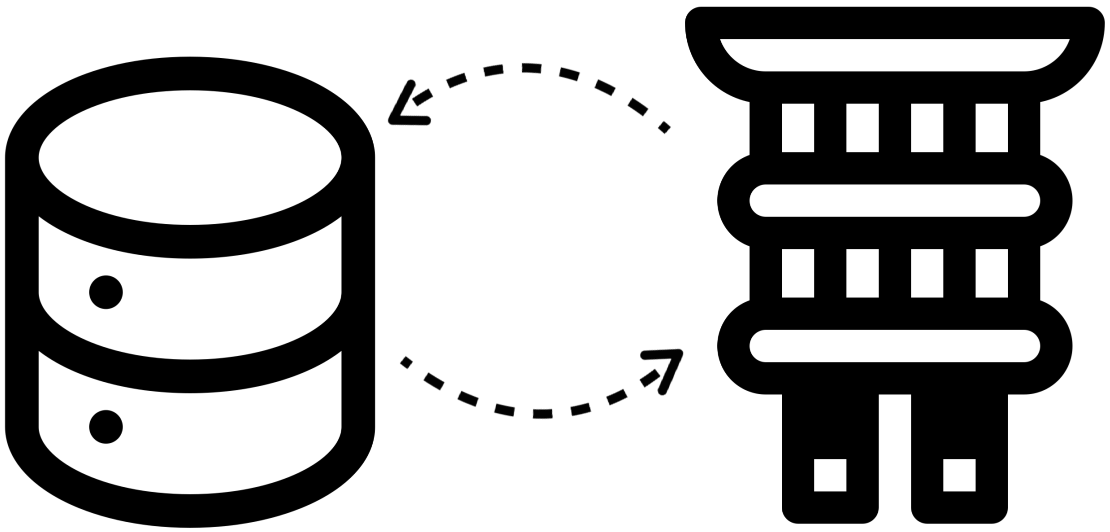
When Quantum is your Hammer: Which Data Management Problems look like Nails?

Stefanie Scherzinger
@SummerSoc 2026

University of Passau



UNIVERSITÄT PASSAU
Fakultät für Informatik und Mathematik

SummerSoc
Service Oriented Computing

Expectation Management

QPUs in the Cloud

IBM Quantum Platform | Search | 3117569 - Stefanie Scherzinger | us-east

Compute resources

Filtered by region: us-east

Access IBM quantum processing units (QPUs) to run quantum workloads.

Processor types View docs →

Retired QPUs View docs →

small problem sizes

high-maintenance

high latencies due to wait queues

error-prone

Search by name

QPU name	Instance	Qubits ↓	2Q error (best)	2Q error (layered)	CLOPS	Status	Pending jobs	Processor type
ibm_pittsburgh		156	6.4[illegible]	3.12E-3	250K	Online	1,033	Heron r3
ibm_kingston		156	9[illegible]	[illegible]	250K	Online	95	Heron r2
ibm_boston		156	6.06E-4	2.15E-3	245K	Online	57	Heron r3
ibm_fez	QC4QCInstance	156	1.43E-3	6.59E-3	220K	Online	150	Heron r2
ibm_marrakesh	QC4QCInstance	156	1.06E-3	3.47E-3	200K	Online	1,481	Heron r2
ibm_torino	QC4QCInstance	133	1.11E-3	1.10E-2	220K	Online	505	Heron r1
ibm_brisbane		127	3.29E-3	1.70E-2	180K	Online	638	Eagle r3

As of 7-Nov-2025

IBM Quantum Technology Qiskit Product Research Blog Community Resources Sign in to Platform

Choose an access plan

For getting started

Open Plan

Access quantum computers for up to 10 minutes of runtime per month.

Free

Sign up

View features

For small-scale work

Pay-As-You-Go Plan

Pay for the quantum computer access you use. Billed per second of usage.

Starts at $96 USD / minute

Sign up

View features

For project-based work

Flex Plan

Pre-purchase time for projects that require execution flexibility or bursts of sustained usage, starting at 400 minutes per year.

Starts at $72 USD / minute

Contact us

View features

For work at scale

Premium Plan

Annual subscrip n
compute capaci per year.

Expensive!

Starts at $48 USD / minute

Contact us

View features

For unparalleled access

On-Prem Plan

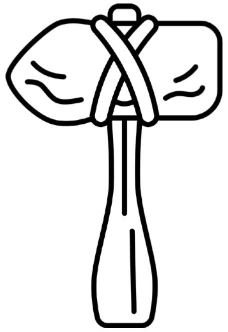
Access to a dedicated on-prem quantum system that is serviced and maintained by IBM Quantum.

Price requires quote

Contact us

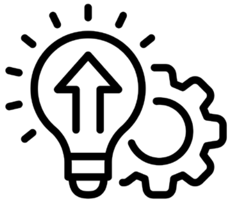
View features

What‘s in it for Data Management Research?



- Hardware is mature enough for early research
- Building up the skills takes time

- Technological prognosis is promising



What‘s in it for Database Systems Research?

- Database systems solve **computationally expensive problems**, and these problems are **commercially relevant**.
- Opportunity for HW/SW co-design, to shape SW interfaces, libraries, benchmarks, …
- Current research questions:
  - **Which problems** are even suitable?
  - **How** can we **correctly encode** these problems?
  - (Not even expecting speedups at this point)
  - Are the **solutions qualitatively different?**
  - How can we **integrate QPUs in DBMS**?

On QUBO

Quadratic Unconstrained
Binary Optimization Problems

Why QUBO?

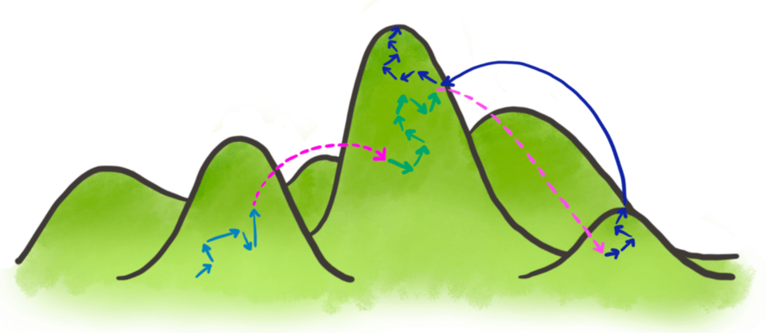
Table I: Recent data management works using quantum computers: an overview

Reference	DB problem	Subproblem	Formulation	Intermediate quantum algorithm	Quantum computer
[20]	Query optimization	Multiple query optimization (MQO)	QUBO	–	Annealing-based
[21], [22]				QAOA	Gate-based
[23]–[25]		Join ordering (JO)		QAOA	Gate-based & annealing-based
[26]				QAOA, VQE	Gate-based & annealing-based
[27]			–	VQC	Gate-based
[28]	Data integration	Schema matching	QUBO	QAOA	Gate-based & annealing-based
[29]–[31]	Transaction management	Two-phase locking	QUBO	–	Annealing-based

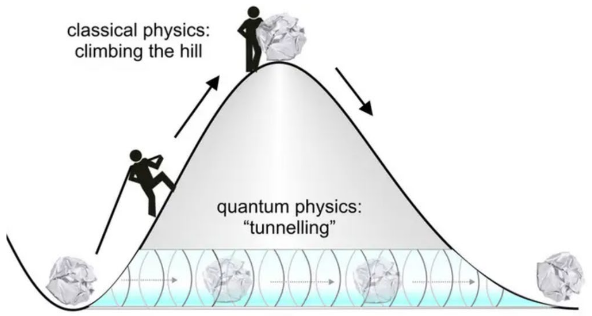
Rihan Hai, Shih-Han Hung, Sebastian Feld:
Quantum Data Management: From Theory to Opportunities. ICDE 2024, Tutorial.

Formulating QUBO Models

- The optimization objective is expressed as a **quadratic polynomial** in the **binary variables**, which we minimize/maximize:



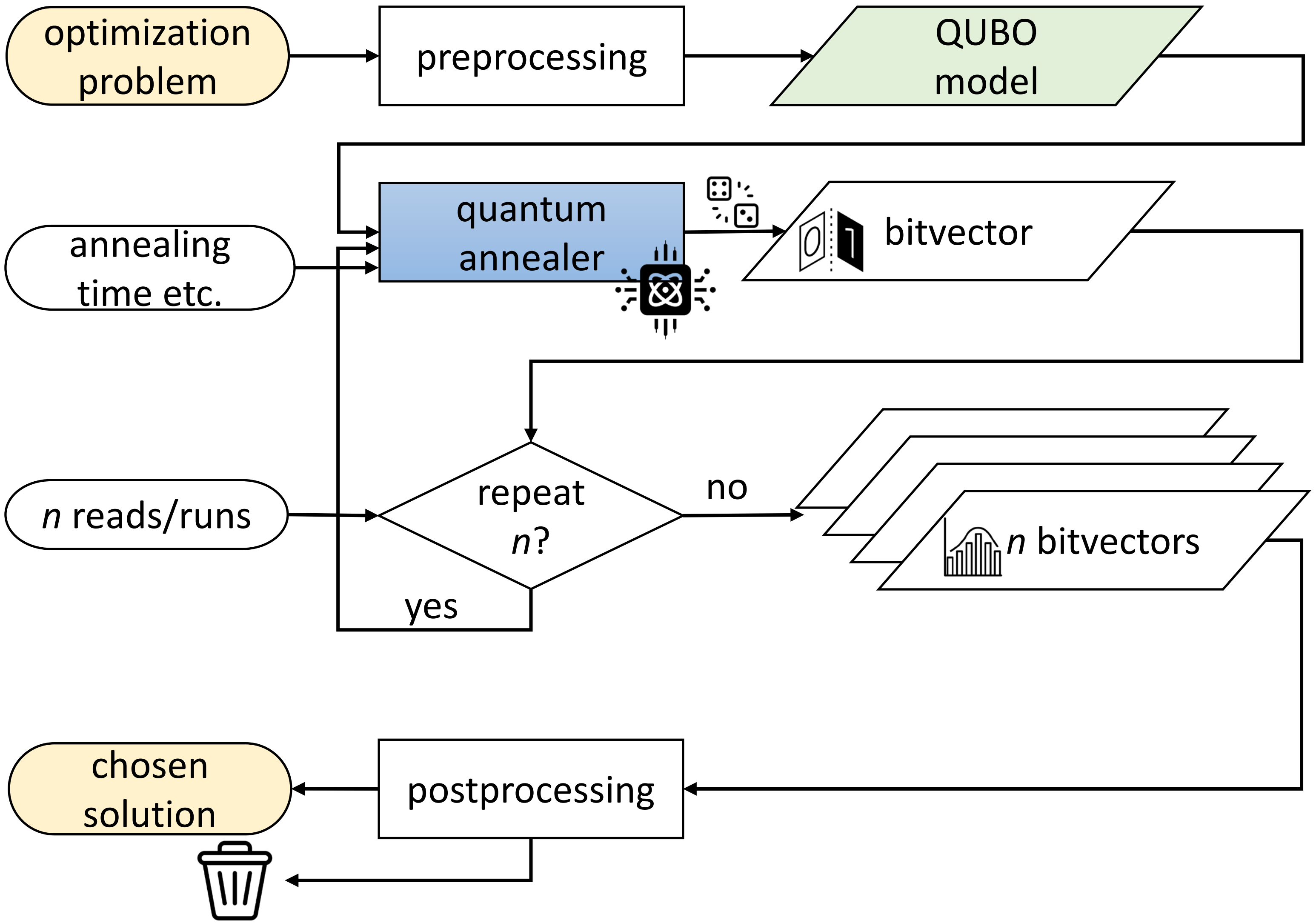
https://vivqu.com/blog/2019/07/12/simulated-annealing/



https://www.mpg.de/549767/electrons-caught-in-the-act-of-tunnelling

- Can be solved by quantum annealers, as well as gate-based QPUs (using QAOA algorithm)

Sample Workflow with Quantum Annealer



Good “nails”:

- optimization problem
- small to encode (qubits are scarce)
- high classical complexity
- pre- and postprocessing should be comp. “cheap”

Quantum Computing for Database Systems

Query Optimization

Multi-Query Optimization

Multi Query Optimization

Immanuel Trummer, Christoph Koch:
Multiple Query Optimization on the D-Wave 2X Adiabatic Quantum Computer.
Proc. VLDB Endow. 9(9): 648-659 (**2016**)

Tobias Fankhauser, Marc E. Solèr, Rudolf Marcel Füchslin, Kurt Stockinger:
Multiple Query Optimization Using a Gate-Based Quantum Computer.
IEEE Access 11: 114031-114043 (**2023**)

Targeted sub-problem:

	Query 0			**Query 1**		**Query 2**		
Plans	p0	**p1**	p2	**p3**	p4	p5	p6	**p7**
Costs	10	**12**	15	**9**	16	7	12	**9**

Combination	**p1,p3**	**p1,p7**	p2,p3	p4,p6	p4,p7
Savings	**4**	**5**	6	7	3

Example from:

Manuel Schönberger, Stefanie Scherzinger, Wolfgang Mauerer.
Applicability of Quantum Computing on Database Query Optimization.
Frühjahrstreffen Fachgruppe Datenbanken in Potsdam (Poster Presentation) 2022.

13

Immanuel Trummer, Christoph Koch:
Multiple Query Optimization on the D-Wave 2X Adiabatic Quantum Computer.
Proc. VLDB Endow. 9(9): 648-659 (**2016**)

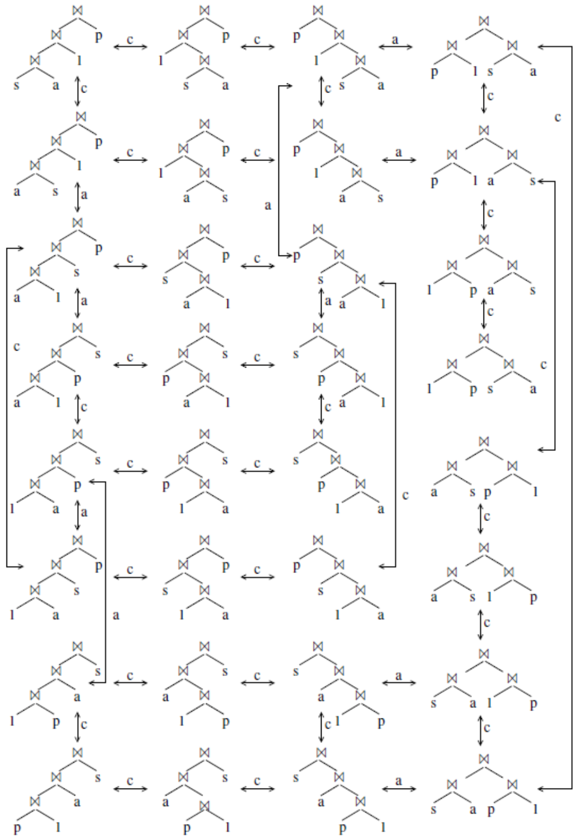
MQO as QUBO

- Binary variable per plan: $x_p = \begin{cases} 1, & \text{plan is selected} \\ 0, & \text{otherwise} \end{cases}$
- To **select a subset of plans**,
  minimize $E_L = -\sum_{p \in P} x_p$
- To **select at most one plan per query**,
  minimize $E_M = \sum_{q \in Q} \sum_{\{p_1,p_2\} \subseteq P_q} x_{p_1} x_{p_2}$
- To **reduce execution costs**, minimize $E_C = \sum_{p \in P} c_p \, x_p$
- To **reward sharing**, minimize $E_S = -\sum_{\{p_1,p_2\} \subseteq P} s_{p_1,p_2} x_{p_1} x_{p_2}$

Cost of plan p

Cost savings due to sharing

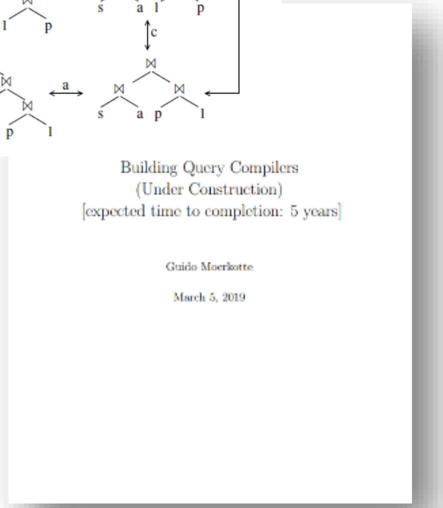
➔ Minimize $w_L E_L + w_M E_M + E_C + E_S$



Query Optimization

Join Order Optimization

Illustration from:



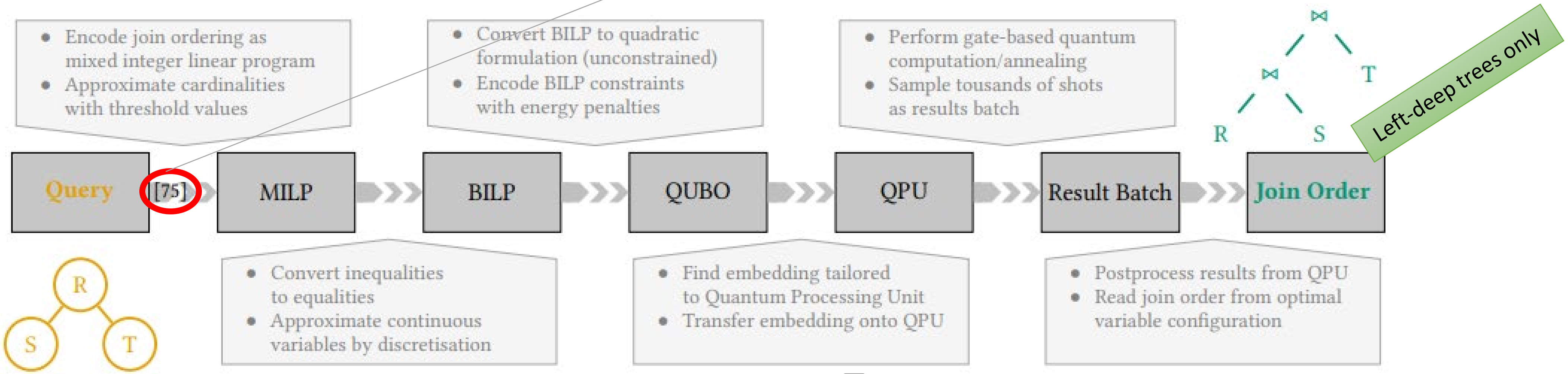
Building Query Compilers
(Under Construction)
[expected time to completion: 5 years]

Guido Moerkotte

March 5, 2019

Join Order Optimization

Immanuel Trummer, Christoph Koch:
Solving the Join Ordering Problem via Mixed Integer Linear Programming.
SIGMOD (2017).



Manuel Schönberger, Stefanie Scherzinger, Wolfgang Mauerer:
Ready to Leap (by Co-Design)? Join Order Optimisation on Quantum Hardware.
Proc. SIGMOD (2023)

Several follow-up works, e.g.

Manuel Schönberger, Immanuel Trummer, Wolfgang Mauerer:
Quantum Optimisation of General Join Trees.
VLDB Workshops 2023

Hanwen Liu, Abhishek Kumar, Federico M. Spedalieri, Ibrahim Sabek:
Hybrid Quantum-Classical Optimization for Bushy Join Trees.
Q-DATA@SIGMOD 2025.

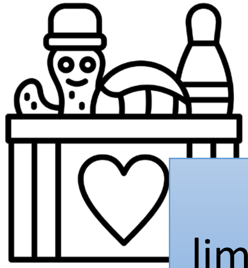
Nitin Nayak, Jan Rehfeld, Tobias Winker, Benjamin Warnke, Umut Çalikyilmaz, Sven Groppe:
Constructing Optimal Bushy Join Trees by Solving QUBO Problems on Quantum Hardware and Simulators.
BiDEDE@SIGMOD 2023: 7:1-7:7

Hanwen Liu, Federico M. Spedalieri, Ibrahim Sabek:
A Demonstration of Q2O: Quantum-augmented Query Optimizer.
VLDB 2025 demo.

Experiments

Table 3. Average fraction of valid and optimal solutions obtained in 1,000 annealing runs (DWave) over 20 JO experiments, depending on annealing time (Δt) and query graph.

Query Graph	Δt [μs]	3 Relations Valid	3 Relations Opt.	4 Relations Valid	4 Relations Opt.	5 Relations Valid	5 Relations Opt.
	10	31.00%	8.69%	1.23%	0.07%	0.12%	0%
Chain	100	37.01%	8.22%	1.53%	0.19%	0.07%	0%
	1000	41.25%	10.30%	1.78%	0.14%	0.15%	0%



Current QPUs
limited to toy examples

Manuel Schönberger, Stefanie Scherzinger, Wolfgang Mauerer:
Ready to Leap (by Co-Design)? Join Order Optimisation on Quantum Hardware.
Proc. SIGMOD (2023)

Quantum Computing for Data Integration

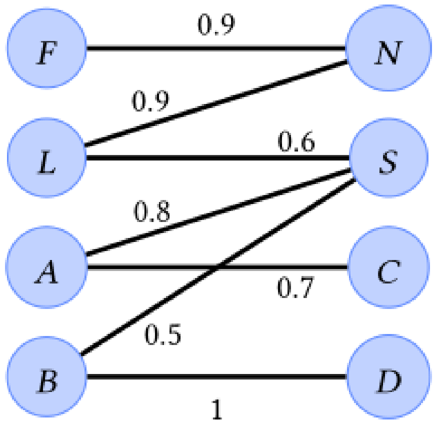
Schema Matching

The Schema Matching Problem

FirstName	LastName	Address	Birthday	ID
Anne	Rose	Domkloster 4, 50667 Köln	15.03.1977	001
Leon	Meyer	Oktavie-Allee, 66687 Wadern	24.12.1958	002
Charlotte	Frey	Maulbeerallee, 14469 Potsdam	09.08.1994	003

Name	StreetNo	City	DateOfBirth
Alice Alison	1402 Broadway Avenue J	Galveston	11/03/1972
Joline Shaw	8601 North Thorne Lane SW	Lakewood	04/23/1981
Bob Smith	80 Hesperus Ave	Gloucester	10/31/1966

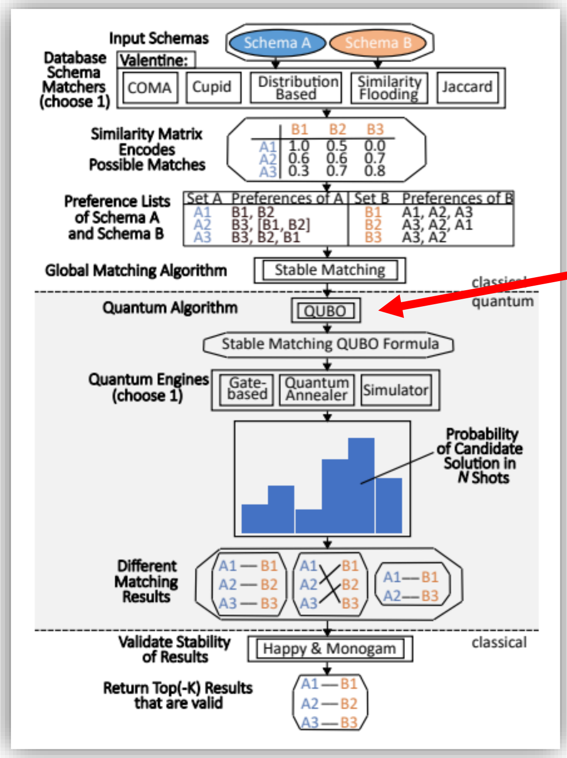
1. local matching



2. global matching?

Example from: Luisa Gerlach, Tobias Köppl, Stefanie Scherzinger, Nicole Schweikardt, René Zander: **A Quantum-Leap into Schema Matching: Beyond 1-to-1 Matchings.** PODS'25.

The Stable Marriage Problem as QUBO Model



$$- p_1 \sum_i x_i \quad + p_2 \cdot \left(\sum_{i,j}^{n} x_{a,b_j} x_{a_i,b} \cdot [\neg b \succ_a b_j \wedge \neg a \succ_b a_i] - \sum_i^{n} x_{a_i,b}[\neg a \succ_b a_i] - \sum_i^{n} x_{a,b_i}[\neg b \succ_a b_i] + 1\right)$$

Penalty | Pair i | Penalty | Pair1: Fixed a and random b | Pair2: Random a and fixed b | Fixed a does not prefer fixed b over Pair1.b | Fixed b does not prefer fixed a over Pair2.a | Pair3: Random a and fixed b | Fixed b does not prefer fixed a over Pair3.a | Pair4: Fixed a and random b | Fixed a does not prefer fixed b over Pair4.b

$$+ p_3 \cdot \sum_{i,j} x_i x_j \cdot [i \neq j]([a_{x_i} == a_{x_j}] + [b_{x_i} == b_{x_j}])$$

Penalty | Pair i and pair j | Pairs are not the same | a from pair i equals a from pair j | b from pair i equals b from pair j

[ ] : boolean expression
$\succ$: strict preference
e.g. a $\succ$ b means a is strictly preferred over b
x_{ab} : pair with candidate a from Schema A and candidate b from Schema B
x_i : matched pair

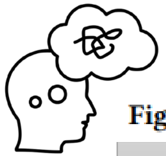
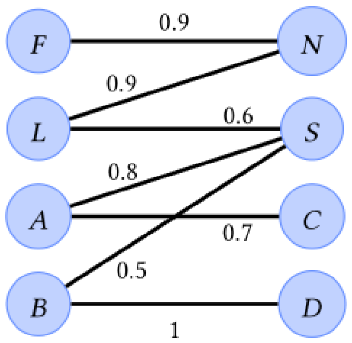


Figure 1: The QUBO formula proposed by [9] for the stable matching problem, annotated for better comprehensibility.

[9] Christoph Roch, David Winderl, Claudia Linnhoff-Popien, Sebastian Feld:
A Quantum Annealing Approach for Solving Hard Variants of the Stable Marriage Problem. I4CS (2022).

Kristin Fritsch, Stefanie Scherzinger: **Solving Hard Variants of Database Schema Matching on Quantum Computers.**
Proc. VLDB Endow. 16(12): Tool demo (2023)

Global Matching Revisited

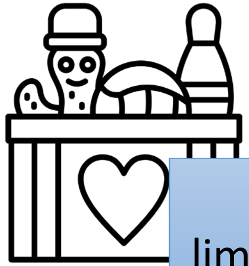


- Novel Quantum Approximate Optimization Algorithm (QAOA) formulation
- Support 1:N/N:1 matchings
- Formal proof that our formulation of the problem is
    - correct
    - NP-complete
- Proof-of-concept implementation: We successfully find solutions for common benchmark scenarios

$$\hat{f}_{\text{no-isol}}(\overline{x}) = (1-x_1)\cdot(1-x_2) + (1-x_2)\cdot(1-x_3)\cdot(1-x_4),$$

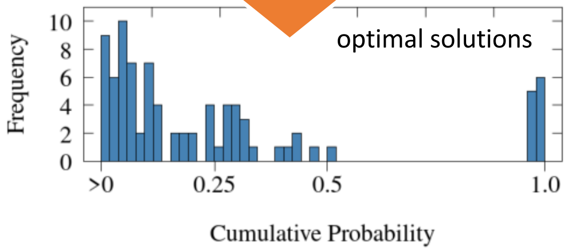
$$\begin{aligned}\hat{f}_{\text{fan-shaped}}(\overline{x}) &= x_1\cdot x_2 + x_2\cdot x_3 + x_2\cdot x_4 + \\ &\quad x_3\cdot x_2\cdot x_1 + x_3\cdot x_4 + x_4\cdot x_2\cdot x_1 + x_4\cdot x_3 \\ &= x_1\cdot x_2 + x_2\cdot x_3 + x_2\cdot x_4 + \\ &\quad x_1\cdot x_2\cdot x_3 + 2\cdot x_3\cdot x_4 + x_1\cdot x_2\cdot x_4,\end{aligned}$$

$$\begin{aligned}\hat{f}_{\text{avg}}(\overline{x}) &= -\frac{0.9+0.9x_1+0.6x_2+0.8x_3+0.7+0.5x_4+1}{1+x_1+x_2+x_3+1+x_4+1} \\ &\quad -\frac{2.6+0.9x_1+0.6x_2+0.8x_3+0.5x_4}{3+x_1+x_2+x_3+x_4}.\end{aligned}$$



Current QPUs
limited to toy examples

$$= \hat{f}_{\text{no-isol}}(\overline{x}) + \hat{f}_{\text{fan-shaped}}(\overline{x}) + \hat{f}_{\text{avg}}(\overline{x}).$$



QAOA with 3 layers,
100 iterations,
and 5K shots

Luisa Gerlach, Tobias Köppl, Stefanie Scherzinger, Nicole Schweikardt, René Zander:
A Quantum-Leap into Schema Matching: Beyond 1-to-1 Matchings. PODS'25.

Latest/ongoing Efforts

Table I: Recent data management works using quantum computers: an overview

Reference	DB problem	Subproblem	Formulation	Intermediate quantum algorithm	Quantum computer
[20]	Query optimization	Multiple query optimization (MQO)	QUBO	–	Annealing-based
[21], [22]				QAOA	Gate-based
[23]–[25]		Join ordering (JO)		QAOA	Gate-based & annealing-based
[26]				QAOA, VQE	Gate-based & annealing-based
[27]			–	VQC	Gate-based
[28]	Data integration	Schema matching	QUBO	QAOA	Gate-based & annealing-based
[29]–[31]	Transaction management	Two-phase locking	QUBO	–	Annealing-based

Since then also
+ index selection
+ data allocation
+ entity matching
+ schema discovery
+ encoding & indexing KGs

+ query containment

Luisa Gerlach, Tobias Köppl, René Zander, Nicole Schweikardt, Stefanie Scherzinger
Quantum Computing for Query Containment of Conjunctive Queries. ArXiv March 2026

Rihan Hai, Shih-Han Hung, Sebastian Feld:
Quantum Data Management: From Theory to Opportunities. ICDE 2024, Tutorial.

Summary

- Quest for suitable database problems continues

- So far, mostly QUBO formulations
- So far, most QUBO formulations presented “on faith”
- So far, most experiments “in vitro”, outside of DBMS, with generous simplifying assumptions

  but also: first attempts at DBMS integration