

# Maps & Macroscopes: Drawing Actionable Insights From Data

**Katy Börner**

Victor H. Yngve Distinguished Professor of  
Intelligent Systems Engineering & Information Science  
Director, Cyberinfrastructure for Network Science Center  
School of Informatics and Computing  
Indiana University Network Science Institute  
Indiana University, USA

*Opening Reception at Virginia Tech's Newman Library in Blacksburg, VA*

*September 6, 2017*



PLACES  
SPACES &  
MAPPING SCIENCE

[scimaps.org](http://scimaps.org)





# EARTH FROM ABOVE

Yann Arthus-Bertrand

How can we communicate the beauty,  
structure, and dynamics of science to a  
general audience?



# The Structure of Science

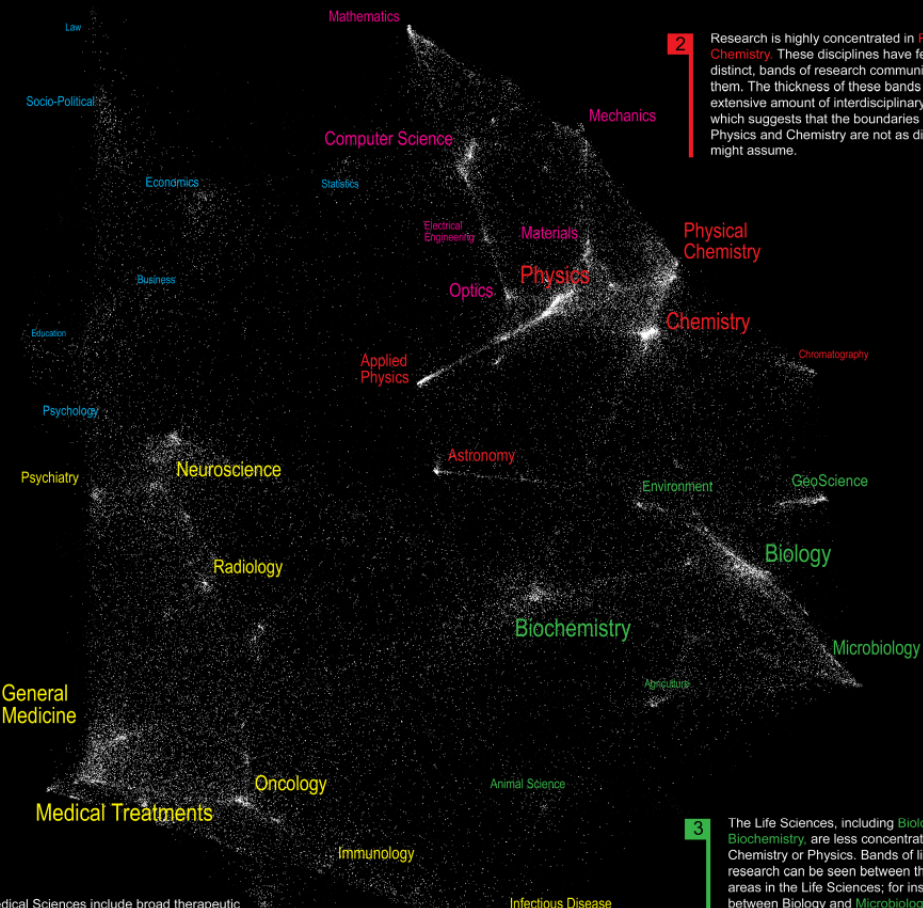
**5** The Social Sciences are the smallest and most diffuse of all the sciences. **Psychology** serves as the link between Medical Sciences (Psychiatry) and the Social Sciences. **Statistics** serves as the link with Computer Science and Mathematics.

**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.

**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.

**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.



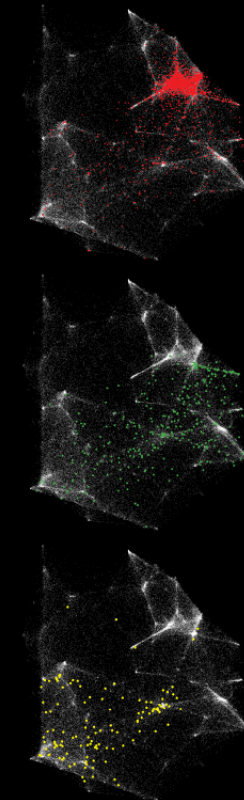
We are all familiar with traditional maps that show the relationships between countries, provinces, states, and cities. Similar relationships exist between the various disciplines and research topics in science. This allows us to map the structure of science.

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.



April, 2005: 101st Annual Meeting of the Association of American Geographer, Denver, Colorado.



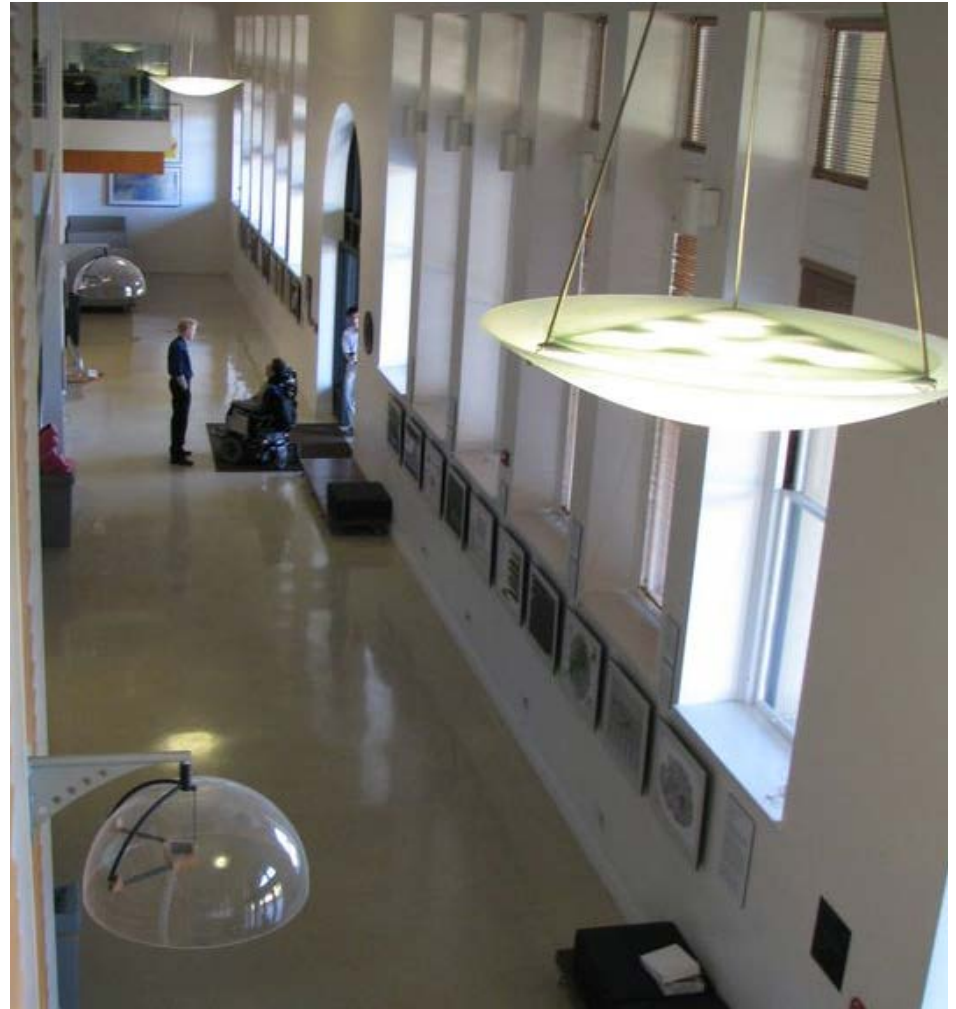


2005: 101st Annual Meeting  
American Geographer, De









Debut of 5<sup>th</sup> Iteration of the Mapping Science Exhibit at MEDIA X in 2009 at Wallenberg Hall, Stanford University.





Science Maps in “Expedition Zukunft” science train visited 62 cities in 7 months. Opening on April 23<sup>rd</sup>, 2009 by German Chancellor Merkel



Ingo Gunther's Worldprocessor globe design on display at the Museum of Emerging Science and Innovation in Tokyo, Japan.





Places & Spaces Digital Display in North Carolina State's Immersion Theater



Exhibit Advisors  
and Ambassadors



**Kristi Holmes** @kristiholmes · Apr 30

Excited for @cnscenter Places&Spaces at @galterlibrary! @katycns  
@NUCATSInstitute #unpackingcrates #viz

*Places & Spaces* at Northwestern University

May 14 - September 23, 2015



*Places & Spaces  
Exhibit* at the  
David J. Sencer  
CDC Museum,  
Atlanta, GA  
January 25-June  
17, 2016.



## **CDC Opening Event: Maps of Health**

Tutorial and Symposium  
February 4-5, 2016



*Places & Spaces Exhibit* at Vanderbilt University, Nashville, TN.  
January 23-April 23, 2017 <http://scimaps.org/vanderbilt>



# Maps



PLACES  
SPACES &  
MAPPING SCIENCE

[scimaps.org](http://scimaps.org)



10 iterations over 10 years

equal

$10 \times 10 = 100$  maps!

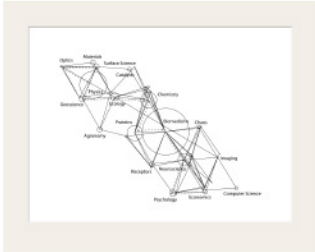
# The Power of Maps 2005



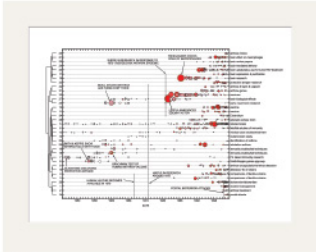
I.1



I.3



I.5



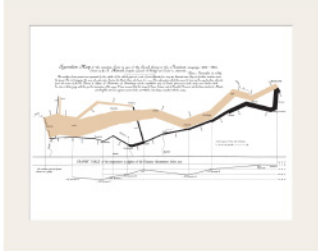
I.7



I.9



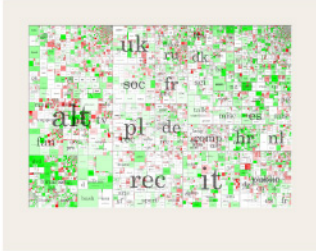
I.2



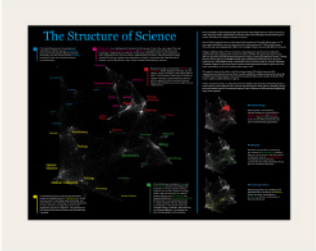
I.4



I.6



I.8



I.10

**Cartographic maps** of physical places have guided mankind's explorations for centuries.

They enabled the discovery of new worlds while also marking territories inhabited by the unknown.

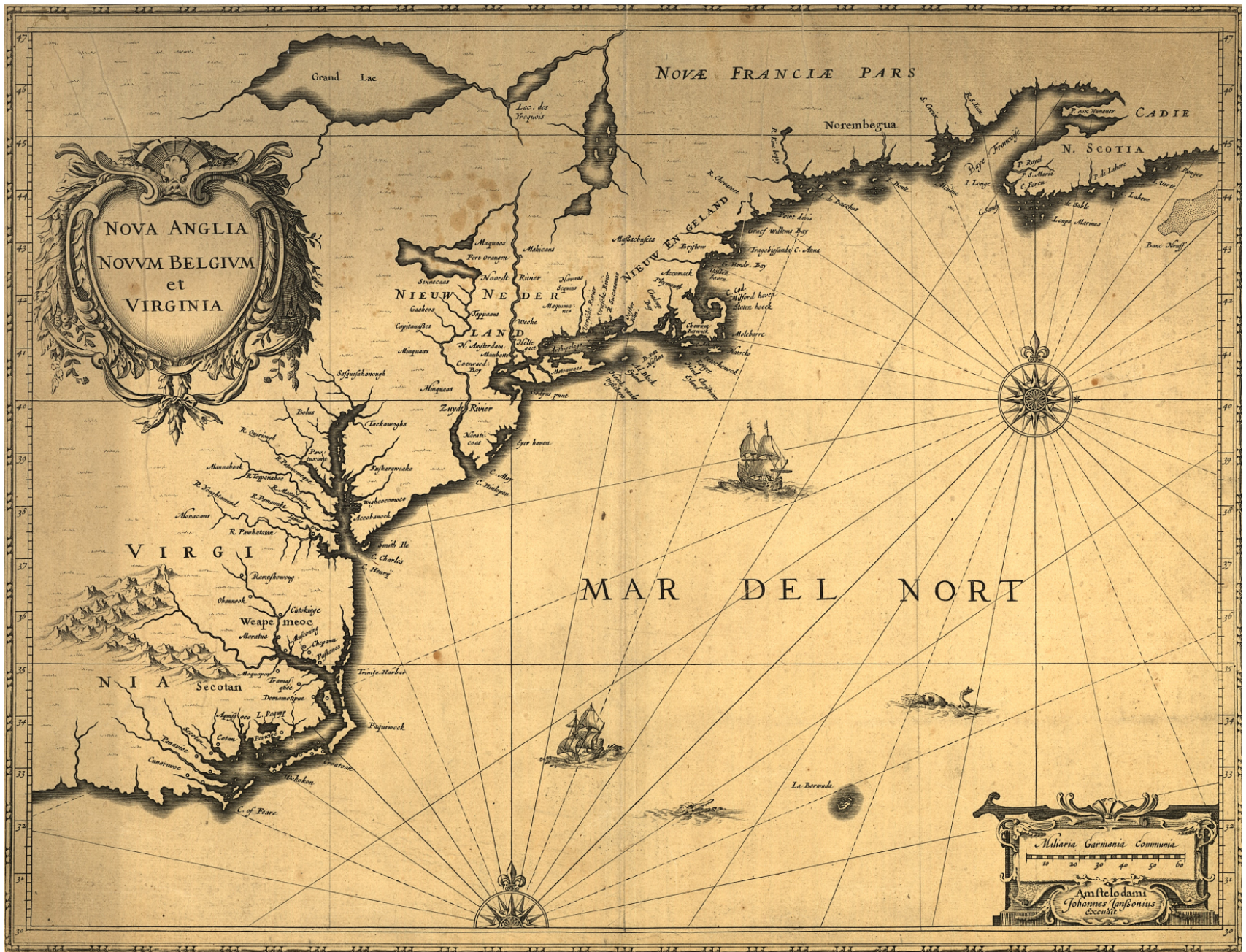
Without maps, we would be lost.





Cosmographia World Map - Claudius Ptolemy - 1482





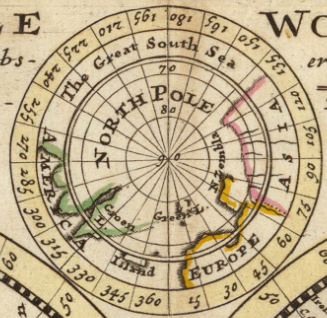
*Nova Anglia, Novvm Belgivm et Virginia - Jan Jansson - 1642*



A New Map of the **WHOLE**  
According to y<sup>e</sup> latest and most Exact Obs-

**WORLD** with the Trade winds  
errations By H. Moll Geographer

In this Maps is inserted A View of y<sup>e</sup> General & Coasting Trade Winds, Monsoons or y<sup>e</sup> Shifting Trade-winds Note that y<sup>e</sup> Arrows among y<sup>e</sup> Lines shew y<sup>e</sup> Course of those General & Coasting Winds, and y<sup>e</sup> Arrows in y<sup>e</sup> void Spaces shew y<sup>e</sup> Course of y<sup>e</sup> Shifting Trade-winds, and y<sup>e</sup> Abbreviation sep<sup>r</sup> & c. Shew y<sup>e</sup> Times of y<sup>e</sup> Year when such Winds Blow.



The Signs of the Zodiac, The First 6 are Northern, the other Southern Signs  
♈ Aries . March      ♌ Leo . July  
♉ Taurus . April    ♍ Virgo . August  
♊ Gemini . May      ♎ Libra . September  
♋ Cancer . June     ♏ Scorpio . October  
♐ Sagittarius . November  
♑ Capricornus . December  
♒ Aquarius . January  
♓ Pisces . February



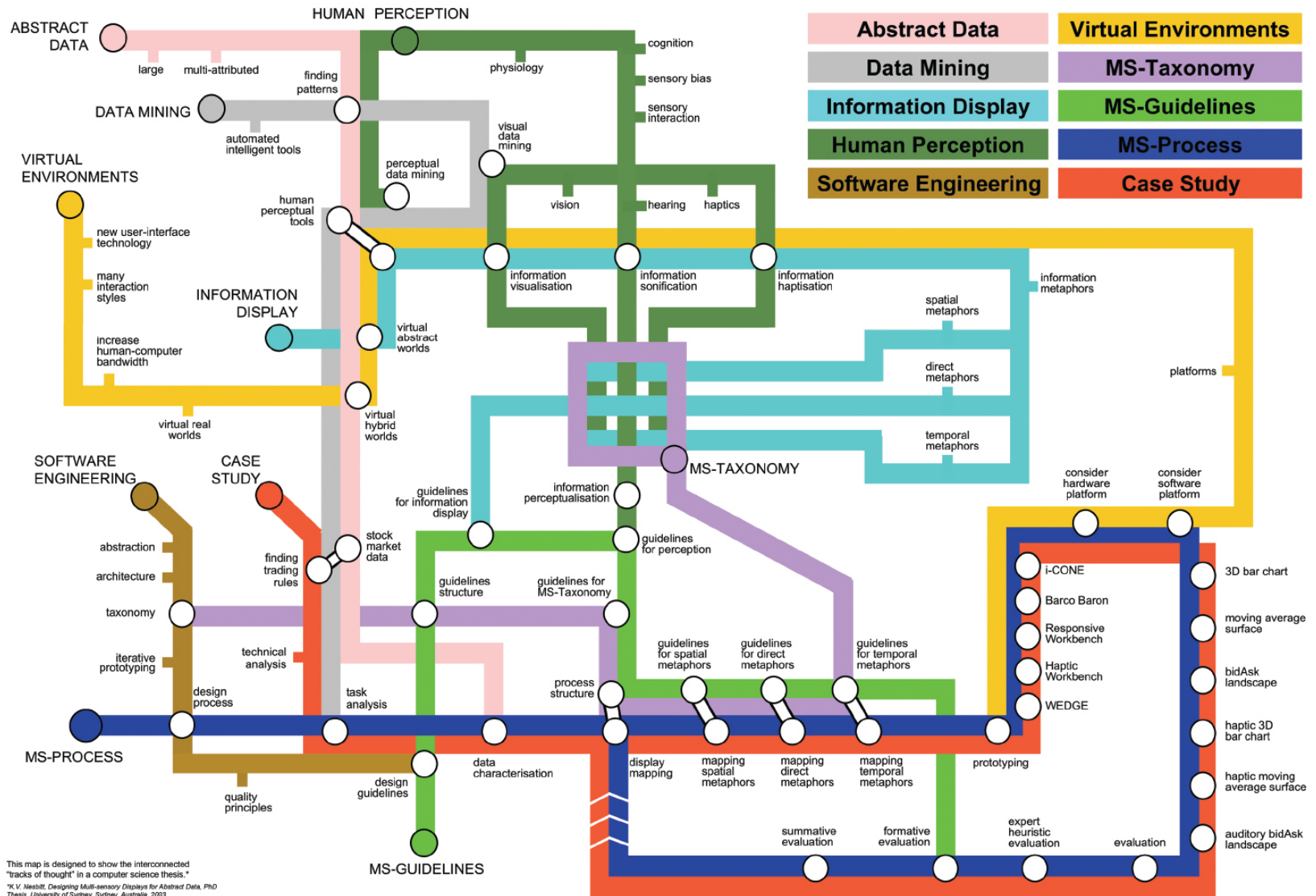
Printed for Tho: Bowles Print and Map Seller next y<sup>e</sup> Chapter- Houfe in S.<sup>t</sup> Pauls Church-yard; and John Bowles Print and Map Seller at the Black-Horse in Cornhill London.

A New Map of the Whole World with Trade Winds According to the Latest and Most Exact Observations - Herman Moll - 1736



**Science maps** of abstract semantic spaces aim to serve today's explorers navigating the world of science.

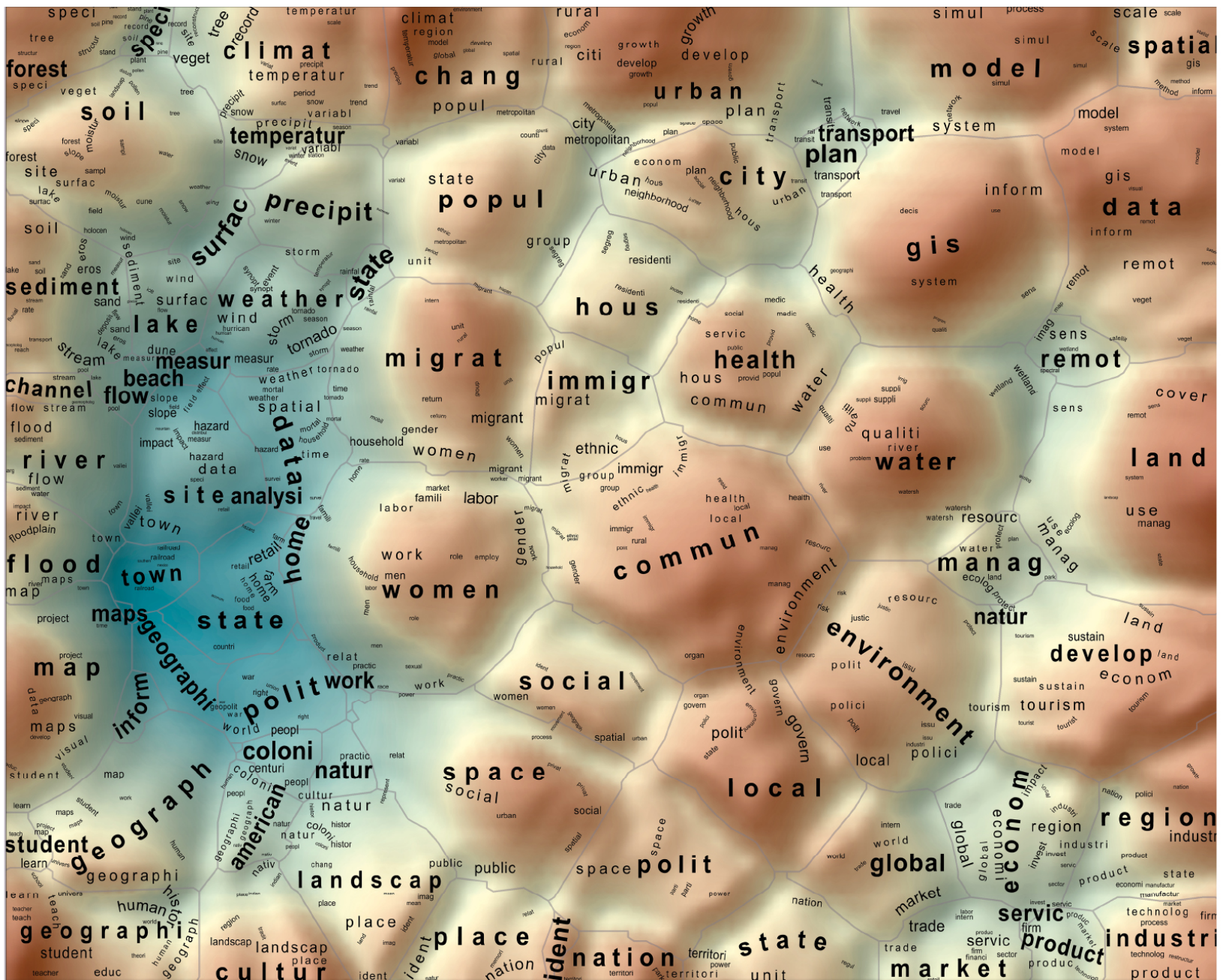
They can be used to identify objectively major experts, institutions, collections. They allow us to track the emergence, evolution, and disappearance of topics and help to identify the most promising areas of research.



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.

*Ph.D. Thesis Map* - Keith B. Nesbitt - 2004



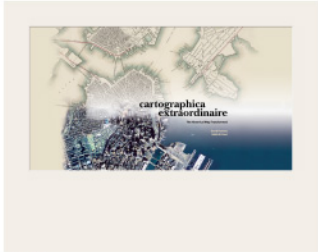


*In Terms of Geography - Andre Skupin - 2005*

# The Power of Reference Systems 2006



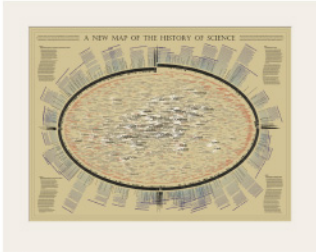
II.1



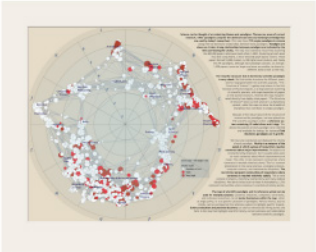
II.3



II.5



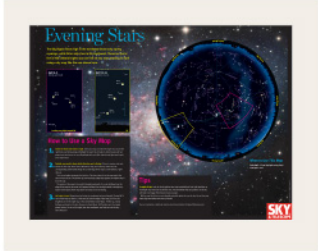
II.7



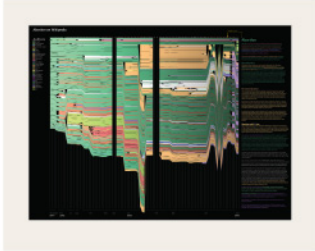
II.9



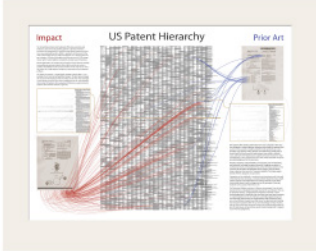
II.2



II.4



II.6



II.8



II.10



# 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.

1 H Hydrogen	2 He Helium																																		
3 Li Lithium	4 Be Beryllium	5 B Boron	6 C Carbon	7 N Nitrogen	8 O Oxygen	9 F Fluorine	10 Ne Neon																												
11 Na Sodium	12 Mg Magnesium	13 Al Aluminium	14 Si Silicon	15 P Phosphorus	16 S Sulfur	17 Cl Chlorine	18 Ar Argon																												
19 K Potassium	20 Ca Calcium	21 Sc Scandium	22 Ti Titanium	23 V Vanadium	24 Cr Chromium	25 Mn Manganese	26 Fe Iron	27 Co Cobalt	28 Ni Nickel	29 Cu Copper	30 Zn Zinc	31 Ga Gallium	32 Ge Germanium	33 As Arsenic	34 Se Selenium	35 Br Bromine	36 Kr Krypton																		
37 Rb Rubidium	38 Sr Strontium	39 Y Yttrium	40 Zr Zirconium	41 Nb Niobium	42 Mo Molybdenum	43 Tc Technetium	44 Ru Ruthenium	45 Rh Rhodium	46 Pd Palladium	47 Ag Silver	48 Cd Cadmium	49 In Indium	50 Sn Tin	51 Sb Antimony	52 Te Tellurium	53 I Iodine	54 Xe Xenon																		
55 Cs Caesium	56 Ba Barium	57 La Lanthanum	58 Ce Cerium	59 Pr Praseodymium	60 Nd Neodymium	61 Pm Promethium	62 Sm Samarium	63 Eu Europium	64 Gd Gadolinium	65 Tb Terbitium	66 Dy Dysprosium	67 Ho Holmium	68 Er Erbium	69 Tm Thulium	70 Yb Ytterbium	71 Lu Lutetium																			
87 Fr Francium	88 Ra Radium	89 Ac Actinium	90 Th Thorium	91 Pa Protactinium	92 U Uranium	93 Np Neptunium	94 Pu Plutonium	95 Am Americium	96 Cm Curium	97 Bk Berkelium	98 Cf Californium	99 Es Einsteinium	100 Fm Fermium	101 Md Mendeleevium	102 No Nobelium	103 Lr Lawrencium																			
																		104 Rf Rutherfordium	105 Db Dubnium	106 Sg Seaborgium	107 Bh Bohrium	108 Hs Hassium	109 Mt Meitnerium	110 Ds Darmstadtium	111 Rg Roentgenium										

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](http://www.chemsoc.org/viselements)

© Murray Robertson/Royal Society of Chemistry 1999-2006

How would a reference system for all  
of science look?

What dimensions would it have?

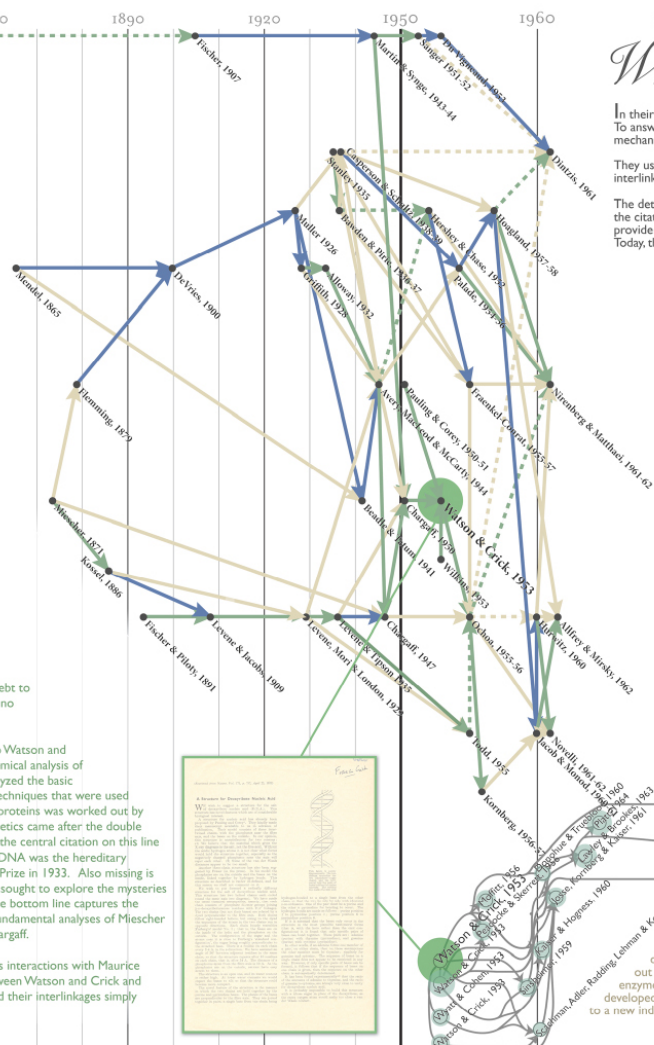
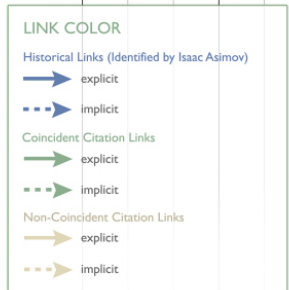
1800 1830 1860 1890 1920 1950 1960 1970 1980 1990 2000 2010

# 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*.

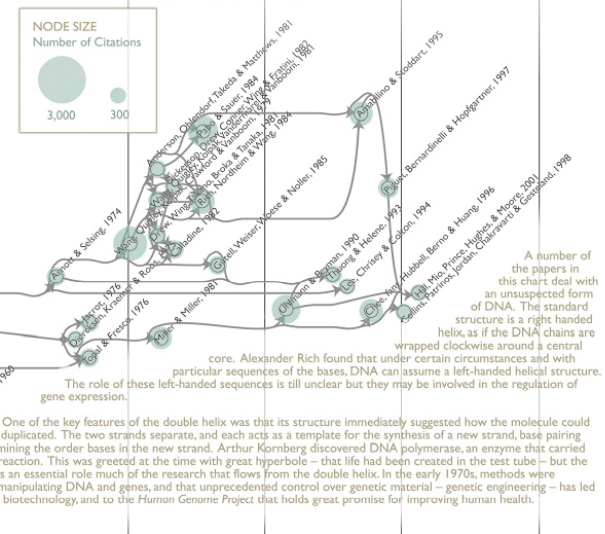
The detailed comparison of both networks demonstrates a high degree of coincidence between Asimov's account of events and the citation data, see also *Foundation* chart. They conclude that the use of citation data to write the history of science might provide a new *modus operandi* for the study of the history of science, research administration, and the sociology of science. Today, their HistCite™ tool generates interactive citation graphs automatically, see *Impact* chart.



# 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.



# 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 Syngde 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.



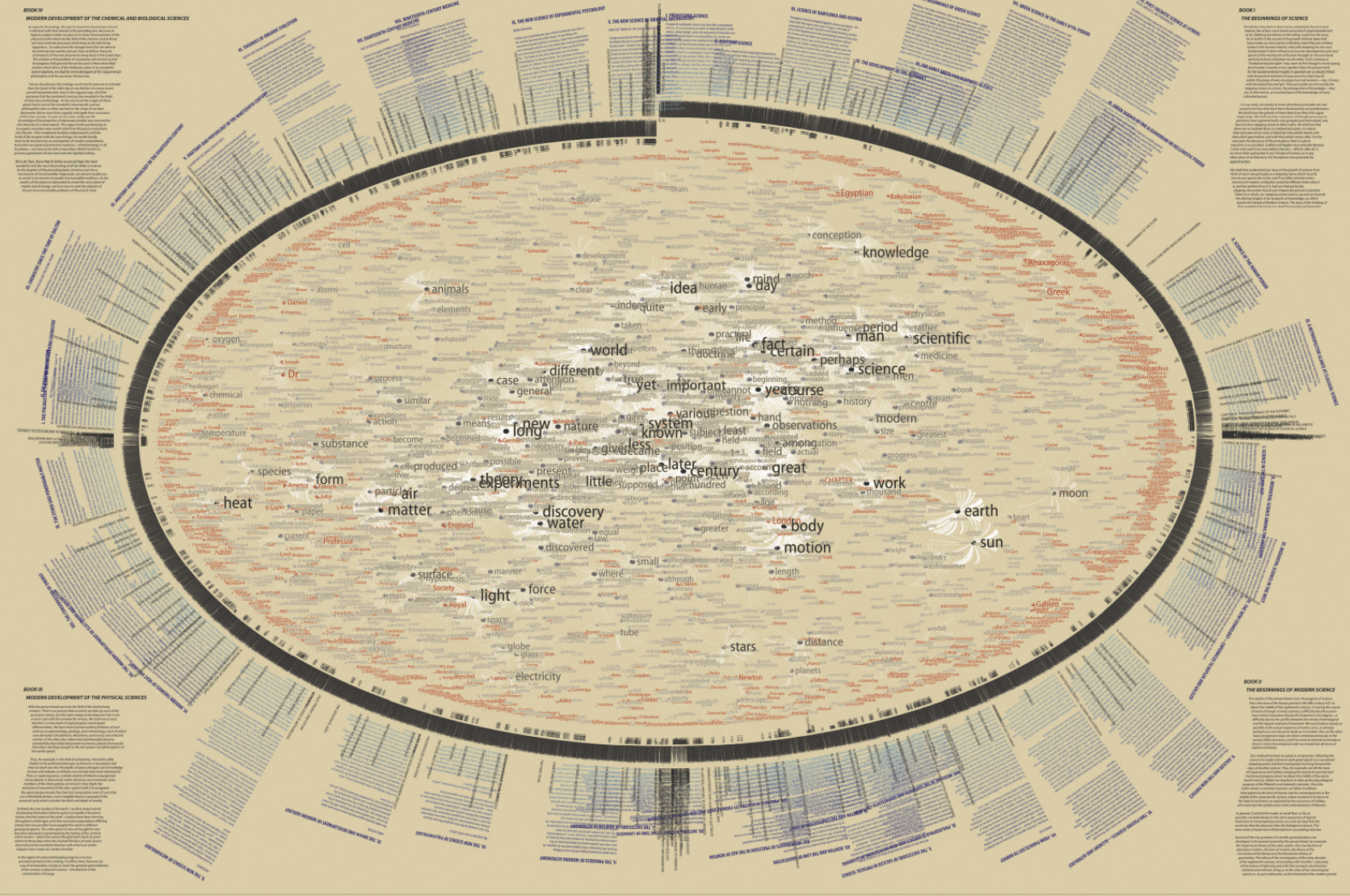
*HistCite™ Visualization of DNA Development* - Eugene Garfield, Elisha Hardy, Katy Börner, Ludmila Pollock, Jan Witkowski - 2006



# A NEW MAP OF THE HISTORY OF SCIENCE

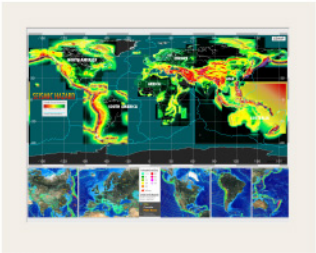
Being a Treatise of sciences 1-10 of A History of Science by Henry Smith Williams, M.D., LL.D., edited by Edward K. Williams, M.D.  
Terms average an entire text in the form of a clock showing how widely, how frequently words and their more than 100 related  
in this average position - all 1000 words published every year. A look for words in a wordlist when the words used.

While you come toward lines in which a word is mentioned. Words get larger and darker the more they are used. This particular TextArc  
has been enhanced to contrast and enlarge historical context: numbers (twenty years) appear inside the arc, chapter headings & introductory  
paragraphs words, book introductions in the center. Typset and down in November, 2007 by W. Bradford Paley, all rights reserved



TexArc Visualization of "The History of Science" - W. Bradford Paley - 2006

# The Power of Forecasts 2007



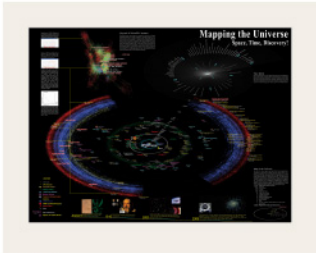
III.1



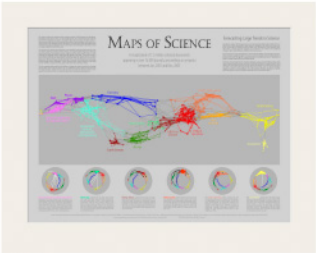
III.3



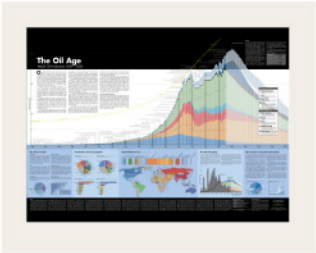
III.5



III.7



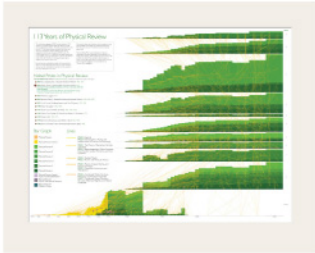
III.9



III.2



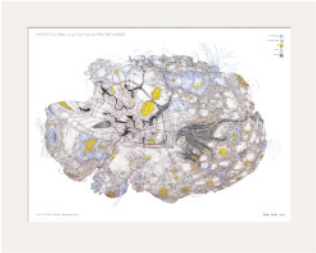
III.4



III.6

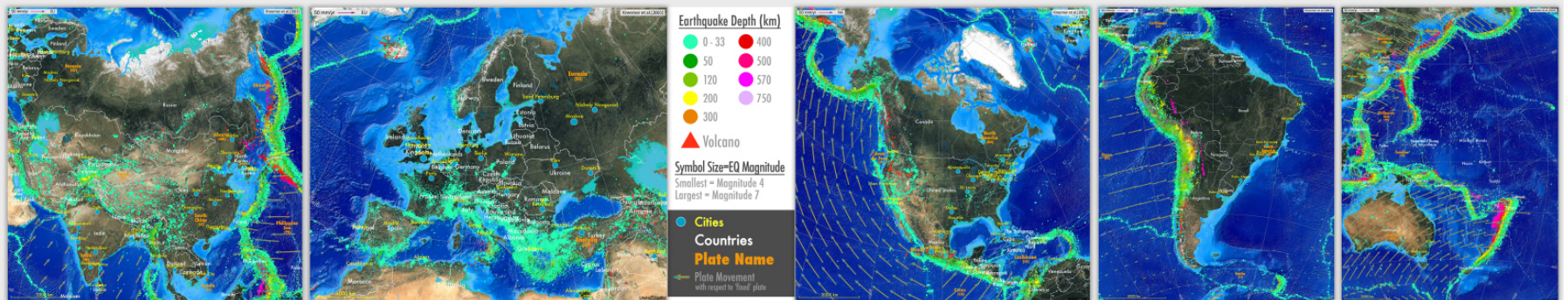
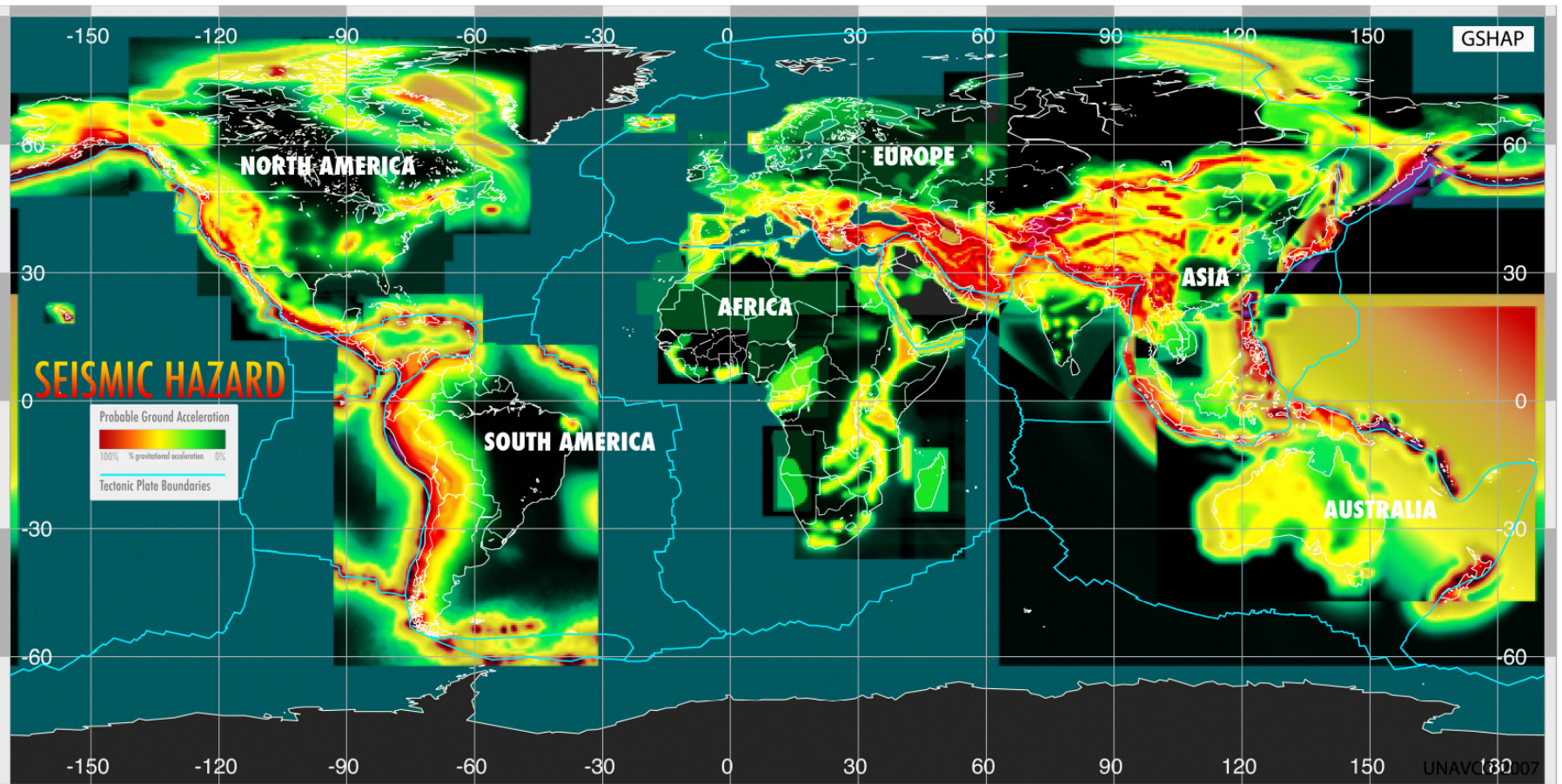


III.8



III.10



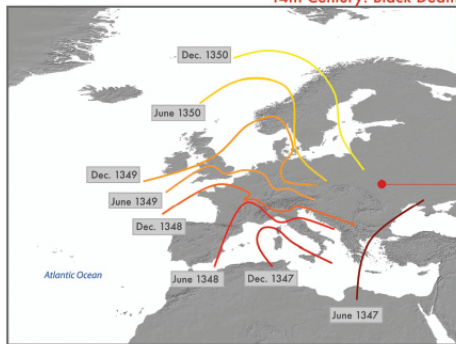


*Tectonic Movements and Earthquake Hazard Predictions* - Martin W. Hamburger, Lou Estey, Chuck Meertens, Elisha Hardy - 2005



# Impact OF Air Travel ON Global Spread OF Infectious Diseases

14th Century: Black Death

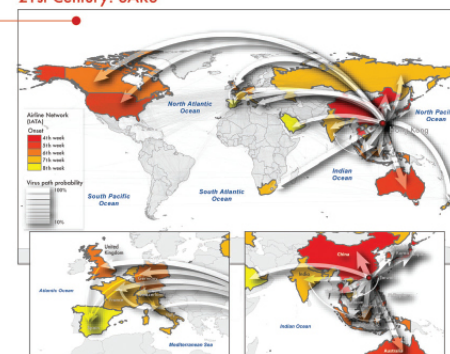


Epidemic spreading pattern changed dramatically after the development of modern transportation systems.

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.

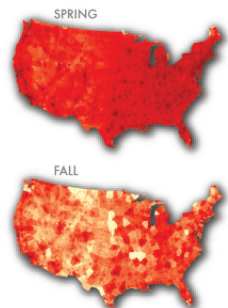
The SARS outbreak on the other hand was characterized by a patched and heterogeneous spatio-temporal pattern mainly due to the air transportation network identified as the major channel of epidemic diffusion and ability to connect far apart regions in a short time period. The SARS maps are obtained with 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

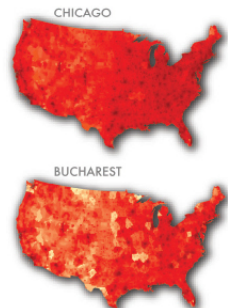
### Seasonal



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 from one city to another by means of the airline transportation network.

### Geographical

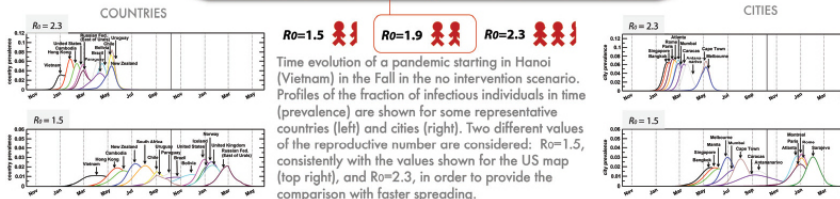
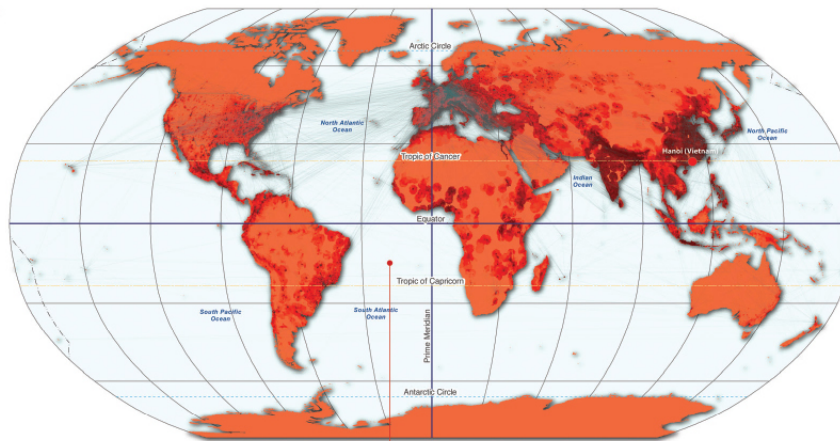


Numerical simulations provide results for the temporal and geographic evolution of the pandemic influenza in 3,100 urban areas located in 220 different countries. The model allows to study different spreading scenarios, characterized by different initial outbreak conditions, both geographical and seasonal.

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



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

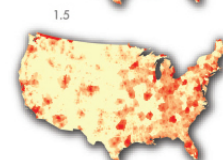
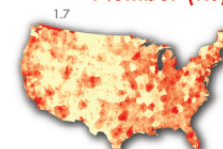


The model includes the worldwide air transportation network (source: IATA) composed of 3,100 airports in 220 countries and  $E=17,182$  direct connections, each of them associated to the corresponding passenger flow. This dataset accounts for 99% of the worldwide traffic and is complemented by the census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

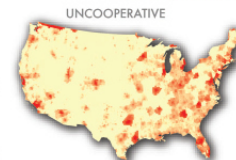
Additional spreading scenarios can be obtained by modeling different levels of infectiousness of the virus, as expressed in terms of the reproductive number  $R_0$ , representing the average number of infections generated by a sick person in a fully susceptible population.

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

### Reproductive Number ( $R_0$ )



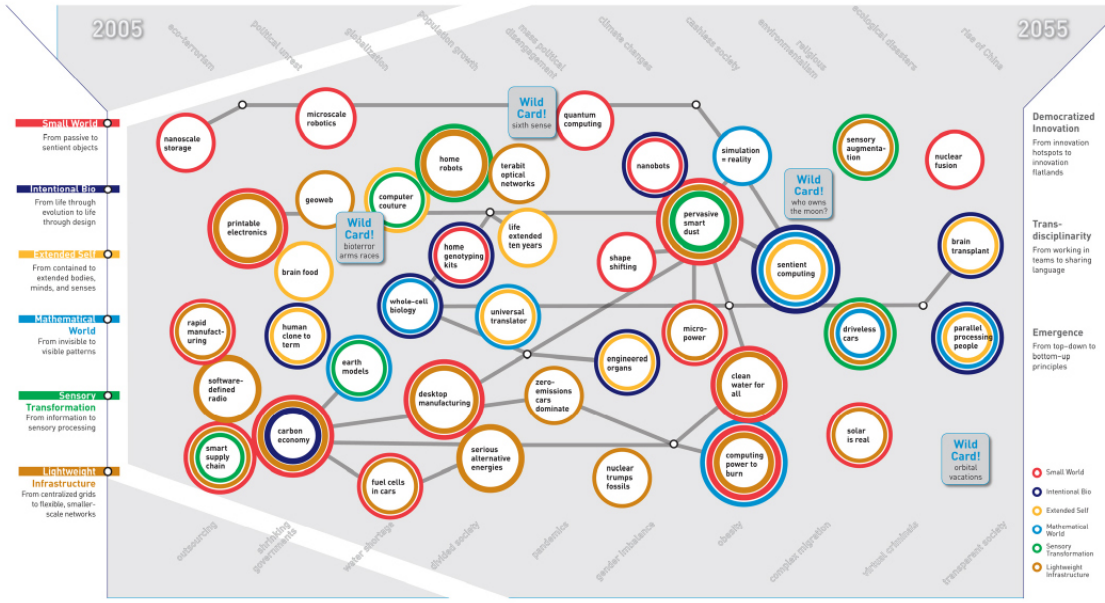
### Intervention



Can one forecast science?

What 'science forecast language' will  
work to communicate results?





SB-1011 ©2006 Institute for the Future. All rights reserved. Reproduction is prohibited without written permission.

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 (ITFF)** 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 ITFF 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 ITFF'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 technologies, 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 milieus 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 technology 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 will 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.

- Democratized Innovation**

From invention hotspots innovation hotlands
- Trans-disciplinarity**

From working in teams to sharing language
- Emergence**

From top-down to bottom-up principles

- Small World
- Intentional Bio
- Extended Self
- Mathematical World
- Sensory Transformation
- Lightweight Infrastructure

- Transdisciplinarity**

In the last two centuries, natural philosophy and natural history fractured into the now-familiar disciplines of physics, chemistry, biology, and so on. The sciences evolved into their current form in response to intellectual and professional opportunities, philanthropic priorities, and economic and state needs. Through most of the 20th century, the growth of the sciences, and academic and career pressures, encouraged ever-greater specialization. In the coming decades, transdisciplinary research will become an imperative. According to Howard Rheingold, a prominent forecaster and author, "transdisciplinarity goes beyond bringing together researchers from different disciplines to work in multidisciplinary teams. It means educating researchers who can speak languages of multiple disciplines—biologists who have understanding of mathematics, mathematicians who understand biology."
- Emergence**

The phenomenon of self-organizing swarms that generate complex behavior by following simple rules—will likely become an important research area, and an important model for understanding how the natural world works and how artificial worlds can be designed. Emergent phenomena have been observed across a variety of natural phenomena, from physics to biology to sociology. The concept has broad appeal due to the diversity of fields and problems to which it can be applied. It is proving useful for making sense of a very wide range of phenomena. Meanwhile, emergence can be modeled using relatively simple computational tools, although those models often require substantial processing power. More generally, it is a richly suggestive way of thinking about designing complex, robust technological systems. Finally, emergence is an accessible and vivid metaphor for understanding nature. Just as classical physics profited from popular treatments of Newtonian mechanics, so too will scientific study and technical reproductions of emergent phenomena likely draw benefits from the popularization of its underlying concepts.



# 113 Years of Physical Review

This visualization aggregates 389,899 articles published in 720 volumes of 11 journals between 1893 and 2005. The 91,762 articles published from 1893 to 1976 take up the left third on the map. In 1977, the Physical Review introduced the Physics and Astronomy Classification Scheme (PACS) codes, and the visualization subdivides into the top-level PACS codes. The 217,503 articles from 1977 to 2000, for which good citation data is not available, occupy the middle third on the map. The 80,634 articles from 2001 to 2005, for which good citation data is available, fill the last third of the map.

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

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

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

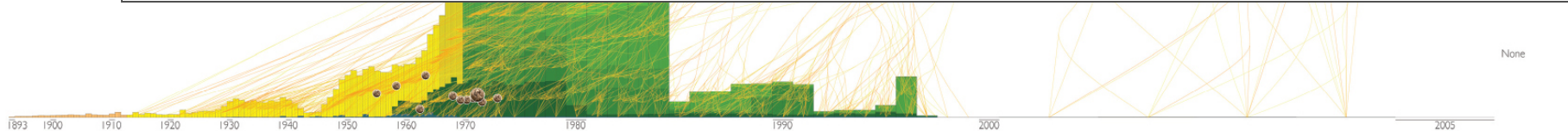
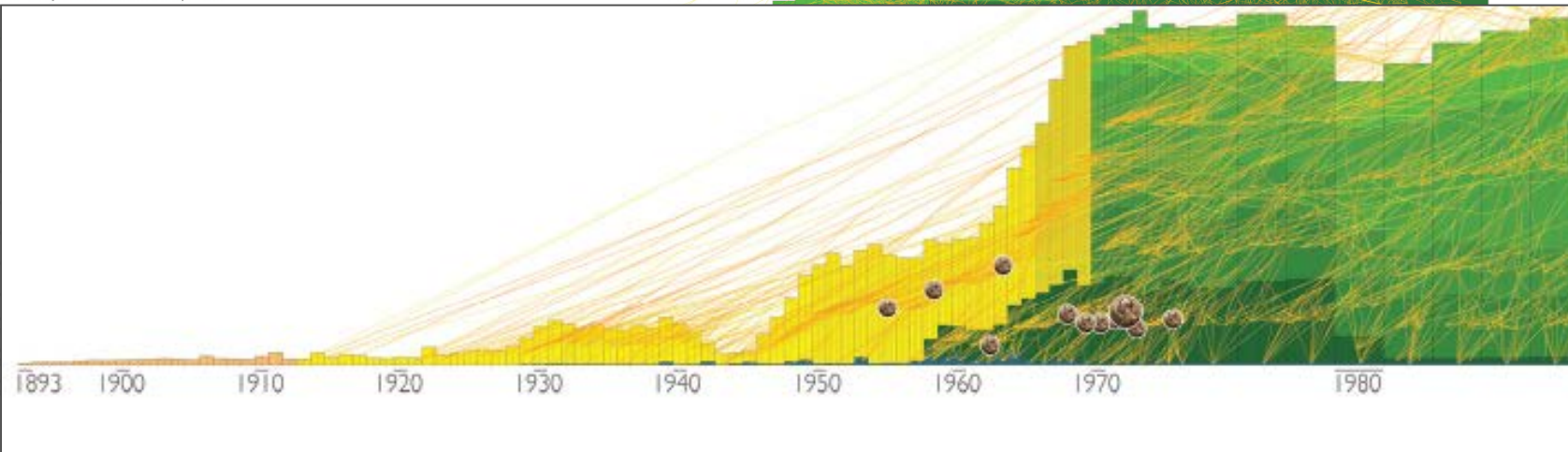
## Nobel Prizes in Physical Review

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

- 2005 Roy J. Glauber, John L. Hall, and Theodor W. Hänsch 1963, 1971
- 2004 David J. Gross, H. David Politzer, and Frank Wilczek 1973  
Thomson ISI successfully predicted a winner in this year, with the following paper:  
Gross D, Wilczek F. Ultraviolet Behavior of Non-Abelian Gauge Theories. *Physical Review Letters* 30: 1343 & 1973
- 2003 Anthony J. Leggett 1970
- 2002 Raymond Davis Jr., Masatoshi Koshiba, and Riccardo Giacconi 1962, 1968, 1987
- 2001 Eric A. Cornell, Wolfgang Ketterle, and Carl E. Wieman 1995, 1996
- 1998 Robert B. Laughlin 1982, 1983
- 1997 Steven Chu and William D. Phillips 1985, 1986, 1988
- 1996 David M. Lee, Douglas D. Osheroff, and Robert C. Richardson 1972
- 1995 Martin L. Perl 1959, 1975
- 1994 Bertram N. Brockhouse and Clifford G. Shull 1955, 1958
- 1990 Jerome I. Friedman, Henry W. Kendall, and Richard E. Taylor 1969

## Bar Graph

- Physical Review
- Physical Review
- Physical Review
- Physical Review
- Physical Review
- Physical Review
- Physical Review
- Physical Review
- Physical Review
- Physical Review Topics Accoles
- Physical Review Physics Educa
- Physical Review Modern Phys

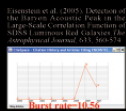


*114 Years of Physical Review* - Bruce W. Herr II, Russell Duhon, Katy Borner, Elisha Hardy, Shashikant Penumarthy - 2007



# Mapping the Universe

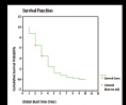
## Space, Time, Discovery!



Fan et al. (2003). A survey of 294,7 papers in the Sloan Digital Sky Survey II. Discovery of three additional classes of  $r$ -type *Extragalactic Journal*, 131, 1644-1650



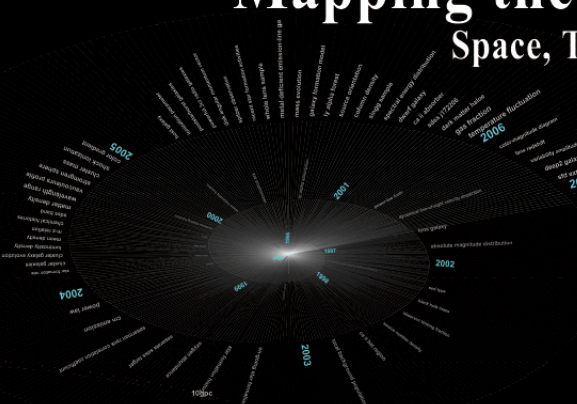
Citation burst detects an abrupt increase of citations received by a scientific paper or research field to be indicated. Papers with long periods of citation burst tend to have a profound impact. The two papers in Figure 1 and 2 are the first of all highlighted here have the highest citation burst rates. Two selected two citation burst examples of two different bursts. One is possible because of the new advance and knowledge that changed subsequent work in the field. The other is possible because of the large volume of space surveyed by SDSS.



The above chart shows the cumulative number of citations of a scientific paper in the first year of citation burst, and the average citation burst in the SDSS literature after 3.5 years.

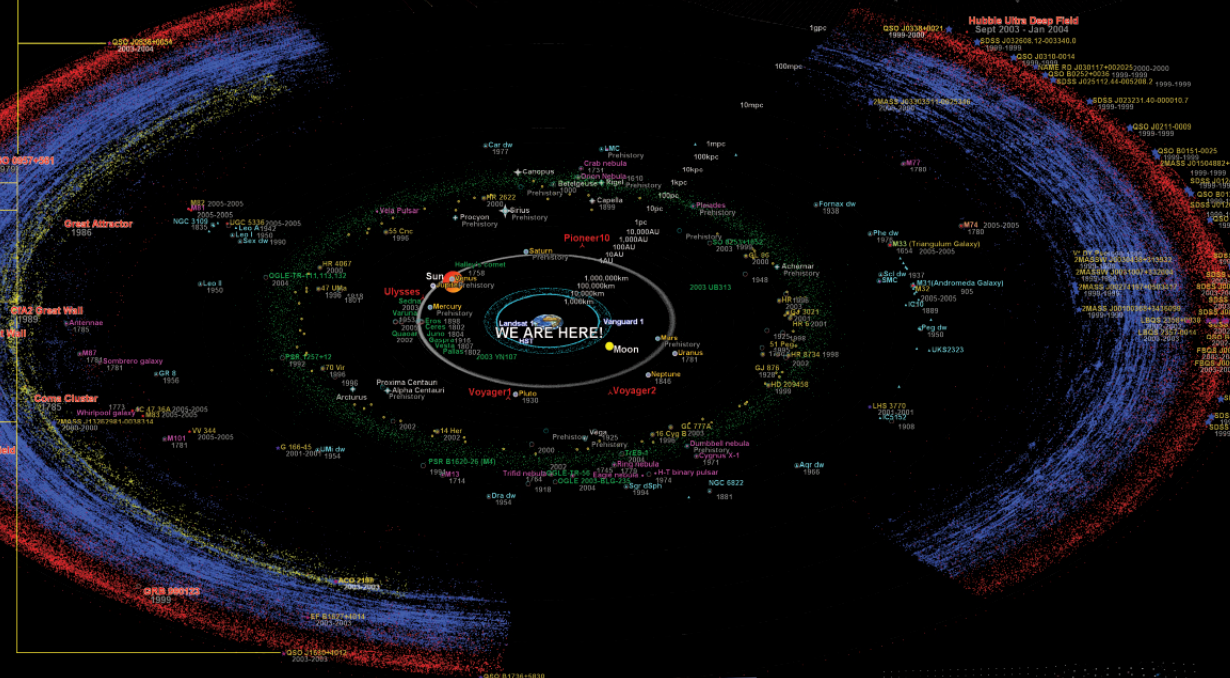
### Network of Scientific Literature

The SDSS literature network gives an example of a collective and dynamic intellectual structure of scientific community. The network consists of 1,502 nodes and 8,231 links. It contains two types of nodes: SDSS papers that have received five or more citations, or selected by subsequent papers, and terms extracted from the SDSS papers. Paper nodes are depicted as circles, whereas terms are shown as triangles. The size of each node represents the number of citations it has received. The color of each node represents the distance of each node from the center of the network.



### Time Spiral

The time spiral organizes new topics that emerged each year in the SDSS literature. These topics are selected based on statistical tests of association between terms found in SDSS papers. Terms are included in the time spiral only if they appear in the first time. Subsequent appearances of the same term are not included in the time spiral. Terms in the time spiral are expected to include emerging areas of future growth of the SDSS literature.



### Map of the Universe

The map of the universe depicts more than 600,000 astronomical objects. The map is identified by the Sloan Digital Sky Survey (SDSS) Community Science Database (CSD) and is available in the SDSS Data Release 7. Each object in the map is positioned based on its right ascension and declination coordinates. Multiple scales of distance are used, namely kiloparsec, astronomical unit, parsec, megaparsec, gigaparsec, and gigaparsec. The spirals, walls of megaparsec and gigaparsec are specifically enlarged to make the details in these areas more readable. Colors and shapes of objects are arbitrarily assigned. The color combination is made it easy to differentiate distinct objects and their original data sources.

- 379,729 SDSS quasar, galaxies, and stars
- 214,779 Asteroids
- 8,620 Satellites
- 6,271 Hipparcos objects
- 214 Large main sequence stars
- 118 Landmark discoveries
- 91 Extragalactic objects
- 46 Objects with unusual bursts
- 43 Local group galaxies
- 24 Messier galaxies
- 11 Stars
- 11 The Sun, the Moon, and the planets in our Solar system
- 4 Star models

418,222 Objects shown in the map of the Universe

- ### LEGEND
- Asteroids
  - CIA2 Galaxies
  - Extragalactic Planets
  - Hipparcos Stars
  - Local Group Galaxies
  - Messier Galaxies
  - Planets in the Solar System
  - Satellites
  - SDSS Galaxies
  - SDSS High Redshift Quasars
  - Space Probes
  - Stars
  - Orion Nebula 1610
  - Date of Discovery
  - Objects with Citation Bursts

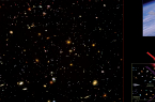
Ancient



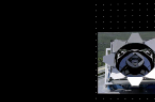
1610



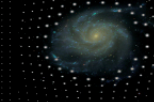
2003



2005



2005



2005



2005

# MAPS OF SCIENCE

## Forecasting Large Trends in Science

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

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

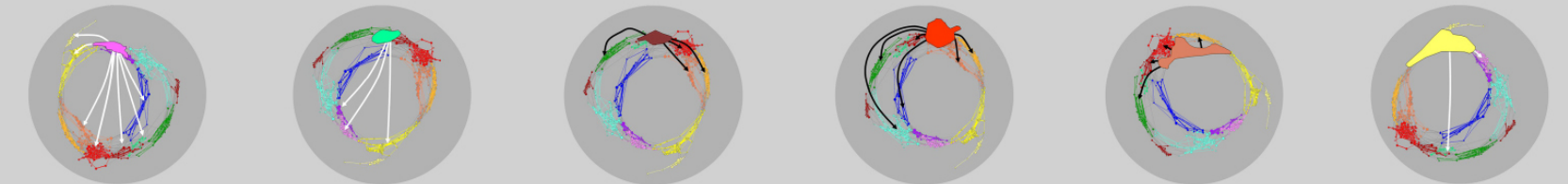
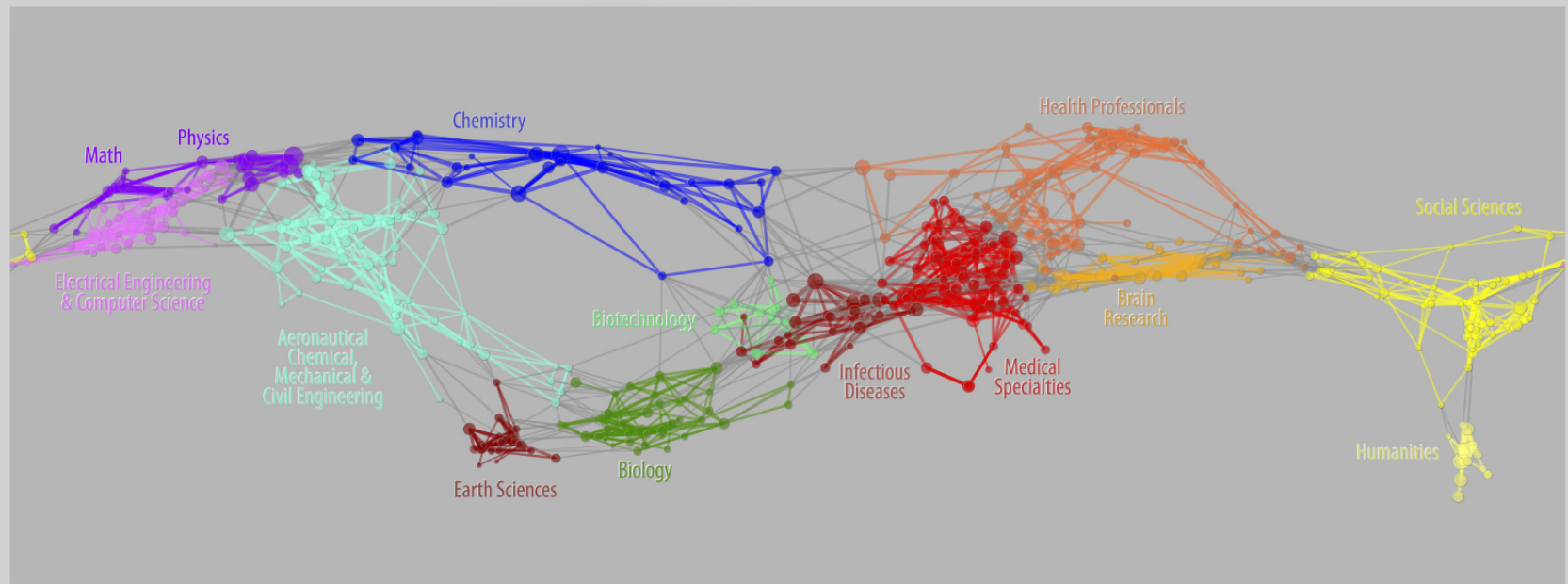
The six map projections shown at the bottom are images of what one would see if looking directly down at the south pole of the map, at six different rotations. When viewed this way, the map looks like a wheel with an inner ring and outer ring. This wheel of science corresponds very closely with the two-dimensional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

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

Calculations were performed using the large colored groupings of disciplines (fields) to determine if any of them were likely to cause large scale changes in the structure of science over time. Connectedness coefficients between fields were calculated for each individual year, 2001-2005. A simple regression analysis was conducted to see if there were significant changes in these connectedness coefficients from year-to-year.

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

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



**Electrical Engineering & Computer Science (EE/CS)**, indicated by the pink shape in the view above, is a field whose connectedness has been increasing much more quickly (15% than expected). Connectedness has increased between EE/CS and all other fields from 2001-2005. The connections with the largest annual increases (>10%) are shown by white arrows. Over time, these stronger connections will distort the map, and may bring EE/CS into a more central position.

**Biotechnology**, indicated by the light green shape above, has the largest overall increase in connectedness with other fields (16%). It has relatively few connections with the EE/CS, Math & Physics, and Social Sciences fields, but these three connections had the largest fractional increase. The connection with EE/CS, which had the single largest growth rate (31% of any connection, reflects recent growth in the area of bioinformatics.

**Infectious Diseases**, indicated by the dark red shape above, has an overall decrease in connectedness (2%) with other fields. Decreases in connection strength between this field and the fields of Biology, Medical Specialties, Health Professionals and Brain Research (all >3%) are shown as black arrows, and will drive a slow dispersion of the medical fields compared to the current structure.

**Medical Specialties**, indicated by the red shape above, has an overall decrease in connectedness (2%) with other fields. This is dominated by decreasing connection strength to the other medical fields and biology, as shown by the black arrows. The only connection increasing in strength is the one to EE/CS, which is not shown here, but was shown as a white arrow in the first story.

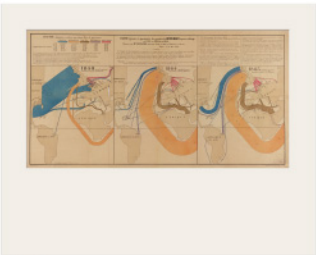
The **Health Professionals** field, indicated by the orange shape above, has the largest overall decrease in connectedness (4%) to other fields. As with the other medical fields, its connection strength with medicine and biology is decreasing in all cases, as shown by the black arrows. With the decreasing connection strengths throughout medicine, we expect the map structure in these areas to relax slightly over time.

The **Social Sciences**, indicated by the yellow shape above, had an overall increase in connectedness (9%) with other fields. Although its greatest connectedness gains were with EE/CS and Biotechnology (see white arrows), it also had consistent connection increases with nearly all the other fields. In general the fields of EE/CS, Biotechnology, and the Social Sciences are become more connected, and are pulling on the physical sciences as well.

Source: University of California, San Diego Knowledge Mapping Laboratory. Color Images: © Regents of the University of California. The underlying data came from two sources: Thomson ISI and Scopus. Mapping methodology and descriptive text by Dick Klavans, President, SciTech Strategies, Inc., and Kevin Boyack, Sandia National Laboratories. Graphics & typography by Ethan Meilner and Mike Patek. Special acknowledgements to Katy Borner, Art Ellis, W. Bradford Paley, Len Simon, and Henry Small. © 2007 by Dick Klavans, all rights reserved.



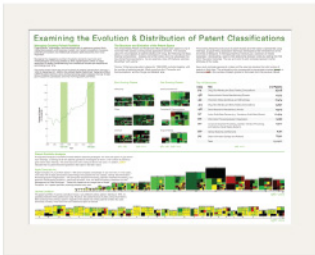
# Science Maps for Economic Decision Makers 2008



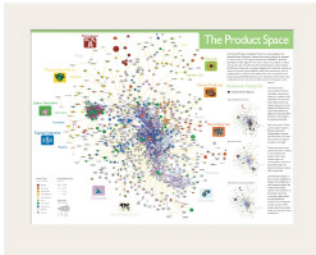
IV.1



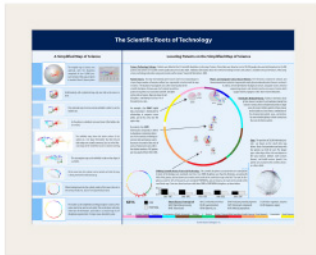
IV.3



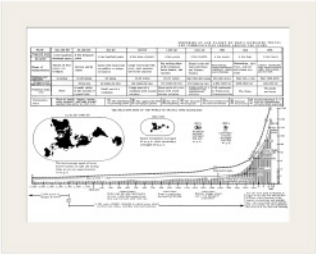
IV.5



IV.7



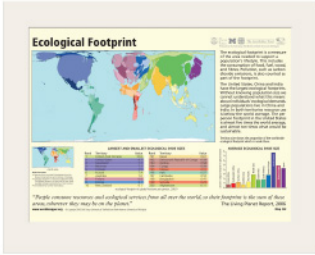
IV.9



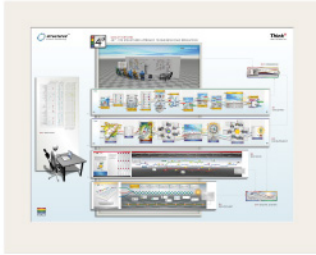
IV.2



IV.4



IV.6



IV.8



IV.10

What insight needs do economic decision makers have?

What data views are most useful?



**LÉGENDE** — Quantités et couleurs pour chaque Pays de provenance.

Importations des Américains	Etats-Unis	Indes (Gambie, Cap, etc.)	Egypte, Soudan	Forêt Indienne (Indes)	Angleterre, Espagne, etc.
1858	532,100 <sup>a</sup>	79,510 <sup>b</sup>	22,810 <sup>b</sup>	8,480 <sup>b</sup>	63,500 <sup>c</sup>
1864	548,100 <sup>a</sup>	180,510 <sup>b</sup>	27,000	9,580	133,300
1865	56,500 <sup>a</sup>	753,510 <sup>b</sup>	27,000	12,100	91,400
1865	10,500	661,000 <sup>b</sup>	71,700 <sup>b</sup>	14,100	105,100
1865	14,510 <sup>a</sup>	535,000 <sup>b</sup>	36,000	17,100	76,700
1865	14,510 <sup>a</sup>	356,500	123,000	37,700	129,400

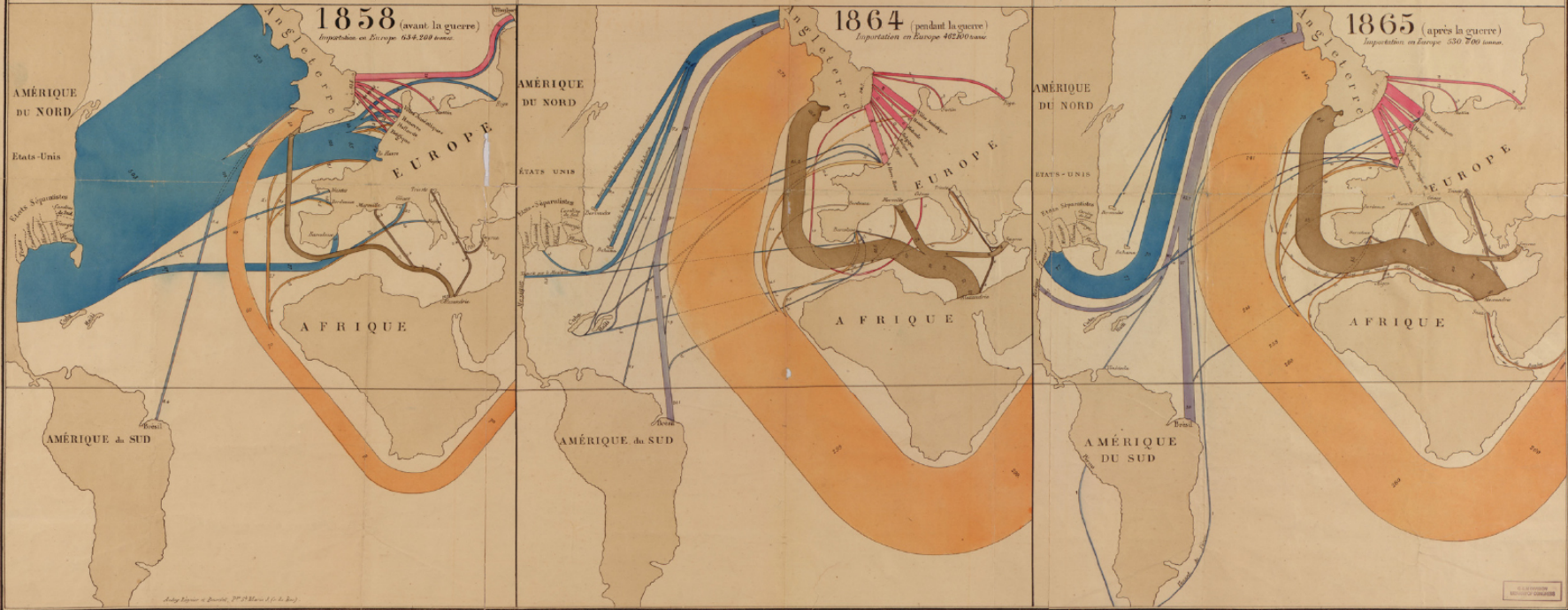
A... Importations plus fortes que celle de 1858, malgré les réformes nationales de la guerre civile, à cause de la vente de tout le Stock.  
 B... Grande diminution due à la guerre civile, et qui est ici encore plus forte si l'on considère le commerce étranger sans l'Espagne.  
 C... Approximation due à la vente subite de la partie du stock d'Amérique, lors de sa présentation par les Etats-Unis.  
 D... Approximation due au passage à la Côte d'Afrique des navires pour le premier, plus en Europe.  
 E... Approximation de la vente par le Mexique et l'Espagne, le poids relativement important plus récemment sans l'Espagne.  
 F... Approximation due à la vente subite de la partie du stock d'Amérique, lors de sa présentation par les Etats-Unis.  
 G... Approximation due à la vente subite de la partie du stock d'Amérique, lors de sa présentation par les Etats-Unis.  
 H... Approximation due à la vente subite de la partie du stock d'Amérique, lors de sa présentation par les Etats-Unis.

**CARTE** figurative et approximative des quantités de **COTON BRUT** importés en Europe  
en 1858 en 1864 et en 1865.  
Dressée par **M. MINARD**, Inspecteur Général des Ponts et Chaussées en retraite.  
Paris, le **14 Mai 1866.**

Les tonnages de coton transportés sont représentés par les largeurs des arcs colorés à raison d'un millimètre pour cinq mille tonnes, et sont de plus exprimés par les nombres écrits en toutes lettres et dans l'ordre où celle figure.  
 Les Cartes ont été dressées sur les Documents de Messieurs François, Agassiz, Bâty, Hollander, Bolander, Antershausen, Le Dictionnaire du Commerce, le Traité de Messieurs de M.J.A. Meunier, la suite de ce Traité et la publication de M. de L'Esperance, le Miroir du Commerce, le Commerce de Lorient, la Revue de Commerce de M. de L'Esperance, etc.

**Observation:** Les importations sont un peu plus fortes que celles de la Carte, parce que j'ai négligé celles d'une demi-tonne et que les Dômes étaient en bleu. Les trois parties anglaises de toute provenance, je n'ai pu les rajouter.

De l'Importation du Coton en 1865. — Les quantités comparatives du coton entré dans des ports nouveaux depuis la guerre civile des Etats-Unis d'Amérique à terre.  
 Suite des parties de Cuba qui ont été importées en Espagne en un seul voyage, et à l'époque de l'été et de la Côte, ainsi que toutes les marchandises de l'Espagne, les autres plus de coton, par exemple, et un seul voyage par des navires à Marseille et le Pérou. Et y a des navires dans un voyage et surtout par les ports de cette partie de la Côte.  
 Suite des parties de Cuba qui ont été importées en Espagne en un seul voyage, et à l'époque de l'été et de la Côte, ainsi que toutes les marchandises de l'Espagne, les autres plus de coton, par exemple, et un seul voyage par des navires à Marseille et le Pérou. Et y a des navires dans un voyage et surtout par les ports de cette partie de la Côte.  
 Suite des parties de Cuba qui ont été importées en Espagne en un seul voyage, et à l'époque de l'été et de la Côte, ainsi que toutes les marchandises de l'Espagne, les autres plus de coton, par exemple, et un seul voyage par des navires à Marseille et le Pérou. Et y a des navires dans un voyage et surtout par les ports de cette partie de la Côte.



*Europe Raw Cotton Imports in 1858, 1864 and 1865 - Charles Joseph Minard - 1866*

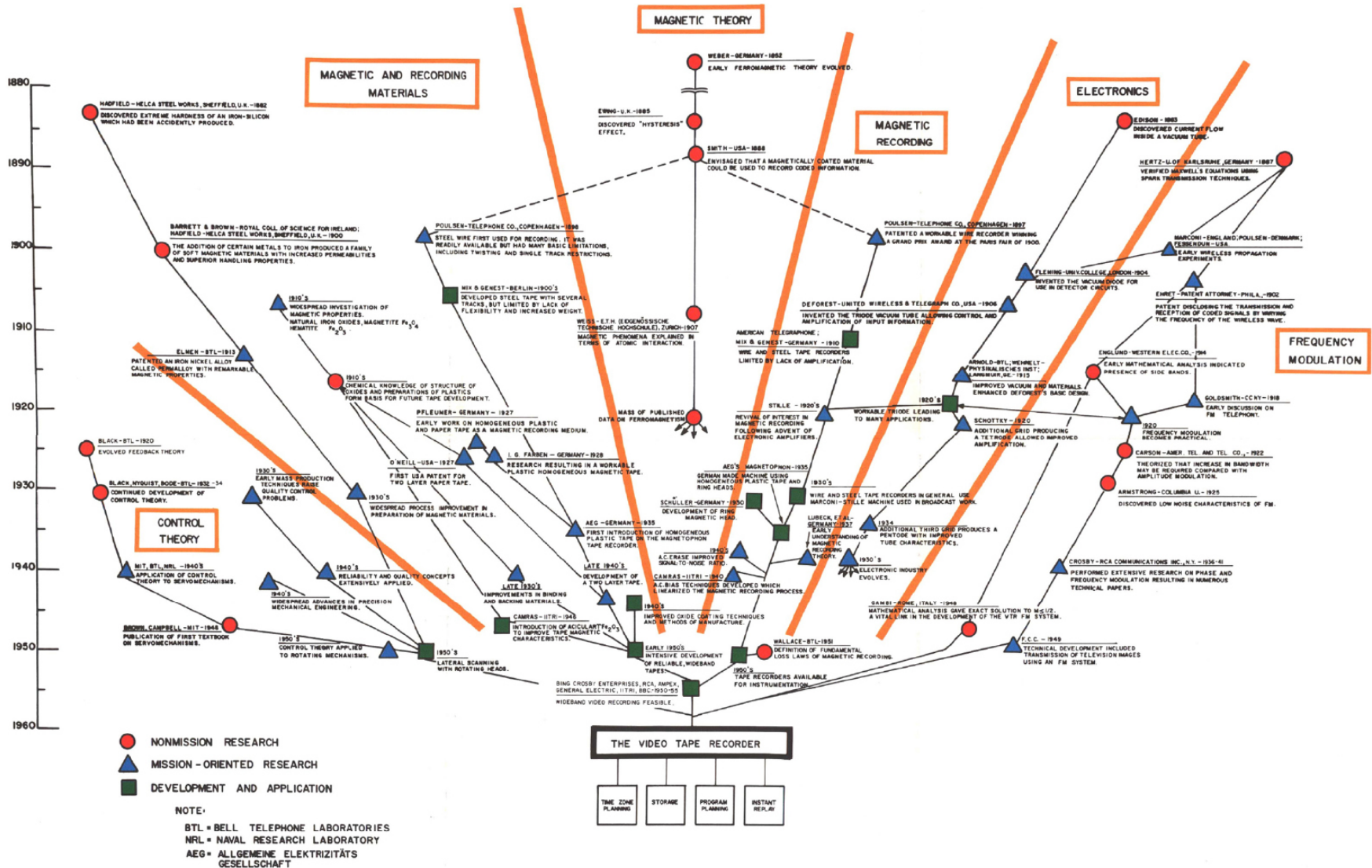
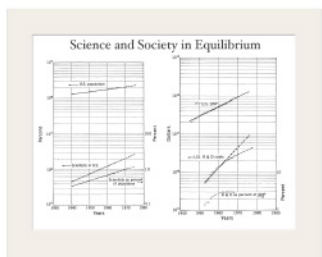


FIG. 7. THE VIDEO TAPE RECORDER

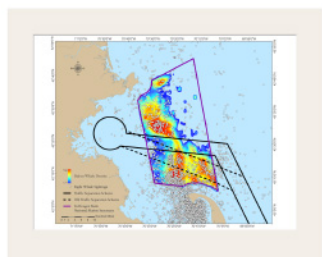
Tracing of Key Events in the Development of the Video Tape Recorder - Mr. G. Benn, Francis Narin - 1968



# Science Maps for Science Policy Makers 2009



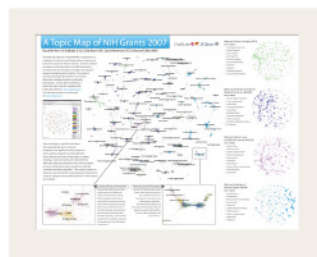
V.1



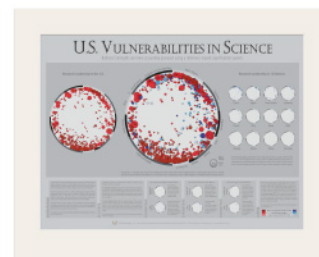
V.3



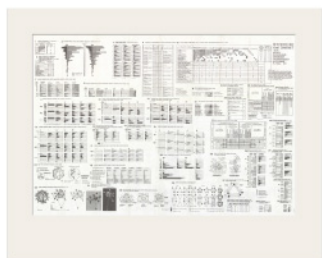
V.5



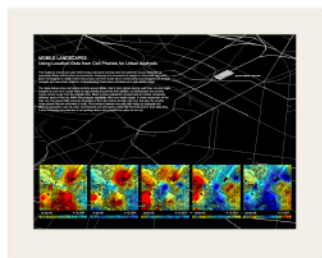
V.7



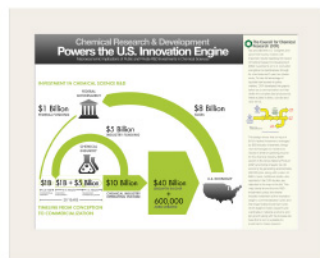
V.9



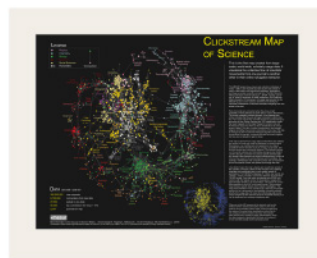
V.2



V.4



V.6



V.8



V.10

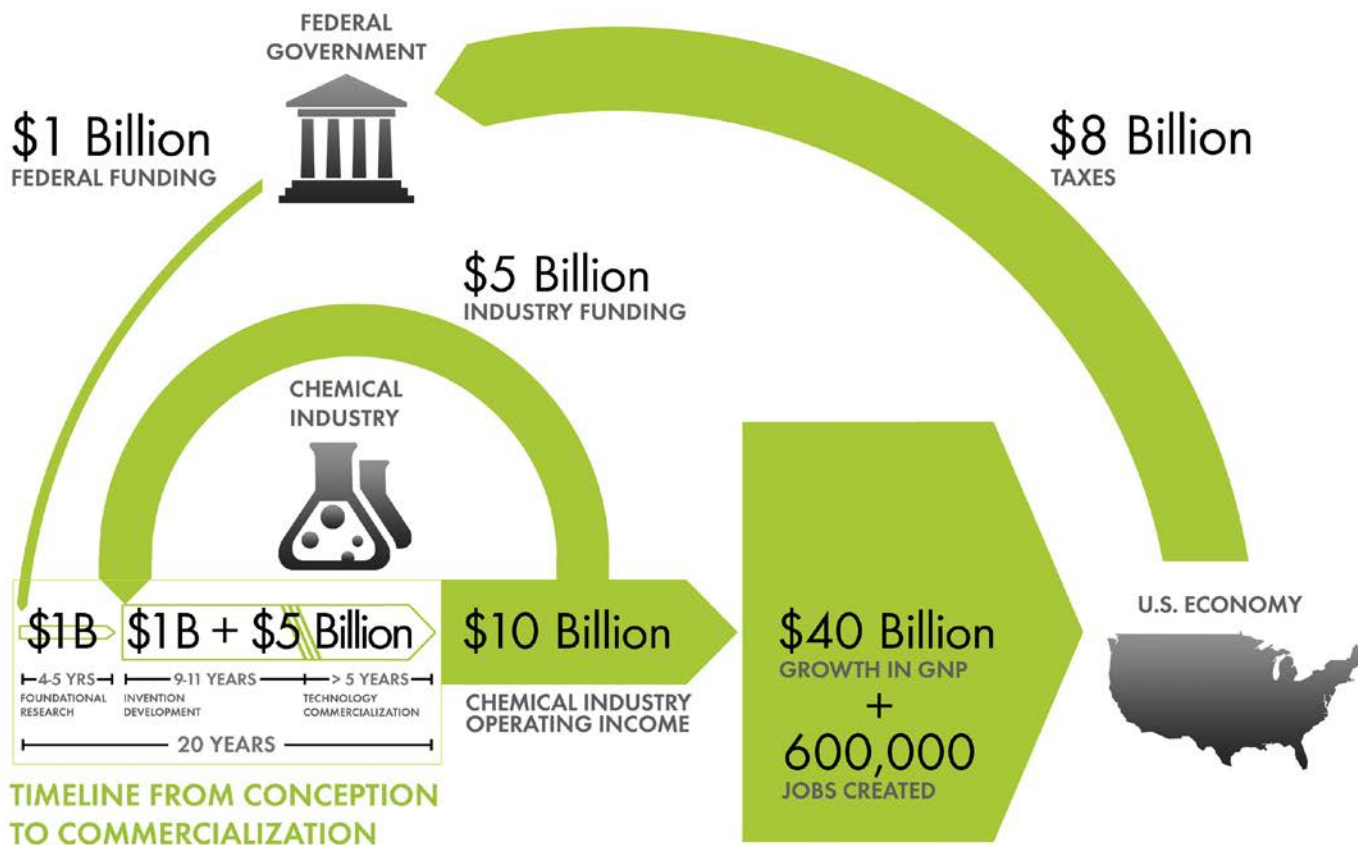
# Chemical Research & Development Powers the U.S. Innovation Engine

Macroeconomic Implications of Public and Private R&D Investments in Chemical Sciences



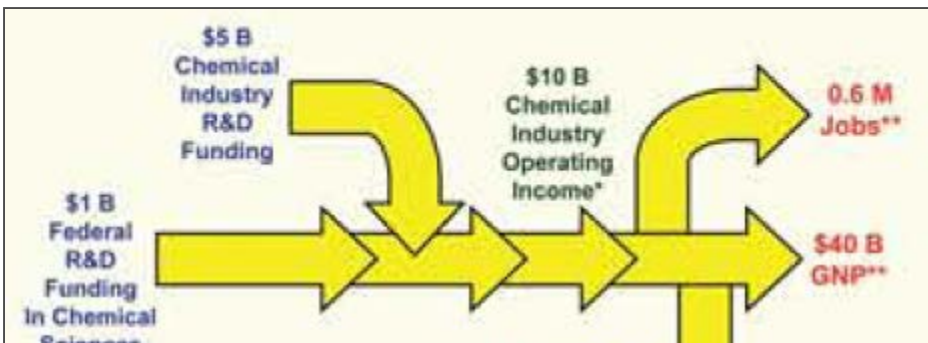
has provided the U.S. Congress and government policy makers with important results regarding the impact of Federal Research & Development (R&D) investments on U.S. innovation and global competitiveness through its commissioned 5-year two phase study. To take full advantage of typically brief access to policy makers, CCR developed the graphic below as a communication tool that distills the complex data produced by these studies in direct, concise and clear terms.

## INVESTMENT IN CHEMICAL SCIENCE R&D



The design shows that an input of \$1B in federal investment, leveraged by \$5B industry investment, brings new technologies to market and results in \$10B of operating income for the chemical industry, \$40B growth in the Gross National Product (GNP) and further impacts the US economy by generating approximately 600,000 jobs, along with a return of \$8B in taxes. Additional details, also reported in the CCR studies, are depicted in the map to the left. This map clearly shows the two R&D investment cycles; the shorter industry investment at the innovation stage to commercialization cycle; and the longer federal investment cycle which begins in basic research and culminates in national economic and job growth along with the increase tax base that in turn is available for investment in basic research.





*Notes:*  
 \*Extrapolated from CCR study  
 \*\*Extrapolated from LMSL study by Thelen, et al. April 2002 using R&M economic model.

The Council

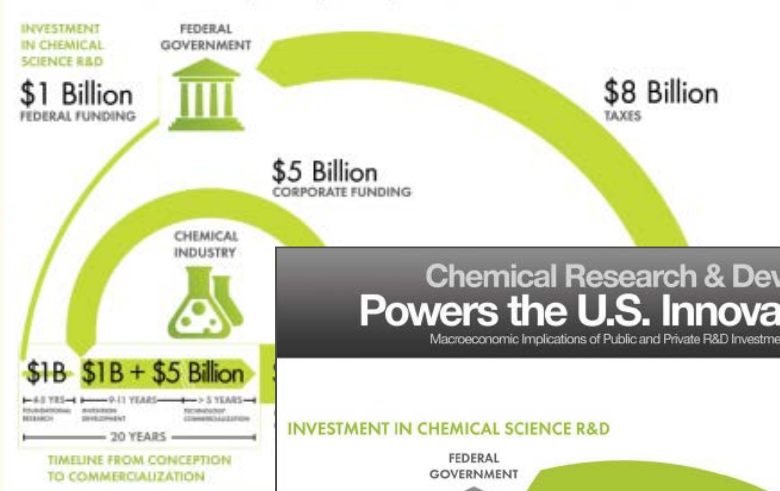
The Council for Chemical Research (CCR) has provided the US Congress and government policy makers with important results regarding the impact of Federal R&D investments on US innovation and global competitiveness through its commissioned 5-year two phase study. To take full advantage of typically brief access to policy makers, CCR developed the graphic below as a communication tool that distills the complex data produced by these studies in direct, concise and clear terms.



Simplistically, the design shows that an input of \$1B in federal investment, leveraged by \$5B industry investment, brings new technologies to market and results in \$10B of operating income for the chemical industry, \$40B growth in the GNP and further impacts the US economy by generating approximately 600,000 jobs, along with a return of \$8B in taxes. Additional details, also reported in the CCR studies, are depicted in the map to the right. This map clearly shows the two R&D investment cycles: the shorter industry investment at the innovation stage to commercialization cycle, and the longer federal investment cycle which begins in basic research and culminates in national economic and job growth along with the increase tax base that in turn is available for investment in basic research.

### Chemical R&D Powers the U.S. Innovation Engine

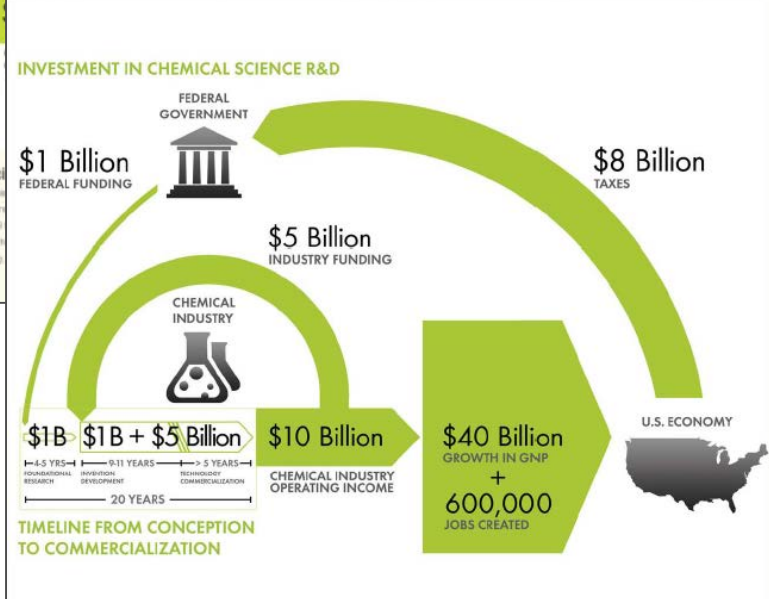
Macroeconomic Implications of public and private R&D Investments in Chemical Sciences



**About the Council**  
 CCR is an organization that membership represents in CCR was formed in 1979 research and encourage the sciences and engineering

### Chemical Research & Development Powers the U.S. Innovation Engine

Macroeconomic Implications of Public and Private R&D Investments in Chemical Sciences



#### The Council for Chemical Research (CCR)

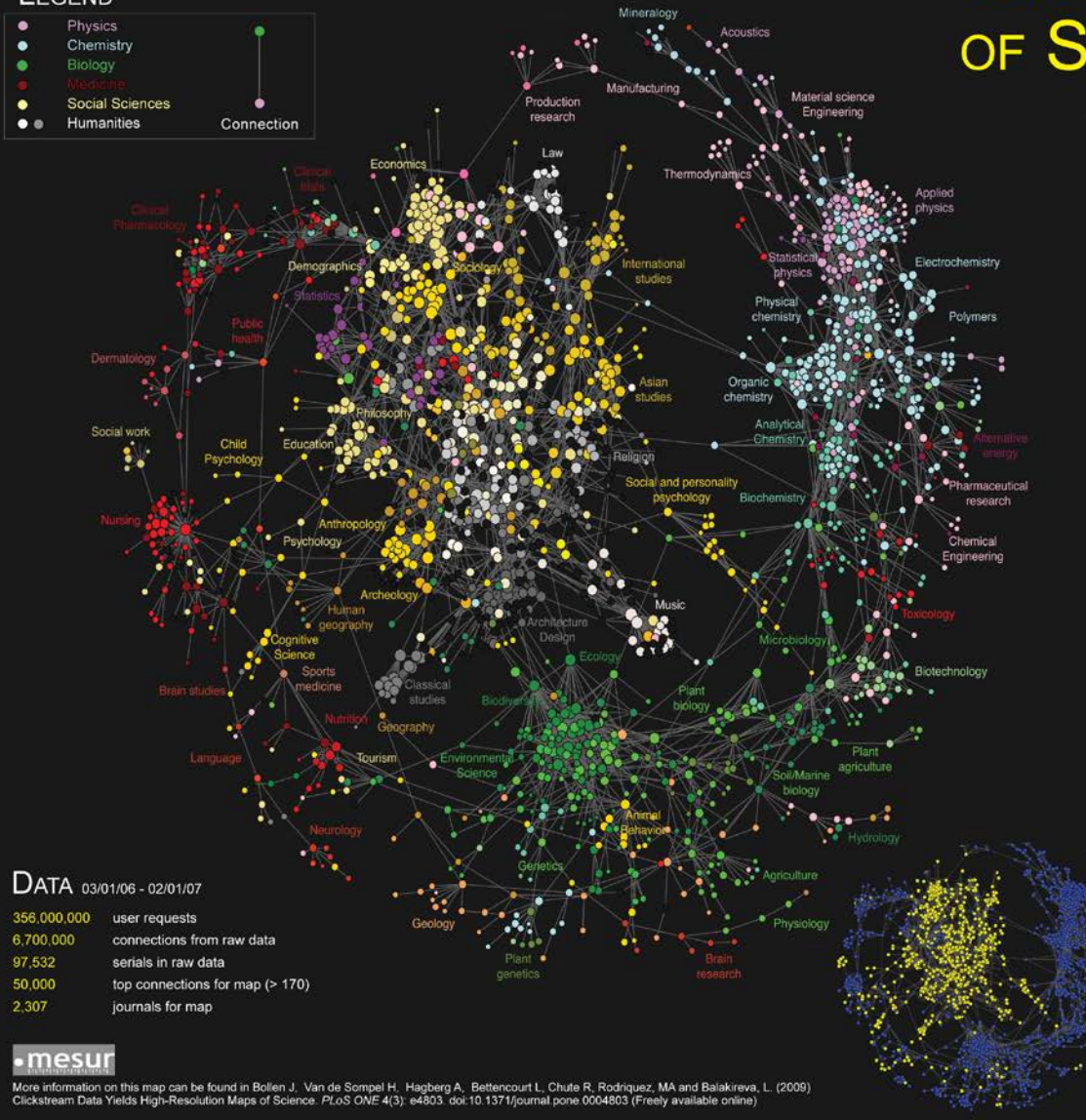
has provided the U.S. Congress and government policy makers with important results regarding the impact of Federal Research & Development (R&D) investments on U.S. innovation and global competitiveness through its commissioned 5-year two phase study. To take full advantage of typically brief access to policy makers, CCR developed the graphic below as a communication tool that distills the complex data produced by these studies in direct, concise and clear terms.



The design shows that an input of \$1B in federal investment, leveraged by \$5B industry investment, brings new technologies to market and results in \$10B of operating income for the chemical industry, \$40B growth in the Gross National Product (GNP) and further impacts the US economy by generating approximately 600,000 jobs, along with a return of \$8B in taxes. Additional details, also reported in the CCR studies, are depicted in the map to the left. This map clearly shows the two R&D investment cycles; the shorter industry investment at the innovation stage to commercialization cycle; and the longer federal investment cycle which begins in basic research and culminates in national economic and job growth along with the increase tax base that in turn is available for investment in basic research.

# CLICKSTREAM MAP OF SCIENCE

## LEGEND



This is the first map created from large-scale, world-wide, scholarly usage data. It visualizes the collective flow of scientists' movements from one journal to another other in their online navigation behavior.

The MESUR project ([www.mesur.org](http://www.mesur.org)) collected a database of nearly 1 billion user requests recorded by the web portals of some of the world's most significant publishers, aggregators and large university consortia, among them Thomson Scientific (Web of Science), Elsevier (Scopus), JSTOR, Indiana University of Texas (9 campuses, 6 health institutions), and California State University (23 campuses). All usage logs acquired by the MESUR project contain session identifiers that identify the individual clickstreams of individual scientists navigating from one article to the next.

Pairs of journals are connected when they have a high probability of being followed by each other in users' clickstreams. The circles represent individual journals. A line between two circles indicates that they are strongly connected in either direction. The colors indicate the scientific domain a journal belongs to according to their Dewey Decimal and JCR classification codes that were mapped into the Getty Research Center's Arts and Architecture Taxonomy (AAT) to allow classifications at various levels of detail. The size of circles corresponds to the strength (degree centrality) of a journal's connections in the map. The map is arranged by the Fruchterman-Reingold algorithm that treats connections like springs: connected journals are drawn together, but they are not allowed to get too close.

This map is derived from usage data and therefore also reflects the actions of those who read the literature but rarely publish themselves, e.g. practitioners and laypersons. As a result, practitioner-driven domains such as nursing, social work, and tourism studies are prominently featured. The natural sciences vs. the social sciences and humanities emerge as two distinct clusters that are connected via various specific interdisciplinary spokes. Most domains are highly interdisciplinary, but this is more so the case for the social sciences and humanities. Surprisingly, mathematics and computer science are not represented as one specific cluster, but spread-out through the map.

Like citation maps, this map is based upon a particular sample of the scientific community, albeit one that includes non-publishing scientists and practitioners and a much greater sample of publications. From MESUR's database of 1 billion user events, we created a matrix of 6 million connections between approximately 100,000 serials. From that matrix we selected only 50,000 connections with the highest number of observations, ranging from approximately 40,000 to 170 observations. This subset of connections pertained to the 2,307 most used journals. This procedure may introduce specific biases which require investigation. This map should therefore not be construed as a final map of scientific activity, but as a showcase for the feasibility of tracking scientific activity from usage data. We hope this methodology will provide unique insights into the real-time structure of scientific activity as it can be observed from scholarly clickstream data.

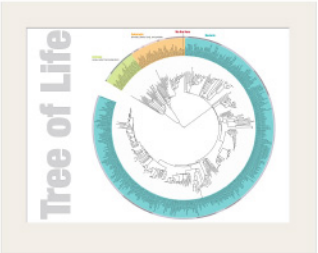
When we cut the AAT taxonomy at the top level, only two distinctions remain: natural sciences (blue nodes) vs. the social sciences and humanities (yellow nodes). Some journals along the spokes of the wheel have classifications (colors) that do not correspond to their location in the map. This indicates either that journal in question is highly interdisciplinary, and/or has been assigned a classification that does not correspond to how scientists actually use the particular journal.

Design layout by: Jeremy D. Chacon

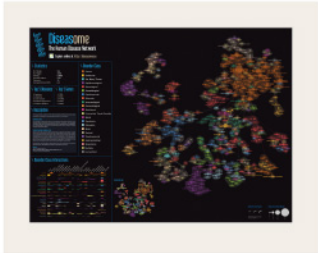
*A Clickstream Map of Science.* Johan Bollen, Herbert Van de Sompel, Aric Hagberg, Luís M. A. Bettencourt, Ryan Chute, Marko A. Rodriguez, and Lyudmila Balakireva - 2008



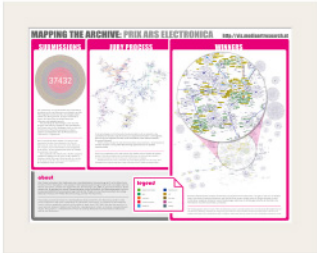
# Science Maps for Scholars 2010



VI.1



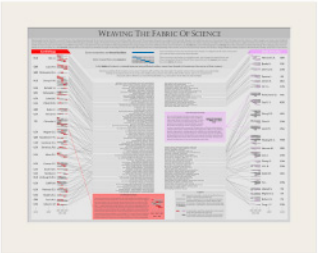
VI.3



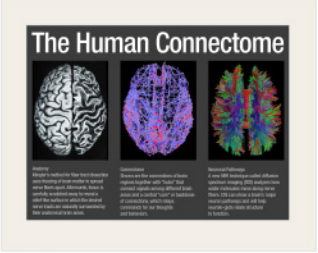
VI.5



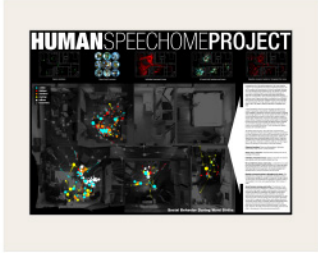
VI.7



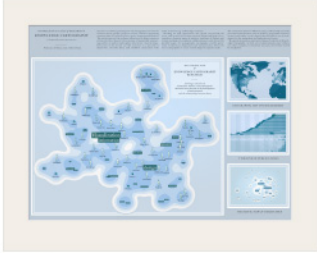
VI.9



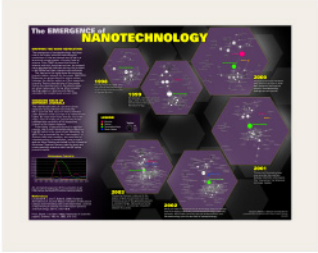
VI.2



VI.4



VI.6



VI.8



VI.10



# Diseasome

## The Human Disease Network

Explore online at <http://diseasome.eu>

### Statistics

# of Nodes: 516  
 # of Edges: 1188  
 Density: 0,0089  
 Average Degree: 9,20  
 Diameter: 15  
 Average Shortest Path: 6,5

### Top 5 Diseases

1. Deafness
2. Leukemia
3. Colon Cancer
4. Retinitis Pigmentosa
5. Diabetes Mellitus

### Top 5 Genes

1. TP53
2. PAX5
3. FGFR2
4. RTN1
5. MSH2

### Description

The map presents a network of 516 diseases linked by 1188 known disorder-gene associations, indicating the common genetic origin of many diseases.

#### MAIN RESEARCH PAPERS

The map offers a novel visual inference of the genetic links between disorders and a valuable global perspective for physicians, geneticists, researchers, and biomedical researchers alike. This new approach may lead to previously unknown regarding to these associated genes, improve the understanding of the causes of disease, and the functions of particular genes.

#### NETWORK REDUCTION TECHNIQUES APPLIED

The map was done using the force-directed layout algorithm ForceAtlas in Gephi. Nodes color corresponds to the disorder class to which the disease belongs, and the size is proportional to its node degree, that overall number of links. Gene's width is proportional to the number of genes linked and proportional to both diseases and affected with the average color between genes and target nodes. Isolated genes are not shown and only the gene component has been kept. The Clusters Menu may locate most remarkable disorder clusters and shows largest sized clusters.

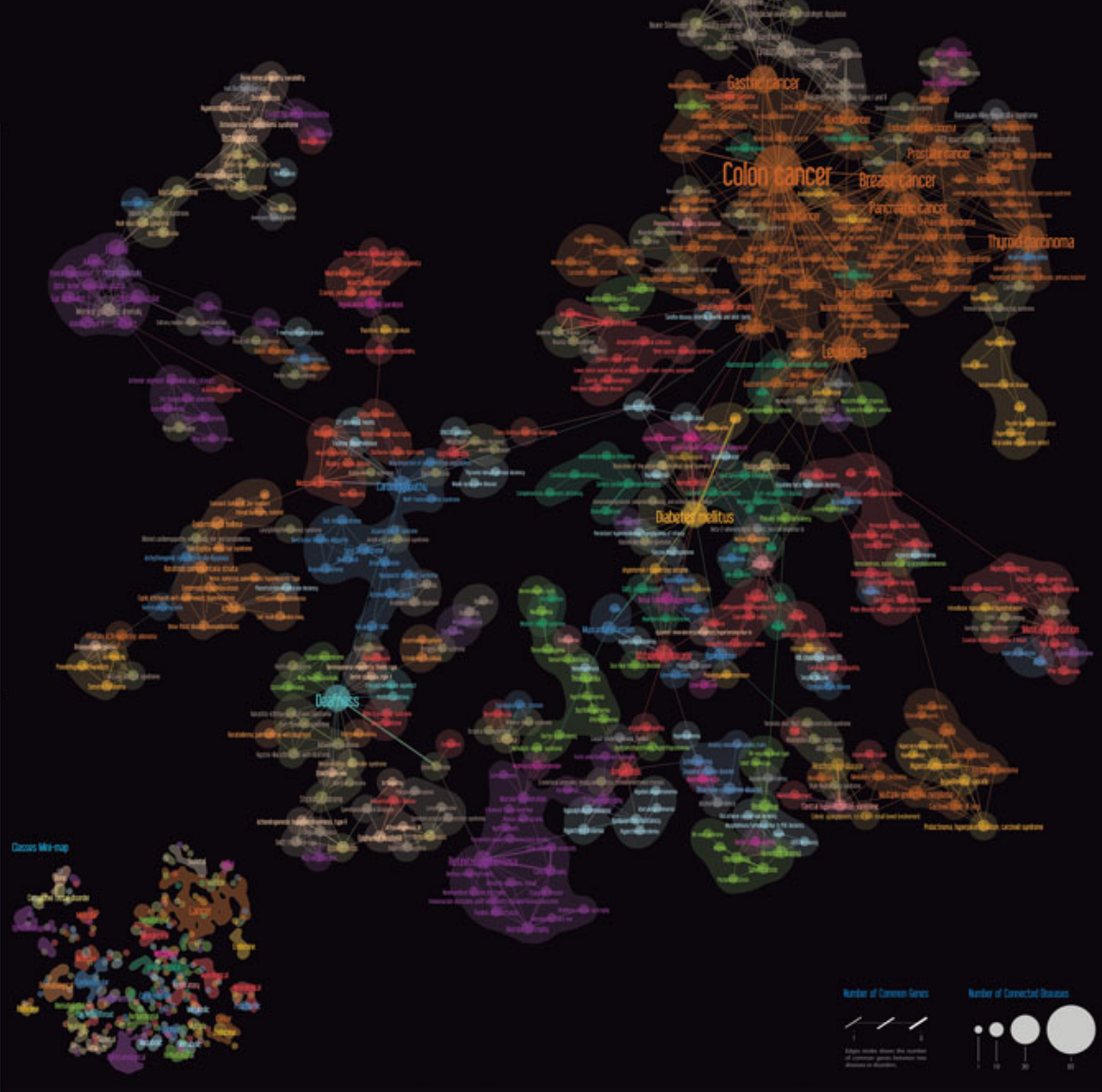
The Disorder Class Interactions graph below shows the interaction level between disorder classes, representing the number of shared genes, up to 85.

**REFERENCES**  
 The Human Disease Network  
 Bastian H, Heymann S, Jacomy S, Chakraborty S, Malmgren M, Bastian H, et al. (2017)  
 Proc Natl Acad Sci U S A 114: 10316-10321

### Disorder Class

- Cancer
- Endocrine
- Ear, Nose, Throat
- Ophthalmological
- Neurological
- Hematological
- Cardiovascular
- Muscular
- Immunological
- Dermatological
- Nutritional
- Connective Tissue Disorder
- Renal
- Psychiatric
- Metabolic
- Bone
- Skeletal
- Developmental
- Gastrointestinal
- Respiratory
- Multiple
- Unclassified

### Disorder Class Interactions





# The EMERGENCE of NANOTECHNOLOGY

## MAPPING THE NANO REVOLUTION

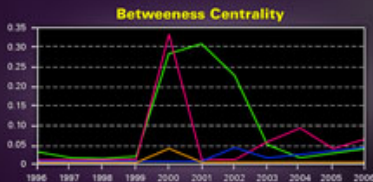
The emergence of nanotechnology has been one of the major scientific-technological revolutions in the last decade and it led to a structural reorganization of major fields of science. Price (1965) showed that fields of science and their development can be mapped using aggregated citations among the journals in the fields and their relevant environments.

The frames to the right show the evolving journal citation network for the years 1998-2003. Distances are proportional to cosine values between the citation patterns of the respective journals. Textual descriptions of key events during the development of *Nanotechnology* are given below each frame. Most notably, leading papers in *Science* and *Nature* catalyzed the breakthrough around 2000.

## CHANGING ROLES OF DIFFERENT JOURNALS

The interdisciplinarity of a journal can be measured using betweenness centrality (BC)—journals that occur on many shortest paths between other journals in a network have higher BC value than those that do not. In the maps, sizes of nodes are proportional to the betweenness centrality of the respective journal in the citation network.

From being a specialist journal in applied physics, the journal *Nanotechnology* obtains a high BC value in the years of the transition, ca. 2001. This is preceded by the "intervention" of *Science*. After the transition, the new field of nanotechnology is established, new journals such as *Nano Letters* published by the influential American Chemical Society take the lead, and a new specialty structure with low BC value journals results.



An animated sequence of this evolution is at: <http://www.leydesdorff.net/journals/nanotech>.

## References

Leydesdorff, L. and T. Schank, 2008, Dynamic Animations of Journal Maps: Indicators of Structural Change and Interdisciplinary Developments. *Journal of the American Society for Information Science and Technology*, 59(11), 1810-1818.

Price, Derek J. de Solla (1965). Networks of scientific papers. *Science*, 149, no. 3683, 510- 515.

**1998**

During the period 1996-2000, the journal *Nanotechnology* is part of a group of journals in applied physics.

**1999**

Increasingly, chemistry journals play a role in the citation impact environment of the journal *Nanotechnology*.

## LEGEND

- Science
- Nature
- Nanotechnology
- Nano Letters

## Values



**2003**

The journal *Science* is relevant in the citation impact environment, but now functions as one of the specialist journals in nanotechnology. *Nanoscience* further develops as an increasingly integrated network of journals.

**2002**

Other journals in nanoscience and technology begin to emerge, and the bridging role of the journal *Nanotechnology* gradually subsides. *Nano Letters* and the *Journal of Nanoscience and Nanotechnology* join the new field of nanotechnology.

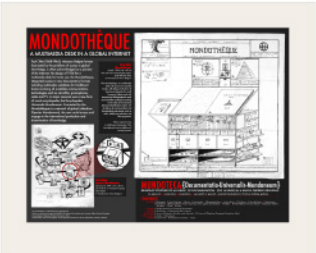
**2000**

The journal *Science* interfaces with relevant journals in both sets: chemistry and applied physics. *Nanotechnology* emerges as core journal.

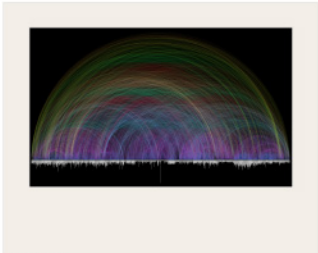
**2001**

The journal *Nanotechnology* now provides the interface between chemistry and physics. The "intervention" by *Science* is no longer needed.

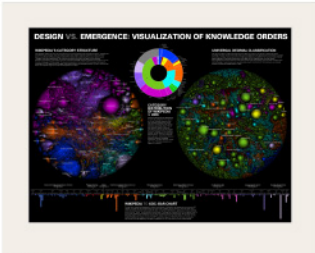
# Science Maps as Visual Interfaces to Digital Libraries 2011



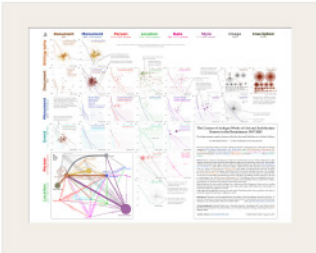
VII.1



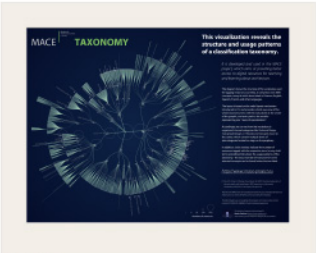
VII.3



VII.5



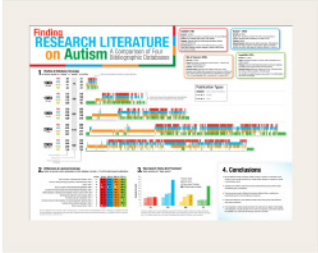
VII.7



VII.9



VII.2



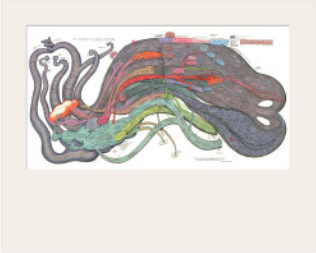
VII.4



VII.6



VII.8



VII.10

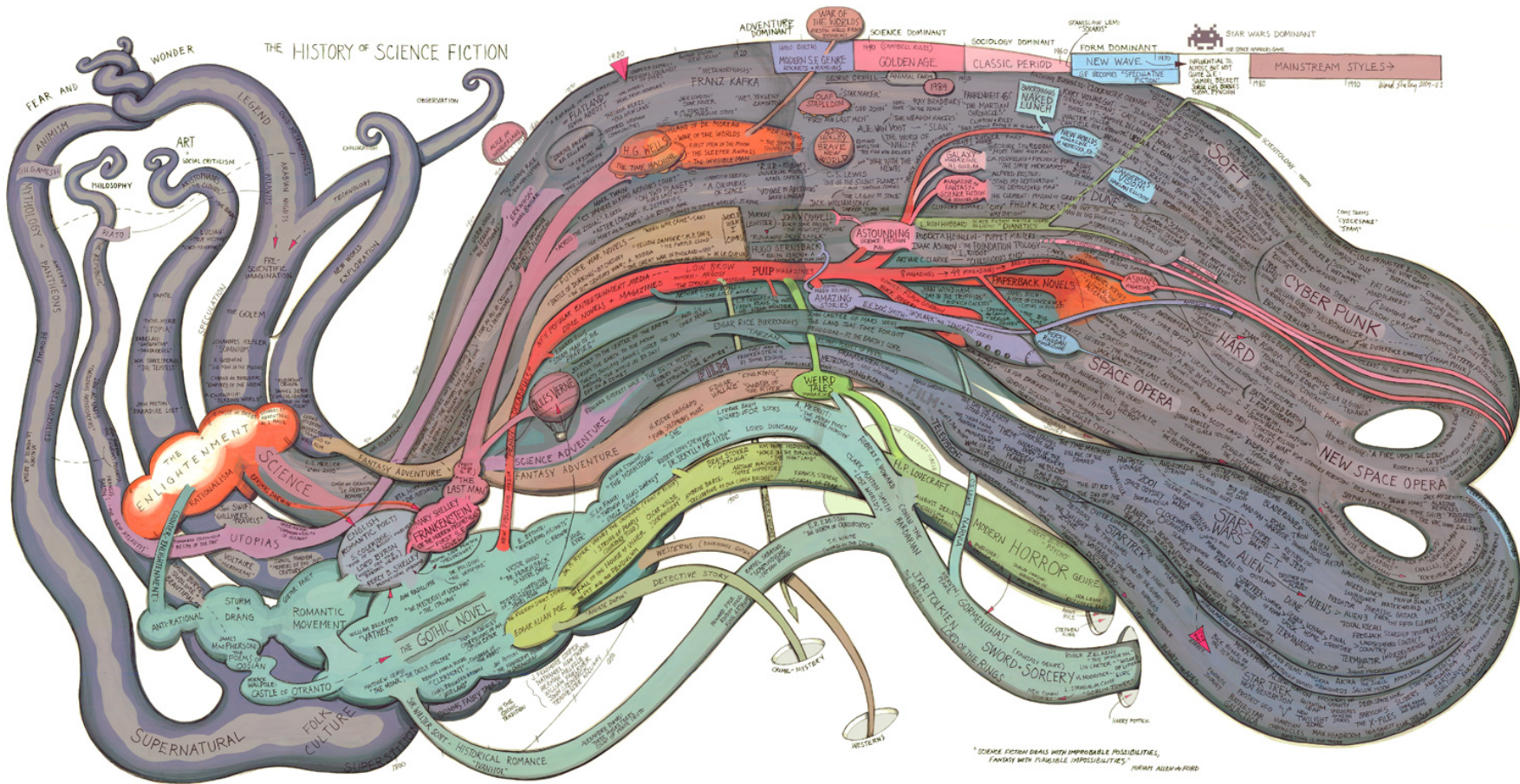


# Map of Scientific Collaborations from 2005-2009



Computed Using Data from Elsevier's Scopus

*Stream of Scientific Collaborations Between World Cities* - Olivier H. Beauchesne - 2012



*History of Science Fiction - Ward Shelley - 2011*



# Check out our **Zoom Maps** online!

**VII.10**  
History of Science Fiction, by Ward Shelley

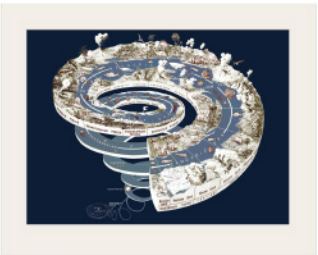
BROOKLYN, NY, 2011  
Courtesy of Ward Shelley Studio

Ward Shelley is an artist identified with the Williamsburg scene in Brooklyn, New York. In this map, he organizes the history of the science fiction literary genre from its nascent beginnings in the 18th century to the present day. The map plots the science fiction literary genre from its nascent beginnings in the 18th century to the present day. The map plots the science fiction literary genre from its nascent beginnings in the 18th century to the present day. The map plots the science fiction literary genre from its nascent beginnings in the 18th century to the present day.

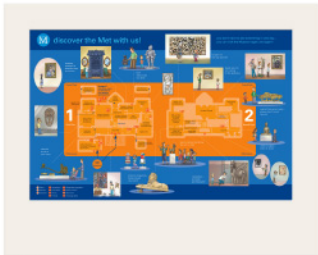
**PLACES & SPACES**  
MAPPING ONLINE

Visit [scimaps.org](http://scimaps.org) and check out all our maps in stunning detail!

# Science Maps for Kids 2012



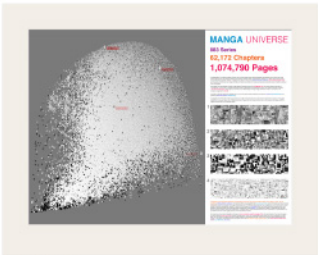
VIII.1



VIII.3



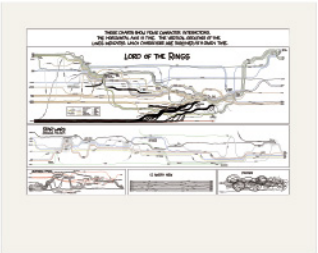
VIII.5



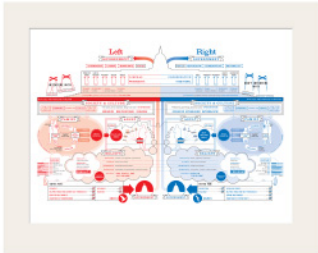
VIII.7



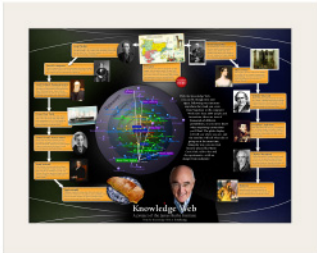
VIII.9



VIII.2



VIII.4



VIII.6



VIII.8



VIII.10



# MANGA UNIVERSE

883 Series

62,172 Chapters

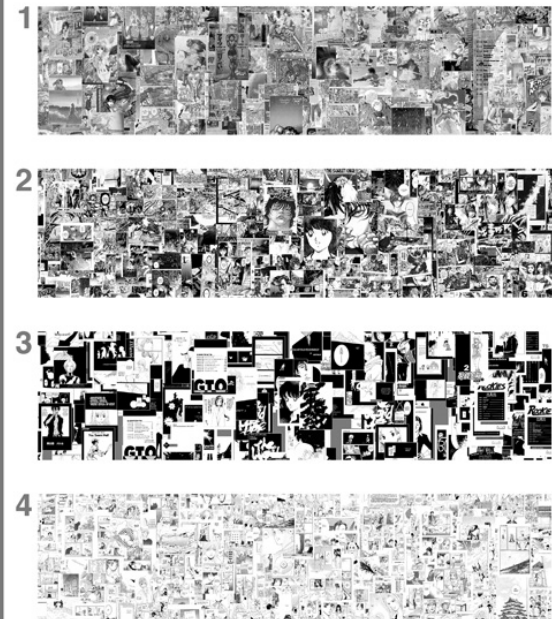
1,074,790 Pages

The digitization of cultural artifacts and the rise of social media create unprecedented opportunities for the study of visual culture. But how can we explore patterns and relations between sets of photographs, designs, or videos which may number in hundreds of thousands, millions, or billions? In 2007, we set up the [Software Studies Initiative](http://www.softwarerestudies.com) (www.softwarerestudies.com) at University of California, San Diego (UCSD) and California Institute for Telecommunication and Information (Calit2) to address these challenges.

In fall 2008, we downloaded all pages of 883 different manga series from [DreadManga.com](http://DreadManga.com), the most popular web site for "scalations," which refer to manga publications that are digitized and translated by fans. The resulting data set contains **1,074,790 manga pages**. Each page is in the form of a JPEG image; average image resolution is 850 x 1150 pixels. The complete image set is 100 GB.

The map on the left shows the complete set of over one million pages organized according to **contrast (horizontal axis)** and **amount of detail and texture (vertical axis)**.

The pages in the lower left of the map consist of a small number of flat areas, with minimum detail and no texture. The pages situated in the top part have lots of detail and texture. Pages with the lowest contrast are on the extreme left; pages with the highest contrast are on the extreme right.



In between the four graphical extremes corresponding to the left, right, top, and bottom edges of the pages "cloud" we see **practically infinite graphic variations**. The density of this map suggests that the **concept of style** as it is normally used may become problematic when we consider very large cultural data sets. The concept assumes that we can partition a set of works into a small number of discrete categories. However, if we find a very large set of **variations** with very small differences between them, any attempt to divide this space into discrete stylistic categories will be **arbitrary**. It is important to keep in mind that this map only shows graphic variations along two dimensions—mapping other visual characteristics such as composition or representation of characters and their faces might split the cloud into distinct clusters.

Our map also shows which graphical choices are **more commonly used by manga artists** (the central part of the cloud of pages) and which appear **much more rarely** (bottom and left parts). If you are a beginning manga artist and want to establish a unique style, you may want to position yourself in either bottom or left parts of the map, which so far have not been explored by other artists. To see other visualizations and read papers about the **one million manga pages project**, visit [www.softwarerestudies.com](http://www.softwarerestudies.com).  
Credits: Lev Manovich, Jay Chow.



# KHAN

## ACADEMY

The Khan Academy is an organization with the goal of changing education for the better by providing a free world-class education to anyone anywhere. It doesn't matter if you are a student, teacher, home-schooler, principal, adult returning to the classroom after 20 years, or a friendly alien just trying to get a leg up in earthly biology. The Khan Academy's materials and resources are available to you completely free of charge.

### KHAN ACADEMY LIBRARY OVERVIEW

**3,101** LECTURES  
**445** HOURS OF VIDEO  
**170** MILLION VIEWS

#### VIDEOS DISTRIBUTION



#### ABOUT THE VISUALIZATION

The diagram shows the complete library of over 3,000 videos published by Khan Academy and their organization in topics, subtopics, and playlists.



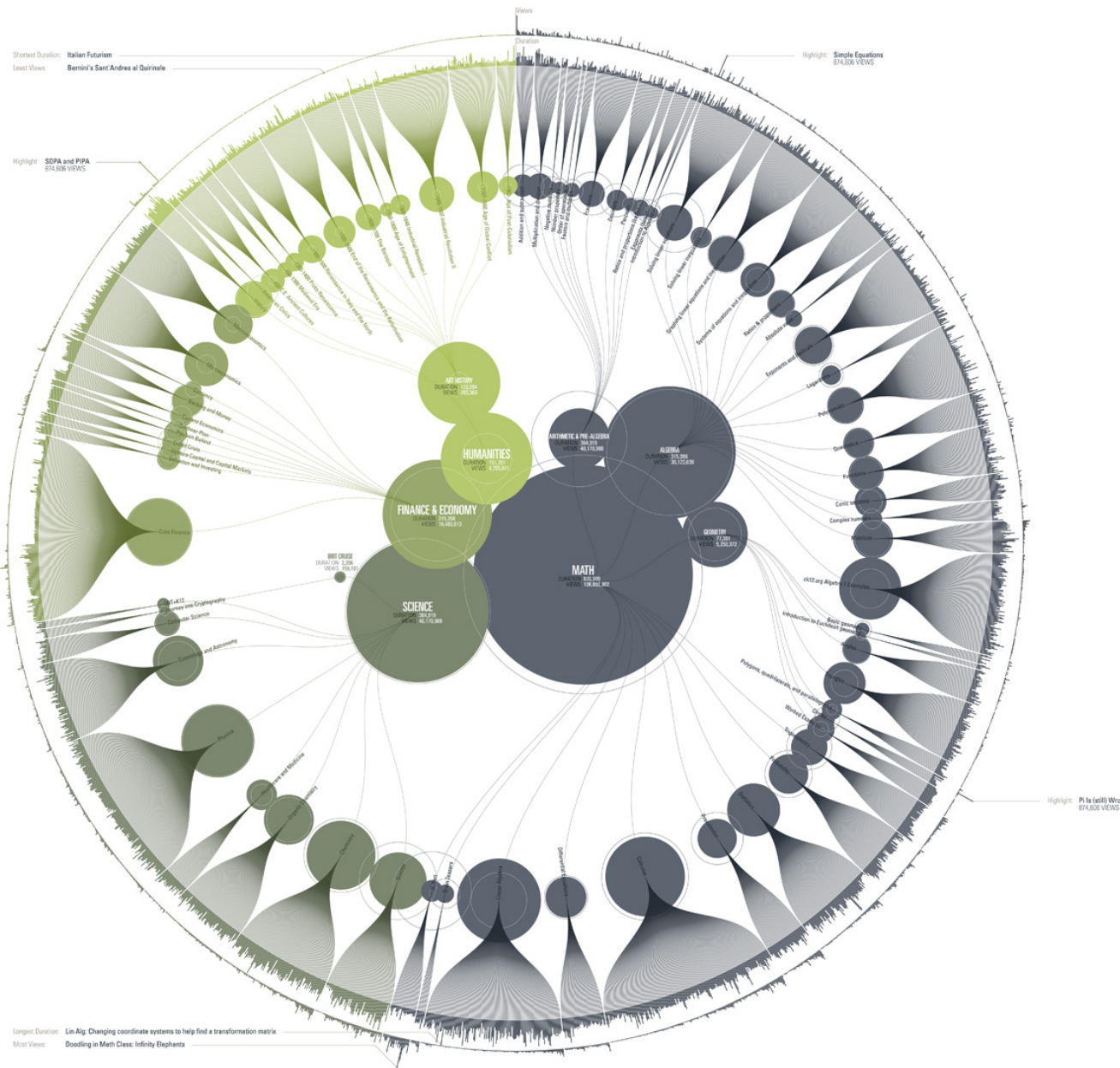
#### ABOUT THE AUTHOR

This visualization was designed and developed by Benjamin Wiederkehr with the support of Jérôme Cukier.

#### ABOUT THE DATA

The data that drives this visualization was collected using the official API provided by Khan Academy on May 13<sup>th</sup> 2012.

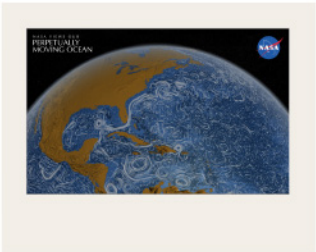
<http://interactiverthings.com> <https://github.com/khan>



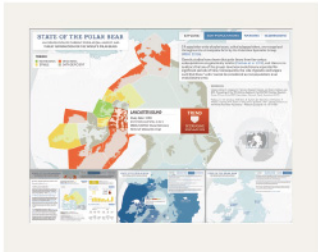
*Khan Academy Library Overview* - Benjamin Wiederkehr and Jérôme Cukier - 2012



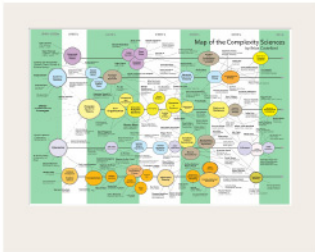
# Science Maps Showing Trends and Dynamics 2013



IX.1



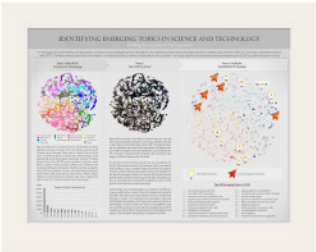
IX.3



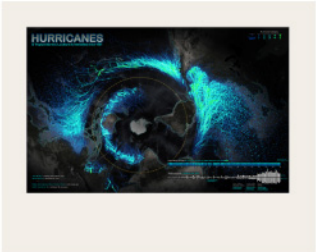
IX.5



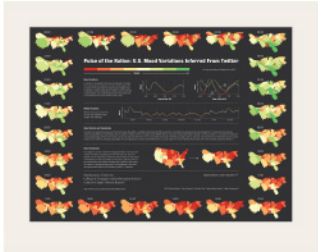
IX.7



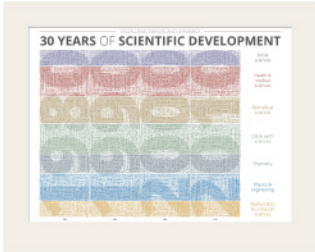
IX.9



IX.2



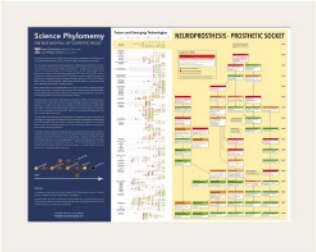
IX.4



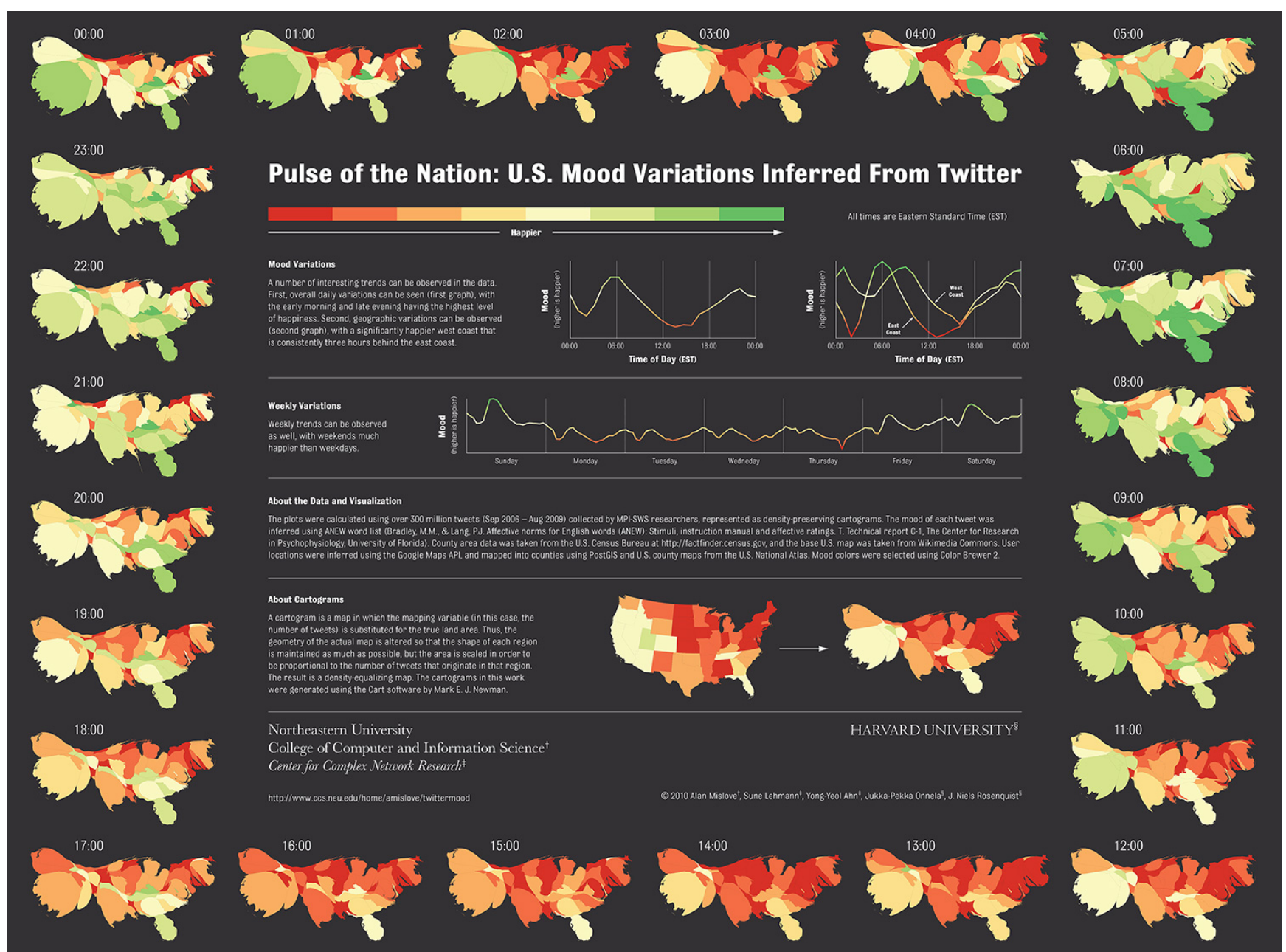
IX.6



IX.8



IX.10



*Pulse of the Nation* - Alan Mislove, Sune Lehmann, Yong-Yeol Ahn, Jukka-Pekka Onnela, and James Niels Rosenquist - 2010



# Who Really Matters in the World

## LEADERSHIP NETWORKS IN DIFFERENT-LANGUAGE WIKIPEDIAS



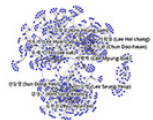
**CHINESE 2011**  
Threshold of 30



**FRENCH 2011**  
Threshold of 250



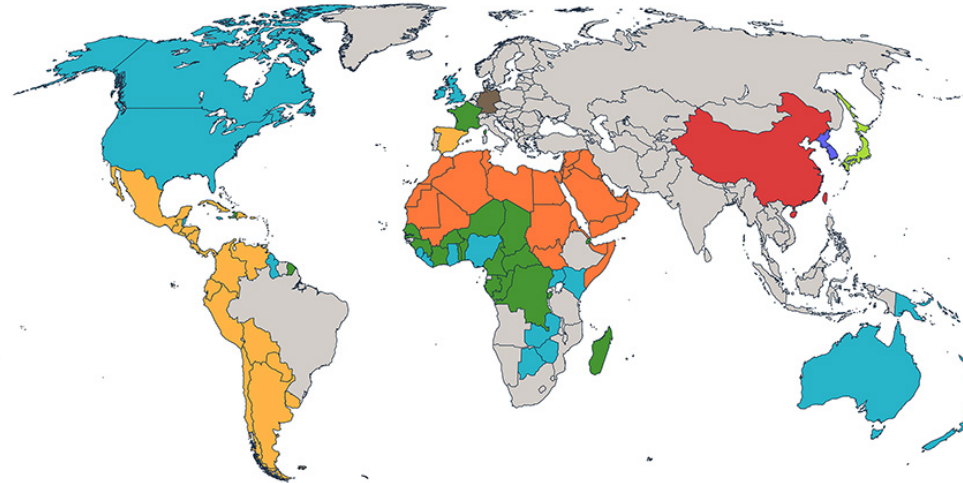
**ARABIC 2011**  
Threshold of 10



**KOREAN 2011**  
Threshold of 10



**ENGLISH 2003**  
Threshold of 10

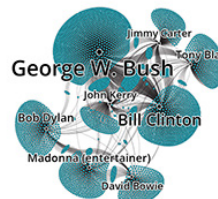


Shown are the networks of living people and their friendship, business, and animosity links retrieved from eight different-language Wikipedias. Network nodes, geospatial regions in which the languages are spoken, and the tabular listing of the number of living people in 2011 are color-coded. The networks show living people interconnection for eight different languages. Because the size of the complete networks was too large, different thresholds were applied (see numbers on map). Native language names and English translations are listed for key people nodes. Different networks have rather different global and local structures revealing the (dis)connectedness of politicians, musicians, athletes, and others. The lower five figures showcase the evolution of the English network between 2003-2011. For example, the U.S. President Barack Obama becomes dominant when he is elected in 2009 and shows a major increase in importance in 2011, providing a near real-time window into current history and culture through the lens of Wikipedians.

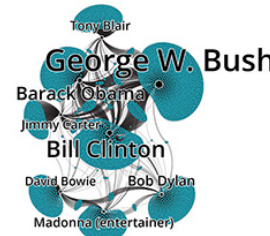
Largest node: **3240 links** | Median node: **1553 links** | Smallest node: **11 links**



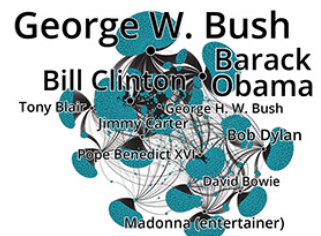
**ENGLISH 2005**  
Threshold of 30



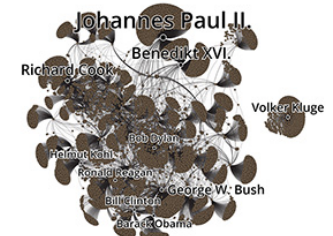
**ENGLISH 2007**  
Threshold of 300



**ENGLISH 2009**  
Threshold of 500



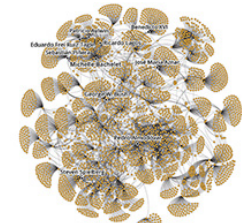
**ENGLISH 2011**  
Threshold of 500



**GERMAN 2011**  
Threshold of 150



**JAPANESE 2011**  
Threshold of 150



**SPANISH 2011**  
Threshold of 50

Color	Language, Year	# of Living People	# of Articles	Ratio
Blue	English, 2003	3,409	109,000	3.13%
Light Blue	English, 2005	38,996	464,000	8.40%
Light Blue	English, 2007	193,058	1,600,000	12.07%
Light Blue	English, 2009	348,552	2,700,000	12.91%
Light Blue	English, 2011	467,340	3,500,000	13.35%
Brown	German, 2011	194,043	1,200,000	16.2%
Green	French, 2011	126,053	1,100,000	11.5%
Yellow-Green	Japanese, 2011	102,082	742,000	13.8%
Orange	Spanish, 2011	41,827	728,000	5.7%
Red	Chinese, 2011	23,963	339,000	7.1%
Purple	Korean, 2011	5,379	158,000	3.4%
Orange	Arabic, 2011	15,921	171,744	9.27%

# Visit us on Facebook!

The screenshot shows a web browser window displaying the Facebook page for "Places & Spaces: Mapping Science". The browser's address bar shows the URL <https://www.facebook.com/mappingscience>. The page header includes the Facebook logo, the page name "Places & Spaces: Mapping Science", and navigation links for Home, Samuel, and a settings gear. Below the header, a status bar indicates the user is logged in as "Places & Spaces: Mapping Science" and provides a link to "Change to Samuel Mills".

The main content area features a large promotional image with the text "The 9th Iteration is Coming Soon!". Below this, a smaller image shows the "PLACES & SPACES & MAPPING SCIENCE" logo. To the right of the logo, a detailed science map is displayed, showing a globe with glowing blue and green lines representing data points. Below the map, a caption reads: "The 9th iteration is devoted to science maps that show general trends and patterns in science and technology (S&T) and predict future developments of S&T. Micro to macro studies using quantitative and/or qualitative data were welcome, and mixed methods approaches were encouraged. Shown here: detail of John Nelson's *Hurricanes & Tropical Storms: Locations & Intensities since 1851*."

Below the main image, the page name "Places & Spaces: Mapping Science" is displayed, along with "508 likes · 7 talking about this". There are buttons for "Update Page Info", "Liked", and a settings gear. Below this, a navigation bar includes "Organization", "About", "Photos", "Likes", "Map", and "Events". The "Organization" section includes the text: "Welcome to the official Places & Spaces: Mapping Science Facebook page!". The "Likes" section shows a thumbs-up icon and the number "508". The "Map" section shows a location pin icon and the text "loomington". The "Events" section shows a small image of a globe and the text "Atlas of Science: Unraveling What We Know".

On the right side of the page, there is a "Promote Page" button and a "Recent" section with a list of years: 2013, 2012, 2011, and "Founded".

Become a fan and see many great photos of the exhibit—  
plus find out when it's coming to a venue near you!

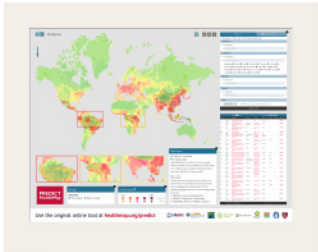
[facebook.com/mappingscience](https://facebook.com/mappingscience)



# The Future of Science Mapping 2014



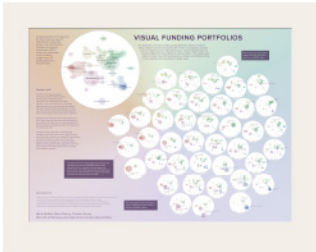
X.1



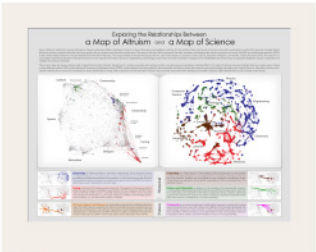
X.3



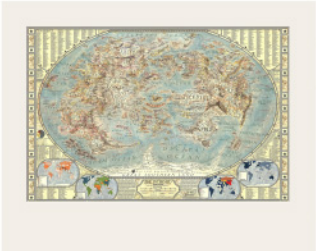
X.5



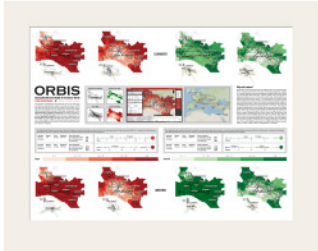
X.7



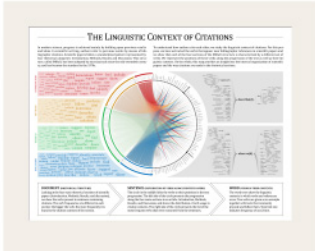
X.9



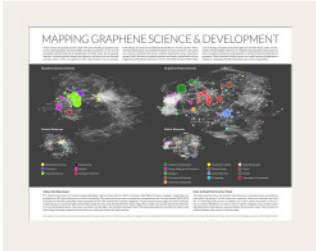
X.2



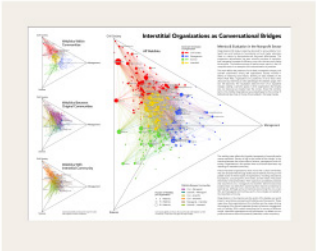
X.4



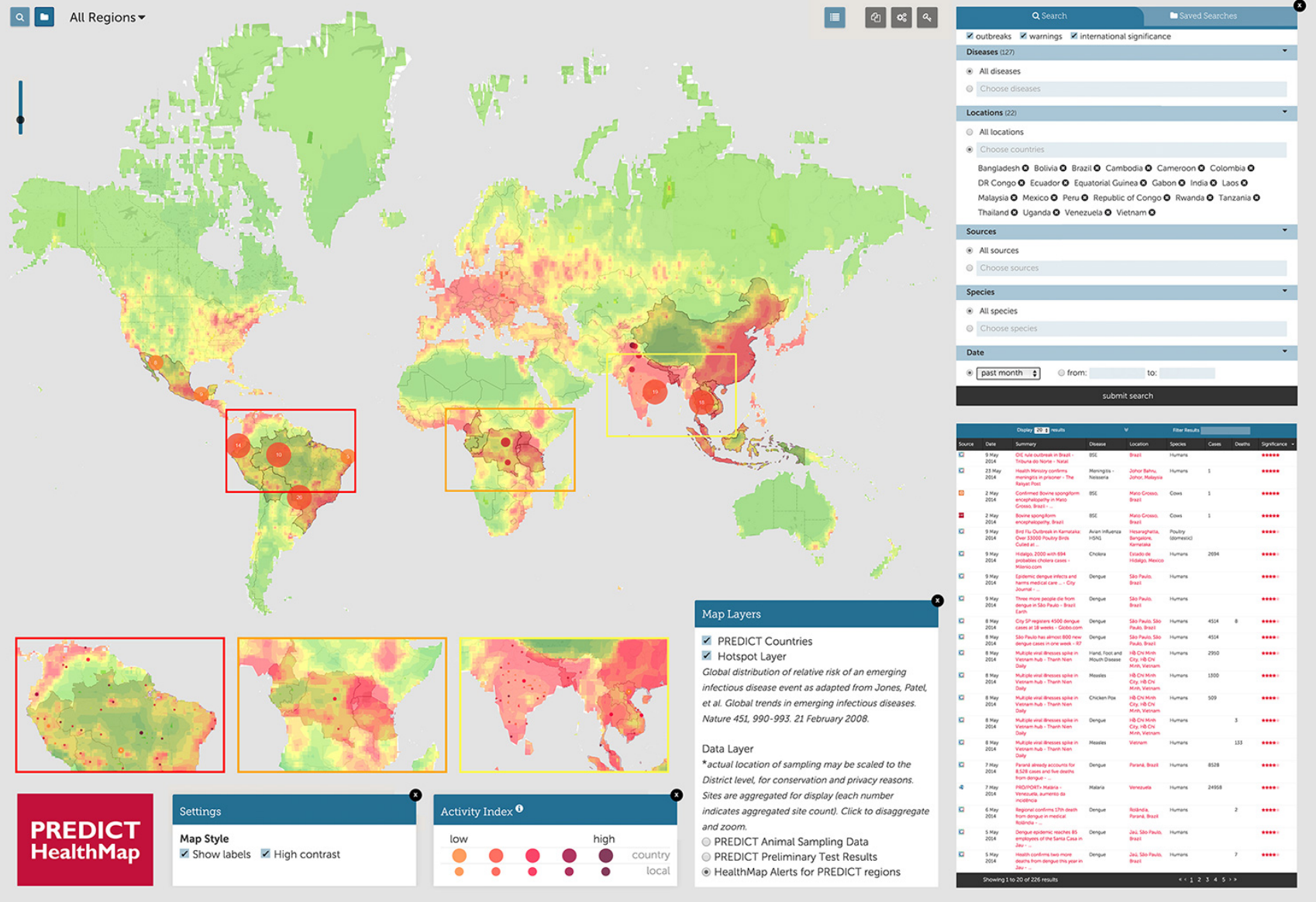
X.6



X.8



X.10



Use the original online tool at [healthmap.org/predict](http://healthmap.org/predict)



*PREDICT: HealthMap* - John Brownstein, Damien Joly, William Karesh, Peter Daszak, Nathan Wolfe, Tracey Goldstein, Susan Aman, Clark Freifeld, Sumiko Mekaru, Tammie O'Rourke, Stephen Morse, Christine Kreuder Johnson, Jonna Mazet, and the PREDICT Consortium - 2014





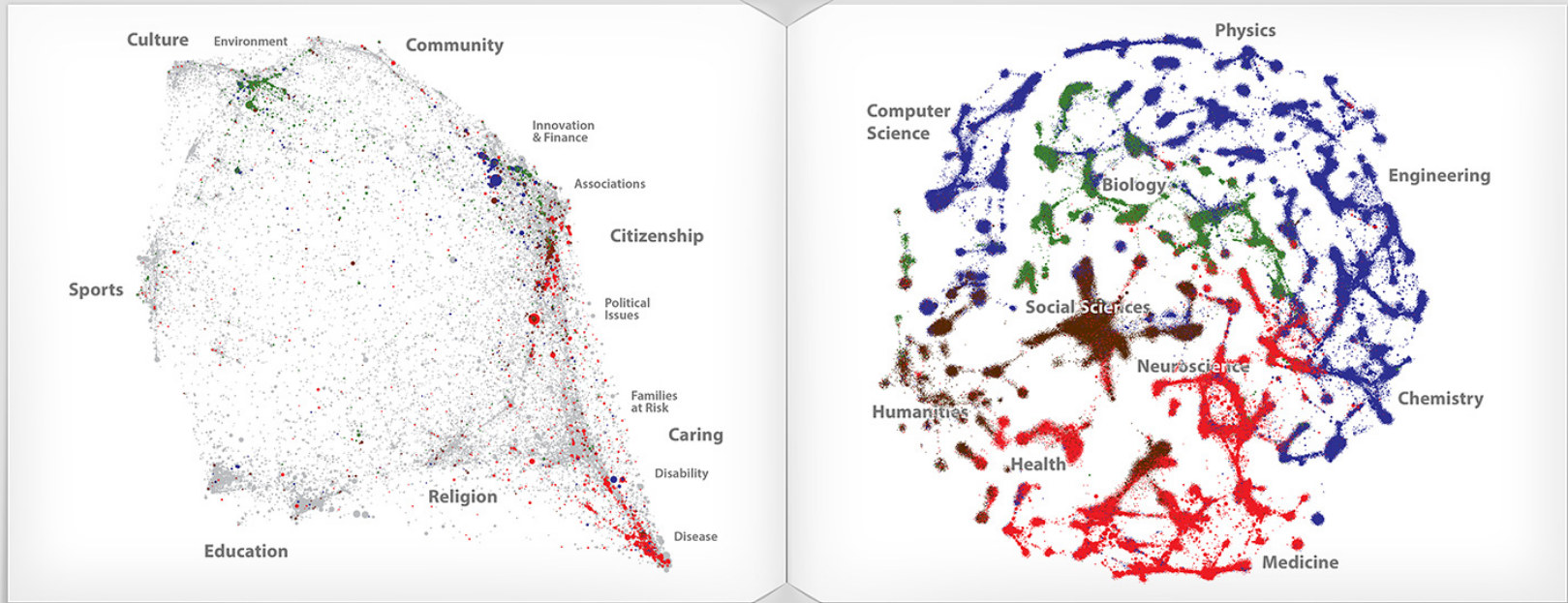
Map of the Internet - Martin Vargic - 2014



# Exploring the Relationships Between a Map of Altruism and a Map of Science

How is altruism related to science? Altruism is about individual selfless intentions. Science is about discovery and problem solving. On the surface these two facets of society may seem unrelated. In reality they may be strongly linked. Altruistic missions explain historical (and may predict future) patterns of scientific investments. The map of altruism (left) represents altruistic missions, and displays the relative positions of nearly 100,000 non-profit organizations (NPOs) in the United States based on mission-related text from their websites. This map of altruism reveals the issues that we care most about as a society: *Culture, Sports, Education, Religion, Community, Citizenship, and Caring*. The map of science (right) represents decades of funded research in the natural and medical sciences, engineering, technology, social sciences and humanities. It displays over 43,000,000 documents that are grouped together using a combination of citation and textual similarity.

These two maps are shown side-by-side to illustrate how the altruistic intentions of a society correlate with where we focus our discovery and problem solving efforts. The map of science has been divided into four major areas, shown in four different colors. NPOs whose National Taxonomy of Exempt Entities (NTEE) codes indicate that they explicitly fund scientific activities in these four areas are correspondingly colored in the map of altruism. Altruistic missions associated with these four areas are considered in more detail below, along with projections of how altruistic missions not currently associated with funding of scientific research might benefit from such funding in the future.

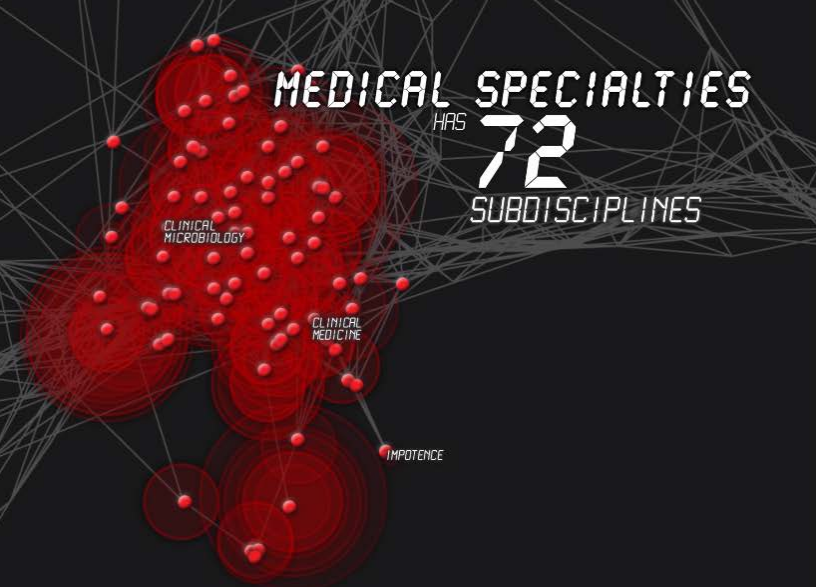


	<p><b>Citizenship</b> is linked to <i>Physics, Chemistry, Engineering</i> and <i>Computer Science</i>. The specific aspect of <i>Citizenship</i> active here is the belief that funding should be provided for entrepreneurship and innovation so that the economy can flourish. The funding of science-based innovation from governments and NPOs is reasonably mature and is expected to remain high.</p>	<p><b>Citizenship</b> is a major factor in the funding of the <i>Social Sciences</i>. The specific aspect of <i>Citizenship</i> active here is aligned with the belief that rational analysis and the scientific method can contribute to the resolution of political issues. "Think tanks" are examples of non-profit organizations that are funded from this altruistic motive.</p>	
	<p><b>Caring</b> is the basis for funding medical research. The aspects of <i>Caring</i> vary, and include curing of disease, providing opportunities for the disabled, and the treatment of mental health issues. A scientific understanding of these issues has been well funded by individuals, e.g., through donations to NPOs; and through government funding, e.g., the National Institutes of Health.</p>	<p><b>Culture and Citizenship</b> contribute to the funding of environmental research. <i>Culture</i> supports that aspect of environmental research that is more concerned with the preservation of our planet for the future enjoyment of our children. <i>Citizenship</i> supports the research focusing on innovative solutions and political tradeoffs which arise from the toxic consequences of current practices.</p>	
	<p><b>All Seven Aspects of Altruism</b> are potentially important for childhood development. Scientific research related to this topic is currently focused on social issues, e.g., risk factors, and <i>Education</i>. The altruism map raises an interesting question: Is this the right balance, or should more scientific attention be paid to childhood development in other areas, such as <i>Culture, Community, Sports, and Citizenship</i>? Time will tell.</p>	<p><b>Community</b> is an important altruistic mission that represents a potential funding opportunity. We know very little about how different communities (geographical, professional, social, etc.) have evolved in terms of providing altruistic services to their members. There are lessons to be learned from how communities variously emphasize <i>Culture, Sports, Education, Religion, Care, or Civic responsibility</i>.</p>	

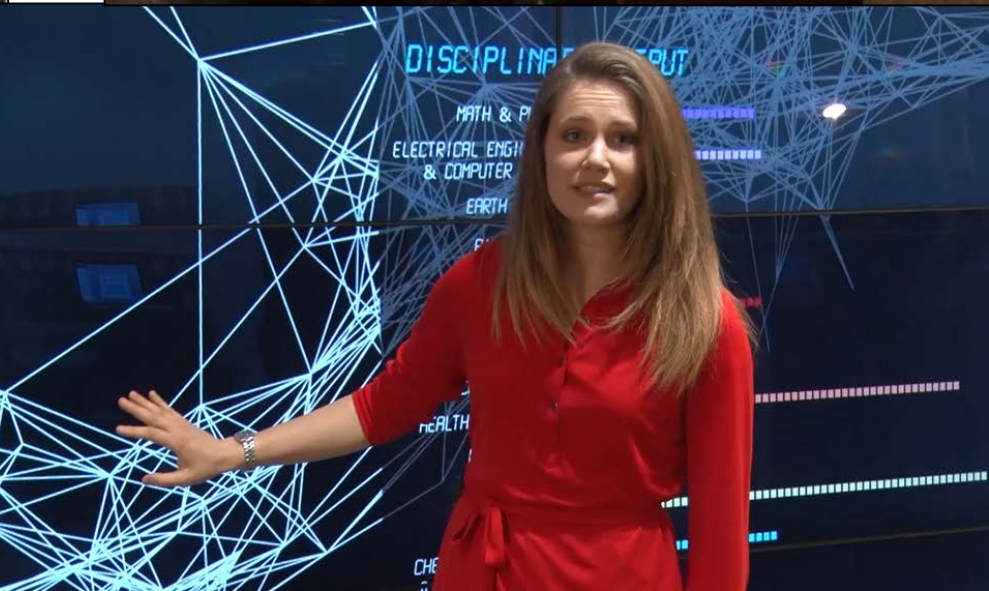
Historical

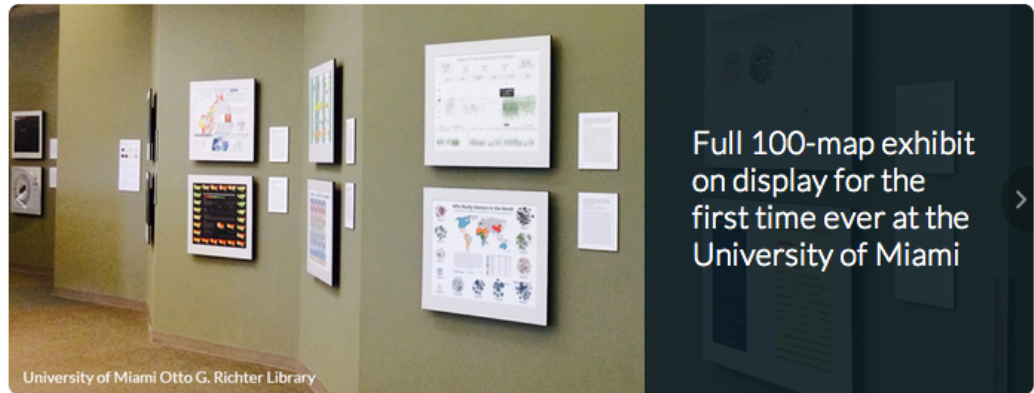
Future





# Science Forecast S1:E1, 2015





▶ **What IS a Science Map?**



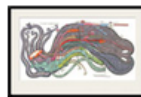
If you're new to science mapping or data visualization, here's an overview

▶ **See the Maps**



Zoom in to all 100 maps that comprise the *Places & Spaces* exhibit to see them in stunning detail

▶ **Purchase Maps & More**



Have a favorite map? Have it printed and framed to hang in your home or office!

▶ **P&S Around the World**



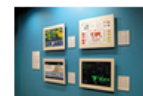
Browse photos of *Places & Spaces* exhibits from around the world and see a full list of venues

▶ **Meet the Mapmakers**



Over the years, the exhibit has employed over 240 mapmakers from around the world

▶ **Host the Exhibit**



Put your institution on the map by hosting the exhibit at your university, museum, or library

**Tweets** Follow

**Katy Borner** @katycns 22 Aug  
Big data visualization "Jax and the Big Data Beanstalk" theater piece now playing at SMM, [bit.ly/1v5stWb](http://bit.ly/1v5stWb) #ivmoooc  
Retweeted by Places & Spaces  
Expand

**Places & Spaces** @mappingscience 18 Aug  
Enjoy a FREE night out @IUcinema & see Humanexus on the big screen! 9/8 at 7pm. FREE tx @ box office night of show. [cinema.indiana.edu/?post\\_type=fil...](http://cinema.indiana.edu/?post_type=fil...)

**Places & Spaces** @mappingscience 18 Aug  
Randall Munroe @xkcd (featured in IT8 & soon in IT10) won a Hugo for "best graphic" [explainxkcd.com/wiki/index.php...](http://explainxkcd.com/wiki/index.php...) ... [thehugowards.org](http://thehugowards.org)

Tweet to @mappingscience

Explore the maps and background information at <http://scimaps.org>



# Macrosopes

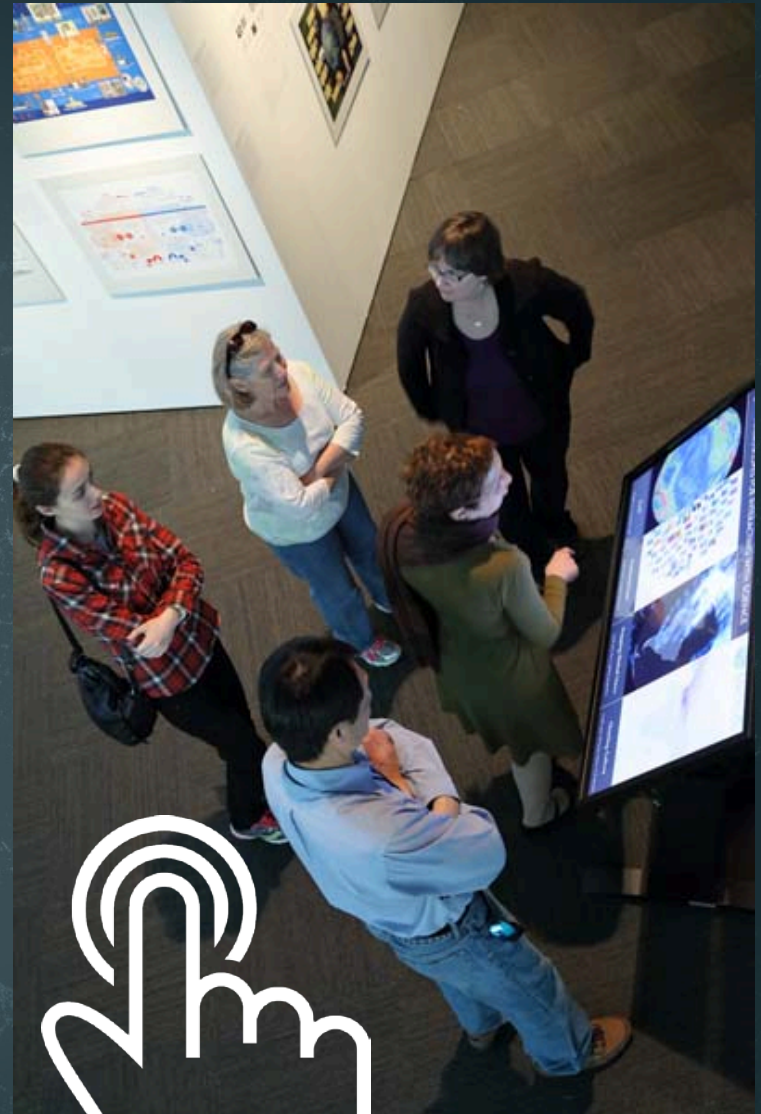


PLACES  
SPACES &  
MAPPING SCIENCE

[scimaps.org](http://scimaps.org)

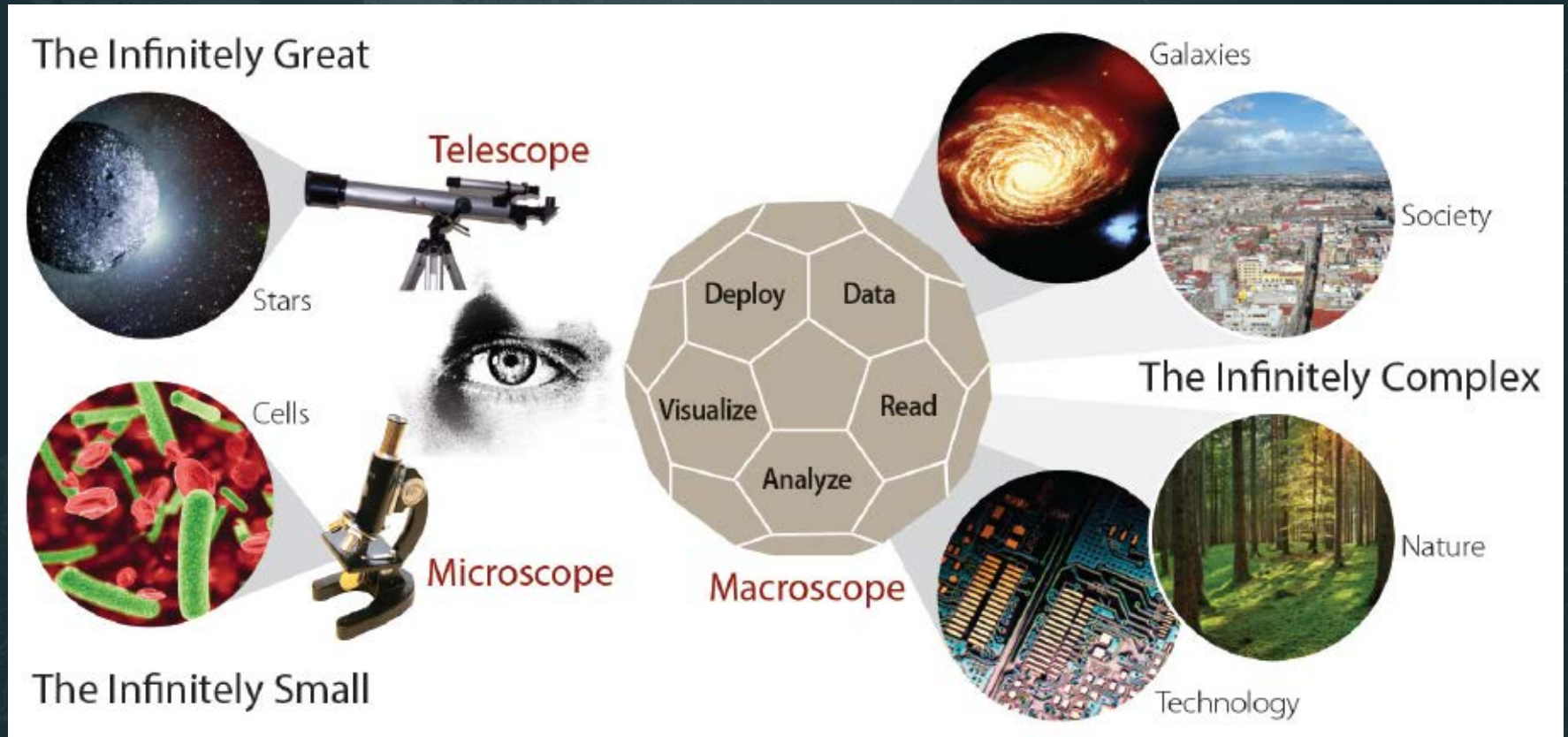


# MAPS vs. MACROSCOPES

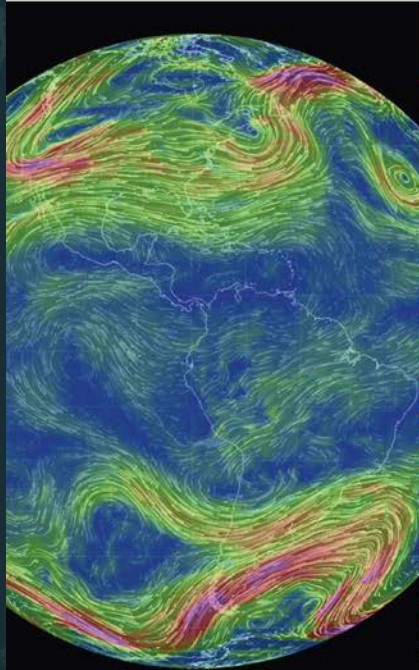




# Microscopes & Telescopes vs. MACROSCOPES



# i MACROSCOPES FOR INTERACTING WITH SCIENCE



**Earth**

*Weather on a worldwide scale*



**AcademyScope**

*Exploring the scientific landscape*



**Mapping Global Society**

*Local news from a global perspective*



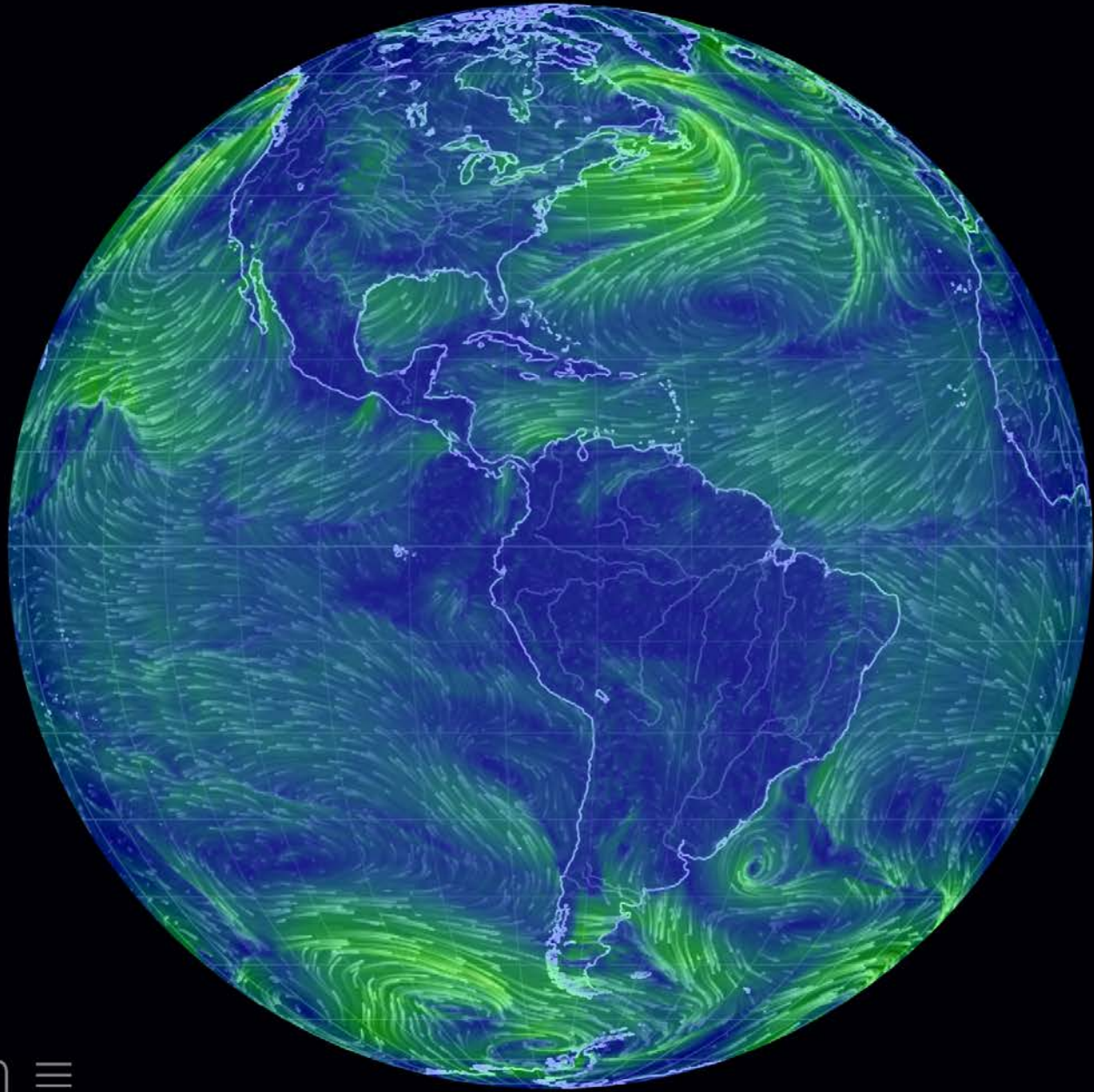
**Charting Culture**

*2,600 years of human history in 5 minutes*

**Iteration XI (2015): Macroscopes for Interacting with Science**

<http://scimaps.org/iteration/11>





earth ≡

*Earth* – Cameron Beccario

Top downloads



- Agriculture
- Behavioral and Social Sciences
- Biography and Autobiography
- Biology and Life Sciences
- Computers and Information Technology
- Conflict and Security Issues
- Earth Sciences
- Education
- Energy and Energy Conservation
- Engineering and Technology
- Environment and Environmental Studies
- Explore Science
- Food and Nutrition
- Health and Medicine
- Industry and Labor
- Math, Chemistry and Physics
- Policy for Science and Technology
- Space and Aeronautics
- Transportation

opic=282



# The News Co-occurrence Globe

An interactive visualization of how countries are mentioned together in the world's news media

+ - UNITED KINGDOM SEARCH ABOUT



2.92K  
COOCCUR%

**UNITED KINGDOM** cooccurrences in: 2,922%  
cooccurrences out: 80%

Timeline: Feb 22, Mar 1, Mar 8, Mar 15, Mar 22, Mar 29, Apr 5, Apr 12, Apr 19, Apr 26, May 3, May 10, May 17, May 24



COOCCUR

IN%

OUT%



**Smelly Maps**

*Charting urban smellscapes*



**HathiTrust**

*Storehouse of knowledge*



**Excellence Networks**

*Publish or perish together*



**FleetMon Explorer**

*Tracking the seven seas*

## Iteration XII (2016): Macrosopes for Making Sense of Science

<http://scimaps.org/iteration/12>





*Smelly Maps* – Daniele Quercia, Rossano Schifanella, and Luca Maria Aiello – 2015



HathiTrust Digital Library

Where are books published?

Drag your finger over the timeline to highlight a period of time. Yellow circles show the location and number of publications during those years.

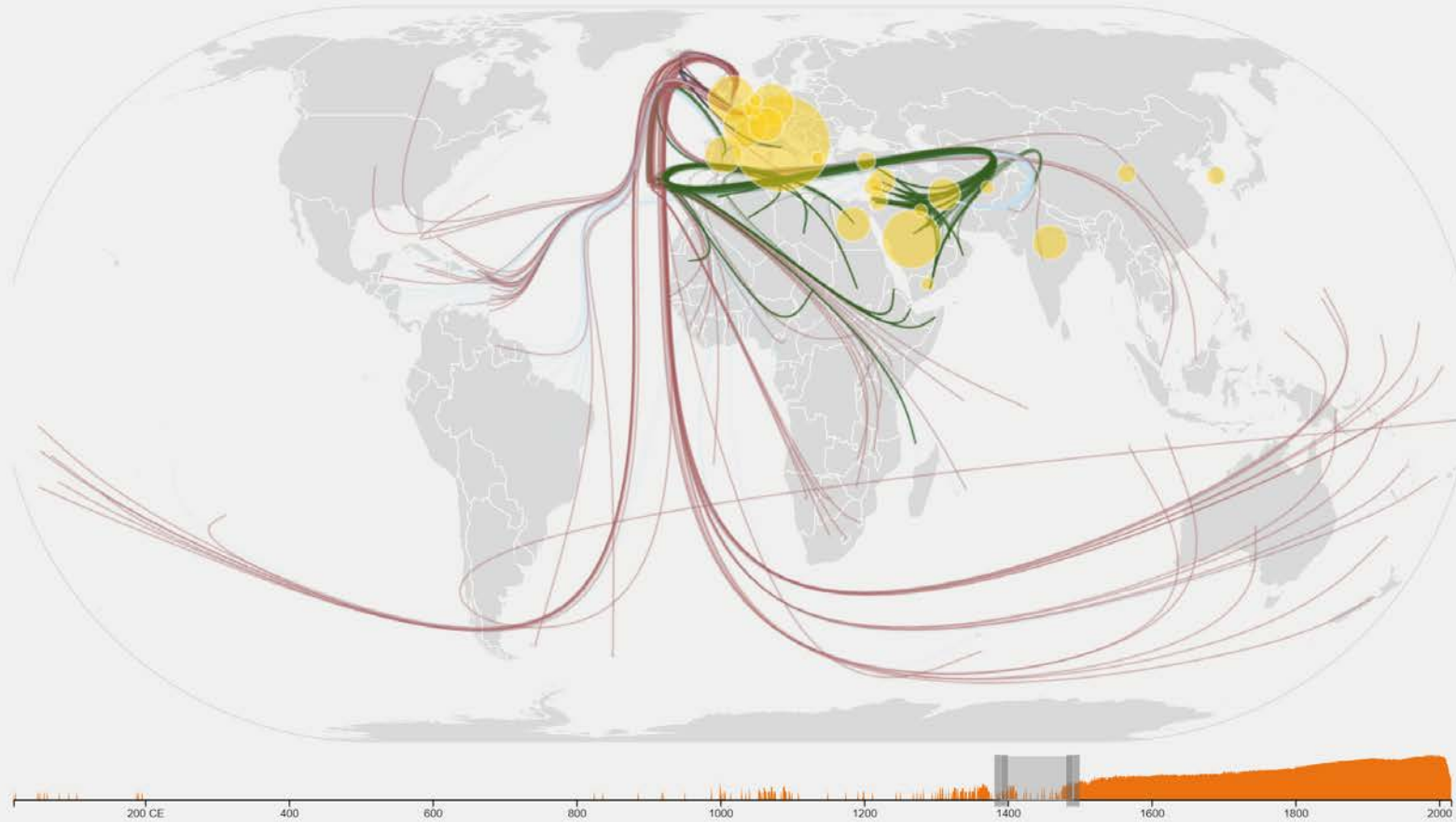
Where are potential readers?

Lines flow from publication locations to countries where the language of publication is spoken in modern times. Each line is colored according to language, with darker colors representing the most popular languages in the current selection.

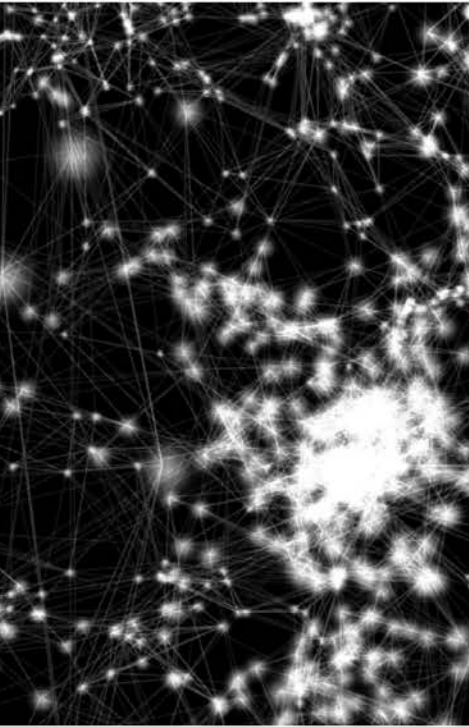
Top Publication Locations

For the years: 1390 - 1490

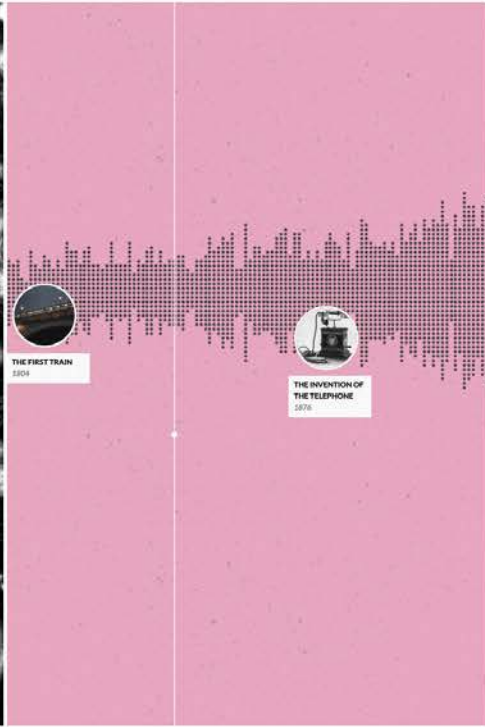
- Italy
- Saudi Arabia
- England
- Germany
- France
- Show all locations



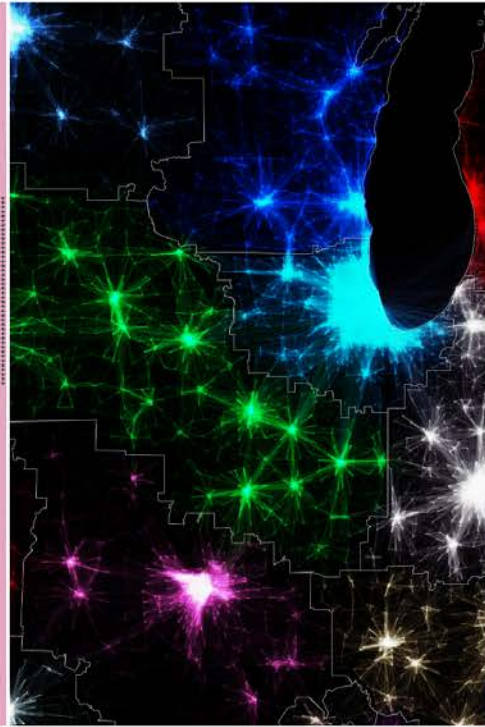




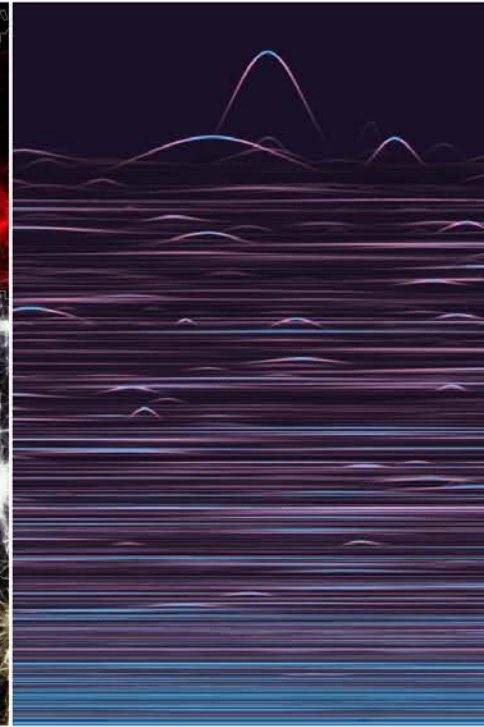
**The Cosmic Web**  
*And the network behind it*



**Histogramy**  
*An interactive timeline*



**Megaregions of the US**  
*Mapping commuter patterns*



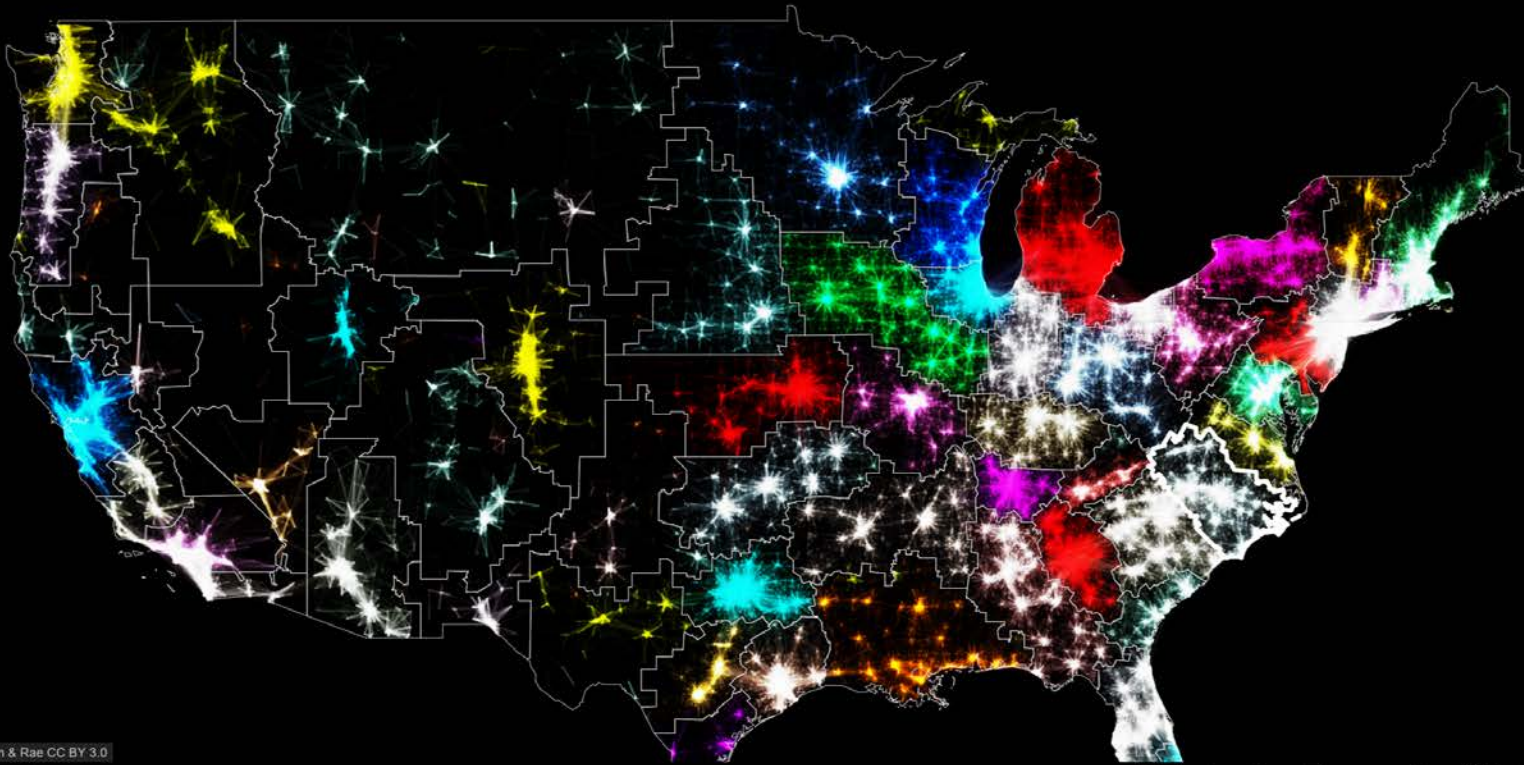
**Science Paths**  
*The random impact rule*

**Iteration XIII (2017): Macroscopes for Playing with Scale**

<http://scimaps.org/iteration/13>

## THE MEGAREGIONS OF THE US

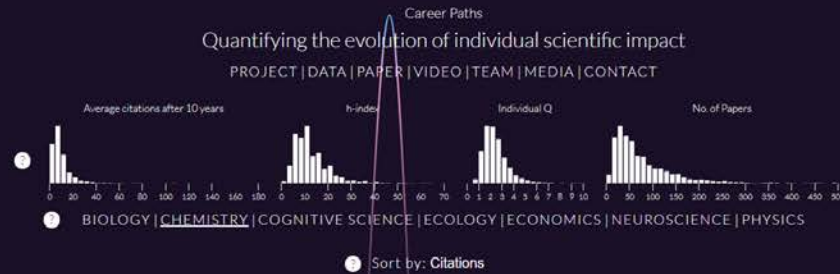
Explore the new geography of commuter connections in the US.  
Tap to identify regions. Tap and hold to see a single location's commuted.



Leaflet | Nelson & Rae CC BY 3.0

This is the Roanoke (Raleigh) megaregion.







A visitor explores the macroscope kiosk at the Eskenazi Museum of Art at Indiana University.

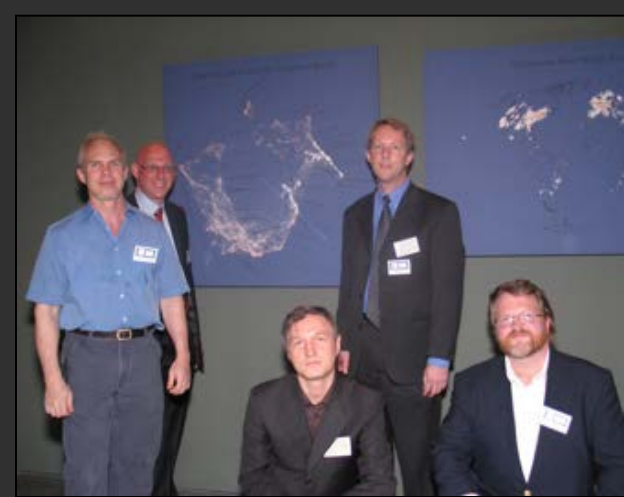
## Call for Macroscope Tools for the *Places & Spaces: Mapping Science* Exhibit (2017) <http://scimaps.org/call>

### Background and Goals

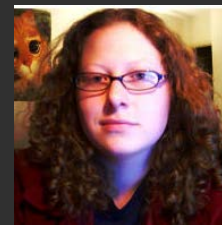
The *Places & Spaces: Mapping Science* exhibit is designed to open people's hearts and minds to the value, complexity, and beauty of maps of science and technology.

Drawing from across cultures and across scholarly disciplines, the *Places & Spaces: Mapping Science* exhibit demonstrates the





# Join the map makers & exhibit ambassadors.



# IVMOOC [cns.iu.edu](http://cns.iu.edu)



PLACES  
SPACES &  
MAPPING SCIENCE

[scimaps.org](http://scimaps.org)

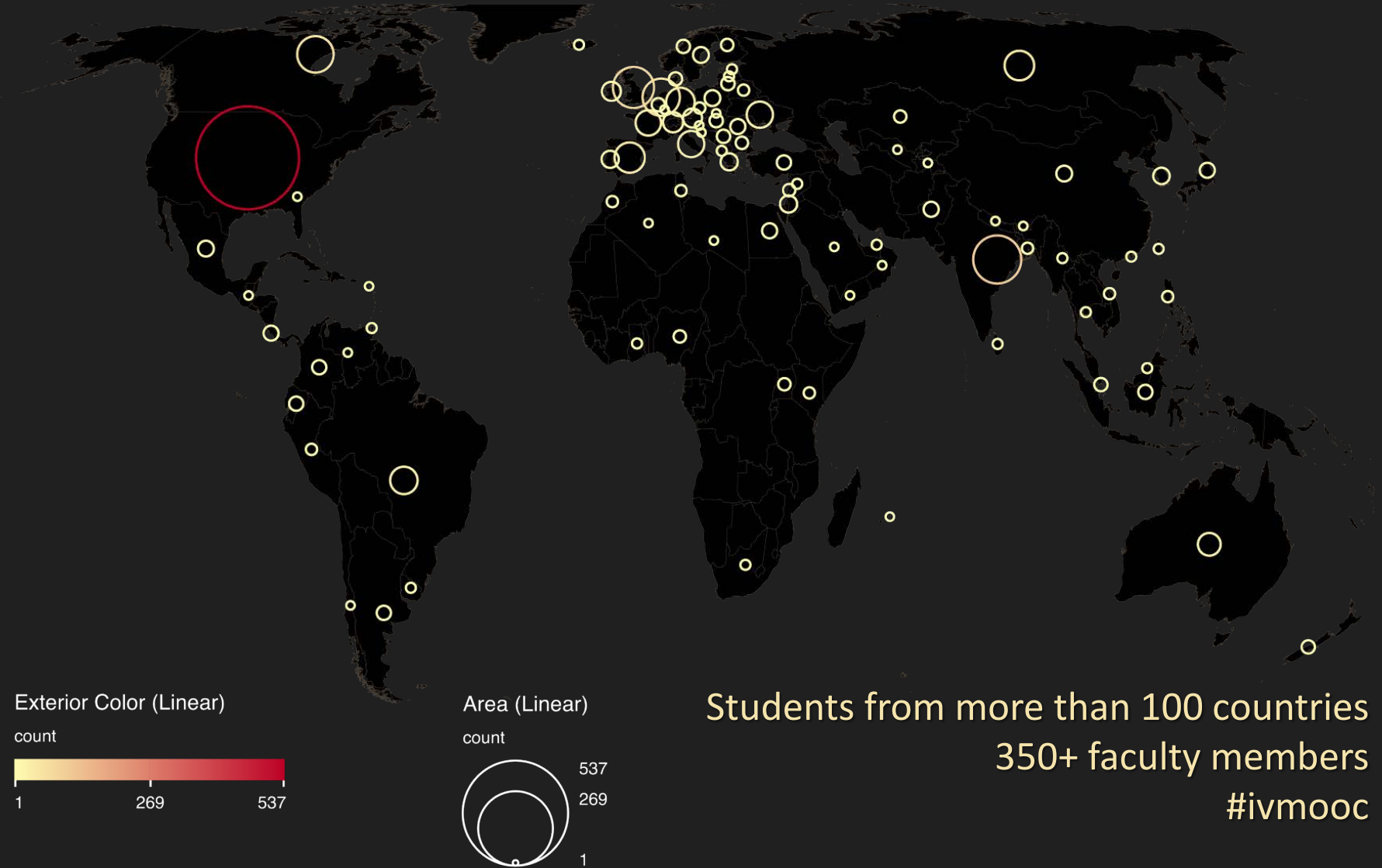




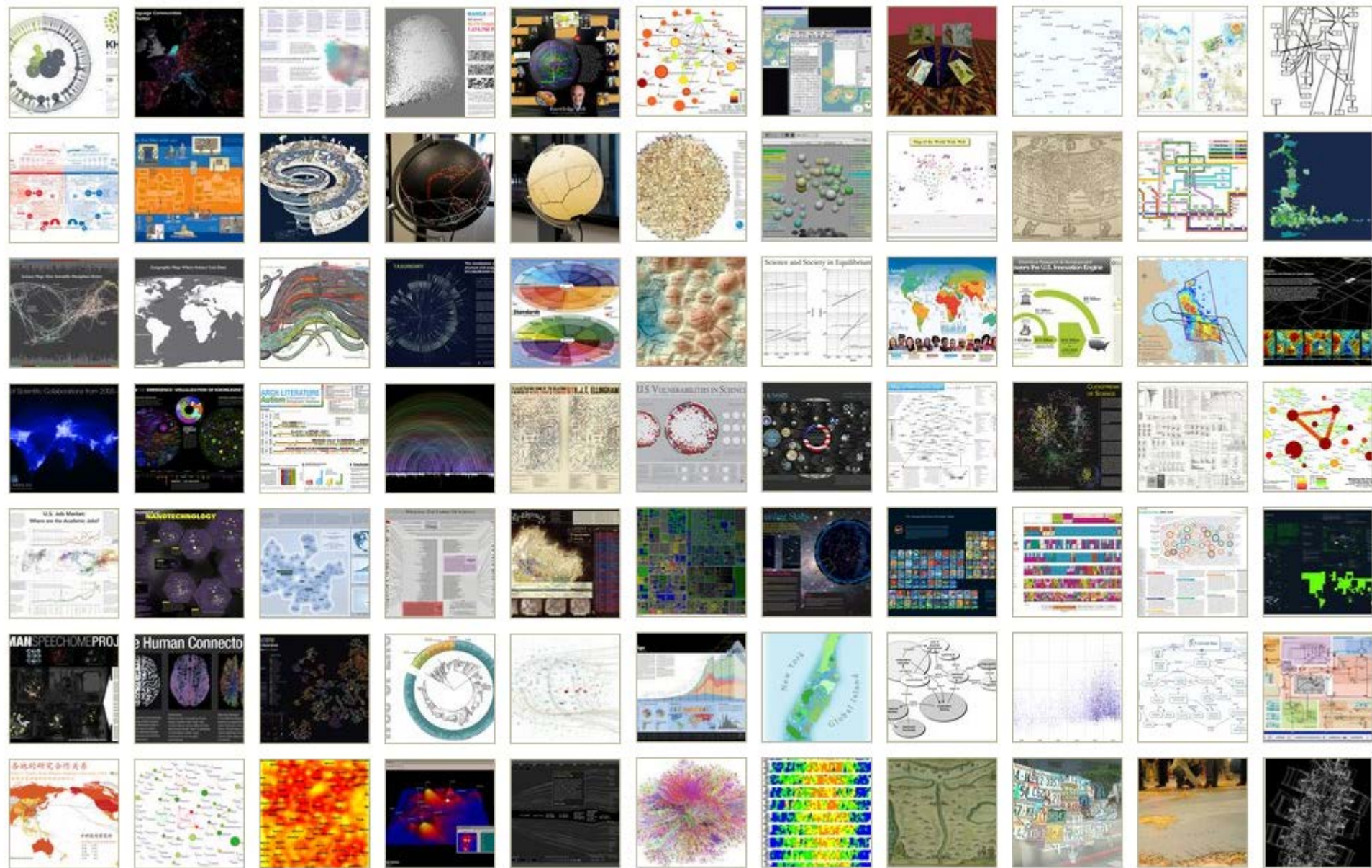
Register for free: <http://ivmooc.cns.iu.edu>. Class restarts Jan 9, 2018.

# The Information Visualization MOOC

[ivmooc.cns.iu.edu](http://ivmooc.cns.iu.edu)









# How to Classify Different Visualizations?

By

- User insight needs?
- User task types?
- Data to be visualized?
- Data transformation?
- Visualization technique?
- Visual mapping transformation?
- Interaction techniques?
- Or ?



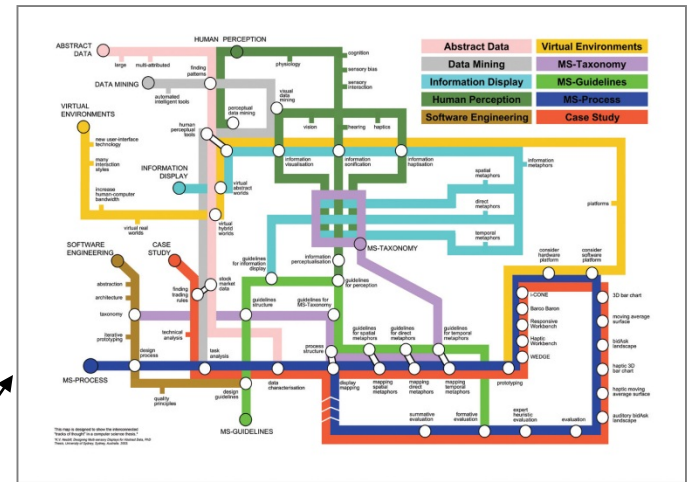


# Different Question Types



Terabytes of data

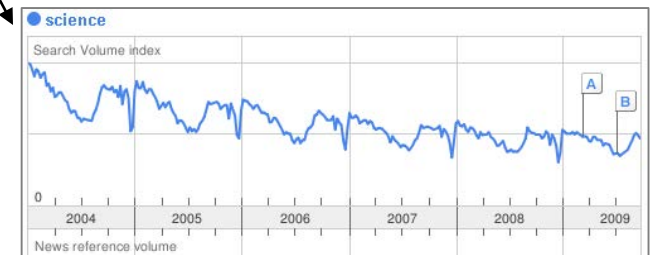
Descriptive & Predictive Models



Find your way



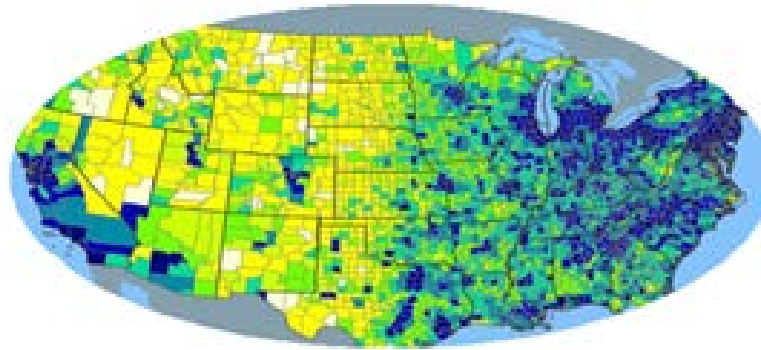
Find collaborators, friends



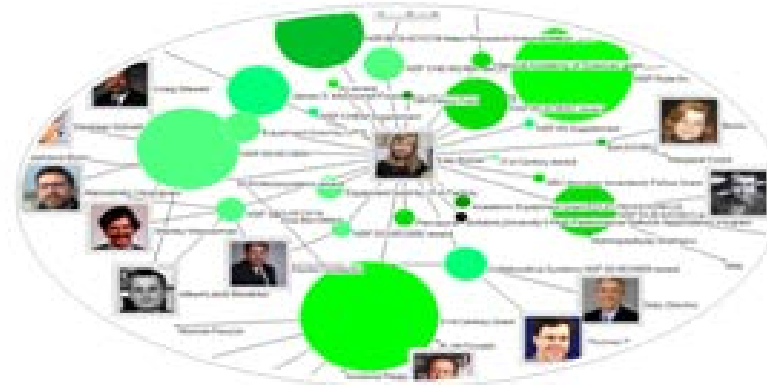
Identify trends

# Different Levels of Abstraction/Analysis

Macro/Global  
Population Level



Meso/Local  
Group Level




Micro  
Individual Level

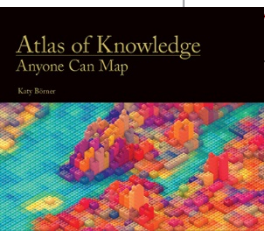




# Tasks

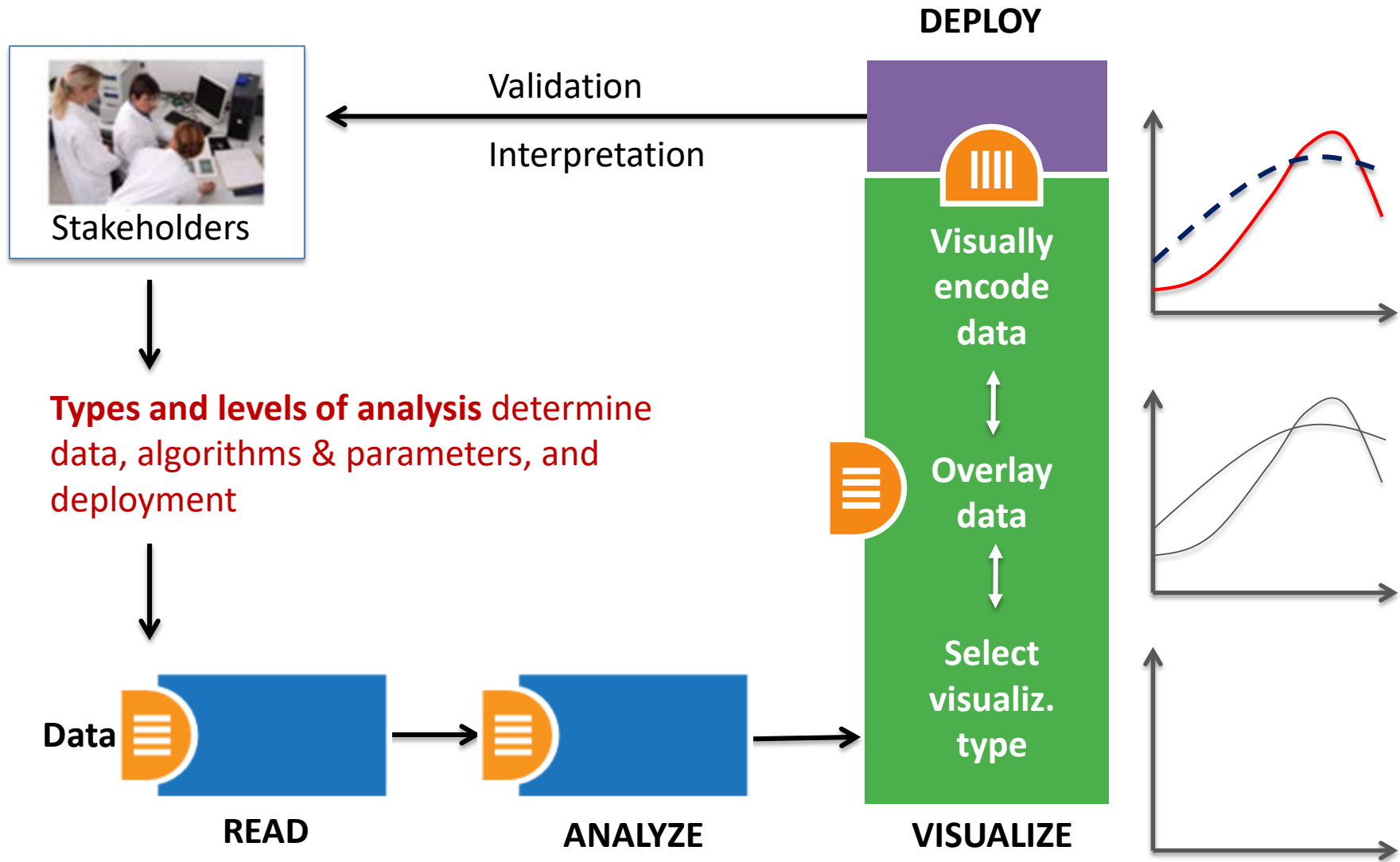
## LEVELS

	<b>MICRO: Individual Level</b> about 1–1,000 records page 6	<b>MESO: Local Level</b> about 1,001–100,000 records page 8	<b>MACRO: Global Level</b> more than 100,000 records page 10
<b>TYPES</b>			
<b>Statistical Analysis</b> page 44	 Knowledge Cartography page 135	 Productivity of Russian life sciences research teams page 105	 Science and Society in Equilibrium Number of scientists versus population and R&D costs versus GNP. page 103
<b>WHEN: Temporal Analysis</b> page 48	 Visualizing decision-making processes page 95	 Key events in the development of the video tape recorder page 85	 Increased travel and communication speeds page 83
<b>WHERE: Geospatial Analysis</b> page 52	 Cell phone usage in Milan, Italy page 109	 Victorian poetry in Europe page 137	 Ecological footprint of countries page 99
<b>WHAT: Topical Analysis</b> page 56	 Evolving patent holdings of Apple Computer, Inc. and Jerome Lemelson page 89	 Evolving journal networks in nanotechnology page 139	 Product space showing co-export patterns of countries page 93
<b>WITH WHOM: Network Analysis</b> page 60	 World Finance Corporation network page 87	 Electronic and new media art networks page 133	 World-wide scholarly collaboration networks page 157



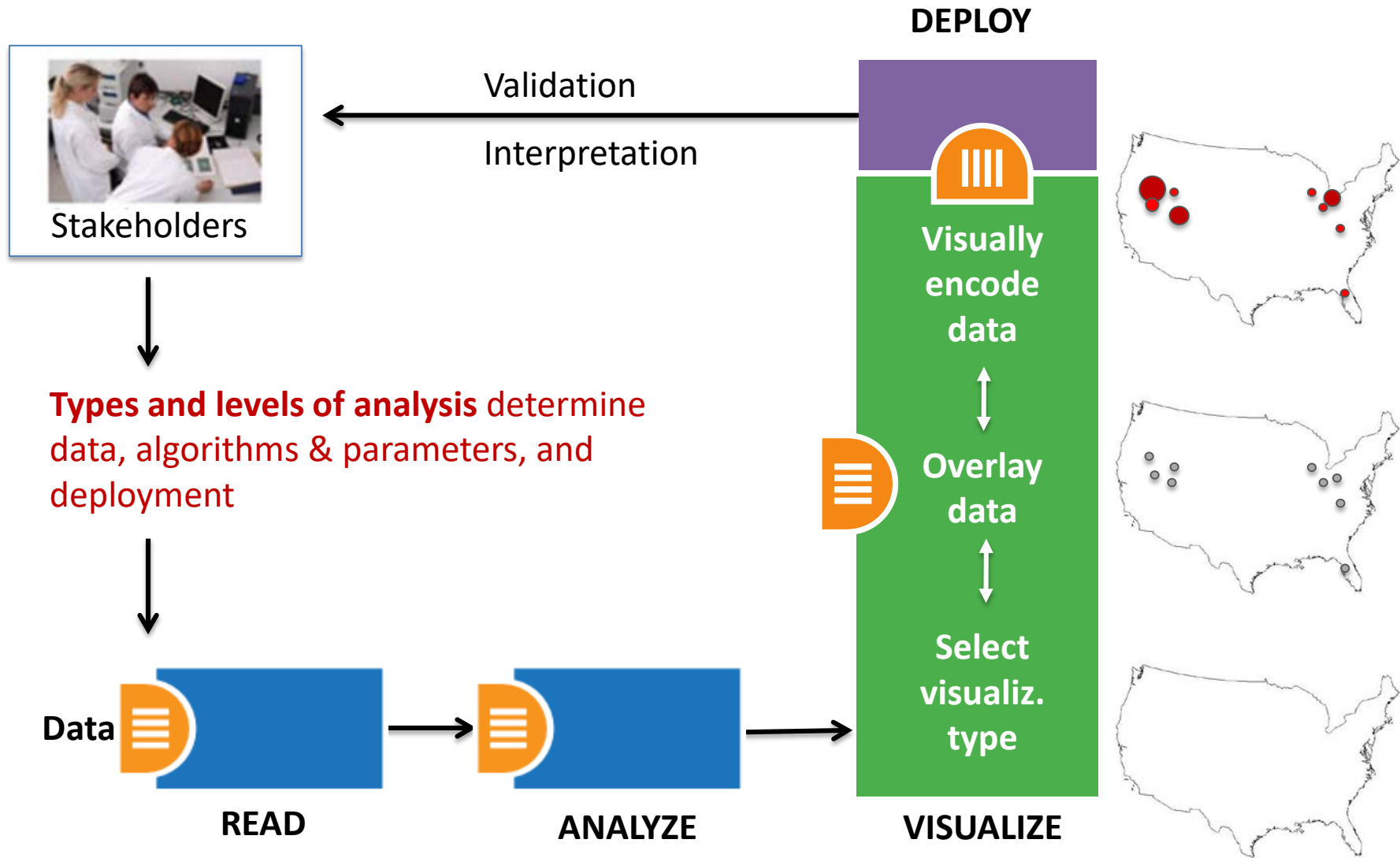
See page 5

# Needs-Driven Workflow Design



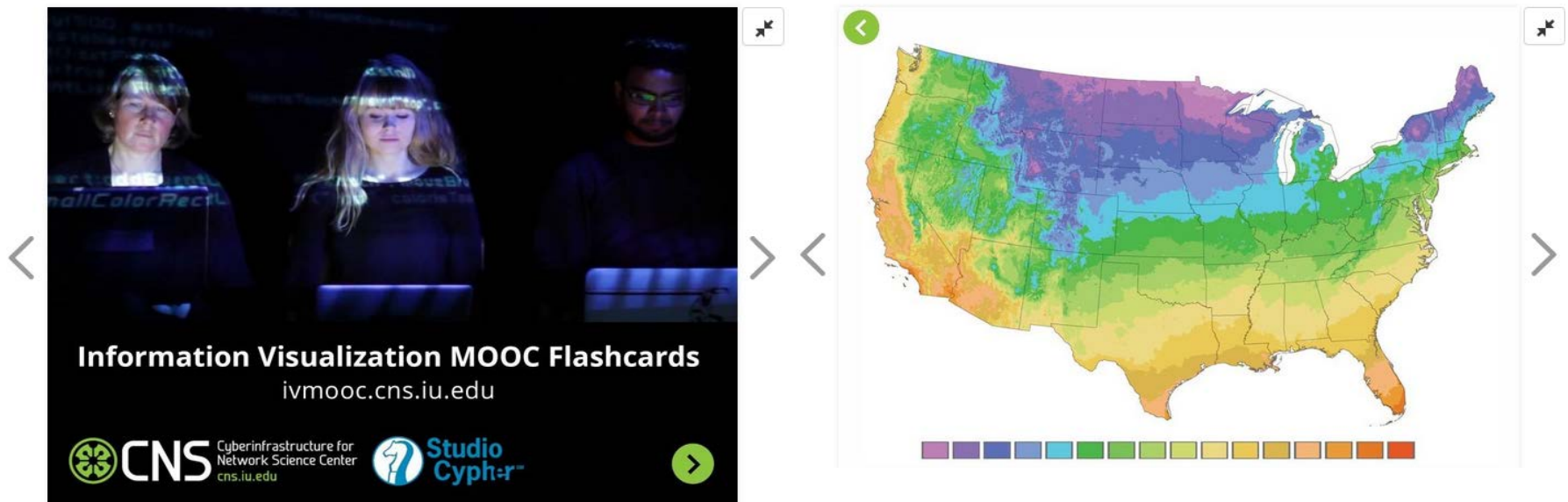
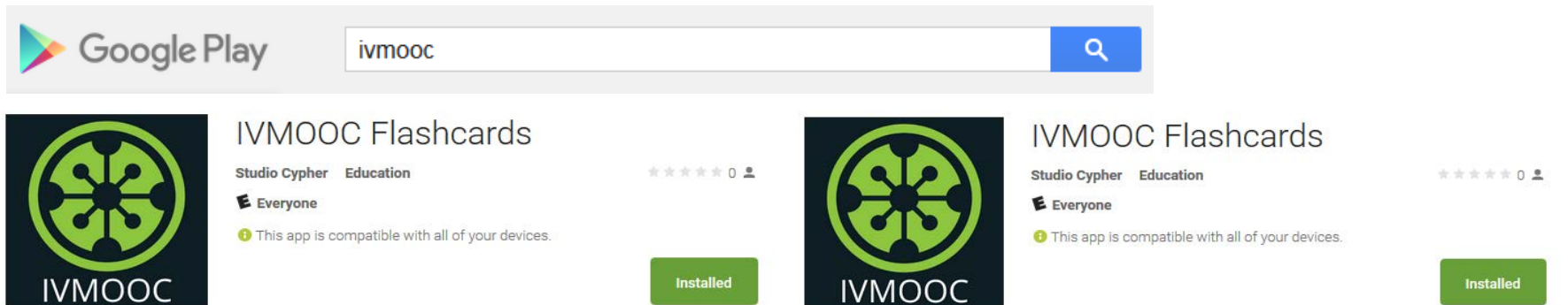


# Needs-Driven Workflow Design



# IVMOOC App – More than 60 visualizations

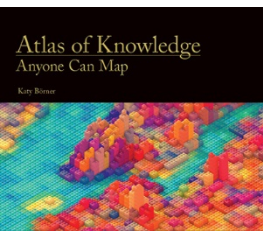
The “IVMOOC Flashcards” app can be downloaded from Google Play and Apple iOS stores.





# Visualization Framework

Insight Need Types page 26	Data Scale Types page 28	Visualization Types page 30	Graphic Symbol Types page 32	Graphic Variable Types page 34	Interaction Types page 26
<ul style="list-style-type: none"><li>• categorize/cluster</li><li>• order/rank/sort</li><li>• distributions (also outliers, gaps)</li><li>• comparisons</li><li>• trends (process and time)</li><li>• geospatial</li><li>• compositions (also of text)</li><li>• correlations/relationships</li></ul>	<ul style="list-style-type: none"><li>• nominal</li><li>• ordinal</li><li>• interval</li><li>• ratio</li></ul>	<ul style="list-style-type: none"><li>• table</li><li>• chart</li><li>• graph</li><li>• map</li><li>• network layout</li></ul>	<ul style="list-style-type: none"><li>• geometric symbols<ul style="list-style-type: none"><li>point</li><li>line</li><li>area</li><li>surface</li><li>volume</li></ul></li><li>• linguistic symbols<ul style="list-style-type: none"><li>text</li><li>numerals</li><li>punctuation marks</li></ul></li><li>• pictorial symbols<ul style="list-style-type: none"><li>images</li><li>icons</li><li>statistical glyphs</li></ul></li></ul>	<ul style="list-style-type: none"><li>• spatial<ul style="list-style-type: none"><li>position</li></ul></li><li>• retinal<ul style="list-style-type: none"><li>form</li><li>color</li><li>optics</li><li>motion</li></ul></li></ul>	<ul style="list-style-type: none"><li>• overview</li><li>• zoom</li><li>• search and locate</li><li>• filter</li><li>• details-on-demand</li><li>• history</li><li>• extract</li><li>• link and brush</li><li>• projection</li><li>• distortion</li></ul>



See page 24

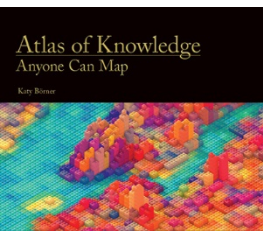
# Visualization Framework

Basic Task Types								
Bertin, 1967	Wehrend & Lewis, 1996	Few, 2004	Yau, 2011	Rendgen & Wiedemann, 2012	Frankel, 2012	Tool: Many Eyes	Tool: Chart Chooser	Börner, 2014
selection	categorize			category				categorize/ cluster
order	rank	ranking					table	order/rank/ sort
	distribution	distribution					distribution	distributions (also outliers, gaps)
	compare	nominal comparison & deviation	differences		compare and contrast	compare data values	comparison	comparisons
		time series	patterns over time	time	process and time	track rises and falls over time	trend	trends (process and time)
		geospatial	spatial relations	location		generate maps		geospatial
quantity		part-to- whole	proportions		form and structure	see parts of whole, analyze text	composition	compositions (also of text)
association	correlate	correlation	relationships	hierarchy		relations between data points	relationship	correlations/ relationships



# Visualization Framework

Insight Need Types page 26	Data Scale Types page 28	Visualization Types page 30	Graphic Symbol Types page 32	Graphic Variable Types page 34	Interaction Types page 26
<ul style="list-style-type: none"> <li>• categorize/cluster</li> <li>• order/rank/sort</li> <li>• distributions (also outliers, gaps)</li> <li>• comparisons</li> <li>• trends (process and time)</li> <li>• geospatial</li> <li>• compositions (also of text)</li> <li>• correlations/relationships</li> </ul>	<ul style="list-style-type: none"> <li>• nominal</li> <li>• ordinal</li> <li>• interval</li> <li>• ratio</li> </ul>	<ul style="list-style-type: none"> <li>• table</li> <li>• chart</li> <li>• graph</li> <li>• map</li> <li>• network layout</li> </ul>	<ul style="list-style-type: none"> <li>• geometric symbols               <ul style="list-style-type: none"> <li>point</li> <li>line</li> <li>area</li> <li>surface</li> <li>volume</li> </ul> </li> <li>• linguistic symbols               <ul style="list-style-type: none"> <li>text</li> <li>numerals</li> <li>punctuation marks</li> </ul> </li> <li>• pictorial symbols               <ul style="list-style-type: none"> <li>images</li> <li>icons</li> <li>statistical glyphs</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• spatial               <ul style="list-style-type: none"> <li>position</li> </ul> </li> <li>• retinal               <ul style="list-style-type: none"> <li>form</li> <li>color</li> <li>optics</li> <li>motion</li> </ul> </li> </ul>	<ul style="list-style-type: none"> <li>• overview</li> <li>• zoom</li> <li>• search and locate</li> <li>• filter</li> <li>• details-on-demand</li> <li>• history</li> <li>• extract</li> <li>• link and brush</li> <li>• projection</li> <li>• distortion</li> </ul>



See page 24

# Graphic Variable Types Versus Graphic Symbol Types

			Geometric Symbols					
			Point		Line		Area	
Spatial	x	quantitative						
	y	quantitative						
	z	quantitative						
Retinal	Form	Size	quantitative	NA (Not Applicable)				
		Shape	qualitative	NA				
		Rotation	quantitative	NA				
		Curvature	quantitative	NA				
		Angle	quantitative	NA				
		Closure	quantitative	NA				
	Color	Value	quantitative					
		Hue	qualitative					
		Saturation	quantitative					



# Graphic Variable Types Versus Graphic Symbol Types

		Geometric Symbols			Linguistic Symbols		Pictorial Symbols	
		point	line	area	surface	volume	Text, Numerals, Punctuation Marks	Images, Icons, Statistical Graphs
Symbol	1							
	2							
	3							
Form	size	NA (Not applicable)						
	shape	NA						
	orientation	NA						
	curvature	NA						
	angle	NA						
	closure	NA						
	value							
	hue							
	saturation							
Texture	spacing							
	complexity							
	pattern							
	orientation	NA						
	accent							
	blur							
	transparency							
	shading							
	stereoscopic depth	Point in foreground - background	Line in foreground - background	Area in foreground - background	Surface in foreground - background	Volume in foreground - background	Text in foreground - background	Icons in foreground - background
	speed							
velocity								
strobium	Blinking point slow - fast	Blinking line slow - fast	Blinking area slow - fast	Blinking surface slow - fast	Blinking volume slow - fast	Blinking text slow - fast	Blinking icons slow - fast	

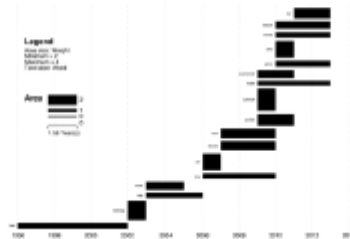
# Load **One** File and Run **Many** Analyses and Visualizations

Times Cited	Publication Year	City of Publisher	Country	Journal Title (Full)	Title	Subject Category	Authors
12	2011	NEW YORK	USA	COMMUNICATIONS OF THE ACM	Plug-and-Play Microscopes	Computer Science	Borner, K
18	2010	MALDEN	USA	CTS-CLINICAL AND TRANSLATIONAL SCIENCE	Advancing the Science of Team Science	Research & Experimental Medicine	Falk-Krzesinski, HJ Borner, K Contractor, N Fiore, SM Hall, KL Keyton, J Spring, B Stokols, D Trochim, W Uzzi, B
13	2010	WASHINGTON	USA	SCIENCE TRANSLATIONAL MEDICINE	A Multi-Level Systems Perspective for the Science of Team Science	Cell Biology   Research & Experimental Medicine	Borner, K Contractor, N Falk-Krzesinski, HJ Fiore, SM Hall, KL Keyton, J Spring, B Stokols, D Trochim, W Uzzi, B

## Statistical Analysis—p. 44

Location	Count	# Citations
Netherlands	13	292
United States	9	318
Germany	11	36
United Kingdom	1	2

## Temporal Burst Analysis—p. 48



## Geospatial Analysis—p. 52



## Geospatial Analysis—p. 52

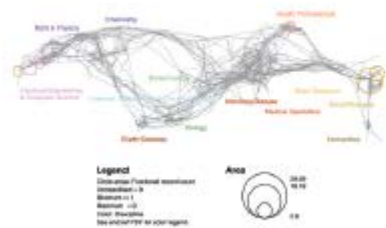




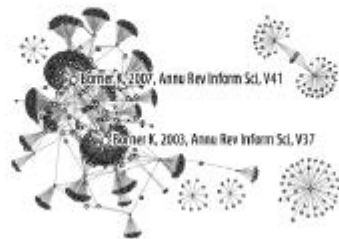
# Load **One** File and Run **Many** Analyses and Visualizations

Times Cited	Publication Year	City of Publisher	Country	Journal Title (Full)	Title	Subject Category	Authors
12	2011	NEW YORK	USA	COMMUNICATIONS OF THE ACM	Plug-and-Play Macroscopes	Computer Science	Borner, K
18	2010	MALDEN	USA	CTS-CLINICAL AND TRANSLATIONAL SCIENCE	Advancing the Science of Team Science	Research & Experimental Medicine	Falk-Krzesinski, HJ Borner, K Contractor, N Fiore, SM Hall, KL Keyton, J Spring, B Stokols, D Trochim, W Uzzi, B
13	2010	WASHINGTON	USA	SCIENCE TRANSLATIONAL MEDICINE	A Multi-Level Systems Perspective for the Science of Team Science	Cell Biology   Research & Experimental Medicine	Borner, K Contractor, N Falk-Krzesinski, HJ Fiore, SM Hall, KL Keyton, J Spring, B Stokols, D Trochim, W Uzzi, B

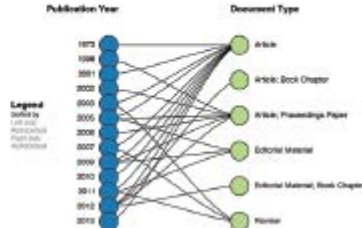
Topical Analysis—p. 56



Paper Citation Network—p. 60



Bi-Modal Network—p. 60



Co-author and many other bi-modal networks.

# Course Schedule

## Part 1: Theory and Hands-On

- **Session 1** – Workflow Design and Visualization Framework
- **Session 2** – “When:” Temporal Data
- **Session 3** – “Where:” Geospatial Data
- **Session 4** – “What:” Topical Data

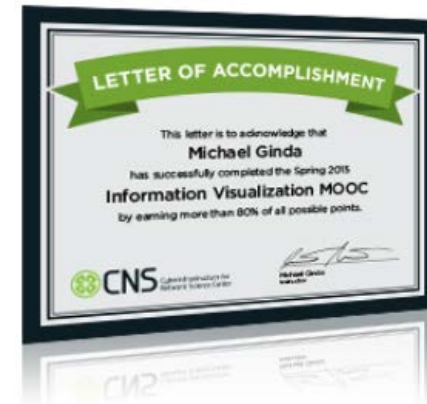
## Mid-Term

- **Session 5** – “With Whom:” Trees
- **Session 6** – “With Whom:” Networks
- **Session 7** – Dynamic Visualizations and Deployment

## Final Exam

## Part 2: Students work in teams on client projects.

Final grade is based on Homework and Quizzes (**10%**), Midterm (**20%**), Final (**30%**), Client Project (**30%**), and Class Participation (**10%**).

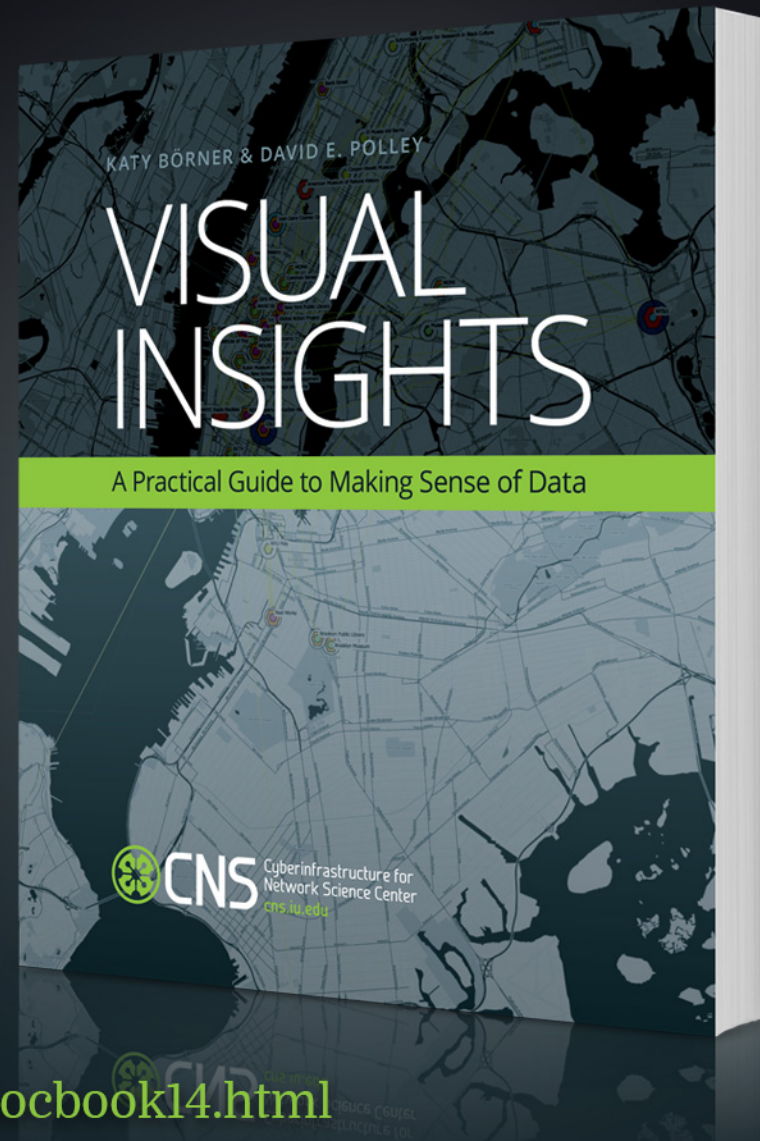




# The IVMOOC Companion Textbook

This textbook offers a gentle introduction to the design of insightful visualizations. It seamlessly blends theory and practice, giving readers both the theoretical foundation and the practical skills necessary to render data into insights.

The book accompanies the Information Visualization MOOC that attracted students, scholars, and practitioners from many fields of science and more than 100 different countries.



[cns.iu.edu/ivmooobook14.html](http://cns.iu.edu/ivmooobook14.html)

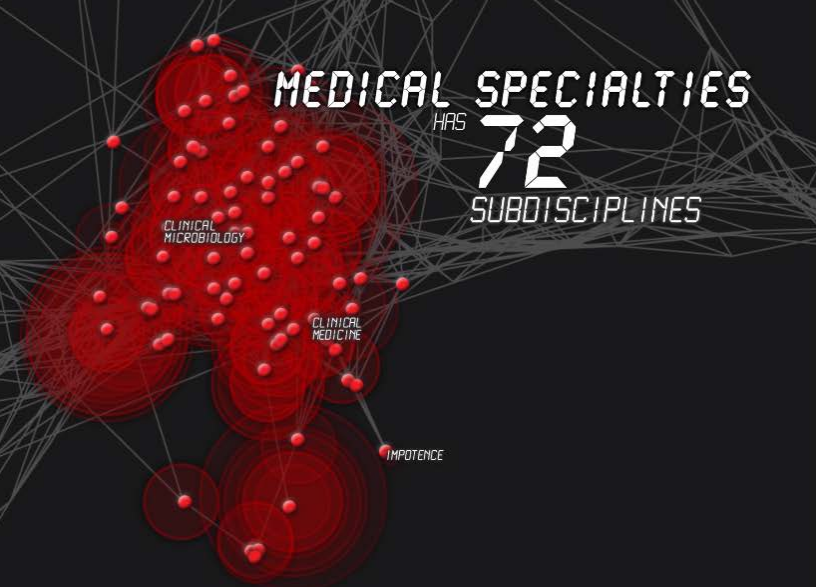
# Forecasting S&T



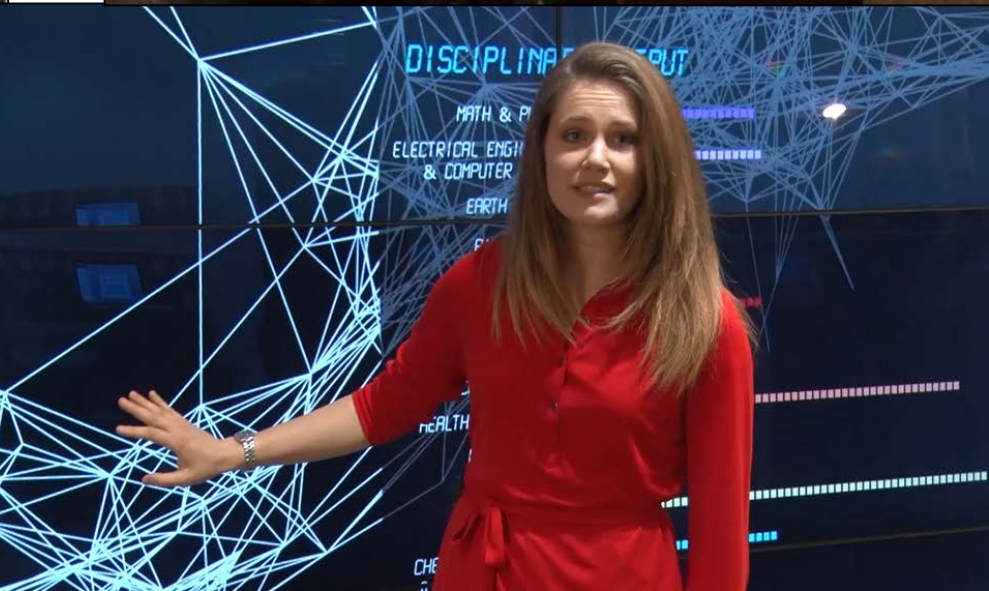
PLACES  
SPACES &  
MAPPING SCIENCE

[scimaps.org](http://scimaps.org)





# Science Forecast S1:E1, 2015







# Modeling Science, Technology & Innovation Conference

WASHINGTON D.C. | MAY 17-18, 2016

[View Agenda](#)

Government, academic, and industry leaders discussed challenges and opportunities associated with using big data, visual analytics, and computational models in STI decision-making.

Conference slides, recordings, and report are available via <http://modsti.cns.iu.edu/report>







- PROGRAMS
- Awards
- Koshland Science Museum
- Cultural Programs
- Sackler Colloquia
  - About Sackler Colloquia
  - Upcoming Colloquia
  - Completed Colloquia
  - Video Gallery
  - Connect with Sackler Colloquia
  - Give to Sackler Colloquia
- Kavli Frontiers of Science
- Distinctive Voices



## Upcoming Colloquia

Unless otherwise indicated, most Sackler colloquia are held at the Arnold and Mabel Beckman Center, in Irvine, California.

### *Reproducibility of Research: Issues and Proposed Remedies*

March 8-10, 2017; Washington, D.C.  
Organized by David B. Allison, Richard Shiffrin and Victoria Stodden  
Registration now open

### *Science of Science Communication III*

November 15-16, 2017; Washington, D.C.  
Organized by Karen Cook, Baruch Fischhoff, Alan I. Leshner and Dietram A. Scheufele  
Registration will open May 2017

### *Modelling and Visualizing Science and Technology Developments*

December 4-5, 2017; Irvine, CA  
Organized by Katy Börner, William Rouse and H. Eugene Stanley  
Registration will open August 2017



SCWS 2017

Connecting the World  
for a Sustainable Future

15th.Nov.-17th.Nov.2017

ACCESS / INQUIRY

EN JP

ABOUT

PROGRAMME

REGISTRATION

MARKETPLACE

SPONSORSHIP

PRACTICAL INFORMATION



# Science Centre World Summit 2017 IN TOKYO

National Museum of Emerging Science and Innovation (Miraikan)

SCWS Session: Visualizing STEAM Data in Support of Smart Decision Making  
November 15-17, 2017, Tokyo, Japan. <http://scws2017.org>



# References

Börner, Katy, Chen, Chaomei, and Boyack, Kevin. (2003). **Visualizing Knowledge Domains**. In Blaise Cronin (Ed.), *ARIST*, Medford, NJ: Information Today, 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](http://www.pnas.org/content/vol101/suppl_1)

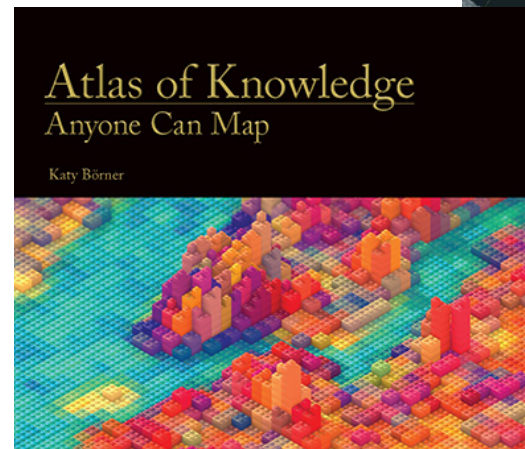
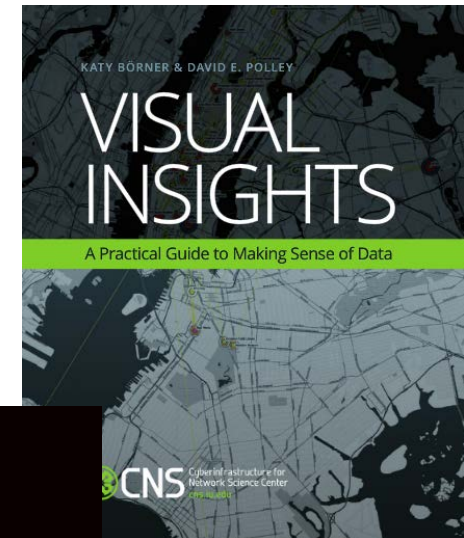
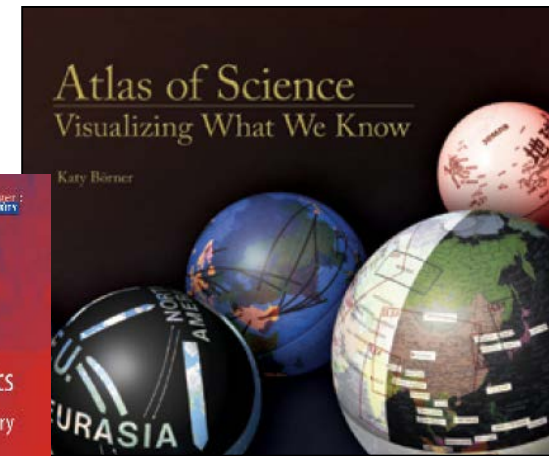
Börner, Katy (2010) **Atlas of Science: Visualizing What We Know**. The MIT Press. <http://scimaps.org/atlas>

Scharnhorst, Andrea, Börner, Katy, van den Besselaar, Peter (2012) **Models of Science Dynamics**. Springer Verlag.

Katy Börner, Michael Conlon, Jon Corson-Rikert, Cornell, Ying Ding (2012) **VIVO: A Semantic Approach to Scholarly Networking and Discovery**. Morgan & Claypool.

Katy Börner and David E Polley (2014) **Visual Insights: A Practical Guide to Making Sense of Data**. The MIT Press.

Börner, Katy (2015) **Atlas of Knowledge: Anyone Can Map**. The MIT Press. <http://scimaps.org/atlas2>






We work closely with clients to provide custom-made data, visualization, and software solutions

▶ Research

 **Open Data and Open Code for Big Science of Science Studies**


▶ Latest News

 **Put your money where your citations are: a proposal for a new funding system (website accessed 9/05/13)**

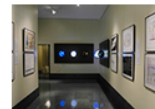
▶ Upcoming Events

- OCT 1** Katy Börner attends PIUG 2013 Northeast Conference
- 10.13** Katy Börner presents Mapping Science Exhibit at WSSF
- 10.15** Ted Polley & Google Team present IVMOOC at EDUCAUSE
- 10.22** Katy Börner presents at the SciELO 15 Years Conference


▶ Development

 **Behind the scenes of the design and development of *AcademyScope***


▶ Outreach

 **See some of the most fascinating data visualizations in the world.**


▶ Videos

 **Watch Katy Börner's full presentation from TEDxBloomington**

▶ Teaching

 **Successful IVMOOC will be offered again in January of 2014**

▶ Our Products

 We work closely with clients to provide custom-made data, visualization, and software solutions

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

These slides are at <http://cns.iu.edu/presentations.html>

CNS Facebook: <http://www.facebook.com/cnscenter>

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