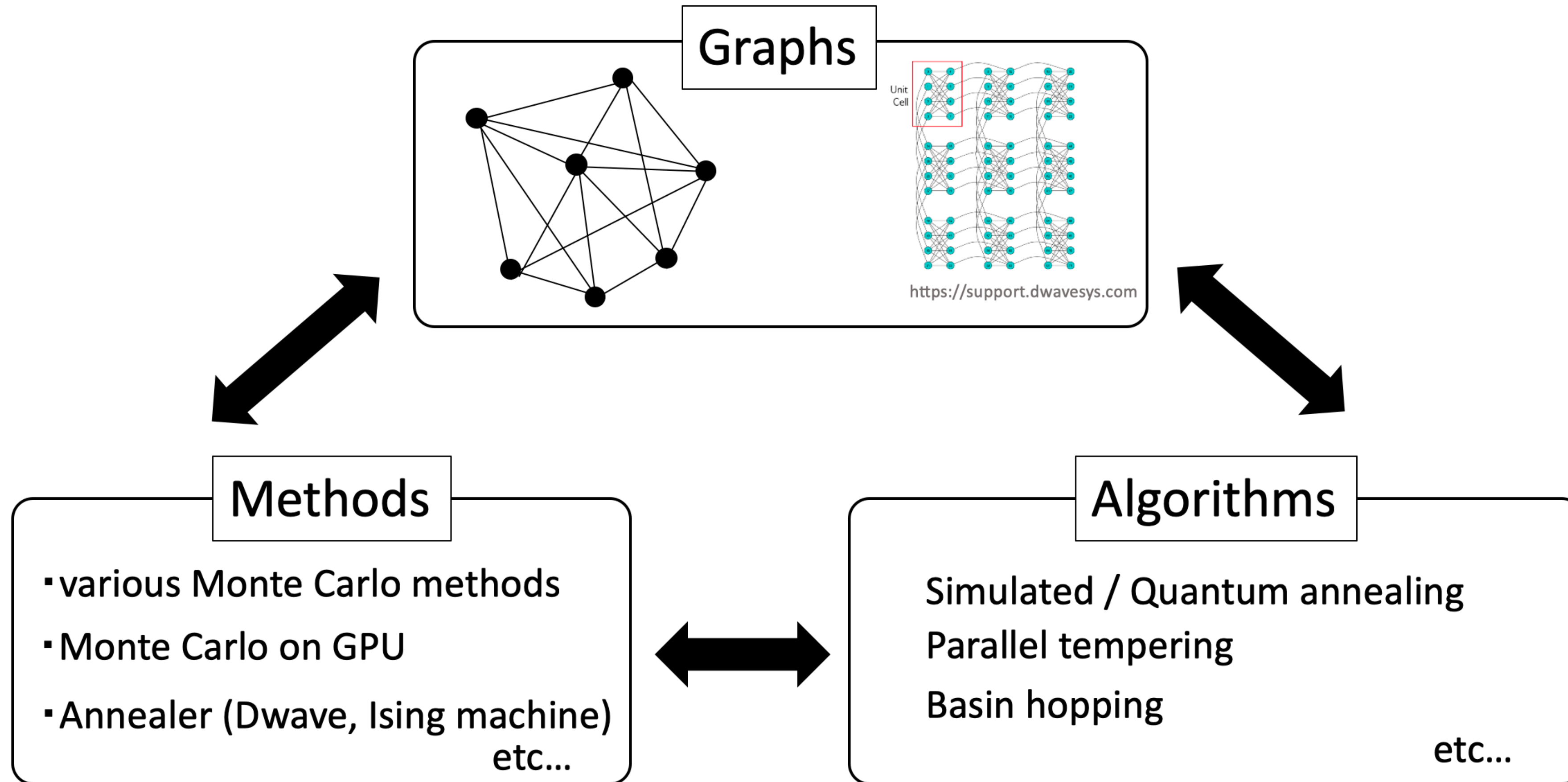
OpenJij / OpenJij

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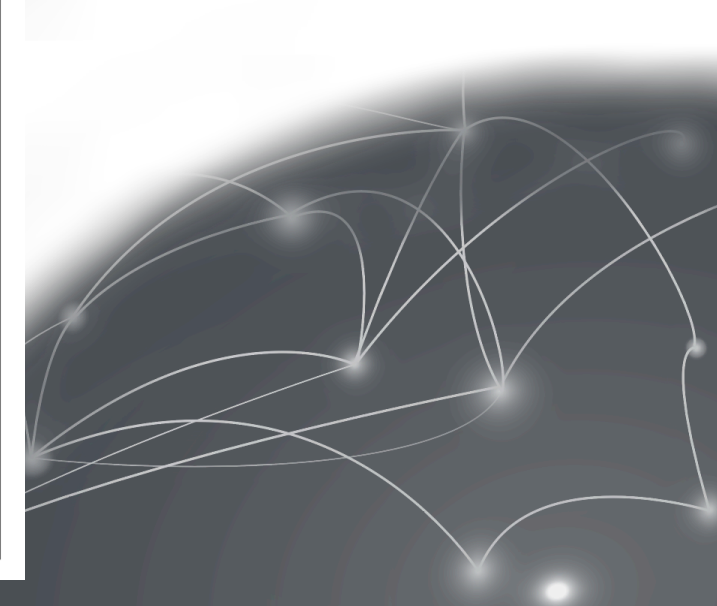
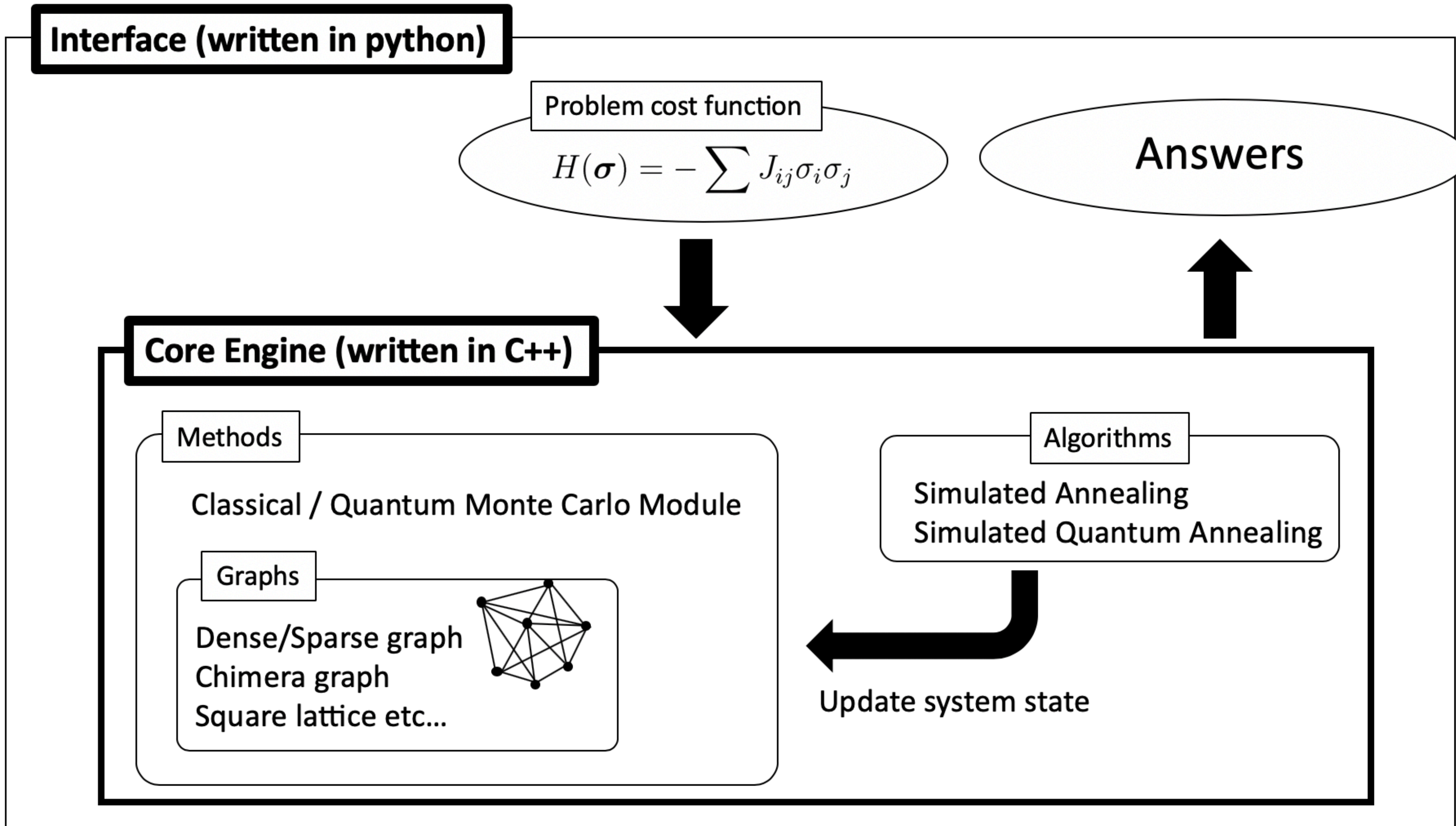
OpenJij : Framework for the Ising model and QUBO. <https://openjij.github.io/OpenJij/> Edit

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# OpenJij

## Structure



# OpenJij

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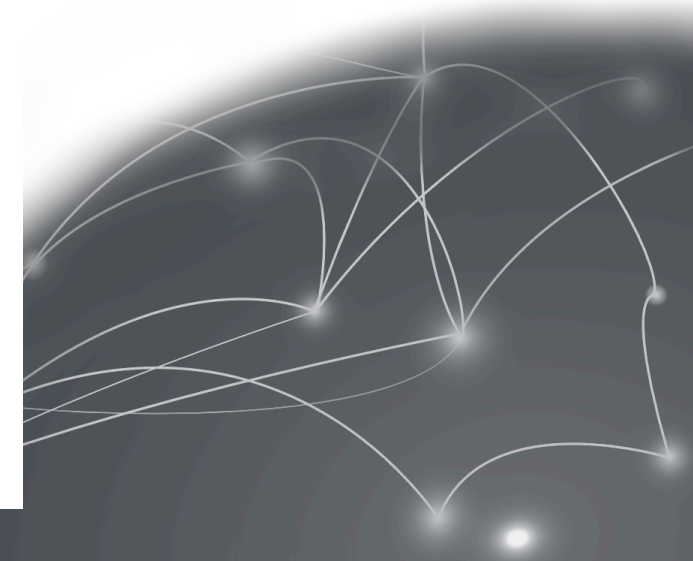
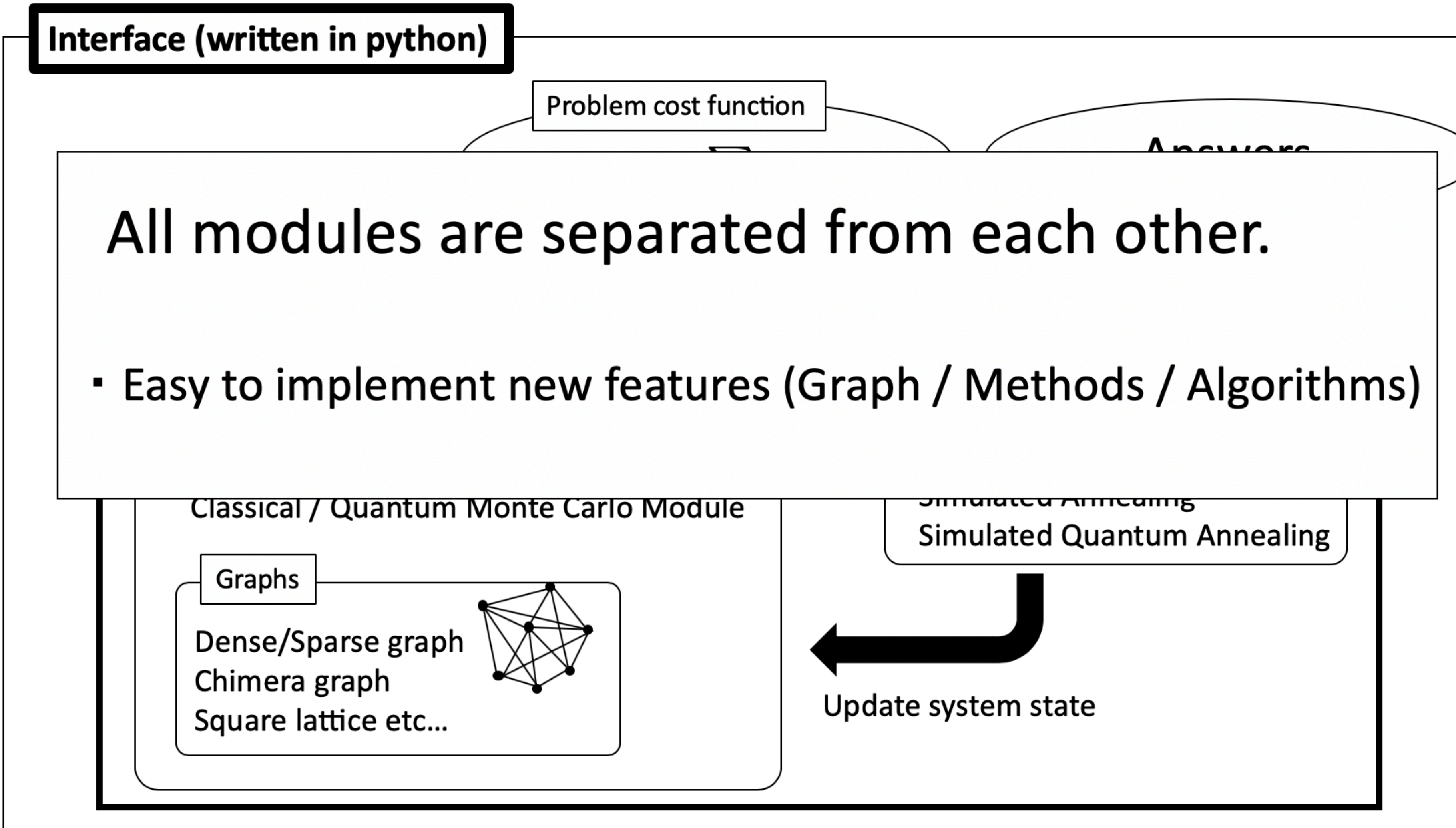
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- Structure



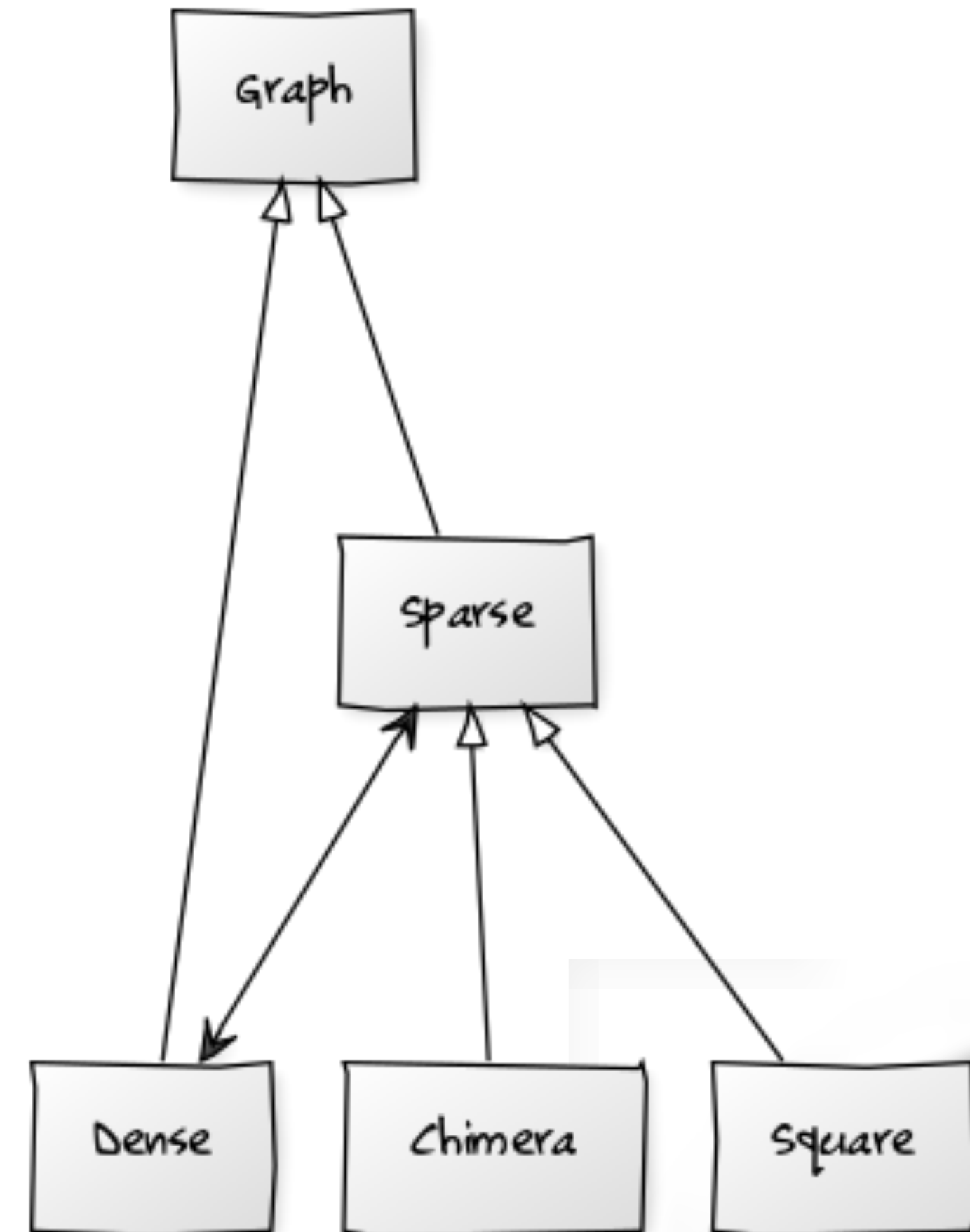


# OpenJij

## Graph

General connectivity (Dense/ Sparse)  
Chimera, square lattice

Pegasus graph



# OpenJij

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## Method

### Classical / Quantum Monte Carlo module

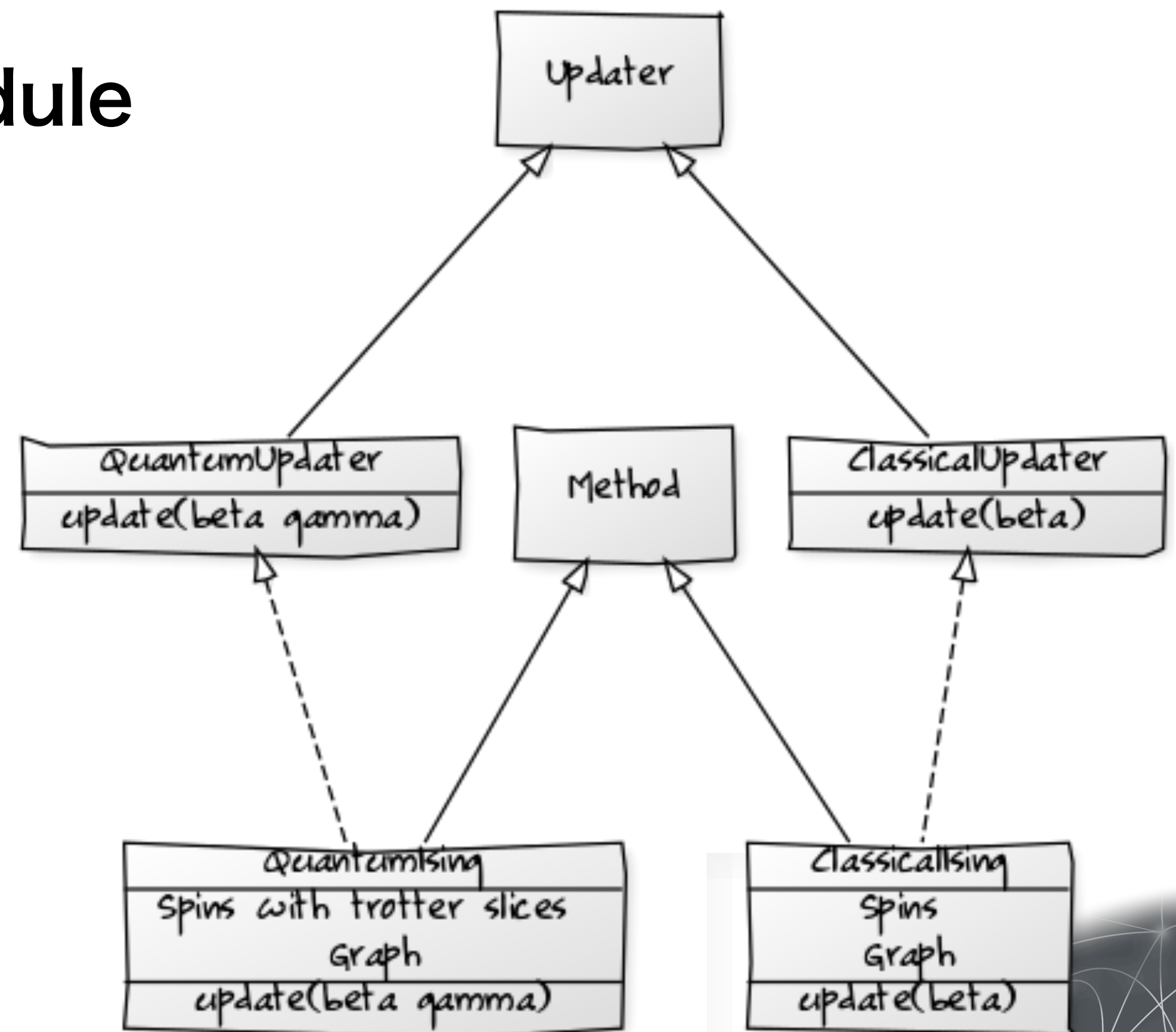
Monte Carlo on CPU (General QUBO)

Monte Carlo on GPU (Chimera graph)

General QUBO will be update soon!

more quantum monte carlo algorithm

(continuous time QMC, SSE, etc ...)



# OpenJij

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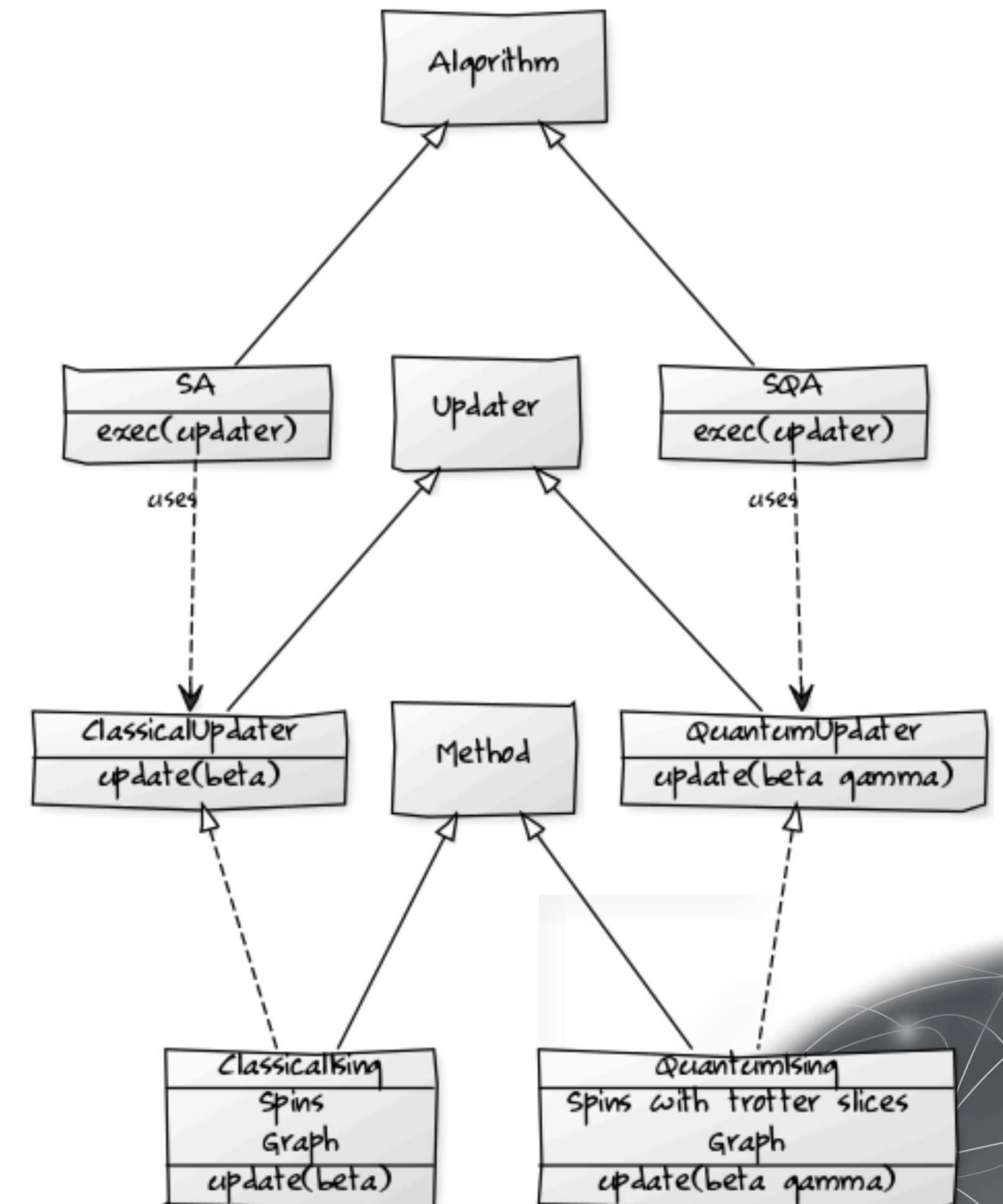
## Algorithms

Simulated annealing

Simulated quantum annealing

New QA algorithms

- Reverse quantum annealing (RQA)
- Inhomogeneous driving (anneal offset)



# OpenJij

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Edit

cmake

optimization

benchmarking

quantum-computing

quantum-mechanics

quantum-annealing

simulated-annealing

Manage topics

## Sample code

```
1 import cxxjij.graph as G
2 import cxxjij.method as M
3
4 ising = G.Dense(10)
5 for i in range(10):
6     for j in range(10):
7         ising[i,j] = -1 if i is not j else 0 # ferromagnetic interaction
8
9 sa = M.ClassicalIsing(ising)
10 sa.simulated_annealing(0.01, 10, 100, 10)
11
```

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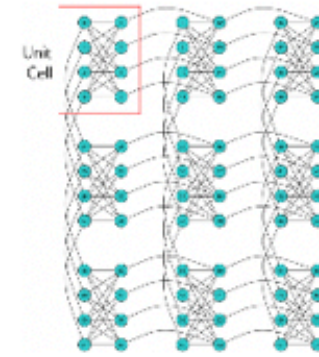
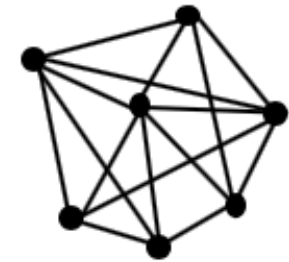
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## Future Structure

### Interface (written in python)

- Embedding
- New methods



- easier interfaces
- Benchmarking (TTS, Constraints)

### Core Engine (written in C++)

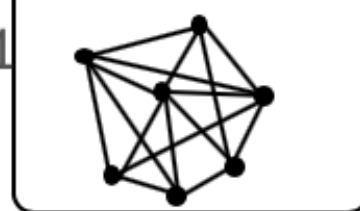
#### Methods

Classical / Quantum Monte Carlo Module  
Monte Carlo on GPU (will be updated soon!)  
Sophisticated Quantum MC algorithm  
(continuous time, SSE, etc...)

state-of-the-arts algorithm  
(isoenergetic cluster moves)

Phys. Rev. Lett. **115**, 077201

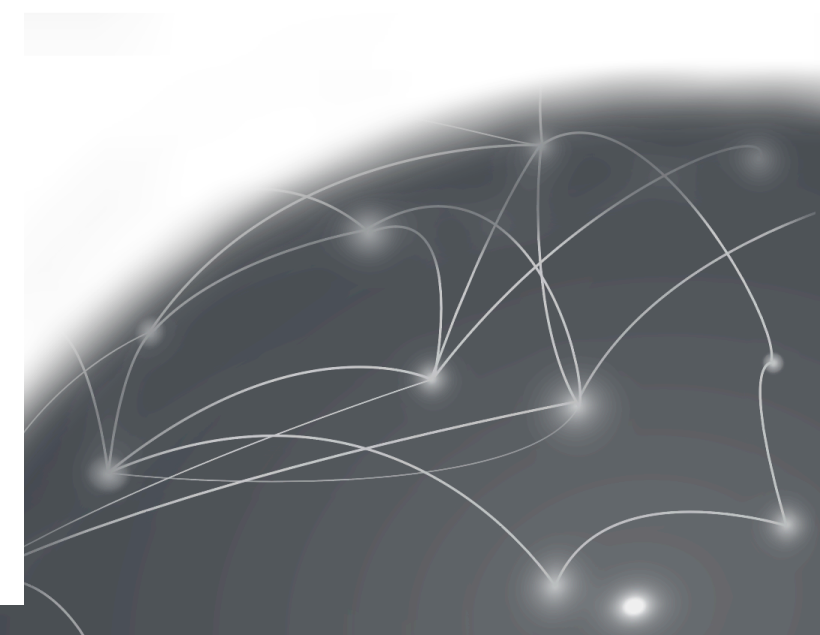
#### Graphs



#### Algorithms

Simulated Annealing  
Simulated Quantum Annealing  
Inhomogeneous, RQA  
Basin hopping  
Optimized schedule

Update system state



# Summary

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OpenJij : An open-source project towards a unified annealing platform.

- You can install “pip install OpenJij”
- Support CPU (SA, SQA), GPU (Chimera graph, SQA)
- Future
  - D-Wave device
  - GPU (General QUBO)
  - New QA algorithms (RQA, Inhomogeneous driving)
  - Other annealing machines

We welcome contributions to OpenJij projects.

<https://github.com/OpenJij/OpenJij>

**Jij**



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We welcome contributions to OpenJij projects.  
<https://github.com/OpenJij/OpenJij>

Jij supports your annealing application development, experiments, and benchmarks.

Contact: [info@j-ij.com](mailto:info@j-ij.com)

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