THE ELUSIVE VISCOUS FINGER

ISIS4827 - SCIENTIFIC COMPUTATION & VISUALIZATION

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PROBLEM DESCRIPTION

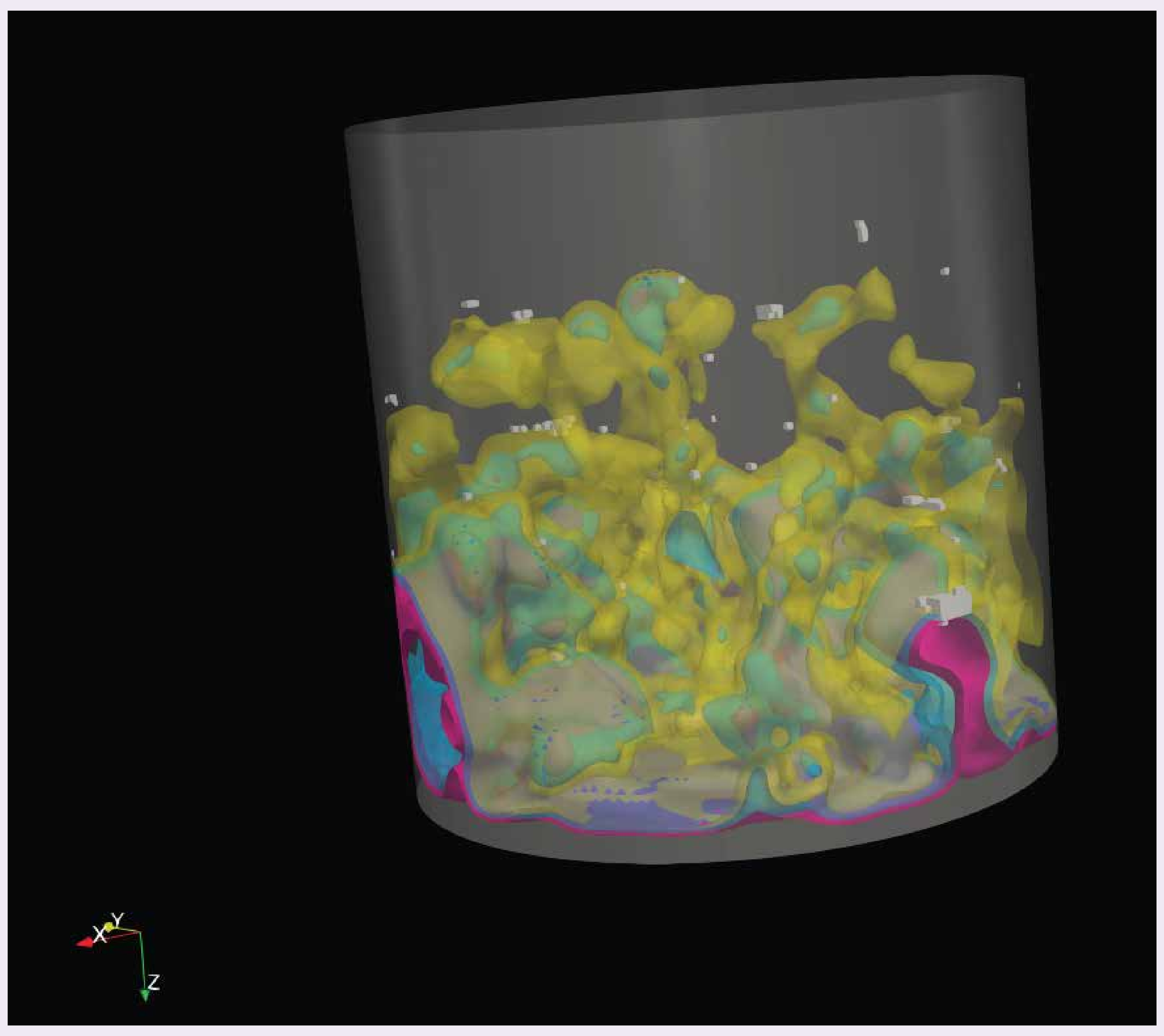
Viscous fingering is a phenomenon produced when two fluids with different viscosities interact, in particular this phenomenon is frequent when a fluid with low viscosity is injected into a fluid with higher viscosity. The process in which this occurs can be described in three steps. First the interface between the fingers is mostly planar, thus the less viscous fluid penetrates the other fluid slowly, forming low and uniform fingers. Then there is a small chain reaction in which the difference in pressure of both fluids tends to favor the increase in the penetration speed of the lower viscosity fluid. Thus larger fingers grow further into the fluid and smaller fingers disappear. Afterwards the large fingers merge and eventually the two fluids mix. The objective is to create visualizations that allow to observe this phenomenon.

DATA DESCRIPTION

The data simulates an experiment in which a cylindrical container is full of water. An infinite source of salt sits at the top of the container, increasing the viscosity of the water and triggering a flow process. Due to the stochastic nature of the process, 20 runs of the simulation are executed with 100 time steps each. The simulation is run at three levels of resolution: 250,000, 650,000 and 1'900,000 (points that discretize the scene). Due to time constraints, only two time steps are provided for this project (only the last step is provided for the highest resolution).

TASK 1

Points aren't represented directly; rather, the concentration of salt at each point is used to render contour surfaces that communicate the shape of the viscous fingers. The use of contour surfaces for the visualization of the fingers allowed us to visualize them as smooth, expressive shapes. On the other hand we carefully designed a concentration-to-opacity transfer function that allows us to see through the fingers' surface and into their interior structure.



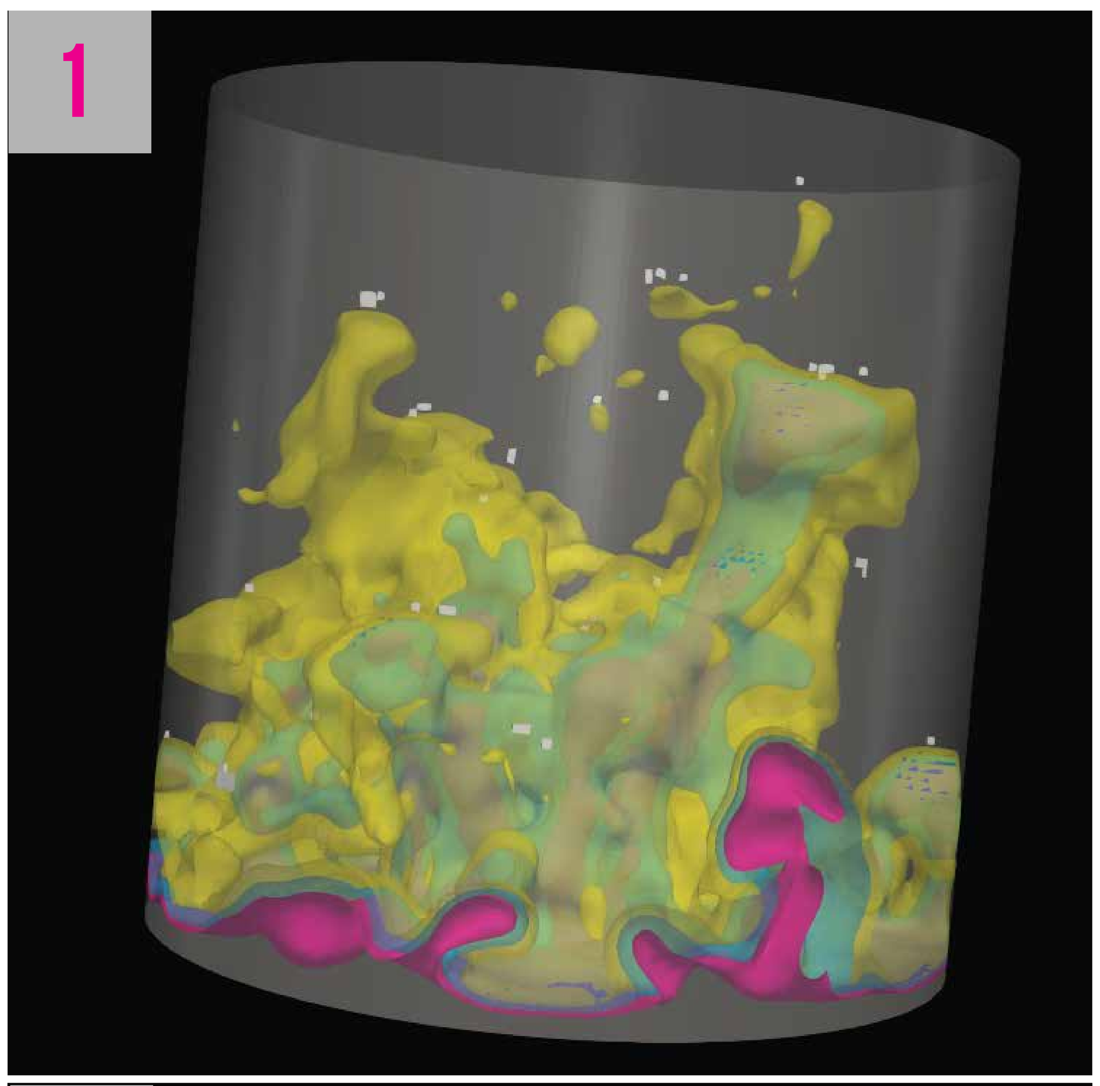
3 semi-transparent surfaces: the yellow (weak concentration isosurface) shows the fingers' shape while the others (stronger concentration) reveal their inner structure. Notice how each finger is internally lead by a high concentration blob near its tip.

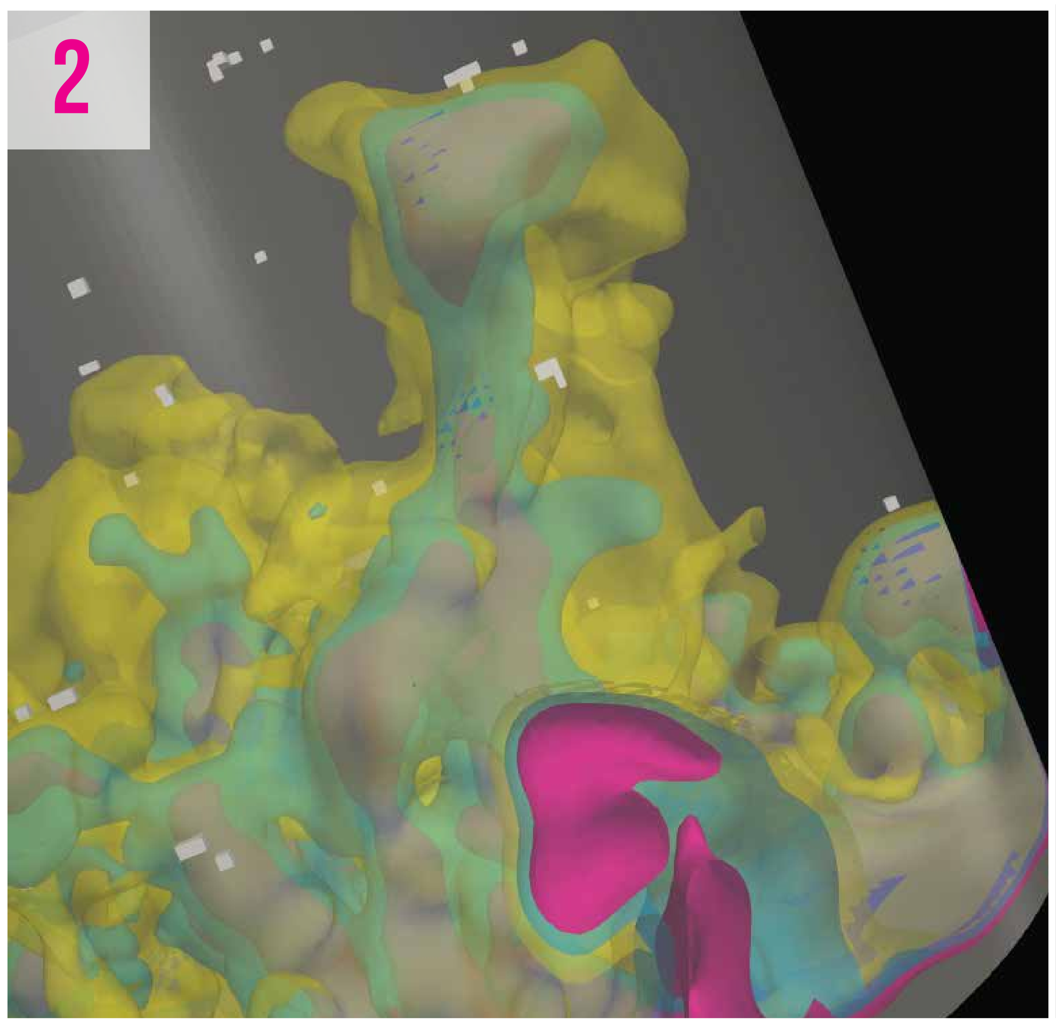
TASK 2

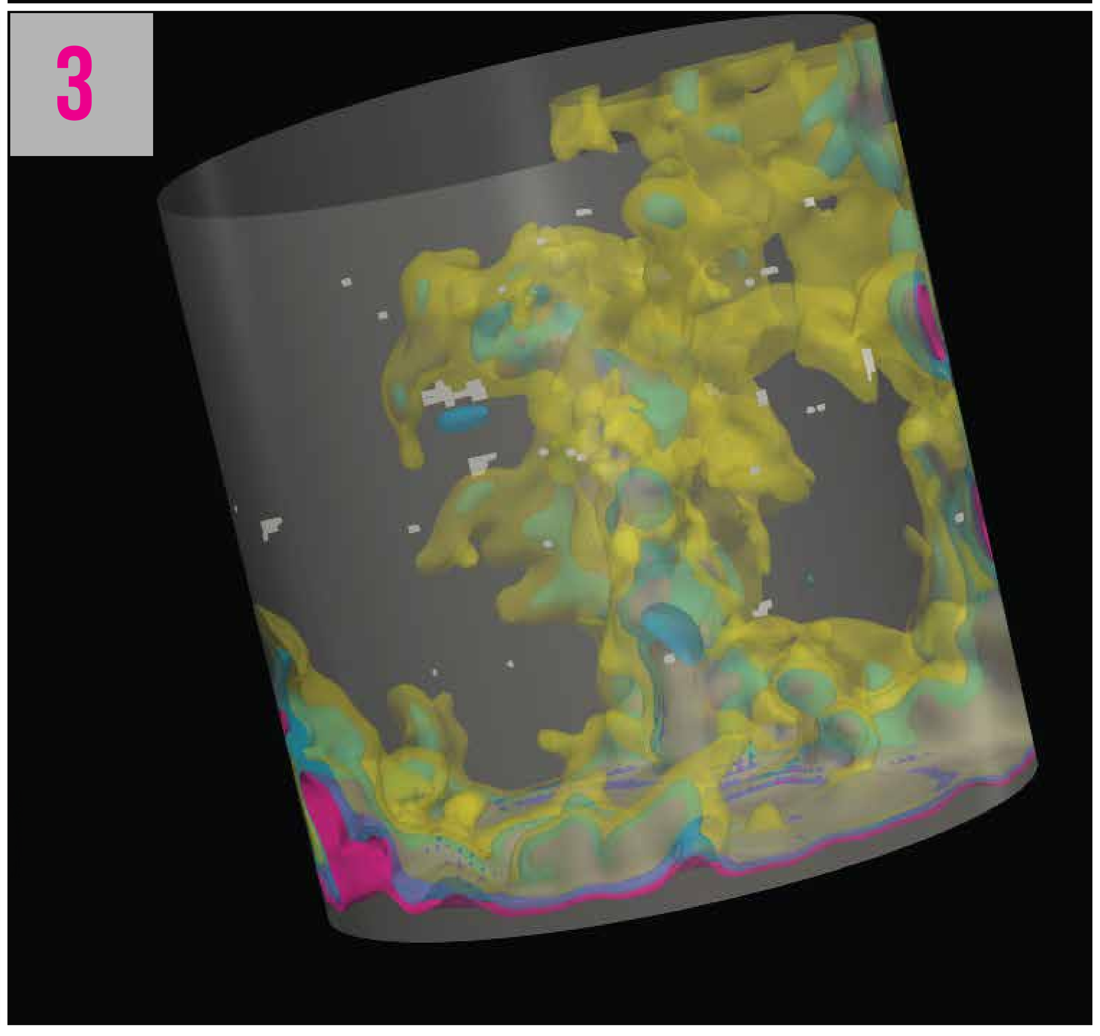
Which approach do you use to identify and visually represent the viscous fingers?
We first discarded the data points with concentrations lower than a set threshold in order to focus in the flow of salty water through the pure water. Next we rendered contour surfaces of equal concentration of salt. These communicate the geometry of the flow, in particular the viscous fingers' structure. We used three contour surface levels, which allows us to see the inner structure of the fingers as well as their outer shape. Lastly, in order to rigorously classify the fingers as such, we scanned the outer contour surface data for local minima in terms of the Z axis. The objective of this is to calculate the location of each finger's tip. The identification of tips allows for the separation of the individual fingers, resembling the work of Favelier [1].

In the following images, the magenta blobs represent the areas with the highest concentration, followed by cyan and yellow, the last one being the one with the lowest concentration.

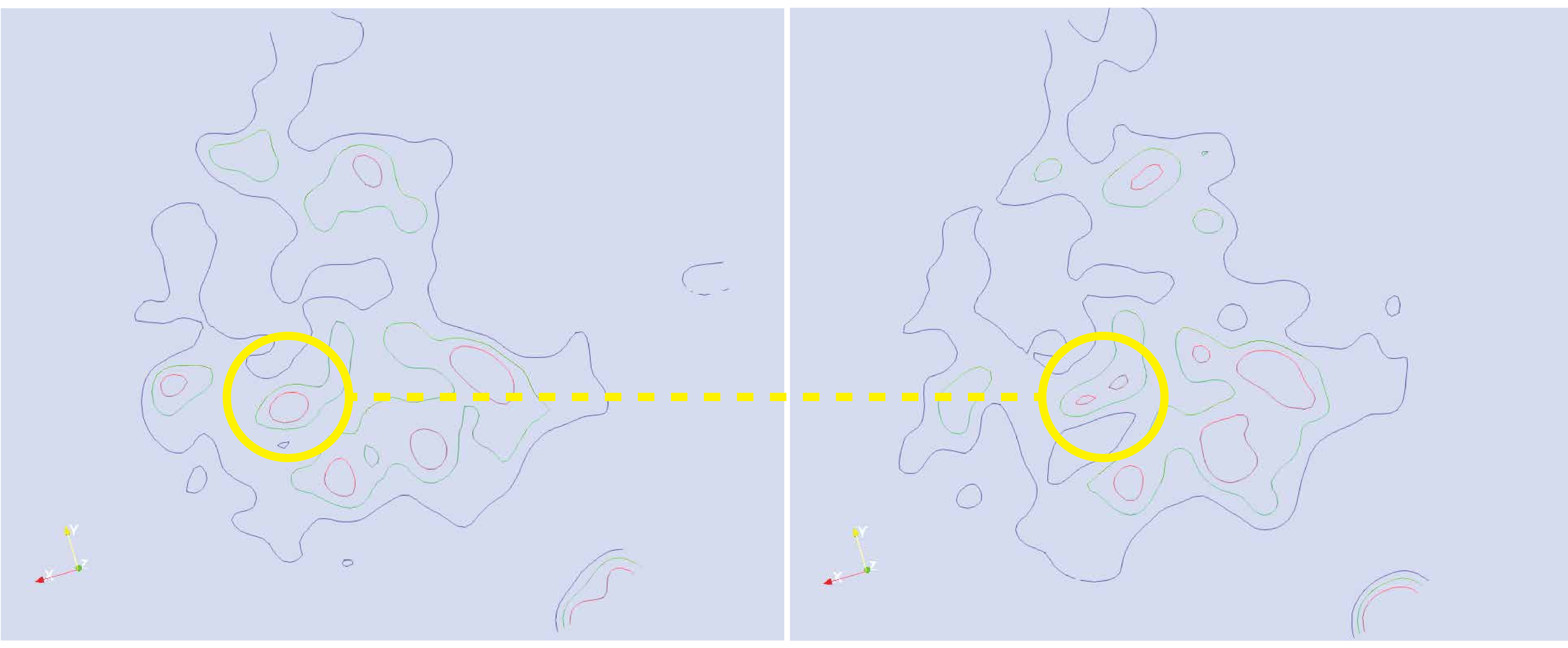
[1] Over four distinct fingers can be clearly told apart from each other. Most are topped by a white cube, signaling the identification of a local maximum and thus of a finger.
[2] Inner structure of a large finger: Lead by a blob, correctly identified (white cube).
[3] At later stages of the process the fingers have mostly dissipated.







We created another visualization of horizontal cross sections of the data that allow us to closely examine the evolution of the fingers' topology as we traverse the cylinder from top to bottom. The lines represent three different concentration level curves. Observe how on a large scale the curves' shape (topology) doesn't change drastically. However, the points where the topology breaks can help us identify the bifurcations of viscous fingers.



[1] Favelier, G., Gueunet, C., Tierny, J. Visualizing Ensembles of Viscous Fingers. IEEE Scientific Visualization Contest, 2016.