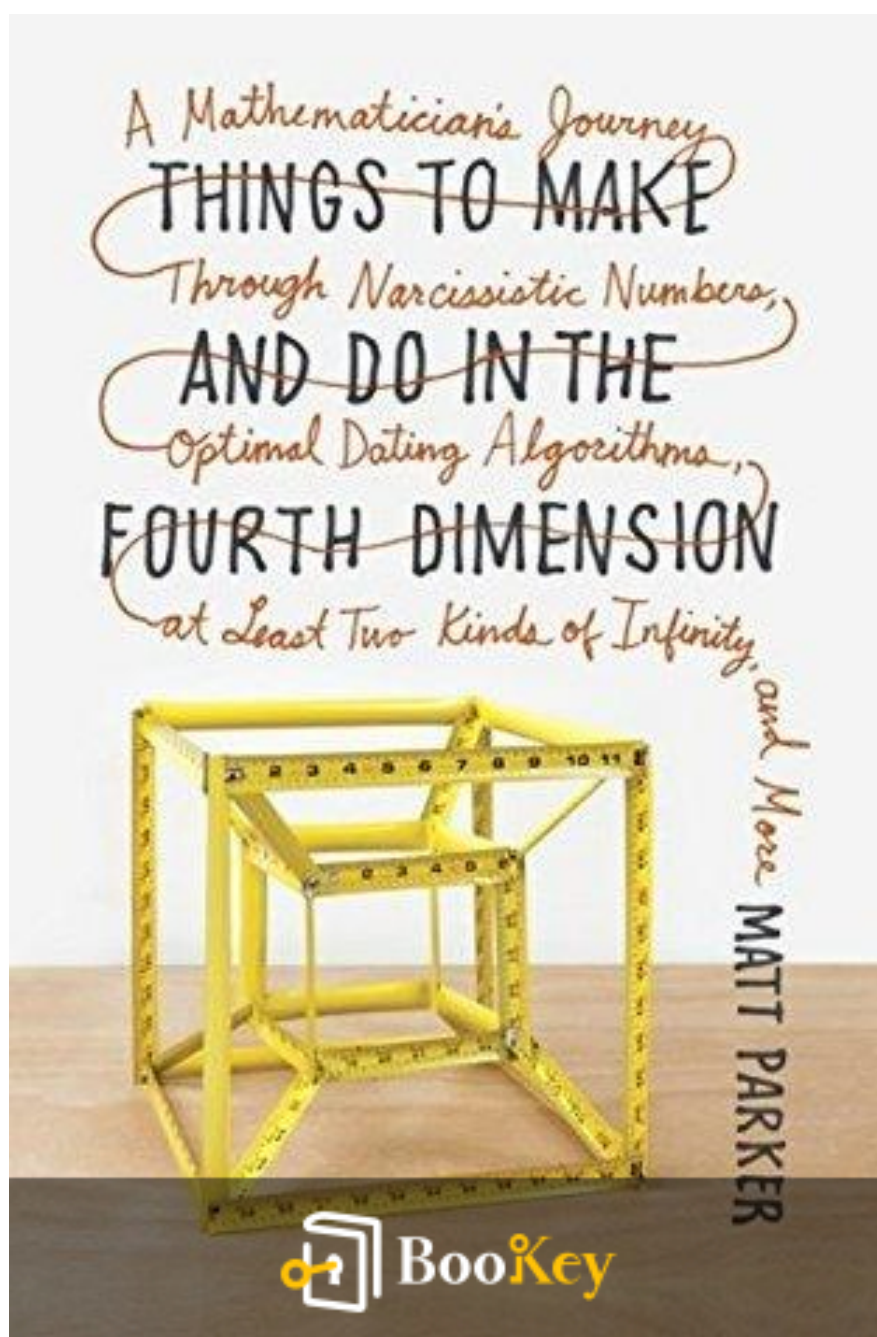


# Things To Make And Do In The Fourth Dimension PDF (Limited Copy)

Matt Parker



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# **Things To Make And Do In The Fourth Dimension**

## **Summary**

Exploring the wonders of higher dimensions through creativity.

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## About the book

In "Things To Make And Do In The Fourth Dimension," mathematician Matt Parker invites readers on a captivating journey through the intriguing realms of mathematics and the mind-bending concept of the fourth dimension. Blending humor, creativity, and intellectual curiosity, Parker challenges us to reconsider our perceptions of space, time, and reality itself, offering hands-on activities, playful thought experiments, and mind-twisting puzzles that not only entertain but also illuminate the deeper truths of the universe. Whether you're a math enthusiast or a curious novice, this book promises a rich exploration of ideas that will expand your understanding and spark your imagination, making the abstract both accessible and exhilarating. Dive in and discover the wonders that lie beyond our three-dimensional existence!

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## About the author

Matt Parker is a distinguished mathematician, comedian, and popular science communicator known for his engaging and entertaining approach to complex mathematical concepts. With a background in mathematics and a strong passion for performance, Parker has made a name for himself by blending humor and intellect through various platforms including live shows, podcasts, and TED talks. He is a former stand-up comedian and currently serves as the mathematics ambassador for several organizations, striving to make math accessible and enjoyable for people of all ages. Parker's enthusiasm for the wonder and creativity found within mathematics shines through in his writing, particularly in his acclaimed work "Things To Make And Do In The Fourth Dimension," where he explores the fascinating interplay between maths, physics, and imagination.

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## Chapter 1 Summary: 0 The Zeroth Chapter

The text introduces the concept of mathematical exploration through everyday experiences, focusing primarily on shapes and dimensions. Observing familiar objects, such as drinking vessels, reveals surprising mathematical properties that most individuals overlook. For example, the circumference of a standard pint glass is greater than its height, challenging perceptions about the dimensions we assess as significant. Through simple demonstrations, like measuring with a hand around the glass, readers are invited to engage with mathematics in a practical and enjoyable manner.

1. The author emphasizes that mathematics encompasses more than tedious exercises often encountered in school. It represents a rich landscape of exploration and creativity, akin to a game. Professional mathematicians, much like athletes, utilize their foundational skills to delve into advanced topics, discovering new patterns and dimensions along the way. The joy in mathematics lies in this playful pursuit of knowledge, rather than merely grinding through arithmetic exercises.

2. The text addresses the common disconnection between students and mathematics by drawing parallels with sports training. Just as physical drills prepare athletes for games, foundational mathematical skills should lead to engaging explorations of the subject. The disconnect arises when students focus only on rote practice without real-world applications—leading to a





lack of excitement in learning.

3. Mathematics is framed as a natural curiosity, driven by the desire to solve puzzles and uncover patterns. While many significant mathematical advancements result in practical applications, the initial motivation often stems from intrinsic enjoyment rather than utility. This perspective highlights the whimsical side of mathematics, characterized by discovery and play.

4. A strong link is established between basic mathematical concepts and their applicability to more complex ideas. Familiarity with foundational topics, such as the mathematical constant  $\pi$ , becomes crucial in understanding the world around us, including why we perceive certain dimensions as larger or smaller. The author notes that school mathematics, though often perceived as dull, lays the groundwork for more exciting explorations.

5. The structure of the book is akin to a ladder, encouraging readers to progress step by step. Each chapter builds on the last, allowing readers to choose their path through mathematics while ensuring they grasp the necessary concepts before exploring advanced ideas. This methodical approach aims to make challenging mathematical ideas accessible and enjoyable.



6. Ultimately, the author advocates for a shift in how mathematics is perceived—transitioning from a purely academic focus to one that encourages fun and exploration. The journey through the book is not just about acquiring knowledge but also about appreciating the unexpected beauty within mathematics, from the fourth dimension to abstract concepts like imaginary numbers. By fostering a playful mindset, readers can confidently venture into realms of mathematics they've never considered before.

In conclusion, the chapter sets the tone for a mathematical adventure that blends playful curiosity with serious exploration, seeking to democratize math for everyone. The journey promises excitement and discovery, encouraging readers to think creatively about mathematics and its applications in the world around them.

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## Chapter 2 Summary: 1 Can You Digit?

In Chapter 2 of "Things To Make And Do In The Fourth Dimension" by Matt Parker, the author explores the intriguing and often misunderstood distinctions between digits and numbers, particularly focusing on how our numerical systems can shape mathematical properties and outcomes. The chapter begins with a playful anecdote about a challenging puzzle involving the arrangement of digits that must satisfy various divisibility conditions, ultimately revealing a unique solution: 381,654,729. This exercise showcases the quaint intricacies of our base-10 system, which is inherently tied to the way we write and perceive numbers today.

Parker highlights that many mathematical marvels and patterns, such as palindromic results from the multiplication of repetitive ones, stem not from intrinsic properties of numbers themselves but rather from the conventions of written digits. He emphasizes the differentiation between a number—an abstract representation of quantity—and a digit, which serves merely as a symbol to express that number in written form. This distinction lays the groundwork for a deeper understanding of mathematical principles and showcases how the same numerical concepts can behave unpredictably when expressed in various numeral systems, such as Roman or Mayan.

To illustrate these ideas, Parker introduces the "37 Trick," which involves taking a digit, replicating it thrice, summing those digits, and dividing the



original number by this sum to always yield the number 37. He explains that this trick works because of algebraic identities tied to our decimal system but would falter under different numeral conventions. Such insights highlight the interplay between mathematical truths that remain constant regardless of digit representation and those that are artifacts of our chosen numeric structure.

Further, Parker delves into the binary (base-2) counting system, demonstrating how the positional significance of digits allows humans to represent vast quantities using straightforward techniques like finger counting. The discussion extends to base-3, base-4, and beyond, explaining how the base effects allow for the expression of every conceivable number, in contrast to the rigid rules governing Roman numerals.

A key point made in this chapter is the quest for generalization within mathematics—aiming to isolate and understand properties that withstand changing numeral contexts. This intrinsic desire drives mathematicians to seek formulas and truths that transcend a single base, reinforcing the idea that while our common base-10 system seems widespread and practical, it isn't the sole vessel through which numbers can be understood or represented.

Parker further entertains the notion of hypothetical extraterrestrial beings with different numerical systems, emphasizing that core mathematical



relationships will still hold through universal principles, even if their numeral representations differ. This notion cements the idea that mathematics transcends cultural and systemic constraints.

A particularly engaging segment features problems that work universally across different bases, such as identifying numbers that cannot be expressed as sums of consecutive integers. He tantalizes readers with playful challenges, recounting how these puzzles can reveal underlying patterns and provoke thought beyond the confines of our familiar base-10 habits.

Finally, the chapter poses reflections on the significance of niche number curiosities like narcissistic numbers, which feature in several ruminations about the nature of numbers and their abstraction from tangible concepts. Parker's engaging narrative weaves a rich tapestry of observation, challenge, and insight into the nature of mathematics, ultimately encouraging readers to look beyond the digits they use on a daily basis and appreciate the more profound language of numbers that connects all sentient beings, regardless of their numeric foundations.

**1. Digits Versus Numbers** The distinction between an abstract number representing quantity and a digit that symbolizes that number in written form has vital implications for understanding mathematical truths.

**2. Base-10 Limitations:** Mathematical properties and puzzles often hinge



on the numeral system used; altering that system can reveal untapped dimensions of mathematical exploration.

**3. Universal Properties:** Certain mathematical truths exist irrespective of how numbers are expressed; these foundational properties endure across numeral systems.

**4. Counting Systems:** The chapter's exploration of finger counting and positional bases illustrates the flexibility and potential of number representation beyond our common decimal framework.

**5. Generalization in Mathematics:** The pursuit of universal solutions drives mathematics forward; an understanding of mathematical frameworks fosters a lens through which to view problems without being constrained by specific numeral systems.

**6. Puzzle Engagement:** Challenges posed in the chapter serve to provoke thought and engagement with mathematical concepts, encouraging readers to explore and discover patterns that transcend the surface details of digit representation.

**7. Connection Beyond Humanity:** The overarching idea is that mathematics may be an innate language shared by all intelligent beings, offering a medium to connect even across the vast potential differences in





numeral systems.

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## Chapter 3: 2 Making Shapes

In "Things To Make And Do In The Fourth Dimension," Chapter 3 delves into the intriguing world of geometric shapes and mathematical puzzles, drawing connections between everyday scenarios and deeper mathematical principles.

### 1. The Author Critiques Conventional Pizza Slicing:

The chapter opens with a critique of traditional pizza slicing methods, which often result in slices that all touch the center, limiting the choices for people who may dislike certain toppings located there. The author proposes an alternative: cutting the pizza into identically shaped slices that don't all touch the center, using a perfectly circular, crustless pizza as the ideal example. This exercise serves as an engaging puzzle, encouraging readers to think creatively while exploring the fundamental properties of circles, one of the simplest yet most significant shapes in mathematics.

### 2. Drawing Circles and Constructing Shapes:

Using a compass, both as a tool and a metaphor, the narrative discusses the

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## Chapter 4 Summary: 3 Be There and be Square

In 1994, NASA concealed an intriguing mathematical exploration within the enigmatic depths of their website, highlighting their fascination with numbers. Among their findings is the decimal representation of the square root of 2, a number which mathematicians frequently obsess over. This irrational number, or 'root 2', presents a whimsical yet challenging endeavor for many mathematicians as it can be expressed up to 10 million digits. The amusement derived from such calculations seems to stem from a playful spirit among NASA engineers, reflecting a broader theme: the joy in the pursuit of mathematics exists simply for its own sake.

1. The allure of square numbers resonates with many, as seen in the traditional practice of squaring whole numbers (1, 4, 9, etc.). This exploration often morphs into puzzles and games, demonstrating the mathematical community's engagement with both numerical and geometric shapes. Puzzles, such as arranging numbers to yield square totals, can illuminate deeper mathematical principles and excite a sense of discovery.

2. Among these discoveries, square numbers can coincide with triangle numbers, as exemplified by 36, the smallest number fitting both classifications. The quest to uncover subsequent triangle-square numbers sparked camaraderie-induced curiosity among mathematicians, leading to calculations via spreadsheets. The challenge did not end with simple



triangles and squares; mathematicians delve deeper into multi-sided polygonal numbers, extending their search to increasingly complex geometric forms.

3. The mathematical journey often raises a critical question: why pursue these elaborate numerical phenomena? While such numbers may not possess direct practical value, they serve as captivating recreational challenges; akin to games or hunts, mathematicians derive immense satisfaction from the thrill of finding solutions and understanding patterns.

4. The exploration of patterns harkens back to historical figures like Pythagoras, who contributed greatly to mathematical theory and abstract thought. Despite Pythagoras's focus on numerical relationships within geometrical frameworks, he encountered resistance regarding the existence of irrational numbers, highlighted through the realization of the square root of 2. This struggle represents a pivotal moment in mathematical history, transforming the view of mathematics from purely practical applications to an abstract pursuit of truth.

5. Sir Walter Raleigh's inquiry regarding the total number of cannonballs in a square pyramid led to discoveries of square-pyramid numbers. A notable example, 4,900, stands out as the only square-pyramid number that is also a perfect square, hinting at the uniqueness of such numbers. This investigation illustrates a delightful collision of mathematics with practical needs and



solutions.

6. Figures like Srinivasa Ramanujan symbolize the self-driven passion for mathematics that can yield groundbreaking insights. Despite struggles with notation and acceptance in the mathematical community, his discovery of the number 1,729 as the smallest number expressible as the sum of two cubes in two different ways has cemented its legacy. This so-called 'taxi-cab number' exemplifies the unforeseen connections that lie within the world of numbers.

7. Overall, the vast and intricate landscape of mathematics thrives not solely on practicality but on the exploration of abstract concepts and the joy they yield. NASA's casual calculations resonate with this spirit, showcasing the delight that can be derived from patterns, games, and the unpredictability inherent in mathematical investigation.

In summary, both historical and contemporary mathematicians engage in pursuits that intertwine enjoyment with intellectual discovery. They delve into the artistic side of numbers, seeking patterns, connections, and the surprising realities underlying the numbers of our world—proving that mathematics remains a rich and rewarding field ripe with possibilities.

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## Chapter 5 Summary: 4 Shape Shifting

In this engaging chapter on "Shape Shifting" from Matt Parker's "Things To Make And Do In The Fourth Dimension," readers are invited to explore the fascinating world of geometric shapes and how they interact with movement and mechanics. Through hands-on activities, Parker illustrates core mathematical concepts, including the dynamics of rolling shapes, constant width, and the intriguing properties of flexagons.

1. The Wobbler: Using scissors and cardboard, readers create a fun contraption called the Wobbler, formed by two slotted circles. When assembled correctly, they wobble and roll along due to their center of mass maintaining a consistent height, a principle essential for understanding how and why certain shapes roll while others do not. The precision of the slit cut at 29.2893% of the radius plays a pivotal role in achieving optimal intersection for sustained movement.

2. Shapes and their Rolling Properties: Parker explains the reasons behind the rolling efficiency of circles and the limitations of squares. Circles roll effortlessly because their centers of mass remain stable, while squares require more force to roll, showcasing the importance of geometry in practical applications.

3. Constant Width Shapes: Readers delve into the properties of shapes with

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constant width, like the Reuleaux triangle, which rolls well and is often overlooked for more traditional shapes. Parker highlights how these shapes can be used in real-world cases, such as drilling nearly square holes, illustrating their versatility.

4. Creating Irregular Shapes of Constant Width: The chapter challenges readers to extend their creativity by constructing their irregular shapes with varying side lengths—but maintaining constant width. Various methods are discussed for designing these unique geometric figures, bringing an exciting challenge to amateurs and enthusiasts alike.

5. Pizza Problems and Polygrins: Parker engages readers with the idea of slicing pizzas using regular shapes of constant width, demonstrating that every odd-sided polygon yields exciting solutions to this culinary conundrum. He introduces the "heptagrin," a playful term for the shape formed from flipping sides inside and exploring infinite ways to cut pizza into equal slices.

6. Flexagons: The chapter concludes with a dive into flexagons, unconventional shapes that can roll into themselves, revealing new faces. Detailed instructions guide readers in constructing a tetraflexagon, encouraging creative design and experimentation with various flexagon types, showcasing the playful intersection of math and art.





Throughout the chapter, Parker's humor and engaging style enrich the reader's understanding of mathematical concepts, making complex ideas digestible and fun. The activities and principles introduced invite readers to think critically about shapes and their interactions, blending theory with hands-on experience, ultimately nurturing an appreciation for the wonders of geometry in everyday life.

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## Chapter 6: 5 Shapes: Now in 3D

In this chapter from "Things To Make And Do In The Fourth Dimension," Matt Parker explores the fascinating world of shapes and dimensions, particularly focusing on how two-dimensional (2D) shapes can transition into three-dimensional (3D) forms. Parker begins with an engaging challenge involving a five-pence coin cutout and a larger two-pence coin, encouraging readers to think creatively about geometry and the concept of dimensions.

1. Engaging with Geometry: Parker emphasizes the social aspect of learning mathematics, highlighting how his understanding of math has been shaped by others sharing interesting concepts. He introduces a playful puzzle and hints at the importance of curvature and the third dimension, demonstrating that a two-dimensional piece of paper can morph into a 3D shape, allowing larger objects to pass through smaller openings unexpectedly.

2. Rethinking Geometry: The discussion shifts to real-world applications, such as the surprising bends in highways that arise from the Earth's

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## Chapter 7 Summary: 6 Pack It Up, Pack It In

In this chapter, the exploration of mathematical packing problems captivates the reader's imagination, revealing the deeper complexities and unknowns surrounding the efficient arrangement of objects within defined spaces. The discussion begins with a practical challenge involving two-pence pieces, demonstrating that seven of these coins can fit perfectly into a specific square size, calculated with mathematical precision. However, as the problem scales to a larger number of coins, like thirty-one, the ability to find the most efficient arrangement remains an open question.

This leads to interesting insights into the fascinating world of packing problems, with the author expressing enthusiasm for this mathematical frontier where knowledge is still being developed. It is noted that while circles are poor at maximizing space, shapes like hexagons can completely fill a plane without leaving gaps—a realization long acknowledged by bees in their honeycomb designs. Despite our understanding of two-dimensional packing, there is still much to be uncovered in this area of mathematics.

**1. Flat Packing:** When considering flat shapes, circles are inefficient due to unavoidable gaps, while hexagons excel at packing due to their ability to cover surfaces completely. Tiling surfaces, a concept which encompasses tessellation, reveals numerous effective patterns beyond just basic shapes. Innovatively, irregular nonagons and combinations of multiple shapes lead



to efficient tiling arrangements, yet many possibilities remain unexplored.

**2. Three-Dimensional Packing:** The situation with three-dimensional packing is even less understood. For example, while cubes effectively fill space, the tetrahedron does not perform as well as once thought—arising from the historical misbelief championed by Aristotle. The exploration of polyhedrons reveals a complex web of categorization, yet a systematic theory for a more comprehensive understanding remains elusive.

**3. Lord Kelvin's Experimentation:** An intriguing historical note discusses Lord Kelvin's conjecture regarding the truncated octahedron as an optimal 3D shape. Echoing this, the exploration of soap film structures provides insight into efficient space-filling designs. The emphasis on Plateau's laws reflects fundamental principles governing the formation of bubbles, where every junction in a foam structure adheres to specific mathematical rules.

**4. Modern Developments:** The narrative progresses to reveal the Weaire–Phelan structure, identified as a superior packing configuration compared to Kelvin's model. This newfound arrangement forms the basis for architectural innovations, such as the Water Cube built for the Beijing Olympics, showcasing practical applications of these mathematical findings.

**5. Kissing Number of Spheres:** The intricacies of sphere arrangements



lead to explorations of the “kissing number” problem—the maximum number of spheres that can touch another sphere simultaneously. While twelve is confirmed, the search for a thirteenth has inspired further investigation. Kepler's conjecture, asserting optimal sphere stacking, was ultimately proven by Thomas Hales, who utilized the computational power of modern technology alongside human intellect to arrive at a solution previously considered impossible.

This chapter effectively illustrates the vast potential for future discoveries in packing problems and the realms they touch upon. As mathematical inquiry continues to evolve, it signals a thrilling frontier slowly being unveiled, leaving room for exploration and breakthrough understanding in this engaging mathematical domain.

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## Chapter 8 Summary: 7 Prime Time

Prime numbers, revered as the “A-list celebrities” of mathematics, hold significant importance due to their unique properties. Firstly, they can only be divided by themselves and one, distinguishing them from other integers. Moreover, there is a fascination surrounding prime numbers especially for those seeking the ultimate challenge: remarkable cash prizes are offered by the Electronic Frontier Foundation for the discovery of increasingly larger primes—up to \$250,000 for one with over a billion digits.

1. The quest for large primes is fueled by projects like the Great Internet Mersenne Prime Search (GIMPS), which began in 1996. This distributed computing initiative enlists the help of millions of processors worldwide, collectively undertaking trillions of calculations per second. It was GIMPS that discovered the first prime exceeding ten million digits in 2009, marking a triumph in both mathematical and computing realms.

The pursuit of primes, however, remains unpredictable. Researchers often rely on educated guesses, specifically examining numbers one less than powers of two—termed Mersenne numbers—despite the fact that not all such cases yield primes. Ancient Greeks began identifying Mersenne candidates, and although Marin Mersenne made several claims, many were proven incorrect over the centuries until Euler verified that one such candidate released a prime.



2. The sheer magnitude of numbers involved in these explorations is vast. For instance, the largest known prime, discovered by GIMPS in 2013, consists of over 17 million digits, illustrating the power of numerical calculations our ancestors could only dream of. Notably, the unlocking of Mersenne prime factors has often led to revelations dating back centuries, tracing the footsteps of famous mathematicians who sought to unravel the mysteries of numbers.

3. The importance and implications of factors are stressed throughout mathematics. By utilizing the analogy of guards unlocking a series of prison cells, the essence of factors influencing the state of these cells represents a fundamental concept: numbers with an odd number of factors—specifically square numbers—remain unlocked. This interaction highlights the critical role that prime factors play in a number's properties, characterizing them as mathematical “atoms.”

The debate over whether 1 should be considered a prime number has historically been contentious, but ultimately, the consensus emerged that it is not classified as such due to its lack of unique factors. Its prime status faded under scrutiny, illustrating the careful definitions and classifications mathematicians must navigate.

4. The topic also introduces amicable numbers—like 220 and 284, which

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exhibit a unique relationship whereby the sum of each number's proper factors equals the other. The allure of these numbers has crossed into cultural realms where they symbolize connection and love. Other numbers, dubbed perfect numbers—like 6 and 28—perfectly equal the sum of their proper factors and have captivated mathematicians since antiquity.

5. Further exploration into prime phenomena reveals fascinating concepts such as twin primes and their standing enigma in the mathematical community. The ongoing discourse remains whether there exists an infinite number of twin primes or a final pairing yet to be discovered. Recent breakthroughs, particularly by mathematician Yitang Zhang, have provided insights into the bounds of gaps between primes, igniting collaborative mathematical efforts to tighten these gaps.

6. The primes extend beyond solitary concepts—patterns within their distribution challenge mathematicians. For instance, squares of primes consistently yield results of one more than a multiple of 24, exposing surprising regularity in an otherwise seemingly chaotic landscape. As mathematicians pursue these patterns, the Riemann Hypothesis emerges as a frontier problem, hinting at deep insights yet to be fully understood.

Throughout history, it has become evident that prime numbers serve not just as abstract mathematical curiosities but as foundations for secure digital communication and current computational technologies. Their properties



serve essential roles in cryptography where the ability to reverse-engineer a prime factorization remains nearly impossible without prior knowledge.

In essence, the study of prime numbers and their corresponding patterns spans a vast history of intellectual exploration and community collaboration, evolving from purely theoretical discussions to increasingly vital applications in modern technology. As mathematical inquiry deepens, particularly in light of computer-aided discovery, the multi-faceted nature of primes will continue to shape both the field of mathematics and its real-world implications.

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## Chapter 9: 8 Knot a Problem

In the exploration of knots and their mathematical intricacies, we delve into key insights and principles that bridge biology, theoretical physics, and practical applications. Notably, bacteria possess a unique Type II topoisomerase enzyme that excels at untangling their DNA, showcasing a remarkable efficiency that surpasses human capabilities. This understanding of knots has potential implications for medical science, particularly in targeting bacterial infections and treating cancerous cells by manipulating their DNA structure.

1. Humans have much to learn from the way bacteria manage knots in DNA—specifically, the potential for developing new antibacterial treatments and cancer therapies hinges on a deeper understanding of knot theory.

2. Knots are not merely practical tools but intricate mathematical figures. Traditionally, sailors classified knots for practical use, but mathematicians have sought to understand the complexities of untangling them. Even simple

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## Chapter 10 Summary: 9 Just for Graphs

In the realm of network theory, fascinating insights have emerged, particularly through the lens of sports analytics and mathematical challenges. Mathematicians from Queen Mary University of London applied statistical analysis to the realm of football during the 2010 World Cup, specifically focusing on ball-passing networks to predict the match outcome between Spain and the Netherlands. They created detailed networks tracking passing statistics, revealing not just the star scorers but also the vital midfielders who facilitated plays. This intricate mapping allowed them to assess which team's strategy could prove more effective, ultimately enabling them to accurately predict Spain's victory.

1. The significance of player centrality was pivotal. Players who were integral links within the team's ball-passing network exhibited high betweenness centrality, meaning their absence could severely disrupt play. By identifying such players, teams could devise strategies to restrict their effectiveness, thus enhancing their own chances.
2. This analytical approach parallels flexagons, where understanding how to navigate between various combinations of sides is akin to mapping networks. Drawing out these connections provides clarity in how different configurations relate, revealing both predictable and unpredictable behaviors.





3. The "utilities problem" serves as a classic challenge within graph theory, requiring a network connecting three houses to three utilities without crossings. This puzzle highlights fundamental principles in network design, illustrating that while some networks are planar (able to be drawn without crossings), others, like the utilities graph, are not.

4. The exploration of planar versus non-planar graphs further delves into how certain conditions govern the shapes networks can take. For example, the presence of fundamental non-planar graphs, such as the Complete 5-Graph or  $K_5$ , can help determine whether a network can be laid out without crossings.

Drawing connections between networks and polyhedra, mathematicians investigate Hamiltonian paths that traverse vertices, encapsulating every unique connection. Such paths can offer insights into both theoretical and practical applications, from planning travel routes to understanding complex network systems.

5. The party problem exemplifies how graph theory can illustrate the social dynamics of groups, demonstrating that in any gathering of six, one can find either three mutual friends or three mutual strangers. This observation acts as a testament to the ways mathematical proofs can yield insight without exhaustive verification.



6. Map coloring, specifically the Four-color Theorem, combines graph theory and geography. It posits that only four colors are necessary to color any map ensuring that no adjacent regions share the same color, a conjecture that propelled significant inquiry. While initially thought to be proven through flawed methods, the theorem's validation through computational means highlights the evolving nature of mathematical proof and the reliance on technology in modern mathematics.

Through these various explorations—be it through sports, puzzles, or social dynamics—the rich tapestry of network theory illustrates profound links across disciplines. The journey through these concepts emphasizes the importance of visualization, mathematical rigor, and the intricate relationships governing both human and abstract networks. As mathematicians continue to unravel these complex structures, they bridge practical applications with theoretical inquiries, reinforcing the significance of understanding networks in a multitude of contexts.

| Key Insights             | Description                                                                                                    |
|--------------------------|----------------------------------------------------------------------------------------------------------------|
| Network Theory in Sports | Analysis of football during the 2010 World Cup focused on ball-passing networks to predict match outcomes.     |
| Player Centrality        | Integral players with high betweenness centrality can disrupt team plays; strategies can target these players. |
| Flexagons                | Mapping networks can be compared to navigating flexagons,                                                      |

| Key Insights                       | Description                                                                                                                            |
|------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|
|                                    | revealing predictable and unpredictable connections.                                                                                   |
| Utilities Problem                  | A classic graph theory challenge illustrating whether networks can exist without crossings, highlighting planar vs. non-planar graphs. |
| Planar vs. Non-Planar Graphs       | Fundamental non-planar graphs can determine network layouts and crossings.                                                             |
| Hamiltonian Paths                  | Exploration of paths that connect all vertices, with practical applications in route planning and complex networks.                    |
| Party Problem                      | An example of social dynamics, proving that any group of six will have mutual friends or strangers.                                    |
| Four-Color Theorem                 | Key insight from graph theory stating four colors suffice to color any map without adjacent regions sharing a color.                   |
| Visualization & Mathematical Rigor | Emphasizes the importance of visualizing connections and maintaining rigor in mathematical proofs across disciplines.                  |

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## Critical Thinking

**Key Point:** The significance of player centrality in network theory.

**Critical Interpretation:** Imagine standing on the sidelines of your own life, viewing your daily interactions as a complex network. Just as vital midfielders in football orchestrate the flow of play, consider the people in your life who hold pivotal roles in your social and professional circles. By recognizing and cherishing these central figures—those whose support and connectivity empower you—you can enhance your strategies for building relationships and fostering community. Their importance underscores a powerful insight: the connections you nurture can make a significant difference in your trajectory, echoing the networked dynamics seen in sports. This revelation could inspire you to invest more intentionally in those connections, empowering not just your pursuits, but also creating a supportive network that uplifts everyone involved.



## Chapter 11 Summary: 10 The Fourth Dimension

In Chapter 11 of "Things To Make And Do In The Fourth Dimension," Matt Parker explores the concept of the fourth dimension and its implications through an assortment of engaging examples and mathematical explorations. The chapter begins by starkly contrasting our three-dimensional existence with the unimaginable reality of interacting with a four-dimensional entity. Such a superior being would possess overwhelming advantages over humans, which are limited to a three-dimensional framework.

**1. Dimensional Perspectives:** The chapter utilizes a vivid analogy of a two-dimensional creature, the "hypoflatical," and illustrates how a three-dimensional being might present itself—passing through the hypoflatical's world and being perceived only as two-dimensional cross-sections. This suggests that a 4D being could observe and manipulate 3D life without us even realizing, enforcing a haunting sense of vulnerability from our perspective.

**2. Interdimensional Visualization:** To clarify the passage of a 4D shape through our 3D space, Parker describes how a 4D cube—when transitioning into our reality—could manifest as various intriguing 3D shapes like a triangular prism or even a dynamic octahedron. These transformations provide insights into how dimensions interact, emphasizing the complexity of higher-dimensional mathematics and perspectives.



**3. Building Models:** Parker proceeds to describe engaging ways to create visual models of 4D shapes using straws. He illustrates how to construct a cube and then extend this to a hypercube by connecting two cubes with straws symbolizing the fourth dimension. This participatory element not only aids comprehension but also sparks curiosity about multidimensional space.

**4. Platonic Solids in Higher Dimensions:** The narrative transitions into discussing the Platonic solids, illustrating that just as there are five Platonic solids in three dimensions, there exist six in four dimensions, including the hyper-diamond, a new form entirely unique to 4D geometry. This solids' exploration emphasizes both the mathematical richness of higher dimensions and our limited capacity to conceptualize them fully.

**5. The Nature of Life in 4D:** Parker poses thought-provoking questions about the life and structure of hypothetical 4D entities—termed “Hypertheticals.” He suggests that their existence would differ dramatically from ours due to the extra dimension, including the impossibility of tying knots and the ability to manipulate space in ways unfathomable to 3D beings. The exploration of these creatures opens up dialogue about the inherent challenges and wonders presented by higher dimensions.

**6. Mathematics Across Dimensions:** Despite our inability to visualize the



fourth dimension intuitively, Parker reassures that mathematical principles remain consistent. Even if the spatial configurations exceed human comprehension, the fundamental arithmetic transcends dimensional barriers, suggesting a universal language through numbers which is crucial for potential interdimensional or extraterrestrial communication.

In sum, Parker deftly interweaves mathematical concepts with creative analogies and models, exploring the significant implications of higher dimensions on our understanding of the universe. He encourages curiosity while also grounding this awe in the logic and structure of mathematics, demonstrating that while the notion of the fourth dimension may be complex and daunting, it is ultimately an accessible and vital field of inquiry.

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# Critical Thinking

**Key Point:** Embracing Complexity and Curiosity

**Critical Interpretation:** As you ponder the mind-bending concept of the fourth dimension, let it inspire you to embrace the complexities of life with a spirit of curiosity. Just as Parker illustrates that our understanding is confined within three dimensions, recognize that your perspectives may also be limited. Allow yourself to explore ideas and experiences outside of your comfort zone, cultivating a deeper appreciation for the richness that lies beyond the obvious. In this journey, you might find that facing the unknown can lead to profound personal growth and new dimensions of understanding in your own life.

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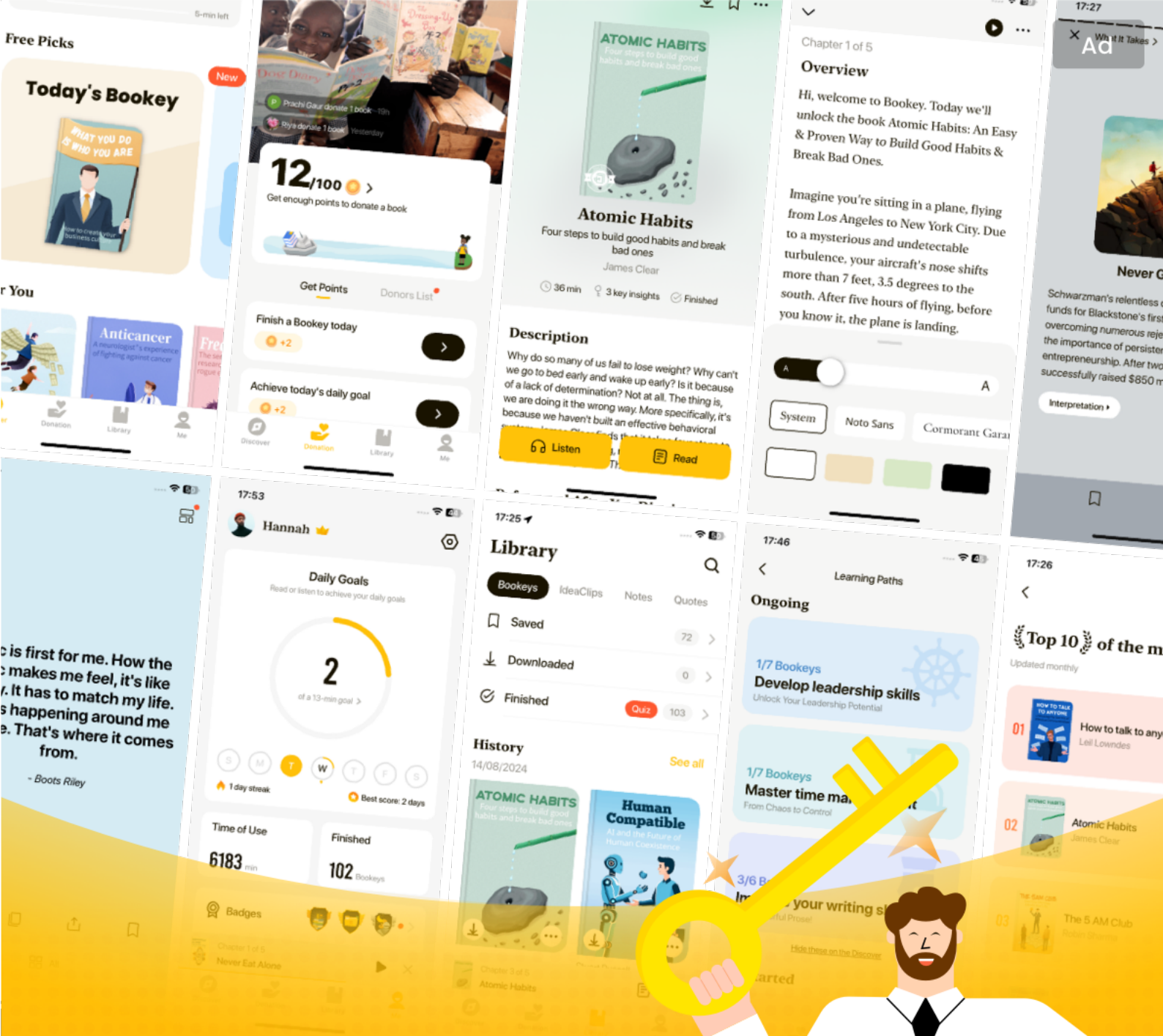
## Chapter 12: 11 The Algorithm Method

In this chapter, Matt Parker explores the intriguing connection between algorithms, decision-making in life, and mathematics, weaving together concepts that may at first seem disparate.

1. The core idea begins with the analogy of precise cooking methods. Just as one would follow a detailed recipe for baking, structured algorithms can guide various life decisions, even significant ones like choosing a life partner. The author presents algorithms as powerful tools, akin to recipes that allow for adaptive decision-making based on the choices made.
2. To illustrate the practicality of algorithms in real-life scenarios, Parker introduces the concept of "optimal stopping problems." He elaborates on the dating strategy which leverages mathematical principles: you first estimate the total number of potential partners, calculate a benchmark based on the square root of that number, date that many individuals, and only then pursue someone better than your initial best. This mathematical approach maximizes the chances of finding an optimal partner—echoing the principles

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## Chapter 13 Summary: 12 How to Build a Computer

Building a computer is a complex yet fascinating journey that demonstrates the interplay between mathematics and technology. It can be likened to navigating a dense jungle; where learning about mathematics involves a detailed, ground-level exploration, computers offer a bird's-eye view that enables a broader understanding of the landscape of mathematics. While the fundamental principles of mathematics remain unchanged, the emergence of computers has accelerated discoveries and facilitated explorations in various fields, particularly in mathematics. A prime example of this is found in the progression of Mersenne primes, where the introduction of computational power has significantly increased the rate and scale of discoveries compared to historical findings.

In the realm of computational mathematics, computers have proven indispensable. Remarkably, computers verify hypotheses and theorems, including the Riemann Hypothesis, by checking massive sets of numbers, although they do not provide intuition or natural understanding of these patterns. Proofs for the four color theorem or the Kepler conjecture also showcase the capability of computers, which independently validate extensive calculations that prove beyond human reach.

However, for all their utility, many people lack an understanding of what makes a computer viable. Delving deeper into the essence of computation

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unfolds the mechanism of electronic circuits that allow machines to compute by responding to inputs, processing it internally, and producing outputs. Even without electronics, foundational concepts of computation can be illustrated through simple analogies, such as using dominoes.

The journey of computational devices began far back in history. Automata like Archytas's mechanical pigeon give a glimpse into humanity's intrigue with machines capable of mimicking life and thought. Mechanical calculators appeared in ancient times, with the Antikythera Mechanism, dating back to 150 BCE, emerging as an astounding device that tracked celestial bodies. Its intricate design exemplifies the intelligence of ancient engineering, signifying an early expression of computational capability.

Fast forward to the 19th century, Charles Babbage conceptualized the computer. Inspired by the inaccuracy of mathematical tables, he dreamed of a machine that could generate these answers more reliably. The Difference Engine was born from this vision, leading to the more ambitious Analytical Engine, which could be programmed using punch cards. Though the Analytical Engine was never built in Babbage's lifetime, Ada Lovelace's collaboration with him heralded the first algorithms, earning her the title of the world's first programmer.

Despite their theoretical underpinnings, Babbage's inventions remained mechanical and could not rival the efficiency of modern electronic



computers. The advent of electricity allowed circuits to replace cumbersome mechanical systems, scaling computational power beyond the limits of Babbage's designs. Logic gates, fundamental to computation, can be represented physically through simple models like dominoes. For instance, a half adder, capable of binary addition, illustrates how basic logic gates can combine to process mathematical operations through cascading outputs based on binary signals.

Constructing a domino computer to teach the principles of computation not only provides a grip on foundational logical operations but also reveals the inherent limitations of physical models. While the domino computer demonstrates the essence of computation, it cannot replicate the speed and efficiency of modern systems that process data at trillions of operations per second.

In summary, understanding computers involves recognizing their historical evolution from mechanical devices to complex electronic systems, underpinned by mathematics and logic. Crucially, this journey from conceptualization to construction emphasizes the role of abstract reasoning and the practical application of ideas, ultimately shaping the powerful computational tools we rely on today.

| Key Concepts | Description |
|--------------|-------------|
|--------------|-------------|



| Key Concepts                     | Description                                                                                                                                                 |
|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Building a Computer              | A complex and fascinating journey that intertwines mathematics and technology, offering diverse perspectives on mathematical landscapes.                    |
| Role of Computers in Mathematics | Accelerate discoveries like Mersenne primes and validate hypotheses and theorems, although lacking in intuitive understanding of patterns.                  |
| Computational Mechanism          | Mechanism of electronic circuits enabling input processing and output generation; can be illustrated through analogies such as dominoes.                    |
| History of Computational Devices | Includes early inventions like Archytas's mechanical pigeon and the Antikythera Mechanism, showcasing ancient engineering intelligence.                     |
| Charles Babbage                  | Conceptualized the computer in the 19th century; created the Difference Engine and the Analytical Engine, collaborating with Ada Lovelace.                  |
| Ada Lovelace                     | Worked with Babbage, created the first algorithms, recognized as the world's first programmer.                                                              |
| Advancements in Computing        | Transition from mechanical systems to electronic, enhancing computational capabilities through logic gates represented by simple models.                    |
| Domino Computer                  | A teaching model illustrating computational principles, revealing limitations compared to modern systems that process at high speeds.                       |
| Conclusion                       | Understanding computers involves recognizing their historical evolution, abstract reasoning, and practical applications shaping modern computational tools. |



## Chapter 14 Summary: 13 Number Mash-ups

In Chapter 14 of "Things To Make And Do In The Fourth Dimension," titled "Thirteen NUMBER MASH-UPS," Matt Parker explores the fascinating world of numbers and their interactions. This chapter highlights the complex relationships between numbers, emphasizing how the correct combination can lead to extraordinary results, particularly in modern technology and computing. The narrative is both educational and entertaining, layered with anecdotes, mathematical concepts, and a dash of humor.

1. Numbers, when combined, yield remarkable outcomes. For instance, the development of video games, like *\*inFAMOUS Second Son\**, showcases how vital precise mathematical functions are in rendering graphics effectively. The dark line that appeared on the character's neck was a result of inconsistent number combinations due to programmers using different rounding functions—floor versus ceiling.
2. Functions serve as systematic methods for processing numbers. Through functions, mathematicians establish rules for combining numbers, a process critical in programming and mathematical computations. Rounding functions demonstrate the importance of agreement in methods for accuracy.
3. Graphing functions provides a tangible representation of mathematical relationships. The conventional way to plot functions involves matching



inputs with outputs, plotting coordinates to visualize data. Parker introduces creative methods for graphing, bringing a sense of fun to mathematical exploration, such as creating heart shapes with coordinates or visualizing the trajectory of a flaming tennis ball.

4. Recursive Functions are introduced through the Fibonacci and Lucas number sequences, revealing how they grow. Each sequence's output is derived from its previous terms, demonstrating intriguing properties in mathematics. Lucas numbers, in particular, are portrayed as a lesser-known yet equally fascinating sequence.

5. Mathematical relationships extend to primality tests. Parker discusses a unique method involving Lucas numbers to provide insight into prime number verification. The Lucas–Lehmer primality test for Mersenne primes showcases how recursive functions can be utilized for complex mathematical verification.

6. The book also delves into the concept of convergence and divergence in infinite sequences. Parker elucidates that while adding infinite numbers typically leads to divergence, certain sequences can converge on a finite value—illustrated through humor with the infinite bar joke, demonstrating that not all infinite sums are infinite.

7. The Basel problem serves as a milestone in mathematics. Euler's



groundbreaking solution, revealing that the sum of the reciprocals of square numbers equates to  $\pi^2/6$ , emphasizes the interconnected mathematical principles, interweaving geometry with number theory.

8. This chapter introduces Bernoulli numbers and their powerful function for summing sequences of different powers. Although they appear complex and cumbersome, Parker characterizes them as beautiful through their utility in connecting different mathematical ideas.

9. The exploration of the sum of an infinite series leads to remarkable results, including the assertion that the sum of all natural numbers equals  $-1/12$ , a concept rooted in Ramanujan's summation methods, challenging common perceptions in mathematics.

10. Finally, Parker brings attention to the Riemann zeta function, a pivotal element in understanding prime number distribution. The unresolved Riemann Hypothesis symbolizes one of mathematics' deepest mysteries, with implications that could significantly shift current mathematical frameworks.

This chapter elegantly marries humor and complex mathematical theory, enriching readers' understanding of how numbers interact, the significance of mathematical functions, and the boundless potential of mathematics to uncover new truths about our world. Through compelling narratives and



thought-provoking examples, Parker invites the audience into a deeper exploration of mathematics, showcasing both its beauty and its challenges.

| Section                       | Summary                                                                                                                       |
|-------------------------------|-------------------------------------------------------------------------------------------------------------------------------|
| Topic Overview                | Explores the relationships between numbers and their importance in technology and computing.                                  |
| 1. Remarkable Outcomes        | Combining numbers results in extraordinary outcomes, such as issues in video games caused by inconsistent rounding functions. |
| 2. Functions                  | Functions are essential for processing numbers systematically and maintaining accuracy in programming.                        |
| 3. Graphing Functions         | Graphing helps visualize mathematical relationships through creative plotting methods.                                        |
| 4. Recursive Functions        | Introduces Fibonacci and Lucas sequences, showing how output is derived from previous terms.                                  |
| 5. Primality Tests            | Discusses Lucas numbers and their use in prime number verification through the Lucas–Lehmer test.                             |
| 6. Convergence vs. Divergence | Clarifies that while infinite sequences often diverge, some can converge on finite values.                                    |
| 7. Basel Problem              | Euler's solution to the Basel problem illustrates the connection between number theory and geometry.                          |
| 8. Bernoulli Numbers          | Although complex, Bernoulli numbers connect different mathematical ideas and have significant utility.                        |
| 9. Infinite Series            | Challenges perceptions with the assertion that the sum of all natural numbers equals $-1/12$ .                                |
| 10. Riemann Zeta Function     | Highlights the Riemann Hypothesis as a deep mathematical mystery related to prime number distribution.                        |



| Section    | Summary                                                                                                   |
|------------|-----------------------------------------------------------------------------------------------------------|
| Conclusion | Finds a blend of humor and deep mathematical theory, showcasing the beauty and complexity of mathematics. |

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## Chapter 15: 14 Ridiculous Shapes

In this chapter, Matt Parker dives into the fascinating world of unconventional shapes, particularly focusing on the Möbius loop and its perplexing properties. The Möbius loop is no ordinary shape; it cannot be cut in half without resulting in a single elongated loop due to its unique twist. To illustrate this, Parker describes a simple experiment where two paper strips are twisted and joined into loops. The untwisted loop behaves like a standard cylinder and is easily cut into two pieces. However, the twisted Möbius loop, upon cutting, unveils unexpected characteristics, leading to the revelation that it possesses only one side and one edge. This intriguing quality suggests that attempts to color the loop will result in both 'sides' being the same, emphasizing its continuity.

Next, Parker explores variations of the Möbius loop, such as the three-twist loop, which introduces a knot when cut, and the two-twist loop capable of being split into identical rings. Each type reveals how different amounts of twisting affect outcomes, with even numbers yielding two pieces while odd numbers produce a single piece. Moreover, when two Möbius loops are

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## Chapter 16 Summary: 15 Higher Dimensions

In exploring the fascinating world of higher dimensions, we traverse a landscape that defies traditional visual comprehension. Although the concept of the fourth dimension has been fully explored, transitioning to and beyond this dimension introduces a multitude of complexities that challenge our perceptual abilities profoundly.

1. The Jump from 3D to 5D: As we move from three to five dimensions, we add yet another orthogonal direction, yielding intriguing structures such as the 5D cube, composed of two 4D cubes interconnected by edges. This complexity continues as we explore higher dimensions, with Hamiltonian paths and various cube analogs leading the way.

2. The Experience of Higher-Dimensional Cubes: Visualizing a 5D Rubik's Cube becomes an exercise in understanding projections, as one attempts to discern shadows of ever-increasing projections from 5D to 2D. Post-5D, visualization becomes increasingly impractical, compelling reliance on mathematical understanding rather than visual aids to comprehend these shapes.

3. The Strangest of Geometries: Higher-dimensional spheres (hyperspheres) exhibit bizarre behavior, such as expanding beyond their enclosing hypercubes. Utilizing Pythagorean principles, we observe dimensional



growth in radius as we explore hyperspheres throughout various dimensions, from 2D to 10D and even higher, culminating in the discovery that they can escape confinement as dimensions increase, growing spiky or protruding.

4. Platonic Solids in Higher Dimensions: Mathematically, moving from 3D to 4D gifts us new forms like the hyper-diamond, and in exploring beyond, we expect to encounter more Platonic solids. However, only three solid families—the hypercube, the simplex, and the cross polytope—survive into the realm of 5D and beyond, showcasing a stark limitation in regular structures at higher dimensions. This reveals an intriguing divide: the wealth of forms in lower dimensions versus the stark uniformity beyond 4D.

5. Mathematical Patterns: The exploration reveals interesting patterns, including a generalized Euler characteristic that consistently describes these higher-dimensional polytopes. This alternation between dimensions offers frameworks to analyze shapes in multi-dimensional space.

6. Packing Challenges: Extending the idea of geometric packing from oranges to hyper-fruit in higher dimensions introduces concepts like "sausage conjecture" and "haggis," illustrating the complexities that arise with more spheres. Each dimension presents unique challenges for efficient sphere packing, revealing surprising shifts in optimal configurations depending on sphere quantity.



7. The Kissing Problem: The quest for understanding how spheres interact leads us to the kissing number—the maximum number of identical spheres that touch a central sphere. This problem extends our comprehension of spatial relations across dimensions, with proven results regarding kissing numbers in various dimensions revealing both predictable patterns and lingering mysteries.

8. Practical Applications: The importance of understanding higher-dimensional shapes transcends theoretical mathematics; it plays a critical role in various practical fields, including computer science and physics, where navigating high-dimensional landscapes is crucial for efficient processing and problem-solving.

9. Discovering the Monster: Our expedition culminates in the existence of "The Monster," a shape residing uniquely in 196,883 dimensions. This discovery represents a pinnacle of mathematical exploration, showcasing how entities can exist beyond comprehension yet still offer valid mathematical constructs. The "Friendly Giant," as it's affectionately known, serves as a reminder of the endless possibilities within mathematical inquiry.

In summary, this chapter navigates the uncharted territories of higher dimensions, illuminating the peculiarities of geometric shapes and relationships. It challenges our innate perceptions, encouraging a mathematical understanding of realities far beyond the tangible. The



exploration of these dimensions not only enhances our knowledge of mathematical theory but also hints at the potential for future discoveries that push the boundaries of human comprehension.

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# Critical Thinking

**Key Point:** Challenging Perceptions of Reality

**Critical Interpretation:** As you delve into the complexities of higher dimensions, envision how this journey can inspire you to challenge your own perceptions of reality. Just as the leap from 3D to 5D opens up an array of interconnected structures that defy your usual understanding, you too can expand your perspective on life's challenges. Embrace the idea that beyond your familiar experiences lie new dimensions of possibility, encouraging you to think creatively and explore solutions in ways you had never considered before. This chapter reminds you that the limitations you perceive are often just a shadow of what is possible, urging you to venture beyond the familiar and embrace the unknown with curiosity and courage.

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## Chapter 17 Summary: 16 Good Data Die Hard

In the exploration of data, particularly focusing on bank card numbers and error-checking methodologies, we learn about the sophisticated systems that are designed to ensure accuracy and security in data handling. The author introduces a practical exercise using a sixteen-digit bank card number, where the process of digit manipulation illustrates an error-checking principle embedded in these numbers, known as the Luhn algorithm. By doubling every alternate digit and summing them to check for a multiple of ten, we see how modern bank card numbers can quickly verify correctness without needing external confirmation from financial institutions.

1. **The Luhn Algorithm:** This foundational method, developed by Hans P. Luhn, illustrates a crucial system for ensuring the integrity of bank card numbers. It includes doubling every second digit and verifying the sum against a modulus of ten, which serves as a rapid error-checking mechanism.
2. **The Historical Context:** Luhn's patent for a mechanical number-checking device predates the electronic computer era, yet his principles are still integral to modern technology. The same checks are found in barcodes, where a similar method of error verification is used, highlighting the widespread application of these principles across different formats of data.
3. **Hidden Patterns in Data:** Beyond bank cards and barcodes, there are secret





checks in various number systems—such as VAT numbers in the UK—designed to catch deception or mistakes. Yet, many of these patterns remain unknown to the general public, showcasing an intricate web of mathematical safeguards that operate beneath the surface.

4. ASCII and Data Representation: The discussion transitions into the realm of how information in different forms—like text, images, and sounds—can be encoded into binary numbers. The author describes a binary scarf as a creative gift and walks through how characters can be transformed into binary code, showcasing the versatility of number encoding in digital communication.

5. Unicode Expansion: The evolution of coding systems from ASCII to Unicode dramatically broadens the range of representable characters and symbols, enabling computers to process diverse languages and scripts efficiently. This system underlines the ubiquity of binary data in our digital interactions.

6. Bits and Bytes: To simplify binary calculations, the author demystifies terms such as bits and bytes, explaining their importance in modern computing. The correlation between the number of errors and the data structure highlights how meticulous organization can prevent data corruption.



7. Hamming's Contribution to Error Correction: The narrative introduces Richard Hamming and his error correction codes, which were initially inspired by the unreliable nature of early computers. Hamming's methods—like the idea of parity bits and the concept of Hamming distance—help computers recognize and correct their own data errors, laying the groundwork for many modern communication protocols.

8. Real-World Applications: The function of these error-checking methods extends to various practical scenarios, including mobile phone communications and text messaging. Over time, the concepts of error detection and correction become vital in ensuring data integrity, especially as the complexity and scale of data transmission grow.

9. Finite Nature of Digital Data: As data is encapsulated in digital form, the infinite variety of real-world nuances is captured within constrained numerical ranges. This inherently affects the uniqueness of digital representations—whether it's colors in images or bits in audio files—indicating a fundamental limit to what can be represented in a fixed format.

10. The Mathematics of Creativity: The concept of a musician's creativity being a selection from a vast yet finite universe of potential compositions embodies the intersection of mathematics and art. Articulating that every new creation is merely discovering a dimension in a hypercube resonates



deeply with the mathematical processes underlying our digital world.

Through this rich tapestry of examples and principles, the chapter illustrates not only the importance of error detection and correction in our digitized lives, but also the ongoing interplay between mathematics and the technologies that define our reality. Each method serves to enhance our understanding and capability, demonstrating that the world of data, while vast, operates under a series of clear mathematical structures.

| Topic                                      | Description                                                                                                       |
|--------------------------------------------|-------------------------------------------------------------------------------------------------------------------|
| The Luhn Algorithm                         | A method for ensuring bank card number integrity through digit manipulation to verify sums against modulus ten.   |
| Historical Context                         | Luhn's principles predate electronic computing and are applied in modern data formats like barcodes.              |
| Hidden Patterns in Data                    | Various number systems have error-checking mechanisms to prevent deception/mistakes, often unknown to the public. |
| ASCII and Data Representation              | Explains encoding different forms of information into binary, showcasing versatility in digital communication.    |
| Unicode Expansion                          | Transition from ASCII to Unicode allows for diverse language and script representation in computing.              |
| Bits and Bytes                             | Clarifies the terms and significance of bits and bytes, emphasizing organization to prevent data errors.          |
| Hamming's Contribution to Error Correction | Introduces Hamming's error correction codes, important for data reliability in computing and communication.       |
| Real-World                                 | Error-checking is critical in mobile communication, text                                                          |



| Topic                         | Description                                                                                                   |
|-------------------------------|---------------------------------------------------------------------------------------------------------------|
| Applications                  | messaging, and data integrity assurance.                                                                      |
| Finite Nature of Digital Data | Digital representation is limited, affecting uniqueness in colors, audio, and other data formats.             |
| The Mathematics of Creativity | Links musical creativity to mathematics, suggesting every creation is a discovery within a dimensional space. |

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## Chapter 18: 17 Ridiculous Numbers

In this chapter from "Things To Make And Do In The Fourth Dimension," Matt Parker explores a fascinating journey through the world of numbers, particularly focusing on Mills' constant and the complexities of mathematical categorization.

Firstly, Mills' constant, known by the Greek letter  $\theta$  for its extraordinary property: when raised to powers that are powers of 3 and rounded down, it yields prime numbers indefinitely. This constant was discovered by William Mills in 1947 and has been calculated to 6,850 digits as of 2005. However, its utility is limited since one cannot derive the constant from primes; rather, the primes must be known beforehand to identify Mills' constant. The ongoing assumption that primes are densely grouped, as suggested by the Riemann Hypothesis, underlines the validity of Mills' constant. If proven true, it would support its unique ability to generate an infinite sequence of primes.

Secondly, the chapter delves into the classification of numbers, beginning

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## Chapter 19 Summary: 18 To Infinity and Beyond

In this chapter, the concept of infinity is explored as both a fascinating and perplexing mathematical idea. Infinity has been present throughout the text, often referenced in the context of sums or quantities that seem to exceed finite bounds. However, the intricacies of infinity remain largely untouched until now, where we bravely confront its challenges and paradoxes.

1. The adventure begins with a thought experiment involving a box and an infinite number of balls, numbered sequentially. The process of adding these balls to the box while removing square-numbered ones (and their square roots) leads to a surprising conclusion: despite the continuous addition of balls to the box, it ultimately ends up empty. This paradox stems from the unique nature of infinity, which differs fundamentally from finite numbers. The count of whole numbers is infinite, yet the act of squaring pulls them out of the box, leaving no whole number behind.
2. The essence of infinity is clarified—it's not merely a large number or an endpoint on the number line, but a measure of an unending quantity of numbers. The journey from contemplating vast numbers to recognizing the entirety of the number line reveals that infinity is indeed more complex than most perceive; it represents the sheer size of an infinite set.
3. Engaging with infinity challenges our intuition, as we are naturally



inclined towards finite numbers. The mathematical exploration inadvertently requires us to abandon our intuitive grasp and embrace the rigorous logical framework of mathematics to navigate this abstract concept.

4. Historical context reveals that the acceptance of infinity as a legitimate mathematical domain was a contentious matter, championed by mathematicians like Georg Cantor and supported by David Hilbert, despite significant resistance from their contemporaries. Cantor intricately detailed the nature of infinity, showing that some infinities could be larger than others, culminating in discussions of the "Hilbert Hotel," an infinite establishment that illustrates many concepts of infinity.

5. In this theoretical hotel, one can cleverly accommodate new guests arriving after the hotel is fully occupied. Infinite guests can shift positions, making room for others, which highlights the rules of managing infinite sets but reveals also that certain infinite groups, like the real numbers, cannot be matched with the whole numbers.

6. Cantor's groundbreaking work led to the realization that infinite sets can be differentiated into countable and uncountable infinities. For instance, the whole numbers and rational numbers (the latter being denser and more vast) can be paired with whole-numbered rooms, but the continuum of real numbers between any two endpoints cannot.





7. The unfolding narrative of infinity leads to Cantor's exploration of larger infinities, denoting them with the aleph symbol. His assertion of various infinity sizes culminated in the Continuum Hypothesis, which posits questions about the hierarchy of infinities.

8. The exploration took a profound turn with Gödel's incompleteness theorems, which asserted the limitations of axiomatic systems in proving every mathematical truth. This revelation shook the very foundations of mathematics, indicating that some conjectures, like the Continuum Hypothesis, could neither be proved nor disproved within established frameworks.

9. In conclusion, the chapter outlines that infinity is not merely an abstract notion but a complex structure rich with varying dimensions and sizes. Infinity is both a thrilling domain of exploration in mathematics and a source of philosophical contemplation on the nature of existence and comprehension, indicating an ongoing journey of discovery, debate, and understanding.

Through rigorous thought experiments and historical context, the chapter both celebrates the beauty of infinity and acknowledges the challenges it poses to our understanding, ultimately reinforcing that in mathematics, infinity is a profound thread worthy of investigation and contemplation.



## Chapter 20 Summary: $n+1$ The Subsequent Chapter

At the conclusion of this introspective journey through the realms of mathematics, we find ourselves reflecting on the evolution of mathematical thought from simple games and shapes to the profound complexities that challenge our understanding of reality. Throughout this exploration, we've encountered an array of mathematical concepts, from knots to graphs, and unraveled how they contribute significantly to modern technology and computing. Despite our extensive discoveries, the allure of Gödel's incompleteness theorems reassures us that the quest for knowledge in mathematics is forever ongoing. There will always be questions that elude resolution, ensuring that future mathematicians will have a continuous stream of challenges to tackle, with results that range from the practical to the purely whimsical.

1. The perplexing relationship between the origins of mathematics and its application in the real world raises an intriguing paradox. Richard Hamming and Eugene Wigner highlighted this "unreasonable effectiveness" of mathematics in their notable works, prompting us to ponder why abstract mathematical constructs, often conceived without practical intent, become essential tools in elucidating the laws of nature.
2. The landscape of mathematics has evolved dramatically, especially in the twentieth century, where previously dismissed abstract notions like



non-Euclidean geometry have proven vital in understanding physical phenomena. Pioneers like Paul Dirac showcased how abstract mathematics could lead to groundbreaking discoveries, such as the prediction of the anti-electron, further establishing the expectation that elegant mathematical frameworks often correlate with empirical truths.

3. String theory exemplifies the tension between the theoretical elegance of mathematics and the challenges of empirical validation. Although it proposes dimensions beyond our familiar four, the allure lies not in proof but in the intrinsic beauty and coherence of its mathematical presentation. This mystery reinforces the idea that while mathematics can illuminate the universe, it exists independently of it, bound by its own logic and structure rather than immediate reality.

4. The relationship between mathematics and physics challenges the notion of a singular "truth," as the same mathematical principles hold across various realities. Whether within 3D or hypothetical higher-dimensional frameworks, mathematics maintains its integrity, inviting us to consider the possibility that different entities could explore the same mathematical concepts while inhabiting disparate realities.

In conclusion, this exploration serves as an invitation to delve deeper into recreational mathematics. From playful cutting of pizzas to the fascinating implications of Möbius loops, the journey does not end here. Even as we



finish this book, the vast expanse of mathematics remains open for continued exploration and amusement. Each encounter with mathematics can spark curiosity, encouraging us to engage with it, discover its wonders, and celebrate the endless adventures it offers for generations to come.

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