Quantum correlations for energy systems

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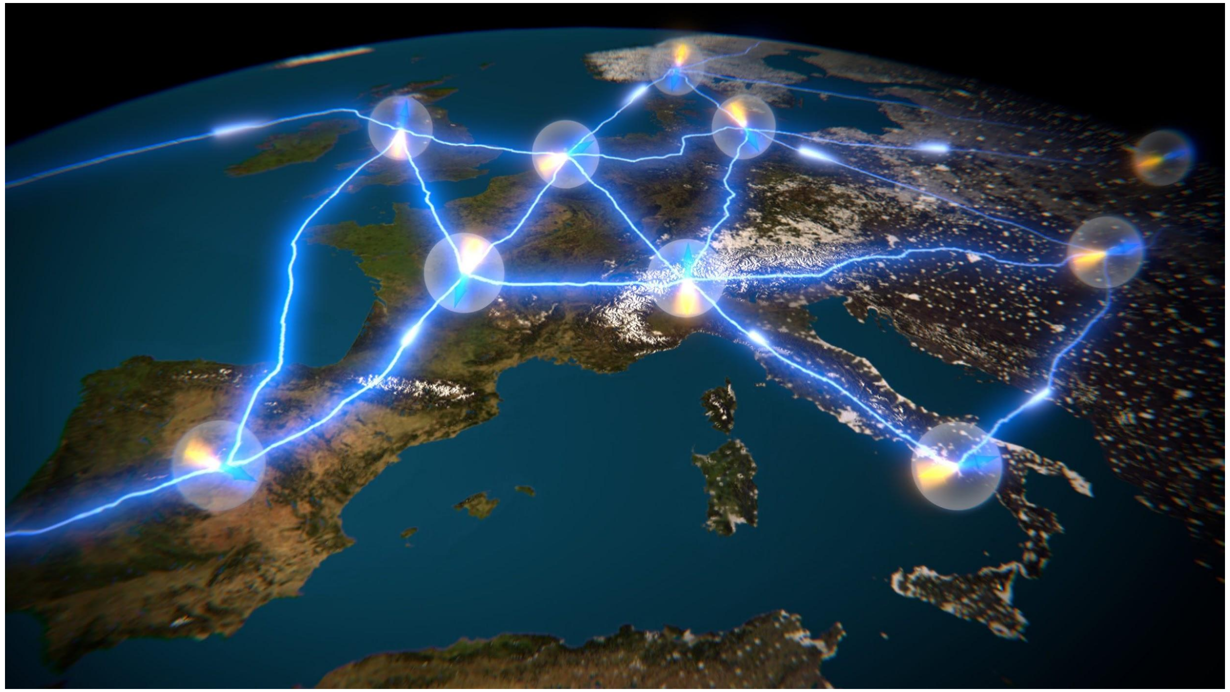
QuTech is a collaboration between TUDelft TNO

Quantum correlations?

Quantum internet: infrastructure to distribute remote entanglement



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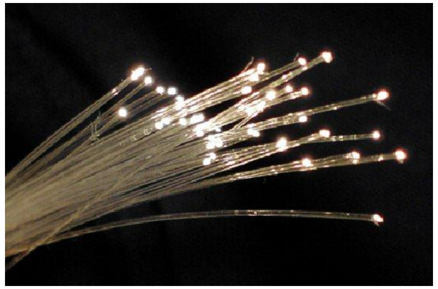
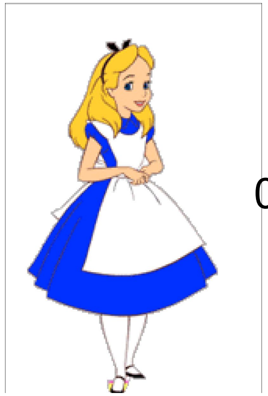
Entanglement

Making entanglement



Physical connection needed!

Using entanglement



0,1,0,0…

1,1,0,0…

Consume **instantaneously**

Non-local games

Alice's input: o_A

Bob's input: o_B

Win condition
$g(d_A, d_B) = f(o_A, o_B)$

Alice's output: d_A

Bob's output: d_B

For some win conditions, Alice and Bob win more with entanglement!

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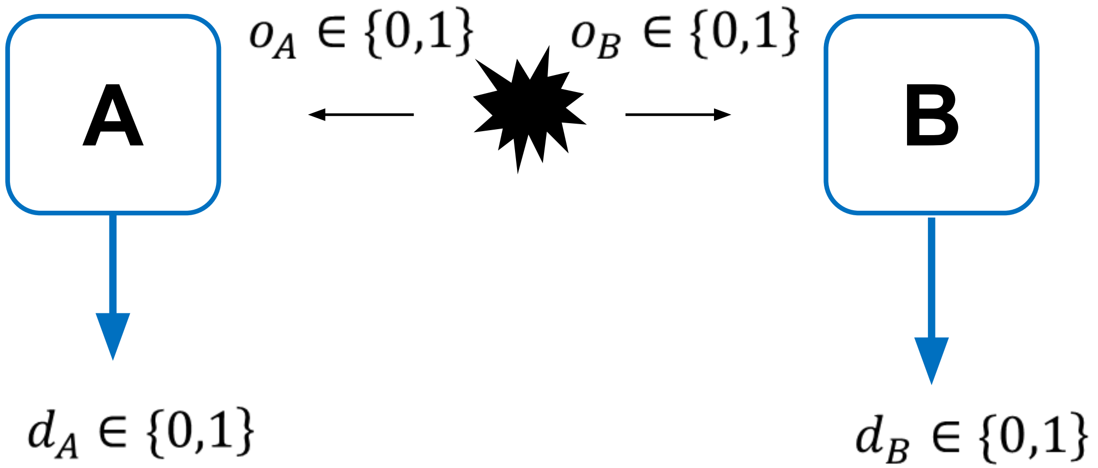
Example: CHSH game



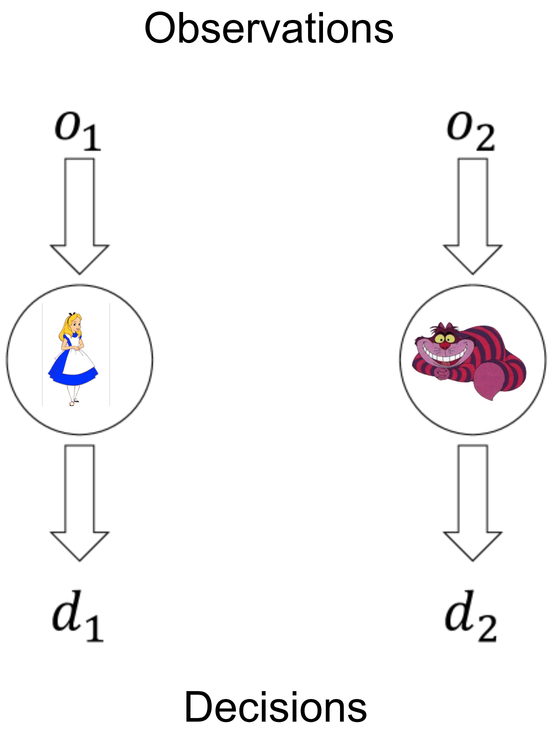
Win condition

$$o_A \cdot o_B = d_A + d_B \bmod 2$$

Classical: $p_{win} = \frac{3}{4}$

Quantum: $p_{win} \approx 0.854$

Latency tacit coordination problems



A **tacit coordination** problem involves **multiple parties** that each make an **observation** followed by a **decision** to optimize a global **utility**.

A **latency tacit coordination** problem involves **multiple parties** that each make an **observation** followed by a **decision** to optimize a global **utility**. The parties do not have enough time to communicate before making a decision.

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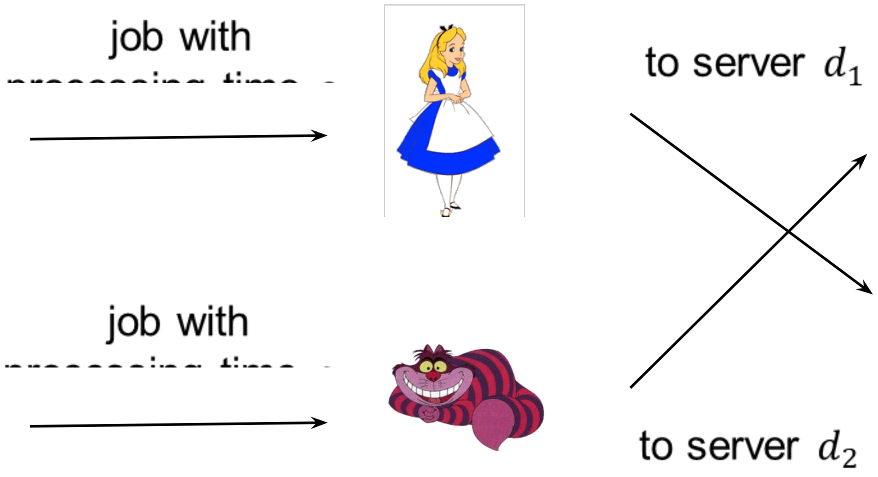
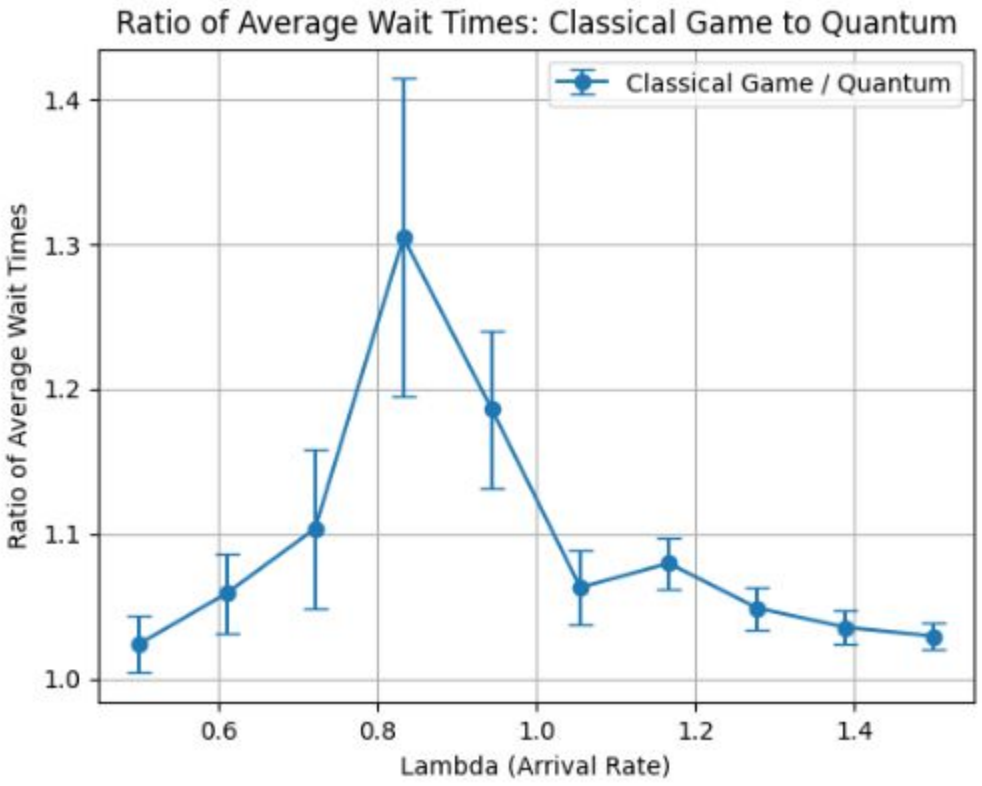
Load balancing as latency tacit coordination problem

Observations: processing time of computing jobs



Decisions: server to send job

Utility: (inverse of) average wait time
threshold-dependent wait time



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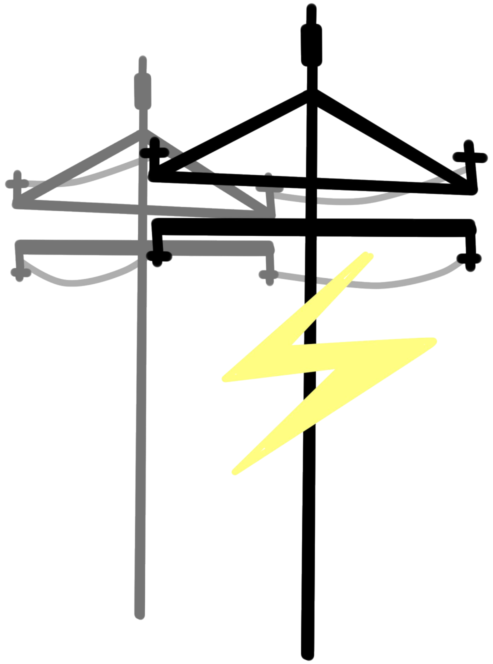
Latency tacit coordination problems in energy systems

Observations: lack of or excess energy

Decisions: (dis)connect from power grid



Utility: function related to grid stability?

Latency tacit coordination problems in energy systems – design process

- Who are  and  ?

- What are their **observations**?

- What are their **decisions**?

- What is the **utility**? How does it relate to a **win condition** with a **quantum advantage**?

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Conclusion

- Latency tacit coordination problems are potential **near-term application** of quantum (communications)
- There are known (academic) **examples** of such problems with **quantum advantage**
- Coming up with more & developing use cases is challenging – but not impossible

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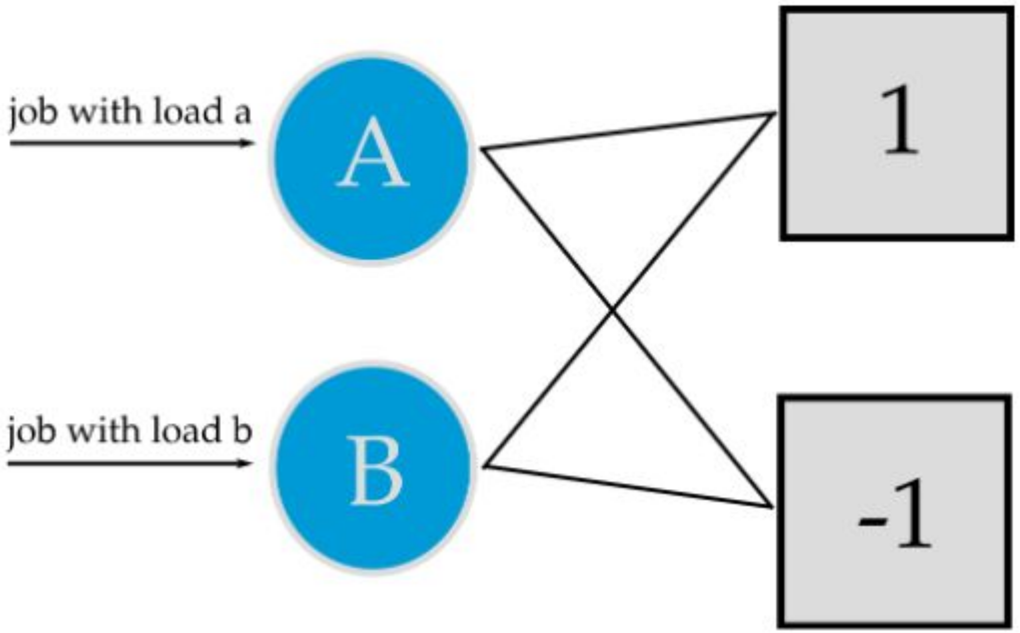
Load sharing with costs for distribution



- Jobs arrive simultaneously following Poisson
- Processing time following exponential
- Equal processing-rate servers

$$t_p = t_1 + t_2 + kc$$

Extra processing time if $t_1 + t_2 > t_t$

$$t_1 \rightarrow t_1 + c$$

$$t_2 \rightarrow t_2 + c$$

Extra processing time separate

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Load sharing with costs for distribution – why?

$t_p = t_1 + t_2 + kc$

$t_1 \rightarrow t_1 + c$

$t_2 \rightarrow t_2 + c$

Extra processing time if $t_1 + t_2 > t_t$

Extra processing time separate

Maybe server slows down if overloaded?

Maybe processing separately incurs extra communication costs?

More importantly: matches non-local game with known quantum advantage!

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Continuous input non-local game

A and B respectively have inputs:

$$a \in [0, m] \;\; b \in [0, m]$$

and outputs:

$$o_a \in \{1, -1\} \; o_b \in \{1, -1\}$$

Win condition:

$$o_a \cdot o_b = \begin{cases} +1, & a + b < m \\ -1, & a + b \geq m \end{cases}$$

Classical win probability: 75%
Quantum win probability: 81.8%

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Mapping the game to load sharing

A and B are sources where jobs appear simultaneously with processing times distributed in

$$t_a \in [0, m] \;\; t_b \in [0, m]$$

They must choose to which of two servers to send their jobs

$$o_a \in \{1, -1\} \; o_b \in \{1, -1\}$$

If the load is below a given threshold, the jobs should be processed together (i.e., correlated outputs); otherwise, apart:

$$o_a \cdot o_b = \begin{cases} +1, & a + b < t_t = m/2 \\ -1, & a + b \geq t_t = m/2 \end{cases}$$

Classical win probability: 75%
Quantum win probability: 81.8%

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