airis4D

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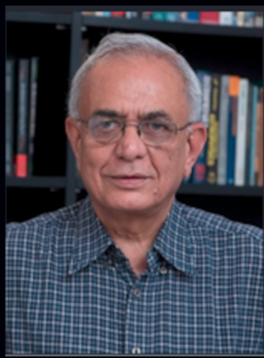
We Dream, Design, Develop and Deploy the Future

Professor Ajit Kembhavi

writes on the latest advances in astronomy and astrophysics.

He will answer questions about his article, and selected readers can participate in an online interactive session with him.



Artificial Intelligence & Machine Learning

Astronomy and Astrophysics

Biosciences

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Artificial Intelligence Research and Intelligent Systems

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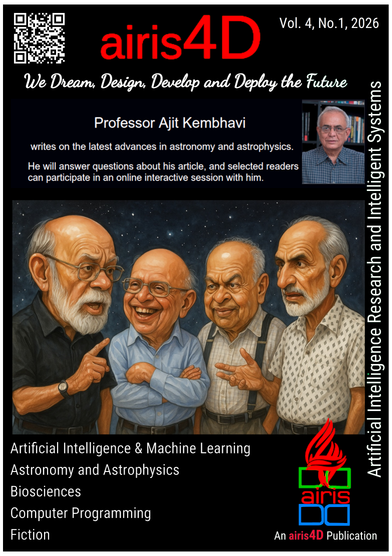

Cover page

Star Talk- conversation amongst the stars of Indian Astrophysics

The four founding fathers and architectural pillars of IUCAA (Inter-University Centre for Astronomy and Astrophysics) and, more broadly, the titans of modern Indian astrophysics left us in 2025.

P. P. Divakaran: A distinguished theoretical physicist (formerly of TIFR) who played a crucial role in the conceptual and academic planning of IUCAA.

Govind Swarup: The "Father of Indian Radio Astronomy." He built the Ooty Radio Telescope and the Giant Metrewave Radio Telescope (GMRT). His collaboration with the other three was essential in making Pune a global hub for astronomy.

Jayant Narlikar: The Founder-Director of IUCAA. He is the face of Indian cosmology and was the primary visionary behind creating a center that connected universities to world-class research.

Naresh Dadhich: A renowned relativist and the second Director of IUCAA. He was a key member of the original team that walked the "IUCAA trail" from its inception.

image credit : Atharva Pathak and ChatGPT

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Editorial

by Fr Dr Abraham Mulamoottil

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This edition starts with: "Star Talk: Conversations Amongst the Stars of Indian Astrophysics pays tribute to the four founding fathers and architectural pillars of the Inter-University Centre for Astronomy and Astrophysics (IUCAA), whose collective vision shaped modern Indian astrophysics and whose passing in 2025 marked the end of a seminal era. The cover honours P. P. Divakaran, a distinguished theoretical physicist and key architect of IUCAA's academic foundation; Govind Swarup, the Father of Indian Radio Astronomy and creator of landmark facilities such as the Ooty Radio Telescope and GMRT; Jayant Narlikar, the founder-director of IUCAA and the iconic face of Indian cosmology; and Naresh Dadhich, eminent relativist and IUCAA's second director. Together, they transformed Pune into a global centre for astronomical research, leaving behind a legacy of scientific excellence, institutional vision, and inspiration for generations to come.

Arun Aniyan's article, The Energy Footprint of AI: Scaling Systems and Environmental Concerns, examines the rapidly growing energy footprint of artificial intelligence as increasingly large and complex models drive exponential rises in computational and power demands. It highlights how both training and everyday use of modern AI systems consume vast amounts of electricity, strain power grids, increase carbon emissions, generate e-waste, and intensify water usage for cooling. In response, technology companies are exploring high-stakes solutions such as space-based data centres and dedicated nuclear power, reflecting the severity of the challenge. The article concludes that the future of AI depends on scaling sustainability alongside performance through more efficient algorithms, cleaner energy sources, and improved hardware design, making environmental responsibility central to AI's long-term viability.

Blesson George, in "Applications of Group Equivariant Convolutional Neural Networks," discusses group equivariant convolutional neural networks (G-CNNs), which extend standard CNNs by embedding symmetry principles, such as rotations, reflections, and permutations, directly into neural architectures. By formulating convolutions over mathematical groups, G-CNNs ensure that feature representations transform predictably under these symmetries, leading to improved generalization and reduced reliance on data augmentation. The article outlines the mathematical foundations of equivariance, highlights rotation-equivariant networks for image data, and demonstrates applications across image classification, object detection, medical imaging, molecular modeling, physics-informed learning, and graph-based data. It concludes that while challenges remain in scalability and computational cost, G-CNNs provide a powerful, theory-driven framework for building robust and data-efficient models across diverse scientific and real-world domains.

Why Simple Measures Still Matter in the Era of Deep Learning by Jinsu Ann Mathew argues that despite the transformative impact of deep learning, simple analytical methods remain essential and often highly effective. It highlights that basic techniques such as counting, averaging, and simple statistical measures are efficient, robust, and easier to interpret, especially when data is limited, noisy, or patterns are clear. While deep learning excels at capturing complex details, simple methods provide better transparency, stability, and practical value in real-world applications like monitoring, healthcare, and decision-making. The article concludes that technological progress depends on balancing simplicity and complexity, choosing methods that best fit the problem rather than assuming deeper models are always superior.

Abishek P S. -Plasma Physics- Fusion Energy- explores the central role of plasma physics in achieving fusion energy and examines the major challenges and emerging solutions in this field. It explains why fusion is a crucial clean and abundant energy source, highlighting its safety, minimal waste, and potential to support global energy security and climate goals. The article details key scientific and engineering challenges, including sustaining ultra-hot and unstable plasma, meeting confinement requirements, developing resilient materials, managing tritium fuel, and reducing high economic costs. It then outlines promising solutions such as advanced magnetic and inertial confinement techniques, improved plasma control using real-time feedback and AI, novel materials, high-temperature superconducting magnets, and international collaboration. Overall, it presents fusion as a global imperative whose success depends on coordinated scientific innovation, engineering advances, economic strategies, and public trust.

Black Hole Stories-23 Binary Neutron Star Merger by Ajit Kembhavi recounts the landmark 2017 observation of a binary neutron star merger (GW170817), the first event detected both through gravitational waves and across the electromagnetic spectrum. It explains how observations by LIGO, Virgo, and multiple space- and ground-based telescopes confirmed long-standing predictions about neutron star mergers, including gamma-ray bursts, kilonovae, and the production of heavy elements like gold and platinum. The event provided deep insights into neutron star physics, the possible formation of a black hole remnant, and the origin of elements heavier than iron. It also enabled an independent measurement of the Hubble constant and confirmed that gravitational waves travel at the speed of light, marking a milestone in multi-messenger astronomy and modern astrophysics.

The article “The Geometry of Truth: Shapley Values for Model Interpretability” by Linn Abraham explains how Shapley values can be used to interpret deep learning models for solar flare prediction by fairly attributing importance to different solar imaging passbands. By treating each passband as a “player” in a cooperative game, the method quantifies how individual wavelengths and their interactions contribute to a model’s predictions, capturing non-linear synergies that simpler importance measures miss. Shapley values enable counterfactual reasoning, allowing researchers to ask “what if” questions and distinguish meaningful physical signals from spurious correlations. Overall, the article presents Shapley-based interpretability as a rigorous bridge between black-box AI models and scientific understanding, helping validate whether models are learning genuine solar physics rather than accidental patterns.

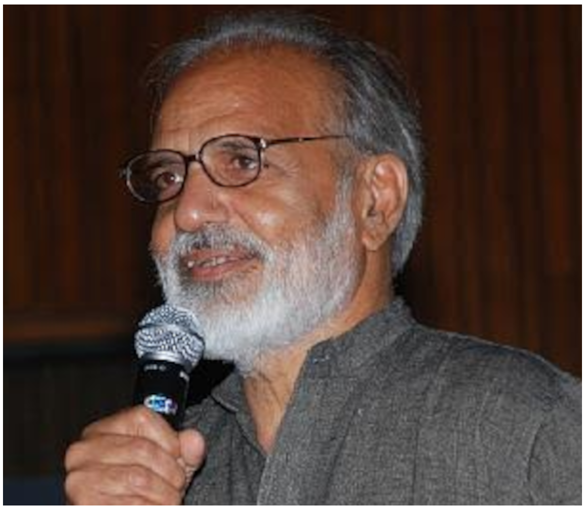
The article ”DNA Damage Assessment at the Single-Cell Level Using the Alkaline Comet Assay by Aengela Grace Jacob presents the Alkaline Comet Assay as a sensitive, rapid, and cost-effective technique for assessing DNA damage at the single-cell level, with wide applications in biomonitoring, cancer research, toxicology, and public health. By visualising DNA strand breaks as comet-like tails formed during alkaline electrophoresis, the assay quantitatively measures damage using parameters such as tail length,

The article “Diabetic Retinopathy- Medical Image Processing” by Geetha Paul provides a comprehensive overview of diabetic retinopathy (DR), a progressive microvascular complication of diabetes and a leading cause of vision loss, detailing its pathogenesis, clinical stages, symptoms, diagnosis, and management. It explains how chronic hyperglycaemia damages retinal blood vessels, leading from non-proliferative changes such as microaneurysms, haemorrhages, and exudates to proliferative disease marked by neovascularisation and severe vision-threatening complications. The article also describes key retinal features including drusen, choroidal neovascularisation, and cystoid macular oedema, and emphasises the importance of early detection and strict metabolic control. A major focus is placed on the role of medical image processing and artificial intelligence, highlighting how retinal imaging, automated lesion detection, and deep learning–based grading pipelines enhance screening efficiency, enable early diagnosis, and support timely intervention to prevent irreversible vision loss.

The article by Neelima Dubey on "Neurological Disorders: A Brief Overview" presents a broad yet integrated overview of neurological disorders, encompassing both neurodegenerative and neuropsychiatric conditions, and highlights their growing global health burden. It outlines how disorders of the central and peripheral nervous systems lead to diverse cognitive, motor, and emotional impairments, with neurodegenerative diseases such as Alzheimer's, Parkinson's, Huntington's disease, ALS, and multiple sclerosis characterised by progressive and often irreversible neuronal loss. The article also emphasises neuropsychiatric and mood disorders—including major depressive disorder, bipolar disorders, postpartum mood disorders, and seasonal affective disorder—linking behavioural symptoms to underlying neurological dysfunction. By discussing disease mechanisms, clinical features, and current therapeutic strategies, the review underscores the need for integrated, multimodal approaches that combine pharmacological treatment, neuromodulation, psychotherapy, and early biomarker-based diagnosis to improve patient outcomes and quality of life.

The article "AI in India: From Policy Vision to Everyday Governance" by Atharva Pathak examines how artificial intelligence in India has evolved from a policy ambition into a practical tool of everyday governance, reshaping decision-making across sectors such as welfare, healthcare, education, climate action, public safety, and research. Anchored by the IndiaAI Mission, India's approach emphasises AI as a public good that augments human judgment rather than replacing it, supported by shared datasets, Centres of Excellence, and capacity building for civil servants. The article highlights AI's growing role in policy design, predictive analytics, environmental monitoring, citizen-centric service delivery, and disaster response, while underscoring the importance of ethics, transparency, and accountability. Overall, it presents India as a model for responsibly integrating AI into governance to improve administrative efficiency, evidence-based policymaking, and public service outcomes.

News Desk - Meomories Never Fade



Contents

Part I

Artificial Intelligence and Machine Learning

The Energy Footprint of AI: Scaling Systems and Environmental Concerns

by Arun Aniyan

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1.1 Introduction

The rapid expansion of Artificial Intelligence (AI) has brought about revolutionary advancements across industries, from autonomous vehicles and personalized medicine to complex financial modeling and large language models. However, this progress is underpinned by massive computational power, raising significant and escalating concerns about the energy consumption and the resulting environmental impact of AI systems.

The sheer scale and complexity of modern AI models, particularly those based on deep learning and transformer architectures, are pushing the limits of current energy infrastructure. Training a single state-of-the-art model can consume the energy equivalent of several homes over a year, releasing substantial amounts of carbon dioxide. This intense energy demand stems from the computational requirements for both the initial training phase—which can involve weeks or months of continuous processing on thousands of specialized chips (GPUs and TPUs)—and the ongoing inference phase when the model is actively used to generate predictions or content.

The escalating energy footprint is forcing technology companies to explore drastic and innovative solutions. As the number of data centers required to house and power these systems grows, so does the strain on local power grids and water supplies (needed for cooling). Consequently, companies are contemplating truly radical measures to secure the necessary power supply. These include speculative, cutting-edge proposals such as sending data centers to space to leverage natural vacuum cooling and solar energy more efficiently, or even building dedicated, small modular nuclear power plants to guarantee a stable, high-density, carbon-free energy source solely for their computational operations.

Ultimately, the future growth of AI is inextricably linked to addressing its environmental cost, demanding a concerted effort in hardware efficiency, algorithmic optimization, and the adoption of genuinely sustainable, low-carbon energy sources.

1.2 The Exponential Scaling of AI and Energy Demand

The relentless pursuit of peak performance in state-of-the-art Artificial Intelligence (AI) models, particularly within the domains of large language models (LLMs) and advanced deep learning systems, has established a direct and undeniable correlation between model capability and sheer scale. Superior accuracy, nuanced understanding, and broader capability are achieved primarily through increasing the model's architectural size and the astronomical volume of data ingested during training. This fundamental drive for enhancement has initiated an era of exponential growth in the computational resources—and consequently, the energy—required to develop and operate modern AI.

The environmental implications of this scaling are stark. The training phase alone for a single, massive AI model can necessitate an energy expenditure that is comparable to, or even exceeds, the lifetime carbon emissions of multiple passenger vehicles. This significant energy footprint is no longer an isolated event; as AI technologies are woven into the very fabric of daily life—powering everything from bespoke personalized digital recommendations and sophisticated autonomous vehicle systems to groundbreaking scientific research and complex global predictive modeling—the aggregate energy demand experiences a steep and continuous ascent. This demand encompasses both the initial, computationally intensive training phase and the ongoing, widely distributed inference phase, where the trained model is actively used to generate results.

A principal catalyst behind this escalating energy hunger is the unwavering industry commitment to developing progressively larger and more powerful models. This trend is most evident in the growth trajectory of leading LLMs. In a remarkably short period, the parameter count—a measure of a model's size and complexity—has ballooned from a few million to over a trillion. Crucially, this aggressive scaling shows no discernible signs of abating. This incessant increase in computational load mandates the construction, maintenance, and continuous operation of colossal, highly optimized data centers. These data centers, which require immense and constant streams of electricity for both computation and cooling, serve as the physical, infrastructural manifestation of AI's burgeoning and voracious appetite for power.

1.3 Innovative, High-Stakes Solutions

In response to this growing energy crisis, major technology companies are exploring unprecedented solutions.

1.3.1 Data Centers in Space

The concept of deploying data centers in space, as recently brought to light by Google's consideration, underscores the increasing severity of the energy and thermal management challenges facing modern AI infrastructure. On Earth, the relentless growth in AI model size and computational demands has pushed existing terrestrial data centers to their limits, particularly regarding the dissipation of immense waste heat.

The primary motivation for this extraterrestrial venture is the exploit the near-absolute zero temperature of deep space, which offers a virtually limitless and energy-free heat sink. This would drastically reduce the need for conventional, energy-intensive cooling systems (like large-scale HVAC and liquid cooling), which currently represent a significant portion of a data center's total energy footprint.

However, moving data centers off-planet introduces a new set of substantial logistical and energetic hurdles:

- **Initial Deployment Energy:** The energy required for manufacturing, assembly, and most critically, launching the data center hardware and supporting infrastructure into orbit or beyond would be astronomical. This initial 'carbon investment' must be offset by long-term energy savings to make the proposition environmentally viable.
- **Maintenance and Longevity:** Regular maintenance, hardware upgrades, and repairs, which are routine on Earth, become incredibly complex, costly, and energy-intensive in space. Missions to service or replace components would require launching further materials and personnel.
- **Communication and Latency:** Communicating with a data center in orbit or on the Moon introduces significant latency delays (light speed limitations) that could be prohibitive for real-time AI applications like autonomous vehicles, high-frequency trading, or interactive virtual assistants. While communication lasers could be used, the continuous, high-bandwidth energy required for uplinks and downlinks would still be considerable.
- **Operational Energy:** Even in space, power is

required for the computational units themselves, internal systems, attitude control, station-keeping, and the sophisticated communication arrays. While solar power in space is highly efficient, the power generation and storage infrastructure must be rugged, redundant, and massive to support an AI cluster.

Ultimately, while the vision of space-based data centers offers a potential long-term solution for thermal management, it also represents an extreme and capital-intensive attempt to manage the escalating energy footprint of scaling AI. It is a stark indicator that terrestrial solutions are rapidly becoming insufficient for the demands of the next generation of artificial intelligence.

1.3.2 Dedicated Nuclear power plans

The escalating energy demands of artificial intelligence, particularly for training and running large language models and complex neural networks, are pushing tech companies to consider radical energy solutions. A prime example is the discussion around industry leaders, such as OpenAI, actively exploring the feasibility of developing and operating their own dedicated nuclear power infrastructure. This initiative, specifically aimed at powering massive, next-generation AI data centers, highlights the sheer scale and consistency of power required that traditional renewable sources or the existing grid may struggle to meet.

Nuclear power presents a compelling, albeit controversial, answer to the AI energy crisis. As a carbon-free energy source, it aligns with sustainability goals by not directly emitting greenhouse gases during operation. Crucially, it offers high-density power that is consistently available—a critical requirement for 24/7 AI operations, unlike intermittent sources such as solar or wind. This reliability makes it an attractive proposition for the intense, constant computational load of advanced AI.

However, the path to nuclear-powered AI is fraught with significant hurdles. The regulatory landscape surrounding nuclear energy is notoriously stringent and complex, demanding exhaustive safety protocols, licensing, and oversight from national and international bodies. Safety concerns remain paramount; while modern reactor designs boast enhanced safety features, the public and environmental risk associated with any nuclear incident remains a powerful factor. Furthermore, the long-term management and disposal of nuclear waste present an enduring environmental and logistical challenge that requires robust, permanent solutions, adding considerable cost and complexity to the entire endeavor. The exploration of proprietary nuclear power for AI underscores a pivotal moment where technological advancement is directly confronting fundamental energy and environmental policy challenges.

1.4 Future Energy Demands and Environmental Impact

The accelerating trajectory of Artificial Intelligence (AI) development is placing an unprecedented and rapidly escalating demand on global energy resources. If the current pace of AI adoption and scaling continues unabated, the electricity consumption of the world's data centers—the essential infrastructure for AI—is projected to consume a significantly substantial and unsustainable portion of the total world's energy usage within the next decade. This growth is driven by the increasing computational complexity of state-of-the-art models (like Large Language Models and foundation models), which require massive, continuous training and inference cycles.

The environmental burden of AI extends far beyond the simple consumption of electricity. A holistic view reveals a complex set of environmental challenges tied to every stage of the AI hardware lifecycle and operation.

1. **Carbon Emissions: The Climate Cost of Computation**
   The most direct and immediate environmental concern is the contribution to greenhouse gas (GHG) emissions. The vast majority of the world's electricity grid still relies heavily on fossil fuels. Consequently, unless the energy

powering massive AI data centers is sourced entirely from verifiable renewable (e.g., solar, wind) or other low-carbon sources (e.g., nuclear), their continuous operation directly contributes to and exacerbates climate change. The process of model training, in particular, can be equivalent to the lifetime emissions of multiple automobiles, making AI a significant new driver of climate vulnerability.

2. **E-Waste and Hardware Lifecycle Challenges**
AI is an extremely hardware-intensive field. The specialized computational accelerators—primarily Graphics Processing Units (GPUs), Tensor Processing Units (TPUs), and other custom silicon—required for high-performance AI processing have a comparatively short effective lifecycle. The constant and rapid evolution of AI models and architectures necessitates frequent upgrades to more powerful, efficient hardware. This relentless cycle of replacement creates a rapidly accelerating and challenging problem of electronic waste (e-waste). This waste stream often contains complex assemblies and toxic materials (including heavy metals and flame retardants), which pose significant risks to human health and the environment when improperly disposed of in landfills. Furthermore, the mining and manufacturing of this specialized hardware are themselves resource-intensive and environmentally degrading processes.
3. **Water Usage: A Hidden Drain on Local Resources**
The immense concentration of power and heat generated by AI data centers necessitates sophisticated and equally immense cooling systems. These systems, particularly those that employ evaporative cooling, require colossal amounts of water. This consumption of water, often measured in the millions of liters per day for a single large facility, puts substantial pressure on local water resources, especially when data centers are located in already arid or hot climates. This excessive water withdrawal can contribute to or exacerbate drought conditions, reduce water availability for agriculture and human consumption, and severely impact local aquatic ecosystems and biodiversity. The competition for water between technological infrastructure and human/environmental needs is rapidly becoming a critical socio-environmental conflict.

1.5 Conclusion

Effectively addressing the profound environmental challenge posed by the scaling of AI will require a comprehensive and multi-faceted approach involving policy, engineering, and research. The primary objectives must include:

1. **Algorithmic Efficiency:** Prioritizing research into developing and deploying more energy-efficient AI algorithms, including techniques like model compression, sparse training, and efficient inference methods, to reduce the computational resources needed for a given performance level.
2. **Renewable Energy Transition:** Mandating and accelerating the shift of data center operations entirely to renewable energy sources through power purchase agreements (PPAs), on-site generation, and strategic location planning that optimizes access to clean power grids.
3. **Hardware Optimization and Longevity:** Improving the energy and thermal efficiency of specialized hardware, while also designing for longer lifecycles, enhanced recyclability, and establishing robust, safe end-of-life protocols for e-waste management.

The conversation surrounding AI must fundamentally shift its focus. It is no longer sufficient to merely discuss scaling capabilities; the imperative now is to scaling sustainability alongside performance to ensure the long-term viability and ethical deployment of this powerful technology.

About the Author

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Applications of Group Equivariant Convolutional Neural Networks

by Blesson George

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2.1 Introduction

Let $f : \mathbb{R}^2 \to \mathbb{R}$ represent an image. A standard convolutional layer applies a filter ψ to f as

$$(f * \psi)(x) = \int_{\mathbb{R}^2} f(y)\psi(x - y)\, dy. \tag{2.1}$$

This operation is *translation equivariant*, meaning

$$T_a(f * \psi) = (T_a f) * \psi, \tag{2.2}$$

where T_a denotes a translation by a.

However, translations alone are insufficient to model many practical symmetries such as rotations and reflections. Group equivariant CNNs extend this idea by incorporating general transformation groups into the convolution operation.

2.2 Group Equivariance: Mathematical Framework

Let G be a group acting on a space X. A function Φ is said to be equivariant with respect to group actions ρ_{in} and ρ_{out} if

$$\Phi(\rho_{\text{in}}(g)f) = \rho_{\text{out}}(g)\Phi(f), \quad \forall g \in G. \tag{2.3}$$

In G-CNNs, the convolution is defined over the group G:

$$(f * \psi)(g) = \sum_{h \in G} f(h)\psi(g^{-1}h), \tag{2.4}$$

for discrete groups, or using integrals for continuous groups.

This formulation ensures that feature maps transform predictably under the action of G.

2.3 Rotation-Equivariant CNNs

For image data, a commonly used group is the planar rotation group C_N or $SO(2)$. A rotation operator R_θ acts on an image f as

$$(R_\theta f)(x) = f(R_{-\theta}x). \tag{2.5}$$

A rotation-equivariant layer satisfies

$$\Phi(R_\theta f) = R_\theta \Phi(f). \tag{2.6}$$

Such networks are particularly effective in applications where object orientation is arbitrary, including aerial imagery and medical imaging.

2.4 Applications in Computer Vision

2.4.1 Image Classification

In image classification tasks, the goal is to learn a mapping

$$F : f \to y, \tag{2.7}$$

where y is a class label invariant under group transformations.

Equivariance at intermediate layers allows the network to build invariant representations at the final layer via pooling over the group:

$$y = \max_{g \in G} \Phi(f)(g). \tag{2.8}$$

This approach improves generalization while reducing reliance on data augmentation.

2.4.2 Object Detection and Segmentation

In segmentation tasks, equivariance ensures that spatial predictions transform consistently:

$$S(R_\theta f) = R_\theta S(f), \tag{2.9}$$

where $S(f)$ denotes the segmentation map.

This property is crucial in remote sensing and biomedical imaging, where object orientation varies significantly.

2.5 Medical Imaging Applications

Medical images can be modeled as functions defined on continuous domains with rotational symmetry. G-CNNs incorporate these symmetries directly, improving performance in tasks such as tumor detection.

For a classifier C, rotational invariance can be enforced as

$$C(R_\theta f) = C(f), \tag{2.10}$$

which is achieved by combining equivariant layers with invariant pooling.

2.6 Scientific and Physical Applications

2.6.1 Physics-Informed Learning

Physical systems often obey symmetry laws. For a physical field $u(x)$ governed by a PDE,

$$\mathcal{L}u = 0, \tag{2.11}$$

equivariance ensures that learned solutions respect transformation symmetries of $\mathcal{L}$.

G-CNNs have been used to learn mappings between physical states while preserving rotational and translational symmetry.

2.6.2 Molecular Modeling

Molecules can be represented as point clouds in $\mathbb{R}^3$. For a molecular property predictor P,

$$P(Rx) = P(x), \quad \forall R \in SO(3), \tag{2.12}$$

ensuring physical consistency. Group equivariant networks naturally satisfy this constraint.

2.7 Beyond Images: Permutation Equivariance

For graph-structured data, node permutations form a symmetry group. A graph neural network layer Φ is permutation equivariant if

$$\Phi(\pi X) = \pi\Phi(X), \tag{2.13}$$

where π is a permutation matrix.

This principle underlies applications in chemistry, social networks, and recommendation systems.

2.8 Challenges and Future Directions

While G-CNNs offer theoretical and practical benefits, challenges remain in scaling to large continuous groups and reducing computational overhead. Hybrid approaches combining group equivariance with attention mechanisms and transformers represent an emerging research direction.

2.9 Conclusion

By embedding symmetry principles directly into neural architectures, group equivariant CNNs provide robust, data-efficient models across diverse application domains. The inclusion of mathematically grounded equivariance constraints bridges the gap between theory and practice in deep learning.

About the Author

Dr. Blesson George presently serves as an Assistant Professor of Physics at CMS College Kottayam, Kerala. His research pursuits encompass the development of machine learning algorithms, along with the utilization of machine learning techniques across diverse domains.

Why Simple Measures Still Matter in the Era of Deep Learning

by Jinsu Ann Mathew

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www.airis4d.com

Deep learning methods such as neural networks, transformers, and convolutional models have transformed modern technology. They power voice assistants, image recognition systems, and automatic translation tools. These methods learn complex patterns by processing large amounts of data through many layers.

However, alongside these powerful tools, simpler analytical methods continue to be widely used. Techniques based on counting, averaging, similarity, or basic statistical summaries still play an important role. Their continued use shows that not every problem requires deep learning—and that simpler approaches often provide strong, reliable answers.

3.1 The Limits of Complexity

Deep learning models are designed to capture very detailed relationships in data. For example, a deep neural network for text analysis may learn sentence structure, word meaning, and context across many layers. While this is impressive, it also introduces challenges.

Such models require large datasets, long training times, and careful tuning. They can also fail in unexpected ways if the data changes slightly. For instance, a deep learning spam filter trained on one type of email may perform poorly when spam styles evolve.

In contrast, simple methods such as keyword counting, frequency thresholds, or basic scoring rules often work surprisingly well. A spam filter that checks how often certain words or symbols appear can already block many unwanted emails. In problems where patterns are clear, complex models may add effort without providing much benefit.

3.2 Seeing the Big Picture

Deep learning excels at learning fine details, but simple measures are better at capturing overall trends. For example, image recognition models analyze pixel-level features across many layers to identify objects. Yet, in some cases, overall brightness, color distribution, or shape size is enough to separate one category from another.

In data monitoring, deep learning models may analyze every signal variation, while a simple average or trend line can reveal sudden changes immediately. For instance, detecting unusual network traffic may only require tracking the total number of requests over time, rather than modeling each connection individually.

Because simple methods summarize data instead of examining every detail, they often remain stable even when data is noisy, incomplete, or imperfect—conditions where deep learning models may struggle.

3.3 Clarity as a Scientific Advantage

One major drawback of deep learning methods is that they are often difficult to explain. A neural network might make an accurate prediction, but explaining why it reached that conclusion can be challenging even for experts.

Simple methods offer clear reasoning. If a document is classified as suspicious because it contains repeated unusual patterns or extreme values, the explanation is easy to understand. This transparency is especially important in areas like healthcare, education, and policy-making, where decisions must be justified.

For example, a medical system that flags patients based on simple risk scores is easier to trust than a complex model that provides no clear explanation, even if the complex model is slightly more accurate.

3.4 Practical Foundations for Sustainable Progress

Simple methods play an important role in making technology practical and sustainable. One of their biggest strengths is efficiency. They work quickly, need less data, and can run on ordinary computers. This makes them useful in situations where time, money, or technical resources are limited. For example, a basic rule-based system can often detect unusual activity in data immediately, without waiting for a complex model to be trained.

Simple methods also act as a starting point for more advanced systems. Before using deep learning, researchers often begin with simple approaches to understand the data. These early steps help answer basic questions such as: Is there a clear pattern? Is the problem really complex? In many cases, these simple checks already provide useful results and may even remove the need for a deep model.

Even when deep learning is used, simple methods remain important for comparison. They act as reference points. If a complex model does not perform significantly better than a simple one, then the extra effort may not be worthwhile. This comparison helps ensure that technology is used wisely and responsibly.

Most importantly, simple methods encourage a balanced view of progress. Advancement does not mean replacing all old ideas with new ones. Instead, it means choosing the right level of complexity for each problem. Simple approaches remind us that understanding, efficiency, and reliability are just as valuable as accuracy. In this way, they support long-term progress that is both practical and meaningful.

3.5 Conclusion

The rapid growth of deep learning has expanded what machines can do, but it has not reduced the value of simple methods. Instead, it has highlighted their importance. Simple measures continue to matter because they are easy to understand, efficient to use, and reliable across many real-world situations.

While deep learning is powerful for complex problems, simple approaches often provide strong results with far fewer resources. They help reveal overall patterns, offer clear explanations, and serve as dependable foundations for advanced systems. In many cases, they guide researchers in deciding whether deeper complexity is truly necessary.

Ultimately, progress in technology is not about choosing between simplicity and complexity, but about balancing the two. Simple methods remind us that effective solutions are not always the most complicated ones—they are the ones that best match the problem at hand.

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About the Author

 Jinsu Ann Mathew is a research scholar in Natural Language Processing and Chemical Informatics. Her interests include applying basic scientific research on computational linguistics, practical applications of human language technology, and interdisciplinary work in computational physics.

Part II

Astronomy and Astrophysics

Plasma Physics- Fusion Energy- Challenges and Solutions

by Abishek P S

AIRIS4D, VOL.4, NO.1, 2026

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1.1 Introduction

Plasma is the essential medium in which nuclear fusion takes place, and understanding its behaviour is central to fusion energy research. Often referred to as the "fourth state of matter," plasma is an ionized gas where electrons are stripped from atoms, leaving behind positively charged ions[1]. Because both ions and electrons carry charge, they interact strongly with electromagnetic fields, making plasma both difficult to control and uniquely suited for fusion reactions. In a fusion environment, plasma provides the conditions where light nuclei such as deuterium and tritium collide and fuse into heavier nuclei, releasing immense amounts of energy. Fusion energy is increasingly seen as a necessity because of the global challenges we face in energy, climate, and sustainability. The world's population and industrial activity continue to grow, driving up electricity demand at a time when fossil fuels are depleting and causing severe environmental damage. Fusion offers a solution that is both abundant and clean. Its fuel hydrogen isotopes like deuterium and tritium can be sourced from water and lithium, which are widely available and evenly distributed across the planet. This means fusion energy could provide a virtually limitless supply of power without the geopolitical tensions associated with oil and gas reserves. Unlike fossil fuels, fusion produces no greenhouse gases, making it a cornerstone technology for combating climate change and achieving net-zero emissions targets.

Another reason fusion is needed is its safety advantages compared to nuclear fission. Fusion reactions do not rely on chain reactions, so there is no risk of runaway meltdowns like those seen in fission reactors. The waste produced is minimal and short-lived, unlike the long-lived radioactive byproducts of fission. This makes fusion far more acceptable from both an environmental and public safety perspective. Fusion also has the potential to deliver continuous, reliable baseload electricity, unlike solar and wind, which are intermittent and weather-dependent. By complementing renewables, fusion could stabilize energy grids and ensure a steady supply of power for industries, cities, and households.

Economically, fusion energy is needed to secure long-term energy independence. Fossil fuels are finite and subject to volatile markets, while fusion fuel is abundant and inexpensive once the technology is mastered. Fusion reactors could also be designed to provide not just electricity but high-grade industrial heat, desalination for freshwater, and even medical isotopes, diversifying their benefits. In the long run, fusion could reduce reliance on imported fuels, lower energy costs, and drive new industries built around advanced materials and superconducting technologies.

Finally, from a societal perspective, fusion represents hope for a sustainable future. It addresses the dual challenge of meeting rising energy demand while protecting the planet from climate catastrophe. It also inspires international collaboration, as seen in projects like International Thermonuclear Experimental Reactor (ITER), where countries pool resources and expertise to achieve a shared goal. Public acceptance of fusion is generally high because it is perceived as safer than fission and cleaner than fossil fuels, but continued investment and transparent communication are needed to maintain trust.

In essence, the need for fusion energy stems from its ability to provide abundant, safe, and climate-friendly power that can sustain human progress without compromising the environment. It is not just a technological ambition, it is a global imperative for energy security, climate stability, and a sustainable future.

1.2 Challenges

Harnessing plasma for fusion energy presents challenges across scientific, engineering, economic, and societal domains. Scientifically, the greatest hurdle is sustaining plasma at extreme temperatures of 100–150 million degrees Celsius. At these conditions, plasma becomes unstable and prone to turbulence, disruptions, and instabilities such as kink and ballooning modes, which can cause sudden energy losses or damage to the reactor. Another critical challenge is meeting the Lawson criterion, which requires the right balance of plasma density, temperature, and confinement time. If this balance is not achieved, plasma cools before fusion reactions can occur, preventing net energy gain.

From an engineering perspective, plasma interacts aggressively with reactor materials. Plasma-facing components such as divertors and first walls are constantly bombarded by high-energy particles and neutrons, leading to erosion, embrittlement, and structural degradation. Developing materials that can withstand these conditions over long durations is a major challenge. Magnetic confinement devices like tokamaks and stellarators also demand extremely precise magnetic fields to keep plasma stable, and even small deviations can destabilize confinement[2,3]. Fuel handling adds further complexity, particularly with tritium, which is radioactive and scarce. Safe and efficient tritium breeding and storage systems are essential for future reactors.

Economically, fusion reactors are expensive to build and operate. They require advanced superconducting magnets, powerful laser systems, and specialized materials, all of which drive up costs. Current experiments often consume more energy than they produce, so achieving net-positive energy output remains a critical milestone. Scaling up experimental devices to commercial power plants introduces additional complexity, as larger systems amplify engineering and financial challenges.

On the societal and regulatory side, fusion is generally considered safer than fission because it does not involve chain reactions, but risks remain. Tritium leakage, neutron radiation exposure, and accidents during plasma disruptions are potential hazards. Strict safety standards are needed to regulate radioactive materials and manage neutron-activated waste. Public acceptance is also a challenge, as fusion projects require long timelines and massive investments, often leading to skepticism about feasibility.

Plasma confinement is one of the greatest obstacles in fusion research. Because plasma cannot touch physical walls without cooling instantly, scientists use magnetic confinement (tokamaks and stellarators) or inertial confinement (lasers or particle beams) to keep plasma stable long enough for fusion reactions to occur. Magnetic confinement relies on strong magnetic fields to trap plasma in a toroidal shape, while inertial confinement compresses fuel pellets so rapidly that the plasma's own inertia prevents it from dispersing.

1.3 Solutions

Addressing the challenges of plasma confinement in fusion energy requires solutions that span science, engineering, economics, and society. On the scientific side, researchers are working to better understand and control plasma instabilities, which are one of the biggest obstacles to sustained fusion. Advanced magnetic configurations in devices like tokamaks and stellarators are being designed to minimize turbulence and disruptions. Real-time feedback systems that use microwaves, neutral beams, or magnetic perturbations are being developed to actively suppress instabilities such as edge-localized modes. In addition, scientists are experimenting with shaping plasma profiles to create transport barriers that reduce energy leakage, while artificial intelligence is increasingly being used to predict and prevent disruptions before they occur[4]. In inertial confinement approaches, precision in laser targeting and capsule design is being improved to achieve perfectly symmetrical implosions, which are critical for ignition.

From an engineering perspective, the focus is on building reactors that can withstand the extreme conditions created by plasma. Plasma-facing materials such as tungsten composites, liquid metals like lithium, and radiation-resistant alloys are being tested to handle intense heat fluxes and neutron bombardment. Divertor systems with innovative geometries, such as the snowflake or super-X designs, are being developed to spread heat loads and protect reactor walls. High-temperature superconducting magnets are another breakthrough, allowing stronger magnetic fields in smaller devices, which improves confinement and reduces reactor size. Tritium breeding blankets are being designed to ensure a self-sufficient fuel cycle, while robotic systems for remote handling are being created to safely replace and repair components without human exposure to radiation[3].

Magnetic confinement devices include tokamaks, which use a combination of toroidal and poloidal magnetic fields along with plasma currents to confine plasma. While effective, tokamaks are prone to instabilities due to their reliance on plasma current. Stellarators, by contrast, use twisted external magnetic coils to generate complex three-dimensional fields that confine plasma without requiring a plasma current, making them more stable for steady-state operation, though their design is far more complex. Simpler devices like magnetic mirrors trap plasma between regions of stronger magnetic fields, but suffer from particle losses and are less efficient for large-scale fusion.

Inertial confinement takes a different approach by compressing tiny fuel pellets, typically deuterium-tritium mixtures, with powerful lasers or particle beams. The implosion is so rapid that the fuel's inertia prevents it from dispersing before fusion occurs. This method achieves extremely high densities, far greater than magnetic confinement, but only for nanoseconds. The main challenge lies in achieving perfect symmetry in the implosion, as even small imperfections can prevent ignition. Despite these difficulties, inertial confinement has shown promise, with facilities like the National Ignition Facility (NIF) achieving significant breakthroughs in recent years.

Ultimately, the central challenge of confinement is plasma stability. Plasmas are highly dynamic and prone to instabilities and turbulence, which degrade confinement and lead to energy losses. Plasma also loses energy through radiation and particle transport, requiring continuous input to sustain fusion conditions. Designing magnetic geometries that minimize instabilities while maximizing confinement time is one of the most difficult aspects of fusion research. In inertial confinement, precision is paramount: the implosion must be perfectly uniform, and lasers must deliver energy with extreme accuracy. Overcoming these challenges is key to unlocking the promise of fusion energy as a safe, clean, and virtually limitless power source.

Economically, fusion projects are exploring ways to reduce costs and accelerate deployment. Compact reactor designs, such as those using high-field superconducting magnets, aim to deliver the same performance as larger devices but at lower cost. Modular construction strategies allow reactors to be built in standardized sections, simplifying maintenance and reducing expenses. Staged deployment, where components are tested in smaller facilities before scaling up, helps spread investment and reduce technical risk. Advances in manufacturing, including 3D printing and precision coil winding, are lowering production costs for complex reactor parts. Fusion plants may also diversify their revenue streams by providing industrial heat, desalination, or medical isotopes in addition to electricity.

On the societal and regulatory side, safety and public trust are critical. Fusion is inherently safer than fission because it does not involve chain reactions, but risks such as tritium leakage and neutron radiation must still be managed. Strict international safety standards are being established to regulate fuel handling and waste management. Transparent communication of milestones and performance data helps build credibility and public support, while global collaboration through projects like ITER pools resources and expertise to accelerate progress. Public engagement programs are also important to explain fusion's benefits and challenges, helping overcome skepticism about its long timelines and high costs.

Taken together, these solutions form a comprehensive roadmap for overcoming the obstacles of plasma confinement. By combining scientific advances in plasma control, engineering innovations in materials and magnets, economic strategies to reduce costs, and societal frameworks to ensure safety and acceptance, fusion energy can move closer to becoming a practical, clean, and virtually limitless power source for the future.

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Black Hole Stories-23
Binary Neutron Star Merger

by Ajit Kembhavi

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In this story we will describe the merger of the two components of a binary neutron star, which was observed by the LIGO and Virgo detectors in August 2017. The electromagnetic emission from the merger was also observed from the ground and space, which led to unprecedented interest in the event by the astronomical community. A very large number of research papers were written, and some effects predicted decades ago were observed. At the time of writing, this remains the only merger observed by gravitational wave detectors which has also been observed at electromagnetic wavelengths.

2.1 Binary Neutron Star Merger Detection

The story began on August 17, 2017, when the advanced LIGO (aLIGO) detectors at Hanford and Livingston, and the advanced VIRGO (aVIRGO) detector in Italy, detected a signal which lasted about 100 seconds. Following convention, the signal was named GW170817. From simple visual inspection of the two aLIGO signals it was apparent that the detection could have been generated by the spiral-in of a neutron star binary.

A cosmic Gamma-ray burst was independently observed by the Gamma-ray burst Monitor (GBM) on the Fermi satellite just 1.7 seconds after the end of the gravitational wave detection. A Gamma-ray burst (see below for a description) is expected in a binary neutron star merger, because of the enormous amount of electromagnetic energy emitted. A world-wide alert was therefore generated so that astronomers could prepare to observe the event with ground and space based telescopes. Quick analysis of data from the three gravitational wave detectors made it possible to locate the source within an area of about 31 square degrees of the sky.

2.2 Neutron Star Binaries

In the case of the black hole binaries detected by aLIGO, the component black holes before the merger, the system during the merger, the ringdown phase after the merger and the final black hole are all invisible electromagnetically. Only the gravitational waves emitted can be detected. Neutron star binaries are quite different from black hole binaries. In BHS-17 and BHS-18, we have discussed in detail the binary pulsar PSR1913+16, in which one component of the binary is a neutron star which is radio pulsar, while the other component is a non-pulsating neutron star. It is the radio pulsations which enabled the discovery of the object, and accurate measurements of the small changes in the observed period led to the identification of the binary system and led to the determination of the properties of the neutron stars and the binary. It was observed that the size of the binary is shrinking, which could be attributed to energy loss due to the emission of gravitational waves by the binary. As the binary becomes more compact, the rate at which energy is lost increases, so that the binary shrinks in size even faster. It is estimated that the spiral-in process will be completed and the neutron stars will merge in about 300 million years. GW170817 is just such a merger.

The process of merger of the two neutron stars is very violent. As the stars approach each other ever more closely, the gravitational field of each neutron star distorts the shape of the other star, like the tides produced in the oceans of the Earth due to the gravitational fields of the Sun and the Moon. As the distance between the two neutron stars becomes comparable to their radius, which is about 10 km, the tidal force becomes so large that each star is torn apart and the matter from the two merges together. The gravitational energy released in the process leads to a tremendous explosion in which some of the matter is ejected from the system. The remaining matter undergoes a collapse due to the large gravitational force dragging the matter inwards. If the mass of the collapsing core is less than the maximum permissible mass of a neutron star, then as discussed in earlier stories, the collapsing object forms a neutron star. But if the mass of the remnant is more than the maximum mass limit for a neutron star, a black hole must be formed from the merger.

2.3 Electromagnetic Counterpart of the Gravitational Wave Detection

Gamma-Ray Bursts:

The explosion which results during the neutron star merger is expected to produce a Gamma-ray burst. In such bursts a tremendous amount of energy is released, in which first there is explosive release of Gamma-rays, which is followed by electromagnetic radiation of various kinds, including X-rays, optical radiation and radio waves. Hundreds of Gamma-ray bursts lasting for various duration, ranging from a fraction of a second to hundreds of seconds and longer have so far been observed. The amount of energy emitted in such a short time is equivalent to the total energy emitted by a star like the Sun in about a trillion years. Some of the bursts with short duration of less than 2 seconds are believed to be produced by merging neutron stars.

Properties of the System:

The detection of the Gravitational wave source GW170817 and the independent detection of a Gamma-ray burst within 1.7 seconds of it generated tremendous excitement, as the event could lead to better understanding of gravitational wave sources, Gamma-ray bursts and very high density matter in its most extreme form. On the gravitational side, analysis of the data from the aLIGO and aVIRGO detectors led to very interesting results. The total mass of the system before the merger was found to be in the range of 2.73 and 2.82 Solar masses, the mass of one of the components was in the range of 0.86 to 1.36 Solar masses, while the mass of the other component was in the range of 1.36 to 2.26 Solar masses. The masses cannot be more accurately determined because these are linked to how much spin the two objects have, and that is not known at the present. Since the two components have merged and do not any longer exist as independent objects, their further observation is not possible. But over time it will be possible to analyse the data in increasingly sophisticated ways, so that more information will be obtained and used to determine the properties more accurately.

A very important quantity associated with the source is its distance from us. For a gravitational wave detection, the luminosity i.e. the total gravitational wave energy emitted by system per second is known, as well as the flux measured on the Earth. From these two quantities the distance to the source is determined. The distance to GW170817 determined from gravitational wave observations is about 130 million light years, which is much less than the distance to the detections made earlier. As a consequence, GW170817 is the most intense gravitational wave source detected at that time. Because it was so intense, the source could be observed by the aVIRGO as well, in addition to the two aLIGO detectors. That allowed the position in the sky to be determined to within an area of 31 square degrees. The source is near the southern end of the constellation Hydra. Astronomers searched this part of the sky with a multitude of telescopes and soon found a transient source which had appeared in the galaxy NGC3993, about 75,000 light years from its centre.

Detailed observations of the source were carried out at optical, near-infrared, X-ray and radio wavelengths by various ground and space based telescopes and a great deal of data was obtained.

2.4 Nature of the Binary Components:

The mass of each component was well within the range of known neutron star masses which were determined from the many known binary neutron stars and X-ray binaries. The two masses were also well below the mass of known black holes associated with binary stellar systems, as determined from gravitational wave and X-ray data. It is therefore reasonable to assume that the two components were neutron stars, and much of the work on the source has proceeded on that assumption. Nevertheless, it is important to keep in mind that either of the objects could have been compact exotic objects like quark stars, or they could be low mass black holes. Further information will be obtained as the analysis of data on GW170817 progresses and more such systems are observed in the future. But it is clear that both objects could not have been black holes. The observation of Gamma-rays and other electromagnetic radiation from GW170817 mean that at least one of the objects must have had finite size, with matter flow having taken place from this object to the other one. If both components were black holes then no electromagnetic radiation would have been detected.

2.5 Nature of the Remnant:

What is the nature of the remnant formed from the merger? The mass of the remnant, which is 2.82 Solar masses, is again in the range of known neutron star masses, but close to the upper limit. So while a large mass neutron star could be formed, depending on its mass an spin, it would be short lived, collapsing in less than a second, or it could be long lived, existing for 10,000s, or even much longer duration, before collapsing to a black hole. It could also be long lived stable neutron star. A neutron star remnant would emit gravitational waves upon formation because of irregularities present in its structure, but these are at high frequencies which cannot be efficiently detected by aLIGO. The merger could also lead to the formation of a black hole, in which case there would be the ringdown gravitational wave emission as in the case of GW150914. But this again is at high frequencies around 6000 Hz, at which the detectors do not have sufficient sensitivity. The nature of the object remains unresolved as of 2025.

2.6 Production of Heavy Elements

Observations of the electromagnetic counterpart of GW170817, known as EM170817, at various wavelengths have led to a great deal of information about the nature of the spectrum in the optical and near-infrared regions. From the shape of these spectra it can be concluded that several elements heavier than iron must be present in the matter being expelled during the merger. The production of such elements has so far remained a puzzle. It is known that the lightest elements hydrogen and helium and some light elements like lithium, beryllium and boron in trace quantities are produced in the Big Bang. More helium and all the heavier elements continuing up to iron are produced in the interiors of stars due to nucleosynthesis. It has long been believed that elements heavier than iron, particularly those which require a mechanism involving the rapid capture of neutrons by atomic nuclei, in what is known as r-process, were produced in supernovae. More recently it has been argued that such elements could be produced in the neutron rich matter present during neutron star mergers. The observed spectra of EM170817 are consistent with this expectation. A total of 16,000 times the mass of the Earth in heavy elements is believed to have formed, including approximately 10 Earth masses just of the two elements gold and platinum (Wikipidia). Some of the nuclei produced in this manner are unstable and undergo radioactive decay, leading to explosive electromagnetic emission which is known as a kilonova. The observed emission from EM170817 is consistent with known theoretical models of kilo novae.

2.6.1 Kilonova:

A number of short lived Gamma-ray bursts have so far been observed. It is believed that the emission from such sources is produced by matter moving in a narrow jet at speeds very close to the speed of light towards the observer. It has also been believed that such short period Gamma-Ray bursts are produced during the merger of neutron stars. Observation of the emission from EM170817 show that while it is indeed a short duration Gamma-ray burst, the rate of Gamma-ray emission from it is about 10,000 times smaller than other such known bursts. Detailed considerations show that EM170817 must be quite different from the earlier sources, and new models are required to explain its behaviour. While several models have been considered, there is no agreement yet as to the correct one which is consistent will all observations.

2.7 Determination of Hubble's Constant and the Speed of Gravitational Waves

Our Universe can be considered to be homogeneous and isotropic, which means that the distribution of its contents is the same at all positions Universe and the same in all directions, when viewed from any position The Universe is known to be expanding, and its scale at a given cosmological epoch is determine by an expansion factor S(t). The form of S(t) is determined by solving Einstein's equations of gravitation whose form is greatly simplified due to the homogeneity and isotropy. The rate of expansion of the Universe is determined by the Hubble parameter

$$H = \frac{1}{S(t)}\frac{dS(t)}{dt}$$

The value of the of H at the present epoch t_0

$$H_0 = \frac{1}{S(t_0)}\frac{dS(t_0)}{dt}$$

known as Hubble's constant is very important for cosmology. The current age of the Universe and the cosmological distances of objects depend on it.

The expansion of the Universe leads to redshift of light received from objects at cosmological distances. The redshift z for an object is

$$z = \frac{\Delta\lambda}{\lambda}$$

where $\Delta\lambda$ is the change in the wavelength λ of some specific spectral line emitted by a source. It is found that for objects at cosmological distances, $\Delta\lambda$and therefore z is positive, so distant objects are moving away from us, which establishes that the Universe is expanding. In the 1930s, it was discovered by Edwin Hubble and Georges Lemaitre that the velocity with which distant objects are receding from us is proportional to their distance, which can be written as

$$v = \frac{c}{H_0}d$$

where c is the speed of light. For v smaller than c, it can be shown from cosmological considerations that

$$z = \frac{v}{c} = \frac{d}{H_0}$$

These relations are approximate and valid only for v $<<$ c, i.e. z $<<$1. Observationally distant galaxies and quasars are found to have z much larger than 1. In such cases exact counterparts of the above equations, derived taking into account the curvature of space-time over large distances, are used.

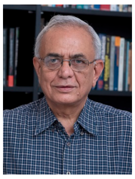
The redshift of an object can be determined from its observed spectrum. If the distances to a number of objects with known z can be measured, then H_0 can be determined. This is a rather difficult exercise, and currently the value of the Hubble constant determined using Supernovae Type Ia as distance indicators is$H_0 = 73km/sec/Mpc$, where Mpc is one million parsec. A smaller value of 67 km/sec/Mpc is obtained using cosmic microwave background data from the Planck mission.

The above methods for determining H_0 use distances obtained through electromagnetic measurements. Observations of the neutron star binary provide an independent way of measuring distances. The distance to the binary merger is determined from the gravitational wave observations as discussed above, while the cosmological redshift is determined from the optical spectrum of the electromagnetic counterpart. Combining the two leads to determination of Hubble's constant. For small redshifts, Hubble's constant obtained in this manner is consistent with the value obtained by conventional means which use only electromagnetic observations. With further neutron star binary observations, the precision with which Hubble's constant is determined from gravitational wave observations will improve.

Distances are also determined for black hole binary mergers. But here the redshift is not determined, since there is no electromagnetic radiation. But if the host galaxy for in which the merger is located is known, then the measured redshift of the galaxy provides the redshift of the merger. The difficulty here is that because the position in the sky of a gravitational wave source is difficult to determine, the host galaxy is not known precisely. There are also other techniques which can be used to estimate the redshift. It is expected that as more data becomes available, a precise value of the Hubble's constant based on gravitational wave measurements will emerge.

The Gamma-ray burst associated with the neutron star merger was observed 1.74 s after the merger. From the delay it is possible to determine that the speed gravitational waves is the same as the speed of light, to within one millionth of a billionth of the light speed, confirming with great precision Einstein's prediction that the two speeds must be the same.

About the Author



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The Geometry of Truth: Shapley Values for Model Interpretability

by Linn Abraham

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3.1 Introduction

In the study of solar flares, we have moved past the era of simple observation into the era of deep learning. While models can now predict flares from SDO/AIA images with high accuracy, they remain "black boxes." To turn these predictions into scientific discovery, we can try to answer a question like which specific AIA passband (e.g., 94Å, 171Å, 131Å) is the primary driver of the model's logic. We achieve this using Shapley values, a method from cooperative game theory that provides a mathematically "fair" way to distribute credit among different physical inputs.

3.2 The Marginal Contribution Experiment

To understand the importance of a passband, we treat the AIA channels as players in a game. The "payout" of the game is the flare probability predicted by the model. The method calculates the Marginal Contribution of each passband. Imagine we are testing the importance of the 94Å (flaring iron) channel. The SHAP (SHapley Additive exPlanations) method follows this protocol:

- It takes a subset of other channels (e.g., just 171Å and 304Å) and records the model's flare prediction.
- It then adds the 94Å channel to that group and records the new prediction.
- The difference between those two scores is the "marginal contribution" of 94Å for that specific combination.
- The Calculation: The final Shapley value is the weighted average of these marginal contributions across every possible combination of channels.

By testing the channel in every possible context, we ensure that we aren't just seeing a fluke; we are seeing the indispensable value of that specific wavelength to the model's "reasoning."

3.3 Problem of Interaction (Synergy)

Solar flares are inherently non-linear, emergent phenomena. Often, a single passband carries very little predictive weight on its own. For example, a slight brightening in the 171Å channel (the quiet corona) might be routine. However, when that brightening occurs in tandem with a specific magnetic configuration in the 1600Å channel (the photosphere), it becomes a critical precursor.

Traditional importance metrics—such as Permutation Importance or Saliency Maps—struggle with this because they often treat features as independent variables. Because the Shapley method calculates the contribution of 171Å within the context of every possible subset (including the subset containing 1600Å), it captures these Interaction Effects. It essentially maps the "team chemistry" of the AIA channels, revealing how different layers of the solar atmosphere work in concert to trigger an eruptive event.

3.4 Causality as a "Fair Share"

Philosophically, we often argue about "The Cause" of a flare. Is it magnetic shear or flux emergence? In reality, it is a "cooperative game" played by multiple physical layers.

Shapley values allow us to move away from looking for a "silver bullet" and instead accept a Distributed Causality. The method is governed by the Axiom of Efficiency, which states that the sum of all Shapley values must exactly equal the final prediction. This satisfies the scientific need for a quantitative, additive explanation: "0.6 of this flare probability was 'caused' by the 94Å channel, and 0.4 was 'caused' by the 131Å channel."

3.5 The Counterfactual Gold Standard

The most powerful aspect of this method is Counterfactual Reasoning. In philosophy, a counterfactual asks: "What would have happened in a world where everything stayed the same, but this one passband was different?" In a standard neural network, you cannot simply "turn off" a passband because the model expects a complete tensor input. To bypass this, the Shapley method uses a "Reference Baseline"—usually the average value of a channel across the entire dataset—to simulate the absence of information.

By mathematically simulating these "alternative solar worlds" during the marginal contribution tests, the method provides a rigorous answer to the "What if?" question. It allows the researcher to move from a vague intuition like "I think this channel is important" to a concrete, evidence-based claim: "I have mathematically proven that this specific 94Å emission is the pivot point upon which the model's entire prediction rests."

3.6 The Geometry of Truth: The Vector Sum

This approach provides what can be described as a Geometry of Truth because of the "Axiom of Efficiency." In many statistical models, the "importance" of various features doesn't necessarily add up to the final result; there is often unexplained variance or overlapping credit. Shapley values, however, create a perfect closed system.

If the model starts at a "base rate" (the average flare probability across your entire dataset, say 5%) and ends at a 90% flare prediction for a specific active region, the Shapley values of the individual passbands act as vectors that must bridge that 85% gap exactly. Each AIA channel pushes the prediction toward or away from the flare. When you sum these vectors, they land precisely on the model's final output. There is no "missing logic" and no overlap. Every percentage point of the model's certainty is accounted for and assigned to a specific physical layer of the Sun. This geometric decomposition ensures that the explanation is as rigorous as the mathematical model itself.

3.7 Resolving the "Clever Hans" Confusion

A common point of confusion in interpretability is whether SHAP shows us how the Sun works. It is vital to clarify: SHAP shows the truth of the model, not necessarily the truth of nature. In machine learning, we often encounter the "Clever Hans" effect—where a model produces the right answer for the wrong reason. For instance, a model might achieve high accuracy by looking at a specific calibration artifact in the 171Å channel rather than the actual magnetic reconnection physics. By using Shapley values, we can perform a "sanity check." If the model consistently assigns high importance to the 94Å and 131Å channels (the hottest plasma), we gain confidence that the model has successfully captured the underlying physics. If it ignores these and relies on irrelevant data, SHAP exposes the model as a statistical fluke rather than a scientific instrument.

3.8 Local vs. Global Insights

Finally, the Shapley method allows us to oscillate between two scales of discovery:

Local Attribution: For one specific flare, we can generate a spatial heatmap. This shows us not just which passband mattered, but where in the image the model was looking—perhaps a specific brightening at the magnetic neutral line.

Global Interpretation: By averaging these values across thousands of images, we can rank the AIA passbands. This tells us which physical "thermometer" the model trusts most across the entire solar cycle.

3.9 Conclusion

By treating the model as a "cooperative game," we bypass messy debates about subjective importance. We treat the model's decision-making process as a territory to be mapped. Shapley values provide the coordinates, showing us exactly which physical "expert" the model trusted most to call the flare.

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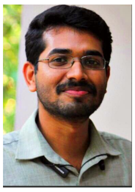
About the Author



Linn Abraham is a researcher in Physics, specializing in A.I. applications to astronomy. He is currently involved in the development of CNN based Computer Vision tools for prediction of solar flares from images of the Sun, morphological classifications of galaxies from optical images surveys and radio galaxy source extraction from radio observations.

Part III

Biosciences

DNA Damage Assessment at the Single-Cell Level Using the Alkaline Comet Assay

by Aengela Grace Jacob

airis4D, Vol.4, No.1, 2026

www.airis4d.com

1.1 Introduction

The cell stands as the fundamental unit of life, a microscopic powerhouse that orchestrates the intricate mechanisms sustaining living systems. This foundational ideology highlights how metabolic changes within cells propagate outward, affecting organismal health, disease progression, and environmental resilience. Disruptions at the cellular level, particularly DNA damage from genotoxic agents like radiation, chemicals, or oxidative stress, can cascade into systemic failures, manifesting as cancer, infertility, or accelerated ageing. Understanding these processes demands precise tools to quantify damage, repair kinetics, and genotoxic potential, bridging molecular biology with public health implications.

Central to this evaluation is the Alkaline Comet Assay, also known as single-cell gel electrophoresis (SCGE), a versatile and highly sensitive technique for assessing DNA integrity at the individual cell level. Developed in the 1980s and refined over decades, it detects single- and double-strand breaks, alkali-labile sites, and incomplete repair intermediates by exploiting the principle of DNA migration under alkaline conditions. Cells are embedded in agarose on microscope slides, lysed to expose nucleoids, subjected to high-pH electrophoresis (pH >13), and stained for fluorescence microscopy. Damaged DNA fragments migrate from the nuclear head to form a comet-like tail, whose morphology directly correlates with lesion severity.

This low-cost, rapid method (yielding results in hours) excels in biomonitoring occupational exposures, predicting cancer radiosensitivity, evaluating chemotherapy efficacy, and screening for environmental pollutants. Quantitative metrics, such as % tail DNA, tail length, and Olive tail moment, provide robust, statistically analyzable data, often surpassing traditional assays in sensitivity. The Olive tail moment (OTM) provides robust, statistically analyzable data in the Alkaline Comet Assay by integrating both the amount of DNA in the tail (% tail DNA) and its migration distance (tail centre of mass relative to the head). By illuminating DNA's vulnerability, the Alkaline Comet Assay enables researchers to safeguard the cellular foundation of life against invisible threats.

1.2 Sample preparation and analysis of data

Preparation of cells

The analysis is conducted on harvested whole blood cells, divided into two sets: one is UV-treated, and the other is UV-un-treated. These are suspended in a physiological buffer, such as PBS, and the culture is embedded in low-melting agarose. The agarose gel is used in proper proportions to avoid gel thickening, and a thin layer of it is added to a microscopic slide. This is done to immobilise the cells and protect their morphology during the subsequent steps.

Cell Lysis

Cell lysis is performed to access intracellular materials for various scientific and industrial applications. A primary objective is to obtain specific components, such as DNA, RNA, proteins, or organelles, for detailed study. Researchers might extract DNA for genomic sequencing, RNA for gene expression analysis, or proteins to understand their functions and interactions. In molecular biology research, it enables the isolation of genetic material for cloning, sequencing, and genetic manipulation. For instance, in drug discovery, lysing cells can help identify potential drug targets by analysing specific proteins or cellular pathways involved in diseases.

Therefore, to induce cell lysis, the slides coated with agarose are submerged in chilled detergent lysis buffer (containing Triton X-100 and SDS), which removes cellular membranes and proteins, leaving the DNA in a nucleoid structure.

Lysis buffer contains Proteinase K, which digests proteins, allowing the separation of DNA from proteins, and RNase A, which degrades RNA. It also includes salt solutions, such as sodium chloride and sodium acetate, for DNA precipitation, as well as buffer solutions like Tris-EDTA for storing and resuspending DNA.

Electrophoresis

The slide is placed in an electrophoresis buffer under an electrical field, causing the fragmented DNA to migrate away from the nucleus toward the anode. The rate and extent of DNA migration indicate the level of DNA damage: more damaged DNA migrates further, resembling a comet tail. An electrophoresis tank is used to allow DNA migration under an electric field of 25-30V and 300-400mA for 20 minutes.

Neutralisation and staining

After electrophoresis, the slides are neutralised with a buffer to stop the DNA unwinding. Now we have to stain the DNA using dyes like Ethidium Bromide (carcinogenic, so it is less commonly used); instead, silver staining is preferred since it is more sensitive to a large number of DNA lesions, and it also ensures a low background noise. The primary disadvantage of silver staining is its cost. Here, in our experimental study, we use SYBR GREEN, a fluorescent dye which is visualised under a fluorescent microscope with the help of MagVision software. The fragments were examined to quantify comet parameters, including tail length, intensity, and tail moment.

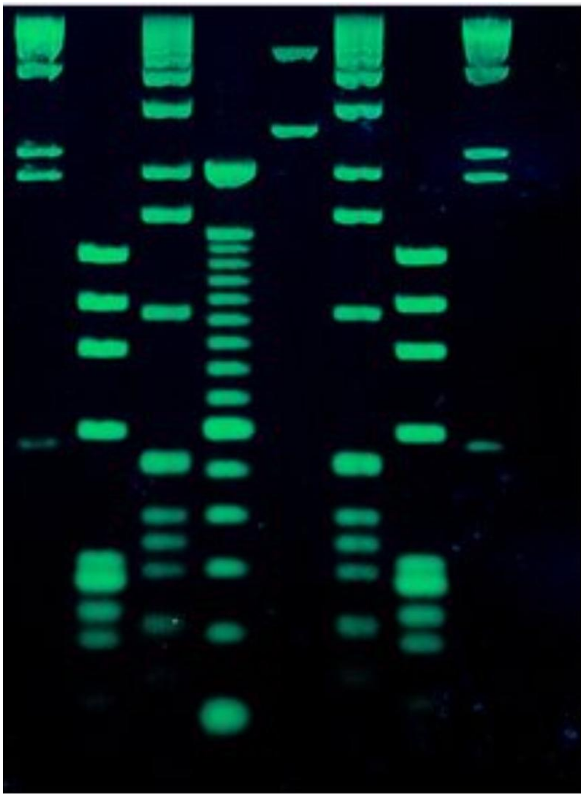
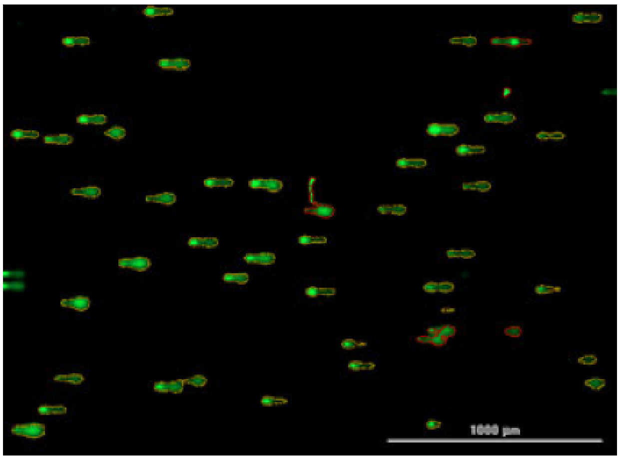


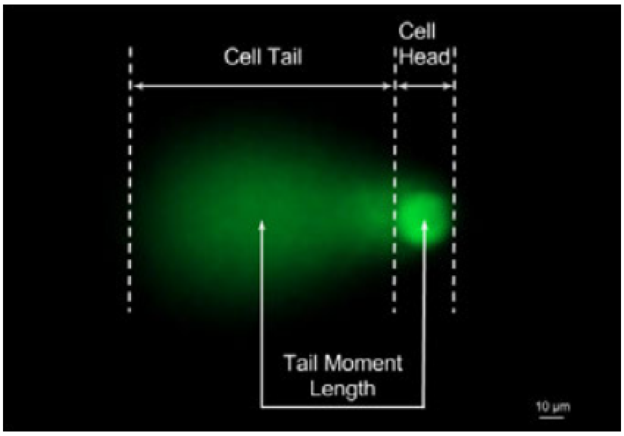
Figure 1: GEL RUN Stained with SYBR GREEN]tiny Image courtesy: https://www.thermofischer.com /order/catalog/product/S7563

Interpretation of data

Alkaline Single Cell Gel Electrophoresis (SCGE) is a standard comet assay for detecting single- and double-stranded breaks, alkali-labile sites, and other forms of DNA damage induced by genotoxic agents like chemicals or radiations or other physiological conditions like oxidative stress; the body's defense against free radicals is provided by antioxidants, but when free radicals outnumber antioxidants, oxidative stress is triggered leading to damage in DNA. The comet image was captured using Magvision Software. The head region represents DNA that migrates outside of the tail. The tail region represents the DNA migrating out of the nucleus due to fragmentation and loss of structure. The more the migration, the more the damage. The primary purpose of the comet assay is to detect these DNA damages and evaluate the DNA repair mechanisms that can be employed. It can also be used to assess DNA damage in sperm cells for male



(a) Total tail analysis



(b) Comet tail analysis

Figure 2: (a) Total comet primary cellular analysis object masks. Object masks are automatically placed around comets from all control cell populations. (b) Comet tail analysis.

infertility studies and for biomonitoring DNA damage in patient samples to assess cancer risk. It is a strenuous process that requires valuable time and effort to assess small quantities of DNA; hence, it's not widely carried out in all laboratories. The new advanced versions utilise comet chips, specifically HTP Comet assay systems (COMPAC-50), which can combine multiple slide processing and analysis steps for higher throughput and also use of automated microscopy systems like Metafer for high content screening of large gel formats

Here, sample images from the study, conducted on UV-treated and UV-untreated blood, are shown. UV-treated blood was observed to have denser, longer tails compared to the untreated blood.

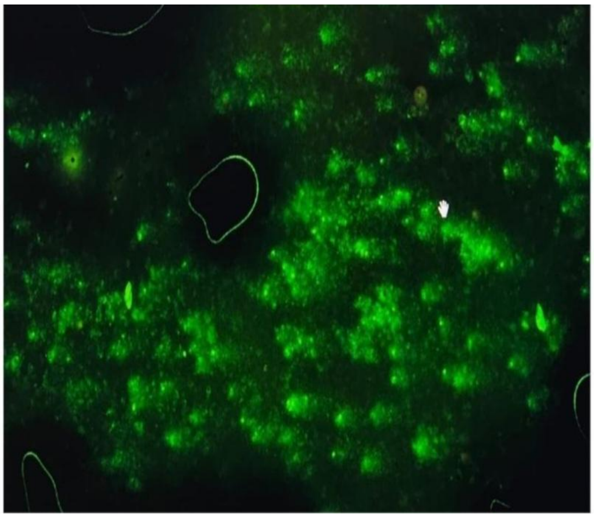


Figure 3: UV-treated blood sample stained by SYBR GREEN.

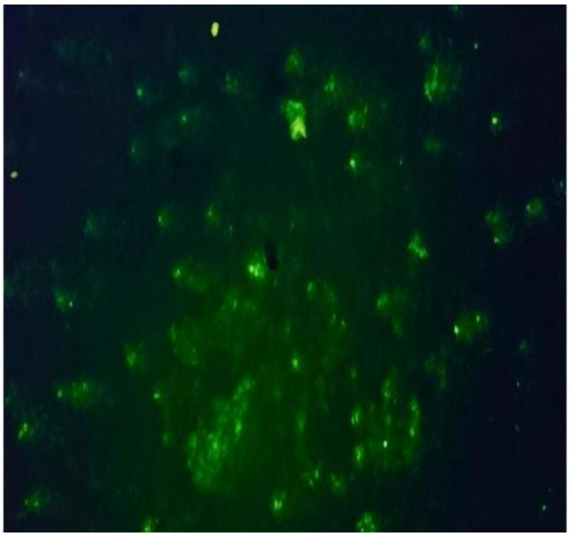


Figure 4: UV-untreated blood sample stained by SYBR GREEN

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Diabetic Retinopathy- Medical Image Processing

by Geetha Paul

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www.airis4d.com

2.1 Introduction

Diabetic retinopathy (DR) is a progressive eye disease and a leading cause of vision impairment and blindness among individuals with **diabetes mellitus**. This microvascular complication primarily affects the retina, the light-sensitive tissue lining the back of the eye, by damaging its small blood vessels due to prolonged exposure to high blood glucose levels. DR can develop in both type 1 and type 2 diabetes and typically advances over the years, often without initial symptoms. As diabetes prevalence grows globally, diabetic retinopathy has become a major public health concern, particularly impacting adults of working age. The primary risk factors include the duration of diabetes, poor glycemic control, hypertension, and dyslipidemia. Early identification and management, through regular eye examinations and optimised diabetic care, are essential to reduce the burden of visual disability caused by this disease.

The pathogenesis of diabetic retinopathy involves continuous injury to the retinal microvasculature. Chronic high blood sugar levels induce metabolic and biochemical changes, resulting in thickening of the capillary basement membrane, loss of pericytes, and the formation of microaneurysms. As the disease progresses, vascular permeability increases, resulting in fluid leakage, retinal swelling (macular oedema), and eventually ischemia due to capillary non-perfusion. In advanced stages, marked by proliferative diabetic retinopathy, abnormal new blood vessels proliferate on the retinal surface in response to ischemia. These vessels are fragile, prone to bleeding, and can precipitate complications such as vitreous haemorrhage or retinal detachment, ultimately risking permanent vision loss if untreated.

Clinically, DR is classified into non-proliferative (NPDR) and proliferative diabetic retinopathy (PDR) stages. NPDR is characterised by microaneurysms, haemorrhages, hard exudates, and sometimes macular oedema, while PDR is distinguished by neovascularisation. The onset and progression of DR may be insidious; therefore, annual comprehensive dilated eye examinations are recommended for all diabetic patients. Treatment options include optimising systemic risk factors, intravitreal pharmacotherapy (e.g., anti-VEGF agents), laser photocoagulation, and surgical intervention for severe cases. Despite advances in therapy, prevention remains the cornerstone of reducing the impact of diabetic retinopathy by achieving strict glycemic, blood pressure, and lipid control.

2. Non-proliferative diabetic retinopathy

Non-proliferative diabetic retinopathy (NPDR) is the early stage of the disease in which symptoms will be mild or nonexistent. In NPDR, the blood vessels in the retina are weakened. Tiny bulges in the blood vessels, called microaneurysms, may leak fluid into the retina. This leakage may lead to swelling of the macula.

3. Proliferative diabetic retinopathy

Proliferative diabetic retinopathy (PDR) is the more advanced form of the disease. At this stage,

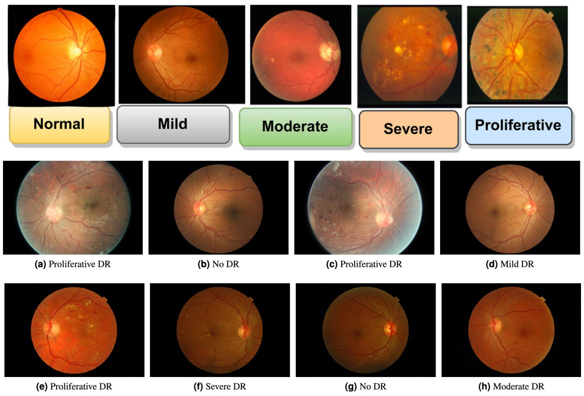

Figure 1: High quality to low quality of DR Retinal images,

Image courtsey:https://www.nature.com/articles/s41598-021-93632-8?fromPaywallRec=false

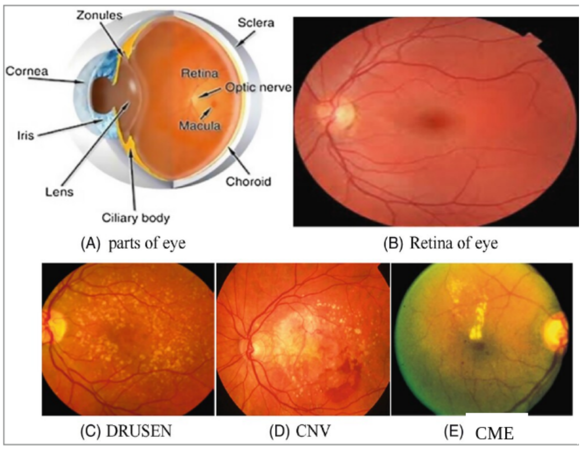

Figure 2: (A) Illustration of the parts of the eye, (B) Retina of the eye, (C) Drusen are yellow deposits under the retina, (D) CNV (Choroidal Neovascularisation) is abnormal blood vessel growth beneath the retina, causing leakage; and CME (Cystoid Macular Oedema): is fluid accumulation causing retinal swelling.

Image courtesy: https://www.nature.com/articles/s41467-021-23458-5

circulation problems deprive the retina of its oxygen supply. As a result, new, fragile blood vessels can begin to grow in the retina and into the vitreous, the gel-like fluid that fills the back of the eye. The new blood vessels may leak blood into the vitreous, causing vision to become cloudy.

Diabetic retinopathy is a leading cause of blindness resulting from damage to retinal blood vessels caused by diabetes. Image processing plays a central role in detecting, grading, and monitoring diabetic retinopathy using retinal fundus photographs.

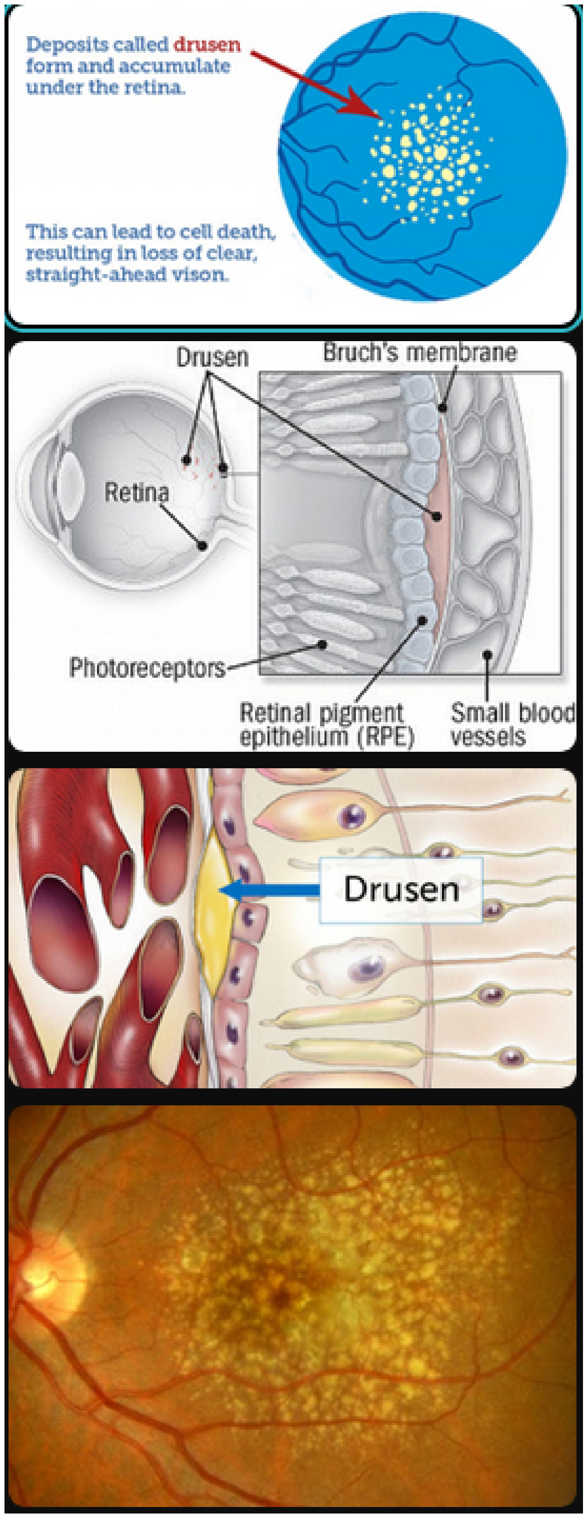

Figure 3: Illustration of Drusen and its formation beneath retina.

Image courtsey: https://www.brightfocus.org/resource/why-is-my-doctor-always-talking-about-drusen/

2.2 Drusen

These are small yellowish deposits of cellular debris, proteins, and lipids that accumulate between the retina and the underlying layer called Bruch's membrane. Drusen are a hallmark feature, especially in age-related macular degeneration, but can also be seen in other retinal conditions. They appear as small spots beneath the retina and indicate waste accumulation resulting from dysfunction of the retinal pigment epithelium.

2.3 CNV (Choroidal Neovascularization):

This is the abnormal growth of new blood vessels from the choroid layer beneath the retina into the subretinal space. CNV is often associated with advanced forms of macular degeneration and can cause leakage and bleeding, leading to vision loss. It is a serious complication that can be seen in diabetic retinopathy as well.

2.4 CME (Cystoid Macular Edema):

This refers to swelling in the macula (central retina) caused by fluid accumulation in cyst-like spaces. CME is a common consequence of diabetic retinopathy that results from vascular leakage and inflammation. It leads to central vision impairment and is a major cause of vision loss in DR.

2.5 Exudates

Exudates in the context of diabetic retinopathy are deposits composed primarily of lipids (fats) and proteinaceous material that leak out from damaged blood vessels in the retina. These deposits accumulate in the outer layers of the retina and appear as yellow or white patches on retinal images.

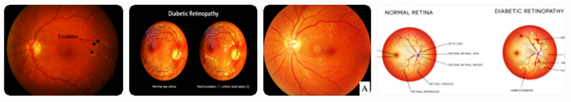

Figure 4: Exudates in Dibetic Retinopathic eye.

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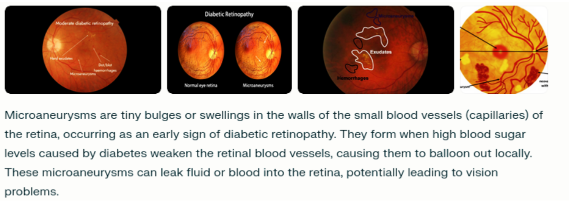

Figure 5: Microaneurysms in Diabetic Retinopathic eye

Image courtsey: https://onlinelibrary.wiley.com/doi/10.1155/2023/1305583

They are caused by the breakdown of the blood-retina barrier due to damaged retinal capillaries, allowing serum proteins and lipids to escape and settle in the retinal tissue. Exudates often indicate leakage and swelling in the retina, and their presence, especially near the macula (central retina), can lead to significant visual impairment.

2.6 Microaneurysms

Microaneurysms are tiny bulges or swellings in the walls of the small blood vessels (capillaries) of the retina, occurring as an early sign of diabetic retinopathy. They form when high blood sugar levels caused by diabetes weaken the retinal blood vessels, causing them to balloon out locally. These microaneurysms can leak fluid or blood into the retina, potentially leading to vision problems.

2.7 Haemorrhages

Haemorrhages in diabetic retinopathy refer to bleeding that occurs when the fragile blood vessels in the retina break and leak blood into the retinal tissue. They can appear in various forms depending on their location and size:

Dot and blot haemorrhages: Small, round haemorrhages found in the deeper layers of the retina, typically resulting from the rupture of microaneurysms.

Flame-shaped hemorrhages: Occur in the

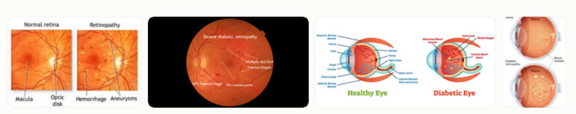

Figure 6: Haemorrhages in Diabetic Retinopathic eye.
Image courtsey: https://www.goodeyes.com/diabetic-retinopathy/

superficial layers of the retina, resembling flame shapes along the retinal nerve fiber layer

Haemorrhages are a sign of worsening diabetic retinal damage and are associated with increased vascular permeability and vessel wall weakening. In severe diabetic retinopathy, especially proliferative diabetic retinopathy, new fragile blood vessels may form and bleed into the vitreous humour, causing vitreous haemorrhage, which can lead to vision loss. The presence and extent of haemorrhages are important clinical indicators used in diagnosing and staging diabetic retinopathy.

2.8 Causes and Progression

High blood sugar from diabetes damages retinal blood vessels, causing increased permeability and blood vessel loss, which leads to retinal ischemia and swelling. The retina reacts by growing abnormal new vessels that are fragile and prone to bleeding. Vision loss occurs particularly when macular edema develops or in the advanced proliferative stage with retinal detachment risks.

2.9 Symptoms

Common symptoms include blurry or cloudy vision, floaters, dark spots or areas in the vision, and eventual vision loss. Early stages may be asymptomatic, making regular screening important for people with diabetes.

2.10 Diagnosis

Diagnosis involves dilated eye exams using ophthalmoscopy or retinal imaging to detect microaneurysms, haemorrhages, exudates, and new vessel growth. Regular screening is crucial since early diabetic retinopathy can be managed before significant vision loss.

2.11 Treatment and Management

Treatment aims to manage diabetes (maintaining blood sugar, blood pressure, and cholesterol control) and directly address eye damage.

Treatments include Anti-VEGF injections to reduce abnormal blood vessel growth and macular swelling, Steroid injections to reduce inflammation and swelling, Laser photocoagulation to seal leaking vessels and prevent bleeding, and Vitrectomy surgery for severe cases with vitreous haemorrhage or retinal detachment.

Strict glycemic control and routine eye exams are essential to prevent progression. Early detection and intervention can prevent 90% of severe vision loss cases. Overall, diabetic retinopathy requires a combination of systemic disease management and targeted ocular treatments for best outcomes

2.12 Role of Image Processing in Diabetic Retinopathy

Retinal imaging techniques, such as fundus photography and optical coherence tomography (OCT), provide high-resolution images of the retina.
Image processing enhances these images through noise reduction, contrast adjustments, and colour channel extraction to highlight key retinal structures.
Segmentation algorithms isolate anatomical features like blood vessels, the optic disc and detect lesions (microaneurysms, haemorrhages, exudates), which are signs of DR.

2.13 Automated Detection and Classification

Machine learning and deep learning models, especially convolutional neural networks, analyse processed images to automatically detect and classify

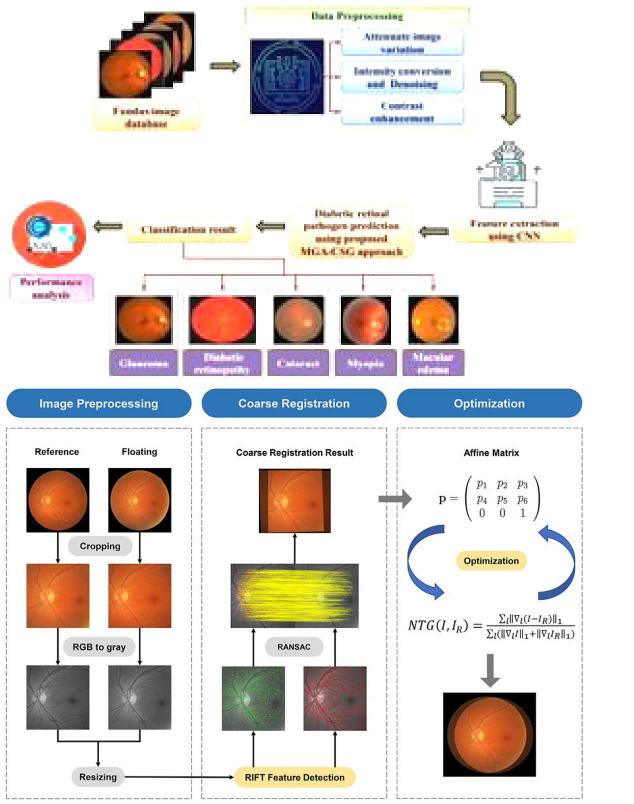

Figure 7: Illustration of the steps in DR -Image processing

Image courtsey: https://www.nature.com/articles/nrdp201612

DR stages.

These systems recognise subtle changes in retinal features associated with early and advanced DR that might be missed in manual examination.

Automated grading and early detection improve screening efficiency, allowing timely intervention to prevent severe vision loss.

2.14 Steps in Diabetic Retinopathy Image Processing

Preprocessing: Involves green channel extraction for higher contrast, histogram equalisation for brightness normalisation, resizing images, and denoising to enhance image clarity.

Feature Extraction: Quantifies biological features such as exudates, microaneurysms, haemorrhages, blood vessel area, and bifurcation points. These features are critical markers of retinopathy and its severity.

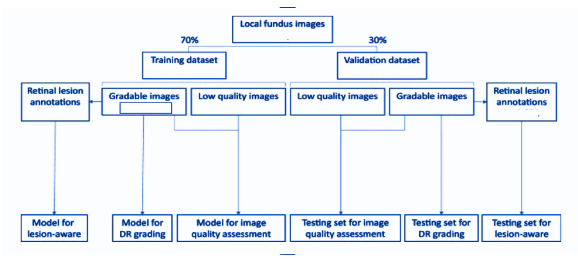

Figure 8: The local fundus image dataset was randomly divided into training and validation datasets. Seventy per cent of the total images in the dataset were used for training the image quality assessment sub-network. The lesion detection sub-network was trained using gradable images with annotations of retinal lesions. Then, the total gradable images in the training set were used to train the DR grading sub-network. All images in the local validation dataset were used to test the image quality sub-network. Finally, the gradable images labelled with retinal lesions were used to test the lesion detection sub-network. DR, diabetic retinopathy.

Image courtesy:https://www.nature.com/articles/s41467-021-23458-5

Segmentation: Localises regions of interest (optic disc, fovea, lesions) using thresholding and edge detection algorithms.

Classification: Machine learning and deep learning models (like CNNs, SVMs, and RSG-Net) automatically detect and classify stages of diabetic retinopathy by analysing extracted features.

Grading: Automated systems grade images into retinopathy stages (none, mild, moderate, severe, proliferative) to guide clinical decision-making.

2.15 DR grading pipeline end-to-end

Data Collection and Preparation

Acquire a large annotated dataset of retinal fundus images graded by DR severity levels (e.g., from public datasets like Kaggle's EyePACS).

Preprocess images by resizing (commonly to 224x224 pixels), normalisation, noise reduction, and enhancing contrast.

Utilise data augmentation techniques (such as rotation, flipping, and zooming) to enhance training data diversity and mitigate overfitting.

Model Architecture and Training

Choose a robust convolutional neural network

(CNN) architecture such as ResNet-50 or a specialized model like RSG-Net for feature extraction.
Apply transfer learning by fine-tuning a pretrained backbone on DR data to leverage prior knowledge.
Train the model for multiclass classification corresponding to DR grading stages (no DR, mild, moderate, severe, proliferative).
Use suitable loss functions (categorical cross-entropy for multiclass) and optimisers like Adam or SGD with tuned learning rates.
Implement regularisation techniques like dropout and batch normalisation to prevent overfitting.
Monitor validation metrics to apply early stopping or learning rate adjustments during training.

Model Evaluation and Validation

Evaluate performance using accuracy, AUC score, sensitivity, specificity, and confusion matrices.
Validate the model on separate test data to ensure generalisation.
Utilise robust metrics to evaluate misclassifications between adjacent DR grades and mitigate class imbalance.

Pipeline Automation and Deployment

Build a workflow to handle data input, preprocessing, prediction, and grading output. Optionally integrate a user interface for uploading images and displaying results.
Containerise the model using Docker and deploy on cloud platforms for scalability.
Implement continuous monitoring and retraining based on new data.
This pipeline encapsulates automated DR detection with high accuracy and practical usability, enabling timely diagnosis and referral for diabetic retinopathy patients.

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Neurological Disorders: A Brief Overview

by Neelima Dubey

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www.airis4d.com

3.1 Introduction

According to the World Health Organization (WHO), neurological disorders encompass all diseases that affect the nervous system and its components entirely or partially. These disorders may involve neurons or neural tracts of the central nervous system (CNS) including the spinal cord and the whole brain or its individual components such as the cerebrum (cerebral cortex), basal ganglia, diencephalon, brainstem (midbrain, pons, and medulla oblongata), and cerebellum. In addition, conditions affecting the peripheral nervous system (PNS) include disorders of the cranial nerves and their nuclei, spinal nerve roots and plexuses, peripheral nerves, the autonomic nervous system, the neuromuscular junction, and skeletal muscles. These abnormalities can be electrochemical, biochemical or structural which ranges from sensory disturbance, difficulty in coordination, confusion, seizures, muscular atrophy, and memory disturbance.

There are numerous etiologies attributed to the advent of various neurologic ailments. According to the WHO, almost one billion people globally suffer from neurologic disorders; this is set to rise in the next few years, making it one of the most important challenges in public health. All age groups and geographical areas are affected by these illnesses. Neurological disorders are broadly classified into neurodegenerative diseases (such as Alzheimer's disease, Parkinson's disease, Huntington's disease, and amyotrophic lateral sclerosis) and neuropsychiatric diseases (such as depression, schizophrenia, bipolar affective disorders, autism, mood disorders, attention-deficit or hyperactivity disorder, and tardive dyskinesia).

3.2 Neurodegenerative Diseases

Neurodegenerative diseases are a group of disorders that gradually destroys the structure and function of neurons in central and peripheral nervous system. These usually develop slowly, and their effect and symptoms tend to appear in the later life. Neurodegenerative diseases are mostly associated with aging, but there are certain types that can develop in childhood or early adulthood. These diseases are chronic, progressive and debilitating, posing significant challenges for both affected individuals and healthcare systems. Understanding the causes, symptoms and mechanism behind neurodegenerative diseases is crucial for developing effective treatments and interventions.

Unlike some diseases that involve temporary or reversible damage, neurodegenerative diseases usually cause irreversible damage and progressively worsen over time. Symptoms of these diseases vary significantly depending on the type of the area of brain affected, individual's age, and the stage of the diseases. Common categories of symptoms include memory loss, confusion and disorientation, sleeping disturbances, apathy, agitation, anxiety, ataxia, tremors or shaking, depression, and personality shifts. On the other hand, the exact causes of neurodegenerative diseases are unknown, but researchers have identified a combination of genetic, environmental, and age-related factors that contribute to these diseases.

The most common neurodegenerative diseases include Alzheimer's disease, Parkinson's disease, Huntington disease, Amyotrophic Lateral Sclerosis, and Multiple Sclerosis.

3.3 Alzheimer's disease

Alzheimer's disease was named after the German Psychiatrist and neuroanatomist Alois Alzheimer in 1906. It is the most common form of dementia and primarily affects memory and cognitive abilities. It is typically seen in patients over the age of 65, but about 5-10% of cases are considered "early-onset" with symptoms appearing before 65. It is characterized by the accumulation of abnormal proteins such as amyloid plaques outside neurons and tau tangles inside neurons, interfering with neuronal functions and causes cell death.

Currently, there is no cure for Alzheimer's disease, although there are available treatments that just improves the symptoms, such as cholinesterase inhibitors, and memantine (glutamate regulator). Donanemab is a recently FDA-approved treatment for earlier onset of Alzheimer's disease.

3.4 Parkinson's disease

Parkinson' s disease is a progressive movement disorder. It is the second most prevalent neurodegenerative disease. Although, its incidence increases with age for above 70 years old, 5-10% of cases are reported to be early onset. It was medically described as "shaking palsy" by British physicist James Parkinson in 1817. Later, William Rutherford Sanders named the condition after him in 1865.

Several known risk factors contribute to the development of Parkinson's disease, such as age, gender, ethnicity, rapid eye movement, sleep disorders, traumatic brain injury, high consumption of dairy products, genetics, and pesticides or herbicides. However, the deficiency of dopamine in the substantia nigra of brain stem is recognized to be the main pathology. Parkinson's disease largely affects the motor system. Common symptoms include tremors, stiffness, and bradykinesia (slowness of movement). Non-motor signs such as dementia (also called Parkinson's disease dementia) and cognitive decline are also noticed. Parkinson's disease dementia is believed to cause by the accumulation of abnormal protein alpha-synuclein. Cognitive decline can also result from the buildup of this abnormal protein, causing neuronal malfunction and cell death. It also shares common features with Alzheimer's disease.

Medications like levodopa and dopamine agonist mostly helps in alleviating motor symptoms. Surgical interventions such as deep brain stimulation may also be helpful in some cases.

3.5 Huntington's disease

Huntington's disease is an autosomal dominant disorder characterized by movement disorder and cognitive decline. It was discovered by George Huntington in 1872, and its genetic cause was later discovered by Nancy Wexler in 1993. Movement defects include chorea and loss of coordination. Psychiatric disorders such as depression, psychosis, obsessive compulsive disorder are common in the patient with Huntington's disease. This disease is caused by abnormal expansion of CAG repeats in HTT gene on chromosome 4, which results in the production of an abnormal protein called huntingtin. This protein gets aggregated and accumulates in the brain region, especially in basal ganglia which is critical for motor control, and cognition.

No treatments can cure the course of Huntington's disease, but medications such as tetrabenazine, citalopram, and Haloperidol may be effective in lessening the symptoms of this disease. Speech therapy and counselling also hold promising in slowing the progression of this disease.

3.6 Amyotrophic Lateral Sclerosis

Amyotrophic Lateral Sclerosis was originally defined as motor neuron disease by Jean-Martin Charcot in 1869. Now it is understood as multisystem neurodegenerative disease. It generally causes degeneration of upper and lower motor neuron, leading to progressive muscle weakness and paralysis. It is categorized into two forms- sporadic (90-95%) which has no genetically inherited component, and familial (5-10%) which is a genetic dominant inheritance factor.

The drugs such as Riluzole and Edaravone focuses on slowing progression, symptoms of the disease and towards enhancing the quality of life.

3.7 Multiple Sclerosis

Multiple Sclerosis is a chronic autoimmune disease primarily affecting the brain, spinal cord, and optic nerves. It shares common features with other neurodegenerative diseases such as progressive neuronal loss, axonal damage, and brain atrophy contributing to long-term disability. Symptoms of this disease generally include muscle weakness, visual impairment, fatigue, and impaired coordination.

There is currently no cure for Multiple Sclerosis, but Disease-Modifying Therapies (DMT), and cognitive therapies may be helpful in slowing the disease progression.

3.7.1 Neuropsychiatry

In contrast to neurodegenerative diseases like Alzheimer's, which involve progressive loss of neurons, neuropsychiatry covers mental symptoms that result from neurological malfunctioning. Studies highlight its emphasis on brain-behaviour interfaces in diseases like epilepsy, traumatic brain injury, and movement disorders, combining psychiatry and neurology for comprehensive care. With advancements in neuroimaging (MRI), this discipline has demonstrated similar pathophysiology in behavioural, emotional, and cognitive symptoms across neural substrates.

Antiepileptics like valproate for mood stabilization in epilepsy, antipsychotics like quetiapine for psychosis in Parkinson's disease, and benzodiazepines for acute agitation in traumatic brain injury are just a few examples of the multimodal approaches used in neuropsychiatry today to treat underlying neurological perturbation. Psychotherapy is tailored to manage cognitive deficiencies, deep brain stimulation for drug resistant patients, and cognitive rehabilitation are examples of non-pharmacological therapies.

3.7.2 Mood disorders

Mood disorders are a group of mental illnesses that have substantial effects on day-to-day functioning and neurocognitive functions. They are defined by disruptions in emotional regulation, which typically demonstrate as sadness, mania, or hypomania. Their variability is highlighted by core symptoms like self-blame, worthlessness, anhedonia, and altered approach or withdrawal behaviours, which are frequently connected to anterior temporal and subgenual brain networks.

Persistent sadness, anger, emotional lability, exhaustion, psychomotor changes, and cognitive difficulties like indecision are among the primary symptoms of mood disorders. These symptoms frequently coexist with physiological problems such disturbed sleep, hunger, and libido. Treatment methods focus on a multimodal approach, incorporating psychotherapy like dialectical behaviour therapy (DBT) and cognitive behavioural therapy (CBT), pharmacotherapy like antidepressants and mood stabilizers, lifestyle changes like exercise, sleep hygiene, and nutritional support, and electroconvulsive therapy (ECT) for refractory cases. Mood disorders can be broadly classified as either bipolar disorder or depression, according to the Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition (DSM-5).

3.7.3 Major Depressive Disorder

According to the DSM-5 criteria, major depressive disorder is a severe form of unipolar depression characterized by persistent low mood or anhedonia, along with symptoms like guilt, low energy, concentration problems, changes in appetite, sleep disturbances, and suicidal thoughts. The diagnosis requires at least five symptoms. Its significant frequency and treatment resistance in up to 60% of cases are highlighted in recent pharmacologic reviews, prompting research into new treatments that address underlying biology in addition to conventional antidepressants. The prognosis includes a higher risk of suicide in twothirds of patients and chronic recurrence with untreated episodes lasting six to twelve months.

Significant weight gain or loss, recurring thoughts of suicide, and feelings of emptiness lasting more than two weeks are all signs of major depressive disorder (MDD). Rapid-acting medications such as ketamine for patients who are resistant to treatment, esmethadone that targets opioid pathways, and dextromethorphan-bupropion combinations that produce 39–46% remission rates better than monotherapy are examples of emerging treatments for the condition.

3.8 Bipolar Disorders

Bipolar disorders are characterized by cyclic mood swings between mania or hypomania and depression. They show more functional impairment compared to unipolar depression. Four basic mood states are identified by analyses: depressed, anxious, irritated, and euphoric. Blame or praise biases and variations in self-worth are identified as an important mechanisms that inform neurocognitive targets such as subgenual networks.

Elevated energy during manic instances, rapid thoughts, impulsivity, distractibility, and depressive lethargy with difficulty concentrating throughout episodes are common symptoms. Atypical antipsychotics like quetiapine, mood stabilizers like lithium or lamotrigine, and supplementary psychotherapy like interpersonal and social rhythm therapy are used in management to control daily activities and stressors.

3.8.1 Bipolar Disorder – I

At least one manic episode, frequently accompanied by depressive phases that cause significant disability and even psychosis, is a hallmark of bipolar I disorder. The major symptoms and the severity of the disorder is associated with a flawed or defective self-structure. However, these patients show variable degrees of personality organization, with less severe identity and aggressiveness deficits than those associated with other disorders such as borderline personality disorder (BPD). BP-I has more overall mood instability but less time spent in depressive states than other form of Bipolar Disorder such as BP-II.

During mania, BP-I symptoms include talkativeness, increased engagement in risky activities, grandiosity, and a decreased desire for sleep, often accompanied by psychotic characteristics. The main therapeutics for BPD-I include Lithium for manic prophylaxis, valproate for acute stabilization. In addition, family-focused therapy is provided to improve adherence and episode detection.

3.8.2 Bipolar Disorder – II

Recurrent depressive episodes and hypomania without complete mania are characteristics of bipolar II illness. This leads to greater chronicity, frequent episodes, and extended depression phases. Up to 40% BP-II patients spend more time depressed than observed in BP-I. Due to the predominance of rapid episodes and prominent depressive symptoms, it is frequently misinterpreted as unipolar depression and carries an increased risk of suicide during mixed states. Patients report higher rates of relapse, decreased mood, and increased symptom variability in BP-II.

Increased goal-directed activity, inflated self-esteem, and flight of ideas without significant impairment or inpatient requirements are examples of hypomanic symptoms in BP-II. Effective treatments include lurasidone or lumateperone for acute bipolar depression, lamotrigine for depression prevention. The psychoeducation to the common people and to the family members of the patients is given to reduce misdiagnosis and promote long-term adherence.

3.9 Premenstrual Dysphoric Disorder

Premenstrual dysphoric disorder (PMDD), according to the DSM-5 criteria in prospective monitoring, is a severe version of premenstrual syndrome that affects women of reproductive age with luteal-phase onset of severe emotional symptoms such as anxiety, depression, irritability, and functional impairment. It is underdiagnosed and thus remains unidentified in the society particularly in Indian society thus making day-to-day living of women with PMDD more difficult. PMDD mandates cycle-specific treatments as the pathology is limited to the luteal phase of the reproductive cycle but impacting the life of young women throughout.

Severe mood swings, stress, enduring wrath, feelings of overwhelm, and physical complaints like breast tenderness or luteal phase joint pain are common symptoms of PMDD. Continuous-dosing oral contraceptives are used to suppress ovulation, luteal-phase SSRIs are used for quick symptom relief, CBT is used to reframe emotional patterns, and GnRH agonists are used for resistant instances. However, these cannot be the permanent cure for PMDD and could adversely affect the reproductive health of the women with PMDD.

3.10 Persistent Depressive Disorder

Formerly known as dysthymia or chronic major depression, persistent depressive disorder (PDD) is characterized by depressed mood on most days for at least two years (one year in adolescents), with symptoms like hopelessness and poor self-esteem that never completely go away. The DSM-5 combines chronic forms with severe comorbidity, disability, and suicide risk, emphasizing duration over severity. Double depression arises when large episodes overlap. It reacts to antidepressants such as SSRIs or MAOIs, and CBT is frequently used to help it go into remission.

Poor focus, indecision, excessive guilt, social disengagement, and persistent low-grade hopelessness without complete inter-episode recovery are some of the symptoms of PDD.

Novel mood stabilizers like lamotrigine are used in conjunction with SSRIs or MAOIs in therapeutic approaches, which have been shown to provide better remission when partnered with psychotherapy for longer than two years.

3.11 Seasonal Affective Disorder

Seasonal affective disorder is characterized by recurring significant depression that coincides with seasonal light variations. It is primarily winter-type and is characterized by hypersomnia, hyperphagia, and low energy as a result of less daylight. Although it has received less attention in evaluations from 2024–2025, it maintains the fundamental characteristics of MDD but exhibits circadian patterns that worsen under stressful conditions such environmental disruptions. In order to prevent relapses, interventions combine regular antidepressants with light therapy.

Carbohydrate cravings that result in weight gain, oversleeping, daytime tiredness, and an increased appetite for carbohydrates during shorter daylight hours are all signs of SAD. First-line treatments include bright light therapy, which reduces mild-to-moderate depression scores when compared to a placebo. CBT and bupropion are also used to prevent seasonal relapses.

3.12 Postpartum Depression

The symptoms of postpartum depression (PPD) are similar to Major Depressive Disorder (MDD), such as persistent sorrow, anxiety, and difficulties connecting with the newborn. However, maternal-infant dynamics are severely impacted by the occurrence of PPD in new mother. PPD can develop weeks to months after parturition. The diagnosis is often missed due to the common occurrence of mood swings during the first week after giving birth called postpartum blues. Therefore, screening of the new mothers using instruments like EPDS identifies patients at the early stages.

The specific symptoms of PPD include excessive concern, panic attacks, hostility toward the infant, and feelings of separation that arise due to the hormonal changes in the body of the mother at the time parturition and days following the birth. Sertraline is a first-line antidepressant given safely to the PPD mother. However, this is not the permanent cure.

3.13 Postpartum Psychosis

Postpartum psychosis (PP) is not a very common condition like other mood disorders. There are ongoing advocacy to include PP under the "Rare Disease" umbrella. However, it is an extremely serious neurological disorder around the globe. It is a psychiatric emergency and required immediate intervention and usually inpatient hospitalization, ideally in a mother-baby unit. Symptoms of PP are as delusions, hallucinations, disordered behaviour, mood swings, and cognitive abnormalities. These symptoms typically manifest in the new mother within the first two to four weeks after parturition. It is characterized by the abrupt onset, and may strike one in every 1000 new mothers in general. According to population-based studies, the prevalence of first-lifetime onset postpartum psychosis ranges from 0.25 to 0.6 per 1,000 births. This risk is much higher among mothers diagnosed with prenatal bipolar diseases. Despite the low absolute prevalence, the relative risk for the onset of affective psychosis is 23 times higher within 4 weeks of birth than it is at any other point in the lifetime of a woman. When delusional perception is present, the infant is frequently the subject of the situation.

The mother may become more protective as a result, or she may be at risk of abuse or neglect the new born in certain situations. Infanticide is also known however is uncommon, occurring in 1–4.5% of all cases. The indications of the homicidal ideas are more common in postpartum psychosis than in non- psychotic episodes of postpartum mood disorder. Mothers with postpartum psychosis are more likely to report thoughts of self-harm than those with psychiatric issues that started at other times. So, the necessity of prompt diagnosis, hospitalization, and treatment commencement highlights the severity of this ailment.

Lithium is the effective drug prescribed for the treatment. It is considered a gold standard for prophylaxis (prevention of relapse) of postpartum psychosis (PPP) and is often used in combination with antipsychotics and benzodiazepines for acute treatment. However, its long-term impact on the individual as well as on the new-born is not yet comprehensively validated.

3.14 Conclusion

Neurological diseases, which include neuropsychiatric symptoms that disturbs emotional and cognitive balance as well as neurodegenerative conditions with unrelenting progression, have a significant impact on the individuals, their families, and the overall society. Aging populations, environmental variables, and changing lifestyle choices are the causes of the increasing prevalence, which exacerbates problems with everyday functioning, healthcare systems, and economic productivity in a variety of geographical areas.

As evidenced by recent paradigms for mood and behavioural disorders, this growing impact highlights the urgent need for integrated treatment approaches that combine pharmacotherapy for symptom control, neuromodulation techniques like deep brain stimulation for refractory cases, and psychotherapy adapted to neurological contexts. The identification of early biomarkers for accurate diagnosis and the creation of tailored therapies to target underlying pathophysiological mechanisms must be given top priority in future research with the ultimate goal of reducing suffering and improving quality of life globally.

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Part IV

General

AI in India: From Policy Vision to Everyday Governance

by Atharva Pathak

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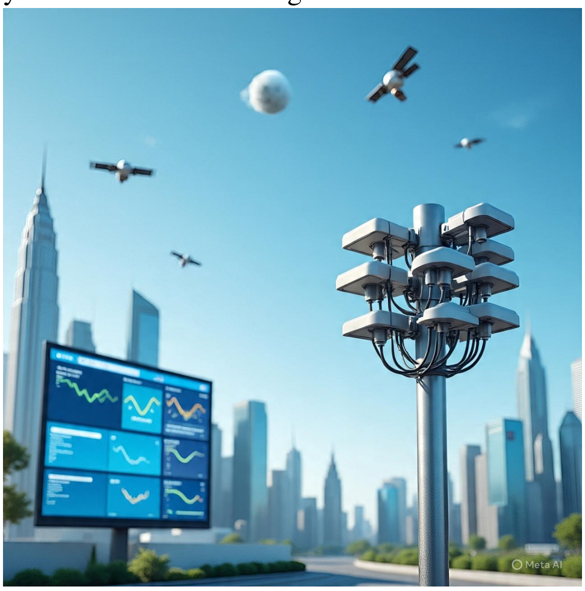
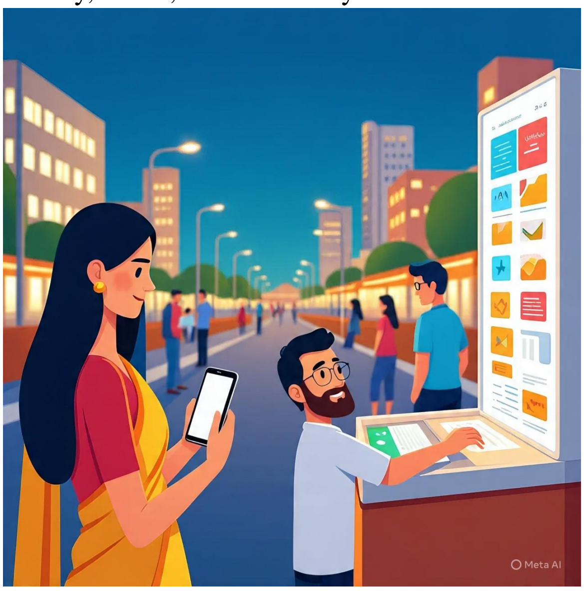
Artificial Intelligence (AI) has rapidly transitioned from an experimental technology to a strategic instrument of governance in India. What was once confined to academic research labs and private-sector innovation hubs is now influencing how policies are framed, implemented, monitored, and refined. Across ministries, state governments, urban bodies, and research institutions, AI—combined with machine learning, data analytics, and high-performance computing—is reshaping administrative efficiency and policy-driven decision-making.



India's approach to AI is distinctive. Rather than focusing solely on automation, the emphasis lies on augmenting human decision-making, improving service delivery, and enabling evidence-based governance at scale. This balance between technology and institutional responsibility defines the country's evolving AI ecosystem.

1.1 India's National AI Vision

The cornerstone of India's AI strategy is the IndiaAI Mission, approved by the Union Cabinet in 2024. The mission positions AI as a national capability, not merely a commercial product. Its scope spans governance, healthcare, agriculture, education, climate action, and scientific research, with a strong focus on accessibility, ethics, and inclusivity.



A senior official associated with the mission remarked during its launch that *"AI must become a public good—available, explainable, and accountable—rather than a black-box privilege." This philosophy underpins initiatives such as the IndiaAI Dataset Platform, which aggregates anonymised datasets from multiple ministries and departments. These datasets—covering demographics, health, environment, transport, and socio-economic indicators—form the backbone for training machine learning models used in governance and research.

Complementing data access are **Centres of Excellence (CoEs)** established across thematic domains. These centres translate policy priorities into deployable solutions, ensuring that innovations move beyond pilot projects into real-world applications. The Union Budget 2025's allocation for an AI Centre of Excellence in education reflects a long-term commitment to institutionalising AI-driven transformation.

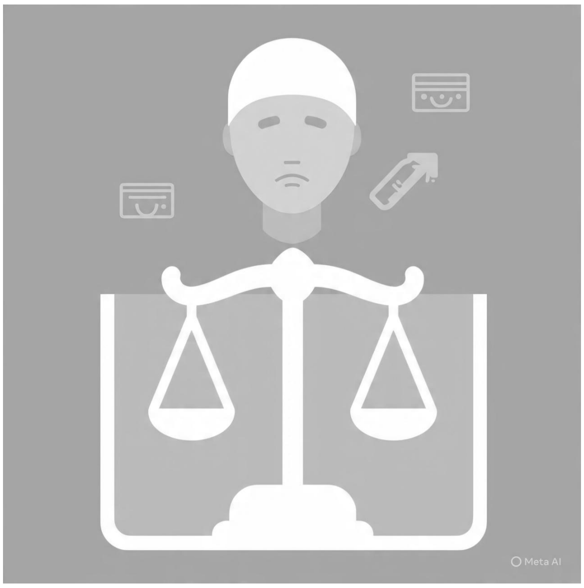
1.2 Capacity Building for AI-Enabled Governance

Technology alone cannot deliver better governance without skilled institutions. Recognising this, India has introduced an AI Competency Framework for civil servants, designed to build foundational AI literacy across administrative roles. The objective is not to turn administrators into data scientists, but to enable them to interpret AI outputs, question model assumptions, and make informed decisions.

This institutional effort aligns with the National Education Policy (NEP) 2020, which embeds AI, data science, and computational thinking into school and university curricula. Initiatives under the IndiaAI Mission further support postgraduate and doctoral research, ensuring a steady pipeline of skilled professionals for governance, industry, and academia.

As one district collector involved in an AI pilot project observed, "AI doesn't replace administrative judgement—it sharpens it by showing patterns we would otherwise miss."

1.3 AI in Policy Design and Decision-Making



One of the most transformative roles of AI lies in policy design and simulation. By analysing large administrative datasets, machine learning models can identify inefficiencies, predict outcomes, and simulate alternative policy scenarios before nationwide implementation.

In welfare governance, AI systems trained on census data, socio-economic surveys, and Direct Benefit Transfer (DBT) records help identify inclusion and exclusion errors. Policymakers can test changes in eligibility criteria digitally, reducing leakages and improving targeting. This marks a shift from reactive governance to anticipatory and adaptive policymaking.

Budget allocation is another area where AI-driven analytics is gaining traction. Predictive models assess programme performance across regions, enabling more rational distribution of resources based on evidence rather than precedent.

1.4 Environmental Governance and Climate Intelligence

AI has become indispensable in environmental monitoring and climate governance. Urban air quality forecasting systems now integrate satellite data, traffic patterns, meteorological inputs, and industrial emissions to generate short-term pollution forecasts. The proposed collaboration between the Delhi government and IIT Kanpur demonstrates how such models can guide traffic restrictions, school advisories, and public health alerts.

In disaster-prone regions, AI-powered flood forecasting models analyse rainfall, river gauge data, and terrain maps to issue early warnings. States such as Assam and Bihar have begun experimenting with these systems to support evacuation planning and resource deployment. Even a few hours of advanced warning can significantly reduce loss of life and infrastructure damage.

1.5 Public Safety, Law Enforcement, and Justice

AI applications in law enforcement focus on decision support rather than autonomous enforcement. The Maharashtra Police's MARVEL (Multi-Agency Research and Vigilance for Enforcement of Law) initiative uses AI to analyse crime patterns across jurisdictions, helping investigators identify repeat offenders and emerging trends.

In the judicial system, natural language processing tools are being explored to summarise lengthy case documents, retrieve relevant precedents, and assist legal research. Legal experts consistently stress that such systems must remain advisory. As one senior jurist noted, "Technology can assist the mind, but justice must always remain a human responsibility."

1.6 Citizen-Centric Service Delivery

AI is increasingly visible at the citizen interface. Platforms such as UMANG integrate hundreds of government services into a single digital ecosystem. AI-powered chatbots, grievance classification systems, and sentiment analysis tools help administrations respond faster and more effectively.

For citizens, this reduces bureaucratic friction and waiting times. For administrators, it provides dashboards highlighting recurring issues and service gaps—enabling continuous service improvement and better accountability.

1.7 AI in Healthcare, Research, and Disaster Response

Public healthcare has emerged as a major beneficiary of AI-driven analytics. Disease surveillance systems analyse hospital admissions, pharmacy sales, mobility data, and weather trends to detect early signs of outbreaks. These insights allow health departments to mobilise resources proactively.

In research, AI is accelerating discoveries across domains such as climate science, astronomy, genomics, and materials engineering. By automating data-intensive tasks and enabling complex simulations, AI is transforming how scientific knowledge is generated and applied in India.

1.8 Ethics, Trust, and Responsible AI

As AI becomes embedded in governance, ethical considerations are paramount. India's evolving AI governance framework emphasises transparency, fairness, privacy protection, and human oversight. Bias audits, explainable models, and accountability mechanisms are essential to ensure that AI strengthens democratic institutions rather than undermining them.

The guiding principle remains clear: AI should enhance human judgement, not replace it.

1.9 Conclusion

Artificial intelligence in India has moved beyond experimentation into practical governance. Through national missions, institutional capacity building, and real-world deployments, AI is enabling smarter policies, efficient administration, and accelerated research.

By aligning policy vision with technological capability and ethical responsibility, India offers a compelling model of how AI can serve as a force multiplier for governance—empowering administrators, supporting researchers, and improving the everyday lives of citizens.

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About airis4D

Artificial Intelligence Research and Intelligent Systems (airis4D) is an AI and Bio-sciences Research Centre. The Centre aims to create new knowledge in the field of Space Science, Astronomy, Robotics, Agri Science, Industry, and Biodiversity to bring Progress and Plenitude to the People and the Planet.

Vision

Humanity is in the 4th Industrial Revolution era, which operates on a cyber-physical production system. Cutting-edge research and development in science and technology to create new knowledge and skills become the key to the new world economy. Most of the resources for this goal can be harnessed by integrating biological systems with intelligent computing systems offered by AI. The future survival of humans, animals, and the ecosystem depends on how efficiently the realities and resources are responsibly used for abundance and wellness. Artificial intelligence Research and Intelligent Systems pursue this vision and look for the best actions that ensure an abundant environment and ecosystem for the planet and the people.

Mission Statement

The 4D in airis4D represents the mission to Dream, Design, Develop, and Deploy Knowledge with the fire of commitment and dedication towards humanity and the ecosystem.

Dream

To promote the unlimited human potential to dream the impossible.

Design

To nurture the human capacity to articulate a dream and logically realise it.

Develop

To assist the talents to materialise a design into a product, a service, a knowledge that benefits the community and the planet.

Deploy

To realise and educate humanity that a knowledge that is not deployed makes no difference by its absence.

Campus

Situated in a lush green village campus in Thelliyoor, Kerala, India, airis4D was established under the auspicious of SEED Foundation (Susthiratha, Environment, Education Development Foundation) a not-for-profit company for promoting Education, Research. Engineering, Biology, Development, etc.

The whole campus is powered by Solar power and has a rain harvesting facility to provide sufficient water supply for up to three months of drought. The computing facility in the campus is accessible from anywhere through a dedicated optical fibre internet connectivity 24×7.

There is a freshwater stream that originates from the nearby hills and flows through the middle of the campus. The campus is a noted habitat for the biodiversity of tropical Fauna and Flora. airis4D carry out periodic and systematic water quality and species diversity surveys in the region to ensure its richness. It is our pride that the site has consistently been environment-friendly and rich in biodiversity. airis4D is also growing fruit plants that can feed birds and provide water bodies to survive the drought.