



# UNDERSTANDING QUANTUM ALGORITHMS WITH BOARD GAMES

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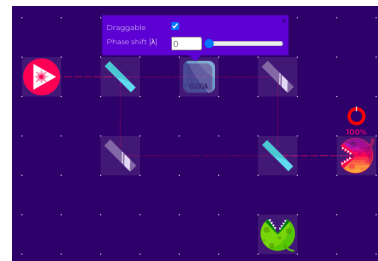
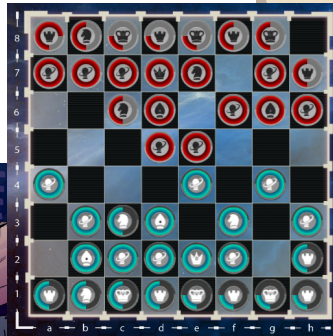
# Quantum Games

An incomplete taxonomy

## Computer Games



2	84	576	576
16	8	32	2
64	128	1024	16
4	256	2	2048



See also: [quantumarcade.org](http://quantumarcade.org)

## Board Games



Save Schrödinger's Cat



## Game-adjacent



**A Search Game**  
**Hadamard's Hoard**

# Hadamard's Hoard

- This game pits a **classical player** against a **quantum player** in a race to find points.
  - **Classical Player:** Searches by flipping over cards.
  - **Quantum Player:** Searches by implementing the quantum algorithm.
  - Divide into groups of 2 (or play as two teams in a larger group).
- The first player to three points in each stage wins
  - As an optional training stage, you will search a database of 4.
  - In the main stage, you will search an unsorted database of 12.
    - Note: Win probabilities roughly balanced for this scenario
  - In the bonus stage, you will search an unsorted database of 30.

# Hadamard's Hoard

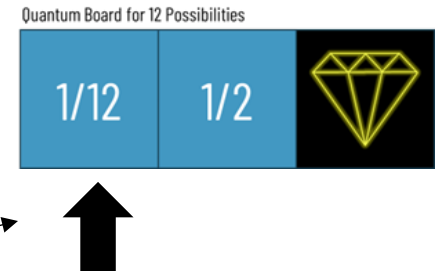
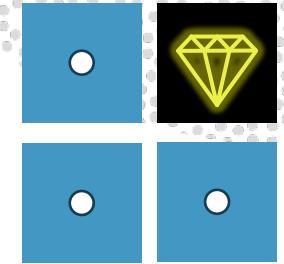
- Intended learning outcomes
  - Role of probability in quantum mechanics and computing
    - An advantage does not guarantee a win each round
  - Scaling differences with input size
    - The advantage grows as the deck grows
  - Pains of trying to actually build the darn thing
    - Hurdles like decoherence mitigate your precious advantage
- Beyond scope
  - Specifics about the Grover construction/oracle
- Misconceptions addressed
  - QCs are just about doing everything in parallel

# Hadamard's Hoard

## *Turn order*

Each turn starts with the classical player, then the quantum player.

- **Classical player:** Turn over one card from your deck.
  - If the card has a gem, collect a point token and re-shuffle your entire deck.
- **Quantum Player:** Choose to either iterate **or** measure.
  - **Measure:** Roll the dice that the arrow currently points to.
    - If the roll is a point, collect a token. If not, do not collect a token.
    - Regardless of the outcome, move the arrow back to the left-most tile after measuring.
    - If the arrow points to the gem tile, you may measure to collect a point without rolling any dice.
  - **Iterate:** Move the arrow one tile to the right.
    - If you move the arrow to the gem tile, you must wait for your next turn to collect the point. This counts as a measurement.
- **Event:** Turn over the top event card and follow the instructions.
  - If this is your first game, you may choose to not include Event cards.
  - Events may affect the Classical Player, Quantum Player, or both.



Special thanks  
Khanjan Soni  
Fiona Thompson  
Jack DeGooyer  
Dev Chauhan  
Stephen Harrigan  
Benjamin Wong

Funded by  
APS Innovation Fund  
CanCode  
Strategic Science Fund

# Thank you!



[www.uwaterloo.ca/iqc](http://www.uwaterloo.ca/iqc)



Quantum for Educators  
Workshop Nov '26



Teacher resources  
[bit.ly/IQC-Teacher-Resources](https://bit.ly/IQC-Teacher-Resources)

# Hadamard's Hoard

- Development flow
  - Conceptualize, go on leave, have time during naps to play around
  - Pilot with a group in a flexible environment (SHAD), feedback, iterate
  - Run by some grad students to ensure you aren't off-the-rails
  - Find some cash in a grant that's about to expire to print some cards
  - Test with some more groups and make it public

Type of group	# of groups	# of participants
High-school	6	139
Undergraduate	2	79
Teachers	3	50



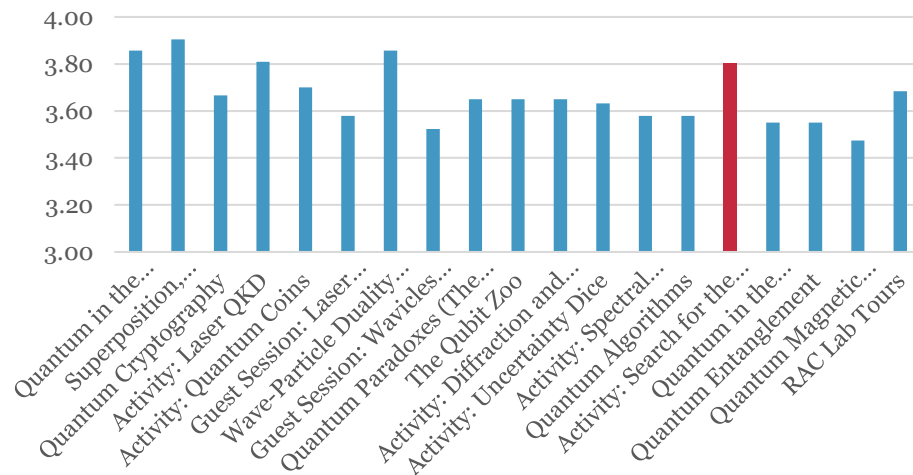
The CENTRE for EDUCATION  
in MATHEMATICS and COMPUTING

# Hadamard's Hoard

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Quantum for Educators 2025  
Most valuable activity for teachers  
from second half of workshop

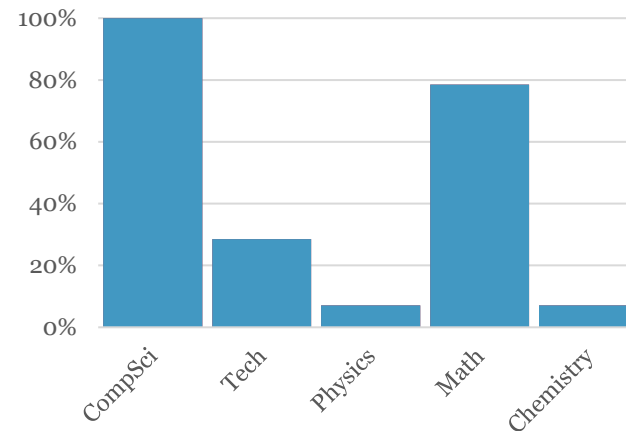
QEd session value by place in schedule, N=21



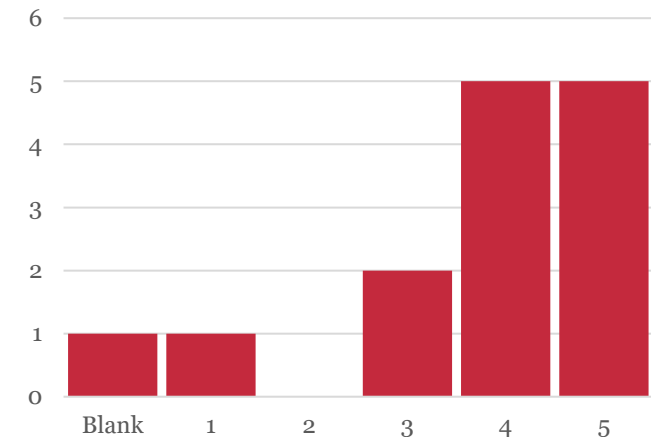
CEMC CS Teachers Workshop 2025  
Strong reports of likelihood to use in class  
(take with a grain of salt)



QSearch Workshop  
Participants by Subjects Taught



QSearch Workshop, Likelihood to Use in Class /5



What was the take-home message?

*Quantum computing will make some things much faster, but not all.*

*Not all tools are better for all tasks.*

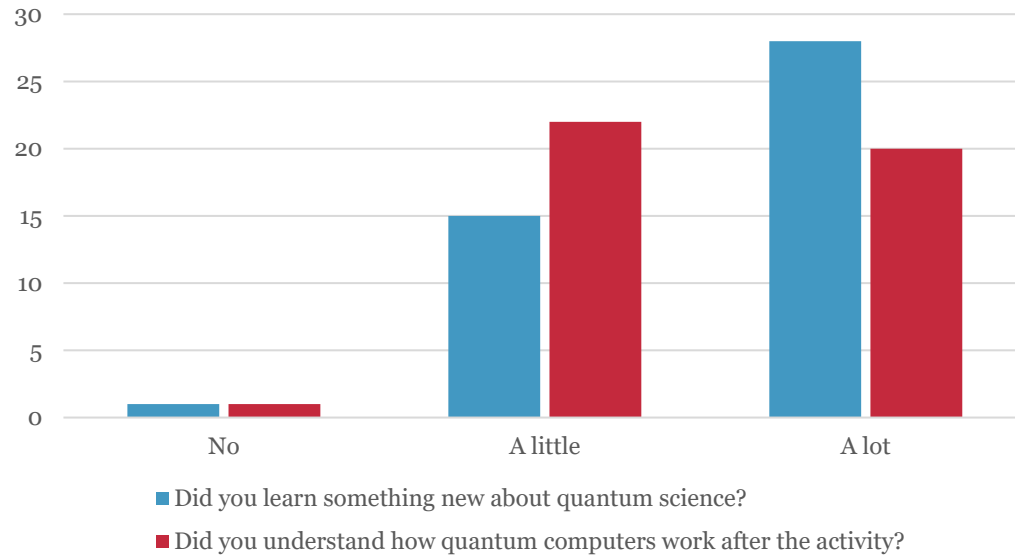
*Quantum can be more accessible than thought.*

*Quantum computing is an important field of studies to follow and experiment with.*

# Hadamard's Hoard



TheMuseum Grade 12 Workshop - QSearch, N=43



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<b>High-school</b>	<b>6</b>	<b>139</b>
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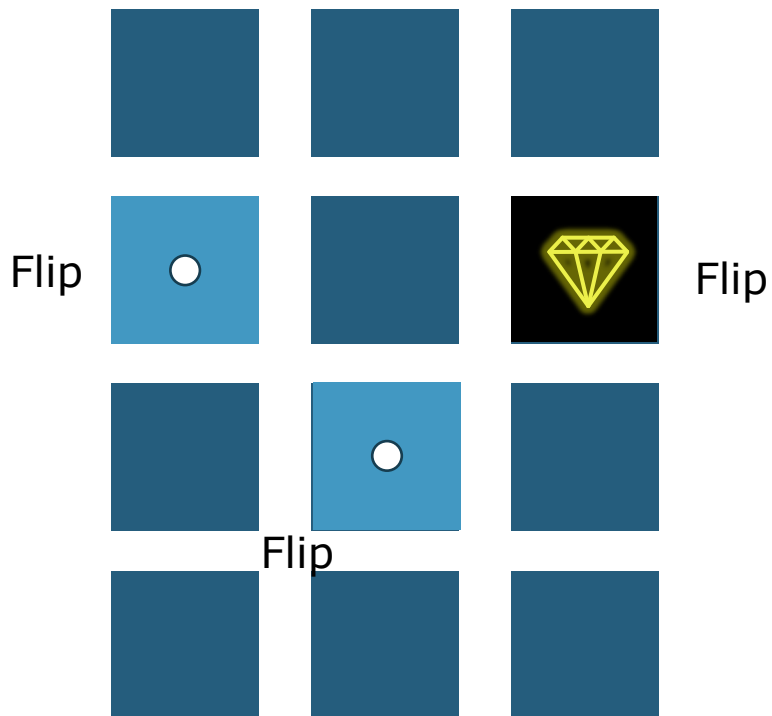
# Hadamard's Hoard

Example Round: Database of 12

Classical Player



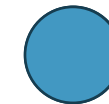
Collect a point



Re-shuffle

Quantum Player

Measure  
(flip coin)



Iterate



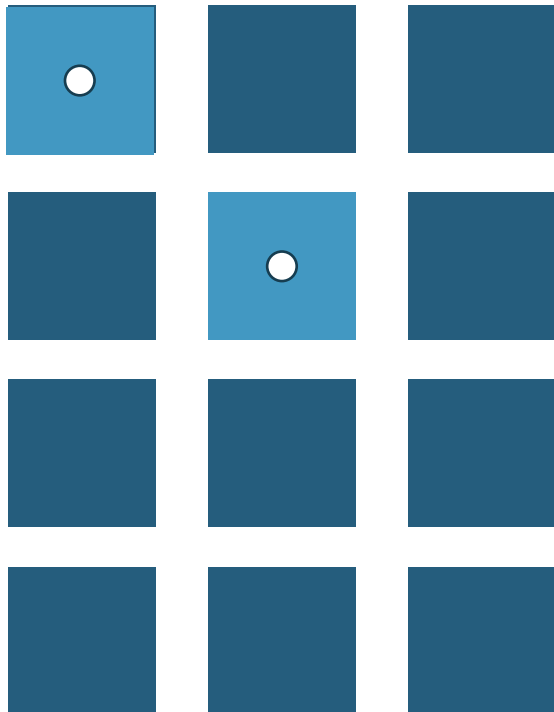
Either way,  
reset to start

(Draw event if using)

# Hadamard's Hoard

*Example Round: Database of 12*

Classical Player



Quantum Player



Measure to collect a point



Iterate



Iterate



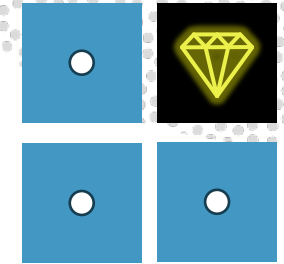
After measurement,  
reset to start

# Hadamard's Hoard

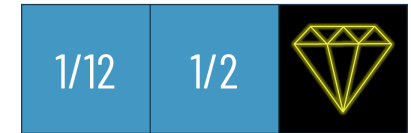
## *Turn order*

Each turn starts with the classical player, then the quantum player.

- **Classical player:** Turn over one card from your deck.
  - If the card has a star, collect a star token and re-shuffle your entire deck.
- **Quantum Player:** Choose to either iterate **or** measure.
  - **Measure:** Roll the dice that the arrow currently points to.
    - If the roll is a star, collect a star token. If not, do not collect a star token.
    - Regardless of the outcome, move the arrow back to the left-most tile after measuring.
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  - **Iterate:** Move the arrow one tile to the right.
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- **Event:** Turn over the top event card and follow the instructions.
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  - Events may affect the Classical Player, Quantum Player, or both.



Quantum Board for 12 Possibilities





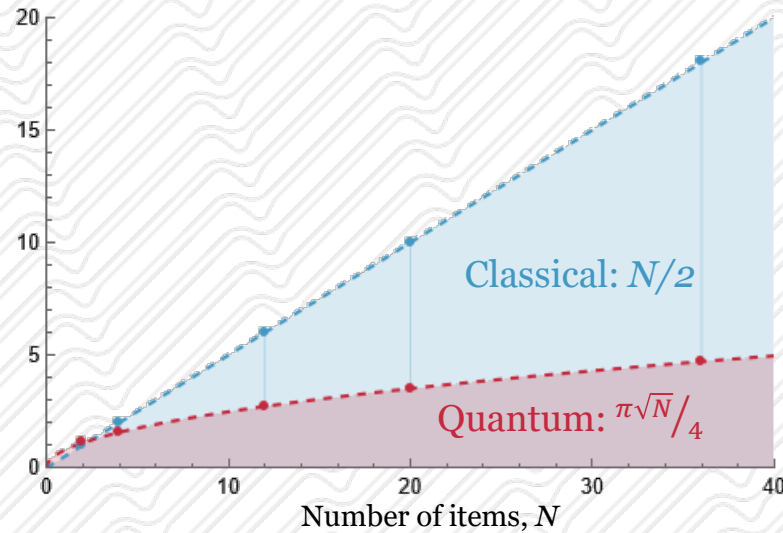
# Hadamard's Hoard

## *Wrap-up*

- Which player has an advantage for a small database of 4?
- Which player has an advantage for a database of 30 elements?
  - The quantum advantage is greater with larger databases
- Is the player with an advantage guaranteed to win?
  - No, the outcomes are probabilistic, it is possible to get lucky or unlucky
- If the classical player can play four times as quickly (draw four cards at a time), who has the advantage for the database of 12?  
What about the database of 30?
  - The extra classical power means they could have an advantage for 12 items, but the quantum player still has an advantage for 30

# Scaling up

Average number of iterations needed



The probabilities in the game are fairly close approximations of the probabilities from an idealized version of Grover's algorithm.

N	Probability of success after X iterations								
	0	1	2	3	4	5	6	7	8
4	25%	<b>100%</b>	25%	100%	25%	100%	25%	100%	25%
12	8%	59%	<b>99%</b>	79%	24%	1%	38%	90%	93%
30	3%	27%	63%	92%	<b>99%</b>	81%	47%	14%	0%
100	1%	9%	23%	42%	62%	80%	93%	<b>99%</b>	98%



# Search for the Stars

## *Wrap-up*

- What does rolling the dice represent in this game?
- Why does the quantum player have to start the process back at the beginning every time they make a measurement?

# Quantum search algorithm

The quantum search algorithm is widely studied and may have some applications, but there are important caveats:

- The database must be compatible with quantum inputs, making it irrelevant for problems like searching “big data”
- The argument only applies to databases which are unsorted and have no structure to take advantage of
- The challenges of using a quantum computer are usually more significant than the advantage of quantum search
  - The advantage over classical is not exponential, like it is for factoring

But similar ideas are applied in other quantum algorithms and technologies.



# **Quantum Search**



# Unsorted Search



You are given a shuffled deck of 52 cards and asked to find the Ace of Spades.

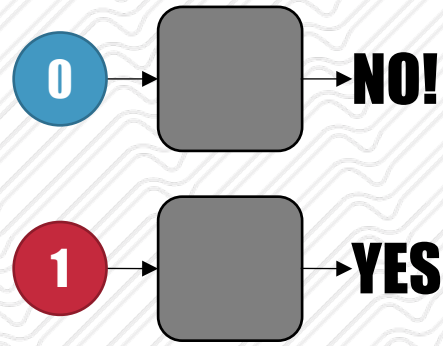
What is the probability you find it on the first try?

On average, how many cards will you need to try to find it?

If there were 1000 cards and only one Ace of Spades, how many would you need to try on average?

This is an example of an *unsorted search* problem. If there is only one “correct” item among  $N$  total items, the number of expected tries is  $N/2$ .

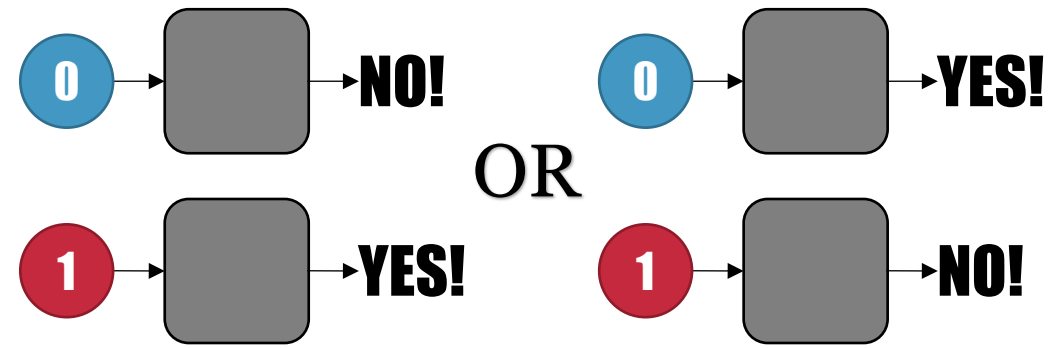
# Quantum Search



Imagine that you had a machine that would say “YES” only if you guessed the correct input, represented a string of bits.

If we could use quantum bits instead, you could send in a superposition of those bits!

The machine will say YES to either 0 or 1.  
What answer will you get if you send in a  
superposition?



**A.** Definitely YES

**B.** Definitely NO

**C.** Something unintelligible

**D.** YES or NO with a 50% probability

The output will also be a superposition,  
which will be one or the other randomly when it  
is measured

**E.** It'll break the machine

# Quantum Search

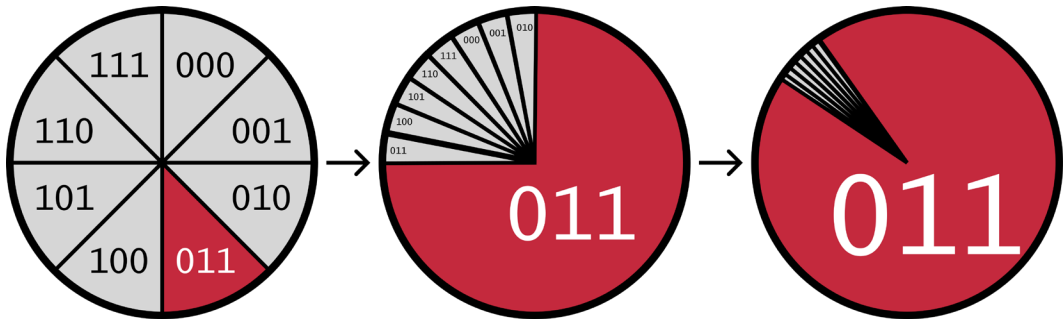
000 → [ ] → NO!

011 → [ ] → YES!

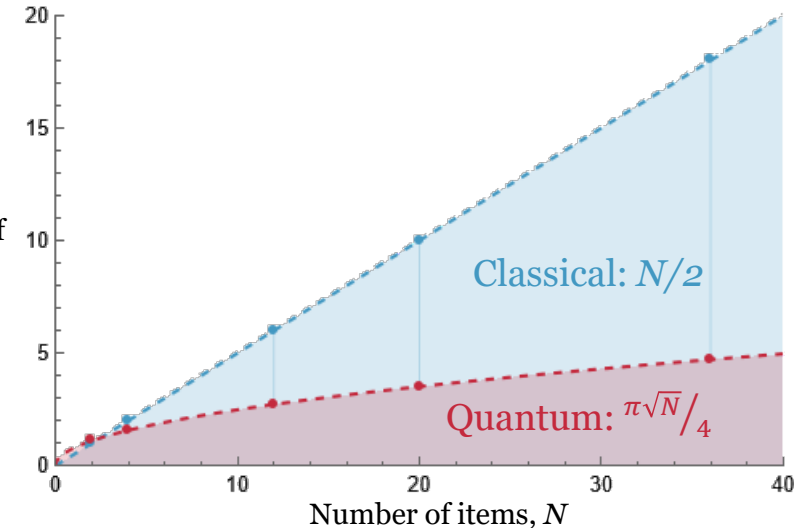
A superposition by itself is not enough, but we can perform other operations on the superposition to change it, similar to phase shifts.

*Grover's algorithm* uses the fact that the superposition changes after interacting with the machine to boost the probability of finding the qubits in the correct state.

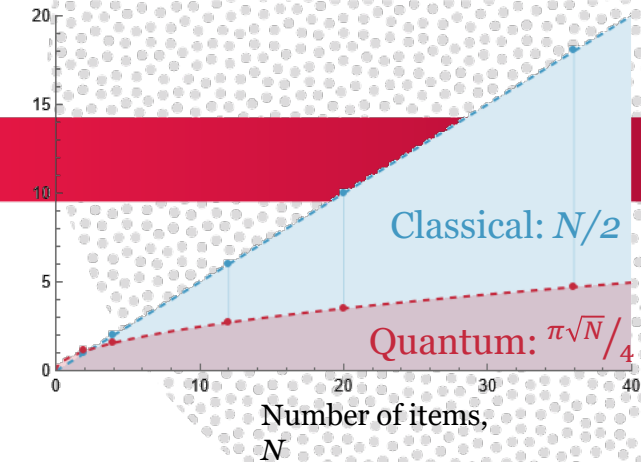
We need to interact with the machine multiple times to find the right answer, on average  $\frac{\pi\sqrt{N}}{4}$  times, much less than  $N/2$ .



Average number of iterations needed



# Quantum vs. Classical



Quantum algorithms can outperform classical ones, but with significant practical challenges:

- **Decoherence:** The quantum superposition is fragile and can be lost over time or due to unintended interaction with the system.
  - **Quantum Error Correction** is one way to build resilience against decoherence
- **Scaling** to larger systems is challenging
  - A classical computer can add more RAM for a linear advantage