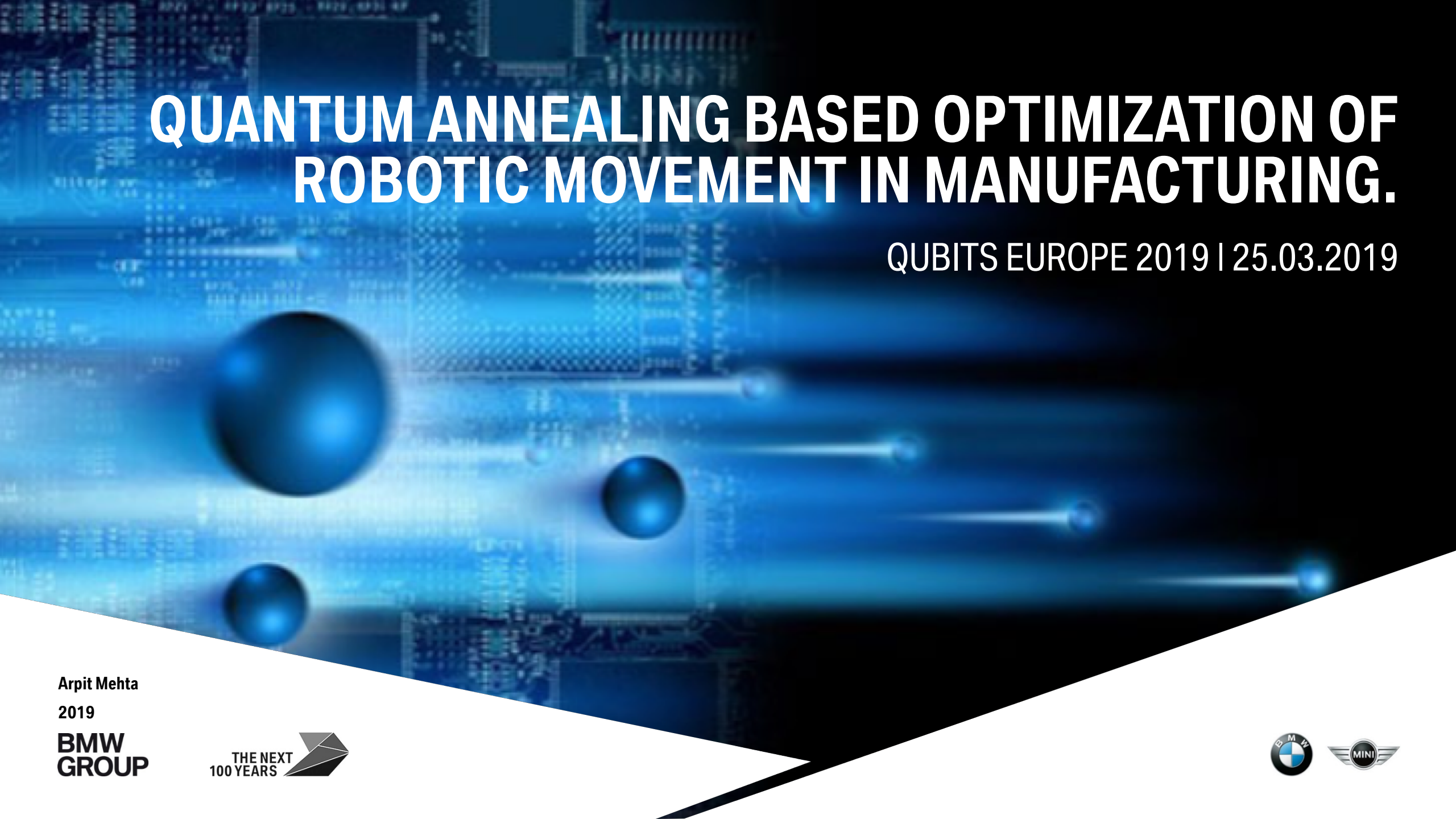


QUANTUM ANNEALING BASED OPTIMIZATION OF ROBOTIC MOVEMENT IN MANUFACTURING.

QUBITS EUROPE 2019 I 25.03.2019

Arpit Mehta

2019

BMW GROUP

THE NEXT 100 YEARS

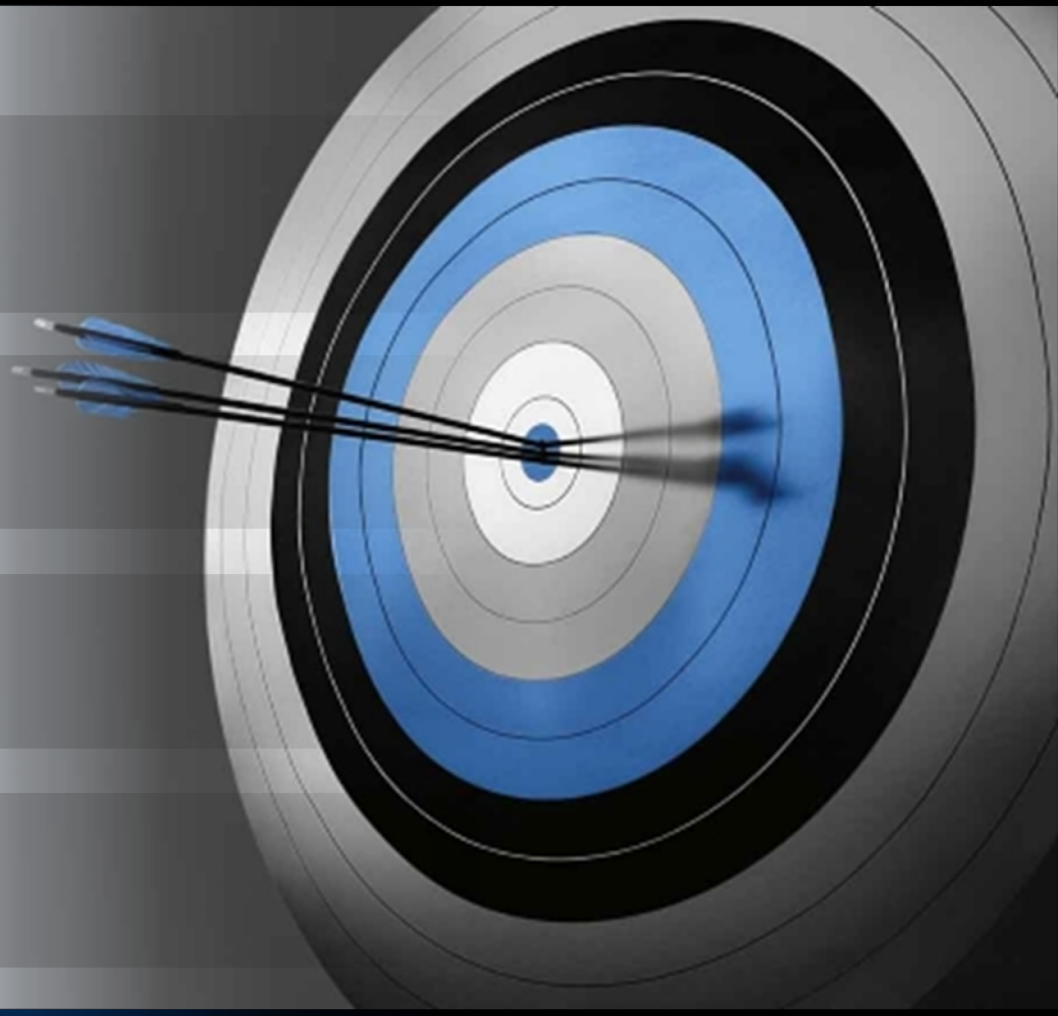
WHO AM I?

arpit.mehta
@bmwgroup.com

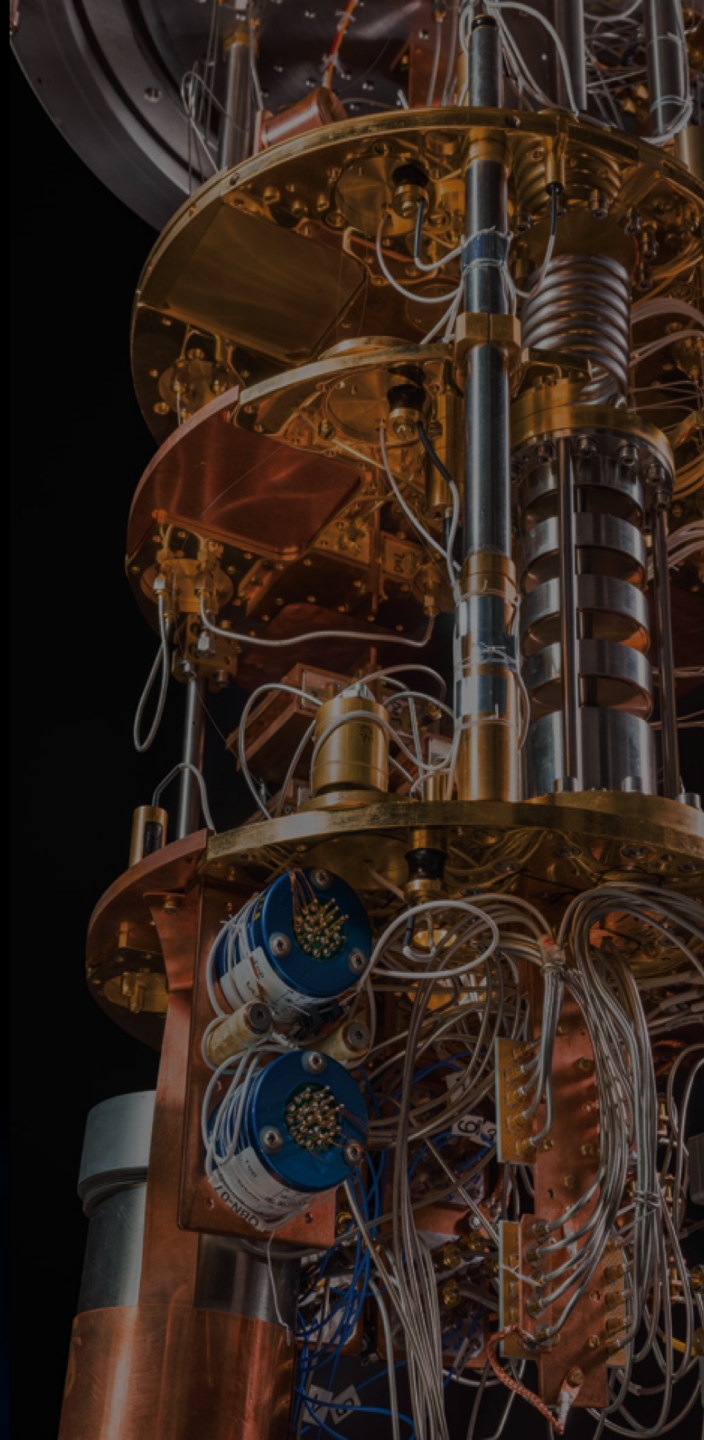
- Solution Architect/Data Scientist
- ML-focused architectures
- Research in QC/AI/ML
- R, Scala, Kafka, Spark, TF
- Loves cycling & traveling

AGENDA.

1. **Use Case Introduction**
   - Why it is relevant for an automotive producer?
2. **Formal Description**
   - Mathematical description of variables and objective functions
3. **Experimental Setup**
   - Hardware and tasks
4. **Result and Conclusion**



Use-Case Introduction



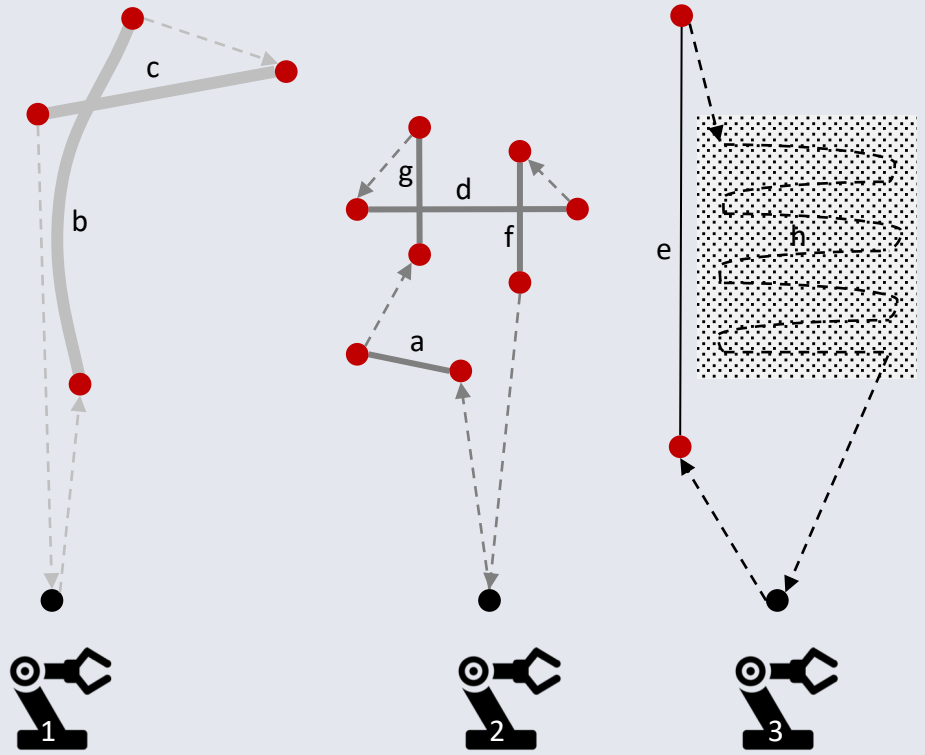
PVC APPLICATION ROBOTIC PROCESS.

PVC Application serves to seal the gaps of joined sheets, thereby preventing the ingress of corrosive media.

INITIAL USE-CASE TASK.

Calculation of a production plan in which all seams are processed within a given cycle time.

Robotic Task

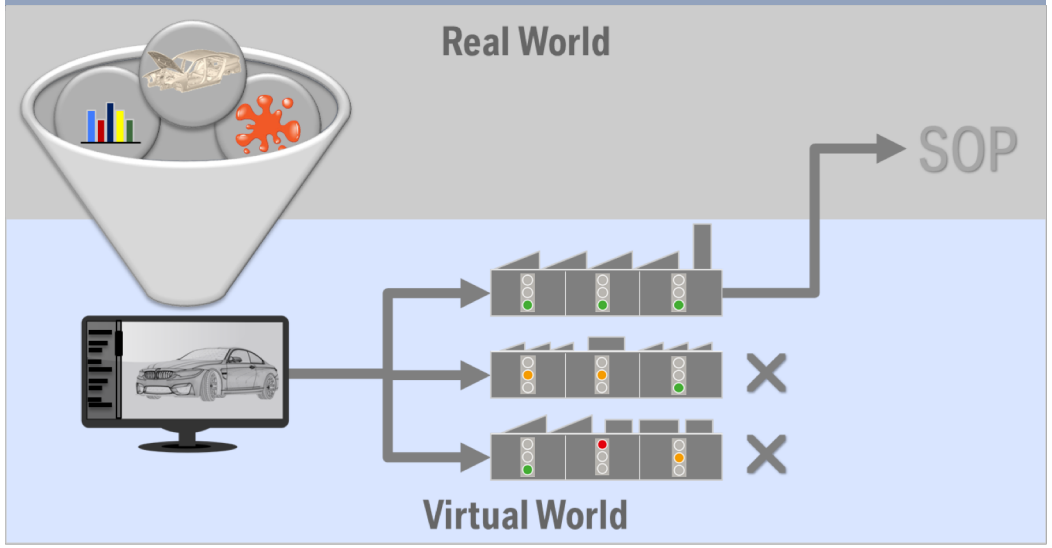


Optimization Tasks

Scheduling:
Efficient allocation of tasks to available robots.

Sequencing and Motion Planning:
Minimizing the routes for all robots and creation of collision-free robot movements.

Vision



CHALLENGES AND SCOPE OF PVC SEALING.

Great effort during robot program creation.

– High requirements with respect to the application.

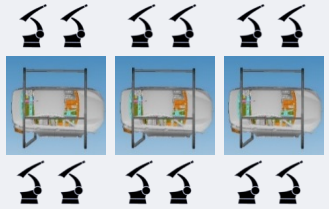
– High complexity.

Number and length of PVC seams

Model	 G12		 G30		 F48	
Engine bay	69	20,9 m	77	14,9 m	53	16,19 m
Underbody	91	33,2 m	101	31,0 m	79	25,44 m
Wheelhouse	50	27,2 m	38	19,3 m	92	30,16 m
Rest	52	22,7 m	59	24,0 m	47	20,46 m
Σ	262	104,5 m	279	89,2 m	271	92,25 m

→ Total length: 89 - 105 m
→ Number of seams: 262 - 279
} Ø-Length 0,35 m

Possible combinations for scheduling

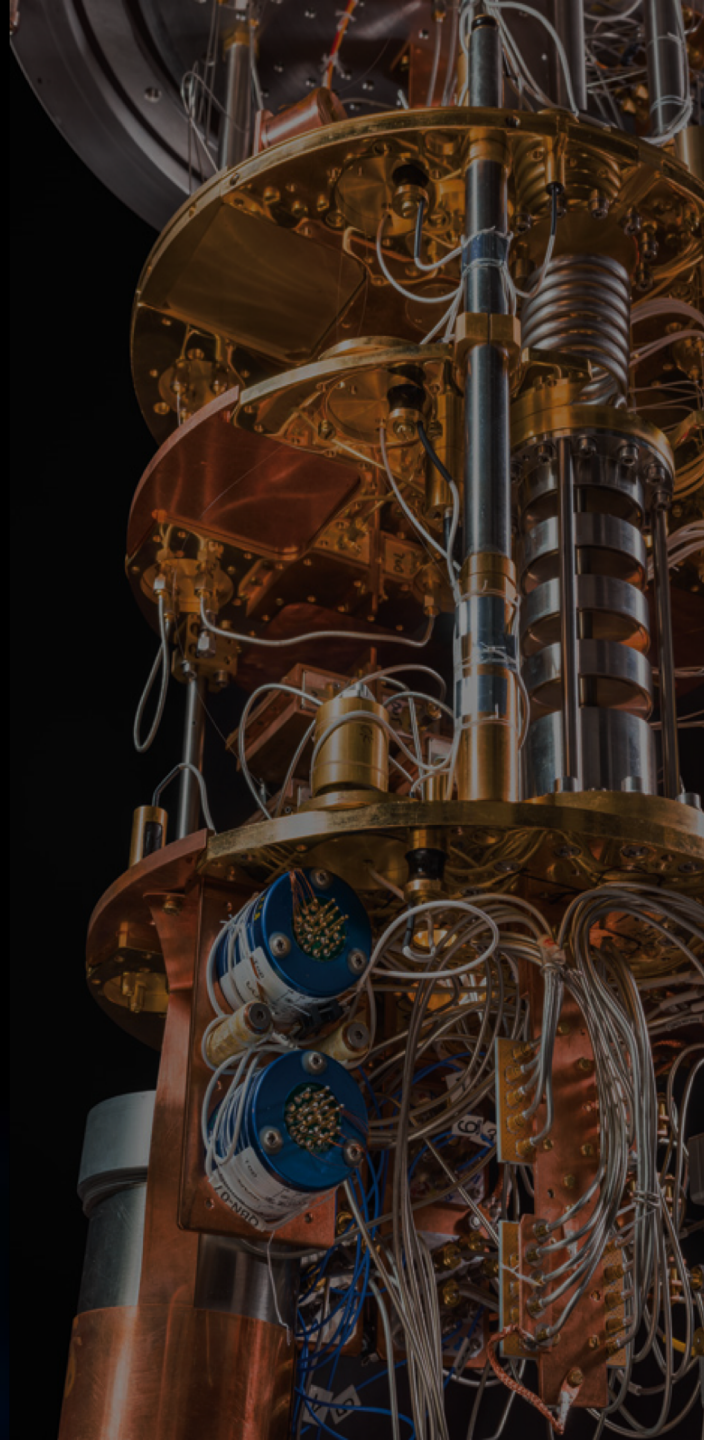
Scheduling Underbody G30			Layout NVU W2.4
26	10	7	
7	1	2	
29	12	7	

Possible allocations in consideration of accessibility:

→ $10^{50} \approx 3^{44} \cdot 3^{20} \cdot 3^{49} \cdot 3^{22}$

The huge amount of possible combinations challenges cognitive abilities of humans.
Support through planning and optimization tools is expedient.

Formal Description



FORMAL DESCRIPTION*.

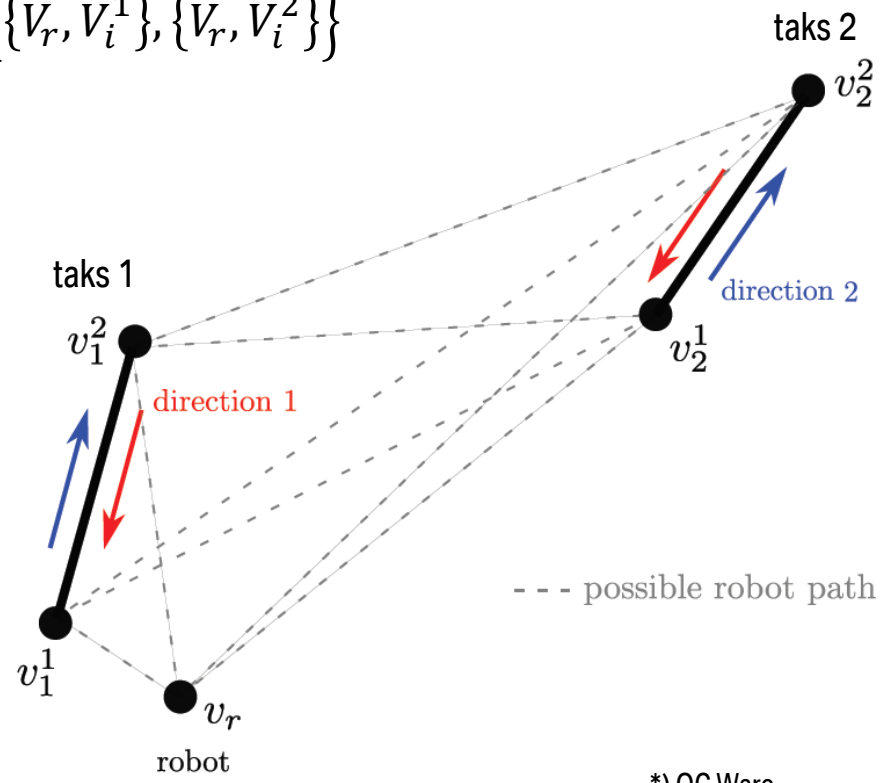
Modelling as weighted graph

- $G = (V, E, W)$
- $V = \{V_r\} \cup \{\cup_{i=1}^{N} \{V_i^1, V_i^2\}\}$
- $E = \cup_{i=1}^{N} \cup_{\substack{j=1 \\ j \neq i}}^{N} \left\{\{V_i^1, V_j^1\}, \{V_i^1, V_j^2\}, \{V_i^2, V_j^1\}, \{V_i^2, V_j^2\}\right\} \cup \cup_{i=1}^{N} \left\{\{V_r, V_i^1\}, \{V_r, V_i^2\}\right\}$
- $W: E \rightarrow [0, \infty)$

Logical variables

- $\boldsymbol{x} = \{0,1\}^{2N^2}$
- Meaning of logical variable $x_{i,t}^{(d)}$:

  Robot should process i[th] task at step t in direction d



*) QC Ware

OBJECTIVE FUNCTION*.

$$f(\boldsymbol{x}) = f_{distance}(\boldsymbol{x}) + f_{tasks}(\boldsymbol{x}) + f_{time}(\boldsymbol{x})$$

Distance travelled by the robot between the tasks.

$$f_{distance}(\boldsymbol{x}) = \sum_{k,l=1}^{2} \sum_{i=1}^{N} \sum_{\substack{j=1 \\ j\neq i}}^{N} \sum_{t=1}^{N} \frac{W\left(\left\{v_i^l, v_j^k\right\}\right)}{2} \left(x_{i,t}^{(l)} x_{j,t+1}^{(k')} + x_{j,t}^{(k)} x_{i,t+1}^{(l')}\right) + \sum_{i=1}^{N} W\left(\left\{v_r, v_i^2\right\}\right) x_{i,1}^{(1)} + W\left(\left\{v_r, v_i^1\right\}\right) x_{i,1}^{(2)}$$

Constraint that all tasks are performed exactly once.

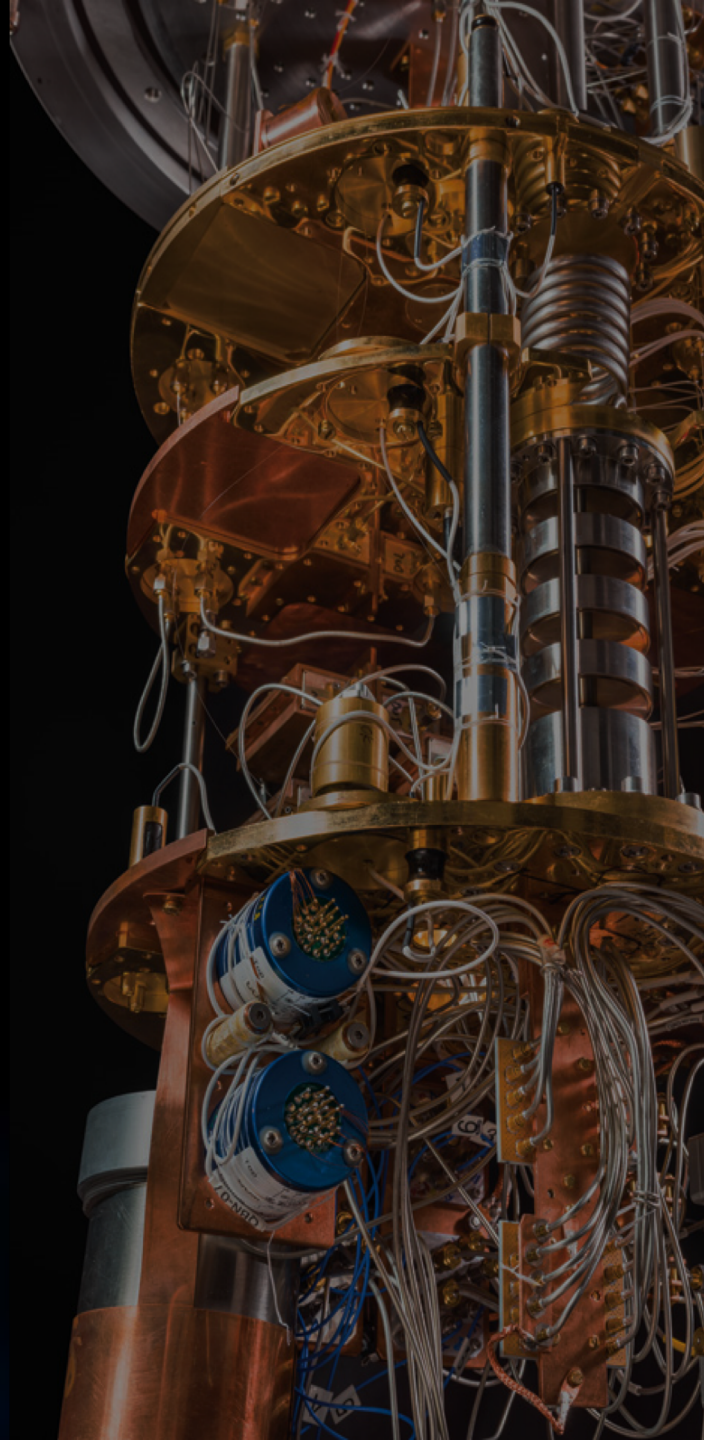
$$f_{task}(\boldsymbol{x}) = \sum_{i=1}^{N} P_{task}^{i} \left(1 - \sum_{t=1}^{N} x_{i,t}^{(1)} + x_{i,t}^{(2)}\right)^2$$

Constraint that at each time step, exactly one task is performed.

$$f_{time}(\boldsymbol{x}) = P_{time} \sum_{t=1}^{N} \left(1 - \sum_{i=1}^{N} x_{i,t}^{(1)} + x_{i,t}^{(2)}\right)^2$$

*) QC Ware

Experimental Setup



EXPERIMENTAL SETUP

Hardware: DWave 2000Q

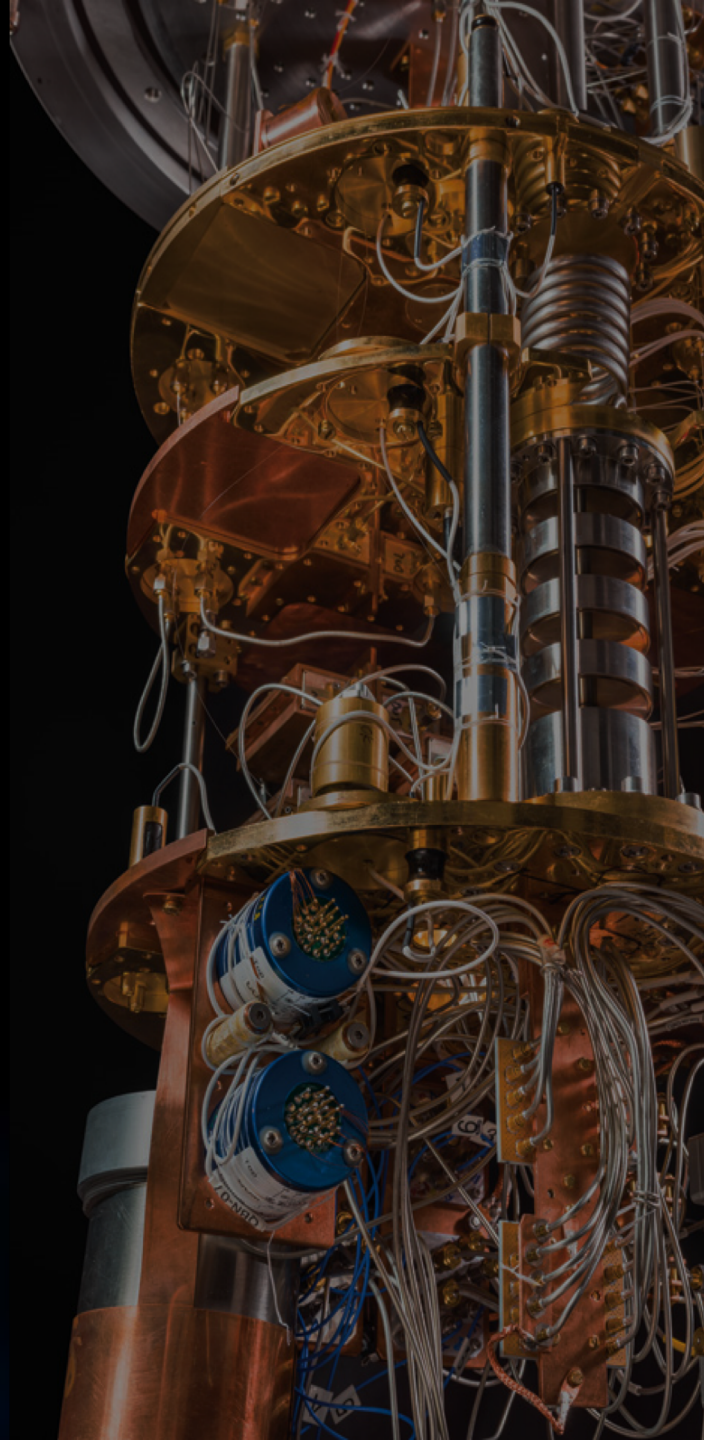
Annealing Cycle:

- Less than 4 tasks 10.000 cycles.
- More than 4 tasks 1.000.000 cycles.

For the testing the use case, the robotic tasks are defined in 2D.
Following is the definition of the tasks along with start and end coordinate of each tasks, along with the velocity of robot.

Task	Start	End	Velocity
a	(287, 619)	(17, 479)	94
b	(595, 627)	(592, 52)	58
c	(488, 353)	(43, 565)	68
d	(450, 142)	(688, 580	63
e	(136, 403)	(630, 170)	70

Result and Conclusion

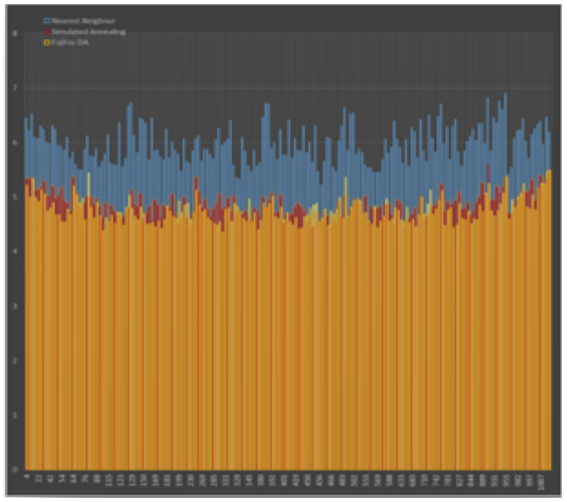


RESULT

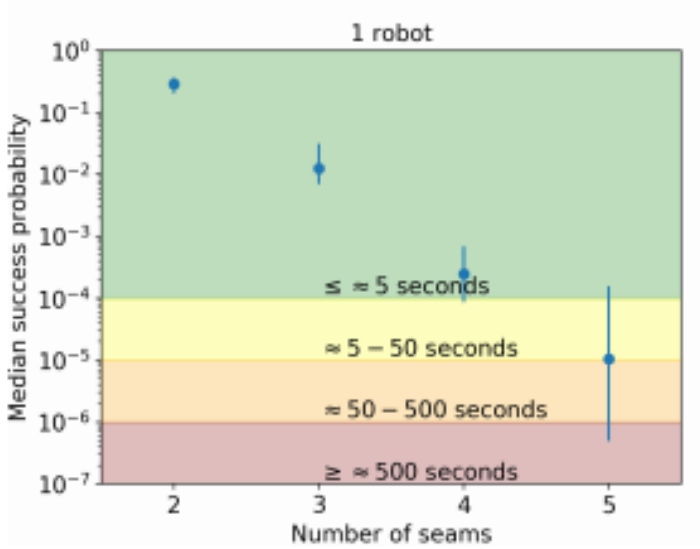
KEY TAKEAWAYS

- QA approach successfully found the optimal solution.
- Due to hardware limitations only roundtrips with up to 5 seams could be solved.
- High Potential in speedup with improved hardware capacity

QA vs Simulated Annealing



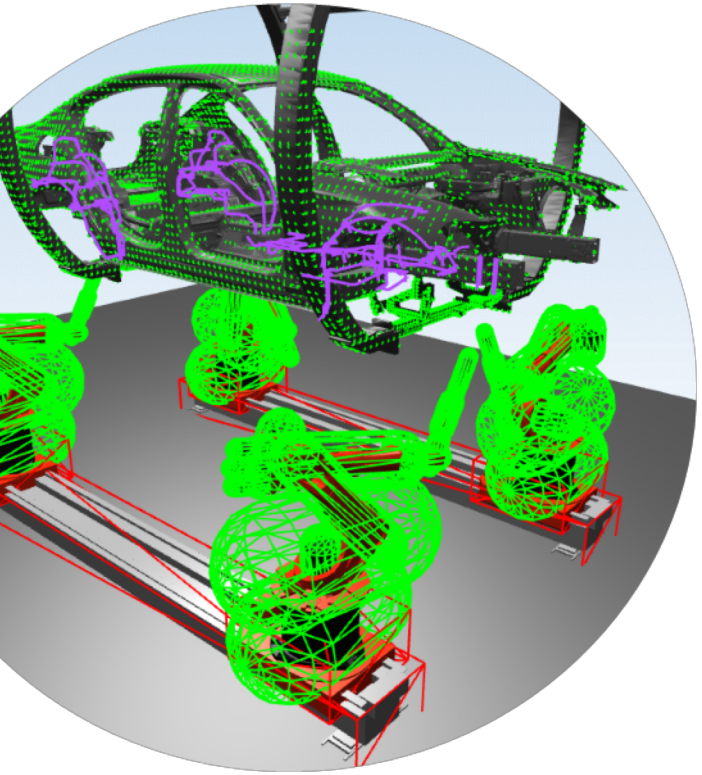
Quantum Annealing Performance



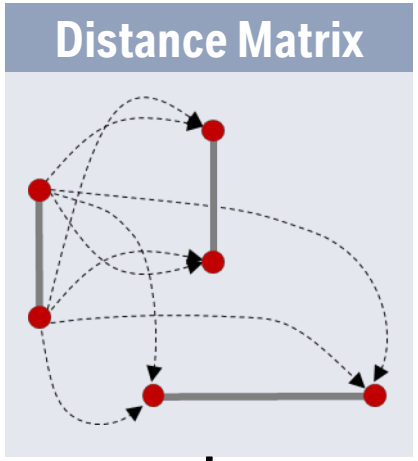
QA Hardware is still in a development phase and requires further development for bringing concrete business value.

FROM THE MANUFACTURING PROBLEM TO A QUANTUM INSPIRED SOLUTION.

1

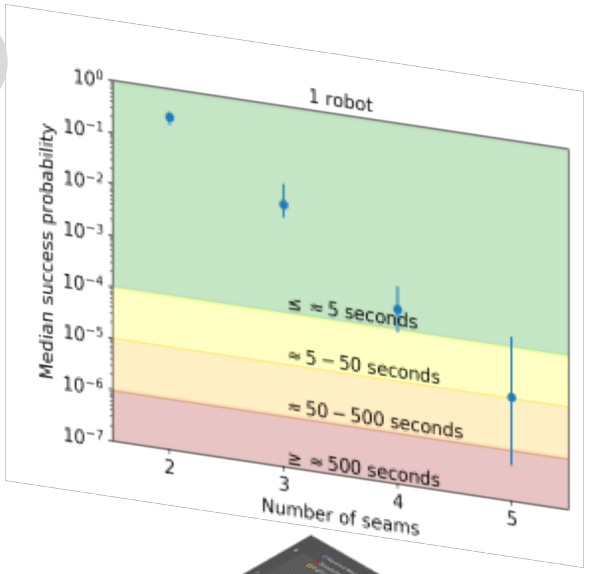


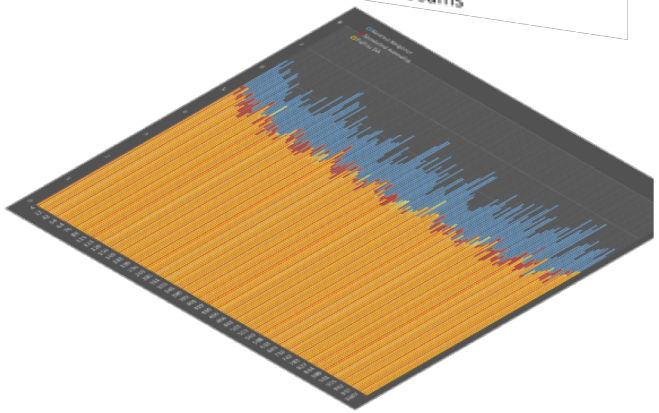
2



Quantum Annealing (QA) | Simulated Annealing (SA) | Digital Annealing (DA)

3



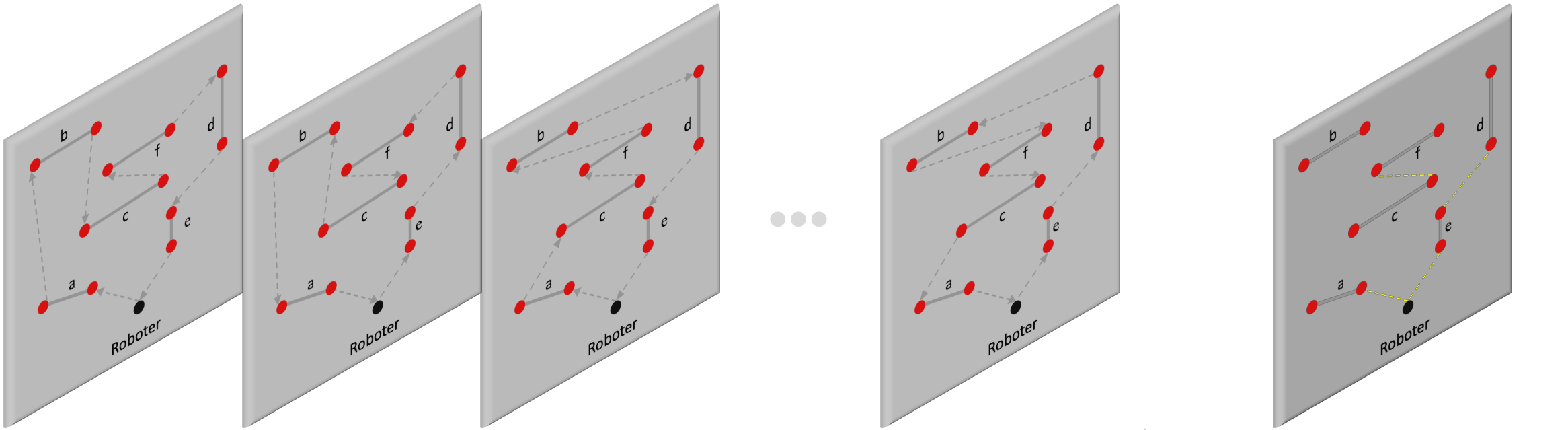


Build model from production process

Experimental implementation

Comparison of the solutions

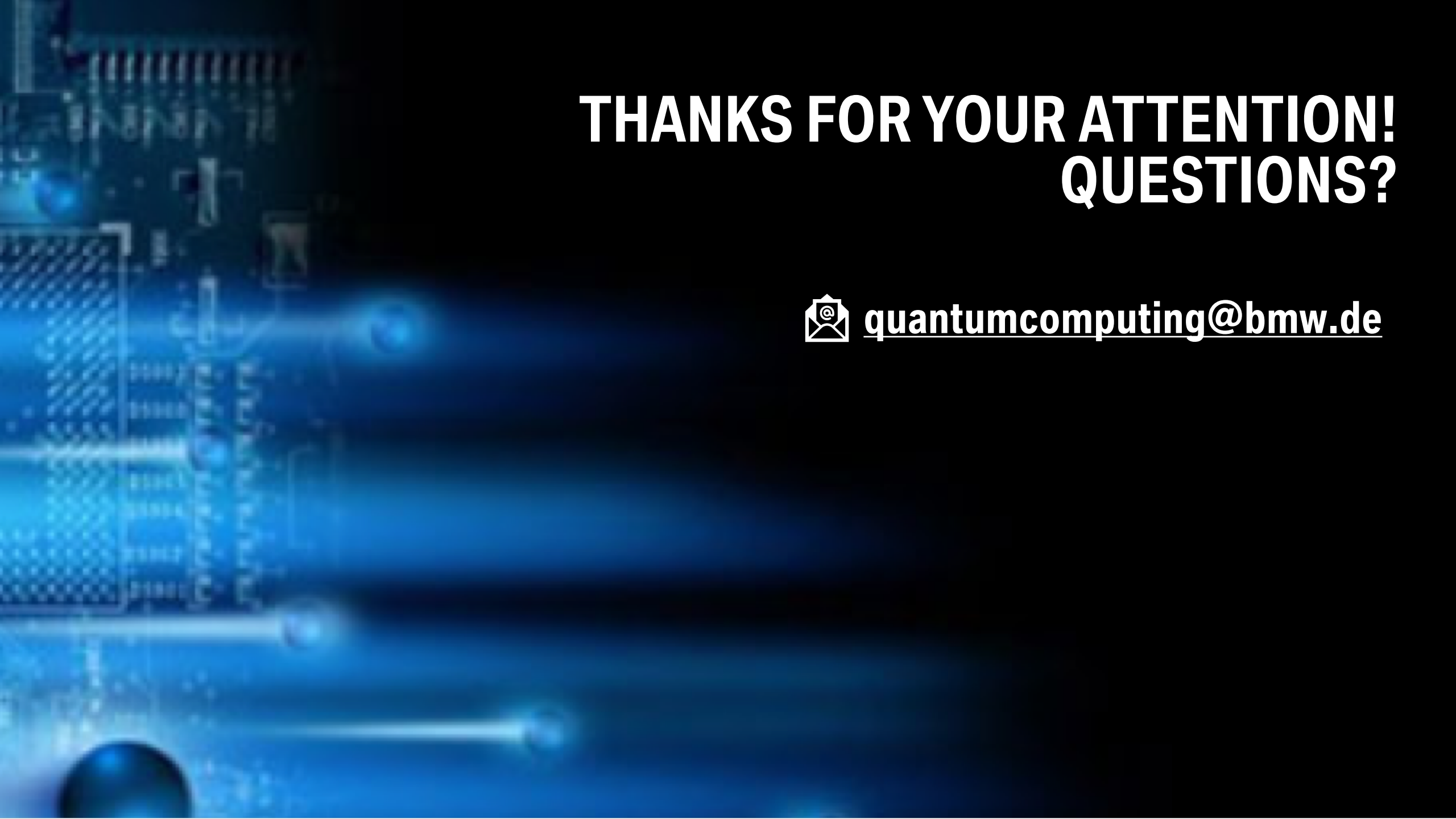
FUTURE WORK.
EMBEDDING OF HEURISTIC METHODS.



Investigation of the best found solutions so far.

Current Pattern

Evaluation of best found solutions to shrink the solution space and improve the convergence behavior through pattern recognition.



THANKS FOR YOUR ATTENTION!
QUESTIONS?

quantumcomputing@bmw.de