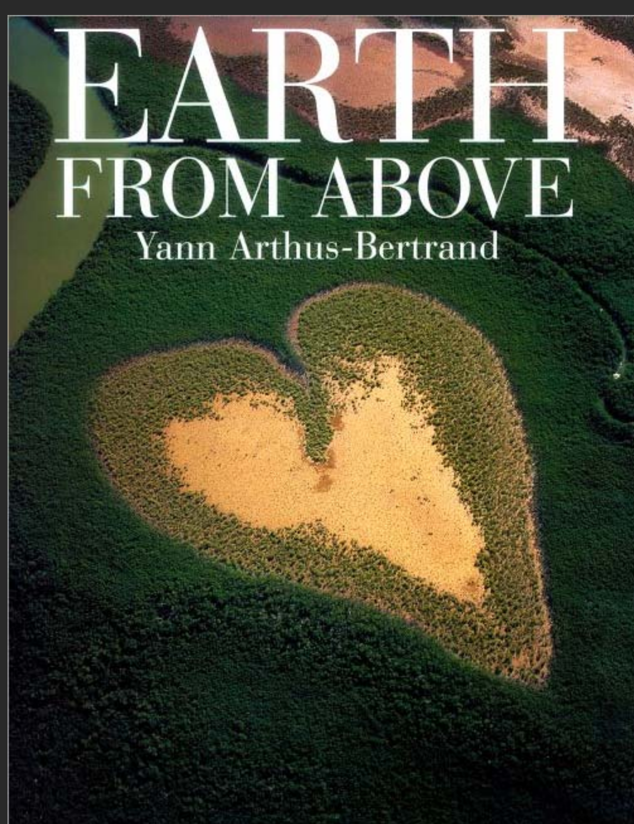
Science from Above

Dr. Katy Börner
Cyberinfrastructure for Network Science Center, Director
Information Visualization Laboratory, Director
School of Library and Information Science
Indiana University, Bloomington, IN
katy@indiana.edu

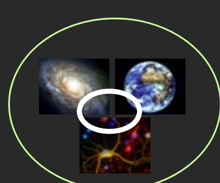
Vanguard Reception
Visualization for Collective, Connective & Distributed Intelligence
Dynamic Knowledge Networks ~ Synthetic Minds
Stanford University, CA: August 12, 2009



The Problem:
Being Lost in (Knowledge) Space

15th Century: One person can make major contributions to **many areas of science**

Mankind's Knowledge



use →

← ***contribute***

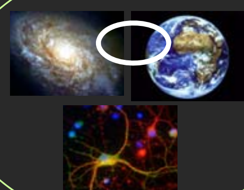
Human Brain

Amount of knowledge
on brain can mange

Leonardo Da Vinci
(1452-1519)

20th Century: One person can make major contributions to **a few areas of science**

Mankind's Knowledge



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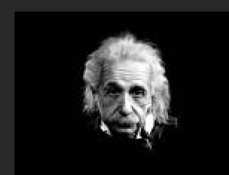
Human Brain

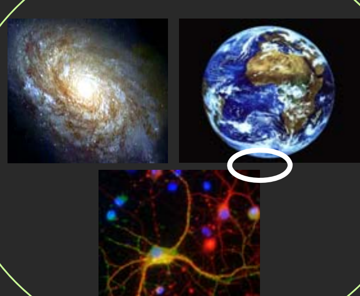
Amount of knowledge
on brain can mange



Albert Einstein
(1879-1955)

21th Century: One person can make major contributions to **a specific area of science**

Mankind's Knowledge



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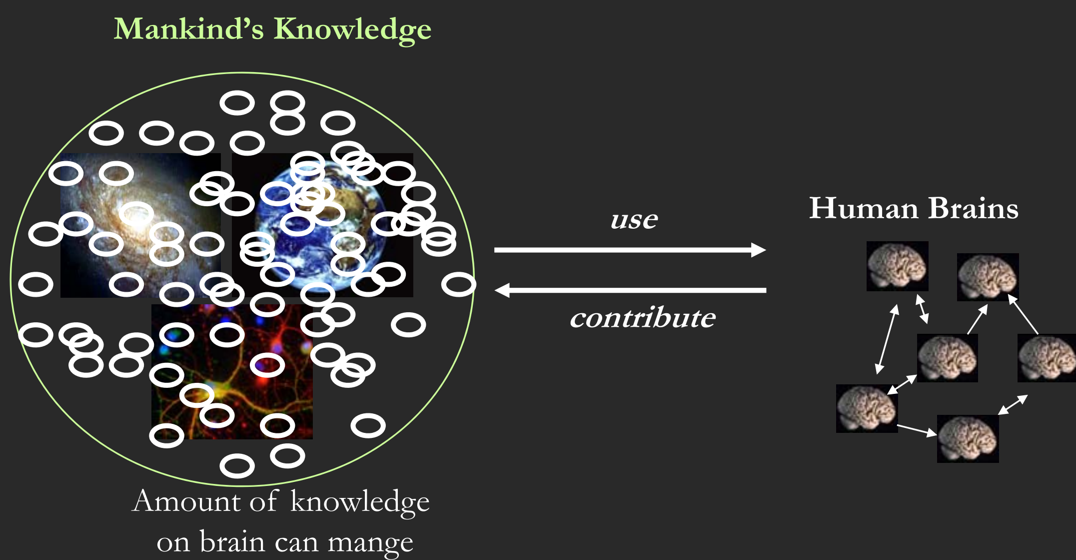
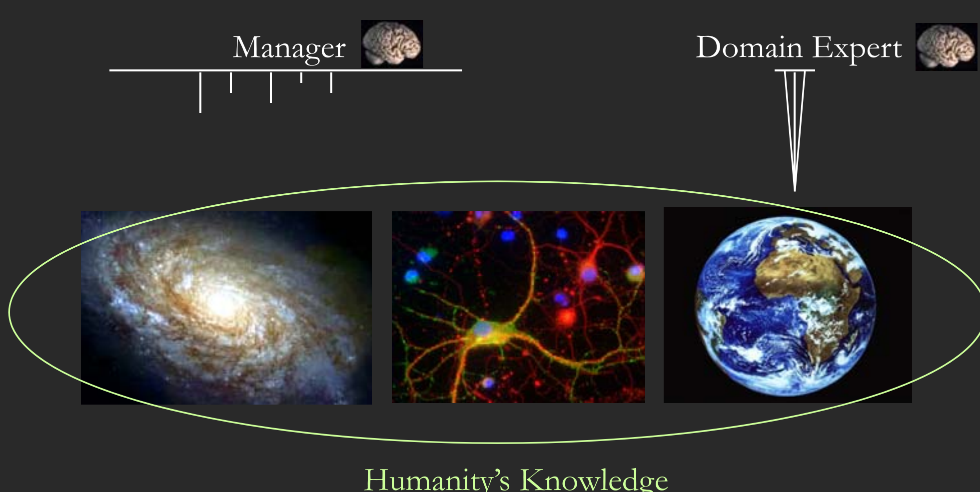
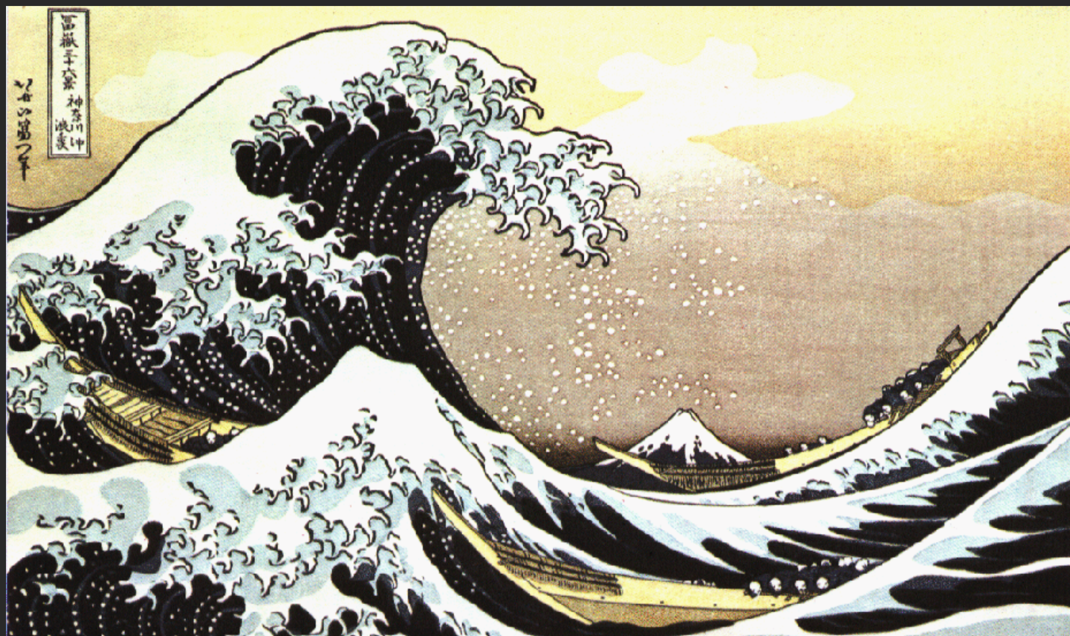
Human Brain

Amount of knowledge
on brain can mange

21th Century: One person can make major contributions to **a specific area of science**







The Great Wave Off Kanagawa (Katsushika Hokusai, 1760-1849)

Mapping Science Exhibit

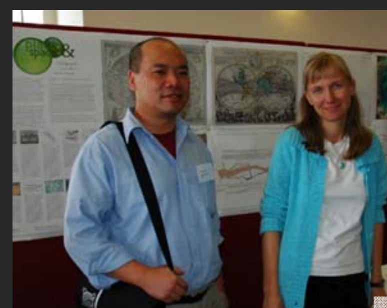
Places & Spaces: Mapping Science

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

Exhibit Curators:

Dr. Katy Börner & Elisha Hardy

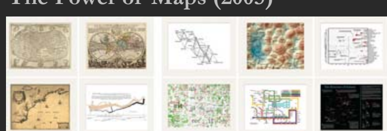
http://scimaps.org



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

The Power of Forecasts (2007)

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
- Wallenberg Hall, Stanford University, CA
- Center of Advanced European Studies and Research, Bonn, Germany
- Science Train, Germany.

ORDER MAPS

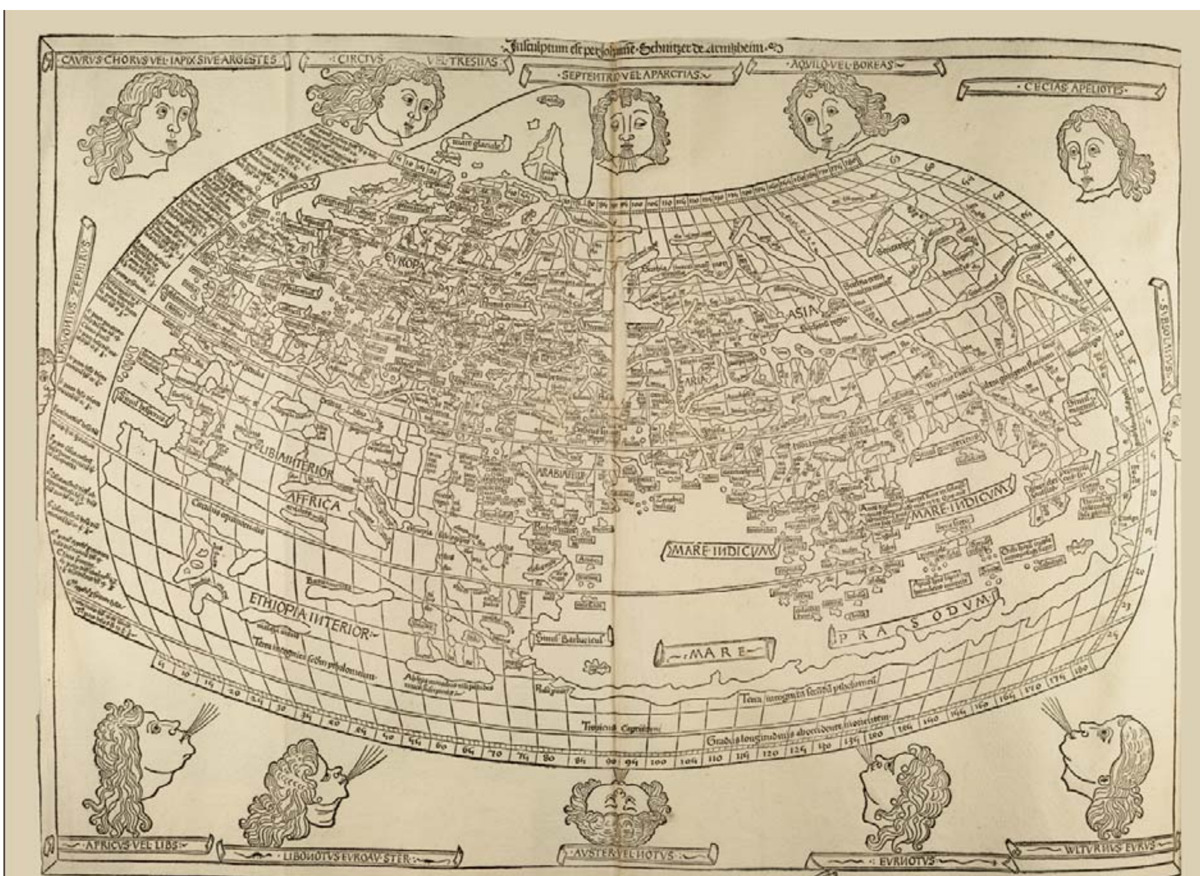
Debut of 5th Iteration of Mapping Science Exhibit at MEDIA X was on May 18, 2009 at Wallenberg Hall, Stanford University, *http://mediax.stanford.edu*, *http://scaleindependentthought.typepad.com/photos/scimaps*

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*

The Power of Maps

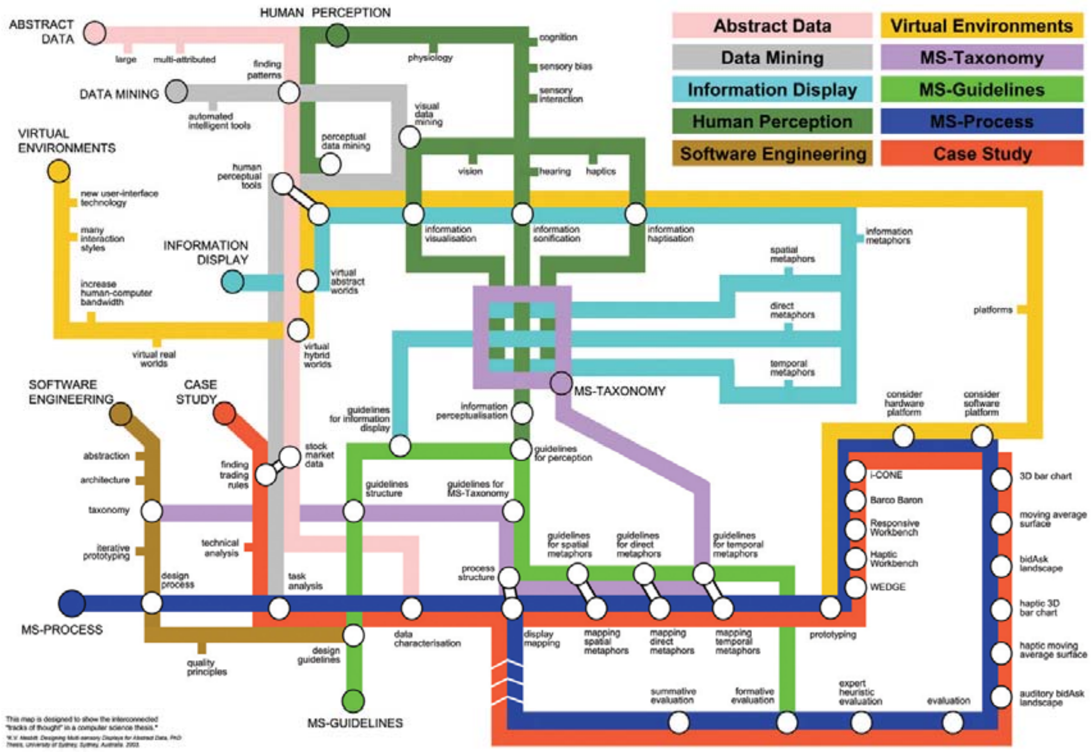
Four Early Maps of Our World
VERSUS
Six Early Maps of Science

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

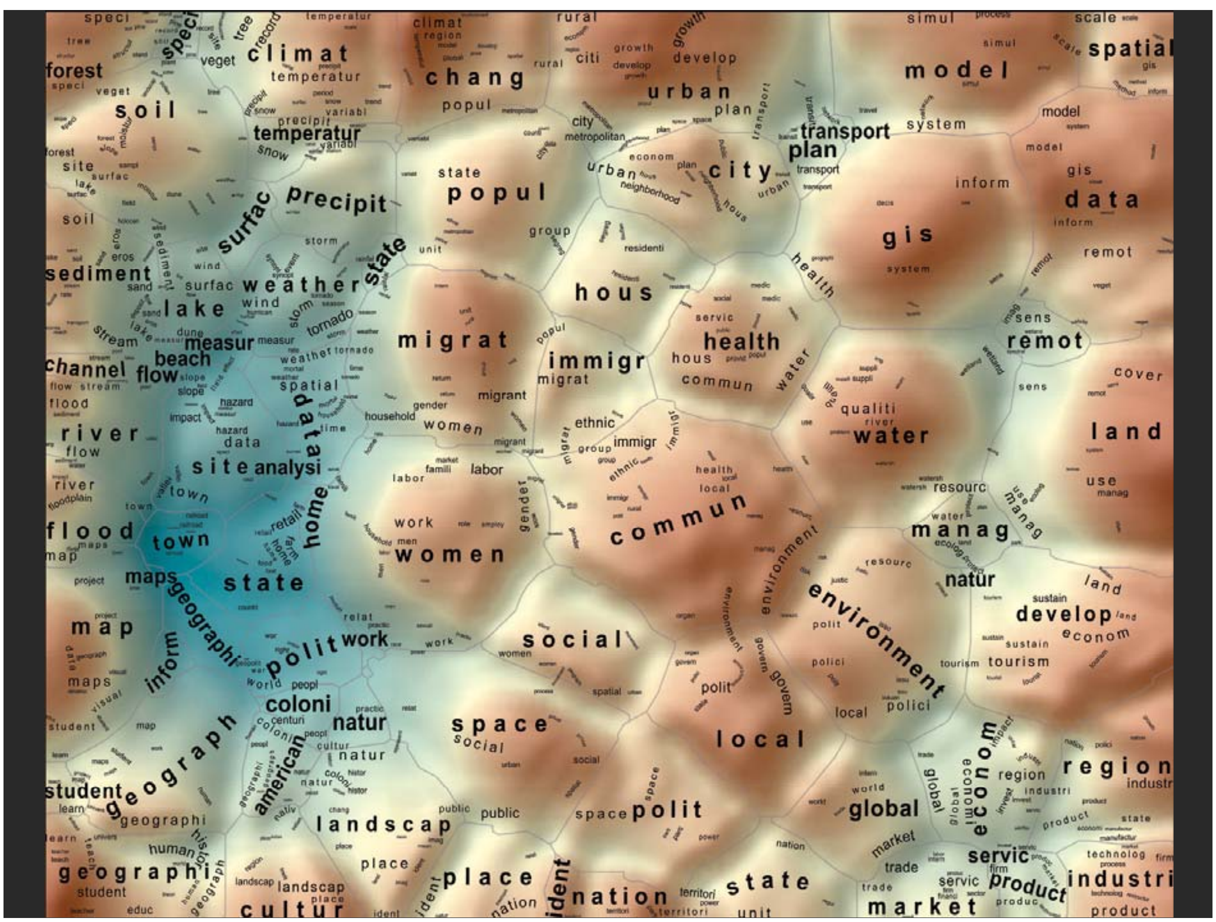


How would a map of science look?

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
This map is designed to show the interconnected "tracks of thought" in a computer science thesis.



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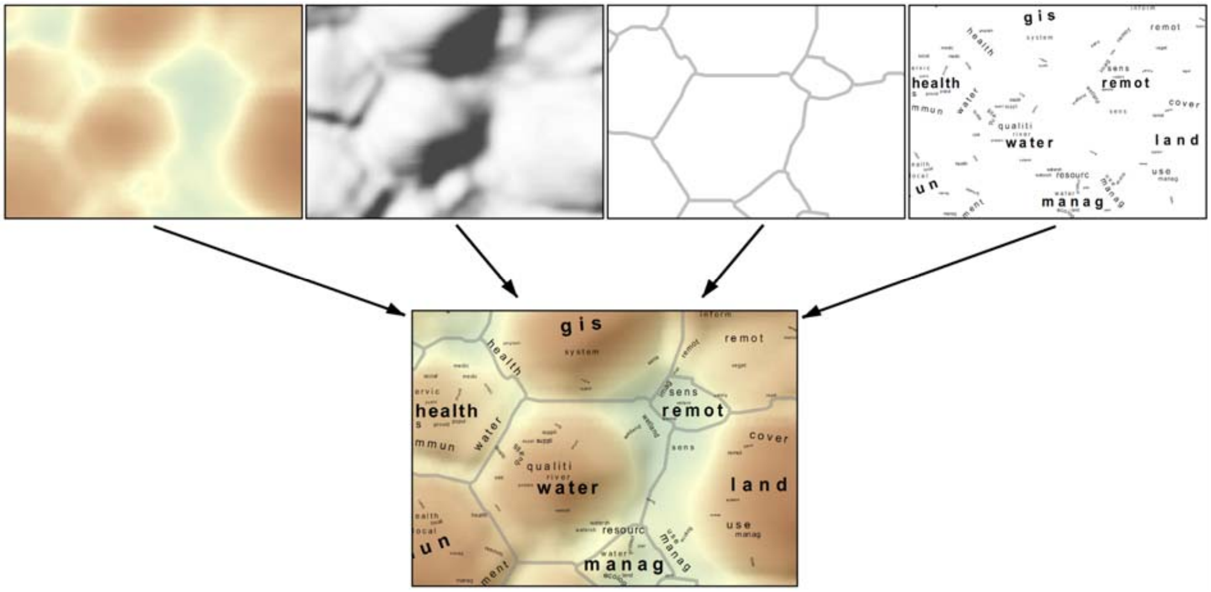
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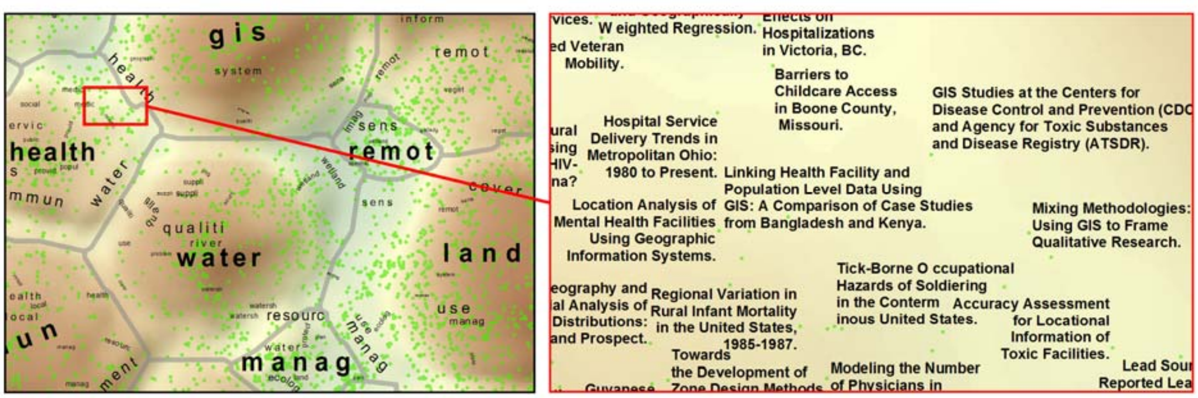
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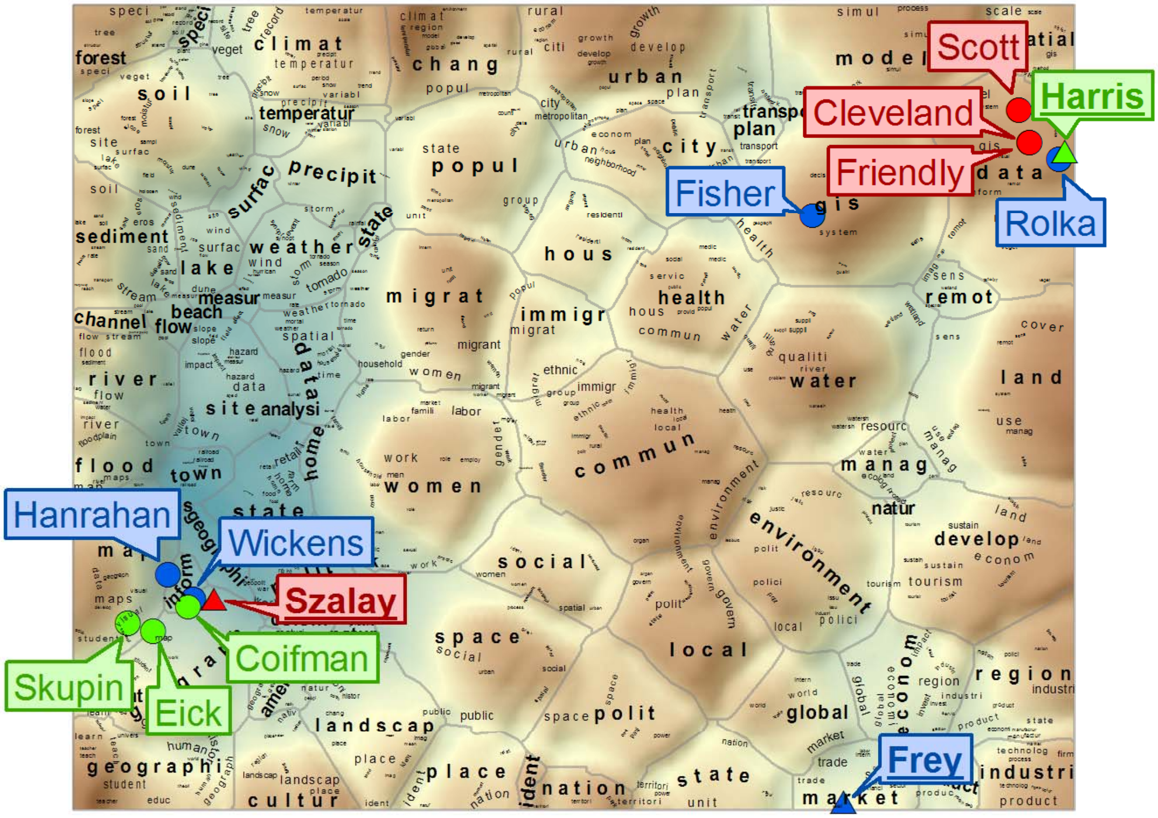
Barriers to Childcare Access in Boone County, Missouri.
GIS Studies at the Centers for Disease Control and Prevention (CDC and Agency for Toxic Substances and Disease Registry (ATSDR).
Hospital Service Delivery Trends in Metropolitan Ohio: 1980 to Present.
Linking Health Facility and Population Level Data Using GIS: A Comparison of Case Studies from Bangladesh and Kenya.
Location Analysis of Mental Health Facilities Using Geographic Information Systems.
Mixing Methodologies: Using GIS to Frame Qualitative Research.
Tick-Borne O ccupational Hazards of Soldiering in the Conterm inous United States.
Regional Variation in Rural Infant Mortality in the United States, 1985-1987.
Accuracy Assessment for Locational Information of Toxic Facilities.
Towards the Development of
Modeling the Number of Physicians in



Conceptualizations
in Geographic Information Science

Discrete Objects	Continuous Fields
weather gauge	temperature
city	elevation
river	sales tax
lake	

Conceptualizations in Geographic Information Science

Discrete Objects	Continuous Fields
weather gauge	temperature
city	elevation
river	sales tax
lake	lakeness

Lakeness	Definition
1	Location is always dry under all circumstances
2	Location is sometimes flooded in Spring
3	Location supports marshy vegetation
4	Water is always present to a depth of less than 1m
5	Water is always present to a depth of more than 1m

M.F. Goodchild and D.C. Ford (1971) Analysis of scallop patterns under controlled conditions. *Journal of Geology* 52–62.

M.F. Goodchild and B.H. Massam (1971) Some least-cost models of spatial administrative systems in Southern Ontario. In R.L. Gentilcore, editor, *Geographical Approaches to Canadian Problems*. Prentice-Hall, Canada, Ltd., 220–228.

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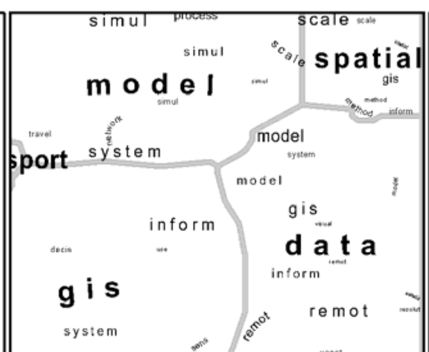

Base Map

M.F. Goodchild and P.J. Booth (1976) Modelling human spatial behaviour in urban recreation facility site location., In *Research Program: Impact of the Public Sector on Local Economies*, Discussion Paper 7. London, Ontario: University of Western Ontario, Department of Economics

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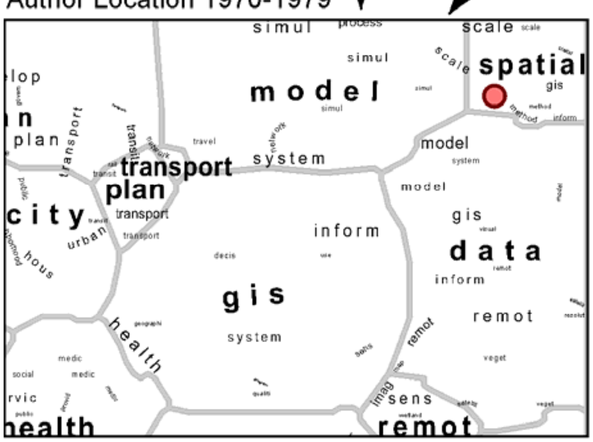
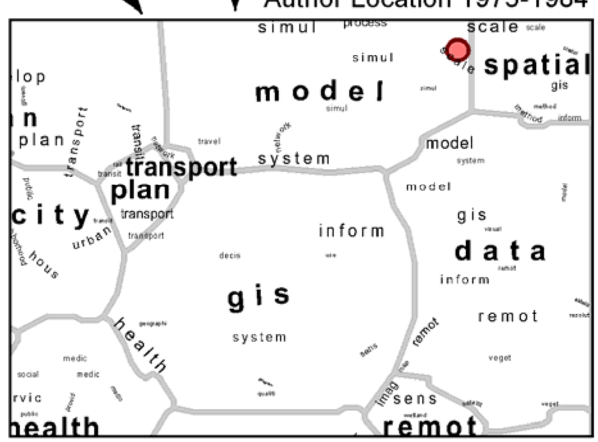
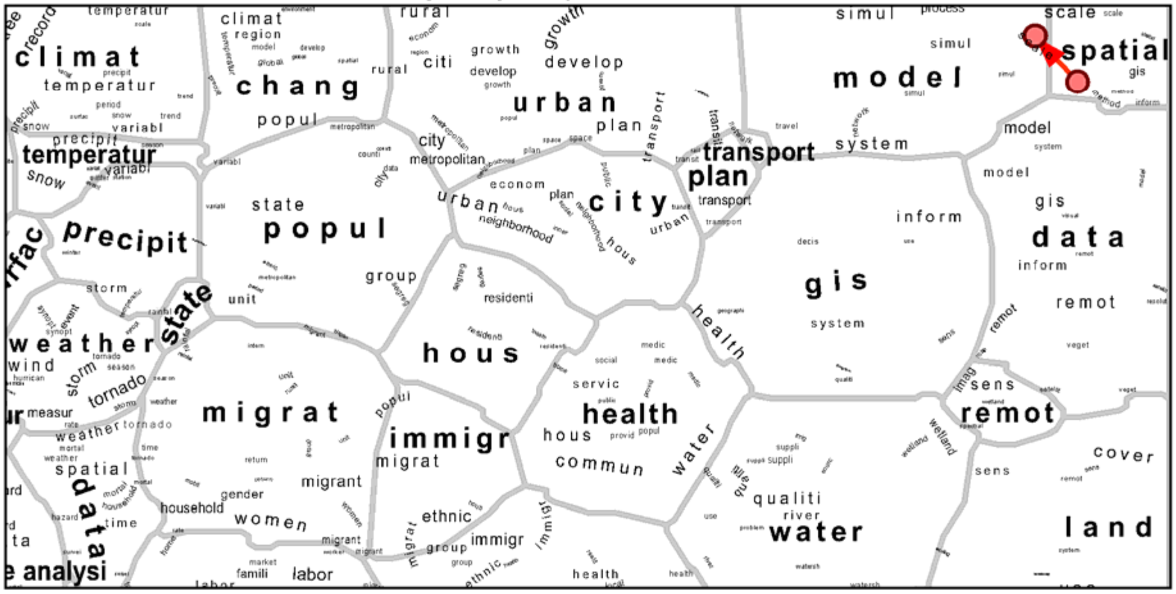
Author Location 1970-1979



Author Location 1975-1984



Author Change Trajectory from 1970-79 to 1975-84



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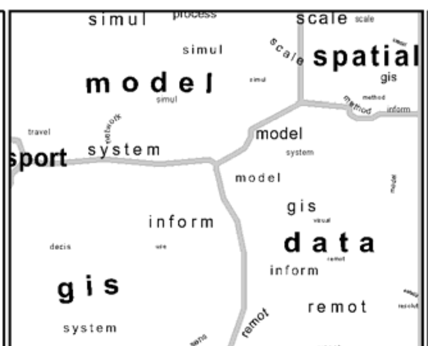

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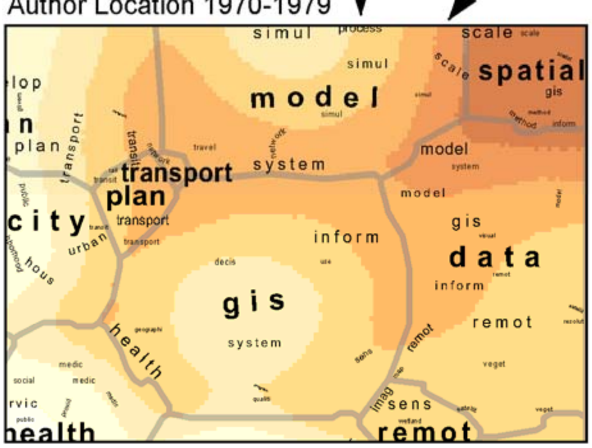
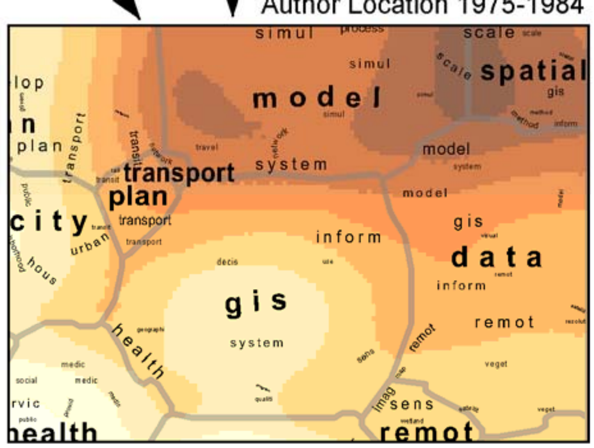
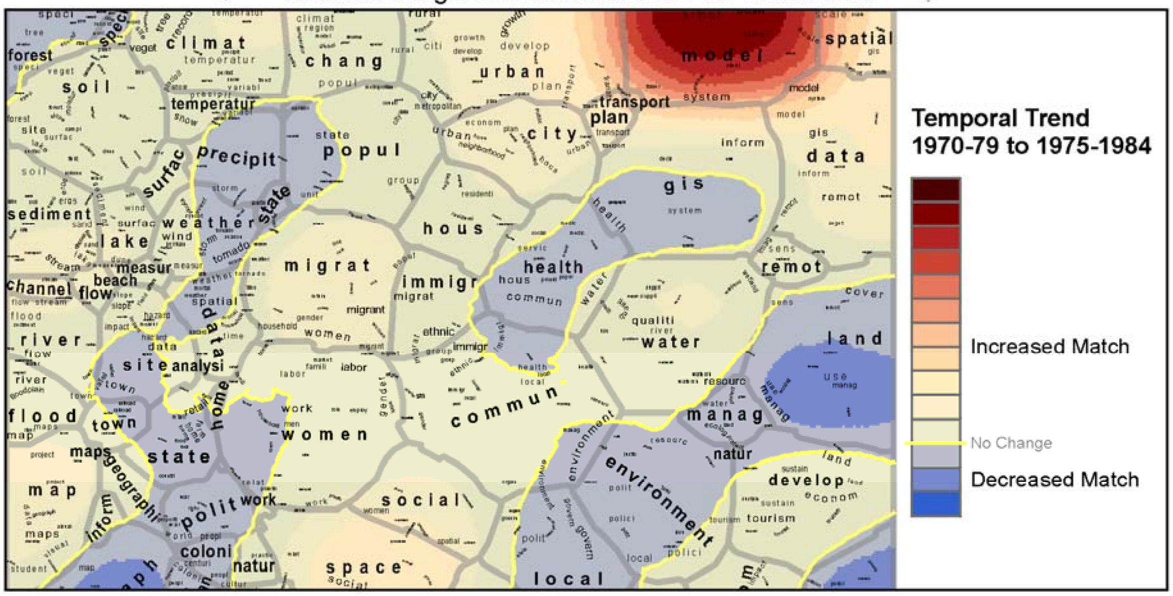
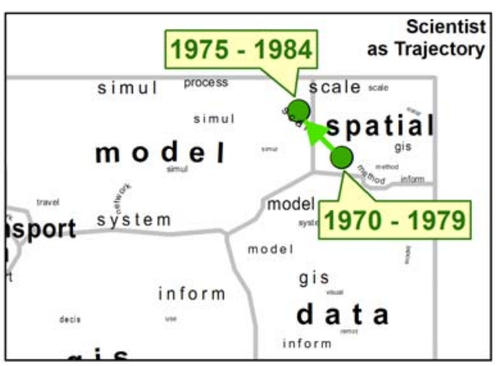


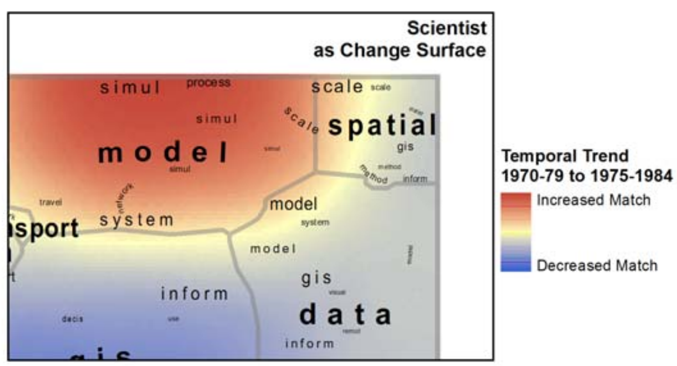
Author Location 1975-1984

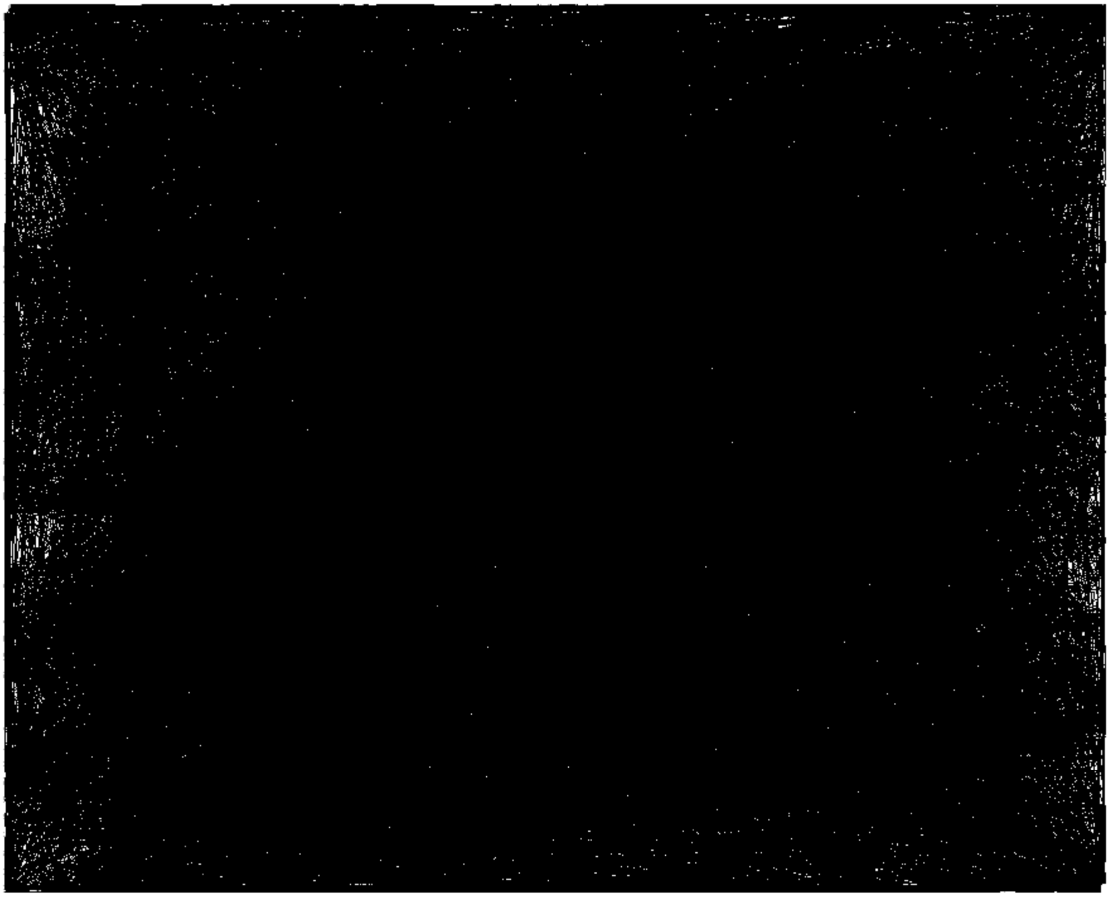


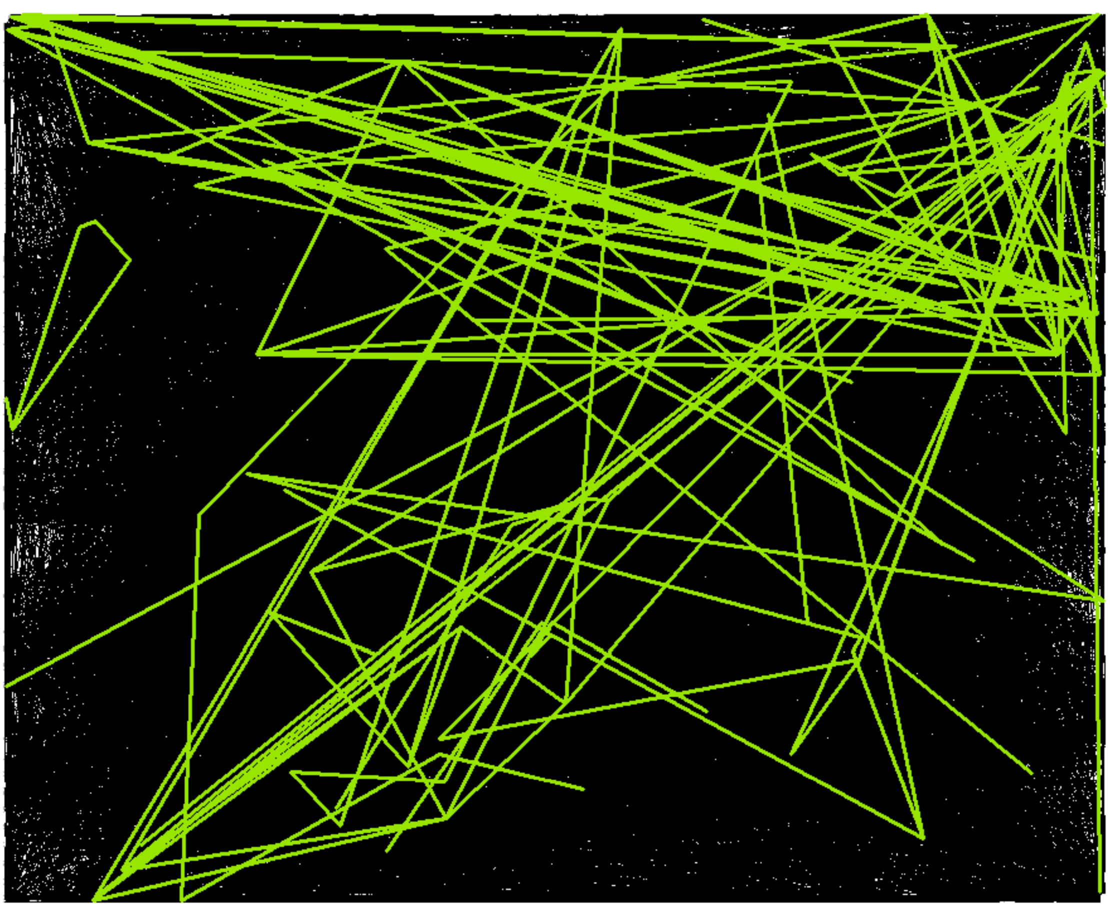
Author Change Surface from 1970-79 to 1975-84

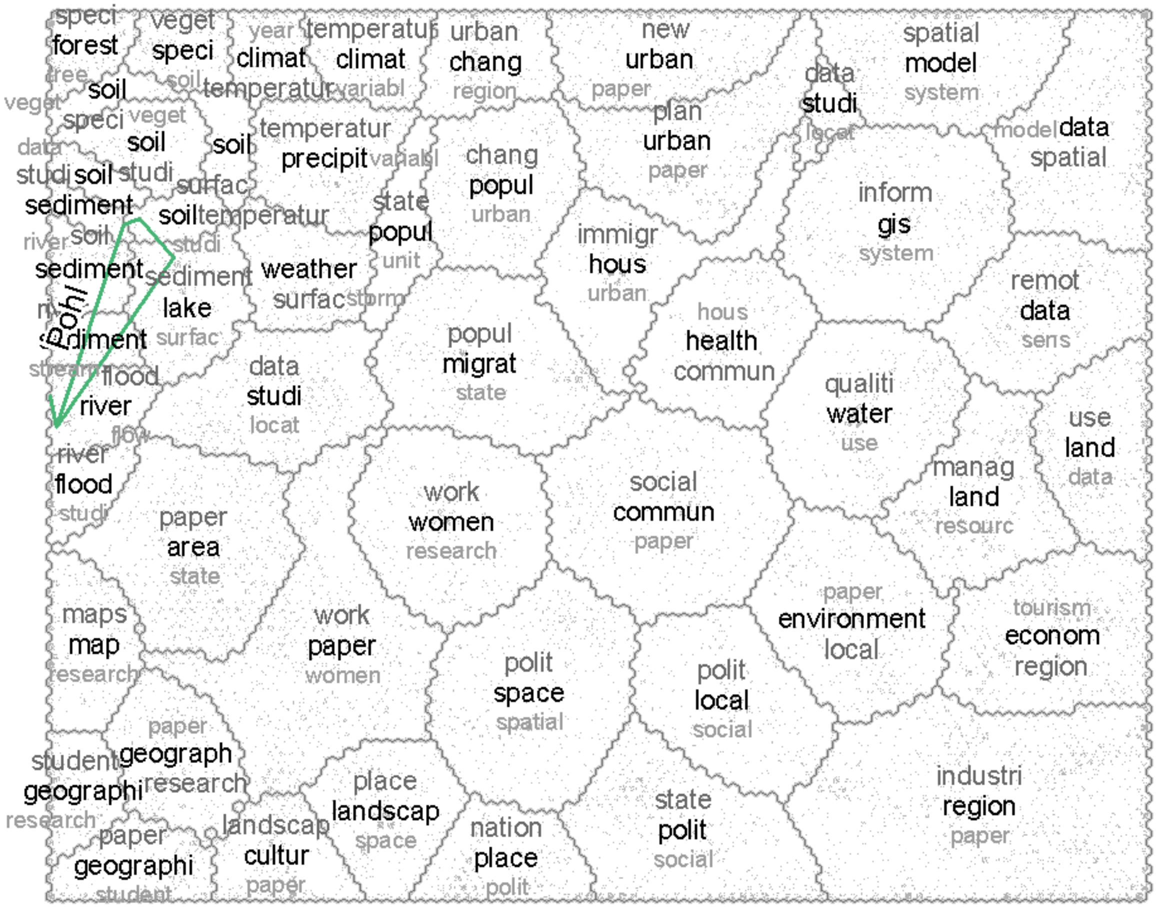








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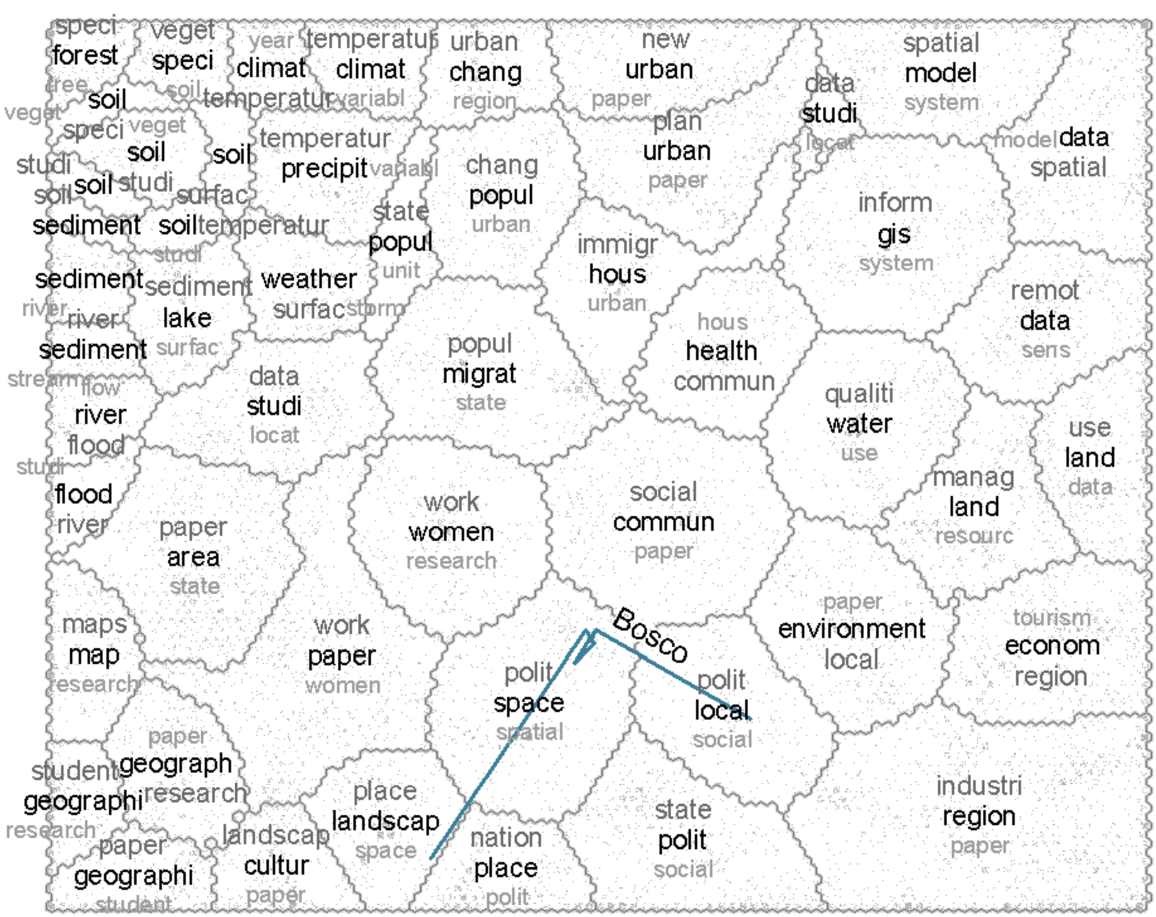
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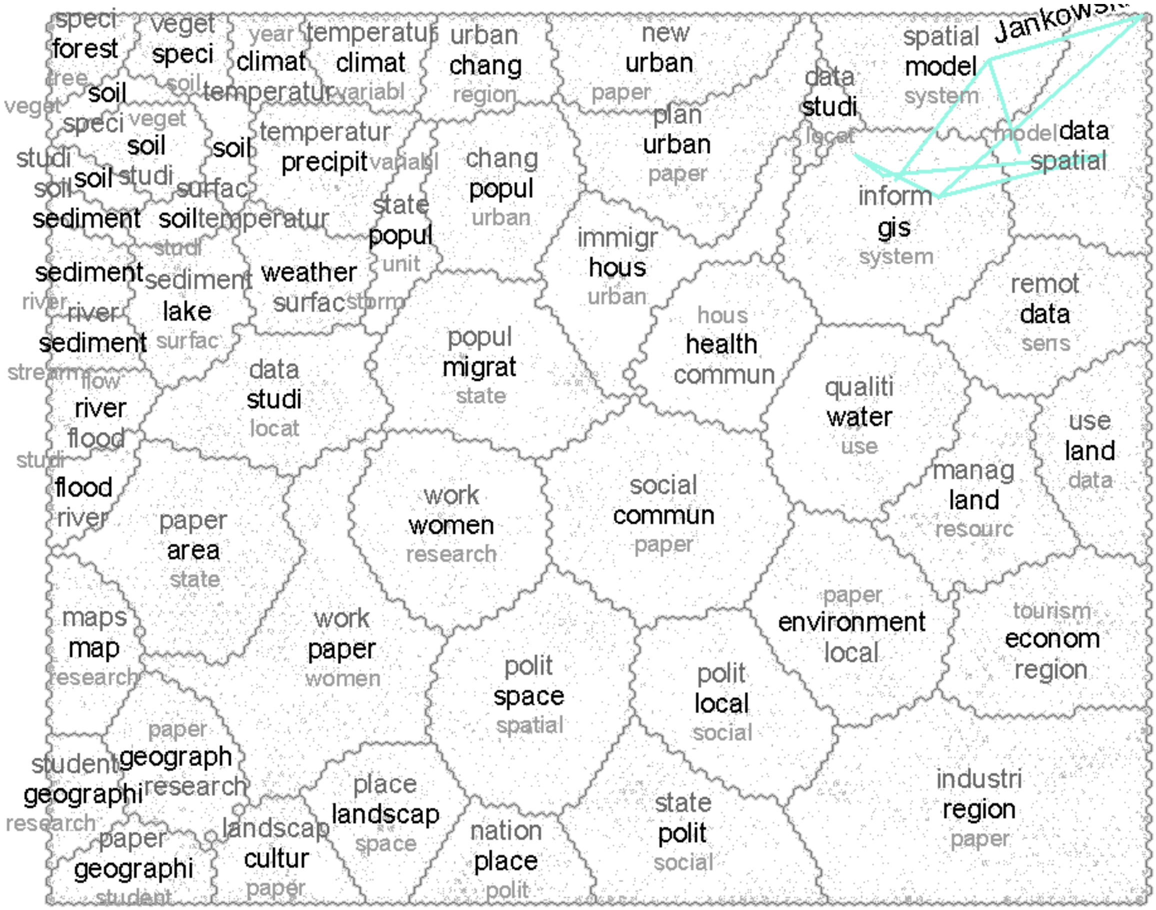
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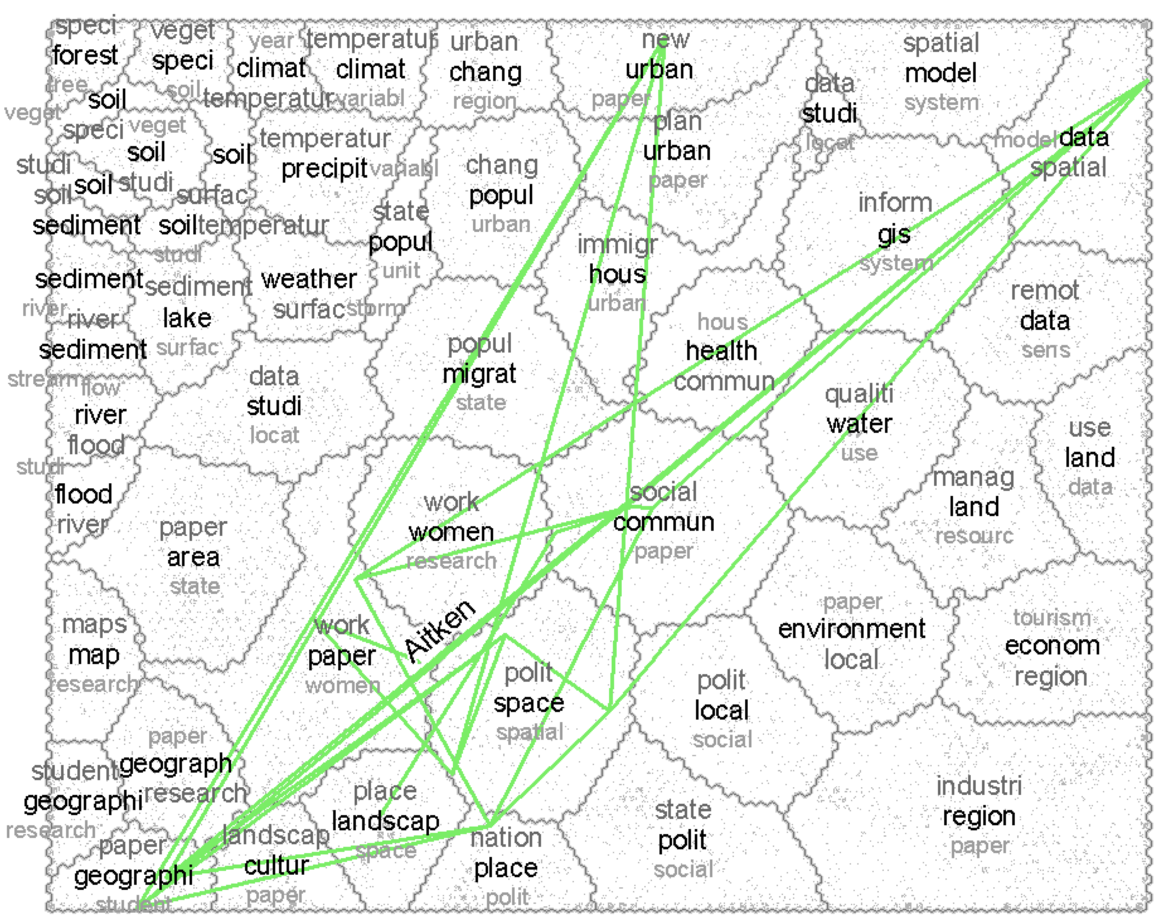
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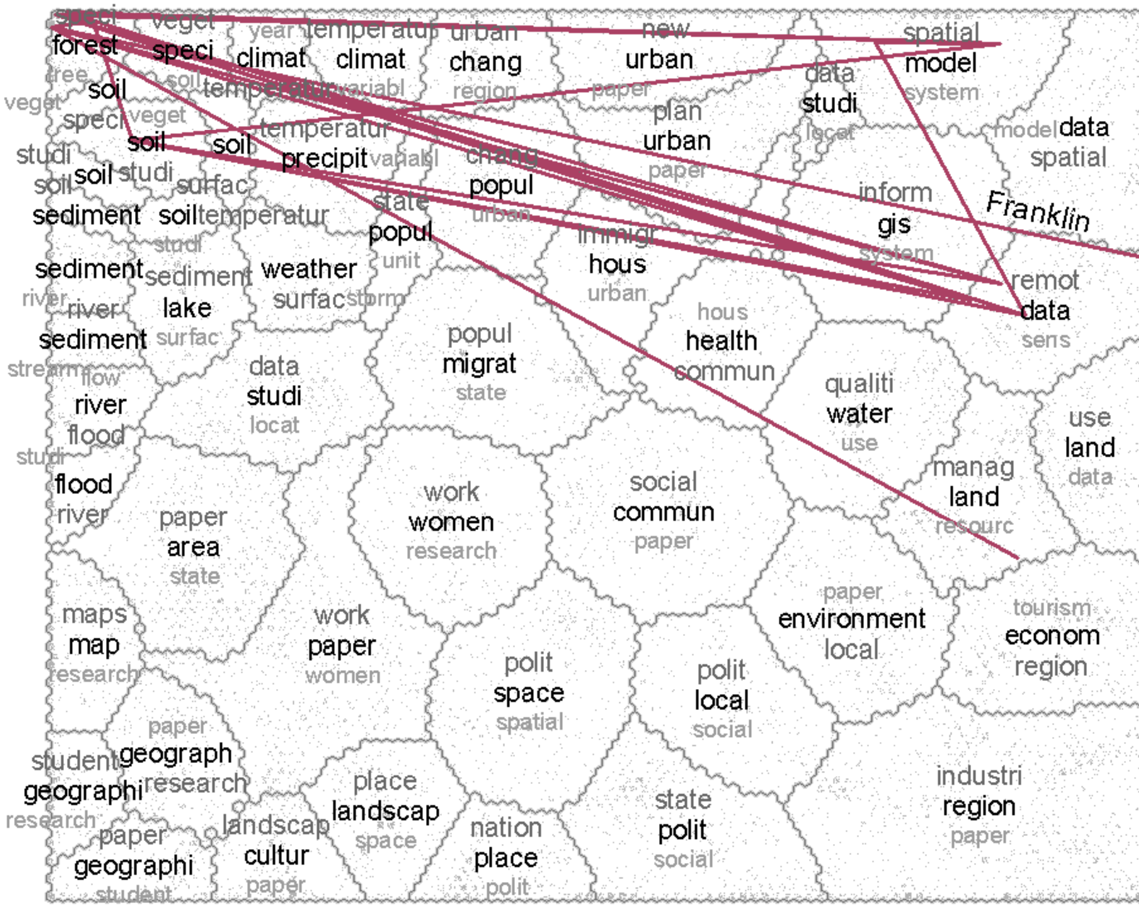
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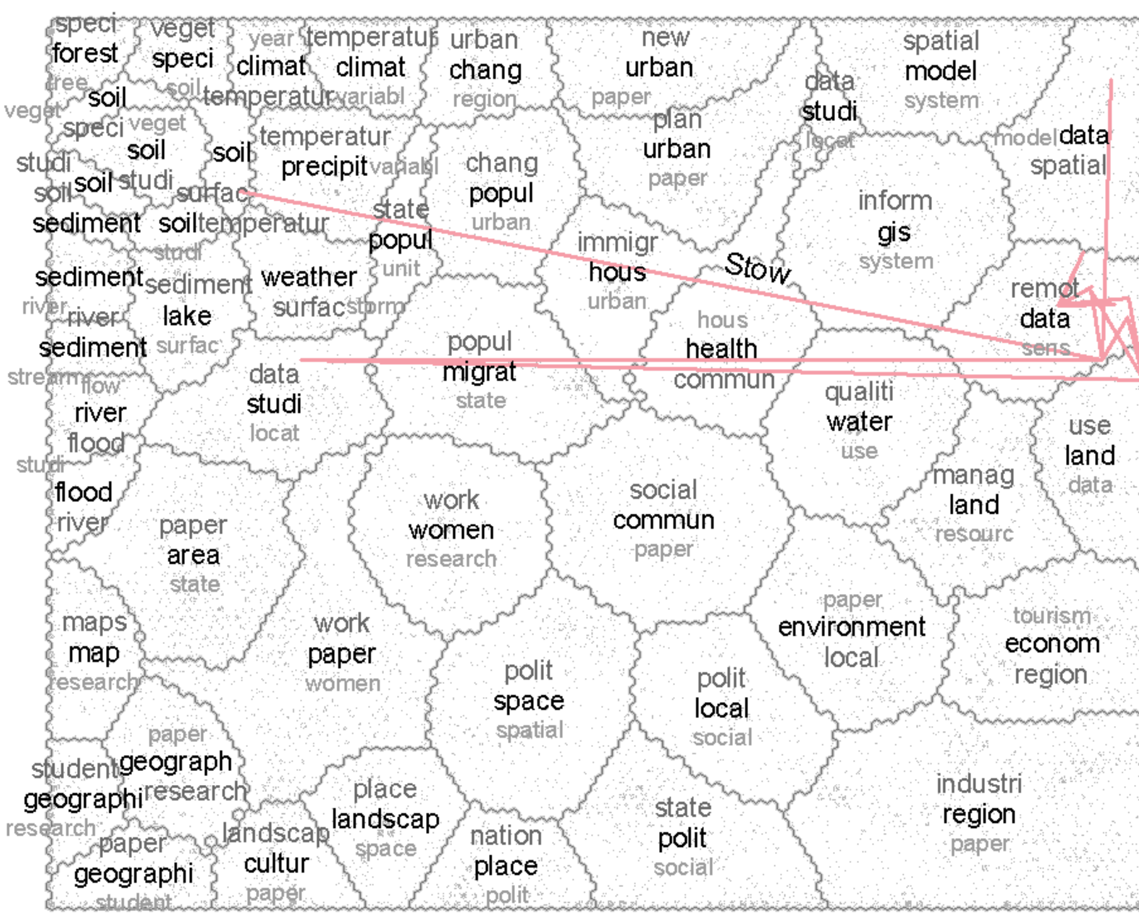
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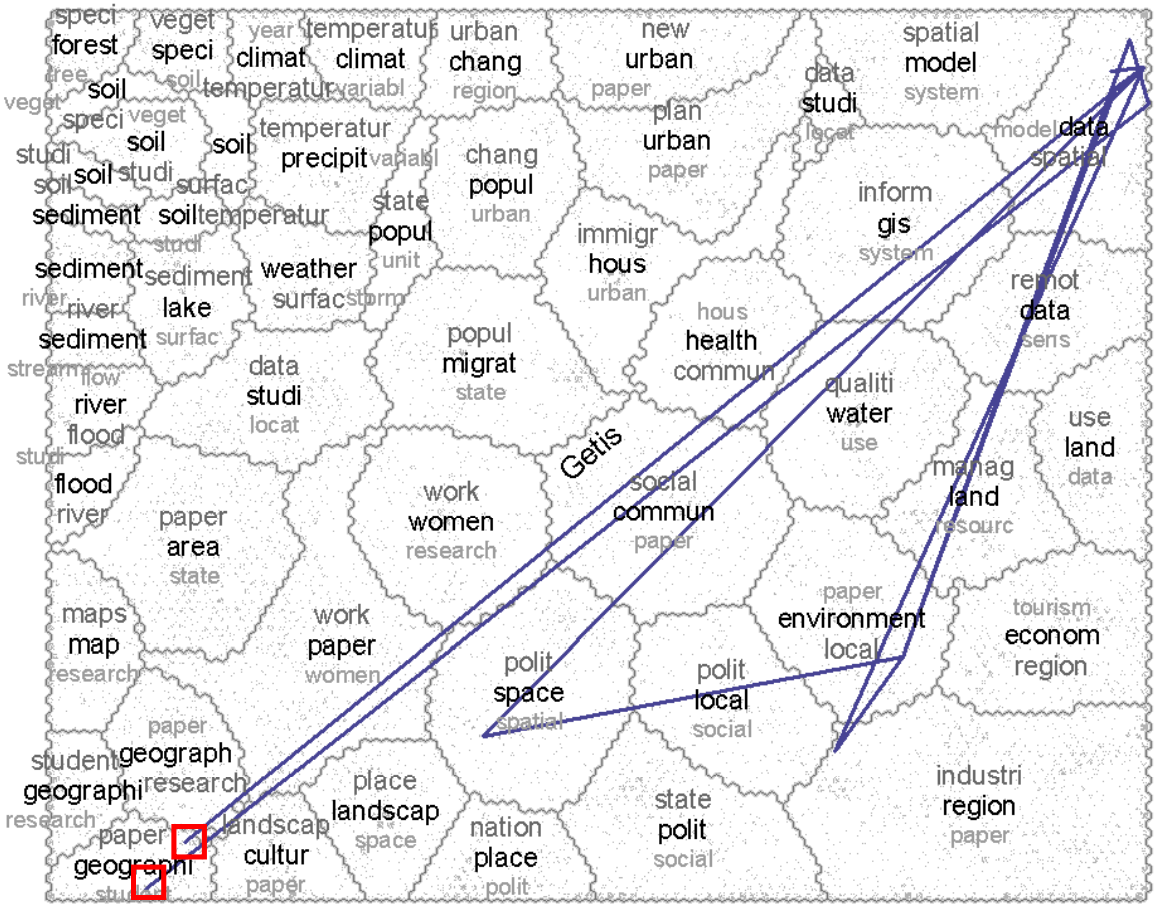

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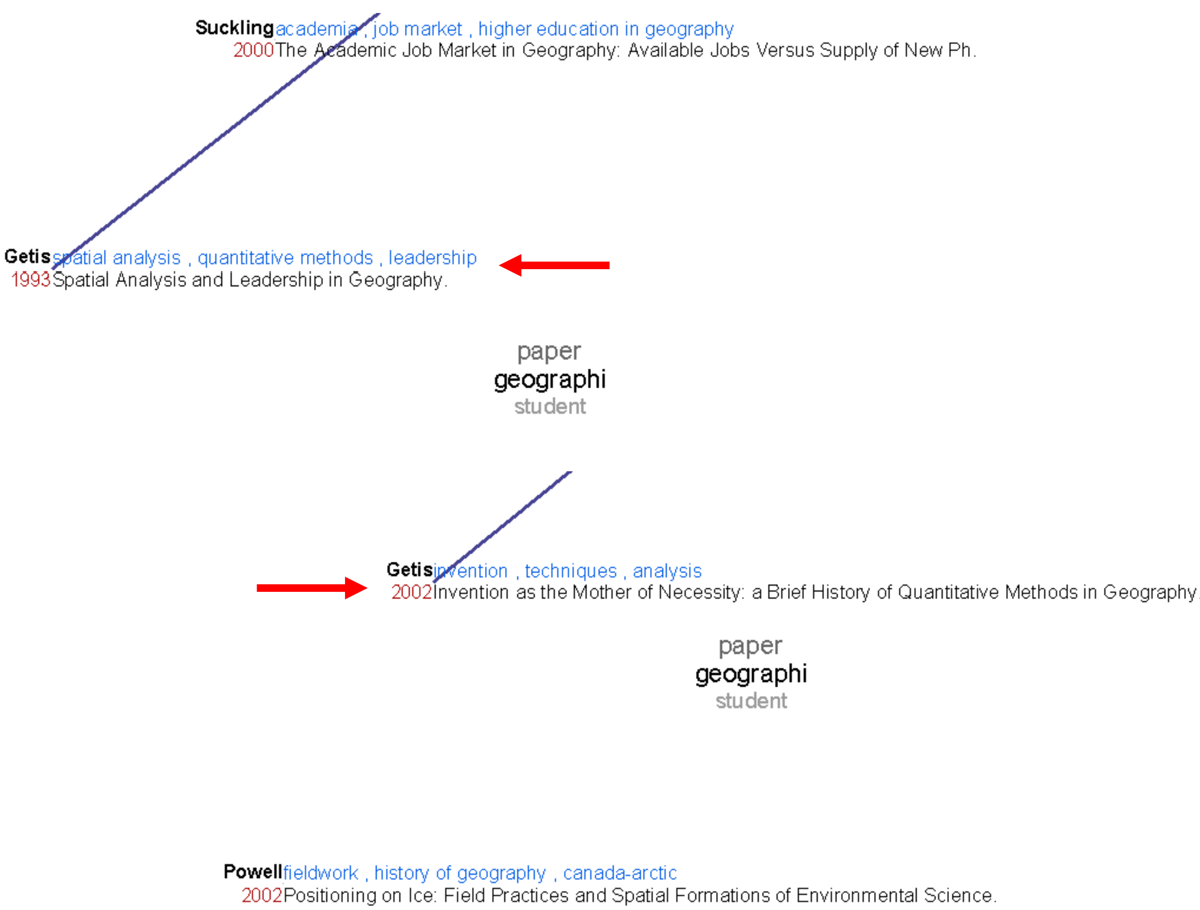

Suckling academia , job market , higher education in geography
2000 The Academic Job Market in Geography: Available Jobs Versus Supply of New Ph.
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1993 Spatial Analysis and Leadership in Geography.
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2002 Invention as the Mother of Necessity: a Brief History of Quantitative Methods in Geography.
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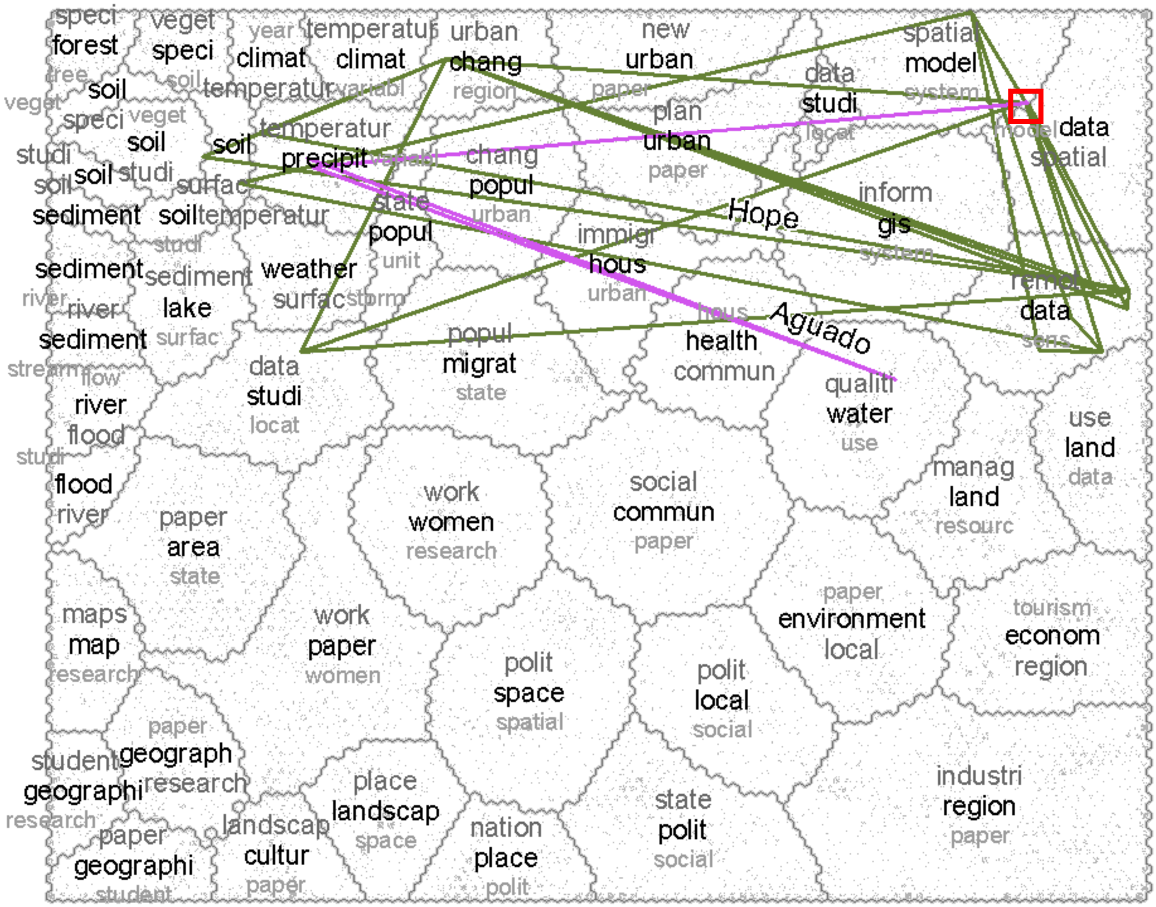
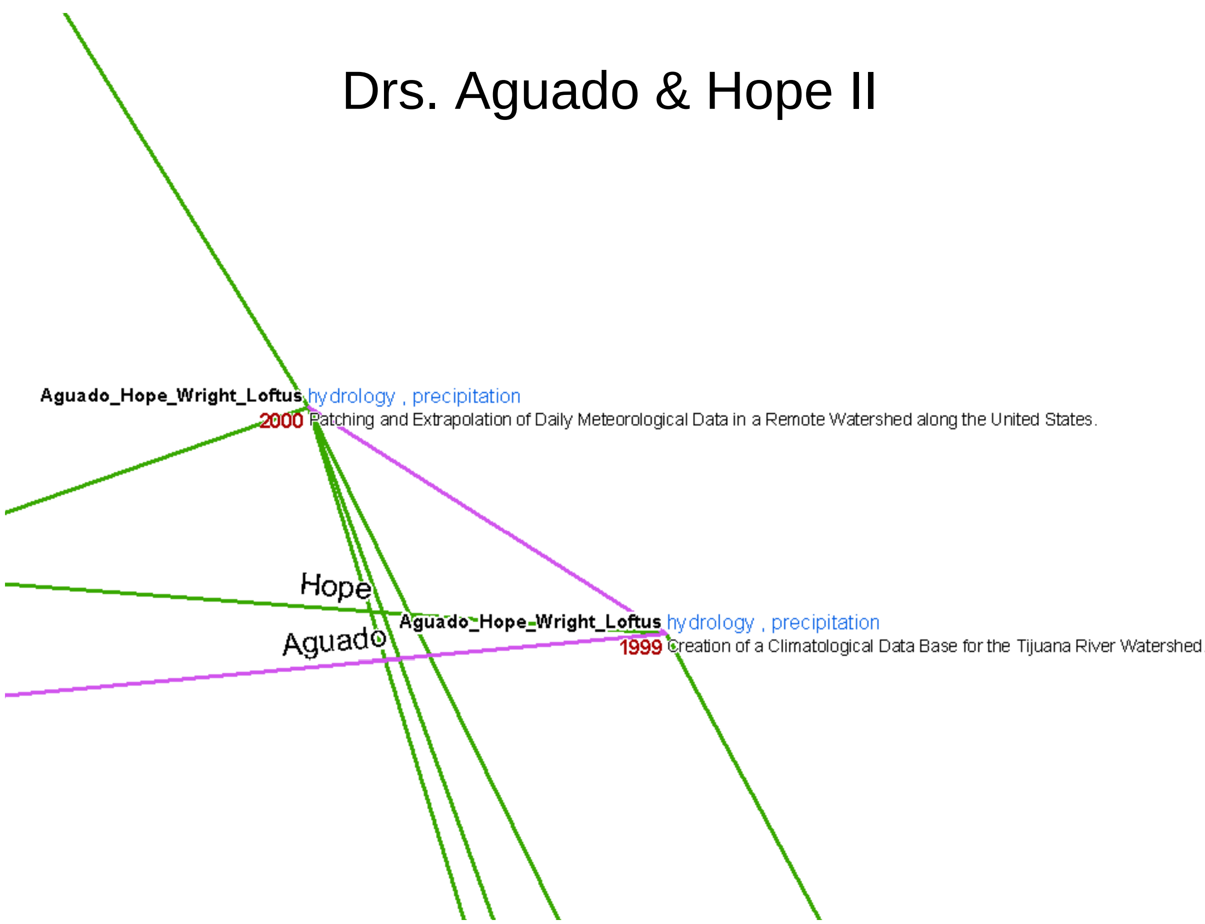
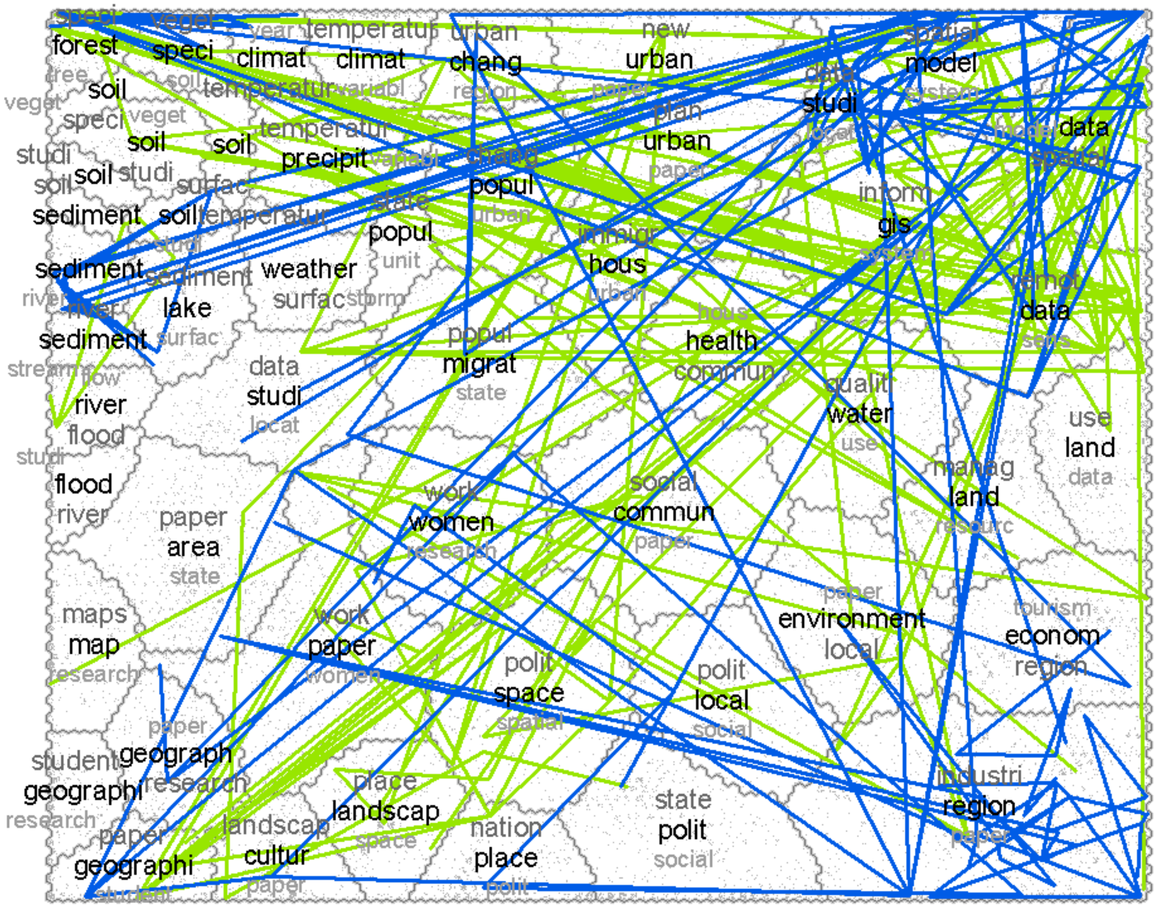
Powell fieldwork , history of geography , canada-arctic
2002 Positioning on Ice: Field Practices and Spatial Formations of Environmental Science.



Drs. Aguado & Hope II

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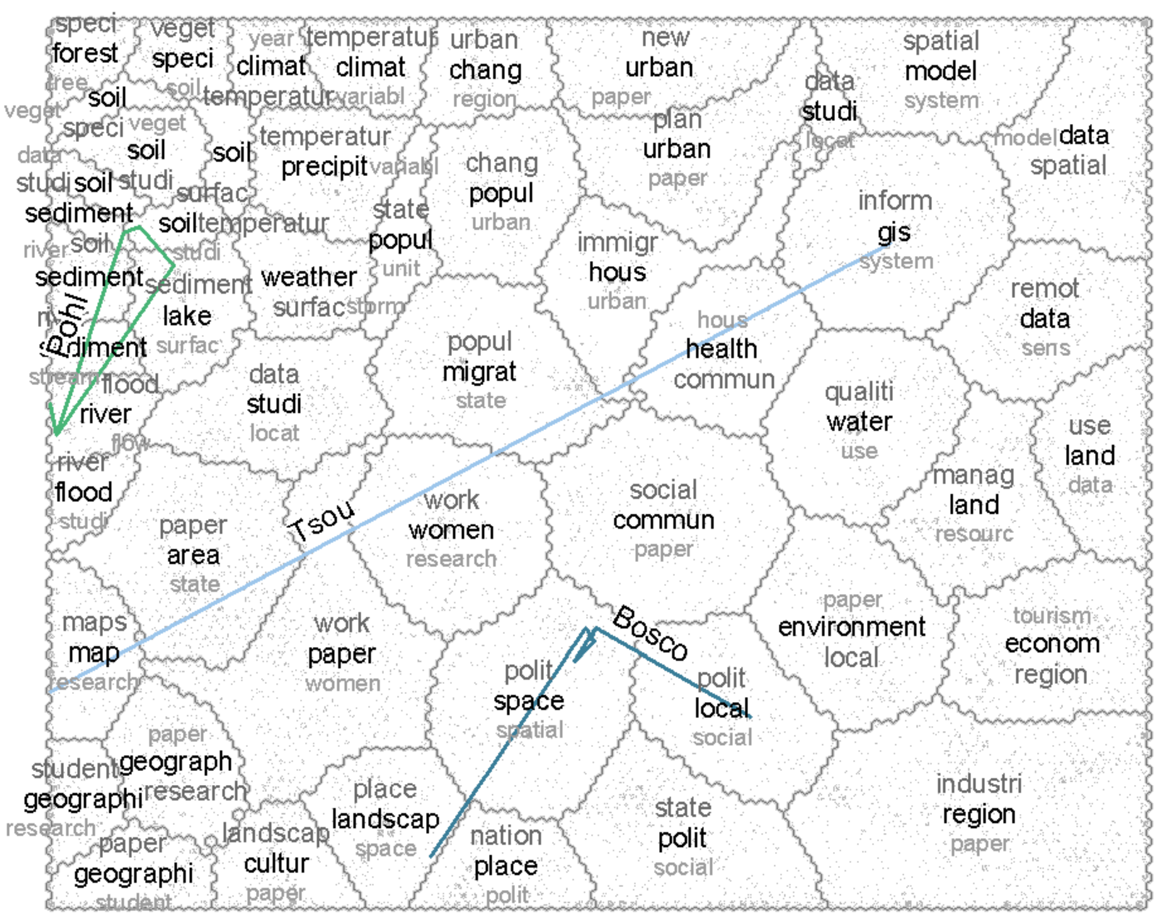
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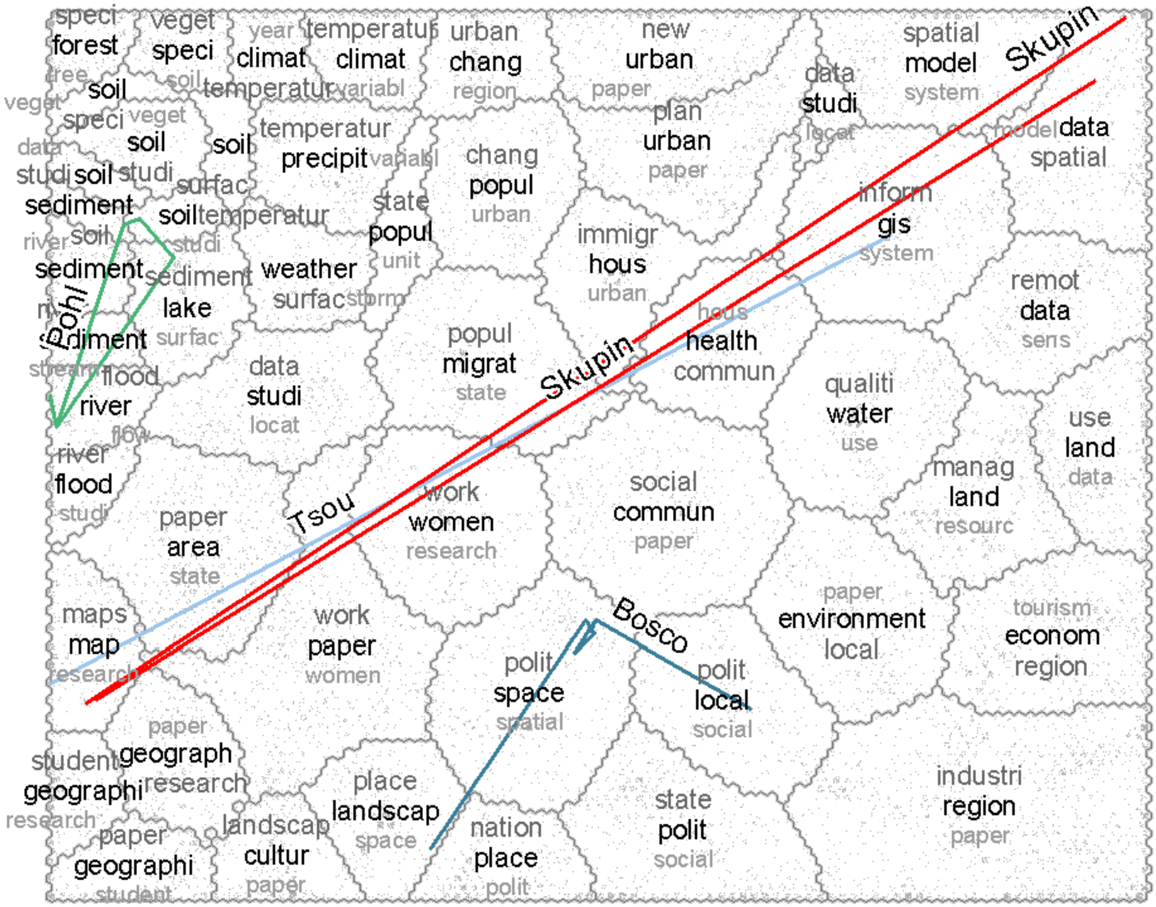
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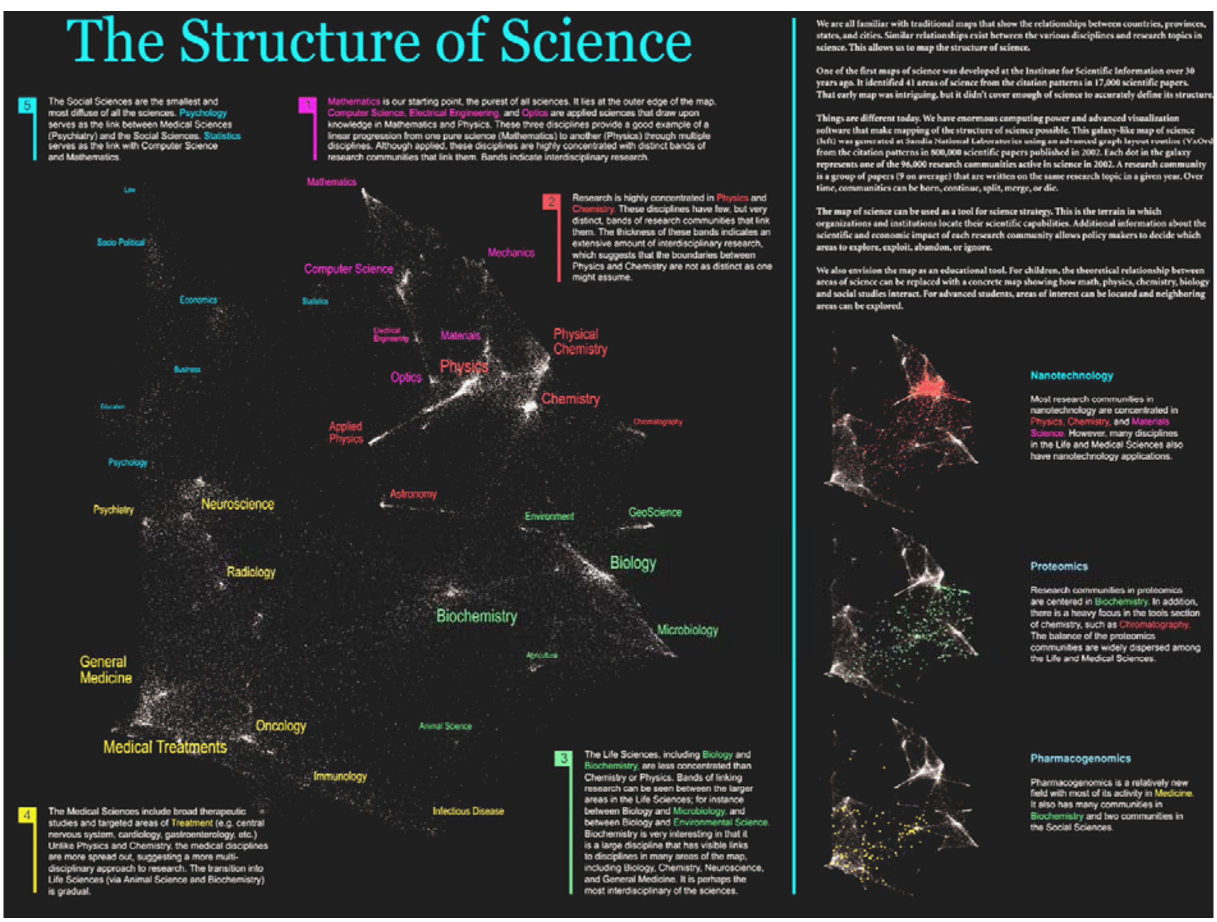
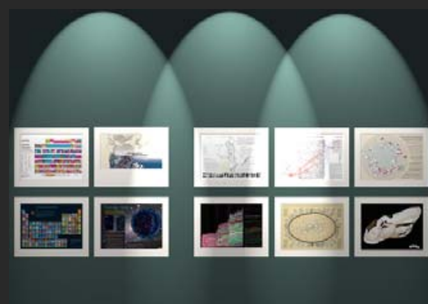
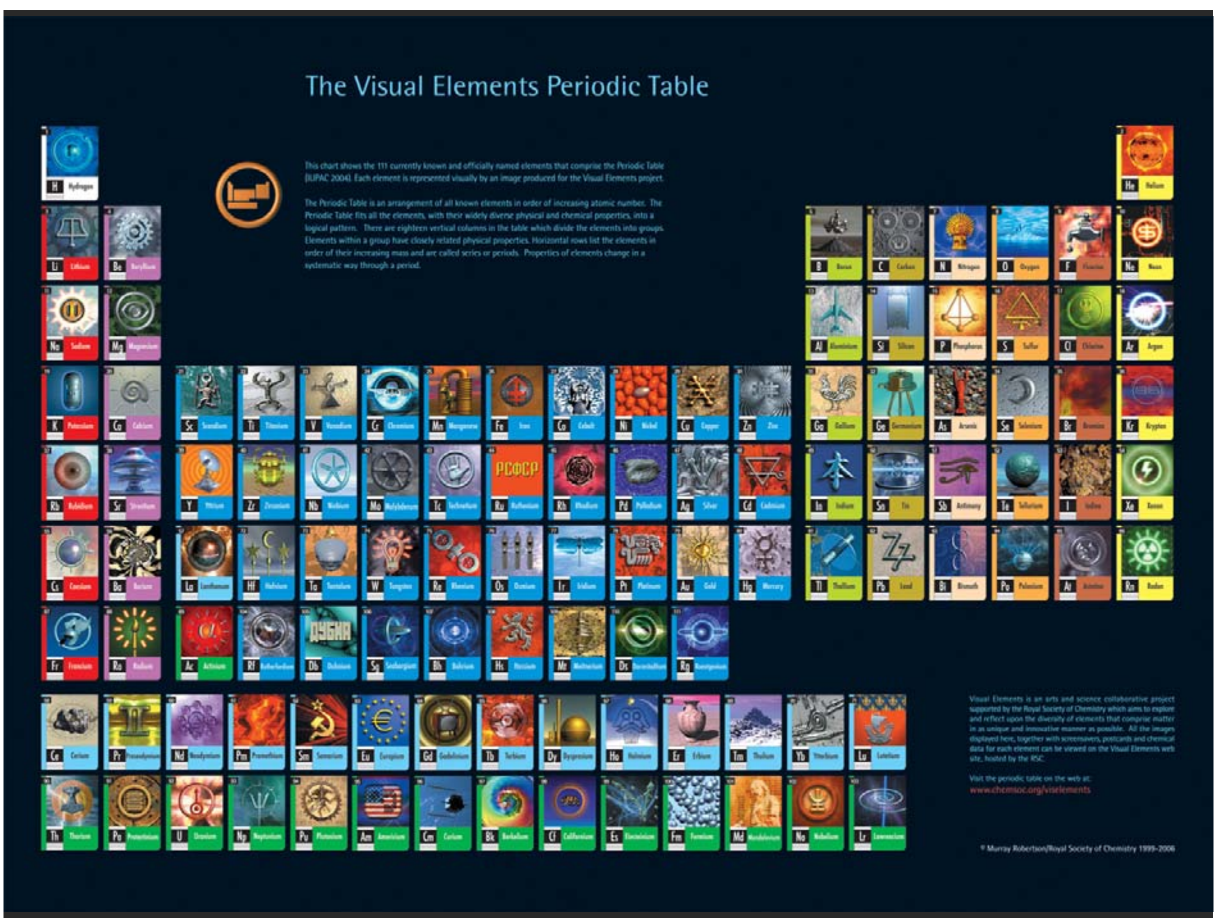

The Structure of Science
5 The Social Sciences are the smallest and most diffuse of all the sciences. Psychology serves as the link between Medical Sciences (Psychiatry) and the Social Sciences. Statistics serves as the link with Computer Science and Mathematics.
1 Mathematics is our starting point, the purest of all sciences. It lies at the outer edge of the map. Computer Science, Electrical Engineering, and Optics are applied sciences that draw upon knowledge in Mathematics and Physics. These three disciplines provide a good example of a linear progression from one pure science (Mathematics) to another (Physics) through multiple disciplines. Although applied, these disciplines are highly concentrated with distinct bands of research communities that link them. Bands indicate interdisciplinary research.
2 Research is highly concentrated in Physics and Chemistry. These disciplines have few, but very distinct, bands of research communities that link them. The thickness of these bands indicates an extensive amount of interdisciplinary research, which suggests that the boundaries between Physics and Chemistry are not as distinct as one might assume.
Mathematics
Law
Socio Political
Mechanics
Computer Science
Economics
Statistics
Electrical Engineering
Materials
Physical Chemistry
Business
Optics
Physics
Chemistry
Applied Physics
Psychology
Psychiatry
Neuroscience
Astronomy
Environment
GeoScience
Radiology
Biology
Biochemistry
Microbiology
General Medicine
Agriculture
Oncology
Animal Science
Medical Treatments
Immunology
Infectious Disease
4 The Medical Sciences include broad therapeutic studies and targeted areas of Treatment (e.g. central nervous system, cardiology, gastroenterology, etc.) Unlike Physics and Chemistry, the medical disciplines are more spread out, suggesting a more multi-disciplinary approach to research. The transition into Life Sciences (via Animal Science and Biochemistry) is gradual.
3 The Life Sciences, including Biology and Biochemistry, are less concentrated than Chemistry or Physics. Bands of linking research can be seen between the larger areas in the Life Sciences; for instance between Biology and Microbiology, and between Biology and Environmental Science. Biochemistry is very interesting in that it is a large discipline that has visible links to disciplines in many areas of the map, including Biology, Chemistry, Neuroscience, and General Medicine. It is perhaps the most interdisciplinary of the sciences.
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 (left) was generated at Sandia National Laboratories using an advanced graph layout routine (VxOrd) from the citation patterns in 800,000 scientific papers published in 2002. Each dot in the galaxy represents one of the 96,000 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.

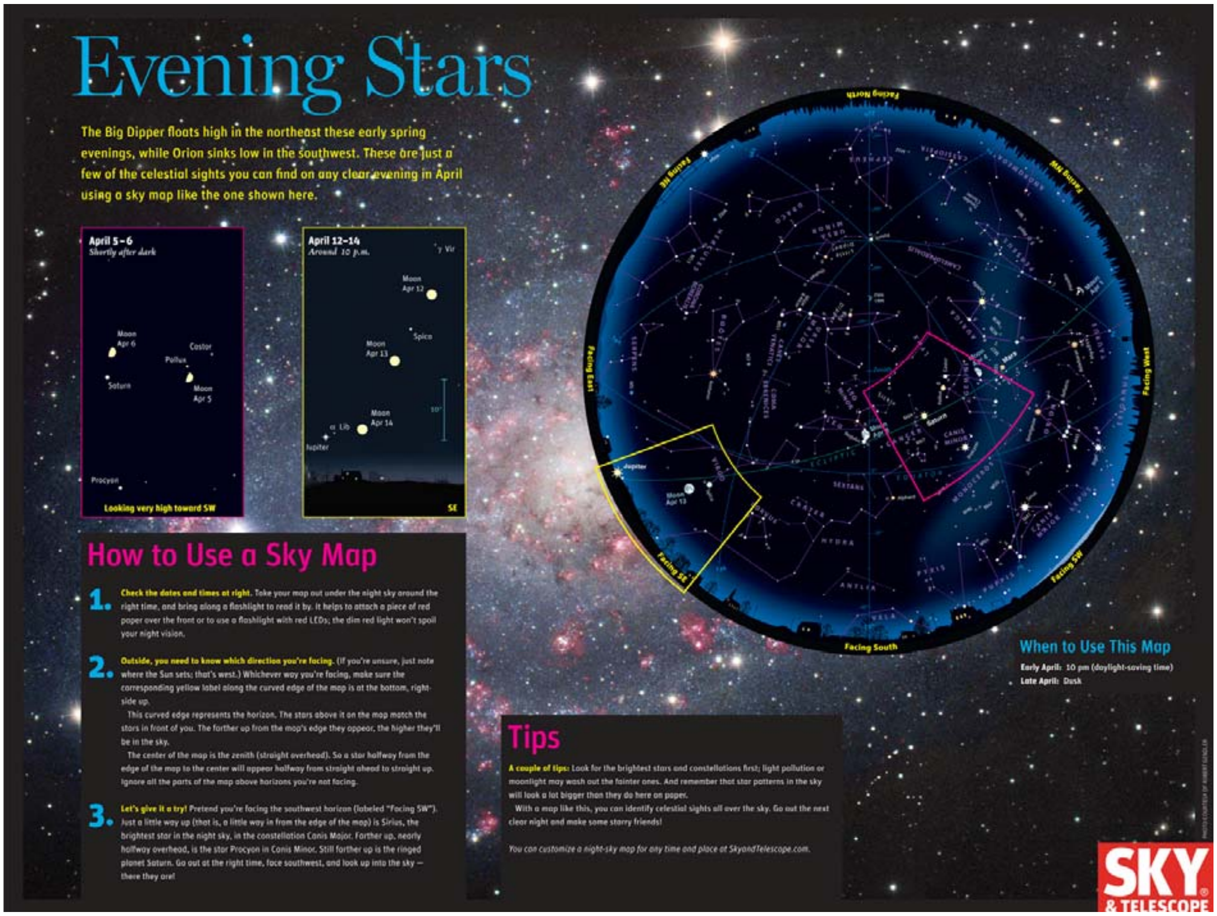
The Power of Reference Systems

Four Existing Reference Systems
VERSUS
Six Potential Reference Systems of Science



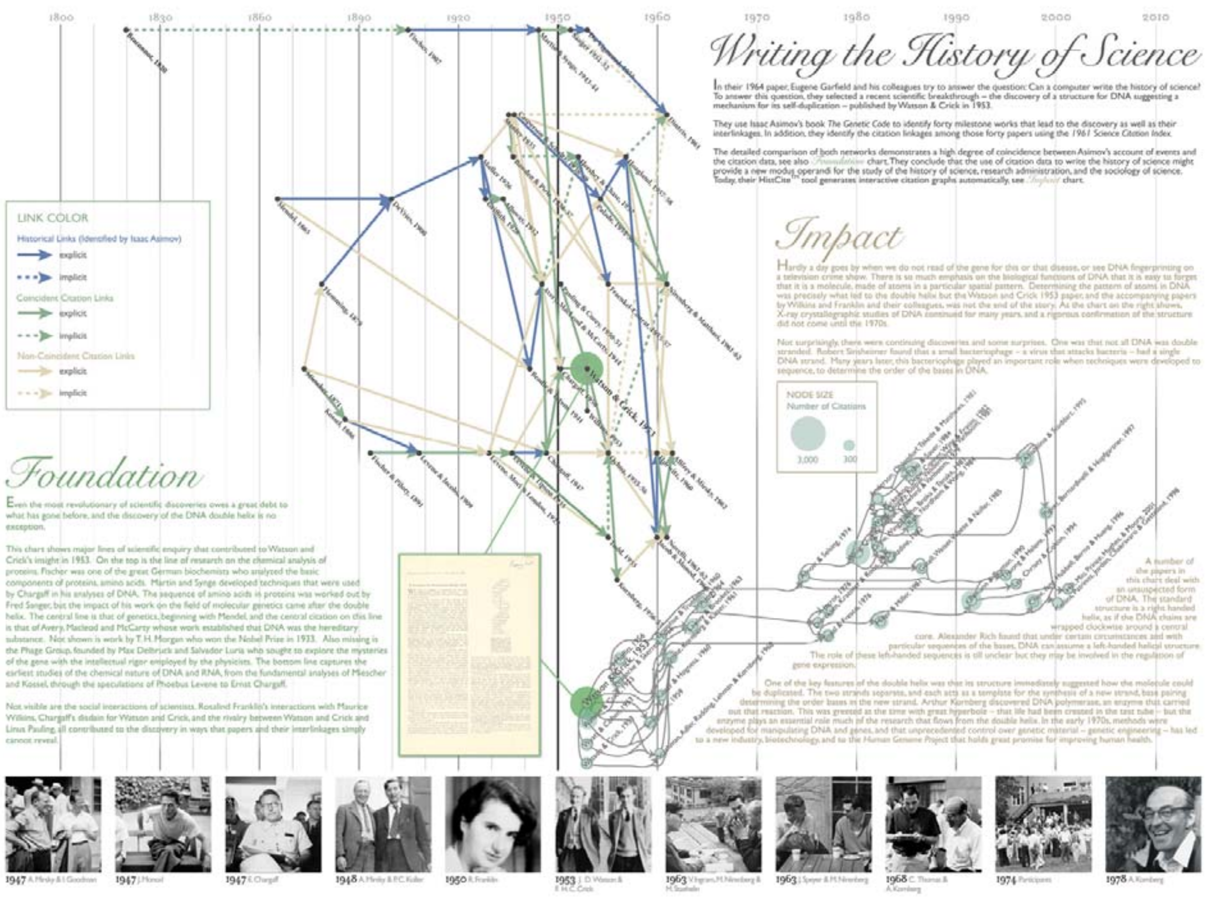
(2nd Iteration of Places & Spaces Exhibit - 2006)





How would a reference system for all of science look?

What dimensions would it have?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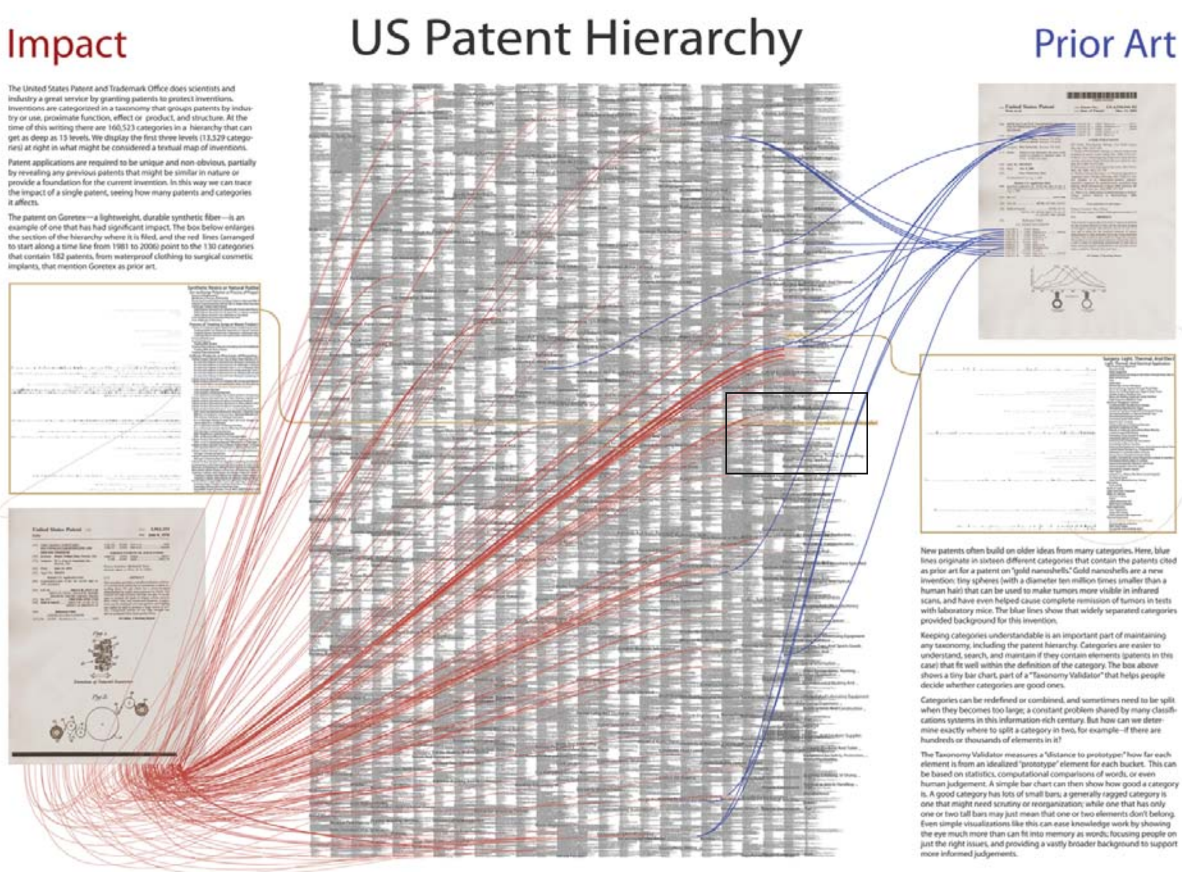
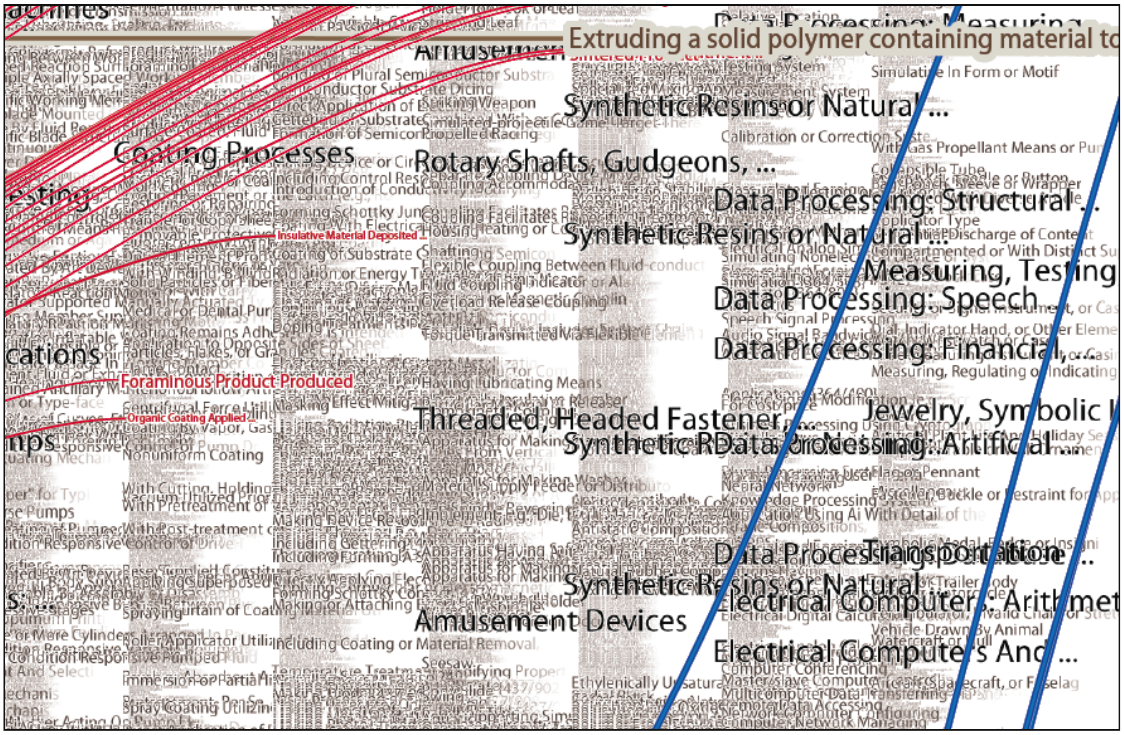
Writing the History of Science
In their 1964 paper, Eugene Garfield and his colleagues try to answer the question: Can a computer write the history of science? To answer this question, they selected a recent scientific breakthrough – the discovery of a structure for DNA suggesting a mechanism for its self-duplication – published by Watson & Crick in 1953.
They use Isaac Asimov's book The Genetic Code to identify forty milestone works that lead to the discovery as well as their interlinkages. In addition, they identify the citation linkages among those forty papers using the 1961 Science Citation Index.
The detailed comparison of both networks demonstrates a high degree of coincidence between Asimov's account of events and the citation data, see also Foundation chart. They conclude that the use of citation data to write the history of science might provide a new modus operandi for the study of the history of science, research administration, and the sociology of science. Today, their HistCite™ tool generates interactive citation graphs automatically, see Impact chart.
LINK COLOR
Historical Links (Identified by Isaac Asimov)
explicit
implicit
Coincident Citation Links
explicit
implicit
Non-Coincident Citation Links
explicit
implicit
Impact
Hardly a day goes by when we do not read of the gene for this or that disease, or see DNA fingerprinting on a television crime show. There is so much emphasis on the biological functions of DNA that it is easy to forget that it is a molecule, made of atoms in a particular spatial pattern. Determining the pattern of atoms in DNA was precisely what led to the double helix but the Watson and Crick 1953 paper, and the accompanying papers by Wilkins and Franklin and their colleagues, was not the end of the story. As the chart on the right shows, X-ray crystallographic studies of DNA continued for many years, and a rigorous confirmation of the structure did not come until the 1970s.
Not surprisingly, there were continuing discoveries and some surprises. One was that not all DNA was double stranded. Robert Sinsheimer found that a small bacteriophage – a virus that attacks bacteria – had a single DNA strand. Many years later, this bacteriophage played an important role when techniques were developed to sequence, to determine the order of the bases in DNA.
NODE SIZE
Number of Citations
3,000
300
Foundation
Even the most revolutionary of scientific discoveries owes a great debt to what has gone before, and the discovery of the DNA double helix is no exception.
This chart shows major lines of scientific enquiry that contributed to Watson and Crick's insight in 1953. On the top is the line of research on the chemical analysis of proteins. Fischer was one of the great German biochemists who analyzed the basic components of proteins, amino acids. Martin and Synge developed techniques that were used by Chargaff in his analyses of DNA. The sequence of amino acids in proteins was worked out by Fred Sanger, but the impact of his work on the field of molecular genetics came after the double helix. The central line is that of genetics, beginning with Mendel, and the central citation on this line is that of Avery, Macleod and McCarty whose work established that DNA was the hereditary substance. Not shown is work by T. H. Morgan who won the Nobel Prize in 1933. Also missing is the Phage Group, founded by Max Delbruck and Salvador Luria who sought to explore the mysteries of the gene with the intellectual rigor employed by the physicists. The bottom line captures the earliest studies of the chemical nature of DNA and RNA, from the fundamental analyses of Miescher and Kossel, through the speculations of Phoebus Levene to Ernst Chargaff.
Not visible are the social interactions of scientists. Rosalind Franklin's interactions with Maurice Wilkins, Chargaff's disdain for Watson and Crick, and the rivalry between Watson and Crick and Linus Pauling, all contributed to the discovery in ways that papers and their interlinkages simply cannot reveal.
A number of the papers in this chart deal with an unsuspected form of DNA. The standard structure is a right handed helix, as if the DNA chains are wrapped clockwise around a central core. Alexander Rich found that under certain circumstances and with particular sequences of the bases, DNA can assume a left-handed helical structure. The role of these left-handed sequences is still unclear but they may be involved in the regulation of gene expression.
One of the key features of the double helix was that its structure immediately suggested how the molecule could be duplicated. The two strands separate, and each acts as a template for the synthesis of a new strand, base pairing determining the order bases in the new strand. Arthur Kornberg discovered DNA polymerase, an enzyme that carried out that reaction. This was greeted at the time with great hyperbole – that life had been created in the test tube – but the enzyme plays an essential role much of the research that flows from the double helix. In the early 1970s, methods were developed for manipulating DNA and genes, and that unprecedented control over genetic material – genetic engineering – has led to a new industry, biotechnology, and to the Human Genome Project that holds great promise for improving human health.
1947 A. Mirsky & I. Goodman
1947 J. Monod
1947 E. Chargaff
1948 A. Mirsky & P.C. Koller
1950 R. Franklin
1953 J. D. Watson & F. H.C. Crick
1963 V. Ingram, M. Nirenberg & H. Staehelin
1963 J. Speyer & M. Nirenberg
1968 C. Thomas & A. Kornberg
1974 Participants
1978 A. Kornberg


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, ...
Foraminous Product Produced
Threaded, Headed Fastener, ...
Jewelry, Symbolic
Amusement Devices
Electrical Computers And ...
Insulative Material Deposited ...
Organic Coating Applied ...
Nonuniform Coating
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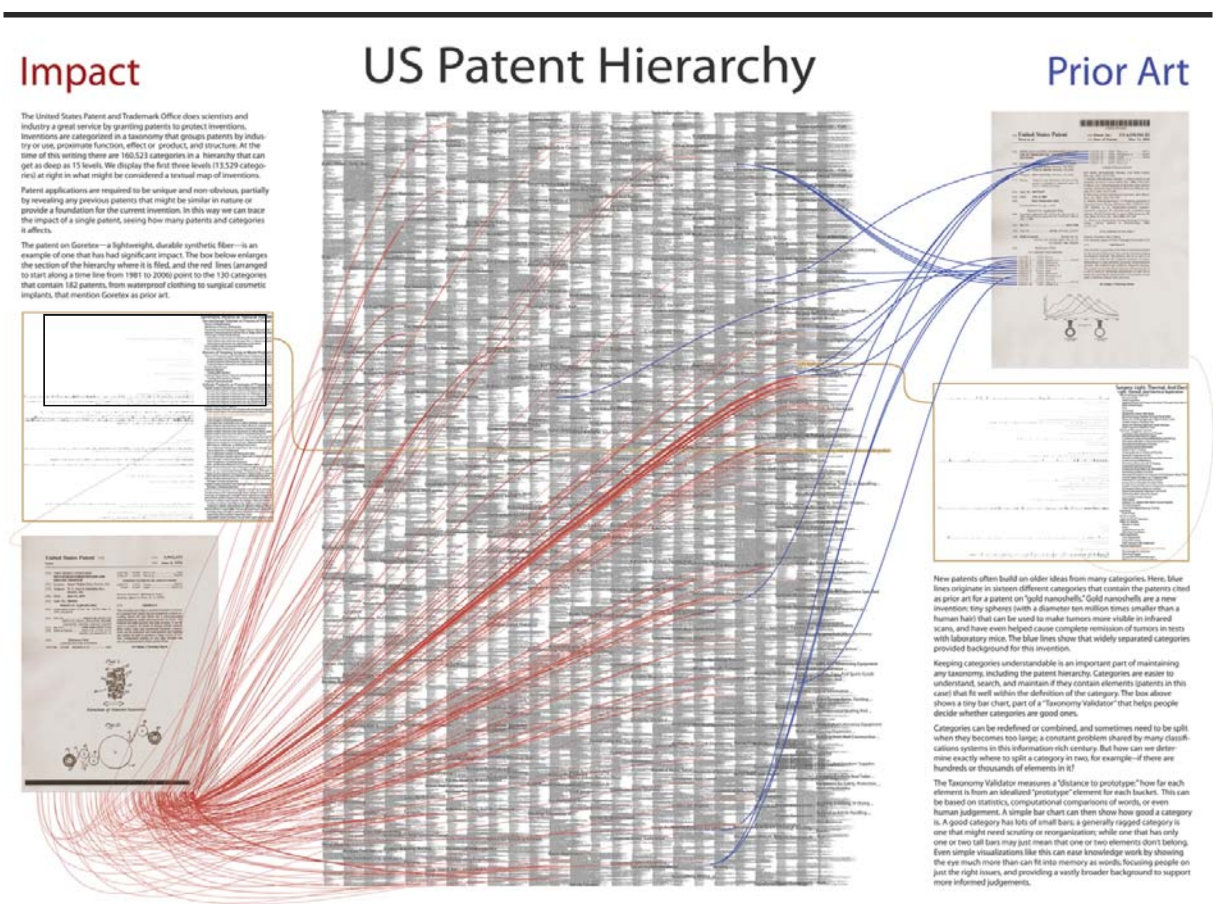
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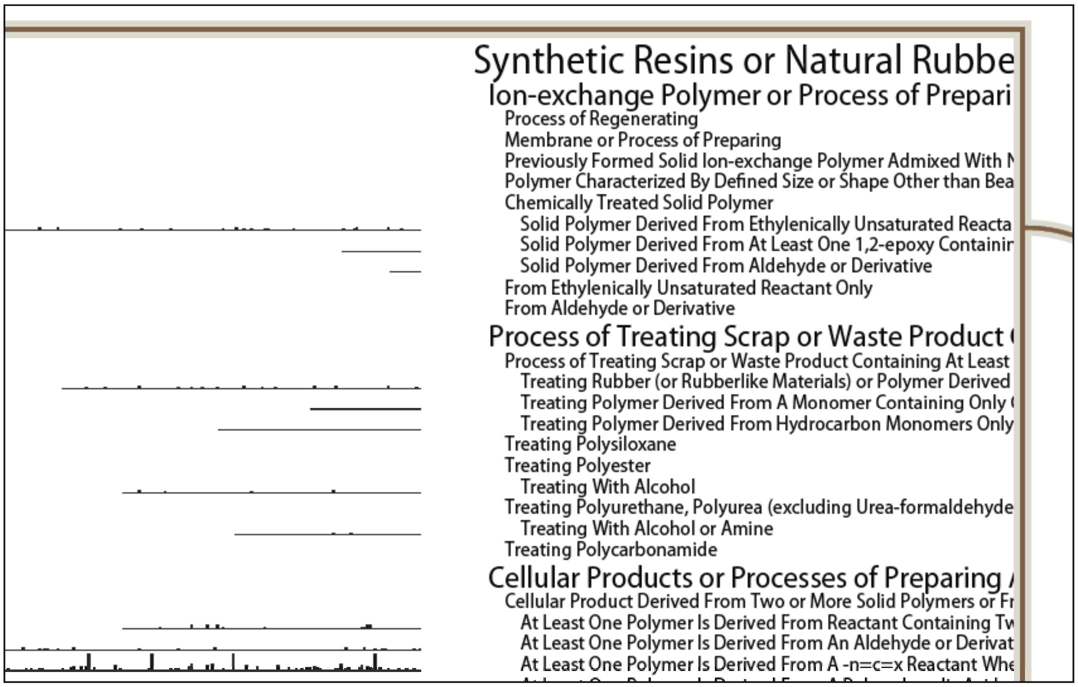
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Treating Polymer Derived From A Monomer Containing Only (
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Treating Polyester
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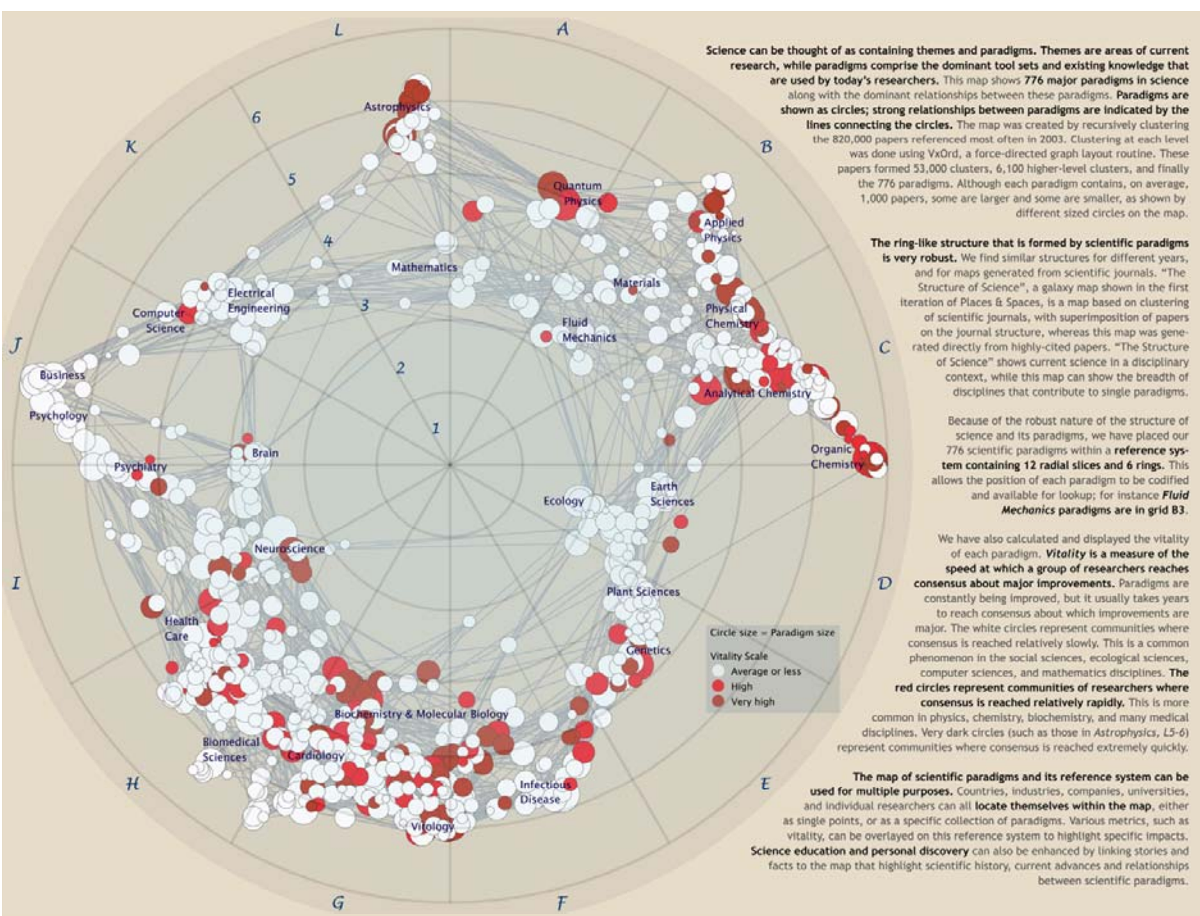
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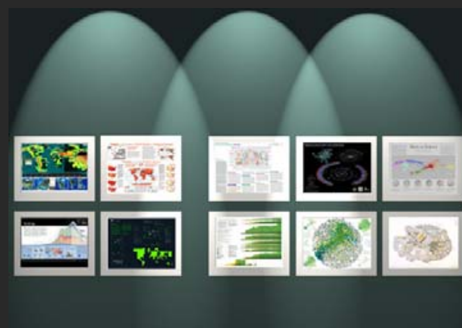
Quantum Physics
Applied Physics
Mathematics
Materials
Physical Chemistry
Fluid Mechanics
Analytical Chemistry
Organic Chemistry
Electrical Engineering
Computer Science
Business
Psychology
Psychiatry
Brain
Ecology
Earth Sciences
Neuroscience
Plant Sciences
Genetics
Health Care
Biochemistry & Molecular Biology
Biomedical Sciences
Cardiology
Infectious Disease
Virology
Circle size = Paradigm size
Vitality Scale
Average or less
High
Very high
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

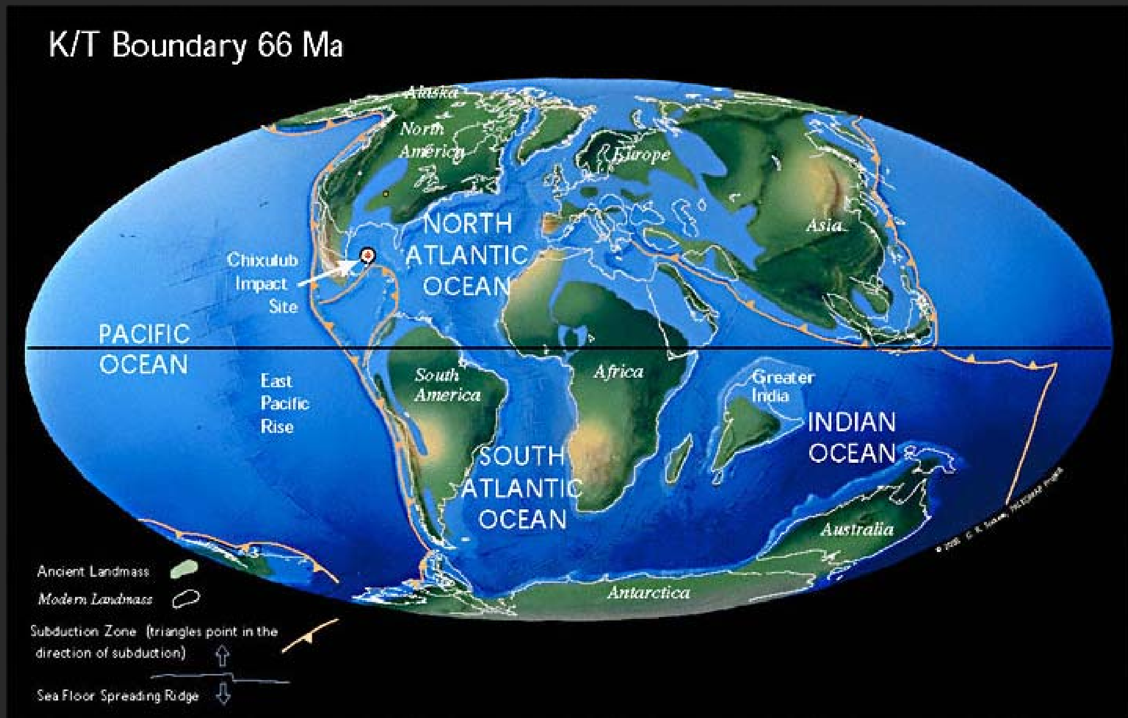
Four Existing Forecasts
VERSUS
Six Potential Science 'Weather' Forecasts



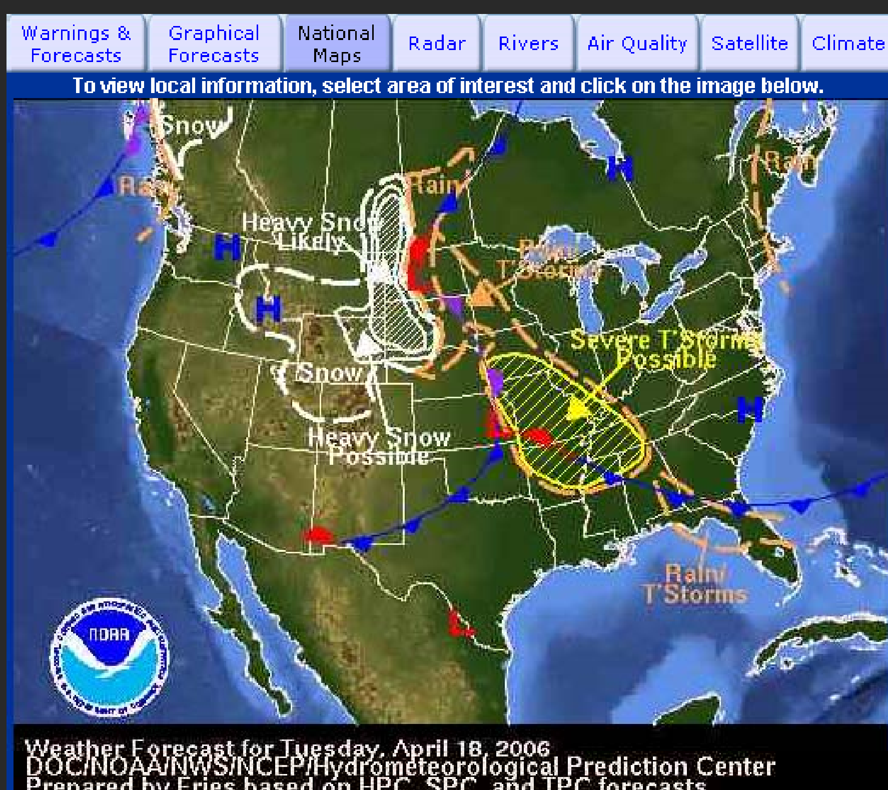
(3rd Iteration of Places & Spaces Exhibit - 2007)

Can one forecast science?

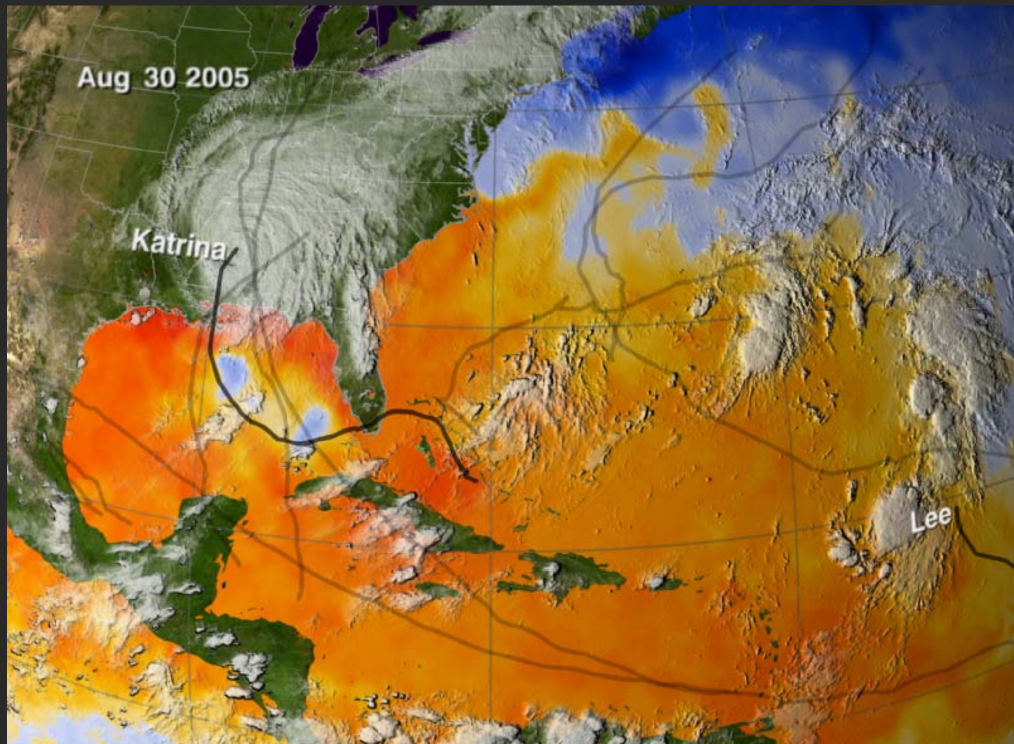
What 'science forecast language' will work?



http://www.scotese.com/



http://www.weather.gov

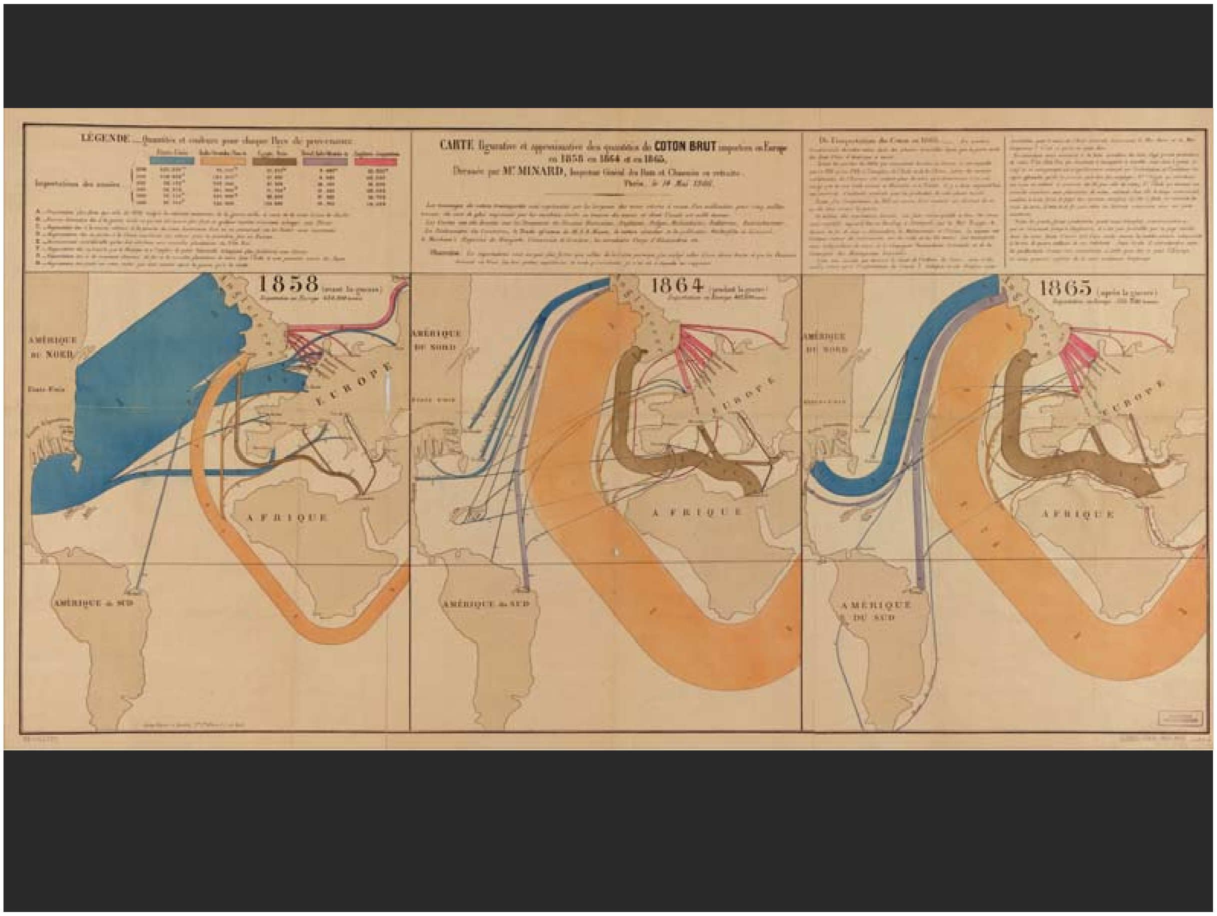


Named Storms, available online at http://svs.gsfc.nasa.gov/vis/a000000/a003200/a003279

Science Maps for Economic Decision Making

Four Existing Maps
VERSUS
Six Science Maps

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



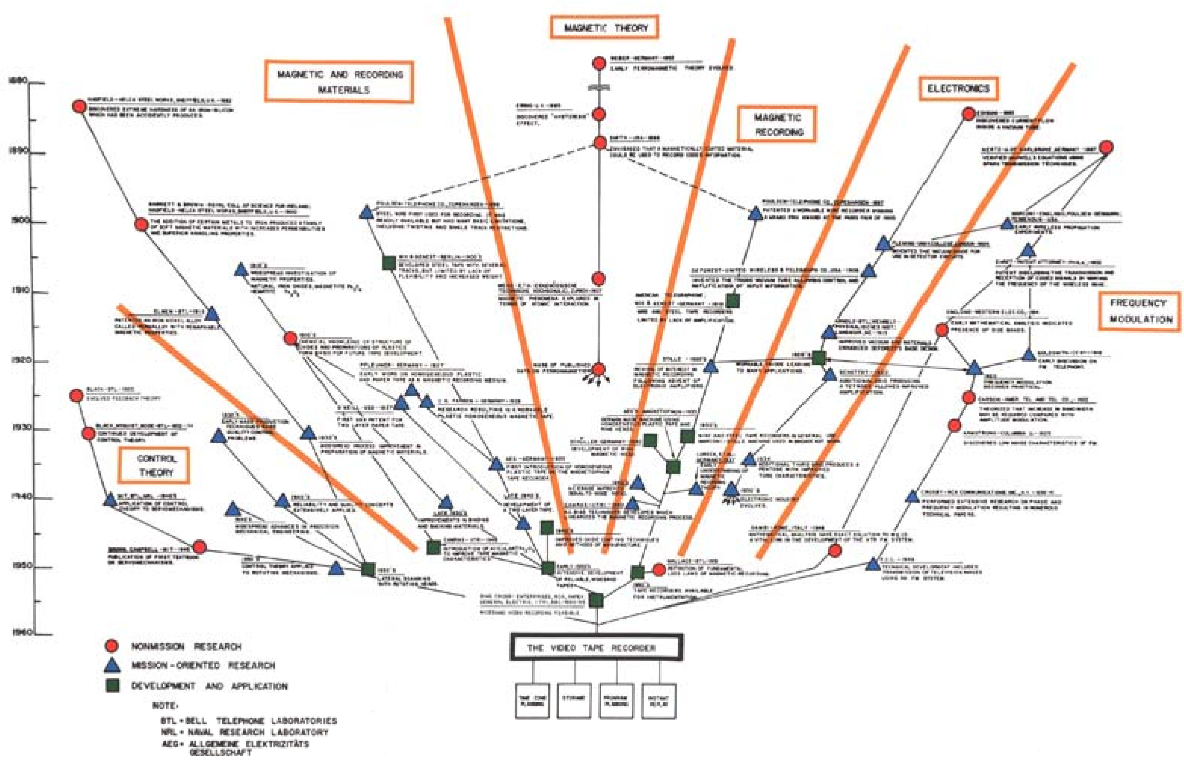
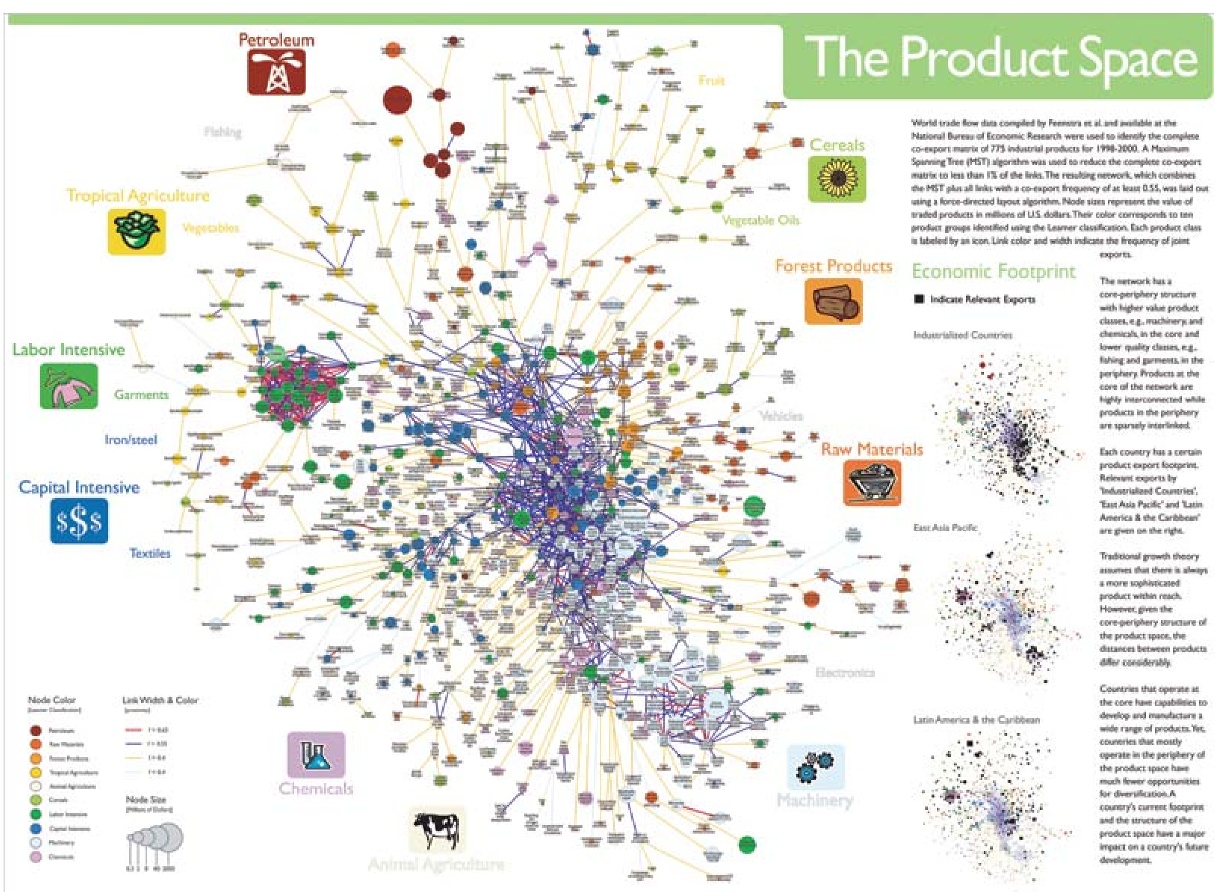


FIG. 7. THE VIDEO TAPE RECORDER

What insight needs to economic decision makers have?

What data views are most useful?

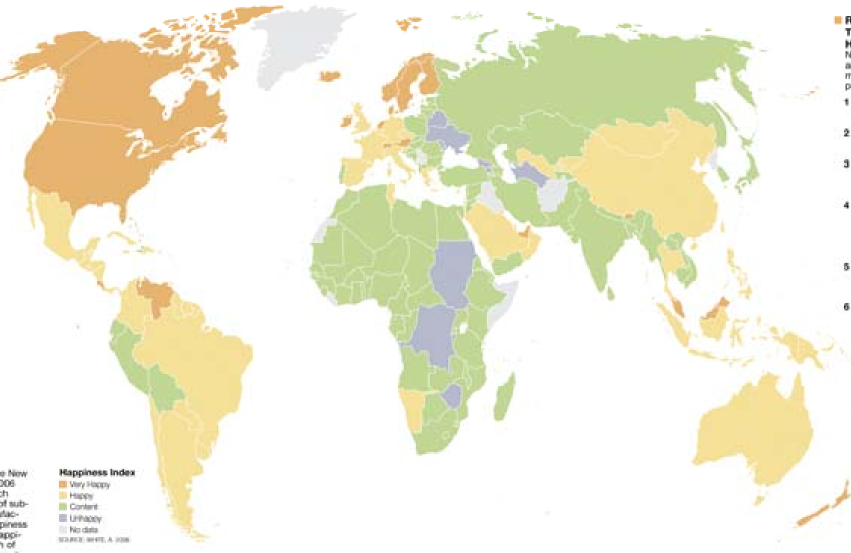


Happiness Depends on Various Factors

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.

"It's time we admitted there's more to life than money."



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.

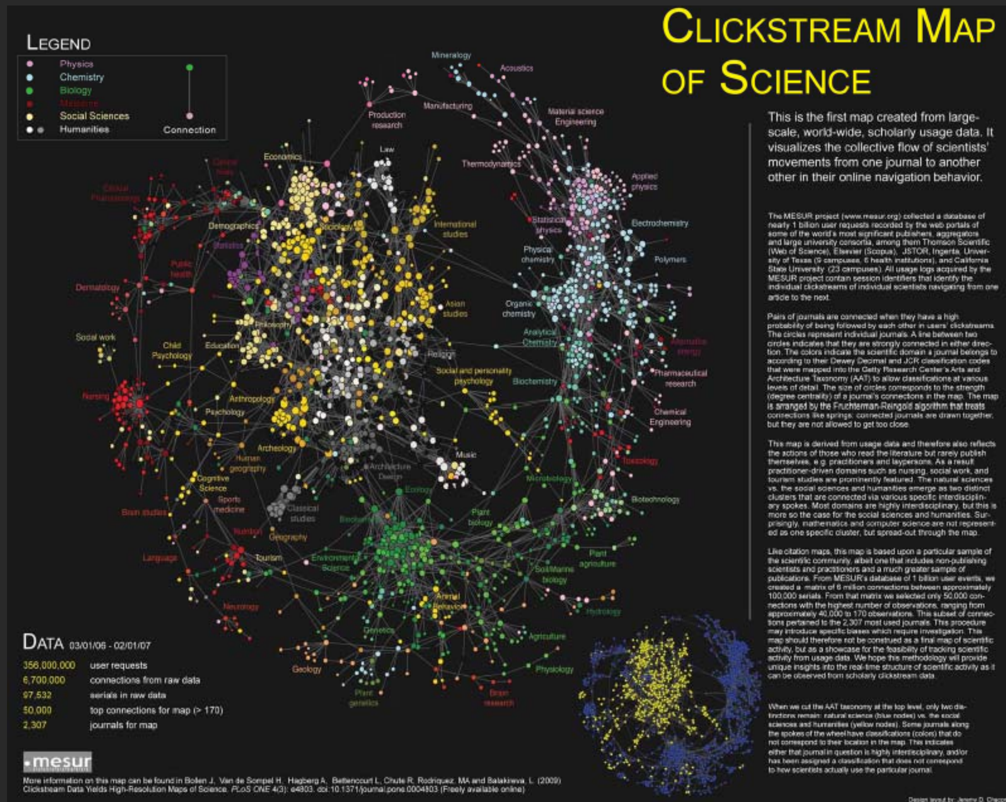
WEALTH
Money still can't buy love, or happiness, and wealthier people aren't always more content. Still, tiny Luxembourg, which takes top rank in per capita Gross Domestic Product (GDP), also rates a 253 on the happiness index. Real poverty means real misery, a fate shared by billions.

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.

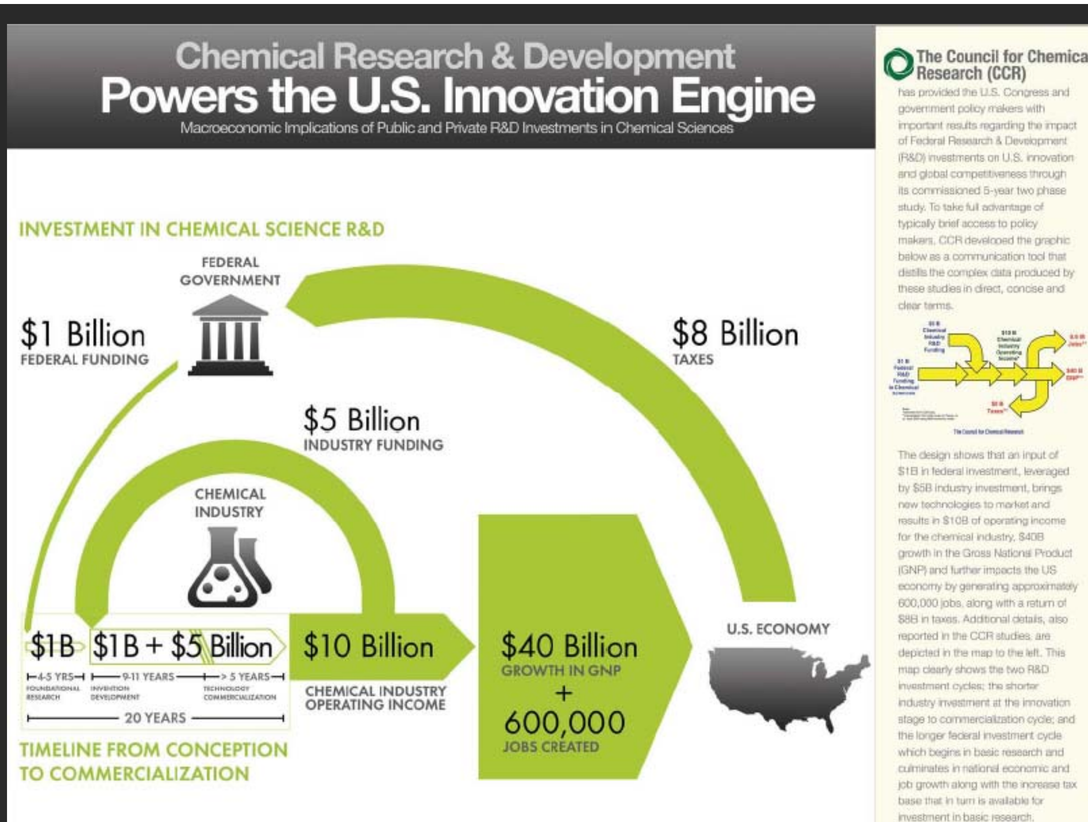
Science Maps for Science Policy Making

Four Existing Maps
VERSUS
Six Science Maps

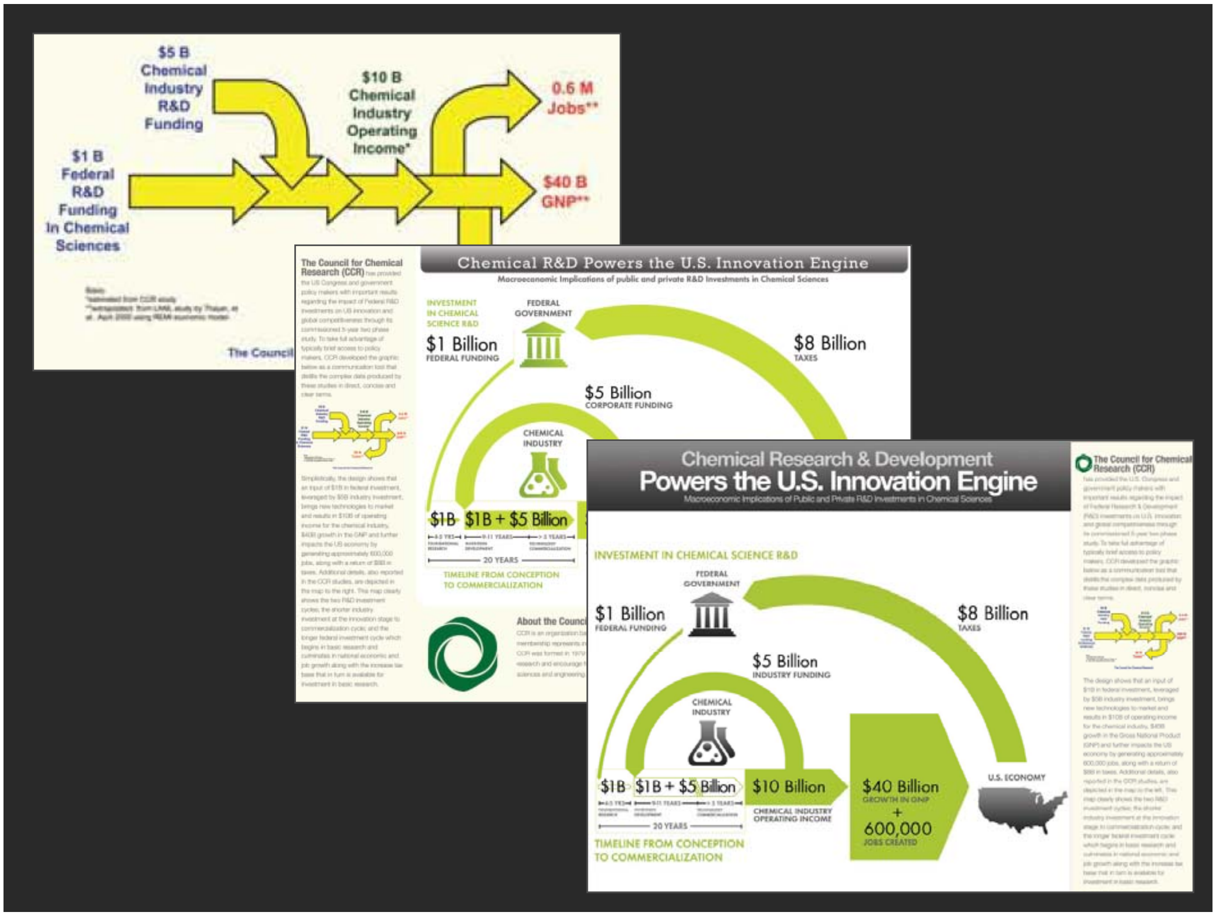
(5th Iteration of Places & Spaces Exhibit - 2009)



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



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



Additional Elements of the Exhibit

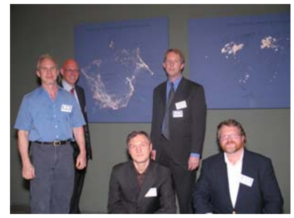
Illuminated Diagram Display

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.

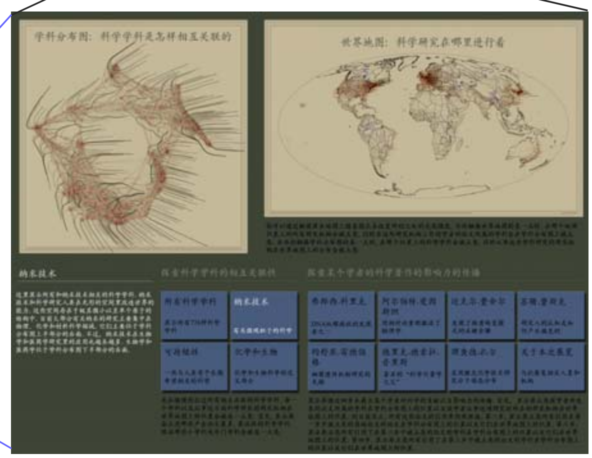


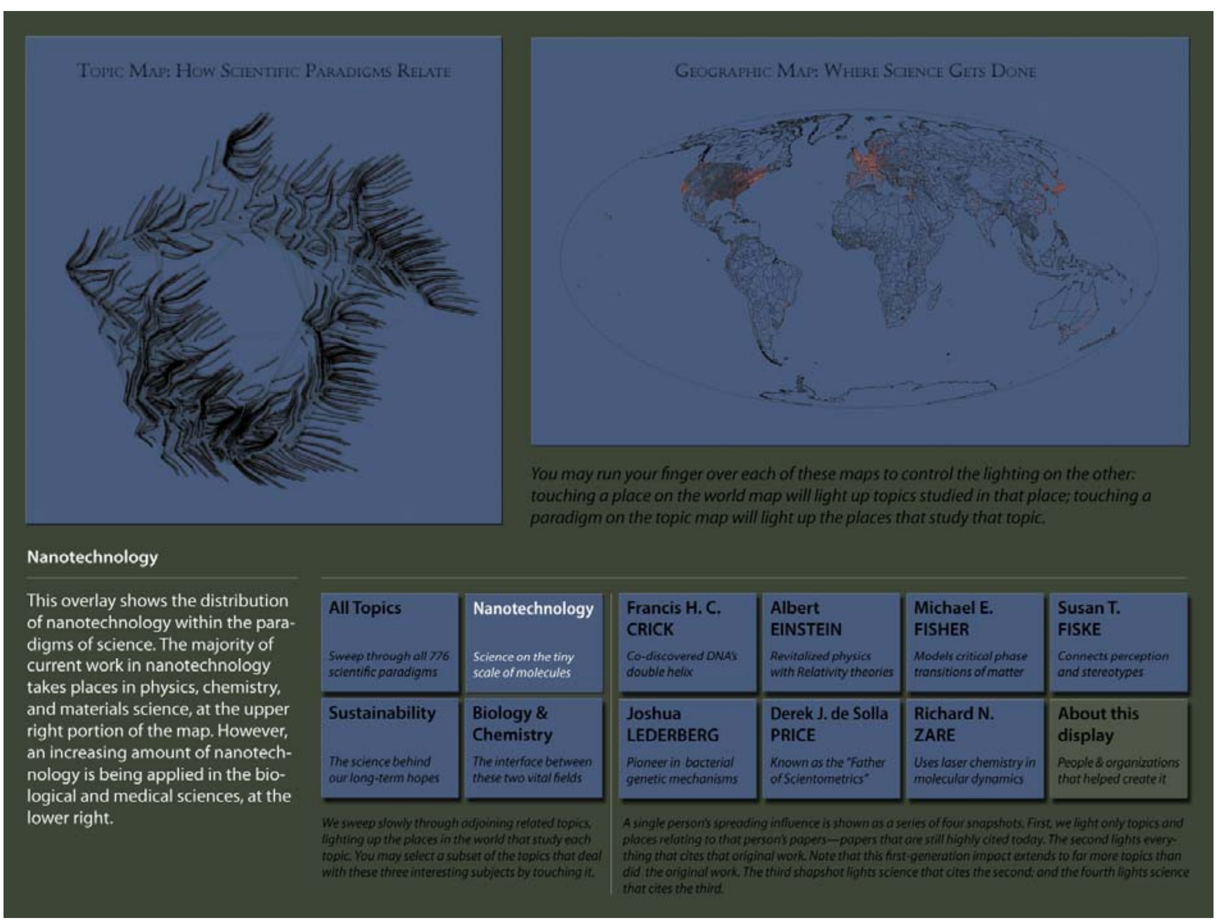
Large-scale, high resolution prints illuminated via projector or screen.

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

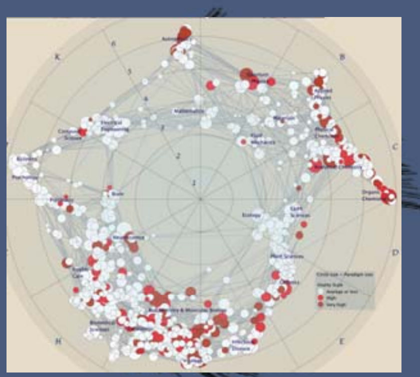
Interactive touch panel.

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

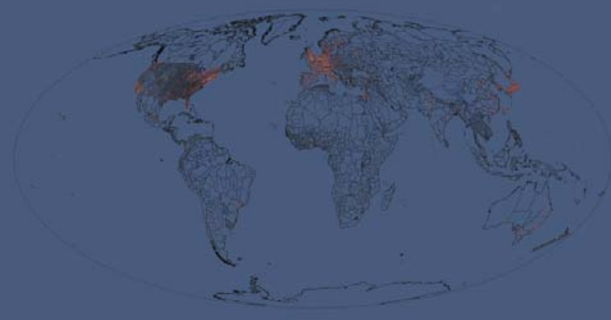




Topic Map: How Scientific Paradigms Relate



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 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*

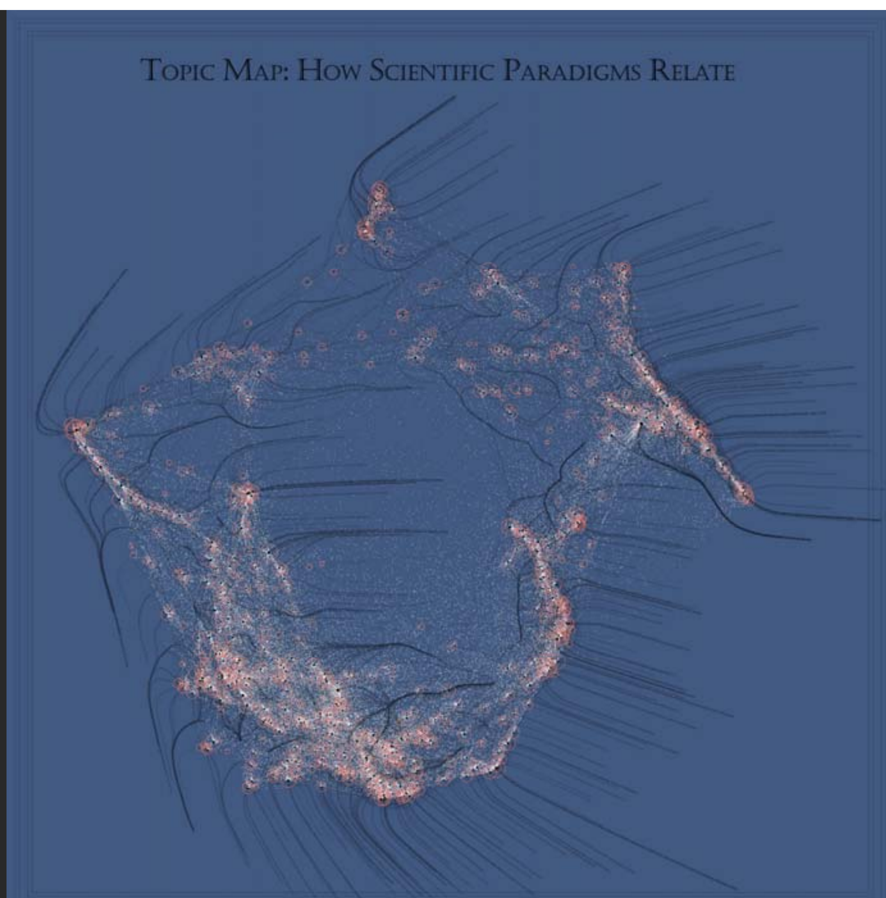
Joshua LEDERBERG — *Pioneer in bacterial genetic mechanisms*

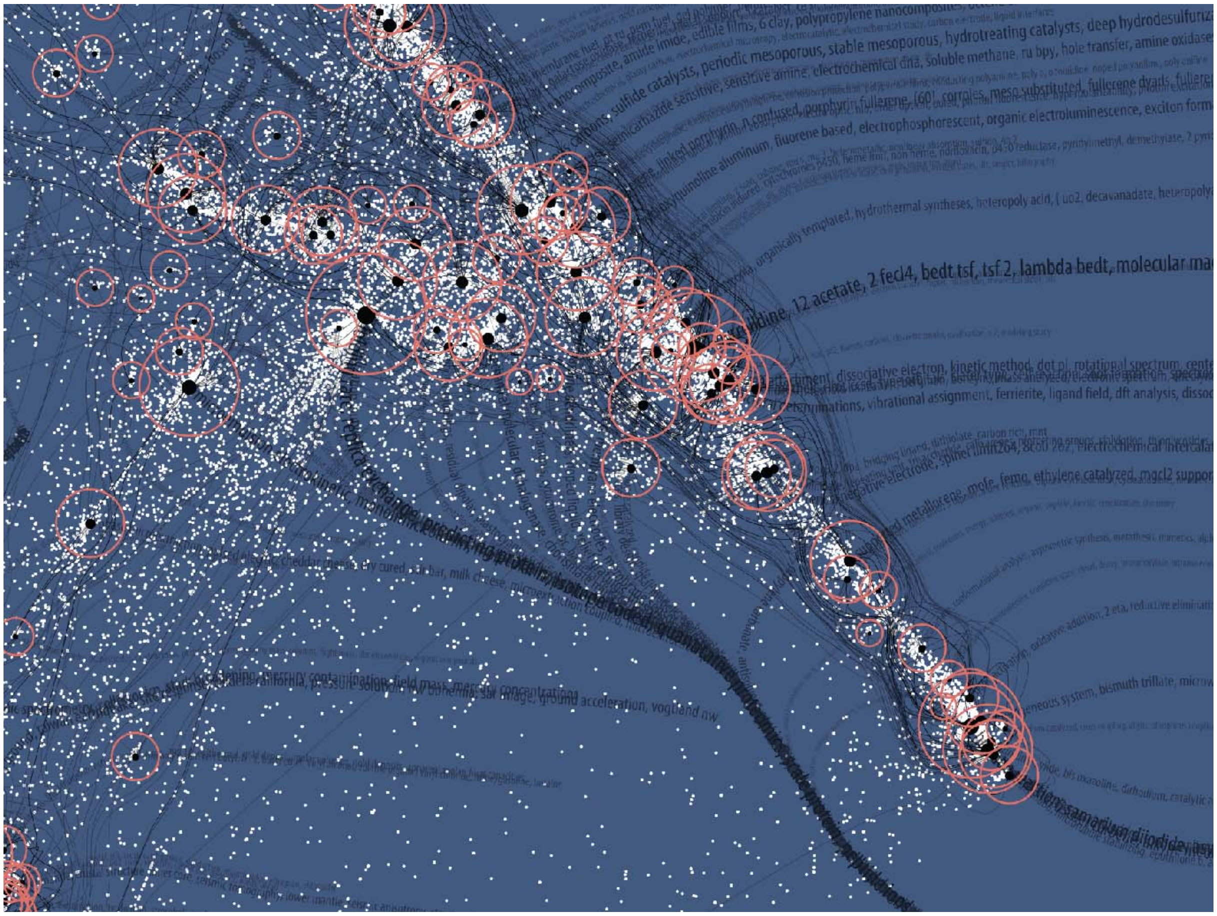
Derek J. de Solla PRICE — *Known as the "Father of Scientometrics"*

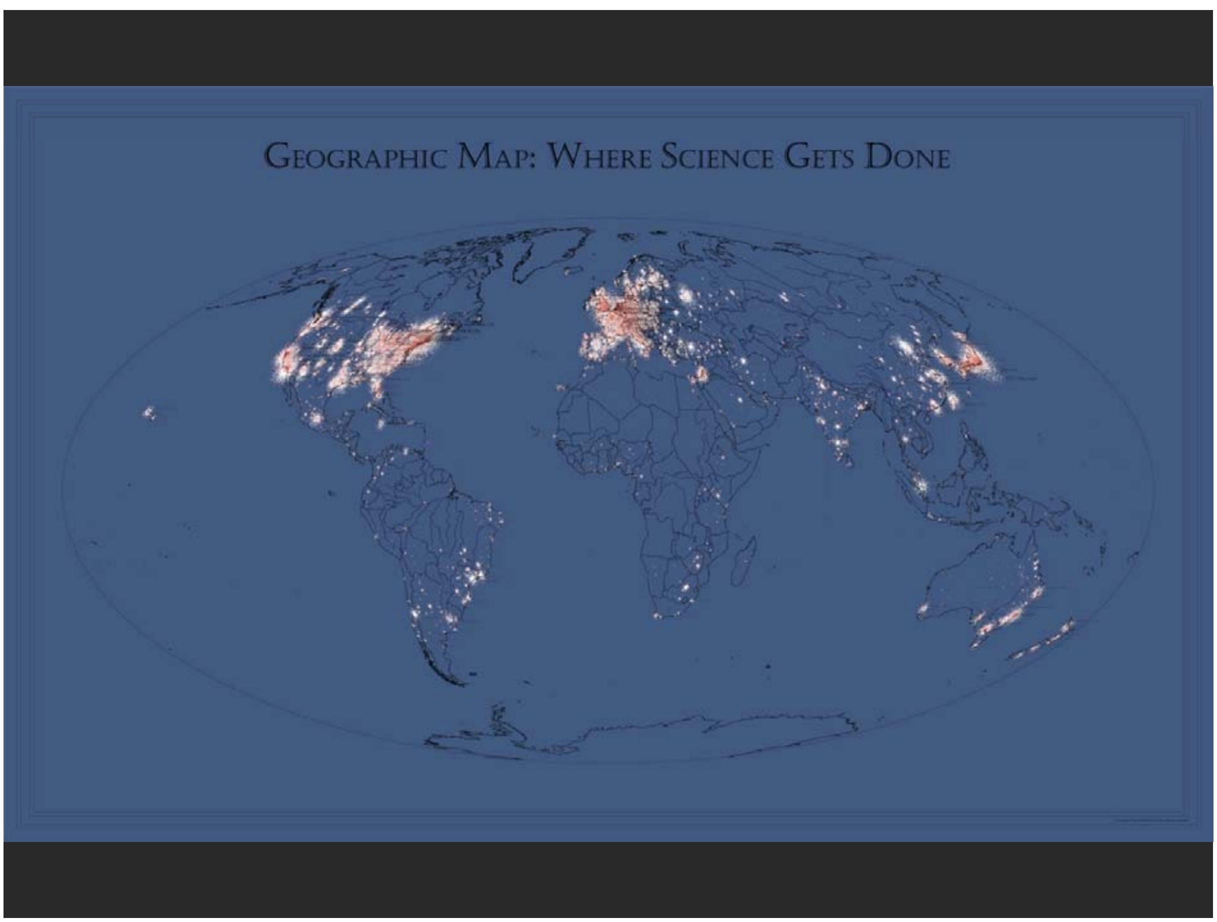
Richard N. ZARE — *Uses laser chemistry in molecular dynamics*

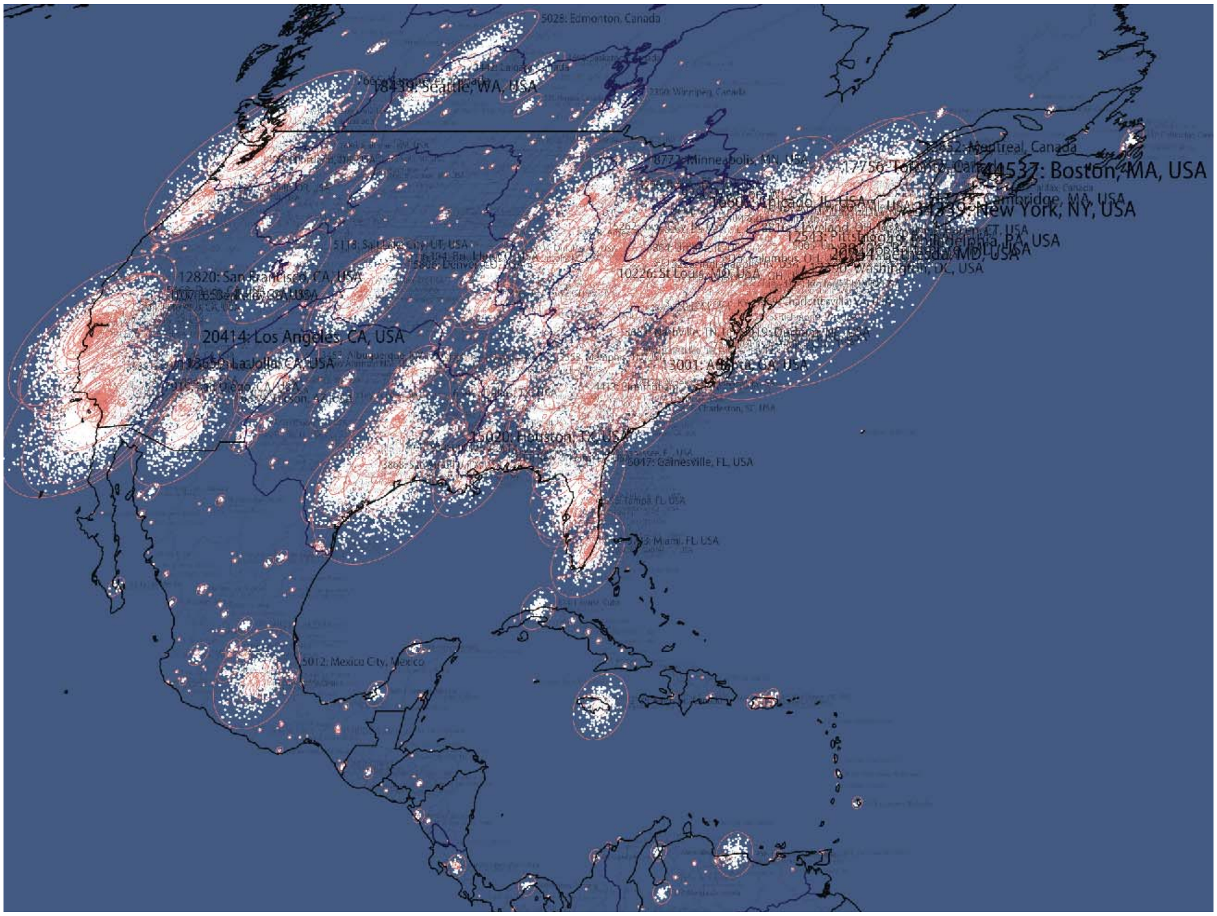
About this display — *People & organizations that helped create it*

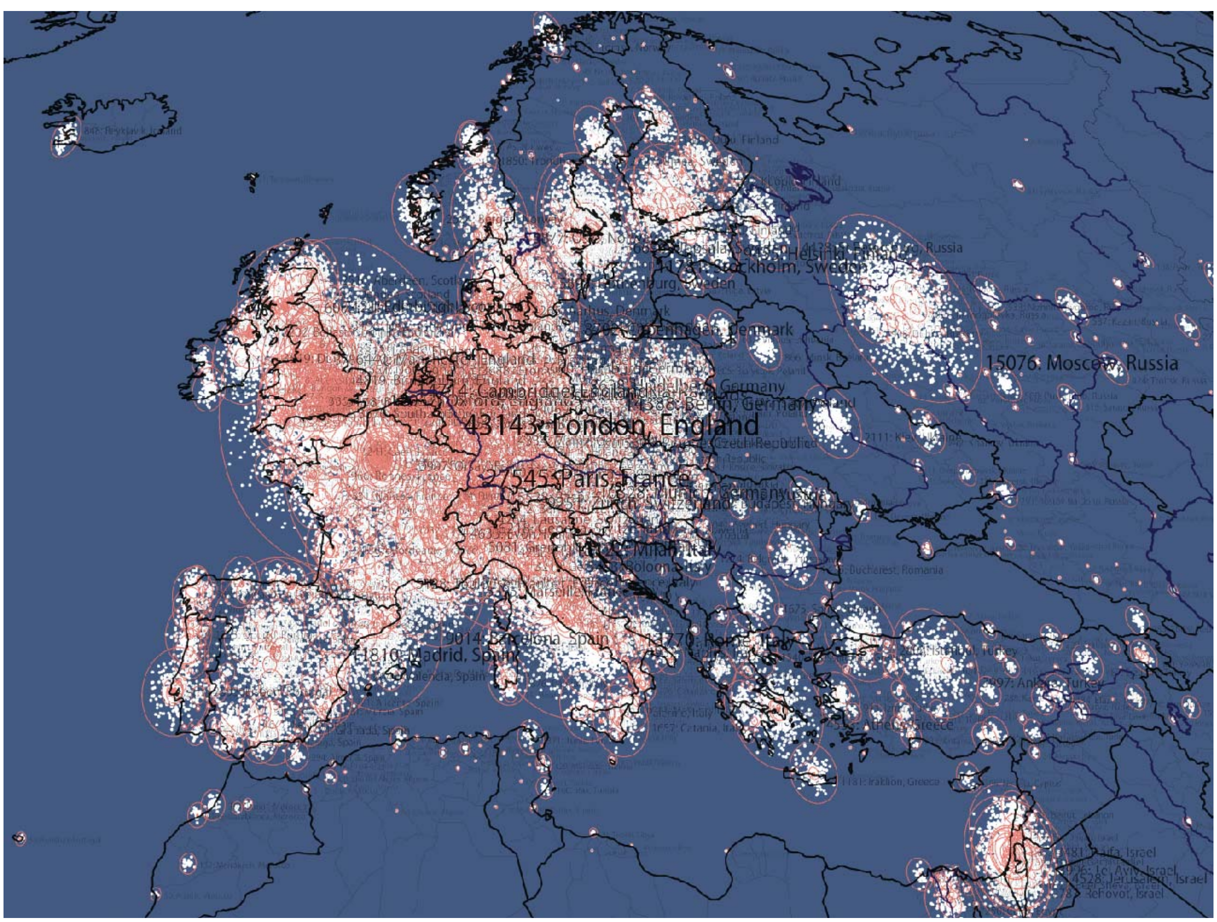
A single person's spreading influence is shown as a series of four snapshots. First, we light only topics and places relating to that person's papers—papers that are still highly cited today. The second lights everything that cites that original work. Note that this first-generation impact extends to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

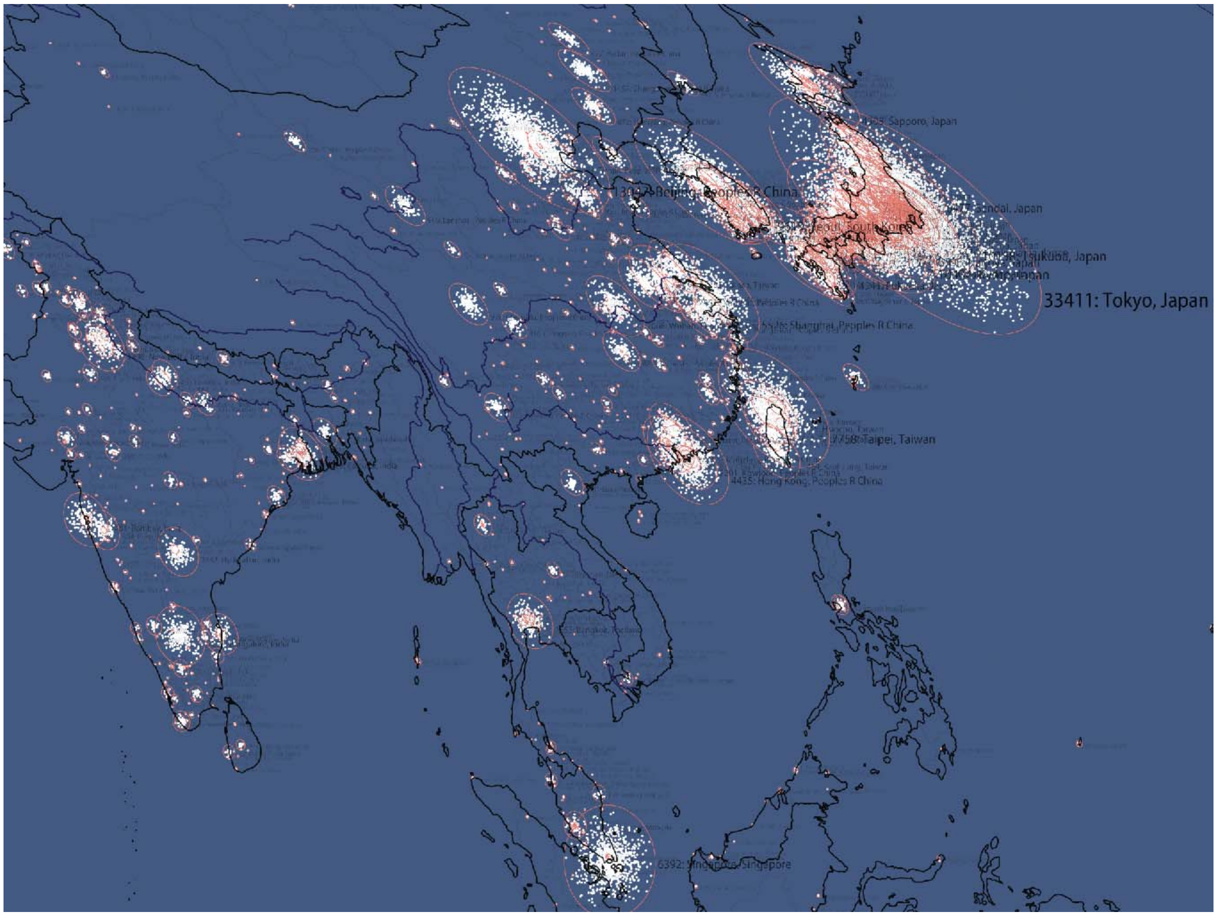


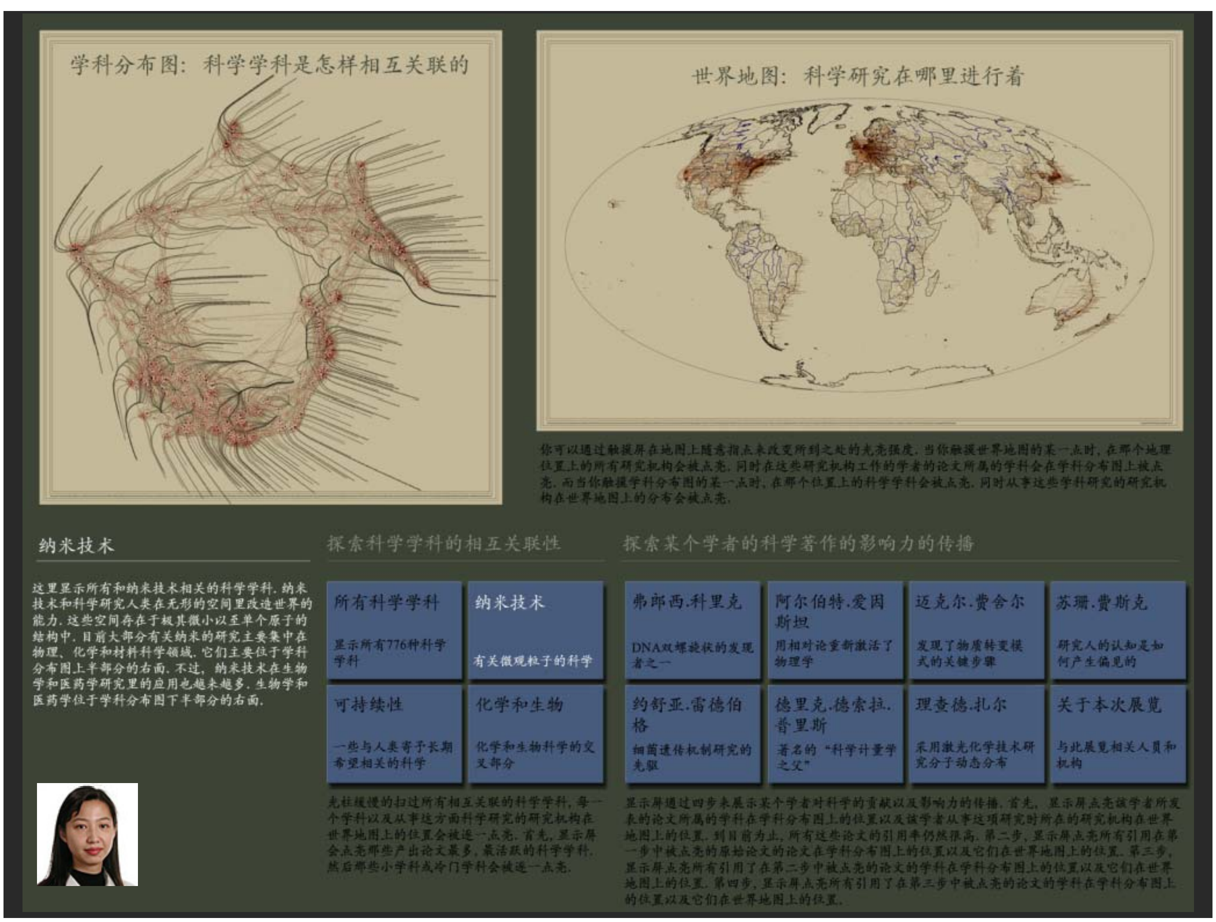



Geographic Map: Where Science Gets Done


5028: Edmonton, Canada
Seattle, WA, USA
Boston, MA, USA
New York, NY, USA
20414: Los Angeles, CA, USA
5017: Gainesville, FL, USA
5012: Mexico City, Mexico

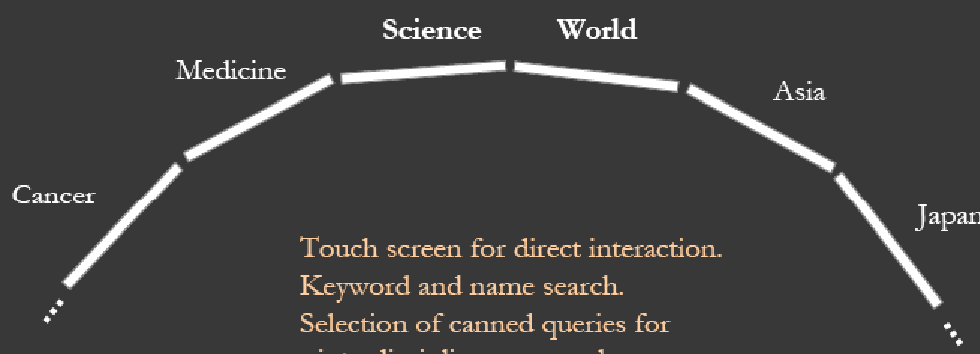

43143: London, England
Paris, France
15076: Moscow, Russia
Stockholm, Sweden
Madrid, Spain
Bucharest, Romania
Haifa, Israel


33411: Tokyo, Japan
Sapporo, Japan
Tsukuba, Japan
Shanghai, Peoples R China
Taipei, Taiwan
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

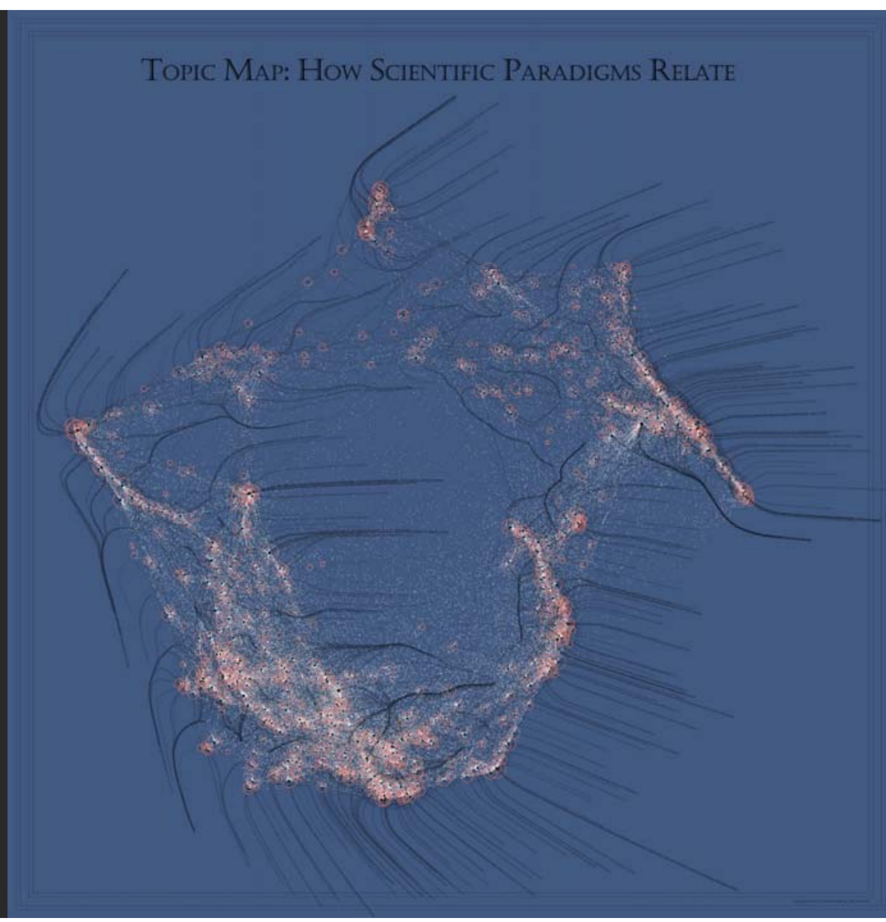
Drives unlimited number of ID screens.



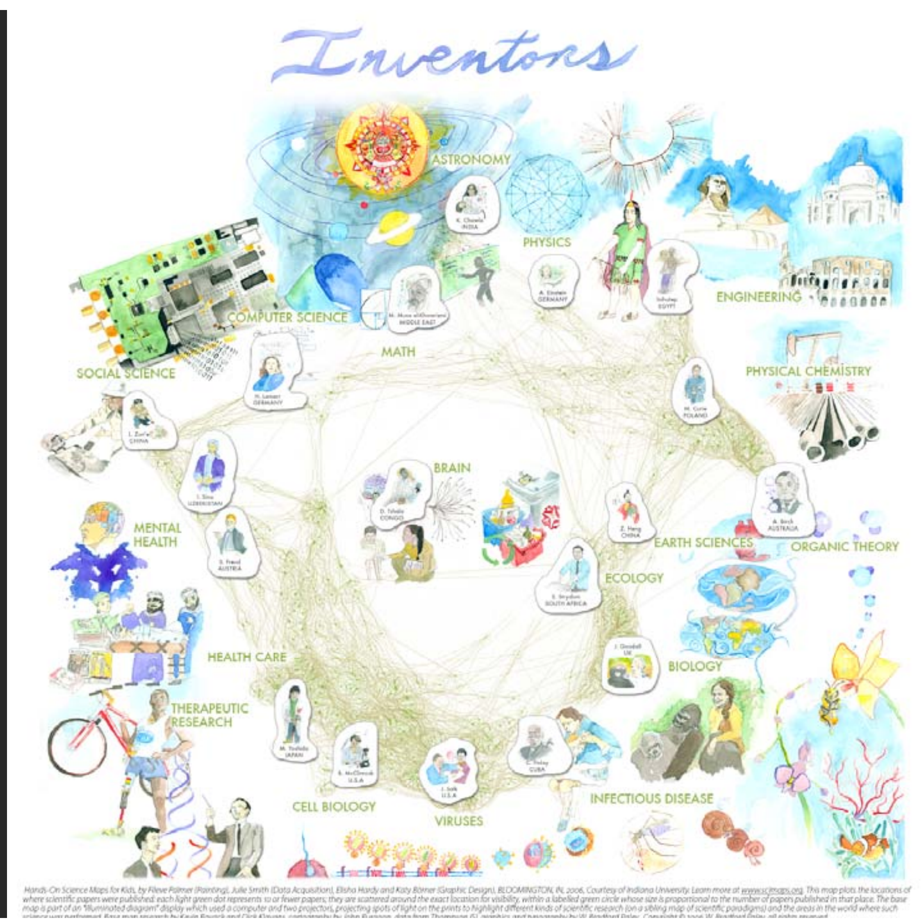
Touch screen for direct interaction.
Keyword and name search.
Selection of canned queries for
- interdisciplinary research areas
- famous people
- activity patterns, e.g., bursts, trends, etc.

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
ENGINEERING
COMPUTER SCIENCE
MATH
SOCIAL SCIENCE
PHYSICAL CHEMISTRY
BRAIN
MENTAL HEALTH
EARTH SCIENCES
ORGANIC THEORY
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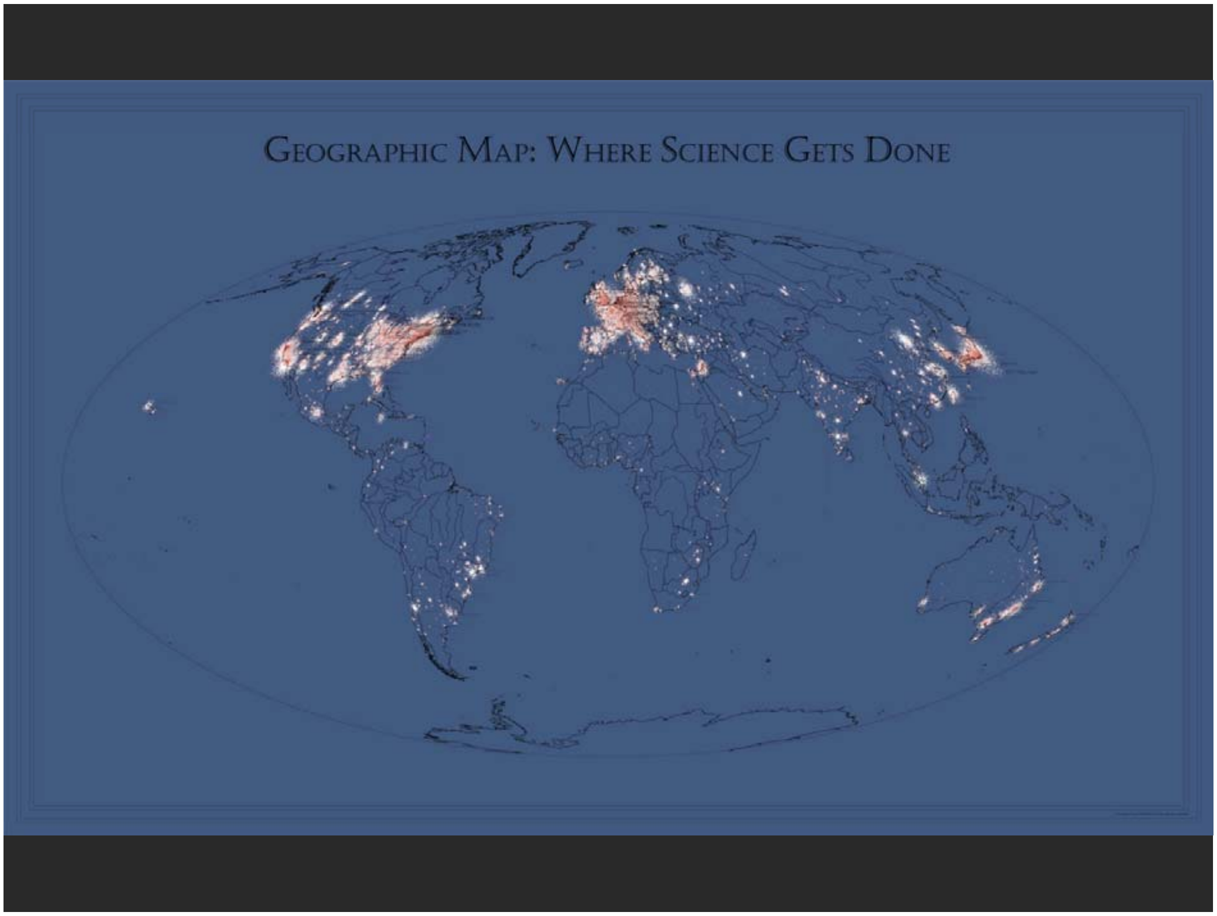
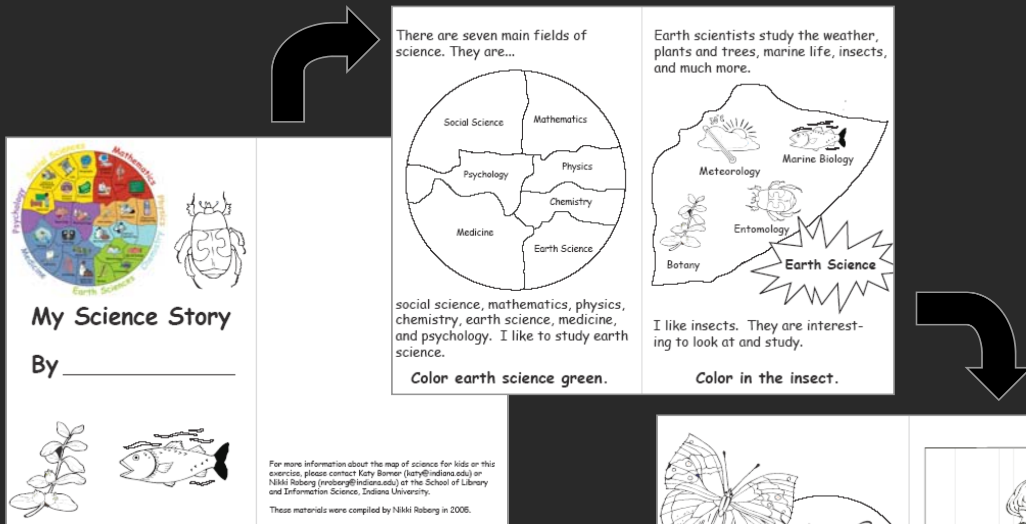
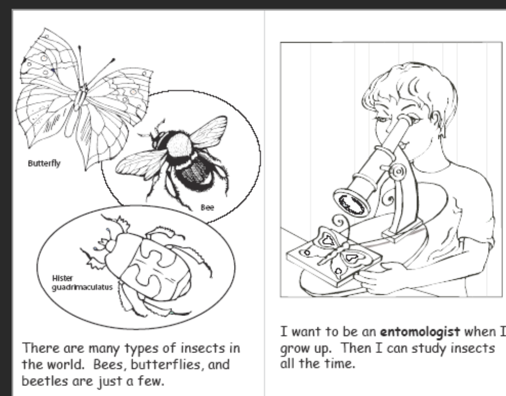
Hands-On Science Maps for Kids, by Fileve Palmer (Painting), Julie Smith (Data Acquisition), Elisha Hardy and Katy Börner (Graphic Design), BLOOMINGTON, IN, 2006. Courtesy of Indiana University. Learn more at www.scimaps.org. This map plots the locations of where scientific papers were published: each 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 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.)

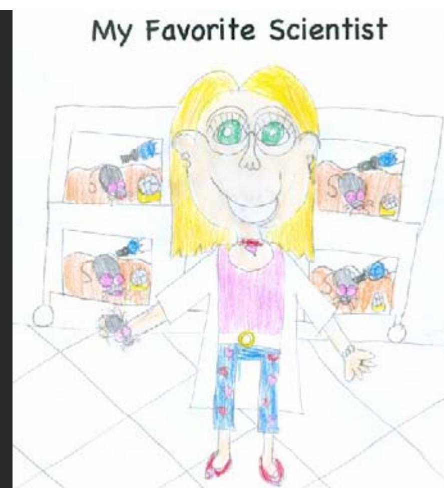

Inventors
Hands-On Science Maps for Kids, by Fileve Palmer (Painting), Julie Smith (Data Acquisition), Elisha Hardy and Katy Börner (Graphic Design), BLOOMINGTON, IN, 2006, Courtesy of Indiana University. Learn more at www.scimaps.org. This map plots the locations of where scientific papers were published: 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.





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?

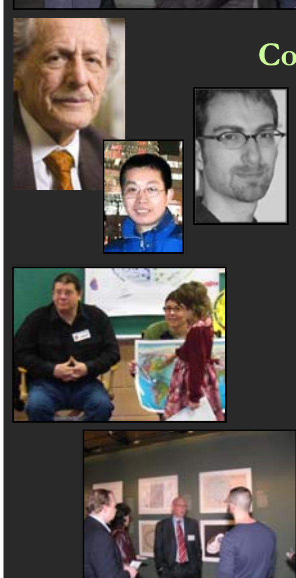


Winners @ AMSE

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

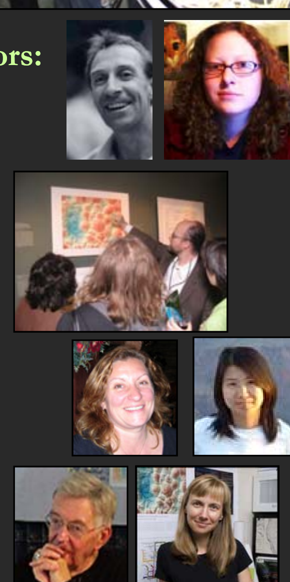
Sascha Richey, age 8, drew a picture of her mother and explained why her mother is her favorite scientist.

Where to go from here?

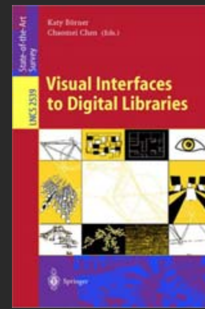


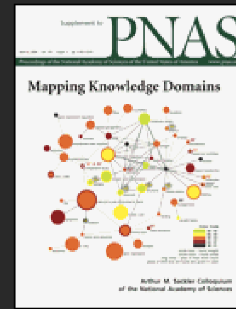
Contact the map makers via the exhibit curators:

Katy Börner (katy@indiana.edu) and Elisha Hardy (efhardy@indiana.edu)



Computational Scientometrics:
Studying Science by Scientific Means

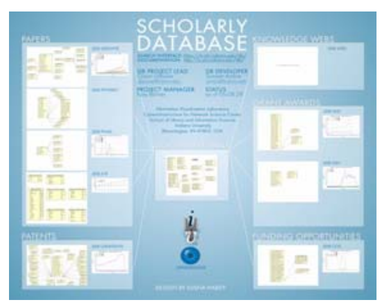




- *Börner, Katy, Chen, Chaomei, and Boyack, Kevin. (2003).* ***Visualizing Knowledge Domains.*** *In Blaise Cronin (Ed.), Annual Review of Information Science & Technology, Medford, NJ: Information Today, Inc./American Society for Information Science and Technology, Volume 37, Chapter 5, pp. 179-255.* 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.), Annual Review of Information Science & Technology, 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

- ***Places & Spaces: Mapping Science*** *exhibit, see also* *http://scimaps.org*.

Cyberinfrastructures for a Science of Science



Scholarly Database of 18 million scholarly records
https://sdb.slis.indiana.edu

James S. McDonnell Foundation

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

Network Workbench Tool and Community Wiki
***NEW* Scientometrics plugins**
http://nwb.slis.indiana.edu

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

Science of Science Cyberinfrastructure PORTAL

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.

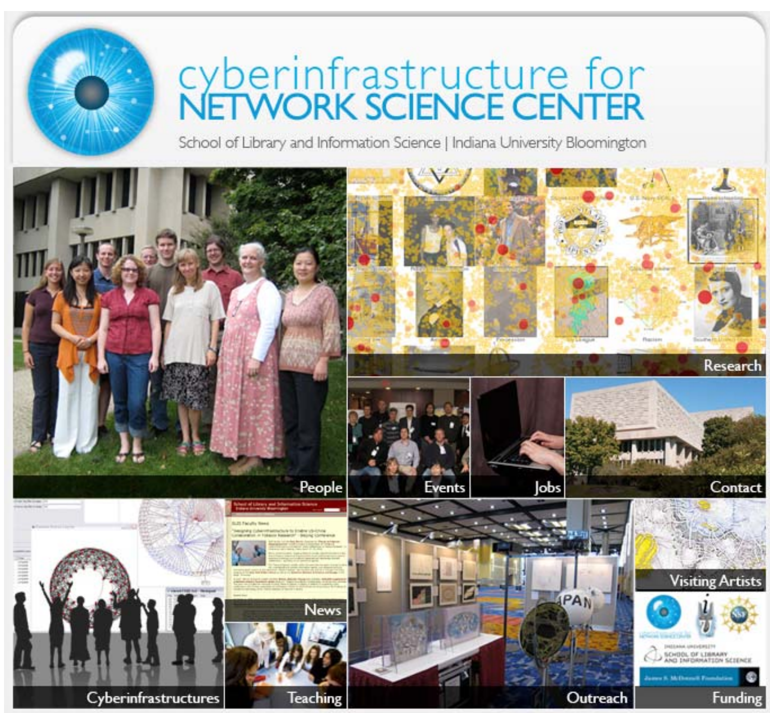
Needs Analysis
As part of the "TLS: Towards a Macroscope for Science Policy Decision Making" NSF SBE-0738111 award, interviews with science policy makers are conducted to identify what 'science of science' research results and tools might be most desirable and effective. So far, 30 formal, one-hour interviews 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*).

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 Bibtex 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

Please join us for a tour of the exhibit.