Ahmedabad University

Illustrated Science

Winter 2025

Illustrated
Science

Issue 4 | Winter 2025

Cover art Ananya Mohan
Executive, Communications

Digital Curve
Centre for Learning Futures
Ahmedabad University

Course Instructors

Bhumi Shah
Fellow, Digital Curve
Centre for Learning Futures

Tana Trivedi
Assistant Professor
Amrut Mody School of Management

Editor

Bhumi Shah

Student Contributors

Aarya Saraswat
BA (Hons)
Class of 2026

Heli Shah
BA (Hons)
Class of 2026

Parshwa Parikh
BBA (Hons)
Class of 2025

Priyal Soni
Integrated MS
Class of 2028

Vaishnavi Dahihande
BS (Hons)
Class of 2026

Vedika Tiwari
BA (Hons)
Class of 2026

Vyomini Devadiga
Integrated MS
Class of 2028

Science Mentors

Aditya Vaishya
Assistant Professor
School of Arts and Sciences

Ashutosh Kumar
Associate Professor
School of Arts and Sciences

Chena Desai
Doctoral Candidate
School of Arts and Sciences

Rama Ratnam
Professor
School of Arts and Sciences

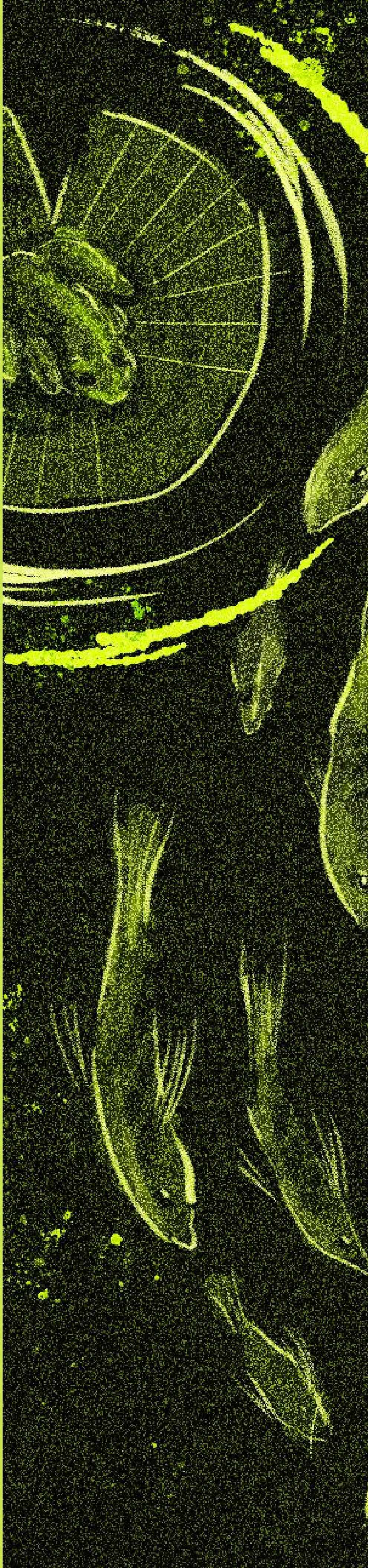
Ratna Ghosal
Associate Professor
School of Arts and Sciences

Ritesh Shukla
Associate Professor
School of Arts and Sciences

Samyaday Choudhury
Assistant Professor
School of Arts and Sciences

Shomen Mukherjee
Associate Professor
School of Arts and Sciences

From *the* Instructors



Dear Readers,

Welcome to the fourth issue of our magazine *Illustrated Science*. It chronicles the semester long efforts of the students from the COM211 Science Communication using Digital Media course at Ahmedabad University.

In an era where scientific advancements significantly impact our lives, the role of effective science communication is crucial. This issue covers previously published articles in sensory ecology, neuroscience, atmospheric environment, machine learning, forensic sciences, aquatic sciences, cancer biology, behavioural ecology, animal cognition and astrophysics.

Join us in celebrating the dedication of these emerging science communicators and illustrators from across different disciplines as they contribute to the ongoing dialogues in Science.

Bhumi Shah & Tana Trivedi

About *the* Course

COM211 Science Communication using Digital Media is a unique, interdisciplinary course offered at Ahmedabad University. The course trains students to bridge the gap between complex scientific concepts, and popular understanding of science through explanatory science illustrations created using digital tools and software. As a part of the course, students engage in the following activities during the semester:

01 | Collaborating with a Science Mentor to simplify and introduce cutting-edge research for the general audience to newer ideas, discoveries and scientific progress. Students work closely with faculty researchers to understand their research and translate it into engaging popular science and illustrated articles.

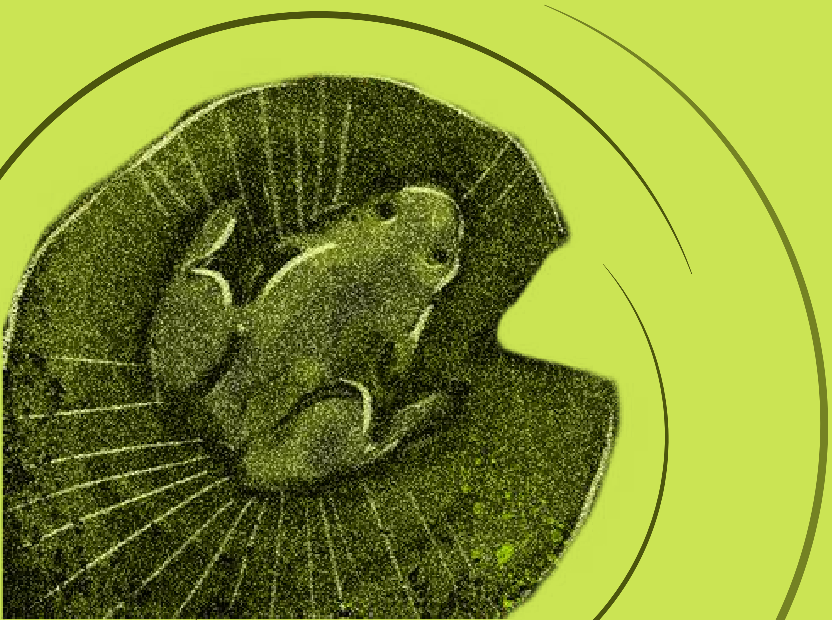
02 | Writing a Feature by observing, describing and explaining. Students learn how storytelling and other literary techniques can help communicate science news. They also understand the difference between science writing and science fiction.

03 | Storytelling Strategies for Graphics by grasping the fundamentals of science graphics, organisation and emphasis, visual Style, colour and typography. Students understand the role that visualisations of data and concepts of science play in enhancing public understanding and increasing engagement with science.

04 | Sketching Digital Illustrations by learning tools like Sketchbook and Inkscape to develop illustrations.

05 | Crafting Illustrated Articles, data visualizations and info-graphics. Students learn to communicate complex ideas and relationships through a visual language of diagrams, charts, maps and imagery with annotated explanations.

Through a combination of creative assignments, readings, listening to podcasts, and field trips, this course exposes students to multiple approaches and perspectives on understanding and communicating science for lay audiences.

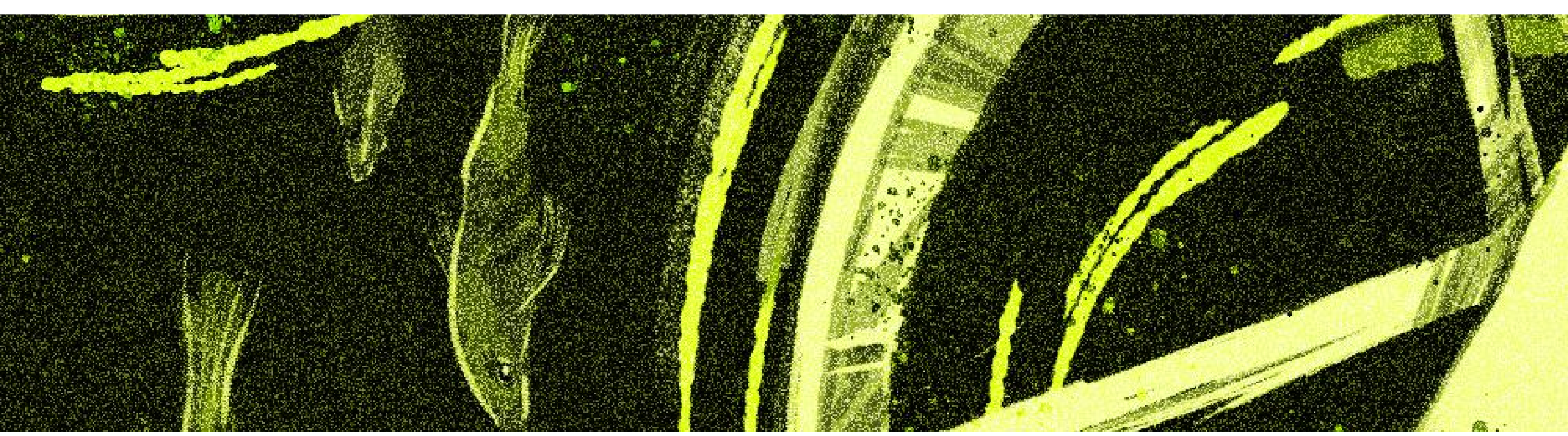


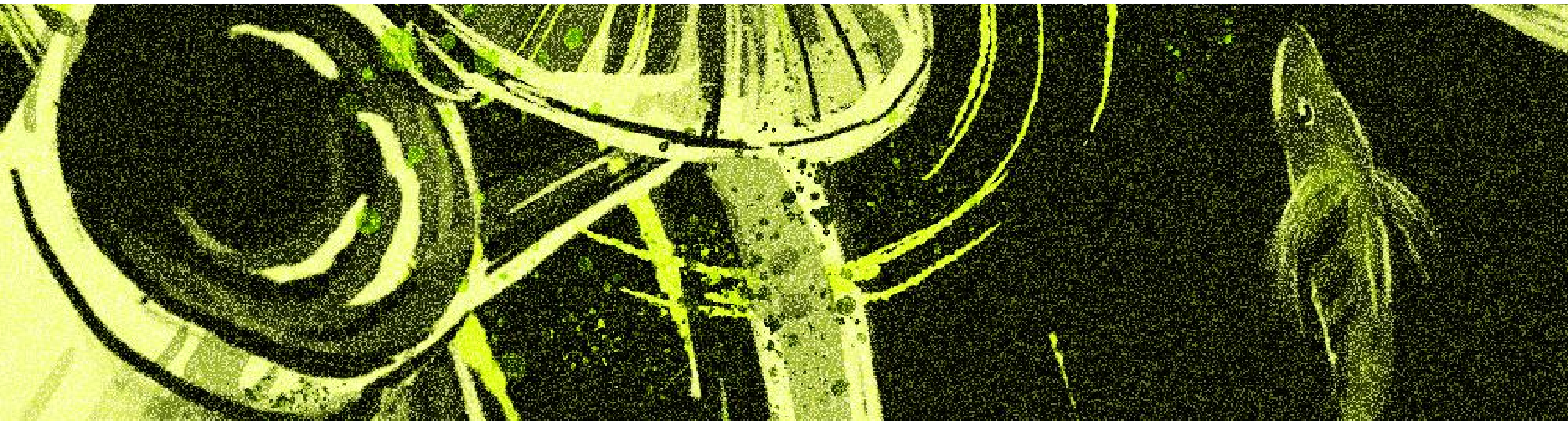
Course *In*structors

Tana Trivedi is an Assistant Professor at the Amrut Mody School of Management at Ahmedabad University. With over seventeen years of teaching experience in business history, literature, literary theory, and postcolonial diaspora studies, her research interest lies in examining the notions of nation and identity formation. At Ahmedabad University, she offers science fiction and science writing courses, both of which she enjoys reading and discussing. She completed her PhD from Christ University and did her Postdoctoral research at the University of Edinburgh.

Bhumi Shah is a Fellow at Digital Curve, Centre for Learning Futures at Ahmedabad University. Her work is interdisciplinary and ranges across learning design, digital heritage, interactive media and research communication. She teaches courses in Interactive Media and Creative Coding at Ahmedabad University. She develops projects with researchers to understand, interpret, and communicate ideas, concepts or processes through interactive media and explanatory illustrations. She holds a Master in Computer Applications, specialising in Mobile Computing, and a Master of Management Studies in Heritage Management.

Inside





Auditory Camouflage

How Frogs Deceive Mammalian Predators

Writer and Illustrator **Aarya Saraswat** | *Science Mentor* **Rama Ratnam**

"It's lunchtime, Shruti!" her mother calls from her right, while her phone rings in front of her. Shruti instinctively knows where both sounds come from. This ability to locate sounds is known as directional hearing. Humans and other animals use *directional hearing* to selectively attend to a given sound among competing sounds in what is called the **cocktail party effect**. It shows how humans filter meaningful sounds from distractions. But frogs, with simpler brains, use unique strategies not just to communicate but also to trick predators with similar hearing abilities. A recent study by D.L. Jones and Rama Ratnam, a Professor of Neuroscience (2022) explores how frogs manage this auditory deception.

Hear Me Out: Tune into the Human Hearing System

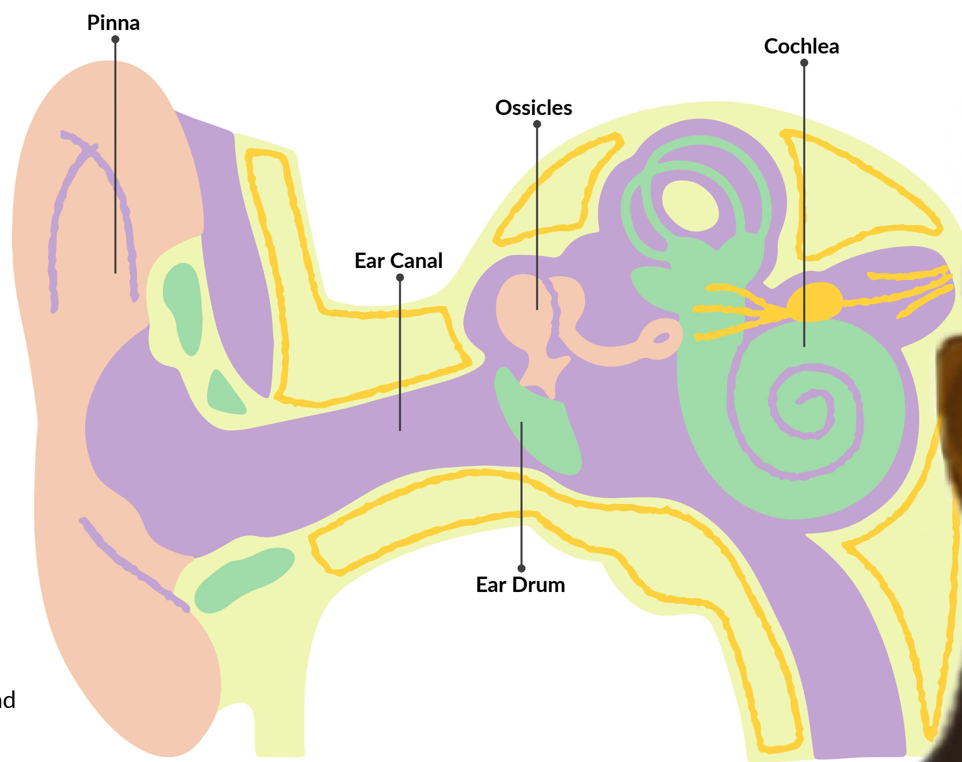
To appreciate the frogs' ingenuity, we must first understand how humans and many other mammals process sound. Imagine you're sitting in your room, and someone calls you from the right side, while your phone rings in front of you—you instinctively know where each sound is coming from. That's because human ears act like two independent microphones on either side of your head, picking up pressure waves from the air. The brain compares the differences in loudness and arrival time of the sound at each ear, known as interaural level difference (ILD) and interaural time difference (ITD), to figure out the direction of the sound. Here's how it works, step by step:

Outer Ear
The outer ear collects sound waves and funnels them to the eardrum.

Middle Ear
The middle ear amplifies these vibrations via three tiny bones.

Inner Ear
The inner ear converts them into electrical signals using hair cells in the cochlea.

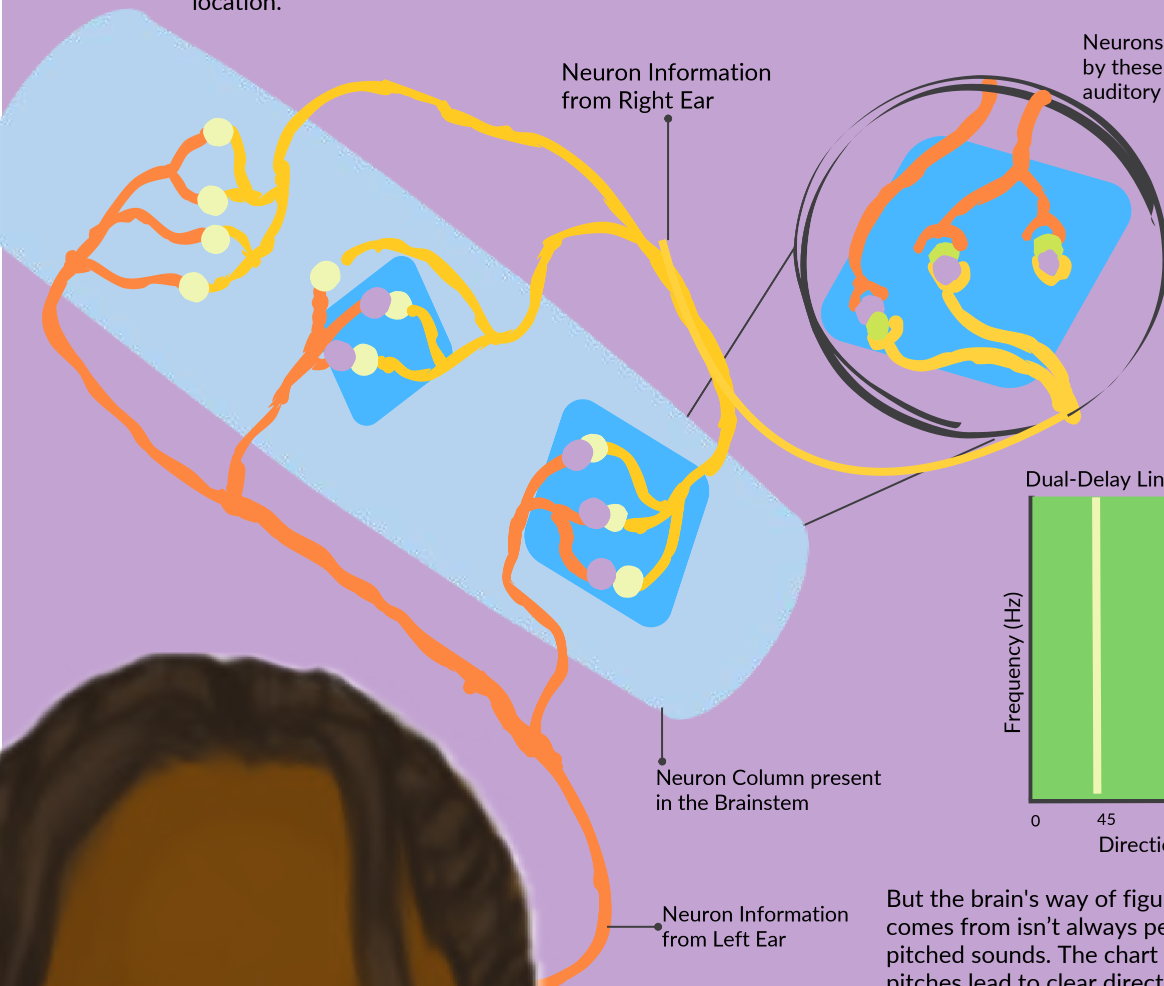
Brain Stem and Auditory Cortex
The signals travel to the brainstem where the location of the sound is computed and then onto the auditory cortex where many features of sound are processed.

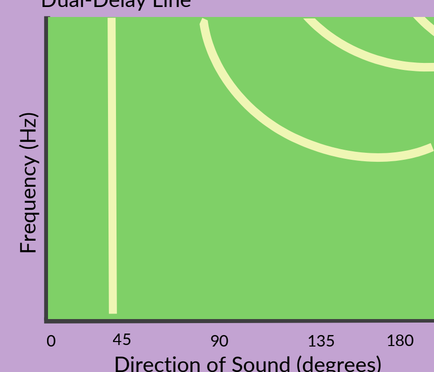


This chain of events enables you to instantly tell whether a sound came from in front of you or from another room—like when your phone rings and someone calls you at the same time.

The Dual Delay Line Model

In mammals, this processing starts in the brainstem. The Jeffress model (1948) explains how the brain uses neural delay lines to compare ITDs. For instance, when Shruti's mom calls from the right, the sound reaches her right ear slightly earlier. The brain detects this and activates neurons that align with that timing. However, this model works best for low-frequency sounds. High frequencies can create ambiguous matches, confusing the brain. To resolve this, mammals compare signals across frequencies, highlighting consistent directions. Think of layering maps to find a single location.





But the brain's way of figuring out where a sound comes from isn't always perfect—especially for high-pitched sounds. The chart (above) shows this: low pitches lead to clear direction detection (correct direction), while high pitches create multiple confusing signals (suggesting many directions).

Overcoming Ambiguity: Brain Shortcuts

As mentioned, mammals use two systems to interpret timing (ITD) and loudness (ILD). Timing is used in low-pitched sounds. Neurons in the brainstem act like matchmakers, detecting when inputs from both ears sync up. Barn owls, for example, use this to build accurate sound maps. But real environments are messy. Echoes and background noise interfere. The brain counters this using the precedence effect: it focuses on the first wave of sound and ignores the echoes. This helps us localise sources in echoey places, like halls or noisy rooms. Special phasic neurons detect quick sound onsets, helping us focus on meaningful sounds, just as the cocktail party effect works. Small mammals like cats and ferrets also combine these cues for accurate hearing. Even though the Jeffress model isn't perfect for all frequencies, the mammalian brain combines timing, frequency, and clever tricks to make sense of sound.

|Shruti

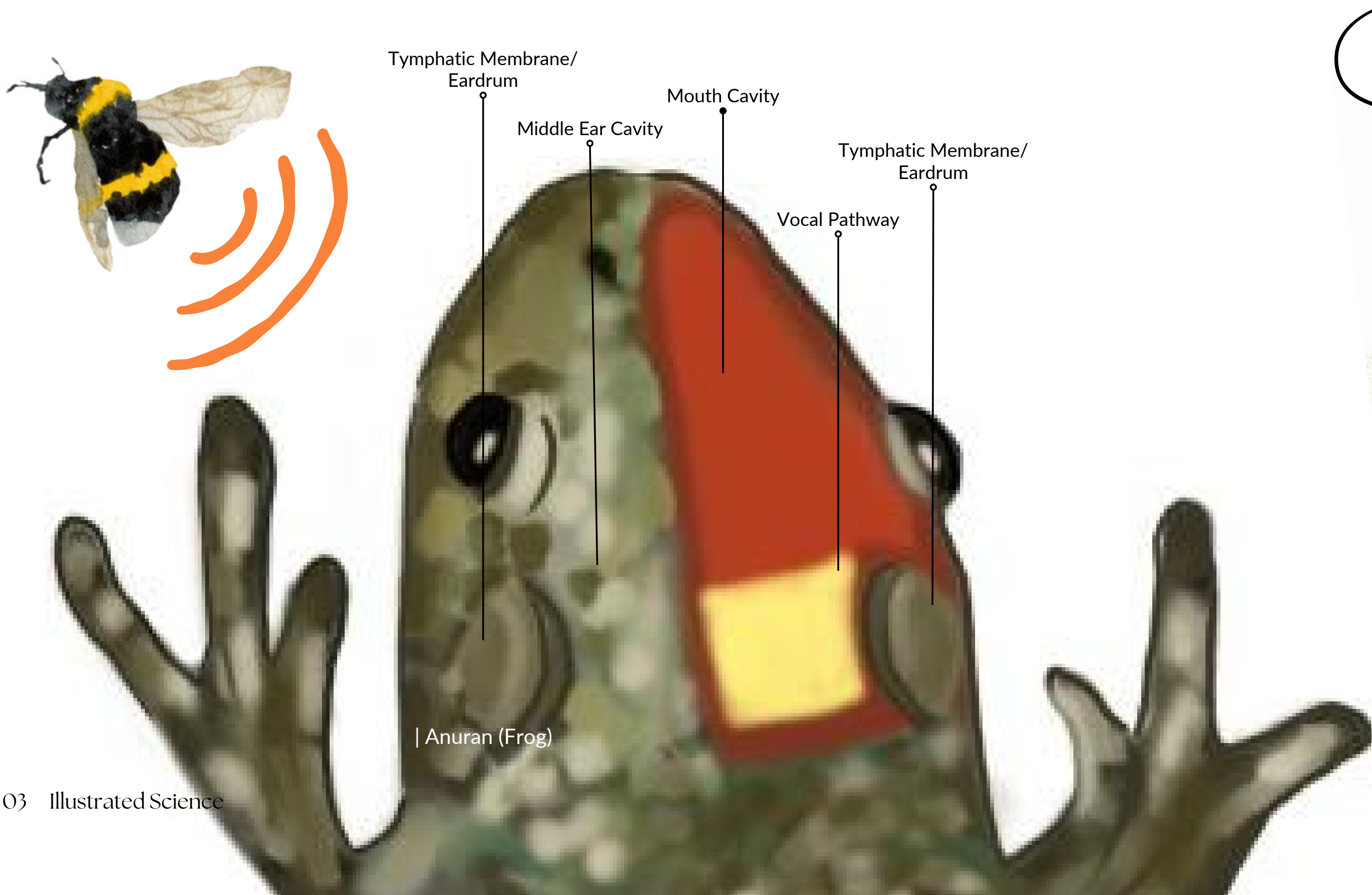
Rama Ratnam with mic - experimental set-up to record frog calls.

What's Different About Frogs Then?

One warm evening in the Texas wetlands, Professor Rama Ratnam heard what sounded like a group of frogs calling all around him. He thought there were at least three or four. But after searching for hours, he found only one frog sitting right next to his foot. Its call location was so ambiguous, it sounded like a whole chorus. That moment captured the mystery of his research: how frogs can be so loud, yet so hard to find.

Before answering those burning questions, we need to understand how different these amphibians are from us. Unlike mammals, frogs have ears that are connected to their mouths. This setup lets sound hit both sides of the eardrum at once, but with different pressure levels.

This design helps frogs figure out where sounds are coming from without needing complex brain work. Instead of using timing, such as mammals do, frogs use subtle pressure differences between the sounds received in each ear. These pressure variations help the frog determine the direction of a sound source, giving it a spatial sense of where the noise is coming from their connected ears. This helps female frogs pick out individual males, even in loud, crowded environments—while predators get confused by the same sounds. Frogs aren't the only animals with this kind of hearing—birds and reptiles have it too. But frogs go a step further by using special calling tricks that make them even harder to find. They've developed such ear structures and clever call patterns that make it hard for predators to tell where the sound is coming from.



| Anuran (Frog)

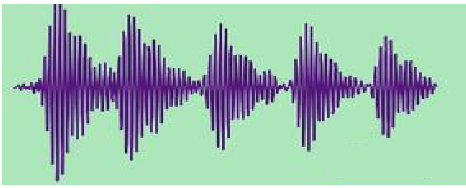
Built to Be Heard—But Not Found

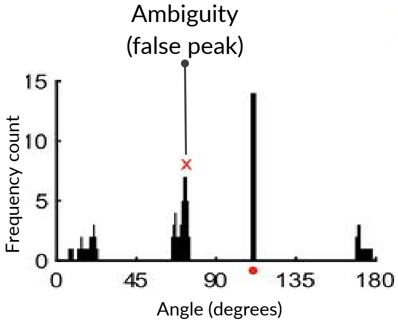
Frogs (or anurans), specifically male frogs, live in a world where they croak to find a mate (to attract the female frog). These calls have an evolutionary significance—females pick mates based on how strong and appealing the calls are to them. The better the call, the better the chances of passing on the genes to the offspring. However, these croaks end up disclosing the frog's location to their predators. Unlike mammals, frogs use entirely different mechanisms to bypass getting caught by their predators, specifically mammals, by calling. Let's take a look at how they do that. Frogs have come up with smart ways to confuse the hearing systems of mammals. This isn't just theory—the researchers analysed vocalisations from three frog species to better understand these strategies: the cricket tree frog (Acris crepitans), the túngara frog (Engystomops pustulosus), and the grey treefrog (Dryophytes versicolor). These samples helped reveal how frog calls exploit the weaknesses of mammalian hearing.

Trick 1: Time Delay Ambiguity

The cricket frog (*Acris crepitans*) uses repeating sounds to confuse predators. These sounds are very regular, which tricks animals like raccoons or foxes who try to figure out where the sound is coming from. Normally, mammals know a sound's direction by checking which ear hears it first. But when the sound repeats in a steady pattern, their brains can get mixed up. The brain thinks the sound is coming from more than one place. This happens because the frog's repeating calls cause false signals in the brain. The cricket frog's call is especially tricky, making a strong fake signal that hides the real one. In noisy places, this confusion works even better, and the predator might not find the frog at all.

Acris crepitans





Adapted from Jones, D. L., & Ratnam, R. (2022)

Scan QR to listen

| Cricket Treefrog

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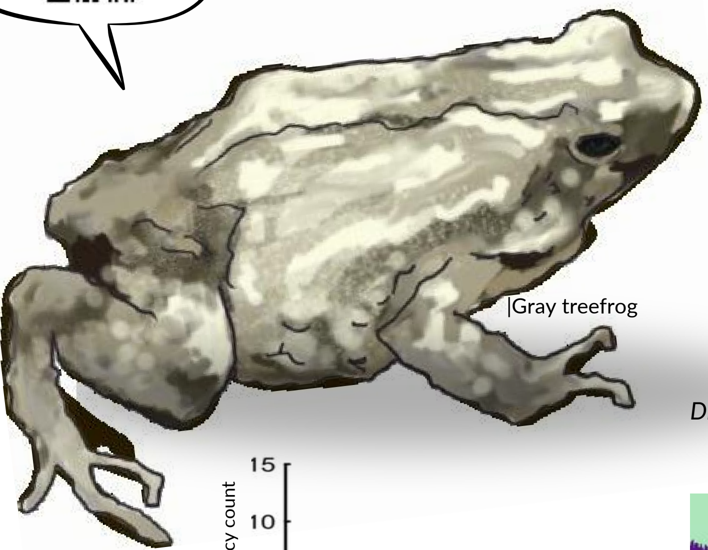
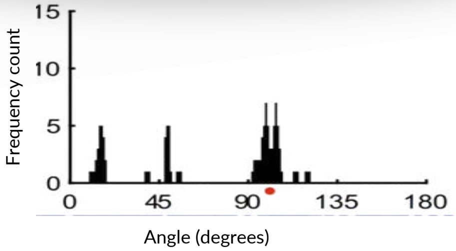


|Gray treefrog

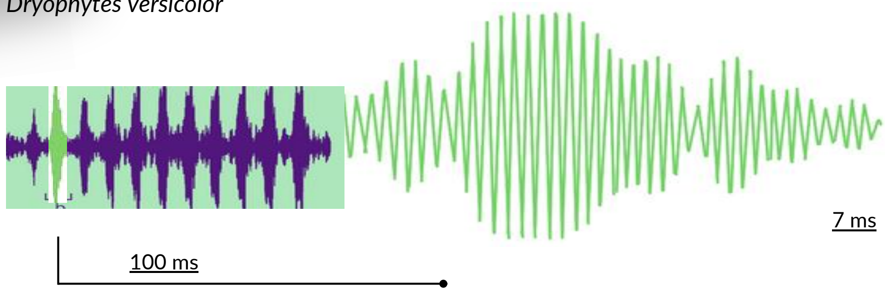


Adapted from Jones, D. L., & Ratnam, R. (2022)

Trick 2: Narrowband Calls

Some frogs, like the grey treefrog, avoid predators by making calls that stay within a narrow range of sound frequencies, like singing one steady note. This makes it hard for predators to tell where the sound is coming from, especially when many frogs are calling at once. Predators usually figure out where a sound is by comparing different pitches, but narrow calls confuse this. The grey treefrog's call is even more focused than what most predators can hear. Its smooth, wave-like sound shape also helps it stay hidden.

Dryophytes versicolor



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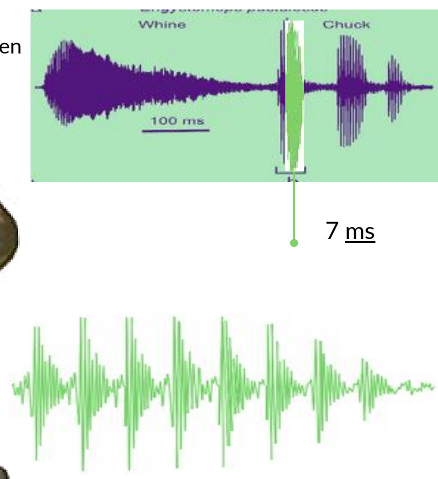
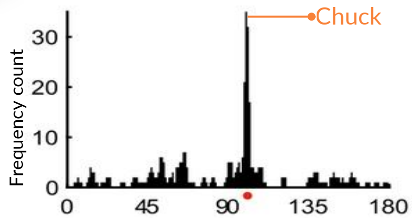
|Túngara Frog

Engystomops pustulosus





Adapted from Jones, D. L., & Ratnam, R. (2022)

The túngara frog makes a call with two parts: a soft "whine" and a louder "chuck." The whine is harder to locate, but the chuck covers more pitches and is easier for predators to hear. Still, female frogs love the chuck, so males include it to attract mates, even if it means taking a bigger risk.

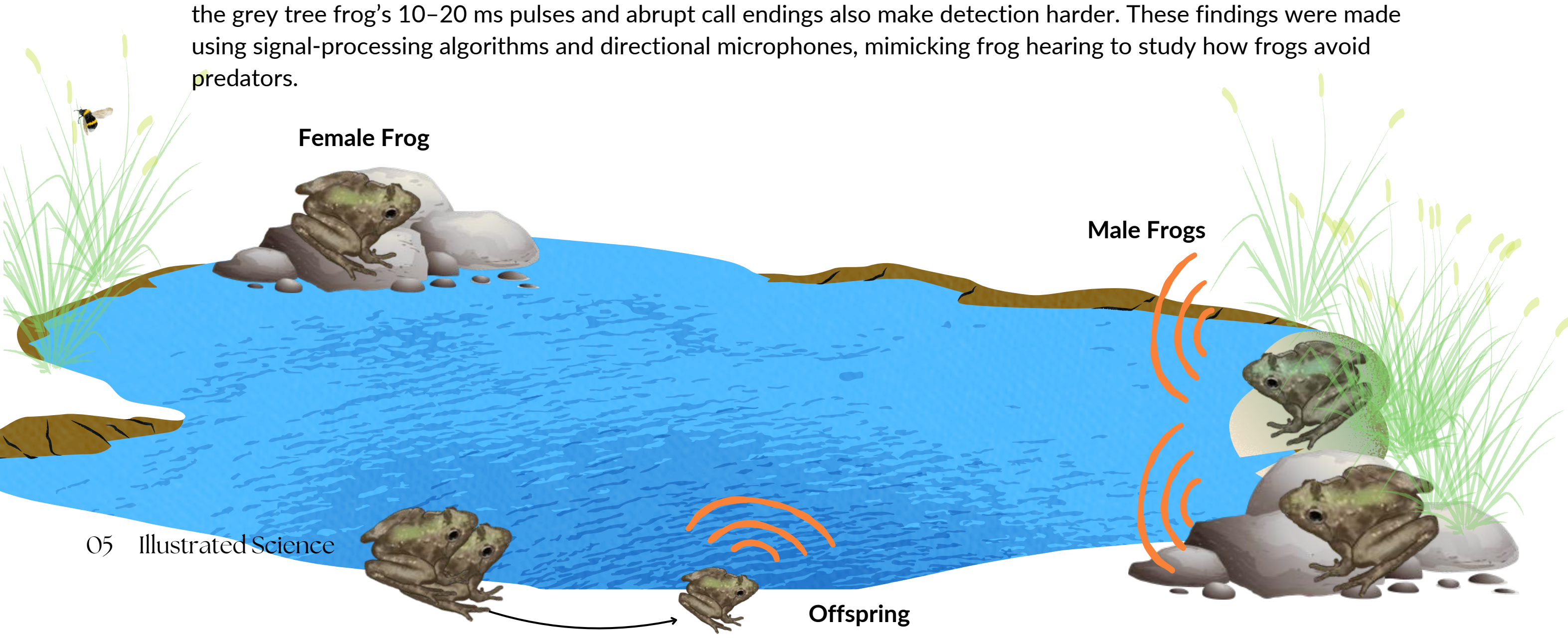
Trick 3: Short-Duration Pulses - Degrading Onset Cues

Some frogs use short, rapid pulses in their calls to avoid being located by predators, especially small mammals. These short pulses—lasting between 3 to 20 milliseconds depending on the species—disrupt how predators detect sound direction. For instance, túngara frogs produce chucks around 3–4 ms long, while grey tree frogs use pulses up to 20 ms. Animals can rely on the beginning of a sound to figure out where it's coming from. This system, however, resets with each new sound onset, making it hard to track repeated, short pulses. If the sound keeps starting and stopping quickly, it becomes difficult for predators to average the sound over time and determine its source. Experiments show that the shorter the pulse, the more inaccurate the predator's sense of direction becomes. With very short pulses (e.g., 5 ms), their guesses are nearly random. Meanwhile, frogs may have adapted their own hearing to recognize these specific call patterns, making communication among themselves easier while reducing the risk of being located by predators.

Trick 4: It's Choir Time

Frogs like the green tree frog (*Hyla cinerea*) call in large choruses to avoid being found by predators. Researchers used microphone arrays placed over ponds to record thousands of frogs and locate individual calls. They found that green tree frogs organise into three calling phases, with neighbours choosing different phases. This pattern disrupts how small mammals use sound timing to locate prey.

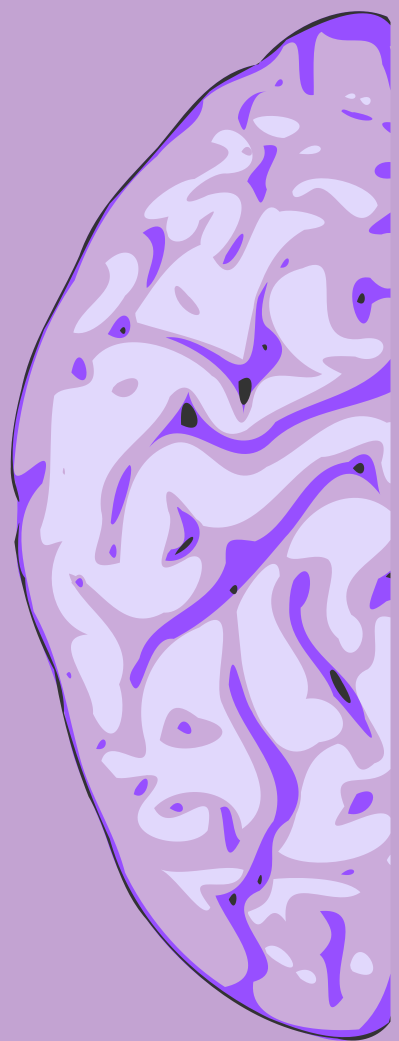
Each frog's call gradually increases in volume, giving others time to join the chorus and create acoustic cover. When neighbours stop calling, a frog drops out almost immediately. This behaviour was tracked by studying six frogs over 20 chorus bouts, showing they joined most calls. Mammals struggle to find a single frog in this noisy environment. In over an hour of data, researchers couldn't find a single isolated call with a signal-to-noise ratio over 10 db. In comparison, the grey tree frog's 10–20 ms pulses and abrupt call endings also make detection harder. These findings were made using signal-processing algorithms and directional microphones, mimicking frog hearing to study how frogs avoid predators.



Auditory Camouflage in Choruses

Frog choruses aren't just noise—they're a survival trick built through millions of years of evolution. Scientists have discovered that frogs use special sound strategies to make their calls hard for predators like mammals to locate. These calls are usually narrowband (focused in a small frequency range), made up of short pulses, and start softly instead of suddenly. When many frogs call together in a dense chorus, it creates so much overlapping sound that predators get confused, making it harder to find any one frog.

Mammals like bats or small carnivores use brain systems to figure out where sounds are coming from by comparing the time and loudness of the sound in each ear. But frog calls mess with these systems. Some confuse the brain's timing tricks, while others take advantage of how sensitive mammal hearing is to background noise. Even well-known models like the Jeffress delay-line system or newer excitation/inhibition brain models struggle with locating frog calls—especially in noisy environments or when the calls are made just right. Researchers have even made synthetic frog sounds to test this, and many of them are hard for humans to locate too—which means small mammals would probably struggle even more. All this shows that frogs aren't just surviving—they're winning an acoustic arms race. So, the next time you hear a bunch of frogs croaking after dark, remember: you're listening to a masterclass in nature's sound-based camouflage, designed not just to find love, but to stay alive.



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Aarya Saraswat is a student of the Bachelor of Arts (Honours) in Psychology at Ahmedabad University. She is an artist deeply inspired by the mysteries of the mind. With a passion for cognitive neuroscience and AI, she explores how art can translate complex scientific ideas — from neural networks to emotional memory — into visuals that spark curiosity and connection. Whether through sketchbooks, digital illustrations, or interactive installations, she seeks to make science not only understood, but felt. To her, every thought is a canvas, and every experiment a story.

Rama Ratnam is a Professor at the School of Arts and Sciences at Ahmedabad University. He is a neuroscientist with a broad interest in brain and behaviour, particularly in neurobiological mechanisms of sensory processing that give rise to perception. His research interests include Neuroscience, Brain And Behavior, Sensory Processing, and Neural Engineering. He obtained his doctoral degree from the University of Illinois at Urbana-Champaign. His engineering roots from IIT Delhi have deeply influenced his research in biology to combine biology a engineering to explore how natural selection mirrors optimal design.

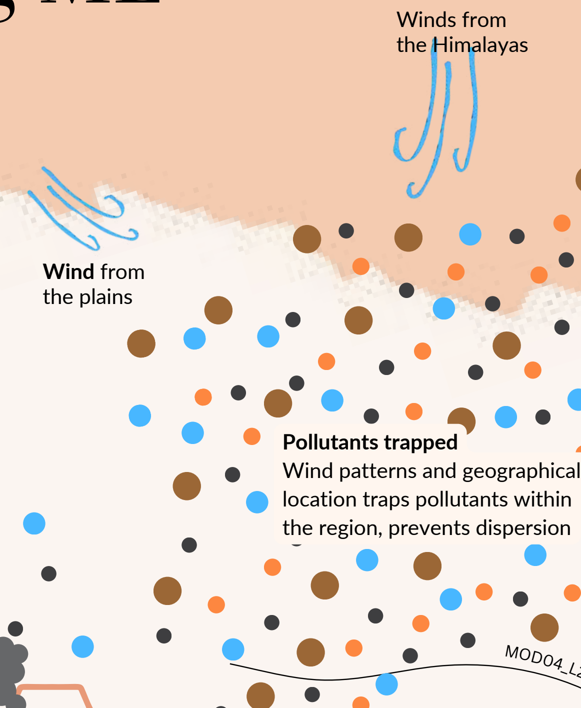
Solving the Climate Puzzle and its missing pieces using ML

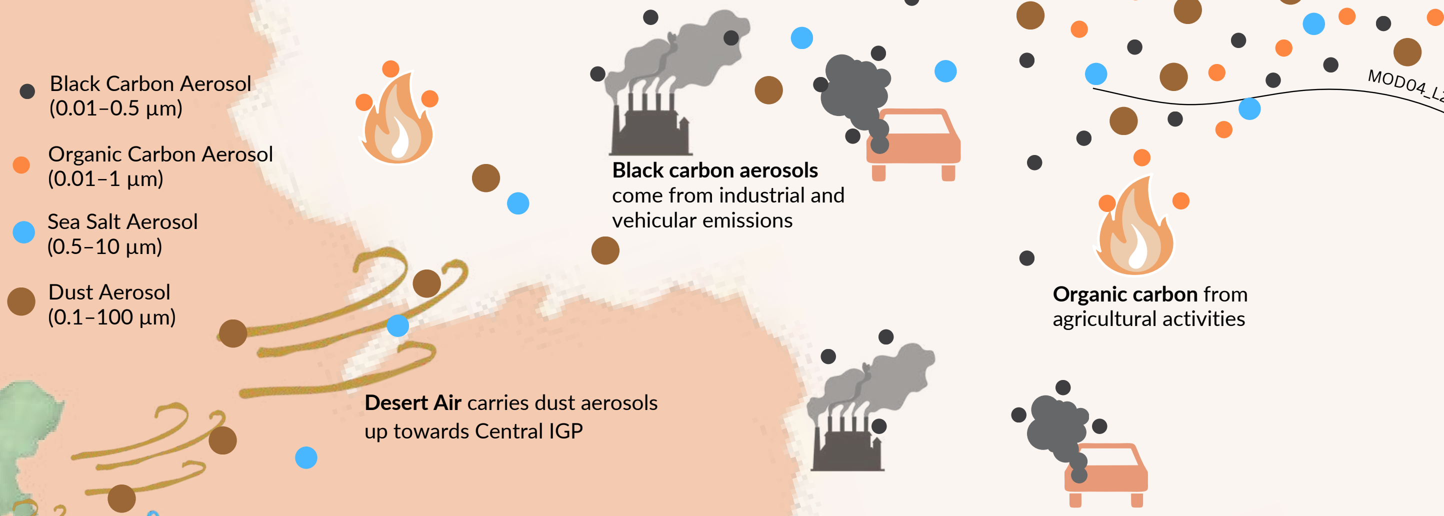
Writer and Illustrator **Heli Shah** | *Science Mentor* **Aditya Vaishya**

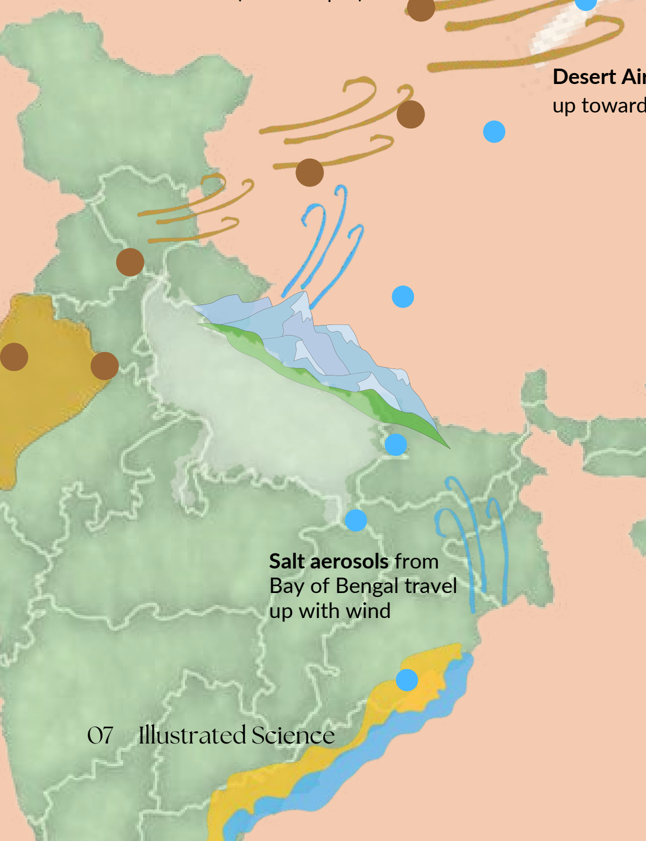
When we talk about climate change, carbon dioxide steals the spotlight—but lurking in the air is a far more dynamic entity: **aerosols**. These tiny, invisible particles, released by both nature and human activity, have the power to cool or warm the planet, affect weather patterns, influence global climate patterns, and define the quality of the air we breathe.

Some aerosols reflect or scatter sunlight, thereby cooling the planet, while others absorb heat, thus contributing to warming. This effect, known as **Aerosol Radiative Forcing** (ARF), creates a complex climate balance that remains one of the greatest challenges in climate science. Without precise aerosol data, climate models remain incomplete, leaving gaps in our ability to predict future climate trends.

Aerosol Types and Size







The **Central Indo-Gangetic Plain (IGP)** is a major aerosol hotspot, where industrial activities, vehicle emissions, and seasonal crop burning produce dense pollution affecting millions. Its geography traps pollutants: the Himalayas block dispersion to the north, the Thar Desert adds dust from the west, and surrounding seas influence wind patterns. Agriculture along the Gangetic plains further contributes through crop-residue burning emissions, which add to the pollution.

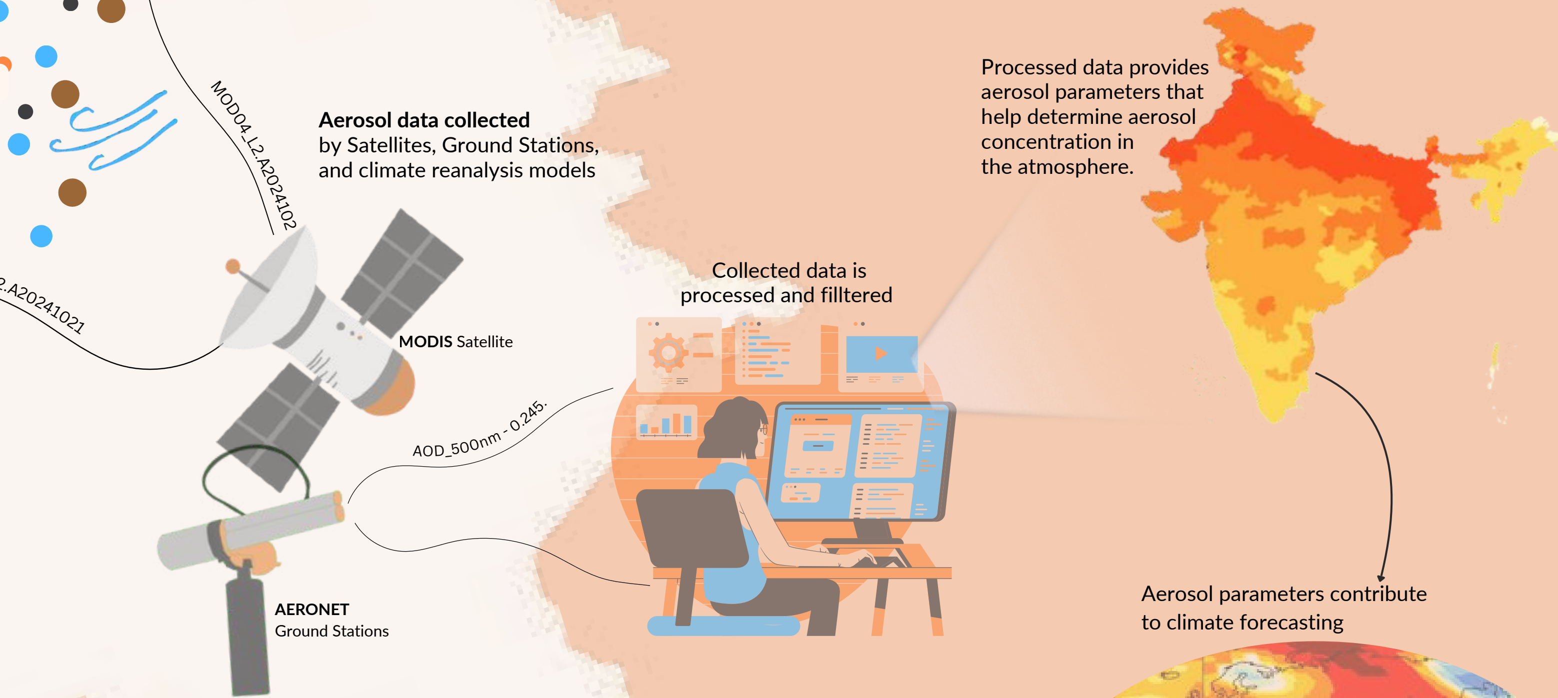
This unique mix of natural and anthropogenic emissions leads to severe haze, poor air quality, and climate effects, making the central IGP critical for aerosol studies. The region's complex pollution sources reflect a broader global challenge—dynamic aerosol behaviour and missing data that continue to hinder reliable climate projections.

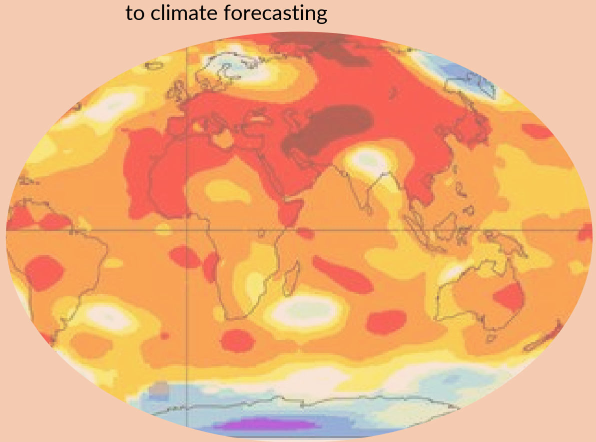
Why Scientists Struggle to Measure Aerosols: The Data Dilemma

The measurement of aerosols presents a crucial challenge in climate science because they constantly vary in terms of size, shape, and chemical composition throughout space and time. Due to the dynamic nature of aerosol properties, scientists struggle to track these particles properly, and even minor data inconsistencies can cause major uncertainties in climate predictions.

Scientists depend on three primary sources of data. **Ground stations**, such as **AERONET**, give precise measurements but are sparse and primarily located in urban areas. **Satellites**, such as **MODIS**, give a global view, but their measurements are uncertain because of cloud cover and sensor issues. The third source, **Reanalysis data models** such as **MERRA-2**, try to complete the missing data by merging observations with simulations, but their reliability depends on the quality of the data on which they are based.

Significant gaps in the observational data needed to understand aerosols have persisted over the decades, limiting comprehensive analysis and interpretation. Reducing these gaps is essential for accurate climate projections and stronger, evidence-based policy. Since aerosols can cool and warm the planet, even minor measurement inaccuracies can substantially affect climate projections. Observational gaps further compound this uncertainty, reducing the reliability of climate models in predicting future climatic situations. Closing these gaps is, therefore, critical to enhancing model accuracy and ensuring robust, data-driven climate policy.





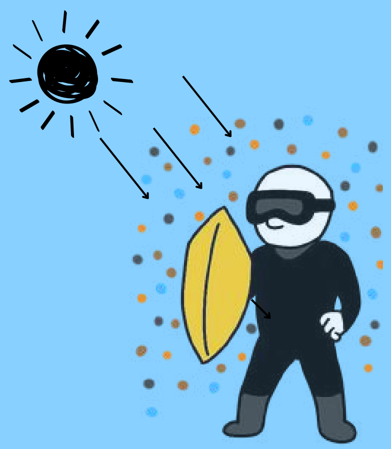
Machine Learning: A New Tool for Climate Science

Machine learning operates as an AI subfield that enables computers to analyse massive datasets for discernible patterns, leading them to make independent prediction outputs without tailored programming for individual circumstances. The data acquisition method outperformed classic statistical approaches to handle missing aerosol information because it teaches itself from past examples instead of using static mathematical rules. ML (machine learning) enhances climate model efficiency when dealing with data deficiencies.

A recent study by Parmar et. al. (2024) demonstrates how machine learning can fill in missing aerosol measurements, thereby generating improved predictions of aerosol parameters. The model enhanced prediction accuracy levels as it combined AERONET data with MODIS and MERRA-2 information.

The Making of the Machine Learning Model

Aerosol Optical Depth (AOD)

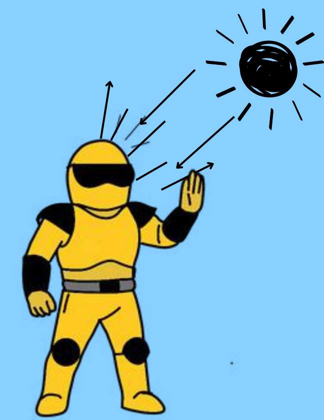


Aerosol Optical Depth (AOD) measures the abundance of atmospheric aerosols by assessing how much sunlight they block.

Single Scattering Albedo (SSA)

Single Scattering Albedo (SSA) indicates whether these particles primarily absorb or scatter light.

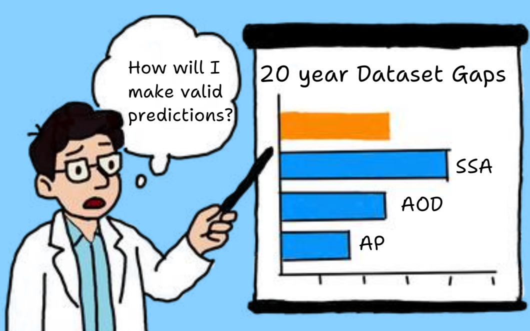
Asymmetry Parameter (AP)



The Asymmetry Parameter (AP) captures the direction of light scattering—whether forward, backward, or evenly distributed.

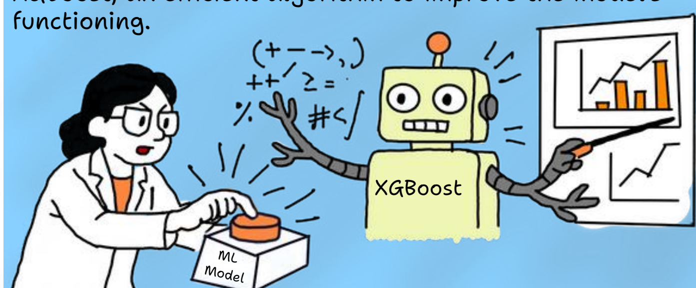
Together, these properties influence atmospheric heating and visibility, with SSA playing a crucial role in the scattering–absorption balance. Simulating AOD, SSA, and AP allows climate scientists to better understand aerosol–climate interactions and improve climate forecasts.

The Problem?



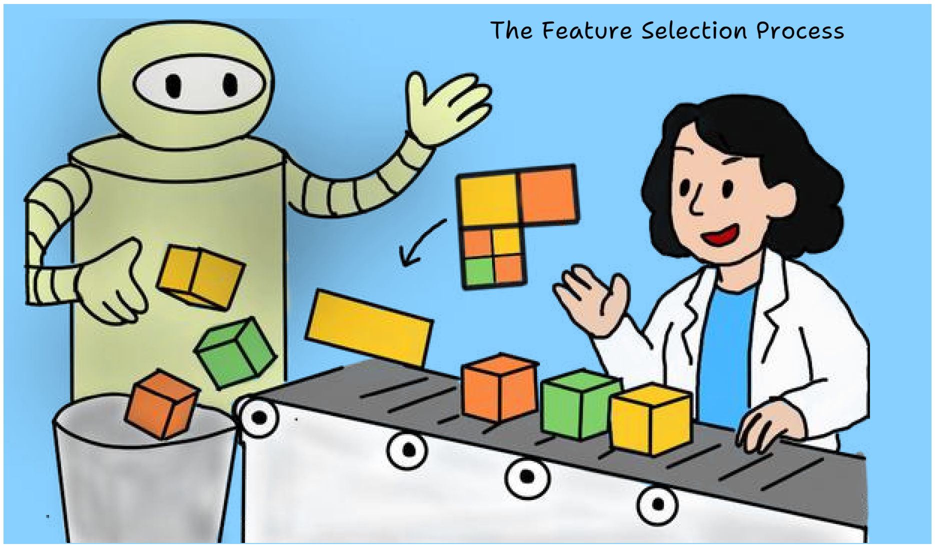
Significant Data Gaps in Aerosol Parameters.

The next step?
In order to regenerate the dataset, the researchers trained a supervised machine learning model based on XGBoost, an efficient algorithm to improve the model's functioning.

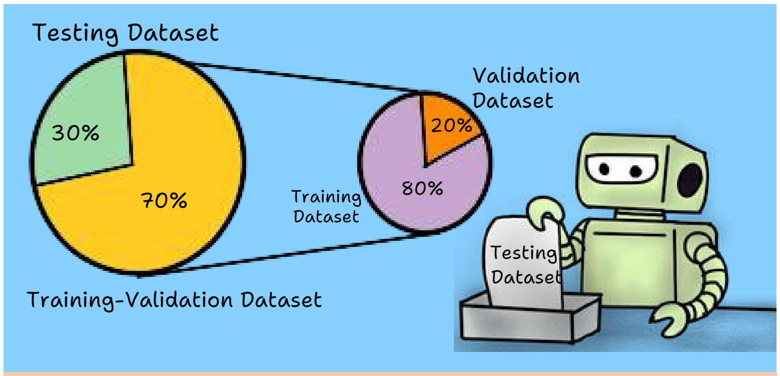


Prep the data to feed the Model!

The Feature Selection Process

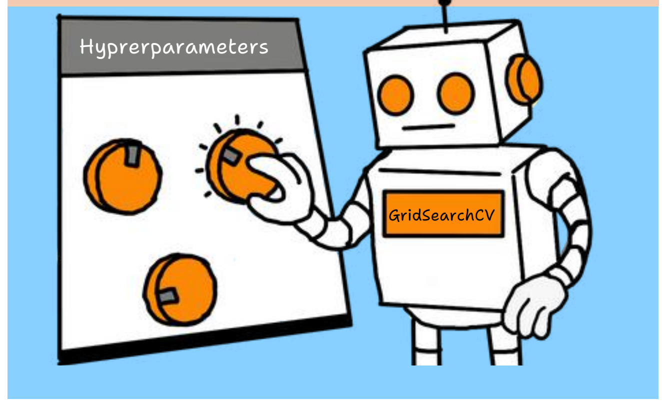


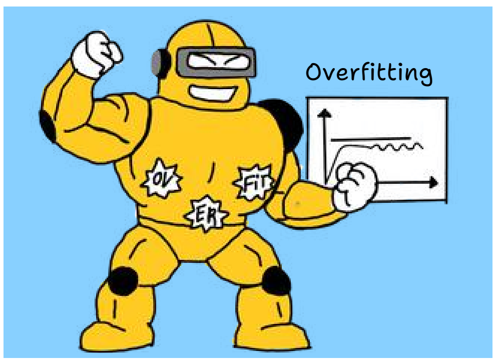
Feature selection improves model performance by removing irrelevant or redundant variables, which may decrease model's accuracy. A correlation heatmap is employed to find features with high positive or negative correlations to the target, and weakly correlated ones—for eg wind speed or temperature - are discarded. Highly correlated features are also removed to resolve multicollinearity. This simplified selection decreases model complexity and overfitting risk.



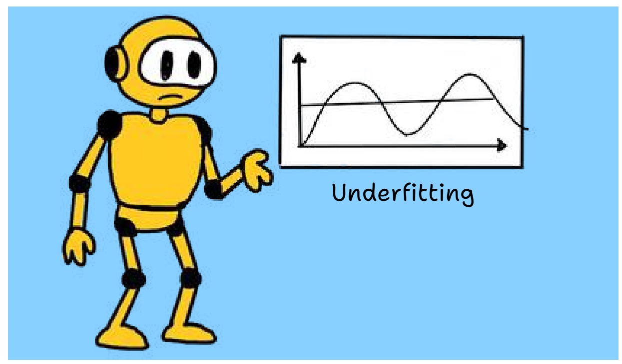
Following feature selection, the data are divided for training, validation, and testing. Training is employed for model construction and fitting, while validation is utilised for parameter tuning and avoiding overfitting. Testing subsequently assesses the performance of the model on unseen data to ensure generalizability.

Training data is utilised to train the XGBoost model. GridSearchCV is used to determine the optimal hyperparameters, which are responsible for maximising accuracy and efficiency. With the optimal configuration, the model is then trained.

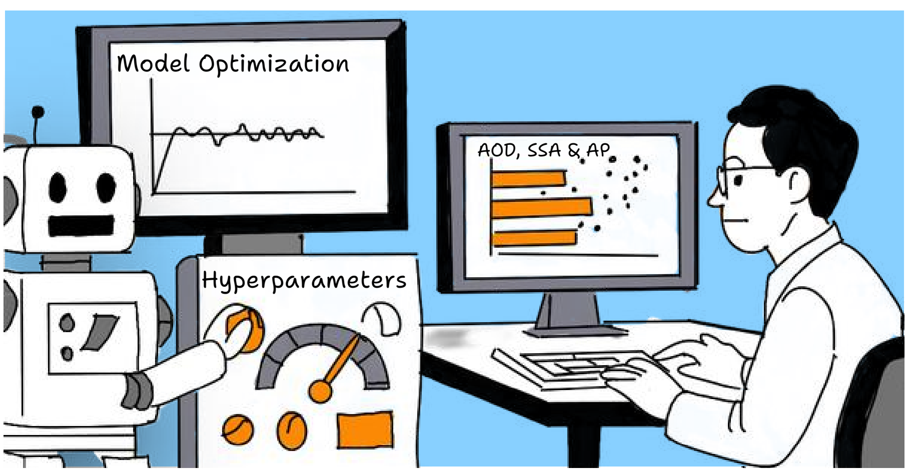




Once the model is trained, its performance is tested based on the validation dataset. The dataset is used to determine how well the model can generalize to new, unseen data.



Overfitting takes place when the model picks up noise within the training data and thus becomes too specialised and cannot generalise to new data, resulting in poor test set performance. Underfitting occurs when the model is not complex enough to understand and replicate data patterns, resulting in poor performance on the training and test sets. Overfitting and underfitting both disrupt the model's capabilities to make reliable predictions on unseen data.

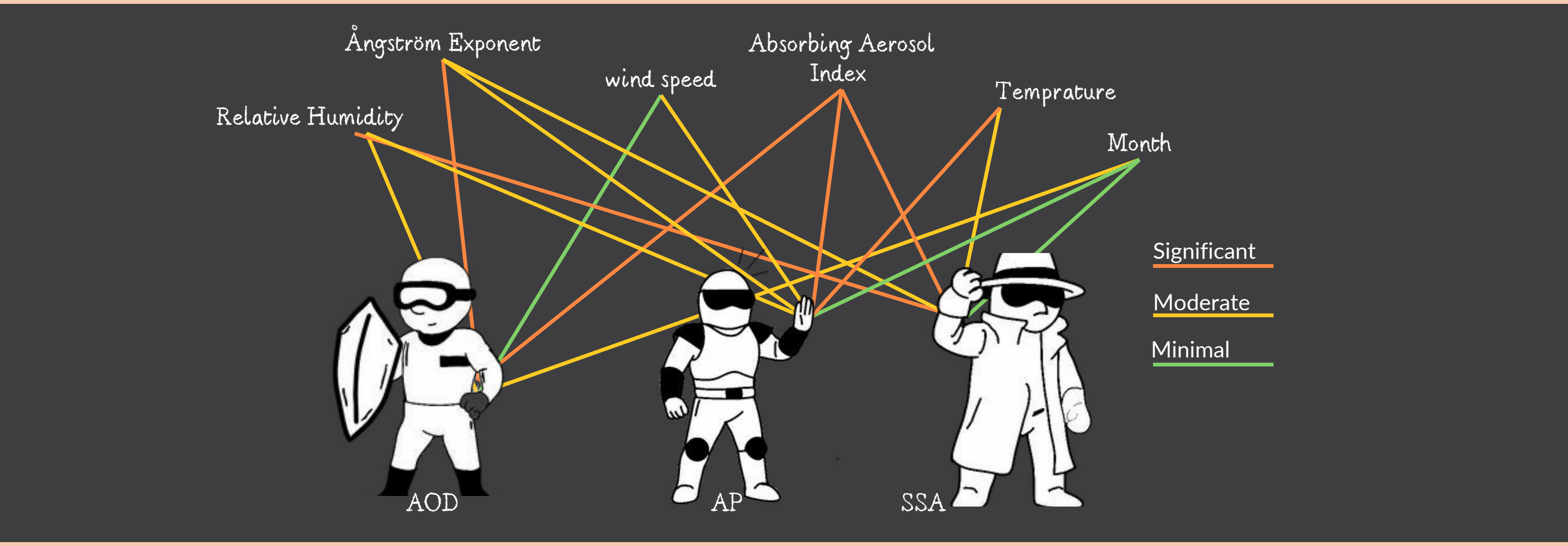


After validation, the model predicts aerosol properties like AOD, SSA, and AP based on the chosen features and optimised parameters. These computations enable researchers to comprehend the behaviour of aerosols under different atmospheric conditions and how they affect the climate. Researchers utilize a tool named SAGE to observe the contribution of each input—such as humidity or dust—to the model's prediction by determining which factors are most important in comprehending the atmosphere.

How Machine Learning Fills the Gaps in Aerosol Data

The optimised machine learning (ML) model, one that was trained using aerosol characteristics and meteorological information, demonstrated that it could sensitively reproduce important aerosol parameters and complete long-standing gaps in observational records, opening the way to clearer estimates of aerosol radiative forcing (ARF) and their effect on our climate. Model performance was significantly enhanced with the addition of MODIS AOD data, reducing overall error in simulating AOD. The accuracy of the model-generated parameters was found to be comparable to, or even better than, that of established datasets such as MODIS, MERRA-2, and AERONET observations. It outperformed traditional models such as Prophet, GAM, and MLR in the representation of intricate aerosol behaviour.

SAGE feature importance analysis revealed important drivers for each property.



Reconstructing Aerosol Records

In total, the machine learning model was able to fill long-standing observational gaps, retrieving around two years of missing data for AOD, five years for SSA, and four for AP. More significantly, it showed that as much as 3 watts per square meter (3 W/m^2) of radiative forcing had been unaccounted for. That might sound small, but it's anything but. Multiply 3 W/m^2 by the whole surface area of the Earth—more than 510 million square kilometres—and you have an invisible energy imbalance of about 1,530 terawatts. That's more power than required to power all of human civilisation, 77 times.

Picture a lone glowing battery for the 20 TW we harness to energise the modern world. Now imagine 77 more of those batteries—all silently affecting our climate from above, but previously absent from our models. While filling these gaps may not represent a major technical milestone, it significantly improves our ability to understand, model, and respond to the factors influencing Earth's atmosphere.

This is no small step—it's a new perspective on planetary energy, fueled by machine learning.

20 TW: Avg. power consumption of humans at any given moment

*1 TW = 1 Trillion watts

The Bigger Picture: Future of AI in Climate Science

This study is a leap forward for climate science. Through machine learning, filling decades-old gaps in aerosol data, scientists have made climate models more reliable and enhanced our knowledge of how aerosols impact the Earth's temperature. These advancements can lead to more reliable climate projections and help in framing better policies.

Though potent, machine learning is not a magic bullet. Its accuracy relies on the quality of the data it's learned from, and its predictions need to be validated against actual observations. Nevertheless, this research demonstrates how AI can aid climate science, particularly in intricate fields such as aerosols, where data has tended to be limited or uncertain.

In the end, this research emphasises the importance of merging science and technology. It is a testament to the hard work of scientists who work across disciplines and bring us closer to understanding the dynamics of our atmosphere and informing more effective responses.

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Heli Shah is a student of Bachelor of Arts (Honours) majoring in Psychology at Ahmedabad University, with a growing interest in how science, whether about the mind or the climate, shapes our everyday lives. While her academic work focuses on human behaviour, she’s equally drawn to the invisible systems that shape our environment. Her passion for science communication comes from a belief that translating complex research into clear, relatable stories is not just valuable, but essential, both for understanding the world and making informed choices.

Aditya Vaishya is an Assistant Professor at the School of Arts and Sciences at Ahmedabad University. He is an Atmospheric Physicist and is leading the ‘Air and Water vertical’ of the Climate Institute, and heads the ‘Air and Climate Research Laboratory’ at Ahmedabad University. His research group is working on the characterisation of regional air quality using a low-cost sensor network, integrating in situ and remote sensing measurements using Machine Learning, air quality modelling, and climate change. He teaches courses in core areas of physics, air quality, atmospheric physics, and climate. He obtained his PhD from the Centre for Climate & Air Pollution Studies and the School of Physics, National University of Ireland Galway.

Cracking the Case with Comets

How DNA's 'Tail' Tells the Tale in Forensics

Writer and Illustrator ***Vedika Tiwari*** **|** *Science Mentor* **Ritesh Shukla**

On a humid night in August in Lucknow, 22-year-old Riya was found lying on the floor unconscious in an abandoned guest house close to the old city bazaar. Investigators were shocked by the discovery, and what annoyed them even more was a disturbing detail: a possible sexual assault and no eyewitnesses. This time, since deposition (TSD) of bodily fluids such as semen is often a crucial feature of whether or not a suspect can be confirmed or ruled out in many assault cases. However, determining that "when" has always been difficult for forensic scientists. Postmortem bodily changes (rigour mortis, algor mortis, livor mortis) and fluid degradation are traditionally used to determine the time of death, but such methods are very sensitive to environmental factors, clothing, and sample conditions.

The Time-Of-Crime Puzzle

A forensic expert, Dr. Meera Joshi, was in charge of the case. She told the police, 'This isn't about who but about when.' In these cases, the time since deposition (TSD) of bodily fluids such as semen is important in confirming or excluding suspects. The cooling rate of the body after death (algor mortis) varies with the environment's temperature- cooler environments speed up algor mortis, while hotter environments slow it down. Rigour mortis, the stiffening of muscles post-death, is hastened by heat and prolonged by cold and body size. Thin bodies stiffen faster in comparison to heavy bodies. There are challenges with estimating time since deposition (TSD) of biological fluids due to heat (Oxidative DNA damage or single-strand breaks), humidity, and sunlight (microbial growth or UV degradation), and substrate or clothing (porous fabric vs. nonporous glass; synthetics degrade fluids faster). The rate of change for all of these factors is not linear or uniform, and therefore, their reliability as forensic evidence is limited.

No witness, no suspect- This case looked difficult to approach at first glance. But then a crucial piece of evidence—a semen stain on Riya's clothing—was collected from the scene.

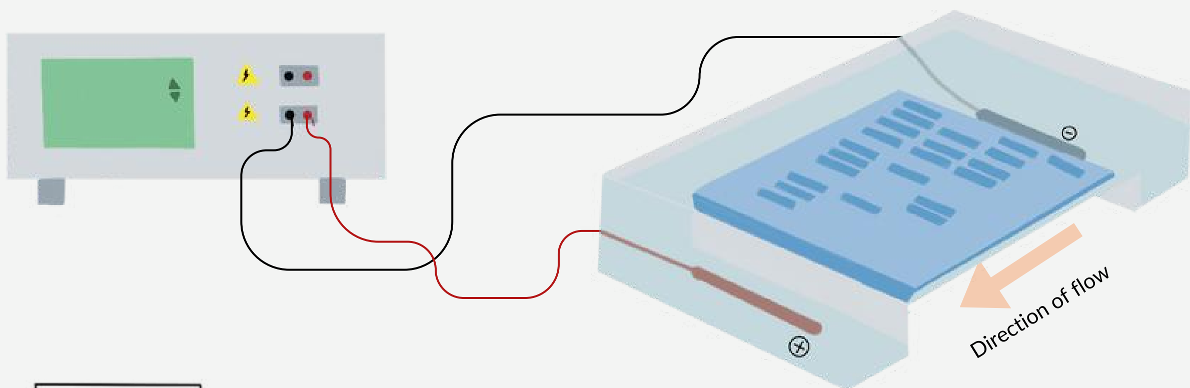
DNA is like a ladder filled with information encapsulated inside each cell. Our bodies keep our DNA in check constantly through a DNA repair mechanism, which ensures that no abnormal mutation is passed onto other cells in the body. However, once cells leave the body—or once we all die— that repair system ceases. This is when the degradation clock starts to tick.

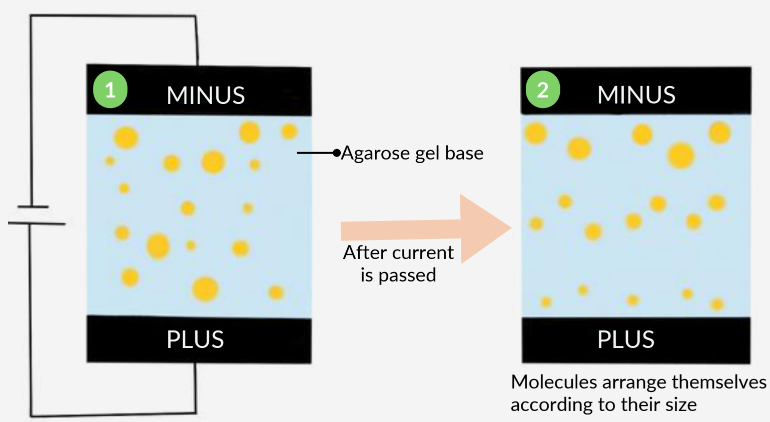
DNA: The Body's Molecular Clock

The rate at which the DNA breaks down depends on how long the DNA has been outside the body. By studying that degradation, scientists can, in turn, estimate how long the sample has been sitting there. The Comet assay, a forensic tool by which we can see and quantify this breakdown, can be a good tool for investigating such cases. This technique has unique aspects where single-cell gel electrophoresis is used; individual cells from the sample are embedded into a thin agarose gel on a slide, lysed, releasing their DNA, and placed under an electric field. Under the microscope, damaged DNA fragments migrate further through the gel and form a 'comet' like shape — a bright head with a trailing tail. At the lab, a semen sample was isolated from Riya's clothing carefully. A technician in gloves and sterile tools prepared the sample for the Comet assay - a procedure that makes DNA damage suddenly, in some ways, visible under a microscope, and now, under a microscope, can estimate how long ago the damage occurred to some accuracy.

Gel Electrophoresis

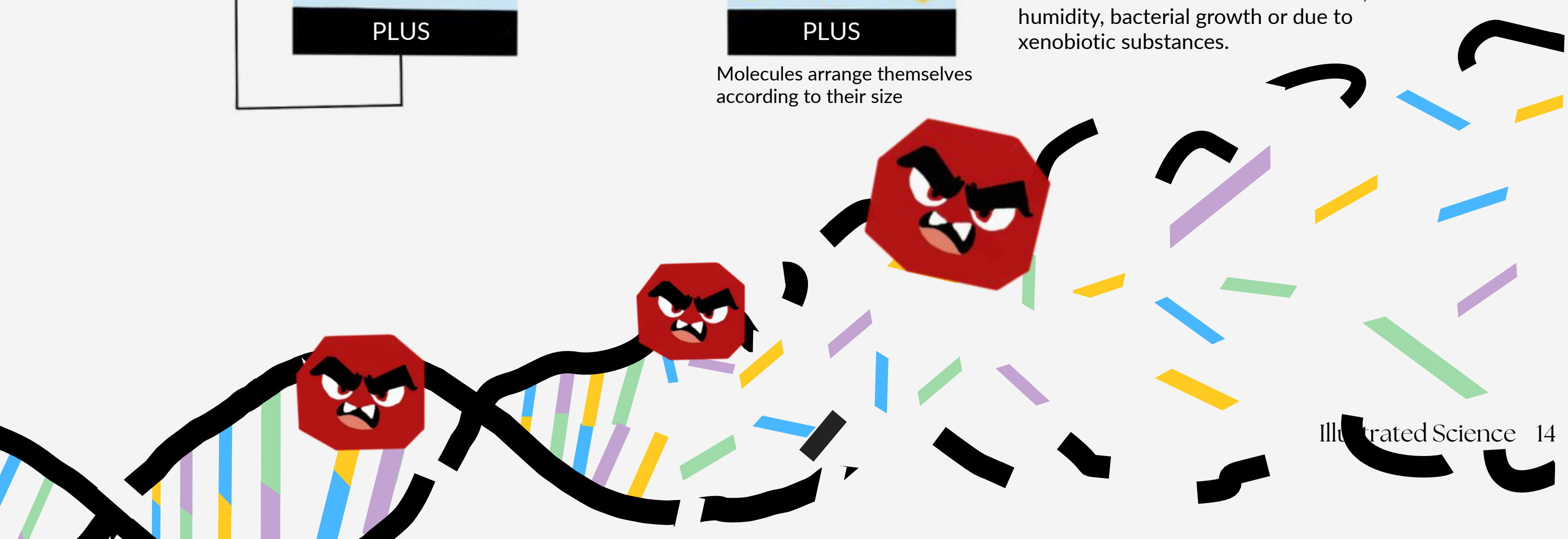
Electrophoresis is a laboratory technique where charged particles, such as DNA, RNA, or protein, are separated using an electric field applied across the gel matrix. Agarose gel is used for this specific technique. The molecules themselves differ in their migration rate through the gel's pores, depending on how big or charged the molecule is. This enables one to analyse and compare molecular components in a sample precisely. When performed at the single cellular level, the electrophoresis technique called single cell gel electrophoresis, commonly known as the Comet assay, detects DNA damage at the level of individual cells, thus contributing towards high-sensitivity applications in genotoxicity testing, clinical diagnostics, and forensics, where cell-specific alterations need to be interpreted. This technique can help provide some answers to forensic investigations in cases of sexual assault.





1 **Xenobiotic Substances**
Chemical substances that are foreign to living organisms (for example: drugs, pesticides, pollutants, food additives).

2 **DNA Degradations** refers to the breakdown of DNA molecules into smaller single or double strand breaks , due to environmental factor like heat, humidity, bacterial growth or due to xenobiotic substances.

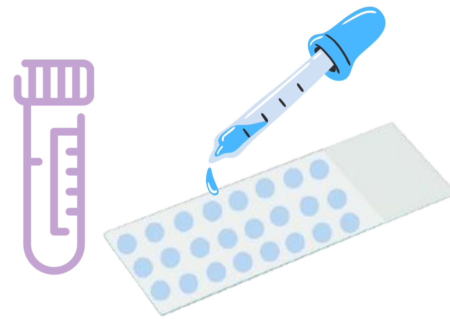


From the Scene to the Slide- Inside the Comet Assay

1

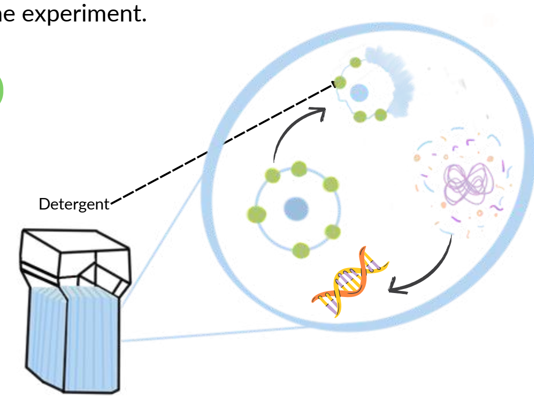
Spermatozoa (Sperm) cells are extracted from dried cloth by soaking the cloth at 37°C for 5 minutes. It is then washed with 200 µl of Phosphate Buffer Saline(PBS). The cells are then collected through centrifugation and resuspended in 1 ml PBS. This suspension is then mixed with 0.7% Agarose to finally prepare the sample for the experiment.

2



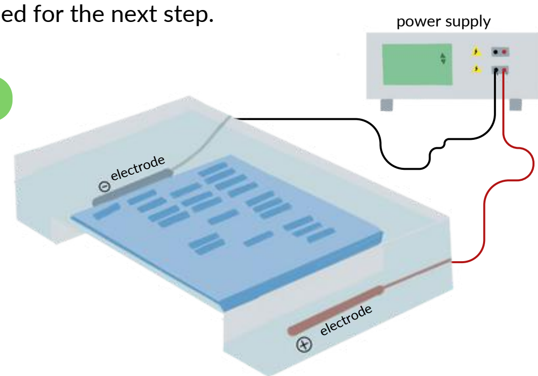
A base slide is pre-coated with 0.7% agarose. The cells prepared in the previous step are placed on the pre-coated slide, then covered with a cover slip to basically sandwich them between layers of agarose. The slide is left at room temperature (5 minutes, or 1 minute if placed on ice), and gently removed to be used for the next step.

3



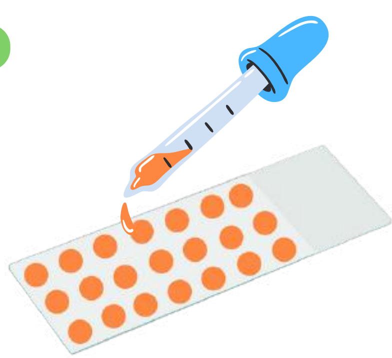
The cover slides are removed, and the cells are placed in a lysis solution for cell lysis. Chemicals (Known as detergents) in the lysis solution help break the cell membrane to release DNA.

4



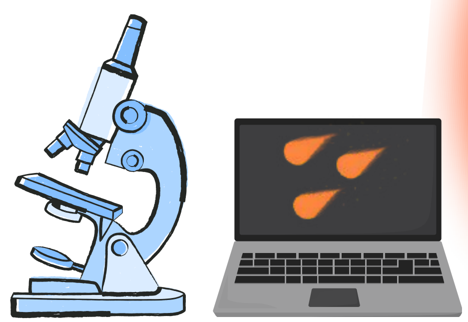
Electrophoresis is performed to cause DNA strands to unwind. The DNA particles start moving because of the electrostatic force created by the electromagnetic field inside the electrophoresis tank.

5



The cells are neutralised using a Tris buffer after electrophoresis. The DNA strand near the anode (positive electrode) is stained with DNA-binding Dye (Ethidium Bromide) to make sure they are visible under a fluorescent microscope.

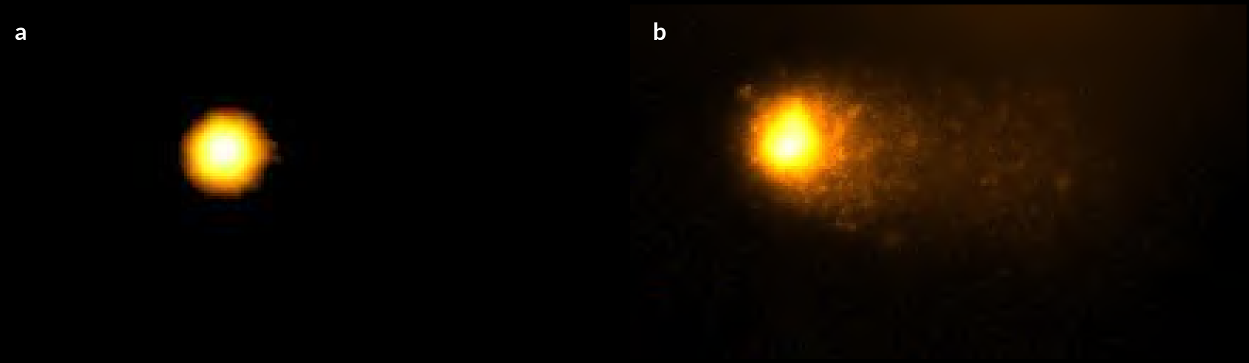
6



The slides are scored using an image analysis system attached to a microscope equipped with a fluorescence attachment. The microscope is connected to a computer which has the analysis software.

How to Tell Time from a Tail

Dr. Joshi looked at the sample under the high-powered microscope, and she saw dozens of comets. But she wasn't just seeing stars under the microscope, she was observing timelines of what happened at the crime scene.



Two major factors are observed in the final assay:

Tail Length: It is the length of migration of DNA particles from their nuclear core.. The tail length is directly proportional to the amount of damage to the DNA. The longer the tail is, the older the damage is.

Tail Intensity: It is the percentage of total DNA present in the tail of migrated DNA. The brighter the tail appears under the microscope, the greater the number of broken fragments of DNA**.**

Comet Assay helps study DNA damage at a single-cell level. One sample has several such comets. 100 comets from the total sample are chosen at random to calculate the Tail Moment, which is a product of tail length and tail intensity. This figure helps calculate the total amount of DNA Degradation. Dr Joshi compared the comets from Riya's case (b) against known reference samples at different time periods (a). The control DNA (a) has an intact, bright head with no visible tail. This indicates that the DNA is intact, with no damage. The comet generated from the semen sample collected from Riya's clothes (b) displays a bright head with a visible tail. There is a transparent migration of DNA particles in the second sample (b), indicating DNA damage. In this case, the window of utmost importance was 18 to 24 hours after being deposited. This timeline allowed the police to eliminate one of the suspects, Riya's ex-boyfriend, with whom she had been for the past two days.

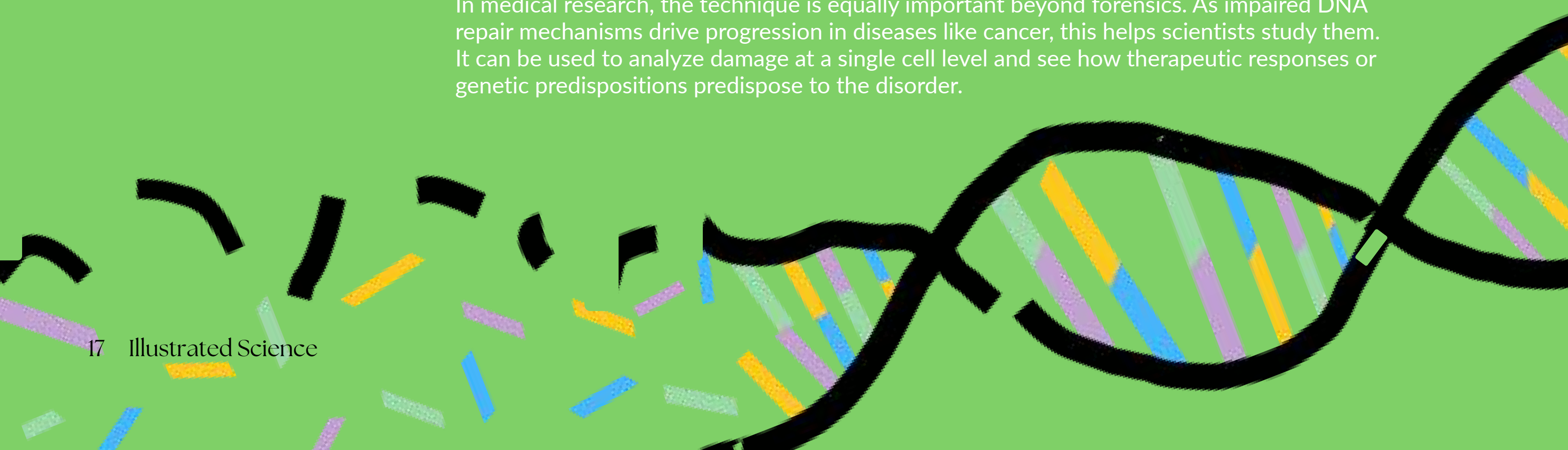
Why the Comet Assay Matters

The Comet assay is excellent at detecting minute amounts of DNA damage, even at the single-cell level. This provides precision for recognising fine cracks in bio specimens that more classical apparatuses could overlook, which can be of higher significance for procedures of occurrence and perversion evidence. The implementation of this technique is as flexible in its use as it is with diverse biological materials, including blood, saliva, semen, and hair follicles. The assay gives consistent, reliable results regardless of sample type, whether a bloodstain on a crime scene or a saliva sample in a lab. Unlike most of the more advanced genomic tools, which require expensive equipment to run and large specialised facilities, the Comet assay costs nothing more than a typical agarose gel, a basic electrophoresis setup, and a standard fluorescence microscope. This would enable even smaller labs to participate in forensic and biomedical research.

Comet Assay in Real World

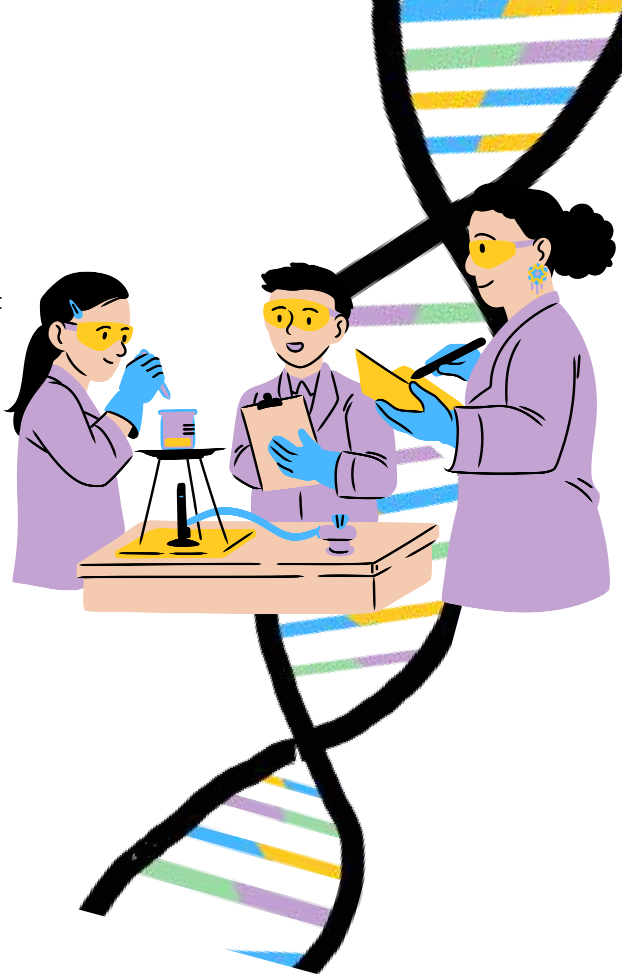
The Comet assay gives forensic teams a scientific method to estimate the time since semen deposition, one of the most important elements for verifying the time periods reported by victims and targeting possible suspects. It quantifies how much DNA degradation has resulted, and allows legal argument about when an assault occurred. It could be revolutionary for forensic science. It is a molecular clock to crime scenes beyond physical evidence. It either validates alibis by proving the age of biological traces or exposes the inconsistencies between the degradation patterns of DNA and the described timeline.

In medical research, the technique is equally important beyond forensics. As impaired DNA repair mechanisms drive progression in diseases like cancer, this helps scientists study them. It can be used to analyze damage at a single cell level and see how therapeutic responses or genetic predispositions predispose to the disorder.



Future Prospects of The Comet Assay

The Comet assay stands poised to become an even more powerful tool in forensic investigations, especially in complex cases like Riya's. With its current strengths- sensitivity, versatility, and cost-effectiveness- it has already transformed how forensic timelines are constructed, and there remain key areas for advancement. Standardising DNA degradation models for different tissues and environmental conditions could greatly improve the precision of TSD estimates. This is particularly relevant in cases like Riya's, where environmental factors and the type of biological fluid can influence.



Additionally, expanding the assay's use in environmental and clinical forensics will help validate its reliability and uncover new applications, while standardised protocols and ethical guidelines will ensure data integrity and privacy. As research continues, the Comet assay's "molecular clock" may soon become a routine part of forensic toolkits, which is what Professor Shukla has tried to facilitate with his paper.

Disclaimer: The case of Riya described in this article is entirely hypothetical and intended solely as an educational tool to illustrate the forensic concepts discussed. Any resemblance to real persons, living or dead, or actual events is purely coincidental. This scenario was created to facilitate understanding and does not depict any real incident or individual.

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Vedika Tiwari is a student of Bachelor of Arts (Honours) Psychology at Ahmedabad University. She has always been interested in true crime, forensic science, and art. The mysteries and untold stories a crime scene holds have greatly intrigued her for the longest time. This project was the perfect opportunity for her to explore her various domains of interest.

Ritest Shukla is an Associate Professor at the School of Arts and Sciences at Ahmedabad University. His research interests include Forensic Nanobiotechnology, Toxicology (Nanotoxicology), DNA Forensics, Food Forensics, and Point Of Care/Detection Diagnostic Devices. Stanford University featured him in the World's Top 2% Scientists in 2022. He has co-authored over 40 research articles in International peer-reviewed journals and 20 book chapters.

To Shoal Or Not To Shoal

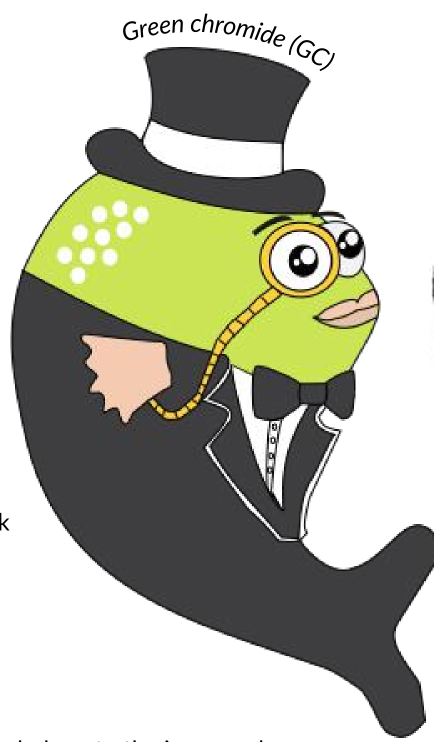
How Green chromides group and why it matters

Writer and Illustrator **Vyomini Devadiga** | *Science Mentors* **Chena Desai and Ratna Ghosal**

The company a young fish keeps in high society can be a matter of utmost importance. Dare it be said, it might as well be a matter of life and death. Meet Finley Green, a young, respected green chromide from the distinguished waters of the River Hoogly. Finley, like other juvenile green chromides and most fish, must find the group that matches a criteria fit of its status. Mr. Finley has graciously allowed us to tail him and his peers as we observe who he so chooses to shoal with. Young, noble green chromides like him are, of course, willing to make compromises if the circumstances are dire, but there are still preferences they must adhere to. A fish, as distinguished, is never desperate. A proper shoal comprises the right members. To understand, from an outsider's perspective, how the green chromides determine who they keep company with, tests have been conducted, the results of which are detailed in the following pages.

Introducing the cast

Ah, but lest we get ahead of ourselves, a proper introduction is just simple courtesy. Known perhaps more commonly as the *karimeen*, Mr. Finley and his species (*Etroplus suratensis*) are quite popular as food fish across several Asian countries, making them highly economically valuable. Green chromides happen to be the only species of their genus that are as widely abundant, as well as the only one that inhabits India, making their presence quite crucial for maintaining ecological biodiversity in our waters.



Fellow member of the subfamily Etroplinae, the orange chromide (*Pseudetroplus maculatus*) is another species that frequents the same waters; they happen to be close family. However, even on home waters, there are nemeses to speak of. Enter: Tilapia, distant international cousins of the green chromides, one of many invasive foreign species introduced to Indian waters, and one of the greater adversaries of the chromides, notorious as they are for their aggression and territorial behaviour. Put delicately: brutes.

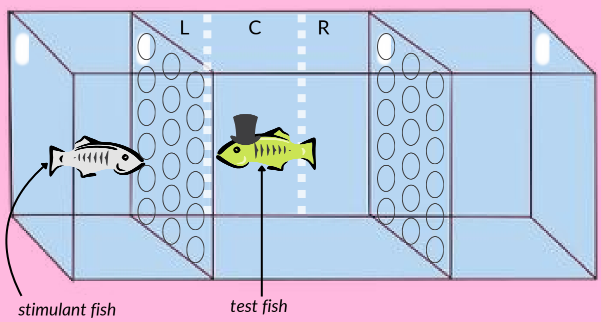
Despite their differences, all three of these esteemed species belong to the immensely prominent Cichlidae family, which, in spite of their prominence across the globe, remains quite mysterious and little-studied, the Green chromide especially so, at least in regards to who they keep company and why. Their complex cognitive abilities and social dynamics are a matter of great intrigue and fascination, since not only can cichlids quite accurately perceive group and body size, exhibiting calculated preferences for shoaling based on them, they can also identify others on an individual level, using a variety of visual, auditory, vibrational and olfactory cues.

Green chromides are quite accommodating in that they can occupy both fresh and brackish waters, and are primarily found in the freshwaters and estuaries along the East and West coasts of India. Mr. Finley and the fellow volunteers for this experiment come from the Hooghly River in West Bengal, while the tilapia participants originate from the Sabarmati River in Ahmedabad.

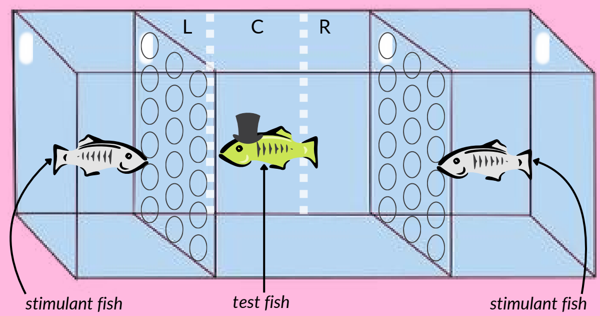
Setting the Stage

Now that the characters are in place, it is time to set the stage. Bring in the fish tanks! Each fish tank is divided into three chambers using perforated plexiglass. We will be observing the behaviour of the green chromide (GC) in the central chamber, donning the top hat, one of our many volunteering test fish. (Please take note that every iteration of this experiment will have a different test GC volunteer.)

One-choice setup



Two-choice setup

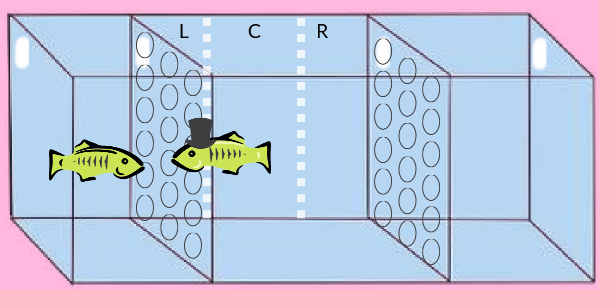


At first, the test GC will be placed in the centre (C), between the dotted white lines. Stimulus fish may be placed in one or both side chambers of the fish tank. If only one side chamber is occupied, the setup is referred to as one-choice, whereas if both are occupied, the tank is said to be in a two-choice setup. The test fish may show grouping preference by moving into either the L(eft) or R(ight) zone, or it may simply not move at all, remaining neutral.

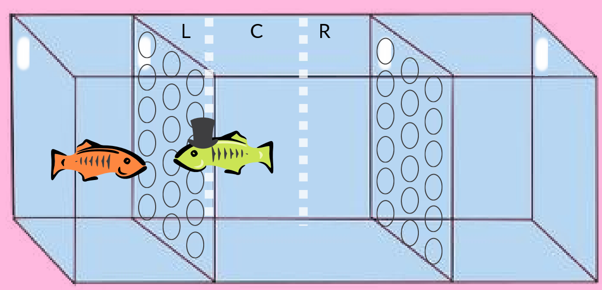
There are three criteria that Mr. Finley and his fellow green chromides consider: species, body size and group size.

Species-based Grouping

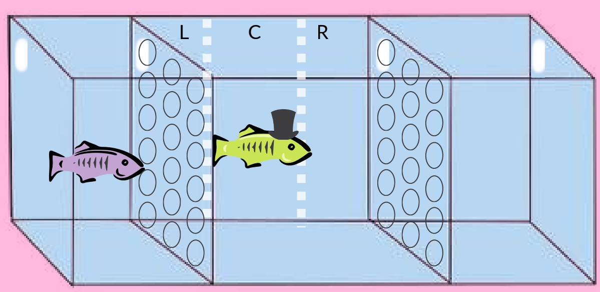
First, the simpler test. Do Green chromides prefer **conspecific organisms** (an organism of their own species) or **heterospecific organisms** (an organism from another species)? Additionally, do GC group with fish outside of their species, and does the degree of closeness in relation by species play a role in the decision?



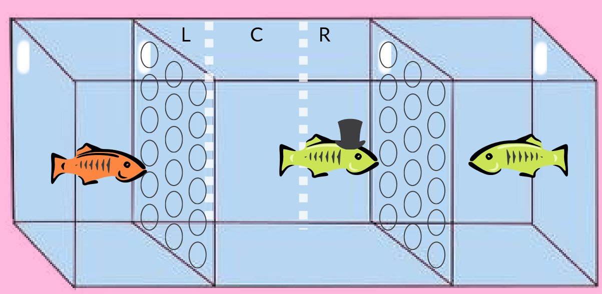
Ding ding ding! The test GC moves towards the green chromide!



The test GC may also move towards the orange chromide!



The test GC remains neutral, proving that among heterospecific organisms, closely-related species are more likely to be chosen.



Phew! Between the GC and the OC, the test GC chooses a fellow green chromide. The conspecifics wins after all!

Closely-related species likely benefit from grouping with each other since they need similar resources and defence against similar predators, as seen also in zebra fish and guppies. However, it can also make for fierce interindividual competition. Since conspecific grouping is preferred, the benefits must *outweigh* the cost. For a behaviour or trait to help an organism adapt, the benefits it creates must outweigh the costs it causes. This is called the **cost-benefit ratio.**

Why Green chromides choose conspecifics...or choose at all

The meaning of life is legacy.

The seemingly human need to be remembered is neither unfounded nor sudden. It is as ancient as life itself. In the animal world, all organisms strive ultimately for a single goal: to pass on their DNA to the future generation of their offspring. This is the basis of the **Ultimate Cause**–the reason why organisms do everything they do. Survival, in order to reproduce and reproduction, in order to prolong their genetic legacy.

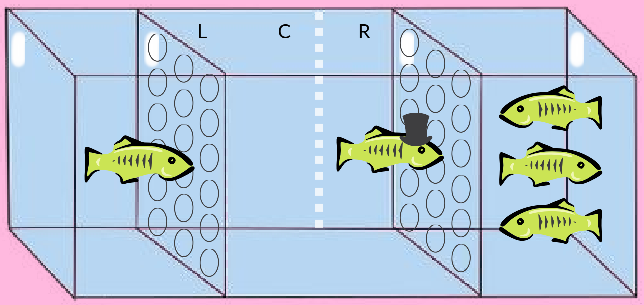
Being in proximity to your own species is a cornerstone of both survival and reproduction, especially for organisms that are at risk of predation. In the case of reproduction, choosing conspecifics becomes infinitely more vital. Offspring resulting from heterospecific parents tend to be sterile, which defeats the Ultimate Cause completely. Although reproduction matters little here, since the study that observes Mr. Finley and his friends specifically pertains to sexually immature fish, it can be estimated that when they mature, likelihood of mating with conspecific organisms increases if they have been grouping with them since they were young.

The primary driving force of preferential grouping in sexually immature green chromides is survival, and this motive is evident in their choices. Grouping can majorly influence predation risk and resource gleaning, which are crucial aspects that the survival of sexually immature green chromides like Mr. Finley heavily depend upon.

Group Size-based Grouping

As observed, green chromides prefer large groups of conspecifics. It was seen that between the options of a group size of one and two, the preference was not significantly biased. However, in choices with a bigger difference in group size, larger groups were preferred.

Forming large groups is a common anti-predator strategy in many prey species. Groups like these are usually amongst conspecific organisms, which greatly helps reduce the **oddity effect**; the less the individual stands out, the less likely it is to catch the predator's eye.

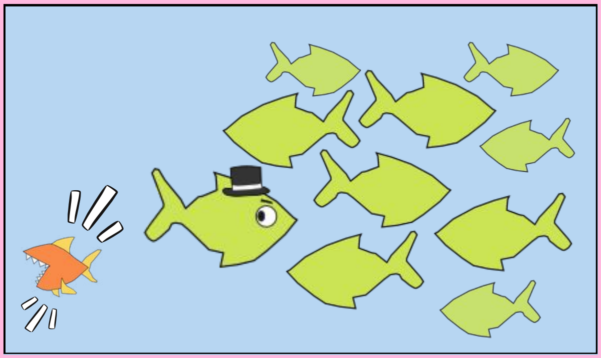


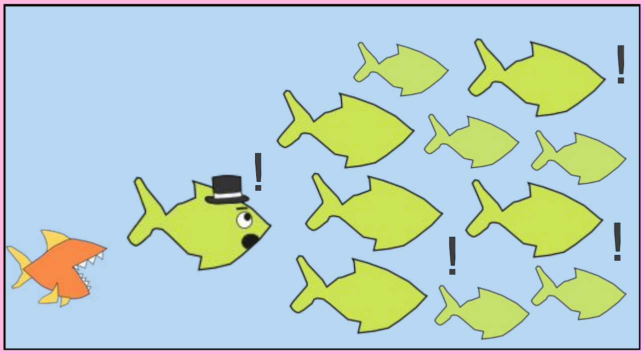
The test fish moves to the right, demonstrating green chromides tend to join groups of larger size.

Grouping like so can be even more beneficial for fish that move across ecosystems – like green chromides often do between freshwater and brackish environments – since shoals can be especially vulnerable to predation in relatively different conditions. Several popular hypotheses explain how large groups can protect prey species from being eaten, of which the Many Eyes hypothesis, the Dilution Effect and the Confusion Effect are detailed here!

Many Eyes Hypothesis

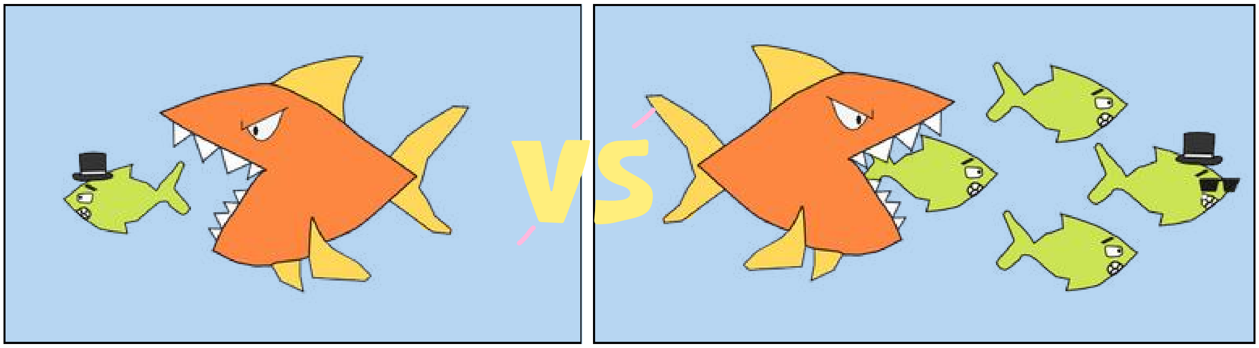
In a group, if even one individual is alerted to the presence of a predator, it can go on to alert the rest of the group, increasing the likelihood of the shoal to escape. This is the basis of the **Many Eyes Hypothesis**.



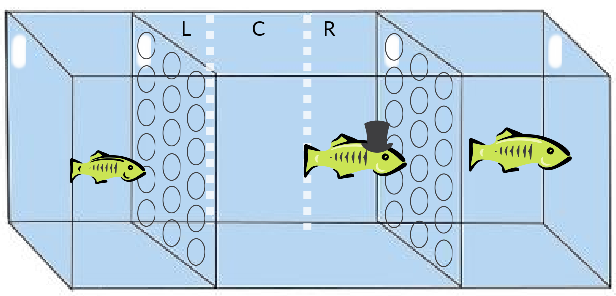


Dilution effect

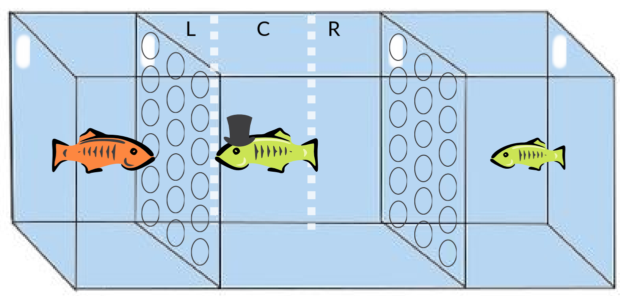
If a predator does begin to chase, an individual is more likely to escape if part of a group than alone – this is called **the Dilution Effect.** The **Confusion Effect**, where predator fish may experience perceptual confusion when they see many similar-looking fish at the same time, which may slow the attack enough to allow for the group to escape!



Body size-based grouping

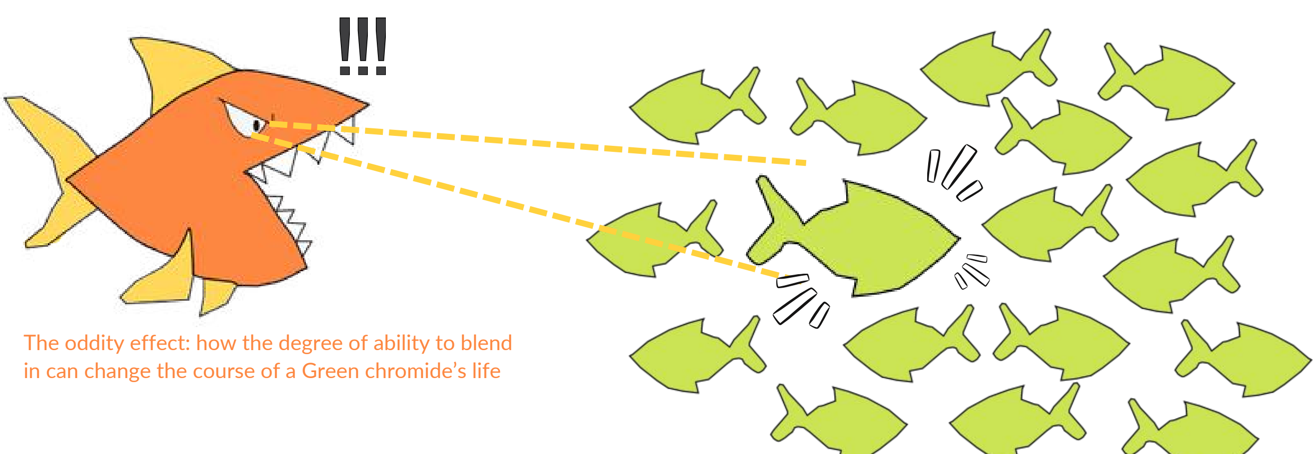


Between the choice of a smaller GC than itself and a GC of similar size, the test GC chooses a fish of **similar size**.



Exceptionally, in a setup between an orange chromide and a small GC, no significant preference was seen towards the smaller green chromide. Body size trumps conspecifics!

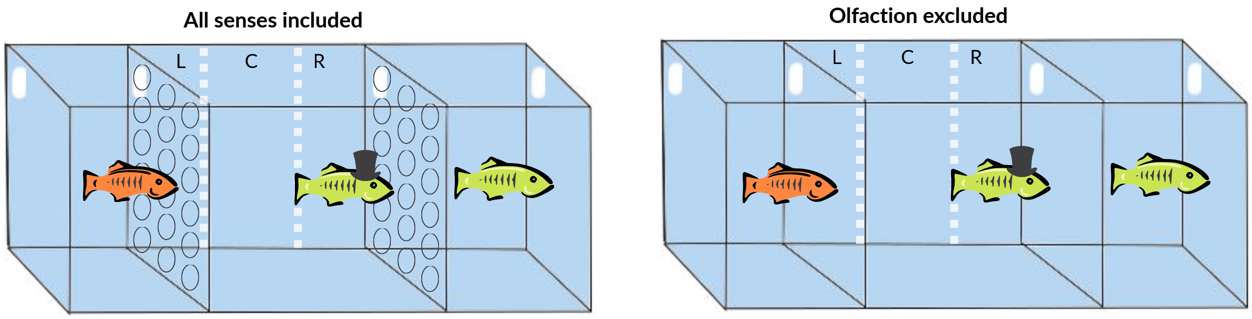
The oddity effect plays a major role in how body size affects grouping choice: being too large or too small in a group can make the individual more visible to predators. In fact, body size can even affect species-based preference – as seen in the illustration, green chromides show **no significant preference** towards conspecifics if they were of smaller size! Notably, body size is an indicator of age, and grouping with conspecifics of similar age can be very beneficial. If all your peers are in the same developmental stage as you, you have similar physiological and ecological needs, which can be fulfilled while also keeping predators away. Being of similar size can also assist in better coordination when moving against currents and between the different environments the green chromides traverse and explore. Of course, this kind of grouping can increase competition between the group, but the benefits largely outweigh the costs.



The oddity effect: how the degree of ability to blend in can change the course of a Green chromide's life

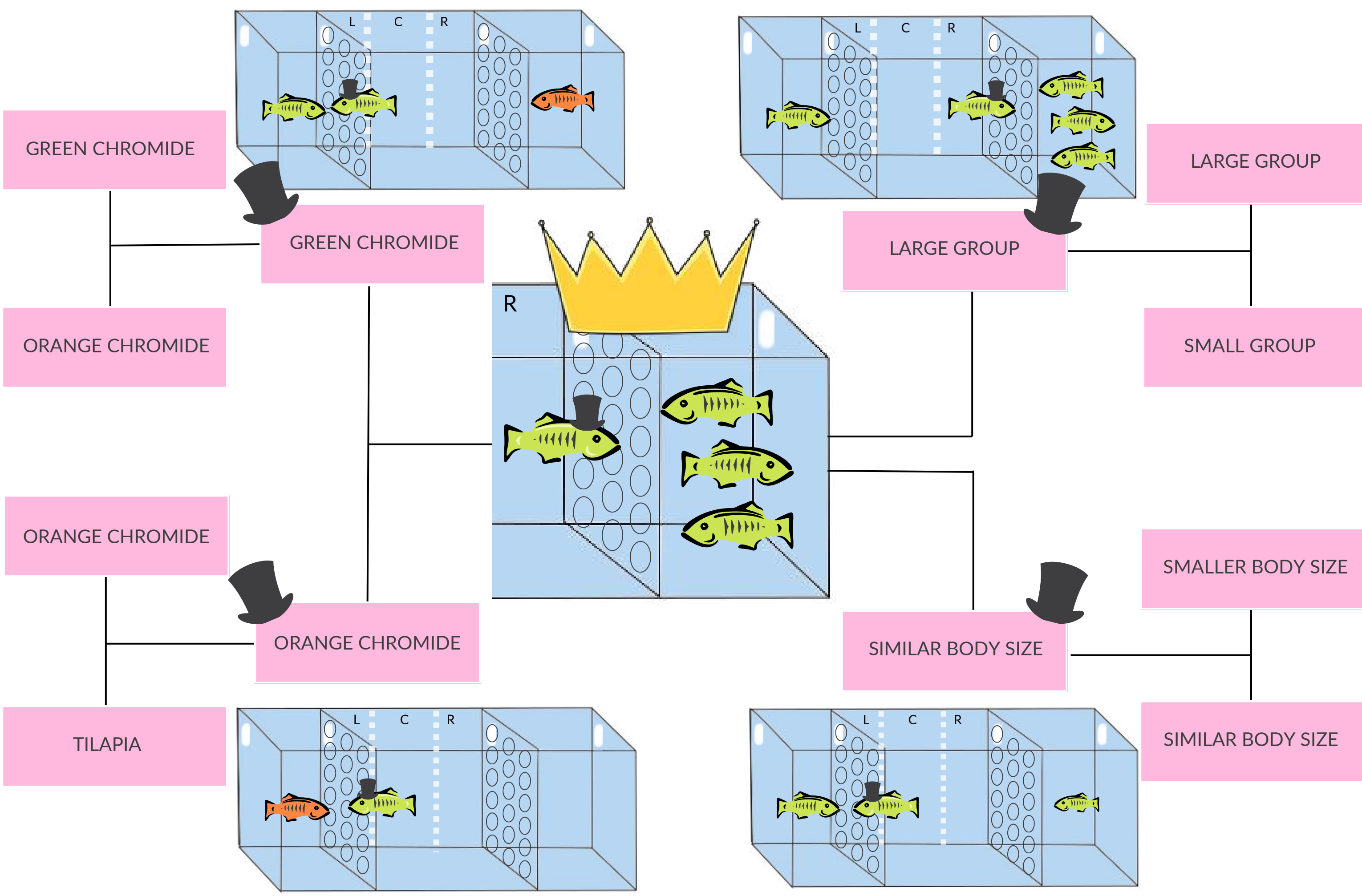
Seeing or smelling?

We can already see that Green chromides are very adept at recognising fish. But how do they do it? To determine whether Green chromides recognise each other by vision or smell, two fish tanks are compared, where we compare our regular setup with OC and GC with one that uses plexiglass that is not perforated so there is no water exchange, preventing the test GC from using its sense of smell for the stimulant fish in either chamber. The results remain the same: both the test fish move towards the GC, as observed initially, meaning that GC recognise other fish using vision.



Green chromide Grouping League

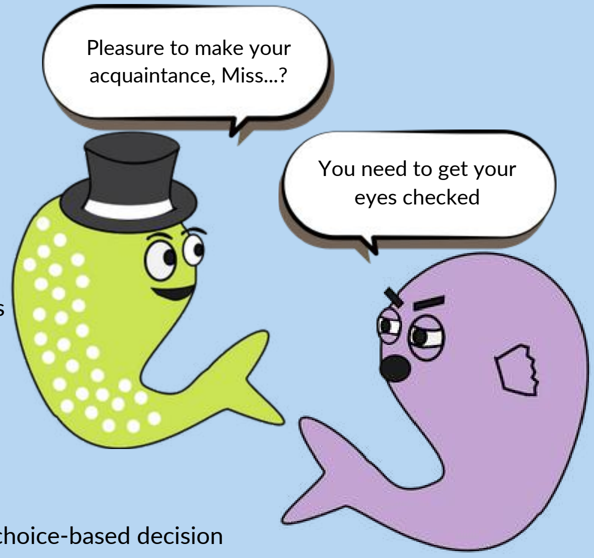
What is the group of every Green chromide's dreams?



The future of shoaling...and how humans may be sabotaging it

It has been established that grouping in the green chromides is not just crucial; their survival depends on it. Green chromides, using visual cues, look for large groups of other conspecific green chromides of similar body size to themselves. However, what happens if their vision is obstructed? With increasing pollution of water bodies, as the water becomes progressively more turbid, the local green chromides may not be able to see too properly, and may not be able to actually view who they surround themselves with, making themselves very vulnerable not just to the aggression of tilapia, but even more life-threateningly to the risk of predation.

The life and (well-informed) decisions of green chromides like Mr. Finley may seem rather inconsequential in the grand scheme of human priorities, but if green chromides were to become endangered or extinct, it would be incredibly detrimental to the biodiversity of many of our waterbodies, especially since green chromides are the only representative species of their genus in India. Every species has a role to play in the vast biome of our world; aquatic biodiversity makes our rivers, our lakes, our estuaries *resilient*, especially against the trials that industrialisation incur. And since industrialisation is caused by us and benefits us alone, it falls into our hands to rejuvenate the world around us of the damage we have caused, the repercussions of which they suffer from simply by existing.



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Vyomini Devadiga is a student of Integrated Master of Science at Ahmedabad University. A literature fiend at heart, Vyomini strives to find a place in biology and the sciences for creative writing to shine. In the future, Vyomini hopes to study behavioural sciences involving the dynamics individual to and interconnecting the human and the animal world.

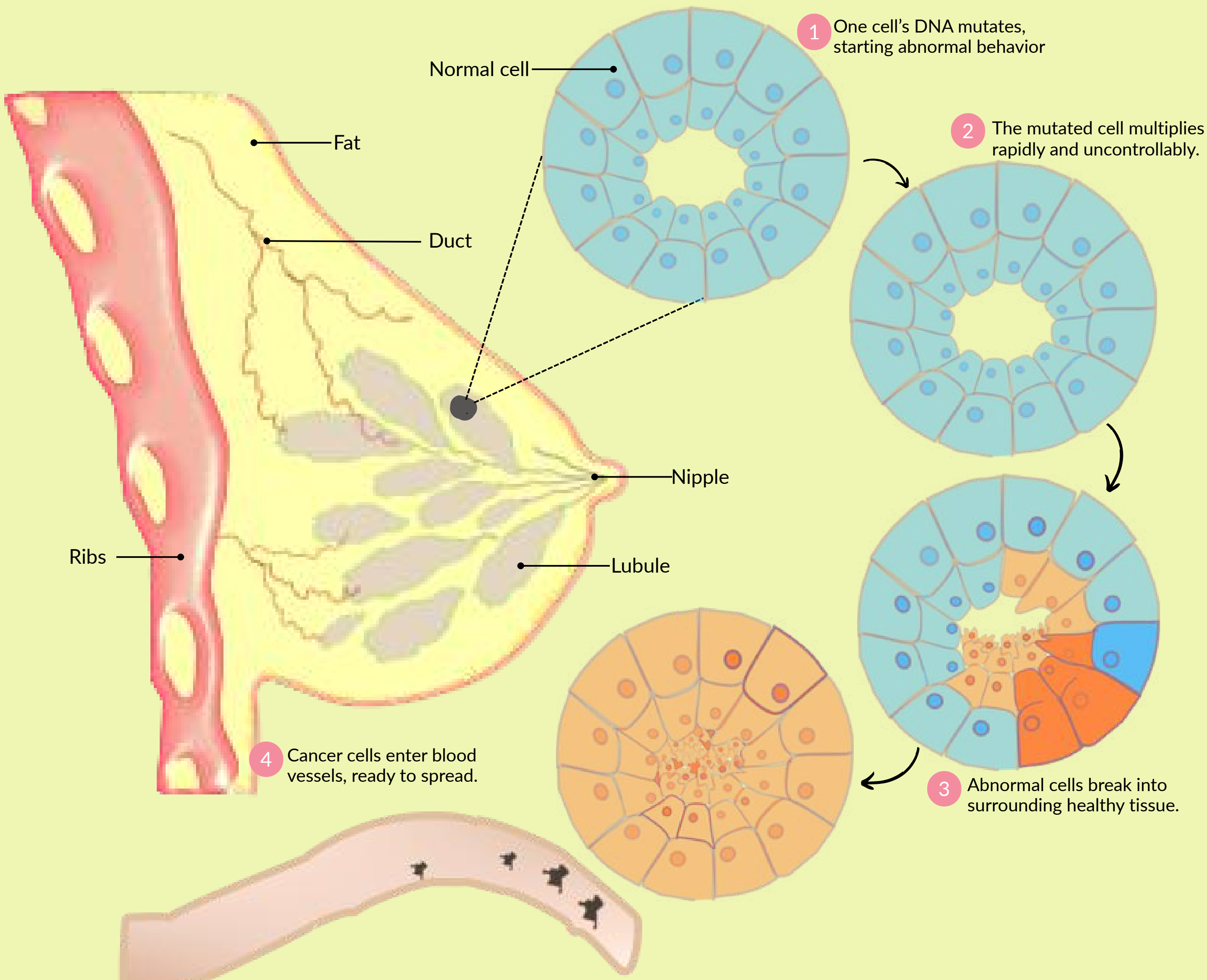
Ratna Ghosal is an Associate Professor at the School of Arts and Sciences, Ahmedabad University. She has a PhD in Ecology from the Indian Institute of Science, Centre for Ecological Sciences, India, and did her BSc and MSc in Zoology from the University of Calcutta, India. With extensive experience as a Research Associate and Post Doctorate Fellow at the University of Minnesota, Dept of Fisheries, Wildlife and Conservation Biology, she is an esteemed researcher and professor in her field.

Chena Desai is a PhD Candidate at the Ecology and Environment Lab at the School of Arts and Sciences, Ahmedabad University, since 2020, studying the causal relationship between environmental stimuli and ecological processes using green chromides (*Etroplus suratensis)*. Ms. Desai completed an Integrated Master of Science at Ahmedabad University and was also working under the Ecology and Environment lab as an Integrated Master's student in 2019.

The Future of Breast Cancer Treatment

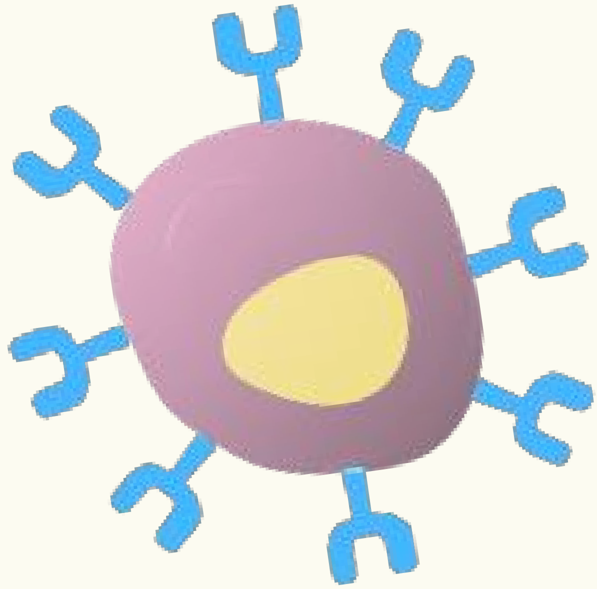
Writer and Illustrator **Vaishnavi Dahihande** | *Science Mentor* **Ashutosh Kumar**

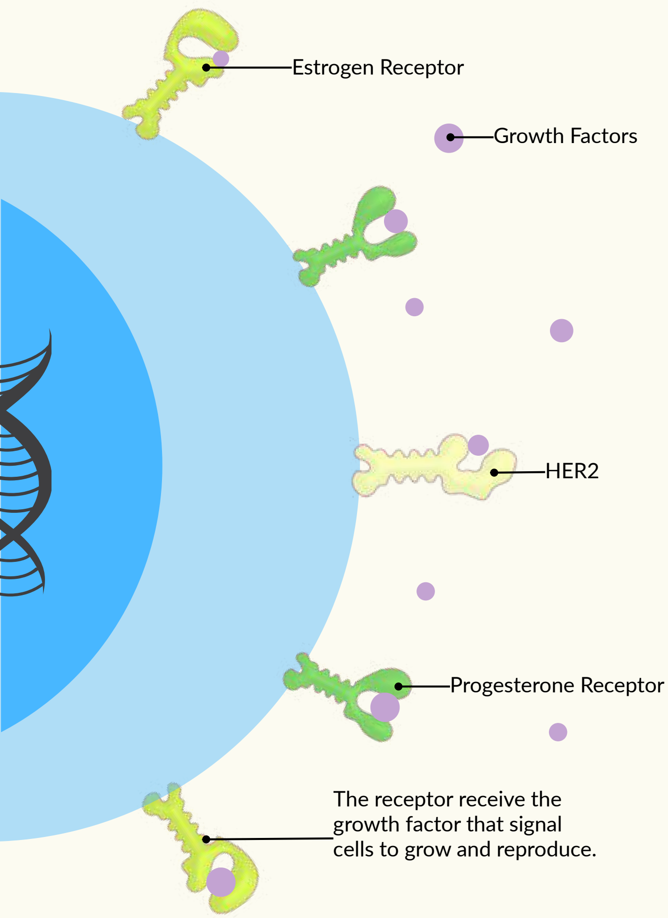
How Breast Cancer Affects Millions? Breast Cancer is one of the most common types, affecting millions of people worldwide. In 2022, there were 2.3 million women diagnosed with breast cancer and 670,000 deaths globally. Breast cancer predominantly affects women, accounting for ~99% of cases, with 0.5–1% occurring in men. Think of breast cancer like weeds growing in a garden. Normally, plants grow more or less in an organized way, each staying in its own space. But sometimes, a few weeds start growing uncontrollably. At first, they might seem harmless, but soon, they spread, taking up space, stealing nutrients, and crowding out healthy plants, and they become quite problematic. If left unchecked, the weeds can spread to other parts of the garden, making it harder to control.
This happens in our body when some cells stop following normal growth rules and keep multiplying. These extra cells form a lump, or tumor, that can invade nearby tissues.



Role of Receptors or Biomarkers in Breast Cancer

In a healthy breast cell, receptors are like antennae or tiny message receivers sitting on the cell's surface. They wait for specific signals—like hormones or growth factors—to bind to them. These signals tell the cell what to do, such as when to grow, divide, or repair. This helps the cell function normally and stay in balance. These receptors help doctors classify the breast cancer subtype, which guides treatment decisions. When a person is diagnosed with breast cancer, doctors run tests to see which receptors are present on the tumor cells. These tests are like looking for clues to figure out what's fueling the cancer.





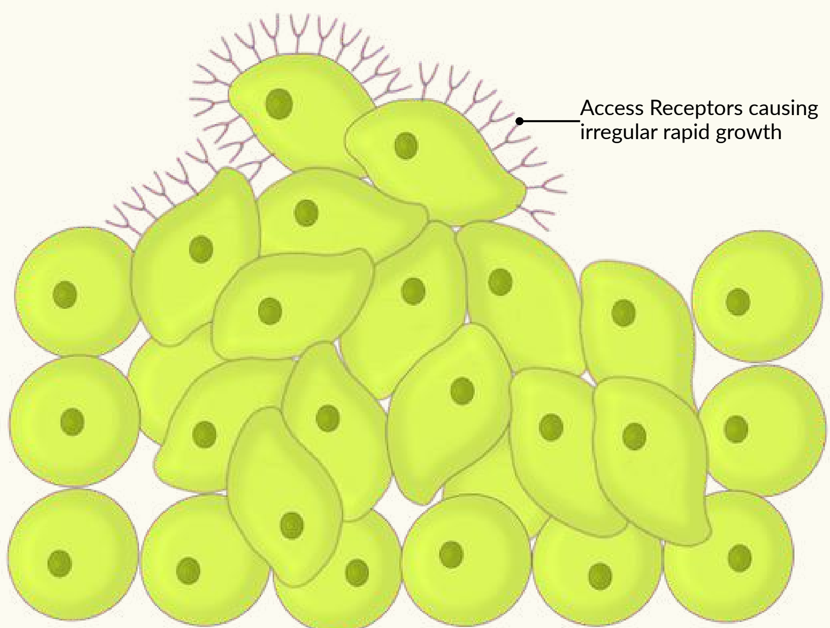
Type of Breast Cancer Receptors

1. Estrogen Receptor (ER) & Progesterone Receptor (PR) – Some breast cancer cells depend on hormones like estrogen and progesterone to grow. If a cancer has ER or PR receptors, doctors can block these hormones with hormone therapy to stop the cancer.

2. HER2 (Human Epidermal Growth Factor Receptor 2) – Some breast cancers produce too much HER2, making them grow and spread faster. If a cancer is HER2-positive, doctors use targeted therapy to block HER2, stopping the tumor from growing.

3. Triple-Negative Breast Cancer (TNBC) – Triple-negative breast cancer lacks ER, PR, and HER2 receptors. This means they cannot be treated with hormone therapy or HER2-targeted drugs. Instead, doctors rely on chemotherapy, immunotherapy, and new experimental treatments.

Growth supported by Receptors

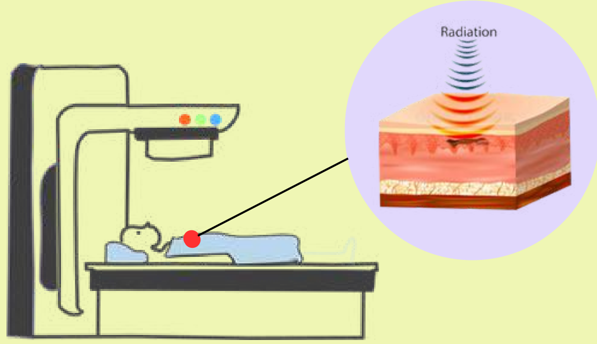


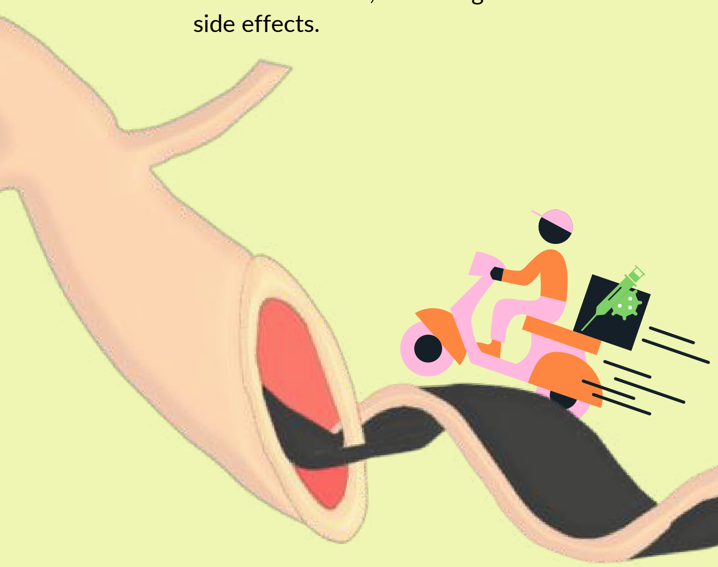
Unlike normal cells, cancer cells don't follow the usual rules. They often have more receptors on their surface, or their receptors are extra sensitive. These receptors pick up messages from the body that tell cells when to grow. Because cancer cells react too strongly, they keep growing even when they should stop. Over time, this leads to a large group of cells piling up, which forms a tumor.

The Old Weapons: How We have Been Fighting Cancer for Decades

For a long time, breast cancer has been treated with surgery, chemotherapy, radiation, and hormone therapy. While these treatments have saved lives, they come with major challenges. Surgery removes the tumor, either through a lumpectomy (removing only the lump) or a mastectomy (removing the whole breast). However, if any cancer cells remain, the disease can return, and losing a breast can be emotionally difficult. Chemotherapy uses strong drugs to kill cancer cells, but it also harms healthy cells, causing hair loss, nausea, fatigue, and a weak immune system. It's like using a strong weed killer that damages healthy plants, too.

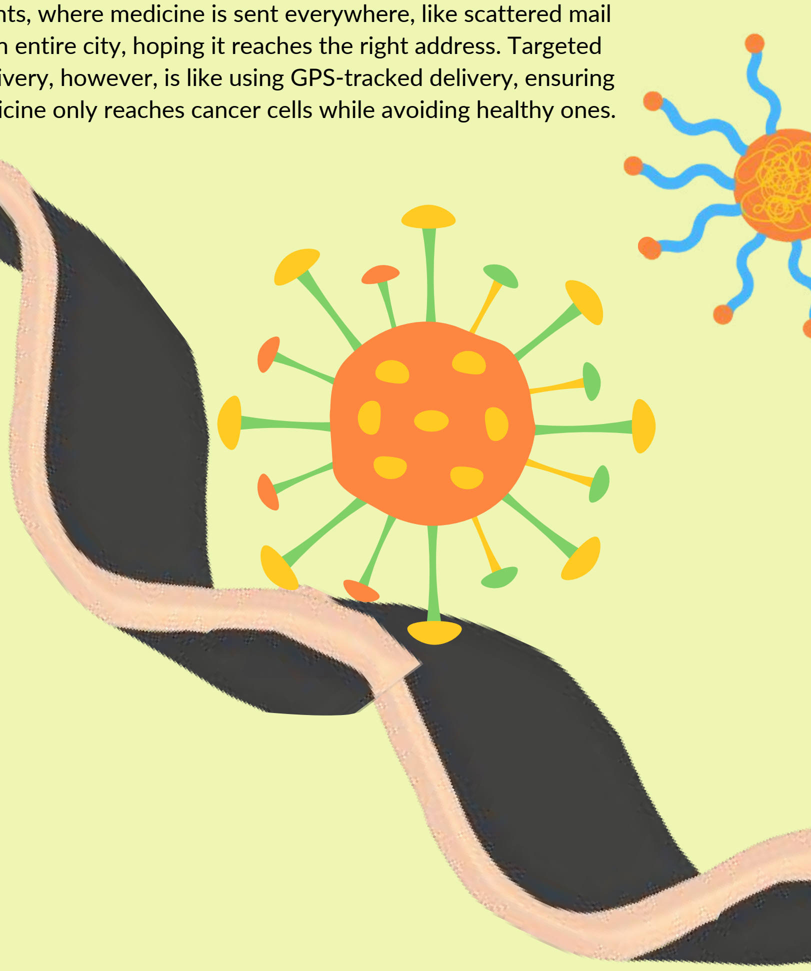
Radiation therapy targets cancer with high-energy rays, but it can also burn healthy tissue, leading to skin irritation, fatigue, and long-term damage. Hormone therapy blocks hormones like estrogen that help some cancers grow, but it causes hot flashes, mood swings, and bone weakness. These treatments are effective but lack precision, harming healthy cells along with cancer. This has led scientists to search for better, more targeted treatments with fewer side effects.





Targeted Drug Delivery

What if we could send medicine only to cancer cells while leaving healthy ones untouched? This is the idea behind targeted drug delivery. Instead of flooding the entire body with toxic drugs, this method delivers medicine directly to cancer cells, reducing harm to healthy tissues. Imagine a package delivery system in traditional treatments, where medicine is sent everywhere, like scattered mail across an entire city, hoping it reaches the right address. Targeted drug delivery, however, is like using GPS-tracked delivery, ensuring the medicine only reaches cancer cells while avoiding healthy ones.



Nanoparticles Used for Drug Delivery

To deliver cancer medicine directly to the tumor, scientists use something called nanoparticles. These are tiny particles so small you'd need a super-powerful microscope to see them. In fact, they are about 1000 times smaller than the width of a human hair! Nanoparticles can be made from materials like fats, metals, or biodegradable plastics and are shaped and designed in very special ways. They act like tiny delivery trucks, carrying cancer-fighting drugs inside them. But they don't just carry the medicine anywhere—they are built to find and reach the cancer cells, stick to them, and release the drug only when and where it's needed. Because they are so small, they can move easily through the bloodstream and even slip into tumor tissues where regular medicine might not reach. This makes them perfect for targeted drug delivery.

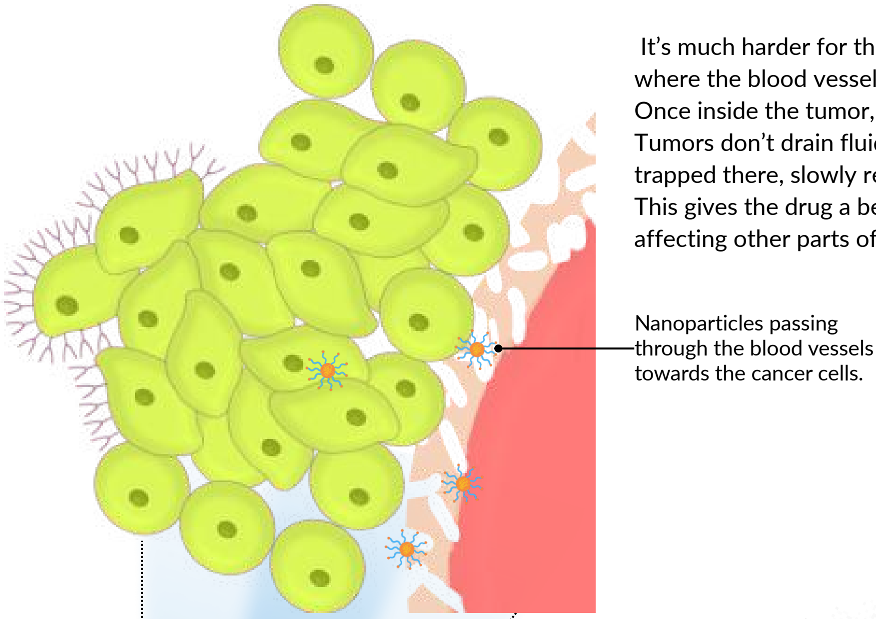
Approaches to Targeted Drug Delivery

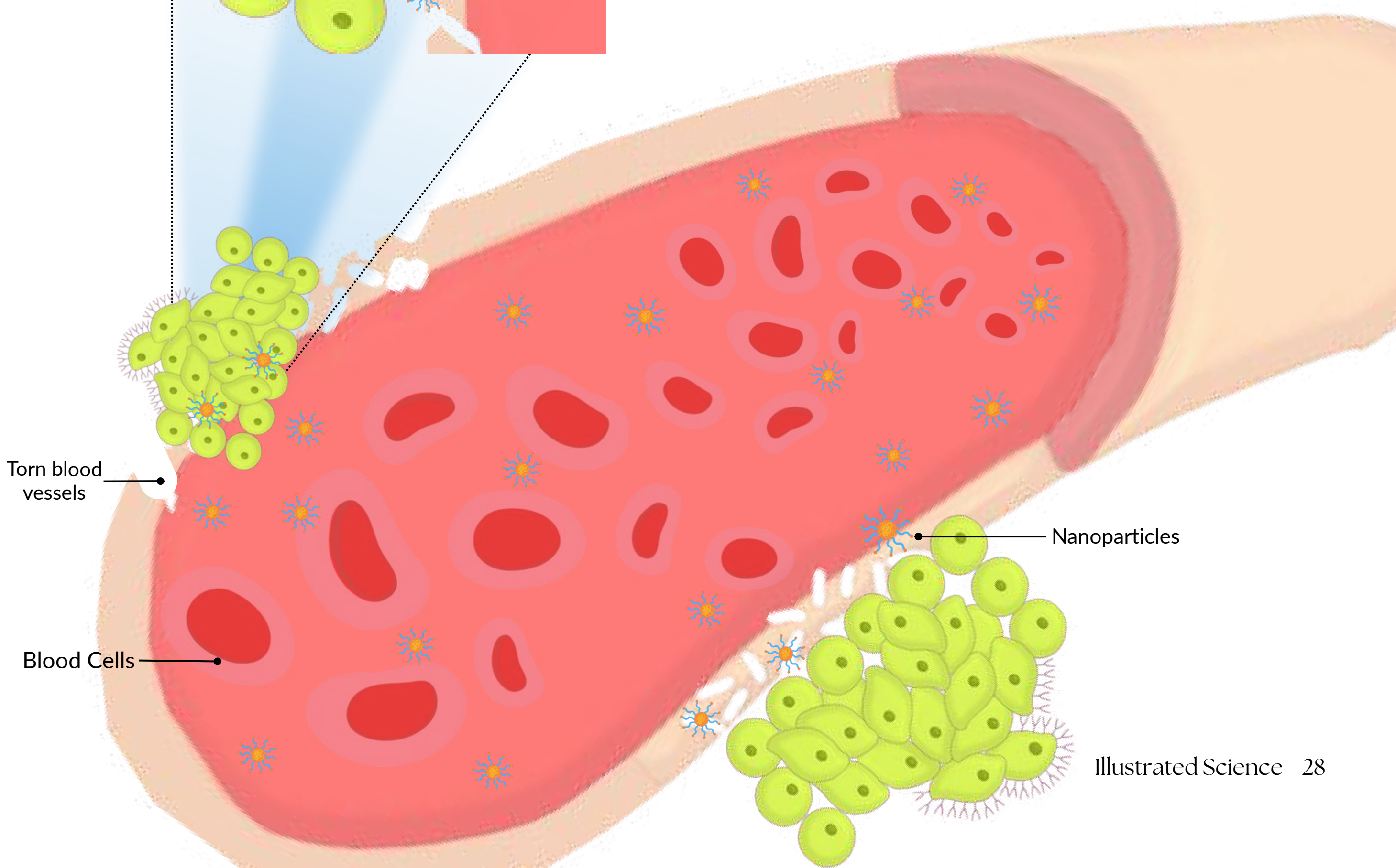
To make sure the medicine reaches only the cancer cells and not the healthy ones, scientists use these tiny carriers called nanoparticles. Scientists have developed three key strategies to deliver drugs directly to cancer cells with minimal damage to healthy tissues:

Passive Targeting

One of the simplest ways to deliver medicine directly to a tumor is by using the tumor's own weaknesses. This approach is called passive targeting, and it works without needing any special guiding system. It relies on the fact that tumors grow in a rushed and messy way, which changes how they're built on the inside. As tumors form and try to feed themselves, they quickly grow new blood vessels to bring in nutrients. But these vessels are not neatly arranged like in healthy tissue. They end up with tiny holes and loose walls, a bit like a pipe that hasn't been sealed properly. This gives nanoparticles—the tiny carriers loaded with cancer medicine—a perfect chance to slip through the gaps in the tumor's leaky blood vessels.

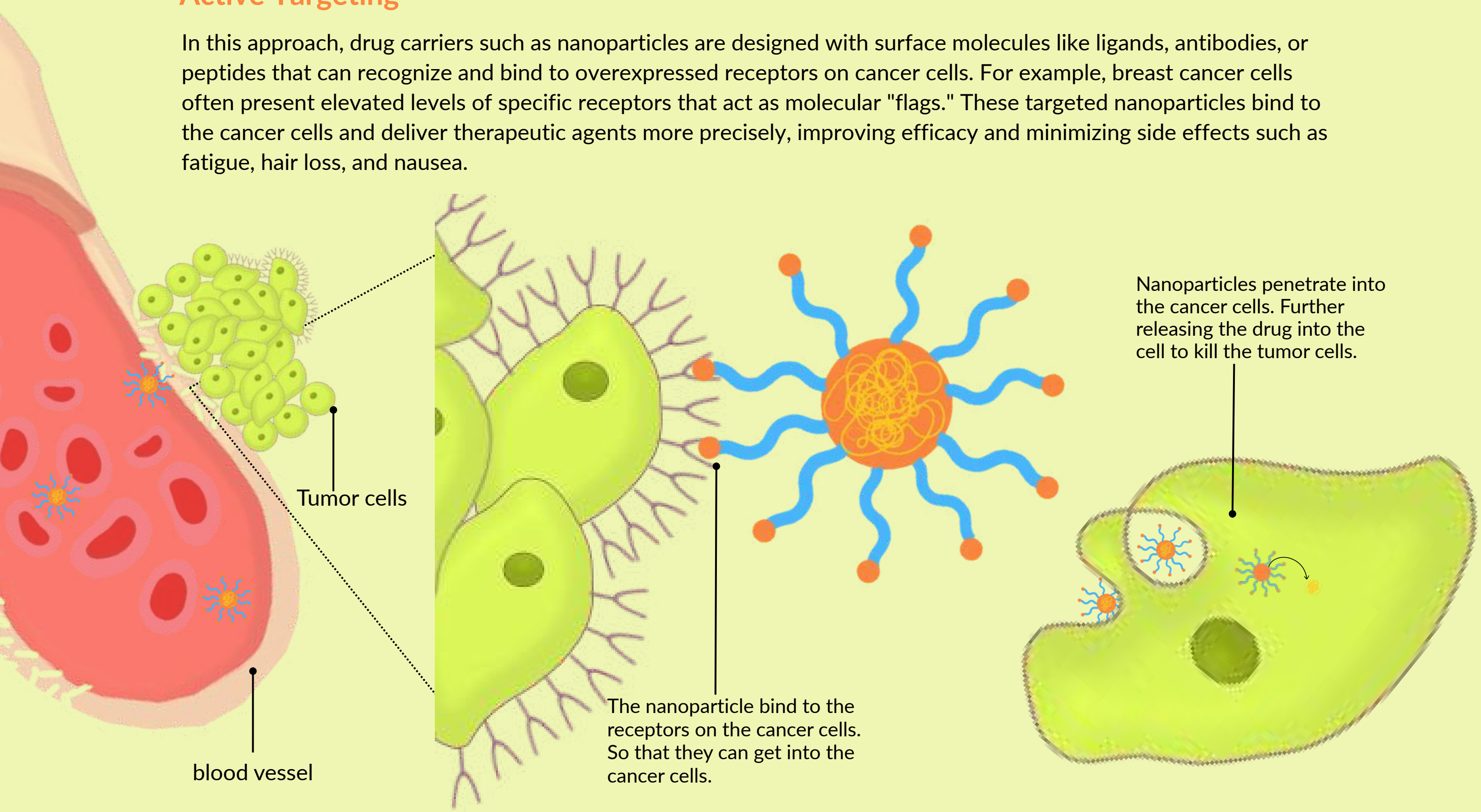
It's much harder for them to enter healthy tissues, where the blood vessels are tightly packed and sealed. Once inside the tumor, something else helpful happens. Tumors don't drain fluids well, so the nanoparticles stay trapped there, slowly releasing the medicine over time. This gives the drug a better chance to do its job without affecting other parts of the body.





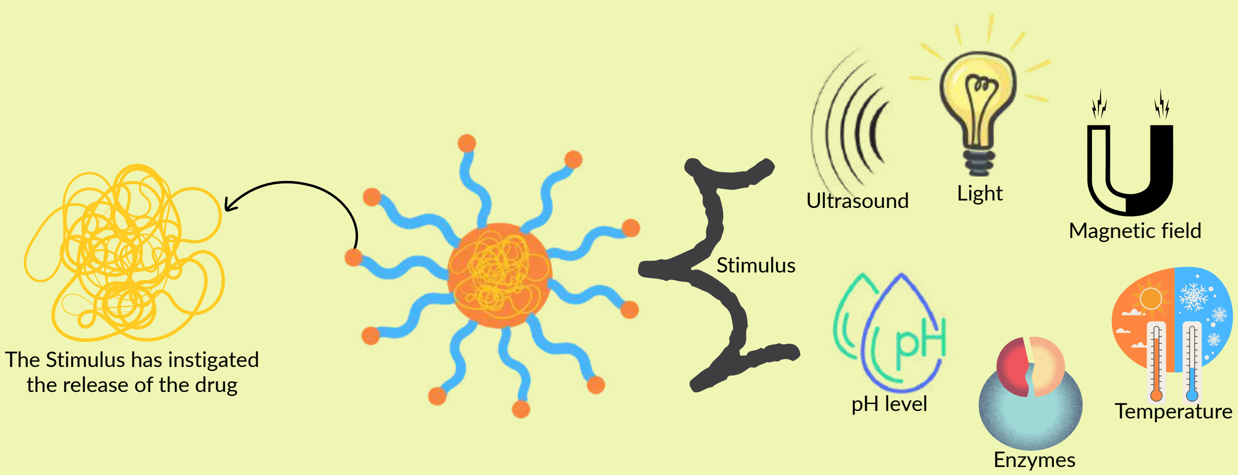
Active Targeting

In this approach, drug carriers such as nanoparticles are designed with surface molecules like ligands, antibodies, or peptides that can recognize and bind to overexpressed receptors on cancer cells. For example, breast cancer cells often present elevated levels of specific receptors that act as molecular "flags." These targeted nanoparticles bind to the cancer cells and deliver therapeutic agents more precisely, improving efficacy and minimizing side effects such as fatigue, hair loss, and nausea.



Stimuli Response Drug Release

Some advanced drug carriers release their medicine only when triggered by specific conditions in the tumor, such as pH-sensitive nanoparticles : Tumors have a more acidic environment than normal tissue, triggering drug release. Temperature-sensitive carriers: Heat therapy can trigger drug release. Enzyme-sensitive systems: Tumors produce unique enzymes that can activate certain drugs. Analogy: Think of a time-release capsule that only dissolves when it reaches a certain temperature or acidity level, ensuring medicine is released exactly where it is needed. By using these strategies, scientists can increase drug effectiveness while reducing side effects—a game-changer in cancer treatment.



The Road Ahead: Challenges and Hope

Targeted drug delivery is a huge step forward, but it's not without its challenges.
One big problem is that tumors are tough to reach. The area around them is often dense and crowded, which makes it hard for the medicine to get through. And even before it gets there, nanoparticles can get blocked—either by the body's immune system or by sticking to other things in the blood, which slows them down or stops them completely. Also, we're still figuring out how to make these nanoparticles in a way that's safe, stable, and works well for different people. And like any treatment, it needs to go through lots of testing before it can be used widely.

That said, there's a lot to be excited about.

- Researchers are working on personalized treatments that match each person's cancer more exactly, using details like their genes and proteins.
- New types of nanoparticles are being built to do more—like carrying multiple drugs or reacting to signals inside the tumor.
- With the help of AI and smart technologies, scientists are getting better at predicting which treatments will work best for each patient.

So even though there are a few bumps in the road, we're headed toward cancer treatments that are smarter, more focused, and much kinder to the rest of the body.

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Vaishnavi Dahihande is a student of Bachelor of Science (Honors) in Computer Science at Ahmedabad. Her interest in this research was sparked by personal life incidents and a desire to explore how nanotechnology is changing how we treat breast cancer. As a science student, she is keen to make science attractive to readers. Passionate about making science easy to understand and visually appealing for the readers. She personally also wanted to exercise creativity, as she enjoys finding creative ways to explain complex ideas.

Ashutosh Kumar is an Associate Professor at the School of Arts and Sciences at Ahmedabad University. His research primarily focuses on nanomedicine with a strong emphasis on its application in Rheumatoid Arthritis and breast cancer. His work explores the development of targeted drug delivery systems and the mechanistic understanding of nano–bio interactions for translational therapeutic applications. He has authored numerous high-impact publications, and his research contributions have earned him recognition among the World's Top 2% Scientists by Stanford University for three consecutive years (2021, 2022, and 2023).

Cro(w)ssings

A Crows' Ability to Navigate Urban Lanes

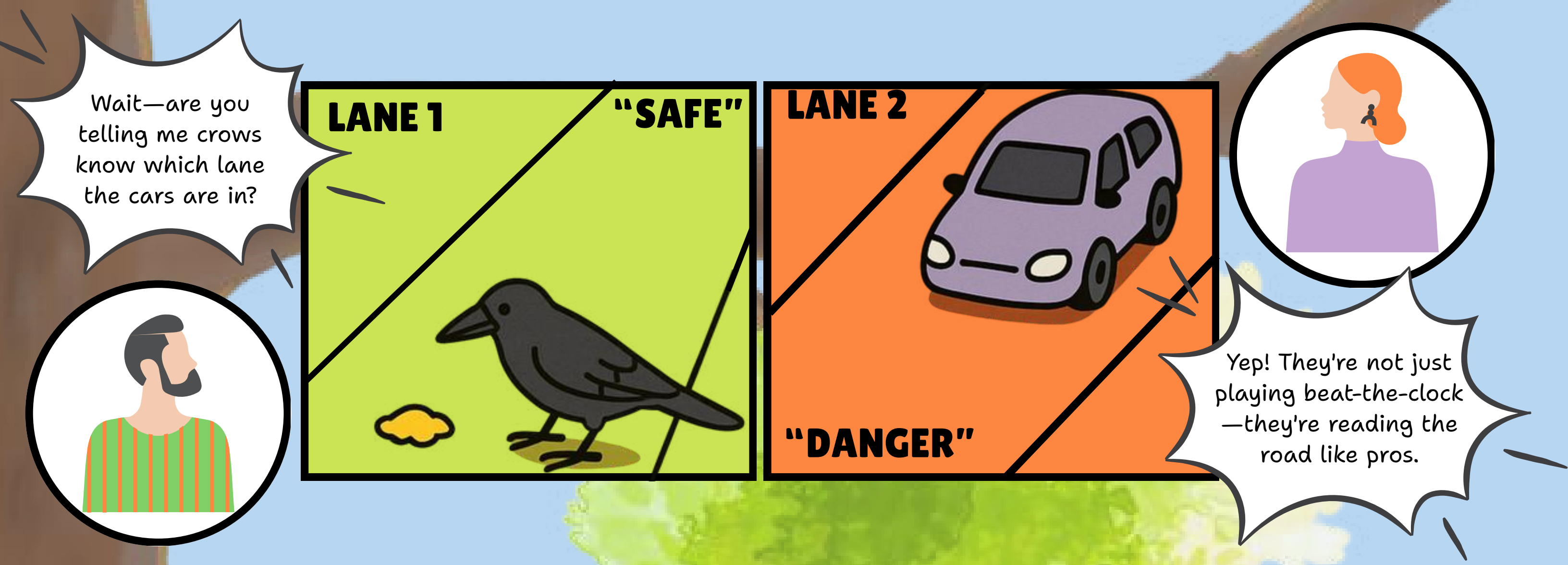
Writer and Illustrator **Priyal Soni** | *Science Mentor* **Shomen Mukherjee**

Picture this: You're going along a quiet road, and a crow is busy pecking at something in the middle of your lane. As your car gets close, rather than fleeing out of panic, the crow moves aside with perfect timing, allowing your vehicle to pass before returning to its roadside banquet. Coincidence? I don't think so.

Crows, especially American Crows (Corvus brachyrhynchos), are among the smartest animals on Earth. It has even been known that they used tools, would place nuts outside of their reach, and would wait for vehicles to crush the nuts so they could feast on the contents; moreover, they could remember and recognise individual human faces. Scientists have long thought that such intelligence came about in response to the requirements of social life: finding food, surviving, and so forth. One big gap remained in answering this question: How do crows deal with risky situations or strange environments such as roads? This article focuses on precisely that. Shomen Mukherjee, an ecology professor at Ahmedabad University, along with his fellow researchers, wanted to know if the American Crows could assess vehicles in real-time and make suitable decisions depending on the threats posed by their presence. More specifically, do they understand how dangerous a vehicle is relative to which lane it occupies? It's not just a question about birds dodging cars. Consider it a question about intelligence and perception and about adapting in the modern world. And as we'll see, these philosophers in feathers might be watching out for the traffic flow more than we are.

A Crow's Game of Chicken

As urban areas have grown, wildlife has learned to somehow sustain itself in spaces increasingly dominated by humans. Roads in particular can be horrifying: they cut habitats, they bring in a constant din of noise, and worst of all, fast-moving vehicles. But to the clever little fellows like crows, roads themselves present opportunities, mostly for scavenging roadkill. These carrion eaters are attracted to roads but are equally at risk of being roadkill themselves. Some animals avoid roads during rush hours-but could crows be smart enough to do so? This study investigates whether crows can actively judge traffic risk, not just by time of day, but by lane position. In other words, would that mean that they are not just accepting roads but are actively understanding them?



Brainpower on Wings

Were the crows ever considered intelligent in the forests and, later, in cities and even science labs? How, then, does their wit perform upon the open road? Rather than avoiding human spaces, these birds sometimes thrive in them, eating roadkill in places many animals shy away from. The quandary raised here, then, is quite interesting: are crows just dodging danger, or are they calculating it?

The researchers had to make their way into Everglades National Park in Florida to unravel this mystery. It is thus a vast, mostly quiet place where crow–car encounters could be safely observed. There, they looked beyond whether crows simply reacted to traffic and asked something deeper: Do crows understand how traffic works—specifically, the direction of threat based on the lane a vehicle is in?

Bird’s Eye View of Traffic

The researchers had a Ford pickup and a notebook as their devices, singing their way down a quiet stretch of two lanes inside the park. Now, the objective? To spot crows feeding on the road and observe their response to an oncoming vehicle, especially if their response changed depending on which lane the vehicle was in. At each sighting, the team would record a whole series of behaviours: Was the crow in the same lane or the opposite one? Did it fly away, walk away, or stay put?

Such moment-to-moment choices, seemingly inconsequential, might hold invaluable clues in how well crows perceive threats and act accordingly. With each of these drives, data were collected over dozens upon dozens of crow encounters (38 crows to be precise). Hence, an emergent pattern that was not random movement, but very deliberate, lane-based, and hinting at an advanced understanding of hazards posed by human entities.

Crows, like many birds, have superb vision. It's no wonder that crows have become so proficient in these areas because of the way they perceive the world around them; a world with huge eyes and a boosted number of photoreceptors that enable them to view movement and magnitude from immense ranges. Their sharp vision aids in discerning out the nearing cars and determining the precise timing of their actions.

Science Hits the Road

In August 2010, researchers left the confines of a laboratory and took to Florida's Everglades, where they recorded crows along a road that spanned 60 kilometres. Using a Ford F-250 pickup truck with a speed of 80 to 90 km/hour, they recorded crows along nine drives. The following results are for the 38 American Crows (19 on each lane) observed on that day. What were the significant findings? Let’s find out!

They found that, unsurprisingly, the crows in the same lane as the vehicle considered the approaching vehicle to be more dangerous, and thus, they ran away from it or changed their lane. However, despite fast-moving traffic only a few meters away, crows in the opposite lane decided to stay in that lane and not fly off. They also found that a few crows walk over to the opposite lane from the driving lane to avoid being killed.

Crows and Curves: Predicting Motion on Complicated Roads

The researchers did not limit themselves to purely linear trajectories; they extended their experiment to include curves. A curved trajectory adds an additional level of difficulty: the angles and paths of the car change quickly, thereby compromising the ability of the crows to assess danger. But then again, the crows demonstrated incredible skill. They adjusted sharply, considering speed, angles, and even small perturbations in a car's movement. Instead of responding to a car's position, the crows anticipated its future positioning- a skill that very few animals, including primates, possess.

The crows seem to mentally project the car's future position like expert drivers driving around winding roads. On curves, if on the driving lane, the birds continued to take off early, while birds in the opposite (safe lane) continued to stay put. Such flexibility indicates an awareness of risk and conscious decision-making, as opposed to just instinct. Their outperformance places them with whales and apes in the company of the most intelligent animals.

Nature vs. Nurture: How Crows Get Street Smart

What these behaviours suggest is that crows have figured out the "rules" of the road as they navigate through it. Researchers do not believe this is purely instinct—it is something learned through watching and adapting over time. Day after day, cars are observed zipping forward in organised and orderly lines. Some cars come within close proximity, while others do not. Opportunities to learn emerge over hundreds of interactions, and eventually, some clever birds learn: "If the car is in the other lane, I'm fine. If it's in my lane, time to go."

Learning of this sort is infrequent and more commonly associated with mammalian species such as primates. In the context of animals, it means learning from others or the environment by actively watching and detecting regularities, along with changing one's behaviour without needing specific instruction. The same might go for crows in cities and along roadsides. Juveniles might learn through watching adults and mimicking their actions, slowly forging their own internal traffic roadmap. As a result, there is now a population of birds that not only fears cars but also deeply comprehends them as well. Not on an individual basis, of course, but as predetermined machines that follow specific patterns. With urban life shaping a bird's survival skills, these skills are not only smart but critical for survival.

Natural Selection: An Evolutionary Adaptation

Natural selection ensures that individuals who thrive in a particular environment can survive and reproduce. The crows unable to gauge vehicles are more likely to die or not able to use the rich food resource (if they avoid roads) than those with good judgment, since poor decision-makers are killed by vehicles. Thus, this process helps the "natural" selection of individuals in species with higher cognitive abilities over time.

A Hybrid Model: Learning Meets Evolution

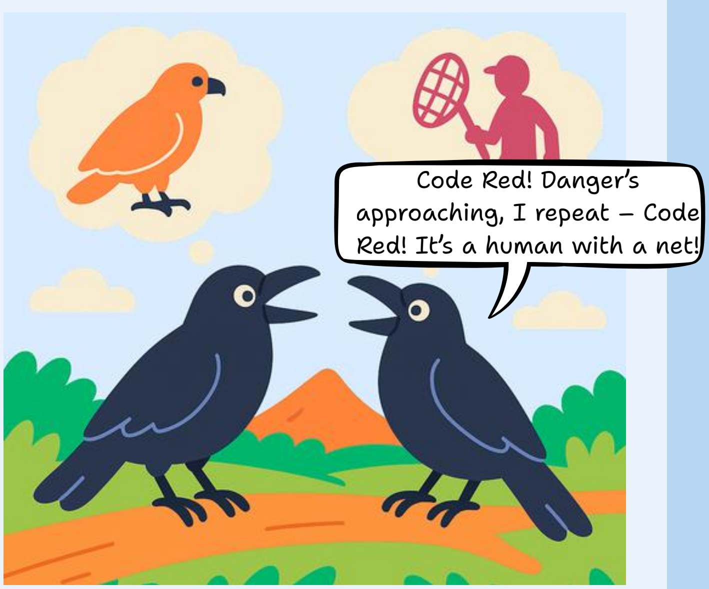
The intelligence of crows is the possible result of both social learning and natural selection. Social learning equips, above all, young crows with requisite survival skills within a short while. On the other hand, natural selection further ensures that the best ones have their genes spread. These combined forces shape the remarkable cognitive abilities enabling the birds to thrive in busy urban environments.

Beyond Traffic - The Science of Crow Intelligence

What makes this study genuinely unique is its real-world approach. Unlike lab experiments, researchers observed crows making life-or-death decisions in actual traffic - revealing intelligence that only shows up in complex, unpredictable environments. Perhaps most astonishing is their ability to use human infrastructure to their advantage. Some crows drop nuts at crosswalks, letting cars crack them open, then wait for the pedestrian signal before safely retrieving their snack - showing they understand traffic light patterns better than some humans!

Tool Innovation: New Caledonian crows don't just use tools - they design them, bending wires into hooks to retrieve food from hard to reach places.

Future Planning: They'll hide food in places they remember being accessible at certain times of the year.

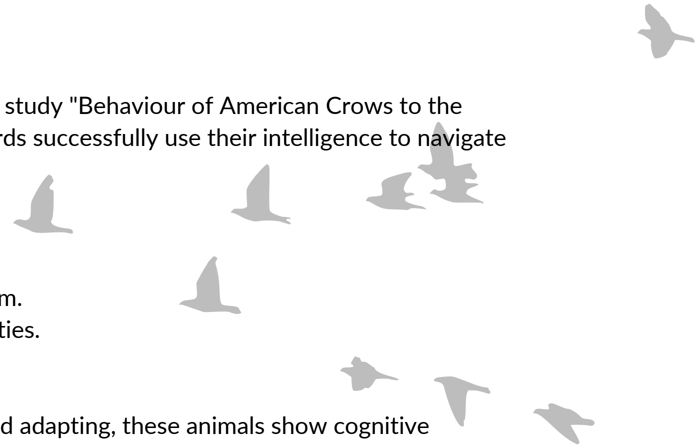


Complex Communication: They have different alarm calls for specific threats like "hawk" vs. "human with a net."

Memory Feats: They remember human faces for years and teach other crows how to avoid dangerous situations and individuals.

Conclusion – A New View of Urban Wildlife

The typical beliefs concerning animal cognition are overturned by the study "Behaviour of American Crows to the Approaching Traffic." Merely surviving in human landscapes, these birds successfully use their intelligence to navigate a complex world.

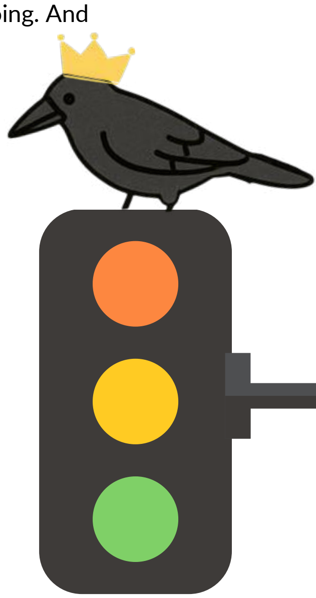


Shows that:

- Crows discern between hazardous and safe patches on roads.
- They forecast the movements of vehicles rather than react to them.
- Social learning and natural selection influence their cognitive abilities.
- Crows can make deliberate and strategic decisions.

Crows are, thereby, active problem solvers. By observing, learning, and adapting, these animals show cognitive flexibility comparable to most intelligent species. This research urges us to rethink our ideas about urban wildlife and appreciate the wondrous adaptive abilities of these birds.

The next time you see a crow standing confidently on a road, remember that it knows precisely what it's doing. And who knows, it might be watching you, too.



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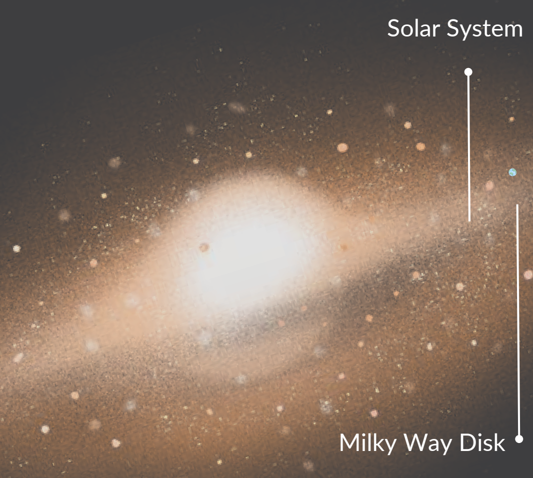
Priyal Soni is a student of the Integrated Master of Science at Ahmedabad University. Her interests include studies of animal intelligence and behavioural ecology, especially the quaintly sophisticated yet practical means animals cope within human-altered landscapes. Her work focused on communicating scientific research in interesting yet accessible ways, especially regarding Human-Animal Interactions. Her motive is to bring together scientific curiosity and impressive storytelling, thus appealing to a wider audience.

Shomen Mukherjee is an Associate Professor at the School of Arts and Sciences, Ahmedabad University. His research is focused on behavioural and community ecology, with an emphasis on animal-adaptive strategies in a changing environment. He has worked with a variety of ecosystems in collaboration with government agencies in India as well as abroad. One of his studies looks into the response of American Crows to oncoming traffic, a relatively novel study on the decision-making of animals in urban terrains. This research complements his larger interests in animal cognition, risk perception, and ecological implications of urban wildlife behaviour.

A Journey into the Large Magellanic Clouds

Writer and Illustrator **Parshwa Parikh** | *Science Mentor* **Samyaday Choudhury**



Imagine gazing up at a starlit sky in the Southern Hemisphere, where amid the familiar stars lies a mysterious, hazy patch—a galaxy that quietly orbits our Milky Way. It is not as bright as the stars, and it does not sparkle like the rest; it is subtle, almost like an ancient storyteller whose tales have been hidden in the soft glow of its distant light. This is the Large Magellanic Cloud, or LMC—a modest yet fascinating neighbour with clues about the cosmic past.

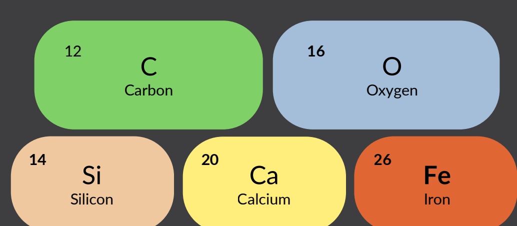
For as long as people have looked at the sky, this smudge of light has inspired wonder. Over time, astronomers began to realise that the LMC was not just a pretty face. It was, in fact, a relic of cosmic history—a living record of a galaxy's life story, almost one hundred fifty kilo light years away from us. Just as an archaeologist studies ruins to uncover the secrets of a lost civilisation, astronomers study the light from distant galaxies to decipher their past. And the key to unlocking that history lies in something called "metallicity."

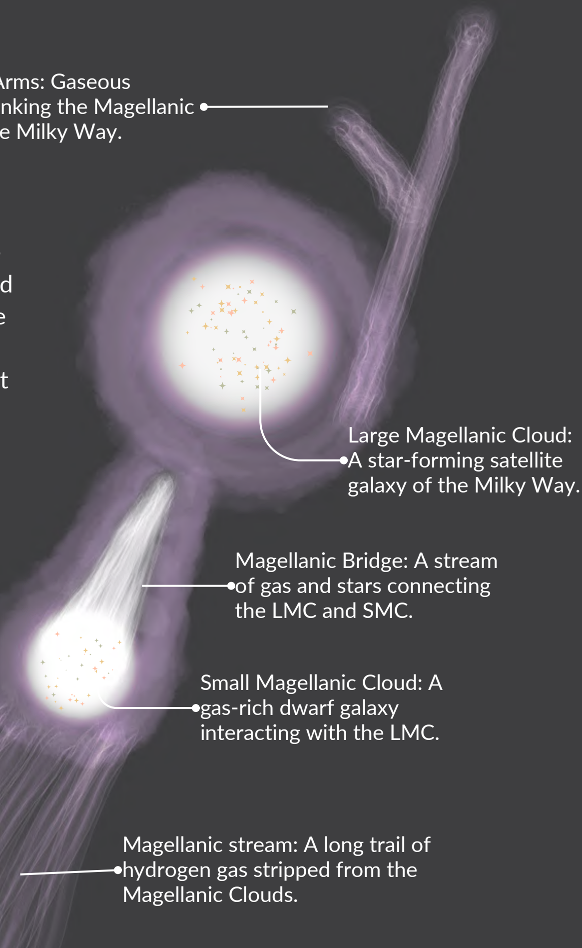
More Than Just a Glow

In everyday life, metals might mean iron or gold, but in the language of the stars, "metals" are any elements heavier than Helium. These elements are forged in the hearts of stars and spread across galaxies when stars die, exploding in spectacular supernovae. Over countless generations, the light from these stellar forges accumulates, leaving behind a chemical fingerprint—a cosmic DNA that tells us how the galaxy evolved over time. The LMC's story, as it turns out, is written in this very metal content. Recent studies have taken a closer look at the LMC, using clever techniques that analyse the light coming from its stars in a way that even dust, which tends to hide the truth, cannot obscure. By using near-infrared light—a kind of light that can see through cosmic dust and combining it with spectrum of the stars—astronomers have created a detailed "metallicity map" of the LMC, revealing patterns that hint at its turbulent past.

A Galaxy of Memories

The central region of the LMC contains stars with slightly higher metal content, indicating sustained star formation over time. As we move away from the center, the metallicity decreases, but only gradually. This shallow gradient suggests that the elements produced by earlier generations of stars have been redistributed across the galaxy, resulting in a relatively even chemical composition rather than a steep decline. One of the most captivating aspects of the LMC's metallicity map is a certain imbalance—a subtle asymmetry that gives the galaxy a unique character. Imagine if you were reading a history book and discovered that one chapter was written in a slightly different tone than the rest. In the LMC, one side, particularly toward what astronomers call the "southwest," appears to be a bit less enriched with metals. This part of the galaxy seems to whisper a different tale, a hint of past interactions and cosmic encounters with another near galaxy called The Small Magellanic Cloud (SMC).





Clues in the Distortion

These irregularities lead us to think about the LMC's relationship with its close companion, the SMC. For billions of years, these two galaxies have been locked in a gravitational dance, influencing each other with their pull. They even share a delicate bridge of gas and stars—the Magellanic Bridge—that connects them like a thread of history. Although the LMC's metallicity map does not shout out dramatic differences, it subtly reflects the memory of these interactions. The slightly poorer patch in the southwest might be a remnant of a past encounter with the SMC—a time when gravitational forces mixed the ingredients of the galaxy in a way that left a faint, yet unmistakable, signature.

To create this cosmic portrait, astronomers focused on a group of stars known as red giants. These stars are the ancient (a few billion years old) residents of the galaxy, their light carrying memories of a long-forgotten past. Much like a weathered book that tells stories of old, red giants have evolved in predictable ways—their brightness and colour change in ways that can be linked to the metal content inside them. By carefully studying the light from these stars with the help of a remarkable telescope in Chile, scientists were able to piece together the LMC's history.

Reading Light, Remembering Time

When you look at the metallicity map, it is not just a random splash of colors. There is an order to it—a pattern that speaks of mixing, movement, and change. The central region, where stars have been forming for eons, shows a richer mix of metals. This central "bar" as astronomers call it, seems to have acted as a kind of mixer, blending the elements over time so that even the outer regions are only slightly different in their composition. In the LMC, the change is subtle—a quiet testament to the gentle, persistent mixing of stars over time.

Heat map showing metallicity, produced by analyzing NIR waves recorded by VISTA Telescope, combining them with spectrum of the Red Giant stars.

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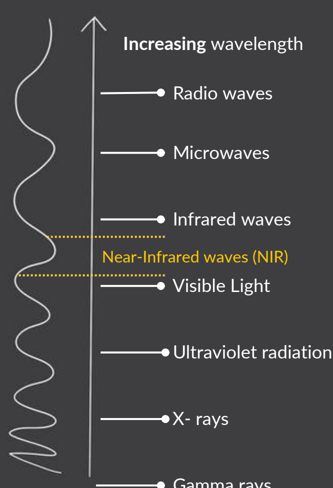

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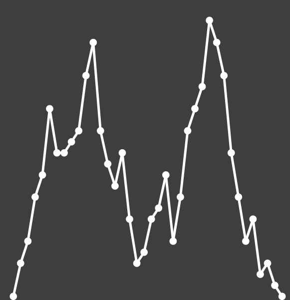


Spectrum of the Red Giant Stars

Red Giant Stars: Evolved stars that have exhausted core hydrogen and expanded while burning hydrogen in a surrounding shell. Their radii could be fifty to hundred times that of the Sun, while their surface temperature could be one half that of the Sun.

VISTA Telescope, Chile- Operated by European Southern Observatory

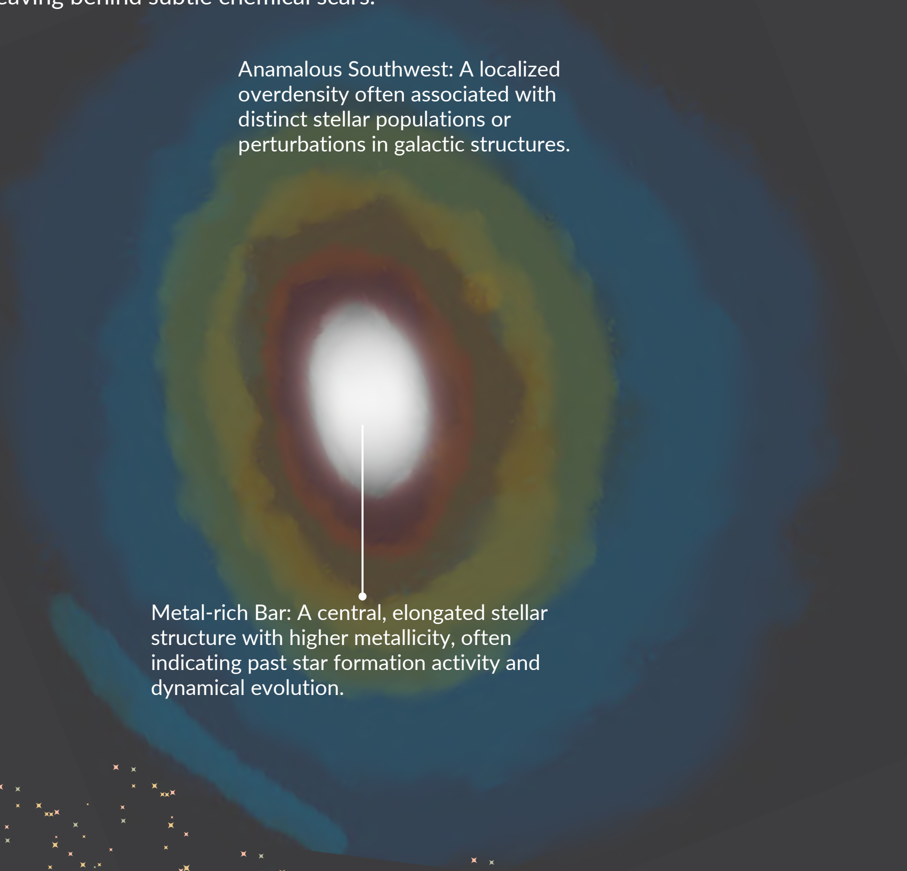
The telescope, designed to see in near-infrared light, peered through cosmic dust clouds that would otherwise obscure the details. Over a vast patch of sky, the telescope collected data from thousands of red giants, each one a tiny storyteller contributing a piece to the larger narrative of the LMC. Through painstaking analysis, researchers converted subtle differences in these stars' colors into a map—a metllicity map that doesn't just show where metals are, but hints at how the galaxy has evolved.

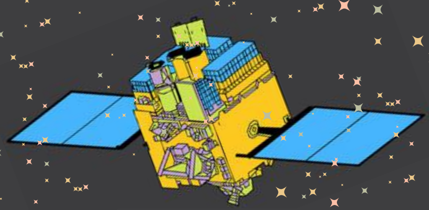
A Galaxy’s Uneven Canvas

Yet, the real intrigue lies in the anomaly—the southwesterly region that does not quite match the rest. This area’s lower metal content could be the residue of ancient cosmic interactions. Imagine two neighboring streams merging, where one carries a different sediment load than the other. Over time, the mixing might not be perfect, leaving patches where the composition is noticeably different. That is the picture that emerges for the LMC: a galaxy that has experienced interactions, perhaps with the SMC, leaving behind subtle chemical scars.

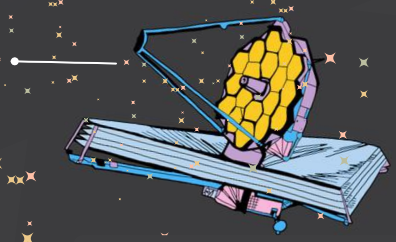
The implications of this research stretch far beyond the LMC itself. Every galaxy evolves, and the way elements mix and spread within a galaxy can tell us about its past encounters, its growth, and even its eventual fate. For instance, there is a possibility of LMC and SMC interacting and merging with The Milky Way Galaxy in the distant future. By studying the LMC now, we’re getting a sneak peek at how such cosmic mergers might influence the chemical evolution of larger galaxies.

Looking forward, new telescopes and surveys promise to add even more layers to our understanding. Telescopes like the James Webb Space Telescope (JWST), AstroSat and next-generation spectroscopic surveys like 4MOST will dive even deeper, revealing finer details of stellar populations and their chemical signatures. These advances mean that our cosmic map of the LMC will soon become even more detailed, unmasking secrets that are currently only hinted at in the soft glow of red giants.





Ultraviolet Imaging Telescope (UVIT) on AstroSat, operated by ISRO, India.



JWST, a collaborative project by NASA, ESA and CSA.

4MOST Survey by VISTA Telescope, Chile. Operated by ESO

Why it matters?

This research is not just about mapping metals—it is about decoding a story written across millions to billions of years. It's a story of cosmic encounters, of subtle yet profound changes, and of the relentless passage of time that shapes every galaxy. The LMC and SMC, with its gentle hues and hidden scars, invites us to wonder about the forces that mould the universe. It reminds us that even the smallest galaxies are filled with drama—a drama that has been unfolding since the dawn of time. As we continue to study our cosmic neighbours, we begin to see that the universe is not a collection of isolated islands. Instead, it is a vast, interconnected tapestry where every galaxy, every star, and every burst of light plays a part in a grand, ongoing narrative. The LMC's chemical story is one chapter in that cosmic epic, a chapter that hints at both the chaos of collisions and the beauty of gradual transformation.

Studying the LMC is not just about mapping the metals within a distant galaxy — it's about understanding how galaxies evolve, interact, and build the ingredients for stars, planets, and life itself. Along with its companion, the SMC, the LMC serves as a nearby testbed for astronomers — a natural laboratory to study the birth and death of stars under physical and chemical conditions different from those in our own Milky Way. Together, the LMC, SMC, and Milky Way form a dynamic trio, offering a rare opportunity to observe the processes of galactic interaction, tidal disruption, and perhaps eventual merging. The subtle metallicity patterns across the LMC — a gently enriched center, a modest gradient, and a chemically distinct southwest region — reflect not just internal stellar activity but the echoes of gravitational encounters.

As we continue to refine our tools and peer deeper into the universe with observatories like JWST, AstroSat and spectroscopic surveys like 4MOST, galaxies like the LMC will help answer fundamental questions: How do galaxies change over time? How do interactions shape their evolution? And how do the elements forged in ancient stars eventually become part of the story of life? The LMC may be just one of many galaxies, but it's the closest window we have into the grand narrative of cosmic transformation — and we are only beginning to read its pages.

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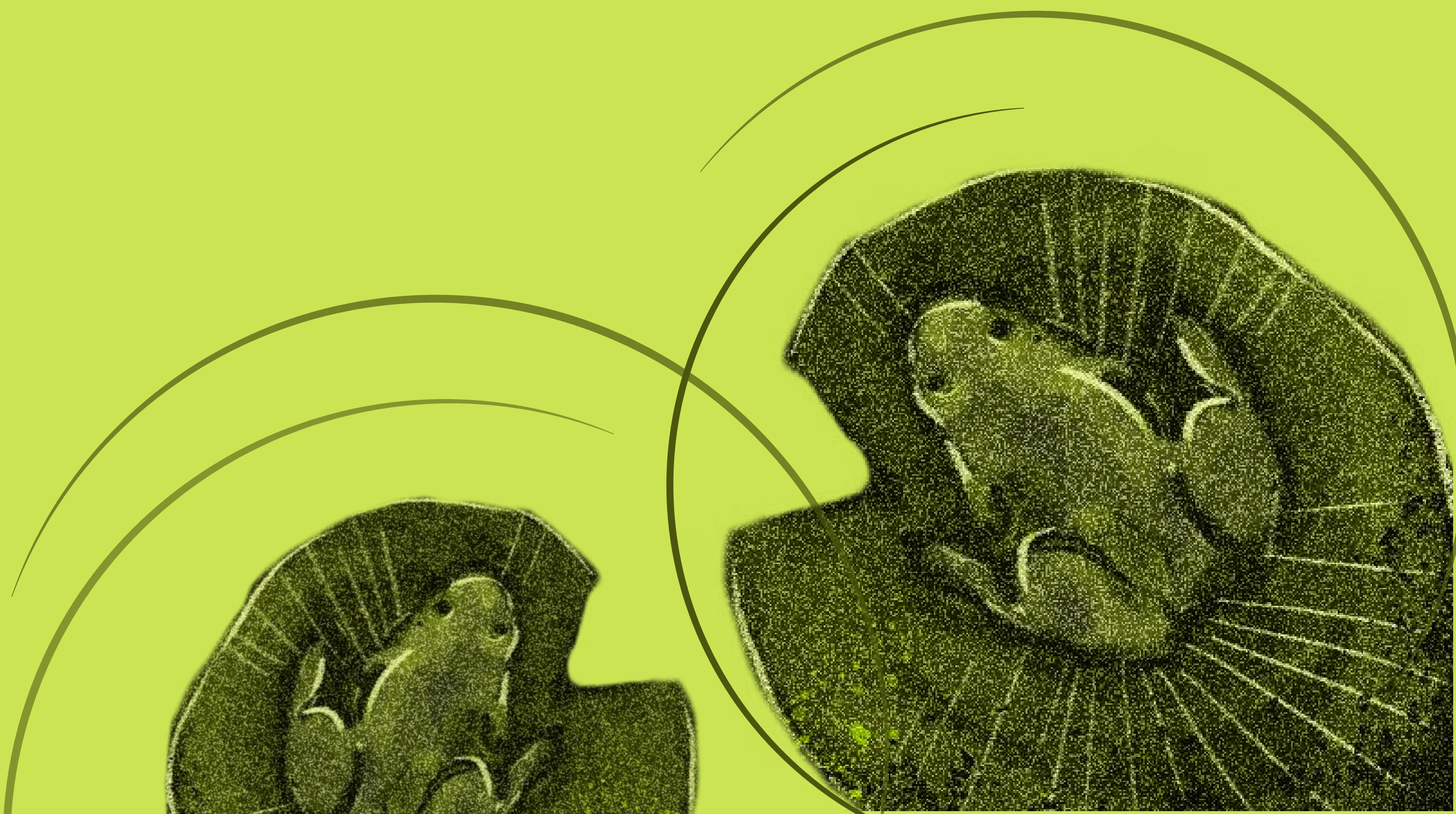
Parshwa Parikh is a student of Bachelors of Business Administration (Honors) Finance and Economics Major at Ahmedabad University. Although being a student of Finance, he maintains his interest in cosmology and astronomy. Stars and Galaxies have amazed him since he was a kid. As an ever-questioning person, he is facinated by power of science and technology to provide him answers. He aims to simplify scientific research to make it more accessible for general audience. In this fast moving world, he believes it is essential to stay updated with latest research.

Samyaday Choudhury is an Assistant Proffessor at the School of Art and Sciences at Ahmedabad University. He earned his PhD degree from the Indian Institute of Science, Bengaluru, under the Joint Astronomy Programme. Prior to joining Ahmedabad University in March 2023, Professor Choudhury was an 'Evolved Star Postdoctoral Fellow' at the Space Telescope Science Institute (USA), the operation centre for prominent NASA space observatories like the Hubble Telescope and the James Webb Space Telescope. After completing his PhD from the Indian Institute of Astrophysics (Bengaluru), he was a 'Lee Wonchul Postdoctoral Fellow' at Yonsei University Observatory (South Korea) and a Postdoctoral Research Fellow at Macquarie University (Australia).



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