FRAMING FLUID FLOWS for challenges in reinforcement learning

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Motivation: Challenges in reinforcement learning

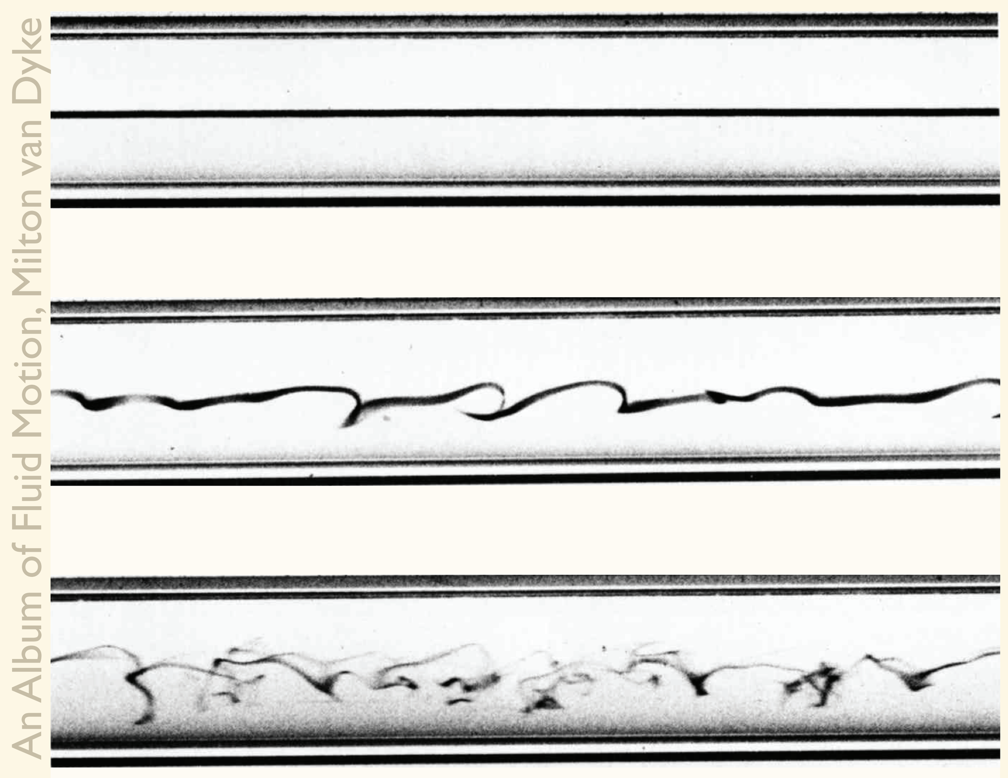
- **Interacting with large, evolving environments**: Flows include ocean waves, weather systems and aircraft contrails.
- **Interacting with high-dimensional environments**: Fluid flows are high-dimensional, with continuously varying quantities.
- **Learning efficiently from limited samples**: Fluid flows have condensed descriptions through conservation equations.

Dynamical models, learned or pre-established, provide a route to efficiently learning from new samples. Flow simulators such as Dedalus and JAX-CFD provide a route to exploring fluid flows as benchmark environments.

We frame two canonical fluid flows as reinforcement learning tasks.

Patterns in a pipe flow

As the speed of fluid flowing through a pipe increases, flow patterns change from smooth to chaotic.



Snapshots of dark colored dye in a pipe flow: As the flow velocity increases from top to bottom, small disturbances to the background flow evolve into increasingly unpredictable chaotic patterns, while the governing equations remain preserved.

Across regimes, the flow is described by the Navier–Stokes equations, $\nabla \cdot \boldsymbol{u} = 0$, and

$$\boldsymbol{u}_t + (\boldsymbol{u} \cdot \nabla)\,\boldsymbol{u} = -\nabla p/\rho + \nu \nabla^2 \boldsymbol{u}.$$

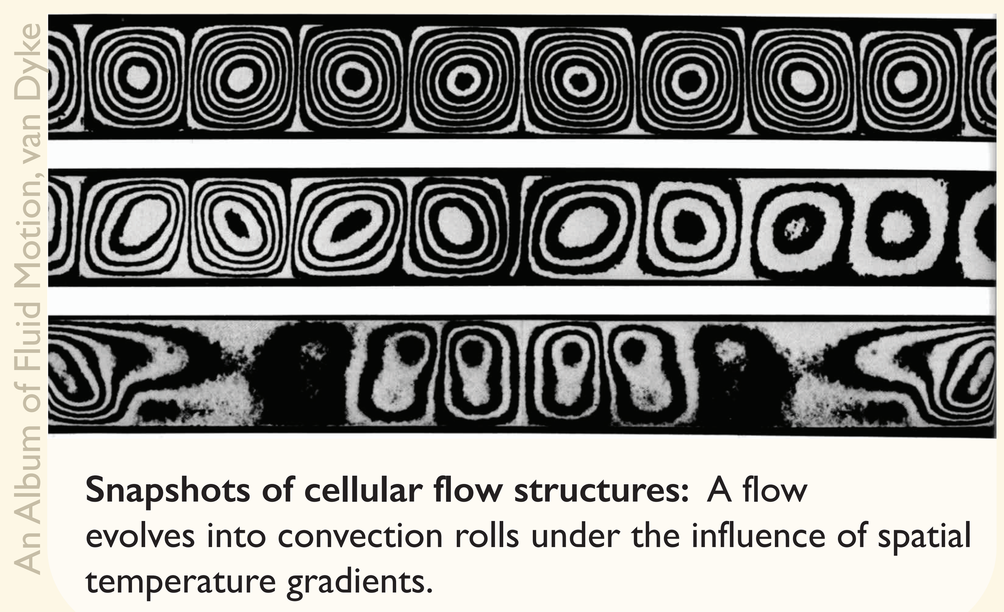
pressure, density, viscosity, velocity

Task: Create patterns in a pipe flow

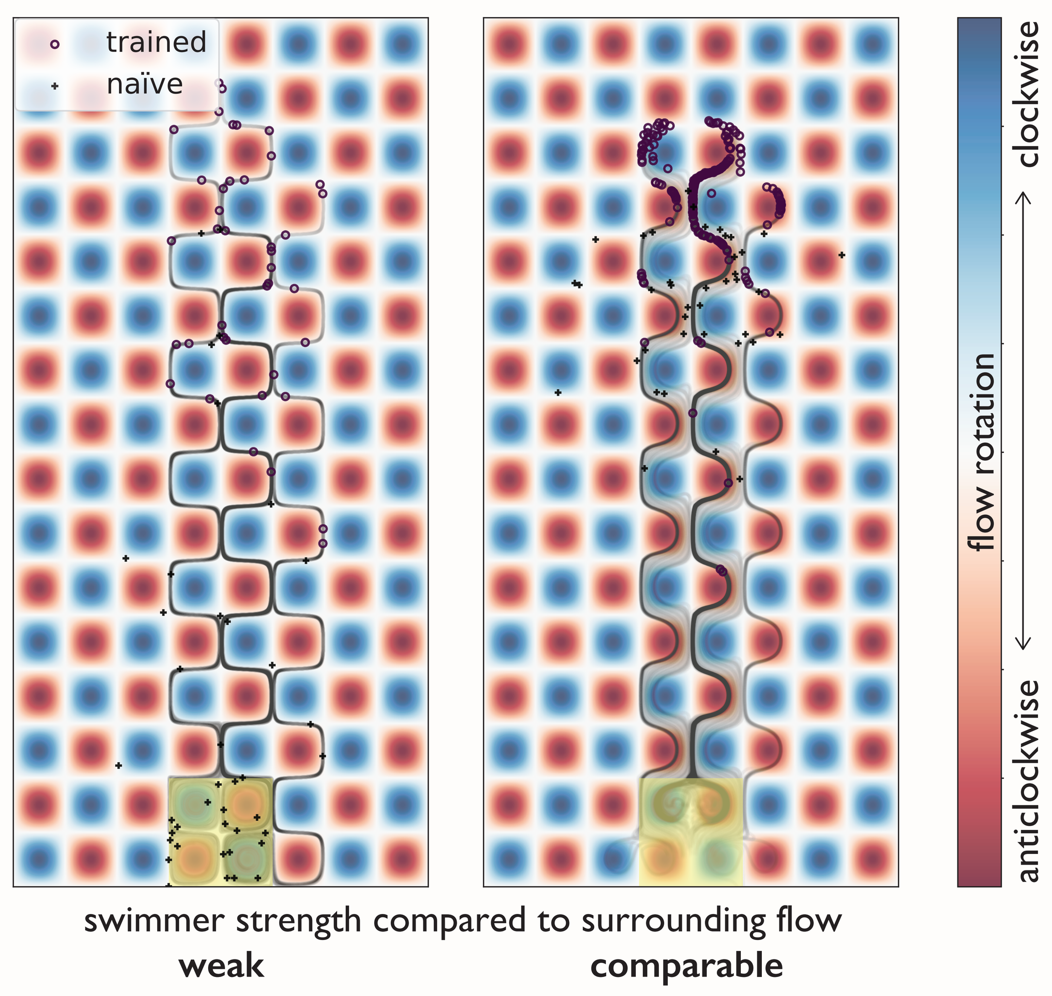
A reinforcement learning agent might be tasked with creating a disturbance that grows the most within a particular time window. The choice of such a disturbance is non-trivial. The agent is thus trying to create a highly nonstationary environment, while mathematical descriptions remain preserved.

Navigation in an evolving cellular flow

Natural and engineering flows can have structures that evolve spatially and temporally.



Snapshots of cellular flow structures: A flow evolves into convection rolls under the influence of spatial temperature gradients.



Task: Navigate an evolving cellular flow

As the strength of swimmers changes across the panels, the learned strategy for moving upwards, from an initial location in the yellow square, changes. An agent tasked with navigating evolving flow structures would thus have to adapt it strategy. Naïve swimmers always orient upwards, and markers indicate the final locations of the swimmers.

Applications of reinforcement learning to questions in fluid mechanics

- How do fluids mix? There is a discrepancy between experimental observations and simulations.
- How does a liquid jet break up into drops?
- How can we simulate the effect of history on complex fluid flows?
- How can we navigate oceans with evolving conditions and rogue waves?