Neural-network-based detection of quantum vortices in ultracold matter

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Quantum vortex

Vortices form in fluids subjected to rotation. A vortex in a stirred cup of coffee is a simple everyday-life example. They can also appear in the type of matter where quantum effects are non-negligible. A typical example of such system is a **superconductor** (zero-resistance material) or an **ultracold gas of atoms** (at almost absolute zero).

We look into systems with vortices to better understand e.g. the presence of effective resitivity in superconductors or the classical turbulence.

FIG. 1. Classical vortex. Such a vortex is an **empty space** (topological defect) **with fluid rotation around its core**.
A quantum vortex can be defined analogously.

Vortex lattices in ultracold gas

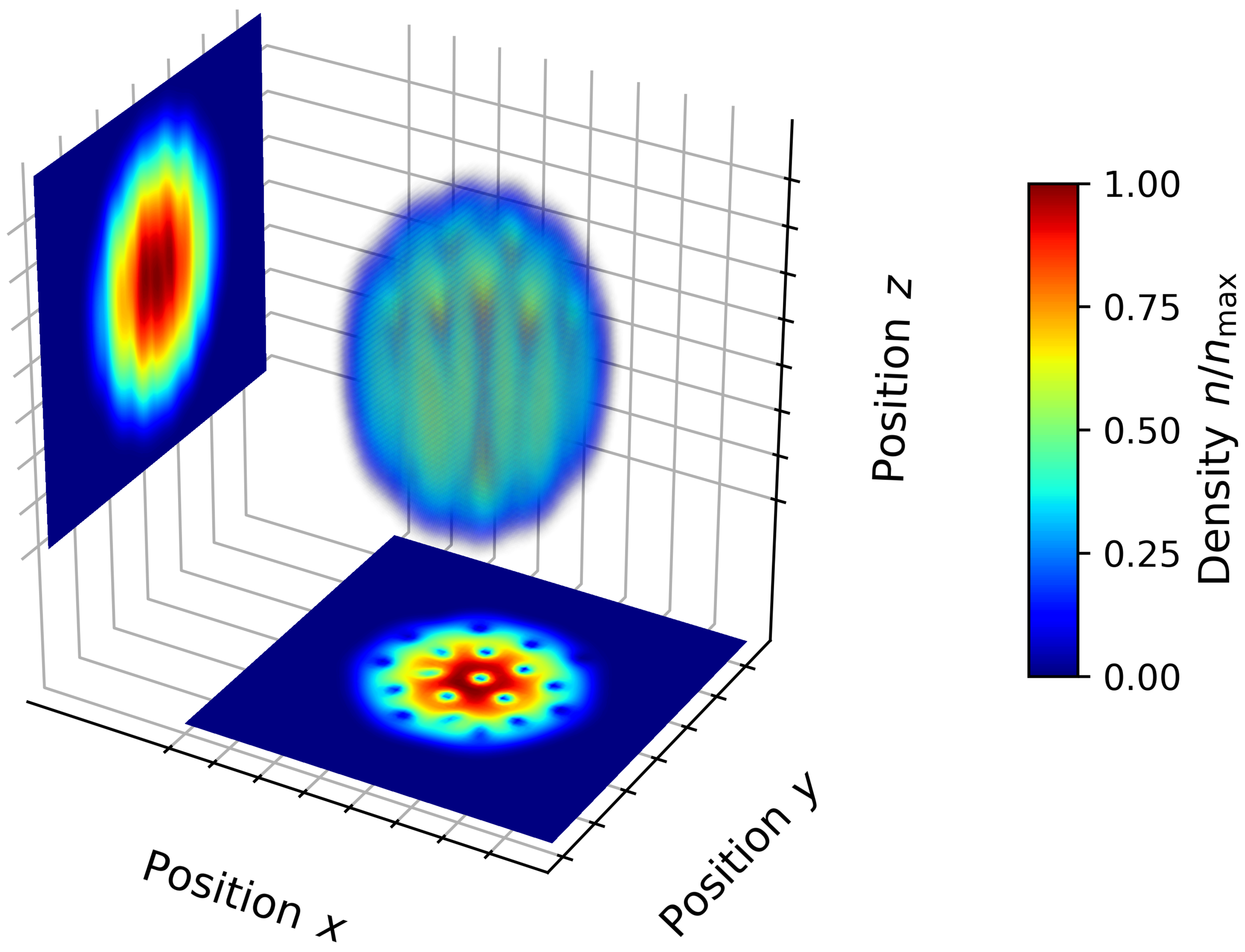


FIG. 2. Numerical simulation of **an ultracold gas in a harmonic trap with quantum vortices** and its integrated density profiles along OX (left) and OY axes (bottom). Taking an **absorption image** (extracting the integrated density) is basically the only way to have an experimental access to the gas density profile.

Neural network for vortex detection

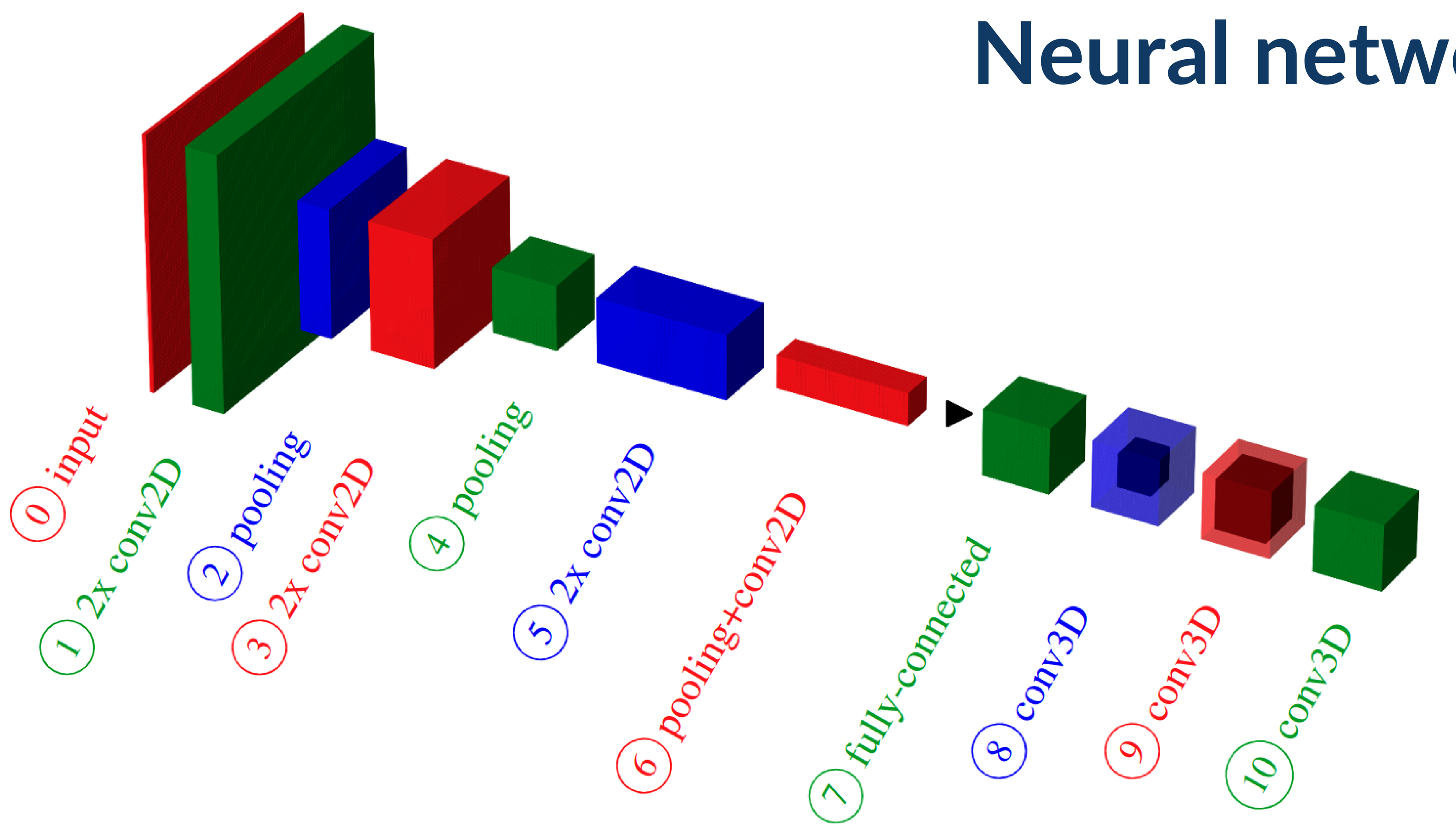


FIG. 3. Prototype architecture of the **neural network reconstructing vortex cores**. The boxes correspond to the data being a layer output. For instance, the input image has the size 64x64, the output of the 5th block has the size of 16x16 and 32 channels, and the output of the 9th block has the size of 16x16x16 with 64 channels.

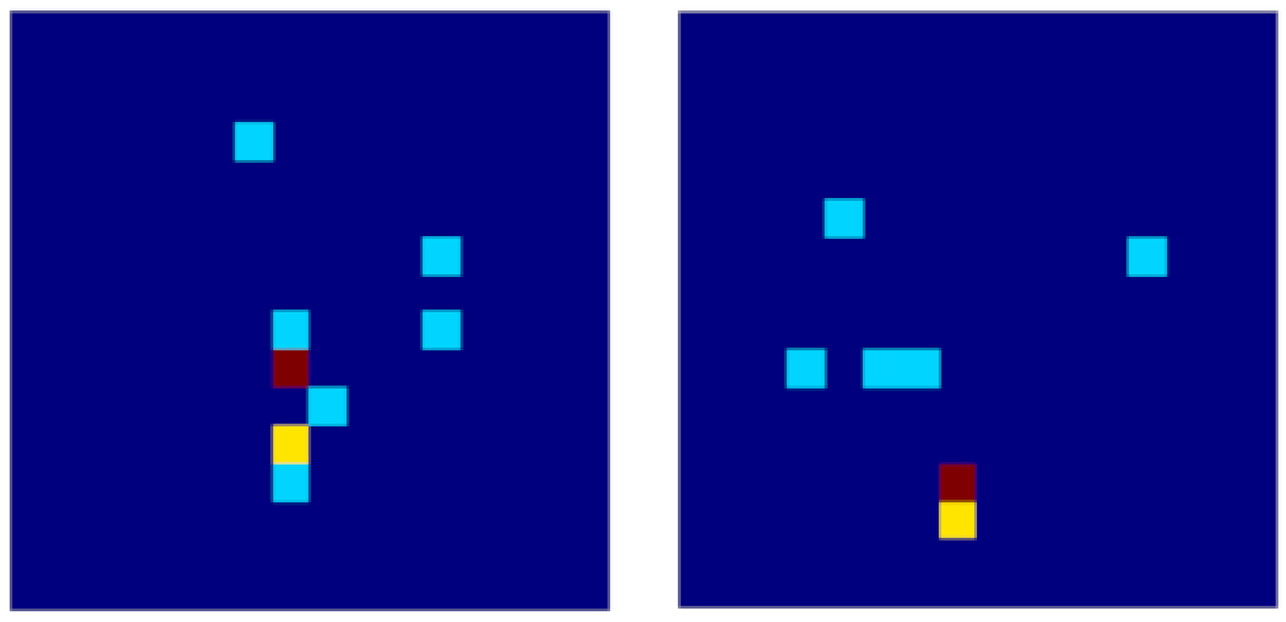
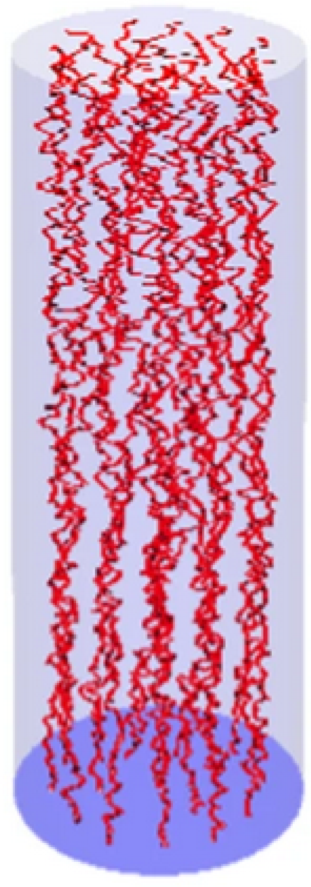


FIG. 4. Two examples of comparisons of the **neural network output** and the ground truth - section through the x-y plane of size 16x16. The **vortices here are placed randomly**, not in a regular lattice. Detection colour coding: dark blue - true negative, light blue - true positive, yellow - false positive, red - false negative.

Exploratory research results

	Cylindrical	Harmonic
Precision	82.34%	71.59%
Recall	82.23%	68.19%
F1	82.29%	69.84%

Outlook



The ultimate goal of this project is to create software, which can give a deeper insight in the experiental images of turbulence in quantum gases.

FIG. 5. Out-of-equilibrium system of vortices (**quantum turbulence**). Vortex cores (red) are bent due to modulations of container rotation frequency and we can observe a transition from a turbulent flow. When the drive is off, the turbulence decays into the laminar flow again.