

# Atlas of Science

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# Mapping Science Exhibit



**places & spaces**

**Cartography of the Physical and the Abstract**

An exhibition created for the conference "Mapping Humanity's Knowledge and Expertise in the Digital Domain" at the 2005 Meeting of the American Association of Geographers that is updated regularly with new maps and explanations.

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**Exhibit Purpose and Goals**

**The Places & Spaces** exhibit has been created to demonstrate the power of maps.

An initial theme of this exhibit is to compare and contrast first maps of our entire planet with the first maps of all of science as we know it.

Come see with your own eyes the extent to which maps can be employed to help make sense of the flood of information we are confronted with and how domain maps can be used to locate complex and beautiful information.

This online part of the exhibit provides links to a selected series of maps and their makers along with detailed explanations of why these maps work. The physical counterpart supports the close inspection of high quality reproductions for display at conferences and education centers. It is meant to inspire cross-disciplinary discussion on how to best track and communicate human activity and scientific progress on a global scale.



**Places & Spaces: Mapping Science**

a science exhibit that introduces people to maps of sciences, their makers and users.

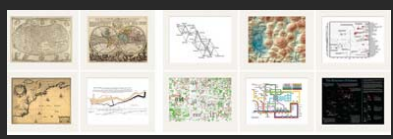
**Exhibit Curators:**  
 Dr. Katy Börner & Elisha Hardy  
<http://scimaps.org>



**Mapping Science Exhibit – 10 Iterations in 10 years**

<http://scimaps.org/>

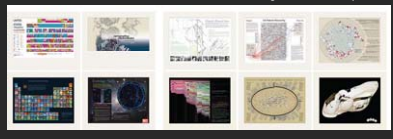
**The Power of Maps (2005)**



**Science Maps for Economic Decision Makers (2008)**



**The Power of Reference Systems (2006)**



**Science Maps for Science Policy Makers (2009)**



**The Power of Forecasts (2007)**



- Science Maps for Scholars (2010)
- Science Maps as Visual Interfaces to Digital Libraries (2011)
- Science Maps for Kids (2012)
- Science Forecasts (2013)
- How to Lie with Science Maps (2014)

Exhibit has been shown in 72 venues on four continents. Currently at

- NSF, 10th Floor, 4201 Wilson Boulevard, Arlington, VA
- Marston Science Library, University of Florida, Gainesville, FL
- Center of Advanced European Studies and Research, Bonn, Germany
- Science Train, Germany.





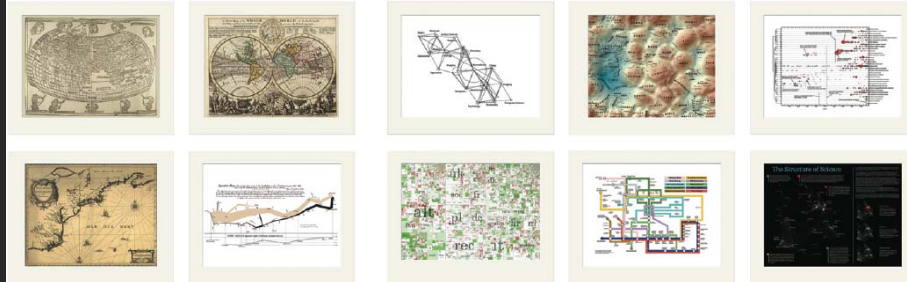
Debut of 5<sup>th</sup> Iteration of Mapping Science Exhibit at MEDIA X was on May 18, 2009 at Wallenberg Hall, Stanford University, <http://mediax.stanford.edu>, <http://scaleindependentthought.typepad.com/photos/scimaps>



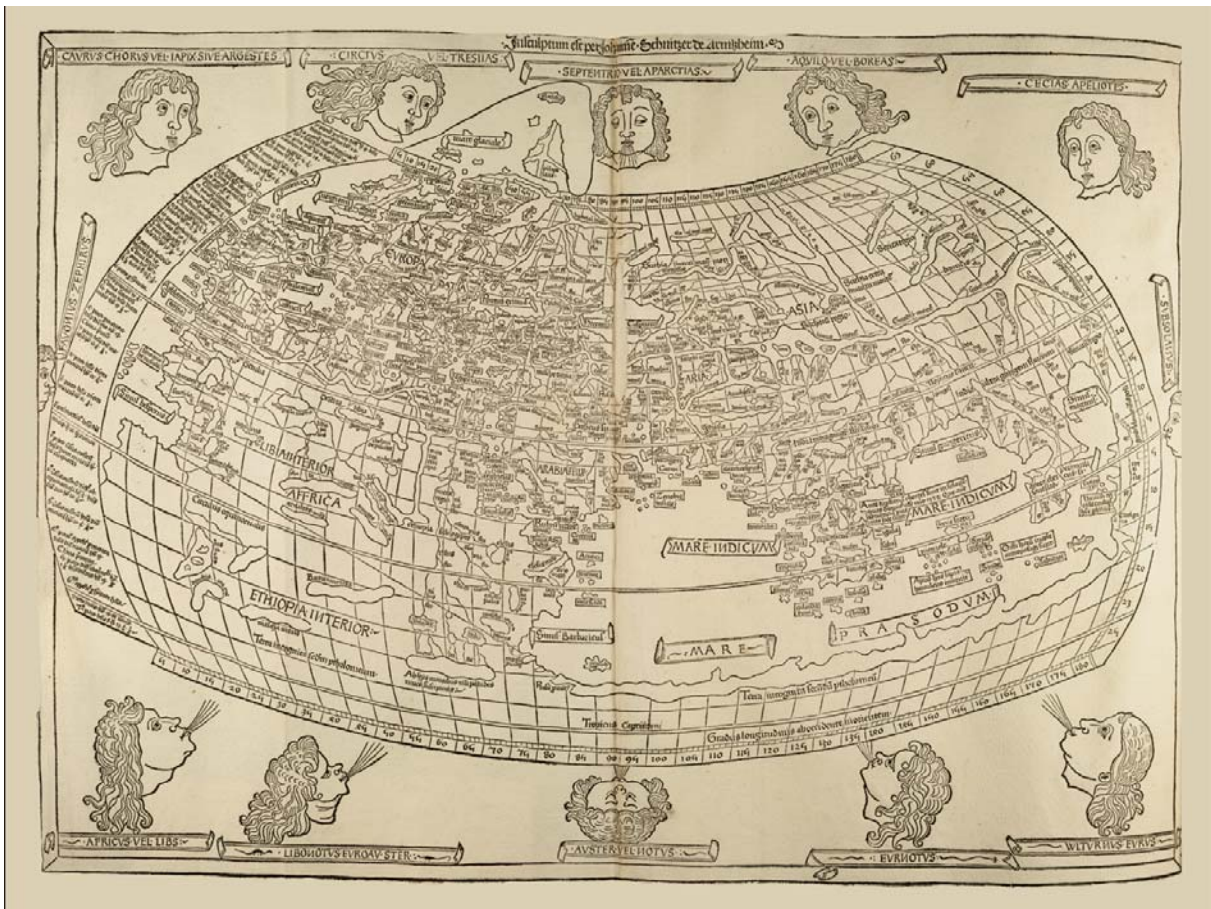
Science Maps in "Expedition Zukunft" science train visiting 62 cities in 7 months, 12 coaches, 300 m long. Opening was on April 23<sup>rd</sup>, 2009 by German Chancellor Merkel, <http://www.expedition-zukunft.de>

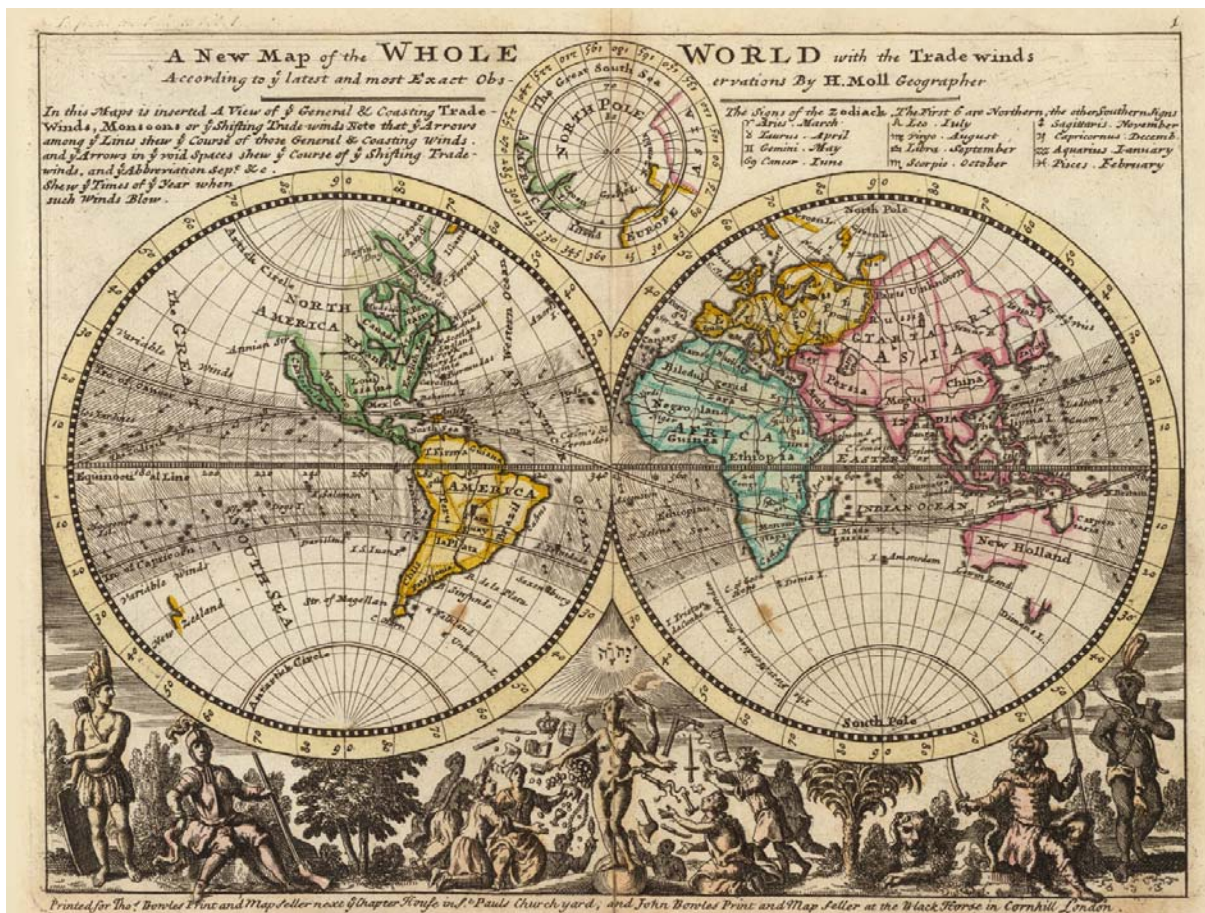
# The Power of Maps

## Four Early Maps of Our World VERSUS Six Early Maps of Science



*(1st Iteration of Places & Spaces Exhibit - 2005)*



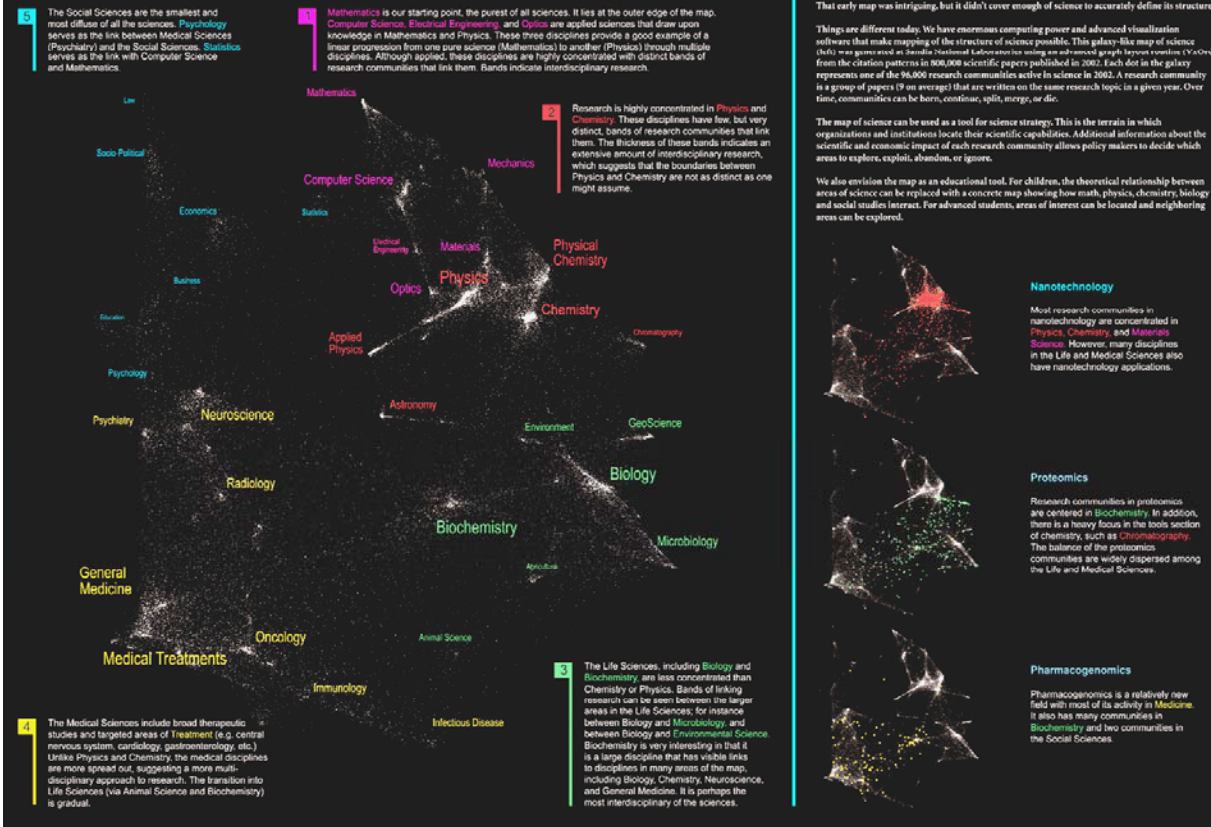


How would a map of science look?

What metaphors would work best?



# The Structure of Science



We are all familiar with traditional maps that show the relationships between countries, provinces, states, and cities. Similar relationships exist between the various disciplines and research topics in science. This allows us to map the structure of science.

One of the first maps of science was developed at the Institute for Scientific Information over 30 years ago. It identified 41 areas of science from the citation patterns in 17,000 scientific papers. That early map was intriguing, but it didn't cover enough of science to accurately define its structure.

Things are different today. We have enormous computing power and advanced visualization software that make mapping of the structure of science possible. This galaxy-like map of science that we present is similar to what astronomers using an advanced graphing program (Voson) from the citation patterns in 808,000 scientific papers published in 2002. Each dot in the galaxy represents one of the 99,000 research communities active in science in 2002. A research community is a group of papers (9 on average) that are written on the same research topic in a given year. Over time, communities can be born, continue, split, merge, or die.

The map of science can be used as a tool for science strategy. This is the terrain in which organizations and institutions locate their scientific capabilities. Additional information about the scientific and economic impact of each research community allows policy makers to decide which areas to explore, exploit, abandon, or ignore.

We also envision the map as an educational tool. For children, the theoretical relationship between areas of science can be replaced with a concrete map showing how math, physics, chemistry, biology and social studies interact. For advanced students, areas of interest can be located and neighboring areas can be explored.

### Nanotechnology

Most research communities in nanotechnology are concentrated in Physics, Chemistry, and Materials Science. However, many disciplines in the Life and Medical Sciences also have nanotechnology applications.

### Proteomics

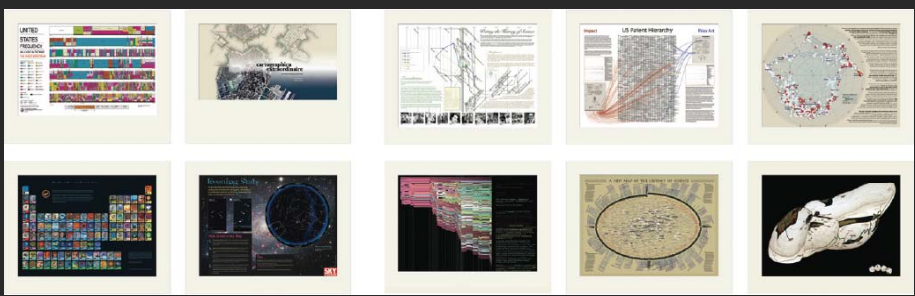
Research communities in proteomics are centered in Biochemistry. In addition, there is a heavy focus in the tools section of chemistry, such as Chromatography. The balance of the proteomics communities are widely dispersed among the Life and Medical Sciences.

### Pharmacogenomics

Pharmacogenomics is a relatively new field with most of its activity in Medicine. It also has many communities in Biochemistry and two communities in the Social Sciences.

# The Power of Reference Systems

## Four Existing Reference Systems VERSUS Six Potential Reference Systems of Science



*(2nd Iteration of Places & Spaces Exhibit - 2006)*

# The Visual Elements Periodic Table



# Evening Stars

The Big Dipper floats high in the northeast these early spring evenings, while Orion sinks low in the southwest. These are just a few of the celestial sights you can find on any clear evening in April using a sky map like the one shown here.



## How to Use a Sky Map

- Check the dates and times at night.** Take your map out under the night sky around the right time, and bring along a flashlight to read it by. It helps to attach a piece of red paper over the front or to use a flashlight with red LEDs; the dim red light won't spoil your night vision.
- Outside, you need to know which direction you're facing.** (If you're unsure, just note where the Sun sets; that's west.) Whichever way you're facing, make sure the corresponding yellow label along the curved edge of the map is at the bottom, right side up. This curved edge represents the horizon. The stars above it on the map match the stars in front of you. The further up from the map's edge they appear, the higher they'll be in the sky. The center of the map is the zenith (straight overhead). So a star halfway from the edge of the map to the center will appear halfway from straight ahead to straight up. Ignore all the parts of the map above horizons you're not facing.
- Let's give it a try!** Pretend you're facing the southwest horizon (labeled "Facing SW"). Just a little way up (that is, a little way in from the edge of the map) is Sirius, the brightest star in the night sky, in the constellation Canis Major. Farther up, nearly halfway overhead, is the star Procyon in Canis Minor. Still farther up is the ringed planet Saturn. Go out at the right time, face southwest, and look up into the sky — there they are!



**When to Use This Map**  
Early April: 10 pm (daylight-saving time)  
Late April: Dusk

## Tips

**A couple of tips:** Look for the brightest stars and constellations first; light pollution or moonlight may mask out the fainter ones. And remember that star patterns in the sky will look a lot bigger than they do here on paper. With a map like this, you can identify celestial sights all over the sky. Go out the next clear night and make some stargazing!

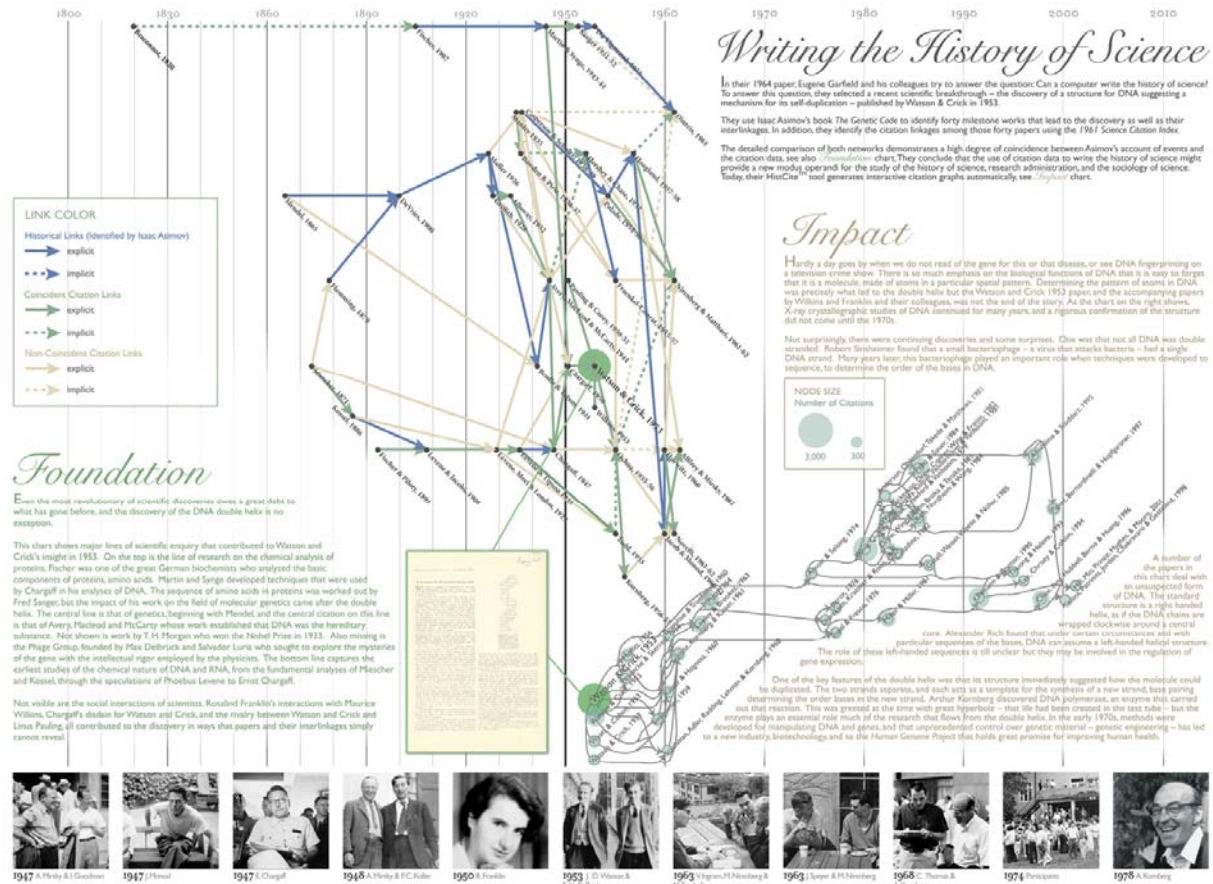
You can customize a night-sky map for any time and place at [SkyandTelescope.com](http://SkyandTelescope.com).

**SKY**  
& TELESCOPE



# How would a reference system for all of science look?

## What dimensions would it have?

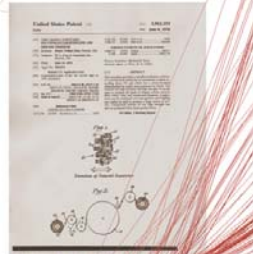


# Impact

The United States Patent and Trademark Office does scientists and industry a great service by granting patents to protect inventions. Inventions are categorized in a taxonomy that groups patents by industry or use, proximate function, effect or product, and structure. At the time of this writing there are 165,523 categories in a hierarchy that can get as deep as 13 levels. We display the first three levels (13,329 categories) at right in what might be considered a virtual map of inventions.

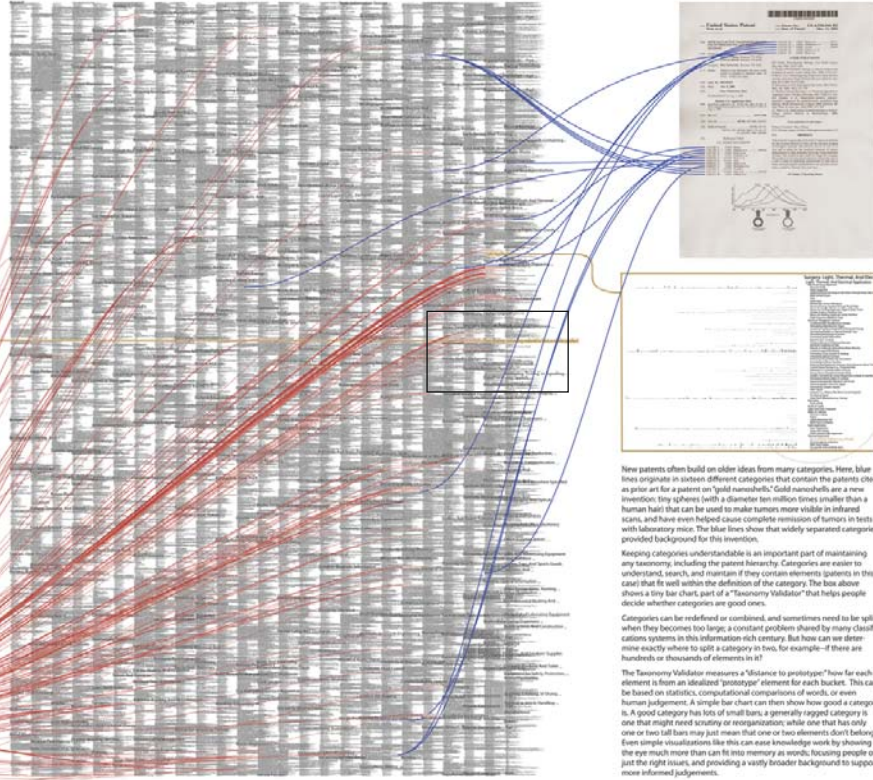
Patent applications are required to be unique and non-obvious, partially by revealing any previous patents that might be similar in nature or provide a foundation for the current invention. In this way we can trace the impact of a single patent, seeing how many patents and categories it affects.

The patent on Gore-tex—a lightweight, durable synthetic fiber—is an example of one that has had significant impact. The box below enlarges the section of the hierarchy where it is filed, and the red lines (enlarged to start along a time line from 1981 to 2006) point to the 130 categories that contain 182 patents, from waterproof clothing to surgical cosmetic implants, that mention Gore-tex as prior art.



# US Patent Hierarchy

# Prior Art

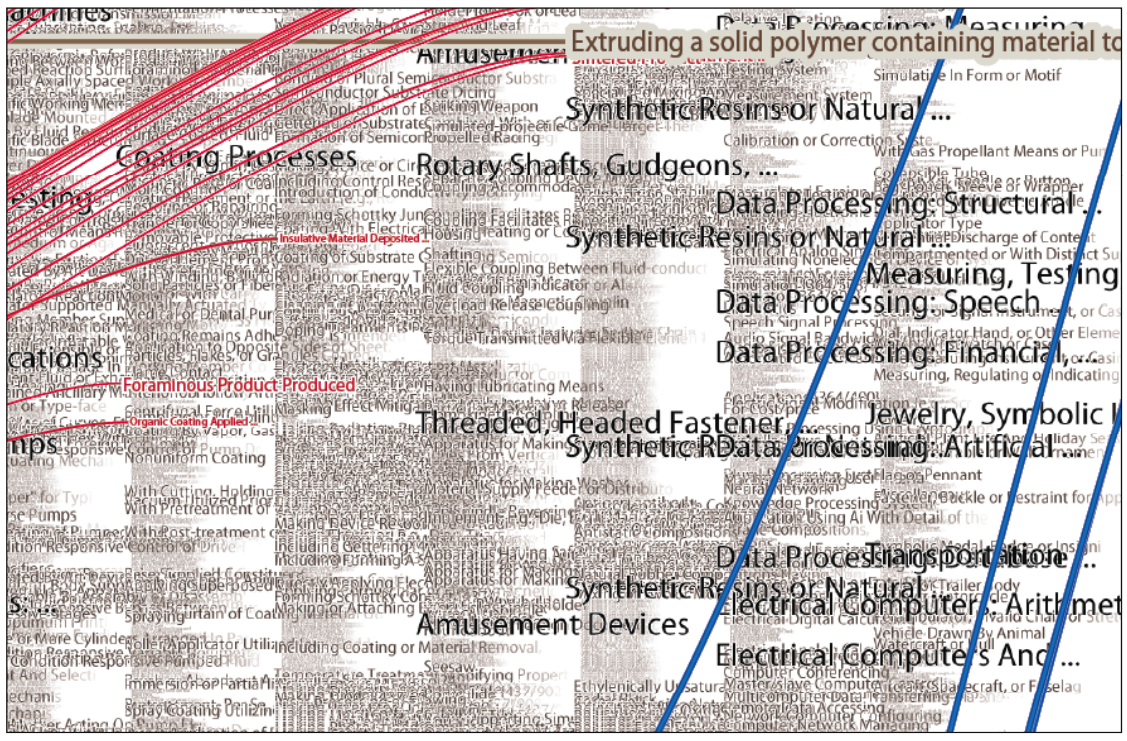


New patents often build on older ideas from many categories. Here, blue lines originate in sixteen different categories that contain the patents cited as prior art for a patent on 'gold nanoshells'. Gold nanoshells are a new invention: tiny spheres (with a diameter ten million times smaller than a human hair) that can be used to make tumors more visible in infrared scans, and have even helped cause complete remission of tumors in tests with laboratory mice. The blue lines show that widely separated categories provided background for this invention.

Keeping categories understandable is an important part of maintaining any taxonomy, including the patent hierarchy. Categories are easier to understand, search, and maintain if they contain elements (patents in this case) that fit well within the definition of the category. The box above shows a tiny bar chart, part of a "taxonomy validator" that helps people decide whether categories are good ones.

Categories can be redefined or combined, and sometimes need to be split when they become too large; a constant problem shared by many classifications systems in this information-rich century. But how can we determine exactly where to split a category in two, for example—if there are hundreds or thousands of elements in it?

The Taxonomy Validator measures a "distance to prototype" how far each element is from an idealized "prototype" element for each bucket. This can be based on statistics, computational comparisons of words, or even human judgement. A single bar chart can then show how good a category is. A good category has lots of small bars; a generally ragged category is one that might need scrutiny or reorganization; while one that has only one or two tall bars may just mean that one or two elements don't belong. Even simple visualizations like this can ease knowledge work by showing the eye much more than can fit into memory as words, focusing people on just the right issues, and providing a vastly broader background to support more informed judgements.



# Impact

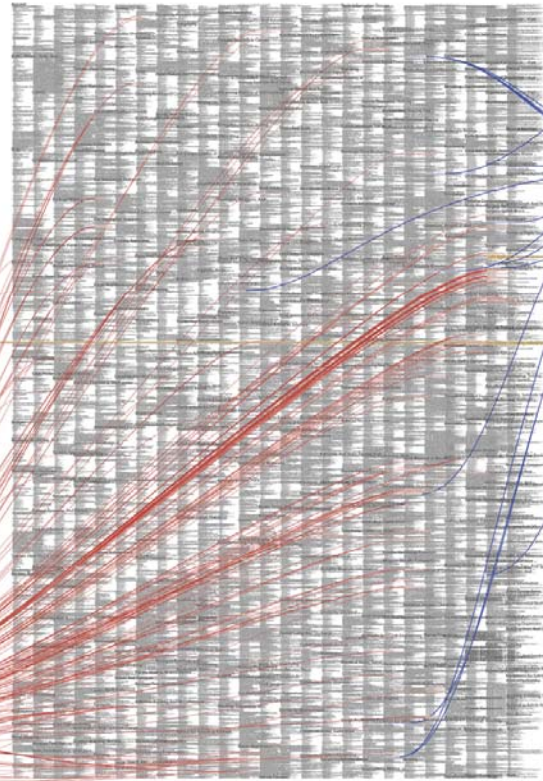
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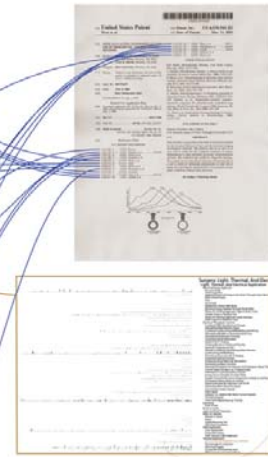
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# US Patent Hierarchy



# Prior Art



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**Synthetic Resins or Natural Rubber**

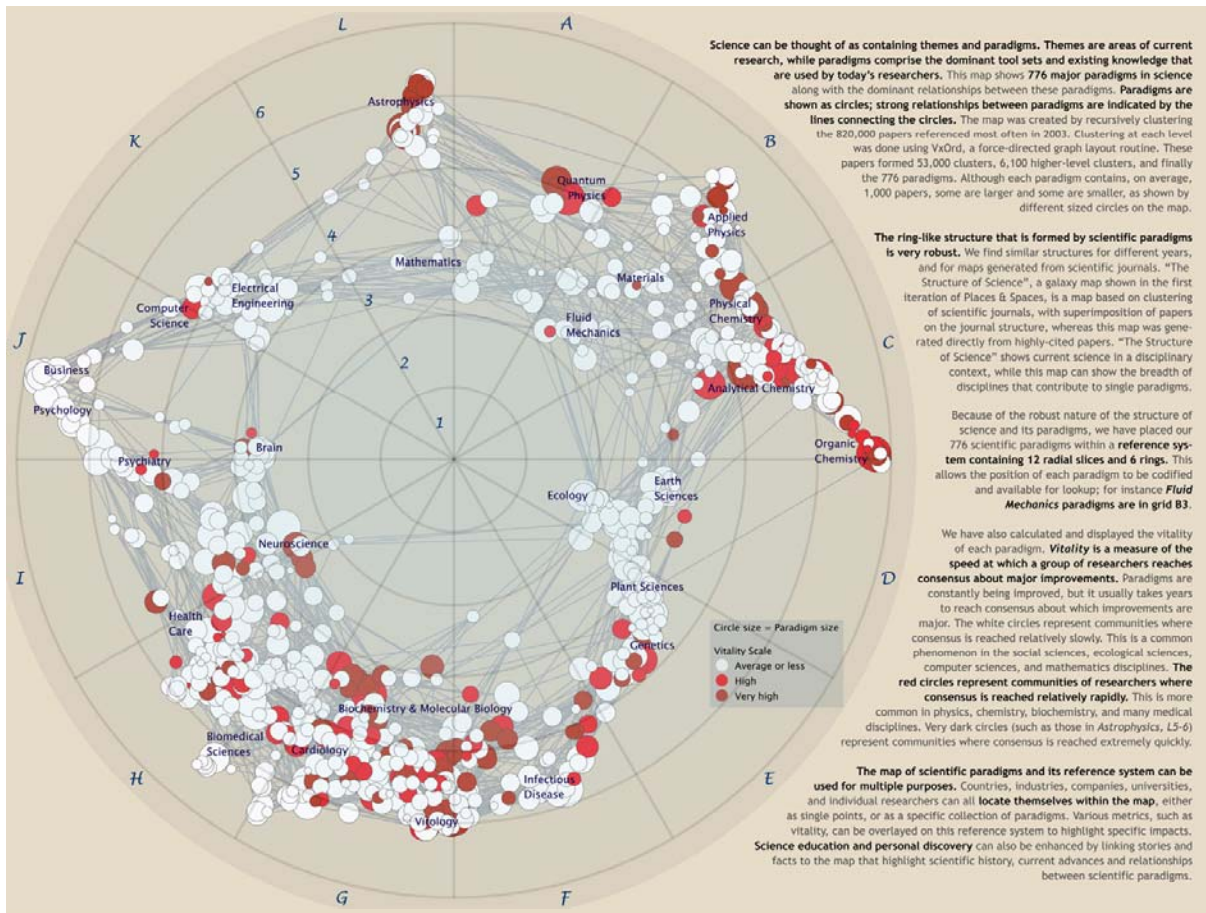
- Ion-exchange Polymer or Process of Preparation
- Process of Regenerating
- Membrane or Process of Preparing
- Previously Formed Solid Ion-exchange Polymer Admixed With Membrane
- Polymer Characterized By Defined Size or Shape Other than Beads
- Chemically Treated Solid Polymer
- Solid Polymer Derived From Ethylenically Unsaturated Reactant
- Solid Polymer Derived From At Least One 1,2-epoxy Containing
- Solid Polymer Derived From Aldehyde or Derivative
- From Ethylenically Unsaturated Reactant Only
- From Aldehyde or Derivative

**Process of Treating Scrap or Waste Product**

- Process of Treating Scrap or Waste Product Containing At Least One
- Treating Rubber (or Rubberlike Materials) or Polymer Derived From
- Treating Polymer Derived From A Monomer Containing Only One
- Treating Polymer Derived From Hydrocarbon Monomers Only
- Treating Polysiloxane
- Treating Polyester
- Treating With Alcohol
- Treating Polyurethane, Polyurea (excluding Urea-formaldehyde)
- Treating With Alcohol or Amine
- Treating Polycarbonamide

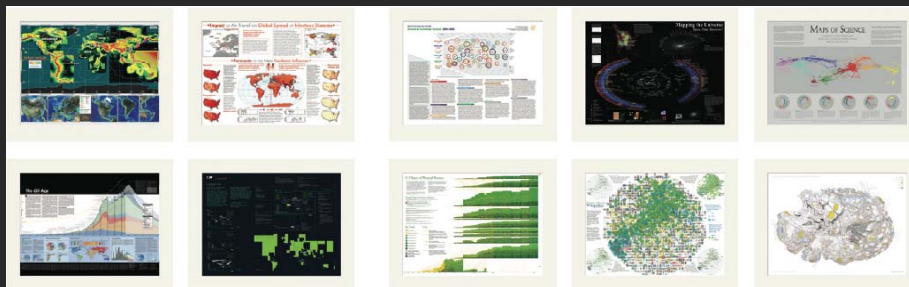
**Cellular Products or Processes of Preparing**

- Cellular Product Derived From Two or More Solid Polymers or From
- At Least One Polymer Is Derived From Reactant Containing Two
- At Least One Polymer Is Derived From An Aldehyde or Derivative
- At Least One Polymer Is Derived From A  $-n=C=x$  Reactant Where

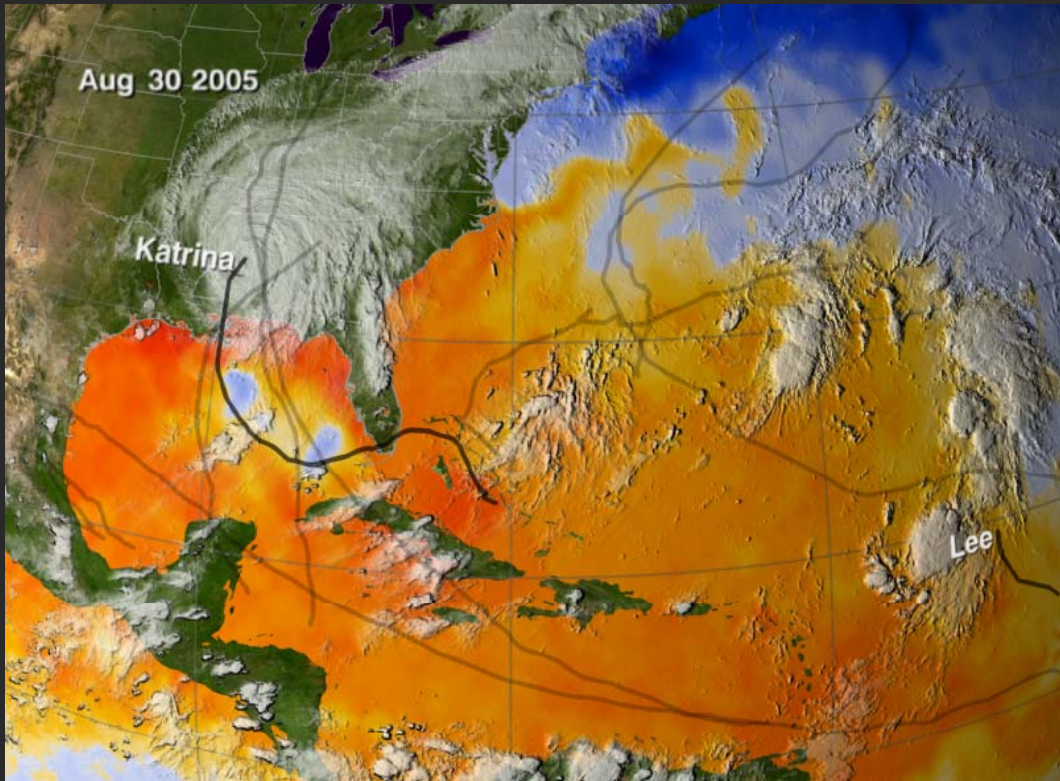


# The Power of Forecasts

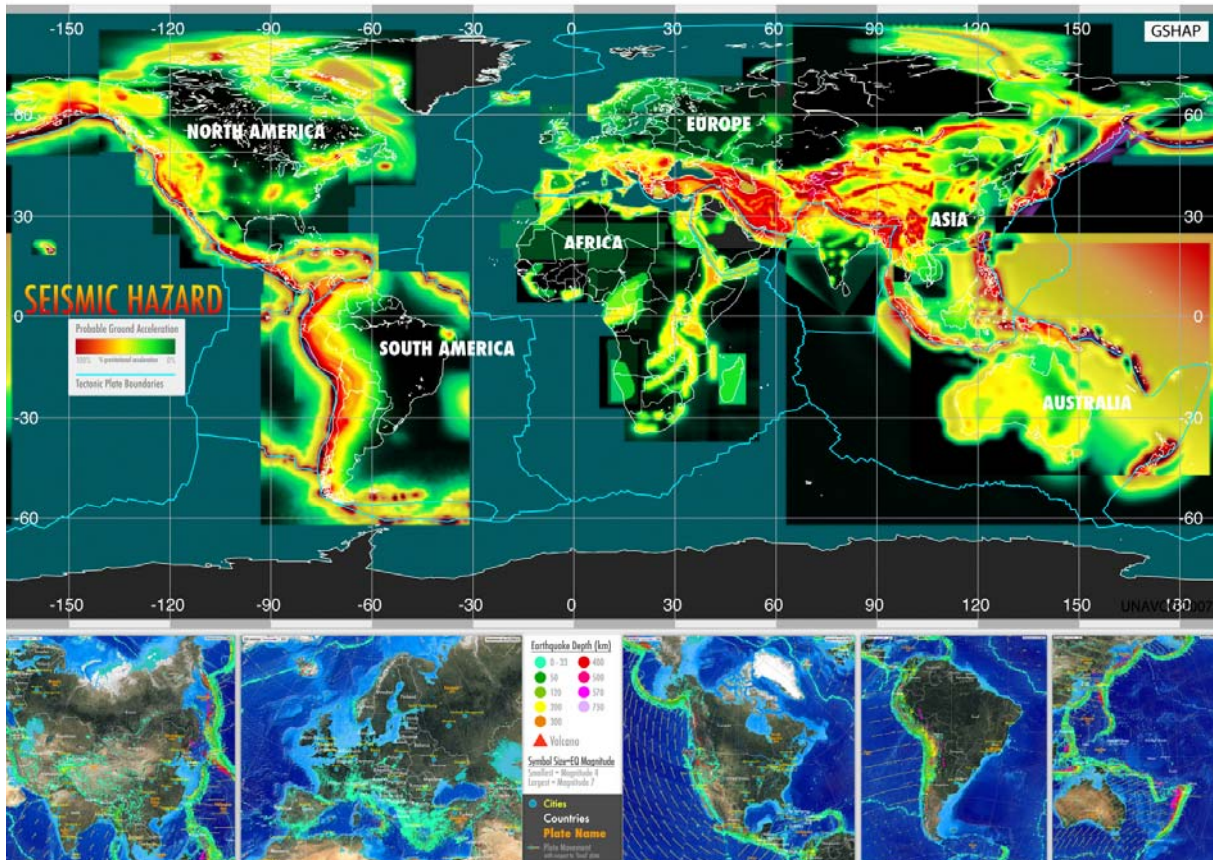
## Four Existing Forecasts VERSUS Six Potential Science 'Weather' Forecasts



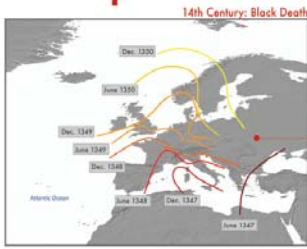
*(3<sup>rd</sup> Iteration of Places & Spaces Exhibit - 2007)*



Named Storms, available online at <http://svs.gsfc.nasa.gov/vis/a000000/a003200/a003279>



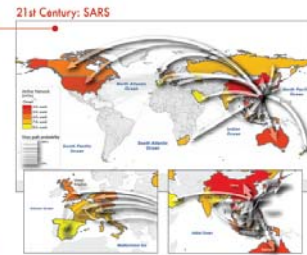
# Impact of Air Travel ON Global Spread of Infectious Diseases



**Epidemic spreading pattern changed dramatically after the development of modern transportation systems.**

In pre-industrial times disease spread was mainly a spatial diffusion phenomenon. During the spread of Black Death in the 14th century Europe, only few traveling means were available and typical trips were limited to relatively short distances on the time scale of one day. Historical studies confirm that the disease diffused smoothly generating an epidemic front traveling as a continuous wave through the continent at an approximate velocity of 200-400 miles per year.

The SARS outbreak on the other hand was characterized by a patchy and heterogeneous spatio-temporal pattern mainly due to the air transportation network identified as the major channel of epidemic diffusion and ability to connect far apart regions in a short time period. The SARS maps are obtained with a data-driven stochastic computational model aimed at the study of the SARS epidemic pattern and analysis of the accuracy of the model's predictions. Simulation results describe a spatio-temporal evolution of the disease (color coded countries) in agreement with the historical data. Analysis on the robustness of the model's forecasts leads to the emergence and identification of epidemic pathways as the most probable routes of propagation of the disease. Only few preferential channels are selected (arrows; width indicates the probability of propagation along that path) out of the huge number of possible paths the infection could take by following the complex nature of airline connections (light grey, source: IATA).



## Forecasts OF THE Next Pandemic Influenza

### Seasonal



Forecasts are obtained with a stochastic computational model which explicitly incorporates data on worldwide air travel and detailed census data to simulate the global spread of an influenza pandemic.

The modeling approach considers infection dynamics (i.e., virus transmission, onset of symptoms, infectiousness, recovery, etc.) among individuals living in urban areas around the world, and assumes that individuals are allowed to travel from one city to another by means of the airline transportation network.

### Geographical

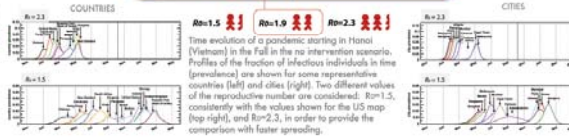
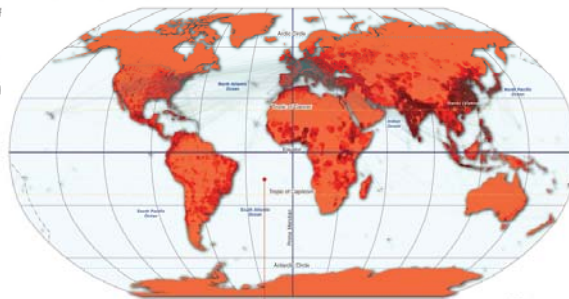


Numerical simulations provide results for the temporal and geographic evolution of the pandemic influenza in 3,100 urban areas located in 220 different countries. The model allows to study different spreading scenarios, characterized by different initial outbreak conditions, both geographical and seasonal.

The central map represents the cumulative number of cases in the world after the first year from the start of a pandemic influenza with  $R_0=1.9$  originating in Hanoi (Vietnam) in the Spring.



The US maps focus on the situation in the US after one year, and show the effect of changes in the original scenario analyzed. Different color coding is used for the sake of visualization.

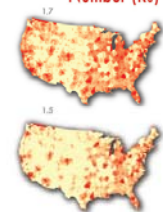


The model includes the worldwide air transportation network (source: IATA) composed of 3,100 airports in 220 countries and  $E=17,182$  direct connections, each of them associated to the corresponding passenger flow. This dataset accounts for 99% of the worldwide traffic and is complemented by the census data of each large metropolitan area served by the corresponding airport.

Additional spreading scenarios can be obtained by modeling different levels of infectiousness of the virus, as expressed in terms of the reproductive number  $R_0$ , representing the average number of infections generated by a sick person in a fully susceptible population.

Intervention strategies modeling the use of antiviral drugs can be considered. Two scenarios are compared: an uncooperative strategy in which countries only use their own stockpiles, and a cooperative intervention which envisions a limited worldwide sharing of the resources.

### Reproductive Number ( $R_0$ )



### Intervention



Can one forecast science?

What 'science forecast language' will work?



A map is a tool for navigating an unknown terrain. In the case of this map, **Science & Technology Outlook 2005–2055**, the terrain we're navigating is the uncharted territory of science and technology (S&T) in the next 50 years. However, the map of the future is not a tool for prediction or, for that matter, the product of prediction. Nor is it a navigation to modern navigation techniques in which we rely on a shrinking number of strong signals, like GPS coordinates, to show the right path. Rather, it's more akin to classical low-tech navigational techniques with their reliance on an array of weak signals such as wind direction, the look and feel of the water, and the shape of cloud formations. Taken together, these signals often prove more useful for navigation than high-tech methods because, in addition to aiding travelers in selecting the "right" path, the signals codetermine information and reveal interdependencies and connections between seemingly unrelated events, thus enriching our understanding of the landscape. That's precisely the mission of this map of the future of S&T—to give the reader a deeper contextual understanding of the landscape and to point to the intricacies and interdependencies between trends.

While developing the map, the **Method for the Future (MFF)** team listened for and connected a variety of weak signals, including those generated during interviews and workshop conversations involving more than 100 eminent U.K. and U.S. experts—academicians, policymakers, journalists, and corporate researchers. The MFF team also compiled a database of outcomes on environments that are likely to impact the full range of S&T disciplines and practice areas over the next 50 years. We also relied on IFTF's 40 years of experience in forecasting S&T developments to create the map and to accompany it with **S&T Perspectives** that discuss issues emerging on the S&T horizon and are important for organizations, policymakers, and society-at-large to understand.

In S&T, six themes are woven together across the 50-year horizon, often resulting in important breakthroughs. These are supported by key technologies, innovations, and disciplines. In addition to the themes, three meta-themes—democratized innovation, transdisciplinary, and emergence—will emerge by the future S&T landscape influencing how we think, learn about, and practice science. Finally, S&T trends won't operate in a vacuum. Wider social, demographic, political, economic, and environmental trends will both influence S&T trends and will be influenced by them. Some of these trends are highlighted around the map to remind us of the larger picture.

**MAP THEMES**

- Small Worlds**  
 After 20 years of basic research and development at the 100-nanometer scale, the importance of nanotechnology as a source of innovation and new capabilities in everything from materials science to medicine is already well-understood. Three trends, however, will define how nanotechnology will unfold, and what impact it will have. First, nanotechnology is not a single field with a coherent intellectual program; it's an opportunistic hybrid, shaped by a combination of fundamental research questions, promising technical applications, and venture and state capital. Second, nanotechnology is moving away from the original vision of small-scale mechanical engineering—which assembles built mechanical systems from individual atoms—toward one in which molecular biology and biochemistry contribute essential tools (such as proteins that build nanowires). Finally, nanotechnology will also serve as a model for transdisciplinary science. It will support both fundamental research and commercially oriented innovation, and it will be conducted not within the boundaries of conventional academic or corporate research departments, but in institutional and social milieus that emphasize heterogeneity.
- Intentional Biology**  
 For 3.5 billion years, evolution has generated biology on this planet. But today, Mother Nature has a collaborator: Ingenious tools to read and rewrite the genetic code of life will bolster our ability to manipulate biology from the bottom up. We'll not only genetically re-engineer existing life but actually create new life forms with purpose. Still, we will not be blind to what nature has to teach us. Evolution's elegant engineering at the smallest scales will be a rich source of inspiration as we build the bio-nanotechnology of the next 50 years.
- Extended Self**  
 In the next 50 years, we will be faced with broad opportunities to reshape our minds and bodies in profoundly different ways. Advances in biotechnology, brain-scientific, information technology, and robotics

- will result in an array of methods to dramatically alter, enhance, and extend the mental and physical hand that nature has dealt us. Weeding these tools on ourselves, humans will begin to define a variety of different "transhuman" paths—that is, ways of being and living that extend beyond what we today consider natural for our species. In the very long term, following these paths could someday lead to an evolutionary leap for humanity.
- Mathematical World**  
 The ability to process, manipulate, and ultimately understand patterns in enormous amounts of data will allow decoding of previously mysterious processes in everything from biological to social systems. Scientists are learning that at the core of many biological phenomena—reproduction, growth, repair, and others—are computational processes that can be abstracted and simulated. Using techniques of combinatorial science to uncover such patterns—whether these are physical, biological, or social—will likely occupy an increasing share of computing cycles in the next 50 years. Such massive computation will also make simulation widespread. Computer simulation will be used not only to help make decisions about large complex scientific and social problems, but also to help individuals make better choices in their daily lives.
- Sensory Transformation**  
 In the next ten years, physical objects, places, and even human beings themselves will increasingly become embedded with computational devices that can sense, understand, and act upon their environment. They will be able to exert a contextualized effect about the physical, social, and even emotional state of people and things in their surroundings. As a result, increasing demands will be placed on our visual, auditory, and other sensory abilities. Information previously encoded as text and numbers will be displayed in richer sensory forms—via graphics, pictures, patterns, sounds, smells, and tactile experiences. This enriched sensory environment will coincide with major breakthroughs in our understanding of the brain—on how we process sensory information and connect various sensory functions.

- Humans will become much more sophisticated in their ability to understand, create, and manage sensory information and ability to perform such tasks will become keys to success.
- Lightweight Infrastructure**  
 A confluence of new materials and distributed intelligence is pointing the way toward a new kind of infrastructure that will dramatically reshape the economics of moving people, goods, energy, and information. From the molecular level to the macroeconomic level, these new infrastructure designs will emphasize smaller, smarter, more independent components. These components will be organized into more efficient, more flexible, and more secure ways than the capital-intensive networks of the 20th century. These lightweight infrastructures have the potential to boost emerging economies, improve social connectivity, mitigate the environmental impacts of rapid global urbanization, and offer new future paths in energy.
- Meta-Themes**
  - Democratized Innovation**  
 Before the 20th century, many of the greatest scientific discoveries and technical inventions were made by amateur scientists and independent inventors. In the last 100 years, a professional class of scientists and engineers, supported by universities, industry, and the state, pushed amateurs aside as a creative force. At the national scale, the capital-intensive character of scientific research made world-class research the property of prosperous advanced nations. In the new century, a number of trends and technologies will lower the barriers to participation in science and technology again, both for individuals and for emerging countries. The result will be a renaissance of the serious amateurs, the growth of new scientific and technical centers of excellence in developing countries, and a more global distribution of world-class scientists and technologists.
  - Transdisciplinary**  
 In the last few centuries, natural philosophy and natural history fractured into the now-familiar disciplines of physics, chemistry, biology, and so on. The sciences evolved into their current form in response to intellectual and professional opportunities, philanthropic priorities, and economic and state needs. Through most of the 20th century, the growth of the sciences, and academic and career pressures, encouraged ever-greater specialization. In the coming decades, transdisciplinary research will become an imperative. According to Howard Rheingold, a prominent futurist and author, "transdisciplinary goes beyond bringing together researchers from different disciplines to work in multidisciplinary teams. It means educating researchers who can speak languages of multiple disciplines—biologists who have understanding of mathematics, mathematicians who understand biology."
  - Emergence**  
 The phenomenon of self-organizing swarms that generate complex behavior by following simple rules—will likely become an important research area, and an important model for understanding how the natural world works and how artificial worlds can be designed. Emergent phenomena have been observed across a variety of natural phenomena, from physics to biology to sociology. The concept has broad appeal due to the diversity of fields and problems to which it can be applied. It is growing useful for making sense of a very wide range of phenomena. Meanwhile, emergence can be modeled using relatively simple computational tools, although these models often require substantial processing power. More generally, it is a timely suggestion as a way of thinking about designing complex, robust technological systems. Finally, emergence is an accessible and vivid metaphor for understanding nature. Just as classical physics profited from popular treatments of Newtonian mechanics, so too will scientific study and technical reproductions of emergent phenomena likely draw benefits from the popularization of its underlying concepts.

**113 Years of Physical Review**

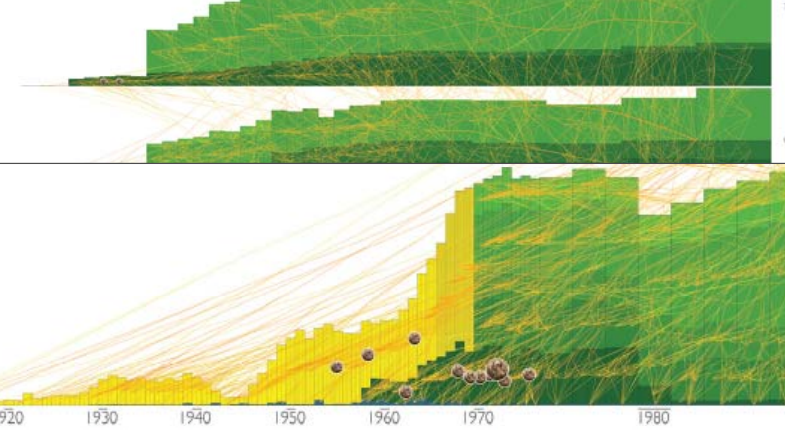
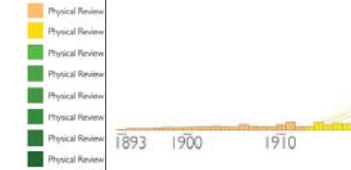
This visualization aggregates 38,899 articles published in 120 volumes of *Physical Review* between 1893 and 2013. The 120 volumes published from 1893 to 1973 are on the left, and the 100 volumes published from 1974 to 2013 are on the right. The visualization includes the *Physical Review Letters* and *Physical Review Special Topics* series, and the *Physical Review* journal series. The visualization includes the *Physical Review* journal series, and the *Physical Review Letters* and *Physical Review Special Topics* series. The visualization includes the *Physical Review* journal series, and the *Physical Review Letters* and *Physical Review Special Topics* series.



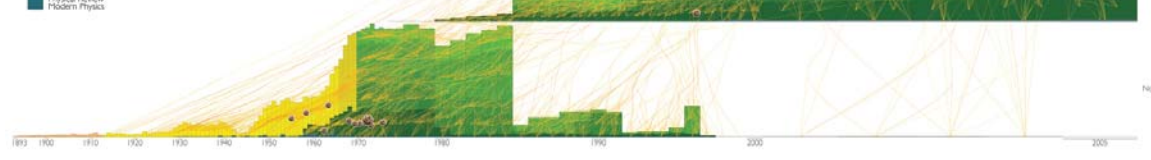
**Nobel Prizes in Physical Review**

- Year of Nobel Prize Winners (Publication Year) (Publication Year) (Publication Year)
- 2004 Ray J. Chua (1984), I. H. Hall, and Theodor W. Hänsch (1981)
- 2004 David J. Gross, H. David Politzer, and Frank Wilczek (1973)
- Thomson G. (1927) (1927) (1927)
- 2003 Raymond Davis Jr., Masatoshi Koshiba, and Riccardo Giacconi (1963, 1968, 1987)
- 2001 Eric A. Cornell, Wolfgang Ketterle, and Carl E. Wieman (1995, 1996)
- 1998 Robert B. Laughlin (1982, 1983)
- 1997 Steven Chu (1982, 1983)
- 1996 David H. Lee, C.
- 1993 Martin L. Perl (1993)
- 1994 Bertram N. Brockhouse (1994)
- 1990 Jerome I. Friedman (1990)

**Bar Graph**



IFTF's Condensed Matter-Electronic Structure, Electrical, Magnetic, and Optical Properties



# MAPS OF SCIENCE

## Forecasting Large Trends in Science

A visualization of 7.2 million scholarly documents  
appearing in over 16,000 journals, proceedings or symposia  
between Jan, 2001 and Dec, 2005

This map of science was constructed by sorting more than 16,000 journals into disciplines, disciplines, represented as circles, are sets of journals that cite a common literature. The links between disciplines are signs of disciplines that share a common literature. A three-dimensional model was used to determine the position of each discipline on the surface of a sphere based on the linkages between disciplines. The model treats links like rubber bands attempting to bring two disciplines close to each other. Pairs of disciplines without links tend to end up on different sides of the map.

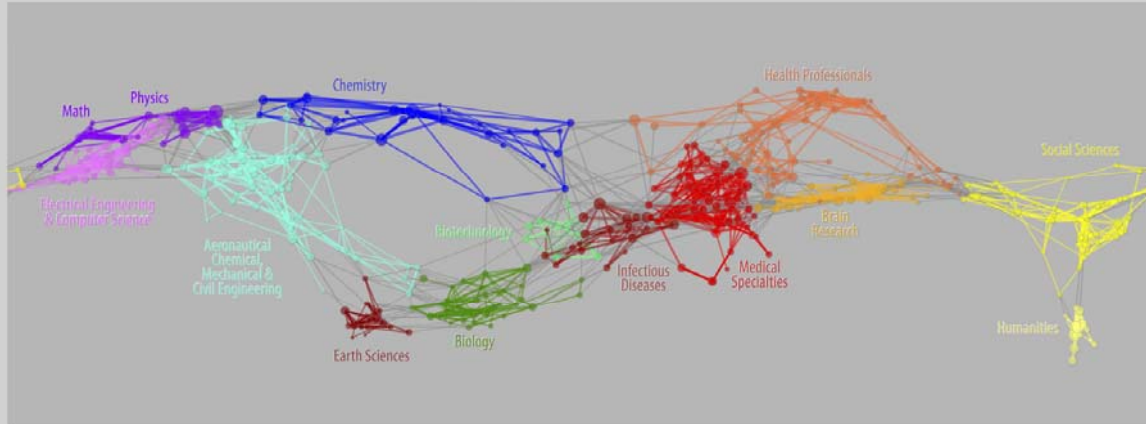
The spherical map, which is not shown here, was unfolded in a map projection (the same one used to show the continents of the earth on a two-dimensional map) to give the large map shown below. This projection allows inspection of the entire map of science at once. Note that the disciplines tend to group along the middle of the map - if this were a map of the earth it would be like a single continent extending along the equator. There are no disciplines at the top (north pole) or the bottom (south pole). Identical projections also introduce distortions. We tend to forget that the left side is connected to the right side, and assume that the middle is most important. In this map, the social sciences (yellow) on the right connect with the computer sciences (pink) on the left in one continuous swath.

The six map projections shown at the bottom are images of what one would see if looking directly down at the south pole of the map, at six different stations. When viewed this way, the map looks like a wheel with an inner ring and outer ring. This wheel of science corresponds very closely with the two-dimensional maps we have previously produced.

Calculations were performed using the large colored groupings of disciplines (fields) to determine a list of those with links to cause large scale change in the structure of science over time. Correlation coefficients between fields were calculated for each individual year, 2001-2005. A simple regression analysis was conducted to see if there were significant changes in these correlation coefficients from year to year.

If the structure of science shown below is moving toward stability, we would expect correlations between neighboring fields to increase, and correlations between distant fields to decrease. We found the opposite, suggesting that the underlying structure is unstable and likely to change dramatically over the next decade.

Six stars, representing how the structure is likely to change, are provided below. Maps with white arrows represent instances of distant fields that are likely to be pulled closer to each other in the future. Maps with dark arrows represent fields that are currently close but that are likely to become more distant. We expect that future maps of science will show changes in structure corresponding to these observations. Medicine will disperse slightly, while the physical sciences will tighten and draw closer to the medical fields.



**Medical Engineering & Computer Science (METS)** indicated by the pink shape above has the largest overall increase in connections with other fields (74%). It has relatively low connections with the fields of Health & Physical and Social Sciences fields, but these three connections had the largest fractional increase. The connections with METS are shown by white arrows. Over time, these stronger connections will draw the map, and may bring METS into a more central position.

**Brain Research**, indicated by the light green shape above, has the largest overall increase in connections with other fields (74%). It has relatively low connections with the fields of Health & Physical and Social Sciences fields, but these three connections had the largest fractional increase. The connections with Brain Research are shown by white arrows, and will draw a close dispersion of the medical field, compared to the current situation.

**Infectious Diseases**, indicated by the dark red shape above, has the largest overall increase in connections with other fields (74%). It has relatively low connections with the fields of Health & Physical and Social Sciences fields, but these three connections had the largest fractional increase. The connections with Infectious Diseases are shown by white arrows, and will draw a close dispersion of the medical field, compared to the current situation.

**Medical Specialties**, indicated by the red shape above, has the largest overall increase in connections with other fields (74%). It has relatively low connections with the fields of Health & Physical and Social Sciences fields, but these three connections had the largest fractional increase. The connections with Medical Specialties are shown by white arrows, and will draw a close dispersion of the medical field, compared to the current situation.

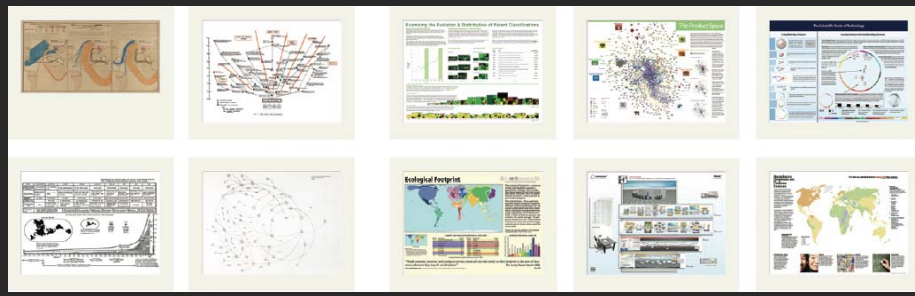
The **Health Professionals** field, indicated by the orange shape above, has the largest overall increase in connections with other fields (74%). It has relatively low connections with the fields of Health & Physical and Social Sciences fields, but these three connections had the largest fractional increase. The connections with Health Professionals are shown by white arrows, and will draw a close dispersion of the medical field, compared to the current situation.

The **Social Sciences**, indicated by the yellow shape above, had the largest overall increase in connections with other fields (74%). It has relatively low connections with the fields of Health & Physical and Social Sciences fields, but these three connections had the largest fractional increase. The connections with Social Sciences are shown by white arrows, and will draw a close dispersion of the medical field, compared to the current situation.

Source: University of Illinois, San Diego-University Mapping Laboratory, California; © Regents of the University of California. The gathering data came from the source: Thomson ISI and Inspec. Mapping technology and design from: Data Systems, Inc., and Steve Brack, San Diego National Laboratory. Copyright © Copyright © Data Systems, Inc. and Steve Brack. All rights reserved. © 2007 by Data Systems, Inc. All rights reserved.

# Science Maps for Economic Decision Making

Four Existing Maps  
VERSUS  
Six Science Maps



(4<sup>th</sup> Iteration of Places & Spaces Exhibit - 2008)



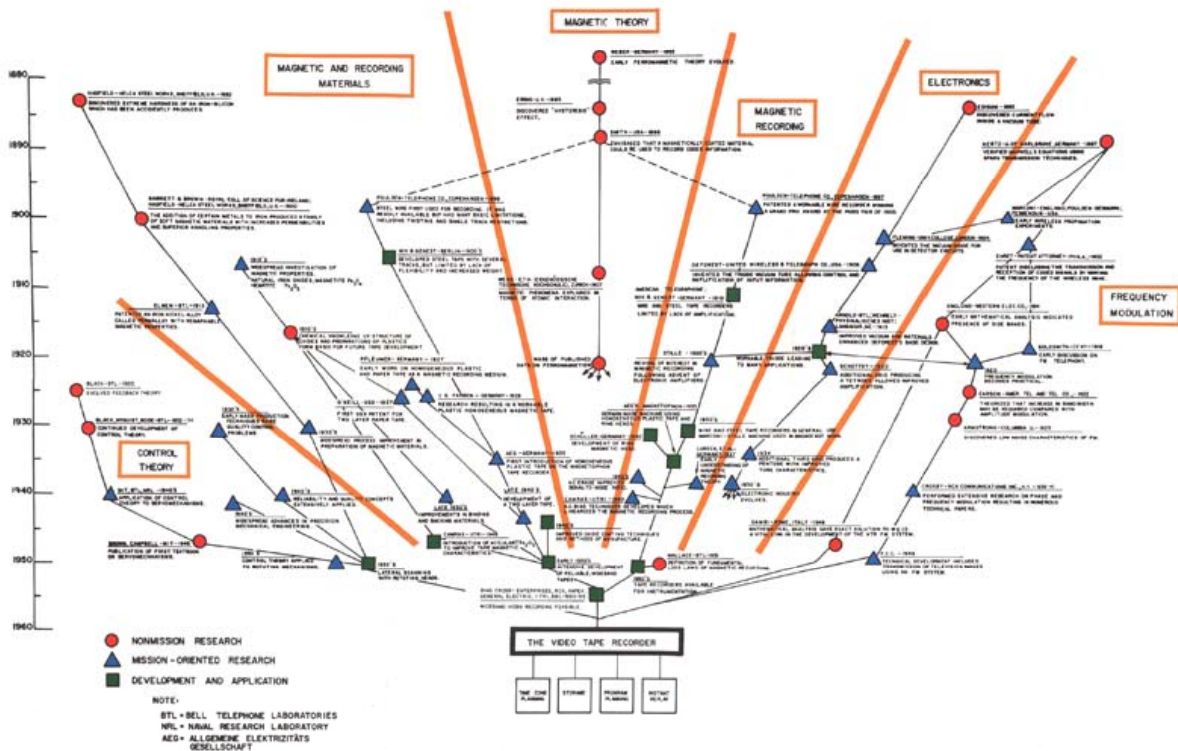
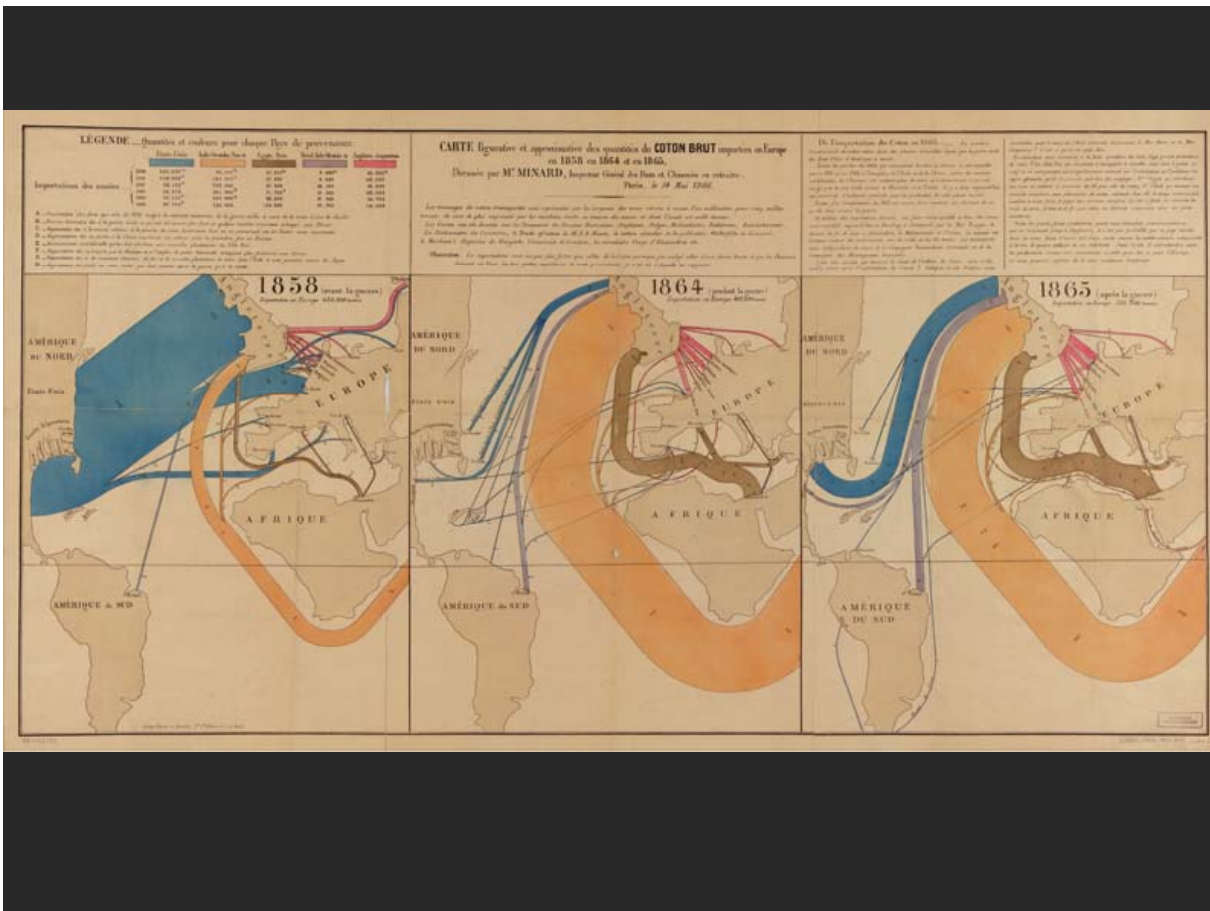
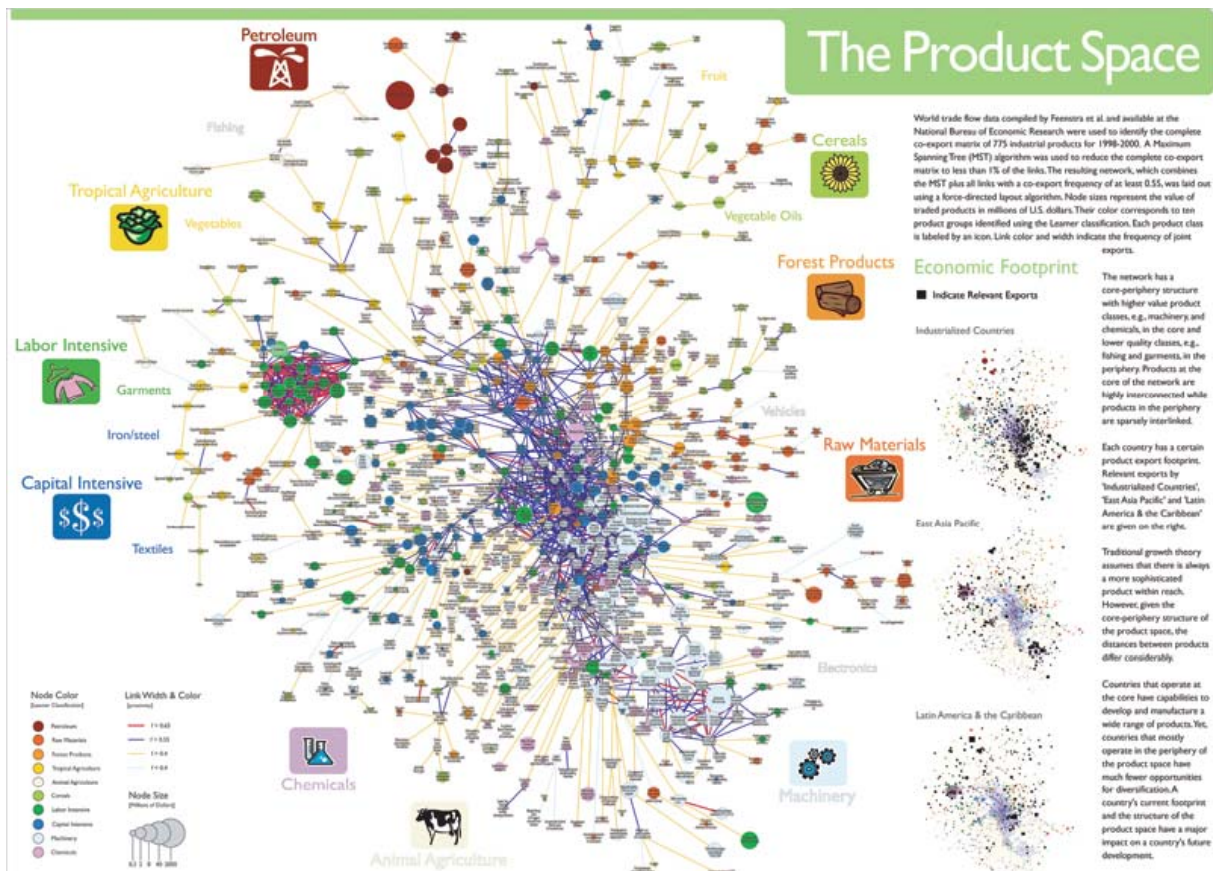


FIG. 7. THE VIDEO TAPE RECORDER

What insight needs to economic decision makers have?

What data views are most useful?



# Happiness Depends on Various Factors

Social scientists are starting to include relative happiness with hard data on economic status, health, and other factors as they assess quality of life. They rely on surveys of "subjective well-being"—how good people feel about their lives. A world map of one "happiness index" shows many, but not all, wealthy northern countries faring well. Residents of sub-Saharan Africa and the former Soviet Union, meanwhile, report particularly low levels of contentment.

Any attempt to measure happiness will fall short—each life is a series of joys, struggles, and sorrows, and satisfaction can depend as much on outlook as on circumstances. Averages obscure the happy moments in struggling nations, as well as people who suffer from poor health, poverty, or discrimination in countries that rank high. Still, happiness indices can help researchers move beyond simple economics as they track progress—or backsliding—over time.

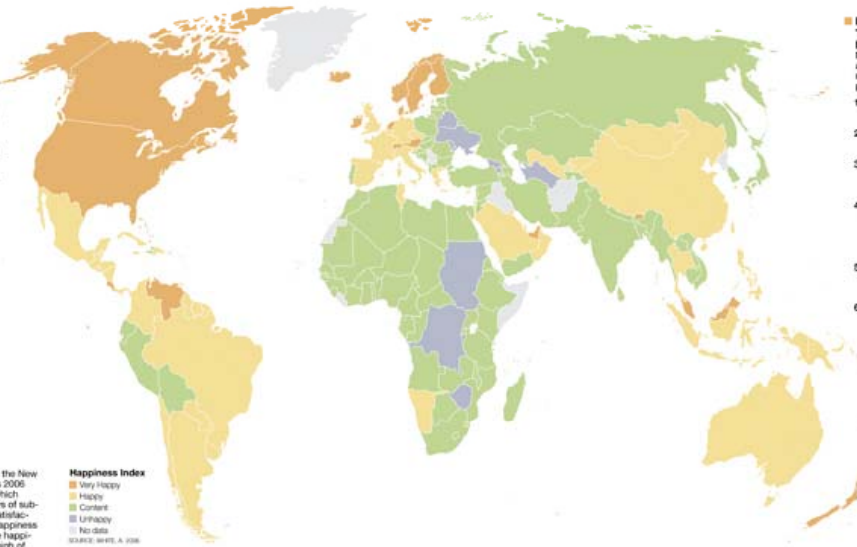
## MEASURING THE INTANGIBLE

The map is derived from the New Economics Foundation's 2006 "Happy Planet Index," which drew on over 100 surveys of subjective well-being. Its "satisfaction with life scale"—a happiness index—ranks the relative happiness of nations, from a high of 273 (Denmark and Switzerland) to a low of 100 (Burundi).

## Happiness Index

- Very happy
- Happy
- Content
- Unhappy
- No data

SOURCE: WIRE, A 2006



## RANKING THE WORLD'S HAPPIEST PLACES

Northern Europe, North America, and several wealthy countries make the list, but so do many less prosperous island nations.

- 1 DENMARK SWITZERLAND
- 2 AUSTRIA ICELAND
- 3 BAHAMAS FINLAND SWEDEN
- 4 BHUTAN BRUNEI CANADA IRELAND LUXEMBOURG
- 5 COSTA RICA MALTA NETHERLANDS
- 6 ANTIGUA AND BARBUDA MALAYSIA NEW ZEALAND NORWAY SEYCHELLES ST. KITTS AND NEVIS UNITED ARAB EMIRATES UNITED STATES VANUATU VENEZUELA

## DEFINING WELL-BEING

By comparing the happiness index to data from the UN, the CIA, and other sources, a U.K. psychologist determined that good health and health care, enough money for fundamental needs, and access to basic education are the most important factors for subjective well-being. European countries top all three measures.



## HEALTH

Japan boasts the world's longest life expectancy—one measure of overall health. Swaziland, at the other end of the scale, is plagued by poverty, disease, and violence. Disparities in access to health care divide many countries into haves and have-nots.



## WEALTH

Money still can't buy love, or happiness, and wealthier people aren't always more content. Still, tiny Luxembourg, which takes top rank in per capita Gross Domestic Product (GDP), also rates a 253 on the happiness index. Real poverty means real misery, a fate shared by billions.



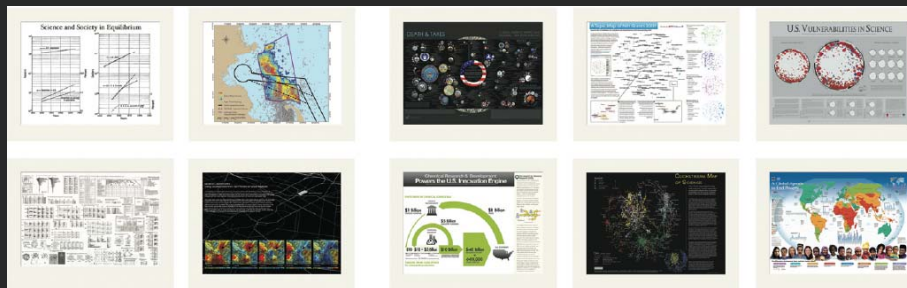
## EDUCATION

Residents of Australia can expect to spend more time in school—an average of almost 21 years—than citizens of any other country. But only a basic education is needed to see a significant jump in overall happiness. Around the world, hundreds of millions lack even that.

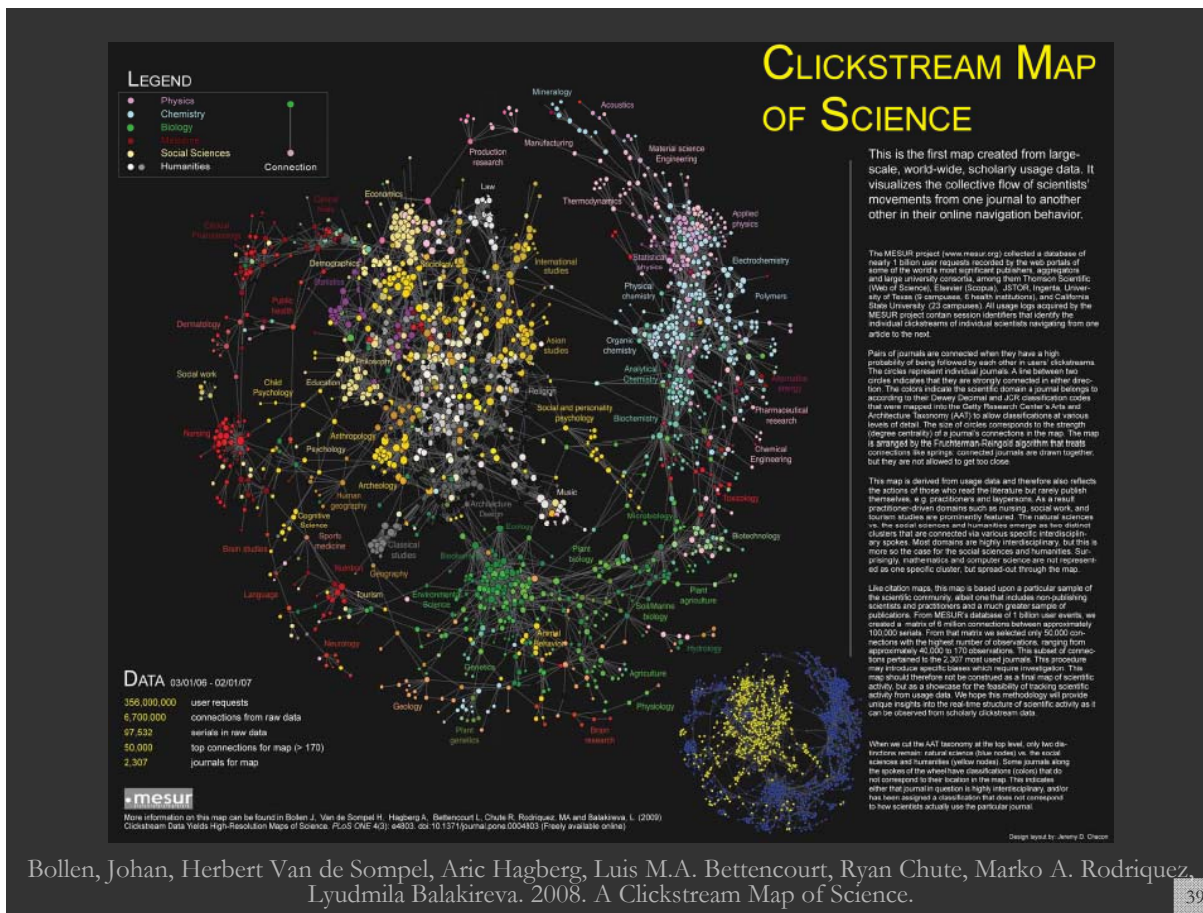
Photo: Robert Huxley/Corbis; Getty Images/Corbis

# Science Maps for Science Policy Making

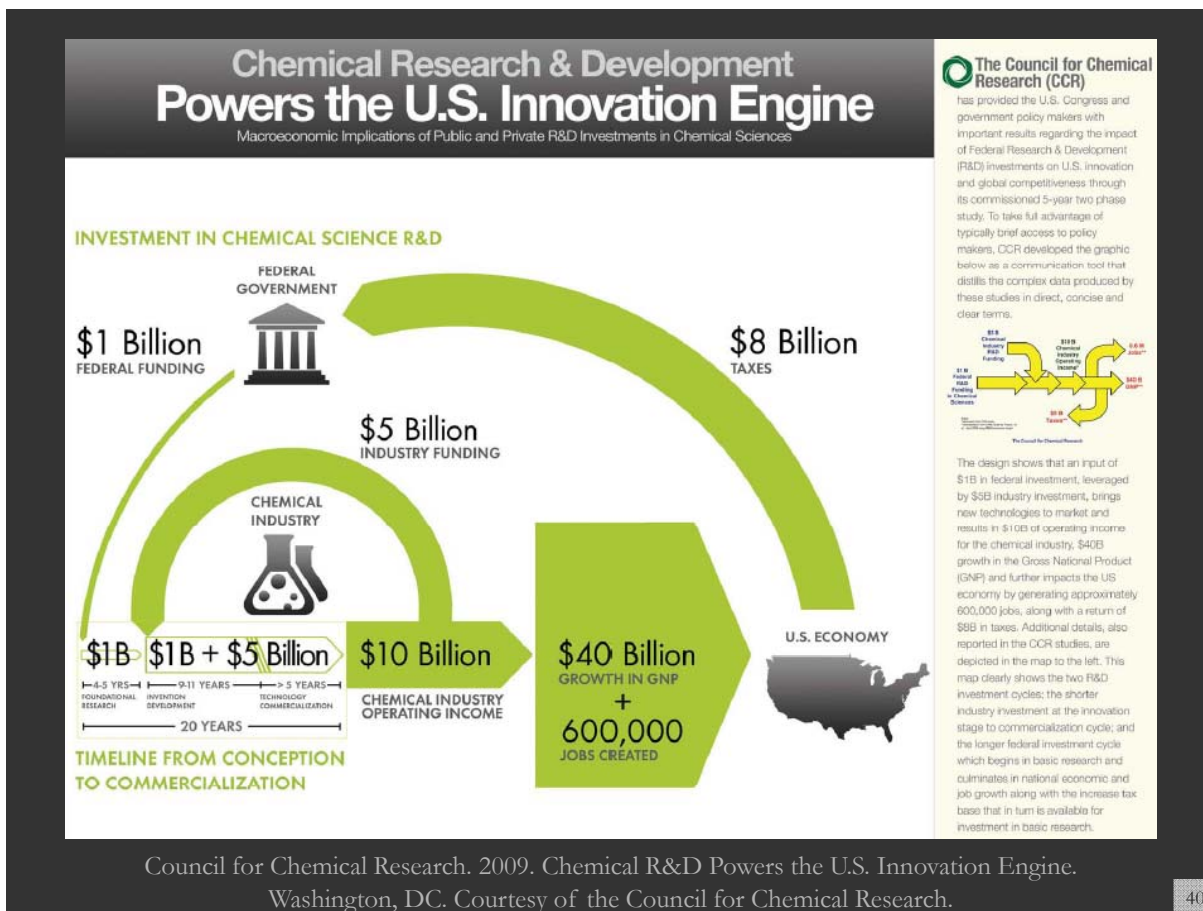
Four Existing Maps  
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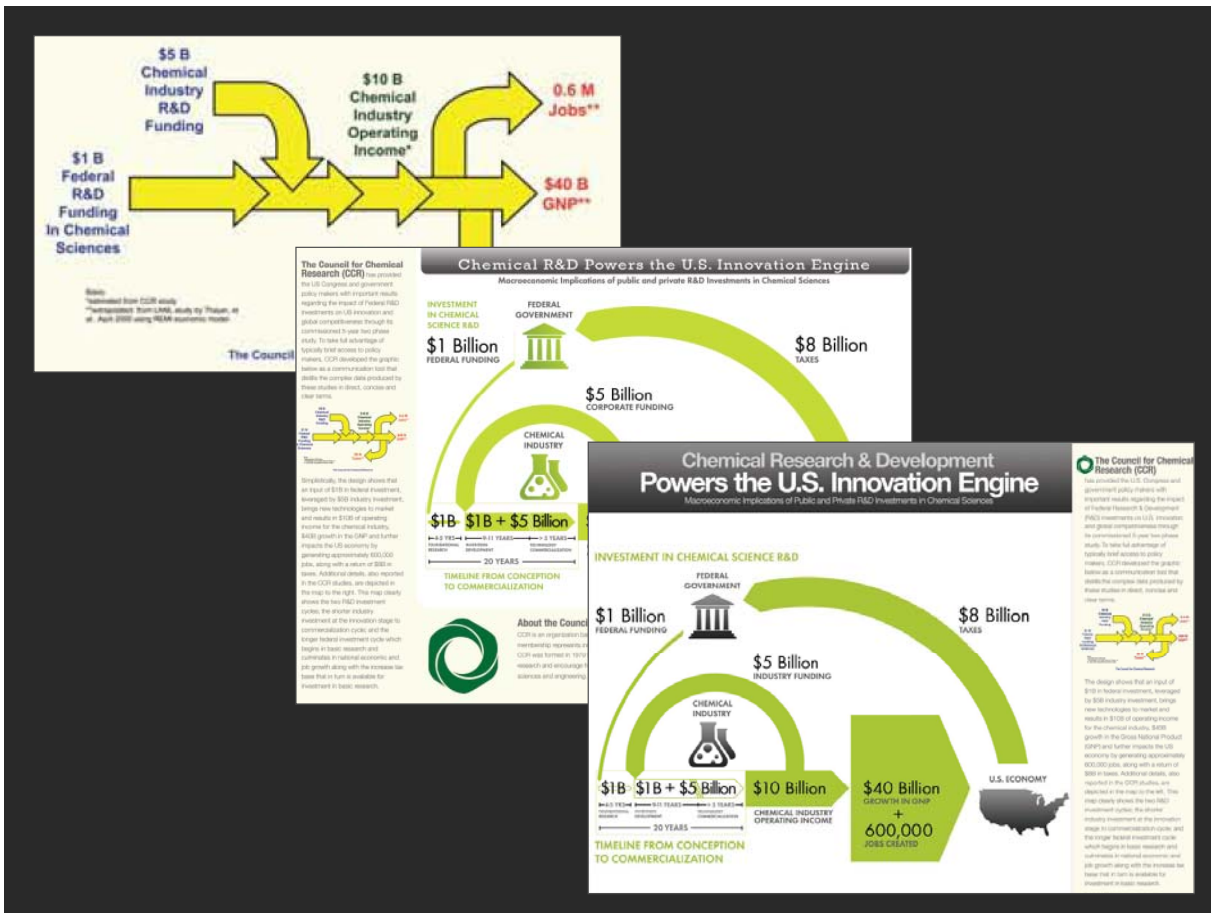


(5<sup>th</sup> Iteration of Places & Spaces Exhibit - 2009)



Bollen, Johan, Herbert Van de Sompel, Aric Hagberg, Luis M.A. Bettencourt, Ryan Chute, Marko A. Rodriguez, Lyudmila Balakireva. 2008. A Clickstream Map of Science. 39





# Additional Elements of the Exhibit

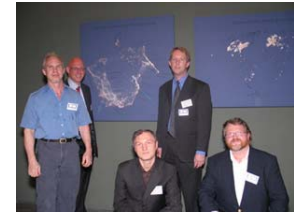
Illuminated Diagram Display

Hands-on Science Maps for Kids

Worldprocessor Globes

# Illuminated Diagram Display

W. Bradford Paley, Kevin W. Boyack, Richard Kavvas, and Katy Börner (2007)  
*Mapping, Illuminating, and Interacting with Science. SIGGRAPH 2007.*



Large-scale, high resolution prints illuminated via projector or screen.

## Questions:

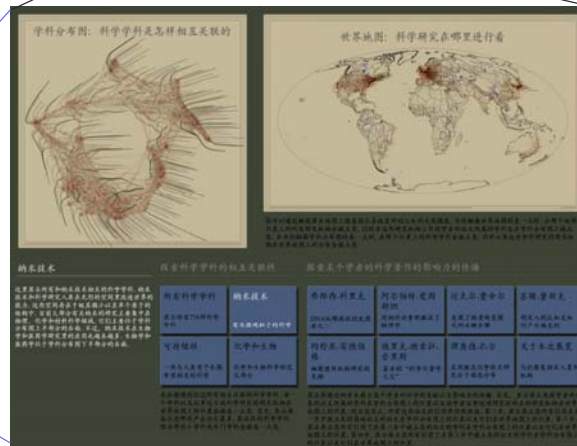
- Who is doing research on what topic and where?
- What is the 'footprint' of interdisciplinary research fields?
- What impact have scientists?

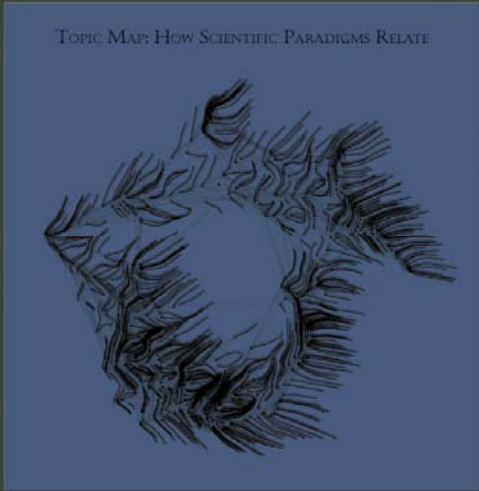


Interactive touch panel.


## Contributions:

- Interactive, high resolution interface to access and make sense of data about scholarly activity.





TOPIC MAP: HOW SCIENTIFIC PARADIGMS RELATE



GEOGRAPHIC MAP: WHERE SCIENCE GETS DONE

You may run your finger over each of these maps to control the lighting on the other: touching a place on the world map will light up topics studied in that place; touching a paradigm on the topic map will light up the places that study that topic.

**Nanotechnology**

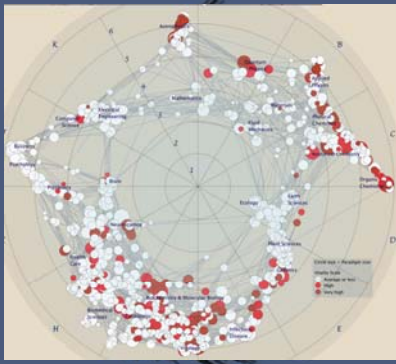
This overlay shows the distribution of nanotechnology within the paradigms of science. The majority of current work in nanotechnology takes place in physics, chemistry, and materials science, at the upper right portion of the map. However, an increasing amount of nanotechnology is being applied in the biological and medical sciences, at the lower right.

<b>All Topics</b>	<b>Nanotechnology</b>	<b>Francis H. C. CRICK</b>	<b>Albert EINSTEIN</b>	<b>Michael E. FISHER</b>	<b>Susan T. FISKE</b>
<i>Sweep through all 376 scientific paradigms</i>	<i>Science on the tiny scale of molecules</i>	<i>Co-discovered DNA's double helix</i>	<i>Revitalized physics with Relativity theories</i>	<i>Models critical phase transitions of matter</i>	<i>Connects perception and stereotypes</i>
<b>Sustainability</b>	<b>Biology &amp; Chemistry</b>	<b>Joshua LEDERBERG</b>	<b>Derek J. de Solla PRICE</b>	<b>Richard N. ZARE</b>	<b>About this display</b>
<i>The science behind our long-term hopes</i>	<i>The interface between these two vital fields</i>	<i>Pioneer in bacterial genetic mechanisms</i>	<i>Known as the "Father of Scientometrics"</i>	<i>Uses laser chemistry in molecular dynamics</i>	<i>People &amp; organizations that helped create it</i>

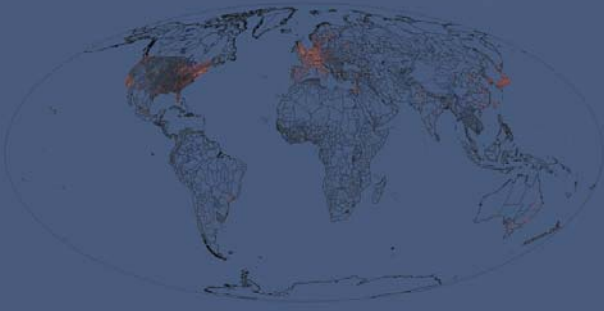
We sweep slowly through adjoining related topics, lighting up the places in the world that study each topic. You may select a subset of the topics that deal with these three interesting subjects by touching it.

A single person's spreading influence is shown as a series of four snapshots. First, we light only topics and places relating to that person's papers—papers that are still highly cited today. The second lights everything that cites that original work. Note that this first-generation impact extends to far more topics than did the original work. The third snapshot lights science that cites the second, and the fourth lights science that cites the third.

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All Topics

Sweep through all 376 scientific paradigms

Nanotechnology

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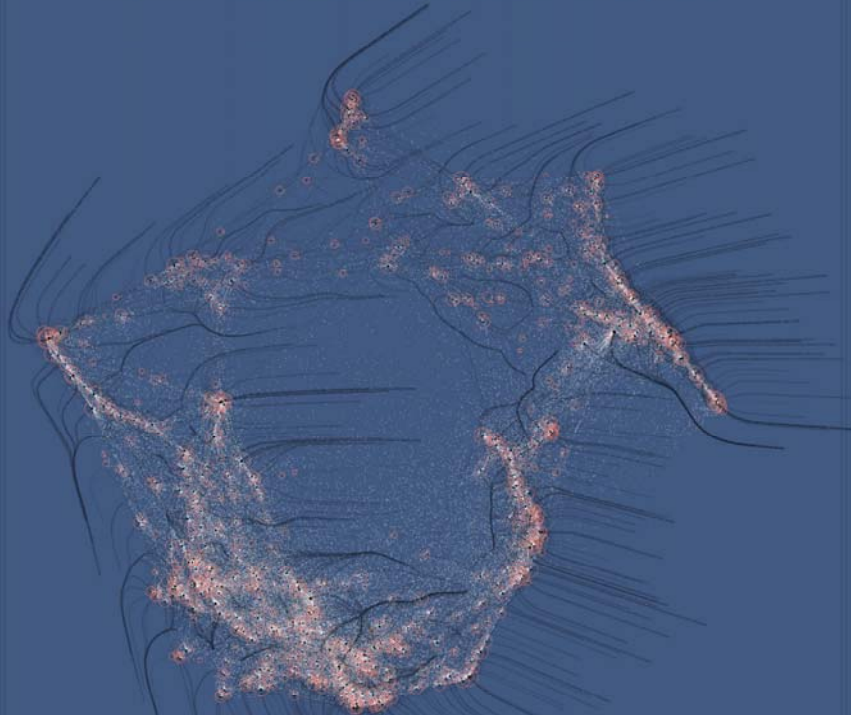
About this display

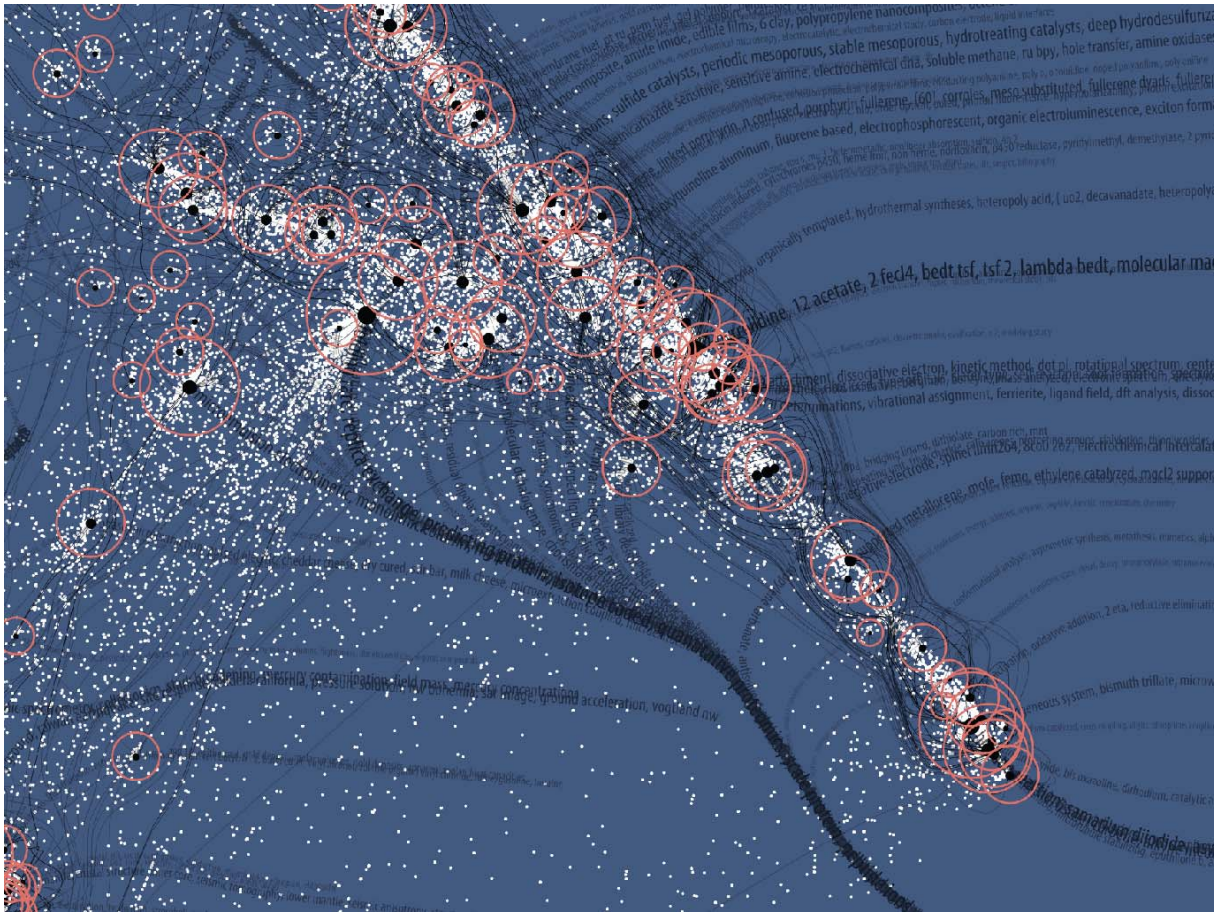
People & organizations that helped create it

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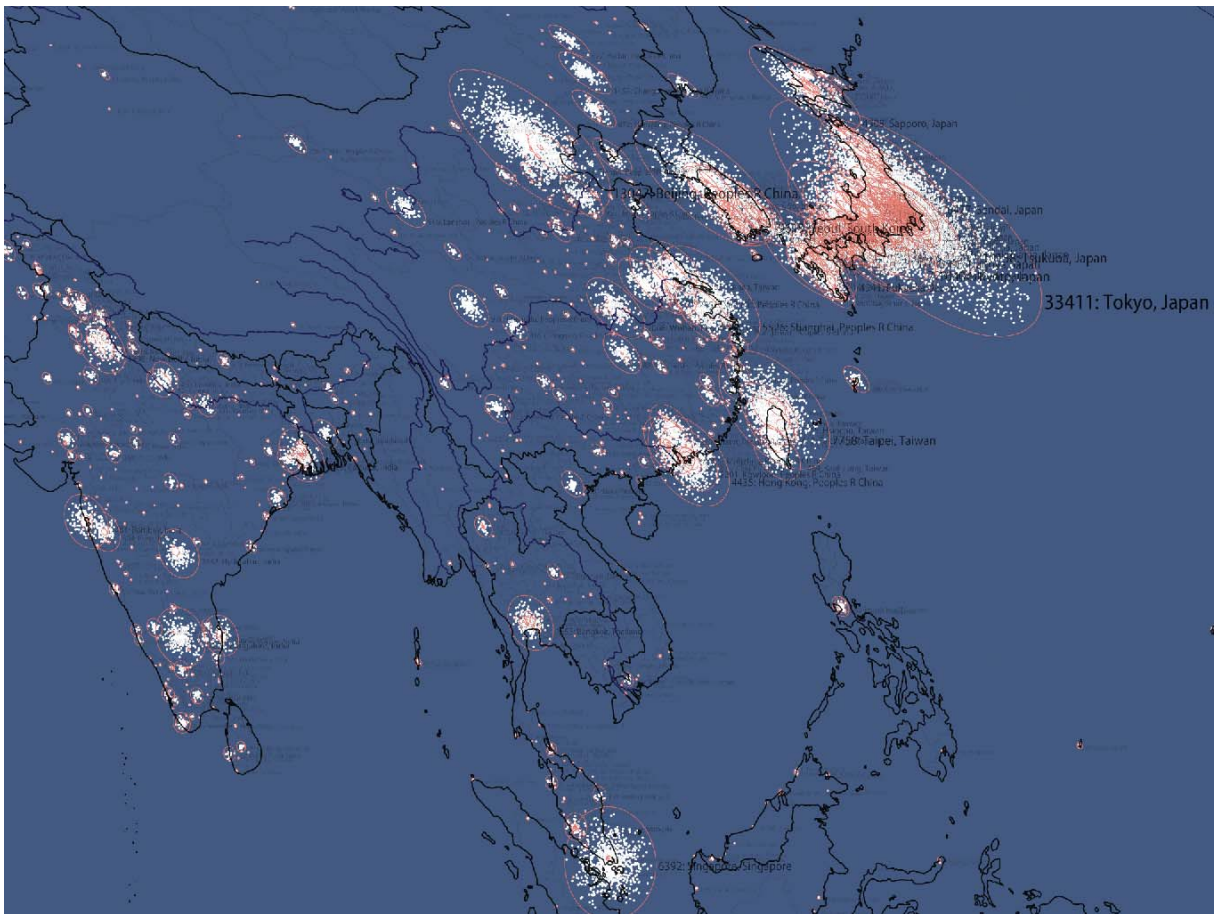
TOPIC MAP: HOW SCIENTIFIC PARADIGMS RELATE



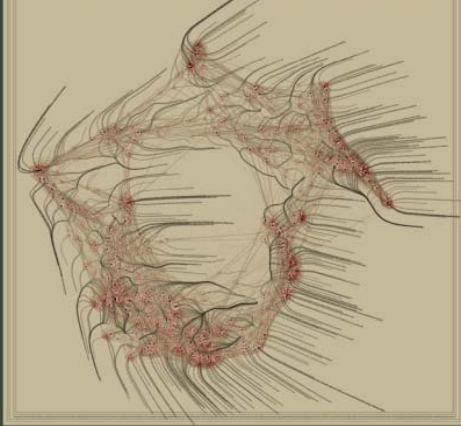




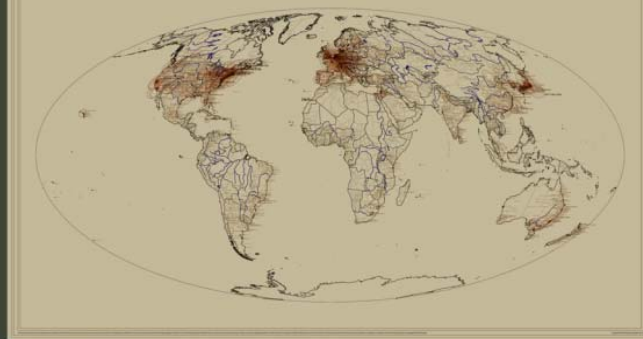




学科分布图：科学学科是怎样相互关联的



世界地图：科学研究在哪里进行着



你可以通过触摸屏在地图上随意指点来改变所到之处的亮度强度。当你触摸世界地图的某一点时，在那个地理位置上的所有研究机构会被点亮。同时在这些研究机构工作的学者的论文所属的学科会在学科分布图上被点亮，而当你触摸学科分布图的某一点时，在那个位置上的科学学科会被点亮，同时从事这些学科研究的研究机构在世界地图上的分布会被点亮。

### 纳米技术

这里显示所有和纳米技术相关的科学学科。纳米技术和科学研究人类在无形的空间里改造世界的的能力。这些空间存在于极其微小以至单个原子的结构中。目前大部分有关纳米的研究主要集中在物理、化学和材料科学领域。它们主要位于学科分布图上半部分的右面。不过，纳米技术在生物学和医药学研究里的应用也越来越多。生物学和医药学位于学科分布图下半部分的右面。



### 探索科学学科的相互关联性

#### 所有科学学科

显示所有776种科学学科

#### 可持续性

一些与人类寄予长期希望相关的科学

#### 纳米技术

有关微观粒子的科学

#### 化学和生物

化学和生物科学的交叉部分

### 探索某个学者的科学著作的影响力的传播

#### 弗郎西·科里克

DNA双螺旋结构的发现者之一

#### 约舒亚·雷德伯格

细菌遗传机制研究先驱

#### 阿尔伯特·爱因斯坦

用相对论重新激活了物理学

#### 德里克·德索拉·普里斯

著名的“科学计量学之父”

#### 迈克尔·费舍尔

发现了物质转变模式的关键步骤

#### 理查德·扎尔

采用激光化学技术研究分子动态分布

#### 苏珊·费斯克

研究人的认知是如何产生偏见的

#### 关于本次展览

与此次展览相关人员和机构

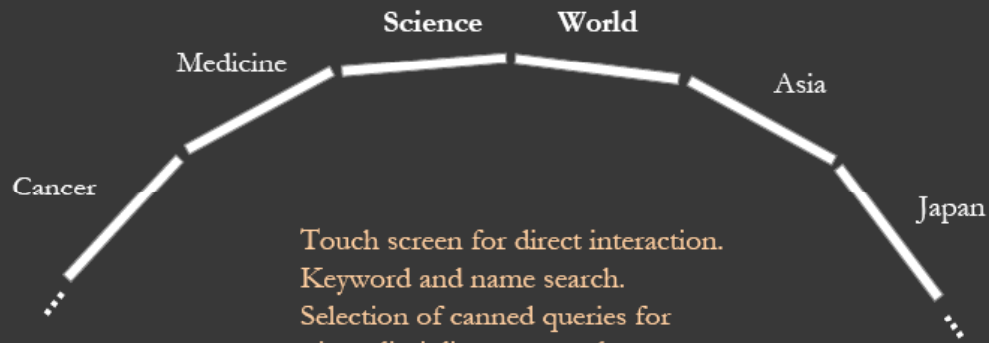
光标缓慢的扫过所有相互关联的科学学科，每一个学科以及从事这方面科学研究的研究机构在世界地图上的位置会被逐一点亮。首先，显示屏会点亮那些产出论文最多、最活跃的科学学科，然后那些小学科或冷门学科会被逐一点亮。

显示屏通过四步来展示某个学者对科学的贡献以及影响力的传播。首先，显示屏点亮该学者所发表的论文所属的学科在学科分布图上的位置以及该学者从事这项研究时所在的研究机构在世界地图上的位置。到目前为止，所有这些论文的引用率仍然很高。第二步，显示屏点亮所有引用在第一步中被点亮的原始论文的论文在学科分布图上的位置以及它们在世界地图上的位置。第三步，显示屏点亮所有引用了在第二步中被点亮的论文的论文在学科分布图上的位置以及它们在世界地图上的位置。第四步，显示屏点亮所有引用了在第三步中被点亮的论文的学科在学科分布图上的位置以及它们在世界地图上的位置。

## Re-implementation of Illuminated Diagram Software

by *Advanced Visualization Lab, Indiana University*

Drives unlimited number of ID screens.



Touch screen for direct interaction.

Keyword and name search.

Selection of canned queries for

- interdisciplinary research areas
- famous people
- activity patterns, e.g., bursts, trends, etc.



## Hands-on Science Maps for Kids



All maps of science are on sale via

<http://scimaps.org/ordermaps/>

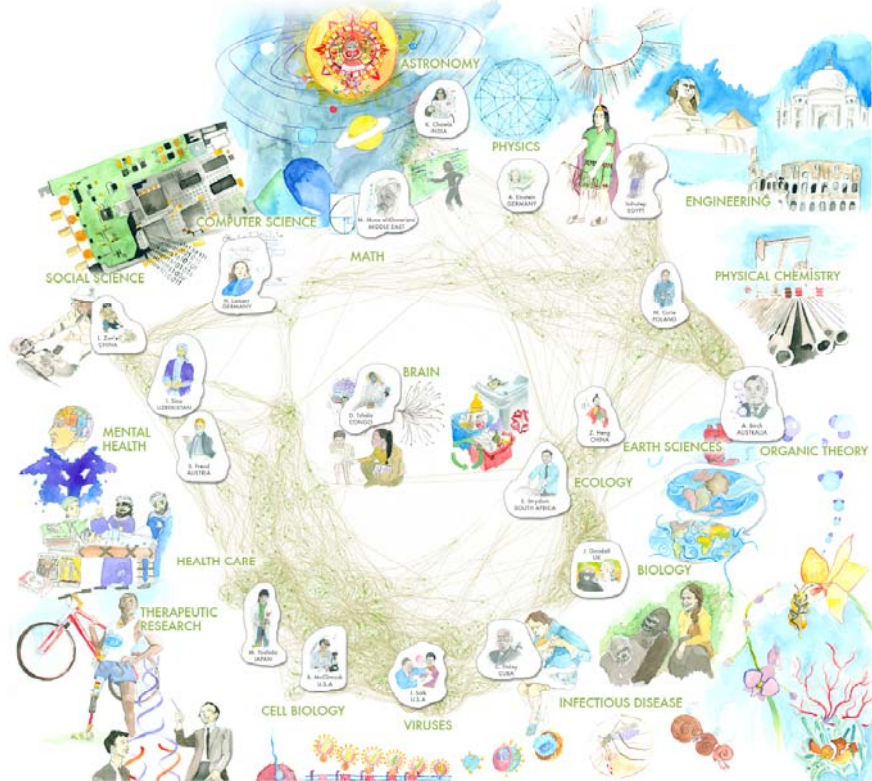


# Inventors & Inventions



Hands-On Science Maps for Kids, by *Flora Palmer* (Paintings), *Julie Smith* (Data Acquisition), *Elisha Hardy* and *Katy Blomer* (Graphic Design), BEDDINGTON, IN, 2006. Courtesy of Indiana University. Learn more at [www.scispace.org](http://www.scispace.org). This map plots the locations of where scientific papers were published: each light green dot represents 10 or fewer papers; they are scattered around the exact location for visibility, within a labelled green circle whose size is proportional to the number of papers published in that place. The base map is part of an "illumination diagram" display which used a computer and two projectors, projecting spots of light on the screen to highlight different kinds of scientific research (see a video map of scientific paradigms) and the areas in the world where each category of research was published. *Flora Palmer* (Paintings), *Julie Smith* (Data Acquisition), *Elisha Hardy* and *Katy Blomer* (Graphic Design), BEDDINGTON, IN, 2006. Courtesy of Indiana University. Learn more at [www.scispace.org](http://www.scispace.org).

# Inventors



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# Inventors



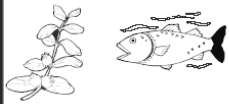
Hands-On Science Maps for Kids, by Filipe Palmer (Painting), Julia Smith (Data Acquisition), Eksha Hardy and Kitty Elmer (Graphic Design), BLOOMINGTON, IN, 2006. Courtesy of Indiana University. Learn more at [www.scmmaps.org](http://www.scmmaps.org). This map plots the locations of where scientific papers were published; each light green dot represents 10 or fewer papers; they are scattered around the exact location for visibility, within a labeled green circle whose size is proportional to the number of papers published in that place. The base map is part of an "illuminated diagram" display which used a computer and two projectors, projecting spots of light on the panel to highlight different kinds of scientific research on a sliding map of scientific paradigms and the areas in the world where such science was performed. Base map: research by Kevin Baksh and Dik Kikstra, cartography by John Deacon, data from Thompson ISI graphics and typography by its Bradford Philp. Copyright © 2006 by Bradford Philp, all rights reserved.





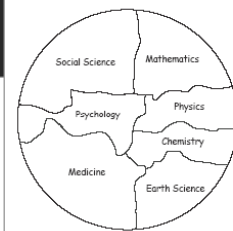
### My Science Story

By \_\_\_\_\_



For more information about the map of science for kids or this exercise, please contact Katy Borvon (katy@indiana.edu) or Nikki Roberg (nroberg@indiana.edu) at the School of Library and Information Science, Indiana University. These materials were compiled by Nikki Roberg in 2006.

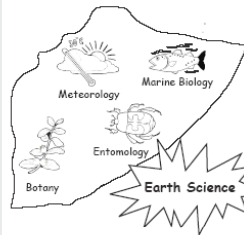
There are seven main fields of science. They are...



social science, mathematics, physics, chemistry, earth science, medicine, and psychology. I like to study earth science.

Color earth science green.

Earth scientists study the weather, plants and trees, marine life, insects, and much more.

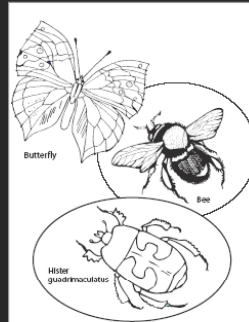


I like insects. They are interesting to look at and study.

Color in the insect.

#### Activities:

- Solve the puzzle.
- Navigate to 'Earth Science'.
- Identify major inventions.
- Place major inventors.
- Find your dream job on the map.
- Why is mathematics important?



There are many types of insects in the world. Bees, butterflies, and beetles are just a few.



I want to be an entomologist when I grow up. Then I can study insects all the time.

## What is Science? KIDS DRAWING CONTEST

#### WHAT

What is Science? Who does Science? What is Science to you? Design a picture of your favorite scientist or science experiment and tell us about it!

#### WHEN

October 1st - 30th: Submit entries  
November 5th: Winners notified  
November 5th - 30th: Winning entries and Top 50 on display at the American Museum of Science and Energy.

#### Judging Criteria

- 25% Appropriateness of contest theme
- 25% Creativity and quality of drawing
- 25% Originality of the story
- 25% Sensitivity of drawing and story

#### Requirements

Kids ages 4-15 are invited to submit their hand-drawn illustrations on 8.5 x 11 paper with a typed story of 25-100 words explaining their drawing and discussing their favorite scientist or experiment.

### PRIZES

1 year family membership & Science Kit from AMSE

Science Kit from the AMSE Discovery Shop

Science Book from the AMSE Discovery Shop

Bring in your contest submission and get into AMSE for FREE

#### Consent

Required: Parental signature granting consent for child to enter contest and agreement that the submitted material will not be returned and will become the property of the Places & Spaces-Museum Science exhibit.

#### Submitting

Mail submissions to: The American Museum of Science and Energy, 600 S. Tulane Ave., Oak Ridge, TN 37830. You may also bring in your submission to The American Museum of Science and Energy.

QUESTIONS? Ask Kim Poyes (kimpoyes@amse.org) | Phone 865-574-9584

Please attach this form to the back of submission



Artist's Name \_\_\_\_\_ Age \_\_\_\_\_ Parent's Name \_\_\_\_\_ Phone Number \_\_\_\_\_

## My Favorite Scientist



Observe  
Discover  
Understand  
Learn  
Simplify  
Explore  
Hypothesize  
Experiment  
Win or Learn

### Winners @ AMSE

JoHanna Sanders, age 12, a picture of someone enjoying nature and a theme that science is all around us.

Sascha Richey, age 8, drew a picture of her mother and explained why her mother is her favorite scientist.

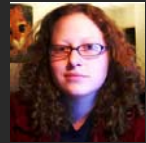


# Where to go from here?



Contact the map makers via the exhibit curators:

Katy Börner ([katy@indiana.edu](mailto:katy@indiana.edu)) and Elisba Hardy ([elhardy@indiana.edu](mailto:elhardy@indiana.edu))



## Computational Scientometrics References

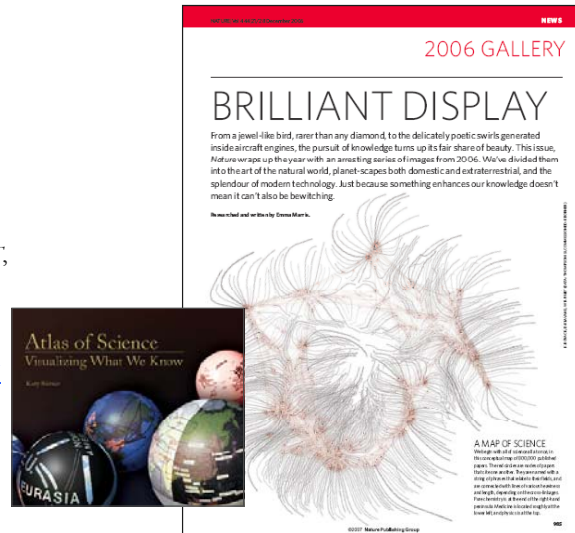
Börner, Katy, Chen, Chaomei, and Boyack, Kevin. (2003). **Visualizing Knowledge Domains**. In Blaise Cronin (Ed.), *ARIST*, Medford, NJ: Information Today, Inc./American Society for Information Science and Technology, Volume 37, Chapter 5, pp. 179-255.  
<http://ivl.slis.indiana.edu/km/pub/2003-borner-arist.pdf>



Shiffrin, Richard M. and Börner, Katy (Eds.) (2004). **Mapping Knowledge Domains**. *Proceedings of the National Academy of Sciences of the United States of America*, 101(Suppl\_1).  
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Börner, Katy, Sanyal, Soma and Vespignani, Alessandro (2007). **Network Science**. In Blaise Cronin (Ed.), *ARIST*, Information Today, Inc./American Society for Information Science and Technology, Medford, NJ, Volume 41, Chapter 12, pp. 537-607.  
<http://ivl.slis.indiana.edu/km/pub/2007-borner-arist.pdf>

Börner, Katy (2010) *Atlas of Science*. MIT Press.  
<http://scimaps.org/atlas>



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## CI for a Science of Science Studies

 **Scholarly Database: 23 million scholarly records**  
<http://sdb.slis.indiana.edu>

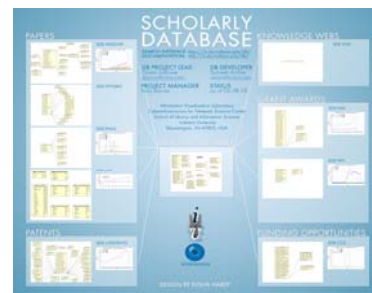


 **Information Visualization Cyberinfrastructure**  
<http://iv.slis.indiana.edu>

 **Network Workbench Tool + Community Wiki**  
<http://nwb.slis.indiana.edu>

 **Sci<sup>2</sup> Tool and Science of Science CI Portal**  
<http://sci.slis.indiana.edu>

 **Epidemics Cyberinfrastructure**  
<http://epic.slis.indiana.edu/>



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## Science of Science Cyberinfrastructure — P O R T A L —

Provided by the [Cyberinfrastructure for Network Science Center](#) at Indiana University.




**Introduction**  
E. O. Wilson writes in *Consilience: The Unity of Knowledge* (1998): "Features that distinguish science from pseudoscience are repeatability, economy, mensuration, heuristics, and consilience." Please see Börner's [recent presentation](#) at the *A Deeper Look at the Visualization of Scientific Discovery* NSF Workshop for a general introduction of the needs and the resources provided here.




**Needs Analysis**  
As part of the "TLS: Towards a Macroscope for Science Policy Decision Making" NSF SBE-0738111 award, interviews with science policy makers are conducted to identify what science of science research results and tools might be most desirable and effective. So far, 20 formal, one-hour interviews have been conducted with science policy makers at university campus level, program officer level, and division director level for governmental, state, and private foundations. Data compilation will start in October 2008 and resulting report can be ordered by sending a request to Mark Price ([maaprice@indiana.edu](mailto:maaprice@indiana.edu)).



**Conceptualization of Science**  
A 'science of science' requires a theoretically grounded and practically useful conceptualization of the structure and evolution of science. A special journal issue entitled "[Science of Science: Conceptualizations and Models of Science](#)" edited by [Katy Börner](#), Indiana University & [Andrea Scharnhorst](#), Royal Netherlands Academy of Arts and Sciences invites contributions on this topic. It will be published in the *Journal of Informetrics* 3(1) in January 2009.



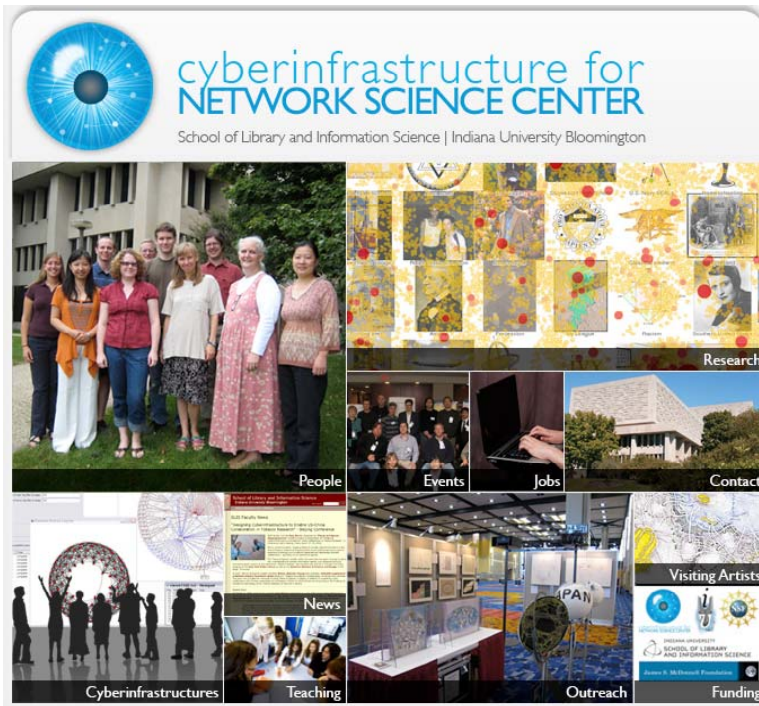
**Scholarly Database**  
The [Scholarly Database \(SDB\)](#) at Indiana University aims to serve researchers and practitioners interested in the analysis, modeling, and visualization of large-scale scholarly datasets. The database currently provides access to over 20 million papers, patents and grants. Resulting datasets can be downloaded in bulk. Register for free access at <https://sdb.slis.indiana.edu/>.



**Cyberinfrastructures**  
The Scientometrics filling of the [Network Workbench \(NWB\) Tool](#) provides a unique distributed, shared resources environment for large-scale network analysis, modeling, and visualization. Thomson Scientific/ISI, Scopus and Google Scholar data, EndNote and Bibtext files, or NSF awards can be read and diverse networks can be extracted and studied. Download [User Manual with focus on Scientometrics](#).

<http://sci.slis.indiana.edu>





<http://cns.slis.indiana.edu>