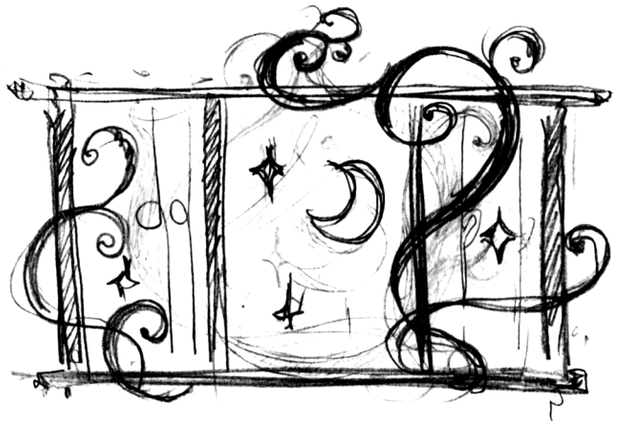
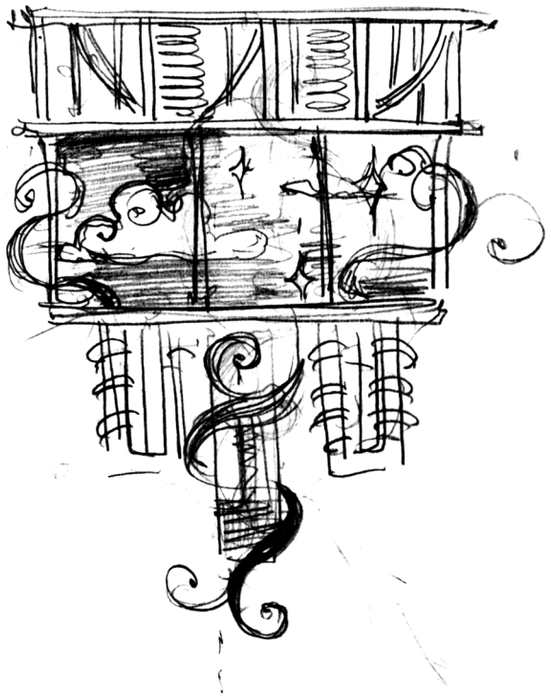
QUANTUM TALES

Spencer Churchill



Acknowledgments

Thank family and friends for reading the stories and listening to me during the process. Thank the Fiverr artist for the illustrations. Thank the Qiskit community for valuable feedback about which quantum algorithms to cover. Thank Unitary Fund for enabling me to write and bring these stories to life.



Introduction

Fairy Tales

- The Cowherd and the Weaver Girl (牛郎侄女) — China
- Goldilocks and the Four Bears — United Kingdom
- Ali Baba and the Forty Thieves (علي بابا والأربعون لصاً) — Syria
- The Tortoise and the Hare (χελώνα και ο λαγός) — Greece

Quantum Algorithms

- Quantum Teleportation
- Deutsch-Jozsa Algorithm
- Shor's Algorithm
- Grover's Algorithm

Quantum Circuits

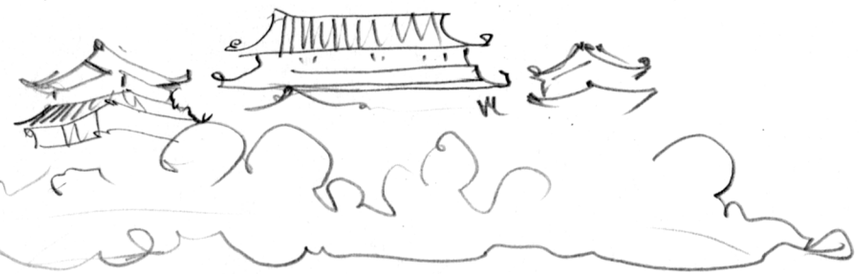
Displayed at the end of each story to show the reader the quantum circuit used in the story.

QR Codes

Links to a gist with the code and how it ties into the story. Readers can scan or click the QR code to learn more about the algorithm.

Ways of Reading

How to read the stories: just story for someone wanting to see future application, story and circuit for those who want a more involved experience, and the QR codes for readers curious about the designing and running of the algorithms on real quantum hardware.



The Cowherd and the Weaver Girl

Quantum Teleportation

One Tuesday afternoon, seven imperial daughters of heaven came down from their palace to bathe in a clear lake. While they were bathing, a breeze blew the skirt of Zhīnǚ, the youngest sister, into the lake. Her six sisters laughed as they put on their dry clothing and returned to heaven.

Passing by the lake to water his oxen, Niúláng saw the lovely girl sitting by the lake. Quickly, he took off his outer suit and covered the lady. She explained to him that her clothes were wet from the lake and Niúláng, charmed by Zhīnǚ, offered to show her the area while her clothes dried.

Niúláng led Zhīnǚ up a nearby hill that overlooked the lake and surrounding countryside. He explained that he often let his cows graze here as he watched the colorful clouds overhead. Niúláng continued describing the hues of these beautiful clouds and had no idea why she was blushing and smiling.

Zhīnǚ fell in love with Niúláng and revealed that she was the one who had woven the clouds from heaven. They returned to the lake together, and Niúláng tossed Zhīnǚ's clothes in the lake and asked her to remain with him until her clothing dried. She smiled and happily agreed.

They continued living together, falling deeper in love, and eventually had two children. All the while, her heavenly dress remained at the bottom of the lake.

Zhīnǚ's mom, Xīwángmǔ, realized her daughter isn't weaving colorful clouds and discovered she had married a mortal. Angry at the princess, She forced her to return to Heaven.

Niúláng was devastated that his wife had been taken from him, but his ox spoke. The ox told Niúláng that, if he killed him and wore his skin, he could ascend to Heaven and find his wife. With a heavy heart, Niúláng killed the ox, covered his shoulders with its skin, and carried his children to Heaven.

Niúláng and Zhīnǚ were so happy to be reunited, but Zhīnǚ knew her mother well and what was to come. She warned Niúláng that his arrival in Heaven would infuriate her mother and they'd most likely be separated again.

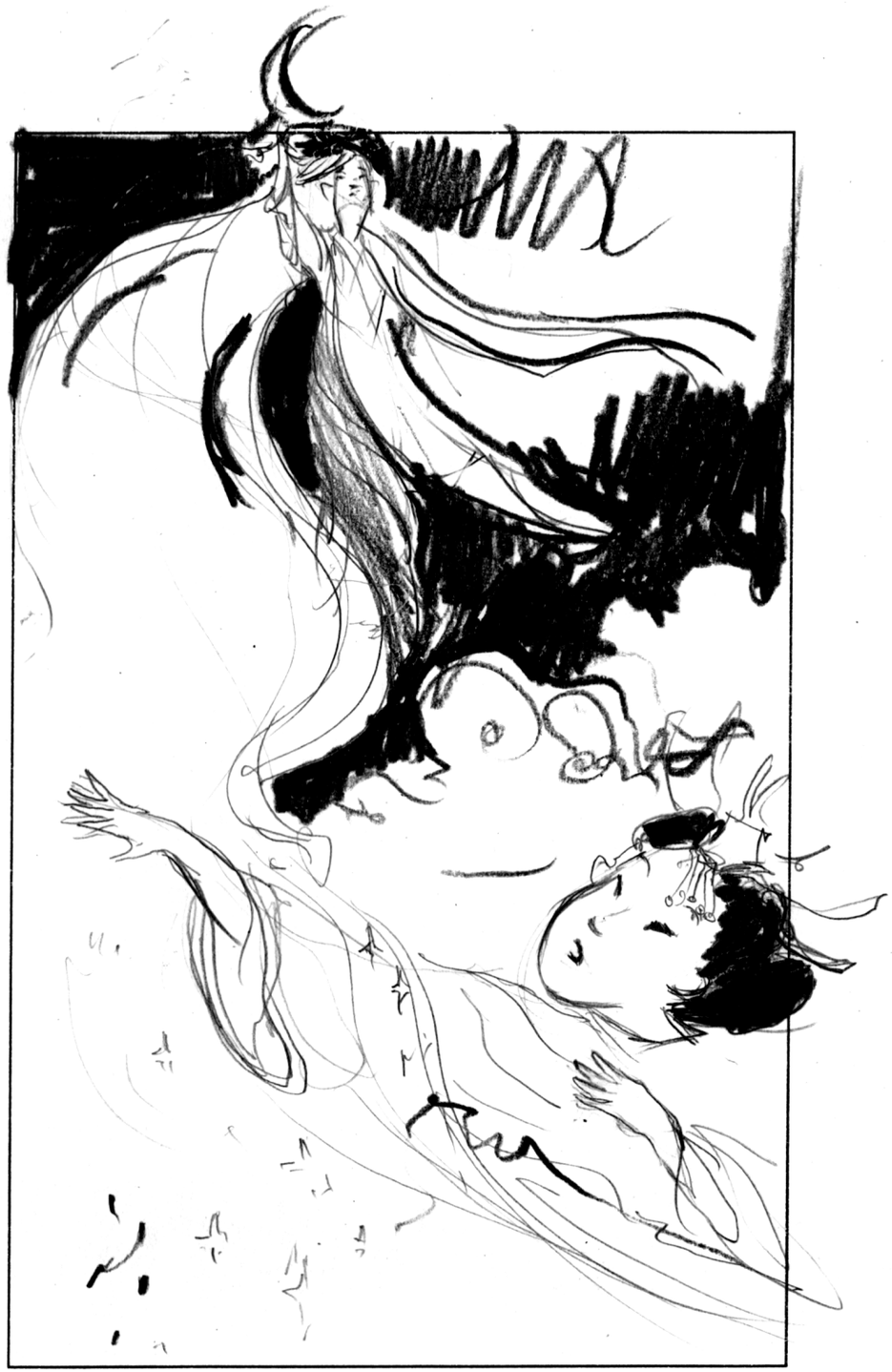
Luckily, Zhīnǚ had learned from Yùhuáng, her dad and incidentally, the ruler of heaven, about how to communicate across heaven.

As any good emperor knows, effective communication is key to maintaining power, and Yùhuáng had devised the best method in the universe. He referred to this method

as Quantum Teleportation, a way to communicate information at the speed of light without fear of spying.

Niúláng listened as Zhīnǚ imparted what her father had explained to her. They could create entangled pairs of particles to use each day to message each other, despite what Xīwángmǔ may try. A qubit state can be sent with two photons across the universe, and act as a key for future messages. In this way, they can encode and send photons carrying quantum information to be received and decoded only by the intended recipient.

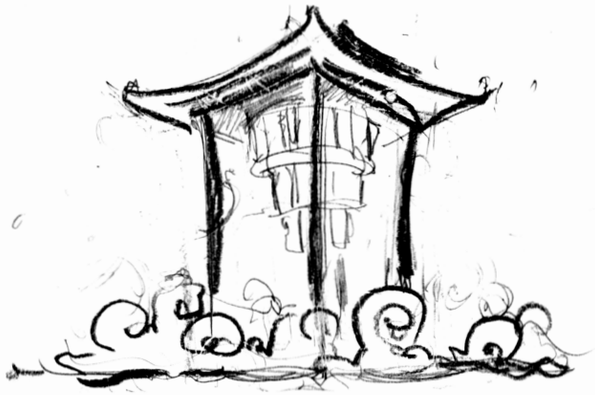
Xīwángmǔ soon saw Niúláng with Zhīnǚ in Heaven. Enraged, she drew her jade hairpin, and as her hair tumbled around her feet, slashed a river between the couple, forming the Milky Way.



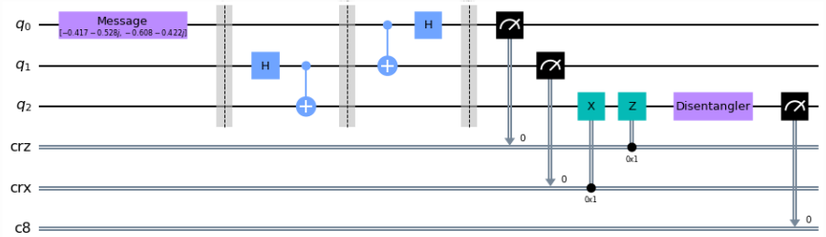
The two lovers now forced apart, remained separated by the heavenly river. But, with their entangled particles, they sent messages back and forth, throughout the year. Though Xīwángmǔ tried her hardest, she could never read the couple's messages.

On Earth, the magpies, curious upon finding a new river of stars in the sky, flew up to ask Zhīnǚ what happened. She explained what her mother had done, and that she and Niúláng needed a way to entangle more particles each year to send messages. The magpies listened and on the seventh night of the seventh moon, flew to Heaven and formed a bridge across the Milky Way.

In this way, despite her mother's interference, Zhīnǚ and Niúláng continue entangling particles and sharing their love across the universe.



Quantum Circuits



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GOLDILOCKS AND THE FOUR BEARS

Deutsch-Jozsa Algorithm

A field of wildflowers extended from a small town toward a forest. Picking her way through the field was a girl with golden hair. As she walked, she hummed and searched for perfect flowers. You see, this girl was Goldilocks, and she needed everything to be just right.

She searched, but not many flowers met her exacting requirements, so she ventured deeper into the forest. After some time had passed, Goldilocks finally had the most beautiful bouquet of honeysuckles and merrybells. But she had been without refreshment for too long and needed a break.

Almost as if she were in a fairy tale, she spied a small house sitting in a small clearing deep in the forest. The house looked cozy, and delicious scents wafted toward her. She hastened to the door, hoping for food and drink.

Goldilocks knew the aroma of fine cuisine, but what she didn't know was that the house was home to three bears.

Luckily for Goldilocks, the three bears had ventured into their forest to work up an appetite and wait for their dinner to cool down.

Goldilocks knocked, waited, then knocked again. There was no response. The smells of freshly-made supper filled the porch and she couldn't help but open the door.

Inside, she found a table with three chairs, three bowls of porridge, and one quantum computer. She waited patiently in the smallest chair, which was just right, sniffing at the bowls of porridge.

Since the lodgers were taking their time, she assumed they weren't hungry and decided to further investigate their porridge.

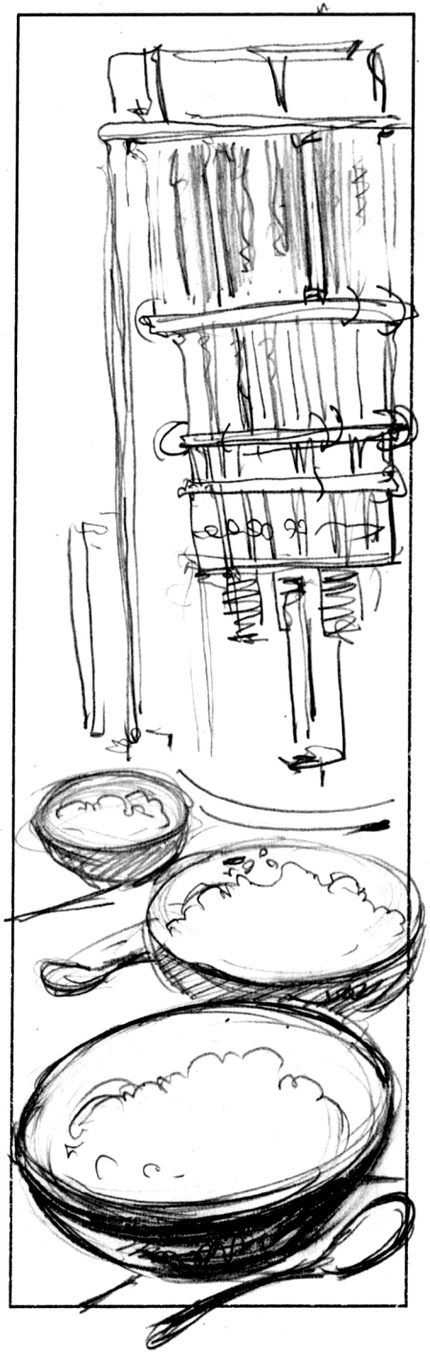
Each bowl was a different size, and she knew that would

change the temperature of the porridge. Not wishing to taste too hot or cold of porridge, she instead turned to the quantum computer.

Goldilocks was a fan of flowers and porridge, but she was also well-versed in quantum algorithms. By considering her porridge problem as each bowl returning a completely hot or cold spoonful of porridge, or a perfect mix of hot and cold porridge, she could apply the Deutsch-Jozsa algorithm.

Initially, David Deutsch and Richard Jozsa only proposed this algorithm to demonstrate a case of quantum superiority over classical computing. The algorithm immediately determines whether a function is constant (returns 100% 0 or 1) or balanced (returns 50% 0 and 50% 1) in one try.

To Goldilocks, however, this



algorithm was the solution to all her problems. She could quickly determine whether something was just right, or balanced, by using the Deutsch-Jozsa algorithm.

She represented each of the bowls of porridge as functions that returned all hot or cold or her preferred mix of hot and cold spoonfuls.

Now instead of experiencing the misfortune of porridge that was either too hot or too cold, she tested the porridge functions. The big and medium porridge functions were constant and therefore either too hot or too cold. The small porridge function was balanced, and thus, she knew it was a perfect mix of hot and cold porridge.

She sat at the table and savored yet another successful application of quantum computing. She continued to savor taste after taste until the bowl was empty. After all her tasting, Goldilocks went to an adjacent room to rest. She laid down on the smallest bed, which was just right, and fell fast asleep.

While Goldilocks was sleeping, the three bears returned and could tell something was amiss. The smallest bear saw his empty bowl and growled loudly for he had quite the appetite.

Goldilocks awoke to this low growl and peeked out. She saw three bears!

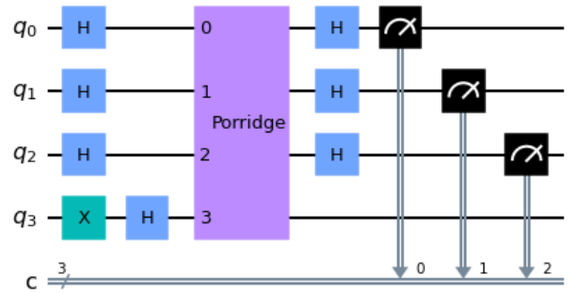
They were approaching where she hid, following the scent of the bouquet. Quickly, Goldilocks threw the flowers away from

her and dashed to the open window.

The bears were distracted by the strong scent of the honeysuckle and Goldilocks was able to leap from the window into the clearing.

The bears saw Goldilocks running toward the trees, but Goldilocks had just eaten and slept while the bears were tired from their ambling. The small bear, his tummy grumbling, sadly watched her escape into the forest while the other two bears happily began slurping their porridge.

Quantum Circuits



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Ali Baba and the Forty Thieves

Shor's Algorithm

Ali Baba and Cassim were brothers and sons of a merchant. Cassim married for wealth and acquired their father's business. Ali Baba married the woman he loved and became a woodcutter.

While cutting wood one day, Ali Baba spied forty thieves laden with treasure. The leader of the thieves approached a sheer mountain face, whispered something, and a cave magically opened. After the thieves deposited their loot, the cave opened to let them out, closing behind them.

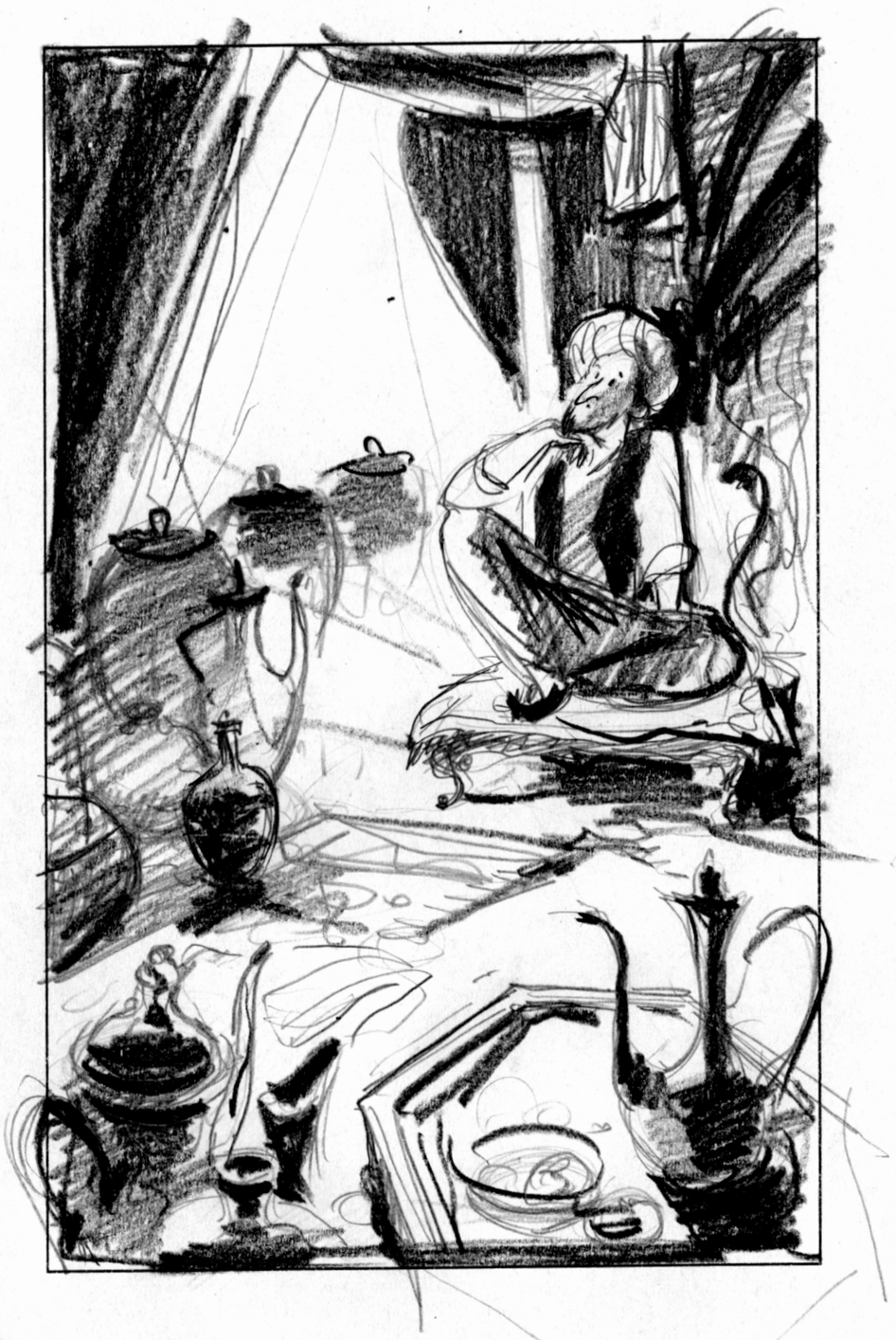
After the thieves had vanished, Ali Baba approached the cliff face and noticed a jumble of letters carved into the rock. He whispered those letters to the mountain, curious if they would open the cave, but alas they did not. He transcribed the letters from the rock and returned home.

Upon returning home, Ali Baba found Cassim anxiously pacing and clenching his fists. Ali Baba asked what was wrong,

and Cassim explained that a fellow trader was just killed in a nearby town. Their entire caravan was looted and destroyed, and the thieves only left an unintelligible letter behind.

Curious, Ali Baba asked to see the letter and was shocked when he saw words as jumbled as those on the mountain face. However, he also spotted a small number written across the corner of the note. "Of course!" cried Ali Baba as a memory from his childhood returned to him.

He had heard stories from a trader of a band of thieves who communicated with secret messages. As they had grown more successful and powerful, they eventually needed a method to communicate with each other without fear of being compromised.



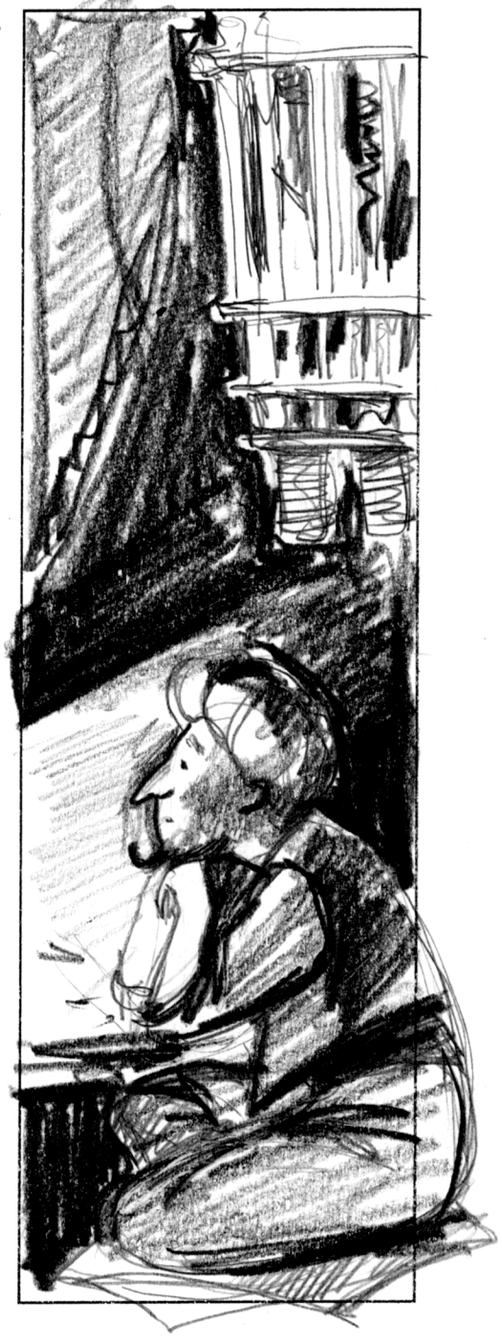
The trader had explained that the thieves' encryption was referred to as RSA, which uses an asymmetric algorithm to encrypt and decrypt information depending on what key is used. A public key could encrypt any piece of information; however, a private key was needed to decrypt that information. Thus, the leader of thieves could receive reports from his members, employ spies, and monitor his thieving throng while remaining safe from prying eyes. It seemed over the past few years, this communication method had helped them become very successful and wealthy.

Ali Baba's father had received in trade a device that used the properties of quantum mechanics for computation. This mysterious quantum computer could find the periods of functions to factor numbers,

a process referred to as Shor's algorithm. Ali Baba had spoken to the computer's seller a few years back and had learned how to implement this Shor's algorithm.

Ali Baba surmised that if he factored the number on the scrap of paper, he could recalculate the RSA keys and decrypt the message on the mountain face. Starting the quantum computer took time as the temperature needed to drop to near zero degrees Kelvin and the pressure to close to zero pascals . Once completed, Ali Baba could use the properties of quantum mechanics to factor the thieves' RSA key.

It was late at night when Ali Baba finally finished implementing Shor's algorithm, but he quickly factored the number and was able to generate the thieves' private key.



Using this key he decrypted the message in the rock and it read "Open sesame."

The next morning, Ali Baba rushed to the mountain, whispered "Open sesame," and watched the cave magically open. Not wishing to be detected, he rushed in and grabbed one sack of gold. Ali Baba returned home to show his wife all the gold he had, and she burst into tears of joy! She went to Cassim to ask for a scale. Curious about what the poor family needed to weigh, Cassim sneakily stuck wax to the inside of the scale.

After weighing the gold, the wife returned the scale. When Cassim saw a piece of gold sticking to the wax, he became very envious. "Ali Baba has so much gold he can't count it! He needs to weigh it all!" he cried.

Driven by suspicion and jealousy, Cassim decided to spy on Ali Baba. When Ali Baba awoke to chop wood, Cassim followed from a safe distance. Cassim watched Ali Baba approach a cliff and a cave, filled with treasure, opened in the rock. Ali Baba quickly left with a bag of gold and the cave closed. Cassim couldn't stand the thought of Ali Baba having more gold than him, so he planned to empty the magic cave.

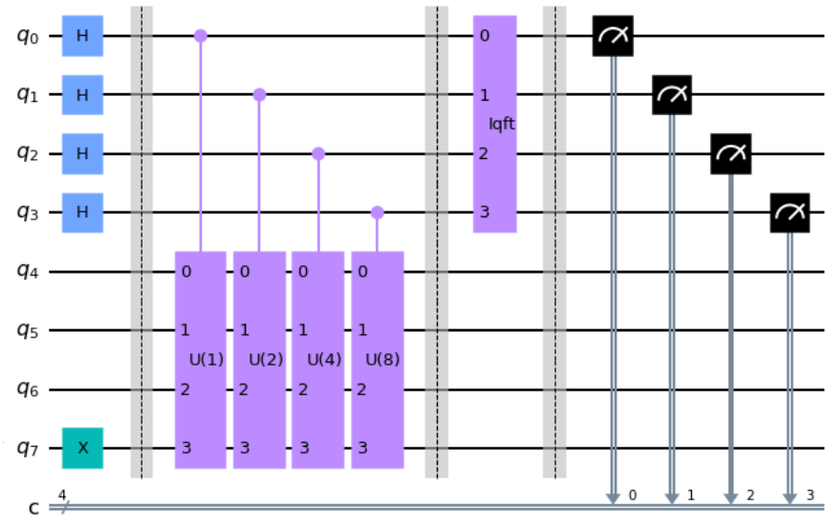
Cassim soon returned home and harnessed great chests to all his mules. He led the caravan toward the cliff; however, when he approached the cave, the rock face would not open. For hours Cassim scratched and smacked and was so engrossed with the cliff, that he didn't notice the forty thieves approaching. Turning around to catch his breath, Cassim was greeted with a dozen scimitars.

The leader of thieves assumed Cassim had spied on them depositing loot and criticized Cassim for being a lousy thief, for they respected talented bandits. The leader then explained that since nobody could know where their treasure was hidden, Cassim must be dealt with. Cassim quickly tried to blurt out that Ali Baba knew about their cave, but the scimitar was quicker.

Some time had passed when Ali Baba asked Cassim's wife where his brother was. She mentioned that he had left with his mules but had not yet returned. Weeks turned to months, and with no sign of Cassim, they correctly guessed that the group of bandits had found his caravan. Ali Baba vowed to have revenge for his brother, and

kept thieving from the thieves. He used the gold for the town and even invested in building a school. There, he taught quantum computation and assured the students quantum algorithms can be quite useful.

Quantum Circuits



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The Turtoise and the Hare

Grover's Algorithm

One afternoon, the Hare was making fun of the Tortoise for being so slow.

"Do you ever get anywhere?" he asked with a mocking laugh after watching the Tortoise spend hours crawling about.

The Tortoise often trudged about as he mused over quantum mechanics. The properties of superposition, entanglement, and interference were far too interesting (some might say spooky) to be ignored.

He spent his long life studying quantum systems and building a quantum computer. He also studied the work of Lov Grover and his quantum search algorithm. In fact, the Tortoise had devised a plan to use Grover's algorithm for this very situation.

This was not the first time the Tortoise had been ridiculed, and per the plan, he haughtily replied, "Yes, in fact, I get there sooner than you think. I'll race you as proof."

The Hare was much amused at the idea of running a race with the Tortoise, but to show all the other animals just how fast he was, he agreed. So the Fox, who had consented to act as judge, marked the destination and started the two off.

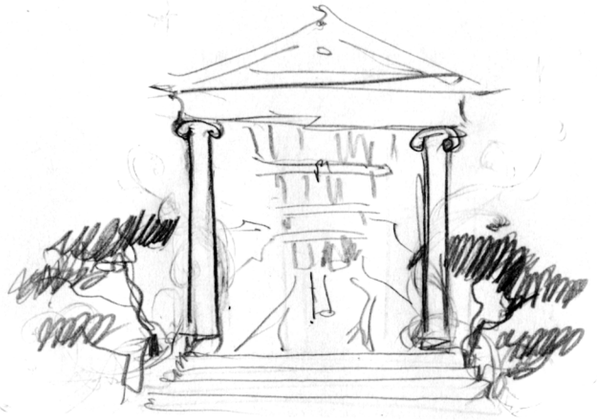
The Hare bounded and zigzagged through bushes and shrubs at an astonishing speed. Occasionally, he'd pause and stretch, looking behind smugly. Not seeing the Tortoise, the Hare scratched his ears, fluffed his tail, and bolted over the worn path toward the destination.

The Tortoise, however, made his way to the quantum computer and represented the paths from start to finish as a list of their associated distances. He used Grover's algorithm to quickly find which path was the shortest and began the race.

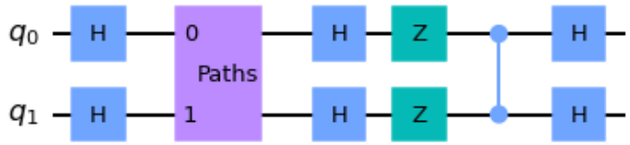
Instead of following the worn path, he held to the path Grover's algorithm outlined, avoiding the bushes and shrubs, and greatly reducing the distance. The Tortoise slowly but directly made his way toward the finish line.

On a nearby hill, the Hare looked behind him, squinting against the sun, trying to spot the Tortoise, and was surprised at how far behind he thought the Tortoise was. The Hare turned around to finish the race. Much to his chagrin, he saw, only a few steps from the goal, the Tortoise trudging forward. The Hare now ran his swiftest, but he could not overtake the Tortoise in time.

The Tortoise looked back at the panting Hare and said, "The shortest path wins the race."



Quantum Circuits



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