Atlas of Science

Katy Börner
CNS, SLIS, IU, Bloomington, IN
katy@indiana.edu | http://cns.iu.edu

All School Day
University of North Texas, Denton ,TX
October 1, 2011

Foreword

…

The explorers whose work is represented in the pages of this rich and fascinating volume face challenges far more daunting. First, the world they strive to represent is an abstract and intellectual one, not a physical reality that can be imaged from space, surveyed on the ground, and depicted in miniature on a map. The interrelationships among the landmarks of this abstract world are real, but they are not easily represented in the simple, straightforward ways that one can convey the distances between, say, three cities.

Second, there is no equivalent in the cartography of science to the standards and conventions upon which we mappers of the physical world comfortably depend. There's no agreed-upon notion of north-as-up, of systems of latitude and longitude, of symbols, scale, and projection. Mapping the world of science requires the invention of a brand-new geography. Not only that, but the new geography then needs to be represented visually using colors, lines, and symbols for which no conventions exist.

…

Third, the world that is being mapped in this book is changing at a dizzying rate. It's a fact of twenty-first-century science that whole realms of inquiry bloom into existence almost overnight, creating new places and spaces in ways that are alien to "normal" cartography. It is as if entire continents and archipelagoes were to constantly erupt on the roiling surface of a map even as that map was being drawn for the first time.

…

Allen Caroll
Chief Cartographer
National Geographic Society

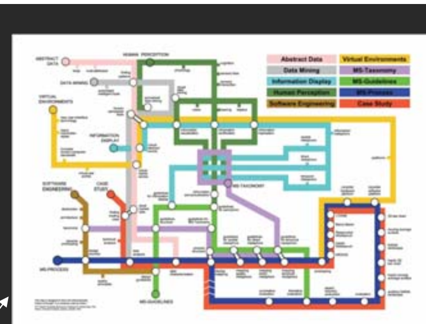
Early Maps of the World VERSUS Early Maps of Science

3D	n-D
Physically-based	Abstract space
Accuracy is measurable	Accuracy is difficult
Trade-offs have more to do with granularity	Trade-offs indirectly affect accuracy
2-D projections are very accurate at local levels	2-D projections neglect a great deal of data
Centuries of experience	Decades of experience
Geo-maps can be a template for other data	**Science maps can be a template for other data**

Kevin W. Boyack, UCGIS Summer Meeting, June, 2009

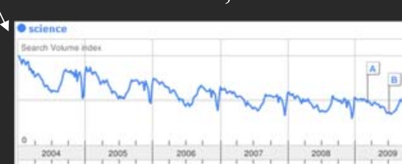
Take terra bytes of data

Black Box



Find your way

Find collaborators, friends



Identify trends

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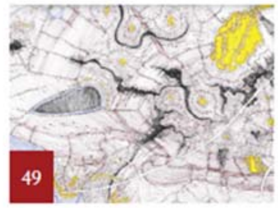
Part 2: The History of Science Maps



Part 3: Toward a Science of Science

Part 4: Science Maps in Action

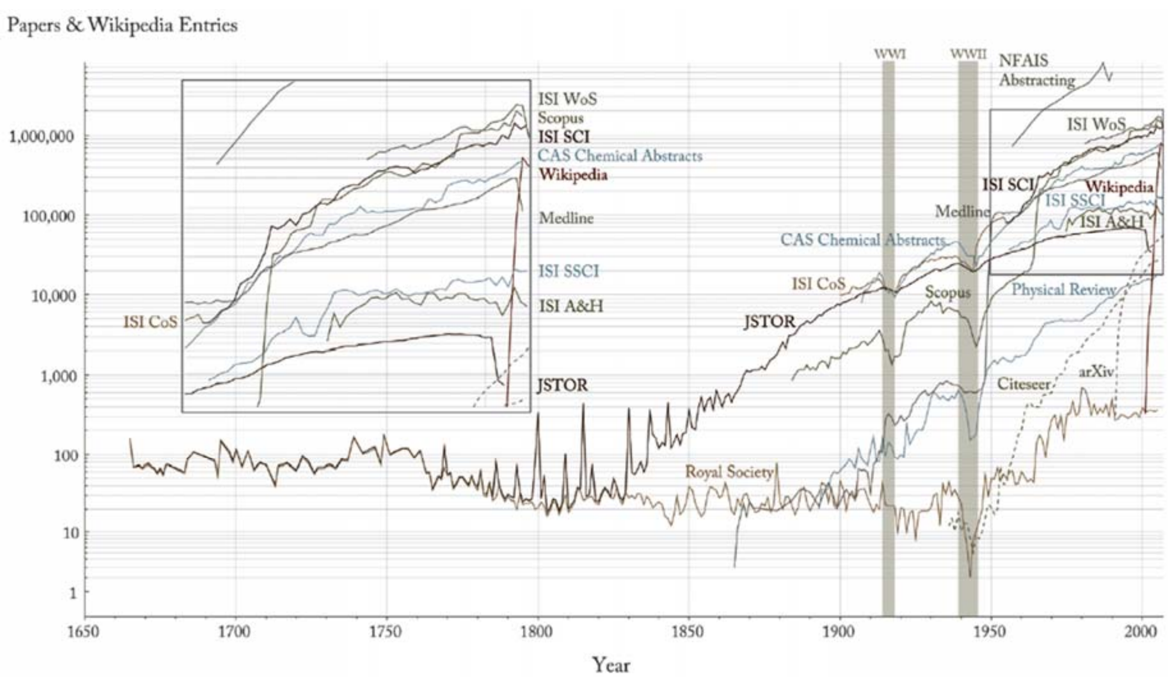
Part 5: The Future of Science Maps

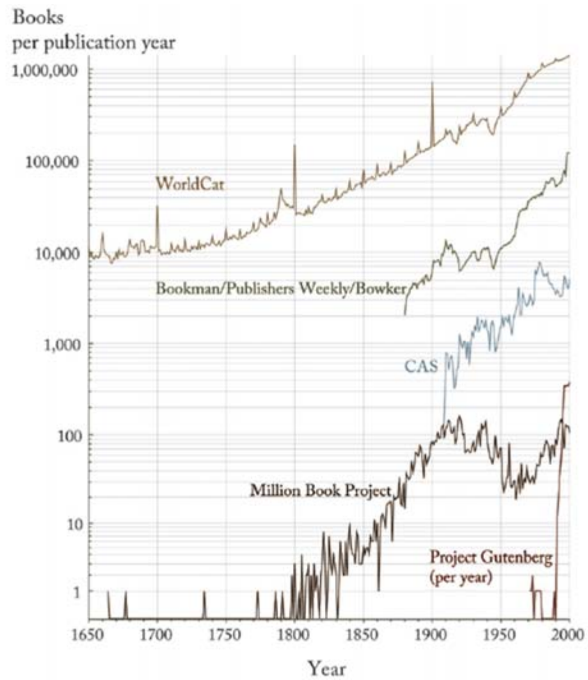
Part 1: Introduction

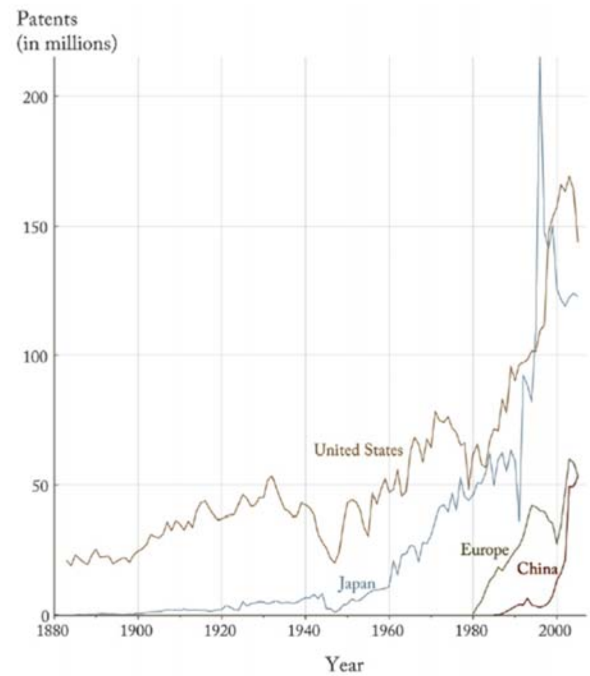
Because of the explosive power of exponential growth, the 21st century will be equivalent to 20,000 years of progress at today's rate of progress. The whole 20th century is equivalent to 20 years of progress at today's rate of progress. Organizations have to be able to redefine themselves at a faster and faster pace.

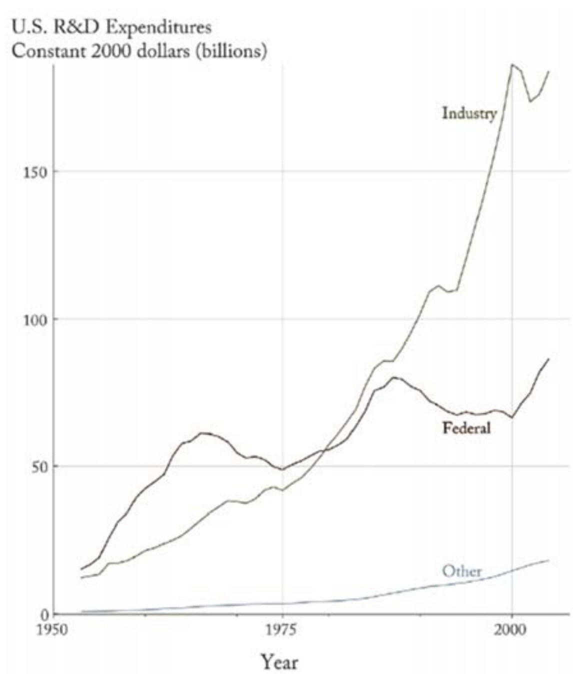
Ray Kurzweil

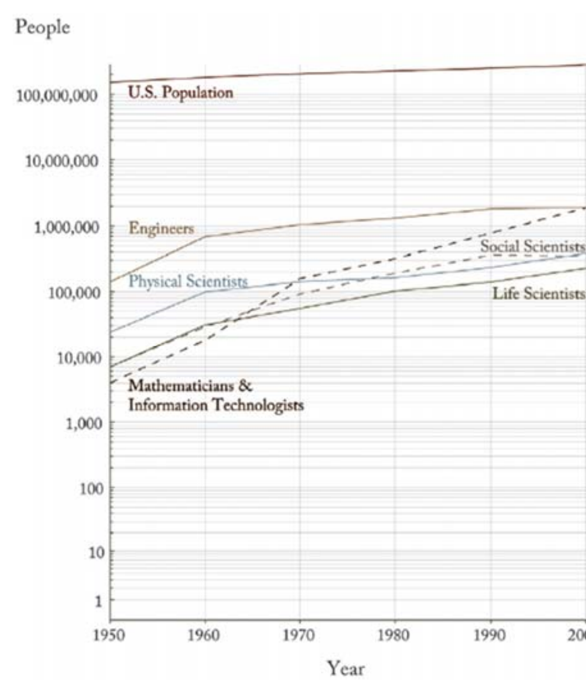
The Rise of Science and Technology




Books
per publication year
1,000,000
100,000
10,000
1,000
100
10
1
WorldCat
Bookman/Publishers Weekly/Bowker
CAS
Million Book Project
Project Gutenberg
(per year)
1650
1700
1750
1800
1850
1900
1950
2000
Year

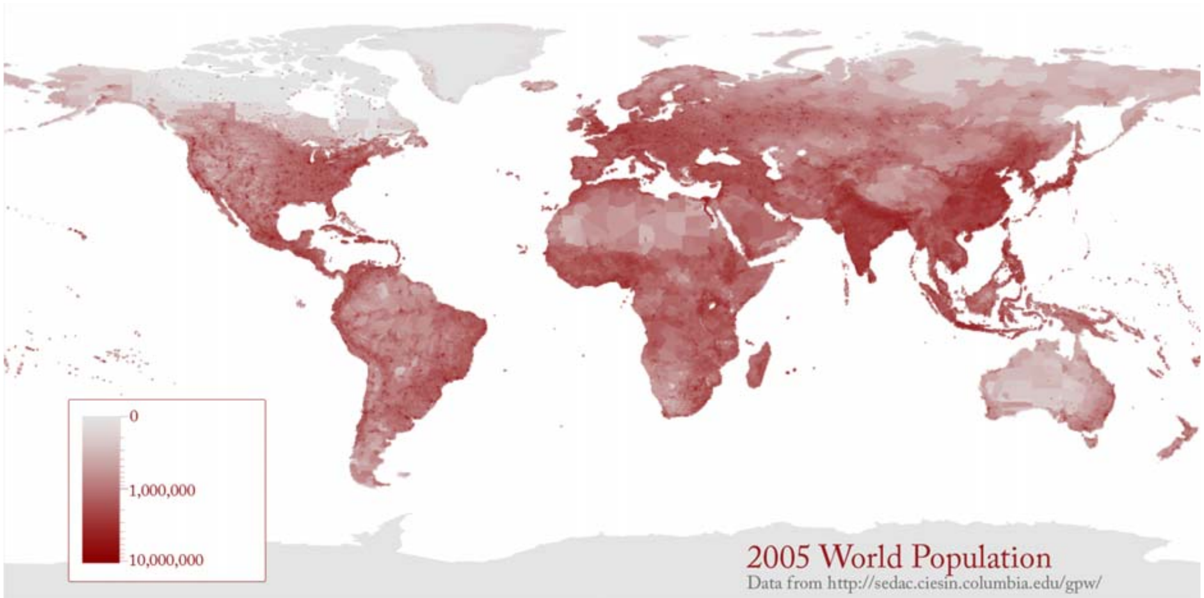

Patents
(in millions)
200
150
100
50
0
United States
Japan
Europe
China
1880
1900
1920
1940
1960
1980
2000
Year


U.S. R&D Expenditures
Constant 2000 dollars (billions)
150
100
50
0
Industry
Federal
Other
1950
1975
2000
Year


People
100,000,000
10,000,000
1,000,000
100,000
10,000
1,000
100
10
1
U.S. Population
Engineers
Social Scientists
Physical Scientists
Life Scientists
Mathematicians &
Information Technologists
1950
1960
1970
1980
1990
2000
Year

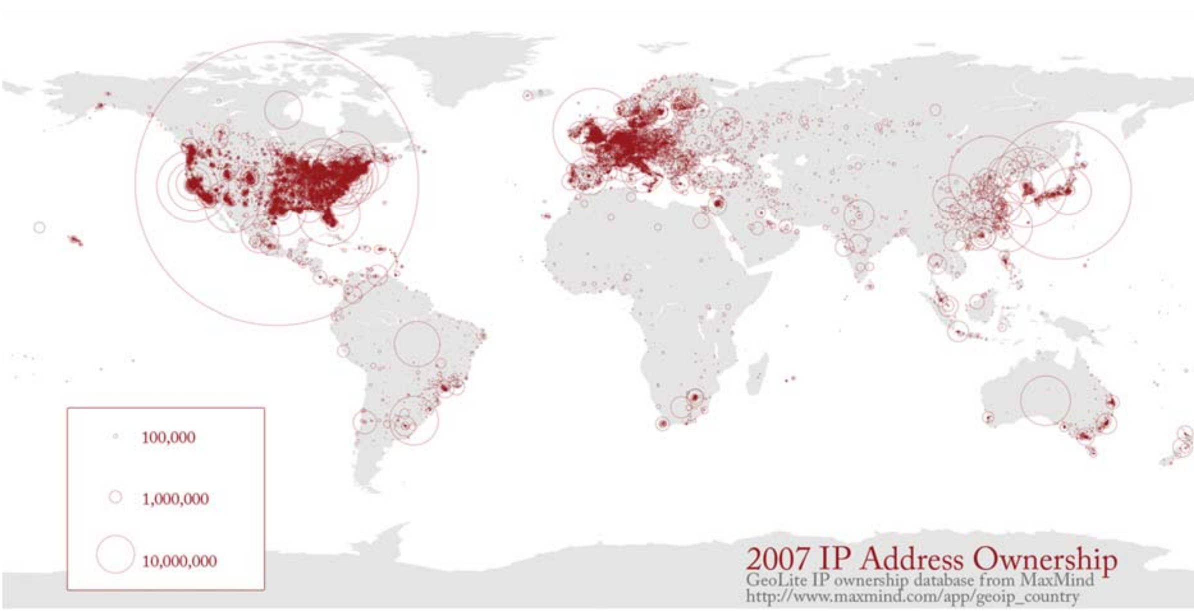
2005 World Population

The population map uses a quarter degree box resolution. Boxes with zero people are given in white. Darker shades of red indicate higher population counts per box using a logarithmic interpolation. The highest density boxes appear in Mumbai, with 11,687,850 people in the quarter degree block, Calcutta (10,816,010), and Shanghai (8,628,088).



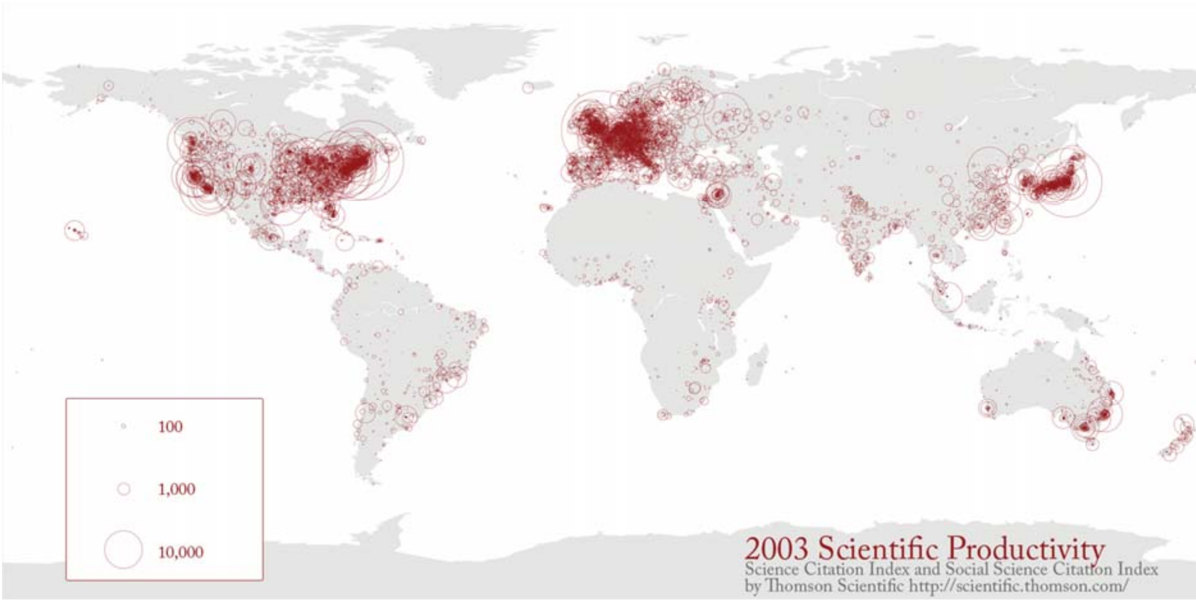
2007 IP Address Ownership

This map shows IP address ownership by location. Each owner is represented by a circle and the area size of the circle corresponds to the number of IP addresses owned. The larges circle denotes MIT's holdings of an entire class A subnet, which equates to 16,581,375 IP addresses. The countries that own the most IP addresses are US (560 million), Japan (130 million), Great Britain (47 million).



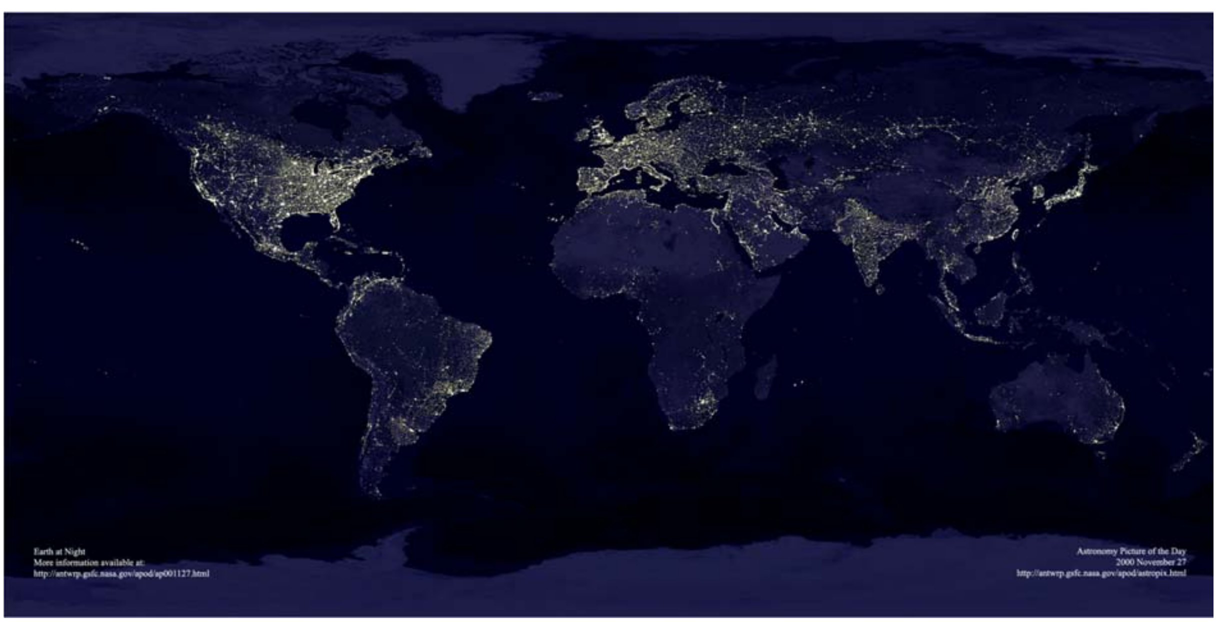
2003 Scientific Productivity

Shown is where science is performed today. Each circle indicates a geographic location at which scholarly papers are published. The larger the circle the more papers are produced. Boston, MA, London, England, and New York, NY are the top three paper production areas. Note the strong resemblance with the Night on Earth and the IP Ownership maps and the striking differences to the world population map.

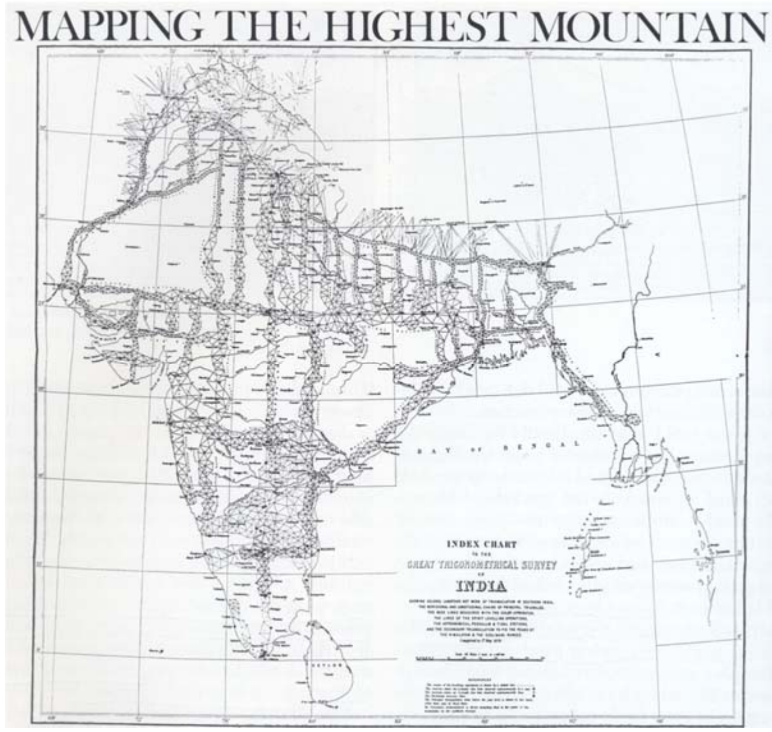


2000 Night on Earth

This image shows city lights at night. It was composed from hundreds of pictures made by orbiting satellites. The seaboards of Europe, the eastern United States, and Japan are particularly well lit. Many cities exist near rivers or oceans so that goods can be exchanged cheaply by boat. The central parts of South America, Africa, Asia, and Australia are rather dark despite their high population density, see map to the left.



Part 1: Introduction

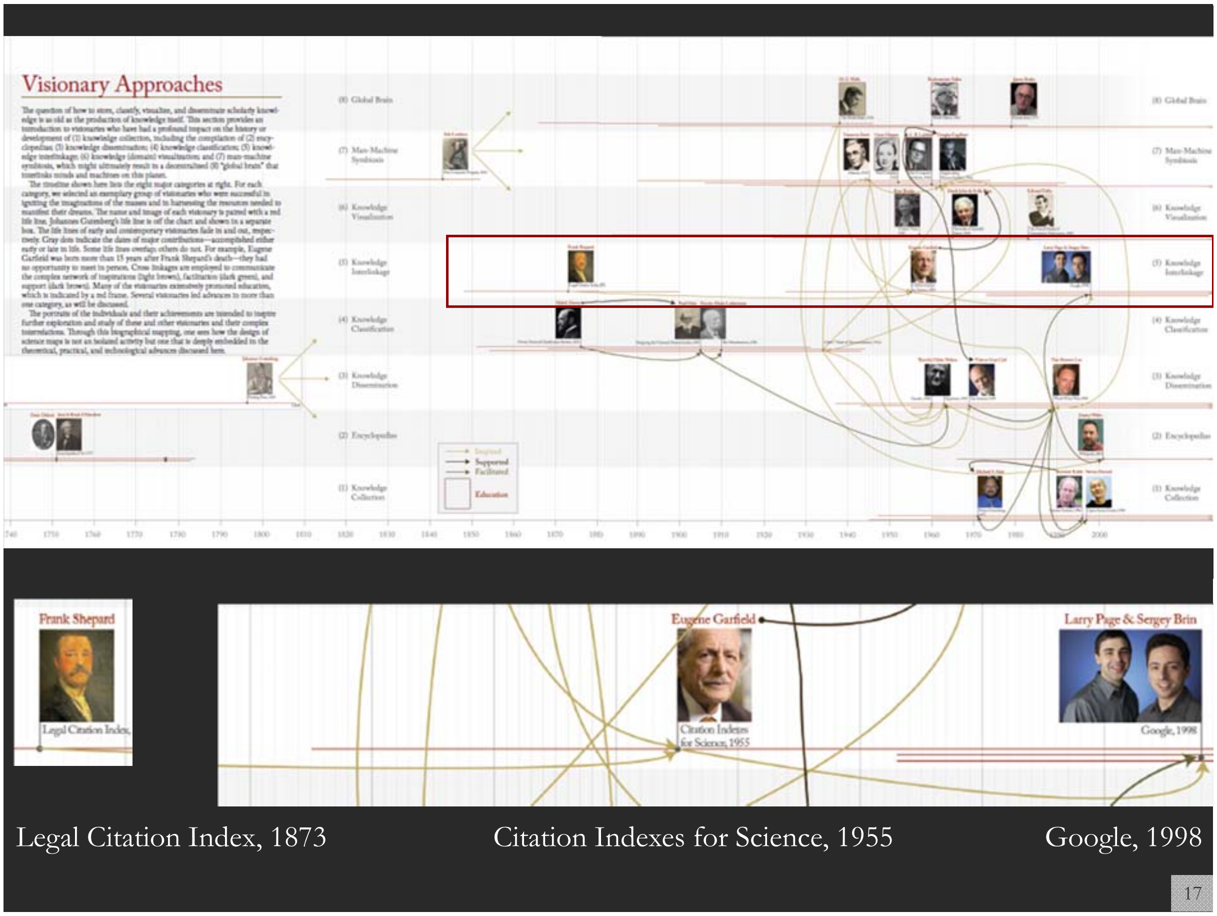


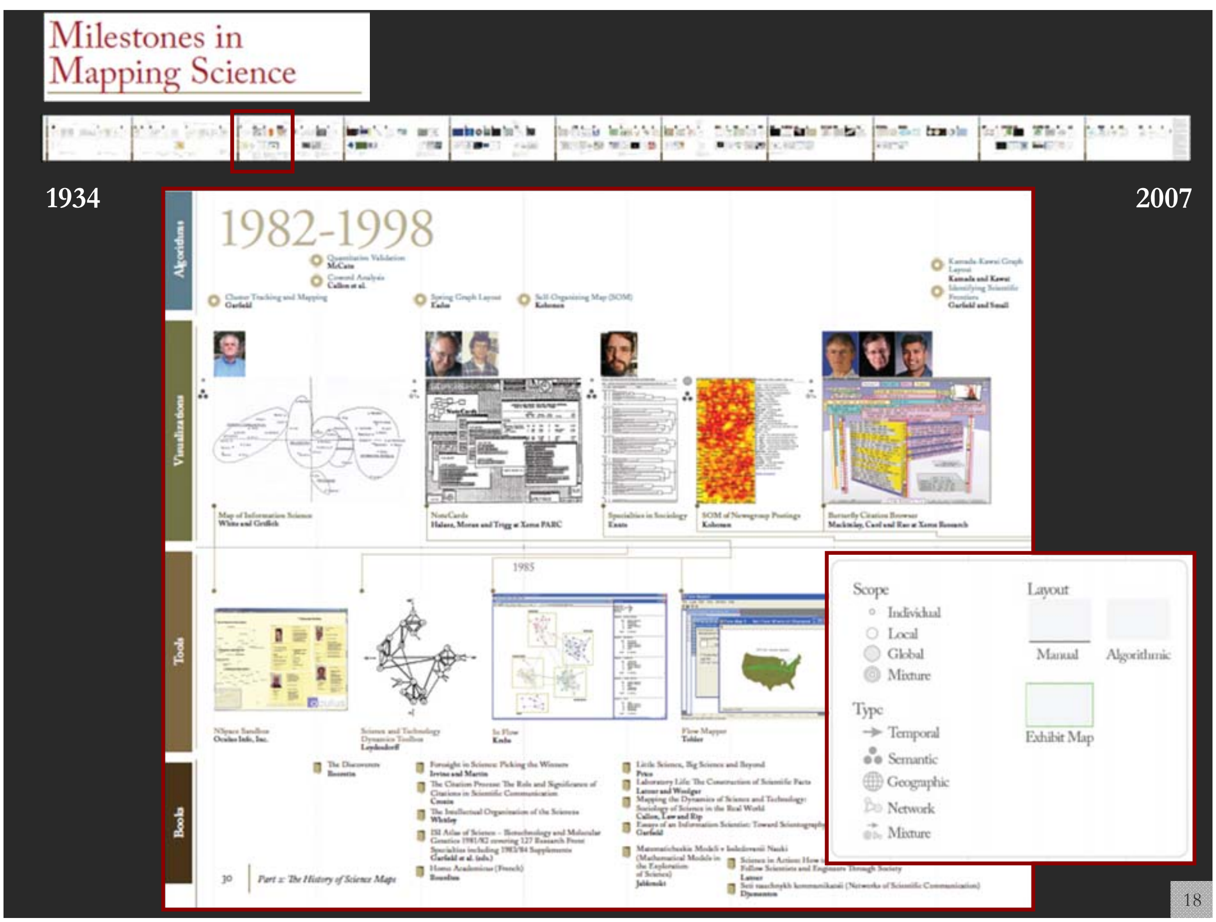
In ***1870****, Captain George Everest embarked to map India by triangulation. For generations, a vast network of repeating sightline triangles was meticulously measured and recorded (see map below). What resembles a pattern of eyelashes on the northern border represents the sightlines to stations built above treetops. While analyzing the triangles in the calculating offices of Calcutta, the mapmakers discovered the highest peak in the world: Mount Everest*

Part 2: The History of Science Maps

Noise becomes data when it has a cognitive pattern. Data becomes information when assembled into a coherent whole, which can be related to other information. Information becomes knowledge when integrated with other information in a form useful for making decisions and determining actions. Knowledge becomes understanding when related to other knowledge in a manner useful in anticipating, judging and acting. Understanding becomes wisdom when informed by purpose, ethics, principles, memory and projection.

George Santayana


Visionary Approaches
Frank Shepard
Legal Citation Index
Eugene Garfield
Citation Indexes for Science, 1955
Larry Page & Sergey Brin
Google, 1998
Legal Citation Index, 1873
Citation Indexes for Science, 1955
Google, 1998
17

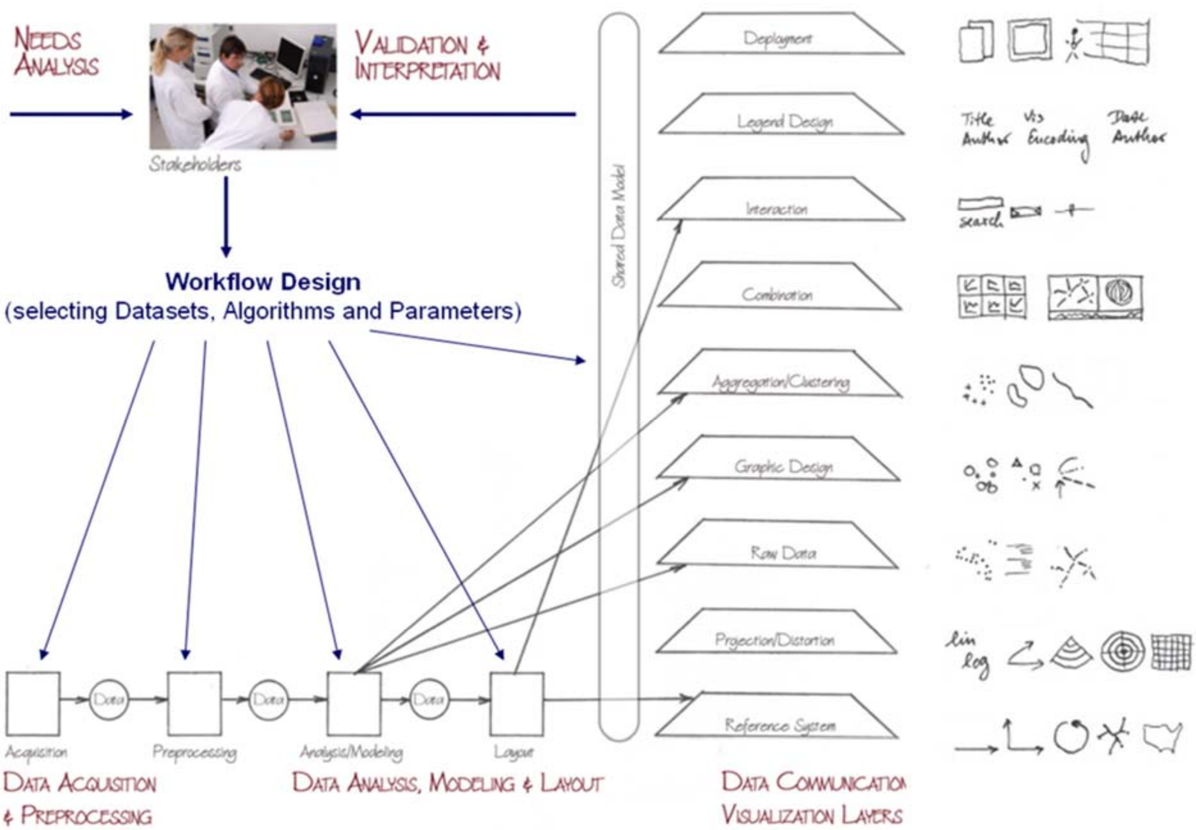

Milestones in Mapping Science
1934
2007
1982-1998
Algorithms
Visualizations
Tools
Books
1985
Scope
Individual
Local
Global
Mixture
Type
Temporal
Semantic
Geographic
Network
Mixture
Layout
Manual
Algorithmic
Exhibit Map
18

Part 3: Toward a Science of Science

Those who cannot remember the past are condemned to repeat it.

George Santayana

Part 3: Toward a Science of Science



Temporal Analysis

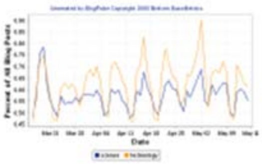
Science evolves over time. Attribute values of scholarly entities and their diverse aggregations increase and decrease at different rates and respond with different latency rates to internal and external events. Temporal analysis aims to identify the nature of phenomena represented by a sequence of observations such as patterns, trends, seasonality, outliers, and bursts of activity.

Data

A time series is a sequence of events or observations that are ordered in time. Time-series data can be continuous (there is an observation at every instant of time; see figure to the right) or discrete (observations exist for regularly or irregularly spaced intervals). Temporal aggregations—over journal volumes, years, or decades—are common.

Algorithms

Frequently, some form of filtering is applied to reduce noise and make patterns more salient. Smoothing (averaging using a smoothing window of a certain width) and curve approximation might be applied. The number of scholarly records is often plotted to get a first idea of the temporal distribution of a data set. It might be shown in total values or as a percentage of those. One may find out how long a scholarly entity was active; how old it was at a certain point; what growth, latency to peak, or decay rate it has; what correlations with other time series exist; or what trends are observable. Data models such as the least squares model (available in most statistical software packages) are applied to best fit a selected function to a data set and to determine if the trend is significant. Kleinberg's burst detection algorithm is commonly applied to identify words that have experienced a sudden change in frequency of occurrence.



Geographic Analysis

Geographic analysis aims to answer the question of where something happens and what impact it has on neighboring areas.

Data

Geographic analysis requires spatial attribute values or geolocations for authors and their papers, extracted from affiliation data or spatial positions of nodes, generated from layout algorithms. Geographic data can be continuous (each record has a specific position) or discrete (a position or area exists for sets of records, like the number of papers per country). Spatial aggregations (for example, merging data via postal codes, counties, states, countries, and continents) are common (see **page 66, Exemplification**).

Algorithms

Cartographic generalization refers to the process of abstraction. This includes (1) graphic generalization: the simplification, enlargement, displacement, merging, or selection of entities without enhancement or effect to their symbology and (2) conceptual symbolization: the merging, selection, and symbolization of entities, including enhancement (such as representing high-density areas with a city symbol).

Geometric generalization aims to solve the conflict between the number of visualized features, the size of symbols, and the size of the display surface. Cartographers dealt with this conflict intuitively in part until researchers like Friedrich Töpfer attempted to solve them with quantifiable expressions.

Flow maps use line thickness and direction to show the number of tangible or intangible entities that diffuse over a geographic location or science space (see CAS coauthor network, below, and **page 158, 113 Years of Physical Review**).

Topical Analysis

The topic coverage and topical similarity of basic and aggregate units of science (authors or institutions) can be derived from the units associated with them (papers, patents, or grants).

Data

The topic or semantic coverage of a unit of science can be derived from the text associated with it. Topical aggregations (for example, over journal volumes, scientific disciplines, or institutions) are common.

Algorithms

Topic analysis extracts the set of unique words or word profiles and their frequency from a text corpus. Stop words, such as "the" and "of," are removed. Stemming can be applied. Coword analysis identifies the number of times two words are used in the title, keyword set, abstract, or full text of a paper. The space of co-occurring words can be mapped, providing a unique view of the topic coverage of a data set (see **page 66, Exemplification**). Similarly, units of science can be grouped according to the number of words they have in common.

Salton's term frequency inverse document frequency (TFIDF) is a statistical measure used to evaluate the importance of a word in a corpus. The importance increases proportionally to the number of times a word appears in the paper but is offset by the frequency of the word in the corpus.

Dimensionality reduction techniques (see table on opposite page) are commonly used to project high-dimensional information spaces (for example, the matrix of all unique papers multiplied by their unique terms) into a low, typically two-dimensional space.

The SOM map below shows the topic landscape of geography abstracts; see **page 102, In Terms of Geography**.

Network Analysis

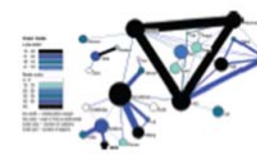
The study of networks aims to increase our understanding of natural and manmade networks. It builds on social network analysis, physics, information science, bibliometrics, scientometrics, informetrics, webometrics, communication theory, sociology of science, and several other disciplines.

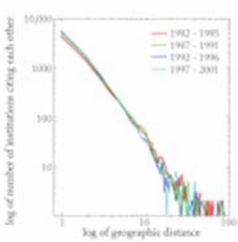
Data

Authors, institutions, and countries, as well as words, papers, journals, patents, and funding, are represented as nodes and their complex interrelations as edges (see **Part 3: Toward a Science of Science/Conceptualizing Science: Basic Anatomy of Science**). Nodes and edges can have time-stamped attributes.

Algorithms

Diverse algorithms exist to calculate specific node, edge, and network properties (see "Network Science" review). Node properties include degree centrality, betweenness centrality, or hub and authority scores. Edge properties include durability, reciprocity, intensity (weak or strong), density (how many potential edges in a network actually exist), reachability (how many steps it takes to go from one "end" of a network to another), centrality (whether a network has a "center" point), quality (reliability or certainty), and strength. Network properties refer to the number of nodes and edges, network density, average path length, clustering coefficient, and distributions from which general properties such as "small-world," "scale-free," or "hierarchical" can be derived. Identifying major communities via community detection algorithms and calculating the "backbone" of a network via pathfinder network scaling or maximum flow algorithms helps to communicate and make sense of large-scale networks. See the coauthor network of information visualization researchers below.



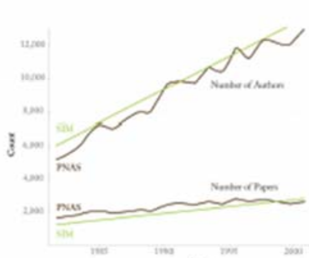


I(b) Log-log plot showing the variation of the number of institutions that cite one another over geographic distance between them for each of the four time slices

I(c) Geographic locations of the top 500 institutions with number of received citations indicated by height and color of bars

II(b) Fruchterman-Reingold layout of word co-occurrence matrix

II(c) Final layout with size- and color-coding, labels, and legend



III(b) Number of authors and papers over time

III(c) Number of received citations over time

Interpretation

Study I: Mapping Knowledge Diffusion and the Importance of Space

This study aimed to determine whether the Internet leads to more global citation patterns (that is, more citation links between papers produced at geographically distant research institutions). A novel approach to analyzing the dual role of institutions as information producers and consumers and to studying and visualizing the diffusion of information among them was developed. Surprisingly, the widespread adoption of the Internet does not seem to have affected the distance over which information diffuses as manifested by citation links. The citation linkages between institutions fall off with the distance between them, and there is a strong linear relationship between the log of the citation counts and the log of the distance that does not change over time. Reasons for local collaborations might include "winner takes all" funding schemes; the demands of complex, large-scale instrumentation; and the need to gain experience, train researchers, and sponsor protégés. , The social component of citation seems to become more important as researchers are flooded with information, and spatial proximity eases the creation and continuation of close personal relationships.

Study II: Identifying Research Topics and Trends

Scientific research is highly dynamic. New areas of science are continually evolving; some may shift in importance, others merge or split. Because of the steady increase in the number of scientific publications, it is challenging to keep abreast of the structure and dynamic development of one's own field, let alone all scientific domains. However, knowledge of "hot" topics, emergent research frontiers, and change of focus in certain areas is a critical component of resource allocation decisions in research laboratories, government institutions, and corporations. This study aimed to increase understanding of the topic coverage and activity bursts of words in highly cited PNAS papers. Interestingly, the burst of words seems to proceed their wide spread usage. . "Protein" and "model" were among the highly "bursty" terms between 1998 and 2001, and they have become important research topics since then.

Study III: Modeling the Coevolution of Author–Paper Networks

Models of scientific structure and evolution can help us understand the inner workings of science (see **page 58, Conceptualizing Science: Science Dynamics**). The TARL model (topics, aging, and recursive linking) describes the coevolution of coauthor and paper-citation networks. Using an agent-based approach, TARL simulates nodes (authors or papers), their edges (undirected coauthor, directed consumed, and directed paper-citation), and their attributes (time and topics). Topics cluster papers and authors *topically*. Aging is an antagonistic force to preferential attachment. Even highly connected nodes receive a decreasing number of links over time. Aging clusters papers and authors *temporally*. Recursive linking refers to the tendency of authors to cite papers referenced in material they are currently reading, which provides a grounded mechanism for the "rich get richer" phenomenon as an emergent property of the elementary activity of authors. According to this model, the number of topics is linearly related to the clustering coefficient of the simulated paper citation network.

Part 4: Science Maps in Action

If we ever get to the point of charting a whole city or a whole nation, we would have … a picture of a vast solar system of intangible structures, powerfully influencing conduct, as gravitation does in space. Such an invisible structure underlies society and has its influence in determining the conduct of society as a whole.

Jacob L. Moreno

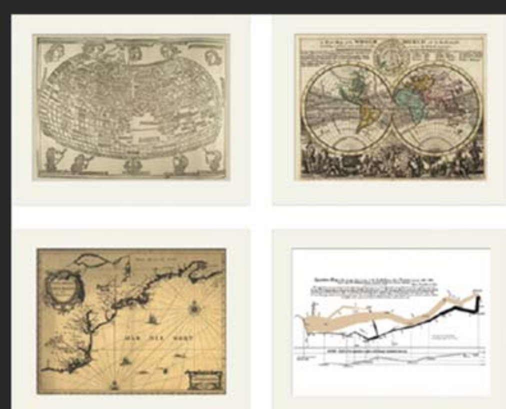
First Iteration of Exhibit (2005): The Power of Maps

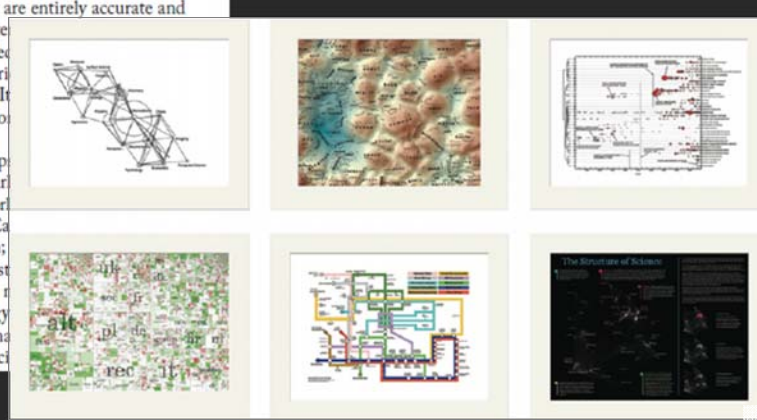
Four Early Maps of Our World
Versus
Six Early Maps of Science

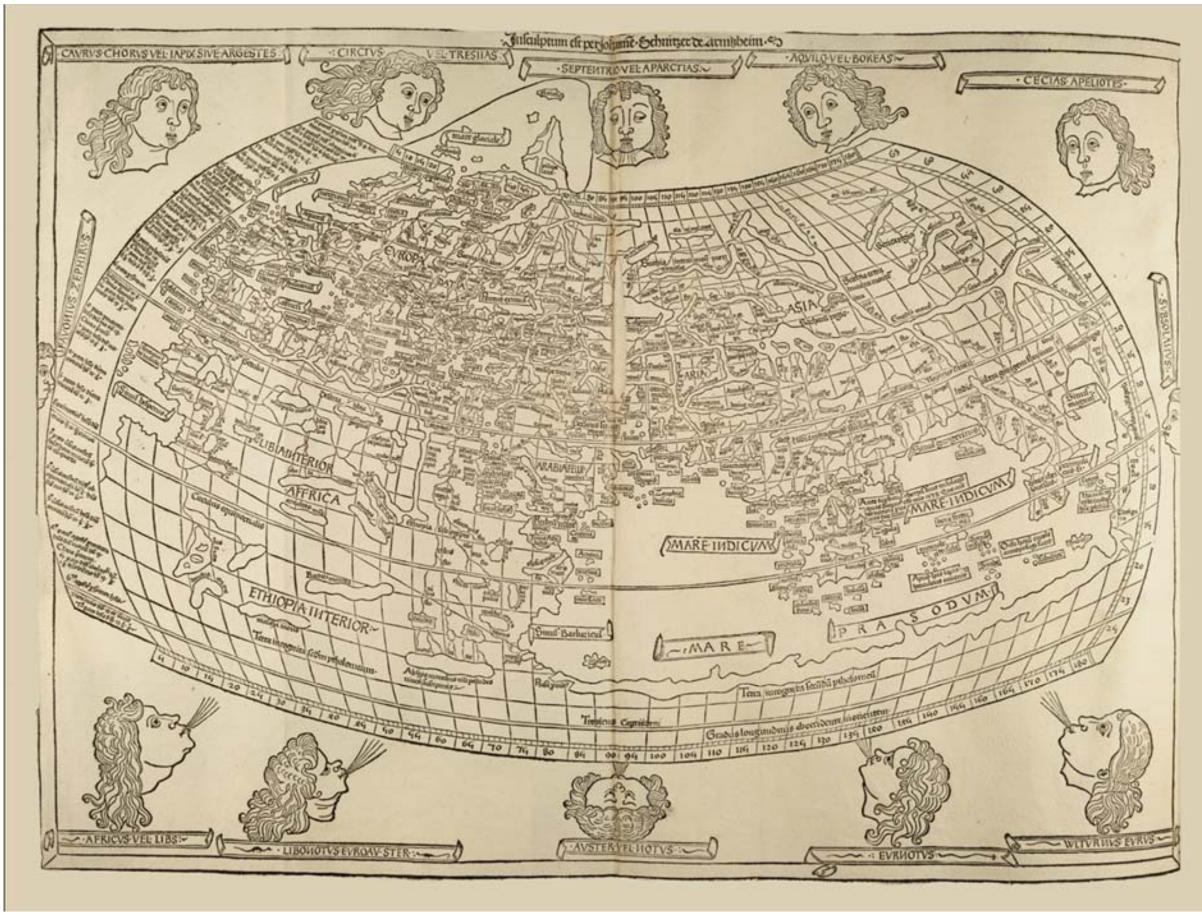
The first exhibit iteration on *The Power of Maps* demonstrates how maps help us to understand, navigate, and manage both physical places and abstract knowledge spaces.

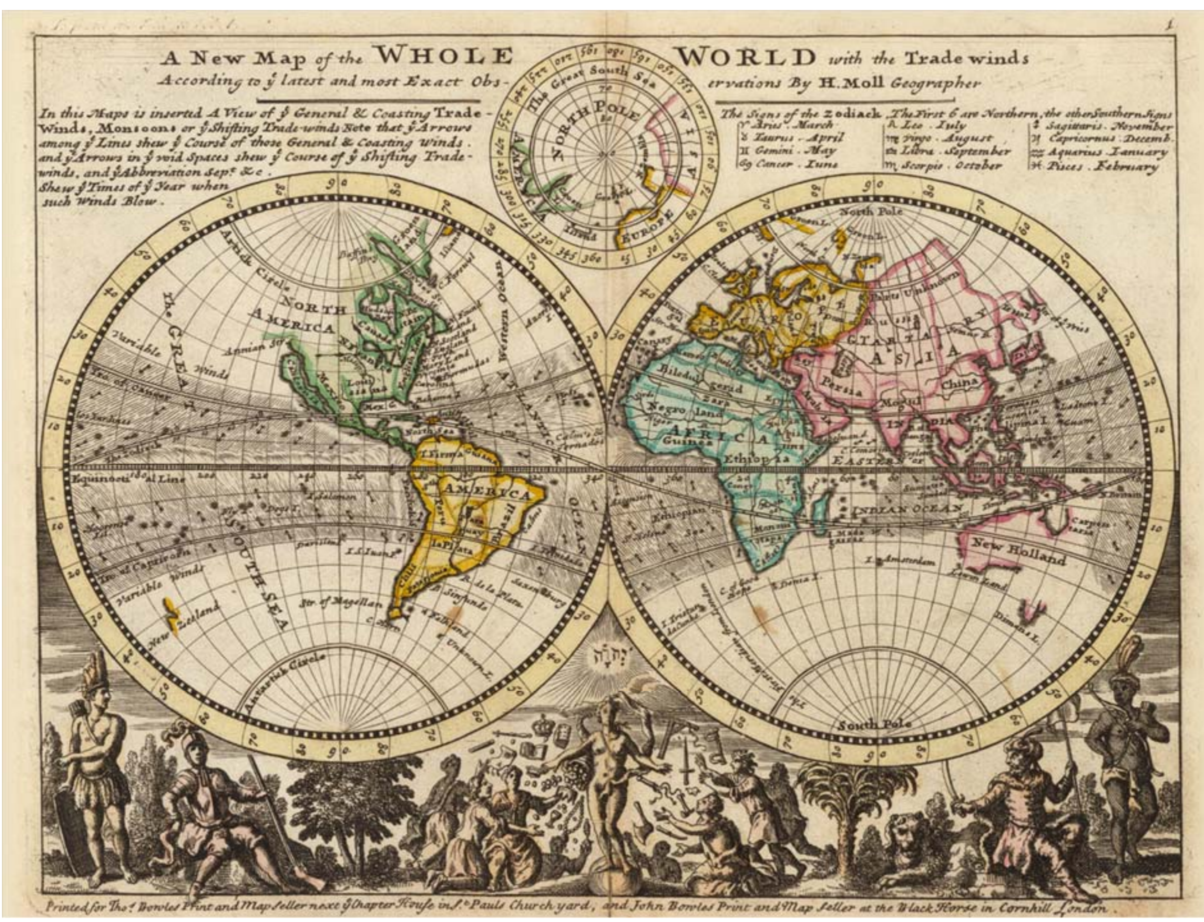
Early maps of our planet were certainly neither complete nor perfect, yet they proved invaluable for explorers. As keys to navigation, exploration, and communication, maps helped explorers find promising new lands while avoiding sea monsters.

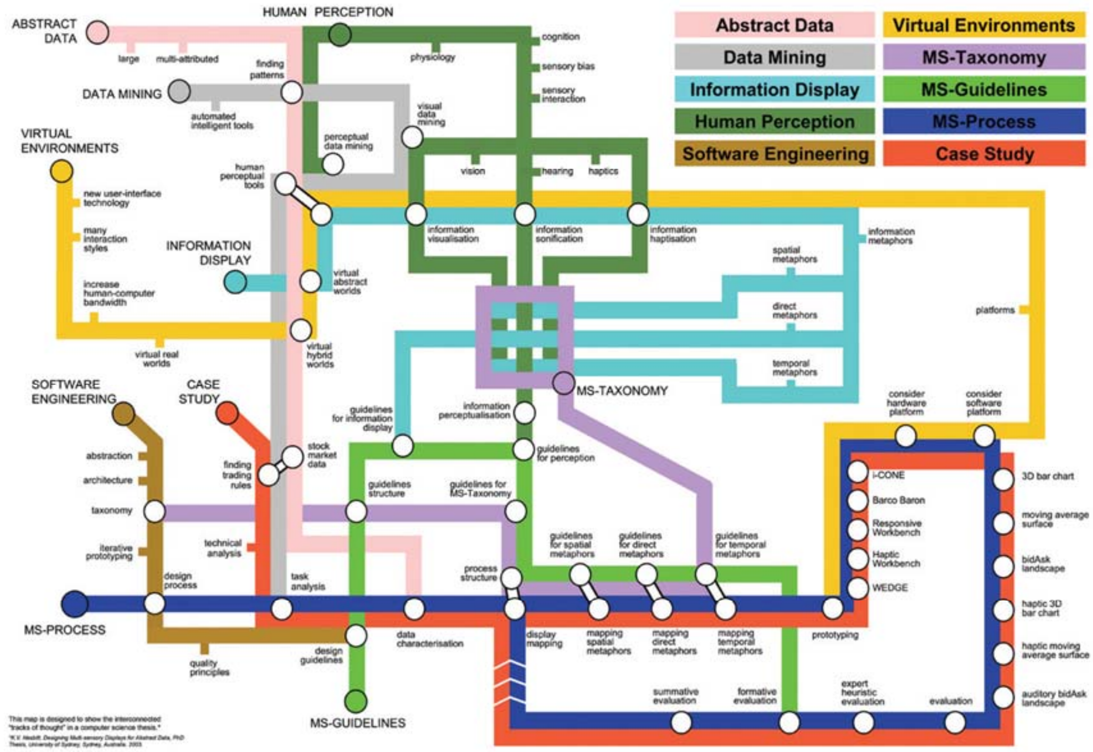
Maps of science today are based on limited knowledge and therefore imperfect. In order to generate comprehensive maps that are entirely accurate and reliable, we must first have proper coverage and inte
multidisciplinary, and multimedia scholarly knowled
The first pictures of Earth from space were experi
mative of their perceptions of life and the cosmos. It
science will increase our appreciation and applicatio
serving as useful navigational tools.
The Power of Maps features four cartographic map
earliest global maps of our world by Ptolemy, an ear
Johannes Janssonius, an early map of the whole wor
early statistical graph by Charles Joseph Minard. Ea
employs a different metaphor: a node-link diagram;
ing map rendered using geographic information syst
a crossmap; and a galaxy view. Which metaphor is r
visual index of our collective science and technology
Note that the makers of the early cartographic ma
ing presses, while the makers of the first maps of sci

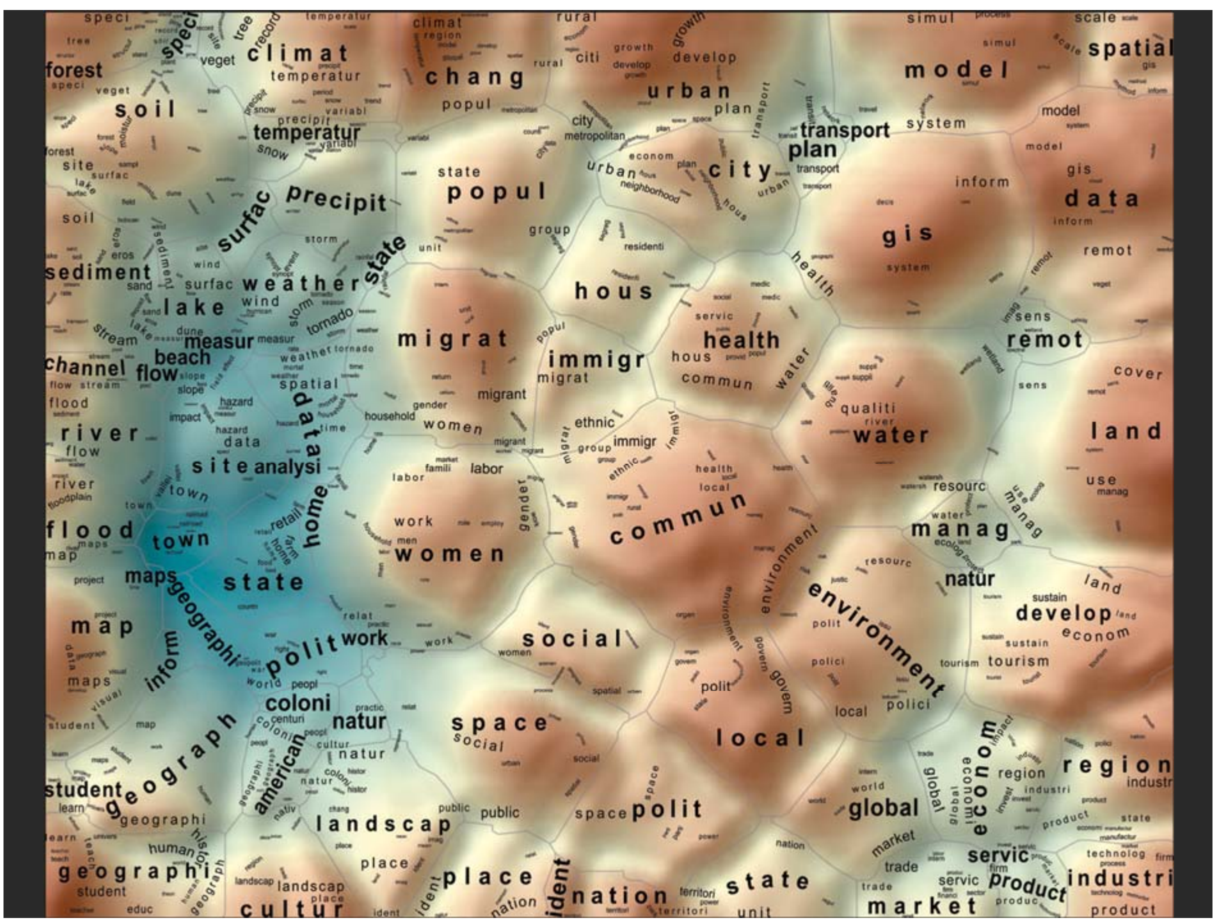





CAVRVS CHORVS VEL IAPIX SIVE ARGESTES
CIRCIVS VEL TRESIAS
SEPTENTRIO VEL APARCTIAS
AQVILO VEL BOREAS
CECIAS APELIOTES
EVROPA
ASIA
AFRICA
MARE INDICVM
ETHIOPIA INTERIOR
MARE
PRASODVM
AFRICVS VEL LIBS
AVSTER VEL NOTVS
EVRNOTVS


A New Map of the WHOLE WORLD with the Trade winds
According to ye latest and most Exact Observations By H. Moll Geographer
In this Maps is inserted A View of ye General & Coasting Trade-Winds, Monsoons or ye Shifting Trade-winds Note that ye Arrows among ye Lines shew ye Course of those General & Coasting Winds. and ye Arrows in ye void Spaces shew ye Course of ye Shifting Trade-winds, and ye Abbreviation Sept. &c. Shew ye Times of ye Year when such Winds Blow.
The Signs of the Zodiack. The First 6 are Northern, the other Southern Signs
♈ Aries . March
♉ Taurus . April
♊ Gemini . May
♋ Cancer . June
♌ Leo . July
♍ Virgo . August
♎ Libra . September
♏ Scorpio . October
♐ Sagittaris . November
♑ Capricornus . Decemb.
♒ Aquarius . January
♓ Pisces . February
NORTH POLE
North Pole
South Pole
NORTH AMERICA
AMERICA
AFRICA
ASIA
INDIAN OCEAN
New Holland
SOUTH SEA
Printed for Thos. Bowles Print and Map seller next ye Chapter House in St. Pauls Church yard, and John Bowles Print and Map seller at the Black Horse in Cornhill London.


Abstract Data
Virtual Environments
Data Mining
MS-Taxonomy
Information Display
MS-Guidelines
Human Perception
MS-Process
Software Engineering
Case Study
ABSTRACT DATA
large
multi-attributed
HUMAN PERCEPTION
physiology
cognition
sensory bias
sensory interaction
finding patterns
DATA MINING
automated intelligent tools
visual data mining
perceptual data mining
VIRTUAL ENVIRONMENTS
new user-interface technology
many interaction styles
increase human-computer bandwidth
virtual real worlds
human perceptual tools
vision
hearing
haptics
INFORMATION DISPLAY
information visualisation
information sonification
information haptisation
information metaphors
virtual abstract worlds
virtual hybrid worlds
spatial metaphors
direct metaphors
temporal metaphors
platforms
MS-TAXONOMY
SOFTWARE ENGINEERING
CASE STUDY
abstraction
architecture
taxonomy
iterative prototyping
design process
finding trading rules
stock market data
technical analysis
task analysis
guidelines for information display
information perceptualisation
guidelines for perception
guidelines structure
guidelines for MS-Taxonomy
guidelines for spatial metaphors
guidelines for direct metaphors
guidelines for temporal metaphors
process structure
consider hardware platform
consider software platform
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
MS-PROCESS
quality principles
design guidelines
data characterisation
display mapping
mapping spatial metaphors
mapping direct metaphors
mapping temporal metaphors
prototyping
summative evaluation
formative evaluation
expert heuristic evaluation
evaluation
MS-GUIDELINES
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
data
gis
sediment
weather
state
hous
lake
measur
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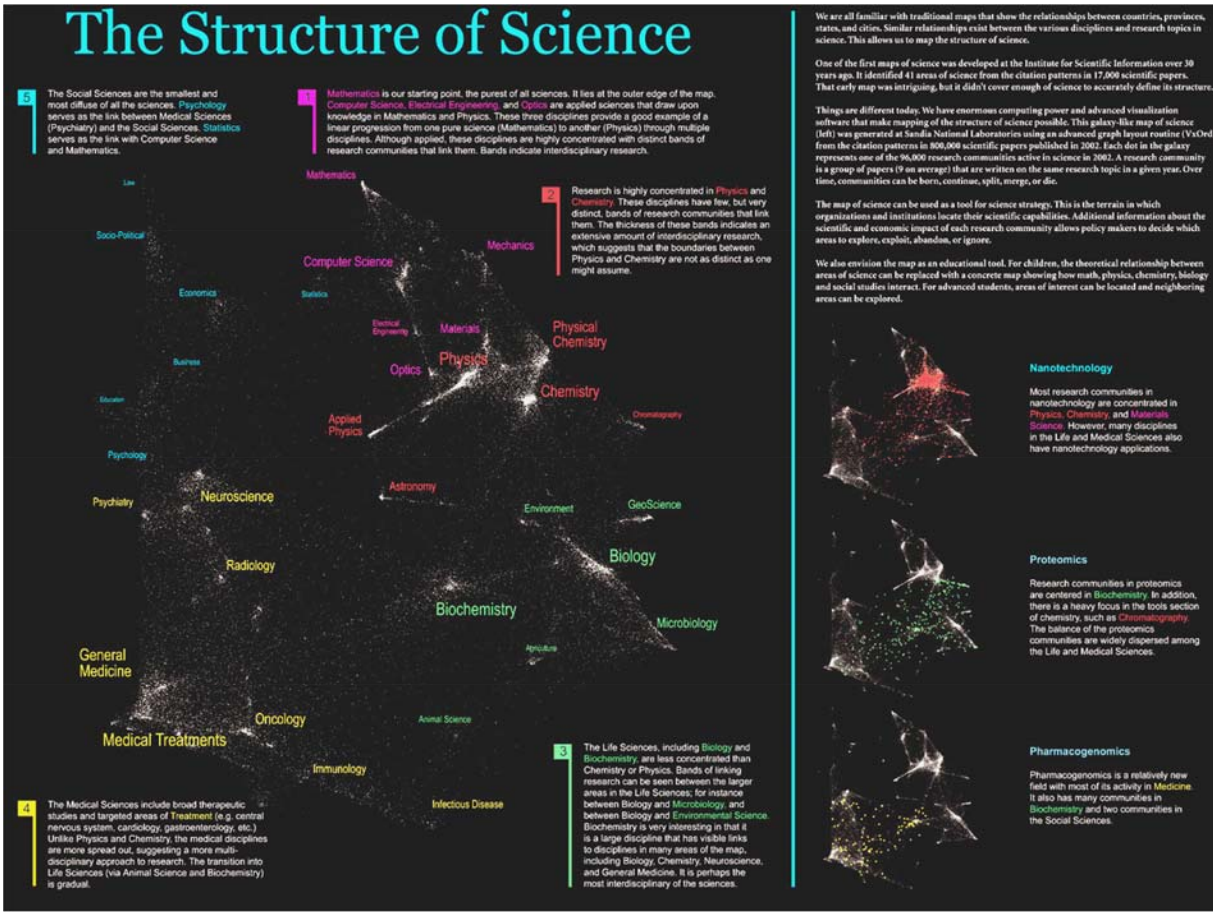


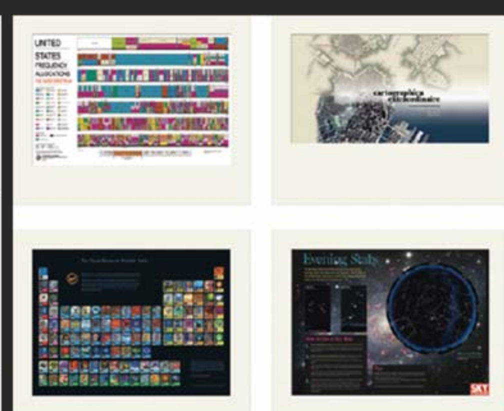
Second Iteration of Exhibit (2006): The Power of Reference Systems

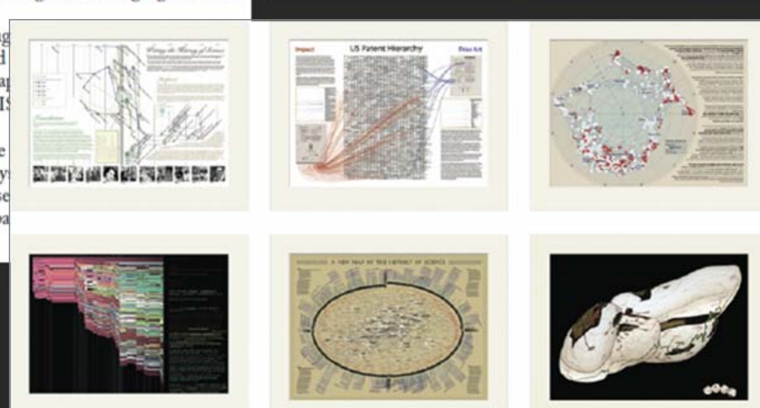
Four Existing Reference Systems
Versus
Six Potential Reference Systems

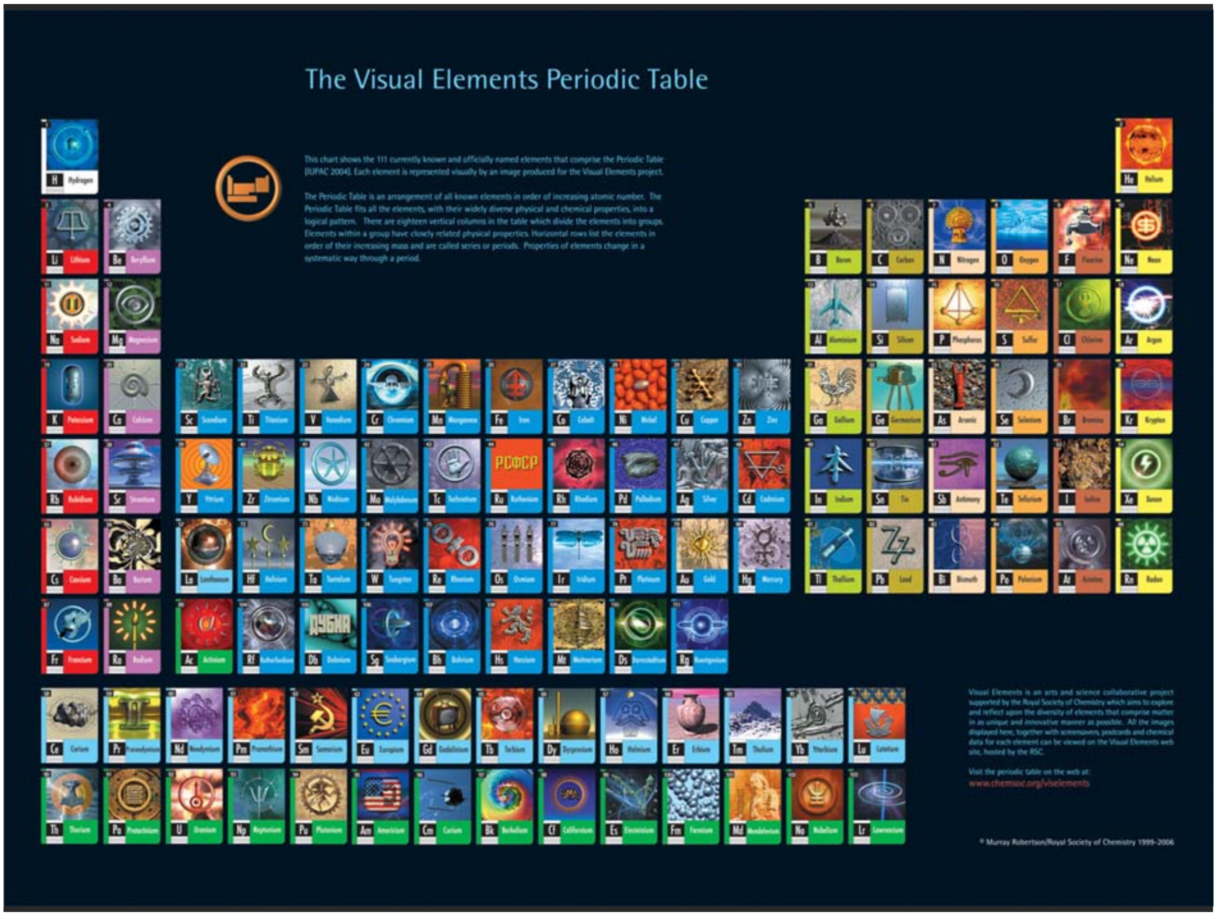
This iteration aims to inspire discussion about a common reference system for all existing scholarly knowledge. Throughout history, scientists have battled to agree on standardized reference systems for their respective fields of research. These standards are invaluable for indexing, storing, accessing, and managing scientific data efficiently.

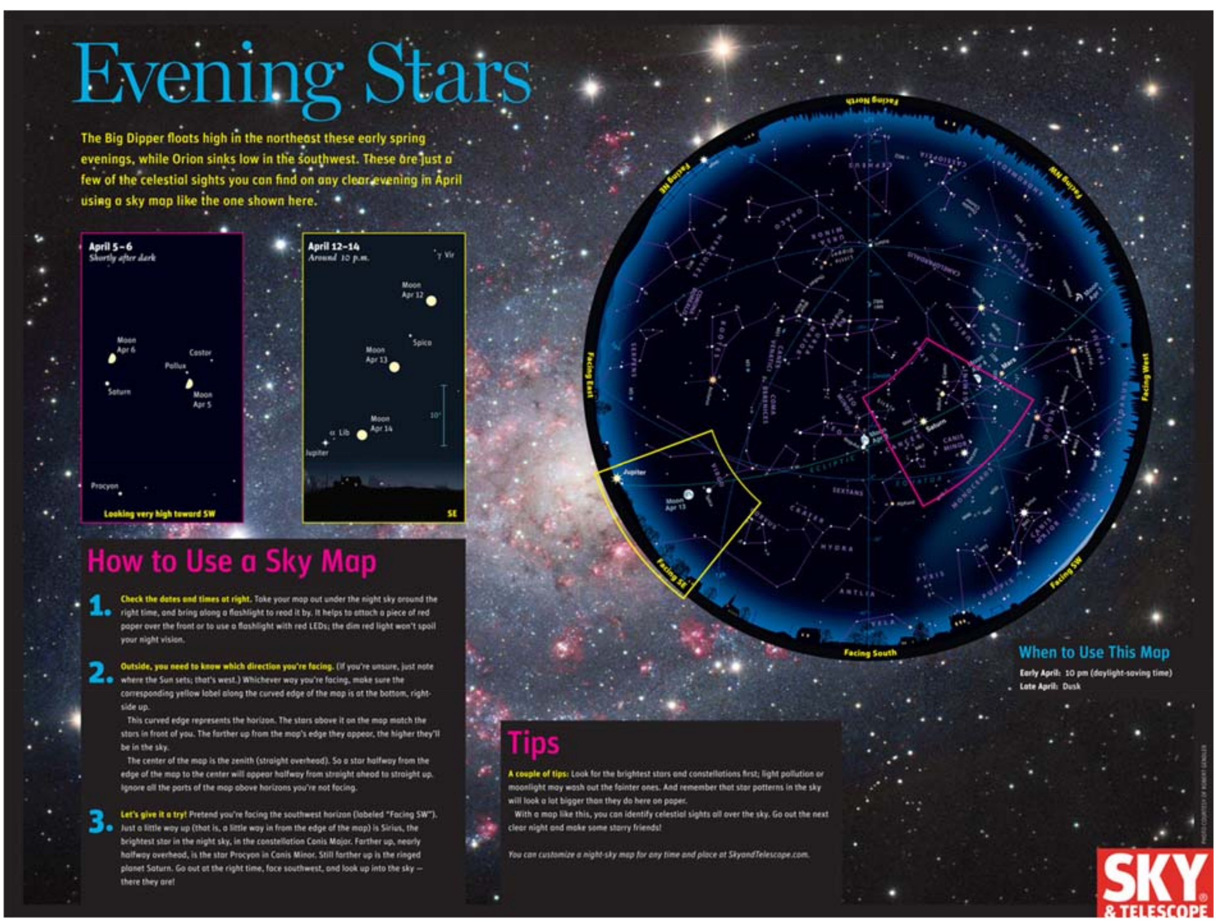
Results include the description of the electromag
odic table of elements, geographic projections, and
systems, shown here. Note that the geographic ma
from paper to geographic information systems (GI
for public use and consumption.

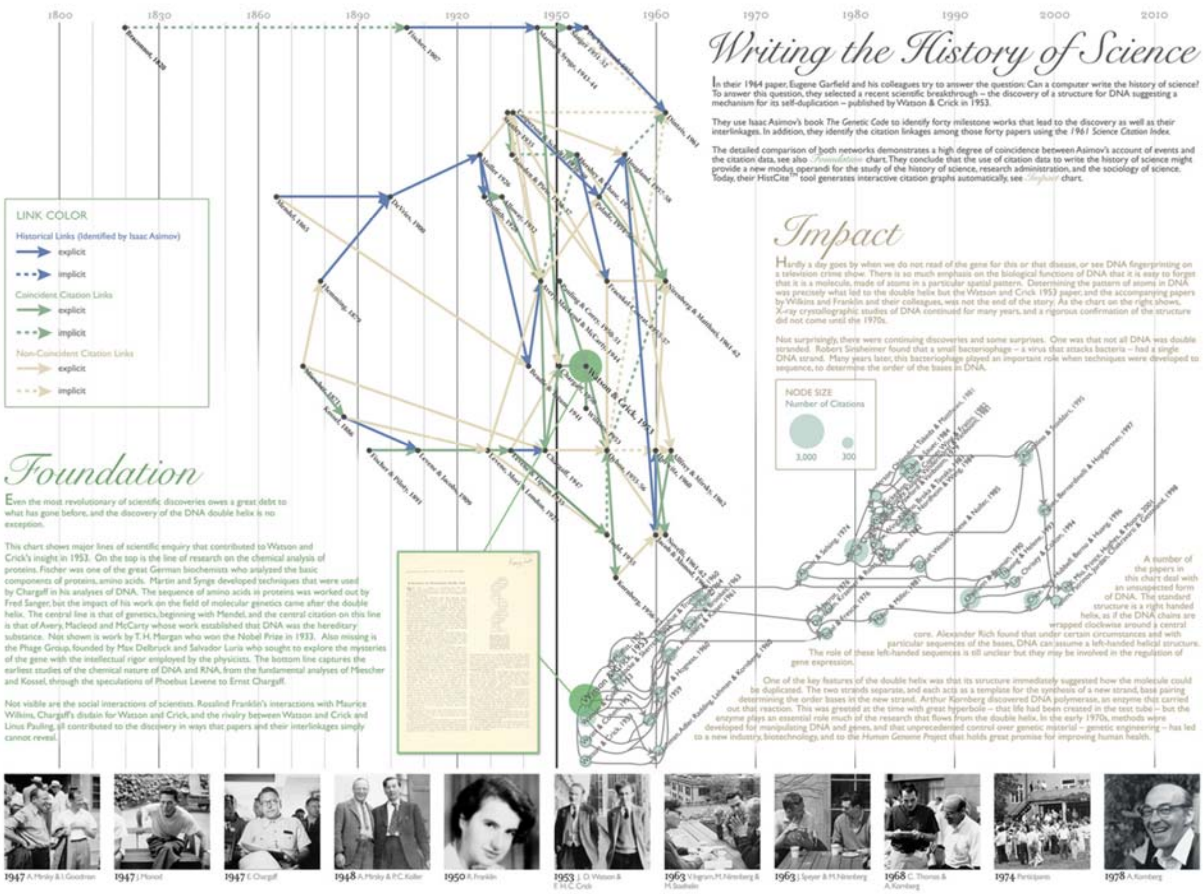
In comparison to these four existing systems are
systems for scholarly knowledge. Each reference sy
sional timeline and the geographic system to the se
used to identify the location of an author, paper, pa
tory or contribution.






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
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!
Facing North
Facing NE
Facing NW
Facing East
Facing West
Facing SE
Facing SW
Facing South
Jupiter
Moon Apr 13
Saturn
Mars
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



1800
1830
1860
1890
1920
1950
1960
1970
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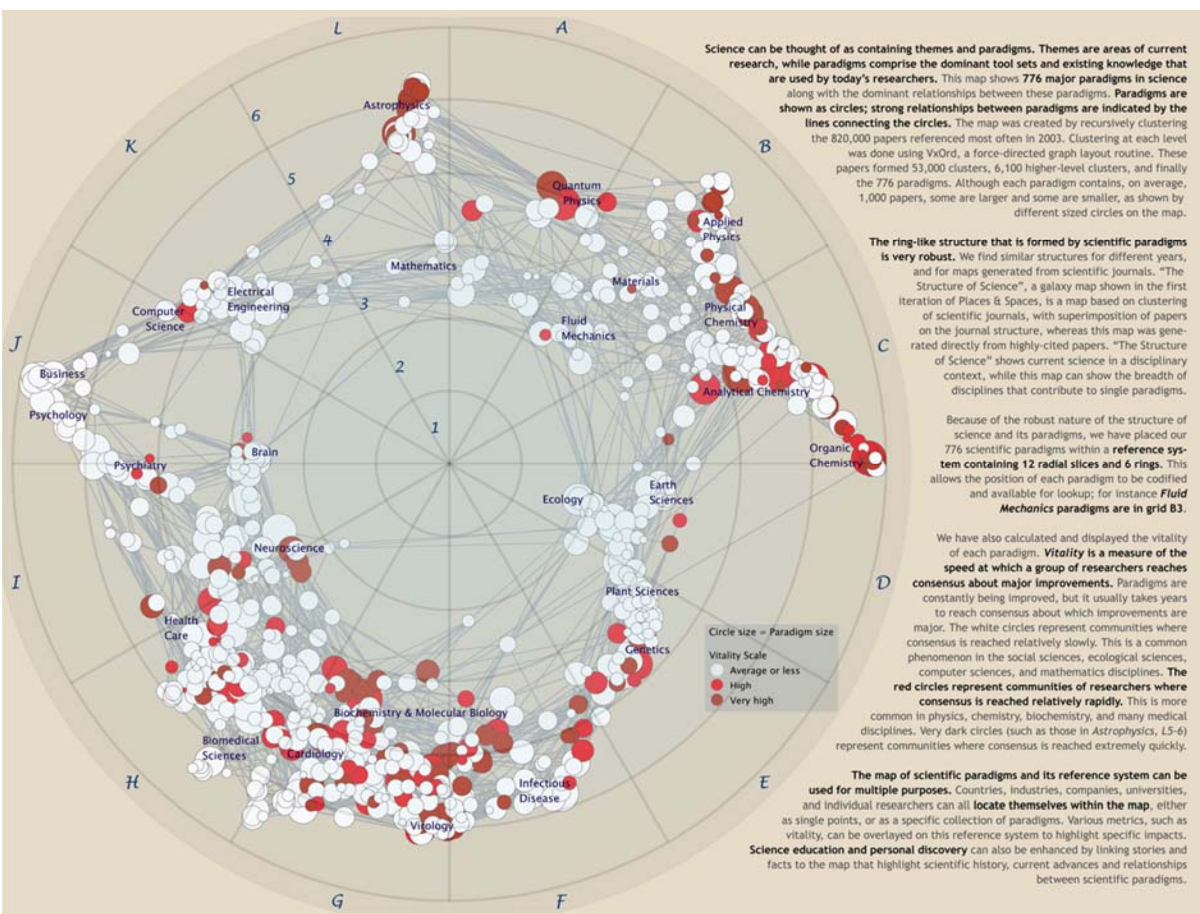
1990
2000
2010
Writing the History of Science
In their 1964 paper, Eugene Garfield and his colleagues try to answer the question: Can a computer write the history of science? To answer this question, they selected a recent scientific breakthrough – the discovery of a structure for DNA suggesting a mechanism 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 till 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 & M. Staehelin
1963 J. Speyer & M. Nirenberg
1968 C. Thomas & A. Kornberg
1974 Participants
1978 A. Kornberg



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Astrophysics
Quantum Physics
Applied Physics
Mathematics
Materials
Physical Chemistry
Fluid Mechanics
Electrical Engineering
Computer Science
Analytical Chemistry
Organic Chemistry
Business
Psychology
Brain
Psychiatry
Ecology
Earth Sciences
Neuroscience
Plant Sciences
Health Care
Genetics
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.

2006

Map of Scientific Paradigms

By Kevin W. Boyack and Richard Klavans

ALBUQUERQUE, NEW MEXICO, AND BERWYN, PENNSYLVANIA, 2006

Courtesy of Kevin W. Boyack and Richard Klavans, SciTech Strategies, Inc.

Aim

Science can be thought of as containing themes and paradigms; themes are current areas of research, while paradigms comprise the dominant tool sets and existing knowledge that are used by current researchers. What would a paradigm map of science look like? How many paradigms are currently active? How large and how vital are they?

Interpretation

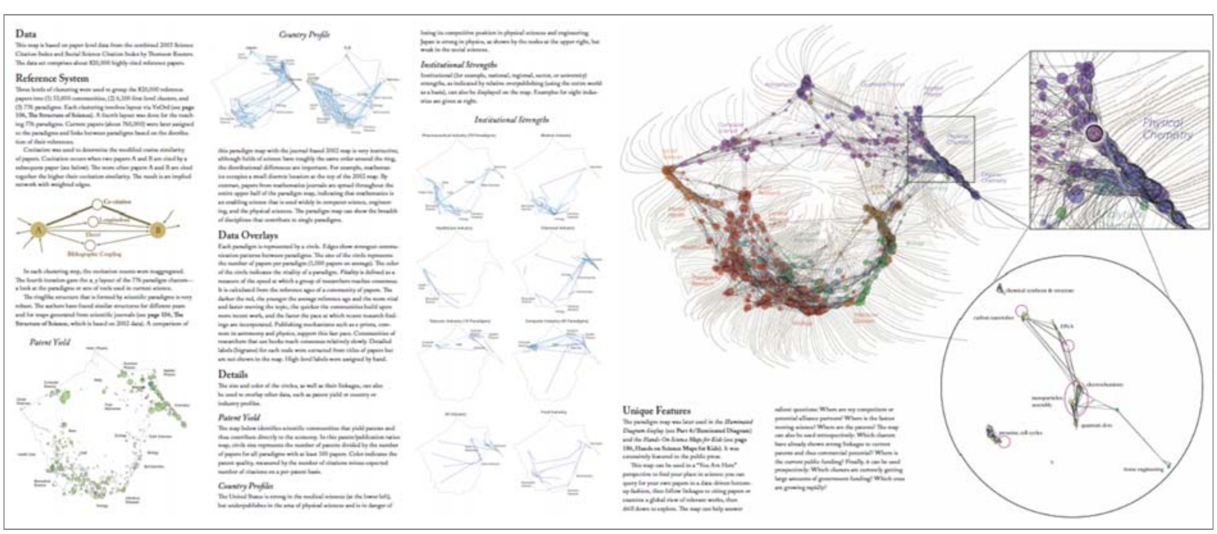
This map was generated by recursively clustering the 820,000 most important papers referenced in 2003 using the processing pipeline described on **page 12, Toward a Reference System for Science**. The result is a map of 776 paradigms, which are shown as circles on the map. Although each paradigm contains an average of 1,000 papers, they range in sizes, as shown by the variously sized circles on the map. The most dominant relationships between paradigms were also calculated and are shown as lines between paradigms. A reference system was added for means of navigation and communication.

Color-coding indicates the vitality of a research topic—the darker the red, the younger the average reference age and the more vital and faster moving the topic. The white circles represent paradigms 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 quantum physics) represent communities where consensus is reached most quickly.

Countries, industries, companies, and individual researchers can all locate themselves within the map, either as single points or as a specific collection of paradigms. Science education and discovery can also be enhanced by linking to the map stories and facts that highlight content and relationships between scientific paradigms.

Kevin W. Boyack joined SciTech Strategies, Inc. in 2007 after working at Sandia National Laboratories, where he spent several years in the Computation, Computers, Information and Mathematics Center. He holds a PhD in chemical engineering from Brigham Young University. His current interests and work are related to information visualization, knowledge domains, science mapping with associated metrics and indicators, network analysis, and the integration and analysis of multiple data types.

Richard Klavans is the president of SciTech Strategies, Inc. He holds a PhD in management from the Wharton School of the University of Pennsylvania. His current work is related to the generation of highly accurate maps of science using multiple techniques, such as bibliographic coupling, cocitation, and coword, as well as the associated metrics and indicators that allow government and industry users to make more effective policy decisions. He is interested in semantics, augmented cognition, and the application of mathematical tools to information spaces.



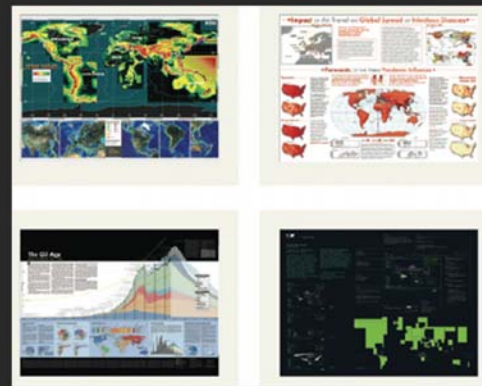
Third Iteration of Exhibit (2007): The Power of Forecasts

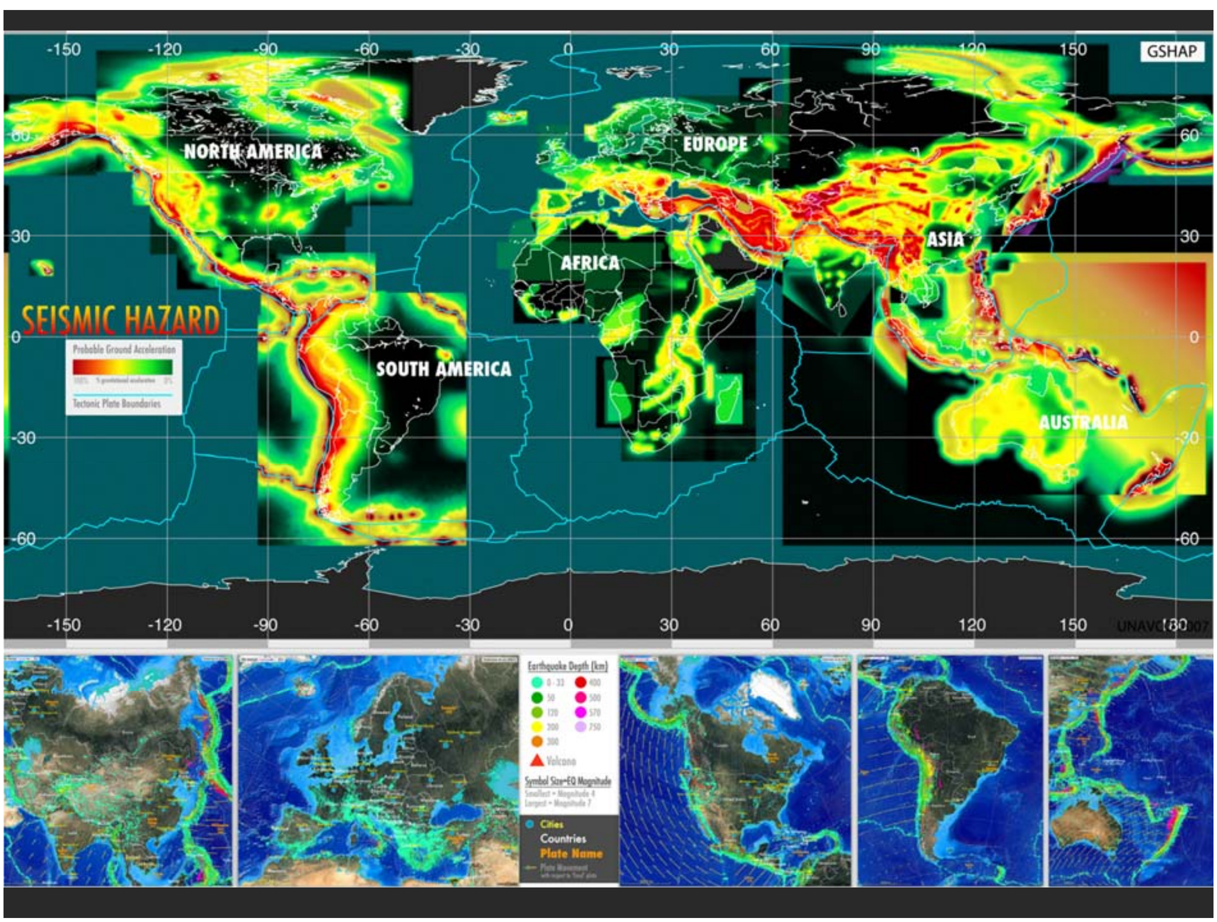
Four Existing Forecasts
Versus
Six Science Forecasts

The third iteration of the exhibit compares and contrasts seismic hazard, economic, resource depletion, and epidemic forecast maps with maps forecasting the structure and evolution of science.

Real-time weather forecasts are served by the National Oceanic and Atmospheric Administration (NOAA) or the National Aeronautics and Space Administration (NASA). Computational models of the movements of tectonic plates help reduce losses due to earthqual tsunamis. Epidemic models make us understand and how actions far away affect us right here. Ec catastrophic and sustainable futures for mankind.

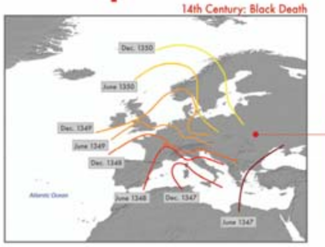
Daily science and technology forecasts would s of top experts/institutions/countries, major activit frontiers, augmenting our knowledge and decisio available on TV, in the press, and online?





Impact OF Air Travel ON Global Spread OF Infectious Diseases

14th Century: Black Death

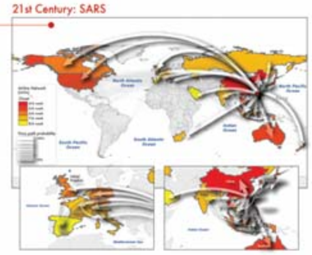


Epidemic spreading pattern changed dramatically after the development of modern transportation systems.

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

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

21st Century: SARS



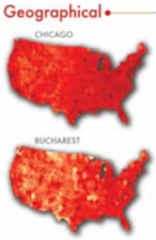
Forecasts OF THE Next Pandemic Influenza

Seasonal

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

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

Geographical

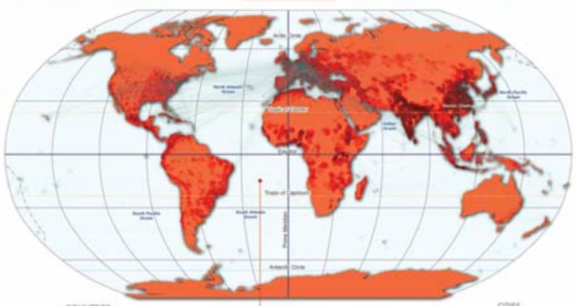


Numerical simulations provide results for the temporal and geographic evolution of the pandemic influenza in 3,100 urban areas located in 220 different countries. The model allows to study different spreading scenarios, characterized by different initial outbreak conditions, both geographical and seasonal.

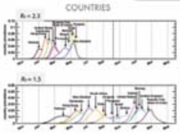
The central map represents the cumulative number of cases in the world after the first year from the start of a pandemic influenza with R_0=1.9 originating in Hanoi (Vietnam) in the Spring.

WORLD # cases USA # cases 10^4 0

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



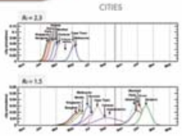
COUNTRIES



R_0=1.5 R_0=1.9 R_0=2.3

Time evolution of a pandemic starting in Hanoi (Vietnam) in the Fall in the no intervention scenario. Profiles of the fraction of infectious individuals in time (prevalence) are shown for some representative countries (left) and cities (right). Two different values of the reproductive number are considered: R_0=1.5, consistently with the values shown for the US map (top right), and R_0=2.3, in order to provide the comparison with faster spreading.

CITIES



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

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

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

Reproductive Number (R_0)

Intervention

INSTITUTE FOR THE FUTURE

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 macro-economic 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

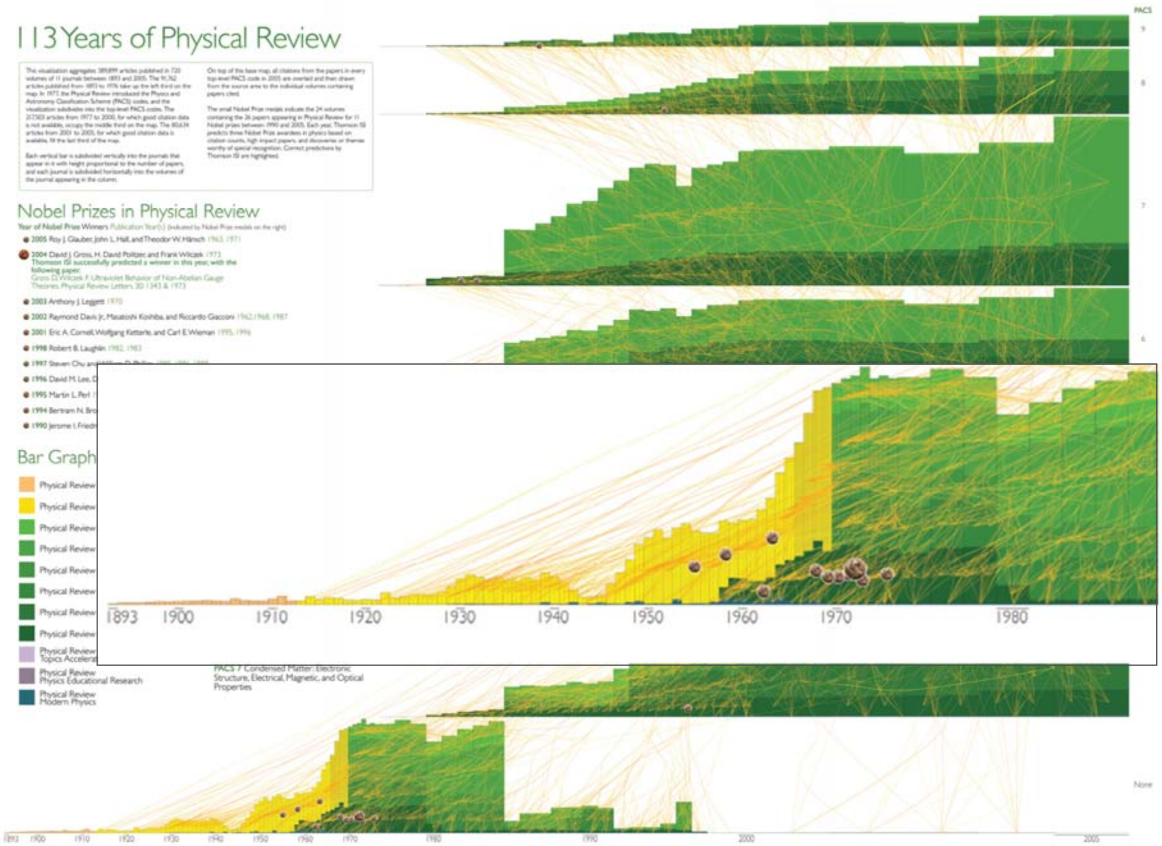
Before the 20th century, many of the greatest scientific discoveries and technical inventions were made by amateur scientists and independent inventors. In the last 100 years, a professional class of scientists and engineers, supported by universities, industry, and the state, pushed amateurs aside as 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 these 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
Nobel Prizes in Physical Review
Bar Graph
PACS
PACS 7 Condensed Matter: Electronic Structure, Electrical, Magnetic, and Optical Properties
None
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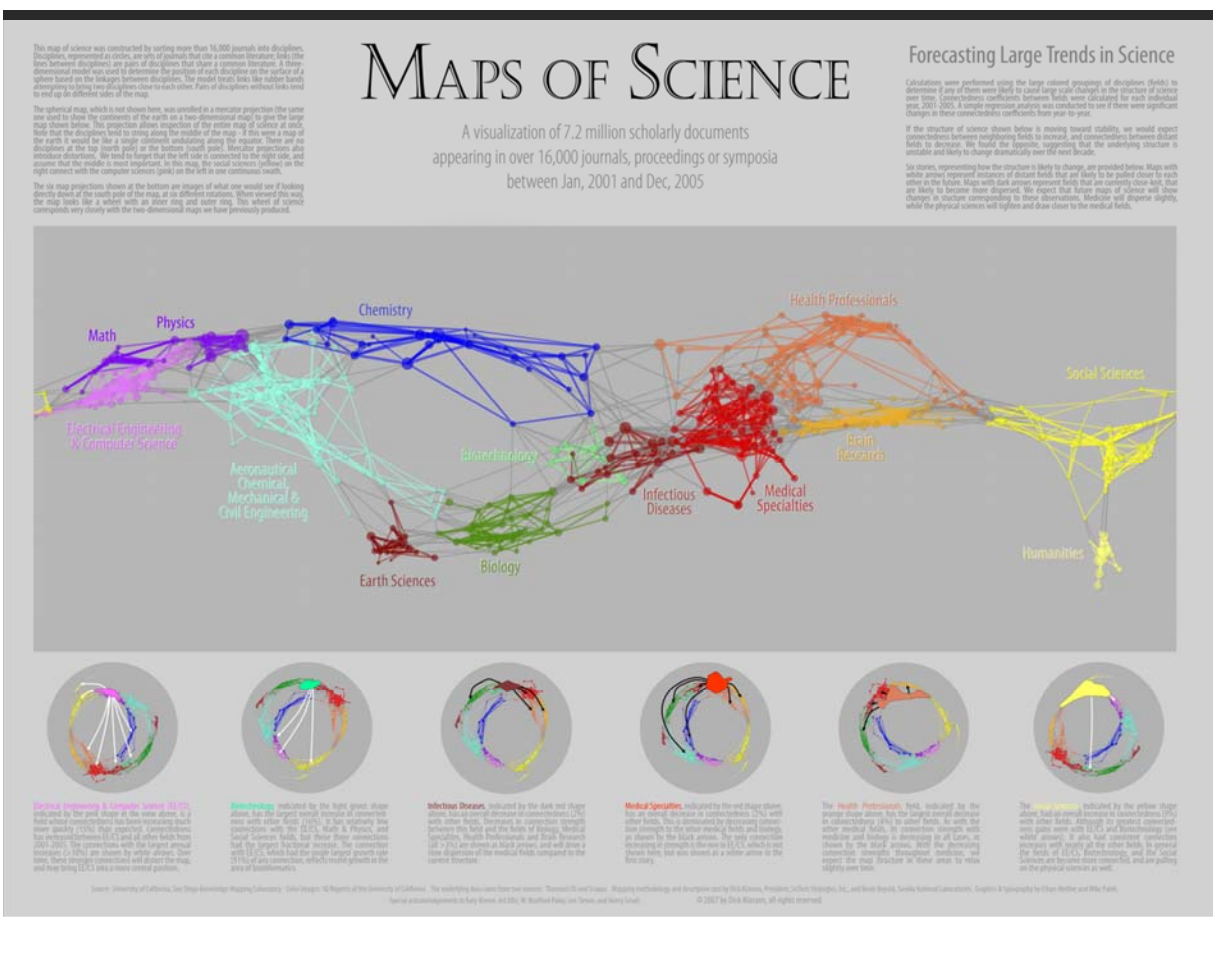
MAPS OF SCIENCE
A visualization of 7.2 million scholarly documents
appearing in over 16,000 journals, proceedings or symposia
between Jan, 2001 and Dec, 2005
Forecasting Large Trends in Science
Math
Physics
Chemistry
Health Professionals
Social Sciences
Electrical Engineering & Computer Science
Aeronautical Chemical, Mechanical & Civil Engineering
Biotechnology
Brain Research
Infectious Diseases
Medical Specialties
Humanities
Earth Sciences
Biology

Additional Elements of the Exhibit

Certainly science maps and data graphs work to engage viewers intellectually—but can they also capture the imagination, as did the early maps of the world? Is it possible to involve viewers in a more dynamic way that heightens both their awareness and appreciation of data, information, and knowledge? What can be learned from theater, movies, and art exhibits—as well as science displays—to improve the ability of science maps to entertain while educating, to inspire while being true to facts, and
ers to engage in scienc
Additional exhibit e
and interact with scien
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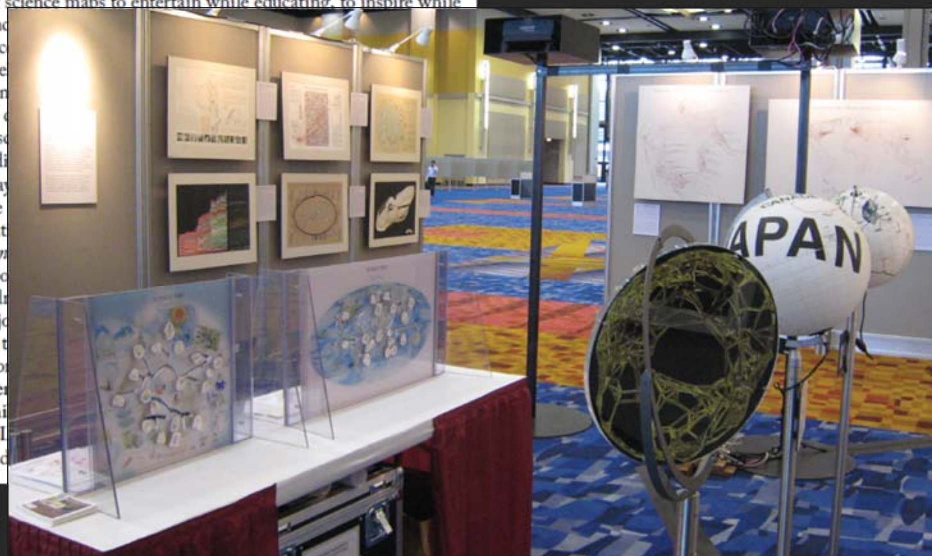


Illuminated Diagram Display

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

Questions:

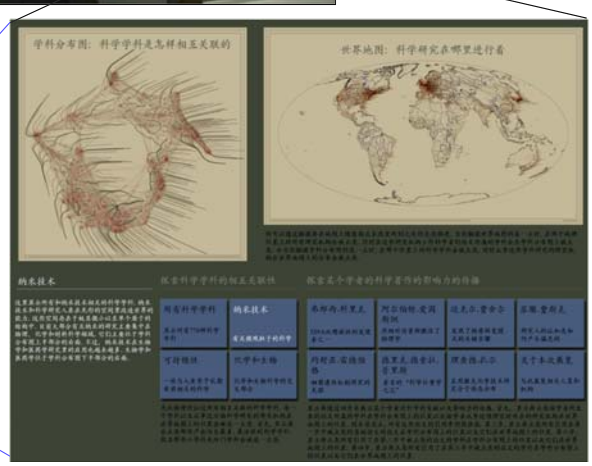
- Who is doing research on what topic and where?
- What is the 'footprint' of interdisciplinary research fields?
- What impact have scientists?

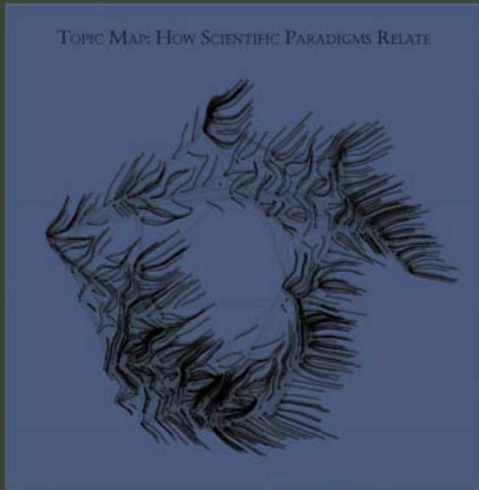
Contributions:

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

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

Interactive touch panel.





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.

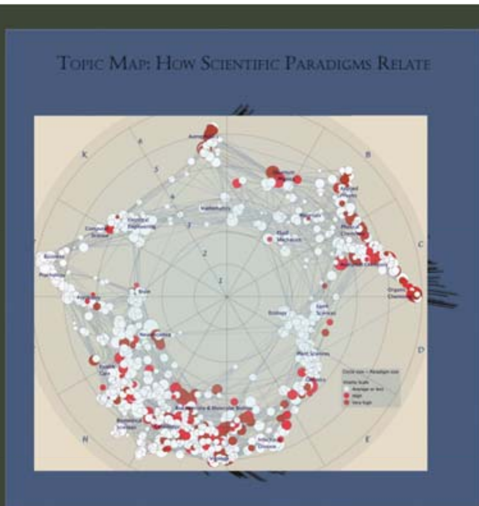
Nanotechnology

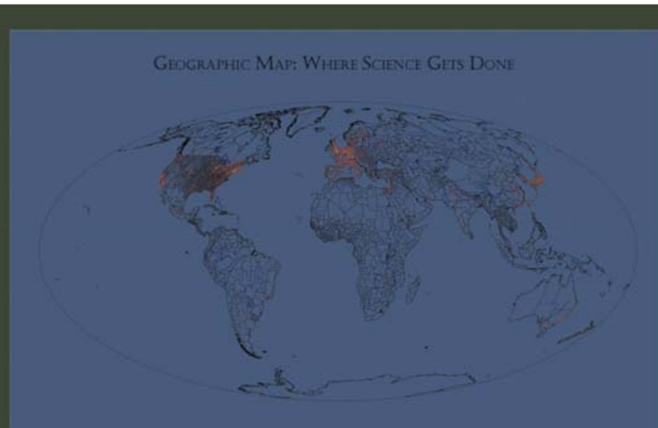
This overlay shows the distribution of nanotechnology within the paradigms of science. The majority of current work in nanotechnology takes places in physics, chemistry, and materials science, at the upper right portion of the map. However, an increasing amount of nanotechnology is being applied in the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

All Topics *Sweep through all 776 scientific paradigms*	**Nanotechnology** *Science on the tiny scale of molecules*	**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*
Sustainability *The science behind our long-term hopes*	**Biology & Chemistry** *The interface between these two vital fields*	**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*

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

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





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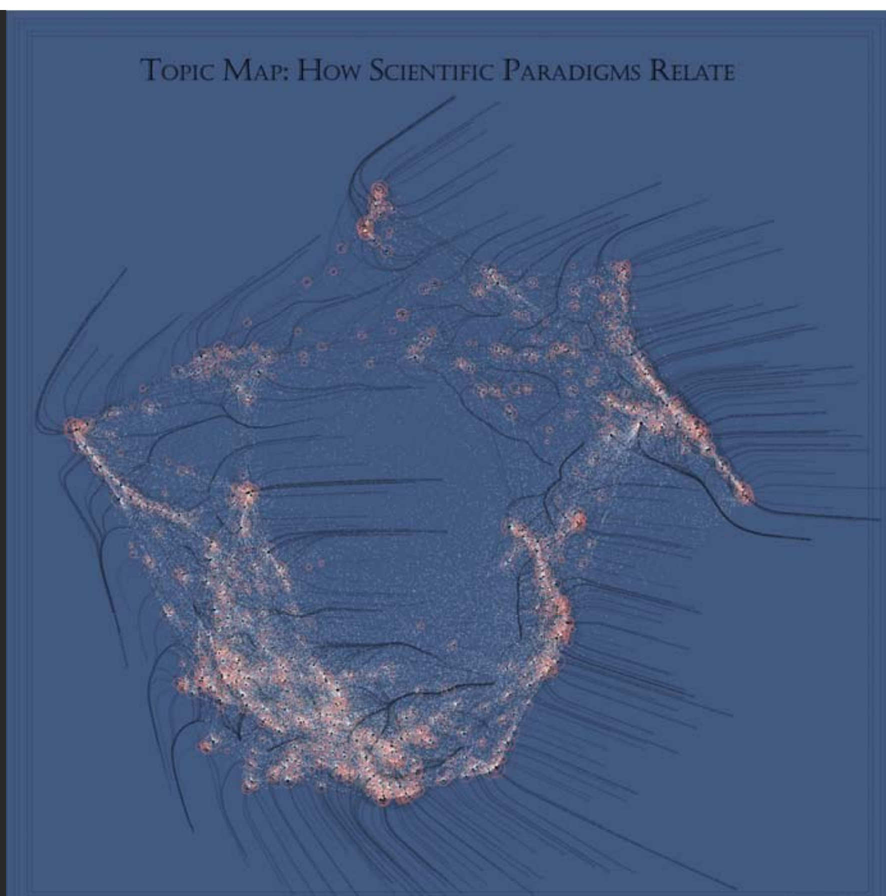
Science Maps in "Expedition Zukunft" science train visiting 62 cities in 7 months 12 coaches, 300 m long
Opening was on April 23rd, 2009 by German Chancellor Merkel
http://www.expedition-zukunft.de



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

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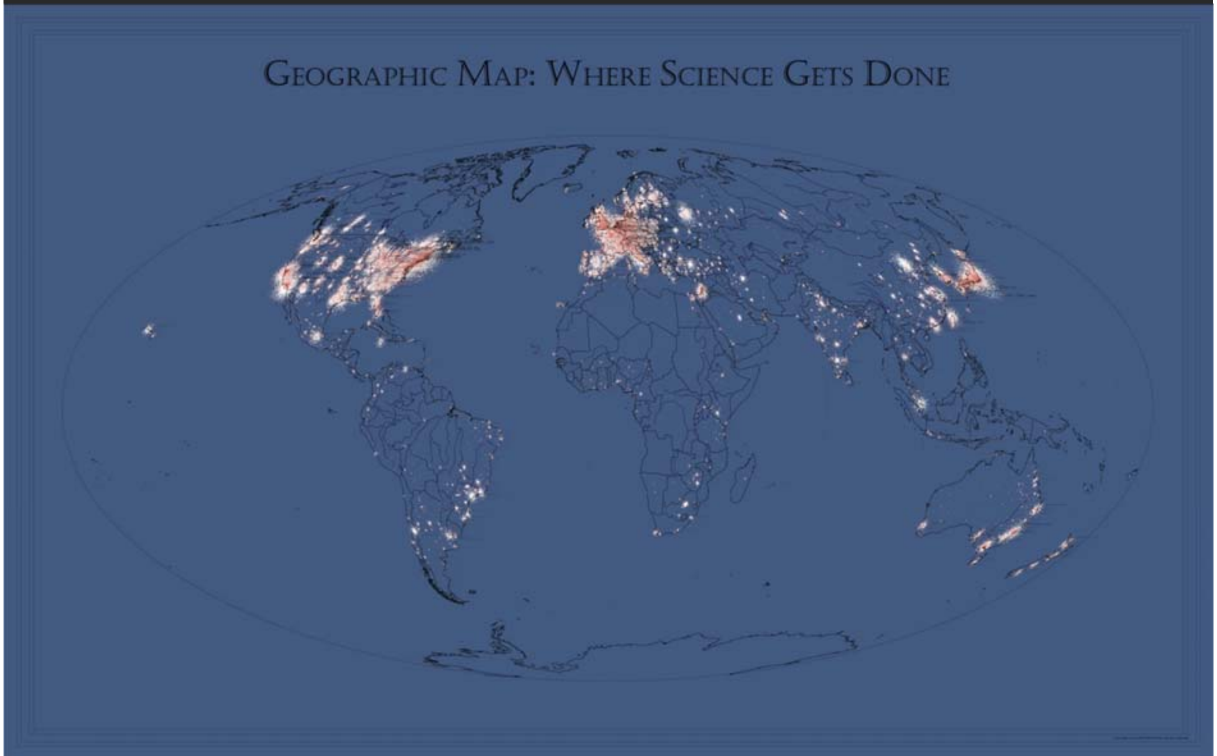
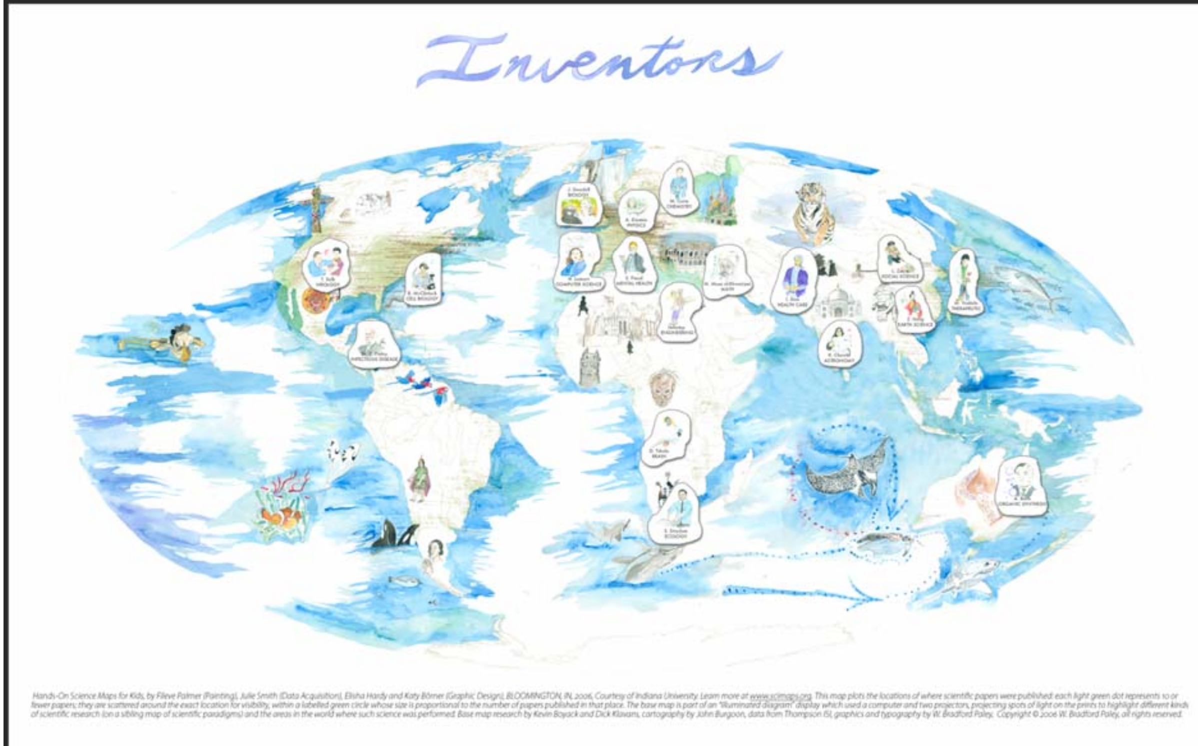
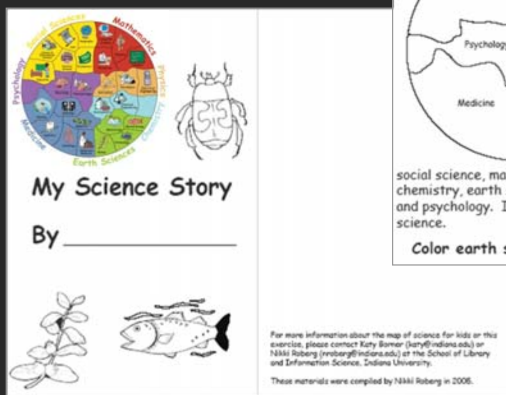
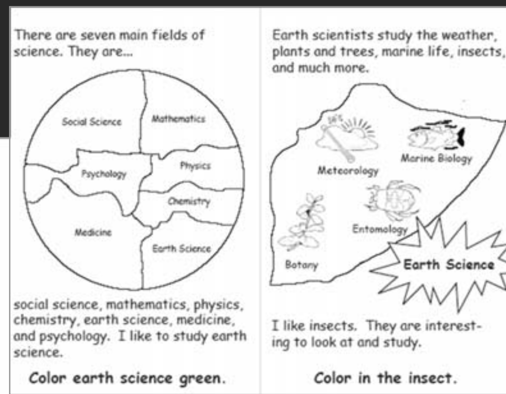
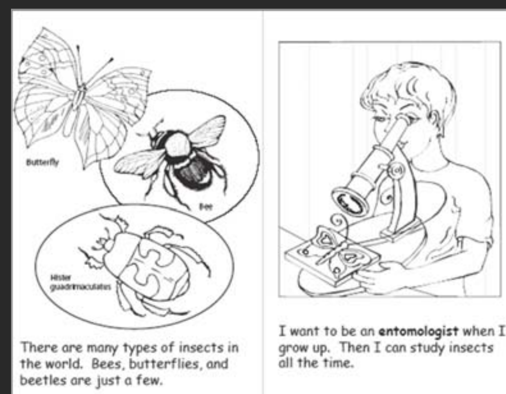


Science Puzzle Map for Kids by Fileve Palmer, Julie Smith, Elisha Hardy and Katy Börner, Indiana University, 2006.
(Base map taken from Illuminated Diagram display by Kevin Boyack, Richard Klavans, and W. Bradford Paley.)


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?

Part 5: The Future of Science Maps

The inspiration of a noble cause involving human interests wide and far, enables men to do things they did not dream themselves capable of before, and which they were not capable of alone. The consciousness of belonging, vitally, to something beyond individuality; of being part of a personality that reaches we know not where, in space and time, greatens the heart to the limit of the soul's ideal, and builds out the supreme of character.

Joshua L. Chamberlain

Part 5: The Future of Science Maps

Mapping Science Exhibit – 10 Iterations in 10 years

http://scimaps.org/

The Power of Maps (2005)

Science Maps for Economic Decision Makers (2008)

The Power of Reference Systems (2006)

Science Maps for Science Policy Makers (2009)

The Power of Forecasts (2007)

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

Exhibit has been shown in 72 venues on four continents. Currently at
- NSF, 10th Floor, 4201 Wilson Boulevard, Arlington, VA
- Center of Advanced European Studies and Research, Bonn, Germany
- Science Train, Germany
- Cultural Dimensions of Innovation, UCD Conference, Dublin, Ireland

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*

Part 5: The Future of Science Maps

References & Credits

This section lists 1,650 citation references, more than 580 image credits, 80 data credits, and 60 software credits. More than 150 scholars provided input on the material presented in the atlas, and their contributions are acknowledged here.

As some spreads have up to 80 references and adding 80 parenthetical references or four-digit numbers to the page layout would considerably hurt readability, the references and credits are not given in the text. Instead, they are listed here by section. References and credits are ordered alphabetically except for those for **Part 2/Timeline,** which are ordered chronologically.

The Web site for the atlas (**http://scimaps.org**) supports pinpoint citations (that is, references and credits are associated with the specific text they support). In addition, the site will make available EndNote and bibtex files containing all the references.

References

Part 1 Part 2 Part 3 **Part 4** Part 5 All References (endnote file)

71

Part 4: Science Maps in Action

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Data Credits

Science Citation Index (SCI), Social Sciences Citation Index (SSCI), and Arts & Humanities Index (A&HI) by Thomson Reuters, 2001–2004; Scopus Database, 2001–2005.

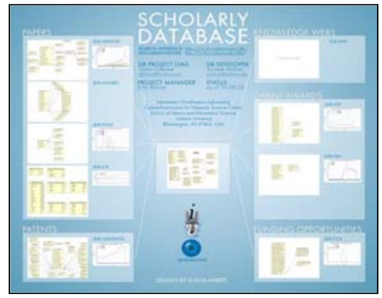
All world and science map overlays for each of the 30 maps: 2002 Base Map, *see* Boyack et al. 2009: Science location of map significance by Elisha F. Hardy (design), Katy Börner (concept).

World Map by Russell J. Duhon, overlay of geographical influence and significance by Elisha F. Hardy (design), Katy Börner (concept).

Image Credits

Extracted from: Skupin, André. 2005. *In Terms of Geography*. New Orleans, LA. In Katy Börner & Deborah MacPherson (eds.), First Iteration (2005): The Power of Maps, *Places & Spaces: Mapping Science*. http://scimaps.org (accessed May 4, 2009).

Computational Scientometrics Cyberinfrastructures



Scholarly Database: 25 million scholarly records
http://sdb.slis.indiana.edu

James S. McDonnell Foundation

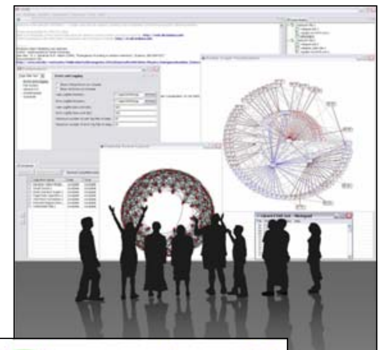
VIVO Research Networking
http://vivoweb.org

Information Visualization Cyberinfrastructure
http://iv.cns.iu.edu

Network Workbench Tool & Community Wiki
http://nwb.cns.iu.edu

Science of Science (Sci^2) Tool
http://sci2.cns.iu.edu

Epidemics Tool & Marketplace
Forthcoming



OSGi Alliance

CIShell cyberinfrastructure shell

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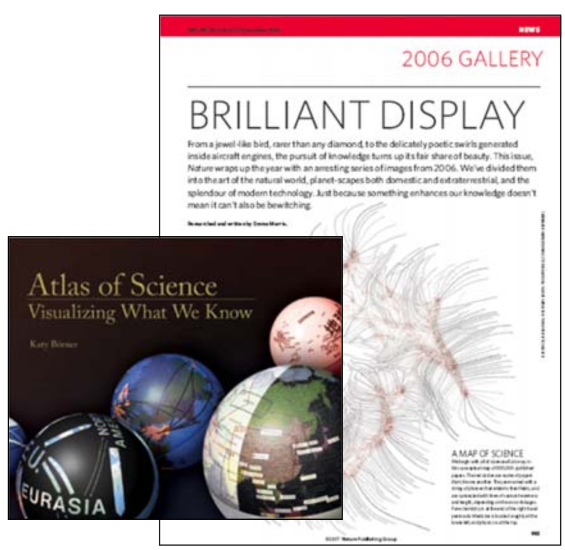

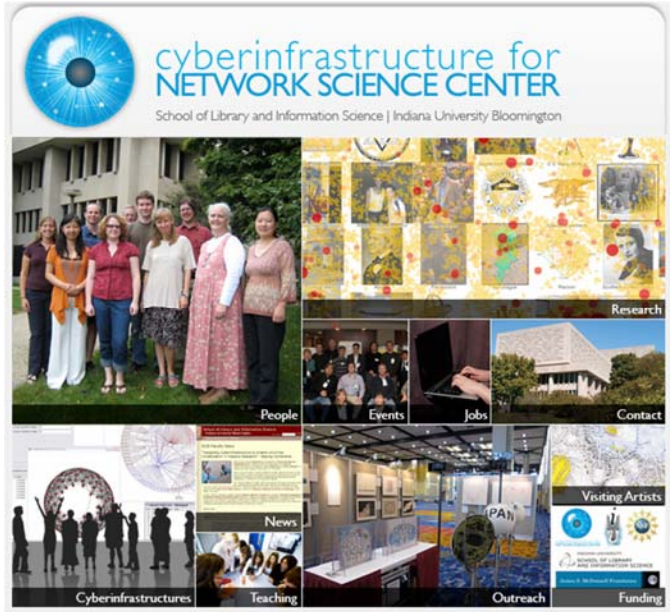

All papers, maps, tools, talks, press are linked from http://cns.iu.edu

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Mapping Science Exhibit Facebook: http://www.facebook.com/mappingscience