Places & Spaces: Mapping Science

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With special thanks to the members at the Cyberinfrastructure for Network Science Center, and the Mapping Science exhibit map makers and advisory board members.

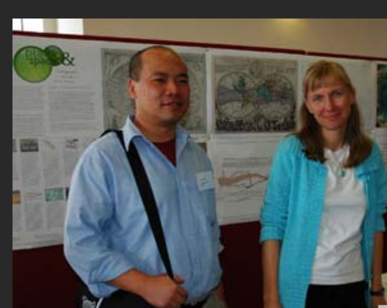
University of Sydney, School of Information Technology Lecture Theater
Sydney, Australia

June 24, 2010

Places & Spaces: Mapping Science

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

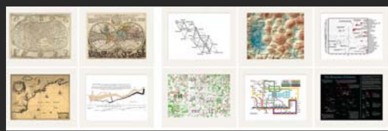
Exhibit Curators:
Dr. Katy Börner & Elisha Hardy
http://scimaps.org



Mapping Science Exhibit – 10 Iterations in 10 years

http://scimaps.org/

The Power of Maps (2005)



The Power of Reference Systems (2006)

The Power of Forecasts (2007)

Science Maps for Economic Decision Makers (2008)

Science Maps for Science Policy Makers (2009)

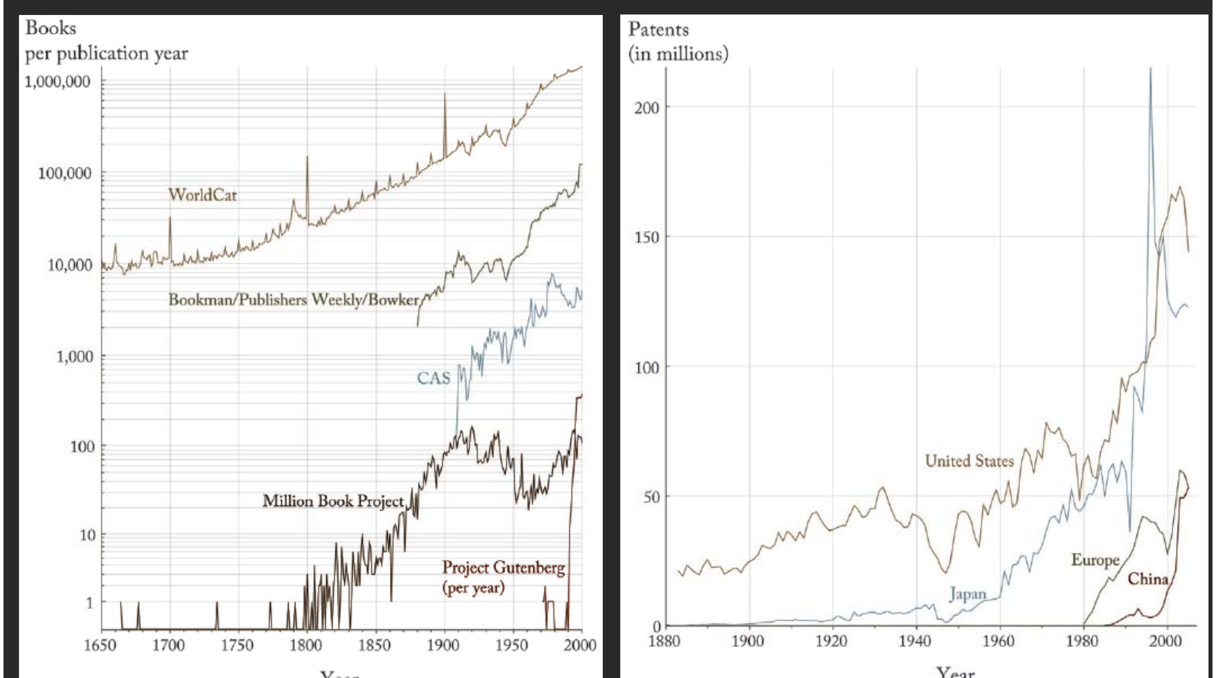
Science Maps for Scholars (2010)
Science Maps as Visual Interfaces to Digital Libraries (2011)
Science Maps for Kids (2012)
Science Forecasts (2013)
How to Lie with Science Maps (2014)

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.

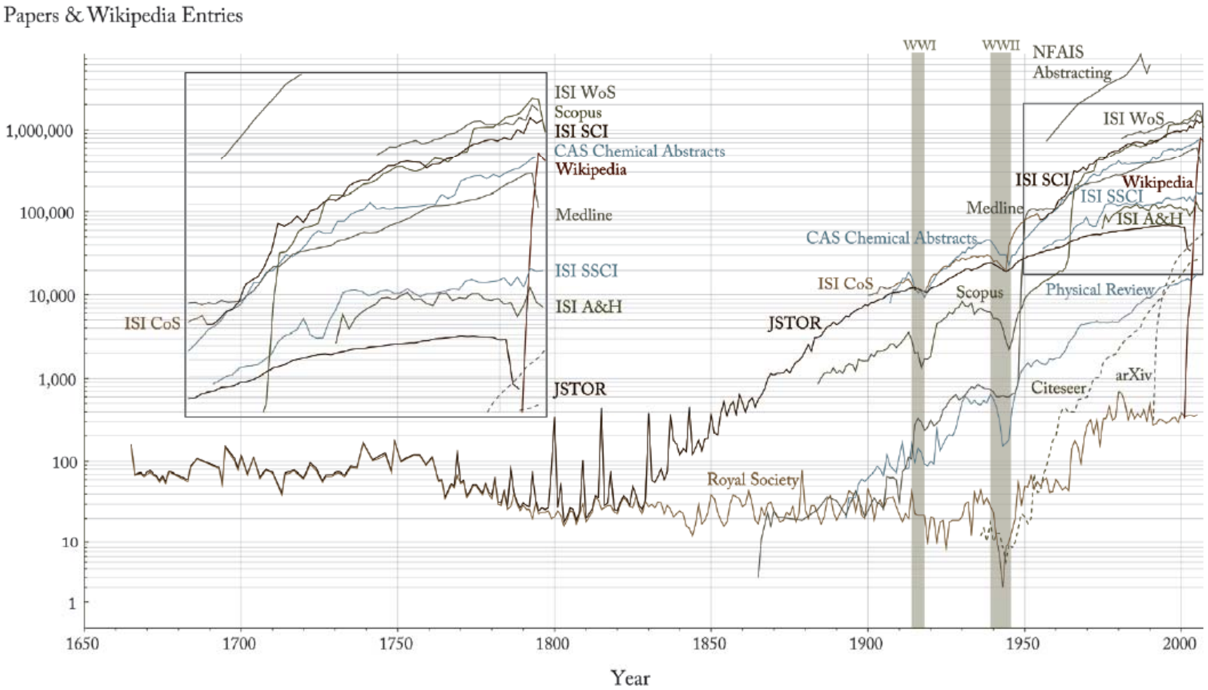
ORDER MAPS

Debut of 5th 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 23rd, 2009 by German Chancellor Merkel, http://www.expedition-zukunft.de



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



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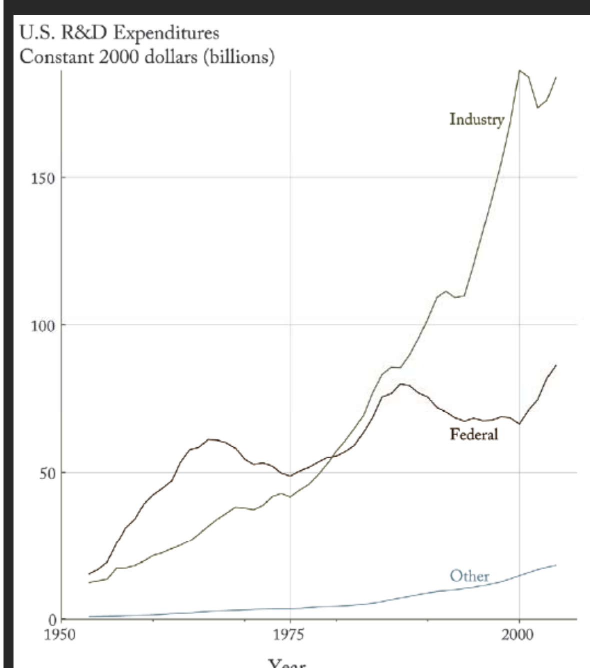

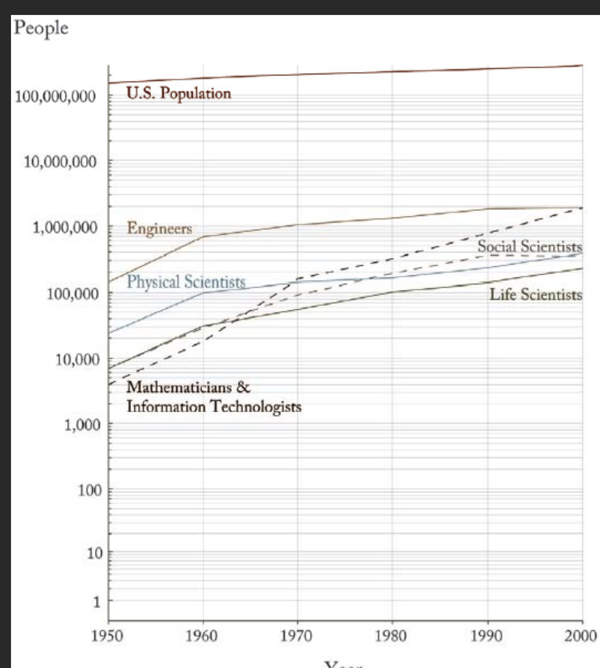

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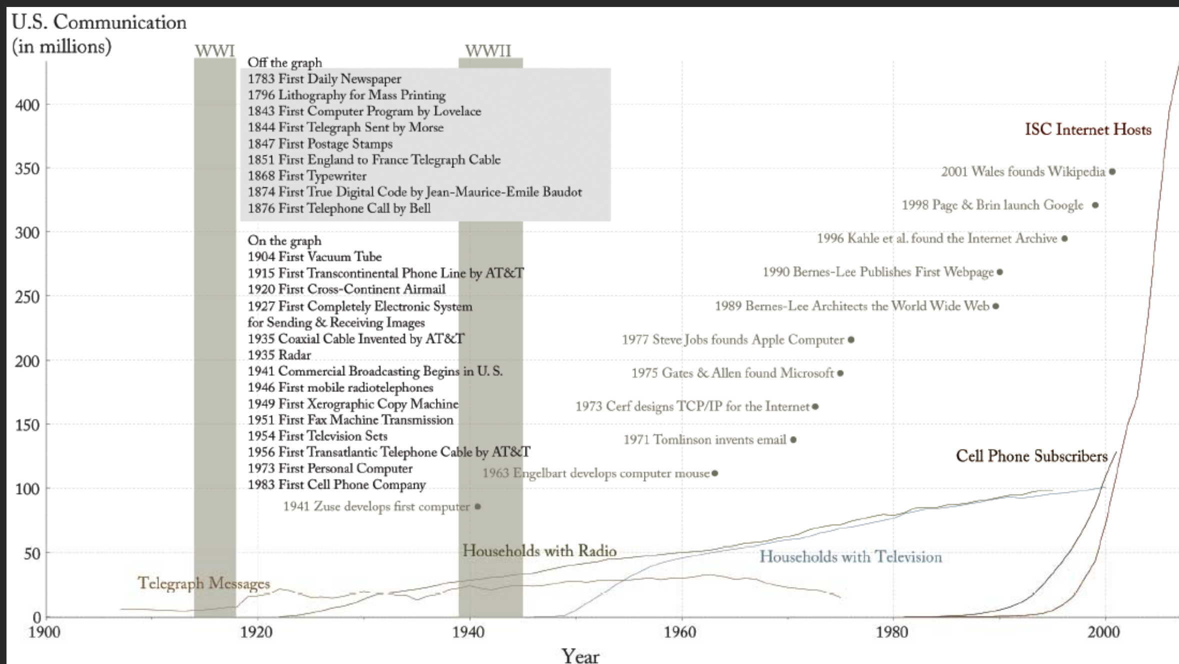


Börner, Katy (2010) Atlas of Science. MIT Press. http://scimaps.org/atlas

S&T Navigation, Management Tools that Different Stakeholders Want

Funding Agencies

- Need to monitor (long-term) money flow and research developments, identify areas for future development, stimulate new research areas, evaluate funding strategies for different programs, decide on project durations, funding patterns.

Scholars

- Want easy access to research results, relevant funding programs and their success rates, potential collaborators, competitors, related projects/publications **(research push).**

Industry

- Is interested in fast and easy access to major results, experts, etc. Influences the direction of research by entering information on needed technologies **(industry-pull)**.

Advantages for Publishers

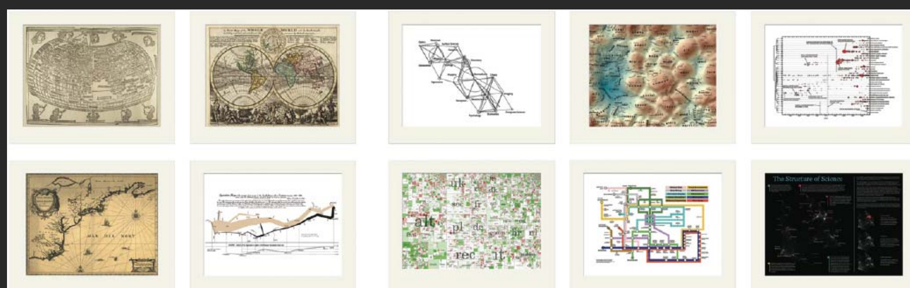
- Need easy to use interfaces to massive amounts of interlinked data. Need to communicate data provenance, quality, and context.

Society

- Needs easy access to scientific knowledge and expertise.

The Power of Maps

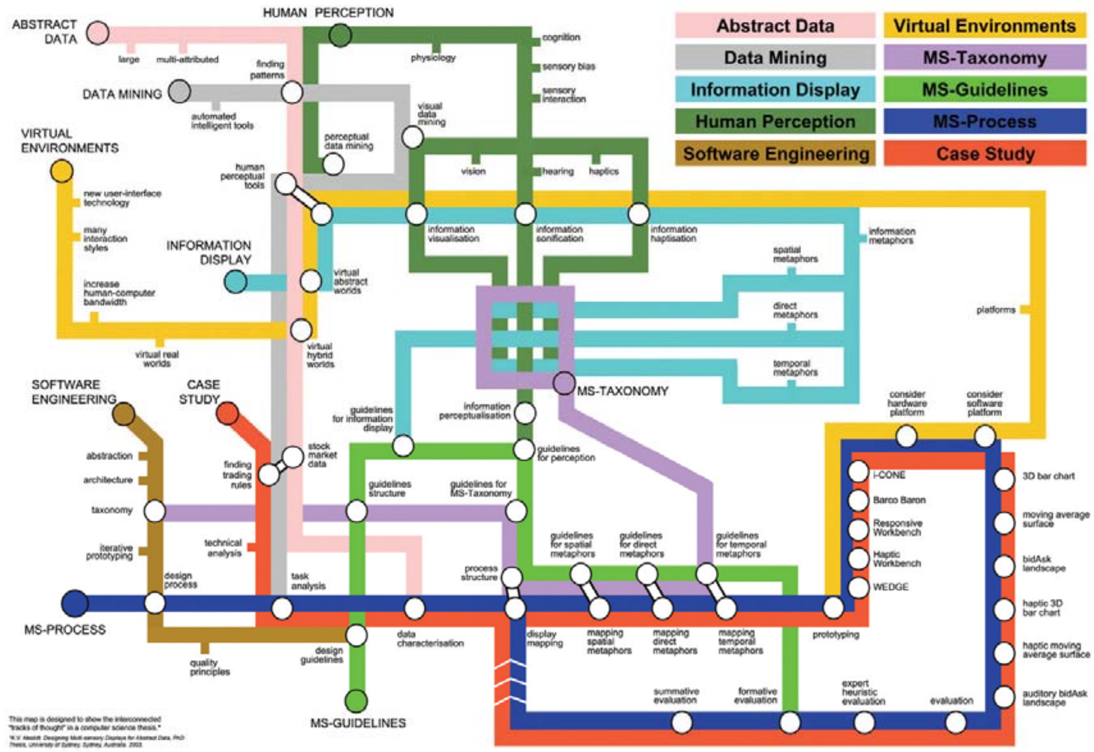
Four Early Maps of Our World
VERSUS
Six Early Maps of Science

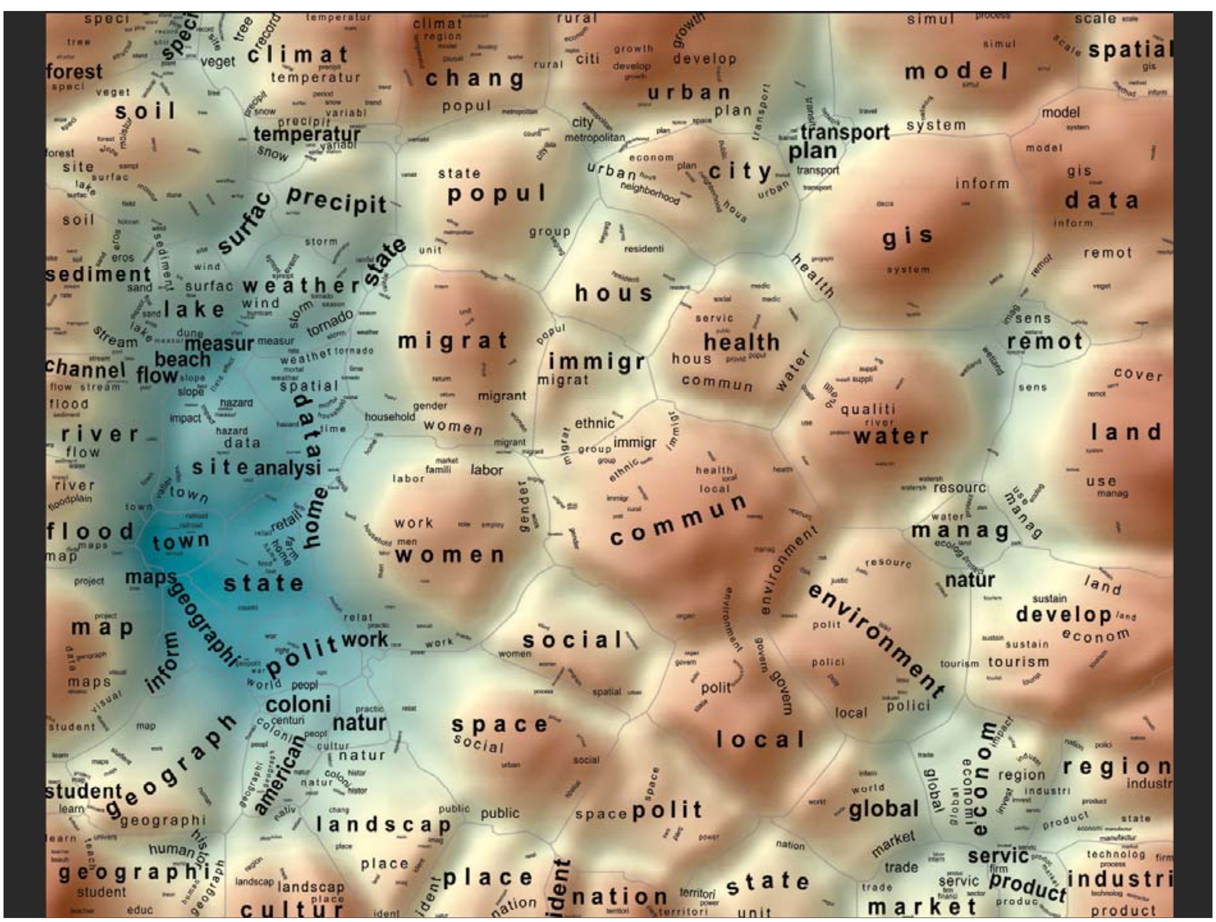


(1st Iteration of Places & Spaces Exhibit - 2005)

How would a map of science look?

What metaphors would work best?


Abstract Data
Virtual Environments
Data Mining
MS-Taxonomy
Information Display
MS-Guidelines
Human Perception
MS-Process
Software Engineering
Case Study
ABSTRACT DATA
HUMAN PERCEPTION
DATA MINING
VIRTUAL ENVIRONMENTS
INFORMATION DISPLAY
SOFTWARE ENGINEERING
CASE STUDY
MS-TAXONOMY
MS-PROCESS
MS-GUIDELINES
large
multi-attributed
finding patterns
automated intelligent tools
cognition
physiology
sensory bias
sensory interaction
visual data mining
perceptual data mining
human perceptual tools
vision
hearing
haptics
new user-interface technology
many interaction styles
increase human-computer bandwidth
virtual real worlds
virtual abstract worlds
virtual hybrid worlds
information visualisation
information sonification
information haptisation
information metaphors
spatial metaphors
direct metaphors
temporal metaphors
platforms
consider hardware platform
consider software platform
information perceptualisation
guidelines for information display
guidelines for perception
stock market data
finding trading rules
technical analysis
abstraction
architecture
taxonomy
iterative prototyping
design process
quality principles
guidelines structure
guidelines for MS-Taxonomy
guidelines for spatial metaphors
guidelines for direct metaphors
guidelines for temporal metaphors
process structure
task analysis
data characterisation
design guidelines
display mapping
mapping spatial metaphors
mapping direct metaphors
mapping temporal metaphors
prototyping
i-CONE
Barco Baron
Responsive Workbench
Haptic Workbench
WEDGE
3D bar chart
moving average surface
bidAsk landscape
haptic 3D bar chart
haptic moving average surface
auditory bidAsk landscape
summative evaluation
formative evaluation
expert heuristic evaluation
evaluation
This map is designed to show the interconnected "tracks of thought" in a computer science thesis.*
*K.V. Nesbitt, Designing Multi-sensory Displays for Abstract Data, PhD Thesis, University of Sydney, Sydney, Australia. 2003.


climat
chang
urban
model
spatial
forest
soil
temperatur
transport
plan
city
popul
precipit
surfac
data
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sediment
weather
state
hous
remot
lake
migrat
immigr
health
channel
beach
measur
flow
river
water
land
site analysi
flood
town
commun
manag
women
maps
geographi
environment
natur
develop
map
polit
work
social
coloni
space
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product
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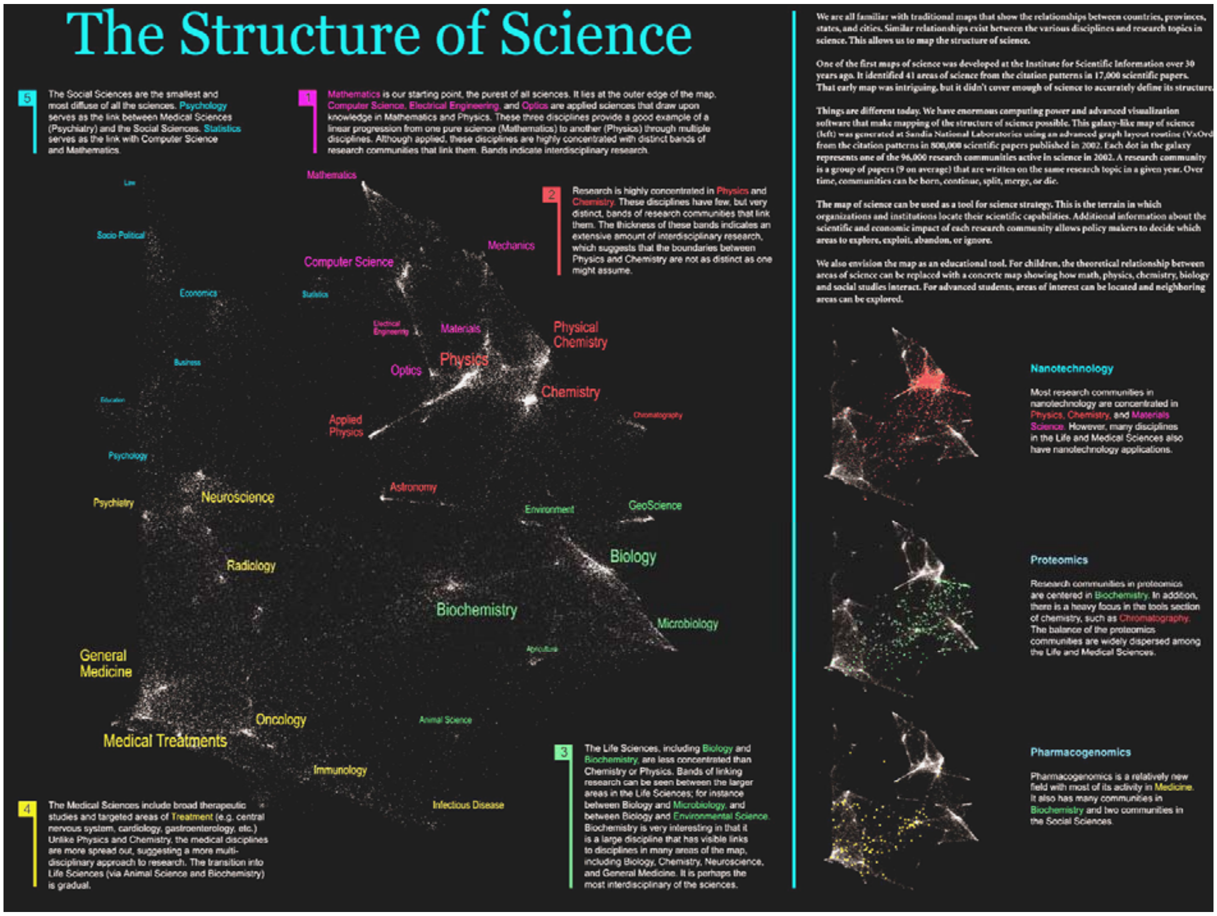
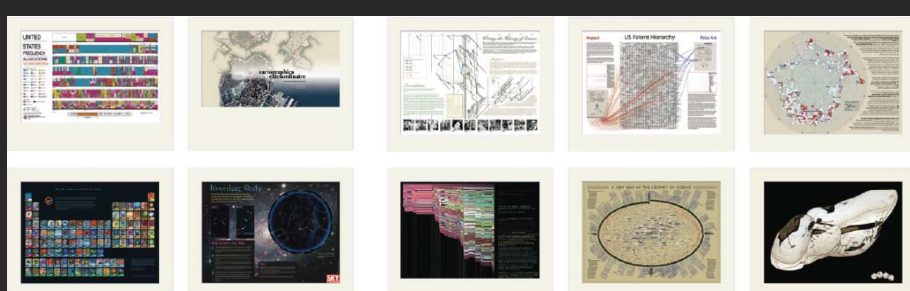
place
nation
ident
cultur
market
state

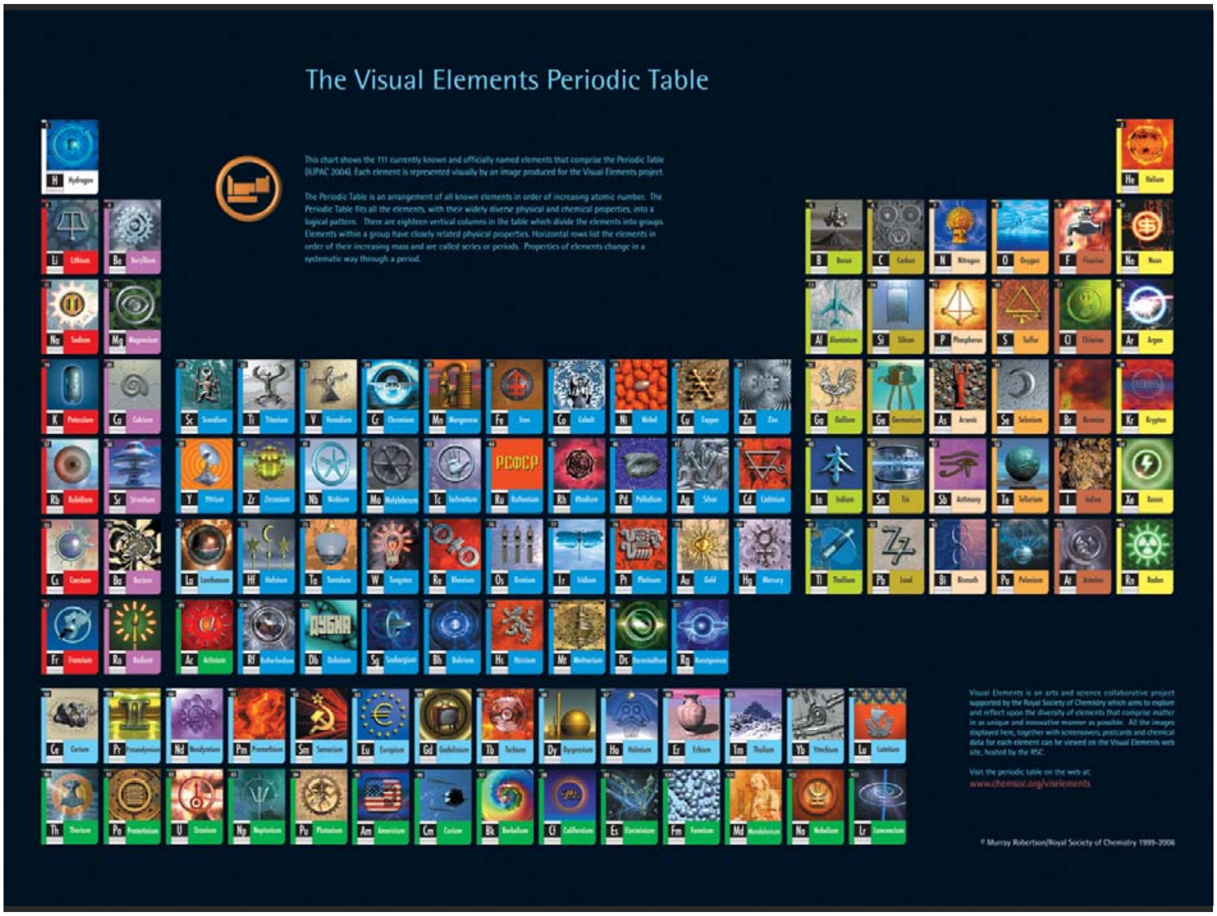


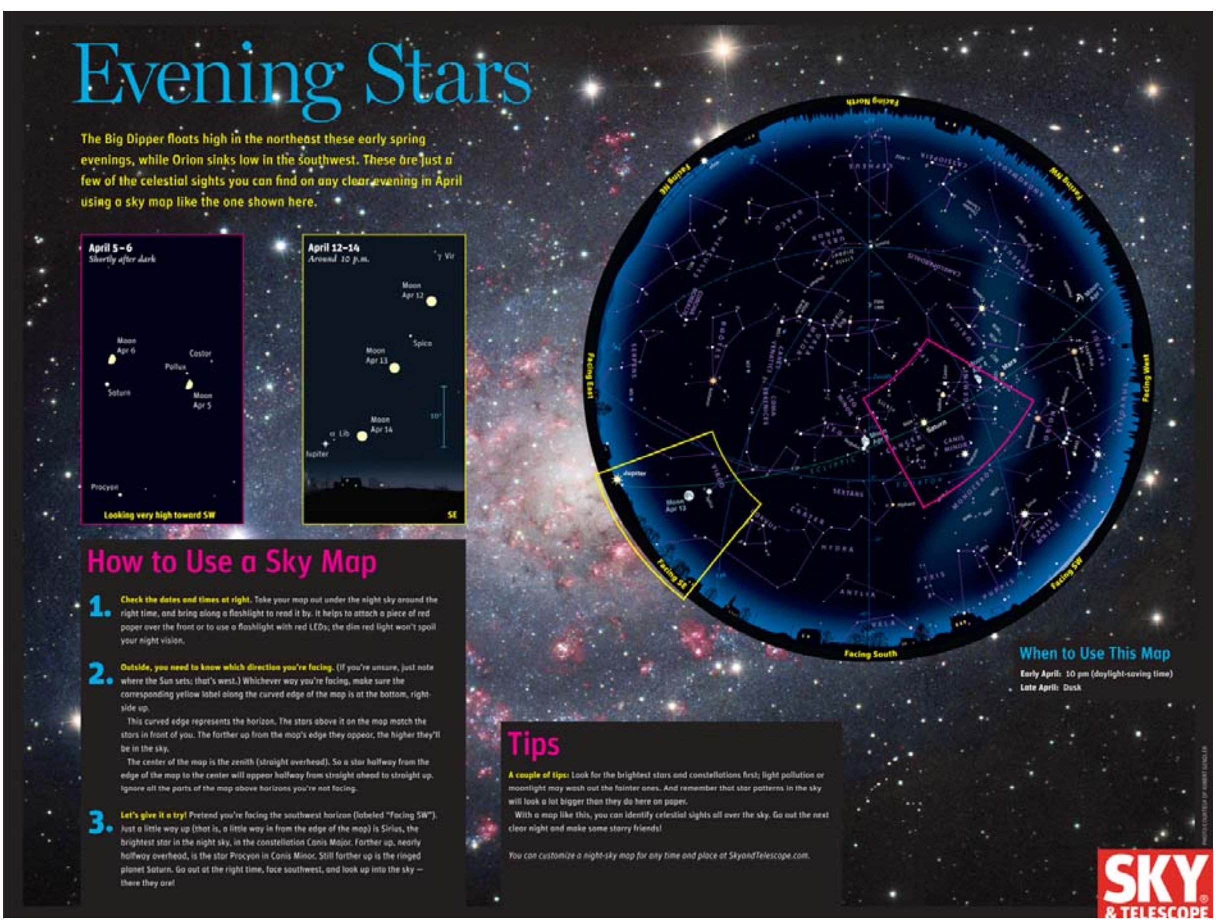
The Power of Reference Systems

Four Existing Reference Systems
VERSUS
Six Potential Reference Systems of Science



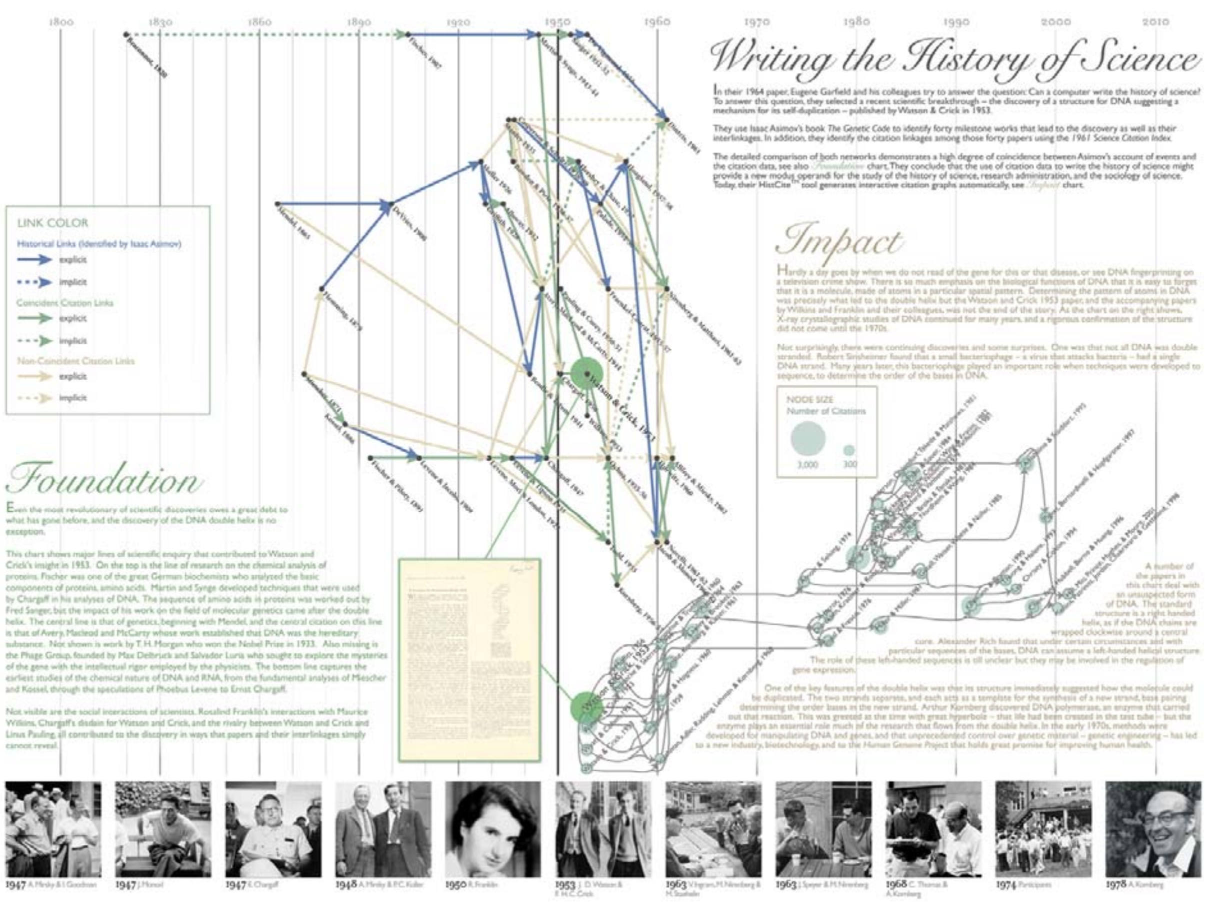
(2nd Iteration of Places & Spaces Exhibit - 2006)

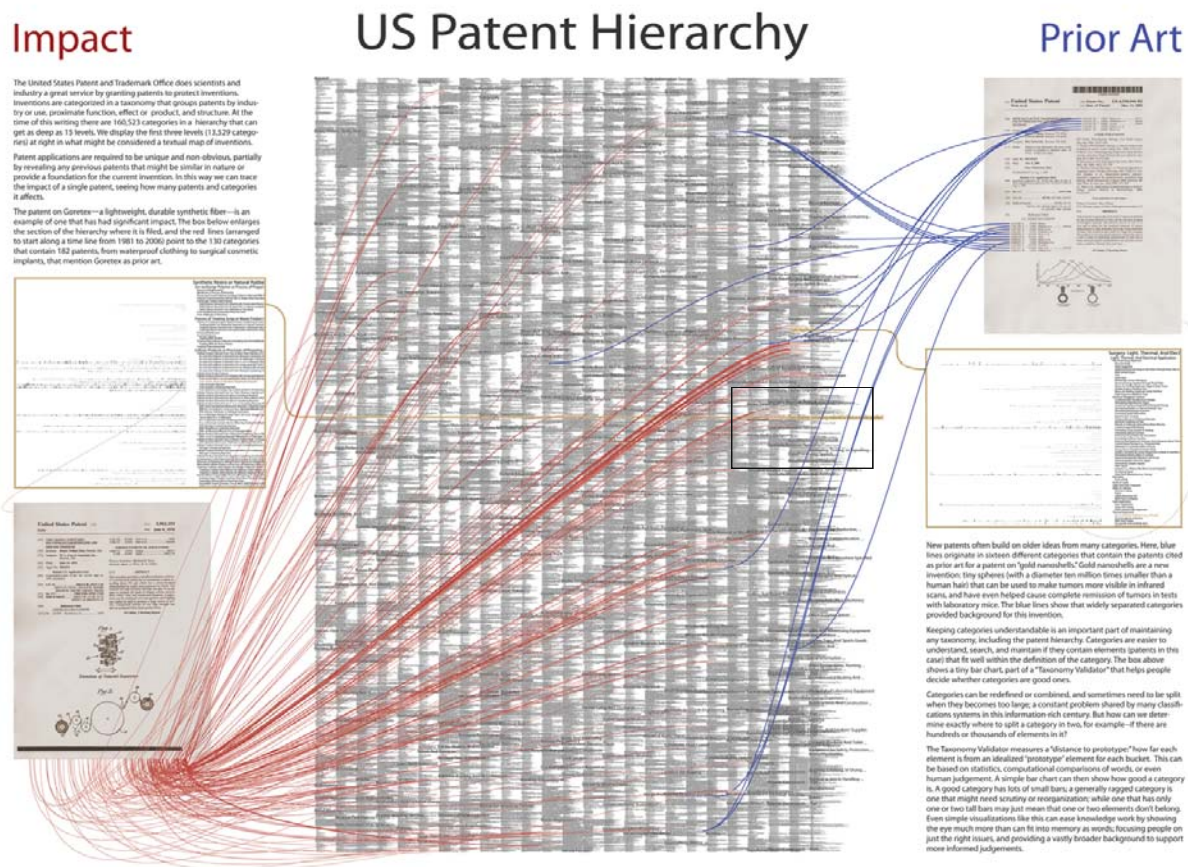

The Visual Elements Periodic Table
This chart shows the 111 currently known and officially named elements that comprise the Periodic Table (IUPAC 2004). Each element is represented visually by an image produced for the Visual Elements project.
The Periodic Table is an arrangement of all known elements in order of increasing atomic number. The Periodic Table fits all the elements, with their widely diverse physical and chemical properties, into a logical pattern. There are eighteen vertical columns in the table which divide the elements into groups. Elements within a group have closely related physical properties. Horizontal rows list the elements in order of their increasing mass and are called series or periods. Properties of elements change in a systematic way through a period.
Visual Elements is an arts and science collaborative project supported by the Royal Society of Chemistry which aims to explore and reflect upon the diversity of elements that comprise matter in as unique and innovative manner as possible. All the images displayed here, together with screensavers, postcards and chemical data for each element can be viewed on the Visual Elements web site, hosted by the RSC.
Visit the periodic table on the web at:
www.chemsoc.org/viselements
© Murray Robertson/Royal Society of Chemistry 1999-2006

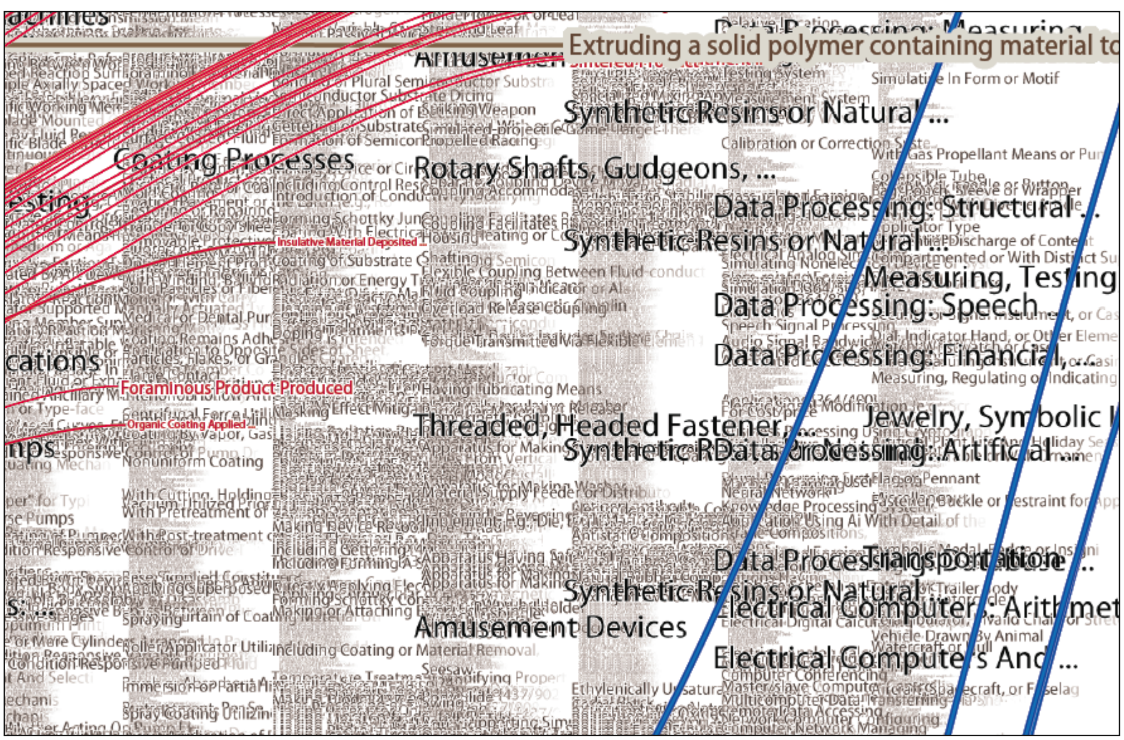

Evening Stars
The Big Dipper floats high in the northeast these early spring evenings, while Orion sinks low in the southwest. These are just a few of the celestial sights you can find on any clear evening in April using a sky map like the one shown here.
April 5–6
Shortly after dark
Moon Apr 6
Castor
Pollux
Saturn
Moon Apr 5
Procyon
Looking very high toward SW
April 12–14
Around 10 p.m.
Moon Apr 12
Spica
Moon Apr 13
Moon Apr 14
α Lib
Jupiter
10°
SE
Facing North
Facing NE
Facing NW
Facing East
Facing West
Facing SE
Facing SW
Facing South
How to Use a Sky Map
1. Check the dates and times at right. 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.
2. 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 farther 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.
3. 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 wash 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 starry friends!
You can customize a night-sky map for any time and place at SkyandTelescope.com.
SKY & TELESCOPE

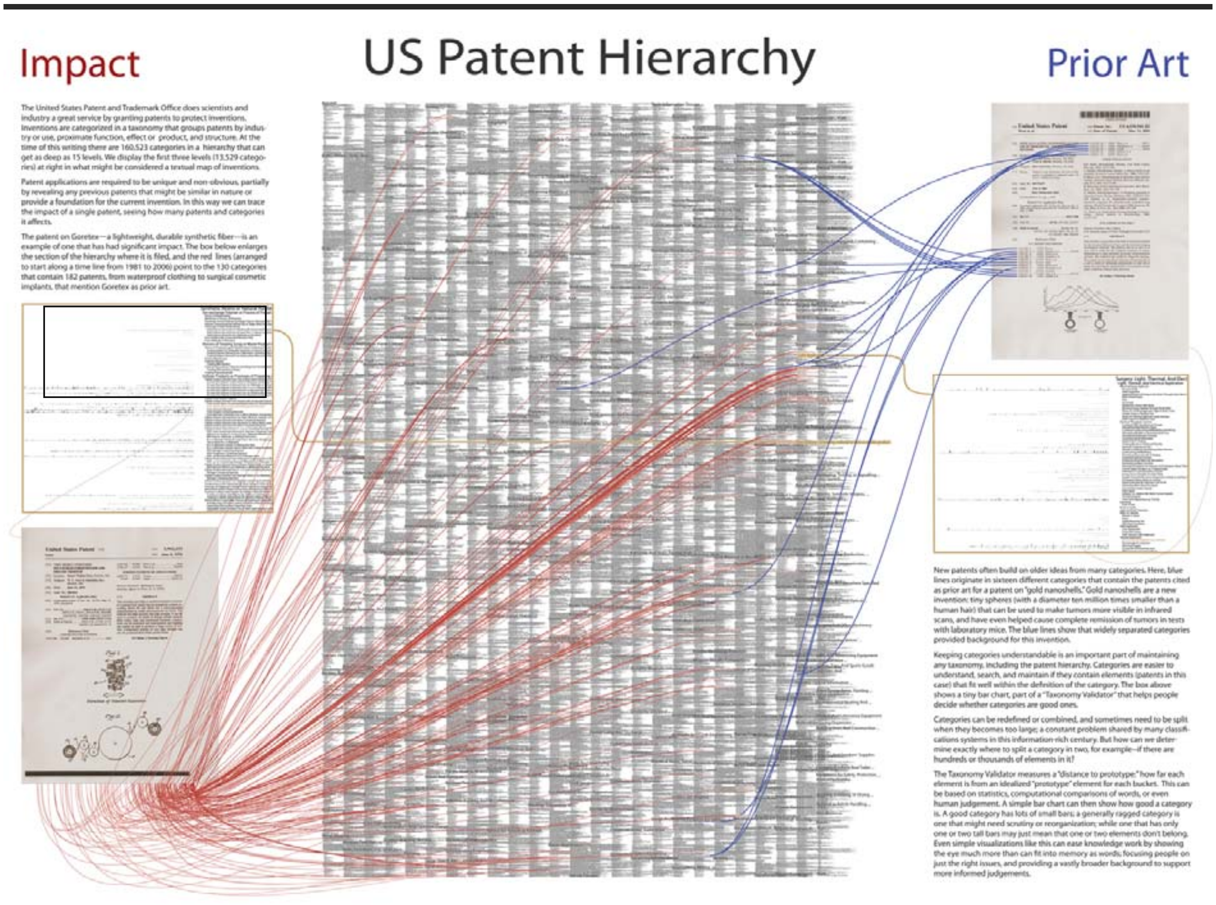
How would a reference system for all of science look?

What dimensions would it have?




Impact
US Patent Hierarchy
Prior Art
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 160,523 categories in a hierarchy that can get as deep as 15 levels. We display the first three levels (13,529 categories) at right in what might be considered a textual 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 Goretex—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 (arranged 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 Goretex as 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 becomes 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 simple 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.


Extruding a solid polymer containing material to
Coating Processes
Rotary Shafts, Gudgeons, ...
Synthetic Resins or Natural ...
Data Processing: Structural ...
Measuring, Testing
Data Processing: Speech
Data Processing: Financial, ...
Insulative Material Deposited ...
Foraminous Product Produced
Organic Coating Applied ...
Threaded, Headed Fastener, ...
Jewelry, Symbolic
Amusement Devices
Electrical Computers: Arithmet
Electrical Computers And ...
Transportation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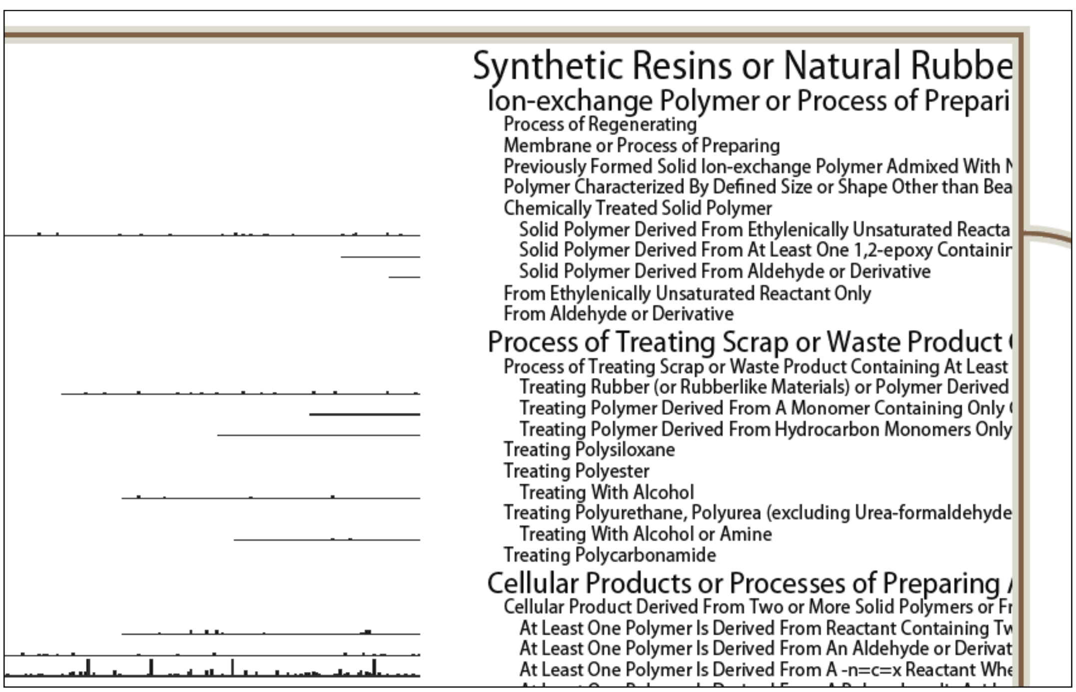
Synthetic Resins or Natural Rubbe
Ion-exchange Polymer or Process of Prepari
Process of Regenerating
Membrane or Process of Preparing
Previously Formed Solid Ion-exchange Polymer Admixed With N
Polymer Characterized By Defined Size or Shape Other than Bea
Chemically Treated Solid Polymer
Solid Polymer Derived From Ethylenically Unsaturated Reacta
Solid Polymer Derived From At Least One 1,2-epoxy Containir
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
Treating Rubber (or Rubberlike Materials) or Polymer Derived
Treating Polymer Derived From A Monomer Containing Only (
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 A
Cellular Product Derived From Two or More Solid Polymers or Fr
At Least One Polymer Is Derived From Reactant Containing Tw
At Least One Polymer Is Derived From An Aldehyde or Derivat
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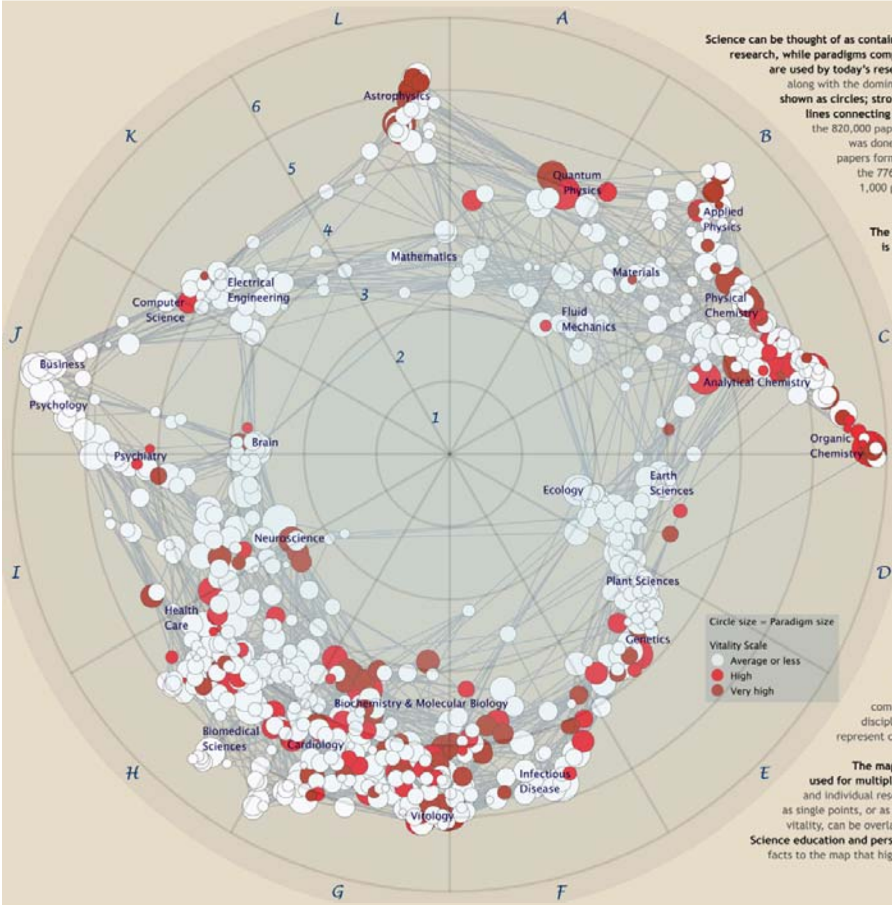


Science can be thought of as containing themes and paradigms. Themes are areas of current research, while paradigms comprise the dominant tool sets and existing knowledge that are used by today's researchers. This map shows **776 major paradigms in science** along with the dominant relationships between these paradigms. **Paradigms are shown as circles; strong relationships between paradigms are indicated by the lines connecting the circles.** The map was created by recursively clustering the 820,000 papers referenced most often in 2003. Clustering at each level was done using VxOrd, a force-directed graph layout routine. These papers formed 53,000 clusters, 6,100 higher-level clusters, and finally the 776 paradigms. Although each paradigm contains, on average, 1,000 papers, some are larger and some are smaller, as shown by different sized circles on the map.

The ring-like structure that is formed by scientific paradigms is very robust. We find similar structures for different years, and for maps generated from scientific journals. "The Structure of Science", a galaxy map shown in the first iteration of Places & Spaces, is a map based on clustering of scientific journals, with superimposition of papers on the journal structure, whereas this map was generated directly from highly-cited papers. "The Structure of Science" shows current science in a disciplinary context, while this map can show the breadth of disciplines that contribute to single paradigms.

Because of the robust nature of the structure of science and its paradigms, we have placed our 776 scientific paradigms within a **reference system containing 12 radial slices and 6 rings.** This allows the position of each paradigm to be codified and available for lookup; for instance ***Fluid Mechanics*** **paradigms are in grid B3**.

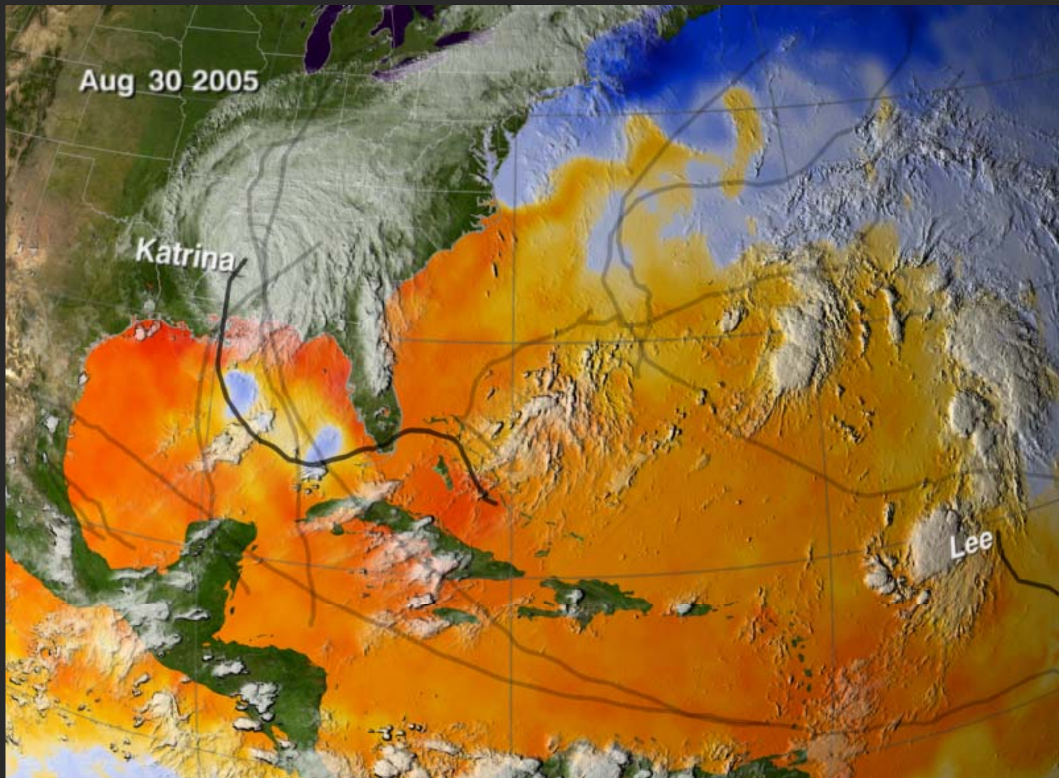
We have also calculated and displayed the vitality of each paradigm. ***Vitality*** **is a measure of the speed at which a group of researchers reaches consensus about major improvements.** Paradigms are constantly being improved, but it usually takes years to reach consensus about which improvements are major. The white circles represent communities where consensus is reached relatively slowly. This is a common phenomenon in the social sciences, ecological sciences, computer sciences, and mathematics disciplines. **The red circles represent communities of researchers where consensus is reached relatively rapidly.** This is more common in physics, chemistry, biochemistry, and many medical disciplines. Very dark circles (such as those in *Astrophysics, L5-6*) represent communities where consensus is reached extremely quickly.

The map of scientific paradigms and its reference system can be used for multiple purposes. Countries, industries, companies, universities, and individual researchers can all **locate themselves within the map**, either as single points, or as a specific collection of paradigms. Various metrics, such as vitality, can be overlayed on this reference system to highlight specific impacts. **Science education and personal discovery** can also be enhanced by linking stories and facts to the map that highlight scientific history, current advances and relationships between scientific paradigms.

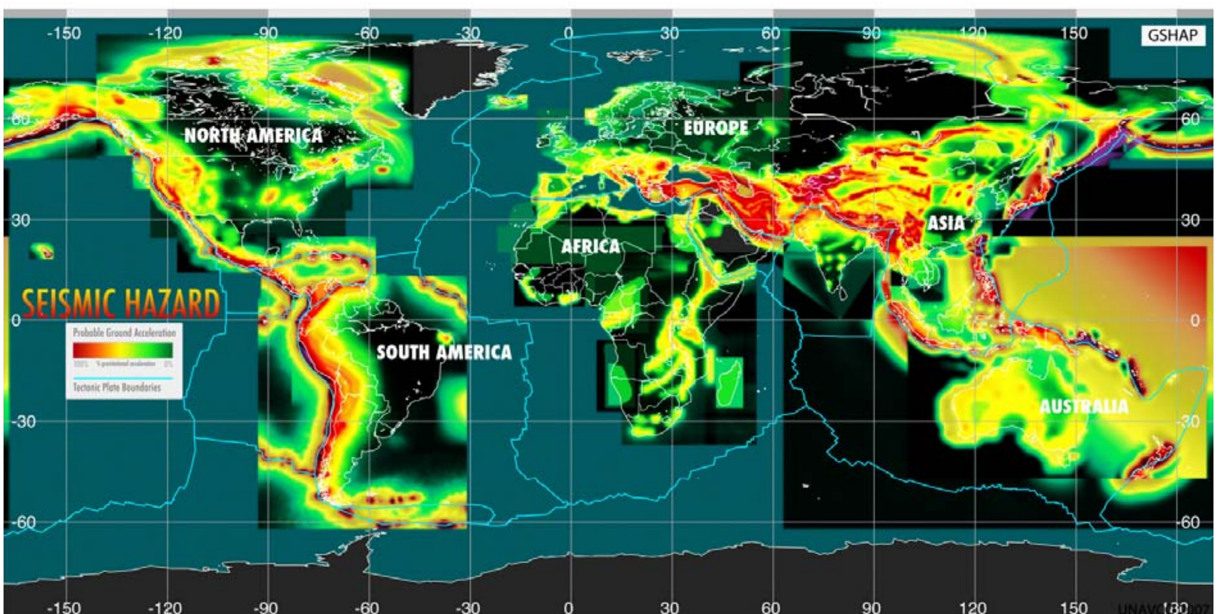
The Power of Forecasts

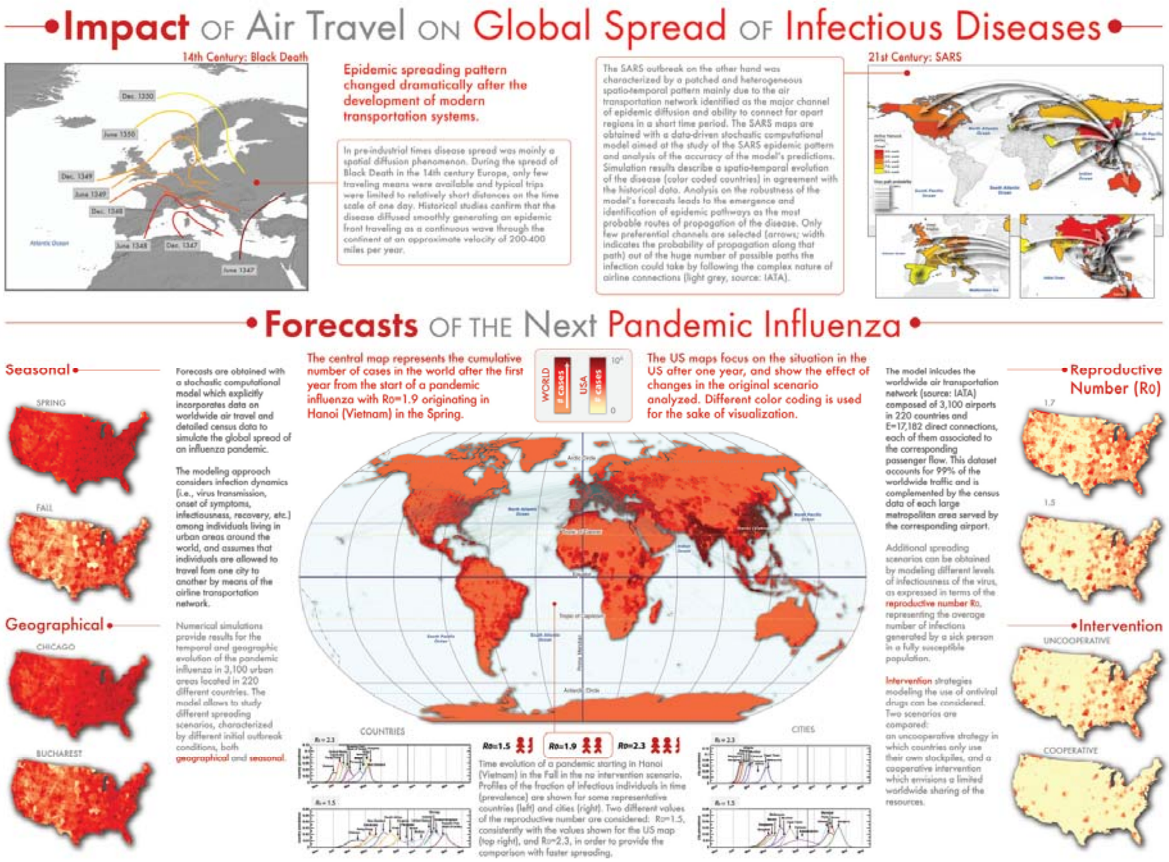
Four Existing Forecasts
VERSUS
Six Potential Science 'Weather' Forecasts

(3rd Iteration of Places & Spaces Exhibit - 2007)



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





Can one forecast science?

What 'science forecast language' will work?

Science & Technology Outlook: 2005–2055

Technology Horizons Program
Institute for the Future
124 University Avenue, 2nd Floor, Palo Alto, CA 94301
t 650.854.6322 f 650.854.7850 www.iftf.org

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 predictions. Nor is it comparable 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 contextualize information and reveal interdependencies and connections between seemingly unrelated events, thus enriching our understanding of the landscape. That's precisely the intention 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 **Institute for the Future (IFTF)** 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 in S&T—academicians, policymakers, journalists, and corporate researchers. The IFTF team also compiled a database of outlooks on developments 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 an accompanying set of **S&T Perspectives** that discuss issues emerging on the S&T horizon and are important for organizations, policymakers, and society-at-large to understand.

On this map, six themes are woven together across the 50-year horizon, often resulting in important breakthroughs. These are supported by key technolgies, innovations, and discoveries. In addition to the six themes, three meta-themes—democratized innovation, transdisciplinarity, and emergence—will overlay the future S&T landscape influencing how we think about, 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 wider trends surround the map to remind us of the larger picture.

MAP THEMES

Small World

After 20 years of basic research and development at the 100-nanometer scale, the importance of nanotechnology as a source of innovations 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 impacts 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—in which assemblers build 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 milieux that emphasize heterogeneity.

Intentional Biology

For 3.6 billion years, evolution has governed biology on this planet. But today, Mother Nature has a collaborator. Inexpensive tools to read and rewrite the genetic code of life will bootstrap 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 remake our minds and bodies in profoundly different ways. Advances in biotechnology, brain science, 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. Wielding these tools on ourselves, humans will begin to define a variety of different "transhumanist" 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 decoded 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 react to contextual clues 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 formats—as graphics, pictures, patterns, sounds, smells, and tactile experiences. This enriched sensory environment will coincide with major breakthroughs in our understanding of the brain—in 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 with be a renaissance of the serious amateurs, the growth of new scientific and technical centres of excellence in developing countries, and a more global distribution of world-class scientists and technologists.

Transdisciplinarity

In the last two 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 forecaster and author, "transdisciplinarity 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 proving useful for making sense of a very wide range of phenomena. Meanwhile, emergence can be modeled using relatively simple computational tools, although those models often require substantial processing power. More generally, it is a richly suggestive as a way of thinking about designing complex, robust technological systems. Finally, emergence is an accessible and vivid a 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 385,899 articles published in 720 volumes of 11 journals between 1893 and 2005. The 91,762 articles published from 1893 to 1976 take up the left third on the map. In 1977, the Physical Review introduced the Physics and Astronomy Classification Scheme (PACS) codes, and the visualization subdivides into the top-level PACS codes. The 217,503 articles from 1977 to 2000, for which good citation data is not available, occupy the middle third on the map. The 80,634 articles from 2001 to 2005, for which good citation data is available, fill the last third of the map.

Each vertical bar is subdivided vertically into the journals that appear in it with height proportional to the number of papers, and each journal is subdivided horizontally into the volumes of the journal appearing in the column.

On top of this base map, all citations from the papers in every top-level PACS code in 2005 are overlaid and then drawn from the source area to the individual volumes containing papers cited.

The small Nobel Prize medals indicate the 24 volumes containing the 26 papers appearing in Physical Review for 11 Nobel prizes between 1990 and 2005. Each year, Thomson ISI predicts three Nobel Prize awardees in physics based on citation counts, high impact papers, and discoveries or themes worthy of special recognition. Correct predictions by Thomson ISI are highlighted.

Nobel Prizes in Physical Review

Year of Nobel Prize Winners Publication Year(s) (indicated by Nobel Prize medals on the right)

- 2005 Roy J. Glauber, John L. Hall, and Theodor W. Hänsch 1963, 1971
- 2004 David J. Gross, H. David Politzer, and Frank Wilczek 1973
  Thomson ISI successfully predicted a winner in this year, with the following paper:
  Gross D, Wilczek F. Ultraviolet Behavior of Non-Abelian Gauge Theories. Physical Review Letters 30: 1343 & 1973
- 2003 Anthony J. Leggett 1970
- 2002 Raymond Davis Jr., Masatoshi Koshiba, and Riccardo Giacconi 1962, 1968, 1987
- 2001 Eric A. Cornell, Wolfgang Ketterle, and Carl E. Wieman 1995, 1996
- 1998 Robert B. Laughlin 1982, 1983
- 1997 Steven Chu an
- 1996 David M. Lee, D
- 1995 Martin L. Perl
- 1994 Bertram N. Bro
- 1990 Jerome I. Fried

Bar Graph

- Physical Review
- Physical Review
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- Physical Review
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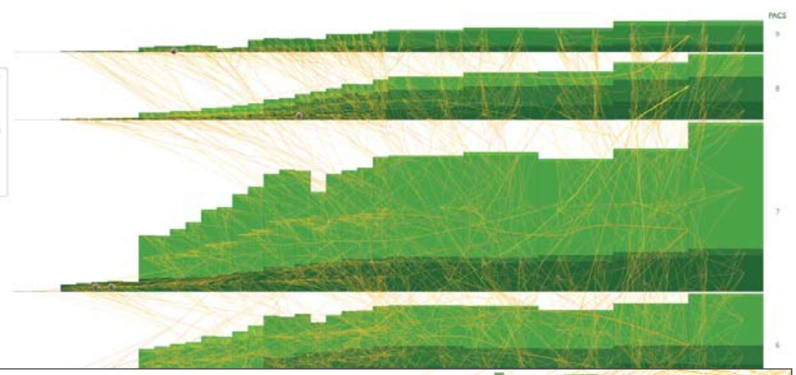
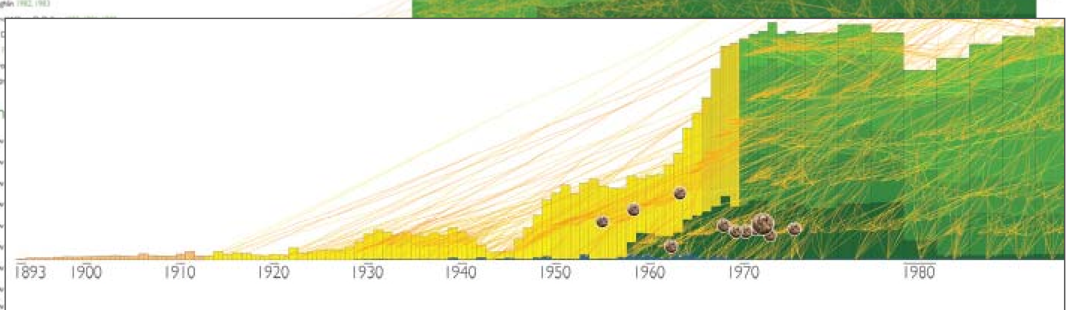
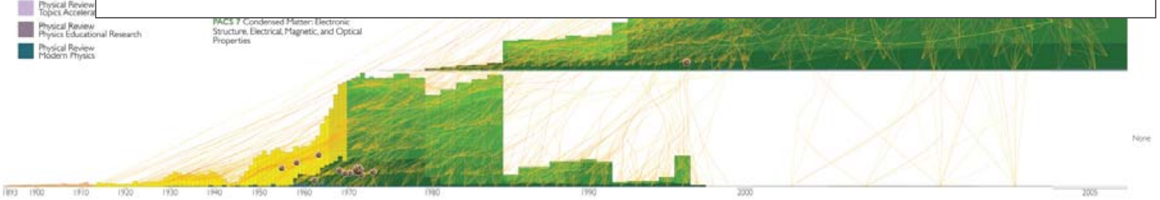
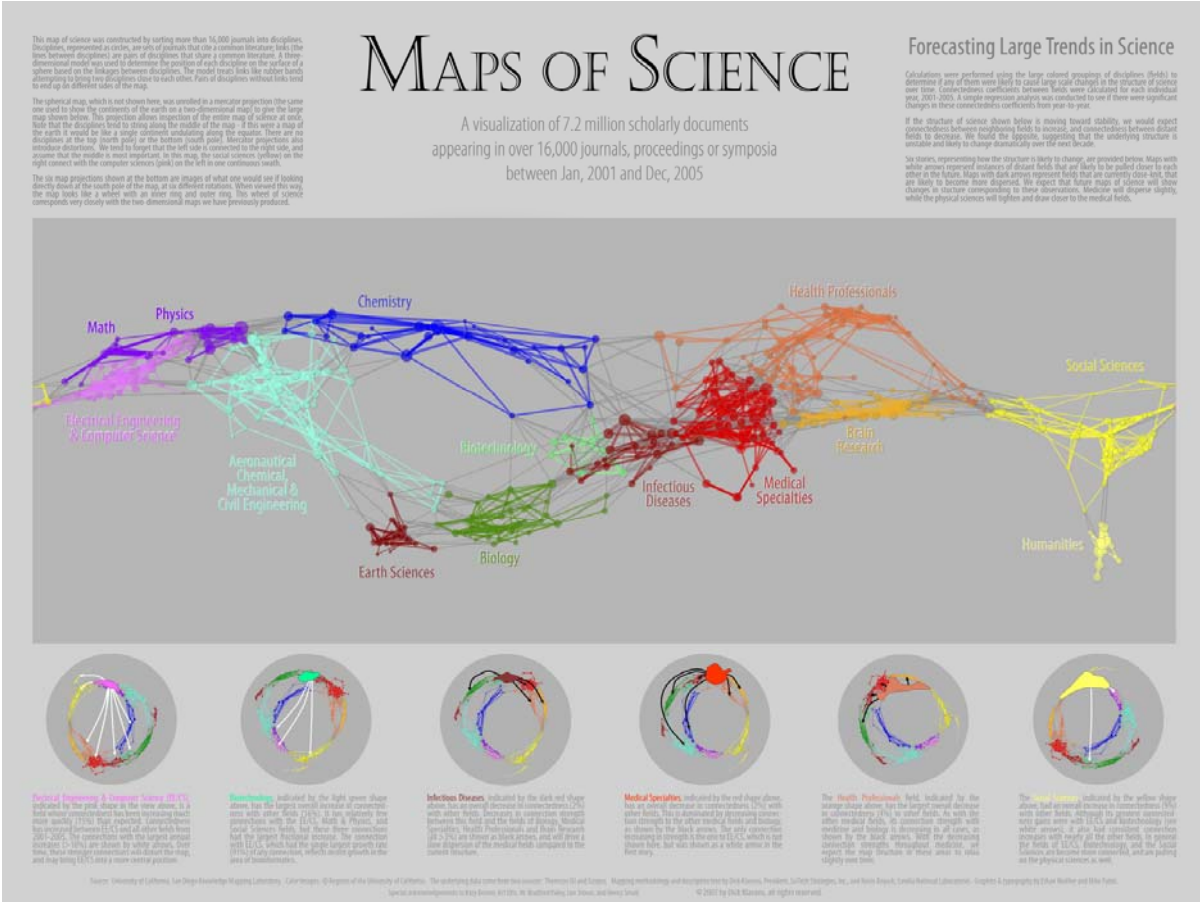
- Physical Review Topics Accelera
- Physical Review Physics Educational Research
- Physical Review Modern Physics





PACS 7 Condensed Matter: Electronic Structure, Electrical, Magnetic, and Optical Properties

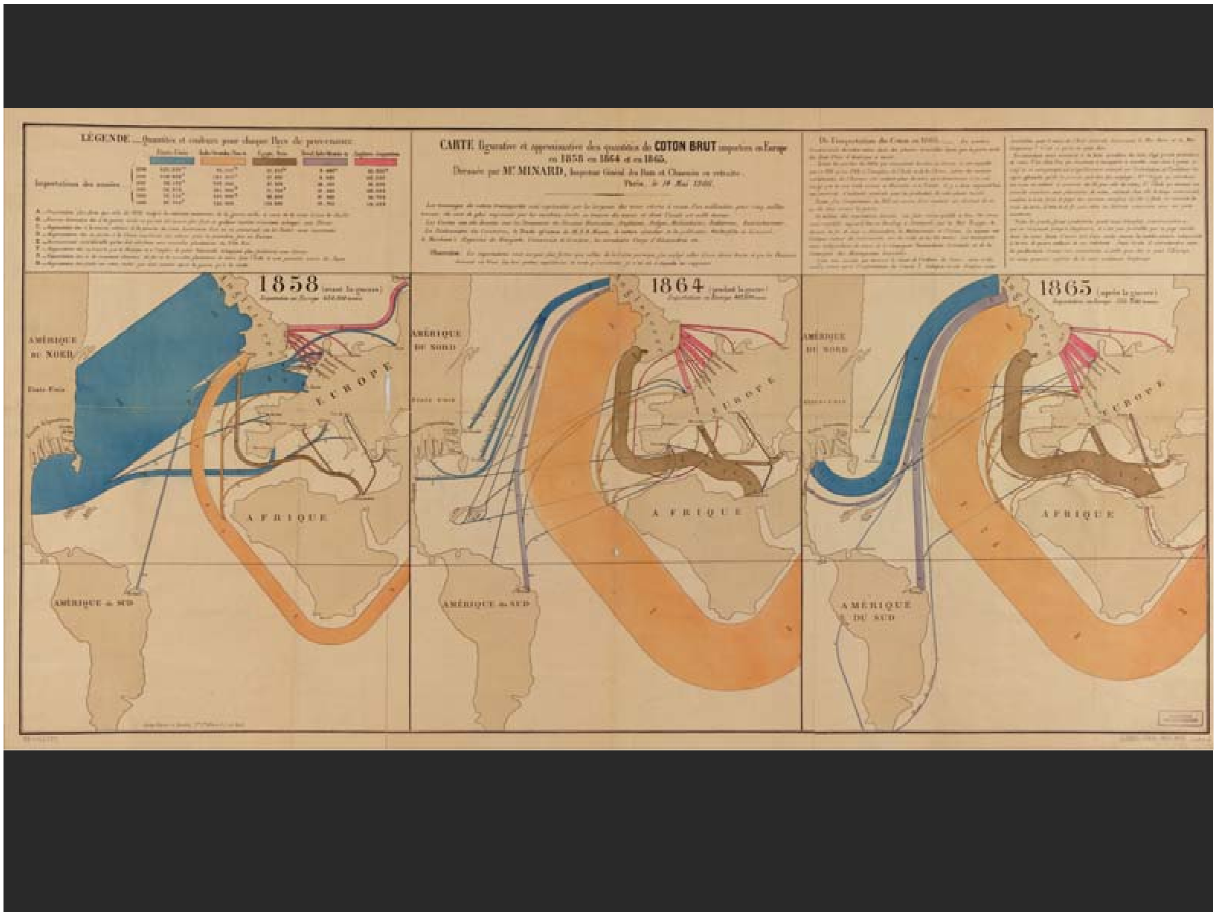




Science Maps for Economic Decision Making

Four Existing Maps
VERSUS
Six Science Maps

(4th Iteration of Places & Spaces Exhibit - 2008)



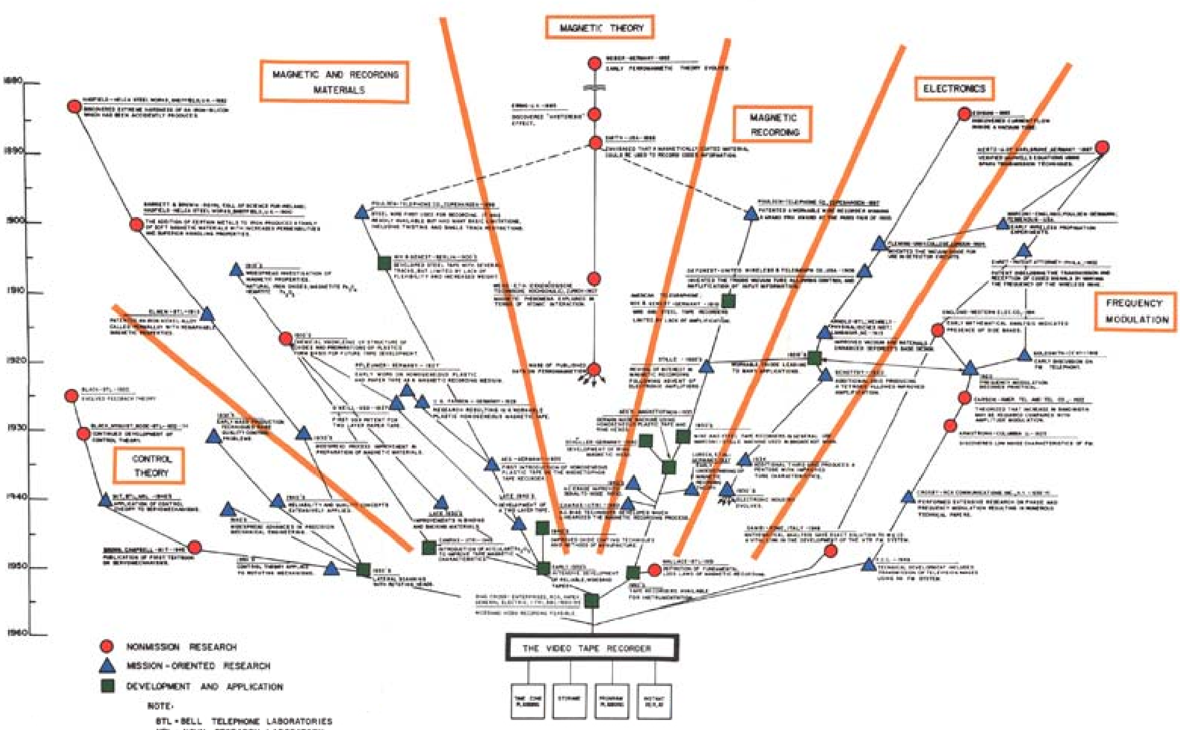
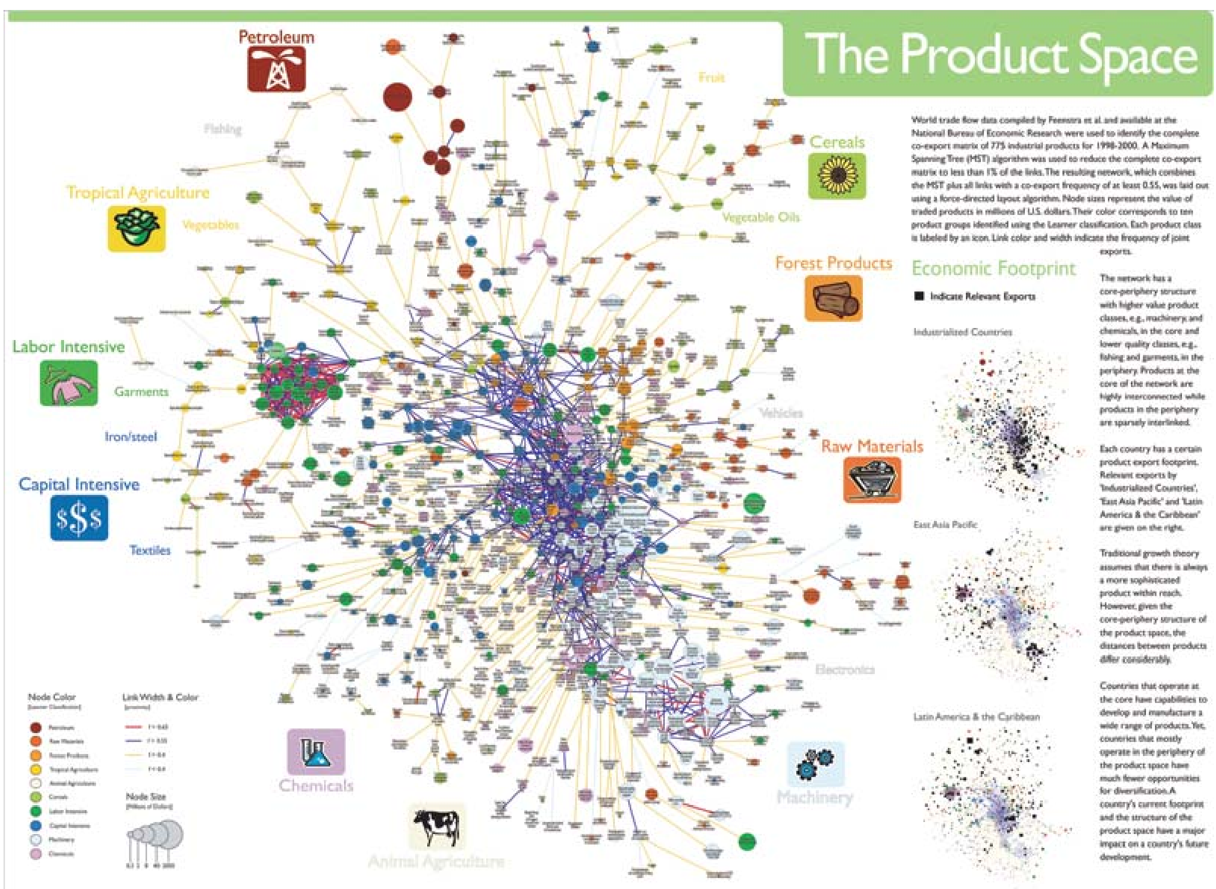


FIG. 7. THE VIDEO TAPE RECORDER

What insight needs to economic decision makers have?

What data views are most useful?

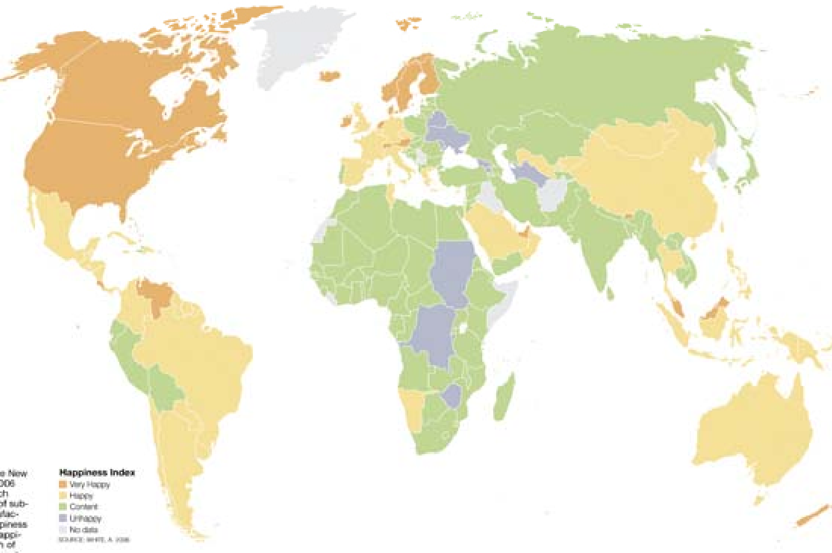


Happiness Depends on Various Factors

"It's time we admitted there's more to life than money."
- David Cameron, U.K. leader of the opposition, 2006

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.



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.

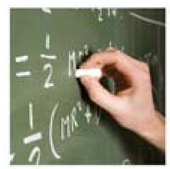
1. DENMARK, SWITZERLAND
2. AUSTRIA, ICELAND
3. BAHAMAS, FINLAND, SWEDEN
4. BHUTAN, BRUNEI, CANADA, IRELAND, LUXEMBOURG
5. COSTA RICA, MALTA, NETHERLANDS
6. ANTIGUA AND BARBUDA, MALAYSIA, NEW ZEALAND, NORWAY, SEYCHELLES, ST. KITTS AND NEVIS, UNITED ARAB EMIRATES, UNITED STATES, VANUATU, VENEZUELA

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).

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.

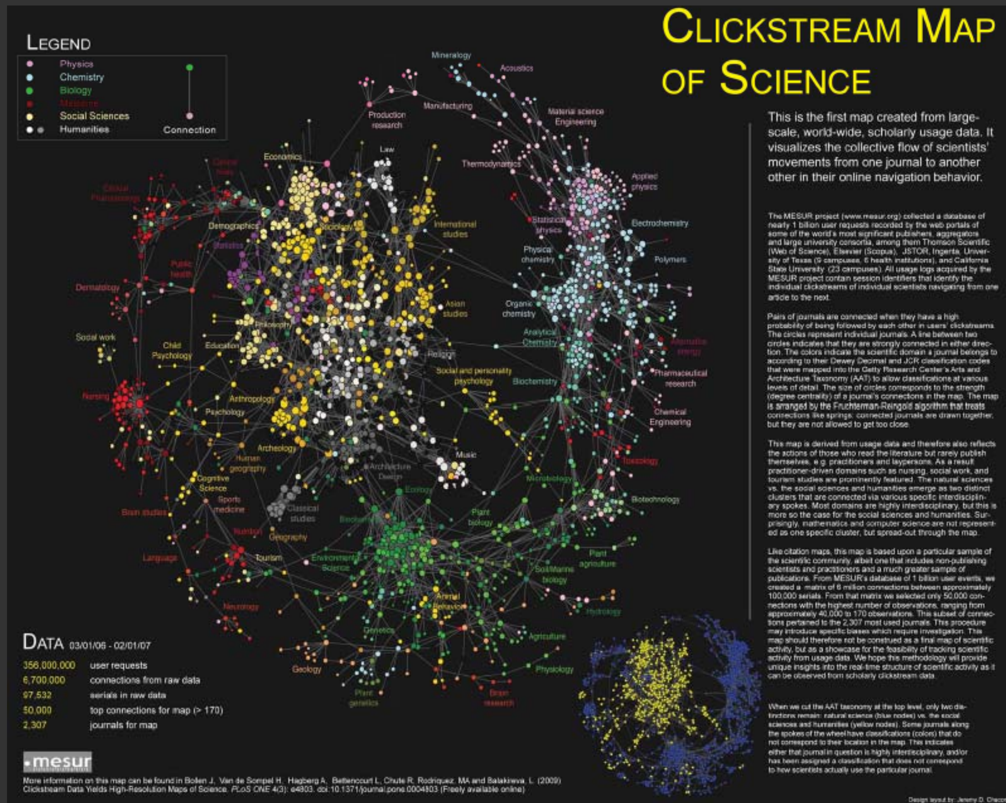


EDUCATION
Residents of Australia can expect to spend more time in school—an average of almost 21 years—than citizens of any other country. But only a basic education is needed to see a significant jump in overall happiness. Around the world, hundreds of millions lack even that.

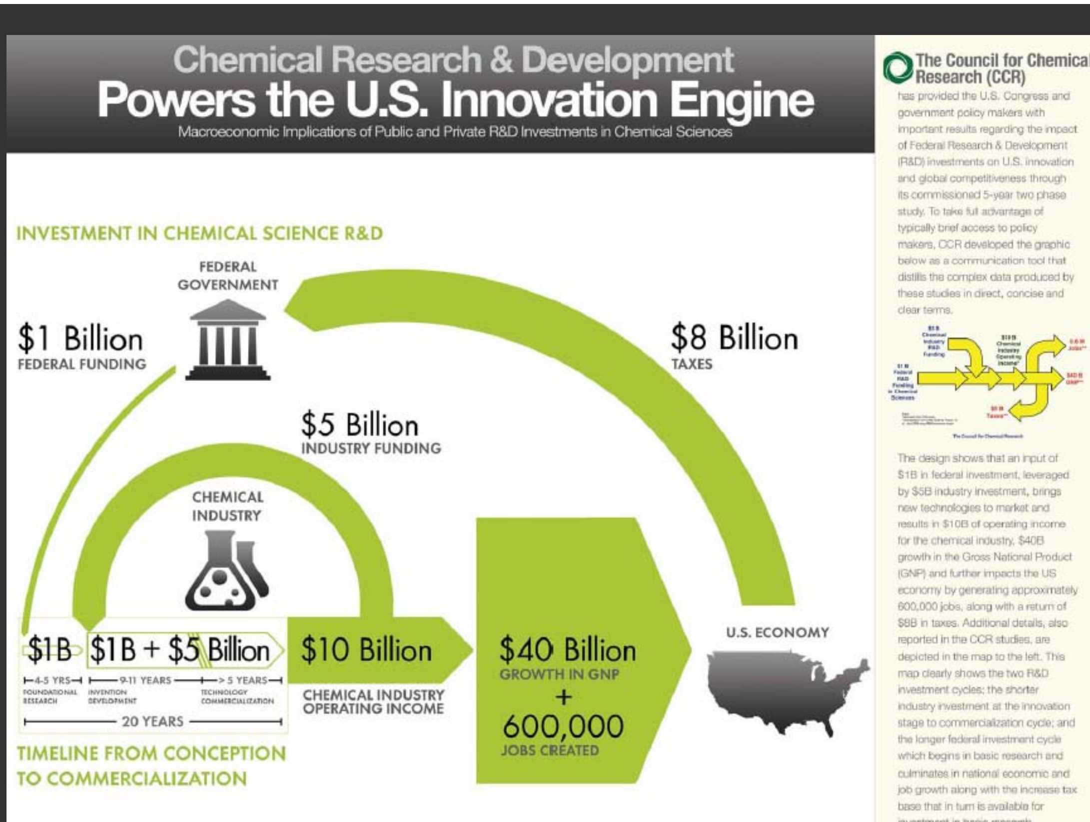
Science Maps for Science Policy Making

Four Existing Maps
VERSUS
Six Science Maps

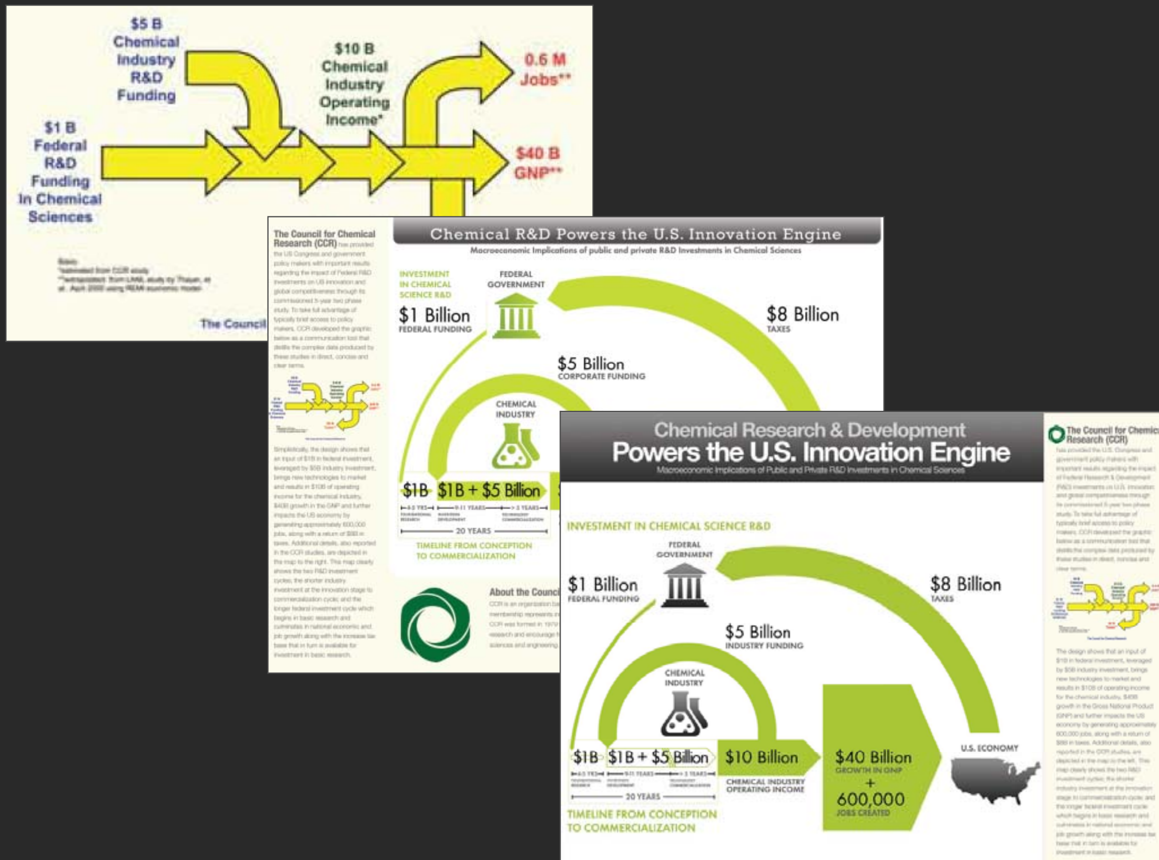
(5th Iteration of Places & Spaces Exhibit - 2009)



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



Council for Chemical Research. 2009. Chemical R&D Powers the U.S. Innovation Engine. Washington, DC. Courtesy of the Council for Chemical Research.



Additional Elements of the Exhibit

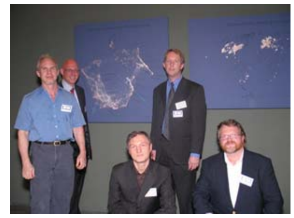
Illuminated Diagram Display

Hands-on Science Maps for Kids

Worldprocessor Globes

Illuminated Diagram Display

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



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

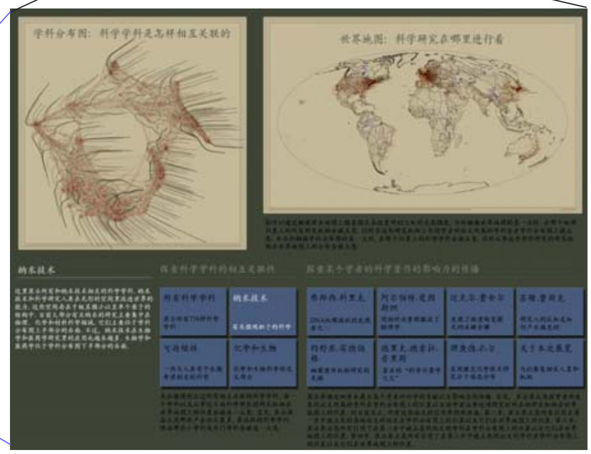
Questions:

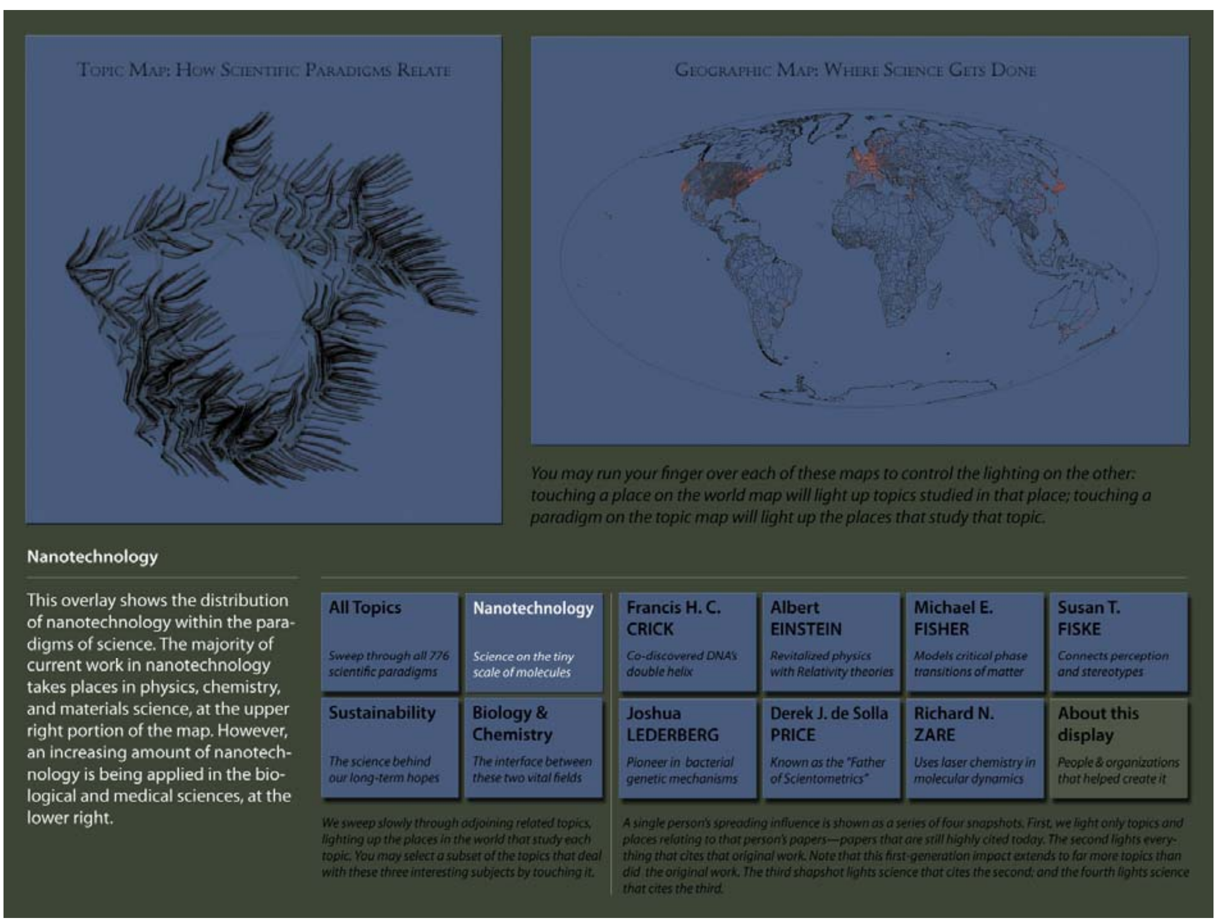
- Who is doing research on what topic and where?
- What is the 'footprint' of interdisciplinary research fields?
- What impact have scientists?

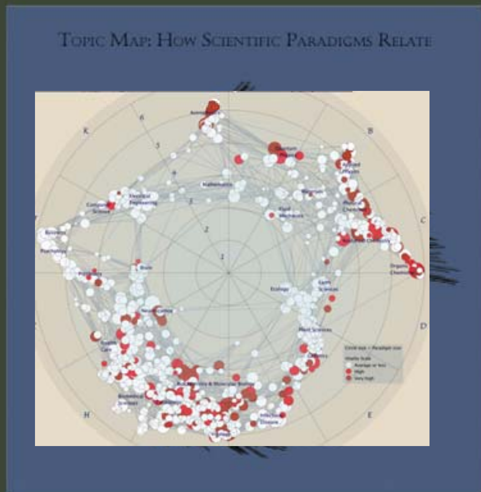
Interactive touch panel.

Contributions:

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







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 places 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.

All Topics — *Sweep through all 776 scientific paradigms*

Nanotechnology — *Science on the tiny scale of molecules*

Sustainability — *The science behind our long-term hopes*

Biology & Chemistry — *The interface between these two vital fields*

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.

Francis H. C. CRICK — *Co-discovered DNA's double helix*

Albert EINSTEIN — *Revitalized physics with Relativity theories*

Michael E. FISHER — *Models critical phase transitions of matter*

Susan T. FISKE — *Connects perception and stereotypes*

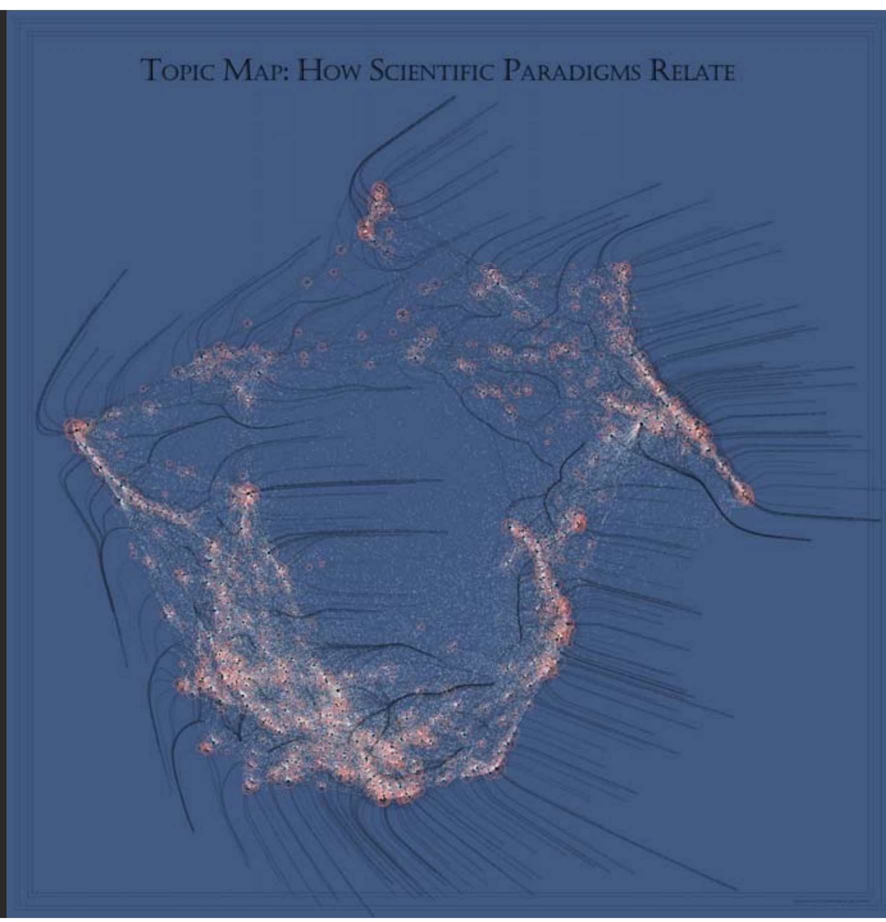
Joshua LEDERBERG — *Pioneer in bacterial genetic mechanisms*

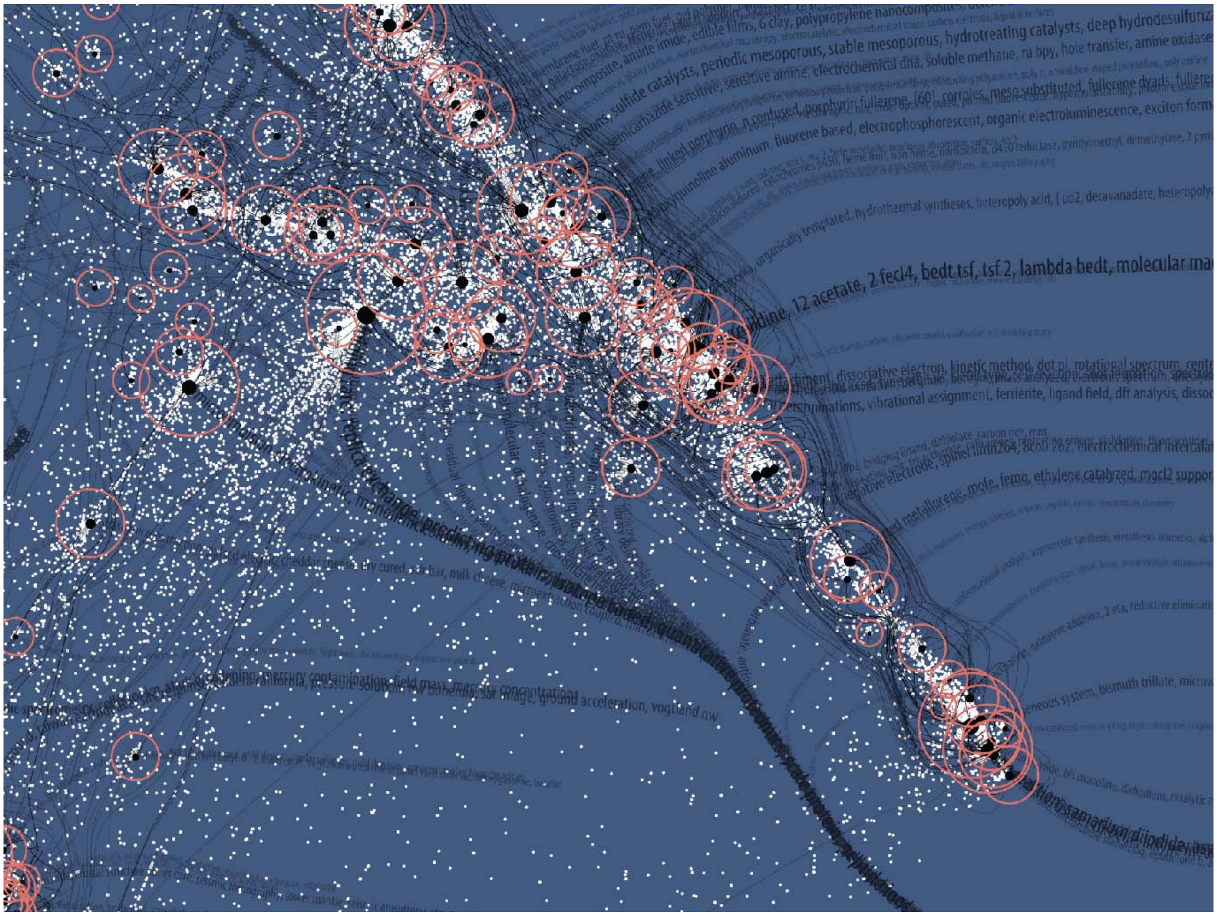
Derek J. de Solla PRICE — *Known as the "Father of Scientometrics"*

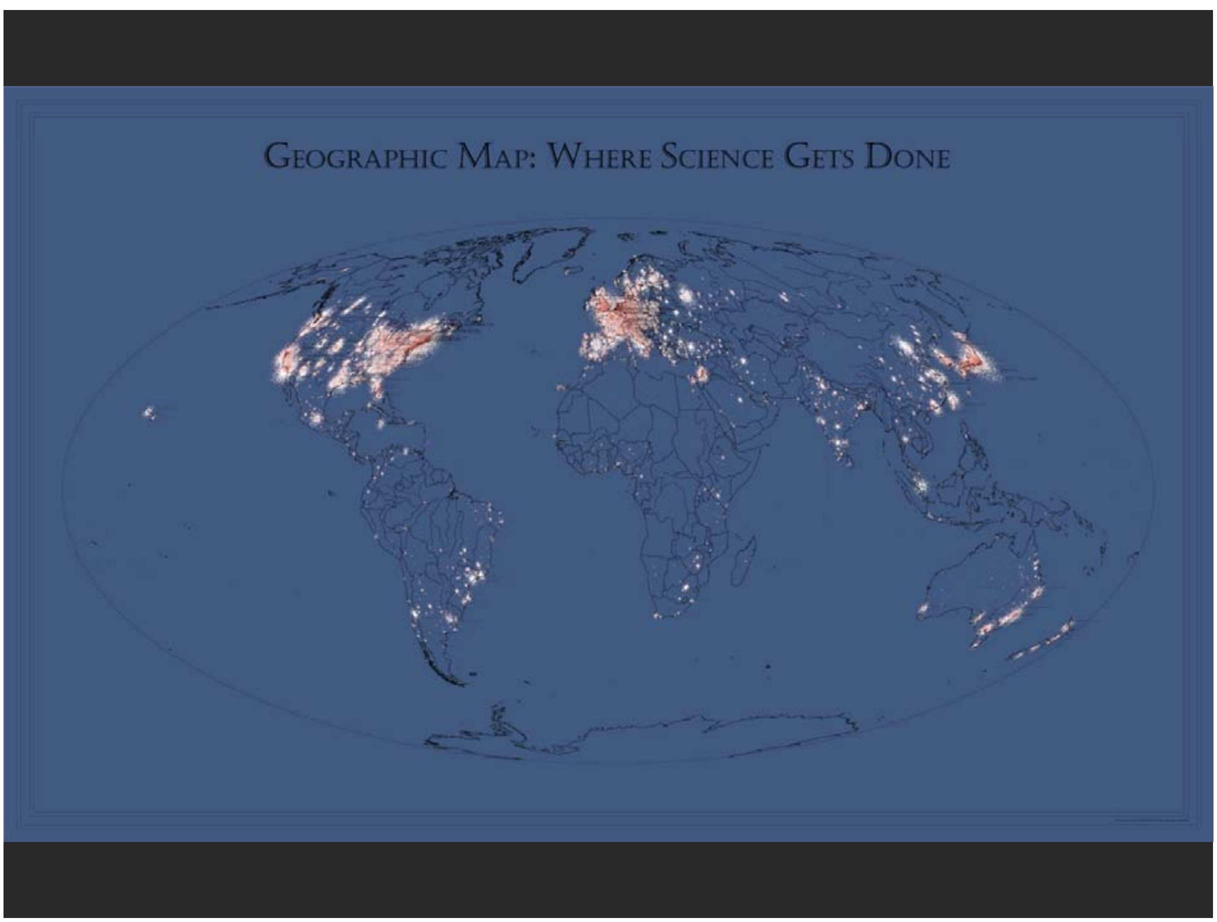
Richard N. ZARE — *Uses laser chemistry in molecular dynamics*

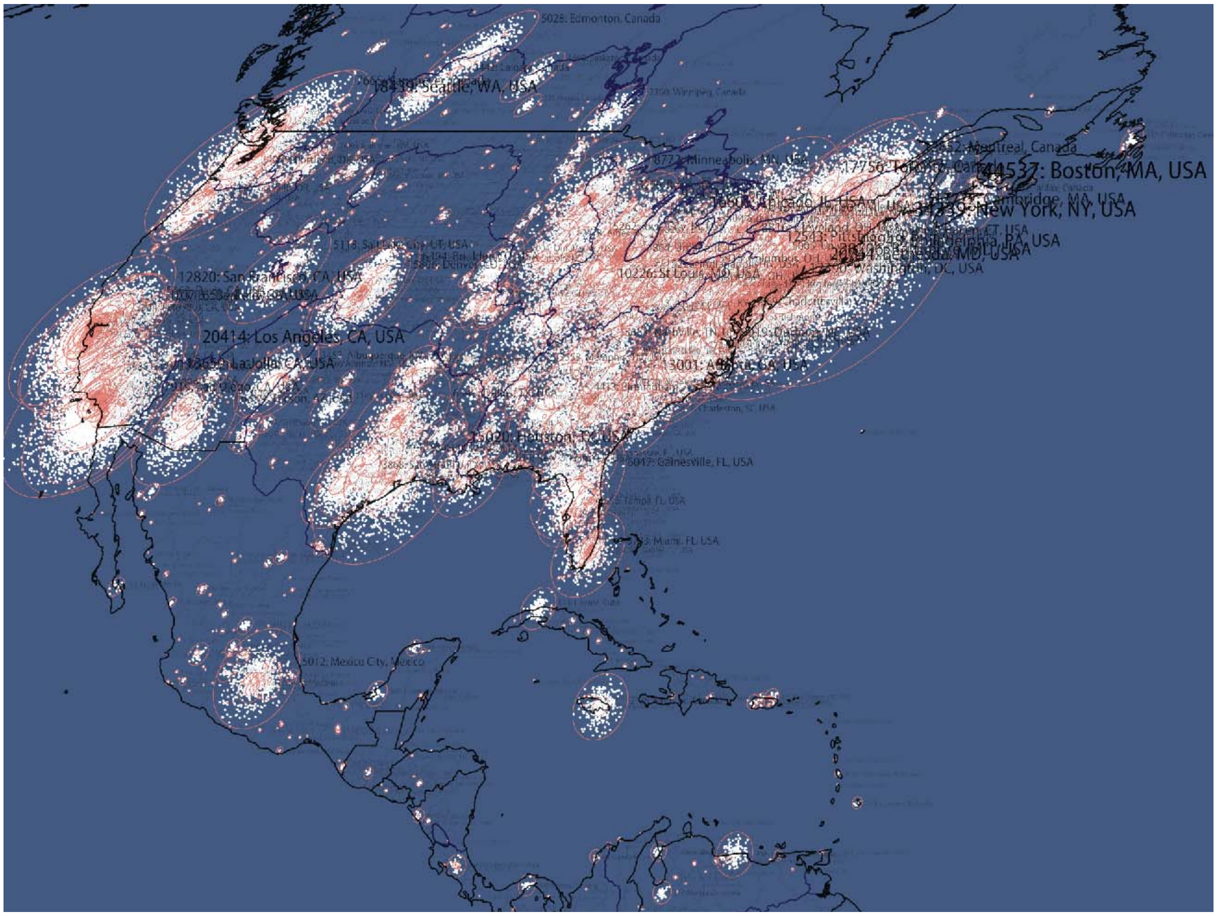
About this display — *People & organizations that helped create it*

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 shapshot lights science that cites the second; and the fourth lights science that cites the third.

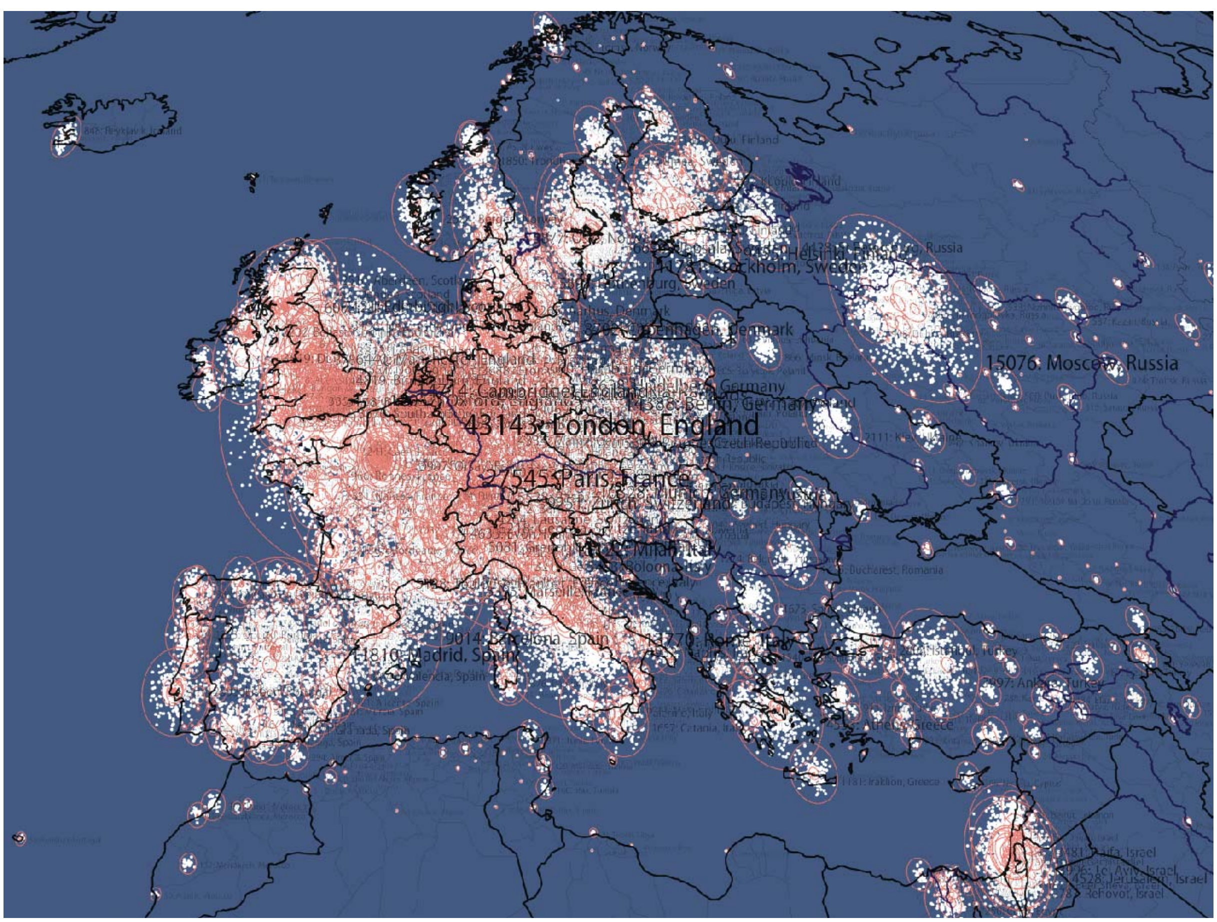



hydrothermal syntheses, heteropoly acid, (uo2, decavanadate
12 acetate, 2 fecl4, bedt tsf, tsf 2, lambda bedt
fluorene based, electrophosphorescent, organic electroluminescence
vibrational assignment, ferrierite, ligand field, dft analysis

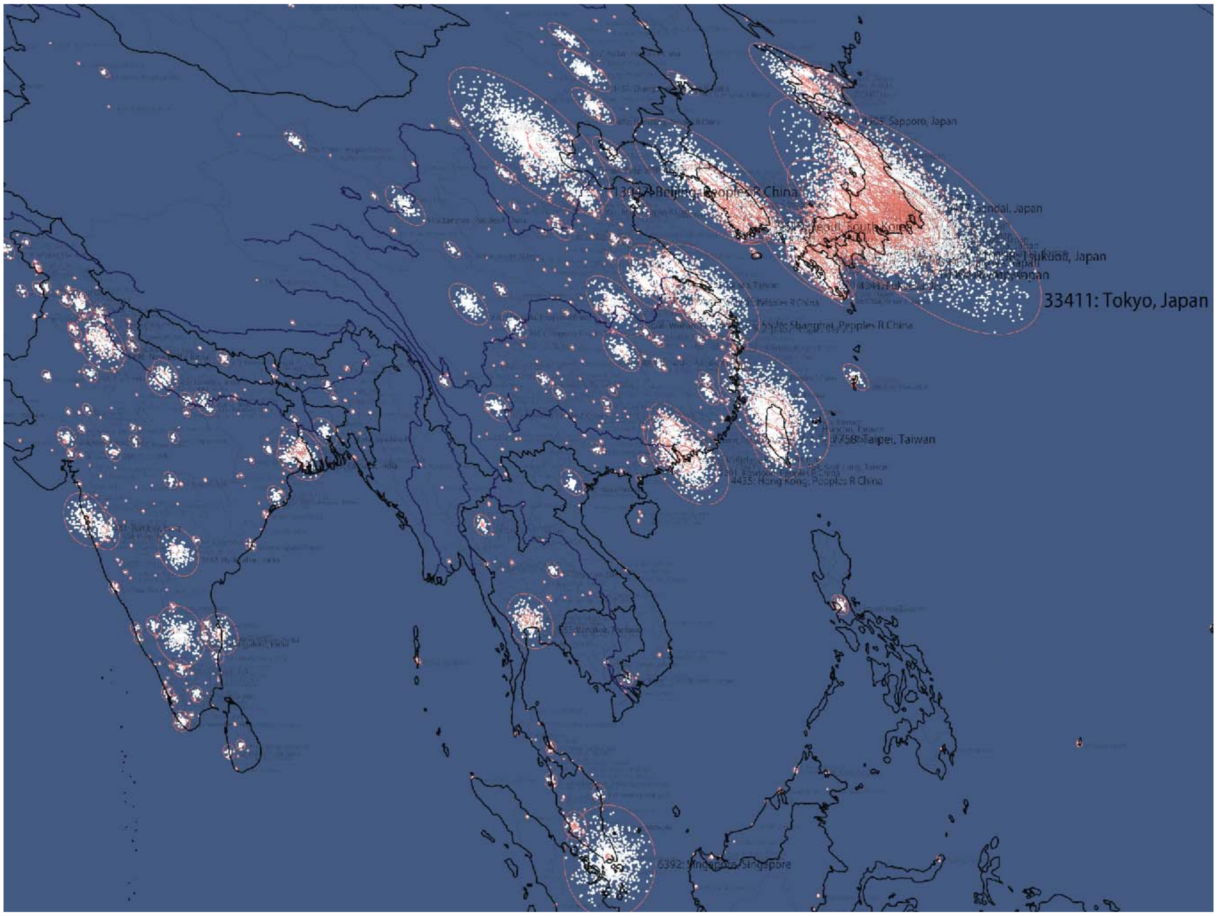

Geographic Map: Where Science Gets Done

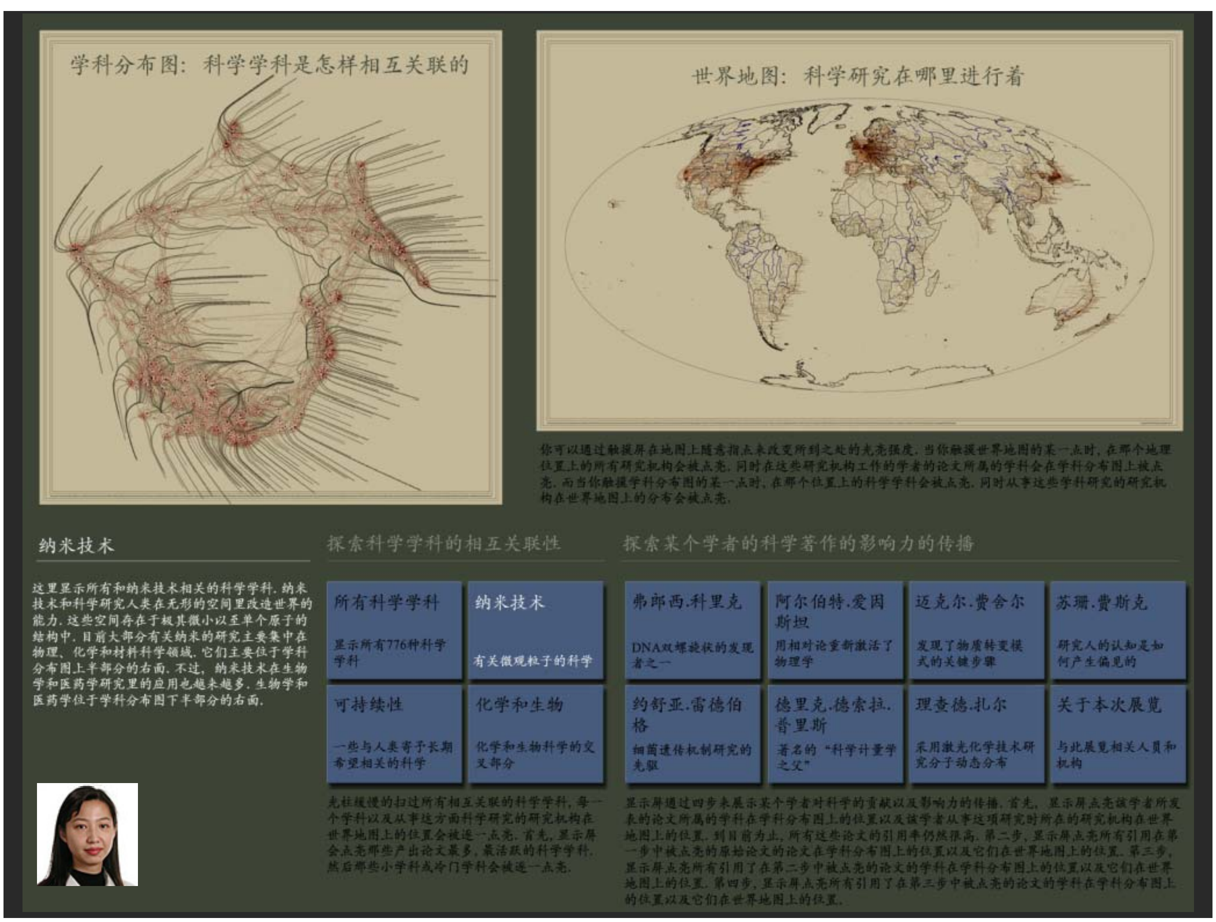


Seattle, WA, USA
Boston, MA, USA
New York, NY, USA
20414: Los Angeles, CA, USA
Washington, DC, USA
Gainesville, FL, USA
Miami, FL, USA



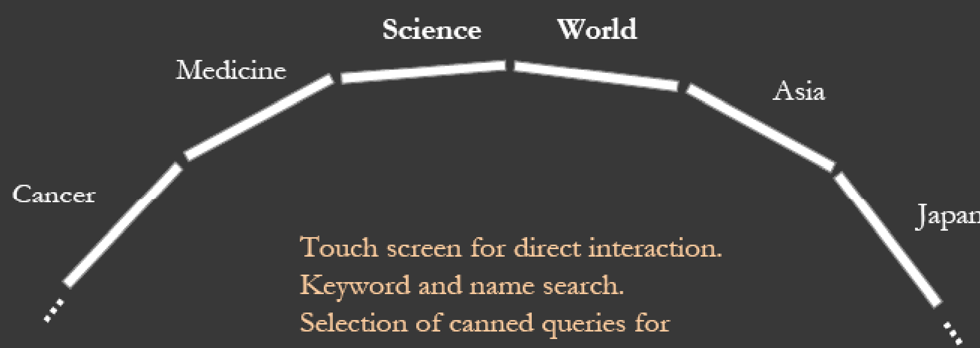
Stockholm, Sweden
15076: Moscow, Russia
43143: London, England
Paris, France
Madrid, Spain
Bucharest, Romania
Haifa, Israel


3041: Beijing, Peoples R China
Sapporo, Japan
33411: Tokyo, Japan
Shanghai, Peoples R China
2758: Taipei, Taiwan
4435: Hong Kong, Peoples R China
6392: Singapore, Singapore


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光亮强度。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
纳米技术
有关微观粒子的科学
可持续性
一些与人类寄予长期希望相关的科学
化学和生物
化学和生物科学的交叉部分
光柱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。
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双螺旋状的发现者之一
阿尔伯特.爱因斯坦
用相对论重新激活了物理学
迈克尔.费舍尔
发现了物质转变模式的关键步骤
苏珊.费斯克
研究人的认知是如何产生偏见的
约舒亚.雷德伯格
细菌遗传机制研究的先驱
德里克.德索拉.普里斯
著名的“科学计量学之父”
理查德.扎尔
采用激光化学技术研究分子动态分布
关于本次展览
与此展览相关人员和机构
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。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

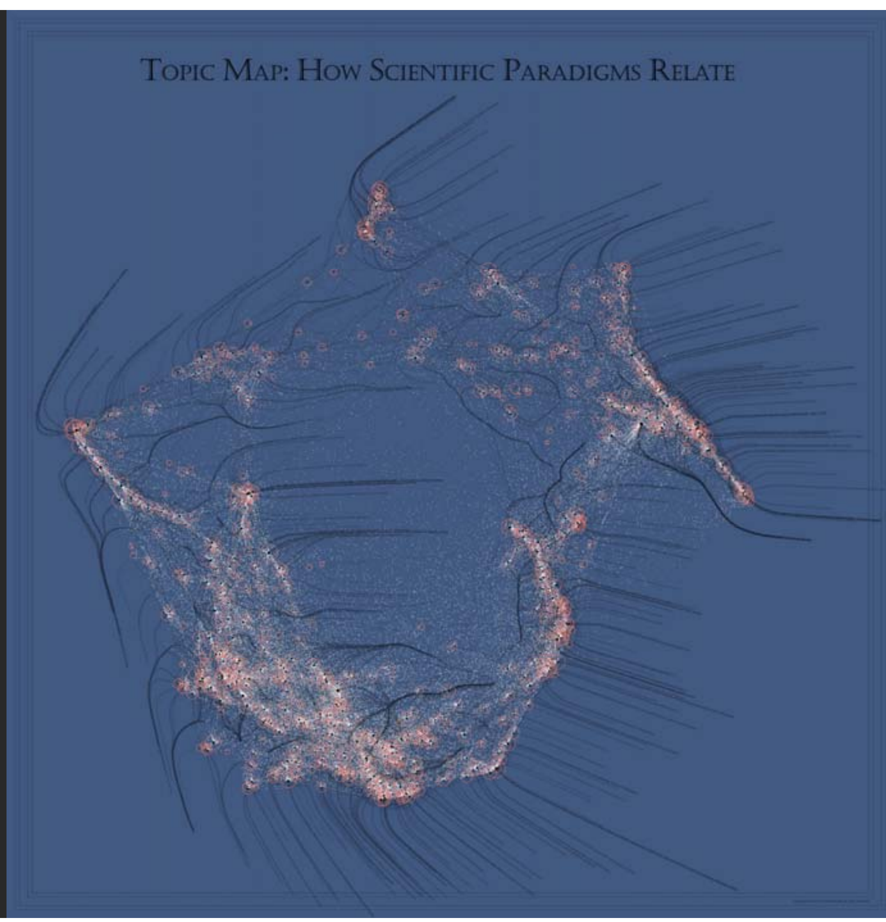
Drives unlimited number of ID screens.



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.

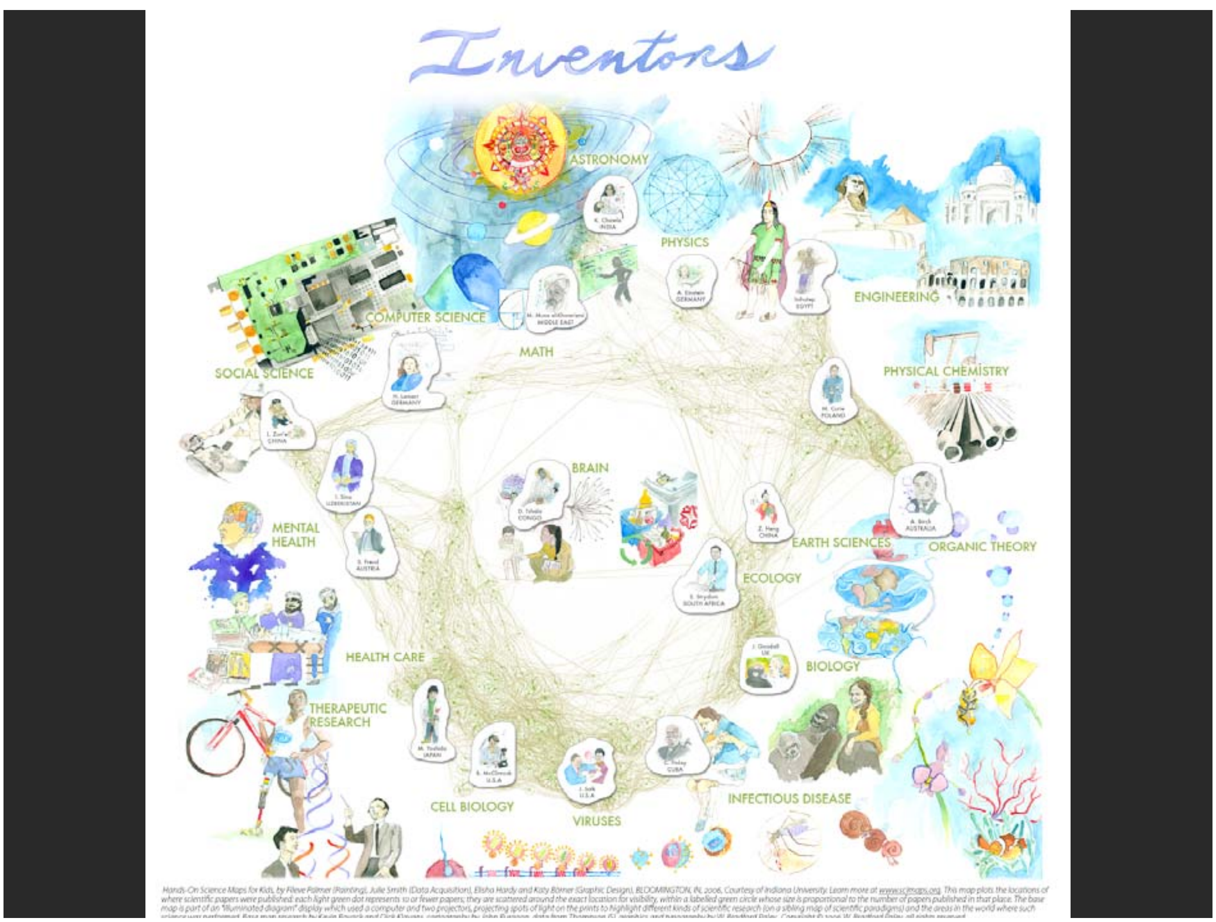
Hands-on Science Maps for Kids

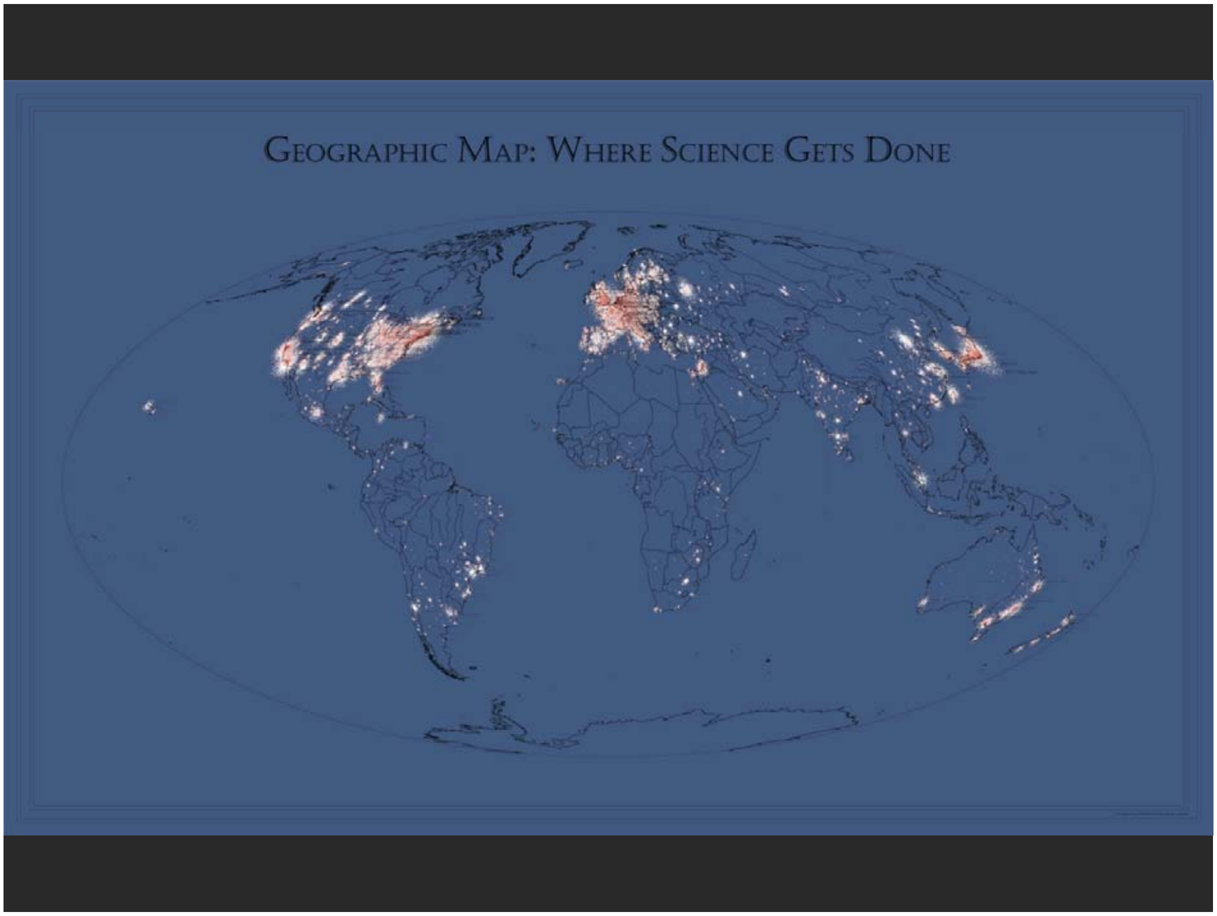
All maps of science are on sale via
http://scimaps.org/ordermaps/

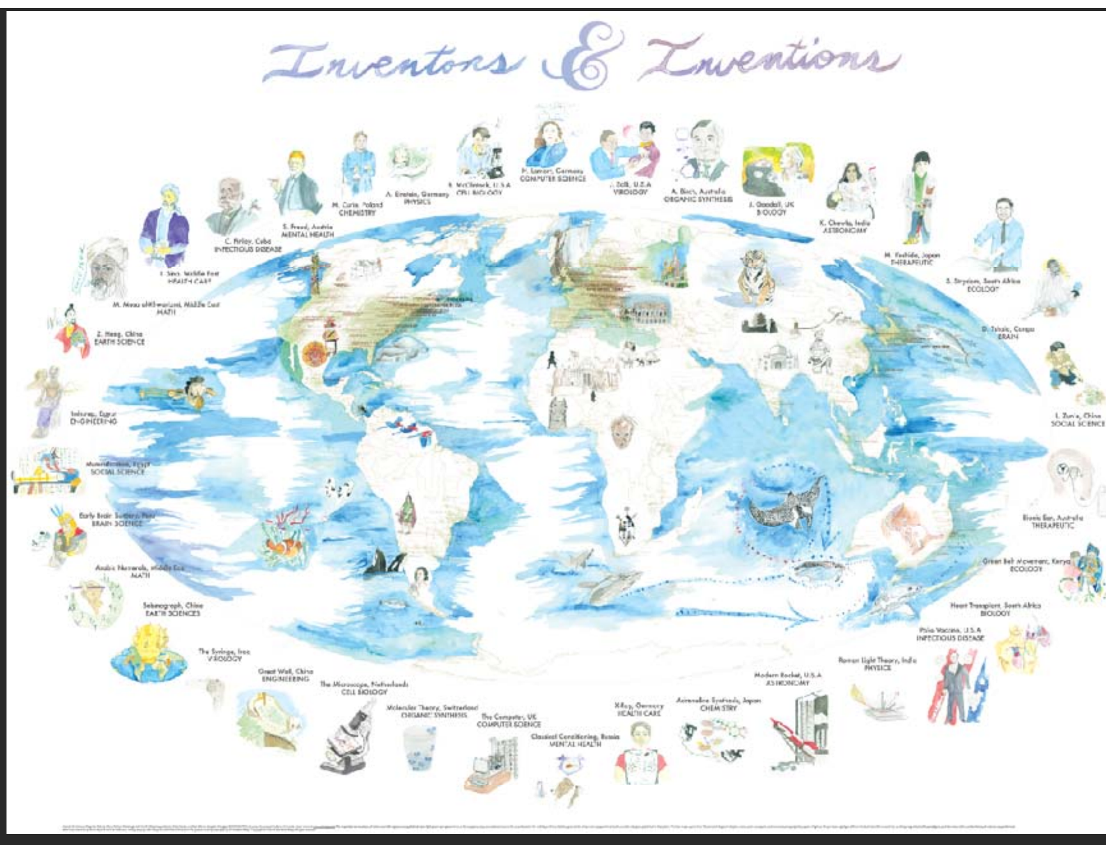


Topic Map: How Scientific Paradigms Relate


Inventors & Inventions
ASTRONOMY
PHYSICS
ENGINEERING
COMPUTER SCIENCE
MATH
SOCIAL SCIENCE
PHYSICAL CHEMISTRY
BRAIN
MENTAL HEALTH
EARTH SCIENCES
ORGANIC THEORY
ECOLOGY
HEALTH CARE
BIOLOGY
THERAPEUTIC RESEARCH
INFECTIOUS DISEASE
CELL BIOLOGY
VIRUSES
Hands-On Science Maps for Kids, by Fileve Palmer (Painting), Julie Smith (Data Acquisition), Elisha Hardy and Katy Börner (Graphic Design), BLOOMINGTON, IN, 2006, Courtesy of Indiana University. Learn more at www.scimaps.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 "illuminated diagram" display which used a computer and two projectors, projecting spots of light on the prints to highlight different kinds of scientific research (on a sibling map of scientific paradigms) and the areas in the world where such


Inventors
ASTRONOMY
PHYSICS
A. Einstein
GERMANY
ENGINEERING
COMPUTER SCIENCE
MATH
SOCIAL SCIENCE
PHYSICAL CHEMISTRY
M. Curie
POLAND
BRAIN
MENTAL HEALTH
S. Freud
AUSTRIA
EARTH SCIENCES
ORGANIC THEORY
ECOLOGY
HEALTH CARE
BIOLOGY
THERAPEUTIC RESEARCH
INFECTIOUS DISEASE
CELL BIOLOGY
VIRUSES

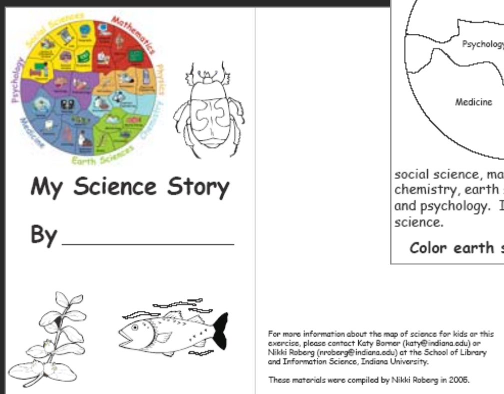


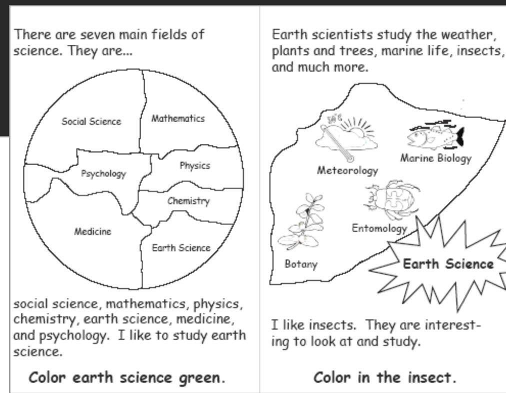


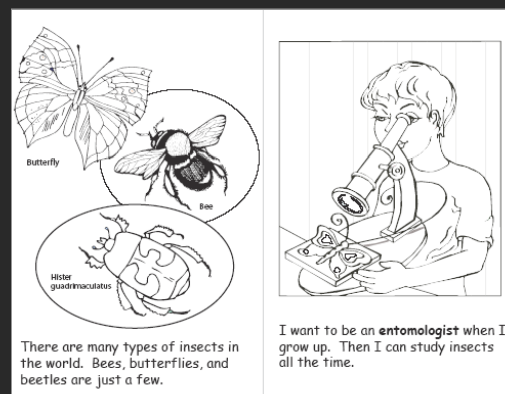
Science Puzzle Map for Kids by Fileve Palmer, Julie Smith, Elisha Hardy and Katy Börner, Indiana University, 2006.
(Base map taken from Illuminated Diagram display by Kevin Boyack, Richard Klavans, and W. Bradford Paley.)


Inventors
Hands-On Science Maps for Kids, by Fileve Palmer (Painting), Julie Smith (Data Acquisition), Elisha Hardy and Katy Börner (Graphic Design), BLOOMINGTON, IN, 2006, Courtesy of Indiana University. Learn more at www.scimaps.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 "illuminated diagram" display which used a computer and two projectors, projecting spots of light on the prints to highlight different kinds of scientific research (on a sibling map of scientific paradigms) and the areas in the world where such science was performed. Base map research by Kevin Boyack and Dick Klavans, cartography by John Burgoon, data from Thompson ISI, graphics and typography by W. Bradford Paley. Copyright © 2006 W. Bradford Paley, all rights reserved.


54
SOCCER

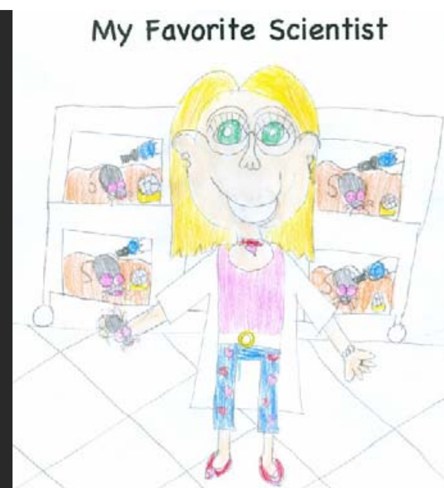






Activities:

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



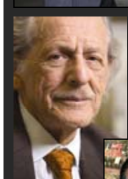
Winners @ AMSE

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

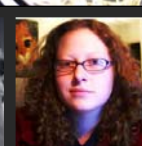
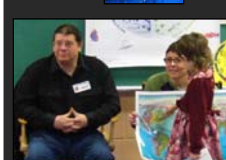
Sascha Richey, age 8, drew a picture of her mother and explained why her mother is her favorite scientist.

Where to go from here?

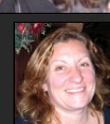
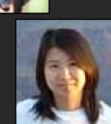


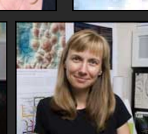



Contact the map makers via the exhibit curators:
Katy Börner (katy@indiana.edu) and Elisha Hardy (efhardy@indiana.edu)





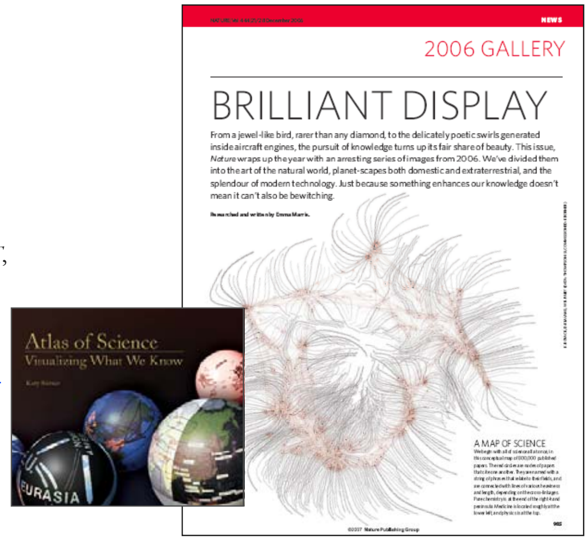
Computational Scientometrics References

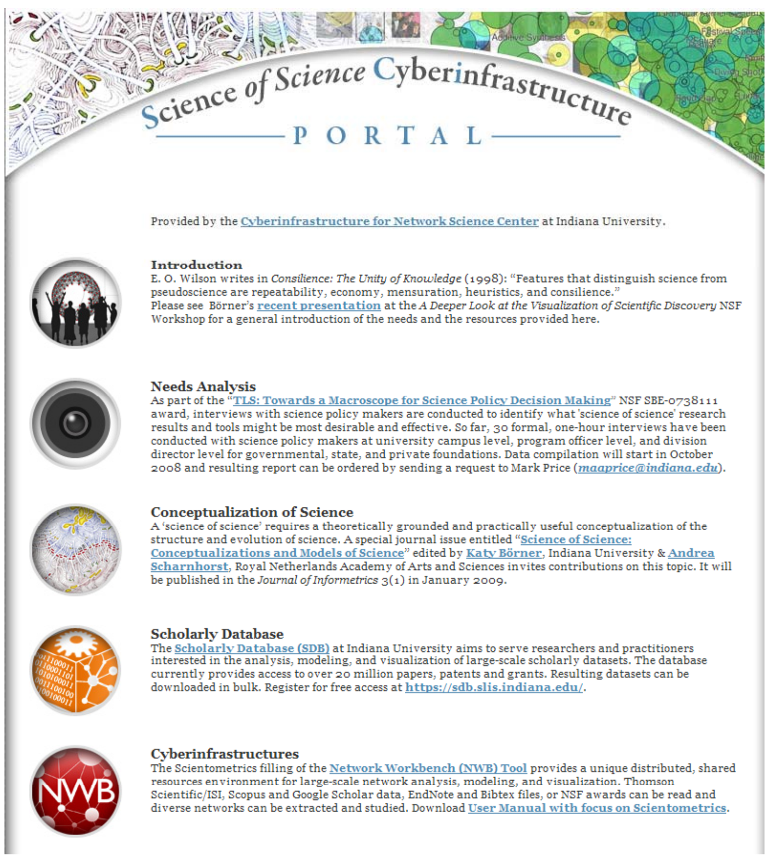
Börner, Katy, Chen, Chaomei, and Boyack, Kevin. (2003). **Visualizing Knowledge Domains.** In Blaise Cronin (Ed.), *ARIST*, Medford, NJ: Information Today, Inc./American Society for Information Science and Technology, Volume 37, Chapter 5, pp. 179-255. http://ivl.slis.indiana.edu/km/pub/2003-borner-arist.pdf

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). http://www.pnas.org/content/vol101/suppl_1/

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

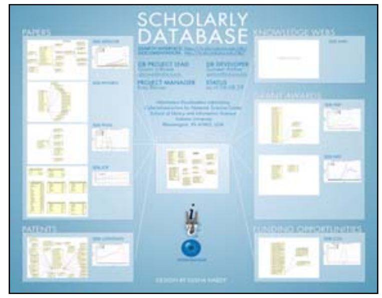
Börner, Katy (2010) Atlas of Science. MIT Press. http://scimaps.org/atlas





http://sci.slis.indiana.edu

Computational Scientometrics Cyberinfrastructures



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

James S. McDonnell Foundation

VIVO Research Networking
http://vivoweb.org

Information Visualization Cyberinfrastructure
http://iv.slis.indiana.edu

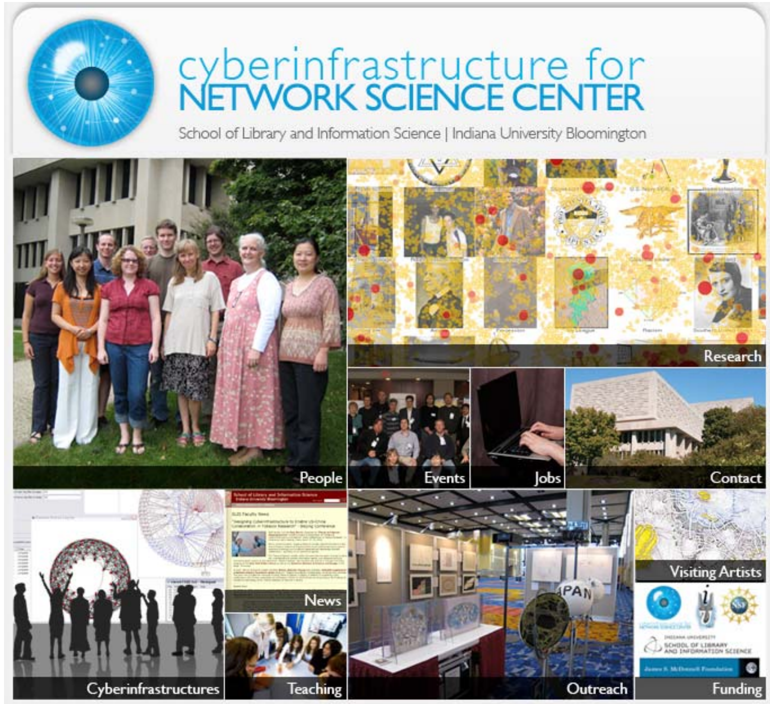
Network Workbench Tool & Community Wiki
http://nwb.slis.indiana.edu

Science of Science (Sci²) Tool and CI Portal
http://sci.slis.indiana.edu

Epidemics Cyberinfrastructure
http://epic.slis.indiana.edu/

OSGi Alliance

CIShell cyberinfrastructure shell



http://cns.slis.indiana.edu