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CML

Fraunhofer Center for Maritime Logistics and Services CML

Quantum Computing in maritime shipping

Oliver Szal
7 February 2025

Agenda

The Fraunhofer Society and the Fraunhofer CML

Applied research for business and society

Fraunhofer Society

30.000
employees

76 institutes
und research facilities

3 bn. €
Financial volume
(30% industry research)

Fraunhofer CML, Hamburg

2010
foundation in Hamburg

Focus
on maritime industry und research

TUHH
Cooperation with the institute for maritime logistics

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Fraunhofer CML: Innovating the Maritime Sector

Forschungsbereiche

Ports and Transport Markets

Analysis and optimization of nodes in the maritime supply chain

Sea Traffic and Nautical Solutions

Technologies for autonomous systems and nautical assistance systems

Port Technologies

Mobile robotics and AI for new applications in port operations

Ship and Information Management

Software development with a focus on digital solutions for fleet management, ship operations and maritime services

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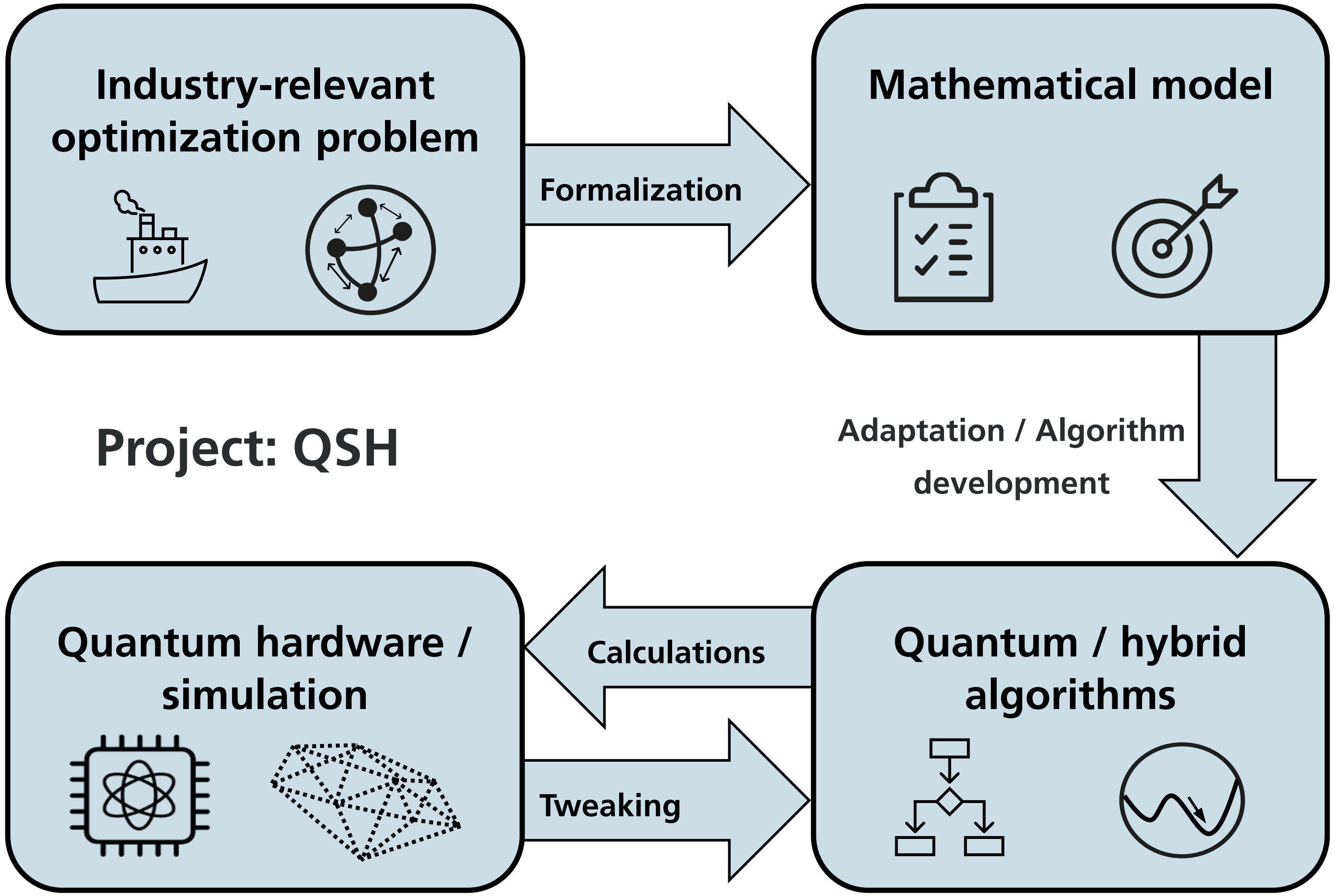
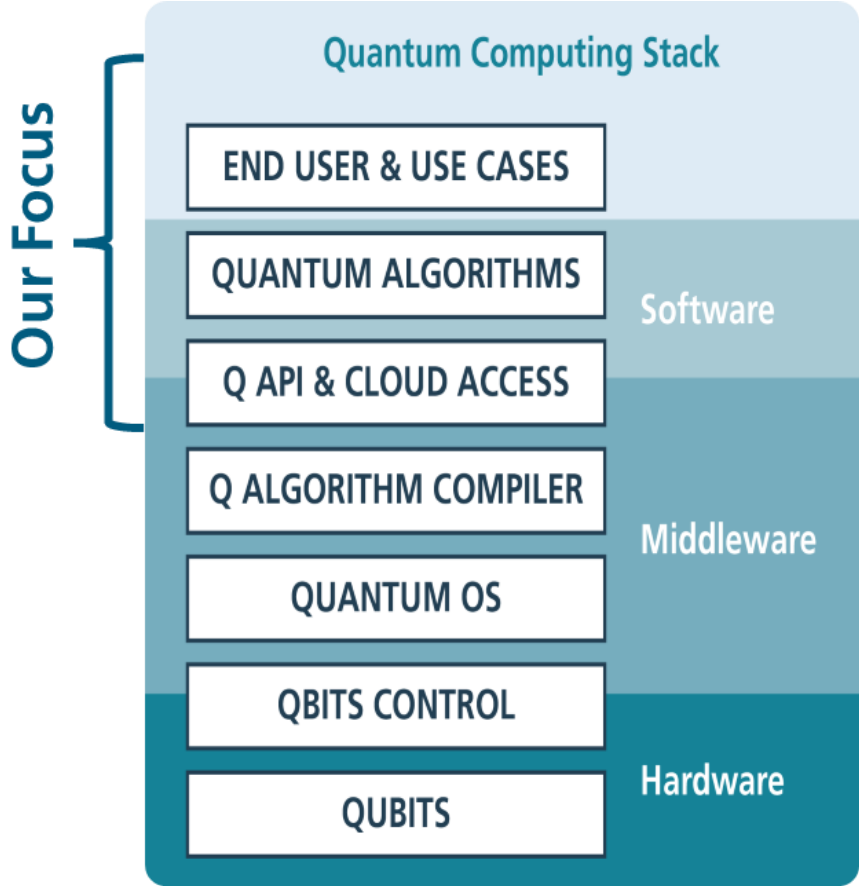
Work on quantum computing

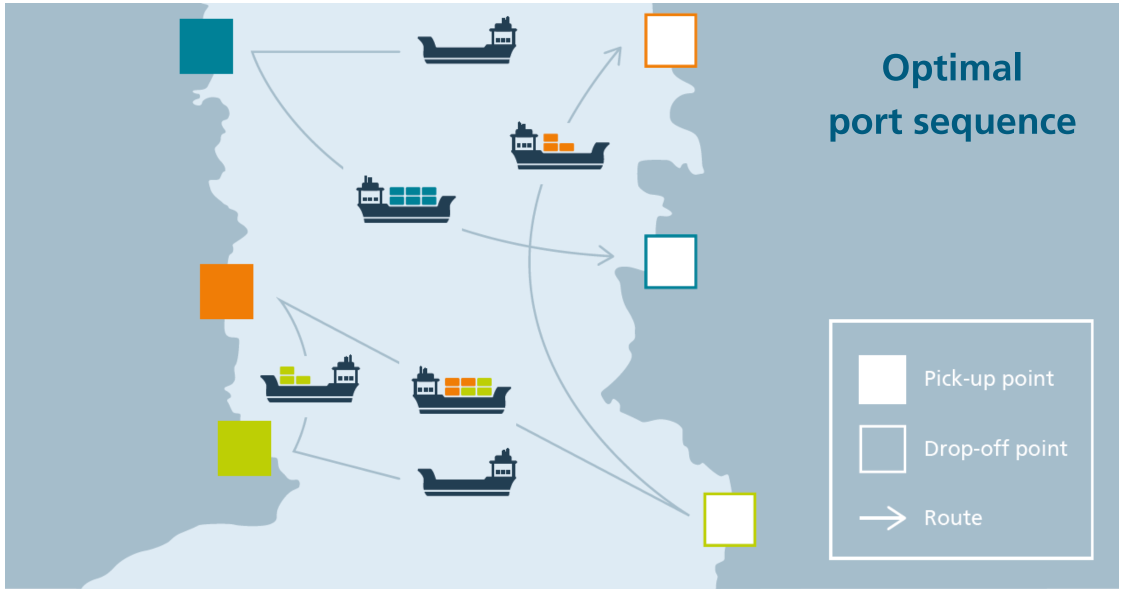


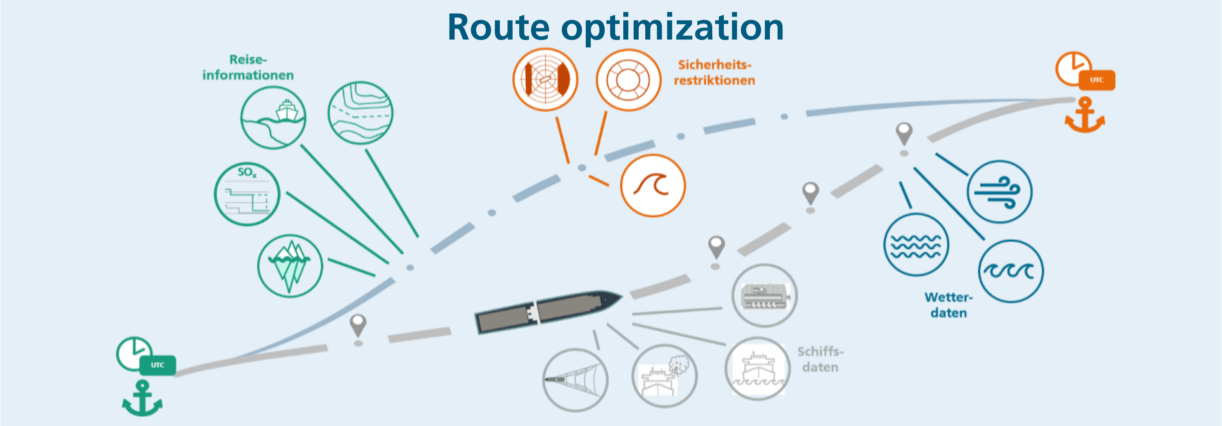


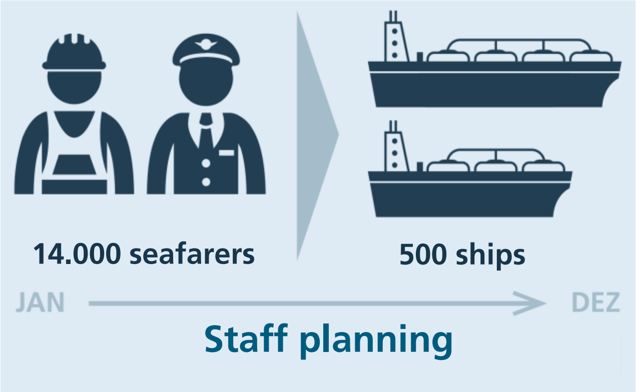
Maritime Use Cases for Quantum Computing

Selected optimization problems from maritime logistics

- Manual, experienced-based and suboptimal processes
- Some problems even too complex for the best computers







The Maritime Inventory Routing Problem (MIRP)

Bulk distribution

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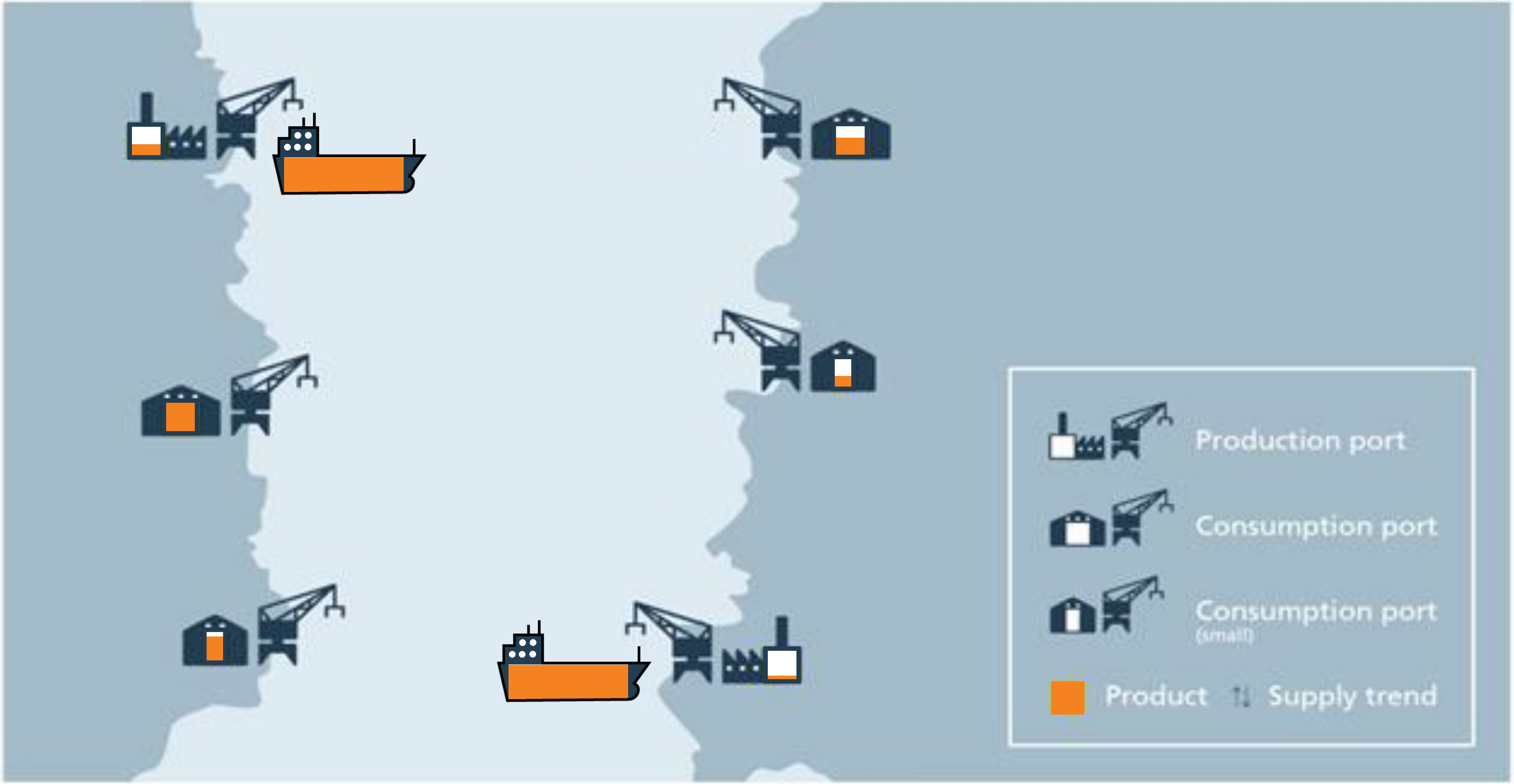

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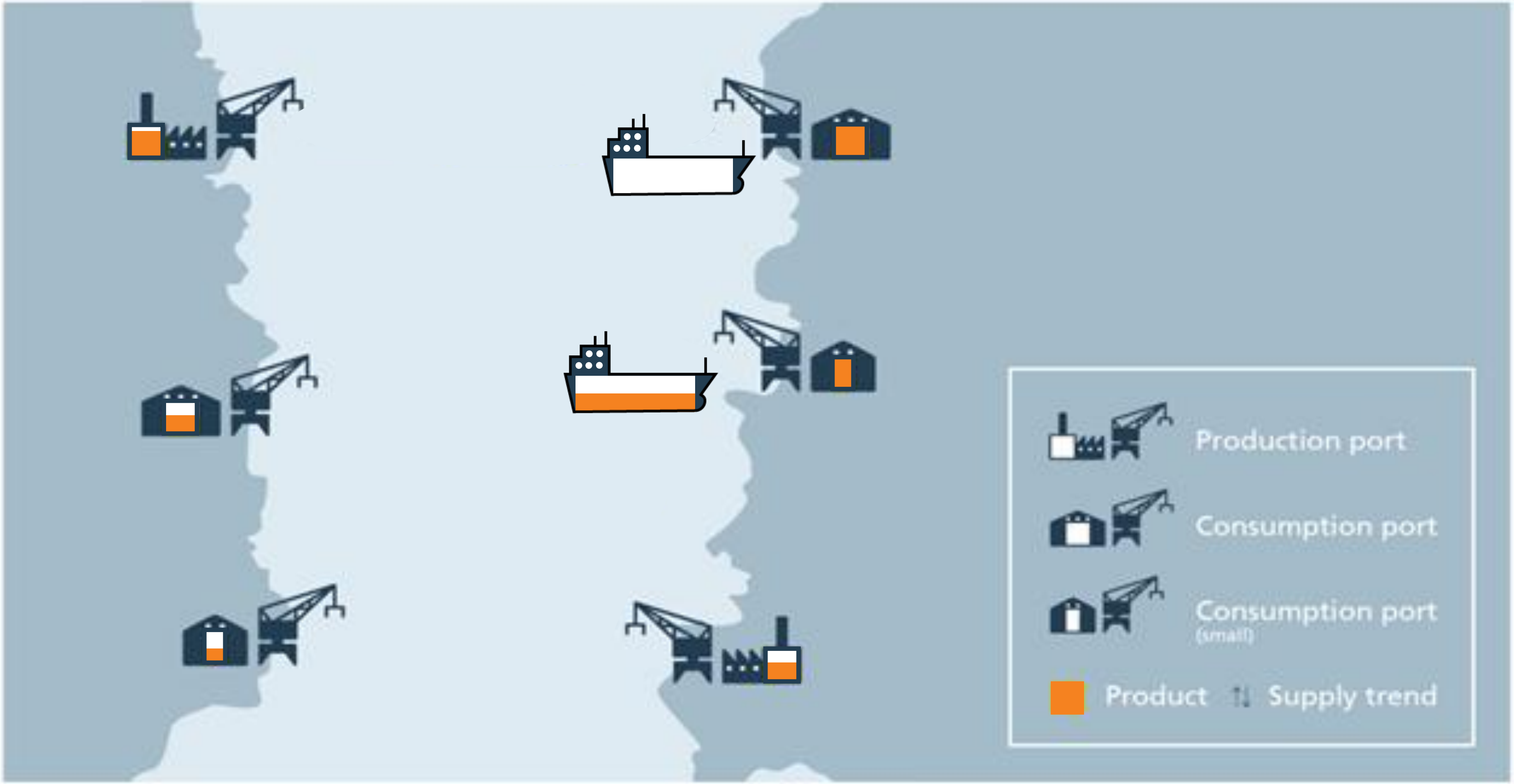

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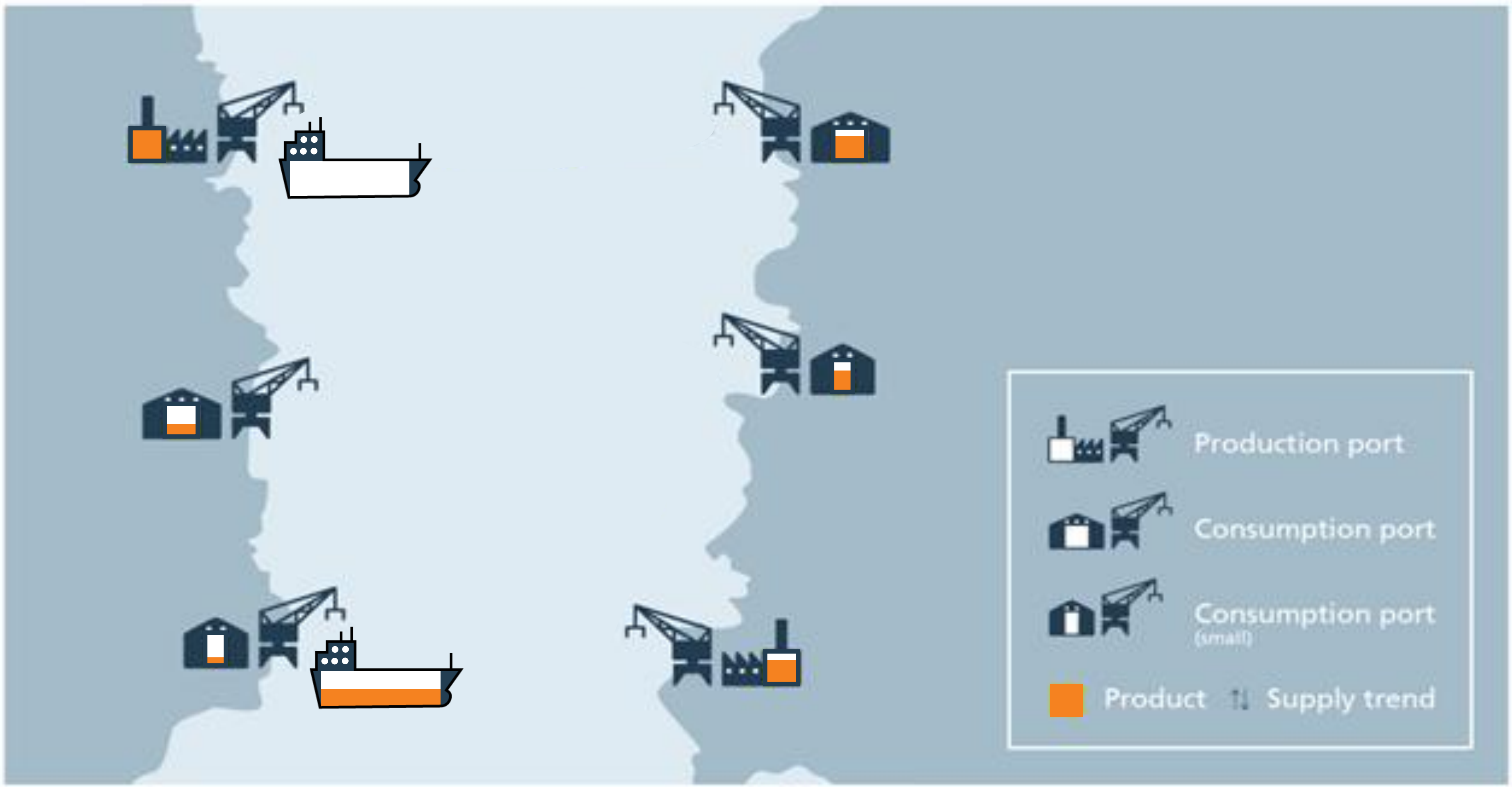

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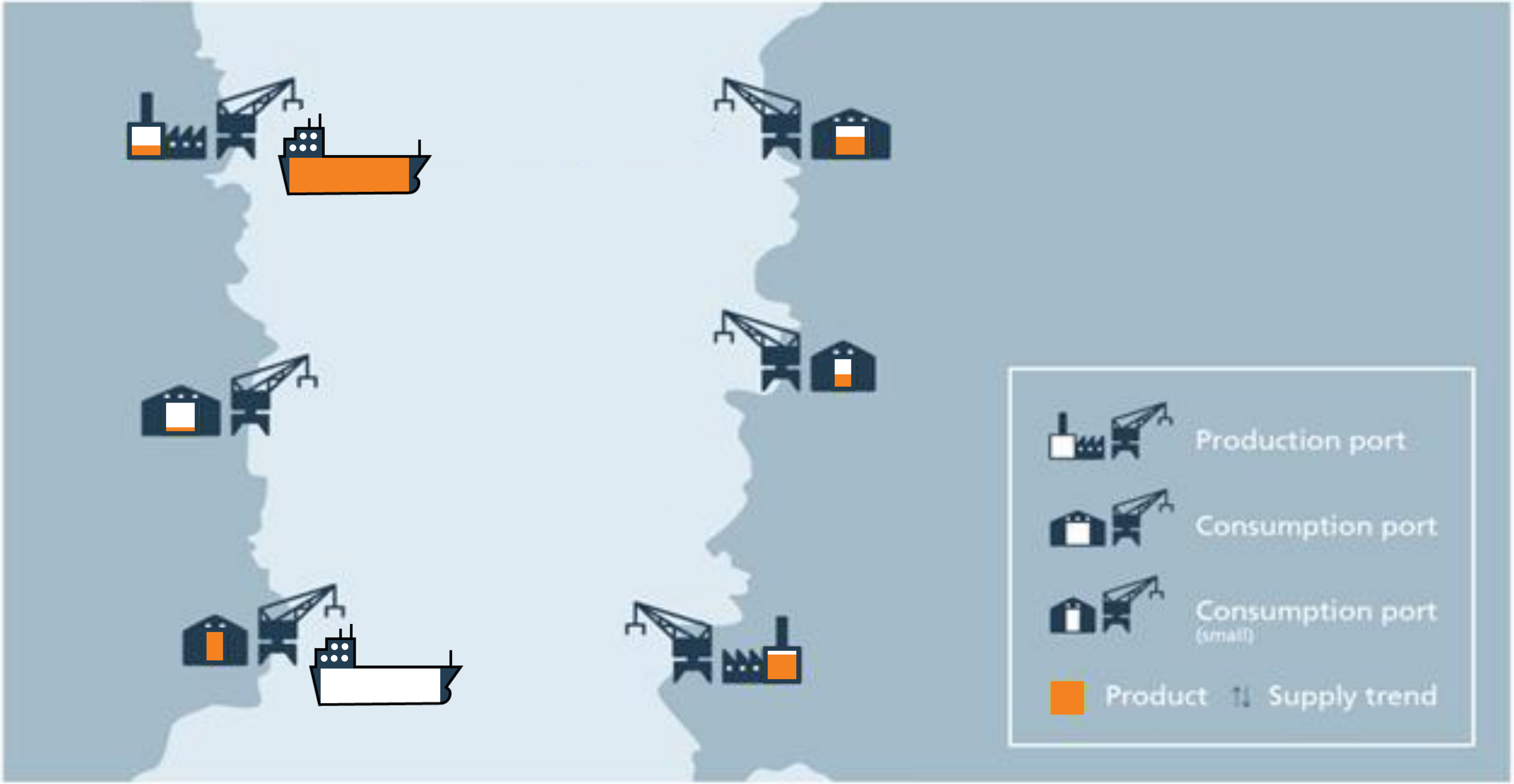

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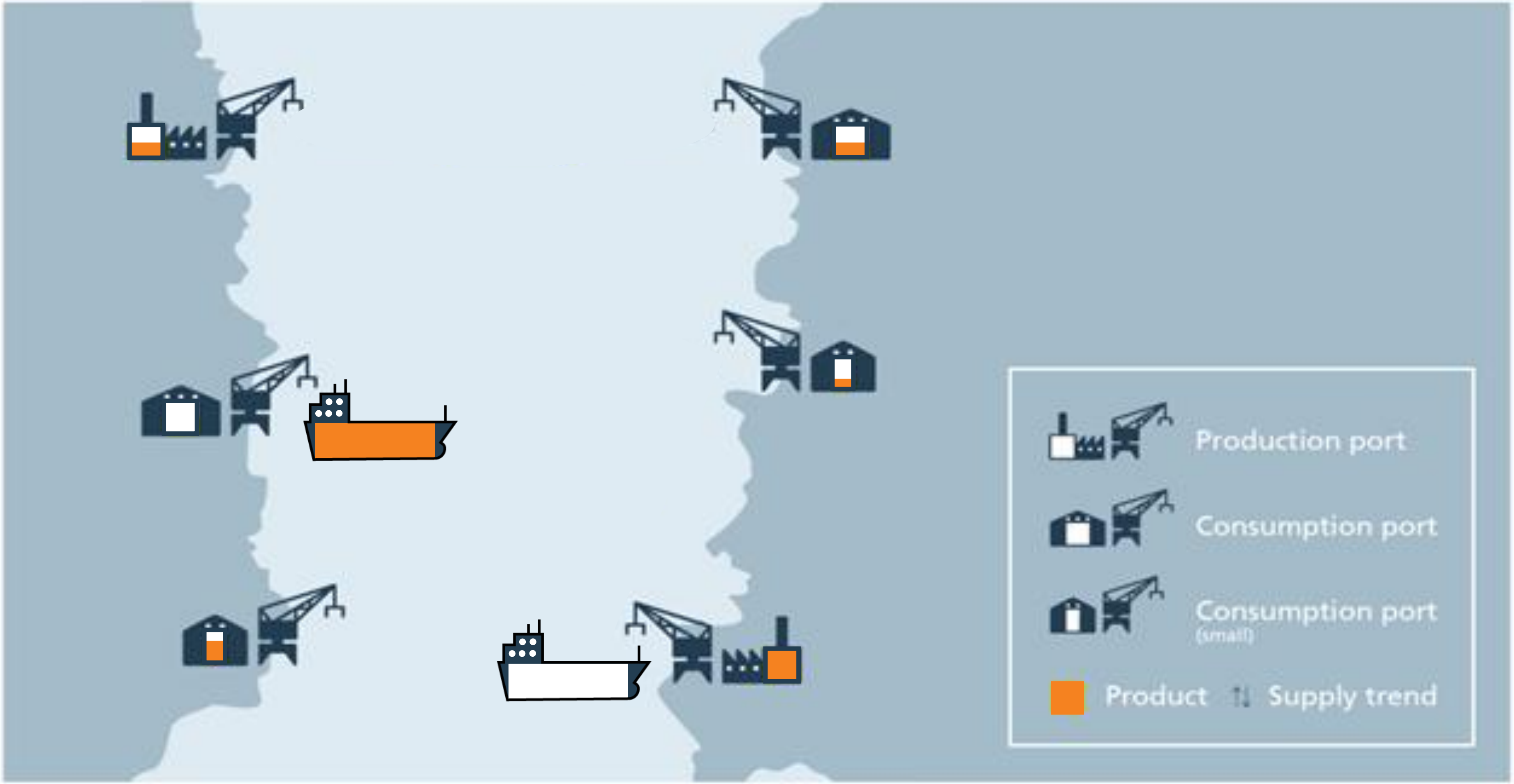

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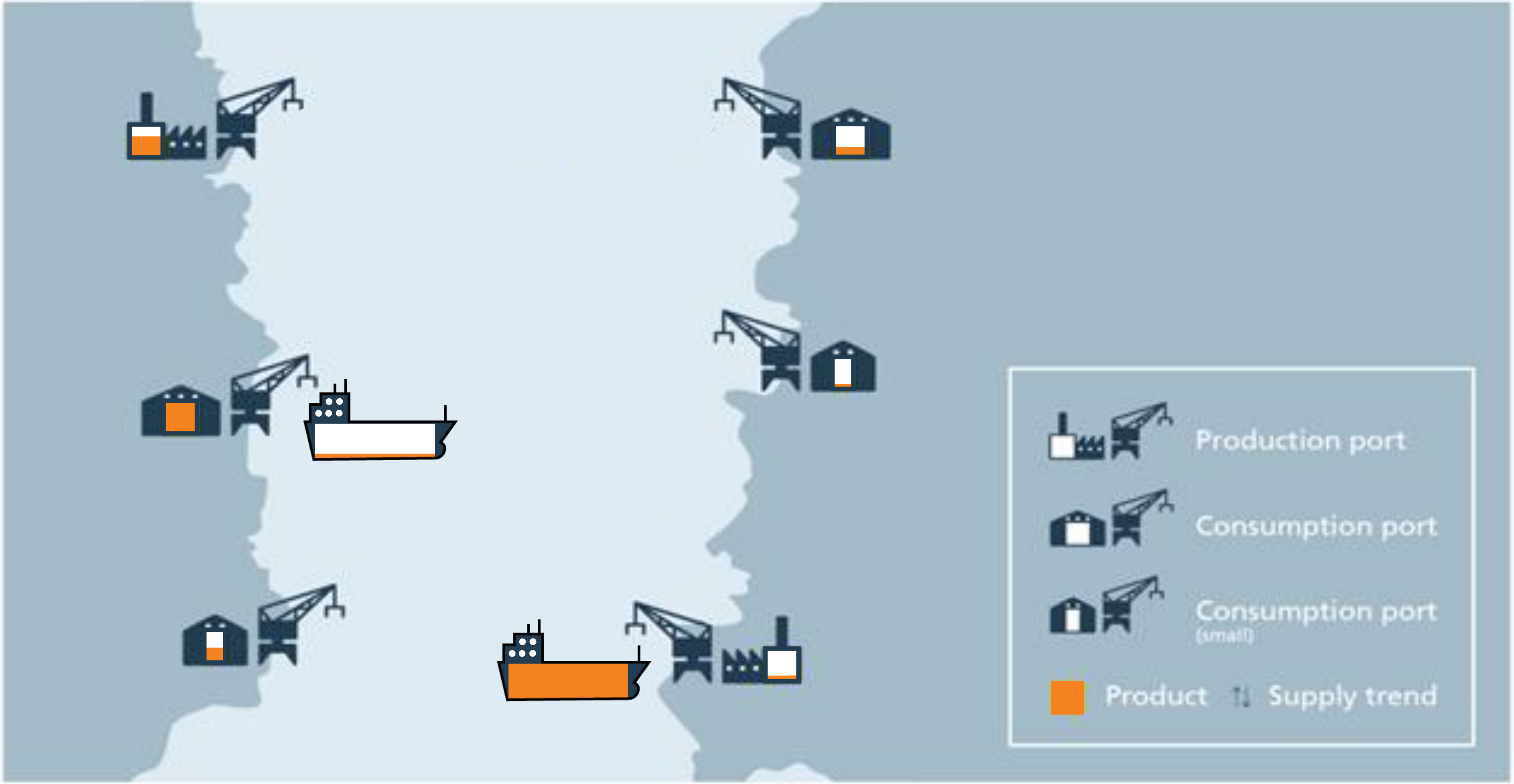

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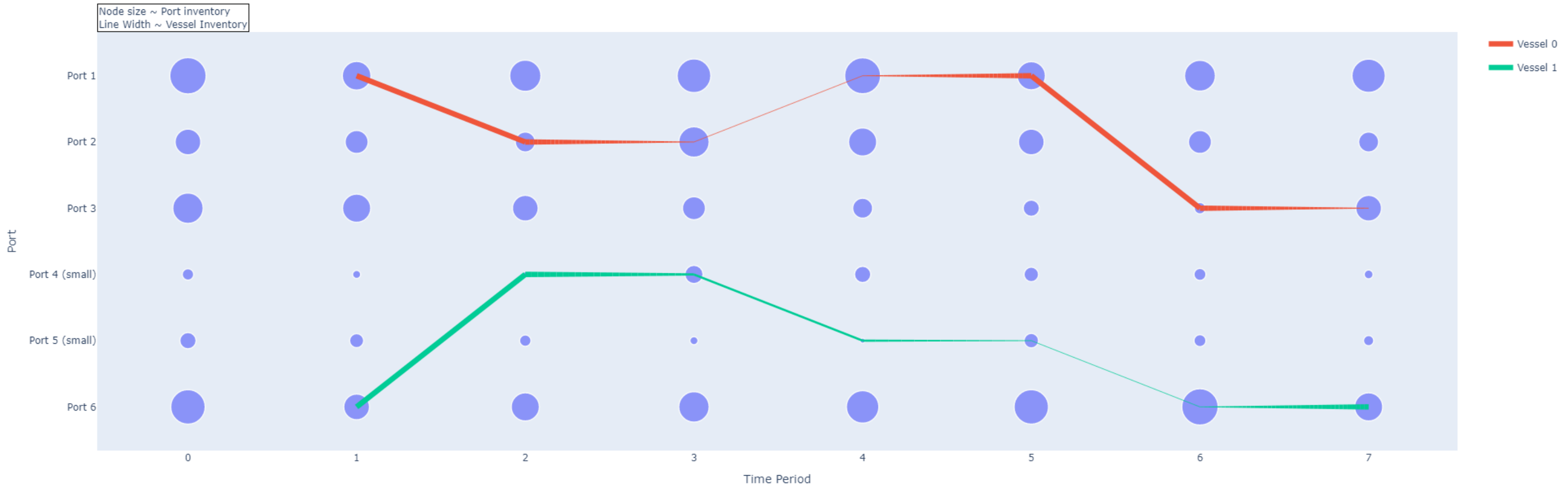
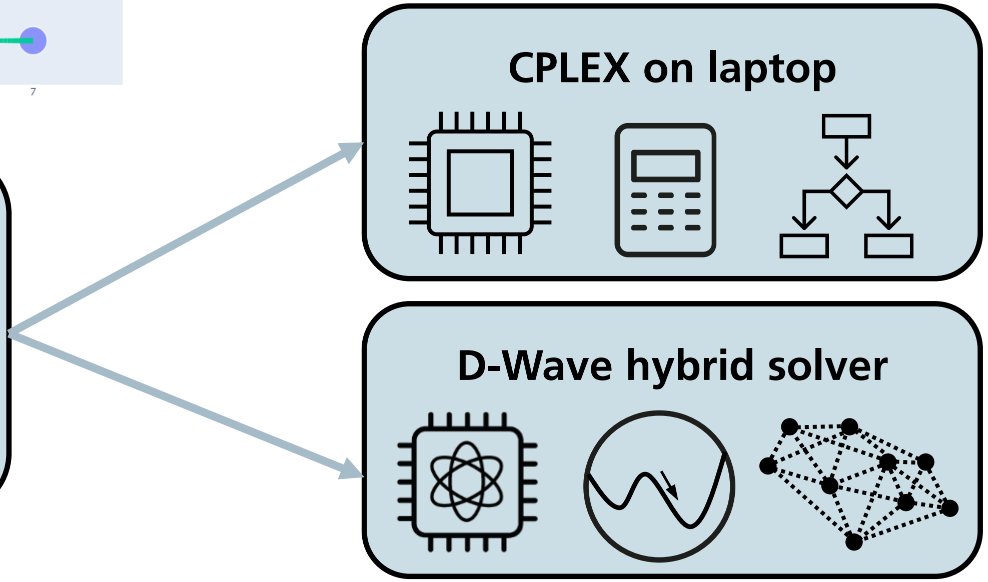
The Maritime Inventory Routing Problem (MIRP)

Formalization



Arc-Flow MILP

$$\sum_{v\in V}\left[\sum_{n\in N}(PP_n\cdot l_n^v - BF_n\cdot b_n^v) - \sum_{a\in A^v} TC_a^v\cdot ta_a^v\right]$$



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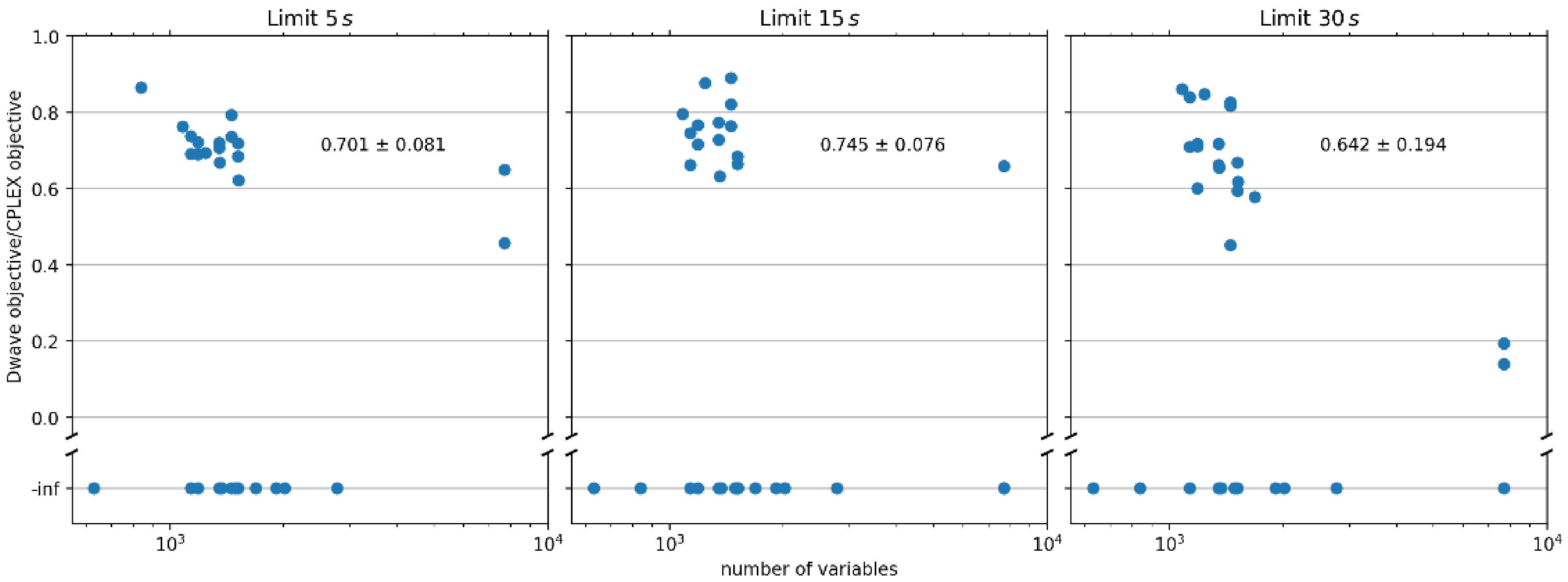
Benchmark results

D-Wave vs. CPLEX



Infeasibilities: 13 15 11

Unfavorable problem formulation for hybrid solver

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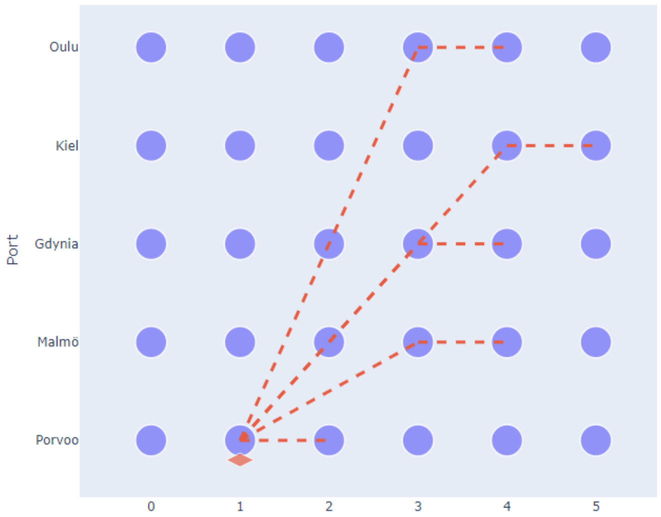
Adaptation

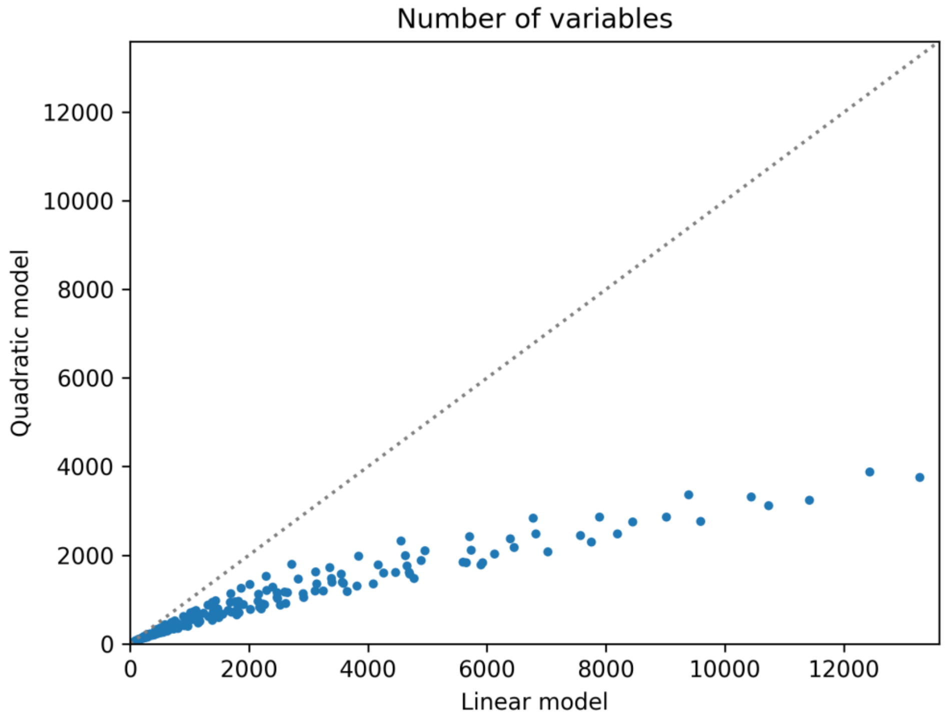
Quadratic problem formulation

Need to adapt problem formulation to the hardware.

Possible approach:

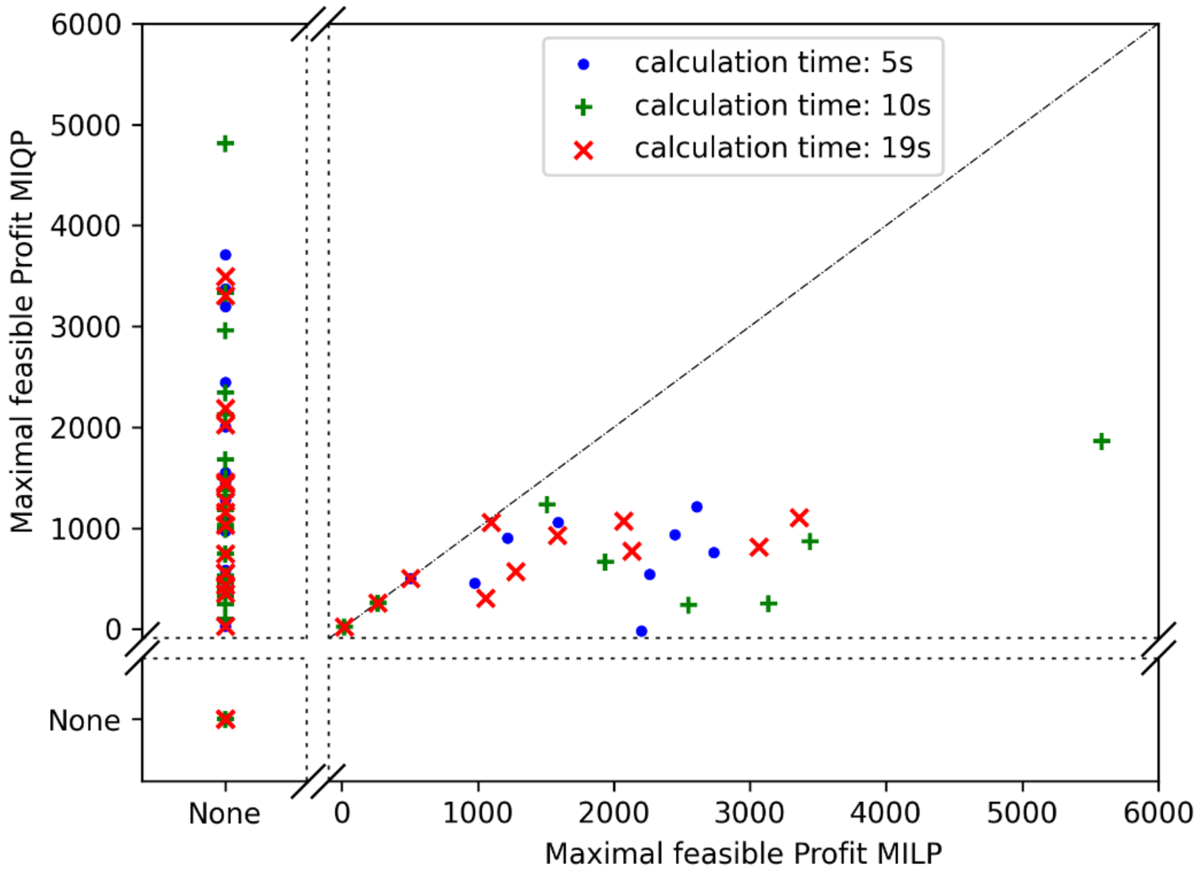
- Position-flow:
  - Quadratic terms
  - Less variables





Benchmark results

MILP vs. MIQP on D-Wave



Not better performance, but more likely to find solutions

Next steps and ongoing work

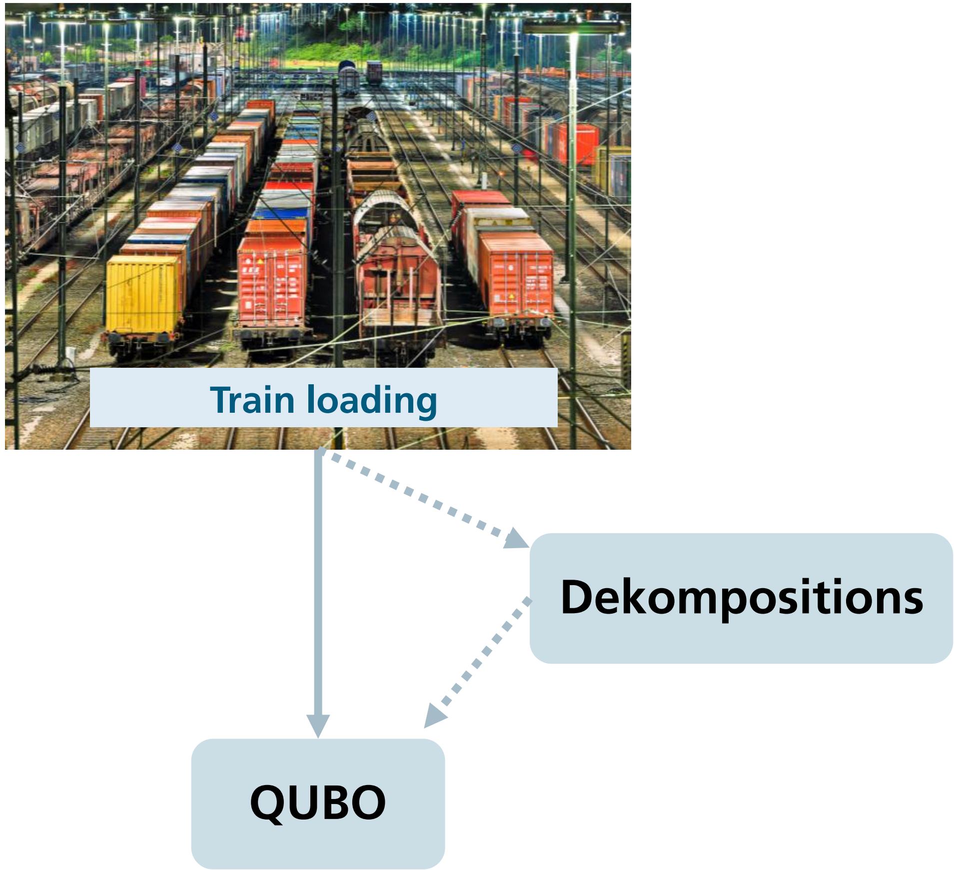
What can be learned from the above?

Solvers and algorithms:

- Move away from Black Box Solvers
- Instead:
  - Decompositions + QC
  - Or QC directly (if possible)

Use cases and models:

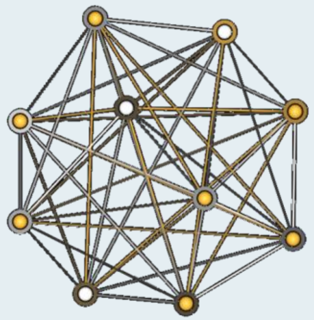
- Choose favourable problem structures
  - preferably binary variables
  - Suitable constraints
  - Adaption to hardware structure



Quantum Optimization and more

Algorithms

Quantum Annealing (QA)



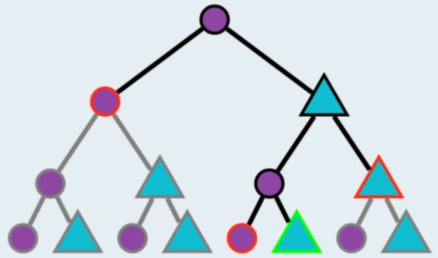
Runs on: Quantum Annealers (Specialized, largest QCs)

Solves: QUBOs

Method: Sample-based probabilistic solver

Applicability: NISQ Era (now)

Quantum Backtracking



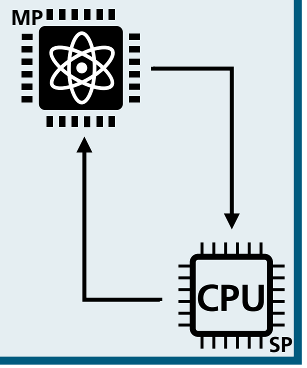
Runs on: Universal QCs

Solves: Constraint Satisfaction Problems

Method: Binary search in decision tree. Quadratic speed-up of classical algorithm

Applicability: Fault-Tolerant Era (future)

Benders Decomposition



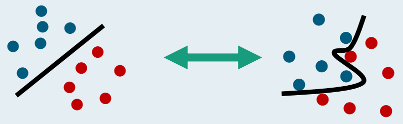
Runs on: Quantum Annealers + classical computers

Solves: Mixed Integer Programs

Method: Hybrid algorithm to solve discrete part with QA and continuous part with classical solvers

Applicability: NISQ Era

Quantum Machine Learning Methods



Support Vector Machines (SVM):

- Training on Quantum Annealer
- Quantum circuits as Kernel function

Quantum-Classical Convolutional Neural Networks:

- Quantum-convolutional layer in preprocessing

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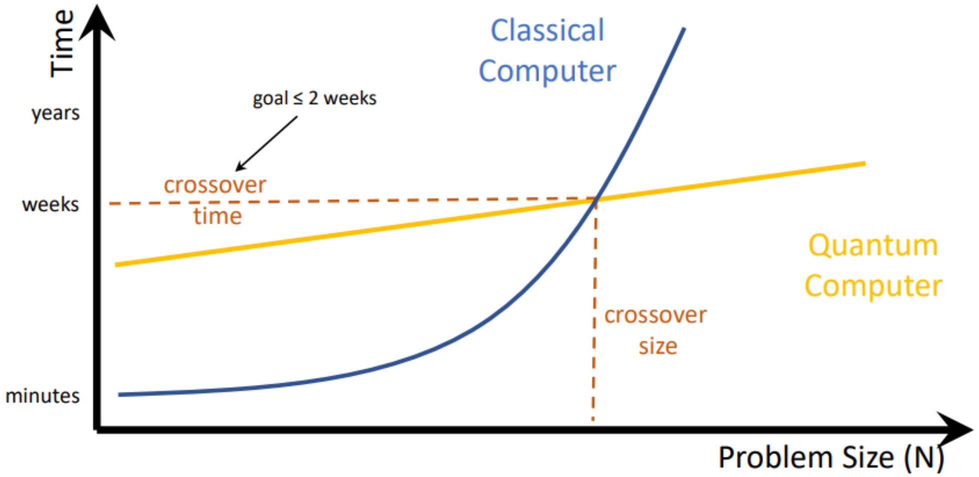
Caveat

Can we expect practical quantum advantage in gate-based optimization?

Problems to overcome:

- Error correction
- Bandwidth of quantum hardware
- Scaling of quantum algorithms



Disentangling Hype from Practicality: On Realistically Achieving Quantum Advantage

TORSTEN HOEFLER, Microsoft Corporation, USA and ETH Zurich, Switzerland
THOMAS HÄNER* and MATTHIAS TROYER, Microsoft Corporation, USA

Operation type	Maximum number of operations for practical quadratic speedup	cubic speedup	quartic speedup
16-bit floating point	0.2	45,800	2,800,000
32-bit integer	0.003	1,630	130,000
Binary (logical)	68	12,500,000	712,000,000

Table 2. **Crossover operation counts for quantum algorithms with quadratic, cubic, and quartic speedups.** We

Even under optimistic assumptions quadratic speed-up not sufficient!

Outlook

Possible advantage of quantum annealing

What is the Computational Value of Finite Range Tunneling?

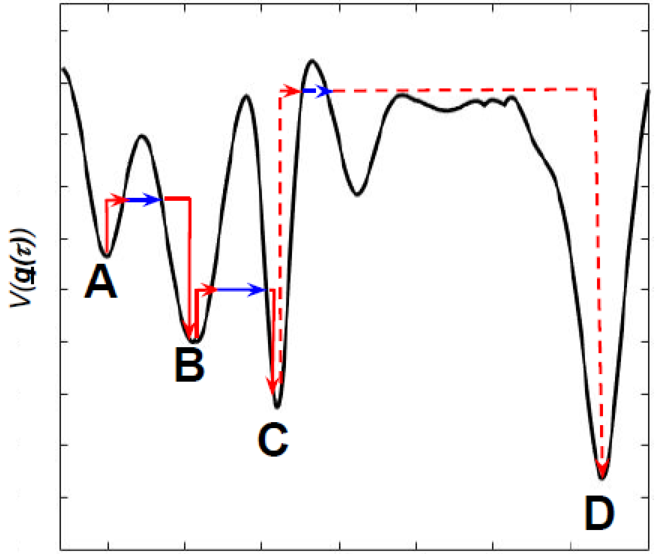
Vasil S. Denchev,[1] Sergio Boixo,[1] Sergei V. Isakov,[1] Nan Ding,[1] Ryan Babbush,[1] Vadim Smelyanskiy,[1] John Martinis,[2] and Hartmut Neven[1]

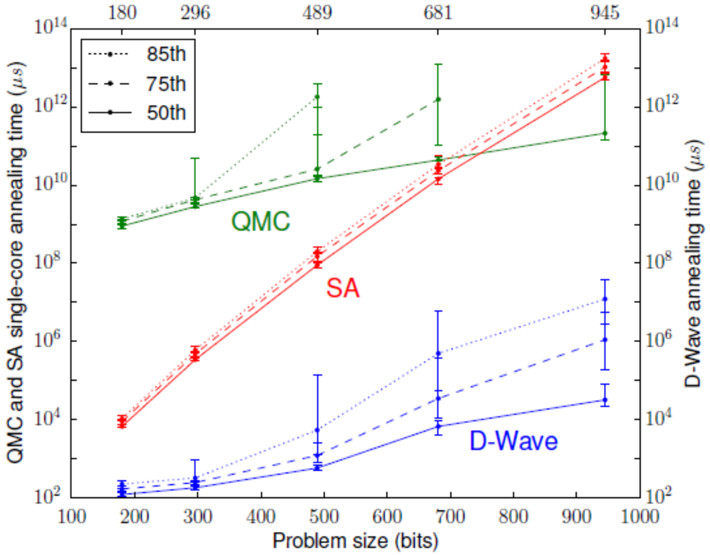
[1] *Google Inc., Venice, CA 90291, USA*

[2] *Google Inc., Santa Barbara, CA 93117, USA*

(Dated: January 26, 2016)

Quantum tunneling:





Focus on Problems / models with narrow barriers!

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QSH project website