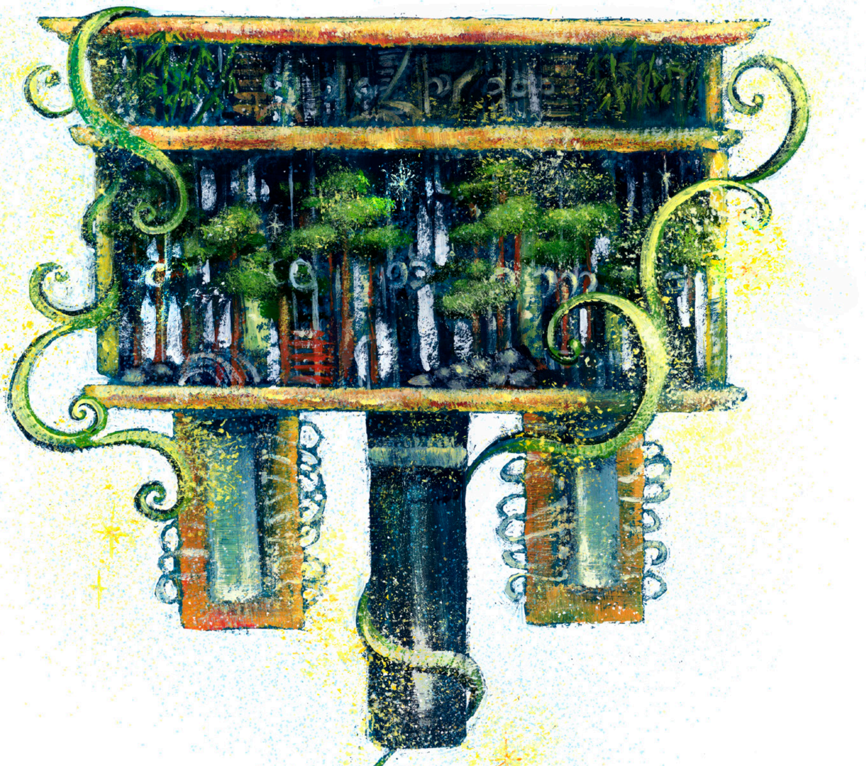
QUANTUM TALES



Spencer Churchill

Illustrated by Larissa Sharina

splch publishing
RSM, CA 92679

ISBN 978–1–7365474–0–3

Library of Congress Control Number: 2021901229

Cover, book design, and illustrations by Larissa Sharina

FIRST EDITION

Table of Contents

INTRODUCTION

Fairy Tales

Quantum Tales borrows fables from around the world to excite and educate readers about quantum algorithms. There are four popular fairy tales from England to China, and they all illustrate various applications for quantum computing.

- The Cowherd and the Weaver Girl is the Chinese Valentine's Day story that was modified to teach Quantum Teleportation.
- Goldilocks and the Three Bears comes from England and is the most fitting story to apply the Deutsch-Jozsa algorithm.
- Ali Baba and the Forty Thieves, a traditional Arabian oral story, perfectly demonstrates the power of Shor's algorithm.
- The Tortoise and the Hare, originating from ancient Greece, is revitalized in a rematch using Grover's algorithm.

Quantum Algorithms

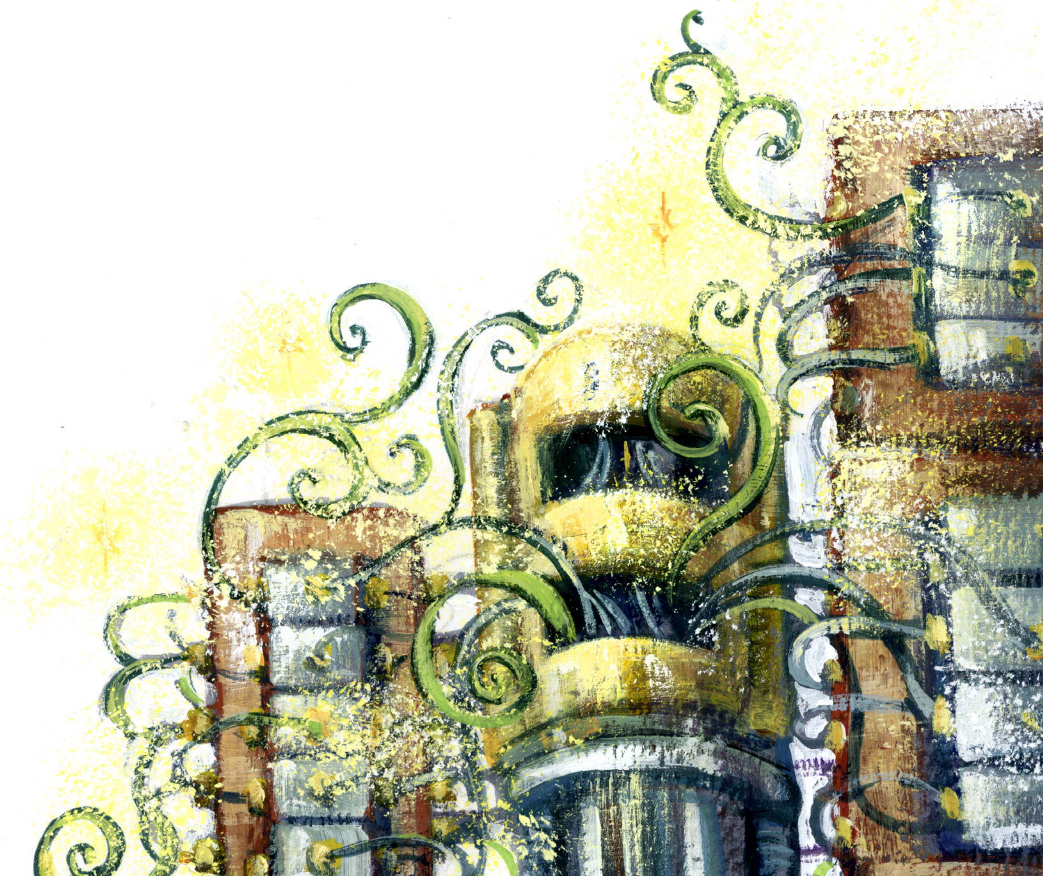
- Quantum Teleportation is used as an example of sending quantum information by classical means.
- The Deutsch-Jozsa Algorithm determines if a function is constant or balanced, meaning it returns either the same value (0 or 1) or both evenly (0 and 1).
- Shor's Algorithm calculates the periodicity of a function and is most useful for prime factorization.
- Grover's Algorithm searches for an item in an unordered list.

QR Codes

There is a QR code in each story for a deep-dive into the content. The QR codes are presented when the protagonist implements the quantum algorithm, and they give a more involved experience. Scan or click the QR codes and be redirected to the GitHub repository. Clicking the Google Colab link will run the code in the browser; the Jupyter Notebook can also be viewed in the repository.

Ways of Reading

For readers looking for an enjoyable twist on classic fairy tales, simply reading the stories is more than enough; however, for curious readers, scan the QR codes and look at the code, variables, and outputs. Also, browse the citations for great quantum resources. For advanced quantum readers, please review the code and submit a pull request on GitHub if anything should be improved.



The Etlangled Love of the Cowherd and Weaver Girl

Quantum Teleportation

As the first peonies broke into bloom, the seven imperial daughters of Heaven, with clouds tracing their steps, descended from their jade palace to bathe in the clear lake. The cool spring breeze swept up their long hair as they removed their silken gowns and draped them on overhanging branches. While they were soaking, the mischievous breeze lifted one of the dresses and laid it gently upon the water. It was Zhīnǚ's dress — the youngest sister. Her sisters giggled at her misfortune as they donned their own dry gowns and returned to Heaven.

Watering his oxen at the lake, the young cowherd Niúláng spied Zhīnǚ sitting unclothed beside the bank. Hastily, he removed his tunic and covered the girl. She explained that her clothes were wet from blowing into the lake and Niúláng, charmed by Zhīnǚ, offered to accompany her on a walk while her dress dried in the sun.

Niúláng led Zhīnǚ up an ocher hill overlooking the water and surrounding countryside. He confessed that he had come here to graze his oxen and watch the colorful clouds overhead. Niúláng eagerly described the beautiful hues of these clouds, unaware of Zhīnǚ's deepening blush, but she soon revealed it was she who weaves the clouds in Heaven.

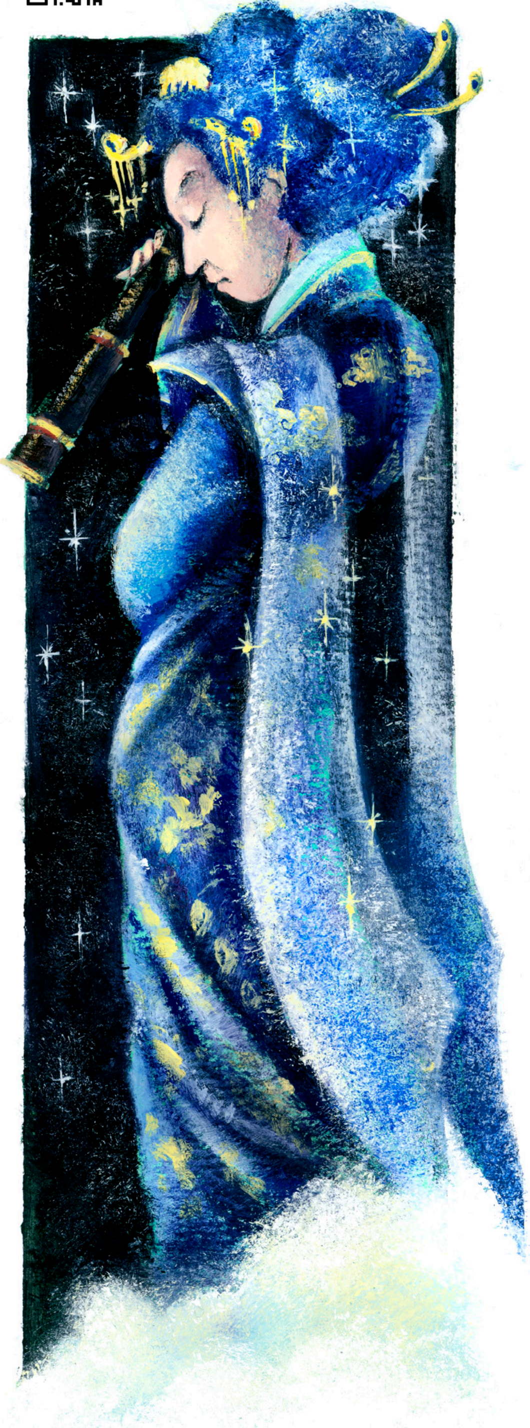
To Niúláng, the clouds were mere shadows of Zhīnǚ's beauty; he would rather see empty skies than be without her.

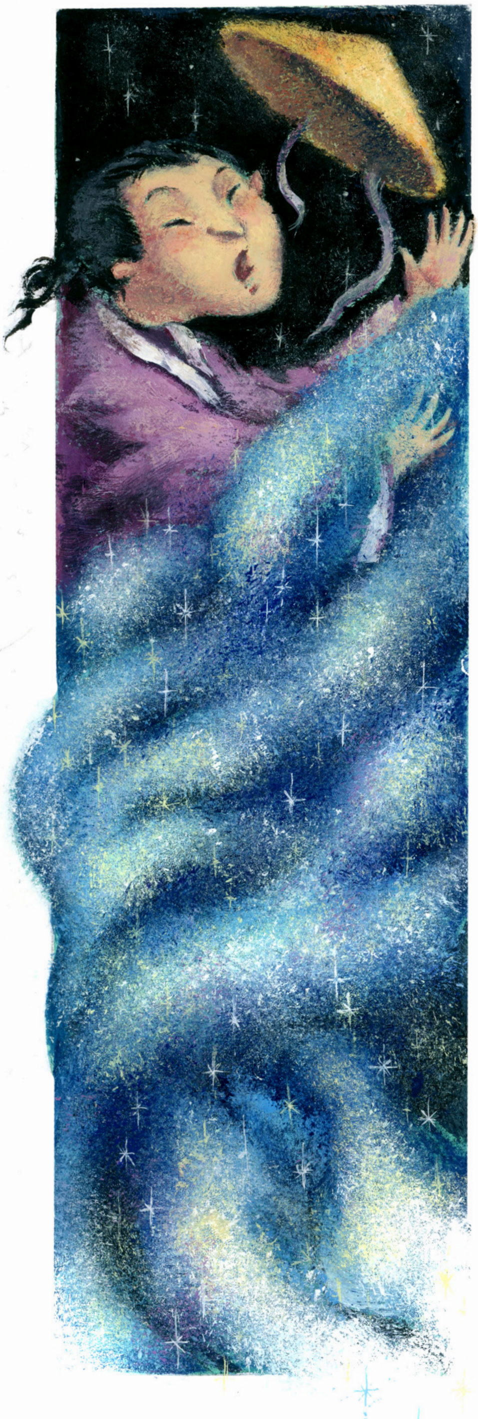
Returning to the lake, Niúláng playfully tossed Zhīnǚ's clothes back into the water and asked her again to stay with him until her clothing dried. Her cheeks grew pink as she smiled and nodded.

The two grew closer, finding themselves lost in love. The jade palace was rarely in Zhīnǚ's thoughts. As their love grew, so did their family, and Niúláng and Zhīnǚ began sharing their tranquil life with two children. All this time, Zhīnǚ's heavenly dress rested along the lake bed.

Xīwángmǔ, Zhīnǚ's mother and Empress of Heaven, was bothered by the suspicious absence of new clouds. After questioning her daughters, she discovered that Zhīnǚ had betrayed Heaven and married a mortal. Driven to rage by her youngest daughter's foolishness, Xīwángmǔ ordered the unwilling princess back to the heavenly palace.

Niúláng, distraught from the loss of his beloved, swiftly returned to the lake. Clutching his wife's sodden dress, he cursed the heavens for stealing her. And a response came, not from the sky, but from Niúláng's most prized ox that had sipped from the heavenly water.





The ox told Niúláng that if he wore its hide as a cloak, he could ascend to Heaven and find his wife. With a heavy heart, Niúláng killed the ox, covered his shoulders with its skin, and climbed toward the heavens with his children.

Overjoyed to be reunited with Niúláng, Zhīnǚ nevertheless knew her mother well and was aware of what would come. She warned Niúláng that the arrival of a mortal and two half-celestials in Heaven would infuriate her mother and that she would separate them again.

As Zhīnǚ prepared for their inevitable separation, she remembered what Yùdì, her father and Emperor of Heaven, had taught her.

As all good rulers know, the exchange of ideas is the currency of power, and Yùdì had devised the strongest method in the universe. He referred to this method as Quantum

Teleportation, a secure way to encode and communicate information across the heavens at the speed of light.

Niúláng listened intently as Zhīnǚ imparted her father's method of communication. Using starlight, they could connect particles and send messages to each other, despite whatever Xīwángmǔ might try. Zhīnǚ demonstrated the process. She unclasped a crystal earring and held it high, splitting a beam of starlight into two photons. This pair, born from the same beam, was tightly related and entangled. If either photon in this entangled pair were changed, even slightly, its twin would reflect the change. Zhīnǚ stored one photon for her and the other for Niúláng.

She handed Niúláng her other earring, and they worked together, entangling enough particles to communicate for an entire year, all organized by pairs. In time, Xīwángmǔ spotted Niúláng with Zhīnǚ in Heaven. Enraged once more, Xīwángmǔ drew her jade hairpin, and as her hair tumbled around her feet, slashed a river between the couple, forming the Milky Way.

This silver river swept the two lovers apart. But with their entangled particles, they sent messages back and forth throughout the year. And though Xīwángmǔ tried her hardest, she could never read the couple's messages.

The magpies, curious upon finding a new river of stars in the sky, flew up to ask Zhīnǚ what had happened. She explained what her mother had done and that she and Niúláng needed a way to entangle more particles. The magpies considered this, and on the seventh night of the seventh moon, flew to Heaven to form a bridge across the Milky Way for the two lovers.

Quantum Teleportation

Even now, despite her mother's interference, Zhīnǚ and Niúláng continue entangling particles each year to share their infinite love across the universe.

Goldilocks and the Quantum Spoon

Deutsch-Jozsa Algorithm

Between a quiet village and a dark forest, there once was a vast field of wildflowers. Picking her way through this meadow 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 and searched, but few flowers struck her fancy: some stems were bent, some petals had brown tips, and some still had bees buzzing and bumbling about, so she turned and ventured toward the forest. Goldilocks knelt over a delicate flower and pulled back a petal. “Is there a bee, or not a bee? That is the question,” she mused.

Goldilocks gathered her final flowers and now held the most beautiful bouquet of honeysuckles and merrybells. But the surrounding trees had blocked the sun, and she lost track of time among their shadowed trunks. So much time, in fact, that she found herself becoming hungry.

As it happened, she spotted a little cottage with a thatched roof in a deep clearing. The cottage looked welcoming, and sweet scents wafted over a tidy porch toward her.

Goldilocks knew the smell of home-cooked porridge, but she did not know that the house belonged to three bears. Fortunately for her, the three bears had sauntered into the forest to scavenge for berries, their preferred topping.

Goldilocks knocked, waited, then knocked again. There was no response. The smells of hot oats and brown sugar filled the entry. Finding the door unlocked, she could not help but peek inside.

From the doorway's old oak frame, she saw a table set for three and one quantum computer. She hoisted herself into the largest chair, but the cushion was too deep, and her feet dangled awkwardly. The smallest chair was much too tight, so she relaxed into the medium chair, and it felt just right. There she waited, sniffing at the bowls of porridge and becoming even hungrier.

She waited and waited, and still, no one came. “They must be very slow,” she thought. “Their porridge will be cold before they get home!” So, she scooted closer to the table.

There were three wooden bowls: one large, one medium, and one small — all filled with porridge. Goldilocks reached for a spoon, then hesitated. “Which porridge to try?” she pondered. Too cold would be unpleasant; too hot might burn her tongue. Goldilocks had been burned before, and it was not going to happen again.

Those close to Goldilocks knew she was well-versed in flowers and porridge, but she also knew her quantum algorithms. The key to this porridge conundrum was to consider each bowl as

either entirely hot or entirely cold, or an equal mix of hot and cold porridge. By doing so, she could apply the Deutsch-Jozsa algorithm.

This algorithm would instantly reveal whether a given bowl was either constant or balanced. A constant bowl of porridge would be completely hot or completely cold. A balanced bowl would be an equal blend of hot and cold porridge.

To avoid the misfortune of tasting the wrong porridge, she put the computer to work testing the bowls. The large and small bowls were both constant and therefore either too hot or too cold. The medium bowl was balanced, and thus, she knew it was just the right mix of hot and cold porridge.

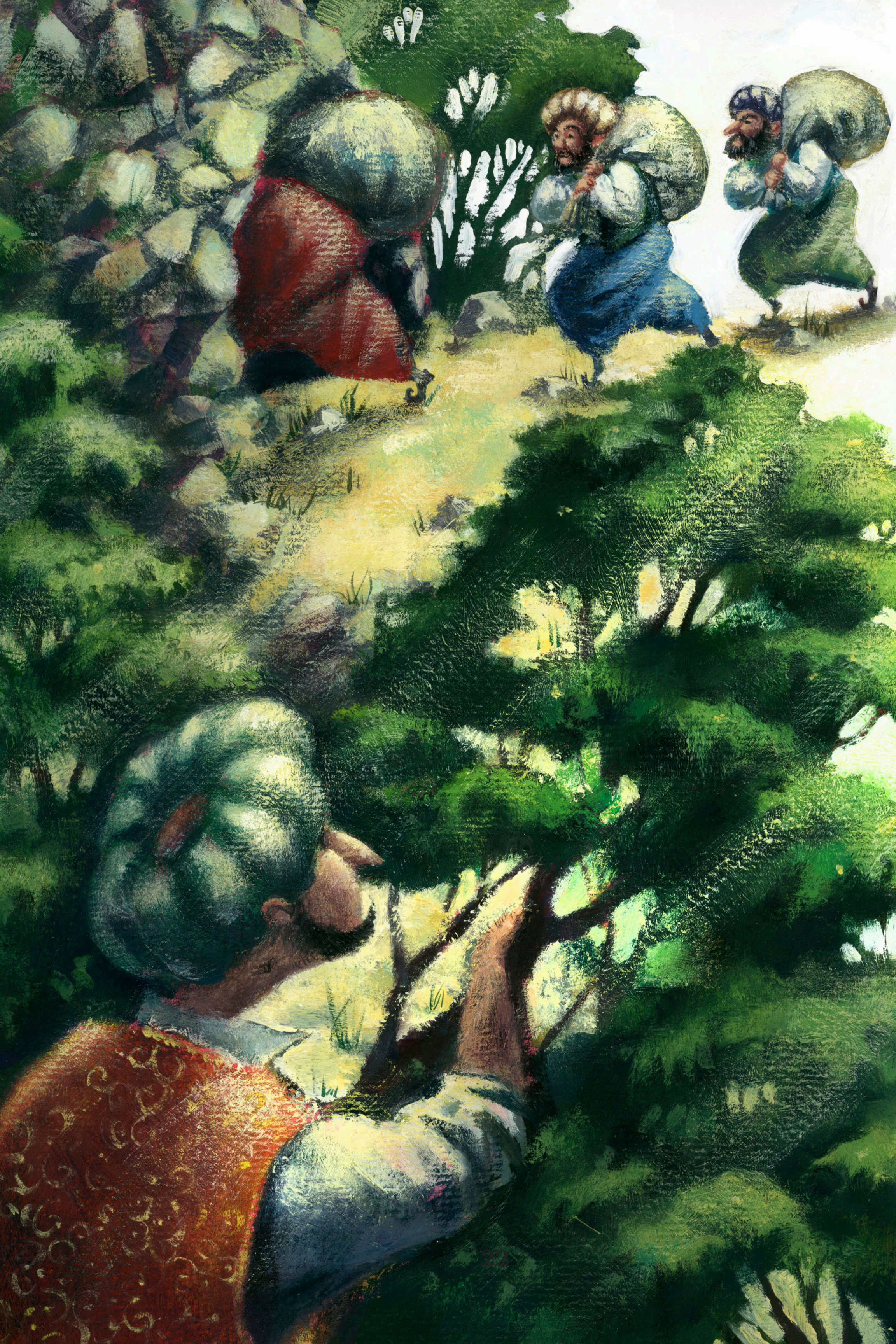
She savored her success at finding the finest porridge and tasted and tasted until the bowl was all tasted. But this tasting had made Goldilocks very sleepy. She gently lifted her bouquet and rose from the table to find somewhere to rest. Upstairs, she entered a bedroom with three beds: one large, one medium, and one small. Goldilocks eyed the large and small beds, but from her experience with the chairs and porridge, she lay decidedly on the medium bed and fell fast asleep.

But while Goldilocks was dreaming of more uses for quantum algorithms, the three bears returned: one large, one medium, and one small. They trundled to their table, put their berry-filled basket down, and settled into their respective chairs. The large and small bears began delicately placing berries upon their porridge, but the third bear sat still in confusion, berries resting in her paw. Never had someone else eaten her breakfast before, and she started to growl, for she was very hungry. The bears soon noticed

their quantum computer had been used as well and began to nose around.

Goldilocks stirred when she heard this commotion. She peeked out and saw three brown bears! They were nearing the bedroom, following the sweet scent of her bouquet. Quickly, Goldilocks threw the flowers away from her and dashed to the open window.

By the time the three bears looked out, Goldilocks was already running toward the trees. Tired and hungry from their ambling, they chose not to follow the thief. The large and small bears happily began slurping up their porridge, and the hungriest bear munched on her berries.

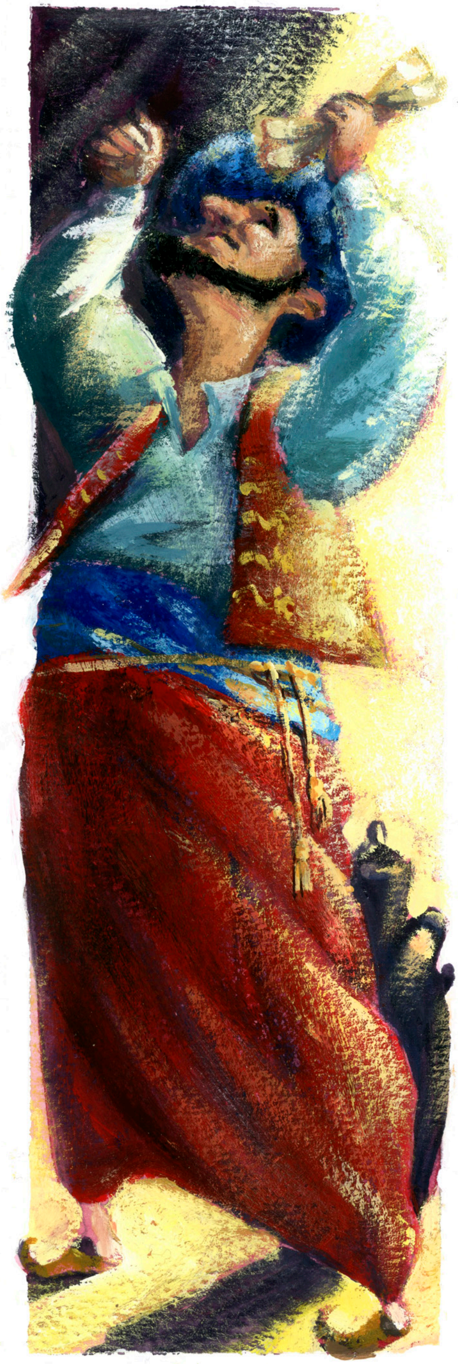


Ali Baba and the RSA Keys

Shor's Algorithm

A wealthy merchant fathered two sons, Ali Baba and Qasim. Qasim prided himself on living comfortably, having acquired his father's business and marrying a wealthy woman. Ali Baba, on the other hand, welcomed a more modest lifestyle — becoming woodcutter and marrying Fatima, the woman he loved.

While chopping wood one day, Ali Baba heard many heavy footsteps passing close by. From behind a large juniper tree, he spied forty thieves laden with treasure. As Ali Baba peeked around the trunk, he saw the thieves' leader, called Lot, approaching a sheer mountain face in the distance. Lot leaned toward the rock face, whispered, and stepped back as the mountain split, revealing a deep cave. One by one, Lot and his fellow thieves entered with their treasure, and the cave closed behind them. Sometime later, the cave opened again to let out the now empty-handed men, closing behind them once more.



After the thieves had vanished, Ali Baba approached the face of the cliff himself and noticed a series of jumbled letters carved into the rock. He whispered them to the mountain, curious if they opened the cave, but alas, they did not. He transcribed the letters from stone to a scrap of paper and returned home to find his brother anxiously pacing in front of his door.

Ali Baba asked him what was wrong, and Qasim disclosed that a fellow trader had just been killed in a neighboring town. Their entire caravan had been plundered, and only an unintelligible note was left among the rubble. Qasim desperately worried for his own family.

Concerned, Ali Baba reached for the note and was shocked to discover letters as jumbled as those he had seen etched into the mountain face. In addition, he spotted a small number jotted on

the corner of the note. Qasim left for his own home, leaving the tattered note behind.

Something about the note tugged at Ali Baba's memory. He recalled hearing stories from a trader about a band of thieves who communicated using secret messages. As they had grown prosperous and powerful, the group recognized they required communications that could not be compromised. Messages that, even if viewed in broad daylight, would appear only as scrambled letters.

The trader had explained that these progressive thieves had begun using a cipher known as RSA to encrypt, or lock, their secret messages. The cipher would scramble messages with a public key and unscramble messages with a private key. Only with the private key was the message able to be read. Thus, the leader of the thieves could receive reports from his members, employ spies, and direct his thieving throng while remaining safe from prying eyes. The RSA cipher had helped them become very wealthy.

Coincidentally, Ali Baba's father had received a device that drew on the nature of atoms for computation. This mysterious computer could uncover the patterns of functions in order to factor numbers, a process referred to as Shor's algorithm.

To decipher their message, Ali Baba needed to factor the number on the note's corner. This number was called the modulus, the product of two prime numbers. These prime numbers were also used to create the public and private keys. Only with Shor's algorithm could Ali Baba swiftly factor the modulus, but he would hold the key to the very same RSA algorithm the thieves used.

It was late at night when Ali Baba finally finished applying Shor's algorithm, and he had indeed succeeded in factoring the modulus and generating the thieves' private key. He unlocked the message etched in stone: "Open sesame."

The next morning, Ali Baba hastened to the mountain, whispered "Open sesame," and watched as it opened to his words. Not wishing to leave any trace of his entry, he rushed in and collected one small sack of gold. Ali Baba returned home to show his wife the gold, and she nearly fainted from shock. After Ali Baba headed for the forest, Fatima hurried to Qasim and asked to borrow a scale. Curious to know what his penniless brother's wife could possibly need to weigh, Qasim secretly applied wax to the inside of the scale.

After weighing the gold, Ali Baba's wife returned the scale. When Qasim discov-

ered a piece of gold stuck to the wax, he became envious. "Ali Baba has so much gold he can't count it! He needs to weigh it all!" he cried.

Driven by greed, Qasim decided to follow his brother. When Ali Baba left for work, Qasim watched from a safe distance. After several hours, he saw Ali Baba approach a cliff and enter a cave through a magical opening — a cave he could see was filled with treasure. Ali Baba quickly emerged with a bag of gold, and the cave sealed itself once again. Qasim, overwhelmed with desire, vowed to return and empty the magic cave of all its treasure.

At home that night, Qasim strapped great wooden chests to all of his mules. He led the caravan toward the cliff, but the entrance would not open when he approached. For hours, Qasim scratched and smacked the rock in frustration, so distracted that he did not notice the forty thieves approaching in silence. Turning at one point to catch his breath, Qasim was greeted with dozens of raised scimitars.

Lot pushed his men aside. "What have we here?" he demanded as his thumb grazed his scimitar's edge. Qasim's eyes bulged.

"Look, habibi," Lot continued, "I appreciate a good theft as much as any other, but this is our secret cave, and now it's not so secret, is it?" He toyed with the hilt of his sword. Qasim quickly tried to explain, but Lot's scimitar was quicker.

After a few weeks, Ali Baba asked Qasim's wife why he had not seen his brother for many days. She lamented that he had gone away weeks ago with his mules but had not returned. After months with no sign of Qasim, the two correctly guessed that the group of bandits had dispatched Qasim and his

caravan. Ali Baba swore to avenge his brother and continued secretly looting the cave. He quietly invested his newfound wealth back into the town, in particular the funding of a new school. There, he taught quantum computation and assured his students that quantum algorithms would prove veryuseful.

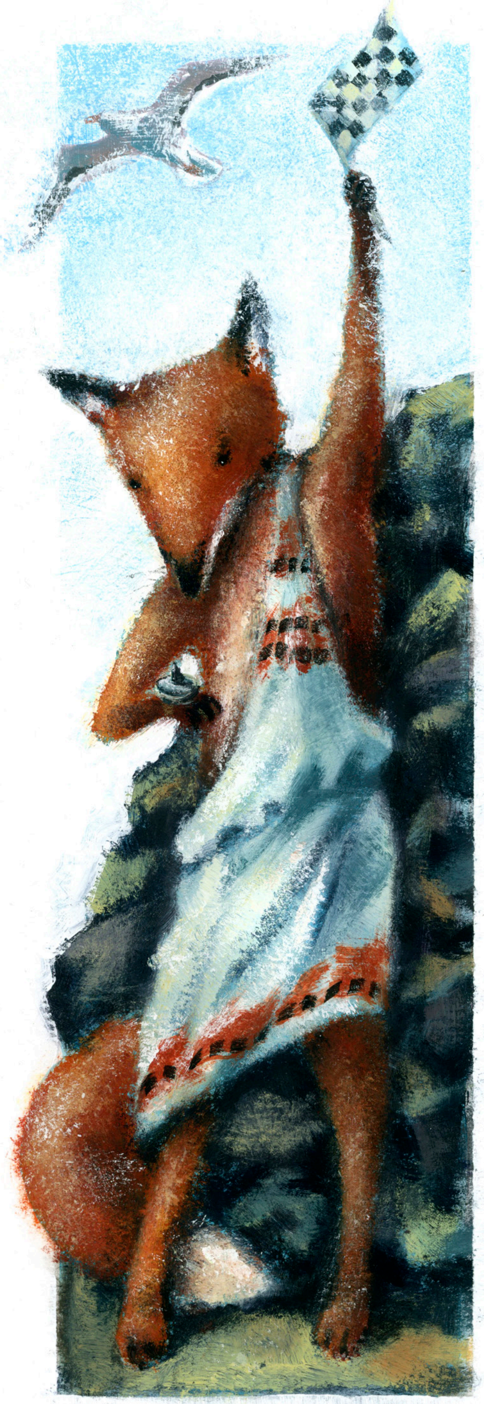
Turtoise vs. Hare — Quantum Rematch

Grover's Algorithm

The wind rushed through his golden fur. The ground shook with his every leap. With ears pinned back, Hare bolted across the green hills. Several animals glanced up as he thundered by. Breaking the beat of Hare's pounding feet, Weasel jeered, "Slowpoke!" Hare swiveled in mid-stride, skidding to a halt. "Who said that? Answer!" He thumped angrily as the surrounding animals howled and squawked with laughter. This was Hare's last straw.

"For more than two thousand years," Hare spat, "I have endured your petty mockery. Well, that ends now!" His tail bristled. "I am the swiftest, most dashing animal, and I will redeem all harekind." His roving eyes narrowed and settled on his dozing nemesis.

After his humiliating loss, in that race Hare wished could be forgotten, he had trained relentlessly. Despite his splendid



improvements in speed and agility, the other animals wantonly teased him.

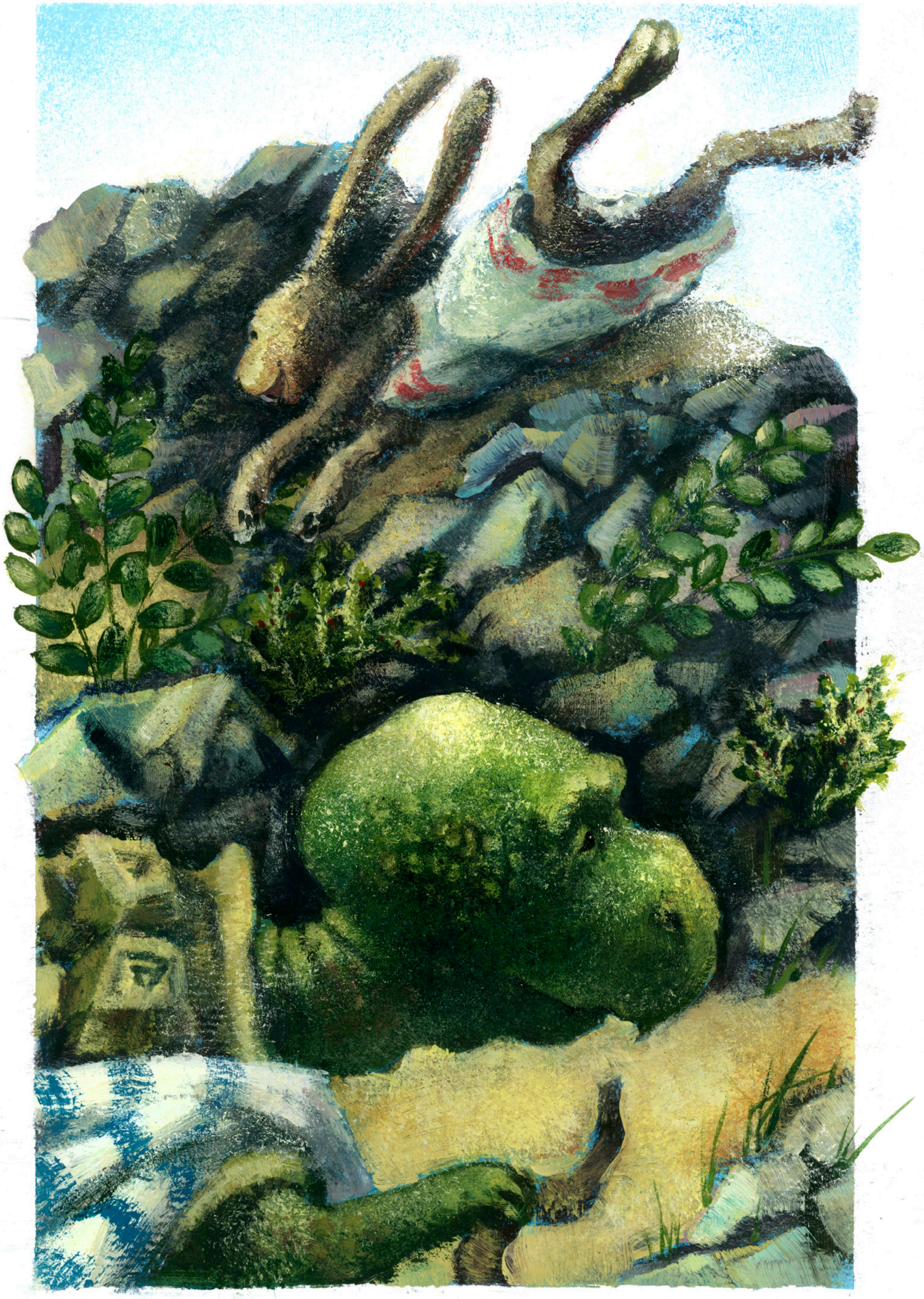
Tortoise, on the other hand, had spent his days musing under an olive tree, contemplating the world. Always introspective, always the philosopher, he was now engrossed in the study of quantum mechanics.

“There is no way you can best me,” Hare huffed. “We must race again, and I will win.”

“You’ve become so quick,” Tortoise began, his eyes opening. “I will certainly need time to get ready.”

Tortoise slowly blinked; Hare’s eye twitched.

The next morning, Tortoise and Hare both awoke early to prepare for the rematch. Hare streaked across the old trail, over and over, improving his time with every passage. When Hare looked to see how his rival was preparing, he noted Tortoise wandering



aimlessly—or so he thought. In truth, Tortoise was dutifully logging the distance of every possible path.

Soon, the day of the fateful race arrived. Fox marked the destination as he had long ago. And with an enthusiastic wave of the flag, Tortoise and Hare started off.

Hare bounded and zigzagged through bushes and shrubs at astonishing speed. Occasionally, he would pause and stretch, looking behind with glee. Never spotting Tortoise, Hare would scratch his ears, fluff his tail, and once again dash over the game trail toward the finish line. It was the best he had felt in years.

Meanwhile, Tortoise trudged to his quantum computer and produced the long list of routes. He remembered that one path would ensure his victory, but he had forgotten the way! There were far too many paths to search, so instead, he resolved to use Grover's algorithm. This quantum algorithm would amplify the path he wanted to find while reducing all others.

Faster than Weasel's jabs, the computer had found the shortest path, so Tortoise headed off in a direction quite different from Hare's.

Instead of following the same worn route, Tortoise kept to the path given by Grover's algorithm, avoiding the bushes and shrubs and reducing the distance covered by Hare's leaps and bounds. Tortoise slowly, but directly, made his way to the finish.

From up on a hill, Hare looked behind once more, squinting against the sun, trying to spot Tortoise. "Ha!" he snorted. "Tortoise is even slower than last time."

Grover's Algorithm

He now turned to finish the race, but when he did, he saw Tortoise trudging forward across the finish line.

Hare charged down the slope but was too late to overtake Tortoise.

"How... how?" panted Hare.

Tortoise winked at his opponent and offered with a wry smile, "It's the shortest path that wins the race."

Acknowledgments

I need to begin by thanking my family and friends for reading the stories and listening to me during the process. I am sure that they would prefer to do anything other than hear me decide between "find," "determine," and "reveal," but their consistent support helped me finish this project.

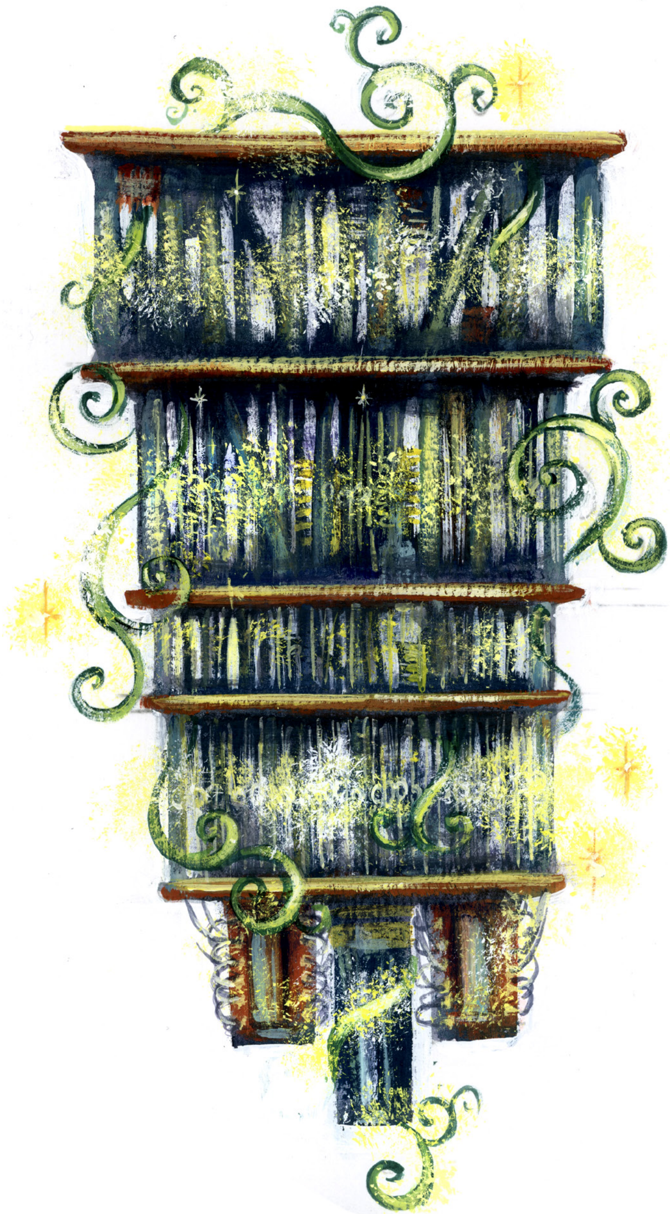
I am so fortunate to have such a talented artist help tell my stories. Larissa's illustrations reinspired me countless times when I was in the midst of writer's block. I can't imagine being asked to illustrate a fairy tale book and then get quantum computers thrown at me, yet she did a wonderful job researching and bringing my vision to life.

For the quantum community that welcomed me, shared invaluable feedback, and kept me excited about quantum, I thank you all. To everyone in the Qiskit community, thank you for ranking the most interesting quantum algorithms that directly shaped this book.

For the first reason there exists any book at all, I extend thanks to the original story-tellers who created these fairy tales. Our world is a much richer place because they exist. I am so grateful that they've been preserved, and can now be shared with a new purpose.

The second reason I am able to publish this book is due to the tremendous support from the Unitary Fund. I came to them with an idea to introduce quantum algorithms through stories, and they have helped me since. Their fund is founded on open-source ideologies and hopes to bring quantum to everyone. It has been an absolute pleasure to work with the Unitary Fund, and use classic tales to share quantum.

I specifically want to thank Travis Scholten for supporting my project to receive funding. I would also like to thank William Zeng and Nathan Shammah for helping me narrow my focus and providing countless resources to bring these stories to publication-standards.



Bibliography

- Æsop. The Æsop for Children. Chicago, Rand McNally, 1919. Library of Congress.
- "Deutsch-Jozsa Algorithm." Learn Quantum Computation using Qiskit, Qiskit, https://qiskit.org/textbook/ch-algorithms/deutsch-jozsa.html.
- Diyab, Hanna. "Ali Baba and the Forty Thieves." Wikipedia, 19 May 2006, https://en.wikipedia.org/wiki/Ali_Baba_and_the_Forty_Thieves.
- "Goldilocks and the Three Bears." Mother's Nursery Tales, by Katharine Pyle, E. P. Dutton, 1918, pp. 207-213. Project Gutenberg.
- "Grover's Algorithm." Learn Quantum Computation using Qiskit, Qiskit, https://qiskit.org/textbook/ch-algorithms/grover.html.
- "Quantum Teleportation." Learn Quantum Computation using Qiskit, Qiskit, https://qiskit.org/textbook/ch-algorithms/teleportation.html.
- Shi, Li Wei. "The Cowherd and the Weaver Girl." Chinaculture.org, 16 August 2010, http://en.chinaculture.org/focus/focus/2010qixi/2010-08/16/content_391106.htm.
- "Shor's Algorithm." Learn Quantum Computation using Qiskit, Qiskit, https://qiskit.org/textbook/ch-algorithms/shor.html.