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Formal Epistemology · *Computational Neuroscience* · *AI Systems*

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§1 Research Profile

Principal Investigator running one research programme across seven fields since 2022, on whether discovery can be engineered rather than left to chance. Trained in biology (visual neuroscience under S. P. Arun, IISc), I moved to formal methods and machine-verified mathematics to build measurement and verification infrastructure for scientific discovery. Core outputs: a Lean4 kernel of formal learning theory with novel mathematical contributions, an open synthetic-discovery pipeline, and computational models of how biological circuits represent structured ignorance. A repeated institution-building pattern (Zetesis Labs, ARCNet Research, JRD Tata Innovation Support Center) turns frontier ideas into shipped prototypes and deployable systems.

Keywords. Formal Epistemology · Computational Neuroscience · Machine-Verified Mathematics (Lean4) · Synthetic Discovery · Bayesian Calibration · Causal World-Models.

biology ⟶ formal methods ⟶ lean4 kernel ⟶ synthetic discovery ⟶ deployed systems

§2 Appointments

2025–Present — **Principal Investigator**, Zetesis Labs; **Innovator-in-Residence**, ARTPARK @ IISc Bangalore.

- Anchoring the Zetesis programme: verification kernels, synthetic-discovery infrastructure, and causal world-models for high-stakes deployment.
- Leading industrial and biomedical pilots; building reusable verification and measurement infrastructure.
- Board Member, ARTPARK Industry 5.0 programme; manufacturing R&D automation pilots with BEL, Bosch, and Toyota.

§3 Leadership (Undergraduate, IISc 2021–2025)

2024–Jun 2025 — **Founder**, ARCNet Research *(deep-tech consultancy).*

- Built and operated a deep-tech consultancy; executed three client projects (remote-sensing QC, multimodal evaluation, lab automation). Transitioned to permanent team, June 2025.

2024 — **PI · Program Lead**, JRD Tata Innovation Support Center, IISc.

- Established and led a summer research programme (40+ students); PI for an 8-project applied-R&D portfolio across robotics, sensing, neuro/AI, BCI, power electronics, and forensics.

2022 — **Team Lead**, iGEM IISc Team (Paris).

- Led a synthetic-biology programme on halocarbon biodegradation; bioreactor concepts and deployment economics. iGEM Gold Medal; Climate-track finalist; two patent-filed bioreactor designs.

§4 Education

2021–2025 — **B.S. (Research), Biology**, Indian Institute of Science, Bangalore.

First Class with Distinction, CGPA 8.8/10. Thesis (A+, Rank 1): *Measuring What Models Miss.* Terrapulse, an open-source gas-composition sensing instrument (∼$150) with three-layer Bayesian calibration and drift accounting; field-deployed in Lahaul–Spiti, 3.8% flux MAE in mass-closure validation, ±2 ppm precision, sub-minute pulse capture.

§5 Selected Work

Neuroscience

- Trained under S. P. Arun (visual neuroscience) and Rishikesh Narayan at IISc; undergraduate project in Arun's lab on system-level energy–information efficiency in visual cortex.
- Clinical neurology internships, Sir Ganga Ram Hospital, Delhi (2022, 2023): patient observation, case-study presentation, and early medtech prototyping (PPG-based critical-patient alerting).
- **Hyper-Resonant Dendritic Oscillations (HDO):** bistable oscillation model in stellate cells with noise-driven switching and calcium-dependent metaplastic regulation as a single-neuron timing primitive. Preprint on request.
- **Information–energy efficiency operator:** complex-valued tradeoff operator for neural computation, validated in Brian2 simulations.
- **Dawn Arbor:** open Python platform converting ModelDB `.hoc` models into a type-inheritance DAG for machine-checked neurobiophysics.

- **CBF project** (with Continue Research): cerebral-blood-flow physics world-model; SPG-based sensing via a novel wearable; brain-phantom construction; transfer learning SPG → PPG; field data collection and physiology modeling.
- Collaboration with NIAS (IISc) on neurochaos-learning methods for sensor calibration.

Formal Theory and Mechanization

- **Formal learning theory kernel:** 21,522 lines of Lean4, machine-checked with no gaps. Novel mathematics: Borel–analytic separation theorem (concurrent with Krapp–Wirth 2024), constructive MWU-based compression proof, PAC-Bayes bound (first Lean4 formalization), Choquet capacitability (absent from Mathlib4). arXiv preprint submitted; ongoing contributions to Lean4 `cslib` and `mathlib`.
- **ICM Unbundling:** Lean4 formalization of OOD geometry for factored knowledge-graph embeddings. Seven theorems proving that independent causal mechanisms make distribution shift geometrically visible, with VC-dimension bounds, risk decomposition, and an entanglement-vulnerability converse.
- **Transformer learning theory:** Lean4 formalization of measurability-theoretic foundations for attention architectures: attention-routing measurability, softmax–argmax equivalence, universality (every measurable router *is* attention), and NullMeasurable necessity.

Synthetic Discovery

- **LLM harness for synthetic discovery**, operational. First Proof Challenge: 4/10 on Harvard's benchmark problems using $32 of commodity API compute on a MacBook.
- **Knowledge-creation engine** (JRD programme): generate-and-verify pipeline for physics problems via compile/filter workflows; 500+ labeled mechanics problems with verified solutions.

Applied and Industrial

- **Ather Energy:** 2,586-node / 7,934-edge causal world-model (internally κ383) for root-cause analysis of welding robots, deployed in production. Geometric belief-function diagnostic (Cuzzolin framework) classifying failure paths by resolvability.
- **Terrapulse:** open-source release of the thesis instrument (hardware, firmware, and Bayesian calibration pipeline) with field-validation datasets from the Lahaul–Spiti deployment.
- **Deterministic hemodynamics via radiometric inference:** physics-driven inference pipeline for cuffless hemodynamics; demonstrated stiffness discrimination under controlled perturbations.
- **BCI/EEG + generative-AI assistant** (JRD programme): neural-signal decoding to text with synthetic augmentation and post-editing; exploratory decoding metrics.
- Cross-programme portfolio (ARCNet + JRD): 11 deep-tech engagements in total (3 ARCNet client projects, 8-project JRD summer programme) spanning robotics, sensing, medical AI, BCI, power electronics, forensics, and lab automation.

§6 Invited Talks

Invited, sponsored panelist, *Prosthetics & Robotics 2026*, Boston, representing IISc. Invited lectures at IIT Delhi and AIIMS Delhi.

§7 Awards and Recognition

iGEM 2022 Gold Medal (Paris), Best Climate-Crisis nomination · KVPY Fellow (AIR 50) · JEE Main 99.94$^{\text{th}}$ percentile · Abhiprajna (AIR 1) · All-India Subject Topper (Biology).

§8 Teaching and Community

Student Branch President, IEEE Computer Society (IISc). Member, Eta Kappa Nu (HKN), IISc IEEE. Workshops and courses across 16 institutions in graph neural networks, neuromorphic computing, and embedded systems. Programme leadership for a 40+-student summer research camp at IISc.

§9 Technical Skills

Modeling & inference. Bayesian calibration (MCMC/PyMC), causal modeling, biosignal signal-processing, time-series reasoning, compartmental neuron modeling (Brian2, NEURON). Formal methods. Lean4, type-theoretic verification, machine-checked proof engineering. AI systems. LLM-harness engineering, structured generation, evaluation pipelines. Sensing & calibration. Phantom-first validation, uncertainty-aware calibration, trace provenance, QC gates. Robotics / controls. Teleoperation protocols, servo/encoder design, safety-first control. Systems. Python, embedded/Linux prototyping, reproducible pipelines, field deployment.

§10 References

Prof. Bharadwaj Amrutur, Professor, Dept. of Electrical Communication Engineering, IISc Bangalore (long-term research mentor). **Gopika Kannan**, Executive Advisor, Zetesis Labs (long-term brain-trust member). **Narayan Rangarajan**, Head of Agile R&D and Product Engineering, Ather Energy. **Dr. Sudip Mondal**, Head of Hardware, Firmware, and Systems Engineering, Ather Energy.