OSCon: Detecting Vortices in a Structured Finite Element Model of High-Temperature Superconductors

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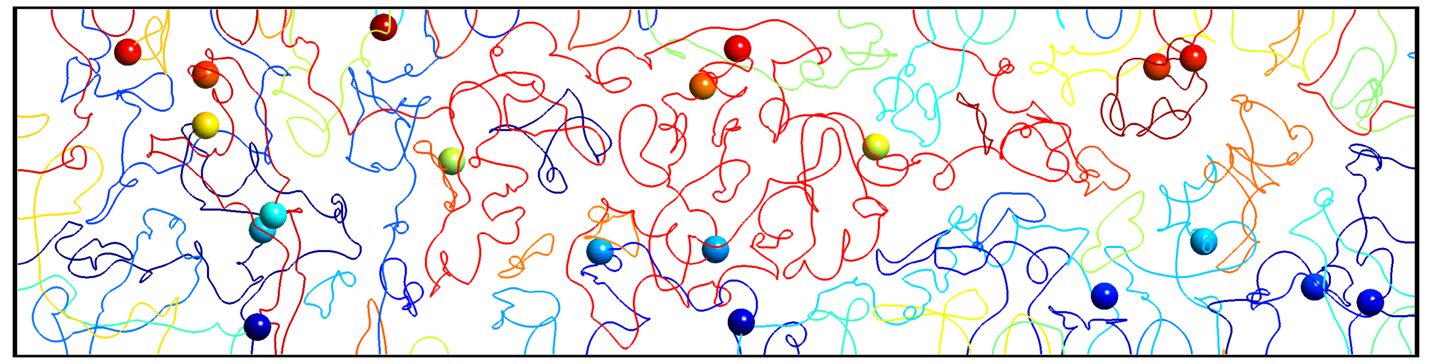
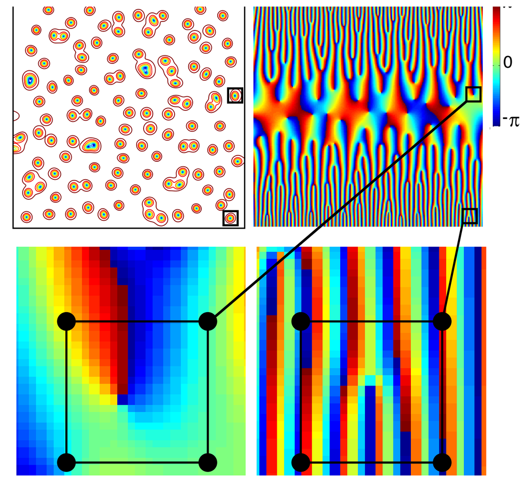
By analyzing the raw data to find, track, and visualize the vortices, we expose the causal link of how and why a certain configuration of defects increases the resistance-free current, the measure of the material's performance

Visualization Techniques



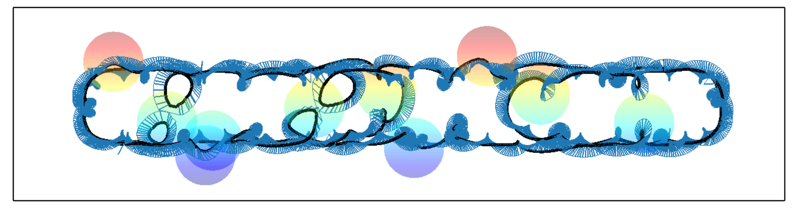


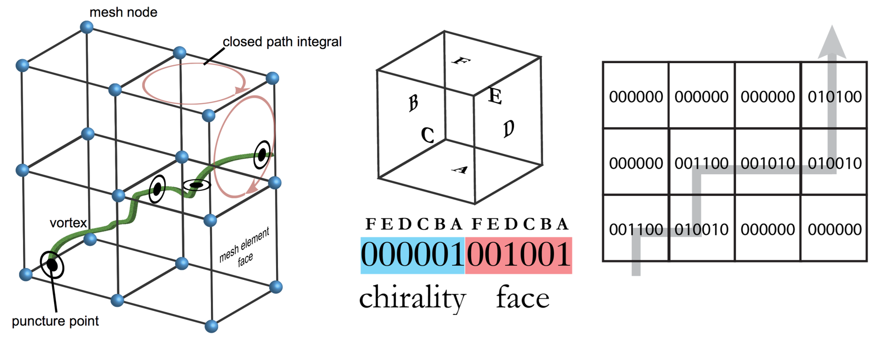
Phase field -

Vortices correspond to phase jumps around contours in the phase field. First the field must be locally transformed by a gauge transformation. Next integration around closed loops in the mesh finds the smallest element containing a phase jumps.

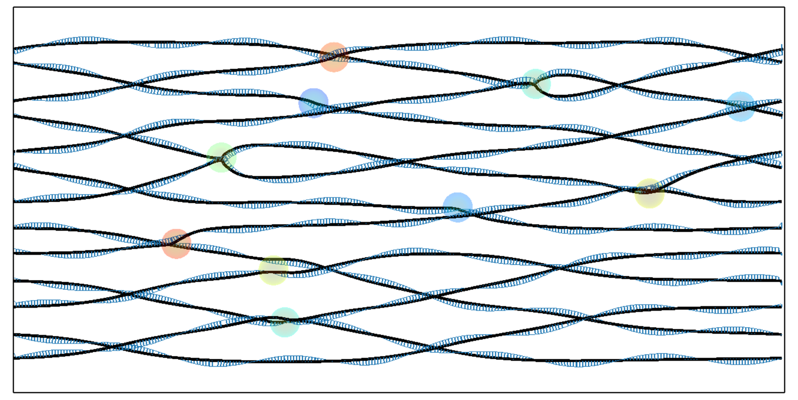
Extracting a Vortex -

Every time the vortex punctures a mesh face, a single point on the vortex is found. By tracing these points through the structured mesh, the data can be partitioned into a set of individual and distinct vortices.





Phillips CL, Peterka T, Karpeyev D, Glatz A, Feature Detection of Magnetic Vortices in Simulations of Superconductors, LDAV, in review, 2014



Chirality and Twist

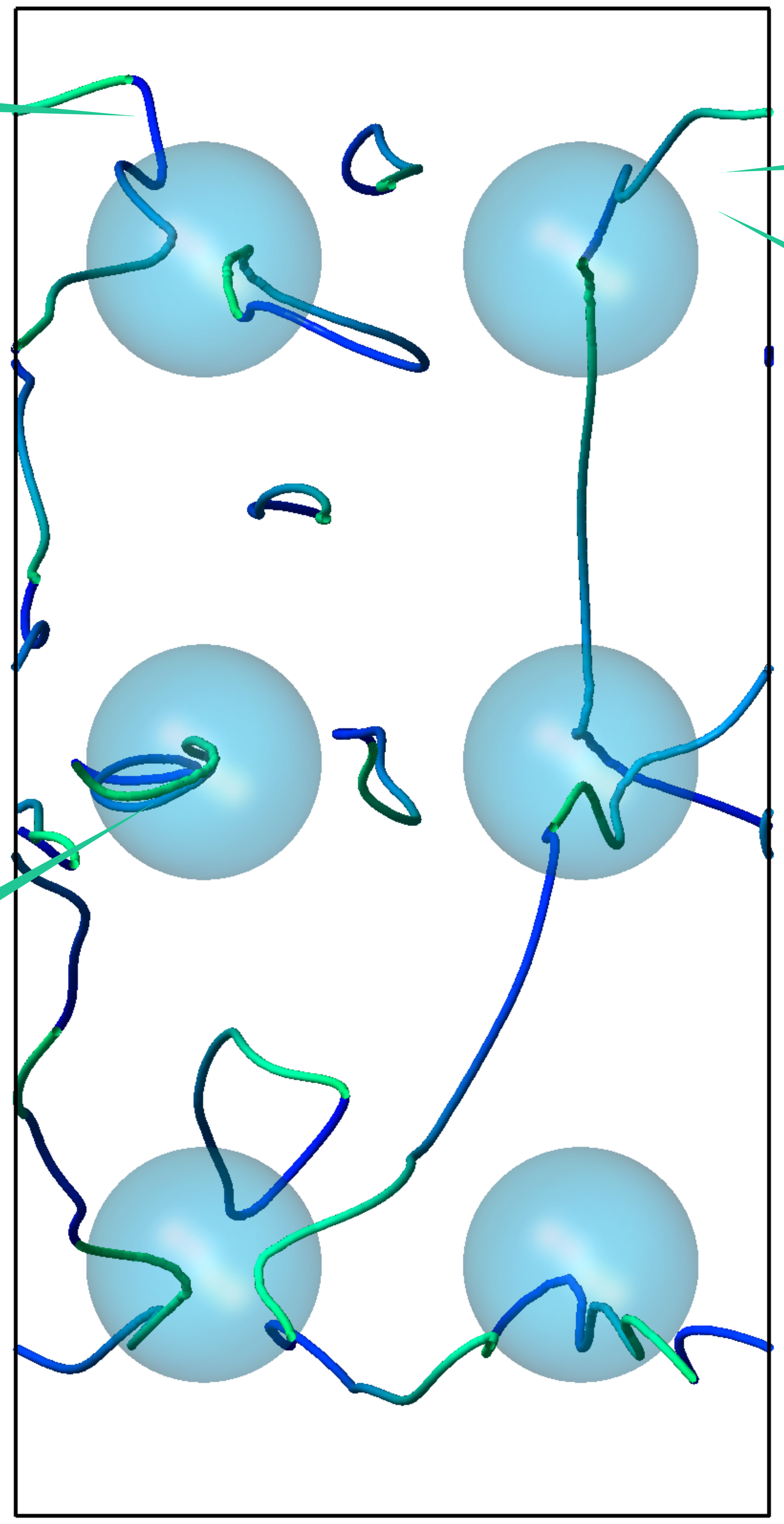
The phase field contains information on the chirality of the vortex (clockwise vs. counter clockwise) and on how the magnetic flux can form a helical twist around the vortex core .

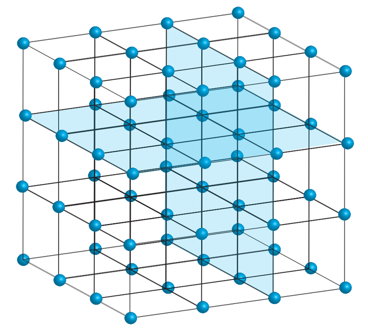
Vortices - Carriers of magnetic flux, these flexible tubes are born, dance through the material, get caught on defects, sometimes merge together and sometimes annhilate each other. Tracking what these tubes are doing tells us why the material is performing well or poorly.

Where are they? - Vortices are hidden inside the superconducting field. In the ANL Mathematics and Computer Science Division, we are developing algorithms to find the vortices inside the data and then measure how they twist and writhe, and track where they go.

Defects - These blue spheres are models of defects in the material. Defects can be a speck of a different non-superconducting material, or just damage to the material. By pinning the vortices and keeping them from dissipating energy, defects can improve the material performance. If you have just the right kinds of defects in the right places, the dance of the vortices can be brought to an end, as each vortex is pinned in place.

Where should they go? - A team in the ANL Mathematics and Computer Science Divison ask, by what set of experiments can we determine what best way is to distribute defects in the material? Each experiment will involve running a very large simulation on the Argonne Supercomputers.





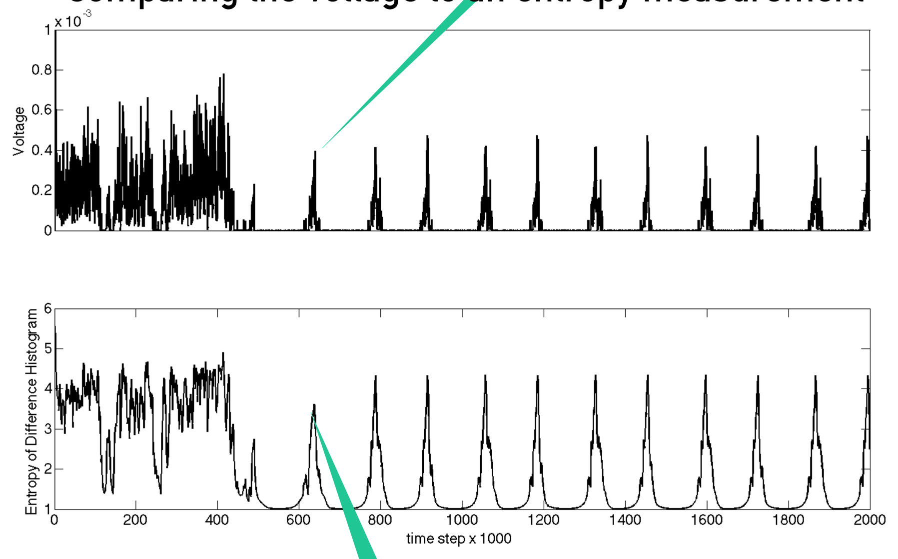
The Model - ANL's Material Science Division is creating a mathematical model of superconductivity that can be calculated on a fine regular grid of points. At each point in time the value of the superconducting field on a grid point can be determined by the local neighborhood of values on the grid. This model captures the effect of external magnetic fields, temperature, applied currents, and defects in the material.

A Better Model - Currently the mathematical model is being run on smaller computers at Argonne. An effort in the Mathematics and Computer Science Division is working on how to rebuild the model on an irregular grid so that larger problems can be studied by distributing the calculations over Argonne National Laboratory's Supercomputer Mira.

Extreme-Scale Data Analysis Collaborations

For an unstable system, voltage jumps correspond to a flurry of vortex movement and rearrangement.

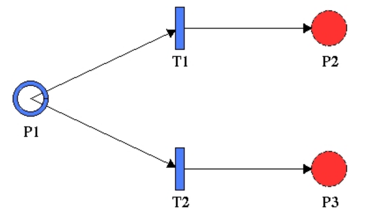
Comparing the voltage to an entropy measurement

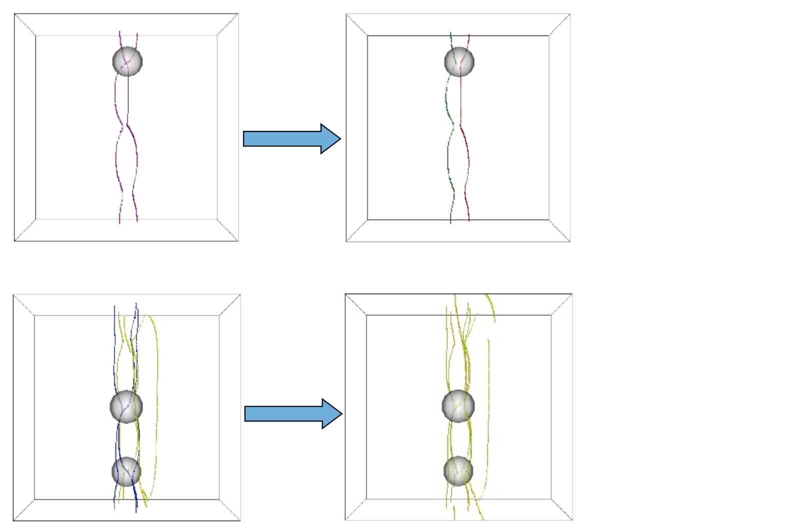


Information Theory Library -

Using the ITL framework developed by the Ohio State University GRAVITY research group under Han-Wei Shen, we can use an entropy measures to detect when the system is changing rapidly and when it is changing slowly. This measure can be used to dynamically guide the frequency of storing system data and performing analyses. ITL is funded by DOE's extreme-scale SDMAV program and the SciDAC SDAV institute.

Low entropy corresponds to a slowly changing system. High entropy correponds to a flurry of activity. The peaks of the bottom plot correspond to the voltage spikes of the top plot.

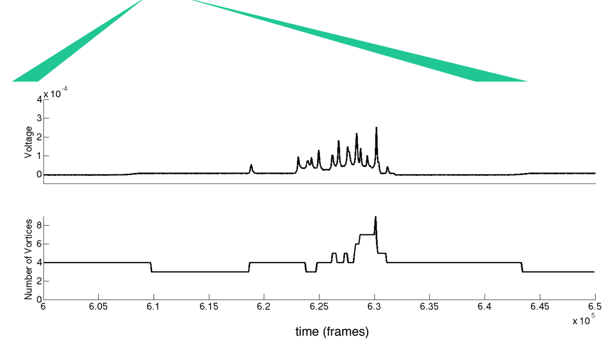




Tracking and Activity Detection -

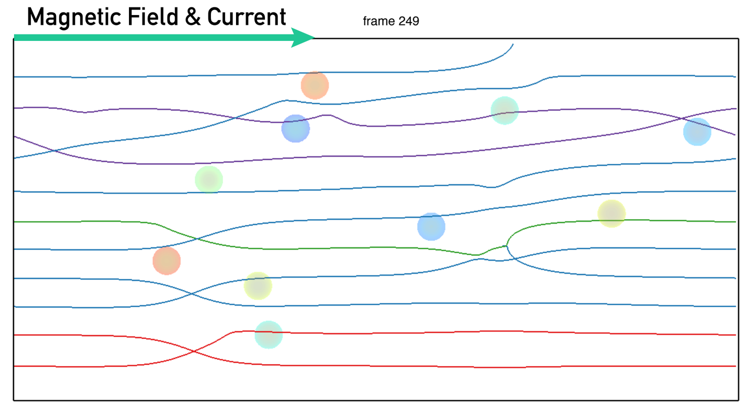
Using token-tracking petri nets, the Rutgers University Visualization Lab under Deborah Silver is developing an algorithm to detect when the vortices undergo events such as being born, merging, splitting, getting pinned and depinned from inclusions, annhilating and dying.

Visualizing an Unstable System of Vortices

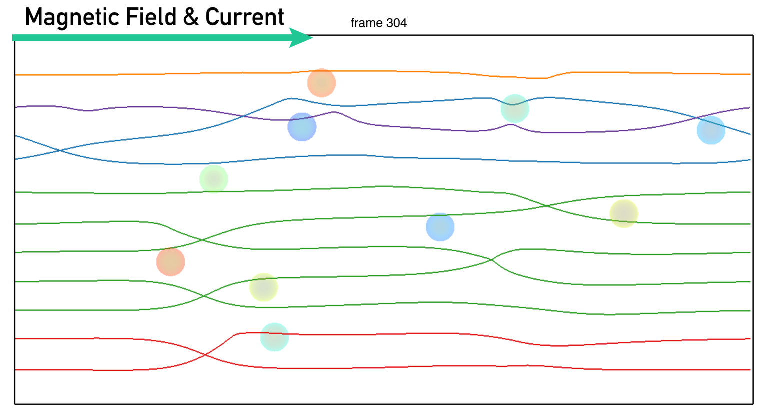


Response of the System

The measured voltage of the system corresponds to the activity of the vortices. The vortices break, recombine, and slip.



When the magnetic field and the supercurrent are aligned, the behavior of the vortices can become unstable. Above, we show the behavior of the voltage over 4.5 millions simulation time steps. While the behavior of the system is unstable, we observe that the system keeps relaxing into attractor states, corresponding to the quiescent periods between the voltage spikes. Below the escape from and return to a particular attractor state is shown.



Periodic behavior -

At the end of the flurry of vortex activity, the configuration of the vortices has relaxed back to a state that looks like how the system began.