# Quantum Computing with Parallel Worlds

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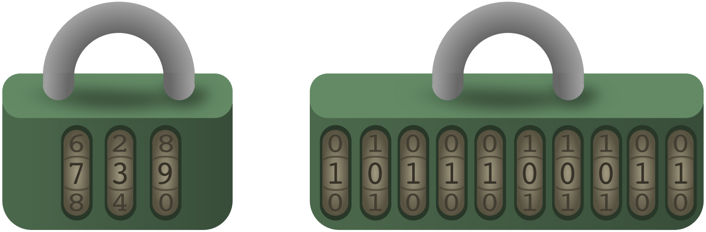
# Introduction

- I'm a theoretical physicist. I study how information escapes from black holes. (Sneakily, is the answer.)

- Sadly, this isn't very techy. So instead, I'll talk about quantum computing and parallel worlds.

# Breaking locks

- Let's focus on a problem: guessing a combination lock. Three-digit locks have $10^3 = 1000$ combinations.




- We could also use a ten-bit lock. This has ten ones and zeroes, with $2^{10} = 1024$ combinations altogether.
- Above, we showed combination 739 in both locks.

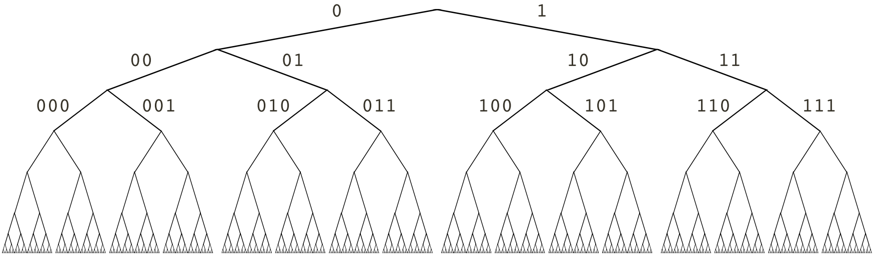
# Brute force

- Brute force is the technique of testing every possibility. For most combinations, this takes a while!

- On average, you will test half the combinations, or $\sim 500$.

# Forking paths

- Let's draw a picture of these choices for the binary lock.

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- In our example, $739 = 1011100011_2$.

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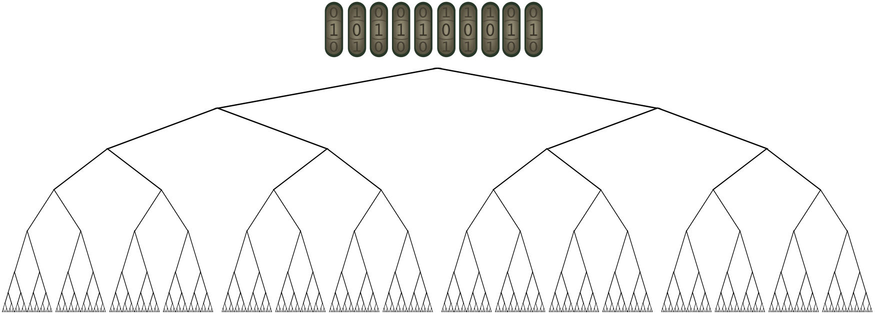

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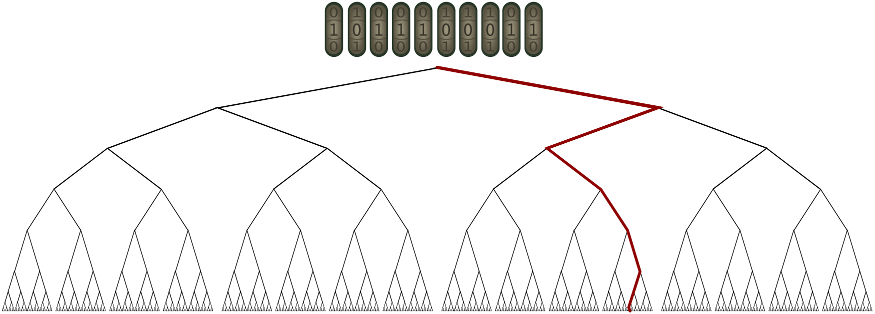

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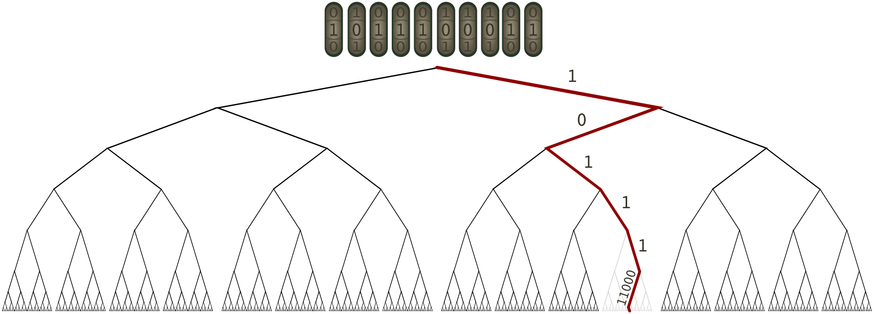


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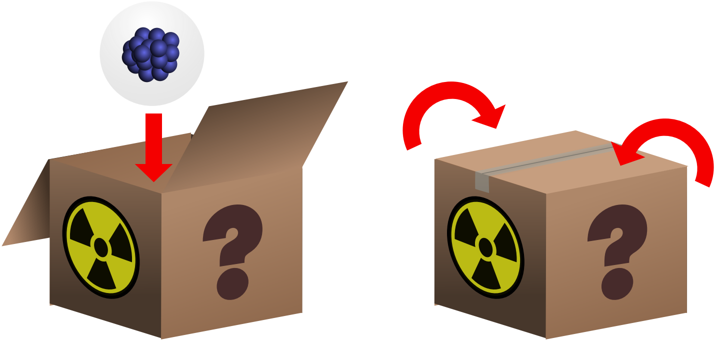
# Parallel worlds

- Each forking path is like a parallel world. Little decisions (like digits in the lock) add up to different realities.


- Breaking the lock means finding the parallel world where we test the right combination. It would be great if we could explore them all at once!

# Schrödinger's magic box

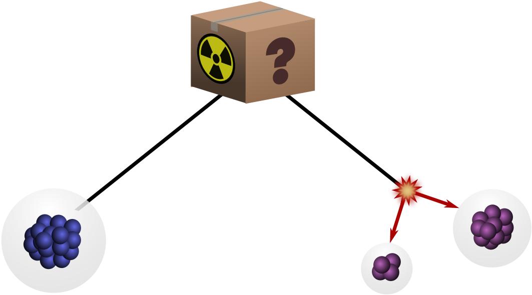
- What if I told you there was a magic box for exploring parallel worlds? And that any box would do?
- It's easy: insert a radioactive isotope and close the lid.



- (This is just Schrödinger's cat, but without the cat.)

# Superposition

- The isotope can either decay or not decay. In fact, according to quantum mechanics, it does both!
- So, our box makes parallel worlds using quantum magic.

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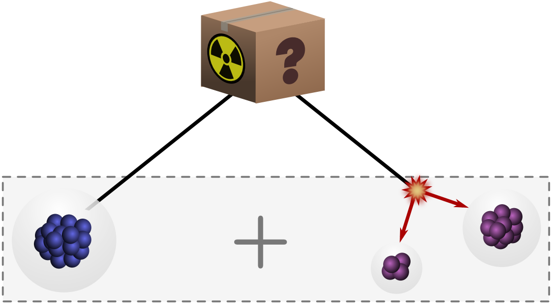


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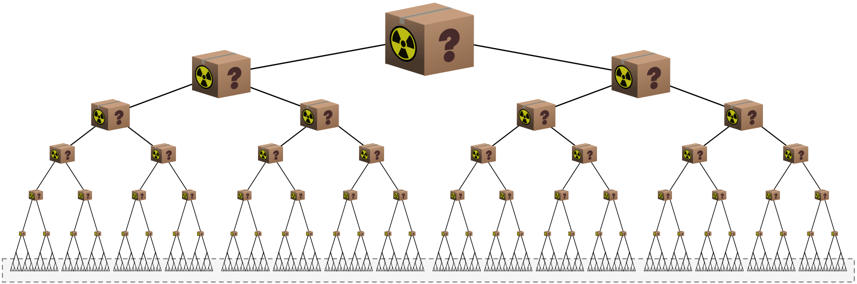
# Parallel (world) computing

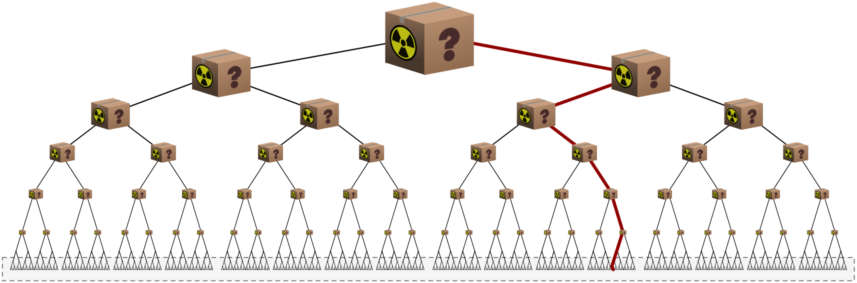
- Maybe you've guessed our next trick: use a magic box to check all lock combinations at once.
- For the ten-bit lock, we need ten isotopes in the box. Each isotope creates parallel worlds for one bit.



- With this superposition, we test all combinations at once!

# The magic portal

- In particular, we test the correct answer. It seems quantum mechanics can break locks instantaneously!



- The catch: looking inside takes you to a random parallel world. Chances are, this isn't the world we broke the lock!
- So, magic boxes are portals to the multiverse!

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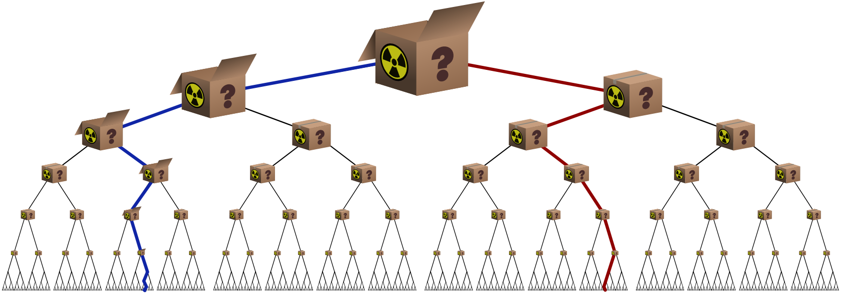

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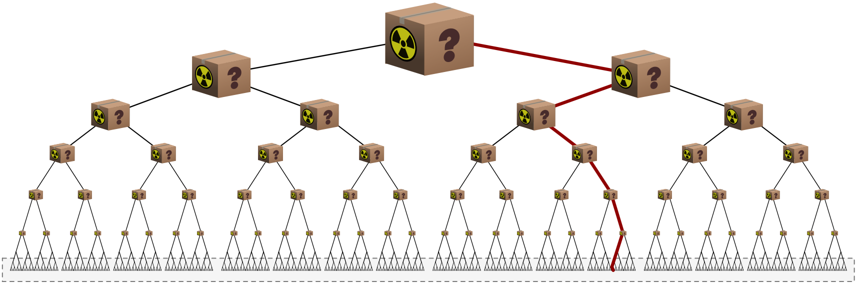
# Shrinking the rectangle

- When we open the box, it takes us to a random point in the grey area. Superpositon giveth and taketh away!



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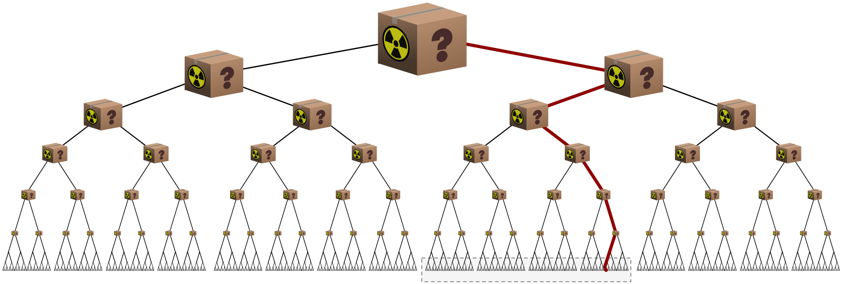

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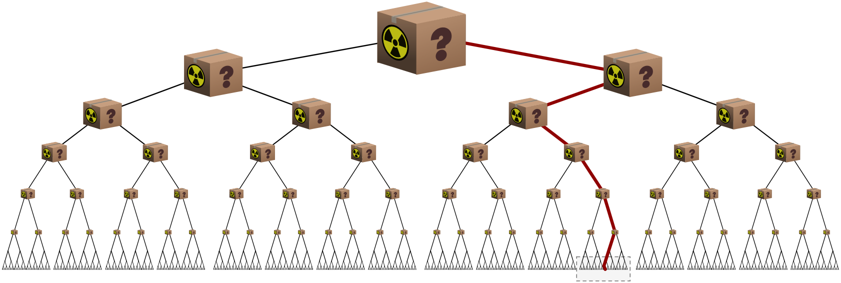

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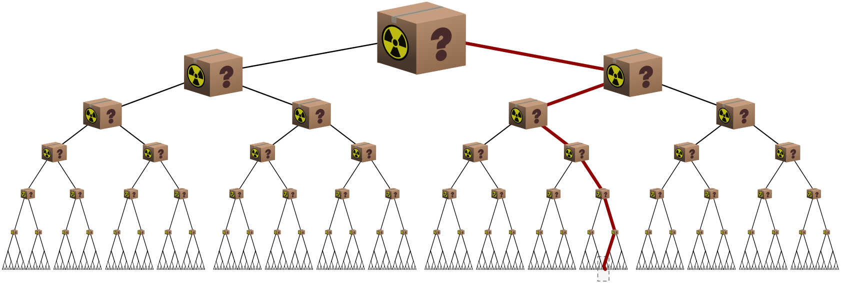

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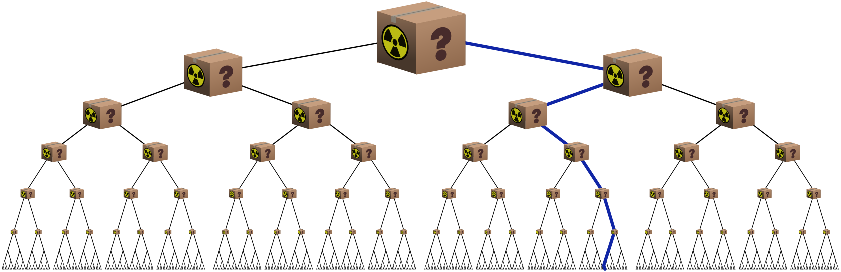

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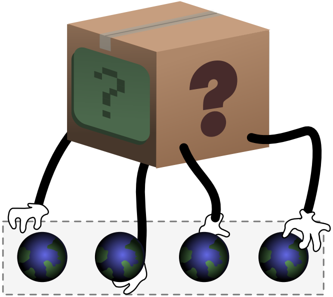
# Quantum computers

- A quantum computer is a magic box to shrinks rectangles. It visits all worlds, ask questions, shuffles them around.



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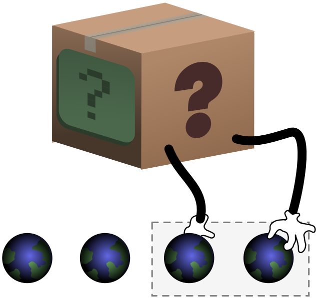

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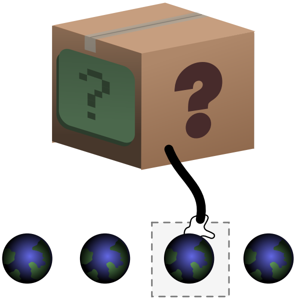


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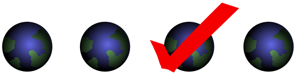

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# The Holy Grail

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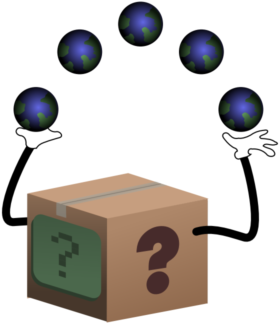
- The long-term Holy Grail is a computer which juggles as many worlds as it likes with long coherence times.



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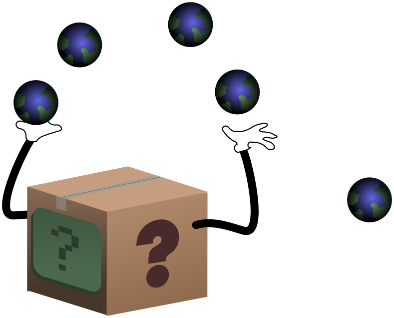


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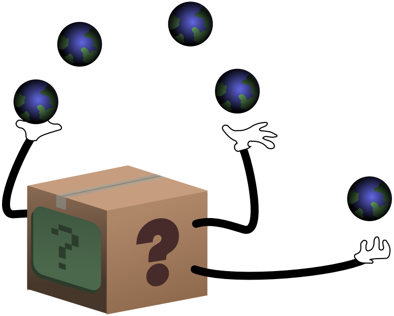

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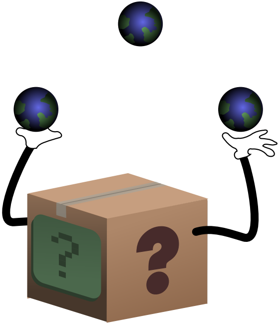
# Breaking the internet

- The Holy Grail is very powerful. It takes about 50 steps to break the combination lock (using Grover search).


- In fact, it can break the internet! Internet security is based on the RSA cryptosystem. This can be immediately broken on a quantum computer using Shor's algorithm.
- So should we be freaking out? Not yet!

# A NISQ-y business

- In reality, the Holy Grail is many years away. It's hard!
- Near term: small, error-prone, and non-universal, also called Noisy Intermediate-Scale Quantum (NISQ).

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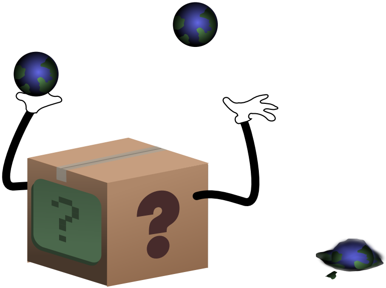

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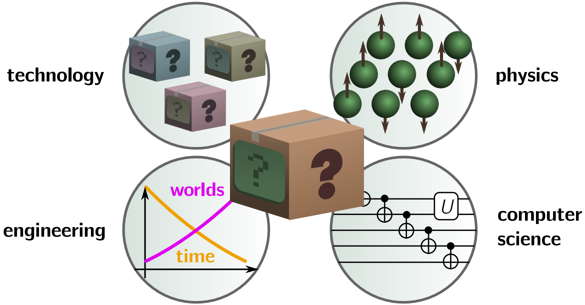
# Conclusion

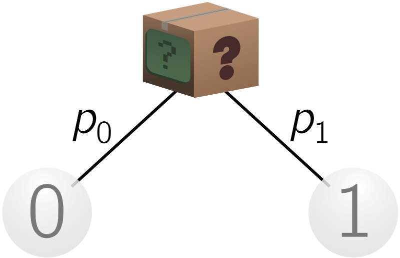
- The billion-dollar question: what can you do with NISQ?
- Short answer: we have no idea! Long answer involves technology, engineering, physics and computer science.




- Career-wise, you could do much worse than trying to build a magic box filled with parallel worlds. Thanks!

# Bonus: quantum lockpicking

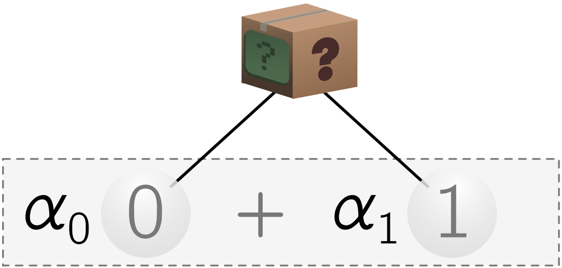
- No doubt, some of you want to know more! Let's see how to break the lock using quantum mechanics.
- For a single bit, if I open the box, I see either 0 or 1.




- These outcomes have different probabilities, which we respectively call $p_0$ and $p_1$. They must add to $p_0 + p_1 = 1$.

# Superpositions and amplitudes

- Remember that a superposition involves both outcomes. We write this as a sum with coefficients $\alpha_0, \alpha_1$.




- The probabilities of seeing 0 or 1 are just these coefficients squared. In math, $p_0 = (\alpha_0)^2$ and $p_1 = (\alpha_1)^2$.

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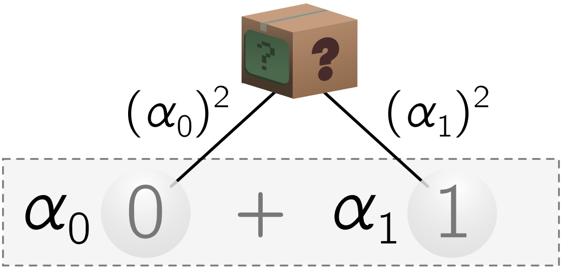


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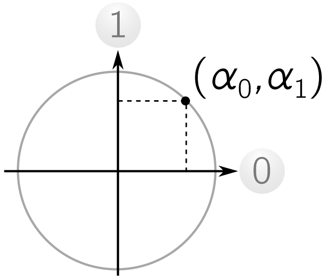
# A circular definition

- But since the probabilities add to 1, this means

$$(\alpha_0)^2 + (\alpha_1)^2 = 1.$$

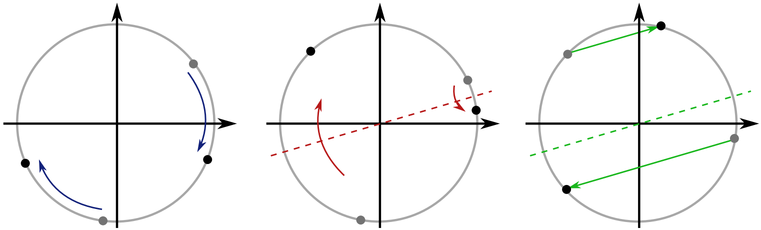
This is the equation of a unit circle!




- So we can draw all the states of a single quantum bit as a circle of radius 1, with coordinates $(x, y) = (\alpha_0, \alpha_1)$.

# Legal moves

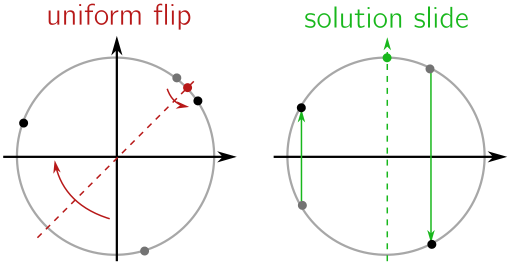
- What moves does quantum mechanics allow? Easy: we can rotate by some angle or reflect around/along an axis.



- You might ask: why are these the legal ones? The answer is that they preserve distances between states.
- (Why is this necessary? Well, because Nature says so.)

# A one-bit lock

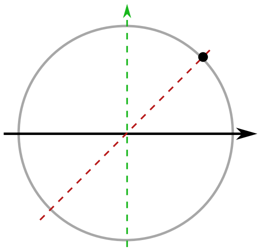
- Let's try and solve a single bit lock. Suppose 1 is the correct combination. We will use two moves:




- The uniform flip flips around the uniform superposition, which has $\alpha_0 = \alpha_1$. The solution slide slides along the axis of the solution, vertical for 1 and horizontal for 0.

# A bit too hard

- Let's start in the uniform superposition and try to get close to the solution. That increases our chances of observing 1 when we open the box! (Right now it's 50%.)



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- At each point, there's only one sensible operation to use, and none get us closer to the answer (the vertical axis).

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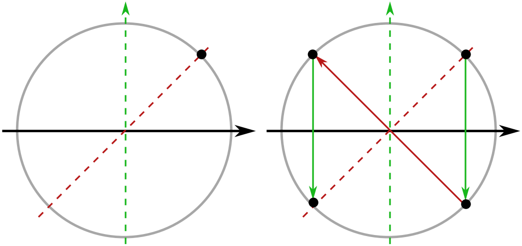

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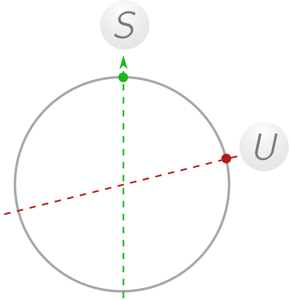
# Many bits make Grover work

- Let's try more bits! We draw a similar circle, containing the uniform superposition $U$ and solution $S$.
- With many bits, the angle between $U$ and $S$ gets bigger.

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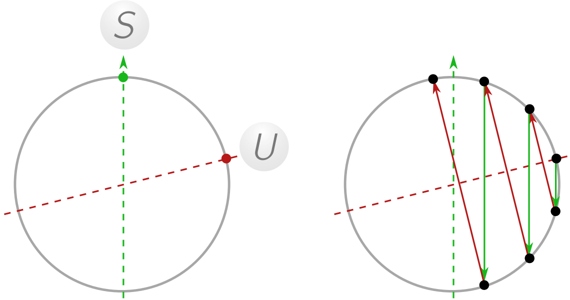


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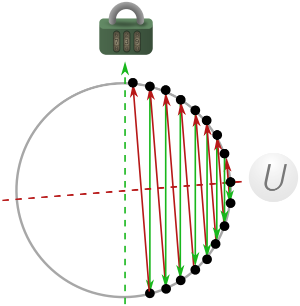
# 49 steps

- In general, for $N$ different lock combinations, it will take around $(\pi/2)\sqrt{N}$ flips and slides.

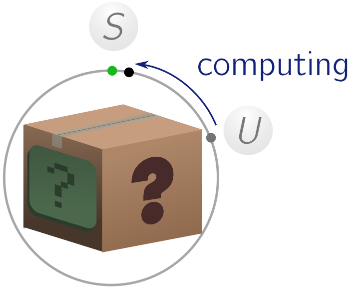



- For instance, for our ten-bit lock, the number of steps is

$$\frac{\pi}{2}\sqrt{2^{10}} \approx 50.$$

# Bonus conclusion

- So, “shrinking the rectangle” really means rotating the state of the magic box close to the answer.




- Then the probability of falling into the universe where we solved the problem (once we open the box) is high.
- Hope this gets you excited to learn more!