



**UNPACKED:  
INVISIBLE NETWORKS  
AND MECHANISMS ALL  
AROUND US**

APRIL 2026

ISSUE #1

WHEN MEDICINE STOPS  
WORKING

SPECTRAL GRAPH  
THEORY

P VS NP - CAN WE CRACK THE  
CODE OF COMPLEXITY

# Hidden Systems

**THE CENTRIFUGE**

# TABLE OF CONTENTS



<u>ABOUT OUR THEME</u>	<b>02</b>
Hidden Systems	
<u>OUR CONTRIBUTORS</u>	<b>03</b>
WRITERS AND EDITORS	
<u>THE WORLD IS GOING BLURRY</u>	<b>05</b>
Understanding the global myopia epidemic	
<u>THE CLOCK YOU NEVER KNEW</u>	<b>12</b>
<u>YOU HAD</u>	
Your DNA's hidden conductor	
<u>INFOGRAPHIC</u>	<b>18</b>
The hidden scale of global data	
<u>WHEN MEDICINE STOPS</u>	<b>19</b>
<u>WORKING</u>	
Invisible invaders outsmarting our medicine	
<u>SPECTRAL GRAPH THEORY</u>	<b>25</b>
<u>AND EPIDEMIC CONTAINMENT</u>	
Mapping the hidden networks of contagion	
<u>THE WATCHLIST</u>	<b>39</b>
Some media recommendations from our team	
<u>YOUR ILLUSION OF REALITY</u>	<b>40</b>
The brain as a prediction machine	
<u>THE HIDDEN ARCHITECTURE OF</u>	<b>46</b>
<u>LOGIC (P VS NP)</u>	
Complexity rules our digital world	
<u>BIBLIOGRAPHY AND FURTHER</u>	<b>53</b>
<u>READING FOR ALL ARTICLES</u>	





We often navigate the world by its surface:

the objects we touch, the people we meet, and the immediate results of our actions. But beneath this visible layer lies a complex web of Hidden Systems. These are the silent conductors of our reality: the invisible networks and mechanisms that quietly shape the world around us, often without our awareness until they begin to fail or shift.

This issue is an invitation to look past the obvious. From the biological rhythms written into our DNA to the mathematical networks that dictate how a virus moves through a city, we explore the underlying structures that connect seemingly unrelated phenomena. Why is the global population suddenly losing its distance vision? What happens to the "logic of the world" when a single mathematical proof like P vs NP remains unsolved?

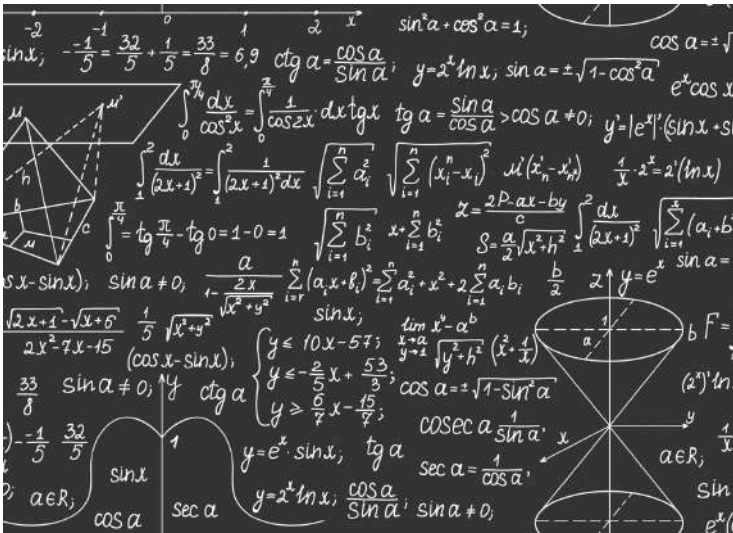
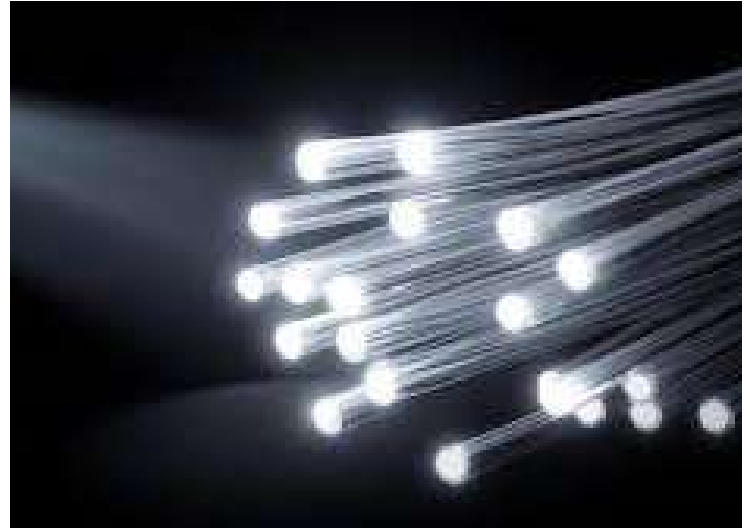
By mapping these hidden architectures, whether they are the neural predictions of our own brains or the spectral graphs used to contain epidemics, we attempt to uncover the true nature of complexity. These systems are not just background noise; they are the active blueprints of our digital, biological, and social lives.

# OUR TEAM



## TERESA PAN

BASED IN VANCOUVER, TERESA IS MOTIVATED BY A FASCINATION WITH THE INTERSECTION OF SCIENCE, WRITING, AND THE POWER OF EDUCATION. HER CURIOSITY EXTENDS FROM THE PRECISE LOGIC OF FRONT-END CODING TO THE EXPANSIVE WORLDS FOUND IN DEEP-DIVE VIDEO ESSAYS AND COMPETITIVE DEBATE. WHEN SHE ISN'T EXPLORING NEW INTELLECTUAL TERRITORIES, SHE IS LIKELY FUELING HER NEXT BIG IDEA WITH A SURPLUS OF COOKIES AND A RELENTLESS DRIVE TO SHARE THE WONDERS OF THE STEM WORLD WITH OTHERS.

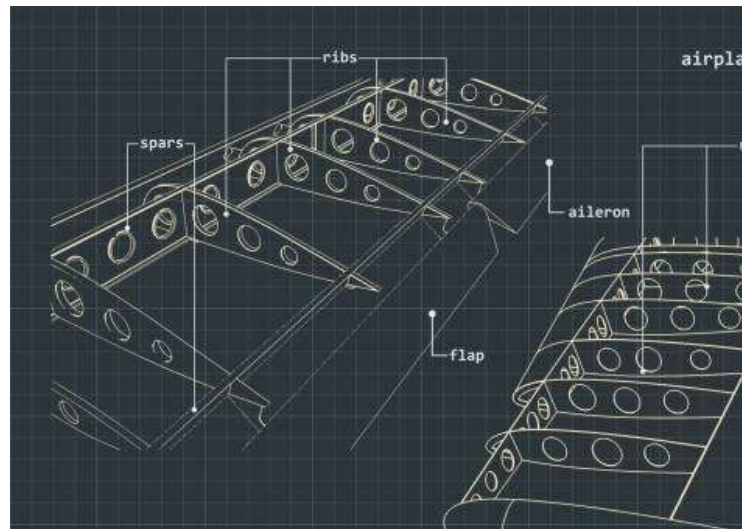


## RITISHA AGARWAL

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# **THE WORLD IS GOING BLURRY:** **UNDERSTANDING THE GLOBAL MYOPIA** **EPIDEMIC**



BY TERESA PAN

Nearly half of americans are nearsighted - and by 2050, more than half the world will be too. Here's what's happening inslude our eyes, why it's getting worse, and what science says we can do about it





## INTRODUCTION

For the first six years of my life, I thought the world was supposed to be blurry. Mountains looked like fuzzy triangles. Street signs were abstract art. Reading the board in class felt like a superpower I simply hadn't unlocked yet.

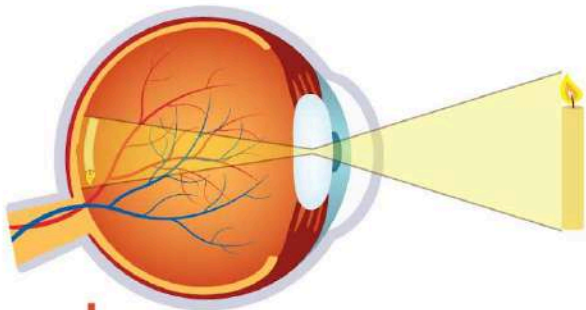
Then, one afternoon at the optometrist, after confidently guessing that the next letter on the eye chart was a P, then an F, then maybe an R – the doctor handed me my first pair of glasses. The world snapped into focus. Street signs had words. Mountains had edges. It wasn't a superpower. It was just physics.

My story isn't unusual. In fact, it's becoming the default. Myopia, the clinical term for nearsightedness, has quietly grown into one of the most widespread visual health crises of the modern era. And the numbers suggest it's only getting worse.

***"By 2050, an estimated 5 billion people, more than half the world's projected population, are expected to be myopic."***

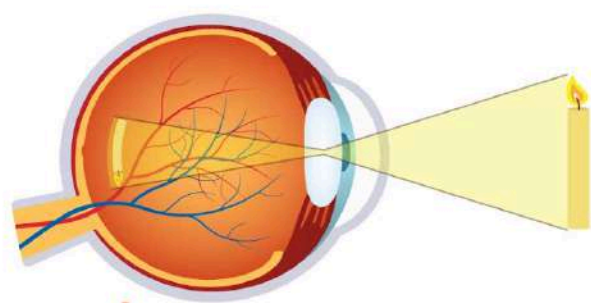
## WHAT IS MYOPIA, EXACTLY?

### Normal eye



Objects are focused on the retina

### With myopia



Objects focus in front of the retina



To understand why myopia is spreading, it helps to first understand what's going wrong inside the eye.

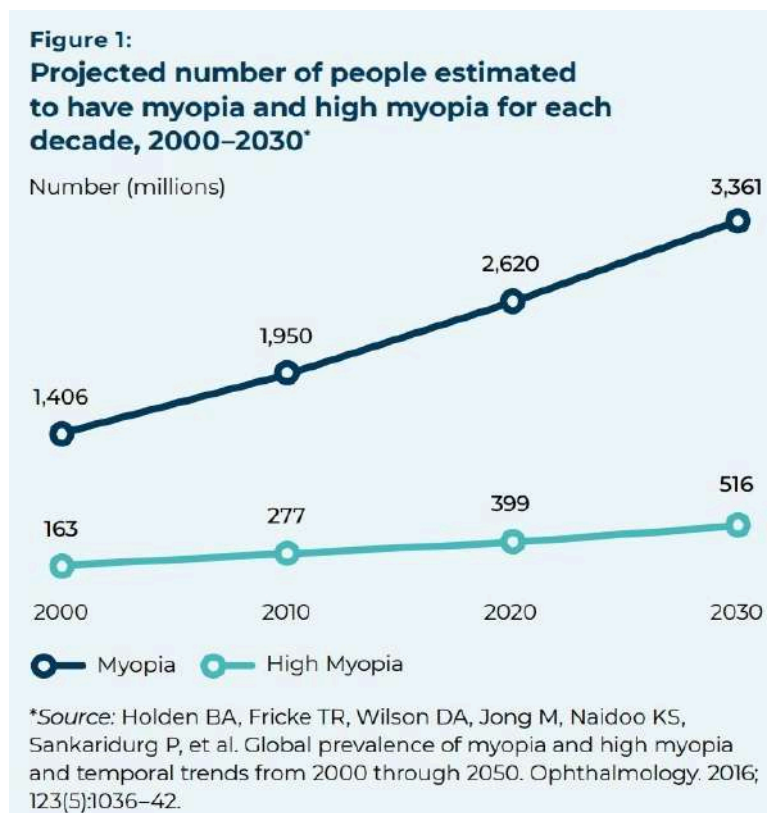
In a healthy eye, light enters through the cornea, passes through the lens, and focuses precisely onto the retina, which is the light-sensitive tissue lining the back of the eye. This focused image is what the brain interprets as clear vision.

In a myopic eye, something disrupts that process. Either the eyeball has grown too long from front to back, or the cornea is curved too steeply. In both cases, the result is the same: incoming light converges at a point just in front of the retina, rather than directly on it. Close-up objects, like text on a phone, can still be seen clearly, because the focal point adjusts with distance. But distant objects go out of focus. The further away something is, the blurrier it becomes.

This is why myopia is commonly called nearsightedness: near things are fine, but far things disappear into blur.

## **THE NUMBERS BEHIND THE EPIDEMIC**

For most of human history, myopia was relatively uncommon. Recorded rates in pre-industrial populations were low, estimated at **under 10%** in many regions. But something changed in the **20th century**, and the shift has been dramatic.





In the United States, myopia prevalence almost doubled in just four decades: from about **25% of the population in 1971** to approximately **42% by 2017**, according to data from the National Eye Institute. Global projections published in the journal *Ophthalmology* estimate that by 2050, around **5 billion** people will have myopia, up from an estimated **1.4 billion** in 2000.

The rises are even more pronounced in East Asia, where myopia rates among young adults in cities like Seoul, Singapore, and Shanghai exceed **80 to 90%**. These are some of the highest rates ever recorded in a human population.

The speed and scale of this change rules out genetics as the primary driver. Human DNA simply doesn't change fast enough to account for shifts occurring across a single generation. Something in the environment has changed.

## **THE TWO MAIN CULPRITS**

### **1. Too Much Close-Up Work**

When you focus on something up close, such as a textbook, a laptop, or a phone screen, the muscles around your eye's lens contract to increase its curvature, sharpening the image. This process is called accommodation and is normal and healthy in short bursts.

The problem arises when eyes spend hours in near-focus mode, day after day, with few breaks for distance vision. Research suggests that sustained close-up work sends a signal to the eye that triggers axial elongation, and the eye literally grows longer to reduce the focusing effort required for near distances. But in doing so, it sacrifices the ability to focus at distance.

Today's children and teenagers spend an extraordinary amount of time on close-up tasks. According to data from Common Sense Media, children **between ages 8 and 18** in the United States average around **seven and a half hours** of daily screen time, not to mention the time spent reading or doing homework. A study from South Korea found that each additional hour of daily screen time was associated with a **21% increased likelihood** of developing myopia.

### **2. Not Enough Time Outdoors**

If close-up work is the accelerator, lack of outdoor time may be the missing brake.

Researchers have found a strong protective effect of outdoor time against myopia development, an association that has held up across dozens of studies and multiple countries. Children who spend more time outside are significantly less likely to develop myopia than those who spend most of their day indoors, even accounting for other factors.



The leading explanation involves light intensity. Natural sunlight on a clear day delivers approximately **100,000 lux** (a unit of illumination) to the eye. A well-lit indoor classroom provides roughly **300 to 500 lux**. The difference is enormous. High-intensity light triggers the release of dopamine in the retina, a neurotransmitter that appears to act as a brake on axial elongation. Without sufficient outdoor light exposure, that brake is not applied.

One widely cited meta-analysis found that each additional hour of outdoor time per day was associated with a **2% reduction** in myopia incidence. An intervention study in Taiwan was conducted where students in grades one through six were given at least two hours of outdoor time per day (including moving some lessons outside) found that myopia incidence dropped from **15% to 8% over a three-year period**.

It bears noting: the protective factor appears to be light exposure itself, not physical activity. Reading a book outside under bright sunlight may offer similar protection to playing soccer, because the key variable is the intensity of the light reaching the eye.

## **BEYOND BLURRY: THE REAL STAKES**

It might be tempting to view myopia as a minor inconvenience. Being myopic may seem like an occasional trip to the eye doctor, a new prescription, or a stylish pair of frames. But the implications are more serious than corrective lenses suggest.

First, there is the medical dimension. In moderate to severe cases of myopia, the elongation of the eyeball puts physical stress on internal structures, such as the retina, the macula, and the optic nerve, raising the risk of serious complications including retinal detachment, glaucoma, and macular degeneration. High myopia, generally defined as a prescription of **-6 diopters or greater**, significantly increases the risk of sight-threatening complications. The risk of retinal detachment is estimated to be up to **22 times higher** in people with high myopia compared to the general population. Myopic macular degeneration, a form of central vision loss associated with severe eye elongation, is now one of the leading causes of uncorrectable vision impairment in East Asia. Unlike a broken arm that heals, or a cavity that can be filled, myopia is a structural change. Once the eye has elongated, it cannot shrink back. Glasses and contacts correct the optical blur, but they do not address the underlying elongation.

Second, there is the access and equity dimension. Glasses are extraordinarily effective and extraordinarily inaccessible for many. **More than 8 million adults** in the United States lack access to vision correction. Globally, the World Health Organization estimates that **826 million** people live with preventable vision impairment due to uncorrected refractive error, with the burden falling disproportionately on low-income communities and developing nations.



## ***"An uncorrected refractive error doesn't just blur vision, it blurs opportunity."***

A child who cannot see the board will fall behind in school. A worker who cannot read fine print will struggle in their job. The costs compound across a lifetime. Providing a single pair of glasses, which can cost just a few dollars to manufacture, has been shown in randomized studies to significantly improve academic performance in school-age children.

### **WHAT CAN ACTUALLY BE DONE?**

The science of myopia prevention is still evolving, but several evidence-based strategies have emerged, operating at the level of individuals, schools, and health systems.

#### **More Time Outside**

The most consistently supported intervention is also the simplest: get children outside more. Public health researchers recommend **at least 2 hours** of outdoor time per day during childhood and adolescence. Taiwan's school-based outdoor program is one of the most robust real-world demonstrations that this works at scale. Countries including Australia, China, and Singapore have since implemented similar policies.

#### **The 20-20-20 Rule**

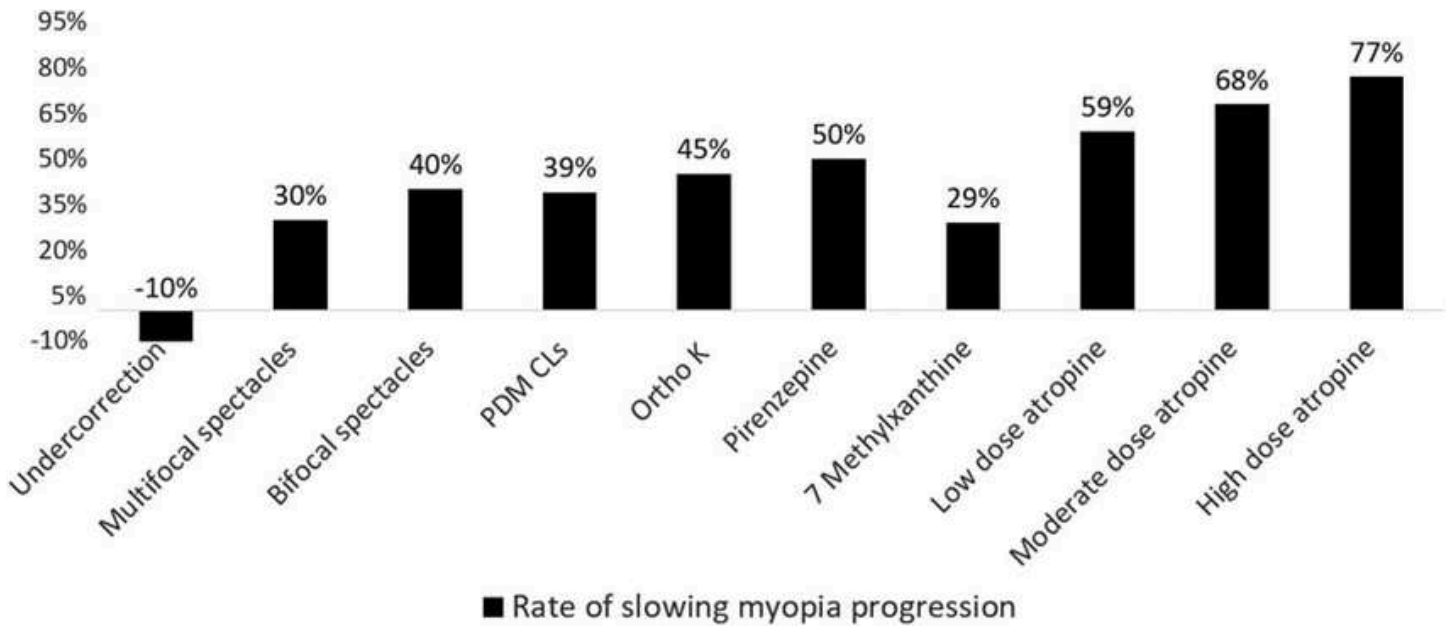
For those spending extended time on screens or near-work, the 20-20-20 rule offers a simple reset: every 20 minutes, look at something at least 20 feet away for at least 20 seconds. This allows the eye's focusing muscles to relax and may help reduce cumulative near-work strain, though it should be seen as a supplement to and not a substitute for outdoor time.

#### **Atropine Eye Drops**

Low-dose atropine eye drops, at **concentrations of 0.01% to 0.05%**, have emerged as one of the most promising pharmacological interventions for slowing myopia progression in children. Multiple clinical trials, particularly in East Asia, have found that low-dose atropine can slow axial elongation by **50 to 60%** compared to placebo, with relatively few side effects at low concentrations. The treatment does not reverse existing myopia, but it may slow its worsening, which matters greatly for long-term risk of high myopia complications. Regulatory approval and clinical availability vary by country.

#### **Orthokeratology and Specialty Lenses**

Orthokeratology, better known as O.K. lenses, refers to the use of rigid contact lenses worn overnight to temporarily reshape the cornea. It has also shown promise in slowing myopia progression. Specially designed soft contact lenses (multifocal or peripheral defocus lenses) are another area of active research and clinical use. These approaches are generally used for myopia control rather than prevention.



### **Systemic Change: Screening and Access**

Individual behavior change has limits if structural barriers remain. Routine vision screening in schools, similar to hearing tests and immunization checks already standard in many countries, could catch myopia early in populations least likely to access private eye care. Programs that subsidize corrective lenses for students in low-income households have shown strong returns on investment, given the link between vision and academic achievement.

### **LOOKING FORWARD**

Myopia is a window into a broader truth: many of the most significant health challenges of the 21st century are not caused by pathogens or genetic mutations, but by mismatches between the environments our biology evolved in and the environments we've built. Our eyes evolved under open skies, scanning horizons. We've redesigned childhood to happen under artificial light, inches from glowing screens.

The good news is that the drivers of this epidemic are, in large part, modifiable. The research is clear enough to act on. The interventions – outdoor time, light exposure, periodic screening, affordable correction – are neither expensive nor technically complex. What they require is will: from parents and educators, from policymakers and health systems, and from the students themselves.

As STEM students and future researchers, health professionals, and policy leaders, you are also the generation that will design the solutions. The science of myopia control is still maturing. Questions remain about the precise mechanisms of axial elongation, the optimal dosing of pharmacological interventions, and the most effective delivery models for underserved populations.

The world doesn't have to stay blurry. We have the tools to bring it into focus. The question is whether or not we use them.

# THE CLOCK YOU NEVER KNEW YOU HAD

BY XINYUE YING





## **INTRODUCTION**

I used to think jet lag was just tiredness. A few too many hours in a cramped seat, a lukewarm meal at 3 a.m., and a body that simply hadn't caught up with the time zone yet. A minor inconvenience – fixed by coffee and stubbornness.

Then I flew from Dubai to Singapore, and for the first few days I genuinely felt like I was living inside a dream I couldn't quite wake up from.

It wasn't fatigue, exactly. It was something harder to place. It was a soft, persistent unreality, like the world had been replaced with a slightly inaccurate copy of itself. Conversations slipped through my fingers before I could hold onto them. I'd reach for a memory from that morning and find nothing there. It was a bit scary even. Things only got worse – I'm bilingual, and somewhere over the Indian Ocean my two languages had apparently decided to swap places without telling me. I'd open my mouth to say something and the wrong language would come out automatically. The people around me were politely confused. I was baffling even to myself.

What I was experiencing wasn't just my schedule being disrupted. It was a system – an ancient, elegant, biological clock – being asked to do something it fundamentally cannot do: change quickly.





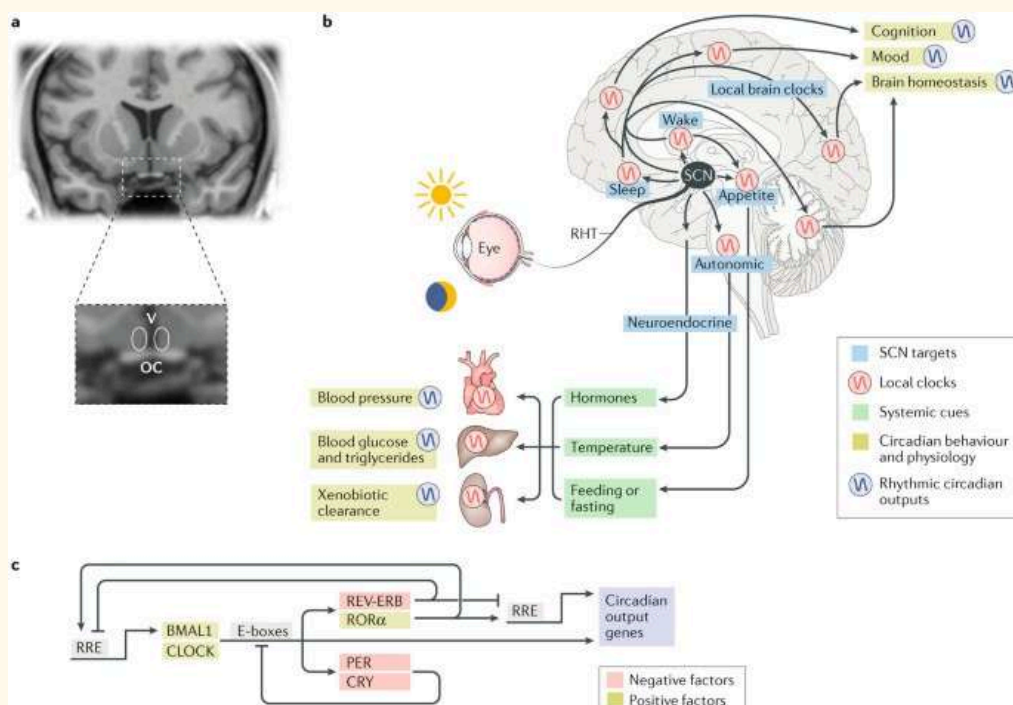
## THE MACHINE INSIDE THE MACHINE

Hidden inside almost every cell in your body is a molecular clock. Not metaphorically – a literal oscillating feedback loop of proteins that completes one full cycle approximately **every 24 hours**. Scientists call it the circadian clock, from the Latin *circa diem*: about a day.

The core mechanism is surprisingly elegant. A cluster of genes – most notably *CLOCK*, *BMAL1*, *PER*, and *CRY* – interact in a self-sustaining loop. *CLOCK* and *BMAL1* proteins bind together and switch on the *PER* and *CRY* genes. *PER* and *CRY* proteins then accumulate through the day until they reach a critical threshold, at which point they switch the whole system off – including their own production. As they gradually degrade overnight, the inhibition lifts, and the cycle begins again.

This loop ticks away in your liver cells, your lung cells, your skin, your immune cells, your gut lining. Each organ carries its own local clock, all loosely synchronised – like a network of slightly imperfect metronomes that have been nudged into agreement.

The conductor of this orchestra lives in a tiny region of the brain called the suprachiasmatic nucleus (SCN), tucked just above where the optic nerves cross. The SCN receives direct light signals from the eyes – specifically from a class of photoreceptors that don't form images at all, but instead measure ambient light levels and feed that information straight into the master clock. This is how light resets your clock each morning. This is why screens before bed are genuinely disruptive. And this is why, flying across time zones, your body's clocks and the local sun suddenly find themselves speaking entirely different languages.





## **WHY ANY OF THIS MATTERS**

The circadian clock is not just a sleep scheduler. It is a global coordinator of biological timing, and its reach is extraordinary.

Your immune system's activity peaks and troughs across the day – one reason why infections that take hold at night can feel worse by morning, and why certain vaccines appear more effective when given at specific times. Your liver metabolises drugs on a **24-hour cycle**, which means the same medication taken at **8 a.m. versus 8 p.m.** can have meaningfully different effects on your body. Tumour cells divide preferentially at certain times of day – a fact that oncologists are beginning to exploit in a field called chronotherapy, timing chemotherapy to attack cancer cells when they are most vulnerable while healthy cells are least so.

Body temperature, blood pressure, cortisol, hunger hormones, cell division, DNA repair – all of them oscillate on roughly **24-hour cycles**, all coordinated by this hidden network. When the system runs smoothly, you barely notice it exists. When it doesn't, you feel it everywhere.

Shift workers offer an uncomfortable window into what happens when the circadian system is chronically disrupted. The research is sobering: long-term shift work is associated with elevated rates of cardiovascular disease, metabolic syndrome, depression, and certain cancers. The body's clocks cannot simply be overridden by willpower. They are set deep in our biology, billions of years old, forged in an era when the rising and setting of the sun was the most reliable fact in the world.

## **A SYSTEM HIDING IN PLAIN SIGHT**

The existence of this clock was only confirmed relatively recently. For decades, biologists assumed that daily rhythms in animals were simply responses to external cues – temperature changes, light, social activity. The idea that the body might contain its own internal timekeeper was considered, at best, an interesting hypothesis.

The proof came from fruit flies. In **1971**, researchers Seymour Benzer and Ronald Konopka discovered mutant flies whose daily activity cycles were disrupted in precise, heritable ways. Some ran short cycles, some long, some had no discernible rhythm at all – and the differences came down to a single gene, which they named period. It was the first direct genetic evidence for a biological clock.



The field didn't stop there. In **2017**, Jeffrey Hall, Michael Rosbash, and Michael Young were awarded the Nobel Prize in Physiology or Medicine for their work unpicking the molecular mechanism – for showing exactly how the PER protein accumulates and feeds back on its own gene, how the whole loop produces its **24-hour rhythm**. It is one of the most beautiful examples of a molecular machine that evolution has produced: a self-winding, self-correcting clock built from proteins, running in every cell of your body, without batteries or external power, since long before clocks were invented.

# The Nobel Prize in Physiology or Medicine 2017



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**Jeffrey C. Hall**  
Prize share: 1/3



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**Michael Rosbash**  
Prize share: 1/3



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**Michael W. Young**  
Prize share: 1/3



## WHAT THE CLOCK REVEALS

There is something quietly profound about the circadian system. It is, in a literal sense, a hidden architecture – invisible and unfelt under normal conditions, but structuring virtually everything about how your body functions. It is the reason a doctor might one day ask not just *what* medication you're taking, but *when* you take it. It is the reason healthy sleep is not simply a matter of getting enough hours, but getting them at the right time for your biology. It is the reason the body is not, as we sometimes imagine, a steady-state machine running at constant capacity – but a system with its own rhythms, its own tides.

What those foggy days in Singapore were really showing me – the dreamlike blur, the memories that wouldn't stick, the languages tangled at the root – was my brain operating on the wrong time entirely. The SCN was still insisting it was the dead of night. The prefrontal cortex, the part responsible for working memory, language retrieval, and clear thinking, runs on the same circadian schedule as everything else. When the clock says it's 3 a.m., it performs accordingly – sluggish, imprecise, reaching for shortcuts. My brain wasn't broken. It was faithfully following a clock that hadn't yet been told where it was.

Jet lag, in the end, is not your body failing. It is a direct encounter with a system that is usually too seamless to notice. For a few days in Singapore, my cells were insisting on a truth that the local sun flatly contradicted – and for once, caught between two languages and a world that felt like it was happening just slightly out of reach, I could feel exactly what that system was doing.

***“Most of the time, it just quietly keeps time for you. You never even know it's there.”***



# THE DATA ICEBERG

Visualizing the 175 zettabytes of invisible architecture running the modern world.

Visible Web

## SECTION 1 – INFRASTRUCTURE SYSTEMS



**1) The Submarine Cable Network:** 99% of international data travels through wires on the ocean floor, not satellites.

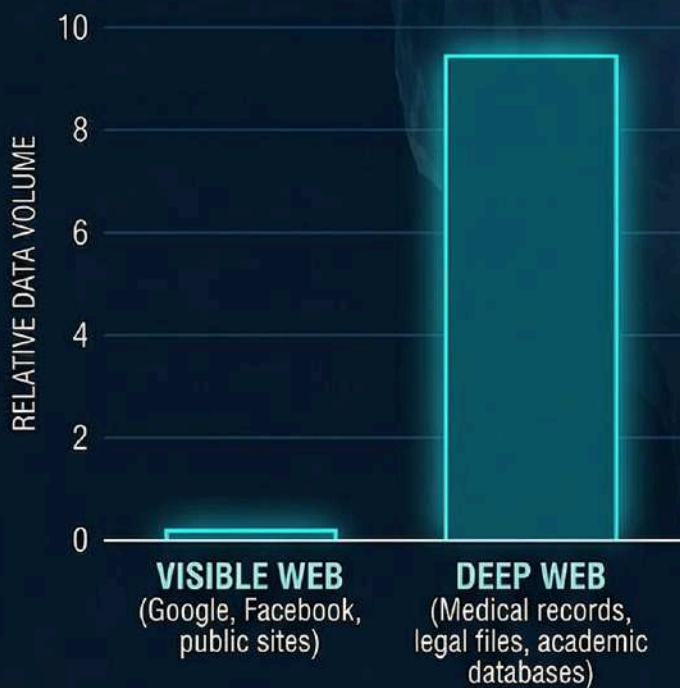


**2) The Shadow Web (IoT):** By 2026, there are over 75 billion connected devices (smart fridges, factory sensors, traffic lights) talking to each other without humans ever seeing the data.

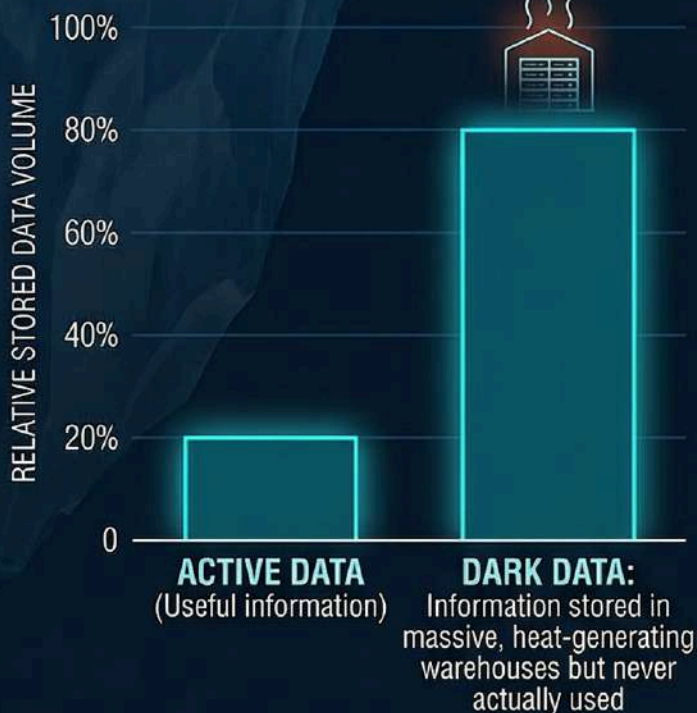


## SECTION 2 – HIDDEN STATISTICS

### 1) Visible Web vs. Deep Web



### 2) Data Waste

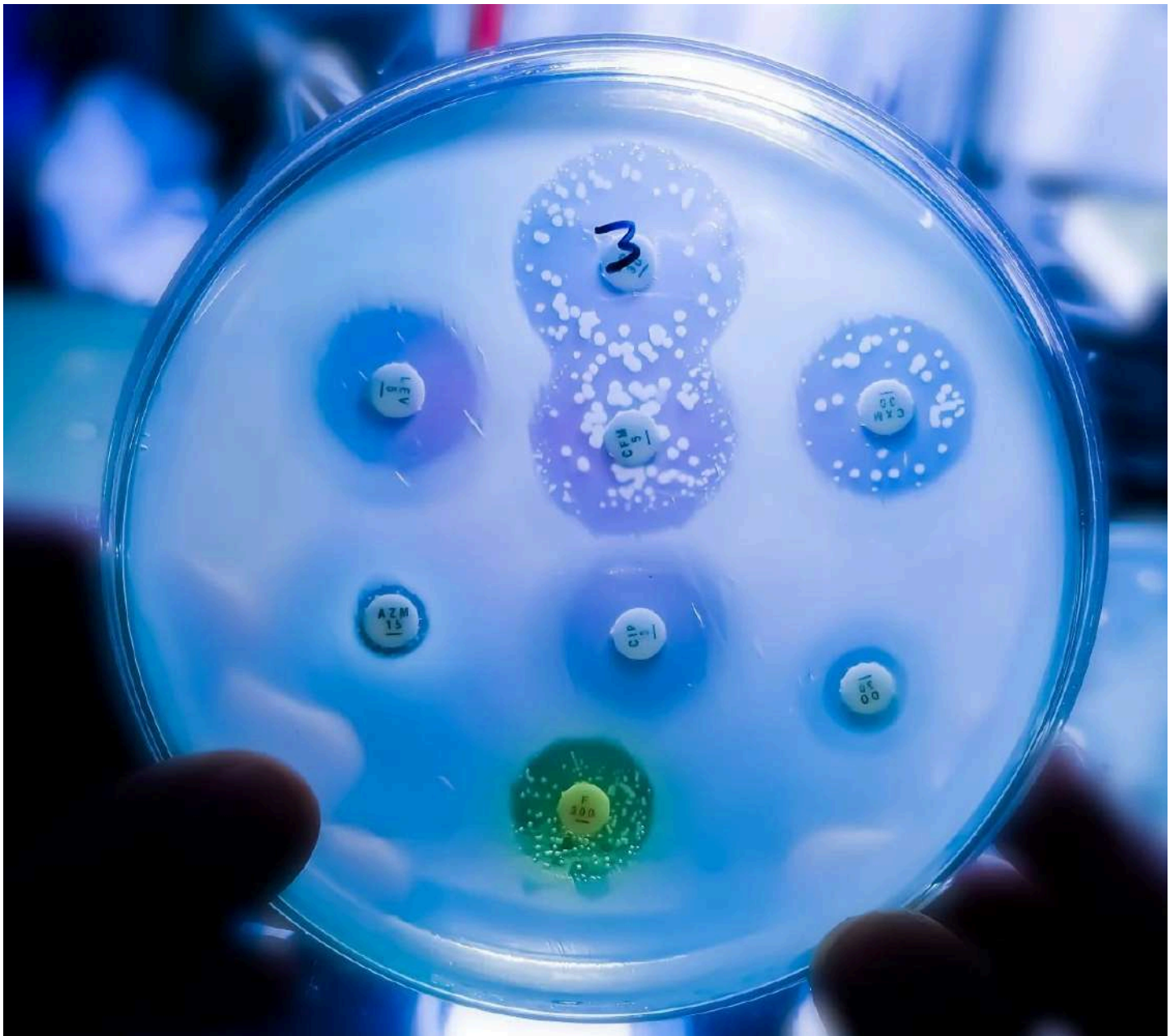


# WHEN MEDICINE STOPS WORKING: THE THREAT OF ANTIMICROBIAL RESISTANCE



BY MARIA MATIAS

Since the discovery of penicillin, in 1928, antimicrobials have saved millions of lives - but an alarming trend has been making them obsolete against the infections they are intended to treat. Here we explore how the resistance mechanisms work, what are their causes and how we can fight this problem before it is too late.





## WHAT IS AMR?

Antimicrobials (AM), which include antivirals, antifungals or antibiotics, are medicines used to treat and/or prevent infections.

Antimicrobial resistance (AMR) is a phenomenon that occurs when pathogens, such as bacteria, viruses, or fungi, mutate or adapt in a way that allows them to develop the ability to resist the effects of antimicrobial agents, resulting in the inefficiency of the medicine and making infectious diseases harder or impossible to treat under the selective pressure of antibiotics. Susceptible bacteria are killed or inhibited, while bacteria that are naturally (or intrinsically) resistant or that have acquired antibiotic-resistant traits have a greater chance of surviving and multiplying.

AMR causes an increase in several diseases' spreadability and the risk of severe illness, disability or death.

## WHAT IS THE PRESENT SITUATION?

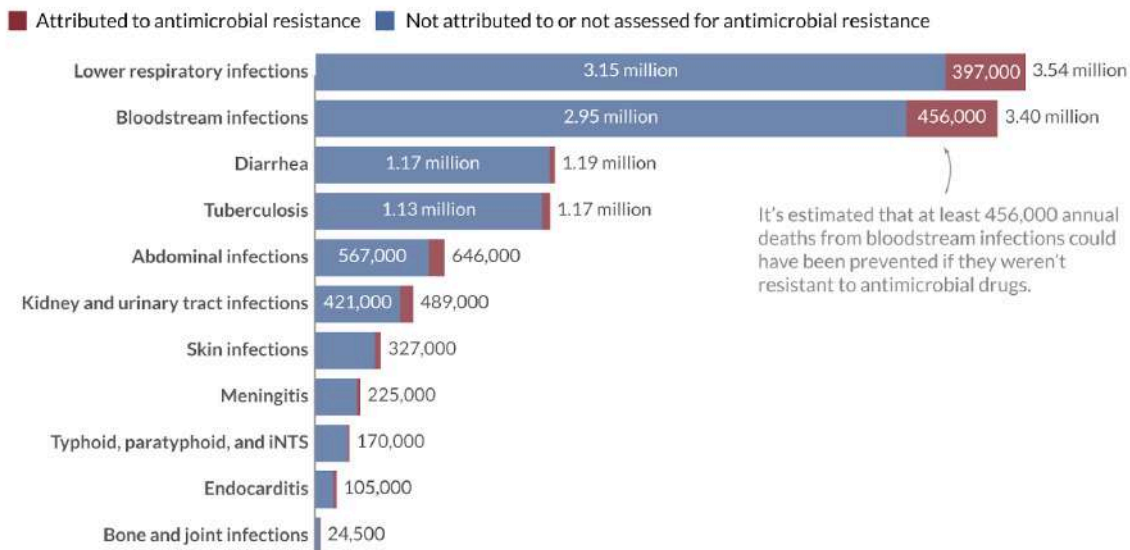
AMR was identified by WHO as one of the top global public health and development threats.

A study from the Global Research on Antimicrobial Resistance (GRAM) estimated that in 2019, 4.95 million people died from drug-resistant infections and, of those, 1.27 million were directly caused by AMR. AMR also puts many of medicine's advances at risk: AMs are essential in procedures such as surgery, caesarean, or chemotherapy, and the AMR substantially increases their risk factor.(Figure 1)

### Global deaths from infectious disease syndromes, broken down by antimicrobial resistance

Our World in Data

Annual data for 2021. Estimates are based on models of causes of death, infection types, pathogens, resistance levels, and their impact on infection duration and complications. Estimates are limited by poor data collection in many regions.



Data source: Institute for Health Metrics and Evaluation (IHME); University of Oxford (2024) OurWorldinData.org/antibiotics | CC BY  
Note: Deaths can be caused by multiple syndromes, so the sum of deaths attributed to each syndrome shown here can exceed the total number of deaths.



This problem impacts all countries at all income levels, although it has a higher incidence and a higher burden level in low-resource settings, with the Sub-Saharan region presenting the highest rate of AMR burden, 23.7 deaths per 100,000 people. AMR also has a larger impact on neonatal and especially older age groups, where mortality related to AMR increased by 80% from 1990 to 2021 in adults 70 years old or over.

This issue has tended to grow over time as, although AMR mortality decreased for children younger than 5 years in all super-regions, AMR mortality in people 5 years and older increased in all super-regions. An analysis by EcoAMR predicted that, if left unattended, AMR could lead to 39 million human deaths between 2025 and 2050.

## **WHAT CAUSES AMR?**

AMR is exacerbated and accelerated by human misuse. The excessive prescription of antibiotics by general practitioners, even in the absence of appropriate indications, self-medication, and incorrect dosage/schedule of antibiotics, are the main contributors to AMR.

In many developing countries, excessive use is due to the easy availability of antimicrobial drugs that can be acquired without a prescription from a professional. In the hospital setting, the intensive and prolonged use of antimicrobial drugs is the main contributor to the emergence and spread of highly antibiotic-resistant infections.

### **1. Urbanisation and Population Growth:**

AMR is deeply connected with urbanisation and population growth. More than half the world's population lives in urban environments. Such a large number of individuals living in proximity provides significant conditions for the rapid proliferation of infectious diseases and, consequently, enhances the possibility of mutation in pathogens. The process of globalisation and the ease of travel also promote the spread of infectious diseases globally. Therefore, a large fraction of the world's population is exposed to pathogens from various environments, complicating the development of treatment for such different diseases.

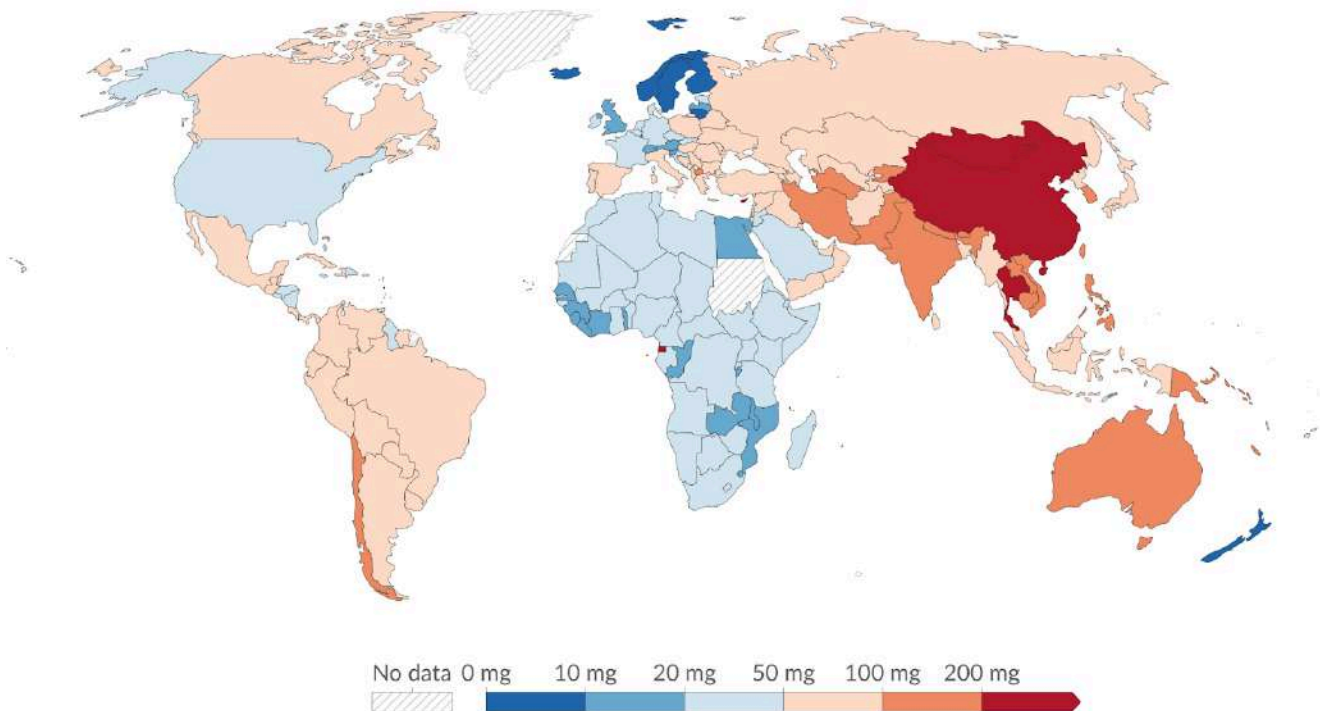
### **2. Agriculture and farming**

A substantial proportion of total antibiotic use occurs outside the field of human medicine. Antimicrobial use in food-producing animals, aquaculture and agriculture for growth promotion and for disease treatment or prevention is a major contributor to the overall problem, as AMR genes have become increasingly abundant and diverse in these contexts. These practices are encouraged by the growing demand for resources, as a great part of the world population still experiences food insecurity and famine.



## Antibiotic usage in livestock per kilogram of meat, 2020

Milligrams of antibiotic use per kilogram of livestock. This is adjusted for differences in livestock numbers and species by standardizing to a population-corrected unit (PCU).



Data source: Mulchandani et al. (2023)

OurWorldinData.org/antibiotics | CC BY

Note: Researchers working on antimicrobial resistance have proposed a threshold of 50mg per PCU, which is shown as a threshold here.

### **3. Sanitation**

The spread of drug-resistant pathogens is also linked to sanitation. Contamination of municipal wastewater due to incomplete metabolism in human beings or incorrect disposal of AMs allows for the proliferation of antimicrobial-resistant microbes, such as tetracycline and sulphonamide-resistant bacteria and sulphonamide-resistant genes.

Consequently, the lack of proper sanitation, poor water quality, and inadequate wastewater treatment are contributing factors to AMR, leading to a higher burden in low-income areas.



## **CROSS RESISTANCE: A CATALYST OF AMR**

The agricultural use of antibiotics is often linked to another mechanism of this problem: cross-resistance.

Cross-resistance occurs when a microbial develops a resistance mechanism to a specific action mode, which is shared by different groups of chemically different antimicrobial medicine. Therefore, a pathogen could acquire multi-drug resistance to a variety of different antimicrobials without having been in direct contact with many of these substances. For example, studies have shown that fluoroquinolone-resistant *E. coli* containing mutations in a topoisomerase gene (*gyrA*) have changed susceptibility of the bacteria to other antibiotics. These changes include increases in resistance to ampicillin, cefoxitin, ciprofloxacin, nalidixic acid, kanamycin, and tobramycin and increases in sensitivity to nitrofurantoin and doxycycline.

The excessive use of antimicrobials have significantly increased the incidence of cross-resistance.

## **AN ECONOMIC CHALLENGE**

This problem has also been shown to take a big toll on the economic level. AMR results in extended hospital stays, more difficult and expensive treatment and loss of workforce for longer periods of time, which places a bigger financial burden on the family and community, as well as in the healthcare system. AMR also causes loss of productivity in livestock production and agricultural efficiency. A study conducted by EcoAMR found that, if no action is taken in 2050, the healthcare costs of AMR could rise to US\$159 billion, and the impact on livestock production could reach US\$40 billion globally.

## **HOW ARE WE COPING?**

Antimicrobial resistance has been acknowledged by key organisations such as WHO (World Health Organisation) and CDC (Center for Disease Control) as an emerging risk for global human health. Many actions are currently being taken, such as the adoption Global Action Plan on AMR (GAP) during the 2015 World Health Assembly, which commits to the development and implementation of multisectoral national action plans with an integrated, unifying approach that aims to achieve optimal and sustainable health outcomes for people, animals and ecosystems. As of November 2023, 178 countries had a national plan aligned with GAP to address AMR.

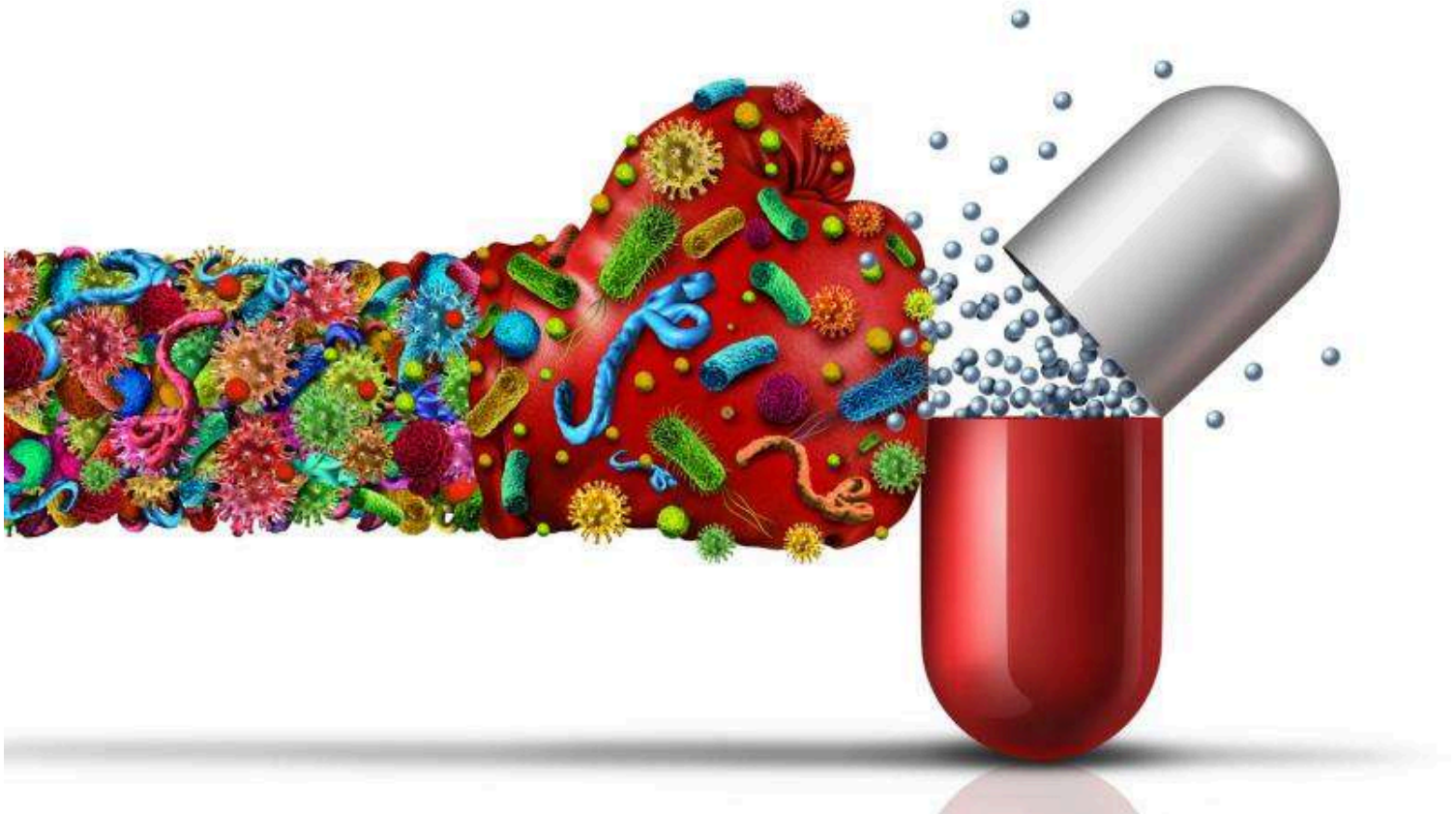
A large, continuous effort to develop new antimicrobials has also been made through the setting of priority on research by various governments and health bodies like WHO, which has published the 'WHO bacterial priority pathogens list' in 2017 to guide research and development into new antimicrobials, diagnostics and vaccines. However, the increasing difficulty of finding effective medicine and the lack of interest in funding this kind of treatment by pharmaceutical companies have led to a decrease in research for new antimicrobials.



## **WHAT CAN WE STILL DO?**

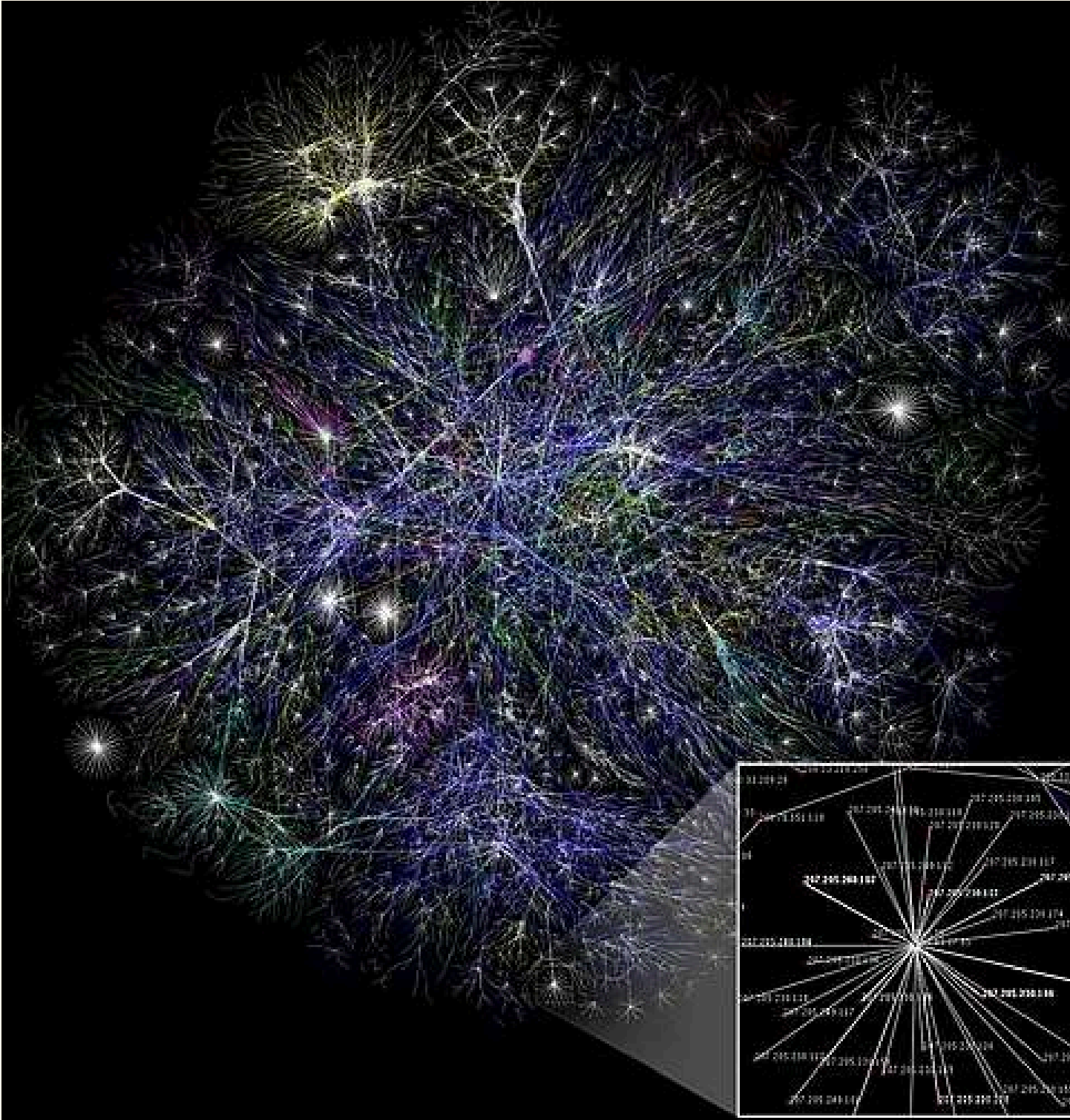
Presently, many initiatives are being taken by global organisations and stakeholders, for example, WHO published a Global Agenda for Antimicrobial Research in 2023, guiding policy-makers and researchers in generating new evidence to inform antimicrobial resistance policies and interventions as part of efforts to address antimicrobial resistance, especially in low- and middle-income countries. But there is still a large journey ahead! Some of the most pressing measures to be taken are as follows:

- Education of the broader public about the proper use of antibiotics and imposing stricter regulations on prescription by medical professionals;
- Improving safe disposal systems of antibiotics;
- Monitoring and restricting the use of AMs in animal farming;
- Improving infection control in healthcare settings;



# SPECTRAL GRAPH THEORY AND EPIDEMIC CONTAINMENT

BY RITISHA AGARWAL





## **WHY MODERN CONTAGION IS NETWORK DRIVEN**

In modern society, contagion rarely spreads at random. From infectious diseases to viral videos, the pathways through which something spreads are determined by complex networks of interactions. These networks can be represented using graphs, where entities are modelled as nodes and their interactions as edges.

The structure of these networks determines how quickly and widely contagion can propagate. In highly connected systems, an infection introduced at a single node may rapidly reach much of the network, while in more fragmented systems outbreaks may die out quickly. Heterogeneity in connectivity can create hub nodes that act as super-spreaders, strongly influencing the dynamics of contagion.

Real-world networks are often dynamic, with connections appearing and disappearing over time. Nevertheless, static representations using matrices can capture many important structural features. These mathematical representations allow us to apply linear algebra to study spreading processes and connect network structure with epidemic behaviour.

This abstraction enables both qualitative understanding and quantitative prediction of spread patterns, allowing us to analyse epidemic thresholds, identify critical nodes, and design containment strategies.

## **REAL-WORLD RELEVANCE (PANDEMICS, SOCIAL MEDIA, CYBERSECURITY)**

Viewing contagion as a network process provides insight into a wide range of real-world systems. Across public health, digital communication, and cybersecurity, spreading processes follow similar mathematical patterns.

A key example is the spread of infectious diseases. Modern transportation networks create highly connected pathways that allow pathogens to move rapidly between distant populations. Nodes may represent cities or airports, while edges correspond to travel routes. Highly connected hubs play a disproportionate role in transmission, allowing local outbreaks to escalate into global epidemics.

Similar mechanisms appear in online social networks, where information and misinformation propagate through user interactions. The structure of these networks determines whether information remains localized or becomes viral, and spectral properties can help estimate thresholds for large-scale cascades.

Network contagion models are also central to cybersecurity. Computer viruses and malware spread through digital infrastructures in ways analogous to biological epidemics. In enterprise networks, nodes represent computers or servers while edges correspond to communication channels. Protecting highly connected machines can significantly reduce systemic risk.



Despite the differences between biological diseases, viral information, and malicious software, the mathematics governing their spread is closely related. In each case, network structure determines the rate and scale of contagion.

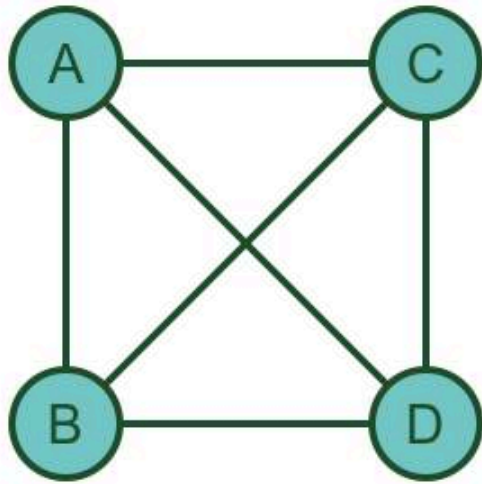


### **FROM ADJACENCY MATRICES TO LAPLACIANS**

To study how contagion spreads through a system, we first need a mathematical way to represent the network of interactions between individuals. In graph theory, a network is represented as a graph, written as

$$\mathbf{G} = (\mathbf{V}, \mathbf{E}),$$

where  $V$  is the set of nodes and  $E$  is the set of edges connecting them. In the context of contagion, nodes may represent people, computers, or locations, while edges represent interactions through which infection or information can spread.



Complete graph

	A	B	C	D
A	0	1	1	1
B	1	0	1	1
C	1	1	0	1
D	1	1	1	0

A convenient way to describe the connections in a graph is with an adjacency matrix. For a network with  $n$  nodes, the adjacency matrix  $A$  is an  $n \times n$  matrix defined by

$$A_{ij} = \begin{cases} 1 & \text{if nodes } i \text{ and } j \text{ are connected,} \\ 0 & \text{otherwise.} \end{cases}$$

Each entry of the matrix records whether two nodes are connected. For example, if  $A_{ij} = 1$ , then node  $i$  can potentially transmit infection to node  $j$ . In many real-world networks, such as contact networks or transportation systems, the connections are mutual, meaning the adjacency matrix is symmetric ( $A_{ij} = A_{ji}$ ).

Using the adjacency matrix, we can also calculate the degree of a node, which is the number of connections it has. The degree of node  $i$  is given by

$$k_i = \sum_{j=1}^n A_{ij}.$$

In simple terms, this equation counts how many neighbours node  $i$  has in the network. Nodes with large degree values are often important in spreading processes because they interact with many others.

Another useful matrix is the degree matrix, denoted by  $D$ . This is a diagonal matrix whose entries are the degrees of each node:



$$D_{ii} = k_i.$$

Using the adjacency matrix and the degree matrix together, we can define the graph Laplacian

$$\mathbf{L} = \mathbf{D} - \mathbf{A}.$$

The Laplacian matrix plays an important role in describing how quantities spread or diffuse across a network. It basically captures how strongly each node is connected to its neighbours and how easily something can flow through the network.

Representing networks with matrices such as  $\mathbf{A}$ ,  $\mathbf{D}$ , and  $\mathbf{L}$  allows us to apply tools from linear algebra to study their behaviour. In particular, properties of these matrices can reveal important information about how quickly contagion spreads and how resilient a network is to outbreaks. In later sections, we will see that certain mathematical properties of the adjacency matrix, known as eigenvalues, play a key role in determining whether an epidemic will persist or die out.

## **SIS AND SIR MODELS ON NETWORKS**

Once a network has been represented using matrices, we can begin to model how a contagion spreads across it. Epidemiologists often describe the spread of disease using compartmental models. These models group individuals according to their infection state.

Two of the most common models are the susceptible–infected–susceptible (SIS) model and the susceptible–infected–recovered (SIR) model.

In both models, each node in the network represents an individual (or device, or location). At any given time, each node is in one of several states describing whether it is infected.

In the SIS model, each node can be in one of two states:

- Susceptible (S) – the node is healthy but can become infected.
- Infected (I) – the node currently carries the infection and can spread it to its neighbours.

An infected node can transmit the infection to its neighbouring nodes along the edges of the network. This occurs at an infection rate denoted by  $\beta$ , which represents how easily the disease spreads. Simultaneously, infected nodes recover at a recovery rate denoted by  $\delta$ . In the SIS model, once a node recovers it becomes susceptible again, because it can be infected repeatedly.

The SIR model adds a third state:

- Recovered (R) – the node has recovered and cannot be infected again.



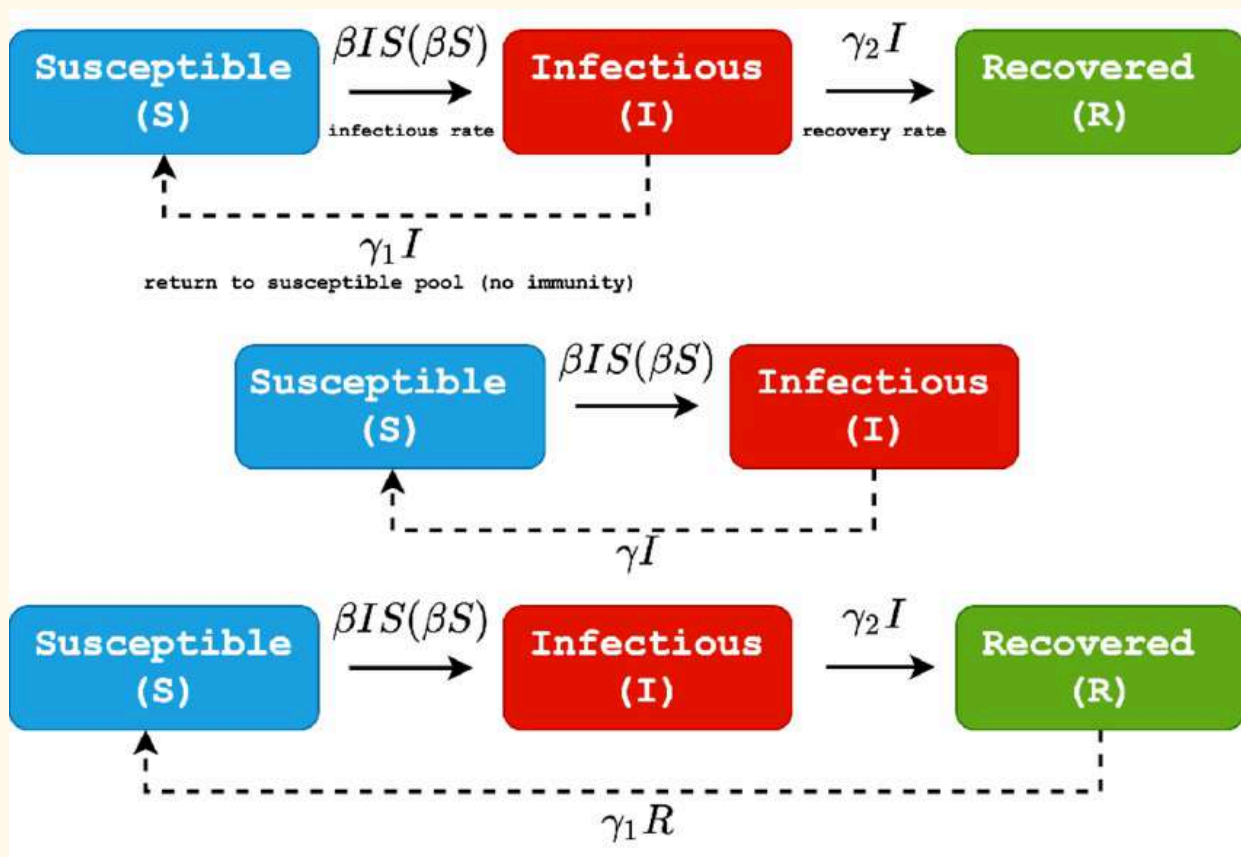
This model is commonly used for diseases that provide immunity after infection. Once all infected nodes recover, the epidemic eventually disappears from the network. When these models are applied to networks, infections can only spread between nodes that are connected by an edge. The adjacency matrix  $A$  therefore determines which transmissions are possible. If  $A_{ij} = 1$ , node  $i$  can potentially infect node  $j$ . To describe the overall behaviour of the network, we can consider a vector  $x$  whose entries represent the probability that each node is infected. A simplified description of the dynamics can be written as

where:

- $x$  is a vector describing the infection level of each node (values between 0 and 1),
- $\beta Ax$  represents new infections spreading through the network,
- $\delta x$  represents nodes recovering from infection.

Note: This is a linear approximation. In reality, the infection probability of a node is always bounded between 0 and 1, and nonlinear effects may occur when many neighbours are infected.

The largest eigenvalue  $\lambda_1(A)$  of the adjacency matrix (the spectral radius) plays a central role in determining epidemic behaviour. In simple terms, this is a number that tells us how strongly connected the network is overall. Networks with higher  $\lambda_1(A)$  have lower epidemic thresholds, making them more vulnerable to sustained outbreaks.





## EIGENVALUE INTERPRETATION

In the previous section, we saw how a network can be represented using matrices such as the adjacency matrix  $A$ . Once a network is written in this form, we can use tools from linear algebra to study its structure. One of the most important concepts in this analysis is that of an eigenvalue.

An eigenvalue is a special number associated with a matrix. It describes how the matrix transforms certain vectors. More precisely, a number  $\lambda$  is called an eigenvalue of a matrix  $A$  if there exists a non-zero vector  $v$  such that

$$Av = \lambda v.$$

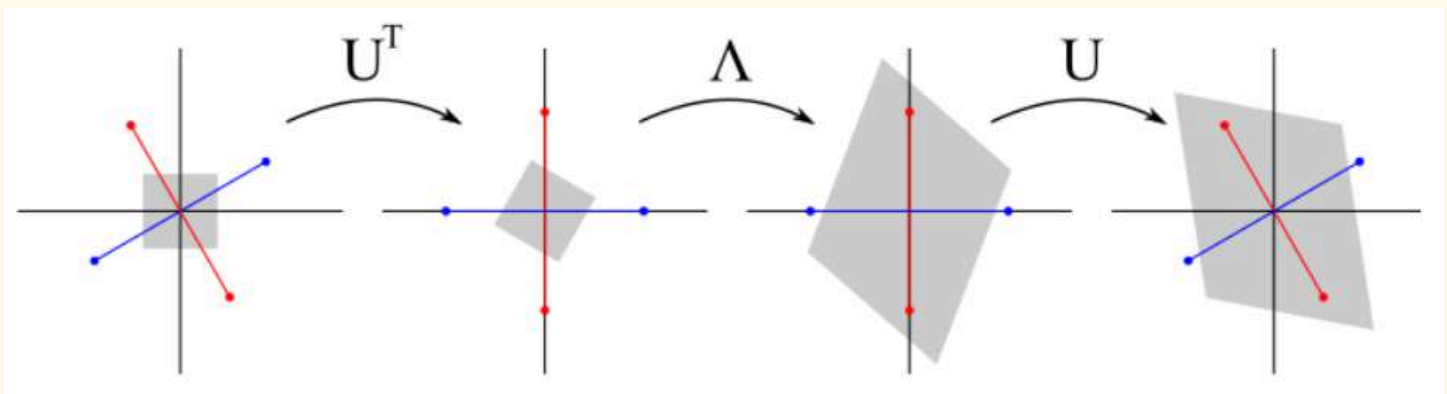
In this equation:

- $A$  is the matrix describing the network (in our case, the adjacency matrix),
- $v$  is a vector called an eigenvector,
- $\lambda$  is the corresponding eigenvalue.

This equation means that when the matrix  $A$  acts on the vector  $v$ , the result is a scaled version of the same vector. The eigenvalue  $\lambda$  tells us how much the vector is stretched or shrunk. For networks, the eigenvalues of the adjacency matrix reveal important information about the overall structure of the graph. In particular, the largest eigenvalue of the adjacency matrix affects many dynamical processes on networks. This value is called the spectral radius and is often written as

$$\lambda_1(A).$$

The spectral radius captures how connected the network is overall. Networks with many connections or highly connected hub nodes tend to have larger spectral radii. Because infections spread along edges, this quantity turns out to be closely related to how easily contagion can spread through the network.





## THRESHOLD FORMULAE AND PRACTICAL MEANING

In epidemic models on networks, the behaviour of an outbreak depends on two parameters: the infection rate  $\beta$  and the recovery rate  $\delta$ . The infection rate tells us how quickly the disease spreads between connected nodes, while the recovery rate describes how quickly infected nodes return to a healthy state.

A useful quantity is the ratio

$$\tau = \frac{\beta}{\delta},$$

which compares how quickly infections occur relative to recoveries. It shows us that if infection spreads much faster than recovery, the disease is more likely to persist.

Spectral graph theory shows that there exists a critical threshold for this ratio. For many network epidemic models, the threshold is approximately given by

$$\tau_c = \frac{1}{\lambda_1(A)},$$

where  $\lambda_1(A)$  is the largest eigenvalue (spectral radius) of the adjacency matrix. This formula has a clear interpretation.

If

$$\tau < \tau_c,$$

then infections die out over time and the epidemic cannot sustain itself. However, if

$$\tau > \tau_c,$$

the infection can persist and potentially spread throughout the network.

In simple terms, this shows that the structure of the network influences whether an epidemic occurs. Networks with larger spectral radii have smaller thresholds, meaning that even small infection rates can lead to widespread outbreaks. Highly connected networks, or networks with influential hub nodes, are therefore more vulnerable to contagion.

This has important practical implications because by understanding how network structure affects the spectral radius, researchers can identify strategies for slowing or preventing epidemics. For example, protecting or removing highly connected nodes can reduce the spectral radius of the network, increasing the epidemic threshold and making large outbreaks less likely.



### **EXAMPLE: A SMALL NETWORK**

To illustrate these ideas, we can consider a simple network of five nodes representing individuals in a community. The connections between them are shown in Figure 1 below.

The corresponding adjacency matrix might look like

$$A = \begin{pmatrix} 0 & 1 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 \end{pmatrix}.$$

Each row describes the connections of one node. For example, the first row shows that node 1 is connected to nodes 2 and 3.

If we compute the eigenvalues of this matrix, we find that the largest eigenvalue (the spectral radius) is approximately

$$\lambda_1(A) \approx 2.41.$$

Using the epidemic threshold formula

$$\tau_c = \frac{1}{\lambda_1(A)},$$

we obtain

$$\mathbf{T_c=0.41}$$

This means that if the ratio between infection rate and recovery rate satisfies

$$\frac{\beta}{\delta} > 0.41,$$

the infection may persist in the network. If the ratio is smaller than this threshold, the epidemic will eventually die out. This example demonstrates how the structure of a network, encoded in the adjacency matrix, directly influences whether contagion spreads or disappears.

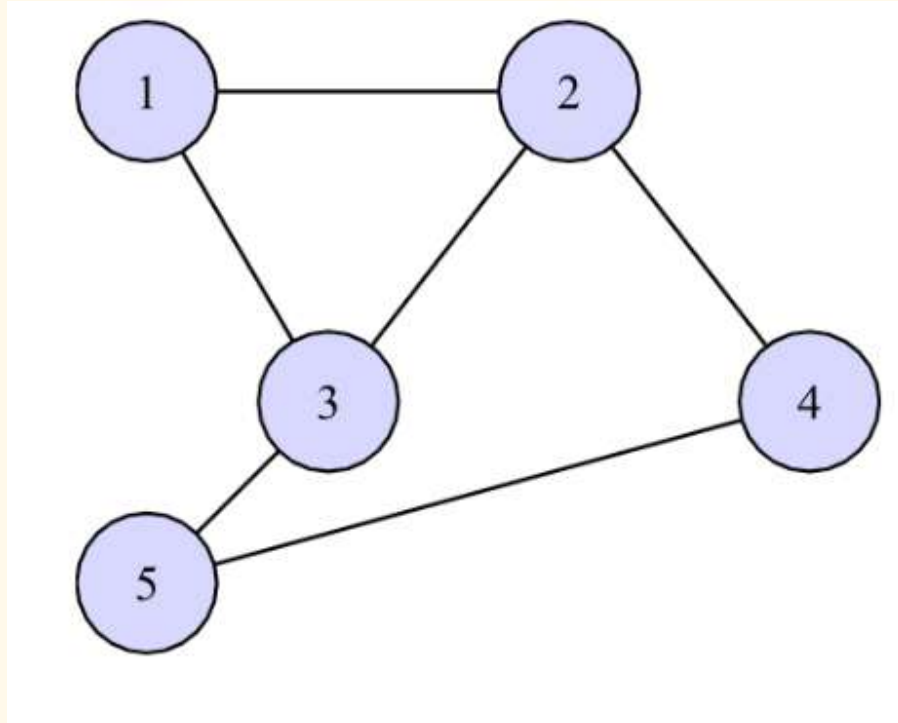


Figure 1: Example interaction network between five nodes. Edges represent possible pathways for contagion transmission.

### **AIRLINE NETWORK COVID EXAMPLE**

Air travel is a major pathway for global disease spread. Airports can be represented as nodes, and direct flights between airports as edges. Highly connected hubs, like major international airports, can act as super-spreaders, allowing infections to travel quickly across continents. Empirical studies of COVID-19 and influenza show that higher international flight volumes are associated with significantly higher transmission rates; for example, one recent analysis found that higher flight volumes from Asia were linked to roughly 21% higher influenza transmission rates and up to 72% higher COVID-19 case rates in receiving regions, after adjusting for public health measures.[web:18]

We can model the airline network using an adjacency matrix  $A$ , where  $A_{ij} = 1$  if a flight connects airports  $i$  and  $j$ . The spectral radius  $\lambda_1(A)$  captures the overall connectivity and “spreadability” of this network. In practice, most traffic is routed through a relatively small number of hubs, so a few nodes contribute disproportionately to  $\lambda_1(A)$  and therefore to global epidemic risk. During the early phase of COVID-19, travel restrictions focused on Wuhan and flights from China were estimated to have reduced the number of cases exported internationally by about 70–80% in the weeks following the initial outbreak, and to have delayed importation of new cases to other countries by several weeks.[web:8][web:13] From the point of view of spectral graph theory, such restrictions effectively remove or weaken edges linked to key hubs, thereby reducing  $\lambda_1(A)$  and increasing the epidemic threshold  $\tau_c = 1/\lambda_1(A)$ .



A simplified example network with five airports is shown in Figure 2. In reality, global airline networks involve thousands of airports and tens of thousands of routes, but the same spectral ideas apply. Studies using network-based models have shown that poorly targeted travel bans are often ineffective, whereas coordinated restrictions on a relatively small set of critical routes can delay the arrival of COVID-19 in new regions by an average of about 18 days and reduce total infections by millions of cases.[web:16] This aligns with the mathematical prediction that small changes to the most central nodes and edges can produce large changes in the spectral radius, and hence in the conditions under which epidemics can sustain themselves.

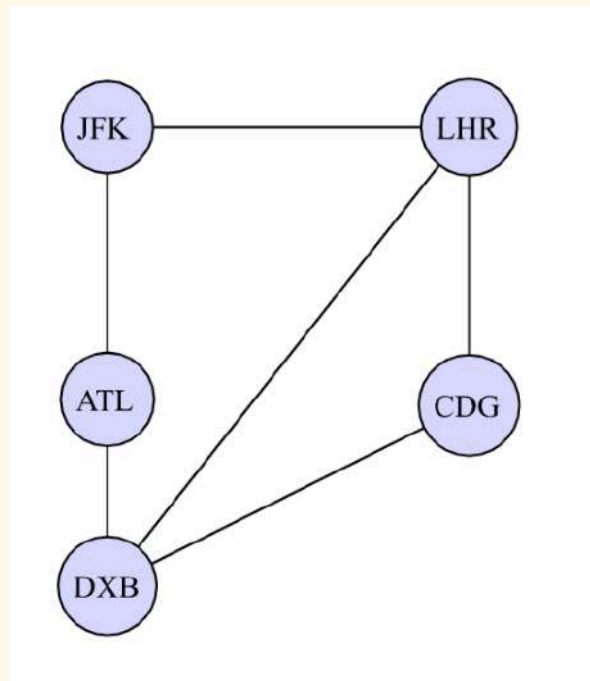


Figure 2: Simplified airline network showing direct connections between airports. Highly connected hubs facilitate rapid disease spread.

### **SOCIAL MEDIA RUMOUR SPREADING EXAMPLE**

Online social networks also behave like contagion networks. Users are nodes, and friendships or follow relationships form edges. A piece of misinformation spreads along these edges much like a virus, with each exposure giving a certain probability that a user becomes “infected” by the rumor. Surveys in the context of elections suggest that around 73% of people report seeing misleading news online, and about half struggle to distinguish true from false information, highlighting how pervasive such “information contagion” can be. [web:6] Mathematical models drawn from epidemiology, such as SIR-type models on networks, have been used to describe this process and to estimate an effective basic reproduction number for misinformation.

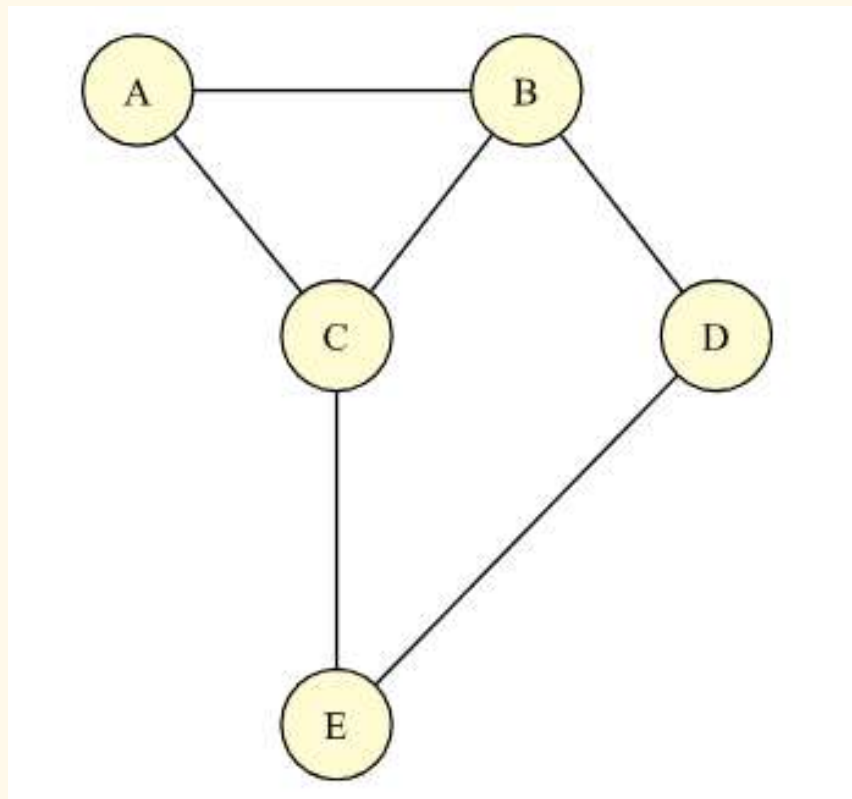


Figure 3: Simplified social network. Influential users with many connections can accelerate rumor propagation.

Figure 3 illustrates a small social network. Highly connected users (influencers) have a disproportionate effect on the spread because they can expose thousands or millions of followers at once. Modelling studies indicate that, for many social media platforms, the effective reproduction number  $R_0$  for misinformation is greater than 1, meaning that a single “infected” post can, on average, generate more than one further infected user and thus sustain an information epidemic.[web:14][web:17] In one example, even when assuming only a 10% chance that a user becomes convinced after exposure, simulations show that the fraction of the population “infected” by election misinformation can grow rapidly unless strong countermeasures are applied.[web:6]

Spectral ideas provide a way to interpret these results. The spectral radius of the follower graph,  $\lambda_1(A)$ , encapsulates how easily influence can percolate through the network. If the effective spreading rate of misinformation (analogous to  $\beta$ ) divided by the “recovery” or debunking rate (analogous to  $\delta$ ) exceeds the threshold  $\tau_c = 1/\lambda_1(A)$ , rumors can go viral and persist. Interventions such as limiting the reach of high-degree misinformation accounts, inserting fact-check labels, or temporarily suspending repeat offenders all act to reduce effective edge weights or remove influential nodes. This, in turn, lowers  $\lambda_1(A)$  and can push the system back below the viral threshold, just as targeted vaccination of central nodes does in biological epidemics.



## **NODE REMOVAL AND IMMUNISATION STRATEGIES**

One way to control epidemics is to target specific nodes for immunization or removal. In network terms, this means reducing the spectral radius  $\lambda_1(A)$  by strategically protecting highly connected nodes.

For example, consider the airline network. Vaccinating travelers from major hubs (e.g., JFK or LHR) reduces the number of possible transmission pathways, effectively increasing the epidemic threshold  $\tau_c$ . Similarly, in social networks, blocking misinformation from high-degree users prevents rumors from spreading widely.

A simple way to visualise which nodes are most critical is by ranking them by degree:

<b>Node</b>	<b>Degree</b>
JFK	4
LHR	3
ATL	2
CDG	2
DXB	1

The table above is an example ranking of nodes by degree. This illustrates which nodes contribute most to network connectivity. Nodes with higher degrees contribute more to the spectral radius and are more influential in the spread of contagion.

## **EIGENVALUE PERTUBATION AND HEURISTICS**

Eigenvalue perturbation theory provides intuition: small changes to a node's connections cause predictable changes in the spectral radius. In practice, this allows us to rank nodes by their influence on  $\lambda_1(A)$  without recomputing eigenvalues repeatedly.

Heuristic strategies are easy to implement:

- High-degree removal: remove the most connected nodes first.
- Randomized immunization: randomly vaccinate nodes if no degree information is available.
- Betweenness-based: remove nodes that lie on many shortest paths. Even simple heuristics often achieve significant containment in practice.



## **OPEN PROBLEMS AND FUTURE WORKS**

Real-world networks are rarely static. Flights are seasonal, social interactions vary daily, and computer connections change constantly. Studying temporal networks, which are networks that change over time, is an active area of research. Understanding resilience under dynamic conditions is essential for accurate epidemic predictions.

In many cases, the network structure is uncertain. For example, some social ties may be unknown, or flight cancellations may occur unexpectedly. Random graph models and probabilistic adjacency matrices are used to study contagion under uncertainty. Developing strategies that work reliably on randomized networks remains a challenging open problem.

Network dynamics also connect to other areas of modern computer science. Graph neural networks (GNNs) in deep learning can predict epidemic spread on complex networks. Distributed systems, such as peer-to-peer networks, face similar propagation problems for malware and information. Understanding the spectral properties of these systems helps design more robust algorithms and containment strategies.

In summary, while we can model contagion and optimize containment on simple networks, many real-world challenges remain, including dynamic, uncertain, and high-dimensional networks.



# THE WATCHLIST BY RITISHA AGARWAL



Recommendations from our team based on Hidden Systems

## THE BOOK – HIDDEN SYSTEMS BY DAN NOTT



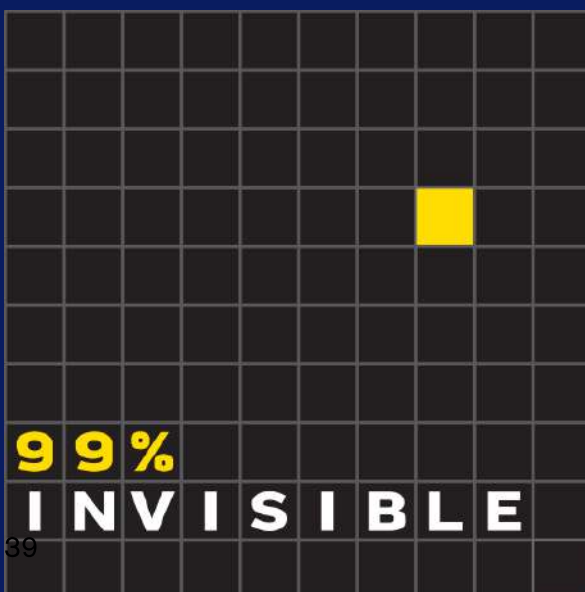
A masterful graphic investigation into the invisible infrastructures, from power grids to the internet, that we rely on but rarely see. It perfectly illustrates our theme by proving that the most essential systems are the ones hiding in plain sight.

This series pulls back the curtain on the surprising, intricate threads that link everything from Saharan dust to cellular signals. It's a visual exploration of the hidden networks of causality that we've highlighted throughout this issue.

## THE DOCUMENTARY – CONNECTED (NETFLIX)



## THE PODCAST – 99% INVISIBLE



An audio masterclass in noticing the unnoticed. By deconstructing the thought and design behind the structures of our world, it reveals the hidden logic embedded in everything from city planning to everyday objects.

# YOUR ILLUSION OF REALITY: THE BRAIN AS A PREDICTION MACHINE



BY PRISHA GOSWAMI

From fleeting moments of misrememberance to intense hallucinations and sleep paralysis, the brain's complex ability to perceive is also the very thing that causes it to see what's not there. Here, we'll go into the system shaping our perception of reality, and what understanding it means for how we see ourselves and others.





## **INTRODUCTION**

When I was little, I thought I was an alien.

I would listen to the conversation my parents were having as I sat next to the open door, cool air slipping through the muggy room and sending the wind-chimes tinkling in the corner. It would occur to me gradually that I had been here before. Not just this place, but this moment in time.

My mother saying the same words.

The song of the wind chime, exactly the same.

My dad was about to stand up and stretch his arms...

- and then he did!

I was a magical alien from a different planet and I could prophesize things.

I held this longstanding belief until I was seven, when I discovered that my classmates had magic too. While one was a fairy and the other was a sorcerer, we all shared the same strange power: déjà vu.

Many people agree that déjà vu is simply an odd phenomenon that everyone experiences - the mind just playing tricks on us. In fact, 97% of the population has experienced déjà vu and 67% percent of adults report experiencing it regularly, according to a 2028 review from the University of Zagreb. But moments like these - while common - expose the fascinating mechanism of how we construct our own reality. Rather than misleading us, the brain is doing exactly what it's meant to do: predicting what comes next.

## **THE BRAIN ISN'T A CAMERA**

We tend to think of perception as a passive mechanism. Light enters our retinas and sound waves enter our ears, and the brain records these details as a coherent picture of reality, constantly re-updating as we live our lives. But modern neuroscience suggests a stronger idea of the brain; not as a simple camcorder, but as an active predictor, blending our version of reality with the truth of it.

In the late 1960's, a small child was spending the hot summer day outside, playing in his garden. He turned over a log and observed as the woodlice underneath scrambled, running from the sun in random directions until they got to the safety of the soil and shade. They weren't moving with any conscious intention, but simply faster in the light and slower in the darkness, which eventually led them to settle in shadier areas. Without any awareness, their behaviour naturally wanted to minimize exposure to conditions that disrupted their stability.



Karl Friston was 7 years old, just like me when I thought I was an extraterrestrial being. But unlike me, he saw a pattern in the woodlice that I couldn't yet capture from my déjà vu. When he grew up to become a neuroscientist, Friston proposed the Free Energy Principle, stating that every self-organizing system (including the brain) is driven to minimize “surprise”, or the gap between its own expectations and the world around it. It seeks to reduce entropy and uncertainty, constantly working to refine its inner model so that reality becomes more and more predictable.

This principle formed a key foundation for what scientists now call the Bayesian Brain Theory. The brain isn't just rebuilding its perception from the ground up every second. Instead, it continuously uses past experiences, or “priors”, to form an expectation of what will come next. It's always asking: “What is most likely going to happen in this second?”

If it gets it right, it doesn't have to use extra processing power to register the experience, so very little effort is needed. The brain sees its expectation and moves on. But if it gets it wrong, it will quickly adjust to match your incoming sensory signals.

Think of your brain as a weather app: it doesn't constantly scan the sky to see if a raindrop falls. Rather, it uses past experiences to expect a sunny day, and only changes its tune when sudden data detects an incoming thunderstorm. Most of the time, this process is seamless and invisible. The brain's predictions are so accurate that they feel indistinguishable from reality itself.

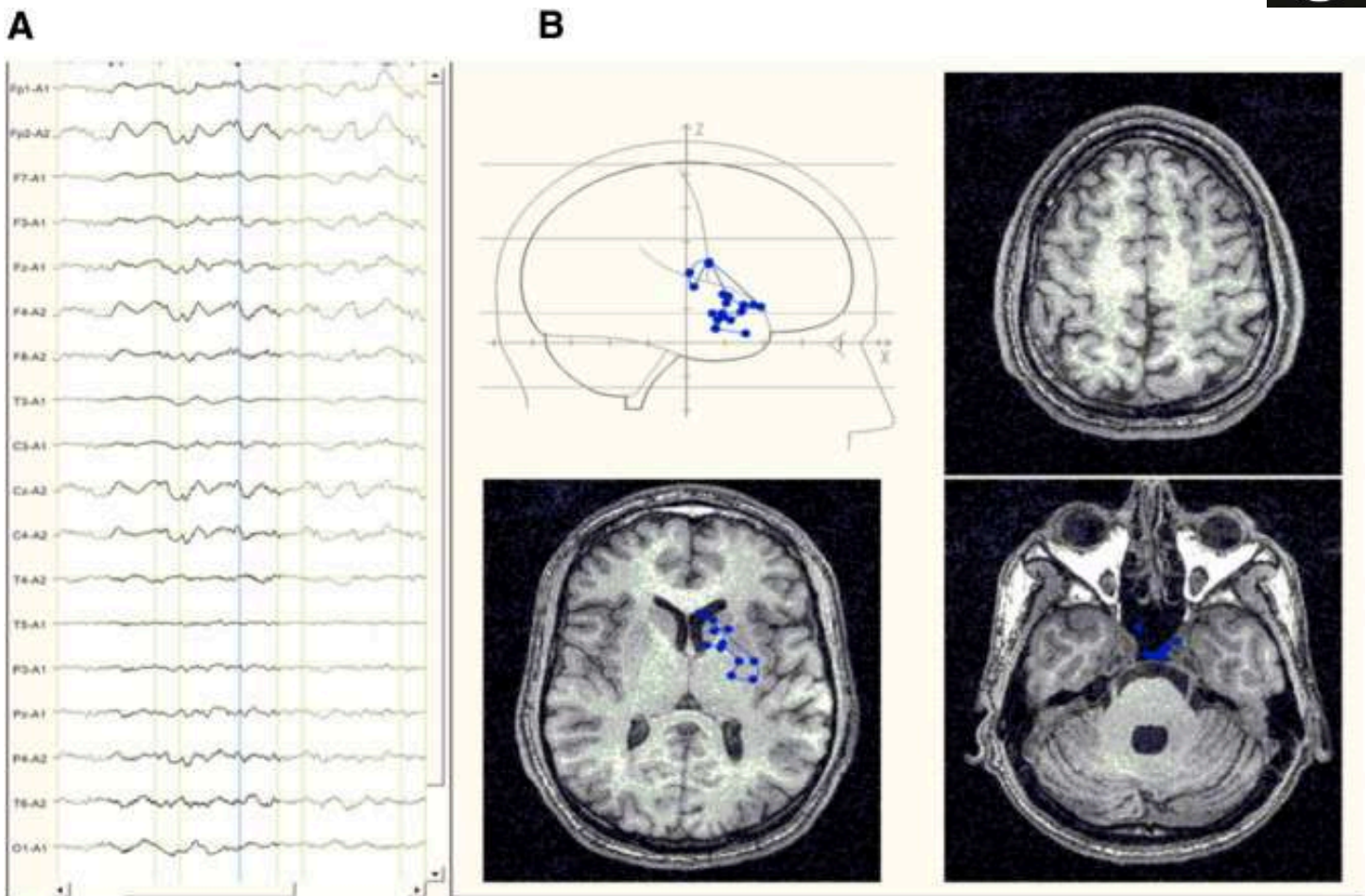
But sometimes, the system glitches. We don't trust our weather apps 100% of the time, and in the same way, we can't always trust our brain.

In those fleeting moments when our reality doesn't align with our expectations, we see that our perception isn't a perfect reflection of the world, but an ever changing, carefully constructed interpretation of it.

## **A MEMORY OR SOMETHING DIFFERENT?**

So when I was sitting by the doorway, convinced I could see the future, what was really going on?

Déjà vu occurs when the brain generates a powerful sense of familiarity without being able to trace where it came from. The moment feels known and lived, but the source of that knowledge is nowhere to be found. It is, in a sense, your own prediction being mistaken for a memory.



Your brain is constantly forecasting what comes next. But in this situation, it encounters a version of reality that's a close match with one of its internal models. Before it can get the chance to truly verify, the pattern produces the feeling of recognition. And for that brief instant while the brain scrambles to make things right, the present feels exactly like the past. The brain believes its own expectation more than the evidence right in front of it.

It's an intriguing but slightly unsettling idea; that we can feel so certain of a moment despite it being an inaccurate version of reality. It begs the question: if the feeling of knowing can exist without truth, what does it mean to truly know anything at all? If we push the same mechanism even farther, we see how this question becomes more important.

Hallucinations are often seen as unexplainable and often dangerous, even from an early age. My mother banned the movie *Alice in Wonderland* from our household, worried that it might encourage "seeing things". But hallucinations don't need to be a vague and unnerving concept. Just like we expect a friend's face when we open our front door, and just like we experience *déjà vu*, hallucinations are the result of your brain trying to make sense of your experiences.



## *"Sleep paralysis affects roughly 8% of people at least once in their lifetime."*

A hallucination is more than just seeing something that's not there. It's what happens when your brain relies too much on your priors and thus treats its own predictions as reality. Under normal circumstances, perception is a balancing act. Incoming sensory information and your internal priors are constantly bartering, correcting each other every moment. But in some cases, such as when sensory input is too weak - such as when the brain is in a state between sleep and wakefulness - or when predictions become too strong - such as when on stimulants or psychedelics - the brain takes a "top-down" approach, relying much more heavily on its internal model. This is why in cases of extreme drug use or sleep paralysis, people can experience scary hallucinations: the brain is working in overdrive to keep you out of danger, and that often means inciting fear so you "get away". That means that the same Bayesian system that allows you to anticipate faces, experiences, or voices, can also create patterns that don't exist.

### **REFRAMING THE SYSTEM**

Experiences like hallucinations or sleep paralysis can feel profoundly unsettling. But they don't come from a broken brain. Perception and hallucination are not opposites, but rather, they exist on a continuum. One relies more on external output, while the other defaults to internal priors. But both are made from the same process: the brain making sense of the world.

Everyday perception and hallucinations exist on a spectrum:

<b>Experience</b>	<b>Dominant Factor</b>
Recognizing a friend's voice	External input
Déjà vu	Input and prediction
Hallucinations/Sleep Paralysis	Internal prediction

When we comprehend that experiencing a hallucination is not that different from the common sense of déjà vu, we can help to reduce the stigma around such experiences. Understanding the mechanisms behind these incidents can reduce the mystery around them and help them feel less isolating for those going through them. The mind never tries to betray us, it simply does what it has evolved to do; predict, interpret, and fill in the unknown.



So if perception is based on prediction, then one begins to wonder: are we ever experiencing reality, or simply our best guess of what reality is? If we're always filling in the gaps, then it could potentially explain a lot. Memories can feel vivid and certain, but still be untrue - because we fill in what we feel fits best based on our past experiences.

Two people can walk away from a conversation with a completely different interpretation.

Perception is not always an objective truth; it's something personal.

### **SO HOW SHOULD WE SEE OUR MINDS?**

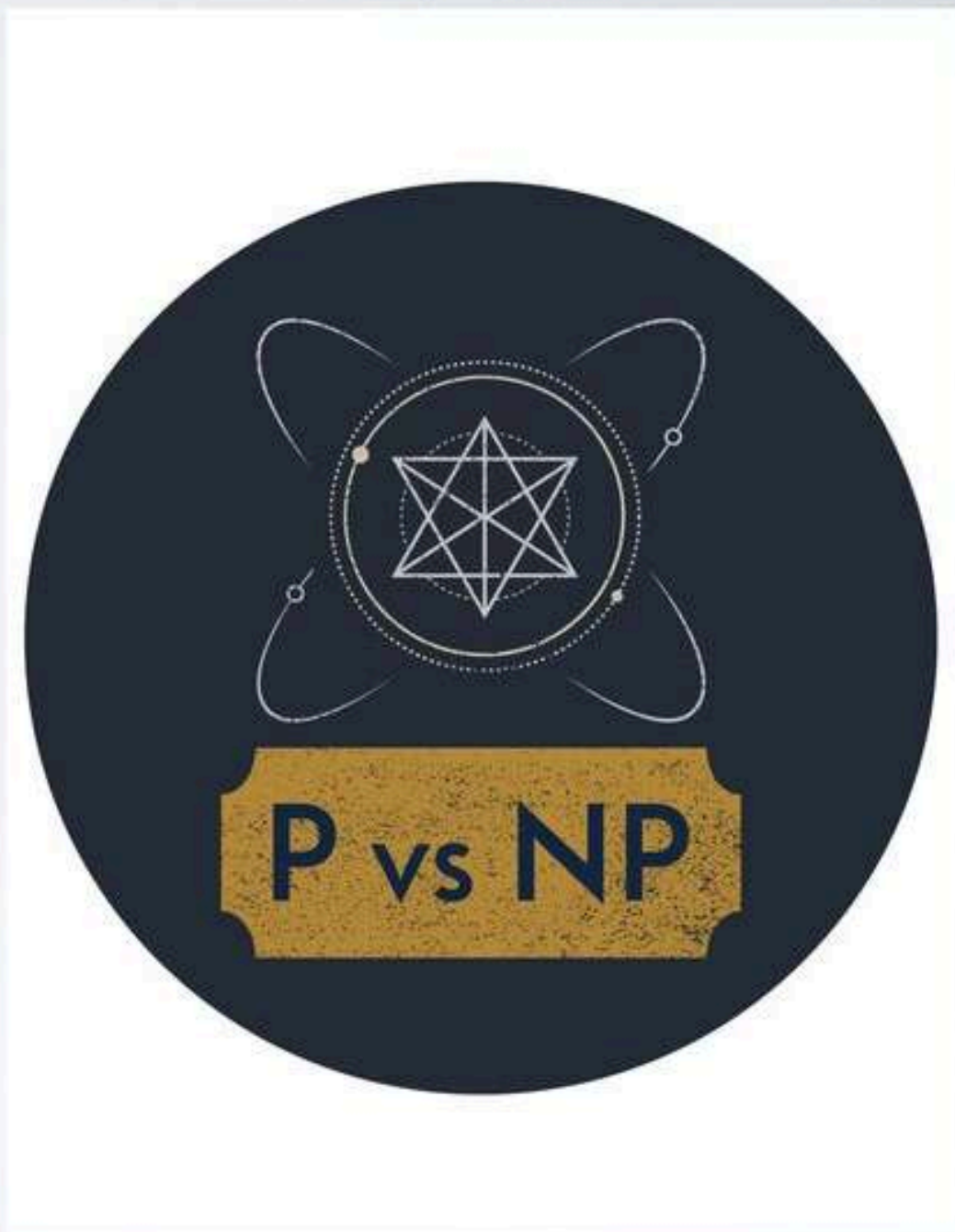
Every moment we experience is a negotiation between truth and reality, and we call that compiled experience our world. But in some rare moments, that illusion falters and the system reveals itself.

Understanding our brain's systems can help us refine our approach to memory and perspectives. If we're all really constructing our own reality, then it might just warrant a more empathetic approach to the experiences of others.



# A MILLION DOLLAR MATH PROBLEM: WHAT IS P VS NP AND WHY IS IT SO HARD

BY ANISH ALAPATI





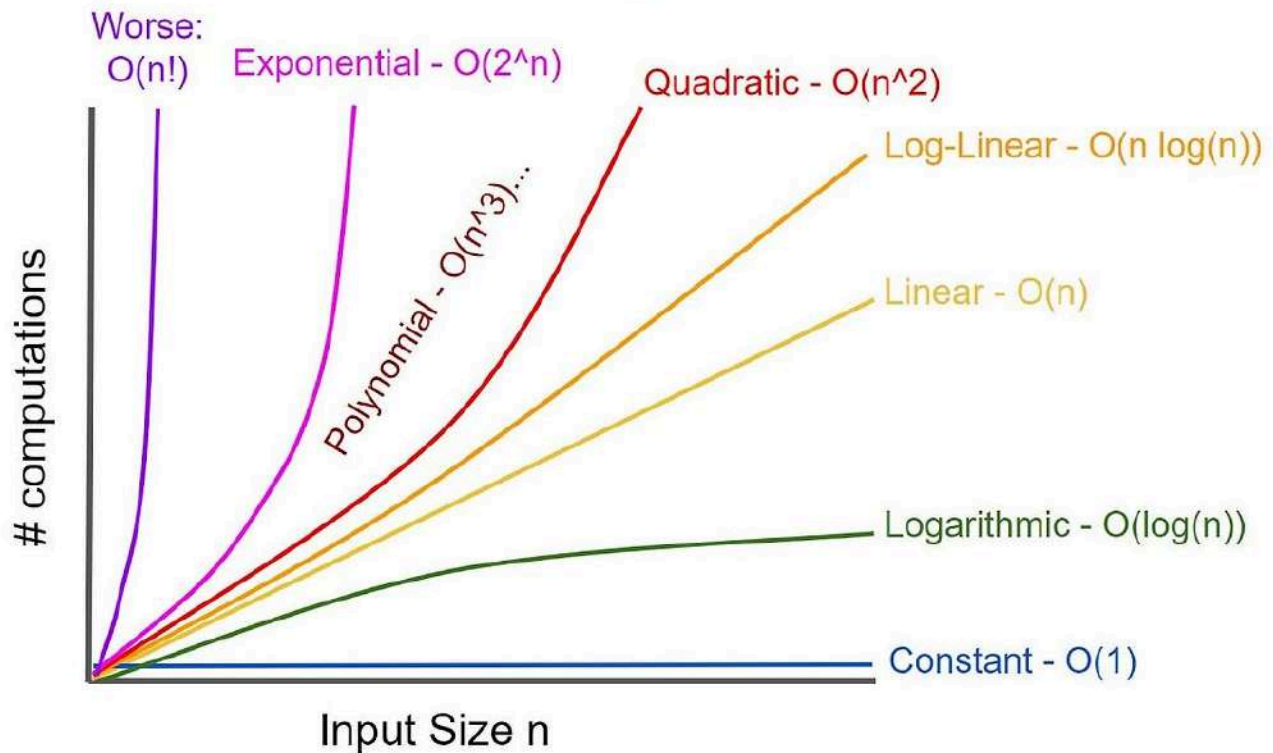
P vs NP is a math problem that is one of the millennium prize problems which are problems that whoever solves will get one million dollars. The prize has been out since 2000 which was 26 years ago yet no one has solved it.

## WHAT IS IT?

Many times in math, problems with simple statements are incredibly difficult to solve. Some problems that follow this are Fermat's Last Theorem that was proved quite recently by Sir Andrew Wiles who had to use super advanced mathematics and the Four Color Theorem which had a proof that was over 400 pages long. The problem this is probably the most true for is P vs NP which has a quite simple statement.

P vs NP can be informally written as: Can every problem whose solution can be quickly verified can also be quickly solved?

First of all, what is quickly? Quickly just means based on the size of the input  $n$ , the running time grows like  $n^2$  or  $n^5$  rather than something like an exponential such as  $ex$ . Another way of saying quickly is polynomial time.





This (above) is a visualization of different time complexities. Exponential gets really high run-times for massive input sizes whereas polynomial time complexities grow much more slowly. This is why computer scientists and programmers often try to look for algorithms that run in polynomial time when working with large datasets as the efficiency saves time and computing power.

P just means that problems could be solved in polynomial time where solved means an algorithm finding a solution that works. While NP means that the solution could be verified in polynomial time which means a computer can check if a solution works quickly.

Of course, P is a part of NP because if a problem can be solved quickly then the verification can be done quickly as well. In fact, solving a problem already produces a valid solution, so checking it is no harder than re-running the same 'quick' algorithm. The hard part is trying to find whether  $P = NP$ .

## **BRIEF HISTORY**

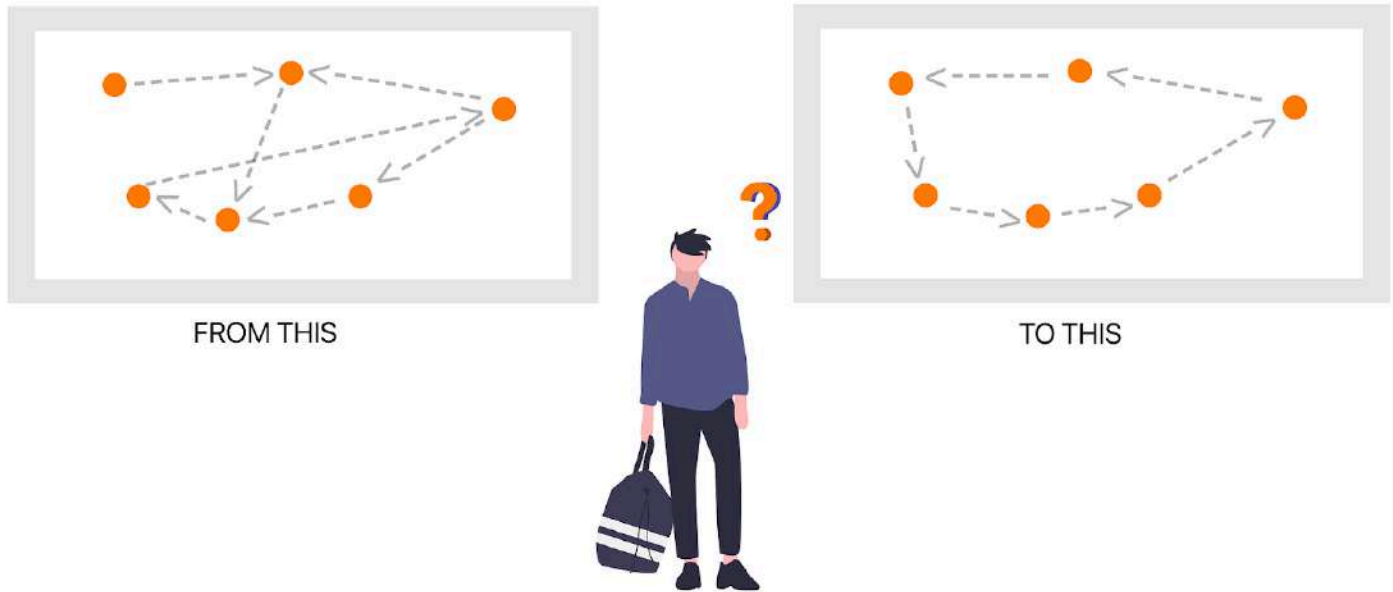
In 1955, John Nash wrote a letter to the NSA (National Security Agency) which discussed whether problems with efficiently checkable solutions must also be efficiently solvable. Nash did not use the language of P or NP but his ideas were close to the central question of P vs NP. The problem was first formally posed by Stephen Cook in 1971 (Leonard Levin in the USSR also independently explored similar ideas).

Cook introduced the concept of NP-completeness which identifies problems whose output is either "yes" or "no" and are essentially the "hardest" in NP. If one NP-complete problem can be solved in polynomial time, then all NP problems can be and so  $P = NP$ . On the contrary, if one of these problems cannot be solved in P then  $P \neq NP$ .

Since then, many problems have been shown to be NP-complete. One example is the walking salesman problem which asks "Given a list of cities and the distances between each pair of cities, is there a route that visits each city exactly once and returns to the origin city and has distance less than K?" Where K can be any number. There are a few more problems shown to be NP-complete, a lot of which are in graph theory.



## Traveling Salesman Problem



Most mathematicians nowadays believe that  $P \neq NP$  because some problems just feel more complex to solve than to check. One example of this is factoring semi-prime numbers, numbers that are written as the product of two primes, something that is used in cybersecurity to protect sensitive data.

To convince yourself, try factoring 221 which can be written as  $13 \times 17$ . Now check if  $13 \times 17 = 221$ . Notice that it was much easier to check the result than to find it. This leads to a broader observation: verifying a solution is often easier than discovering it.

While factoring itself is not NP-complete, it shows the intuition behind the beliefs of the mathematicians about the P vs NP problem.

However, even with this intuition, this problem is incredibly hard to solve due to a multitude of reasons.



## **WHY IS IT SO HARD?**

Mathematicians struggle on P vs NP because to prove  $P \neq NP$ , it requires proving that a strict upper bound exists regardless of whatever clever tricks, discoveries, or methods that can be used to optimize the solving algorithm of the problem. This is different from most areas of mathematics, where progress comes from constructing examples or finding new techniques. Here, one must rule out all possible efficient methods, even ones that have not been created yet, which is incredibly hard to do.

Another reason the problem is so difficult is that many of the standard tools mathematicians rely on have been shown to be insufficient. Over time, researchers have identified major “barriers” that prevent common proof techniques from resolving the question. As a result, even partial progress is hard to achieve. The combination of needing to rule out future methods and resistance to known methods is what has kept P vs NP unsolved for decades, despite the fame of the problem and the efforts of some of the world’s best mathematicians.

## **WHAT EFFECTS DOES THE PROBLEM HAVE?**

The effects can be broken down into two scenarios: 1.  $P = NP$  and 2.  $P \neq NP$ . Both of these results have large implications in many fields.

If  $P = NP$ :

This would mean that every problem whose solution can be quickly verified could also be quickly solved. Modern cryptography, a field that is incredibly important as it protects sensitive data from getting stolen or leaked, relies on problems being much harder to solve than to check. If a problem is hard to solve then hackers would have a difficult time to find the solution and thus making it harder to get to the data and if a problem is easy to check then the transfer of this data would be quick and efficient. However, since no problem like this exists, these methods would become insecure and will allow hackers to develop efficient algorithms to find solutions to these hard problems and thus get access to the encrypted data. The entire field of cryptography would have to change its methods to be effective at countering hackers.

The effects would also go outside of cryptography to other fields that heavily require optimization. Many complex optimization problems in areas like logistics, engineering, and medicine could be solved quickly. This would culminate very heavily in the transformation of Artificial Intelligence.



Many AI problems can be framed as searching through a large number of possible solutions to find the best one. Today, these tasks are often slow or require approximations because the number of possibilities grows exponentially while including massive datasets. If  $P = NP$ , computers could efficiently find optimal solutions instead of settling for the inefficient ones. This could lead to breakthroughs like perfectly optimized systems, more powerful models, and possibly even models that can automatically discover mathematical proofs.

If  $P \neq NP$ :

This would mean that some problems are harder to solve than to verify, no matter how advanced our algorithms or computers become. This would help modern cryptography as many encryption systems rely on certain problems being difficult to solve efficiently.

In artificial intelligence, it means that many tasks will always require approximations when dealing with large and complex datasets. Instead of finding the best possible answer, AI would have to aim for solutions that are good enough within a reasonable time.

## **WHY DOES IT HAVE A MILLION DOLLAR PRIZE?**





P vs NP is part of the Millennium Prize Problems which is a set of seven problems that the Clay Mathematics Institute offers a prize of 1 million dollars to anyone who can solve any one of these problems. Out of the seven, only one has been solved which is the Poincaré conjecture (fun fact: Grigori Perelman, the person who solved this problem, refused the prize as he felt that the institute's failure to acknowledge Richard Hamilton's contribution to the Poincaré conjecture proof was unjust).

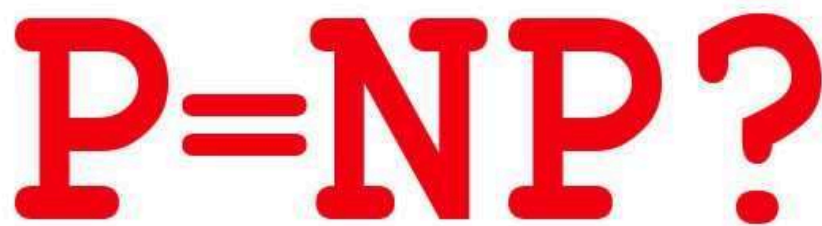
There are many reasons that P vs NP is on this list. 1. The problem spans many different fields like computer science, cybersecurity, artificial intelligence, economics, and mathematics. 2. Thousands of researchers have tried to solve this problem over many decades and it is still unsolved. 3. It has wide implications on the world.

Ultimately, this prize tag fosters the creation of new ideas and increases the interest in mathematics as it spreads awareness of the problem and it offers an incentive.

## CONCLUSION

The most important point in this article is: P vs NP is a math problem that works with the limits of computers.

Despite having a simple statement, the problem goes into some of the deepest areas of mathematics and has remained unsolved for decades. It is resistant to the very methods we use to make progress in mathematics. Whether  $P = NP$  or  $P \neq NP$ , the answer will have massive consequences.

A large, bold, red text graphic that reads "P=NP?". The text is centered on a white rectangular background with a soft drop shadow, set against a light yellow gradient background.

# FURTHER READING AND BIBLIOGRAPHY



## THE WORLD IS GOING BLURRY

- Holden BA et al. (2016). Global Prevalence of Myopia and High Myopia. *Ophthalmology*, 123(5), 1036–1042.
- Wu PC et al. (2013). Myopia Prevention and Outdoor Light Intensity in a School-Based Cluster Randomized Trial. *Ophthalmology*, 120(10).
- Yam JC et al. (2019). Low-Concentration Atropine for Myopia Progression (LAMP) Study. *Ophthalmology*, 126(1).
- World Health Organization. (2019). *World Report on Vision*. Geneva: WHO Press.
- National Eye Institute, NIH. Myopia Data and Trends. [nei.nih.gov](http://nei.nih.gov)
- American Academy of Ophthalmology. Sharp rise in myopia around the world. YO Info. [aao.org/young-ophthalmologists/yo-info/article/sharp-rise-in-myopia-around-the-world](http://aao.org/young-ophthalmologists/yo-info/article/sharp-rise-in-myopia-around-the-world)
- Guan H et al. (2018). The effect of providing free eyeglasses on children's mental health outcomes in China: A cluster-randomized controlled trial. *International Journal of Environmental Research and Public Health*, 15(12), 2749.

## THE CLOCK YOU NEVER KNEW YOU HAD

- *Circadian Clocks* – Russell Foster & Leon Kreitzman (2004)
- Hall, Rosbash & Young Nobel Lecture (2017): [nobelprize.org](http://nobelprize.org)
- Smolensky & Lamberg, *The Body Clock Guide to Better Health* (2000)
- *Chronotherapy* – Keith Hermitage & Alison Coates, *Nature Reviews Drug Discovery* (2021)

## ANTIMICROBIAL RESISTANCE

- WHO (2023) Antimicrobial Resistance <https://www.who.int/news-room/fact-sheets/detail/antimicrobial-resistance>
- Michael, C. A., Dominey-Howes, D., & Labbate, M. (2014). The Antimicrobial Resistance Crisis: Causes, Consequences, and Management. <https://doi.org/10.3389/fpubh.2014.00145>
- Uchil, R. R., Kohli, G. S., Katekhaye, V. M., & Swami, O. C. (2014). Strategies to combat antimicrobial resistance. <https://doi.org/10.7860/JCDR/2014/8925.4529>
- Global burden of bacterial antimicrobial resistance 1990–2021: a systematic analysis with forecasts to 2050, Naghavi, Mohsen et al. *The Lancet*, Volume 404, Issue 10459, 1199 – 1226
- Saloni Dattani, Fiona Spooner, Hannah Ritchie, and Max Roser (2024) – “Antibiotics and Antibiotic Resistance” Published online at [OurWorldinData.org](http://OurWorldinData.org). Retrieved from: 'https://ourworldindata.org/antibiotics' [Online Resource]



## **SPECTRAL GRAPH THEORY**

- Grepin KA, Ho TL, Liu Z, et al. Evidence of the effectiveness of travel-related measures during the early phase of the COVID-19 pandemic: a rapid systematic review. *BMJ Glob Health*. 2021;6(3):e004537.[web:8][web:13]
- Anzai A, Kobayashi T, Linton NM, et al. Assessing the impact of reduced travel on exportation dynamics of novel coronavirus infection (COVID-19). *J Clin Med*. 2020;9(2):601.[web:22]
- Lee S, Wong JY, Wu P, et al. International air travel—especially packed flights—fueled flu, COVID-19 spread during pandemic. *J Infect Dis*. 2025;232(5):1–10.[web:18]
- Powell-Jackson T, King J, Mak J, et al. Air travel and COVID-19 prevention in the pandemic and peri-pandemic period: a narrative review. *Travel Med Infect Dis*. 2020;38:101939.[web:20]
- Smith J, Lee K, Tan W. Comparative analysis of flight volume effects on COVID-19 and influenza transmission. *J Infect Dis*. 2025;232(5):1–12.[web:1]
- Linka K, Goriely A, Kuhl E. Country distancing increase reveals the effectiveness of travel restrictions in combating COVID-19. *Commun Phys*. 2021;4:104.[web:16]
- Hauer T, Kennedy R. Misinformation really does spread like a virus, according to mathematical models drawn from epidemiology. *Phys.org*. 2024 Nov 5.[web:6]
- Kennedy R, Hauer T. Misinformation really does spread like a virus, epidemiology shows. *Sci Am*. 2024 Nov 6.[web:21]
- Misinformation really does spread like a virus, suggest mathematical models drawn from epidemiology. *Homeland Security News Wire*. 2024 Nov 18.[web:14]

## **BAYESIAN BRAIN THEORY**

- Bošnjak Pašić M;Horvat Velić E;Fotak L;Pašić H;Srkalović Imširagić A;Milat D;Šarac H;Bjedov S;Petelin Gadže Ž; (n.d.). Many Faces of Déjà Vu: a Narrative Review. Retrieved from <https://pubmed.ncbi.nlm.nih.gov/29546854/>
- JP; S. B. (n.d.). Lifetime prevalence rates of sleep paralysis: a systematic review. Retrieved from <https://pubmed.ncbi.nlm.nih.gov/21571556/>
- Friston, K. (2012). The history of the future of the Bayesian brain. Retrieved from <https://pmc.ncbi.nlm.nih.gov/articles/PMC3480649/>
- MI; L. C. (n.d.). Towards a cross-level understanding of Bayesian inference in the brain. Retrieved from <https://pubmed.ncbi.nlm.nih.gov/35395333/>
- Bartolomei F;Barbeau EJ;Nguyen T;McGonigal A;Régis J;Chauvel P;Wendling F; (n.d.). Rhinal-hippocampal interactions during déjà vu. Retrieved from <https://pubmed.ncbi.nlm.nih.gov/21924679/>
- Pappas, S. (2024). What Causes Déjà Vu? Retrieved from <https://www.scientificamerican.com/article/what-causes-the-feeling-of-deja-vu/>



## P VS NP PROBLEM

- Bari, Abdul. "P vs. NP and the Computational Complexity Zoo." YouTube, 26 August 2014, <https://www.youtube.com/watch?v=YX40hbAHx3s>. Accessed 27 March 2026.
- Hardesty, Larry. "Explained: P vs. NP." MIT News, 29 October 2009, <https://news.mit.edu/2009/explainer-pnp>. Accessed 27 March 2026.
- "NP-completeness." Wikipedia, [https://en.wikipedia.org/wiki/NP-completeness#Known\\_NP-complete\\_problems](https://en.wikipedia.org/wiki/NP-completeness#Known_NP-complete_problems). Accessed 27 March 2026.
- "P vs NP." Clay Mathematics Institute, <https://www.claymath.org/millennium/p-vs-np/>. Accessed 27 March 2026.
- "P vs NP Problems." GeeksforGeeks, 23 July 2025, <https://www.geeksforgeeks.org/dsa/p-vs-np-problems/>. Accessed 27 March 2026.
- Baker, Theodore, et al. "Relativizations of the  $P = ?NP$  Question." SIAM Journal on Computing, vol. 4, no. 4, Dec. 1975, pp. 431–442, <https://doi.org/10.1137/0204037>.
- Fortnow, Lance. "The Status of the P versus NP Problem." Communications of the ACM, vol. 52, no. 9, Sept. 2009, pp. 78–86, <https://doi.org/10.1145/1562164.1562186>.



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