Crack the Code: An Interactive Journey Through Optimization

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Let's do a quick round of introductions!

I'll start...

- Hometown: Chennai, India.
- Hobbies: Board Games and Puzzles.
- Education/Training:

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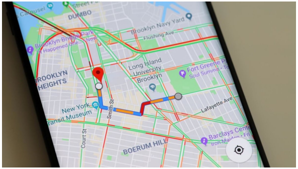
Who are you? What are your interests?

Where Do You See Math Here?



ChatGPT

What decisions are optimized in each application?

What is an Optimization Problem?

Three Key Ingredients

1. **Decisions**: What choices can we make?
2. **Constraints**: What limits or rules must we follow?
3. **Goal**: What are we trying to maximize or minimize?

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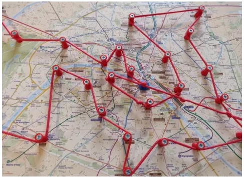
Pizza Topping Example

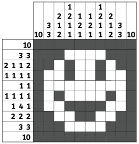
You have a budget of $10, can choose up to 4 toppings, and want to get the *most delicious* pizza possible.

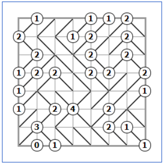
Real-World Applications and Careers Using Optimization

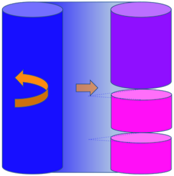
- **Amazon/UPS**: Plan millions of delivery routes every day.
- **Costco/Walmart**: Optimize store layouts & shelf restocking.
- **Lyft/Uber**: Match drivers to riders in real time.
- **Google Maps**: Re-route you around traffic jams.
- **Airlines**: Schedule crews and aircraft efficiently.
- **Netflix/TikTok/YouTube**: Personalize recommendations to keep you engaged.
- **Tesla, IKEA**: Reduce waste and optimize factory workflows.
- **Airbnb/Expedia**: Set prices dynamically based on demand.
- **Finance**: Build investment portfolios balancing risk vs return.
- **Power Grid Operators**: Which generators to run each hour.
- **Chemical Plants**: Mix and heat chemicals efficiently, safely, and with minimal waste.
- **ChatGPT/Gemini**: Adjust billions of settings to generate better answers and fewer mistakes.

Line-Up of Hands-On Activities









Today We Will...

1. Help Taylor Swift plan her next tour (the smart way).
2. Solve a puzzle where logic meets art.
3. Play a game called Slant — it's trickier than it looks!
4. Explore the science of cutting things without wasting material.

Outline

1. Activity 1: Help Taylor Swift Optimize Her Next Tour!
2. Activity 2: A Puzzle Where Logic Meets Art!
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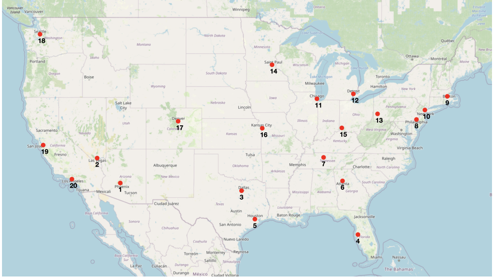
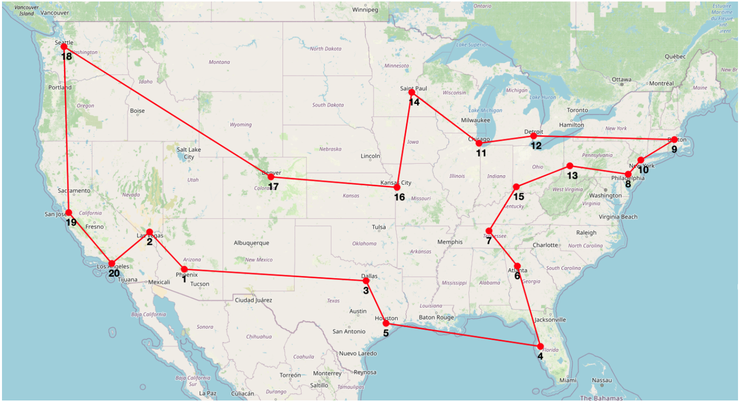
4. Activity 4: The Science of Cutting Things Without Wasting Material.

Help Taylor Swift Optimize Her Next Tour!



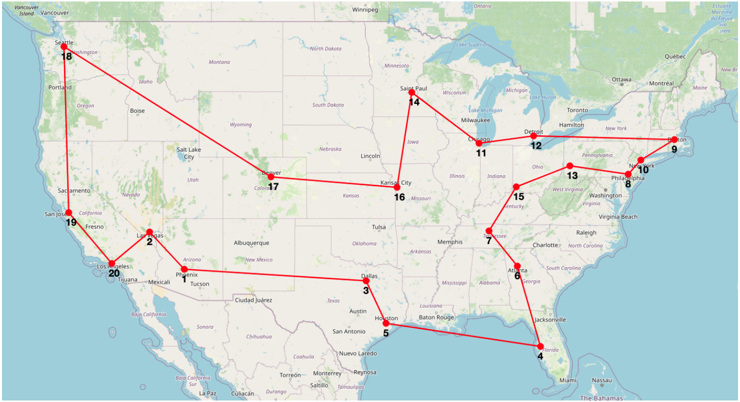
- **Scenario:** Taylor needs your help planning her next tour!
- She wants to start in Phoenix (#1), visit each venue exactly once, and return to Phoenix.
- Work in teams of two to help Taylor minimize the total distance traveled.

Help Taylor Swift Optimize Her Next Tour!



- **Original Tour Distance:** 11,016 miles
  (based on the order of cities in the original tour)
- **Optimized Tour Distance:** 8,221 miles (25% shorter!)

Help Taylor Swift Optimize Her Next Tour!



- **Original Tour Distance:** 11,016 miles
  (based on the order of cities in the original tour)
- **Optimized Tour Distance:** 8,221 miles (25% shorter!)
- But what's wrong with this solution?

Traveling Salesperson Problem

Optimal tour through 50 landmarks in the U.S., computed using data from Google Maps.
https://www.math.uwaterloo.ca/tsp/usa50/index.html

Real-World Applications: Amazon, UPS, Uber, Google Maps, ...

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Optimization Model

- *Variables*: $x_{ij} = 1$ if we travel directly from location $i \to j$.
- *Visit Each Location Once*: Each city must be entered and exited exactly once.
- *No Sub-tours*: Prevent smaller loops that don't include all cities.
- *Objective*: Minimize total distance $\sum_{i,j} d_{ij} x_{ij}$.

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Research Question: How can we design algorithms that still work when there are thousands of locations?

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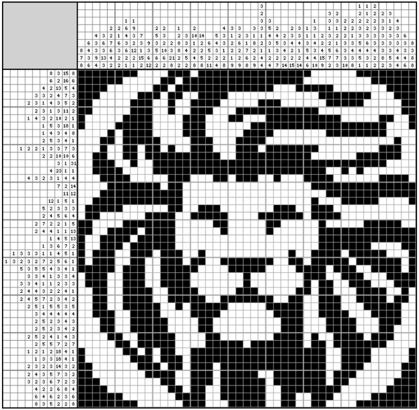
Nonogram: Logic Meets Art



- Fill squares to satisfy row/column clues.
- Hidden pixel picture appears!
- Interested? Try solving more at:
  - `https://www.nonograms.org/`
  - `https://www.puzzle-nonograms.com/`

Let's Solve a Simple Nonogram Together

You have a grid of squares. Your goal is to shade the correct squares.

- Numbers next to each row and column tell you how many groups of shaded squares are in that line and how long each group is. For example, "3 1" means a group of 3 shaded squares, then a group of 1, with at least one blank square in between.
- Use logic to figure out which squares to shade or leave blank.
- Use a small X or dot to mark squares you are sure should stay blank.

	4	3	1	1	2 2
2 2					
3 1					
2					
1 1					
1					

Can You Solve This Larger Nonogram?

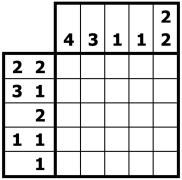
	4	1 1	1 1	3	1 3	3 5	1 3	9	8	6
6										
2 1 3										
1 3										
2 3										
1 3										
1 5										
1 4										
7										
3 1										
3										

How Can We Solve Nonograms Using Optimization?

						2
		4	3	1	1	2
2	2					
3	1					
	2					
1	1					
	1					

- Fill squares to satisfy row/column clues.

How Can We Solve Nonograms Using Optimization?



- Fill squares to satisfy row/column clues.

Optimization Model

- *Variables*: $x_{ij} = 1$ if square (i, j) is filled; include additional variables to track where each block starts in a row or column.
- *Constraints*: Ensure at least one blank square between consecutive blocks; satisfy the given clues.
- No objective — want *any* solution that satisfies all constraints.

How Can We Solve Nonograms Using Optimization?

	4	3	1	1	2 2
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Related Real-World Applications: circuit board design, classroom scheduling, image segmentation.

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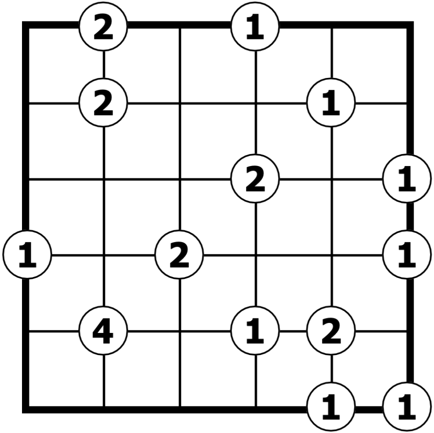
Let's Play a Game of Slant

Place a diagonal line (either / or \) in every cell of the grid

- Numbers at the corners show how many lines meet at that point (from the surrounding one, two, or four cells).
- The lines must not form a closed loop anywhere in the grid.

All you need is logic and a pencil!



Can You Solve This Harder Puzzle?

Place a diagonal line (either / or \) in every cell of the grid

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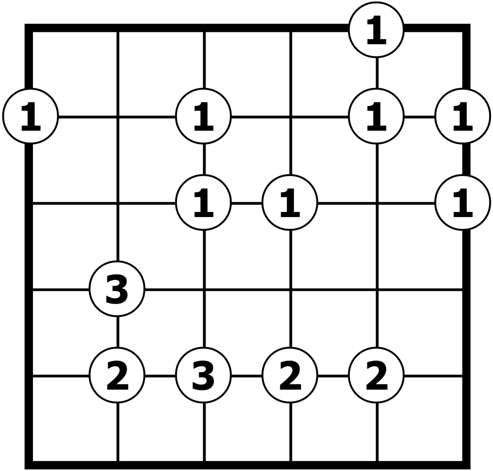
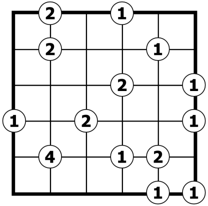
- The lines must not form a closed loop anywhere in the grid.



How Can We Solve Slant Using Optimization?



Curious? Try solving more at: `https://www.puzzle-slant.com/`

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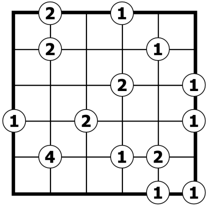

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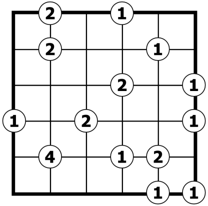
Optimization Model

- *Variables*: $x_{ij} = 1$ if square (i, j) contains a $/$; $y_{ij} = 1$ if it contains a $\backslash$.
- *Constraints*: $x_{ij} + y_{ij} = 1$; satisfy the numbered clues at the corners; avoid forming any loops.
- No objective — want any solution that satisfies all constraints.

How Can We Solve Slant Using Optimization?



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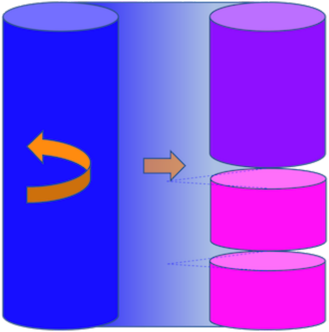
Real-World Applications: designing loop-free telecommunication networks, routing wires on chips to avoid short circuits.

Outline

Cutting Stock: The Science of Not Wasting Material



- Start with a large roll or sheet.
- Cut it into smaller sizes people ask for.
- Try to waste as little material as possible.
- **Real-World Applications:** Nike (cutting fabric), steel mills, and furniture makers.

Cutting Stock Problem: Craft Sticks Challenge!

- You have craft skill sticks of fixed length (about 11.3 cm).
- Your task: Use a pencil and ruler to mark how you would cut each stick to fulfill this customer order:
  - 6 pieces of 3 cm
  - 7 pieces of 4 cm
  - 5 pieces of 5 cm
- **Goal:** Use the fewest number of full sticks possible.
- Work in teams of two to plan your cuts and mark the sticks.

Cutting Stock Problem: Craft Sticks Challenge!

Solution using 7 sticks

- Stick 1: 4 cm + 4 cm + 3 cm $\implies$ 11 cm used, 0.3 cm leftover
- Stick 2: 4 cm + 4 cm + 3 cm $\implies$ 11 cm used, 0.3 cm leftover
- Stick 3: 4 cm + 4 cm + 3 cm $\implies$ 11 cm used, 0.3 cm leftover
- Stick 4: 5 cm + 3 cm + 3 cm $\implies$ 11 cm used, 0.3 cm leftover
- Stick 5: 5 cm + 5 cm $\implies$ 10 cm used, 1.3 cm leftover
- Stick 6: 5 cm + 4 cm $\implies$ 9 cm used, 2.3 cm leftover
- Stick 7: 5 cm + 3 cm $\implies$ 8 cm used, 3.3 cm leftover

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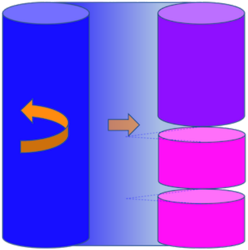
Can you prove that we need at least 7 sticks to fulfill the order?

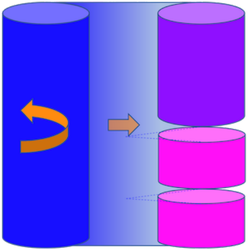
Cutting Stock: The Science of Not Wasting Material



Optimization Model

- *Patterns j*: different ways to cut up a sheet.
- *Variables y_j*: how many sheets we cut using pattern j.
- *Demand rule*: make enough of each piece to fill all the orders.
- *Goal*: use as few big sheets as possible.

Cutting Stock: The Science of Not Wasting Material



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There can be billions of possible cutting patterns in practice, so we need smart algorithms to find the best solution fast!

Key Take-Aways

- The same recipe applies to every problem:

  Optimization = Decisions + Constraints + Objective.
- Optimization helps save money, time, energy, and resources.
- The puzzles you solved today are simplified versions of real challenges faced in industry!
- There are still many important optimization problems we don't know how to solve efficiently — maybe you'll help someday!
- If you enjoy logic & creativity, consider studying:
  - Industrial and Systems Engineering (ISE) — Optimization (a.k.a. Operations Research) is a core area.
  - Computer Science.
  - Mathematics.
  - Other engineering fields.
- Careers in Amazon, Apple, Capital One, Disney, Doctors Without Borders, ExxonMobil, Google, Microsoft, NASA, Procter and Gamble, Southwest, Uber, World Bank/IMF, and many more organizations!

Questions?

Thanks for playing — and optimizing!

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