Using the 5000 qubit D-Wave quantum annealer for improved near-surface characterization

Assoc. Prof. Matthias Möller
Dept. Applied Mathematics, EEMCS

Delphi Consortium Meeting, The Hague
Thursday, June 2, 2022
What can quantum computing do for you today?

A first-of-its-kind application to residual statics estimation and other opportunities in geosciences

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About

- Simulation & optimization, HPC, quantum computing
- 6 PhDs, QAIMS lab +4PhDs, BSc/MSc student projects
- Past and ongoing collaborations
Quantum computing

Hype or reality?
Quantum supremacy using a programmable superconducting processor

Hype or reality?
# Quantum computing

## Hype or reality?

<table>
<thead>
<tr>
<th>Country</th>
<th>EU Funding Source, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>15.0</td>
</tr>
<tr>
<td>European Union</td>
<td>7.2</td>
</tr>
<tr>
<td>United States</td>
<td>1.3</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1.2</td>
</tr>
<tr>
<td>India</td>
<td>1.0</td>
</tr>
<tr>
<td>Japan</td>
<td>1.0</td>
</tr>
<tr>
<td>Russia</td>
<td>0.7</td>
</tr>
<tr>
<td>Canada</td>
<td>0.6</td>
</tr>
<tr>
<td>Israel</td>
<td>0.5</td>
</tr>
<tr>
<td>Singapore</td>
<td>0.3</td>
</tr>
<tr>
<td>Australia</td>
<td>0.2</td>
</tr>
<tr>
<td>Others</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Quantum Delta NL wants to tap 13.6 billion euros in investment potential.

Quantum Delta NL is launching LightSpeed, a program that can bring Dutch quantum startups into contact with 13.6 billion euros in investment capital, placed with European and American funds.

Quantum startups are working on applications for the quantum computer and the quantum internet. This is a new kind of computer in which the processor uses the principles of quantum mechanics. Such a processor can perform the same calculations in one go (in parallel) over a very large amount of data.

The Netherlands currently has 7 official quantum

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**Figures:**
- Germany: 41.9%
- France: 28.0%
- European Union: 14.0%
- Sweden: 11.9%
- Others: 2.6%
# Quantum-computing use cases per industry

## Distribution of quantum-computing use case, 2019, %

<table>
<thead>
<tr>
<th>Industry</th>
<th>Near term</th>
<th>Estimated value at stake¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finance</td>
<td>28</td>
<td>High, Medium, Low</td>
</tr>
<tr>
<td>Global energy and materials</td>
<td>16</td>
<td>High, Medium, Low</td>
</tr>
<tr>
<td>Advanced industries</td>
<td>11</td>
<td>High, Low</td>
</tr>
<tr>
<td>Pharmaceuticals and medical products</td>
<td>9</td>
<td>High, Medium, Low</td>
</tr>
<tr>
<td>Telecom, media, and technology</td>
<td>9</td>
<td>High, Medium, Low</td>
</tr>
<tr>
<td>Public/social sector, professional services</td>
<td>7</td>
<td>High, Medium, Low</td>
</tr>
<tr>
<td>Healthcare systems, services</td>
<td>6</td>
<td>High, Medium, Low</td>
</tr>
<tr>
<td>Travel, transport, and logistics</td>
<td>6</td>
<td>High, Medium, Low</td>
</tr>
<tr>
<td>Insurance</td>
<td>4</td>
<td>High, Medium, Low</td>
</tr>
<tr>
<td>Consumer goods</td>
<td>3</td>
<td>High, Medium, Low</td>
</tr>
</tbody>
</table>

¹. Approximate timing for medium term is by the year 2025, for long term, by the year 2035. Experts consider these values at stake to be a snapshot in time. Fully developed quantum computing will lead to additional value within and shifts between industry verticals.

Source: Expert interviews; McKinsey analysis
Gate/circuit model
Universal/programmable
~ 100 qubits
TRL 4-5 (TRL 9 expected 2035)
Few use cases/algorithms

Quantum Annealing
Task specific (optimization)
5000+ qubits
TRL 8-9
Many use cases

( theoretical )
speed-up

optimal
solutions

Sources: https://www.fz-juelich.de/ias/jsc/EN/Research/ModellingSimulation/QIP/QTRL/_node.html
Michielsen K., FZ Jülich: Quantum Annealing for Optimization and Classification | D-Wave Qubits 2021
Outline

• Quantum annealing 101

• Residual statics estimation using quantum annealing

• Outlook and opportunities for collaboration
Local versus global optima

Local minimum

Global minimum
Brute force sampling
Brute force sampling
Quantum annealing

$H_{\text{init}}$  $H_{\text{problem}}$
Quantum annealing

$same\ for\ all\ problems$

$H_{init}$

$H_{problem}$

depends on your objective function
Quantum tunneling
Outline

• Quantum annealing 101
• Residual statics estimation using quantum annealing
• Outlook and opportunities for collaboration

Stan v.d. Linde
Matthias Möller

Niels Neumann
Frank Phillipson

Marcin Dukalski
Diego Rovetta

TU Delft
TNO
Further information

• Talk and paper at

☞ M. Dukalski
June 7, 2022
10:10-10:30 AM

• Recordings on Youtube
Refraction residual statics estimation (RRSE)

Stack-power maximization in a nutshell
Stack-power maximization in a nutshell

\[
d_m(t_{x_m}) = \sum_{a=1}^{K} \delta_{x_m, a} d_m(t_a)
\]

\[
\max_{\Delta \tau_m} \| \sum_{m=1}^{M} d_m(t - \tau_m) \|_2^2
\]

Ronen & Claerbout (1985)
Stack-power maximization on a quantum annealer

\[
\max_{x \in \{0,1\}^{MK}} \sum_{i=1}^{M} \sum_{j=i+1}^{M} \sum_{a=1}^{K} \sum_{b=1}^{K} x_{ia} x_{jb} (d_i(t_a), d_j(t_b)) - p \sum_{i=1}^{M} \left( \sum_{a=1}^{K} x_{ia} - 1 \right)^2
\]
Synthetics: 16 traces, 4 shifts – problem size $4^{16}$
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SEAM Arid model – problem size $16^{108}$
SEAM Arid model: inputs

Gather of the input traces
SEAM Arid model: deterministic output
SEAM Arid model: hybrid quantum output
This is what quantum computing can do for you today

• ~10% better solutions with hybrid quantum solver than with deterministic solver upon first try out

• results computed within seconds with hybrid solver
This is just the beginning ...


Greer and O’Malley (2020) An approach to seismic inversion with quantum annealing. SEG Conference
... with more to come in the next years
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NWO OTP consortium
- Geophysical applications
- Practical quantum algorithms

Thank you!