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Medical Software has Astronomers Seeing Stars

By Pam Frost Gorder

A project at Harvard University is proving that two very different disciplines have very much in common. The Astronomical Medicine Project (http://astromed.iic.harvard.edu/) is working to convert medical imaging software into tools that fuel discoveries in astronomy. But if the scientists behind the project have their way, any discipline that relies on large, complex data sets will reap the benefits.

Common Ground

As different as a radio telescope might seem from a magnetic resonance imaging (MRI) machine, both detect the radio waves naturally emitted by atoms; both produce images that experts must interpret; and, most importantly for the Astronomical Medicine Project, both must clearly display many different variables—each variable being another dimension of data—in that image if the expert is to interpret it correctly.

Differences exist between the two, of course. Doctors use MRI images to make life or death decisions. Because doctors need to analyze images with some urgency, the medical community has created visualization tools that process multidimensional data fast and without a supercomputer's help.

That's the goal of the Surgical Planning Laboratory at Brigham and Women's Hospital, a teaching affiliate of Harvard Medical School: to give doctors the tools they need to access all of a patient's data quickly and comprehensively. Michael Halle is the lab's director of visualization.

The idea for Astronomical Medicine came to him in 2004 when he attended the National Institutes of Health/National Science Foundation Workshop on Visualization Research Challenges. There, Harvard astronomer Alyssa Goodman gave a talk on the current state of visualization in astronomy. New instruments were gathering large, complex data sets, but astronomers lacked the tools to visualize all of the data.

"I thought that her challenges sounded a lot like the challenges of medical imaging," Halle remembers. "And then I thought about how medical researchers use the Surgical Planning Lab. To them, it's a kind of incubator—a place where they can create a visualization and develop their ideas to a point where they can apply for research funding. I wondered if we could do the same for astronomers."

Ron Kikinis, a medical doctor and the lab's director, agreed. The Astronomical Medicine Project was created within Harvard's Initiative in Innovative Computing (IIC), where Goodman is the founding director.

Creative Visualization

Astronomer Gus Muench was an early adopter of Astronomical Medicine. A visiting scientist at the Harvard-Smithsonian Center for Astrophysics, he was 10,000 miles from home—at a radio telescope in the Australian outback—when he first used 3D Slicer (www.slicer.org/), one program in the project's open source software package.

He'd gone all that way to study the Pipe Nebula, a dust cloud in the constellation Ophiuchus. One night the local weather was against him—cloudy skies blocked the radio frequency he was trying to detect. As he sat in the control room, he decided to open his laptop computer and create a 3D visualization of the data he'd gathered so far. As the nebula's purple and green filaments rotated on his screen, other astronomers stopped to take a look. They asked, "What's that?"

"When they realized what it was, they wanted to know how to render their data as well. They instantly knew that this was the right way to visualize their data sets," he recalls.

That's how the Astronomical Medicine concept is spreading: by word of mouth. Di Li, an astronomer at NASA's Jet Propulsion Laboratory, discovered the project at the January 2008 meeting of the American Astronomical Society, when he happened to stop by the Harvard exhibition booth to talk to some friends. The 3D Slicer demo caught his eye. Now he's using it to map interstellar clouds. "Slicer allows us to define surfaces and add color to realize structures from a different perspective," he says.

Tracey DeLaney, an astronomer at MIT, is using the program to trace debris streaming from the supernova remnant Cassiopeia A. She found 3D Slicer easier to use than other visualizers. "I didn't have to perform any wild pig calls or brew any witches stews to get an initial output," she quips. "Once I had an output, then I could adjust my data to get something useful."

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Data Cubes

Goodman says that the need for multidimensional visualization is growing in astronomy.

"In the last decade, the ability to do high resolution spectroscopy very fast—and to do it with very sensitive detectors—has gotten better and better," she says. "So the amount of data you get has skyrocketed. Suddenly, you have a lot of 3D data sets, when once they were very rare."

In medicine, 3D images generally convey the three dimensions of space. In an MRI image of a patient's brain, a 3D view is critical for doctors to gauge a tumor's location and extent, for instance.

But in astronomy, 3D usually means something different: a combination of an object's 2D image as seen in the sky and some other variable of interest, such as the object's velocity. Astronomers call these data sets *data cubes*, and they can be visualized as if the third variable is just another spatial dimension.

That's what Muench was doing on that otherwise unproductive night in Australia. "In addition to my own data, I had a 3D velocity data cube from the literature that was not very useful in its basic format," he says. "I quickly used the Astronomical Medicine tools to convert the data into Slicer format. My own observations traced some interesting kinematic features of the cloud. Viewing the velocity cube in Slicer allowed me to see these features on a scale much larger than my own data could sample, and also to visualize their relative sizes."

He foresees a day when the term "data cube" will be a misnomer because astronomy data sets will regularly include many more dimensions. New instruments and telescopes will soon produce extensive 7D data sets: the object's two spatial dimensions as seen in the sky, the object's distance from Earth, two measures of velocity for the object's proper motion (its movement along those first two spatial dimensions compared to the rest of the sky), it's velocity in the line of sight (whether it's approaching or receding), and time.

Astronomers will be able to gather such data for individual stars over a very large portion of our galaxy. "Such data are poorly sampled in any one direction, but clustered together we can trace things like spiral arms, expanding associations of stars, and gravitationally bound star clusters. Astronomical Medicine could develop the existing tools to render such sparsely sampled multidimensional data sets," Muench says.

Desktop Model

The original medical version of 3D Slicer was developed by Kikinis and colleagues at Brigham and Women's Hospital and the MIT Artificial Intelligence Laboratory. Astronomical Medicine has also adapted a second program, OsiriX (www.osirix-viewer.com/), for use with astronomy. OsiriX was originally developed by a team of doctors at the University of California, Los Angeles, who are now at the University of Geneva.

Both are free, open source programs based on free, open source graphics toolkits. One is the National Library of Medicine's Insight Segmentation and Registration Toolkit (ITK, www.itk.org/) and the other is the Visualization ToolKit (VTK, www.vtk.org/), which is supported by imaging software maker Kitware (www.kitware.com).

These programs let users create multidimensional objects, rotate them, zoom in on particular features, and crop them if needed. Users can turn different parts of the model on and off.

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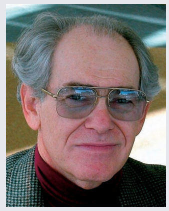
Internet Abstractions Meet the Law



By Rubin Landau, Department Editor

It was a dark and dreary March morning, when in the damp, cold comfort of my basement home office, I attended a live, hour-long lecture by Susan Crawford, a professor of the Benjamin Cardozo School of Law. The subject was US Internet access policy, and the lecture was part of the Educause Live Professional Development series (www-cdn.educause.edu/live). Appropriately, it was a Web seminar (webinar) delivered over the Internet using Abode Connect, which lets participants use their mice and keyboards to ask questions during the talk or communicate with each other without interrupting the speaker. Although we didn't see Crawford as she spoke, we heard her and saw her slides with no technical glitches (I was using a cable modem).

As a theoretical physicist who has spent many years thinking and analyzing physical phenomena and computation, it's fascinating for me to learn how a legal scholar thinks and analyzes a phenomenon on which I have spent much time. Two aspects of the talk remain with me still. The first is how the Internet means different things to different people, depending on the level of abstraction with which they view the Internet. (Crawford doesn't use the term abstraction, but I believe it's appropriate and helpful to hackers like us.) The second is how US government policy regarding access to and regulation of the Internet differs (or maybe should differ) depending on the level of abstraction used. Crawford has several papers on these subjects available on the Internet (of course); one, "Internet Think" (http://papers.ssrn.

Users can run the programs on normal desktop and laptop computers. But at the moment, neither fully supports the standard image file type endorsed by the International Astronomical Union—the Flexible Image Transport System, or FITS. Goodman says that her team is working to add this capability. Until then, they have incorporated partial FITS capability in the newest version of 3D Slicer, and they offer a converter program that will format FITS data for OsiriX.

Example projects are on the Astronomical Medicine Web site (http://astromed.iic.harvard.edu/). One, a study of star-forming molecular clouds in the constellation Perseus, offers stunning visuals. An animation shows a colorful (but two-dimensional) infrared image of the nebula com/sol3/papers.cfm?abstract_id=962596), is the most accessible to my nonlegal mind.

In some ways, it's hard to answer the question of what the Internet is because we all think we know the answer. We can define the Internet by displaying its various concrete manifestations (wires, for instance) as an abstract concept (a social community) or as a practically necessary mix of the two (TCP/IP, for example).

Three Views of the Internet

The concrete definition of the Internet is the pipes and switches that carry the signals. Telephone companies—who Crawford calls telcos—advocate this view, as do, apparently, many in the US Congress. Yet even if this view is too simple, the connections that compose the Internet aren't simple, obvious, or inexpensive. First, there is the backbone, originally set up by DARPA and the US National Science Foundation (NSF), which is composed of optical connections following the Internet Protocol (IP). The NSF originally required that the telephone companies make connections available to all qualified users on academic campuses. In 1995, however, after its importance had been proven, the NSF defunded the project and opened the Internet up to commercial users.

On one end of the Internet are the ISPs and their local connections to the backbone. On the other end are end users at the mercy of local ISPs who (for a healthy fee) connect them to the backbone. It's this last piece that has been a problem for many of us, and still seems to be especially problematic if you live in a nonurban area or don't have the money to buy access. Even though the pipes are now used to connect computers and transmit data, the telcos still argue that this isn't all that different from people talking on telephones. It's not surprising that this concrete view of the Internet in terms of hardware is considered to be the common sense one for

continued on p. 8

NGC 1333 taken by NASA's Spitzer Space Telescope as it's transformed into a rotating 3D model, with the dark clouds around the nebula made visible. The visualization helped IIC research assistant Michelle Borkin identify expanding gas clouds within the nebula.

Building Bridges

When the 3D Slicer development team needed to renew its funding from the National Institutes of Health, Kikinis emailed everyone who had downloaded the program to ask for testimonials. He was shocked at the response—not just because so many users were willing to help, but because they'd used the program in ways that nobody had envisioned. He published the submissions in the "Slicer

continued from p. 7

many people, including lawmakers (who have been known to accept contributions from telcos).

A more abstract definition of the Internet, but still involving some concrete constructs, is the one given by the engineers who originally designed it. To them, the Internet isn't just a bunch of wires and switches connected to each other, it's the logical architecture underlying the Internet that lets you connect your computer to other computers on different networks all over the world. As Crawford documents, the engineers who designed the Internet didn't envision, or possibly want, users to store information on the Internet (it isn't the Web), or have control of the communications. Considering how well TCP/IP, HTML, and HTTP has worked, it's reasonable to consider the founders' views seriously.

The most abstract view of the Internet is probably that of the group of visionaries that Crawford calls the "netheads." These are people like Vannevar Bush, Doug Engelbart, Norman Wiener, and J.C.R. Licklider who foresaw the impact of communications and computation on a human level, and helped make devices and interfaces so that people could interact on a personal level with computers and information. In this view, the Internet is more than just a medium, it's a state of mind, the social worlds and creative conversations that the Internet permits, and also the controls and interactivity that humans have via their communications (recall my cyberinfrastructure sidebar from the March/April 2008 issue?).

These three views aren't just of academic interest (although there is nothing wrong with academic interests as far as I'm concerned). They also influence how different groups view the Internet and influence their approaches to regulating it. Crawford pointed out in her webinar that the government, historically, viewed telcos according to the *common-carrier principle*, which lets them charge for providing the service of transport, but requires equal access to all. In contrast to telephone networks, broadcast networks aren't viewed as common carriers and are regulated with regard to content, access, political fairness, and decency. This regulation is more restrictive than how the government handles the press, which has constitutional protection. But the Internet transmits news, entertainment, personal communications, and so on, so its regulation isn't clear.

Big Government Steps In

In 1971, the US Federal Communications Commission (FCC) wanted to keep AT&T from extending their telephone monopoly to computing and networking. The FCC ordered AT&T out of the data processing business and required it to let other companies use its networks on a common-carrier basis. (I suspect that this is one of the reasons why the US is significantly behind other countries, such as South Korea and Japan, in computer networks.) The result was a clumsy separation of data from phone communications, and then a really confusing transition to the Internet. Crawford concludes that history matters here because it determines what sort of regulation will be used (often a problem for the government regarding new technologies), and that free speech protection should extend to communication over a network. This gives some context to the 1996 FCC regulation that information isn't covered by the common-carrier precedent, and that its transfer should be unfettered by regulation. However, the FCC didn't address access as a right.

If we put these analyses together, it becomes clear that problems arise because the Internet's switched packets all travel on wires owned by companies that are in the legitimate business of making money. These packets can carry many different kinds of information—email, video, music, news, phone service, instant messaging, spam, or pornography—that all look the same from the outside. Yet, if the packets contain news, then the Internet is like a newspaper and should have freedom of the press protection. But if the packets contain pirated music, then the file sharers are using the Internet to transport stolen goods across state and possibly international boundaries, which leads to the argument that the owners of the pipes shouldn't be assisting crimes. Furthermore, is it right that the network owners, who often have interests in entertainment companies as well, be allowed to slow down the transfer of their competitor's products as long as they don't deny them access? (Common-carrier regulations require equal access, not speed.)

From the legal viewpoint, it appears that how the Internet gets regulated—and who has access to it—depends on how the Internet is defined and the historical precedent that goes with that definition. The common-carrier principle provides for liberty of travel. Maybe it's too much of a stretch to apply it to a general purpose, global communications network? It's clear that no one person or body is in charge of the Internet—which might be a beautiful or scary thing—so regulation or control (the original meaning of cyber) isn't simple to enact. There are groups that argue for government protection from spam and pornography and those that argue for information sharing and freedom of access.

What is the conclusion? Maybe this is one of those subjects, like religion, where everybody believes so strongly that the other guy's understanding of the details is faulty, that agreement on general principle becomes impossible. Or maybe this is one of those areas, also like religion, where we respect the wisdom of the founders, who in this case are saying that the best thing for the government to do is to remove itself as much as possible. I agree with Crawford's conclusion that there are legitimate reasons for the government to exercise some regulation of the Internet, but that society and technical progress is best served if that regulation is kept to the essential minimum.

Community" section of www.slicer.org. Among the applications he expected—models of surgeries, cancer therapies, and human anatomy—were studies of dinosaur fossils, rat skulls (meant to shed light on climate adaptation in early hominids), and sinus cavities in a species of antelope. One project even modeled a floodplain's sediment erosion.

Halle agreed that geospatial research could make good use of 3D Slicer. He would like to see Astronomical Medicine change other disciplines the way he sees it changing astronomy. "It used to be that if you discovered one new star-forming region in a nebula, that was reason enough to publish a paper," he says. "But now we can create visualizations that reveal scores of star-forming regions in one image. So we're not just enabling discoveries, we're changing the way people make those discoveries." Any area of science that's struggling with large, multidimensional data sets could profit from better visualizations.

As to future improvements to the Astronomical Medicine software package, the users interviewed for this story would all appreciate easy ways to share their visualizations with others. The Web is enabling researchers to publish addendums to their journal papers, Li points out, so users can share animations that way. And DeLaney would like to be able to output her 3D graphics in formats that are compatible with publicly available programs like Adobe Acrobat.

Ultimately, Halle hopes that the Astronomical Medicine project will help create an online community that builds bridges between diverse areas of science. Many researchers create custom software toolkits for their research, he says, and everyone could benefit from sharing them. "In the world where engineering and science meet, the ability to distribute pictures—and to distribute the programs that generated them—is starting to become just as important as publishing a paper or giving a talk at a conference," he says.

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