

Danny Raj M

Curriculum Vitae

Assistant Professor,
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DOB: 08.08.1990 (33 years old)

I like to work at the **interface of the physics of collectives and data-science research**, where I combine *agent-based models* for collectives (droplets, sperm cells, traffic, etc.) with techniques from *systems engineering and data science* like optimisation (sparse, evolutionary, etc.), classification, neural-networks, model-based feedback control, etc., along with *simple experiments* to, *i*) understand how the **dynamics of the collective** affects one's ability to **engineer a collective or infer characteristics from data** and, *ii*) develop **hybrid models that combine the knowledge of the physics of group dynamics and data-based models**—for the missing physics, closure, etc., and *iii*) understand the **emergence of functionality or intelligence** in collectives across a wide spectrum of cognitive capabilities.

Education

Department of Chemical Engineering, IIT Madras, Chennai, India, *MS & PhD (Dual-degree)*, 2011–2016, *CGPA: 9.24/10*

Department of Chemical Engineering, A.C. Tech, Anna University, Chennai, India, *B Tech*, 2007–2011, *CGPA: 8.1/10*

Honours and Awards

3. Featured as **outstanding reviewer of the month** (July 2021) by Nature Communications Physics journal ([Link](#)).
2. Awarded the **DST INSPIRE Faculty fellowship** (July 2017 call), offered by Department of science and technology, India (DST). Evaluation grade obtained during the March 2023 evaluation by expert committee: **excellent**. Comments included: **Research and publication work excellent**.
1. **Best presentation award** as chosen by the editor in chief of the Journal of fluid mechanics (JFM) during the JFM symposium- Chennai edition (2017).

Publications

15. **M Danny Raj** and Rupesh Mahore, "Emergence of intelligent collective motion in a group of agents with memory", **Chaos**, 33, 093131, 2023.
14. Arshed Nabeel, Vivek Jadhav, **Danny Raj M**, Clément Sire, Guy Theraulaz, Ramón Escobedo, Srikanth K. Iyer, and Vishwesh Guttal, "Data driven discovery of stochastic dynamical equations of collective motion", **Physical Biology**, 20, 056003, 2023.
13. **M Danny Raj**¹, Pavithra Sivakumar and Arshed Nabeel, "Inferring the stability of concentrated emulsions from droplet configuration information". **EPJ ST**, 2022.
12. Arshed Nabeel, **M Danny Raj**¹, "Disentangling intrinsic motion from neighbourhood effects in heterogeneous collective motion", **Chaos**, vol 32, 063119, 2022.
11. Vivek Jadhav, Vishwesh Guttal and **M Danny Raj**¹, "Randomness in the choice of neighbours promotes cohesion in mobile animal groups", **Royal Society Open Science**, vol 9 issue 3, 2022
10. **M Danny Raj**¹ and Kumaran V, "Moving efficiently through a crowd: a nature inspired traffic rule", **Physical Review E**, vol 104, no 5, 2021.
9. Jitesh Jhavar, Richard G. Morris, U. R. Amith-Kumar, **M. Danny Raj**, Tim Rogers, Harikrishnan R., Vishwesh Guttal, "Noise-Induced Schooling of Fish", **Nature Physics**, vol 16, no 4, 2020.
8. C G Danny, **M Danny Raj**, Vvr Sai, 'Ray optics model for U-bent fiber optic sensors', **Journal of Lightwave Technology**, vol 38, no 6, 2020.
7. **M. Danny Raj**, A. Gnanasekaran and R. Rengaswamy, "On the role of hydrodynamic interactions in the engineered assembly of droplet ensembles", **Soft Matter**, vol 15, no 39, 2019.

¹Corresponding author and Project coordinator

6. **M. Danny Raj** and R. Rengaswamy, "Interacting coalescence avalanches in a 2D droplet assembly", **AICHE Journal**, vol 65, no 3, 2019.
5. **M. Danny Raj** and R. Rengaswamy, "Averaged model for probabilistic coalescence avalanches in two-dimensional emulsions: Insights into uncertainty propagation", **Physical Review E**, vol 95, no 3, 032608, 2017.
4. **M. Danny Raj** and R. Rengaswamy, "Coalescence of drops in a 2D microchannel: critical transitions to autocatalytic behavior", **Soft Matter**, vol 12, no 1, 2016.
3. **M. D. Raj** and R. Rengaswamy, "Investigating Arrangement of Composite Drops in Two-Dimensional Microchannels Using Multi-Agent Simulations: A Design Perspective", **Ind. Eng. Chem. Res.**, vol 54, no 43, 2015.
2. S. Thiripuranthagan, **Danny Raj**, and K. Kannan, "Photocatalytic Degradation of Congo-red on Silica Supported Ag Impregnated TiO₂", **J. Nanosci. Nanotechnol.** vol 15, no 6, 2015.
1. **M Danny Raj** and R. Rengaswamy, "Understanding drop-pattern formation in 2-D microchannels: a multi-agent approach", **Microfluid. Nanofluidics**, vol 17, no 3, 2014.

Under Review or In-Preparation

4. Badal D, Kumar A, Singh V and **Danny Raj M**, 'A dynamic fluid landscape mediates the spread of bacteria', under review. [[ArXiv:2205.02645](#)].
3. Arshed Nabeel, Ashwin Karichannavar, Shuaib Palathingal, Jitesh Jhavar, **Danny Raj M**, Vishwesh Guttal, "Discovering stochastic dynamical equations for ecological time series data", under review. [[ArXiv:2309.05351](#)].
2. **Danny Raj M** and Vishwesh Guttal, 'Configuration space mixing in flocks and the effectiveness of mean-field models', under preparation.
1. Damini S K, Ashutosh S, **Danny Raj M** and Picardo J R, Data-driven reduced-order modelling of early-time laminar dispersion, under preparation.

Conference Proceedings

3. **M Danny Raj** and Arvind Nayak, "Collective traffic of agents that remember", TGF 2022 (in press). [[ArXiv:2302.03253](#)]
2. Christina G Danny, **M Danny Raj**, Vvr Sai, "Ray Optics Model for Light Attenuation in U-Bent Fibre Optic Sensors", in **IEEE SENSORS 2018**, New Delhi, 2018, pp. 1-4.
1. **Danny Raj M** and R. Rengaswamy, "Understanding Control in Microchannels to Manipulate Drop-Drop Interactions," in 2014 **European Control Conference (ECC)**, 2014, pp. 1055–1060.

Research Experience

April 2018–Present **DST-INSPIRE faculty**, [[Ongoing research – in blue](#)], Department of Chemical Engineering, IISc Bangalore, Bengaluru, India

- **Collective dynamics of droplets in microchannels:** *i)* Understanding the stability of 2D emulsions as a function of the topology of how the droplets are packed using formalism from network science, and developing data–physics hybrid models for predicting the stability. *ii)* **Industrial collaboration:**ⁱⁱ Design, operation and process intensification of microfluidic networks with traps.
- **Data science approaches to studying collectives:** *i)* Discovering governing equations from data: PDE models that describe the macroscopic features of the collective, etc.ⁱⁱⁱ *ii)* Deriving physics–inspired data–based models for droplet systems: identifying the rules that describe agent–interactions.^{iv} *iii)* Inferring agent–characteristics of a heterogeneous collective from trajectory–data: towards a theory for inference.
- **Group behaviour in social organisms:**^v *i)* Developing tools to extract the characteristics of noise in data: deriving interpretable SDEs for 'noisy' real world collectives. *ii)* Exploring the role of configurational space mixing in making the dynamics 'mean-field', in flocking systems.^{vi} *iii)* Understanding the emergence of functionality in animal collectives. How organisms capable of very simple interaction rules achieve *cohesion* and *polarisation*. *iv)* Optimisation approaches to discover the interactions between organisms, that best explain the observed phenomena.

- **Collective cell migration:** *i)* **Industrial collaboration:**^{vii} Developing tools to estimate sperm motility and its functional relationship with physiology for medical diagnostics.. *ii)* Understanding the role of dynamically changing landscape of Yeast lawns on the collective motility of bacterial cells.^{viii}
- **Dynamics of traffic systems:** *i)* Quantifying pedestrian crowd risk from movement information using measures of entropy.^{ix} *ii)* Investigating the dynamics of agents capable of cognition. *iii)* Collective dynamics in Indian traffic at a round-about: data-collection and analysis. *iv)* Engineering movement strategies in a dense crowd using insights from intruder movement through granular material etc.^x
- **Other:**^{xi} *i)* Optimisation approaches to estimating blood loss from images. *ii)* Investigating the effect of different lockdown strategies, testing rates, etc. on the spread of COVID-19 using a network model.

September 2016–March 2018 **Post-Doctoral Fellow with Prof. Raghunathan Rengaswamy**, *Department of Chemical Engineering, IIT Madras, Chennai, India*

- Developed a data–first-principles hybrid model of an aluminium smelting process that involved reconstructing missing input (sponsored by General Electric, Bangalore).
- Setting up a spinning disk atomiser for production and collection of mono-dispersed droplets.

September 2014–January 2015 **Visiting Research Scholar with Prof. Debangshu Bhattacharya**, *Department of Chemical Engineering, West Virginia University, Morgantown, USA*

- **Modelling health of refractories in gasifiers:** A discrete-element model was developed to diagnose the health of a gasifier-refractory which is subject to extreme conditions—high temperature and corrosion.

July 2011–September 2016 **Graduate Scholar with Prof. Raghunathan Rengaswamy**, *Department of Chemical Engineering, IIT Madras, Chennai, India*

- **Thesis – Drops as agents: understanding complex behaviour in 2D microchannels.**
 - **Droplets self-organise as they flow through 2D channels.** This dynamic assembly emerges due to the hydrodynamic interactions between the several droplets and the channel boundary. We propose agent-based models that sufficiently capture the forces on the droplets due to these interactions and simulate the group-level organisation phenomena. The computational simplicity of the models allows us to incorporate them in optimisation frameworks to identify non-trivial, optimal operating strategies and channel design to engineer droplets as required.
 - **Concentrated droplet systems exhibit coalescence avalanches.** Coalescence of a pair of droplets can trigger an avalanche of similar events that propagate, rather probabilistically, through the entire emulsion, destabilising it. We propose a stochastic agent based model that helps us understand the nature of the avalanching phenomenon and how it depends on the system parameters like the geometry (or the topology) of the emulsion, number of triggers, anisotropy and propensity of local propagation, etc.

July 2010–July 2011 **Undergraduate research with Prof. T Sivakumar**, *Department of Chemical Engineering, A.C.Tech, Anna University, Chennai, India*

- **Catalyst improvement studies:** We performed controlled doping of (noble metals) and substrate immobilisation of TiO₂ catalysts to synthesise visible-light active photocatalysts with high surface area. Their activity was tested based on their ability to degrade standard water pollutants from the textile industry (sponsored by UGC, India).

Experience as a Reviewer

Have refereed articles for *Nature Communications Physics, Nature Physics, PLOS computational biology* and *eLife*.

IN COLLABORATION WITH:

ⁱⁱ[Industrial] Shilps Sciences Bangalore (Dr. Ashwin Lal)

ⁱⁱⁱProf. Jason R Picardo, IIT Bombay

^{iv}SENAI, Prof. Raghunathan R, IIT Madras

^vTEELAB, Prof. Vishwesh Guttal, CES, IISc

^{vi}Prof. Guy Theraulaz, CNRS, France

^{vii}[Industrial] Metflux Research Pvt Ltd. (Prof K.V. Venkatesh, IIT Bombay)

^{viii}Prof. Varsha Singh, MRDG, IISc

^{ix}Prof. Ashish Verma, Civil Engg, IISc

^xProf. V Kumaran, CE, IISc

^{xi}Prof. Christina Danny, MSRIT, Bengaluru

Teaching Experience

- March 2023 **Combining physics-based modelling approaches with data-science methods**, *Mechanistic and data-driven modelling in biology*, Lectured at Stella Maris College.
- Mechanistic modelling of simple interacting populations: how to choose the right terms to model, how to analyse steady states and the overall dynamical behaviour and systematically scale the equations to reduce the parameter space.
 - Novel techniques in data-science were introduced which helped one to learn interpretable, simple equations from data.
 - Agent based models were introduced as alternate means to model interacting populations. Methods to describe the population-level properties were introduced and population-level equations were derived using the data-driven techniques.
 - All the lectures were complemented by Python tutorial classes to carry out simulations and test out the techniques learnt.
- May 2020 **Designed and taught a course on writing**, *Cultivating the joy of writing in research*, IISc
- Offered to scholars in the department of chemical engineering, IISc Bangalore (online) as a non-credit course.
 - Lectures and assignments: styles of writing, classic style, curse of knowledge, thought and language, visualisations etc.
- 2016 **Teaching assistant for graduate course**, *Complex hydrodynamics*, IIT Madras
- Holding tutorials for the visualisation of flow fields for point singularities in flow.
- 2013, 2014 **Teaching assistant for undergraduate course**, *Process control*, IIT Madras
- Lectures on modelling physical systems for control, use of Laplace transforms in control.
 - Holding tutorials on a weekly basis: preparing problem sets for demonstration and classwork.
 - Setting up question papers for quizzes and end semester; grading answer sheets.

Invited Talks

18. Delivered a series of lectures on, 'Mechanistic and data-driven modelling in biology', as part of the *Scholar-in-residence program* organised by Stella Maris College, Chennai, Tamilnadu from 27-31 March 2023.
17. Invited talk on, 'Inferring the heterogeneity of a collective from data', in the symposium for the Physics of cells and tissues held at BSSE, IISc Bangalore, 15-16th February 2023.
16. A invited talk on the topic, 'Understanding collective phenomena from the underlying interaction networks', at the International Center for Theoretical Sciences (ICTS) Bangalore, 8th July 2022.
15. Invited talk on, 'Inferring intrinsic properties of agents in heterogeneous collectives', at Descriptive & Normative Models of Collective Behaviour Workshop, organised by the School of Mathematics, University of Leeds, UK, 23rd June 2022.
14. Invited talk on, 'Modelling collective phenomena', at the International Conference on the Recent Strategies in Mathematics and Statistics (ICRSMS 2022), organised by Stella Maris College, Chennai, India, 21st May 2022.
13. A invited talk on the topic, 'Understanding collective phenomena from the underlying interaction networks', at the Department of Chemical engineering, IIT Gandhinagar, 24th March 2022.
12. A lecture on, 'Introduction to collective phenomena', for undergraduates and faculty at the Department of Chemical engineering, MVJ college of Engineering, Bangalore on 13th November 2021.
11. A seminar on the topic, 'Observing and inferring the characteristics of a collective', as part of the department seminar series in the department of mechanical engineering, IISc Bangalore on the 18th December 2020.
10. A lecture on, 'Simple models for soft matter', in the Soft matter young investigators meet (SMYIM), held virtually on the 3rd December 2020.
9. Organised a special session on, 'Modelling collective phenomena' and presented an overview of the topic in the Synergies in computational, mathematical, statistical and physical sciences (FIM), held virtually on the 24th November 2020. ([YouTube](#))

8. A lecture on, 'Engineering droplets in a microchannel', for scholars and faculty attending a two-week certificate course, Centre for Micro Nano Design and Fabrication, Saveetha Engineering College, Chennai on 24th July 2020.
7. A lecture on, 'Droplet microfluidics: the science and engineering of small-scale flows', for undergraduates and faculty at the Department of Chemical engineering, MVJ college of Engineering, Bangalore on 21st September 2019.
6. A talk on, 'Moving through a crowd: nature inspired traffic rule', in the Collective Behaviour Symposium organised by the Center for Ecological Sciences, IISc Bangalore on 13th September 2019.
5. A lecture on, 'Simulating complex systems with MATLAB', research scholars from Mathematics, Applied Mathematics and Computer science as a part of the workshop IWDAM 2019 (International workshop on Data Analytics and MATLAB) September 2019.
4. An invited talk at the 1st Indian Process Systems Engineering (IPSE) at IIT Madras on, 'A systems approach to droplet microfluidics', 18th August 2019.
3. A lecture on, 'Collective behavior of a group of interacting agents: droplets, fishes and traffic', as part of the department seminar series in the department of chemical engineering, IISc Bangalore on the 15th November 2018.
2. A lecture on, 'A peek into chemical engineering', to students in their high school and first year in bachelors, as part of Sanjog 2017, a program for children of the staff of Indian Army, held in IIT Madras on 6th June 2017.
1. A talk on, 'Understanding collective behavior of drops in 2D microchannels: an agent-based approach', in the Department of chemical engineering, University of Florida, Gainesville on the 17th Nov 2015.

Extra-curricular Activities

- Have passed grade 8 in Western-classical piano practical and grade 5 in music theory examinations conducted by the Associated Board of the Royal School of Music (ABRSM), London.
- I conduct choirs, involve myself in church choral music where I play the piano and sing bass. (Check out my [blog post](#) for interesting connections between choral singing and collective phenomena).