The computer screen displays a delicate and colorful array of tiny dots. Pink, purple, blue, green, and orange pixels create a three-dimensional cylinder that hovers in space and rotates with the brief click and pull of a mouse. This computer model reconstruction represents a steel. Each dot is a single atom. Blue is iron. Green is nickel. Red is copper. And so on.

“When I was a graduate student, I thought steel was boring,” says Dieter Isheim, materials science and engineering and manager of the Northwestern University Center for Atom Probe Tomography (NUCAPT). “Over time, I changed my opinion because I realized the extreme complexity of the material.”

And when viewing the layered patchwork of different atoms within this single specimen of a nano-structured metal, one has to agree.

The image on the computer screen is from an experiment run at NUCAPT using atom-probe tomography, a micro-analytical instrument that produces an atom-by-atom, three-dimensional reconstruction of a sample in direct space.

A tiny, sharply pointed sample – in this case a fragment of steel that is 200 nanometers long by 60 nanometers wide – is placed inside of an ultra-high vacuum system. An ultraviolet laser dissects the sample causing the atoms to evaporate from the surface, giving researchers the ability to study the three-dimensional arrangement of atoms inside the specimen.

“Each atom is analyzed in two ways,” explains David Seidman, materials science and engineering and founding director of NUCAPT. “First, we can see an atom’s position within the specimen, and, second, we can determine the chemical identity of each atom. This analysis tells us about the internal structure and chemistry of the sample on a subnanoscale.”

The ability to see the internal structure allows researchers at NUCAPT to understand the material’s properties and how they evolve during the material’s processing and lifetime. This information can be used to improve various materials, such as making a lighter and stronger aluminum alloy for use at elevated temperatures, for prosthetics and even medical tools.

While other instruments allow close examinations of materials, atom-probe tomography is the only device that allows researchers to use this knowledge to create atomically resolved, three-dimensional computer reconstructions in direct space.

“In electron microscopy, people perform tomography, but the tomographic resolution is not yet at the atomic level,” Seidman explains.

Tomography equipment itself has become increasingly fine-tuned over the years. When Seidman acquired the atom-probe tomograph in December 2004, Northwestern became the first academic institution in the United States to have the instrument installed. Since then, it has been upgraded multiple times and drastically improved.

“When I joined Northwestern 14 years ago, a big data set was 40,000 atoms in one day,” says Isheim. “Now we can see 50 million atoms in one hour.”

Although a few other institutions since have added the instrument, it is still a rare find, causing NUCAPT to attract clients from various institutions both domestically and internationally, including Argonne National Laboratory, University of Chicago, University of California at Davis, NASA, Glen Research Center, and a Max Planck Institute in Halle, Germany.

And the variety of examined materials equals the variety of diverse clientele. Seidman, for example, is currently using this technique to analyze nickel-based superalloys used in the blades of turbine engines. Turbine blades operate at very high temperatures, so the challenge is to understand the relationship of the microstructure of the material and its strength and creep resistance at such high temperatures. He also is collaborating with a postdoc and two undergraduates on work exploring thermal barrier coatings for the blades. Funded by the Institute for Sustainability at Northwestern (ISEN), this work will allow turbine engines to run at higher temperatures, resulting in higher efficiency.

Seidman emphasizes that atom-probe tomography can be used to analyze not just metallic alloys but a broad range of materials, including semiconductors and oxides.

One project he’s particularly fascinated by is the work of Derk Joester, materials science and engineering, who studies the organic/inorganic interfaces in biominerals. Joester’s most recent work examines how simple sea urchins use inorganic minerals to build self-sharpening teeth.

For those interested in using atom-probe tomography, NUCAPT is now accepting new clients. Clients can be trained to use the equipment or the facility’s staff can prepare and run samples for them. For more information, please visit http://arc.nucapt.northwestern.edu/Seidman_Group or contact David Seidman directly at d-seidman@northwestern.edu.