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PUBLIC PERCEPTION
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SCALE
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TRUTH
DECISION MAKING
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DESIGN
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DEMOCRACY
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CARBON
DIPLOMACY
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MAPMAKING HAS A NEW CHALLENGE FAR MORE INVOLVED THAN DEPICTING THE TRAITS OF THE PHYSICAL WORLD. AS REVEALED IN A STUNNING NEW COLLECTION, THE ATLAS OF SCIENCE, THE TASK AT HAND IS AT ONCE AMBITIOUS AND AMORPHOUS: TO MAP THE WORLD OF SCIENTIFIC KNOWLEDGE, THE COLLECTIVE WISDOM THAT HUMANS HAVE ACCUMULATED OVER TIME — AND CONTINUE TO GENERATE AT AN EVER-INCREASING PACE.

Mapping Science

INNOVATION / BY IRIS MONICA VARGAS / JANUARY 24, 2011

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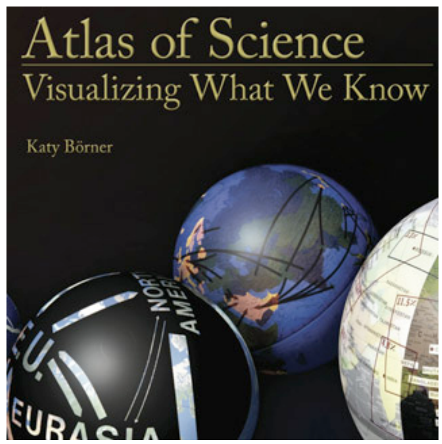

During the month of June of the year 1812, at the border between Russia and Poland, a group of men begin a singular march. It is the Grande Armée of Napoleon Bonaparte. Their goal is to invade Russia — a task for which 422,000 men have been summoned. It will be a futile effort, however. Utter destruction will come to them during the last months of the year.

Fifty-seven years later, while in his eighties, a French civil engineer who has enjoyed studying streams and physics, and drawing maps of economic phenomena, will shift his interest to historical subjects.

Charles Joseph Minard will depict the soldiers' travesty in a single map one that has become irrevocably linked to Bonaparte's march, and in its own way, just as iconic.

Overlaid on the map of Russia, a brown band represents the diminishing size of Napoleon's forces as the army moved up and down the latitude and longitudes of the vast country. The troops had passed the frozen Niemen River at a gallop, going from Kovno to Vilna before splitting at Polotzk. By September of 1812 only 100,000 soldiers had reached Moscow. Perhaps in the works of M.M. Thiers and the unpublished diary of Jacob, a pharmacist of the Army, Minard absorbed these details, as well as what happened next: With much of Moscow incinerated (historians debate whether the Muscovites deliberately set their own city ablaze, or whether the fires where accidental), the Czar and Moscow's citizens fled the city. A stunned and empty-handed Napoleon was forced into retreat.

***Atlas of Science*, based on the popular exhibit, "Places & Spaces: Mapping Science," features more than 30 full-page science maps, 50 data charts, a timeline of science-mapping milestones, and 500 color images. You can get the *Atlas* at Amazon.com, Barnes & Noble, or directly from the MIT Press.**

Visit the Places & Spaces Exhibit.

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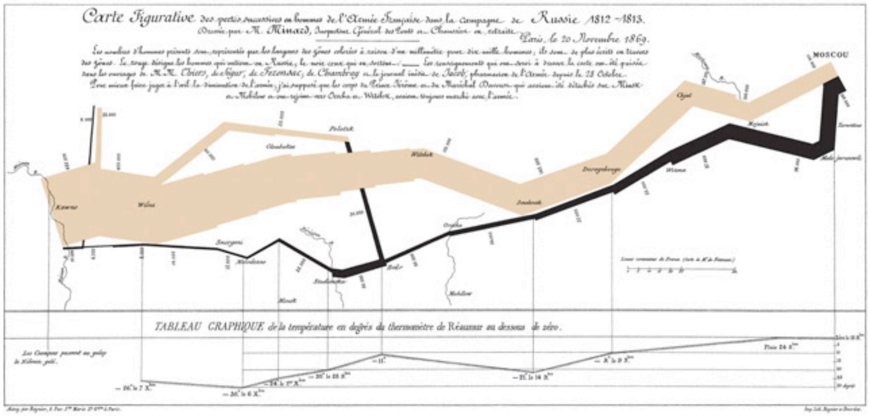

A flowmap of Napoleon's 1812 March to Russia by Charles Joseph Minard (1869).

On Minard's map a second path, this one in black, traces the retreat. Running parallel to the brown band but at only a fraction of its width, the black band makes the army's losses all the more poignant. Some 22,000 men never made it across the Berezina River. The cruelty of winter has set in, and a jagged line at the bottom of the graph plots the plummeting temperatures — -20 degrees, -24 degrees, -30 degrees. Of the 422,000 men who marched to Moscow, a thin black line stands now for a mere 10,000 men — the only ones who succeeded in returning to their point of departure. History will record it as the onset of the collapse of Napoleon's Continental Empire.

Minard's illustration, hailed as one of the best, does what most maps, early and contemporary, do: it visually represents something that is known and valued in the world of the mapmaker. It helps navigate, explore, make sense of, and communicate ideas that might otherwise fade into abstraction, or never materialize at all.

It's not alone in its intent. A Babylonian cave map made of clay is probably one of the earliest, and simplest, examples. And then there's the medieval Peutinger, the so-called "quintessential travel map." A 20-foot x 1-foot scroll depicting the entire Roman Empire, the Peutinger could be carried by travelers on their voyages, its jagged lines marking roads and its symbols indicating cities, military camps, rivers, and rocks. These are early examples of the physical geography maps with which so many people are most comfortable.

The science of geography has continued to flourish in the information age. Currently, more than 20 global positioning system satellites and the reference coordinate system they use (the World Geodetic System) allow for precise calculations of geographic position and navigation. Any person with a laptop connected to the internet, for instance, can search practically any location in the world and immediately learn how to get to it, how long such a trip would take, or even what the location would look like.

But the field of mapmaking has a new challenge far more involved than merely depicting the easily identifiable traits of the physical world. The task at hand is at once ambitious and amorphous: to map the world of scientific knowledge, the collective wisdom that human beings have accumulated and preserved over the past several centuries. This job goes far beyond searching for facts within scholarly papers and books. It is to navigate these materials in such a way that data — or "noise with a cognitive pattern," as the Spanish philosopher George Santayana once called it — can become information, that is, something that serves to "inform."

If this information can in turn be related to other information, we will have laid the foundation for something much greater. Something like greater knowledge, perhaps even greater understanding. Minard's map of Napoleon's march to Moscow is a good attempt at this type of synthesis — including six distinct categories of information, it is far more complex than most geographical maps, past or present. It also conveys hints of what might be possible.

Enter the Science Mapmakers

As of January 2010, the total amount of digital content that humans had collectively produced was estimated at 1 zettabyte. To put this into perspective, the letter "z" in a standard Word document amounts to roughly 1 byte. A typed page comes to about 2,000 bytes. A high-resolution photograph? 2 million bytes, or megabytes. Add six more zeros and you get two terabytes — the equivalent of all the information contained in the U.S. academic research library. Another six zeros (we're now at 18) brings us to the exabyte. Five exabytes, according to some scholars, could store all the words ever spoken by human beings. One thousand exabytes equals one zettabyte, the total amount of digital content in the world as of this time last year.

Just as much of our data, past and present, is linked to science, a big chunk of our future zettabytes will also be scientific. Take for example, the new Square Kilometer Array, a massive telescope slated for construction in either South Africa or Australia beginning in 2016. According to the CSIRO, astronomers expect to be processing 10 petabytes of data every hour from this telescope—a flurry of activity that will yield about one exabyte every four days of operation. IBM expects the traffic to be even greater: the company is currently designing new storage hardware to handle the full exabyte of data it anticipates the telescope will generate every day. That's one with 18 zeros, demanding the storage capacity of 1 billion PCs. If envisioning all of this data is exhausting, imagine trying to map it.

Yet that is just what these intrepid science mapmakers are trying to do. Their numbers are small—there are only about 300 in the world—and they are attempting to survey the unimaginable amount of scientific data in existence, convinced that by giving it some shape, structure, or interactive presence, they will be helping to build that critical bridge from data to information to knowledge. And that in so doing, they will be rendering data into a form not only useful in making decisions and determining daily actions, but also within reach of every person on this planet.

Far from mapmakers of 17th century, elderly bearded men in tweeds and gabardines who cloistered themselves in ivory towers, the science mapmakers of the twenty-first century are a mix of computer-savvy males and females, young as well as old. They are cartographers and historians, cognition specialists and graphic designers. Spanning academia, business, and government, they are experts schooled in perception, education, data mining, informetrics, webometrics, and more.

Katy Borner, the Victor H. Yngve Professor of Information Science at Indiana University's School of Library and Information Science, is one of them. She has recently produced the *Atlas of Science* — a voluminous collection of science maps interwoven with the fascinating turns of history, events, and people that led to their making. In the *Atlas*, we encounter the spectrum of ideas that, in one way or another, evolved into this new cartographic challenge: how to represent the known world in a visual way that is accessible to all — a sort of socialism of scientific knowledge.

If the aim of the classical cartographer was to depict the three-dimensional complexity and facts of the "real" world into a two-dimensional page, Borner's goal, and that of her colleagues is perhaps slightly more daunting. "First," says *National Geographic* Chief Cartographer Allen Caroll, "the world they strive to represent is an abstract and intellectual one, not a physical reality that can be imaged from space, surveyed on the ground, and depicted in miniature on a map. The interrelationships among the landmarks of this abstract world are real, but they are not easily represented in the simple, straightforward ways that one can convey the distances between, say, three cities."

But just like maps of Earth that have long helped travelers — especially seafaring men and women — take to the oceans, find their land destinations, and return safely to their loved ones, these new maps of science will, ideally, help their users understand where they are on the landscape of science. Given the abstract way that science is often taught in today's classrooms, this landscape will strike many students as foreign ground. "It's as if scientific disciplines weren't interconnected," says Borner. "It's biology and chemistry and physics and astronomy, and you don't really know how they all go together. But there are very interesting networks of connections and dynamics among them."

Increased computing power and visualization software allowed a team from SciTech

Strategies, Inc. to render a map of similar purpose using the largest set of scientific literature yet mapped. The data set comprised about 7.2 million papers published in more than 16,000 unique journals during the years 2001 to 2005. First, to avoid imposing artificial boundaries, the data was displayed in a three-dimensional layout where different groups of journals were projected as topography over a globe. Then, a Mercator projection was used to flatten the spherical layout, in much the same way that Mercators render the Earth onto a two-dimensional map.

On the resulting Maps of Science, developed by SciTech's Kevin W. Boyack and Richard Klavans, each colored node represents a discipline or set of journals in a discipline — biology, physics, math, earth science, and chemistry, among others — that cite a common literature. The lines between nodes symbolize shared citations. Thus, closely related disciplines like computer science and math will also share a dense network of lines, bringing them close together over the spherical surface.

Courtesy of Katy Borner

The result is as intriguing as its construction. "If this were a map of the Earth it would be like a single continent undulating along the equator," writes Klavans. He and his mapmaker colleagues have been monitoring the changes in the interconnectedness of the circles in different regions of the map between 2001 and 2005. Connectedness between neighboring fields has increased, and the opposite has occurred between distant fields. Their forecast? The underlying structure of science is unstable and is likely to change dramatically over the next decade.

Using this map, researchers can search for common patterns, identify emerging trends, and explore relationships across disparate fields, from computer science (pink) to infectious disease (maroon) to the humanities (yellow). The SciTech map is currently the most accurate and comprehensive map in existence, and it will soon be updated to include years 2006 to 2010.

Mapping science can be done in different ways, however. Other reference systems than the ones used for building the Maps of Science exist. "Maps can be made of different levels. The simplest you could make, for example, would be a map of yourself," explains Borner. "So if you'd like to understand what your social networks are, what your scholarly network is, you could go to a database for scientists, such as the NIH or NSF, download all data of how you are connected to other people, friends, and colleagues by co-authorship, co-investigator links, spatial closeness, topical closeness, etc. That kind of map is very readable because people immediately know all the people represented in it."

Other interesting things to map? How about the record of how many times Wikipedia's entry about "abortion" has been edited since it was first published, including every time it was completely deleted? Done. Or perhaps take a manuscript of a thousand lines and figure out the main characters that drive the story, their relationships and interactions, and the topics it covers *without actually reading the book*? That has been done too—in such a way that each line of the text forms an arc, stepping clockwise, starting and ending at twelve o'clock in a circular reference system in which words can be placed according to their original occurrence. And the same technique has been used to draw a map of the history of science. These examples are included in the *Atlas of Science*, as well as Places and Spaces, an exhibit produced by Borner and her colleagues that, since 2005, has toured in more than 50 national and international venues and has also developed an extensive online gallery.

Whatever the type of map, the idea, says Borner, is to produce what she calls a "global brain," a name coined by sci-fi author H.G. Wells in his iconic 1939 book, *World Brain.* "It's the idea that you would interconnect people around the globe, and empower large numbers of people, rich and poor, to really understand science and technology. You want to give them, she emphasizes, "the data and expertise to trigger certain behavior that is beneficial for the planet and species."

The maps in the *Atlas of Science*, and science mapping itself, are a visual interface of what we collectively know. And they are meant to be visually stunning. To "deeply engage the minds," as Borner puts it, you need to stir people not only intellectually but also emotionally.

"Many people understand that it's bad to drive a big car or to drive instead of bicycling because it puts a lot of waste in our environment, and it uses energy that might be needed for other purposes. However, there are very few people who then say, 'Alright, I'll just get a smaller car or sell my car and I will use my bicycle more often.' I think in order to change people's behavior, people have to be touched emotionally."

The cognitive process Borner and colleagues attempt to trigger is one that will be familiar to any artist, writer, or marketing guru. "In some cases you read a sentence and it deeply impacts you all your life," Borner says. "A quote from a writer sometimes does this to you. And it might also happen that you see a table and you realize, 'Wow. The number of cancer patients or the number of autistic children in the U.S is increasing.' " Visualizations, Borner believes, aren't "the only thing that can change your behavior or touch your life deeply," but they make ideas easier to understand and remember.

In fact, Borner envisions something like a Weather Channel for science mapping. "I believe that we should have a national science forecast, Borner says. "We could map science every day, see how it evolves, view the technology that becomes available as a result. We could see what happens with a scientific question over time, or what results from funding a scientific project, for instance." This type of national science forecast would be a transparent and easy way to access — and assess — what we collectively know, and the kind of products and inventions that we've created. The goal, says Borner, is to improve the diffusion of information, displaying not only what works, but especially what doesn't, reducing time, cost, useless repetition of research, and improving continuity.

A map-based national science forecast certainly sounds alluring. But is there a risk that by generating these maps, we are artificially shaping conclusions that aren't necessarily real, visualizing trends that aren't really there, or promoting ones that are there but aren't important?

Consider the limitations. Not all reference systems that researchers currently use are freely available. Many of the maps themselves are tucked away in private libraries and computer servers, out of the average person's reach. Even if maps were universally accessible, making sense of them is another matter. Science maps are not taught in school and hence few people know how to read or use them correctly. Connecting all of these elements — a universal reference system, a common metaphor for data representation, and a standard for picture-science education — remains the coveted grail. "I think we are just in the beginning of our understanding of how to render the structure and dynamics of science for a general audience," says Borner.

And there are other poignant limitations. For example, most of the science maps in the *Atlas* are created from data in the English language. "Many people believe that if you just map the papers that have been published in English you get very comprehensive maps. I think we need other languages in there as well," says Borner. The United States, for instance, could have benefited from the knowledge of water dam construction accumulated in the Netherlands. "There's a rich body of literature on the subject but it's mostly written in Dutch," she says. "It would have been very useful to deal with the aftermath or even prevent the effects of Hurricane Katrina in New Orleans. The same is true for other areas of science and technology." The *Atlas* encourages readers to see science from a variety of angles, using an array of distinct reference systems and algorithmic approaches to predicting and forecasting science.

With so many different science mapmakers and approaches to mapmaking, how much objectivity is possible in the creative process?

A recent study by Boyack and Klavans shows that if one takes 20 pioneering large scale maps of science that have been generated over the last hundred years, and reviews the thirteen major areas of science in those maps, the same relations amongst areas emerge. “The structure of science, independent of the data or algorithm used to analyze this data, seems to be relatively stable,” Borner says.

Large-scale maps of science could thus serve as a context for smaller-scale scientific research representations. Like in any other experiment, however, where different people, different types of data and analysis are involved, anybody should be able to replicate your map, large scale or small.

Perhaps one day we can create a base map of science, analogous to a map of our world, upon which different types of data can be overlaid and communicated effectively.

Not long ago Borner and some mapmaking colleagues and researchers presented their science maps to the toughest of all audiences — a classroom filled with curious and demanding nine-year-olds.

“We first showed them a map of the world and we explained to them where different fields of science developed, and how the areas interlink with each other. We talked about other researchers like Einstein and discussed how many of them had made major contributions and had helped cross-pollinate multiple areas of science,” says Borner. “We asked them to indicate where they might like to work when they grow up, and a little girl said, ‘I want to be a nuclear physicist,’ pointing to the correct area on the map. It was very touching that they had now a guide to find their place in science.”

About the Author
Iris Mónica Vargas is a physicist, poet, and science journalist with master’s degrees in Physics from the University of Puerto Rico, and in Science Writing from the Massachusetts Institute of Technology. She previously produced an award-winning science bi-monthly column for El Nuevo Dia, Puerto Rico’s main newspaper, and currently writes about the biomedical sciences, human nature, physics and technology..