

Tools for applied math research.

Indranil Ghosh

<https://indrag49.github.io>

3 December, 2025



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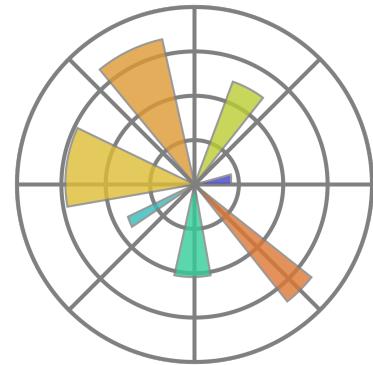
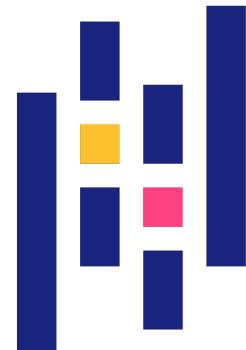
What is applied math research?

1. We try to describe and understand real world systems using mathematical modelling.
2. These include physical, biological, and social problems. We formulate ODEs, DDEs, PDEs, and discrete-time models for complex dynamical behaviour.
3. We also use network science to examine interactions among coupled subsystems (neurons, epidemiology, etc.).
4. We create models from experimental data. We also perform large and small scale data analysis.
5. We sometimes also integrate machine learning.

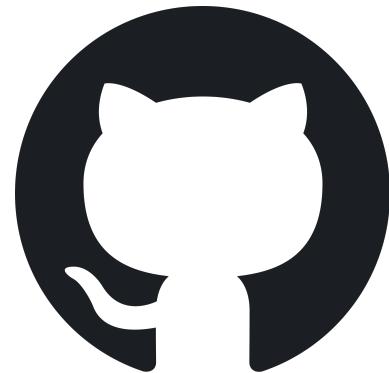
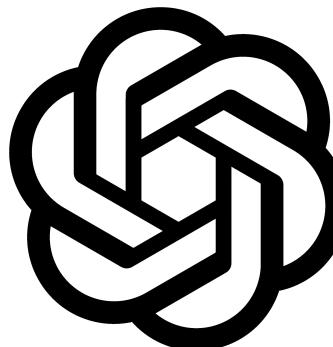
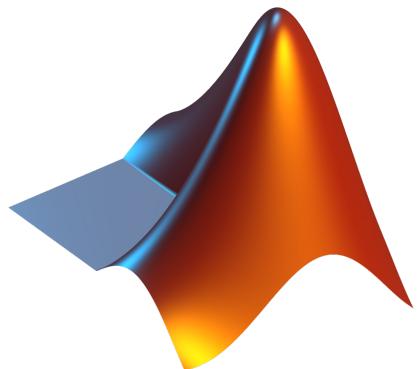


source: https://hero.fandom.com/wiki/Cuthbert_Calculus

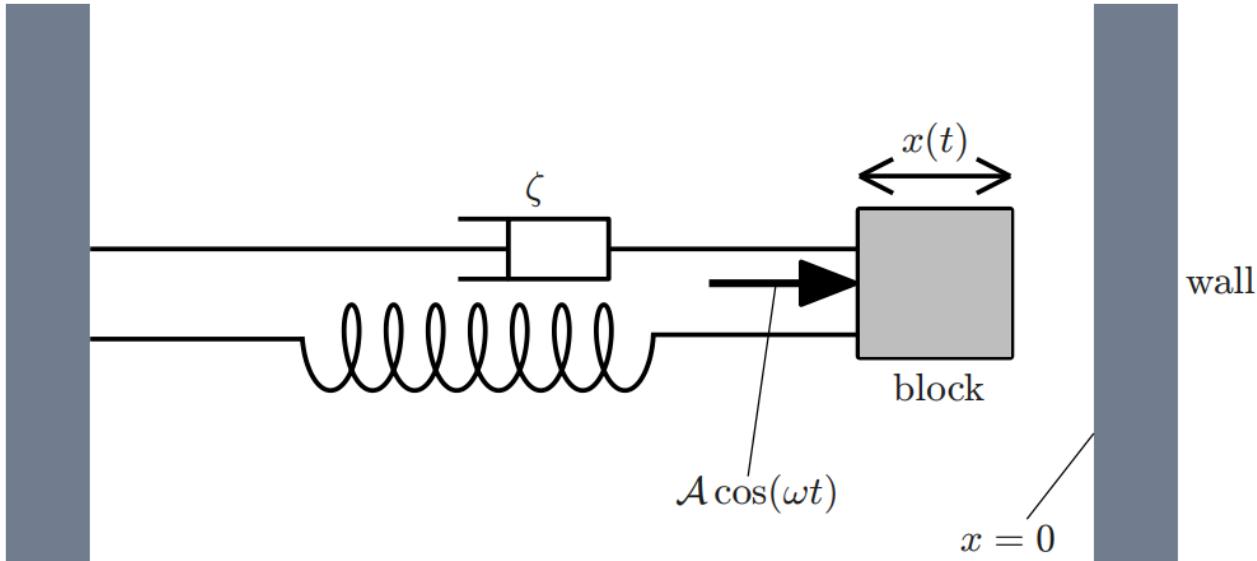
General spectrum of resources.



julia



Physical systems (hybrid impact oscillator).



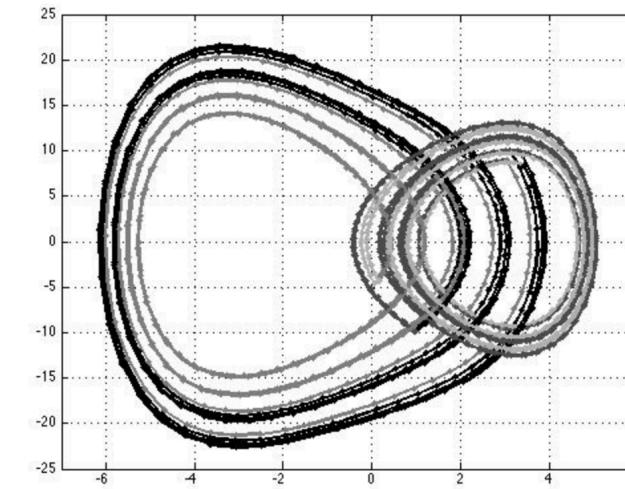
$$\begin{aligned}\ddot{x} + 2\zeta\dot{x} + x + 1 &= \mathcal{A} \cos(\omega t), \quad \text{for } x < 0, \\ \dot{x} &\mapsto -\epsilon\dot{x}, \quad \text{whenever } x = 0,\end{aligned}$$

COCO - Continuation Core and Toolboxes for Matlab

By [Harry Dankowicz](#) and [Frank Schilder](#)

Print

The Computational Continuation Core (COCO) is a Matlab-based software platform for numerical continuation of constrained solutions to nonlinear equations, e.g., those arising from discretization of finite- and infinite-dimensional boundary-value problems. COCO aims to provide a platform for advanced toolbox and atlas algorithm development, but also to enable all the functionality of existing continuation packages in a user-accessible format.



Periodic orbit in a nonlinear oscillator with piecewise constant forcing.

Social systems (epidemiology).

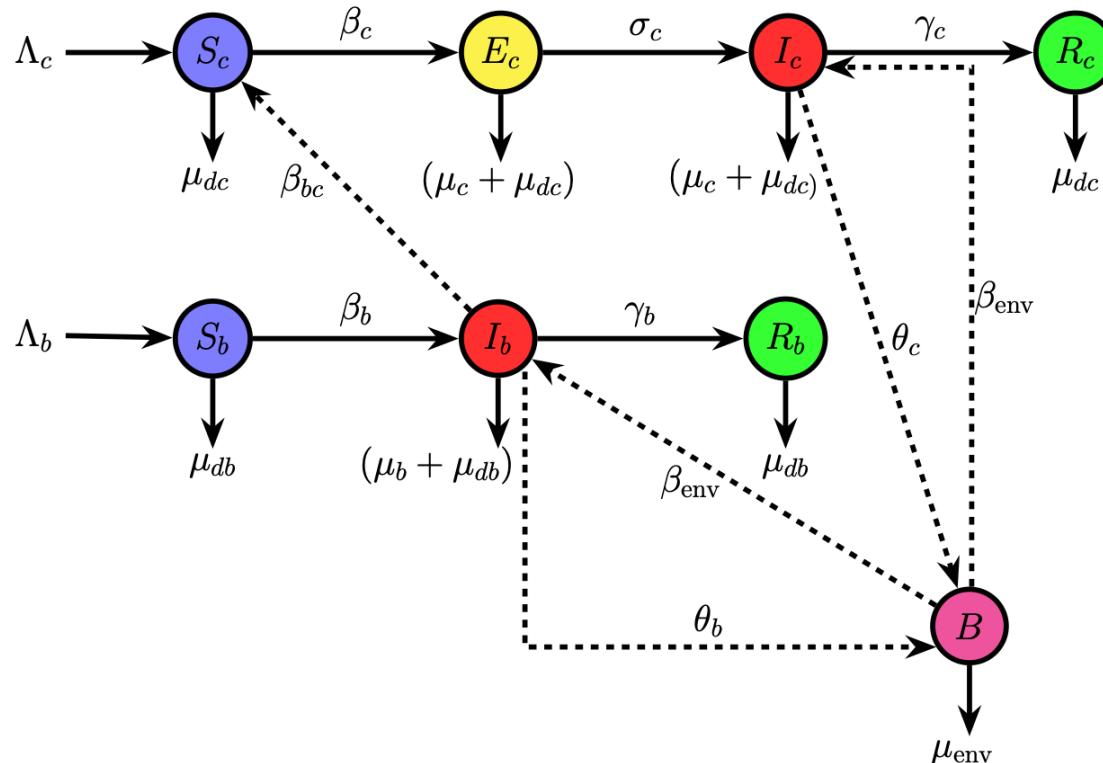


Figure 1: Flow diagram illustrating the transmission routes of the HPAI virus among cattle, wild birds, and the environment. The cattle population is represented by four compartments ($S - E - I - R$), the wild bird population by three compartments ($S - I - R$), and the environment by a single compartment (B)



Biological systems (coupled neurons).

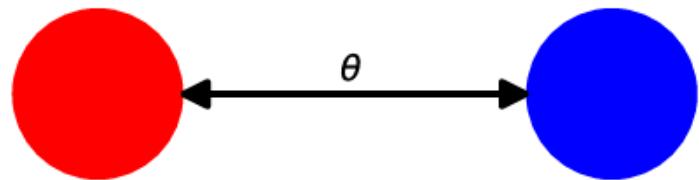


Fig. Electrical (gap-junction) coupling

$$\begin{aligned}\dot{x}_i &= f(x_i, y_i, I_i) + \sum_{j \in B(i)} \theta(x_j - x_i), \\ \dot{y}_i &= g(x_i, y_i, I_i), \\ \dot{I}_i &= h(x_i, y_i, I_i),\end{aligned}$$

↑
Coupling term

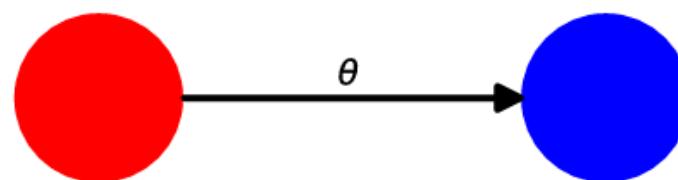


Fig. Chemical coupling

$$\begin{aligned}\dot{x}_1 &= f(x_1, y_1, I_1), \\ \dot{x}_2 &= f(x_2, y_2, I_2) + \theta \frac{v_s - x_2}{1 + \exp\{-\lambda(x_1 - q)\}}, \\ \dot{y}_i &= g(x_i, y_i, I_i), \\ \dot{I}_i &= h(x_i, y_i, I_i),\end{aligned}$$

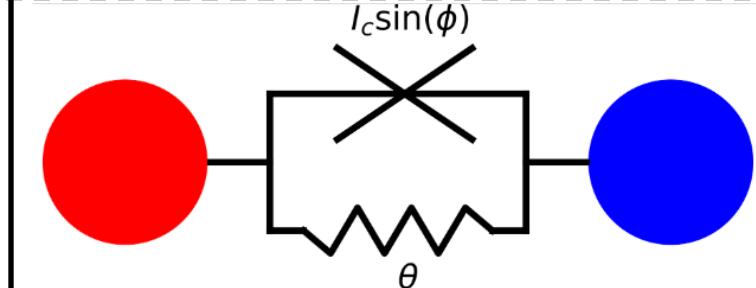
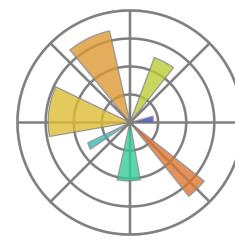


Fig. Josephson junction coupling

$$\begin{aligned}\dot{x}_1 &= f(x_1, y_1, I_1) - I_c \sin(\phi) + \theta(x_2 - x_1), \\ \dot{x}_2 &= f(x_2, y_2, I_2) + I_c \sin(\phi) + \theta(x_1 - x_2), \\ \dot{y}_i &= g(x_i, y_i, I_i), \\ \dot{I}_i &= h(x_i, y_i, I_i), \quad i = 1, 2, \\ \dot{\phi} &= \mu(x_1 - x_2),\end{aligned}$$



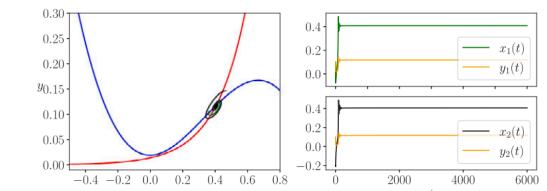
Biological systems (contd.).

$${}^C D_0^\beta x_1 = x_1^2(1 - x_1) - y_1 + I + \theta(x_2 - x_1),$$

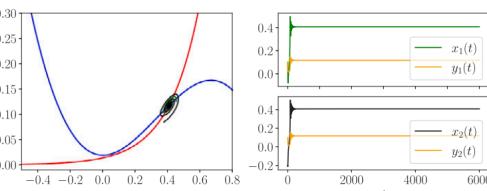
$${}^C D_0^\beta y_1 = Ae^{\alpha x_1} - \gamma y_1,$$

$${}^C D_0^\beta x_2 = x_2^2(1 - x_2) - y_2 + I + \theta(x_1 - x_2),$$

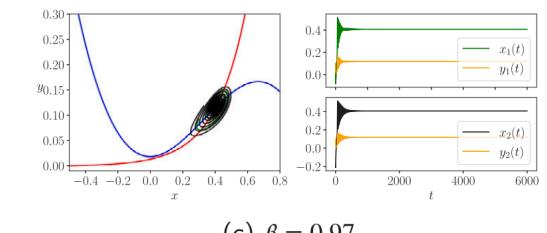
$${}^C D_0^\beta y_2 = Ae^{\alpha x_2} - \gamma y_2.$$



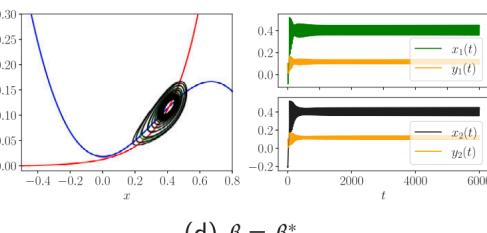
(a) $\beta = 0.9$



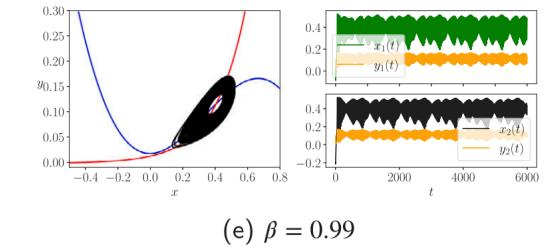
(b) $\beta = 0.93$



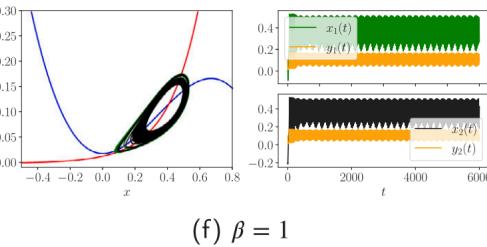
(c) $\beta = 0.97$



(d) $\beta = \beta^*$

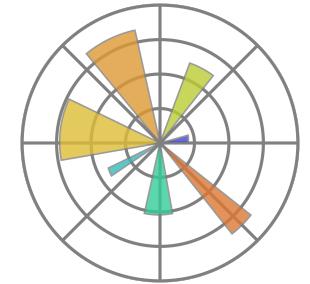


(e) $\beta = 0.99$



(f) $\beta = 1$

julia



JuliaTurkuDataScience/
FdeSolver.jl



FdeSolver.jl: A Julia package for the numerical solution of fractional differential equations (FDEs) as well as systems of equations.

3
Contributors

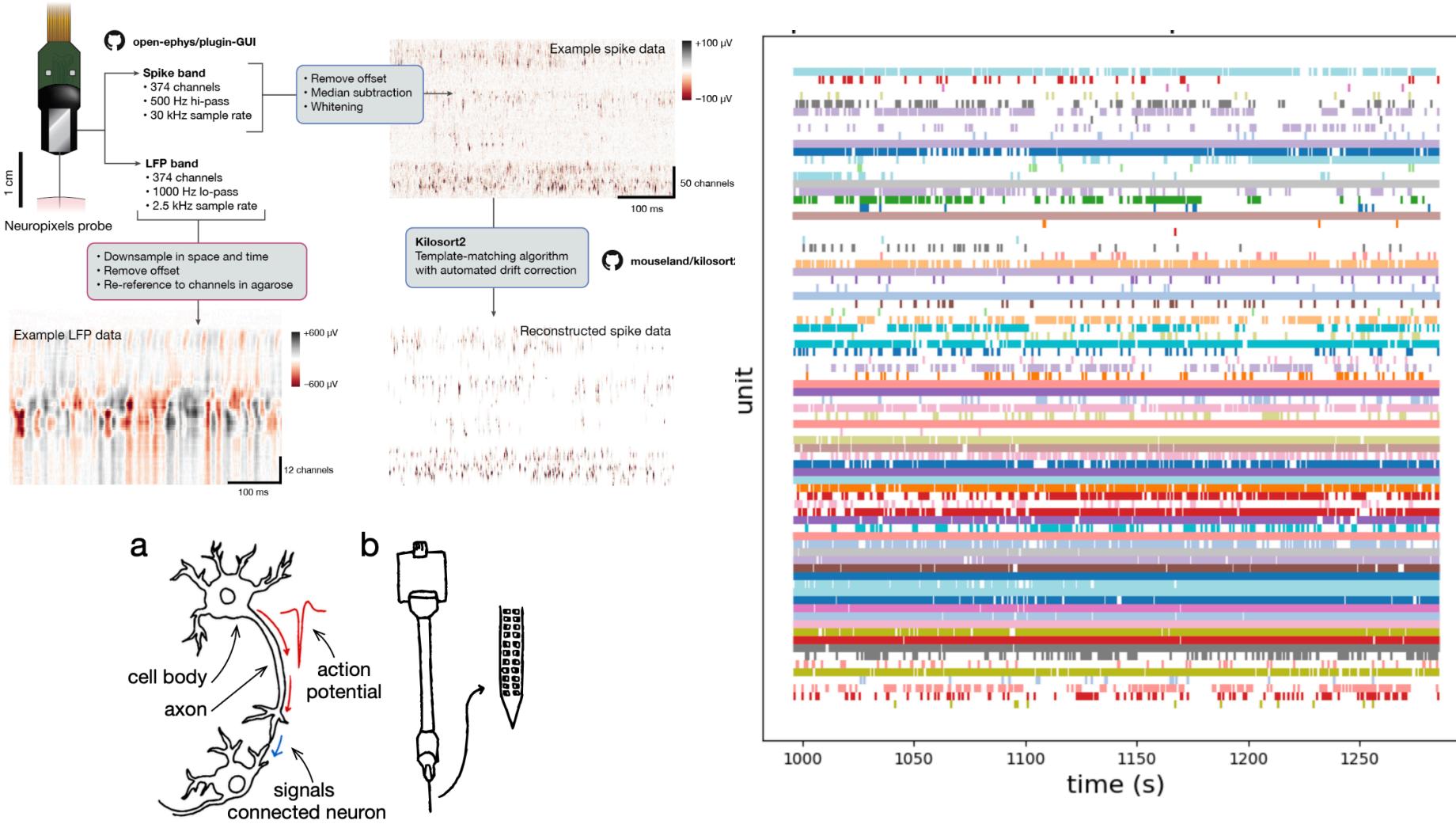
2
Issues

17
Stars

4
Forks



Allen institute dataset (SDKs)



1. Open source data and notebooks.
2. Respects the “Reduction” aspect of the European 3Rs.



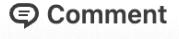
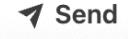
Ines Montani's keynote (Python Ireland 2025).

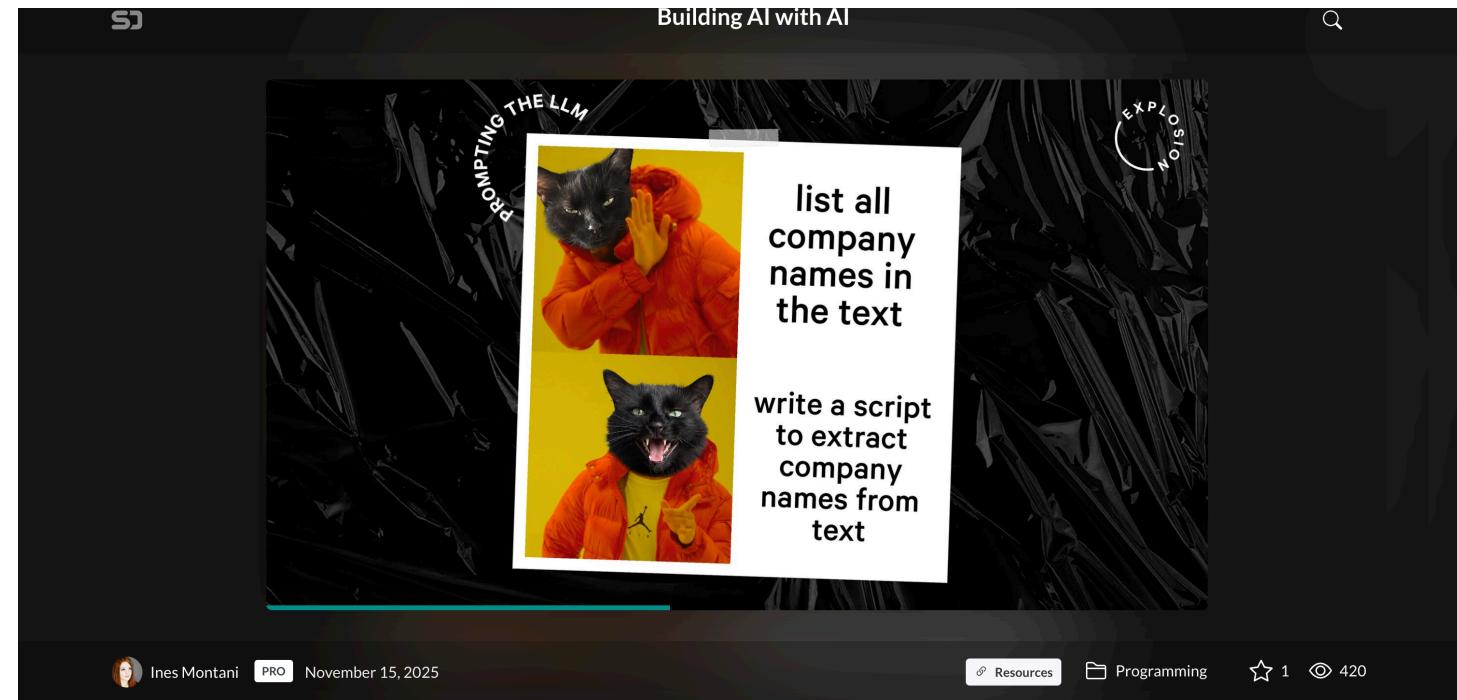
 **Ines Montani**  • 1st
Founder at Explosion (spaCy, Prodigy)
[Visit my website](#)
1w · 

Back from a great PyCon Ireland in Dublin! Here are some of my personal highlights: ...more



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PROMPTING THE LLM

list all company names in the text

write a script to extract company names from text

Ines Montani PRO November 15, 2025

 Resources  Programming  1  420

“Ask LLMs not to do a task, but to write a script to do it!”: reduces the risk of hallucinations.

Enter  : “say your prayers, code your prompts”

Enter



: “say your prayers, code your prompts”

I have a slide with title "Enter ChatGPT", how can I add the Metallica reference here?

A slick way to pull off a **Metallica reference** on a slide titled "**Enter ChatGPT**" is to echo the vibe of "**Enter Sandman**" without being cheesy.

Here are options — ordered from subtle → bold — depending on your style and the audience.

🎸 Subtle (professional but fun)

Under the title:

| Say your prayers, code your prompts.

or

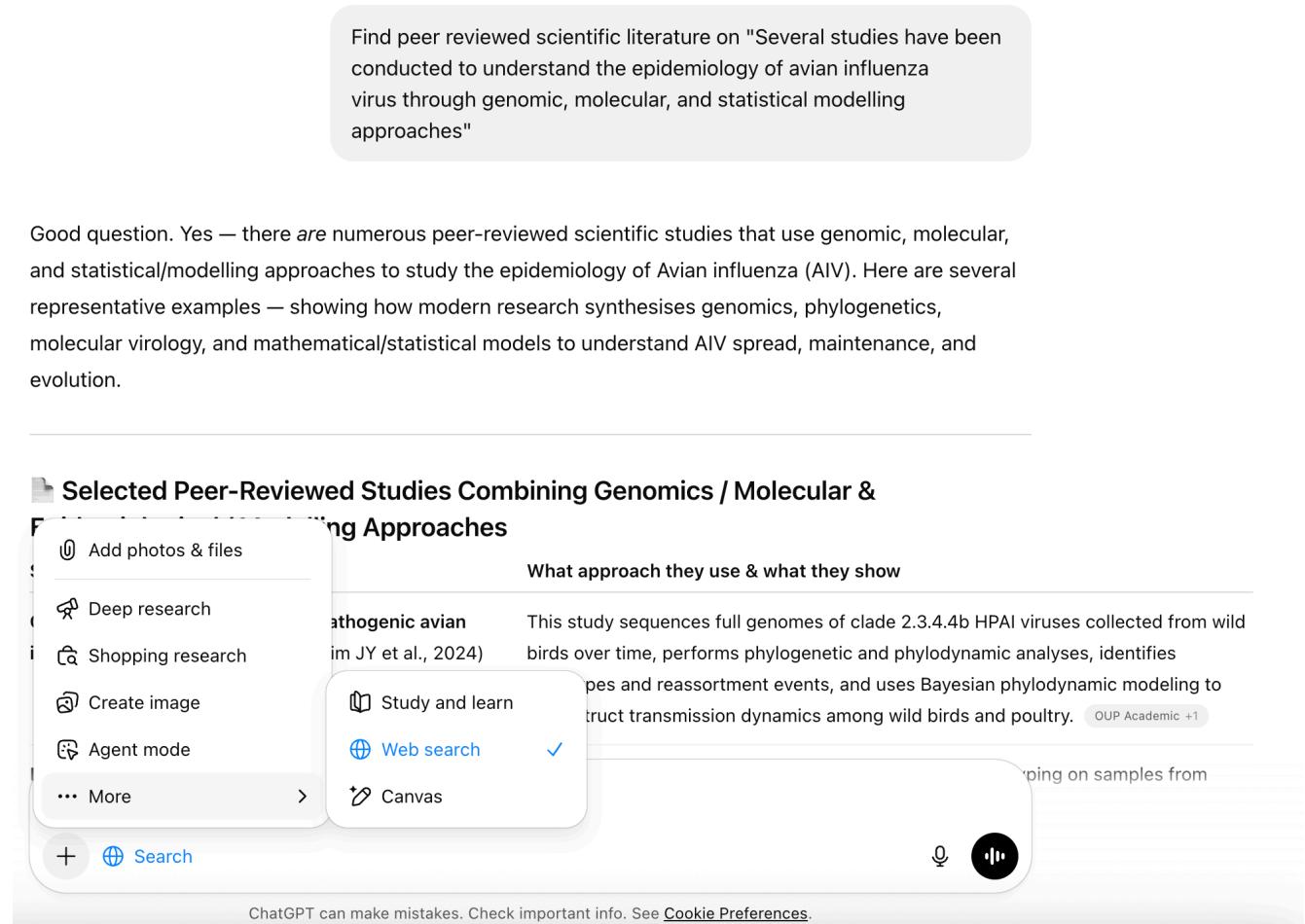
| Off to never-neural land...

(plays on "off to never-never land" — people will catch it instantly)



Enter (contd.): accelerated literature search.

1. Careful relevant prompt is essential!
2. Turn on the “web search”.
3. Be very critical of every literature provided.
4. Go on and read every citations, at least the “Abstract”.
5. Make sure the paper actually exists!!!!



The screenshot shows a ChatGPT interface. A user prompt asks for peer-reviewed scientific literature on "Several studies have been conducted to understand the epidemiology of avian influenza virus through genomic, molecular, and statistical modelling approaches". The AI response suggests numerous peer-reviewed studies using various approaches like sequencing full genomes, phylogenetic and phylodynamic analyses, and Bayesian modeling to understand AIV spread, maintenance, and evolution. A specific study by Kim JY et al., 2024, is highlighted, detailing its methods and findings. The interface includes a sidebar with options like Deep research, Shopping research, Create image, Agent mode, More, Search, and a footer note about cookie preferences.

Find peer reviewed scientific literature on "Several studies have been conducted to understand the epidemiology of avian influenza virus through genomic, molecular, and statistical modelling approaches"

Good question. Yes — there are numerous peer-reviewed scientific studies that use genomic, molecular, and statistical/modelling approaches to study the epidemiology of Avian influenza (AIV). Here are several representative examples — showing how modern research synthesises genomics, phylogenetics, molecular virology, and mathematical/statistical models to understand AIV spread, maintenance, and evolution.

Selected Peer-Reviewed Studies Combining Genomics / Molecular & Statistical Approaches

Add photos & files

Deep research

Shopping research

Create image

Agent mode

... More

Study and learn

Web search

Canvas

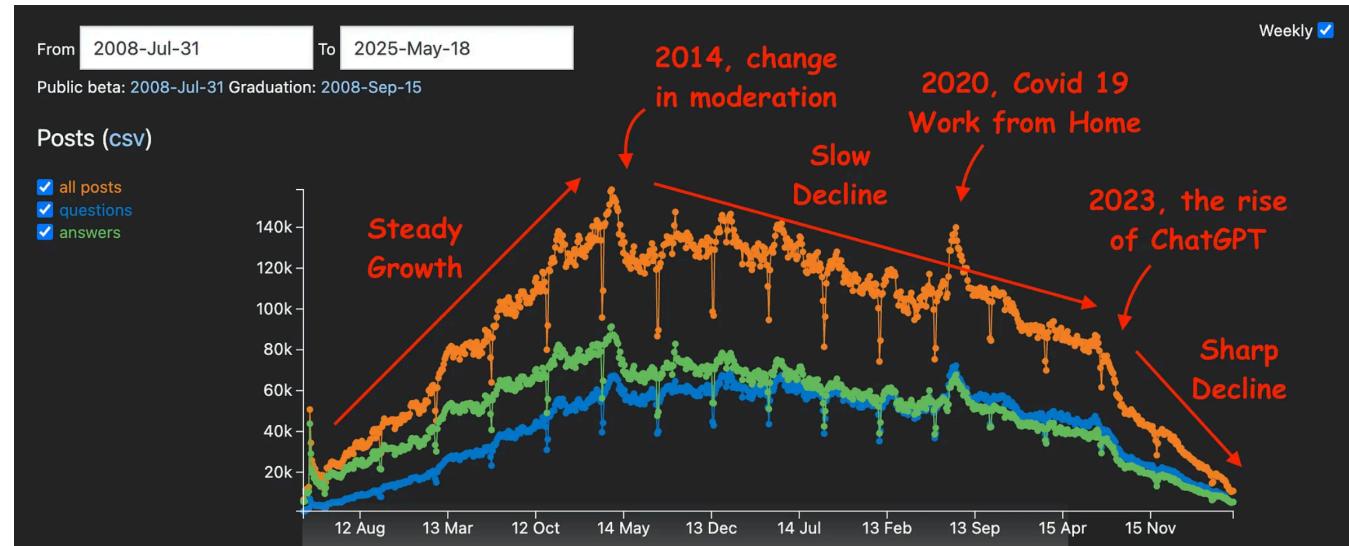
What approach they use & what they show

This study sequences full genomes of clade 2.3.4.4b HPAI viruses collected from wild birds over time, performs phylogenetic and phylodynamic analyses, identifies reassortment events, and uses Bayesian phylodynamic modeling to reconstruct transmission dynamics among wild birds and poultry. OUP Academic +1

ChatGPT can make mistakes. Check important info. See [Cookie Preferences](#).

Enter (contd.): accelerated coding.

1. Decline of “Stack Overflow”.
2. I strongly recommend basic coding knowledge before prompting LLMs.
3. I use for code debugging.
4. ChatGPT is very good with handling edge cases which humans might miss.
5. Ensure you follow everything from the last slide.



Source: <https://medium.com/tech-ai-chat/did-ai-kill-stack-overflow-i-hope-it-survives-798f66d9a6da>

Enter



(contd.): creating apps, accelerating frontend.

Choose coupling type:
Josephson Junction

θ (coupling strength):
-5

A:
0.0041

α:
5.276

y:
0.315

ε:
0.0005

Ic:
3

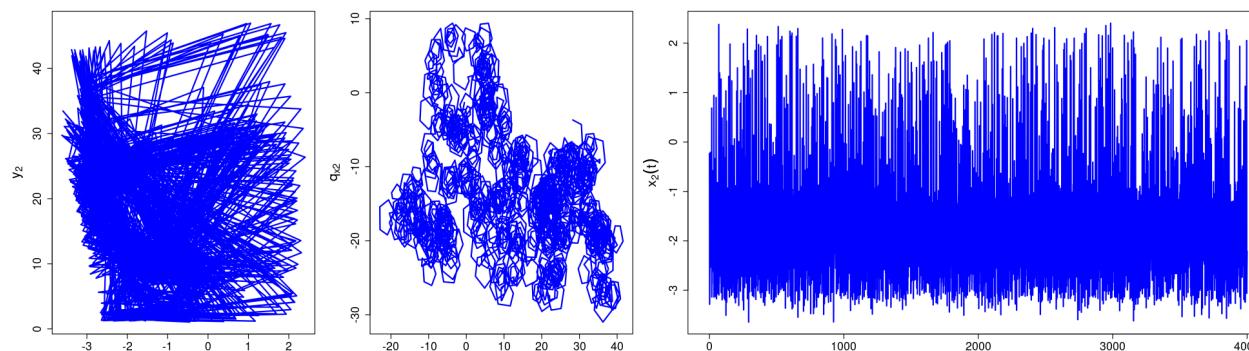
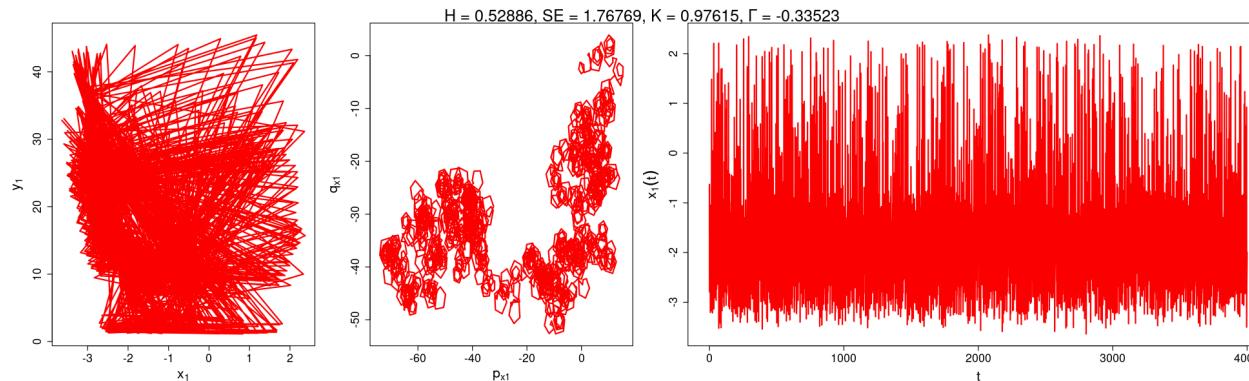
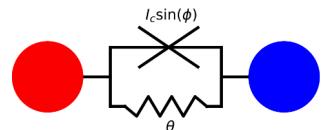
μ:
3

Run Simulation

Note: Adjust parameters and click 'Run Simulation' to update plots.

Model Equations:

$$\begin{aligned}\dot{x}_1 &= x_1^2(1 - x_1) - y_1 + I_1 - I_c \sin(\phi) + \theta(x_2 - x_1), \\ \dot{y}_1 &= A e^{\alpha x_1} - \gamma y_1, \\ \dot{I}_1 &= \varepsilon \left[\frac{1}{60} \left(1 + \tanh \left(\frac{0.05 - x_1}{0.001} \right) \right) - I_1 \right], \\ \dot{x}_2 &= x_2^2(1 - x_2) - y_2 + I_2 + I_c \sin(\phi) + \theta(x_1 - x_2), \\ \dot{y}_2 &= A e^{\alpha x_2} - \gamma y_2, \\ \dot{I}_2 &= \varepsilon \left[\frac{1}{60} \left(1 + \tanh \left(\frac{0.05 - x_2}{0.001} \right) \right) - I_2 \right], \\ \dot{\phi} &= \mu(x_1 - x_2).\end{aligned}$$



Enter (contd.): reading a manuscript.

1. Upload a PDF to start with.
2. Then upload screenshots of paragraphs or figures you are mostly interested in.
3. Relevant and specific prompts are essential
4. I have seen ChatGPT perform silly mistakes, however gives a great general overview.
5. Be critical! ALWAYS!

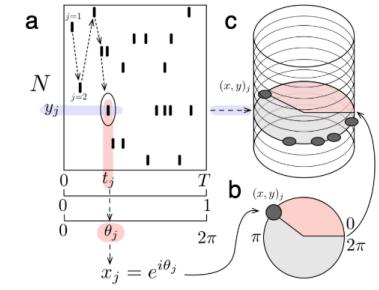


Figure M1. **Cylindrical geometry** (a) Schematic of example spike pattern across N neurons over T seconds. Spikes are indexed by j in temporal order (indicated by dashed arrows). Transformation from recorded spike time to complex-valued time is shown for example spike $j = 5$ (circled). (b) Example spike represented on the unit circle in the complex plane. Red shaded region indicates time from start of window. (c) Example spike depicted on cylinder, along with other spikes from the same neuron (shaded blue arrow, shaded grey circle).

[Tell me about this](#)

Excellent — this figure ("Cylindrical geometry") is fundamental to understanding the mathematical foundation of the **Discrete Helix Transform (DHT)**.

It shows **how spikes (neuron × time events)** are mapped into a **cylindrical coordinate system**, which is the geometric core of the "helix" representation.

Let's break it down carefully, because this is the bridge between the **raster plot** and the **helix transform mathematics**. 

Enter (contd.): exam preparation!

1. I don't highly recommend this. But I am experimenting.
2. Usually recommended for preparation of exams where the sample MCQs do not have the solutions.
3. Upload the PDFs to start with.
4. Be critical! ALWAYS! ChatGPT makes mistakes.
5. Also do not cheat!

How might you recognise hypothermia (animal is cold) in an animal ?
Mark one

Question 1Select one:

- a.
Hair loss
- b.
Is drinking excessively
- c.
Excessive grooming
- d.
A loss of elasticity in the skin
- e.
Piloerection (hair standing on end)

Correct answer:
e. Piloerection (hair standing on end)

 Explanation:

Piloerection (fur standing on end) is a classic sign of hypothermia in animals. It occurs as a thermoregulatory response — the animal raises its fur to trap an insulating layer of air and reduce heat loss.

Option	Explanation
<input checked="" type="checkbox"/> a. Hair loss – This is usually due to barbering, parasite  , dermatological issues, not acute hypothermia.	

Enter (contd.): writing blogs.

1. I have found ChatGPT very useful for accelerating blog writing!
2. Very well integrated with Github.
3. Design and frontend is very sophisticated.
4. This use case can have low criticisms.
5. However, prone to breaches!

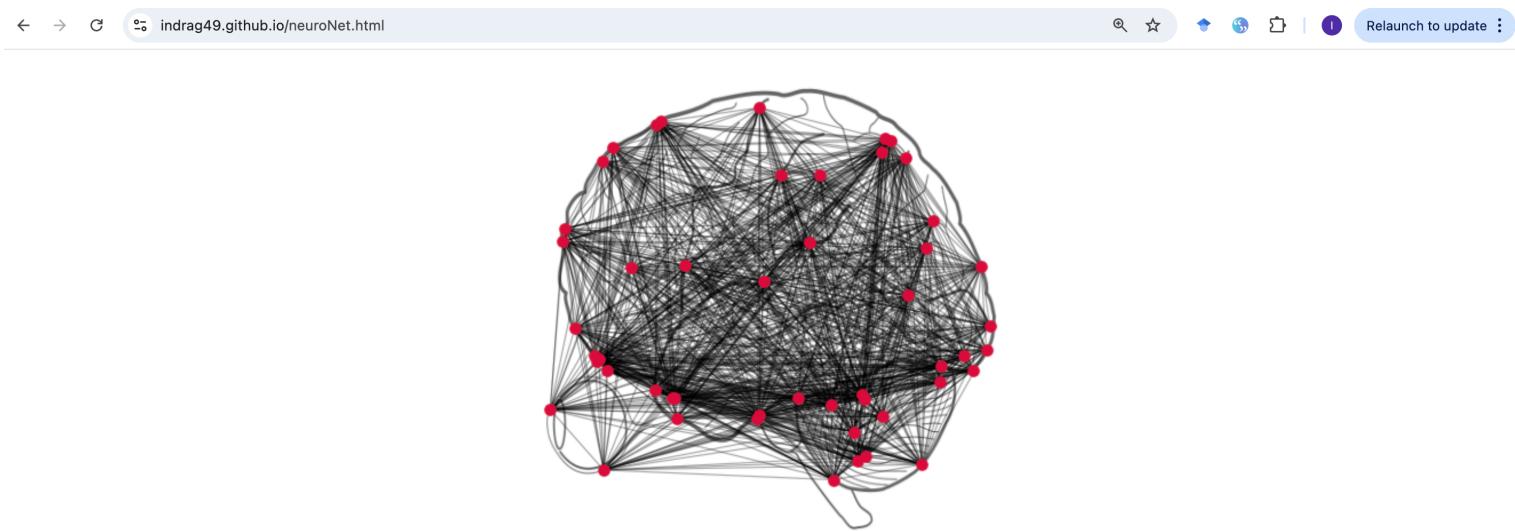


Figure 1. Erdős–Rényi network overlaid on the brain. (Brain schematic taken from Wikipedia)

Each neuron, represented by a red node in [Figure 1](#), has its own internal dynamics governed by [1](#). Because each neuron is dynamic, the whole network is a temporal network which evolves in time. The couplings (represented by edges) can be either static or evolving, depending upon the topology one wants to analyse.

Danger zones ! 💀 ⚡ while using LLMs.

1. Don't blindly trust as LLMs often sound confident while spewing gibberish.
2. Don't share sensitive info.
3. Don't use LLMs to replace your thought process., because they don't think.
4. Don't blatantly copy paste. Prone to plagiarism.
5. Don't use it to cheat or perform unethical actions.

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Large language models: 6 pitfalls to avoid

From security and privacy concerns to misinformation and bias, large language models bring risk along with rewards.

By [Eoin Wickens, Marta Janus](#)

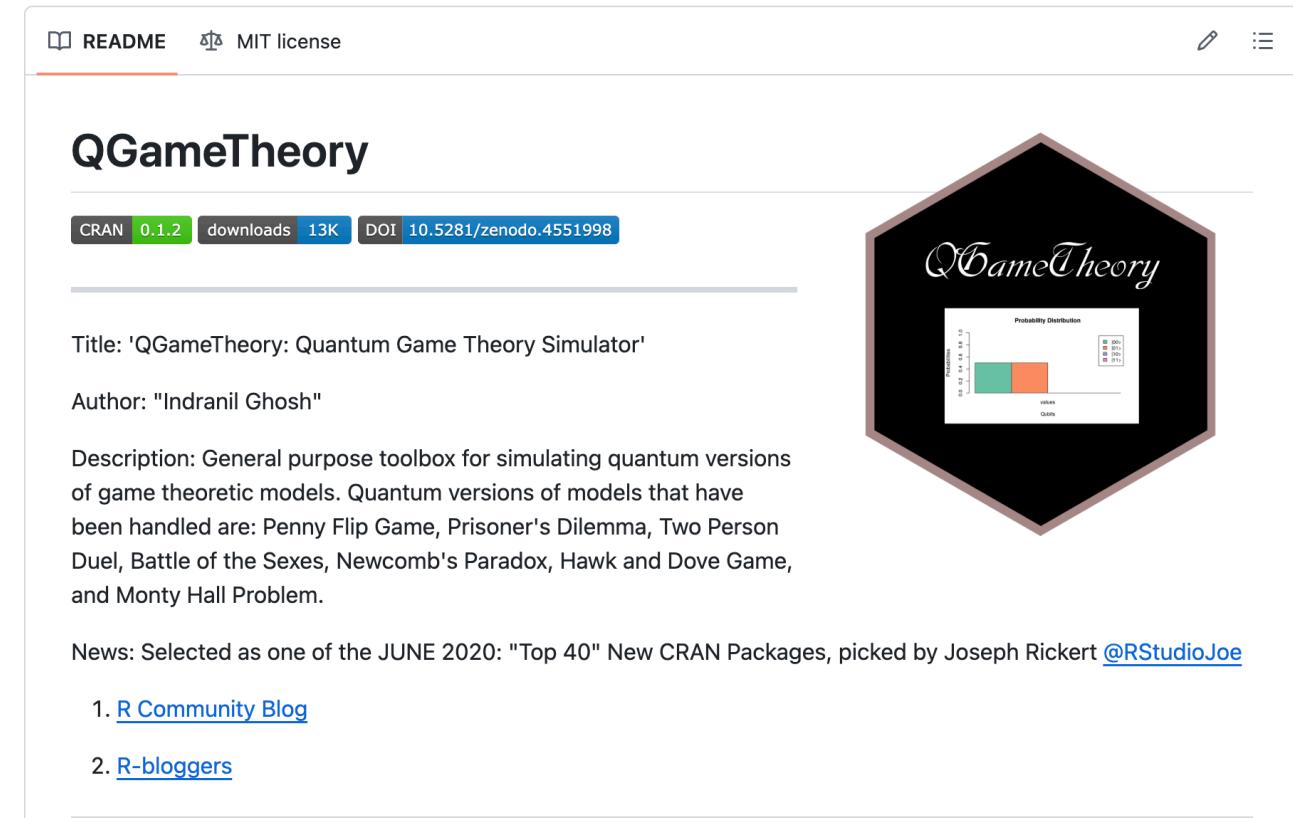
May 4, 2023 | 6 min read

45 readers like this.

There has recently been incredible progress in artificial intelligence (AI), due mainly to the advances in developing large language models (LLMs). These are the beating

Open source code with .

1. Package your code. ChatGPT can help with proper commenting and increase readability.
2. Increases transparency, reproducibility, and collaborations (unless you dream of commercialising!)
3. Accelerates progress and prevents duplication.
4. Professional reputation and portfolio grow.

A screenshot of a GitHub repository page for the 'QGameTheory' package. The page includes a navigation bar with 'README' and 'MIT license'. Below the title 'QGameTheory' are badges for CRAN (0.1.2), downloads (13K), and DOI (10.5281/zenodo.4551998). The description section states: 'Title: 'QGameTheory: Quantum Game Theory Simulator'' and 'Author: "Indranil Ghosh"'. The description text reads: 'Description: General purpose toolbox for simulating quantum versions of game theoretic models. Quantum versions of models that have been handled are: Penny Flip Game, Prisoner's Dilemma, Two Person Duel, Battle of the Sexes, Newcomb's Paradox, Hawk and Dove Game, and Monty Hall Problem.' A 'News' section mentions it was selected as one of the JUNE 2020: "Top 40" New CRAN Packages, picked by Joseph Rickert. There are two links: '1. [R Community Blog](#)' and '2. [R-bloggers](#)'. To the right of the main content is a dark hexagonal badge with the package name 'QGameTheory' and a small probability distribution plot.

Probability Distribution

Value	Probability
0.00	0.50
0.50	0.50

A recent good read.

Early science acceleration experiments with GPT-5

Sébastien Bubeck¹, Christian Coester², Ronen Eldan¹, Timothy Gowers³, Yin Tat Lee¹,
 Alexandru Lupsasca^{1,4}, Mehtaab Sawhney⁵, Robert Scherrer⁴, Mark Sellke^{1,6},
 Brian K. Spears⁷, Derya Unutmaz⁸, Kevin Weil¹, Steven Yin¹, Nikita Zhivotovskiy⁹

¹OpenAI

²University of Oxford

³Collège de France and University of Cambridge

⁴Vanderbilt University

⁵Columbia University

⁶Harvard University

⁷Lawrence Livermore National Laboratory

⁸The Jackson Laboratory

⁹University of California, Berkeley

November 20, 2025

Abstract

AI models like GPT-5 are an increasingly valuable tool for scientists, but many remain unaware of the capabilities of frontier AI. We present a collection of short case studies in which GPT-5 produced new, concrete steps in ongoing research across mathematics, physics, astronomy, computer science, biology, and materials science. In these examples, the authors highlight how AI accelerated their work, and where it fell short; where expert time was saved, and where human input was still key. We document the interactions of the human authors with GPT-5, as guiding examples of fruitful collaboration with AI. Of note, this paper includes four new results in mathematics (carefully verified by the human authors), underscoring how GPT-5 can help human mathematicians settle previously unsolved problems. These contributions are modest in scope but profound in implication, given the rate at which frontier AI is progressing.

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Questions, comments, suggestions?

Before ChatGPT



After ChatGPT

