TAQOS: A Benchmark Protocol for Quantum Optimization Systems

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Context and Approach

Context

Existing types of quantum benchmarks:

- Descriptive benchmark
- Competitive benchmark

Benchmark indicators:	Strict Quantum advantage:
• Solution quality: q	$q_q^* \geq q_c^*$
• Budget: e	$e_q^* \leq e_c^*$
• Wall clock time: t	$t_q^* \leq t_c^*$

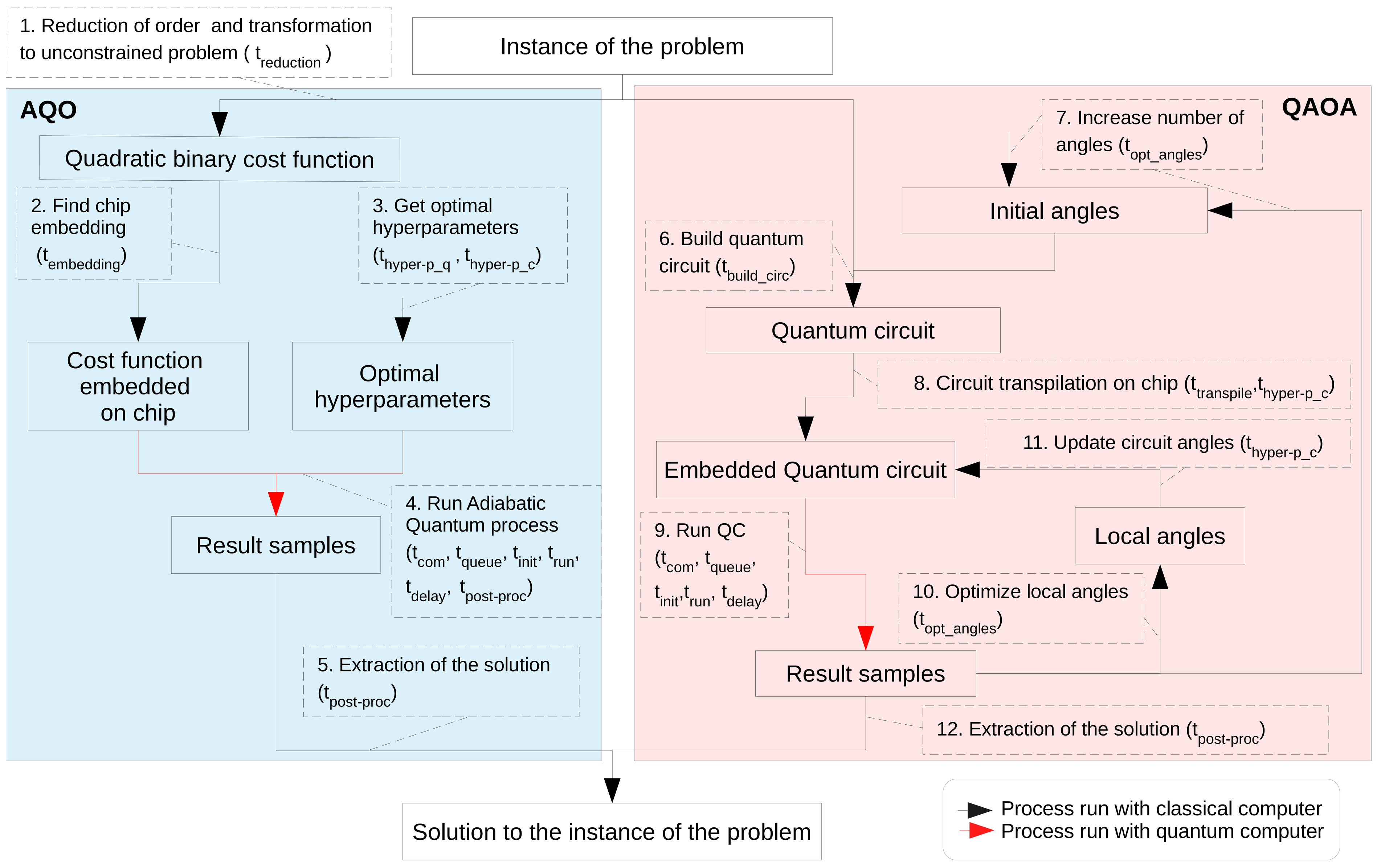
How to evaluate the robustness of our benchmark instances ?

Related work

Protocol	Competitive	Descriptive	Efficient	Agnostic	Quantities
Quantum Volume [1]	×				quality
CLOPS [2]	×				quality & speed
Cross-Entropy [3]	×	×			quality
Qbas [4]	×		×		quality
Q-Score [5]	×		×	×	quality
MNR [6]	×		×	×	energy

Some existing benchmark frameworks:
QED-C[7], QASMBench [8]

Quantum Computer Models Workflows



Quality metric

Ratio of the reference cost (inspired from [9]):

$$r_{\text{ref}}(c^*, c_{\text{ref}}) \begin{cases} < 0 \text{ if the solution of cost } c^* \text{ is \textbf{better} than solution of cost } c_{\text{ref}} \\ > 0 \text{ if the solution of cost } c^* \text{ is \textbf{worse} than solution of cost } c_{\text{ref}} \end{cases}$$

Number of instances which solutions is within ϵ_1 of the cost c_{ref}. $\epsilon_1 \in \{0, 0.01, 0.05, 0.1\}$:

$$r_{\epsilon_1}(\mathcal{I}) = \frac{|\{I_i \in \mathcal{I} \text{ with } r_{\text{ref}}(c^*, c_{\text{ref}}) < \epsilon_1\}|}{|\mathcal{I}|}$$

Coverage metric

Evaluation of the coverage of an instance set, following the work of Dunning I. et al. [10]. Coverage metrics are problem-dependent.

c_{ϵ_2} : coverage of a metric f of an instance I_i

ϵ_2 : coverage factor in [0, 1] ($\epsilon_2 = 0.05$ in our experiments)

Coverage of a single instance:

$$c_{\epsilon_2}(f, I_i) = [f(I_i) - \epsilon_2, f(I_i) + \epsilon_2] \cap [0, 1]$$

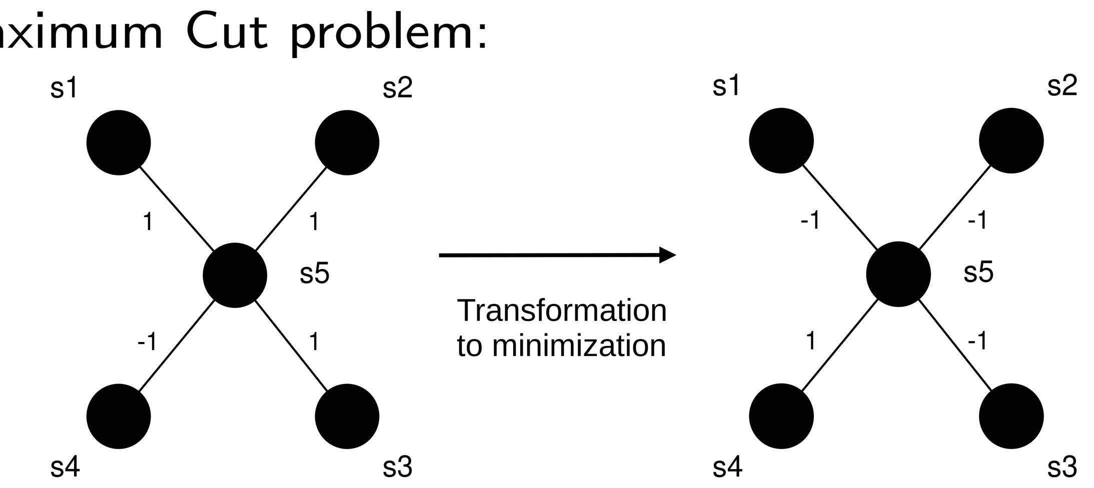
Coverage of a single metric on a set of instances:

$$C_{\epsilon_2}(f, \mathcal{I}) = \bigcup_{I_i \in \mathcal{I}} c_{\epsilon_2}(f, I_i)$$

Experiment and Results

Problem and Instances

The Maximum Cut problem:

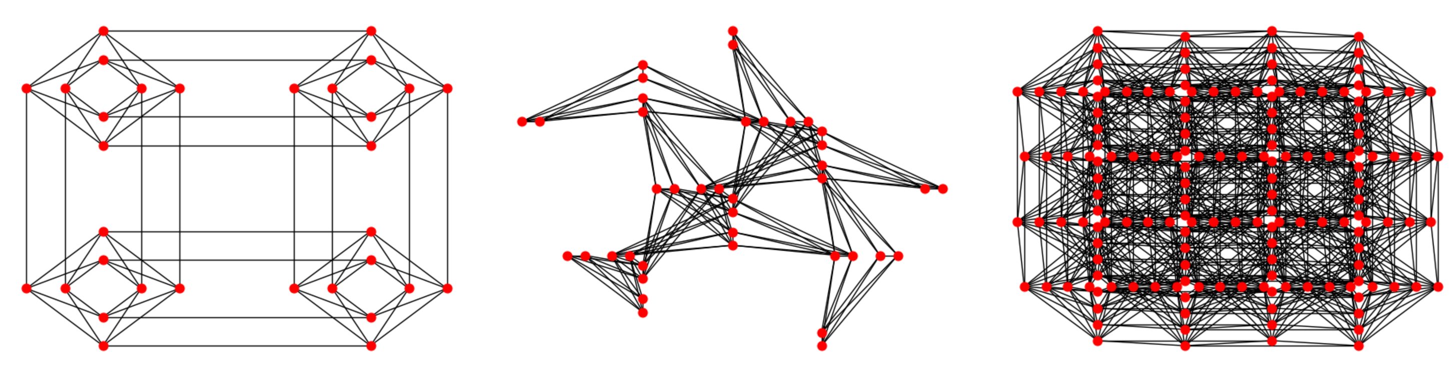


$$s_i \in \{-1, +1\}$$

Objective cost function:

$$\text{Minimize } -(-s_1 s_5 - s_2 s_5 - s_3 s_5 + s_4 s_5)$$

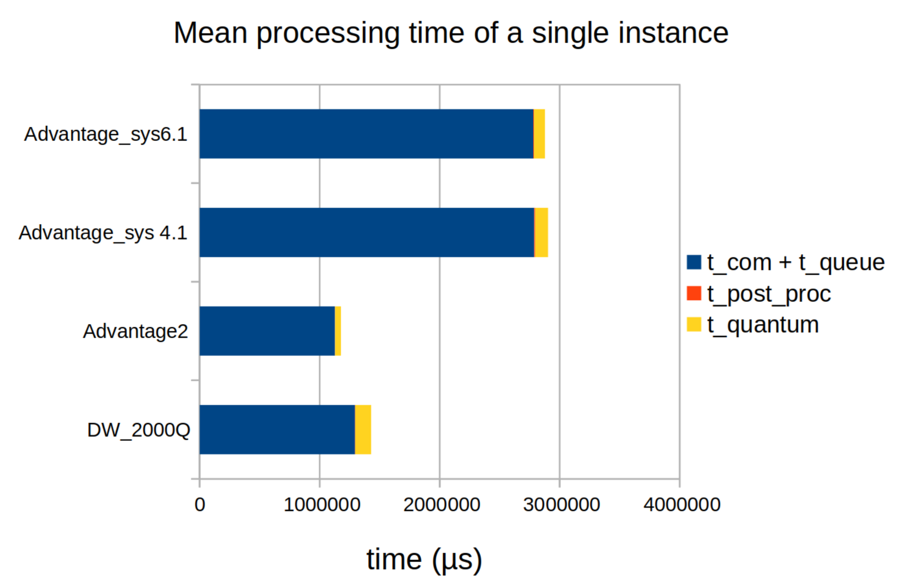
Instances structure:

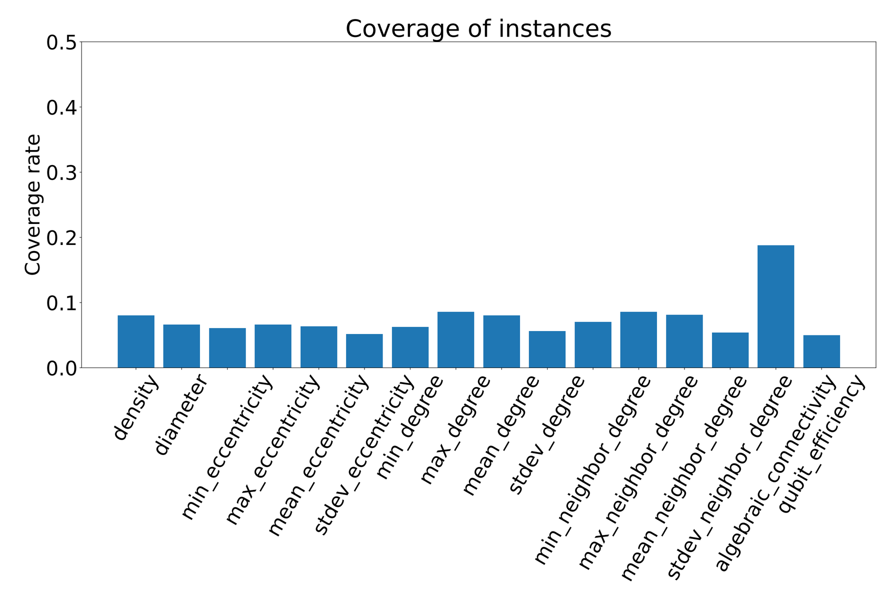


Chimera Pegasus Zephyr

Results

Quantum solvers	Wall clock time (s)	Chimera graph DW_2000Q $\lvert\mathcal{V}\rvert : 2041$ $\lvert\mathcal{E}\rvert : 5974$				Pegasus graph Adv4.1 $\lvert\mathcal{V}\rvert : 5621$ $\lvert\mathcal{E}\rvert : 40279$				Pegasus graph Adv6.1 $\lvert\mathcal{V}\rvert : 5616$ $\lvert\mathcal{E}\rvert : 40135$				Zephyr graph Adv2 $\lvert\mathcal{V}\rvert : 563$ $\lvert\mathcal{E}\rvert : 4790$			
DW2000Q	1.43	c_{ref}				/				/				/			
Adv4.1	2.90	/				c_{ref}				/				/			
Adv6.1	2.88	/				/				c_{ref}				/			
Adv2	1.18	/				/				/				c_{ref}			
Classical		r_0	$r_{0.01}$	$r_{0.05}$	$r_{0.1}$	r_0	$r_{0.01}$	$r_{0.05}$	$r_{0.1}$	r_0	$r_{0.01}$	$r_{0.05}$	$r_{0.1}$	r_0	$r_{0.01}$	$r_{0.05}$	$r_{0.1}$
Random	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.03
DUARTE 2005	1	0	0	0.97	1	0	0	0.9	1	0	0	0.7	1	0.1	0.3	1	1
	10	0	0	1	1	0	0	1	1	0	0	1	1	0.23	0.47	1	1
	100	0	0	1	1	0	0	1	1	0	0	1	1	0.4	0.6	1	1
FESTA 2002 GPR	1	0	0	0	1	0	0	0	0.37	0	0	0	0.53	0	0.17	0.93	1
	10	0	0	0.9	1	0	0	0	1	0	0	0	0.9	0.3	0.5	1	1
	100	0	0	1	1	0	0	0	1	0	0	0	1	0.3	0.53	1	1
FESTA 2002 GVNS	1	0	0	0	1	0	0	0.03	1	0	0	0	1	0	0.07	0.97	1
	10	0	0	0	1	0	0	0.03	1	0	0	0.07	1	0.1	0.3	1	1
	100	0	0	0	1	0	0	0.33	1	0	0	0.23	1	0.17	0.5	1	1
FESTA 2002 GVNSPR	1	0	0	0.03	1	0	0	0.03	1	0	0	0	1	0.07	0.27	1	1
	10	0	0	1	1	0	0	0.17	1	0	0	0.2	1	0.3	0.6	1	1
	100	0	0	1	1	0	0	0.5	1	0	0	0.37	1	0.4	0.67	1	1





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