

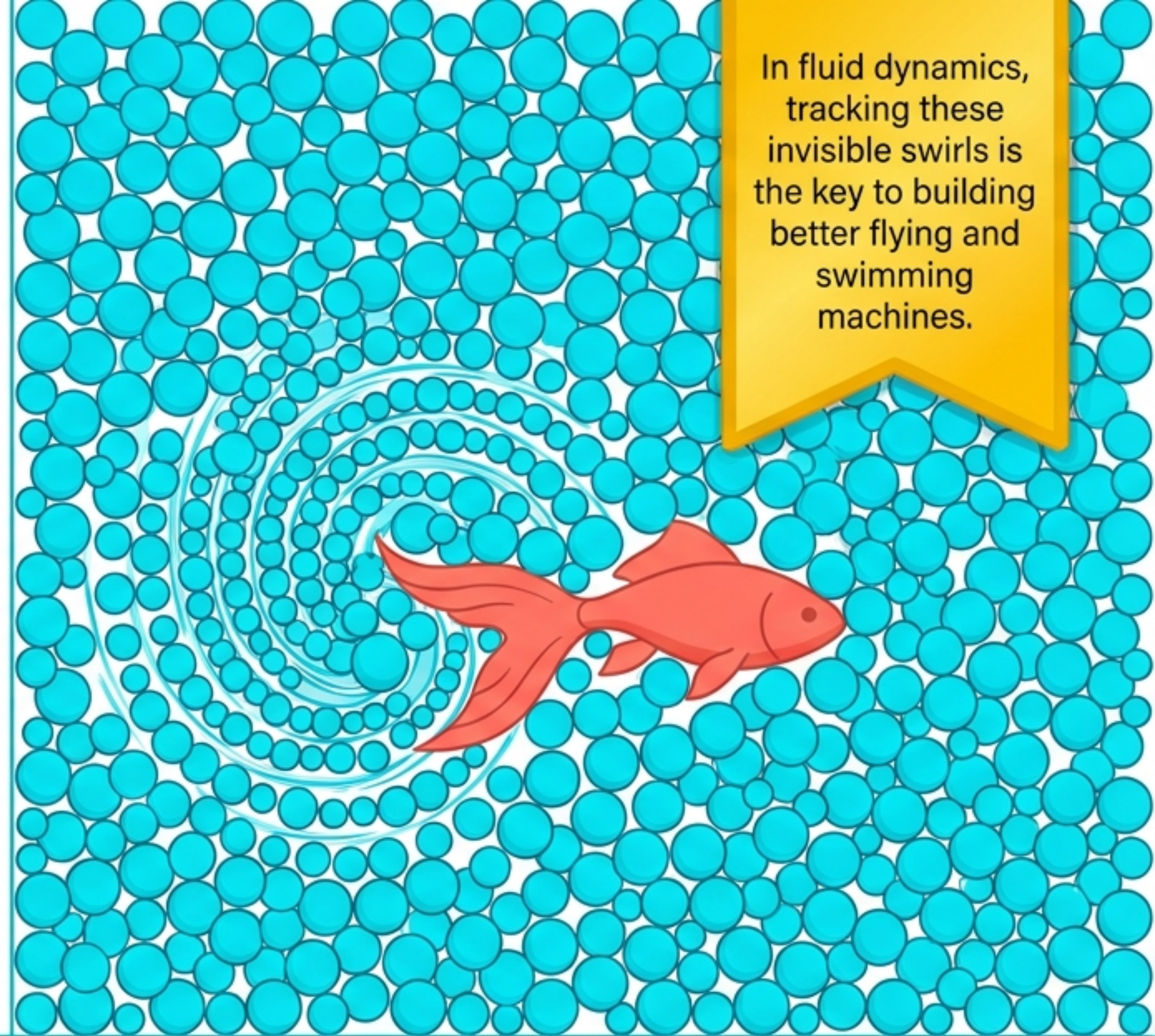
Catching the Invisible Wind

Teaching AI the rules of fluid dynamics to see what we cannot see.



A visual summary of the PhD Thesis by Rahul Sundar
IIT Madras, Department of Aerospace Engineering

To our eyes, birds and fish move through empty space.

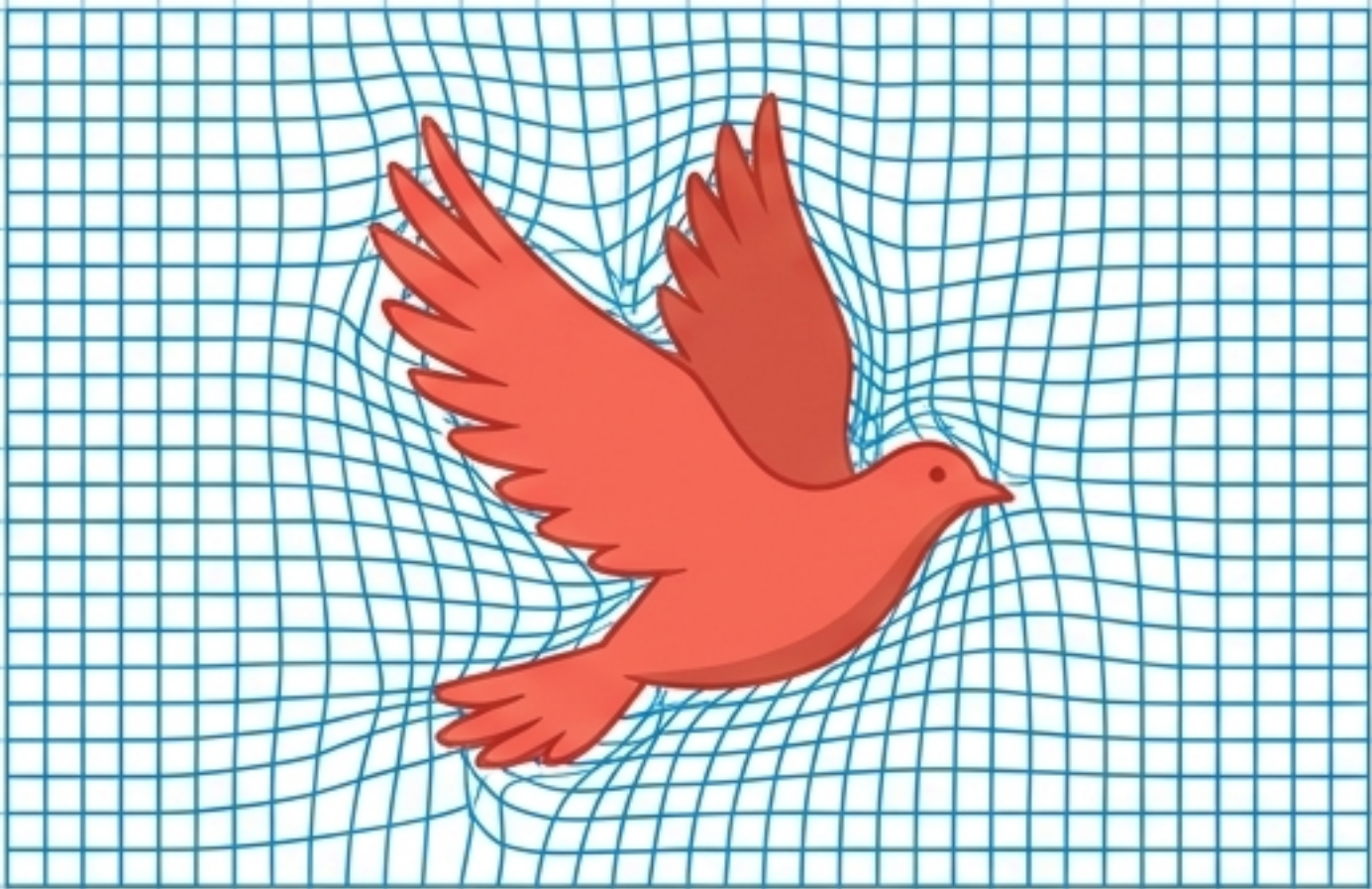


In fluid dynamics, tracking these invisible swirls is the key to building better flying and swimming machines.

Air and water act like a giant, invisible ball pit. Every time a wing flaps or a fin sweeps, it displaces the fluid, creating swirling wakes that give the animal lift and thrust.

How Computers Track the Wind

The Old Way: The Stretchy Canvas



Arbitrary Lagrangian–Eulerian (ALE)

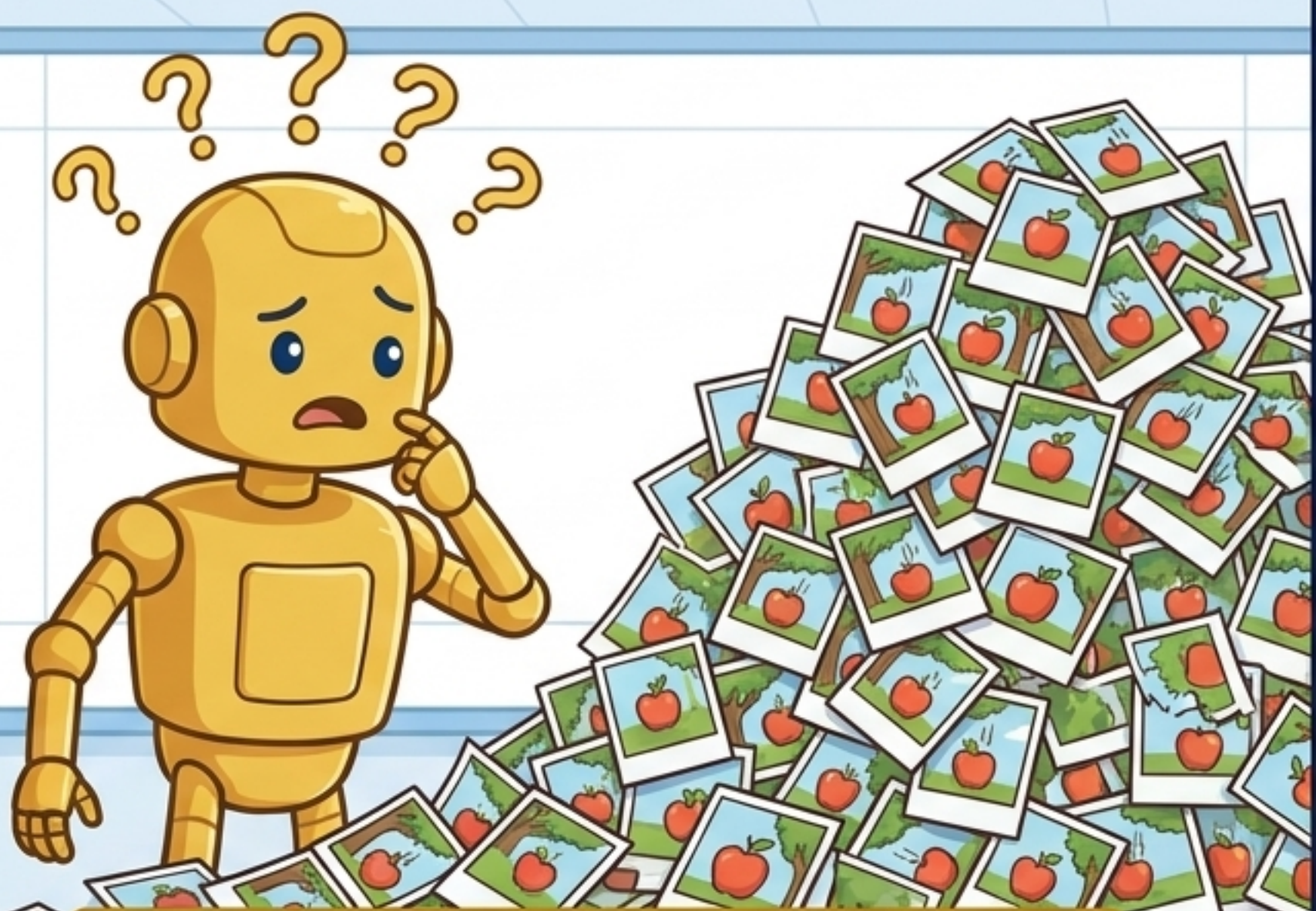
Accurate, but computationally exhausting. The computer has to painstakingly redraw the entire grid every microsecond as the body moves.

The New Way: The Fixed Canvas



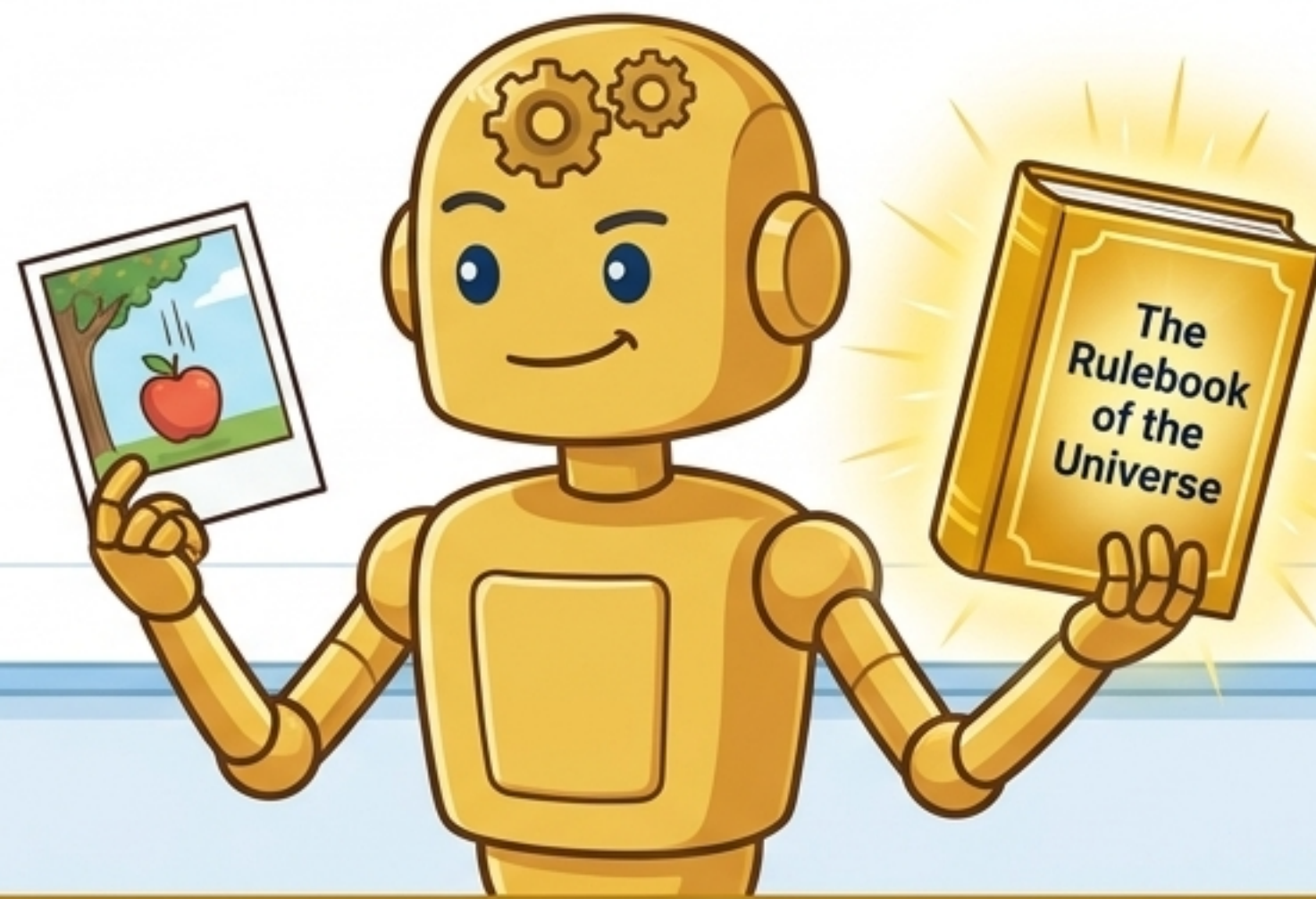
Immersed Boundary Method (IBM)

Extremely fast and handles complex motion easily. But, it creates “fake” fluid data inside the solid object that confuses standard analysis.



Standard AI

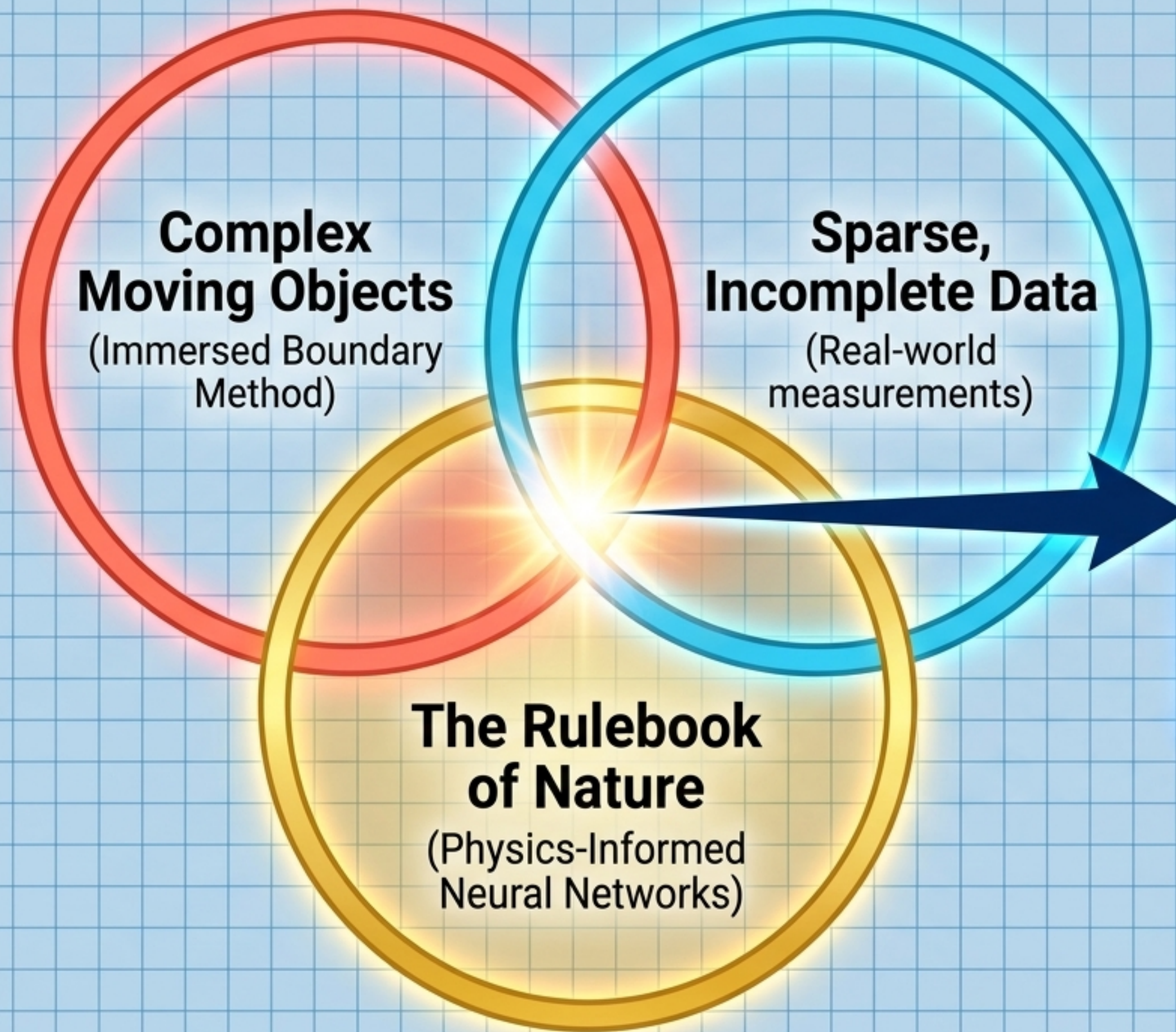
Guesses what happens next based purely on memory and massive amounts of data. Fails if it sees something completely new.



Physics-Informed AI (PINN)

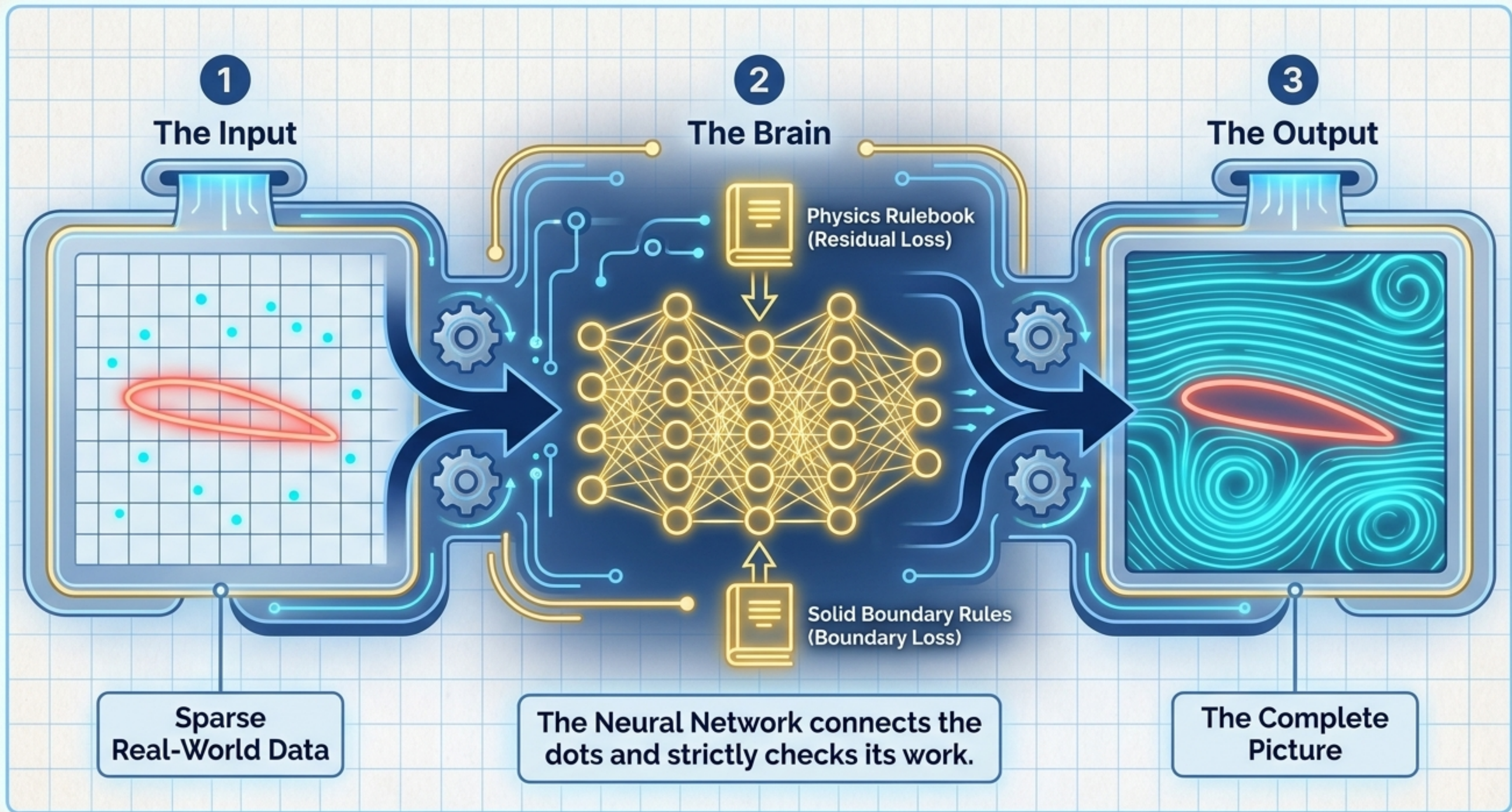
Guesses what happens next by checking the data against the exact mathematical laws of physics. Needs very little data to make perfect predictions.

Takeaway: Physics-Informed Neural Networks (PINNs) don't just find patterns; they obey the laws of nature.

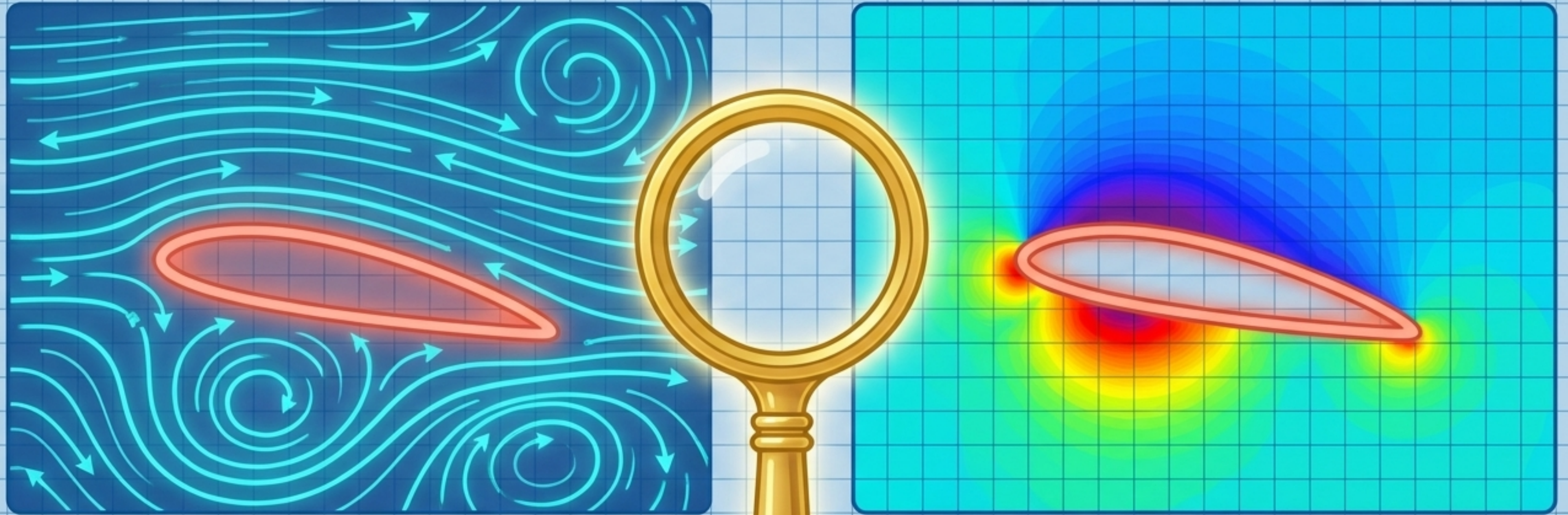


The IBA Framework
Immersed Boundary Aware Surrogate Modeling

The author's PhD breakthrough: A unified system that allows AI to perfectly understand moving bodies on a fixed canvas, using only partial data, without breaking the laws of physics.



Magic Trick #1: Finding the Invisible Squeeze



What we can see.

Cameras can only see how fast the wind is swirling (Velocity).

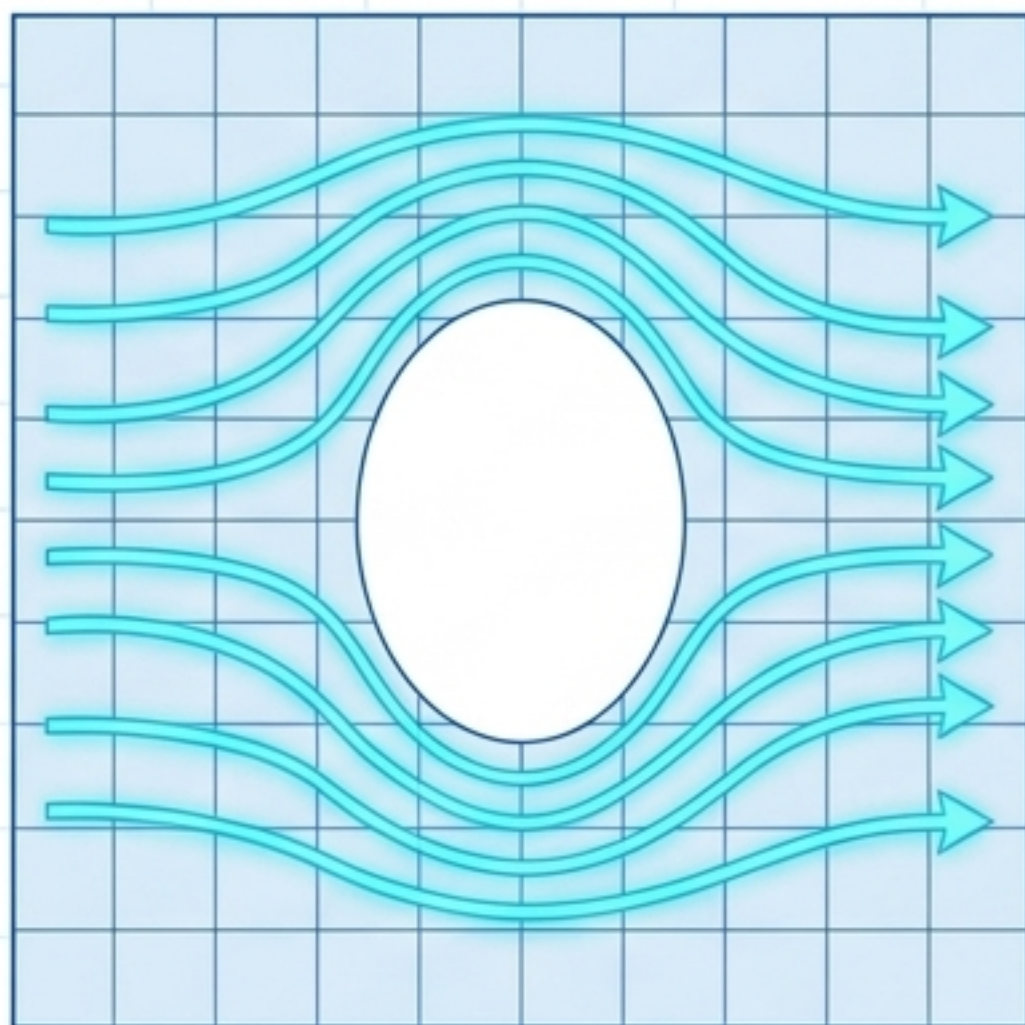
What the AI reveals.

By looking at the swirl and reading the Rulebook, the IBA Framework calculates the hidden, invisible forces squeezing the wing (Pressure).

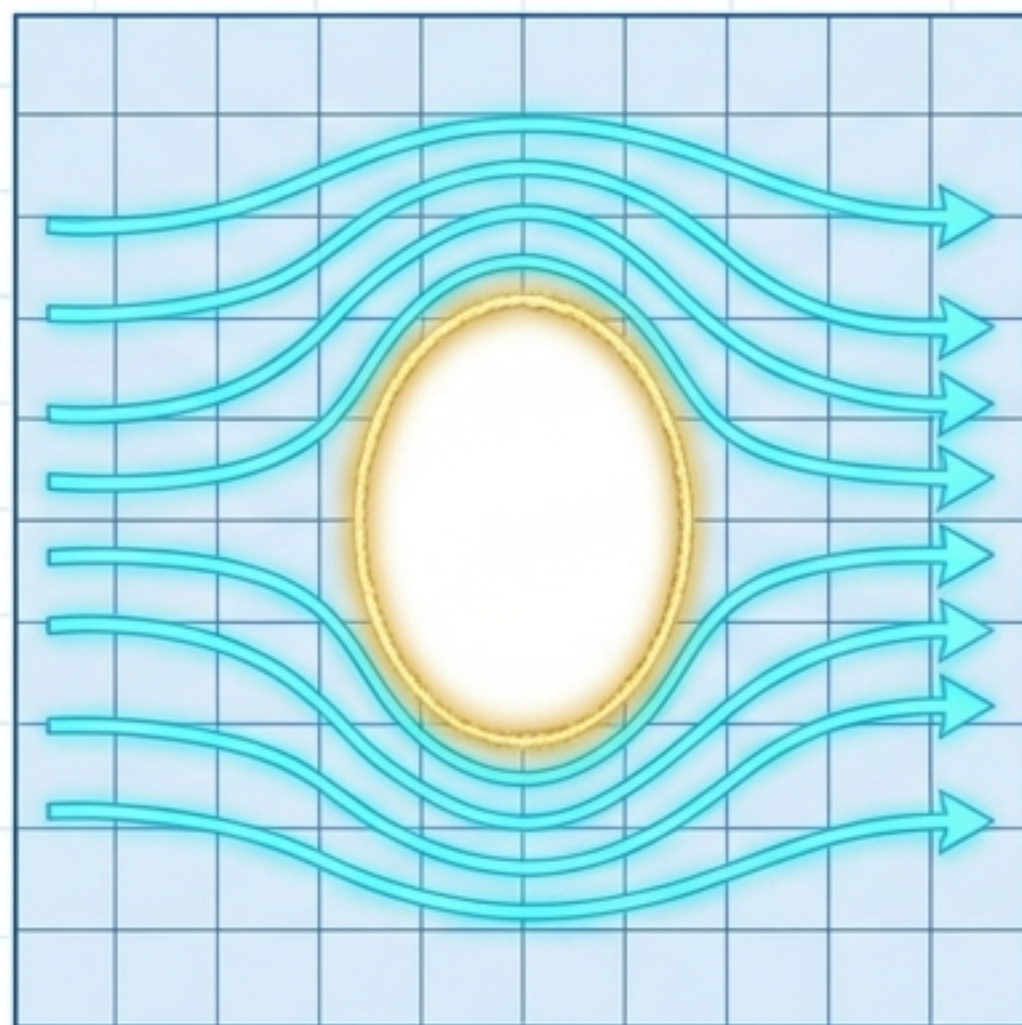
Why it matters: This allows engineers to calculate lift and drag on a drone without attaching a single physical sensor to it.

Magic Trick #2: Finding the Invisible Bird

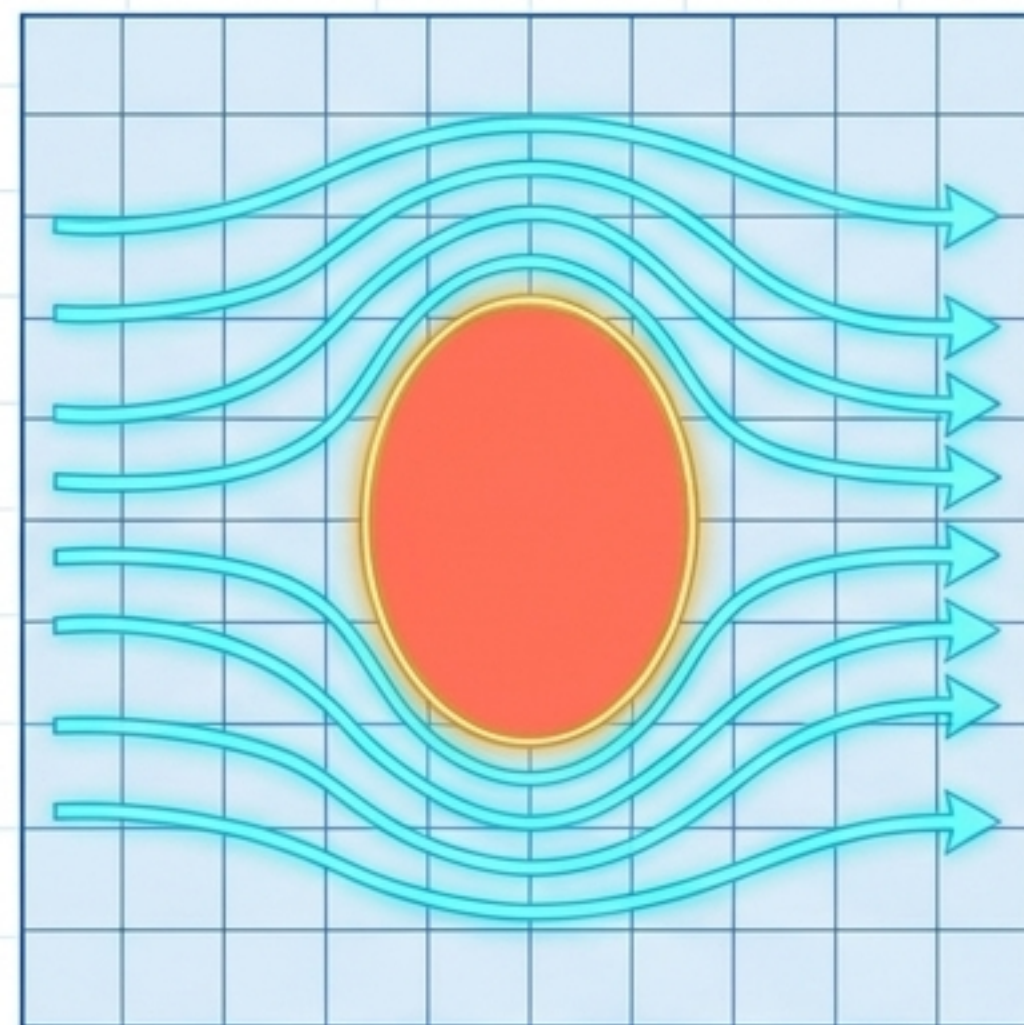
Even if the camera entirely misses the object, the AI can perfectly recreate its shape, speed, and position purely by analyzing how the surrounding air gets pushed out of the way.



1. The Wind Hits a Wall



2. The AI Guesses the Shape



3. The Perfect Match Revealed

Magic Trick #3: Magic Glasses for Bad Cameras

High-speed cameras or fast computer simulations often output grainy, low-quality data to save time and memory.

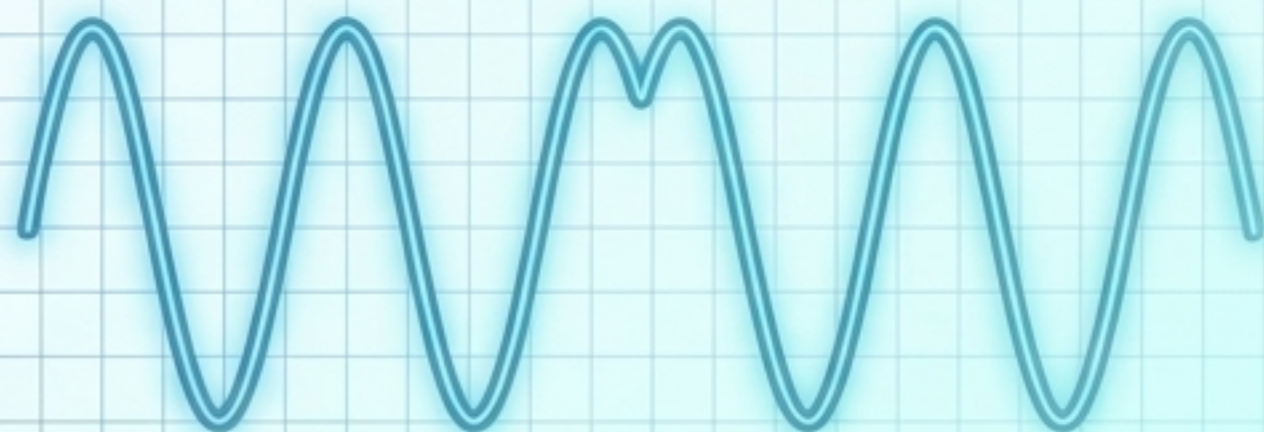
The IBA framework acts as a magnifying glass, upscaling this data into physically perfect, high-resolution flows—saving massive amounts of supercomputer time.



Low-Resolution
Coarse Data

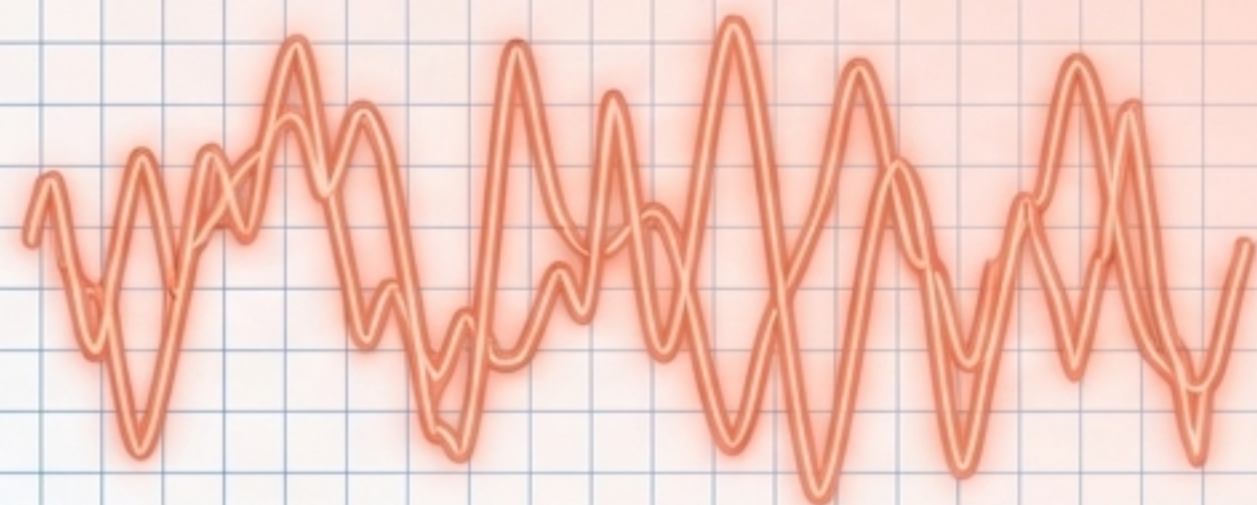
AI Super-Resolution

The Problem of Time: Simple vs. Messy



Simple Time (Periodic Flow)

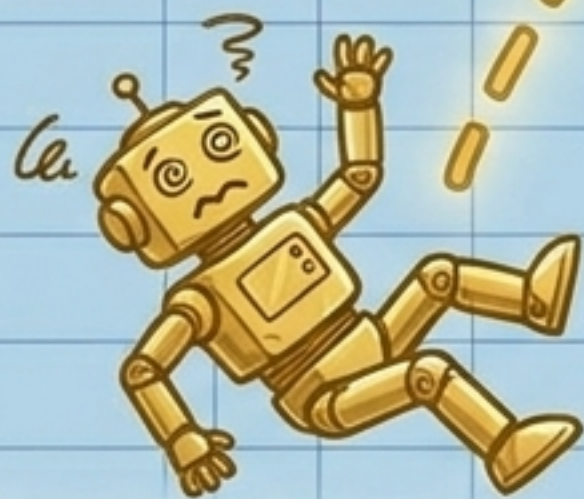
The wind repeats the exact same swirling pattern every single flap. Standard AI learns this easily, like memorizing a simple song.



Messy Time (Quasi-Periodic Flow)

Nature isn't perfect. Swirls crash into each other, creating messy, non-repeating chaos. Standard AI gets overwhelmed by the math and completely forgets the past.

The Solution: Slicing Time into Steps



Standard Learning
(Trying to memorize the whole messy timeline at once and crashing.)



Sequential Learning
(Taking bite-sized steps and passing the 'memory' forward.)

By learning short bursts of time and passing the memory forward, the AI perfectly reconstructs highly chaotic, long-lasting wind patterns without crashing.

Building the Future of Bio-Inspired Flight

Micro-Aerial Vehicles



Designing tiny, flapping-wing drones that can navigate chaotic urban wind gusts like real insects.

Efficient Submersibles



Understanding pressure and wake dynamics to build silent, ultra-efficient underwater robots.

Sustainable Computing



Reducing the massive energy and memory footprint required by supercomputers to simulate complex aerodynamics.



Seeing the Unseen.

By combining the Fixed Canvas of modern fluid dynamics with the **Physics Rulebook of Artificial Intelligence**, the Immersed Boundary Aware framework allows us to perfectly reconstruct the unseen forces of nature from the barest whispers of data.