The Story of Science Maps

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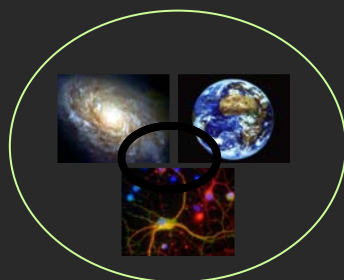
Indiana University, Bloomington, IN

Network Science Conference, May 25th, 2006

The Problem:
Being Lost in Space

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

Mankind's Knowledge



use

contribute

Human Brain

Amount of knowledge
on brain can mange

Leonardo Da Vinci
(1452-1519)

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

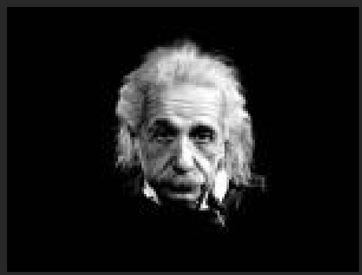
Mankind's Knowledge

use

contribute

Human Brain

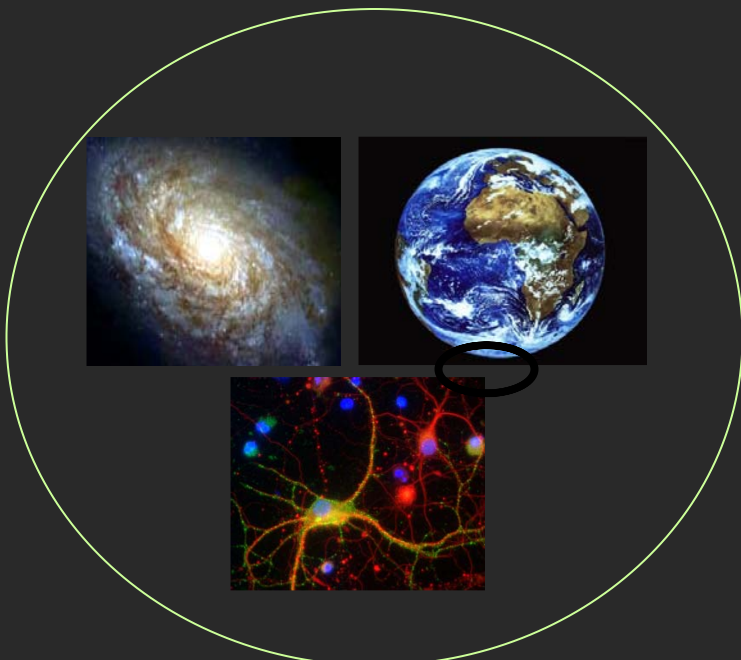
Amount of knowledge
on brain can mange



Albert Einstein
(1879-1955)

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

Mankind's Knowledge



Amount of knowledge
on brain can mange

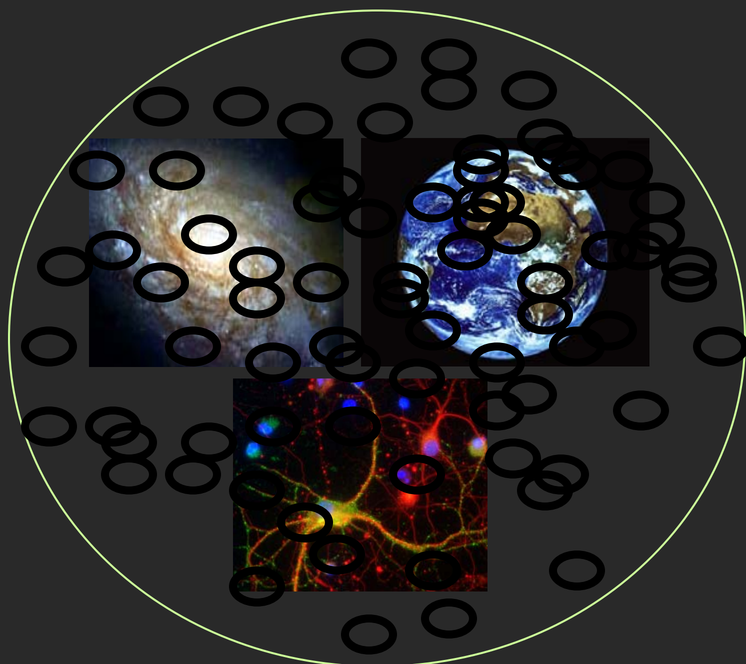
use

contribute

Human Brain

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

Mankind's Knowledge

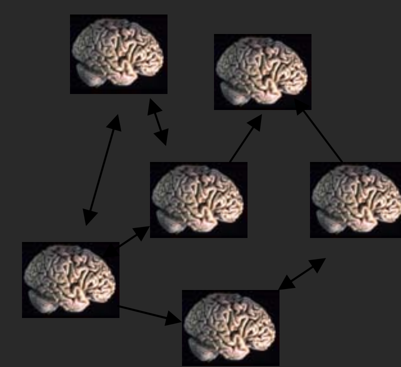


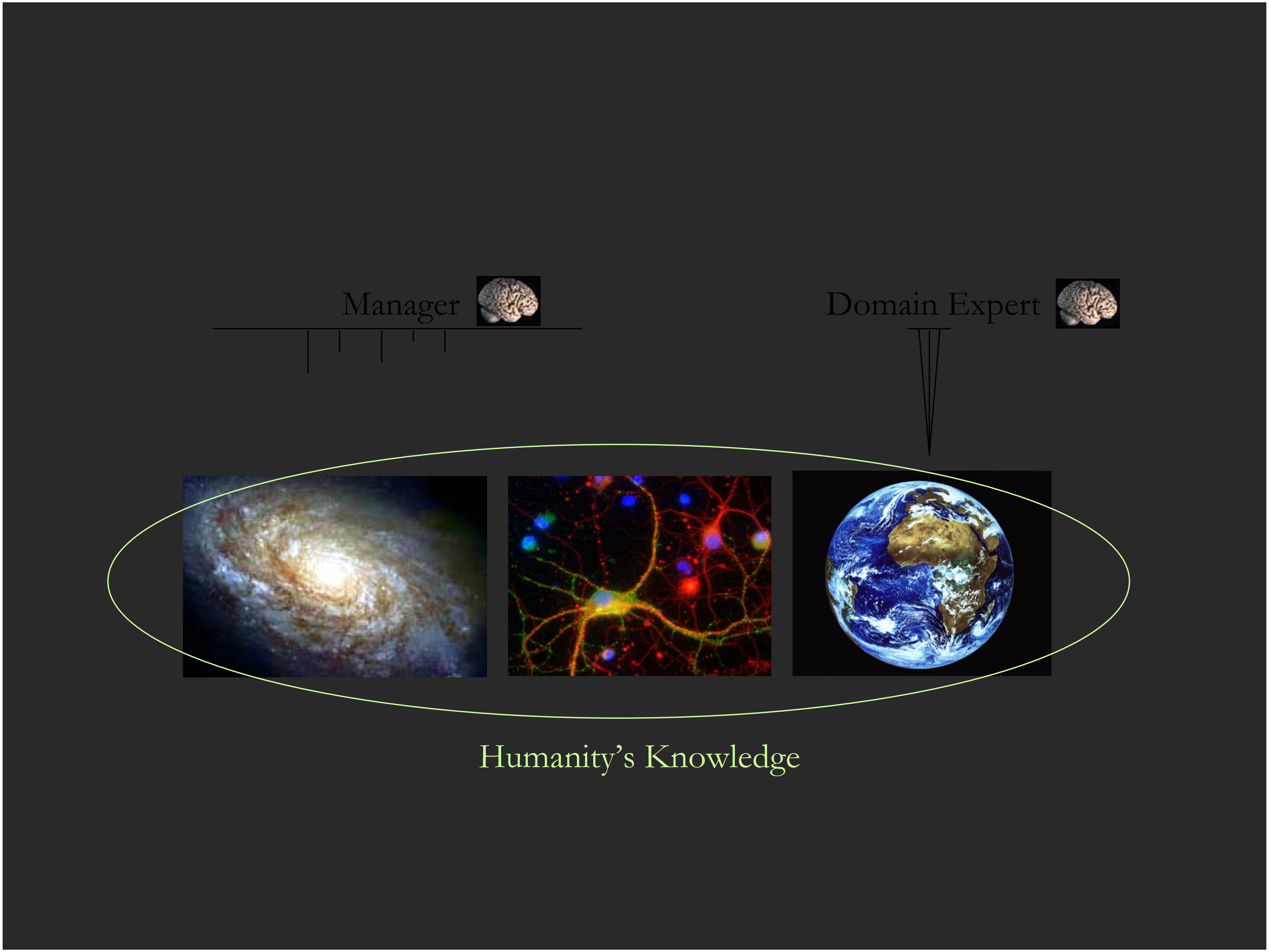
Amount of knowledge
on brain can mange

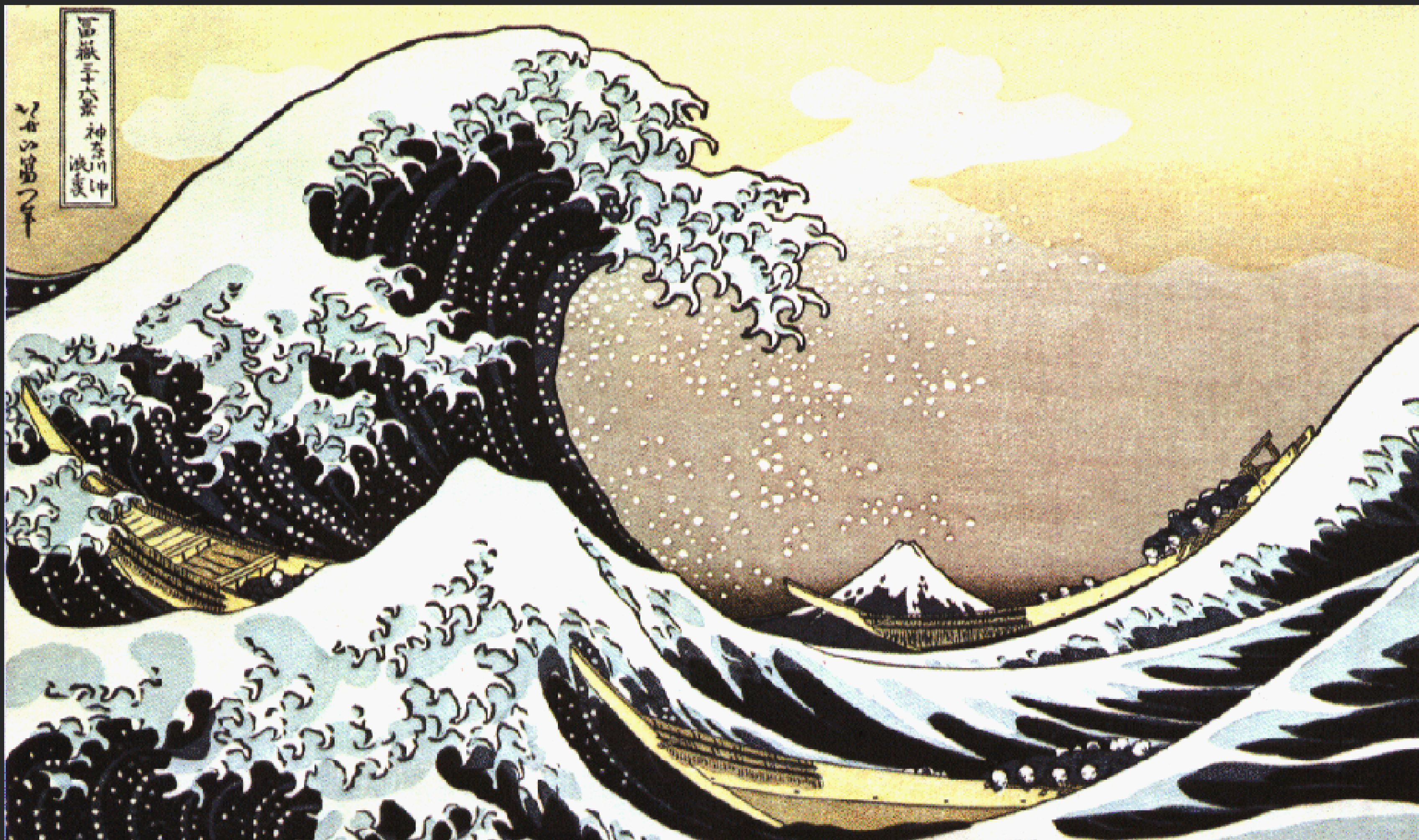
use →

← ***contribute***

Human Brains




Manager
Domain Expert
Humanity’s Knowledge



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

A Solution:
Science Maps

Places & Spaces: Mapping Science

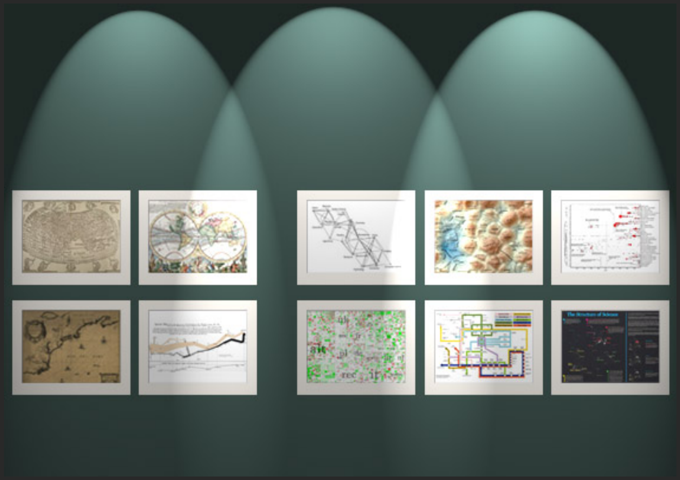
a science exhibit that introduces people to maps of sciences, their makers and users.

Exhibit Curators:

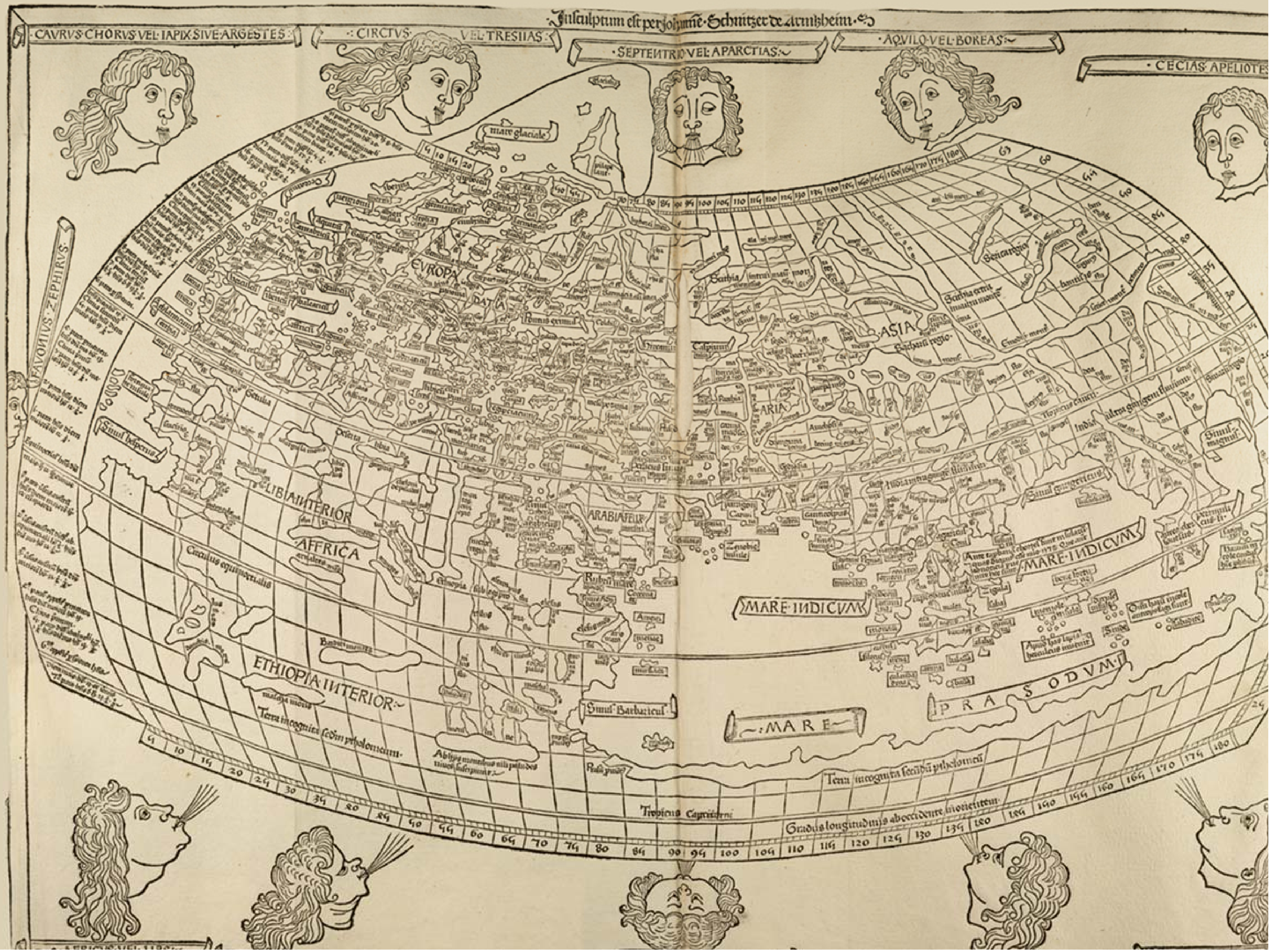
Dr. Katy Börner &
Deborah MacPherson

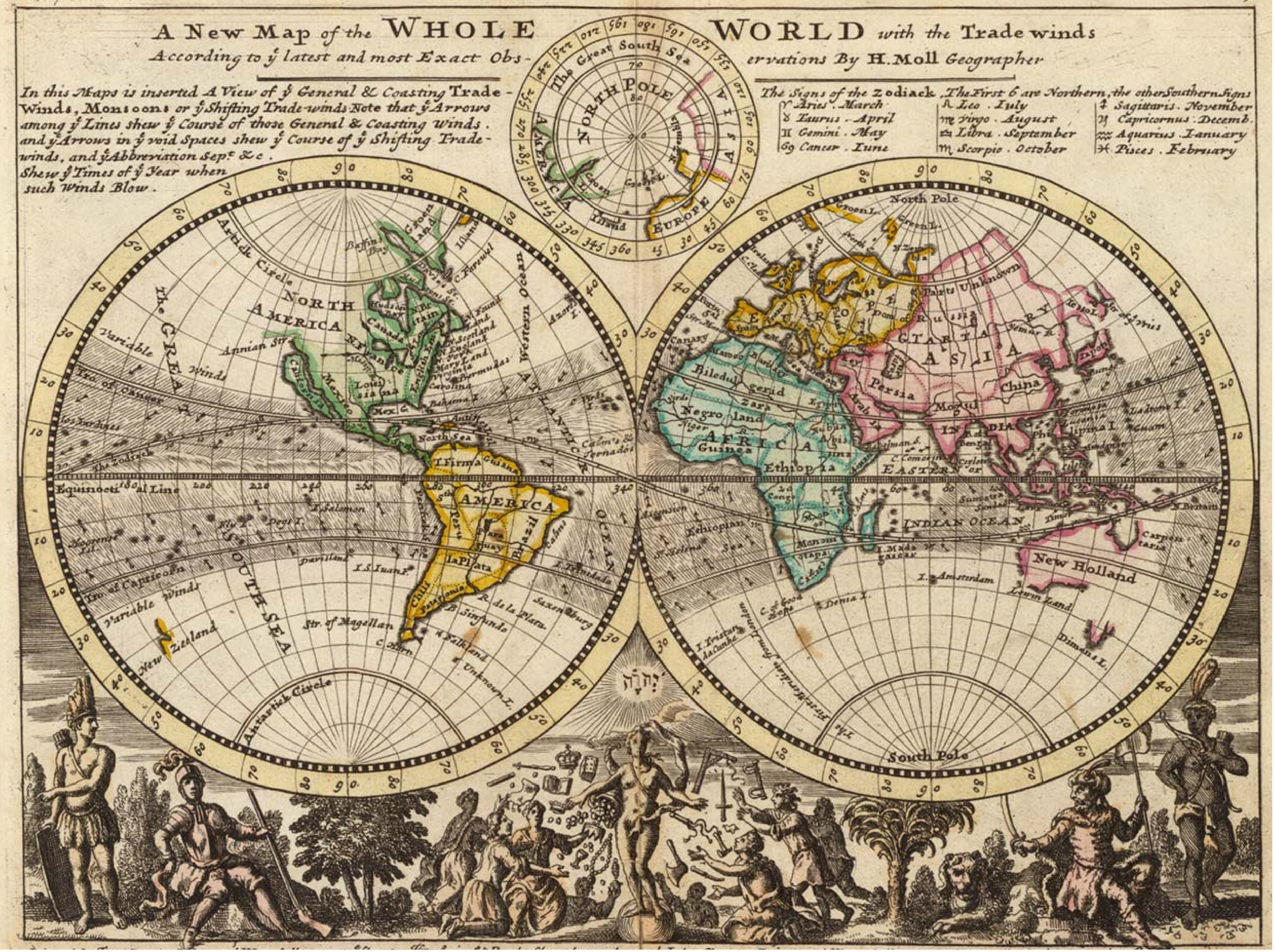
The Power of Maps

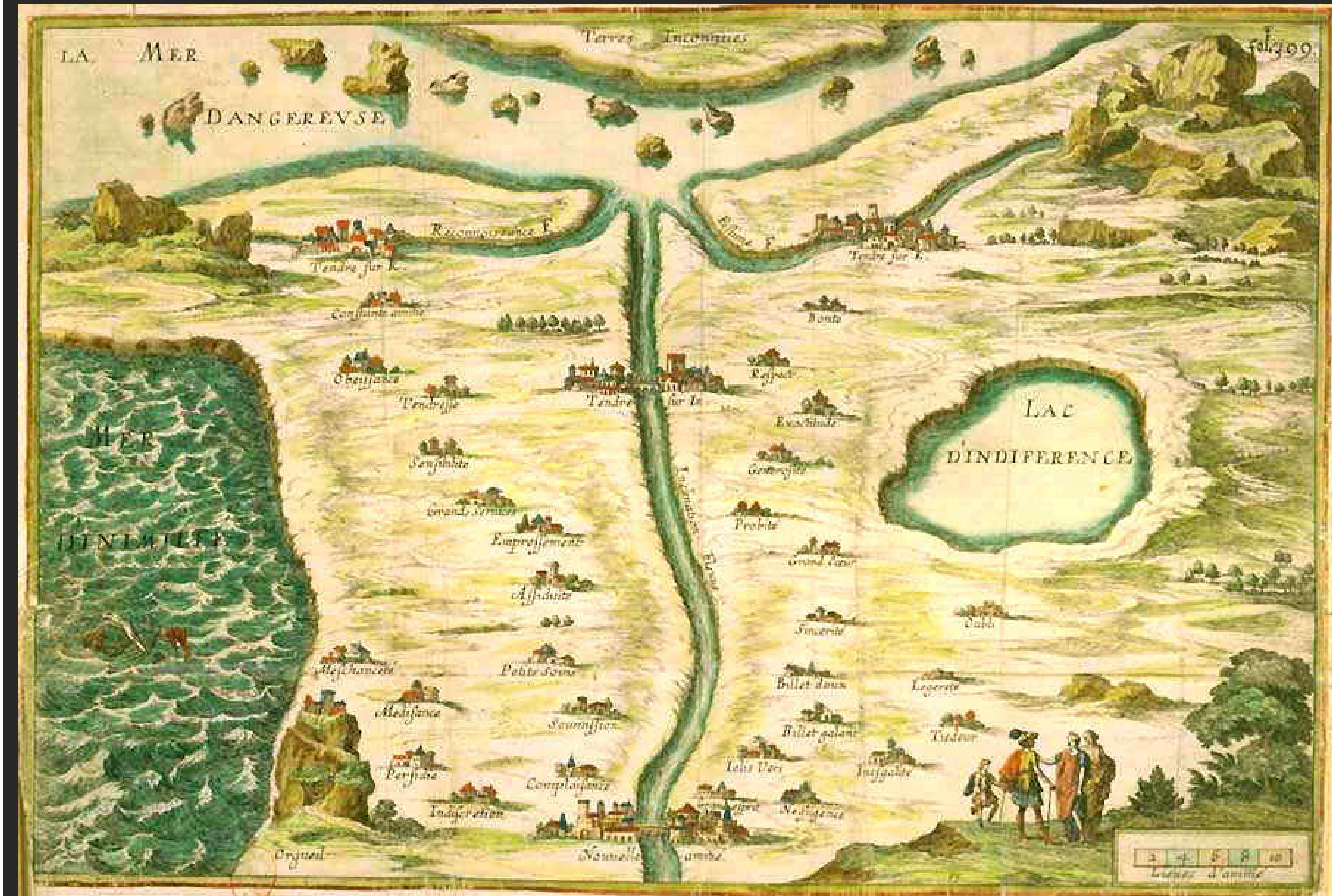
Four Early Maps of Our World
VERSUS
Six Early Maps of Science



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


Insculptum est per Johanne Schnitzer de Armssheim
CAVRVS CHORVS VEL IAPIX SIVE ARGESTES
CIRCIVS VEL TRESIIAS
SEPTENTRIO VEL APARCTIAS
AQVILO VEL BOREAS
CECIAS APELIOTES
FAVONIVS ZEPHIRVS
mare glaciale
EVROPA
DATIA
ASIA
ARIA
ARABIA FELIX
LIBIA INTERIOR
AFFRICA
ETHIOPIA INTERIOR
MARE INDICVM
MARE INDICVM
MARE
PRASODVM
Sinus Barbaricus
Sinus magnus
Circulus equinoctialis
Terra incognita secundum ptholomeum
Terra incognita secundum ptholomeum
Tropicus Capricorni
Gradus longitudinis ab occidente in orientem


A New Map of the WHOLE WORLD with the Trade winds
According to ye latest and most Exact Observations By H. Moll Geographer
In this Maps is inserted A View of ye General & Coasting Trade-Winds, Monsoons or ye Shifting Trade-winds Note that ye Arrows among ye Lines shew ye Course of those General & Coasting Winds. and ye Arrows in ye void Spaces shew ye Course of ye Shifting Trade-winds, and ye Abbreviation Sept. &c. Shew ye Times of ye Year when such Winds Blow.
The Signs of the Zodiack, The First 6 are Northern, the other Southern Signs
♈ Aries . March
♉ Taurus . April
♊ Gemini . May
♋ Cancer . June
♌ Leo . July
♍ Virgo . August
♎ Libra . September
♏ Scorpio . October
♐ Sagittaris . November
♑ Capricornus . Decemb.
♒ Aquarius . January
♓ Pisces . February
The Great South Sea
NORTH POLE
AMERICA
ASIA
EUROPE
NORTH AMERICA
SOUTH AMERICA
The GREAT SOUTH SEA
Western Ocean
ATLANTICK OCEAN
Artick Circle
Antartick Circle
Equinoctial Line
Tro. of Cancer
Tro. of Capricorn
Variable Winds
New Zeland
Str. of Magellan
Brazil
Mexico
Canada
California
Louisiana
Bermudas
North Sea
Terra Firma
Guiana
Peru
Chili
la Plata
Patagonia
C. Horn
I. S. Juan F.
I. Salomon
North Pole
South Pole
EUROPE
ASIA
AFRICA
Tartary
Russia
Persia
China
Mogul
INDIA
Arabia
Biledulgerid
Zara
Negroland
Guinea
Ethiopia
Egypt
Ethiopian Sea
INDIAN OCEAN
EASTERN OCEAN
New Holland
Carpentaria
Dimans L.
I. Amsterdam
C. of Good Hope
I. Madagascar
Japan
Philipina I.
N. Britain
Green L.
Parts Unknown
I. Tristan da Cunha

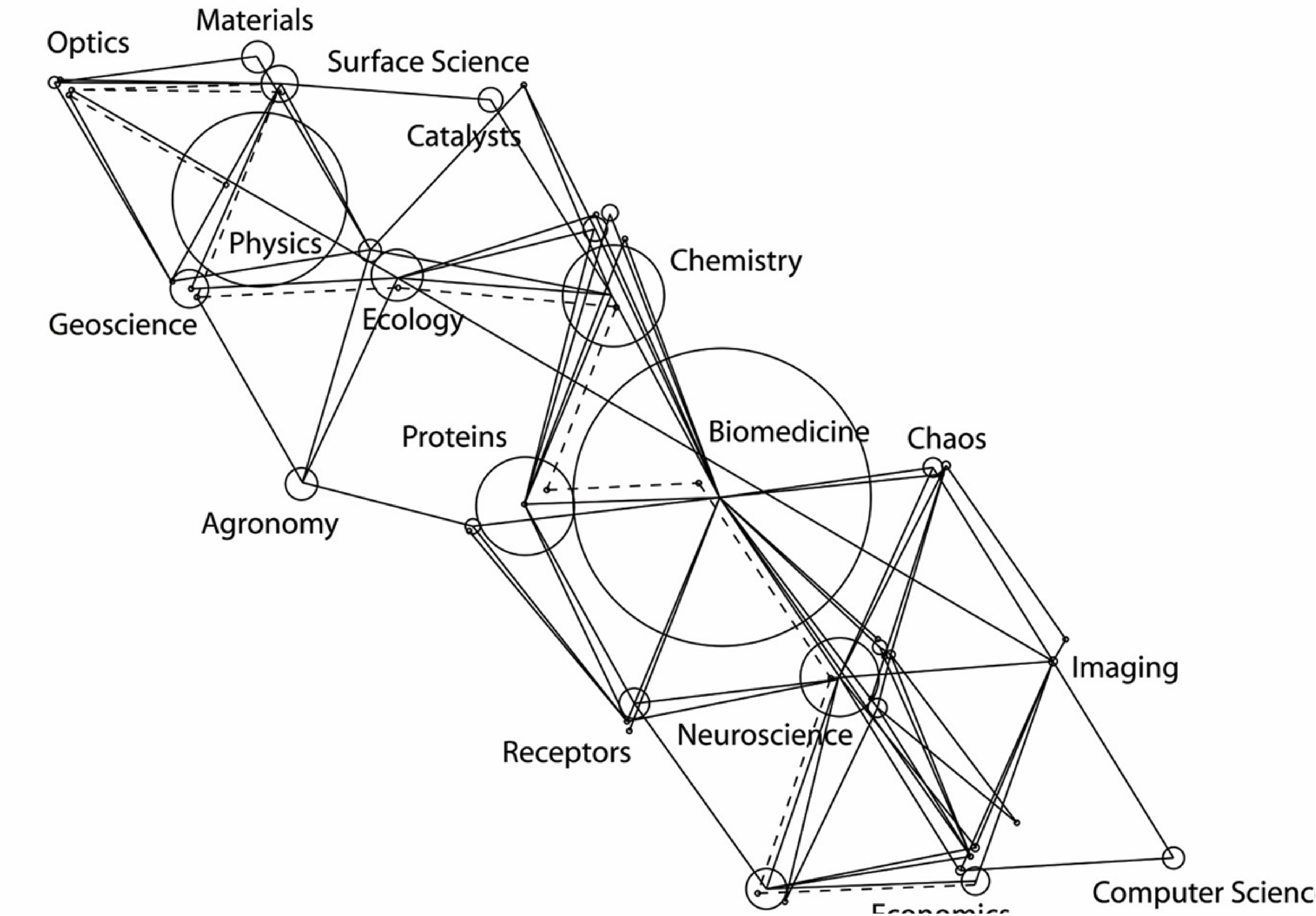


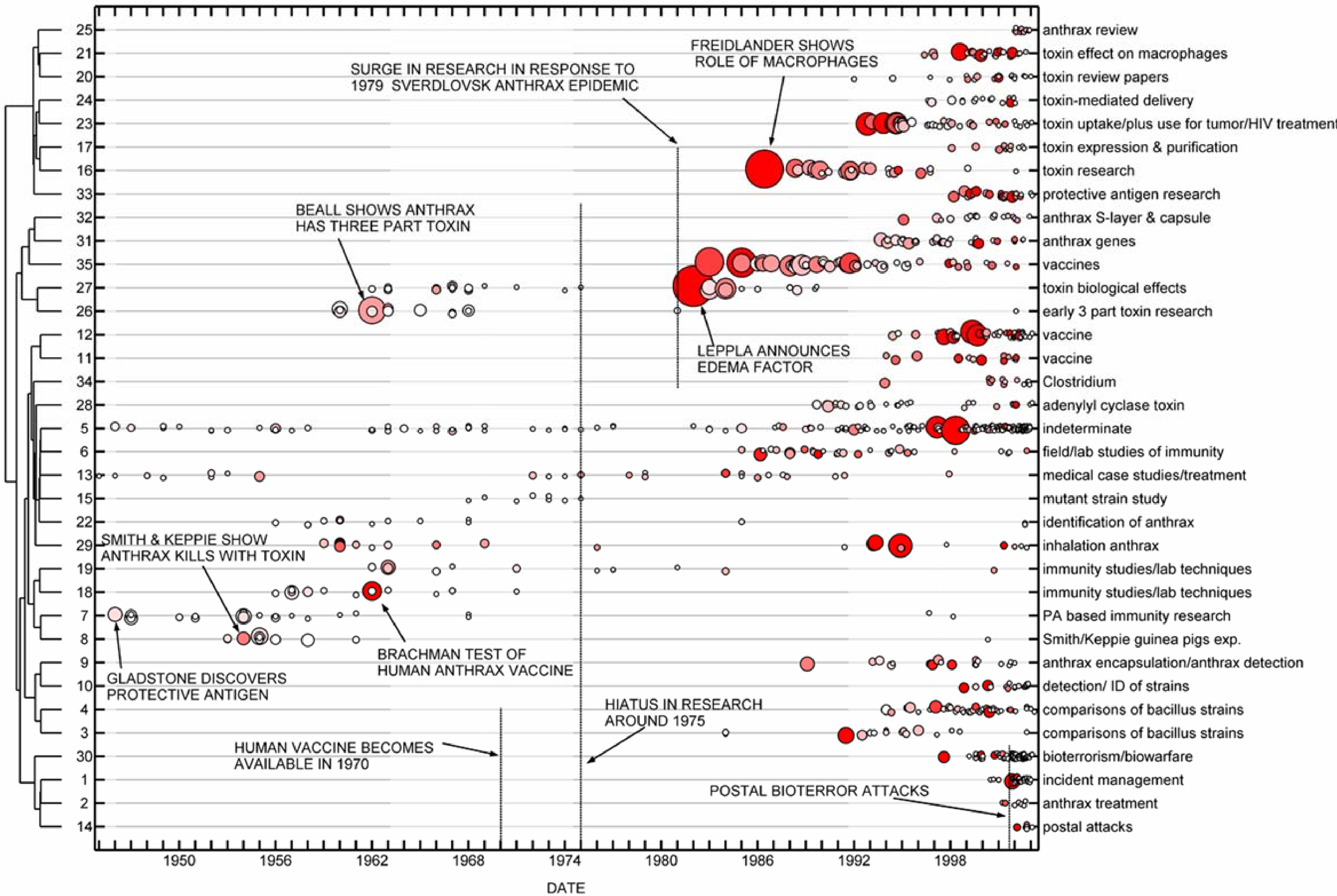
Madeleine de Scudéry (b. 1607-d. 1701), Clélie, histoire romaine, première partie, Paris, 1654.

geography of the 3D role-playing adventure game EverQuest, by 989 Studios. Available at http://www.cybergeography.org/atlas/muds_vw.html

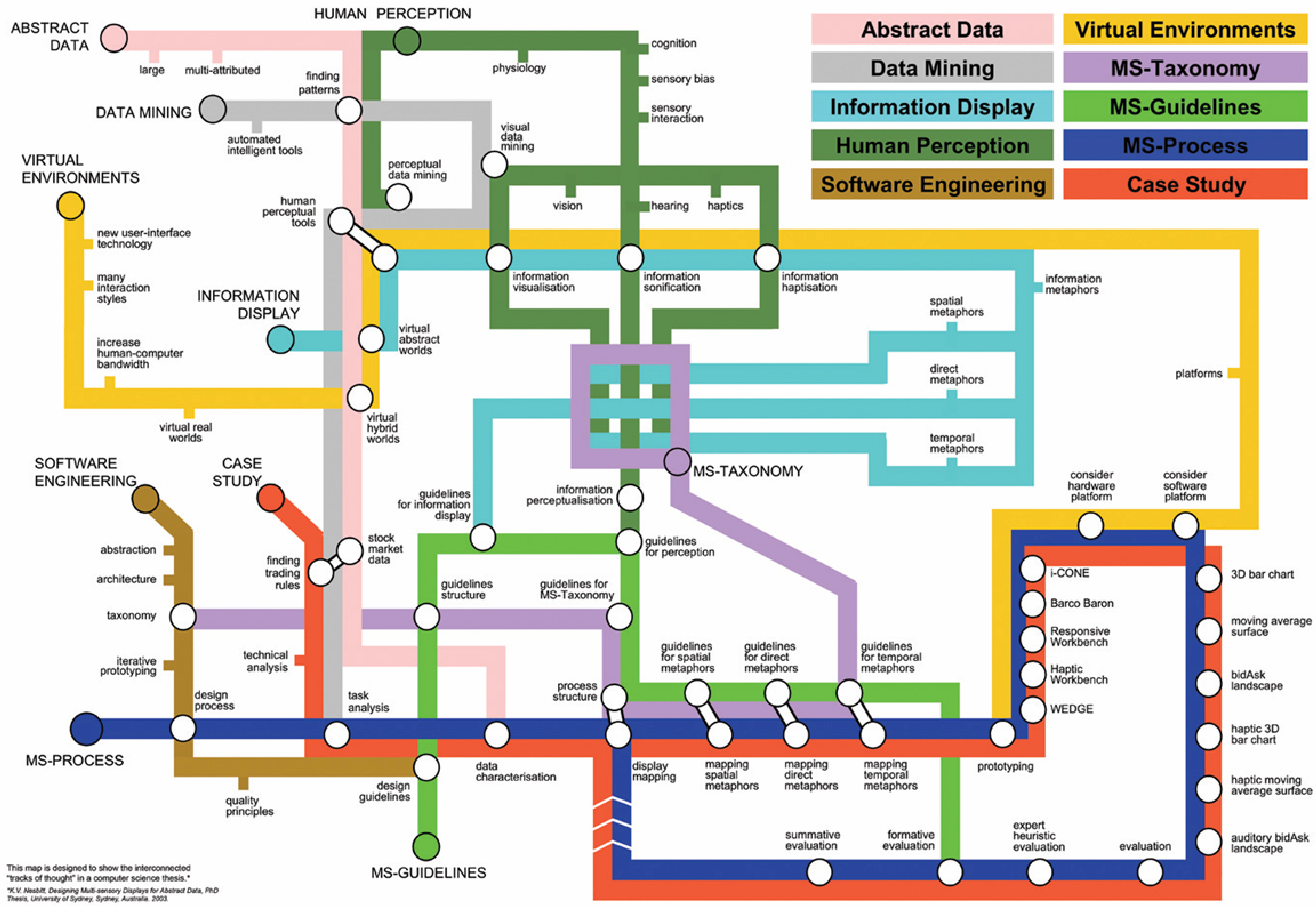
How would a map of science look?

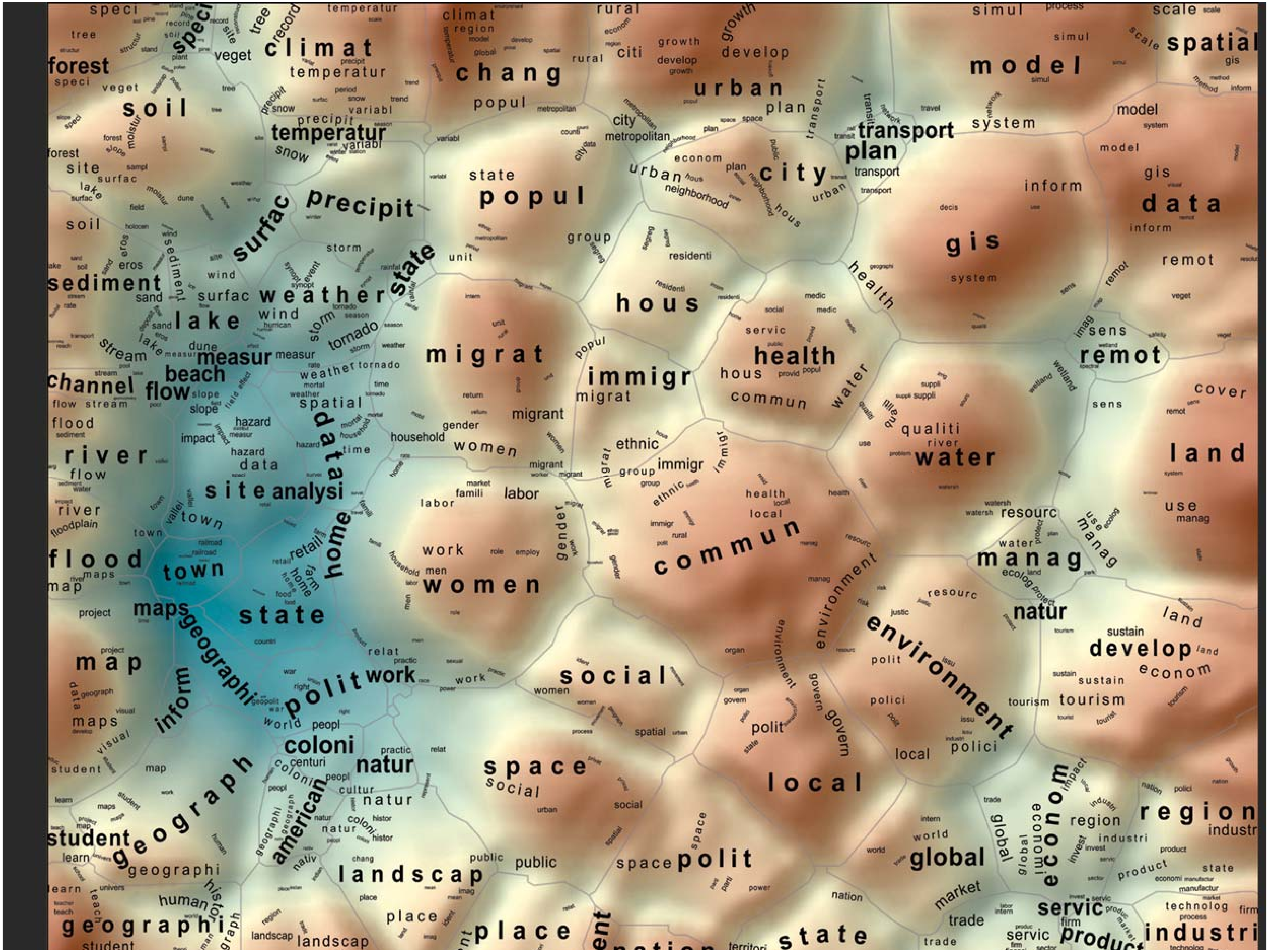
What metaphors would work best?


Materials
Optics
Surface Science
Catalysts
Physics
Chemistry
Geoscience
Ecology
Proteins
Biomedicine
Chaos
Agronomy
Imaging
Neuroscience
Receptors
Computer Scienc



FREIDLANDER SHOWS ROLE OF MACROPHAGES
SURGE IN RESEARCH IN RESPONSE TO 1979 SVERDLOVSK ANTHRAX EPIDEMIC
BEALL SHOWS ANTHRAX HAS THREE PART TOXIN
LEPPLA ANNOUNCES EDEMA FACTOR
SMITH & KEPPIE SHOW ANTHRAX KILLS WITH TOXIN
BRACHMAN TEST OF HUMAN ANTHRAX VACCINE
GLADSTONE DISCOVERS PROTECTIVE ANTIGEN
HIATUS IN RESEARCH AROUND 1975
HUMAN VACCINE BECOMES AVAILABLE IN 1970
POSTAL BIOTERROR ATTACKS
25 anthrax review
21 toxin effect on macrophages
20 toxin review papers
24 toxin-mediated delivery
23 toxin uptake/plus use for tumor/HIV treatment
17 toxin expression & purification
16 toxin research
33 protective antigen research
32 anthrax S-layer & capsule
31 anthrax genes
35 vaccines
27 toxin biological effects
26 early 3 part toxin research
12 vaccine
11 vaccine
34 Clostridium
28 adenylyl cyclase toxin
5 indeterminate
6 field/lab studies of immunity
13 medical case studies/treatment
15 mutant strain study
22 identification of anthrax
29 inhalation anthrax
19 immunity studies/lab techniques
18 immunity studies/lab techniques
7 PA based immunity research
8 Smith/Keppie guinea pigs exp.
9 anthrax encapsulation/anthrax detection
10 detection/ ID of strains
4 comparisons of bacillus strains
3 comparisons of bacillus strains
30 bioterrorism/biowarfare
1 incident management
2 anthrax treatment
14 postal attacks
1950
1956
1962
1968
1974
1980
1986
1992
1998
DATE


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



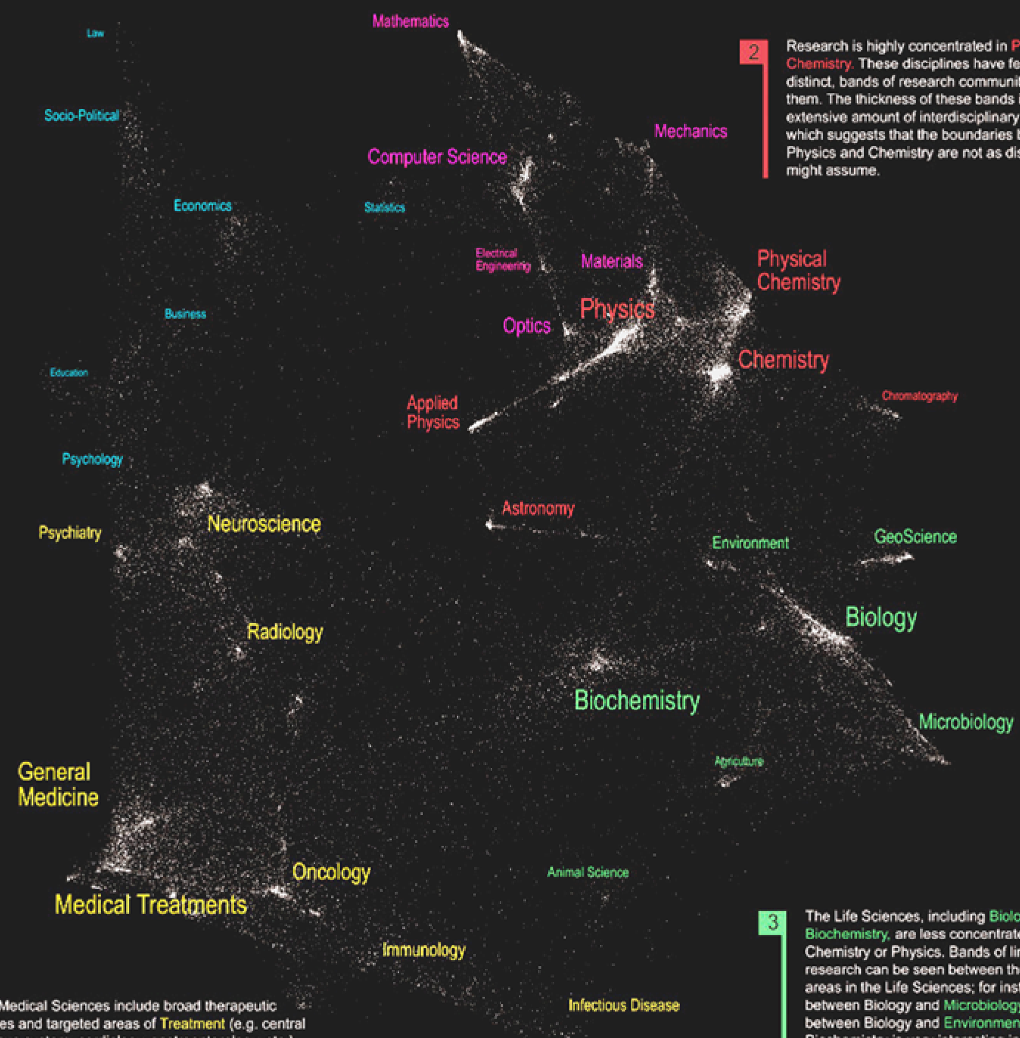
forest
soil
sediment
lake
channel
flow
river
flood
town
map
maps
student
geograph
geographi
climat
temperatur
precipit
surfac
weather
state
measur
beach
site analysi
data
home
polit
coloni
natur
american
landscap
place
chang
popul
migrat
women
work
labor
migrant
immigr
hous
health
commun
social
space
local
polit
environment
urban
city
transport
plan
model
spatial
data
gis
remot
land
water
manag
develop
econom
region
global
servic
industri
product
tourism
polici
govern

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.



4 The Medical Sciences include broad therapeutic studies and targeted areas of Treatment (e.g. central nervous system, cardiology, gastroenterology, etc.) Unlike Physics and Chemistry, the medical disciplines are more spread out, suggesting a more multi-disciplinary approach to research. The transition into Life Sciences (via Animal Science and Biochemistry) is gradual.

3 The Life Sciences, including Biology and Biochemistry, are less concentrated than Chemistry or Physics. Bands of linking research can be seen between the larger areas in the Life Sciences; for instance between Biology and Microbiology, and between Biology and Environmental Science. Biochemistry is very interesting in that it is a large discipline that has visible links to disciplines in many areas of the map, including Biology, Chemistry, Neuroscience, and General Medicine. It is perhaps the most interdisciplinary of the sciences.

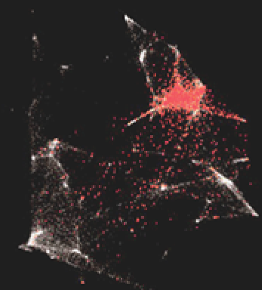
We are all familiar with traditional maps that show the relationships between countries, provinces, states, and cities. Similar relationships exist between the various disciplines and research topics in science. This allows us to map the structure of science.

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

Things are different today. We have enormous computing power and advanced visualization software that make mapping of the structure of science possible. This galaxy-like map of science (left) was generated at Sandia National Laboratories using an advanced graph layout routine (VxOrd) from the citation patterns in 800,000 scientific papers published in 2002. Each dot in the galaxy represents one of the 96,000 research communities active in science in 2002. A research community is a group of papers (9 on average) that are written on the same research topic in a given year. Over time, communities can be born, continue, split, merge, or die.

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

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



Nanotechnology

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

Proteomics

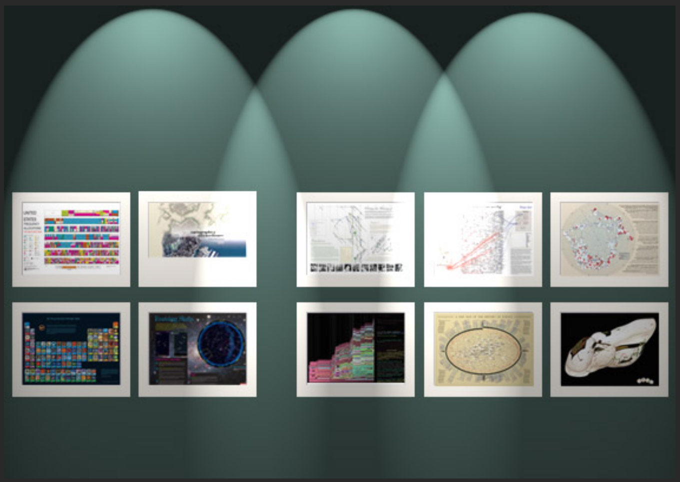
Research communities in proteomics are centered in Biochemistry. In addition, there is a heavy focus in the tools section of chemistry, such as Chromatography. The balance of the proteomics communities are widely dispersed among the Life and Medical Sciences.

Pharmacogenomics

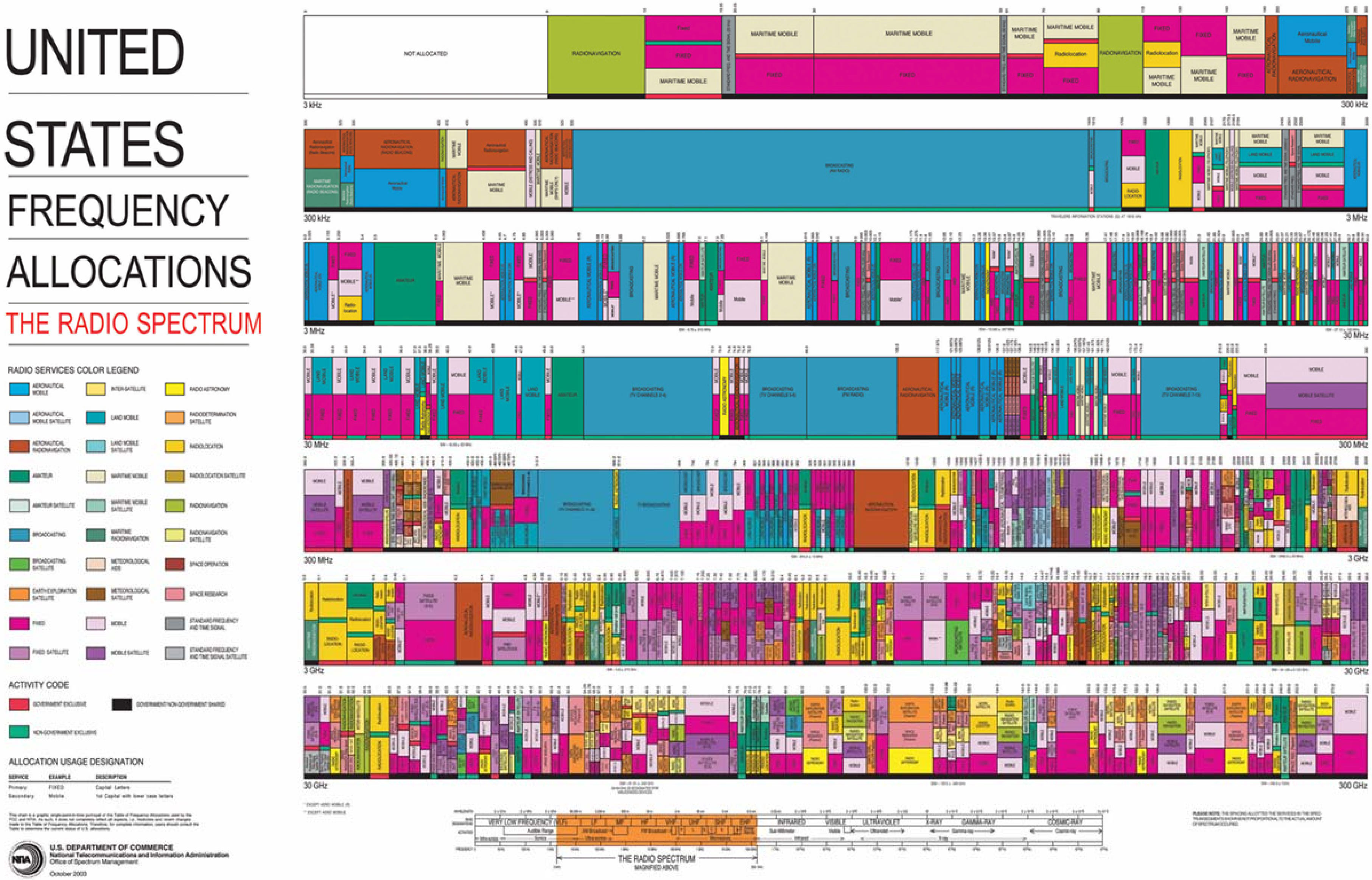
Pharmacogenomics is a relatively new field with most of its activity in Medicine. It also has many communities in Biochemistry and two communities in the Social Sciences.

The Power of Reference Systems

Four Existing Reference Systems
VERSUS
Six Potential Reference Systems of Science



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


UNITED STATES
FREQUENCY
ALLOCATIONS
THE RADIO SPECTRUM
RADIO SERVICES COLOR LEGEND
ACTIVITY CODE
ALLOCATION USAGE DESIGNATION
U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management
October 2003
3 kHz
300 kHz
3 MHz
30 MHz
300 MHz
3 GHz
30 GHz
300 GHz
NOT ALLOCATED
RADIONAVIGATION
MARITIME MOBILE
FIXED
THE RADIO SPECTRUM

The Visual Elements Periodic Table

This chart shows the 111 currently known and officially named elements that comprise the Periodic Table (IUPAC 2004). Each element is represented visually by an image produced for the Visual Elements project.

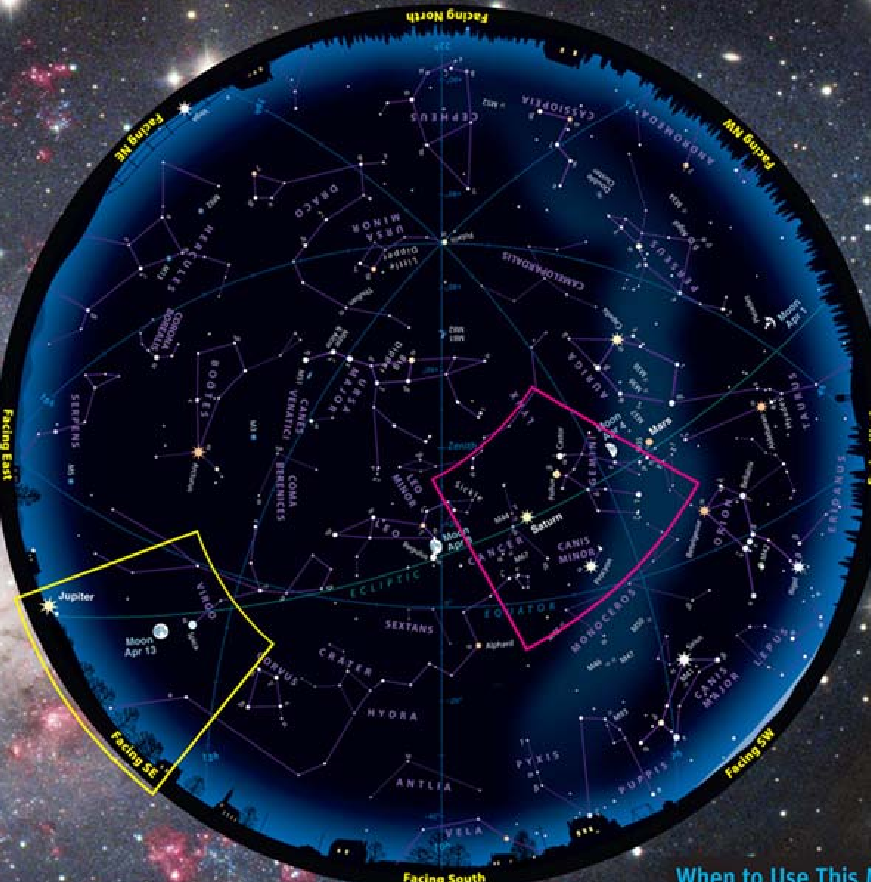
The Periodic Table is an arrangement of all known elements in order of increasing atomic number. The Periodic Table fits all the elements, with their widely diverse physical and chemical properties, into a logical pattern. There are eighteen vertical columns in the table which divide the elements into groups. Elements within a group have closely related physical properties. Horizontal rows list the elements in order of their increasing mass and are called series or periods. Properties of elements change in a systematic way through a period.

Visual Elements is an arts and science collaborative project supported by the Royal Society of Chemistry which aims to explore and reflect upon the diversity of elements that comprise matter in as unique and innovative manner as possible. All the images displayed here, together with screensavers, postcards and chemical data for each element can be viewed on the Visual Elements web site, hosted by the RSC.

Visit the periodic table on the web at:
www.chemsoc.org/viselements

Evening Stars

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



How to Use a Sky Map

1. **Check the dates and times at right.** Take your map out under the night sky around the right time, and bring along a flashlight to read it by. It helps to attach a piece of red paper over the front or to use a flashlight with red LEDs; the dim red light won't spoil your night vision.

2. **Outside, you need to know which direction you're facing.** (If you're unsure, just note where the Sun sets; that's west.) Whichever way you're facing, make sure the corresponding yellow label along the curved edge of the map is at the bottom, right-side up.

This curved edge represents the horizon. The stars above it on the map match the stars in front of you. The farther up from the map's edge they appear, the higher they'll be in the sky.

The center of the map is the zenith (straight overhead). So a star halfway from the edge of the map to the center will appear halfway from straight ahead to straight up. Ignore all the parts of the map above horizons you're not facing.

3. **Let's give it a try!** Pretend you're facing the southwest horizon (labeled "Facing SW"). Just a little way up (that is, a little way in from the edge of the map) is Sirius, the brightest star in the night sky, in the constellation Canis Major. Farther up, nearly halfway overhead, is the star Procyon in Canis Minor. Still farther up is the ringed planet Saturn. Go out at the right time, face southwest, and look up into the sky — there they are!

Tips

A couple of tips: Look for the brightest stars and constellations first; light pollution or moonlight may wash out the fainter ones. And remember that star patterns in the sky will look a lot bigger than they do here on paper.

With a map like this, you can identify celestial sights all over the sky. Go out the next clear night and make some starry friends!

You can customize a night-sky map for any time and place at SkyandTelescope.com.

When to Use This Map

Early April: 10 pm (daylight-saving time)
Late April: Dusk

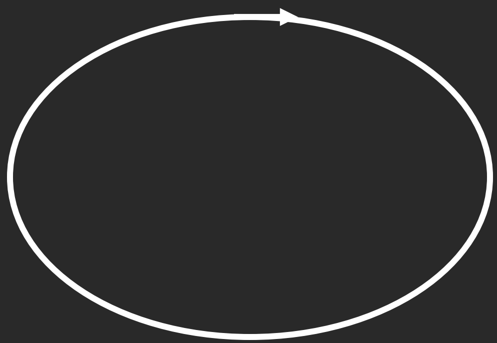
SKY & TELESCOPE

How would a reference system for all of science look?

What dimensions would it have?

Reference Systems

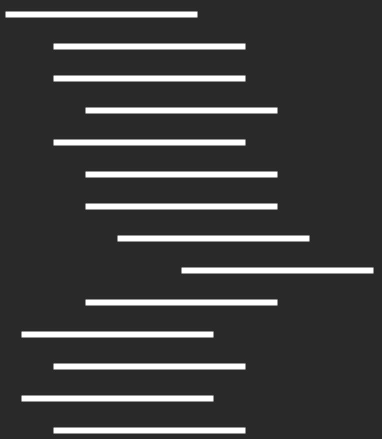
1D



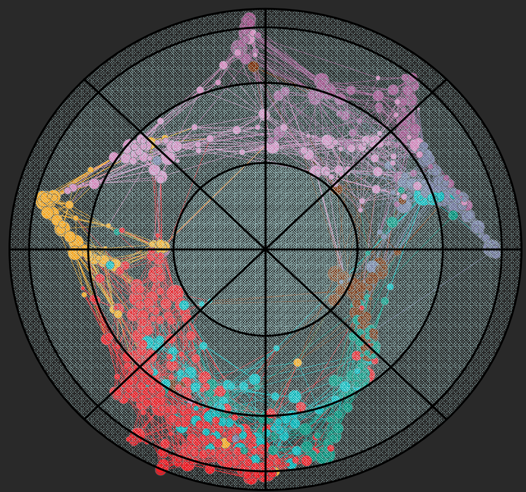
Circular

Geo Map

2D



Hierarchy



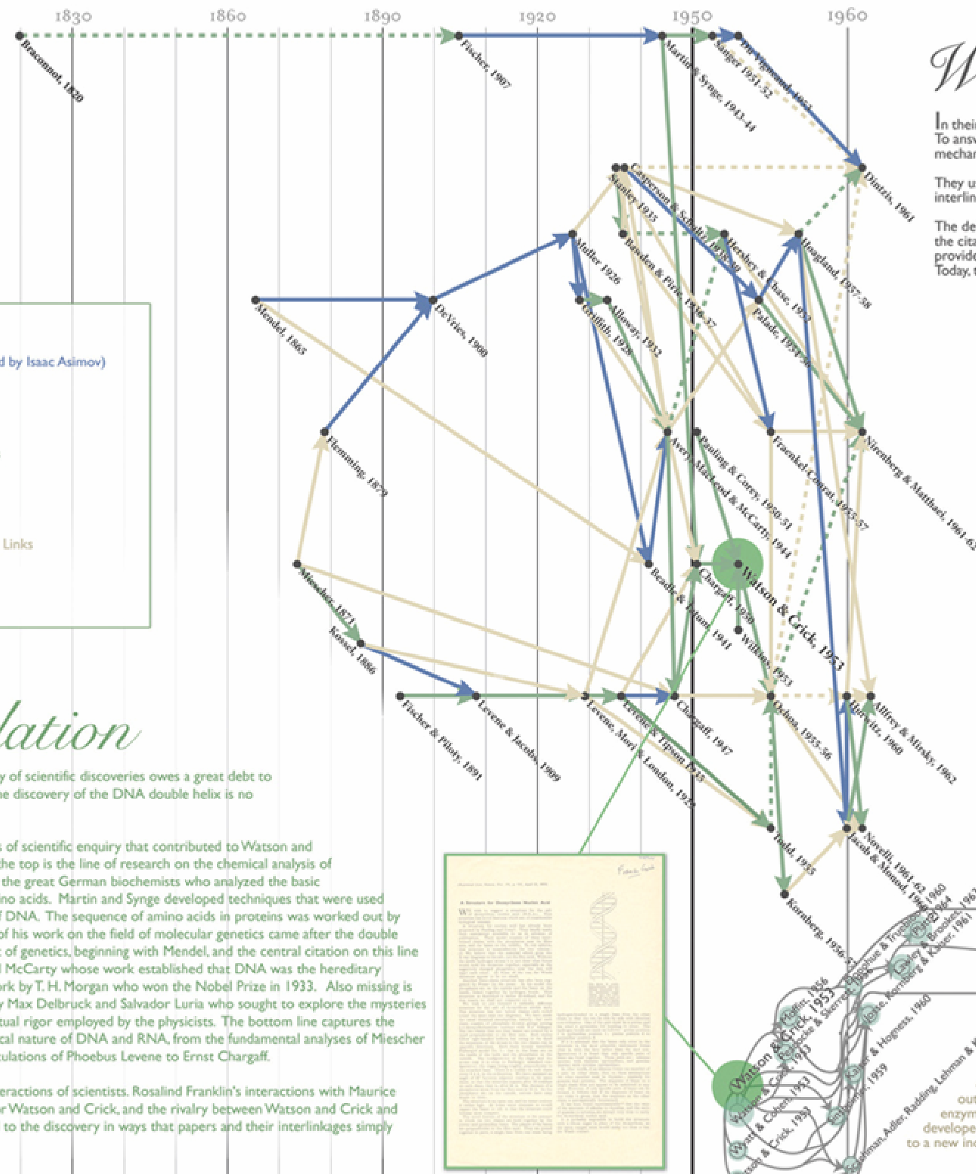
Semantic Map

Writing the History of Science

In their 1964 paper, Eugene Garfield and his colleagues try to answer the question: Can a computer write the history of science? To answer this question, they selected a recent scientific breakthrough – the discovery of a structure for DNA suggesting a mechanism for its self-duplication – published by Watson & Crick in 1953.

They use Isaac Asimov's book *The Genetic Code* to identify forty milestone works that lead to the discovery as well as their interlinkages. In addition, they identify the citation linkages among those forty papers using the *1961 Science Citation Index*.

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



LINK COLOR

Historical Links (Identified by Isaac Asimov)
- explicit
- implicit

Coincident Citation Links
- explicit
- implicit

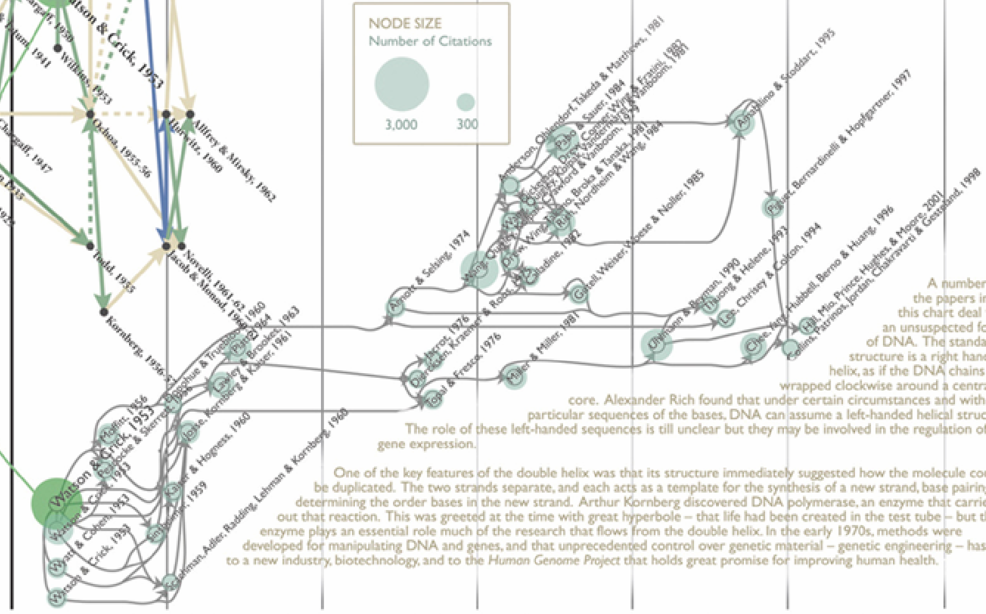
Non-Coincident Citation Links
- explicit
- implicit

Impact

Hardly a day goes by when we do not read of the gene for this or that disease, or see DNA fingerprinting on a television crime show. There is so much emphasis on the biological functions of DNA that it is easy to forget that it is a molecule, made of atoms in a particular spatial pattern. Determining the pattern of atoms in DNA was precisely what led to the double helix but the Watson and Crick 1953 paper, and the accompanying papers by Wilkins and Franklin and their colleagues, was not the end of the story. As the chart on the right shows, X-ray crystallographic studies of DNA continued for many years, and a rigorous confirmation of the structure did not come until the 1970s.

Not surprisingly, there were continuing discoveries and some surprises. One was that not all DNA was double stranded. Robert Sinsheimer found that a small bacteriophage – a virus that attacks bacteria – had a single DNA strand. Many years later, this bacteriophage played an important role when techniques were developed to sequence, to determine the order of the bases in DNA.

NODE SIZE
Number of Citations
3,000 300



A number of the papers in this chart deal with an unsuspected form of DNA. The standard structure is a right handed helix, as if the DNA chains are wrapped clockwise around a central core. Alexander Rich found that under certain circumstances and with particular sequences of the bases, DNA can assume a left-handed helical structure. The role of these left-handed sequences is till unclear but they may be involved in the regulation of gene expression.

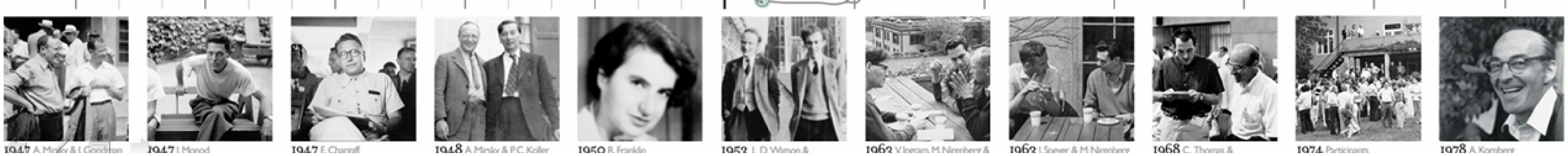
One of the key features of the double helix was that its structure immediately suggested how the molecule could be duplicated. The two strands separate, and each acts as a template for the synthesis of a new strand, base pairing determining the order bases in the new strand. Arthur Kornberg discovered DNA polymerase, an enzyme that carried out that reaction. This was greeted at the time with great hyperbole – that life had been created in the test tube – but the enzyme plays an essential role much of the research that flows from the double helix. In the early 1970s, methods were developed for manipulating DNA and genes, and that unprecedented control over genetic material – genetic engineering – has led to a new industry, biotechnology, and to the *Human Genome Project* that holds great promise for improving human health.

Foundation

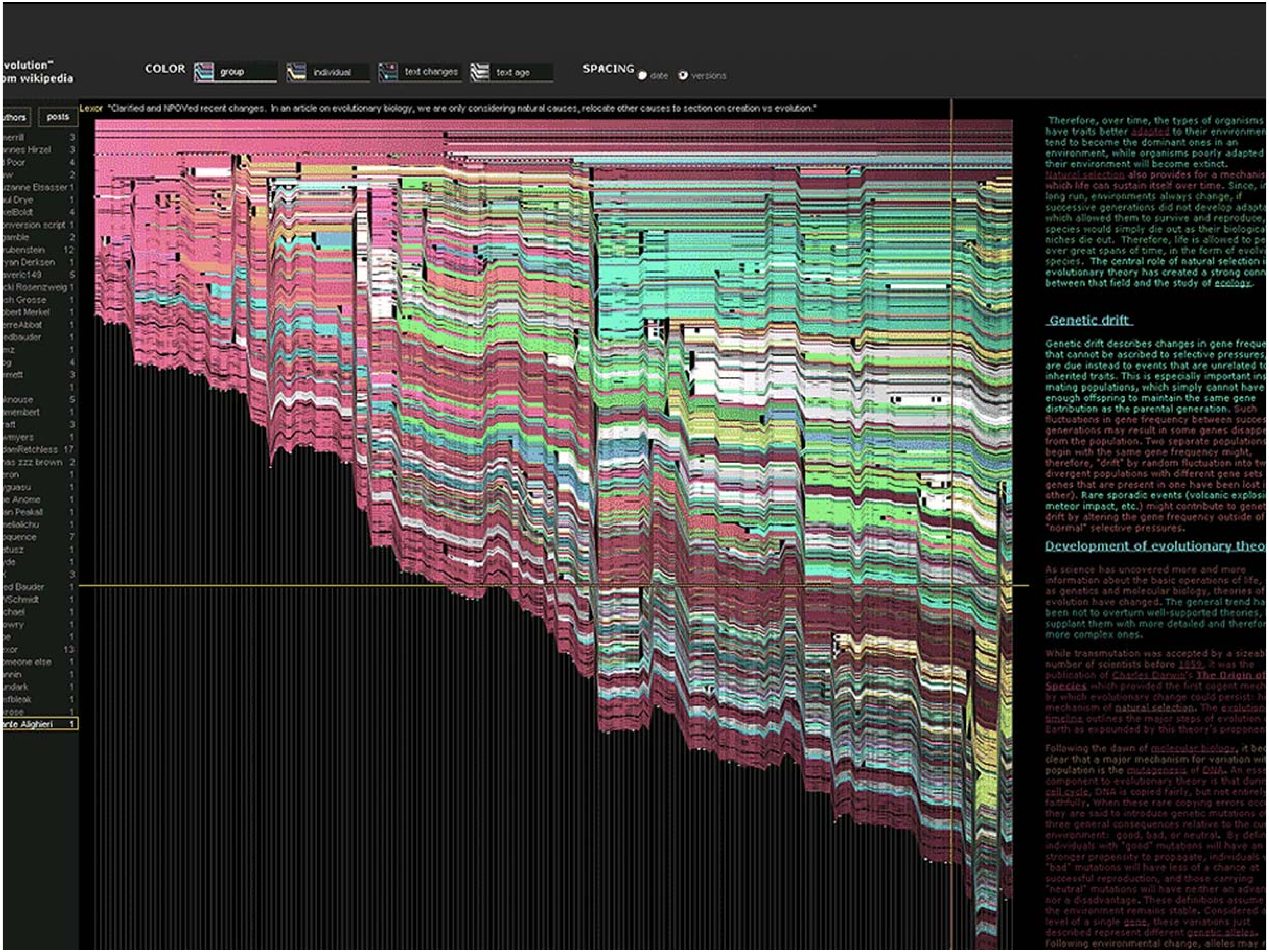
Even the most revolutionary of scientific discoveries owes a great debt to what has gone before, and the discovery of the DNA double helix is no exception.

This chart shows major lines of scientific enquiry that contributed to Watson and Crick's insight in 1953. On the top is the line of research on the chemical analysis of proteins. Fischer was one of the great German biochemists who analyzed the basic components of proteins, amino acids. Martin and Synge developed techniques that were used by Chargaff in his analyses of DNA. The sequence of amino acids in proteins was worked out by Fred Sanger, but the impact of his work on the field of molecular genetics came after the double helix. The central line is that of genetics, beginning with Mendel, and the central citation on this line is that of Avery, Macleod and McCarty whose work established that DNA was the hereditary substance. Not shown is work by T. H. Morgan who won the Nobel Prize in 1933. Also missing is the Phage Group, founded by Max Delbruck and Salvador Luria who sought to explore the mysteries of the gene with the intellectual rigor employed by the physicists. The bottom line captures the earliest studies of the chemical nature of DNA and RNA, from the fundamental analyses of Miescher and Kossel, through the speculations of Phoebus Levene to Ernst Chargaff.

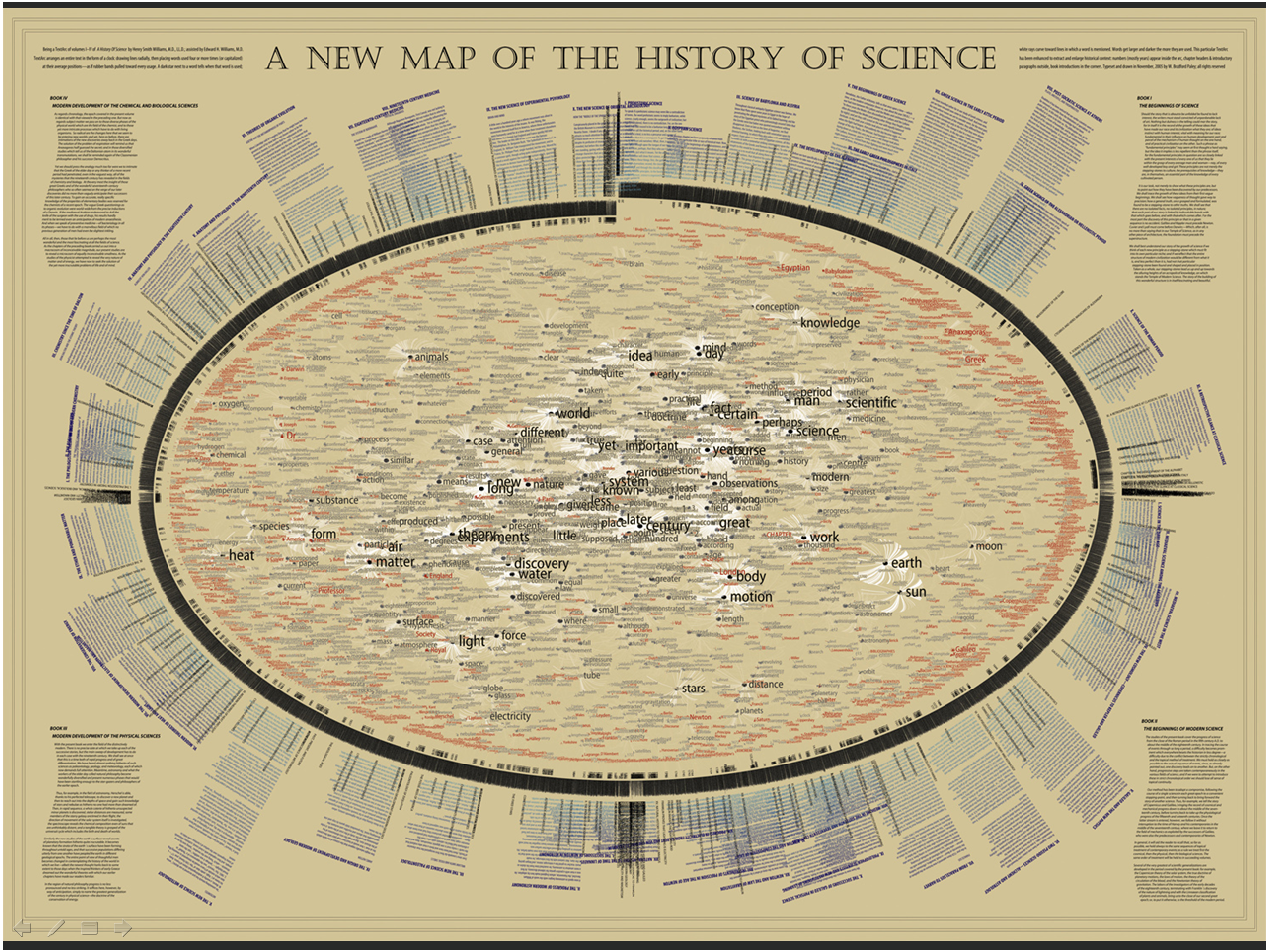
Not visible are the social interactions of scientists. Rosalind Franklin's interactions with Maurice Wilkins, Chargaff's disdain for Watson and Crick, and the rivalry between Watson and Crick and Linus Pauling, all contributed to the discovery in ways that papers and their interlinkages simply cannot reveal.



1947 A. Mirsky & I. Goodman · 1947 J. Monod · 1947 E. Chargaff · 1948 A. Mirsky & P.C. Koller · 1950 R. Franklin · 1953 J. D. Watson & · 1963 V. Ingram, M. Nirenberg & · 1963 I. Spever & M. Nirenberg · 1968 C. Thomas & · 1974 Participants · 1978 A. Kornberg



COLOR
group
individual
text changes
text age
SPACING
date
versions
posts
Lexor "Clarified and NPOVed recent changes. In an article on evolutionary biology, we are only considering natural causes, relocate other causes to section on creation vs evolution."
Genetic drift



A NEW MAP OF THE HISTORY OF SCIENCE
Being a Textile of volumes I–IV of A History Of Science by Henry Smith Williams, M.D., LL.D.; assisted by Edward H. Williams, M.D. Textiles arranges an entire text in the form of a clock: drawing lines radially, then placing words used four or more times (or capitalized) at their average positions—as if rubber bands pulled toward every usage. A dark star next to a word tells when that word is used;
white rays curve toward lines in which a word is mentioned. Words get larger and darker the more they are used. This particular Textile has been enhanced to extract and enlarge historical context: numbers (mostly years) appear inside the arc, chapter headers & introductory paragraphs outside, book introductions in the corners. Typeset and drawn in November, 2005 by W. Bradford Paley; all rights reserved
BOOK IV
MODERN DEVELOPMENT OF THE CHEMICAL AND BIOLOGICAL SCIENCES
BOOK I
THE BEGINNINGS OF SCIENCE
BOOK III
MODERN DEVELOPMENT OF THE PHYSICAL SCIENCES
BOOK II
THE BEGINNINGS OF MODERN SCIENCE
knowledge
idea
mind
day
world
fact
certain
man
period
scientific
science
different
yet
important
years
course
system
known
various
new
long
nature
modern
observations
theory
experiments
form
air
matter
heat
discovery
water
work
great
century
later
place
little
earth
sun
body
motion
moon
light
force
surface
stars
distance
electricity
substance
species
animals
oxygen
Darwin
Egyptian
Babylonian
Anaxagoras
Greek
Newton
Galileo
London
England

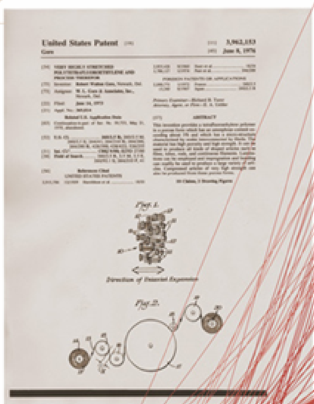
US Patent Hierarchy

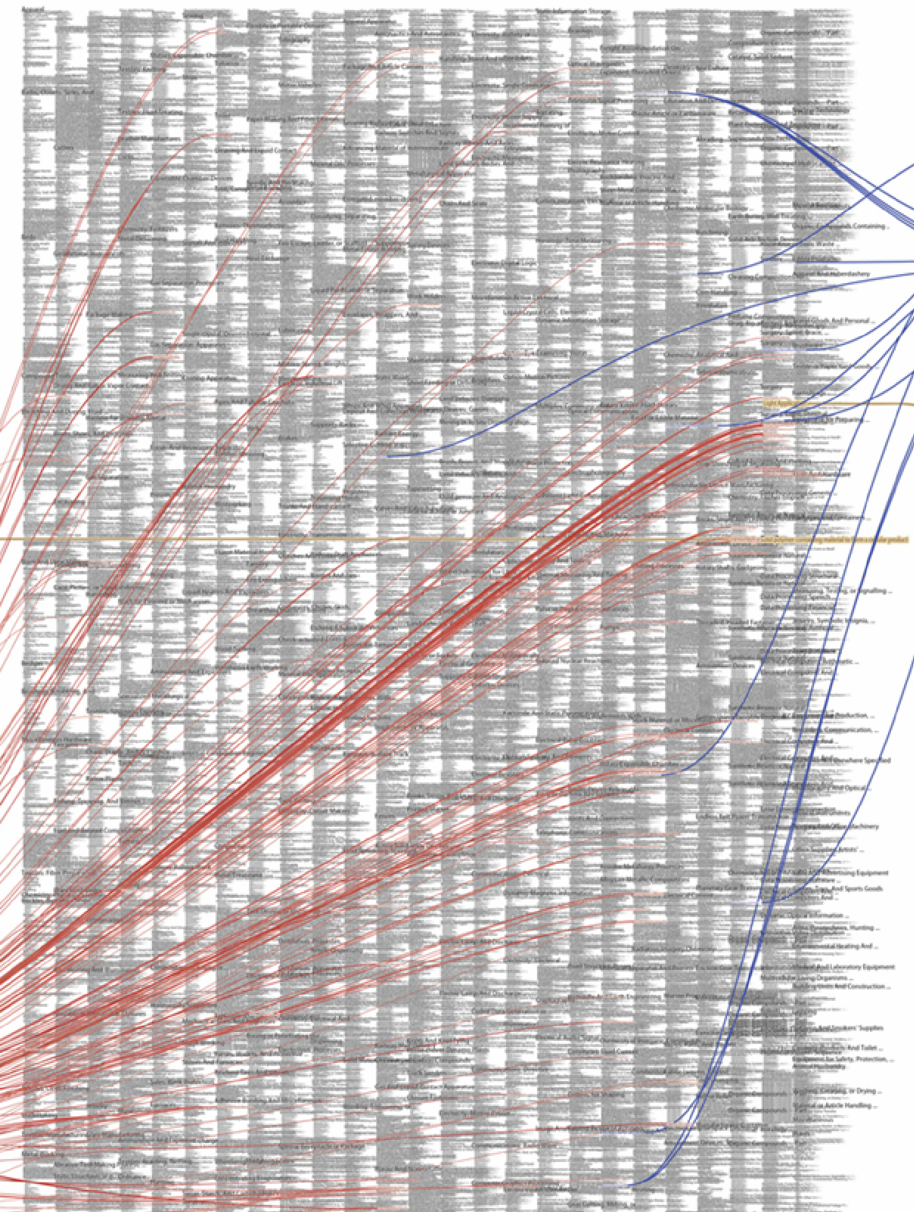
Impact

The United States Patent and Trademark Office does scientists and industry a great service by granting patents to protect inventions. Inventions are categorized in a taxonomy that groups patents by industry or use, proximate function, effect or product, and structure. At the time of this writing there are 160,523 categories in a hierarchy that can get as deep as 15 levels. We display the first three levels (13,529 categories) at right in what might be considered a textual map of inventions.

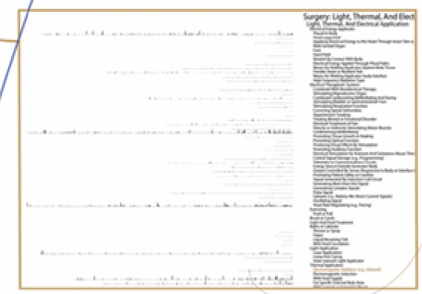
Patent applications are required to be unique and non-obvious, partially by revealing any previous patents that might be similar in nature or provide a foundation for the current invention. In this way we can trace the impact of a single patent, seeing how many patents and categories it affects.

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





Prior Art

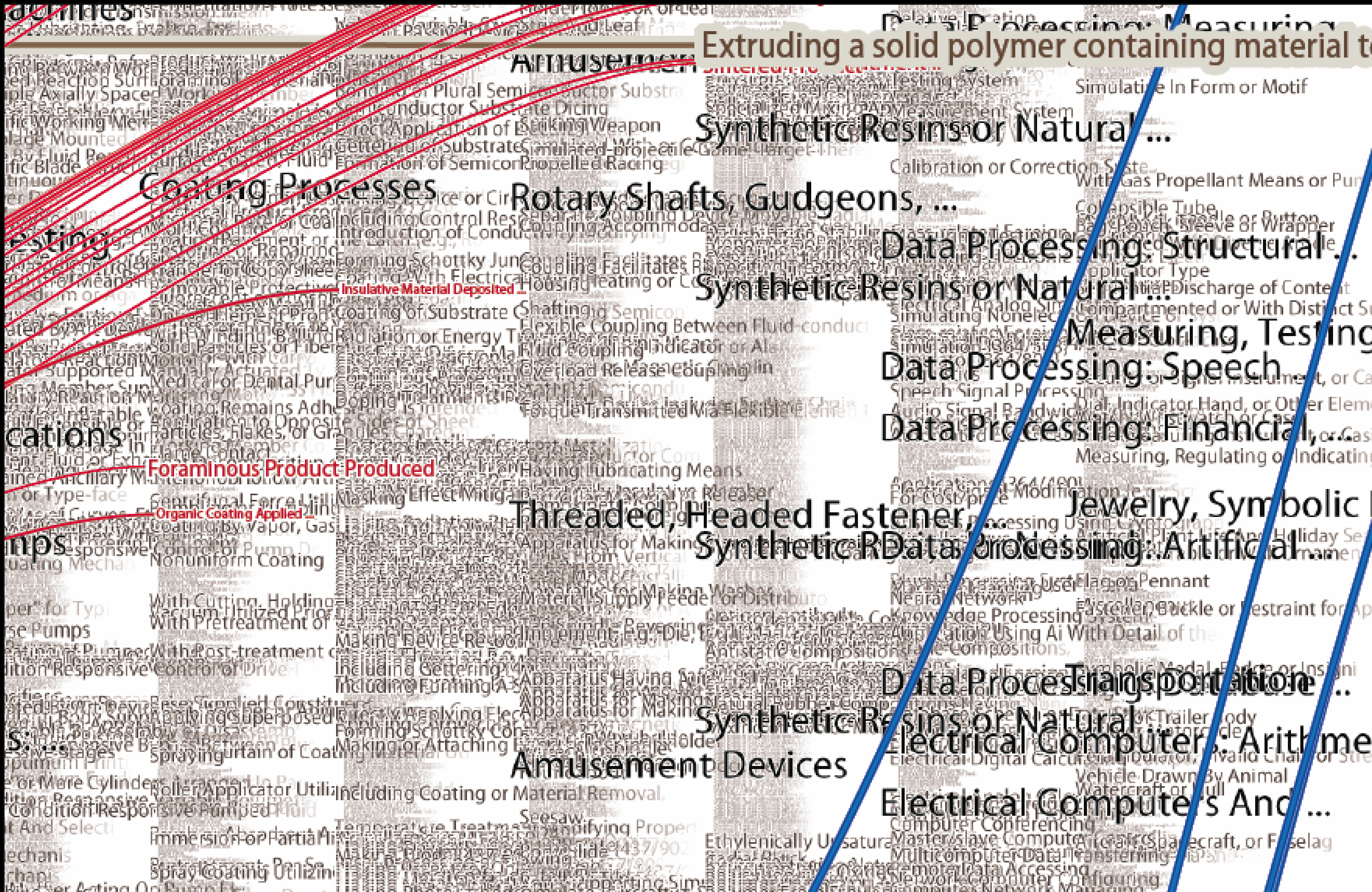


New patents often build on older ideas from many categories. Here, blue lines originate in sixteen different categories that contain the patents cited as prior art for a patent on "gold nanoshells." Gold nanoshells are a new invention: tiny spheres (with a diameter ten million times smaller than a human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

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

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

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


Extruding a solid polymer containing material to
Coating Processes
Rotary Shafts, Gudgeons, ...
Synthetic Resins or Natural ...
Data Processing: Structural ...
Insulative Material Deposited ...
Measuring, Testing
Data Processing: Speech
Data Processing: Financial, ...
Foraminous Product Produced
Organic Coating Applied ...
Jewelry, Symbolic I
Threaded, Headed Fastener, ...
Nonuniform Coating
Transportation
Electrical Computers: Arithmet
Amusement Devices
Electrical Computers And ...

Impact

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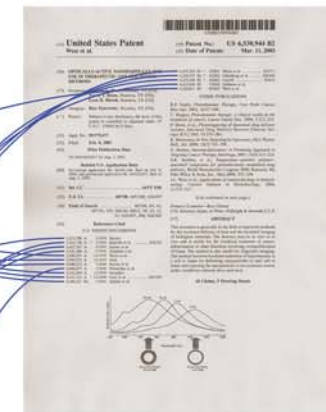

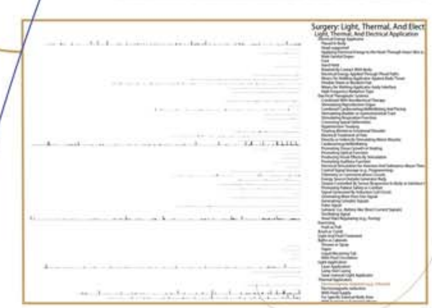

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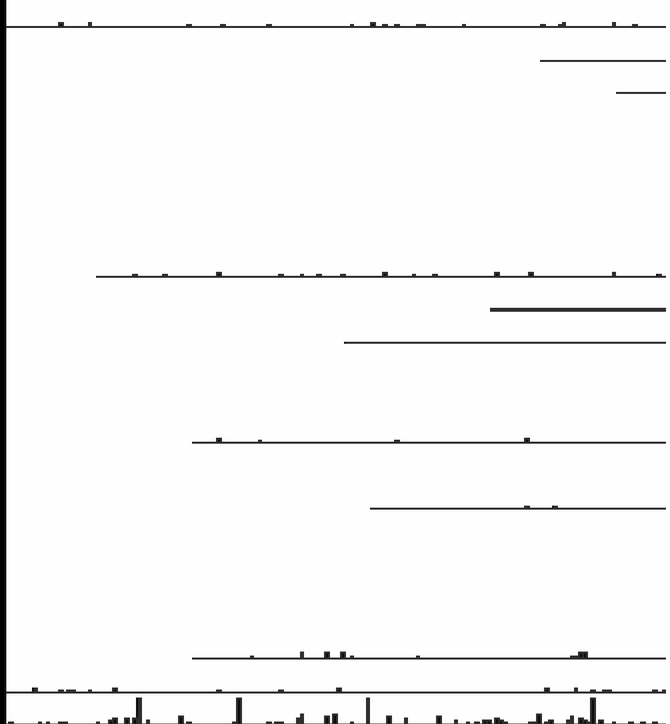
Synthetic Resins or Natural Rubbe

Ion-exchange Polymer or Process of Prepari

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

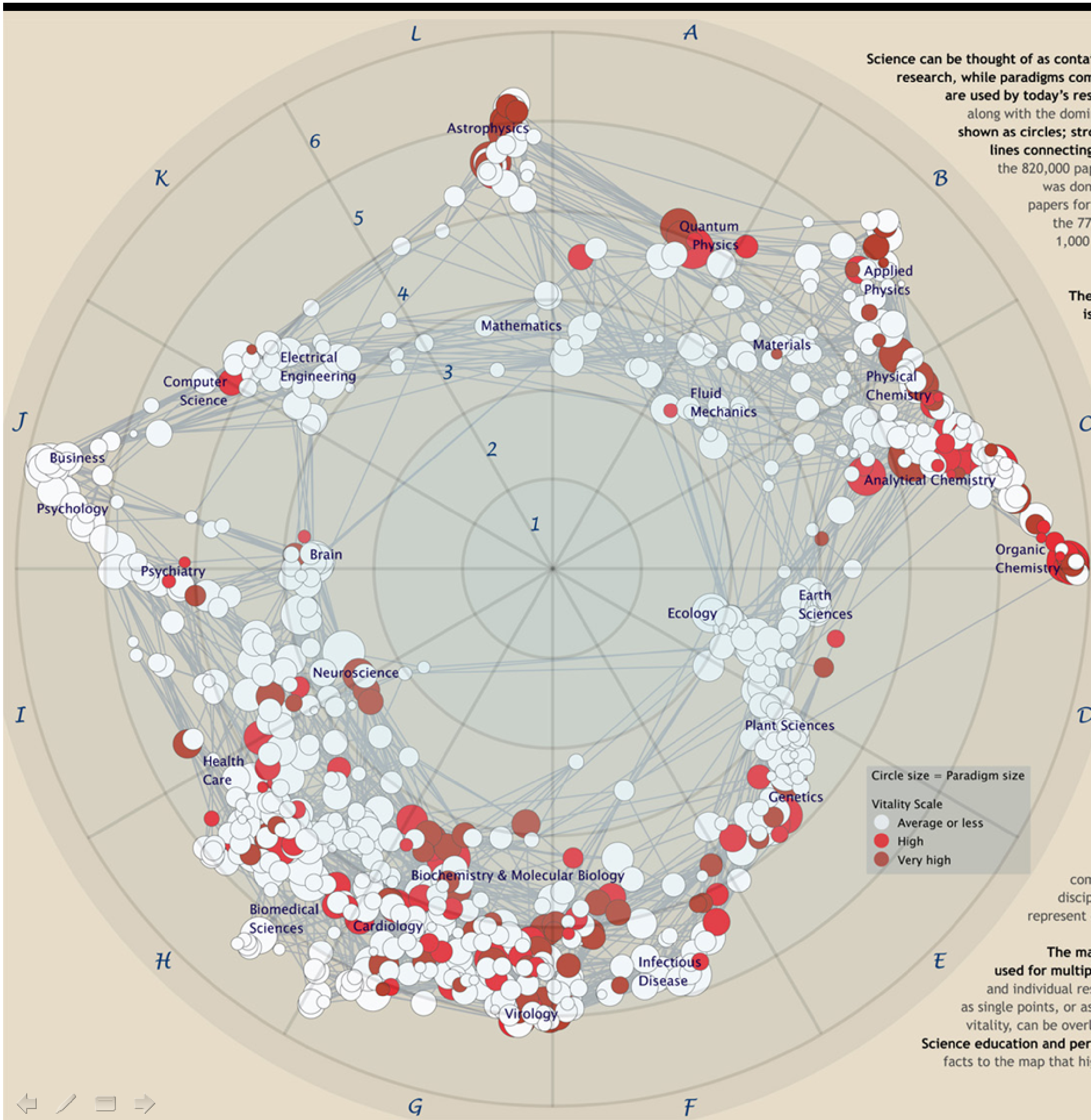


Process of Treating Scrap or Waste Product (

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

Cellular Products or Processes of Preparing /

Cellular Product Derived From Two or More Solid Polymers or Fr
At Least One Polymer Is Derived From Reactant Containing Tw
At Least One Polymer Is Derived From An Aldehyde or Derivat
At Least One Polymer Is Derived From A -n=c=x Reactant Whe



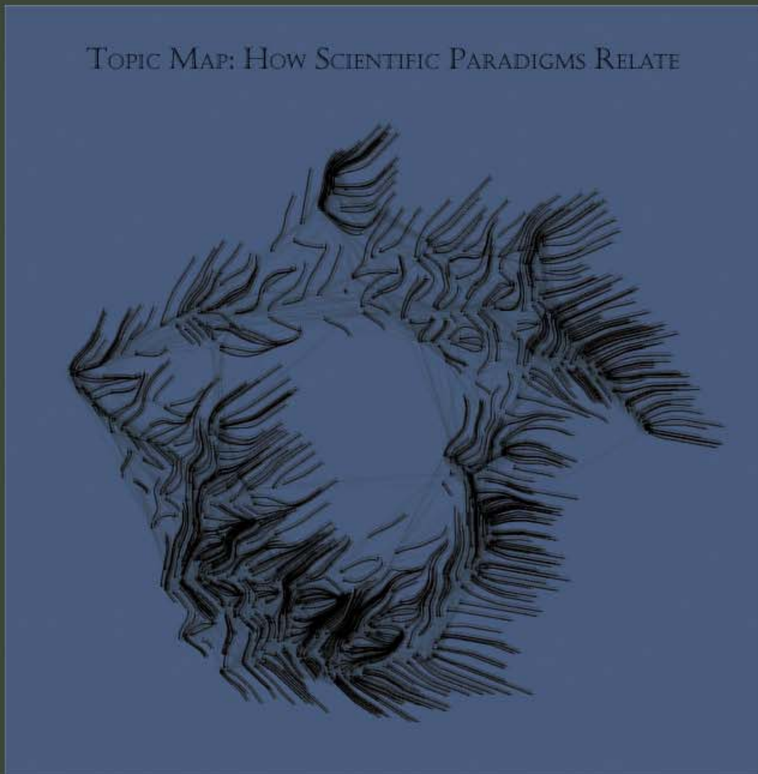
Science can be thought of as containing themes and paradigms. Themes are areas of current research, while paradigms comprise the dominant tool sets and existing knowledge that are used by today's researchers. This map shows **776 major paradigms in science** along with the dominant relationships between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

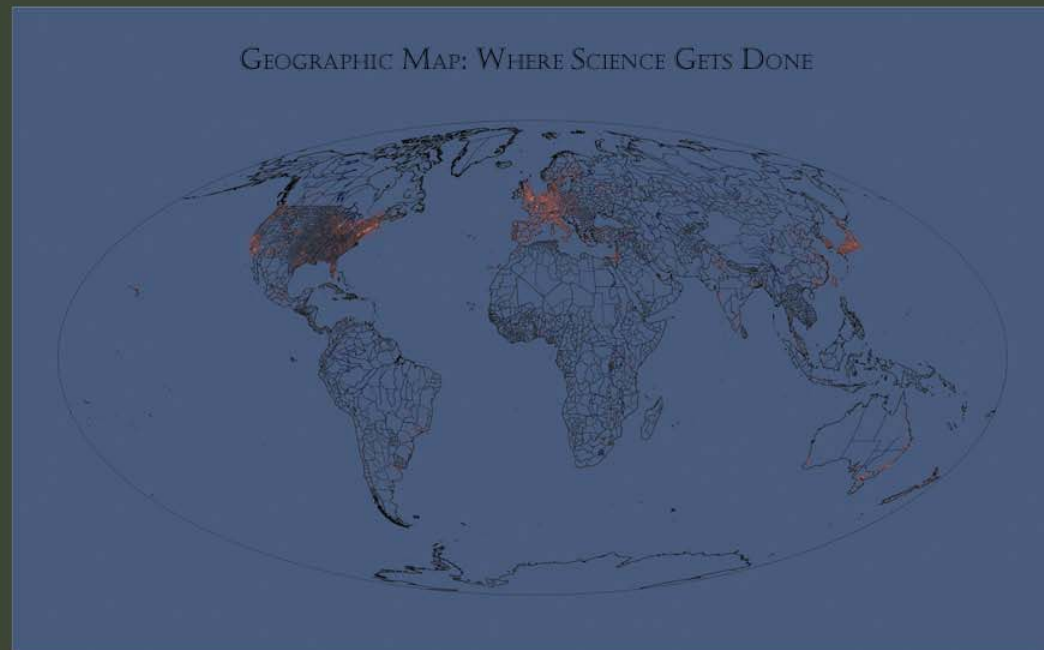
The ring-like structure that is formed by scientific paradigms is very robust. We find similar structures for different years, and for maps generated from scientific journals. "The Structure of Science", a galaxy map shown in the first iteration of Places & Spaces, is a map based on clustering of scientific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

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

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

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





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

Nanotechnology

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

All Topics
Sweep through all 776 scientific paradigms

Nanotechnology
Science on the tiny scale of molecules

Sustainability
The science behind our long-term hopes

Biology & Chemistry
The interface between these two vital fields

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

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

Albert EINSTEIN
Revitalized physics with Relativity theories

Michael E. FISHER
Models critical phase transitions of matter

Susan T. FISKE
Connects perception and stereotypes

Joshua LEDERBERG
Pioneer in bacterial genetic mechanisms

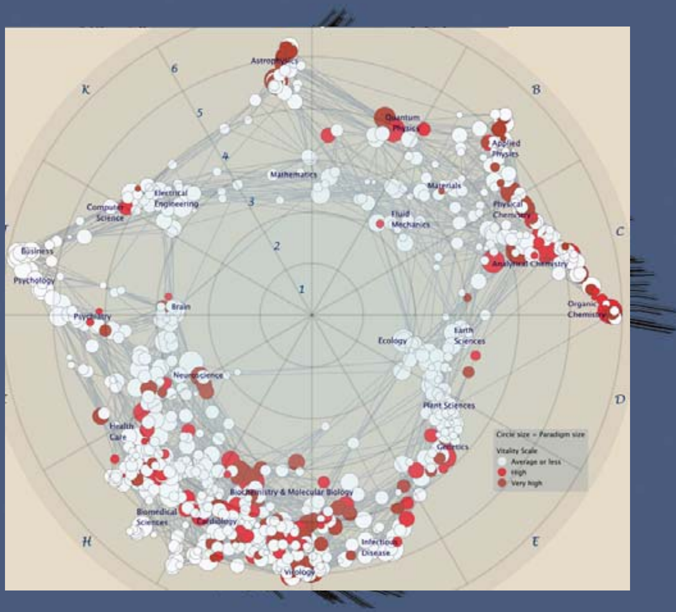
Derek J. de Solla PRICE
Known as the "Father of Scientometrics"

Richard N. ZARE
Uses laser chemistry in molecular dynamics

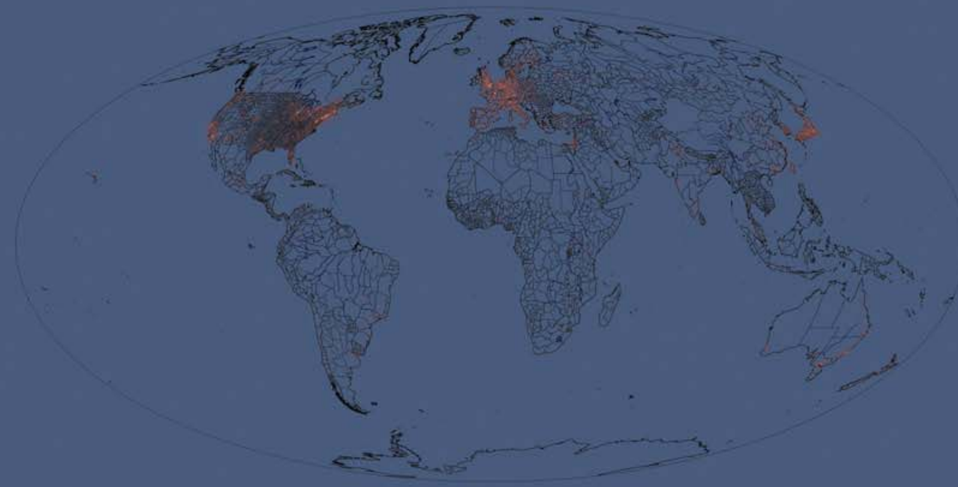
About this display
People & organizations that helped create it

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

Topic Map: How Scientific Paradigms Relate



Geographic Map: Where Science Gets Done



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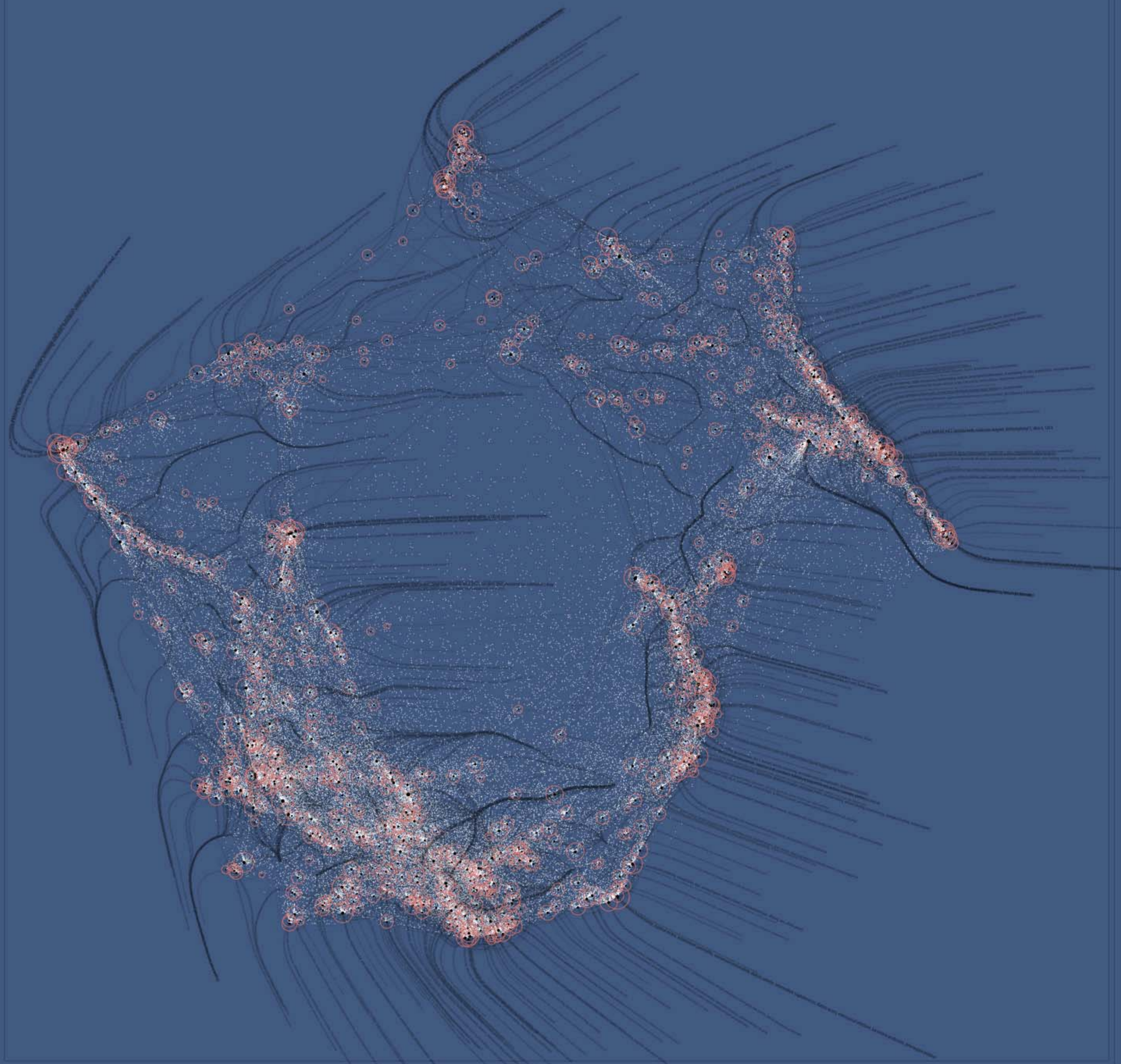
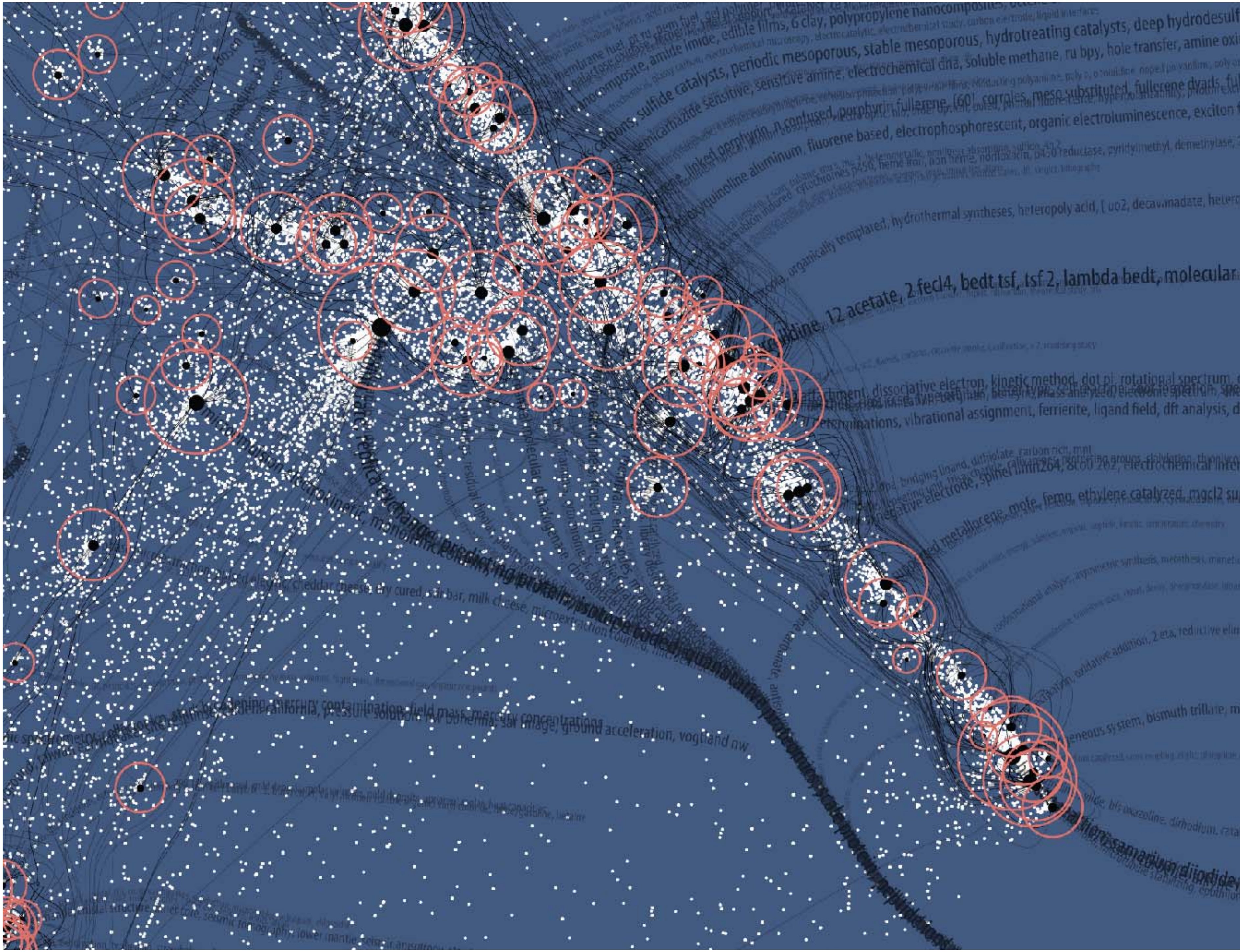
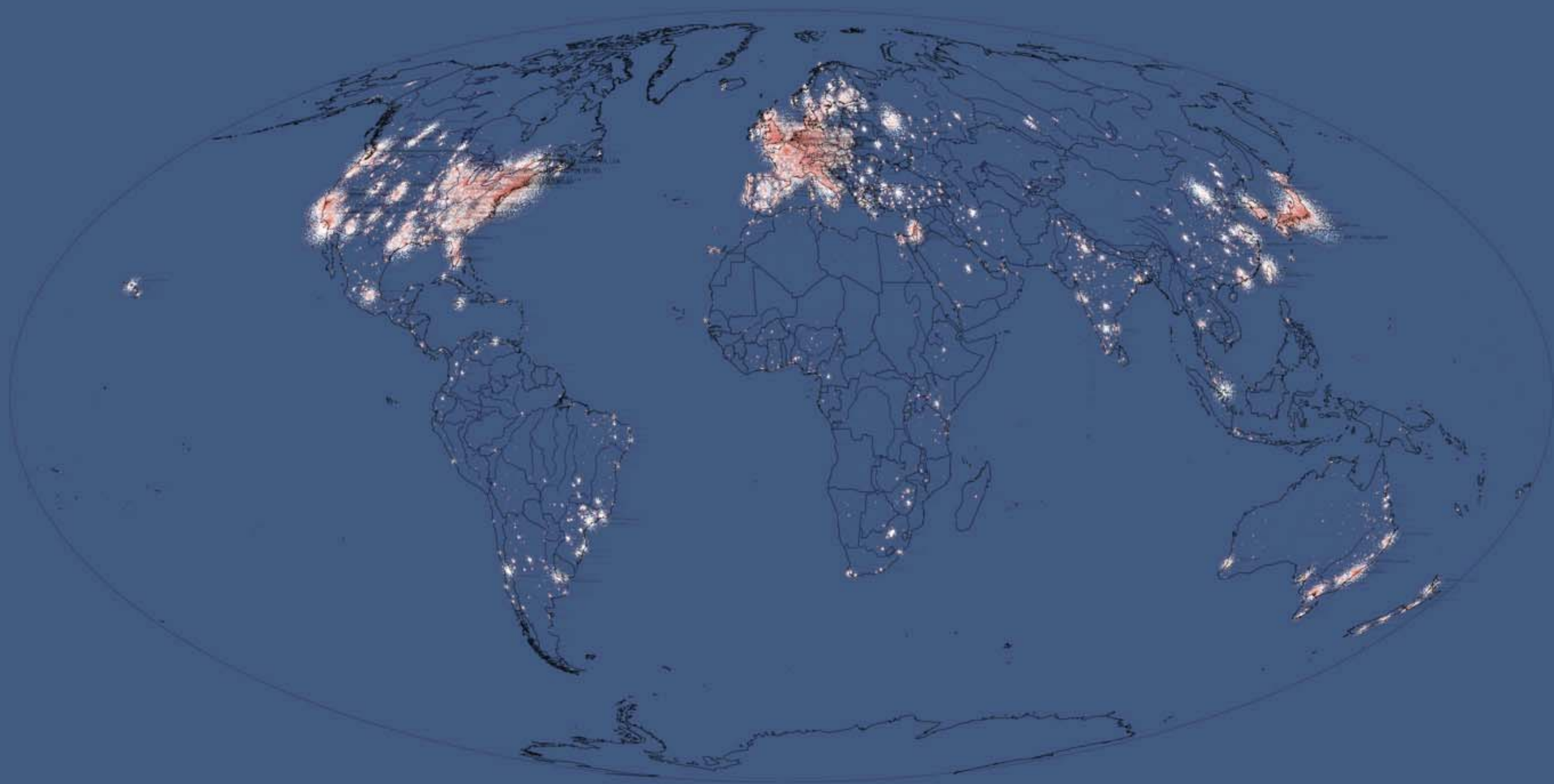
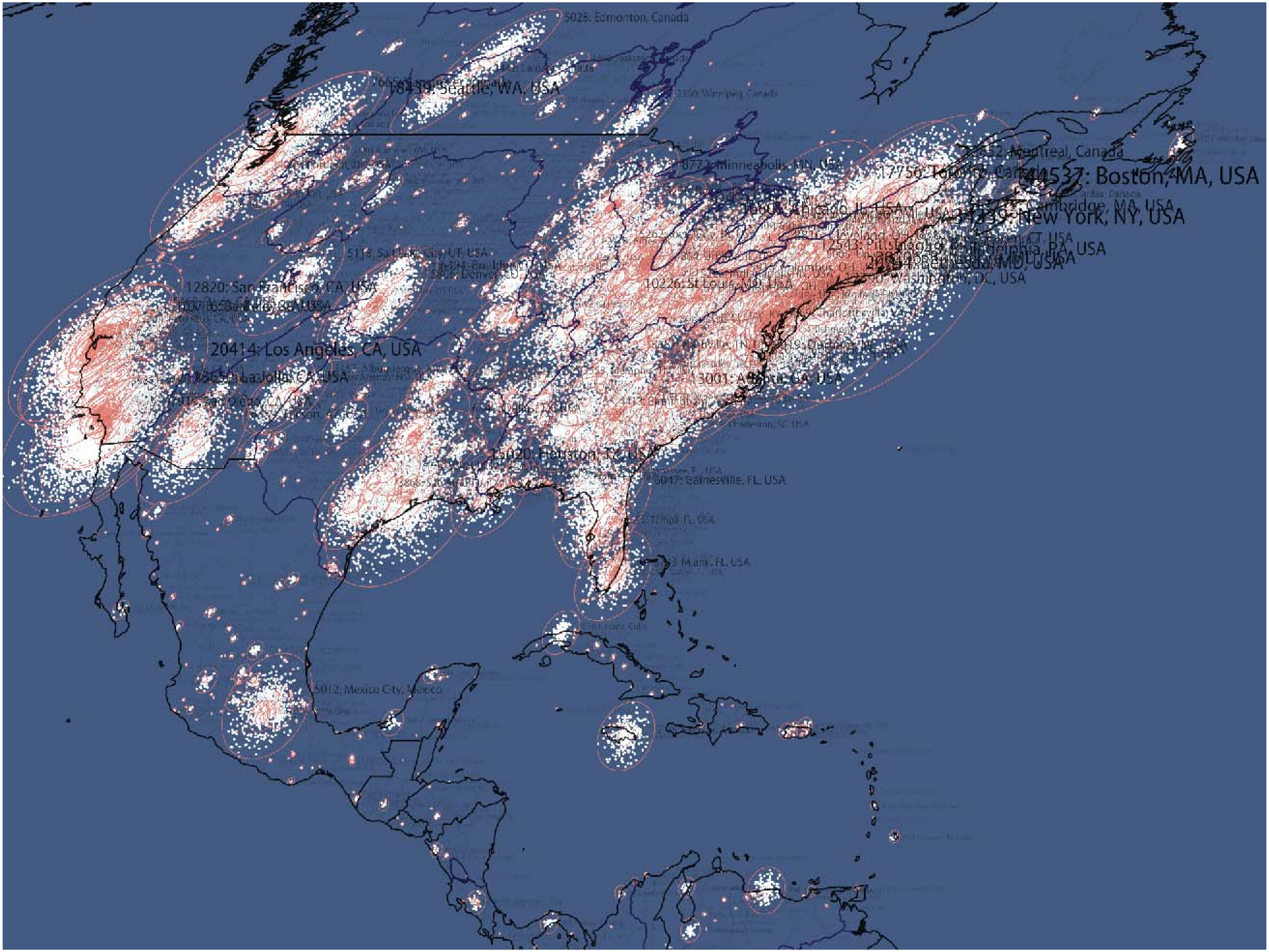
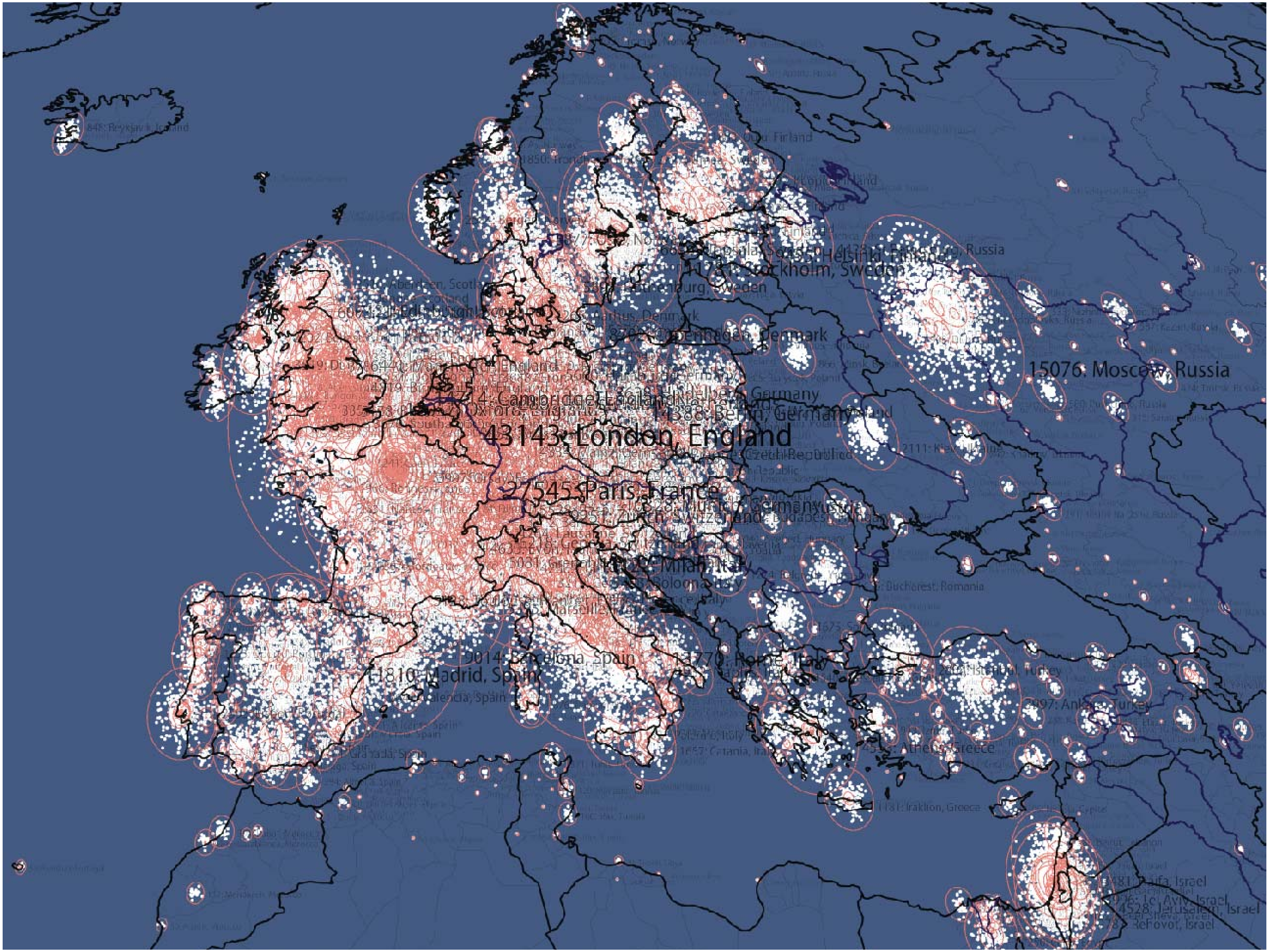


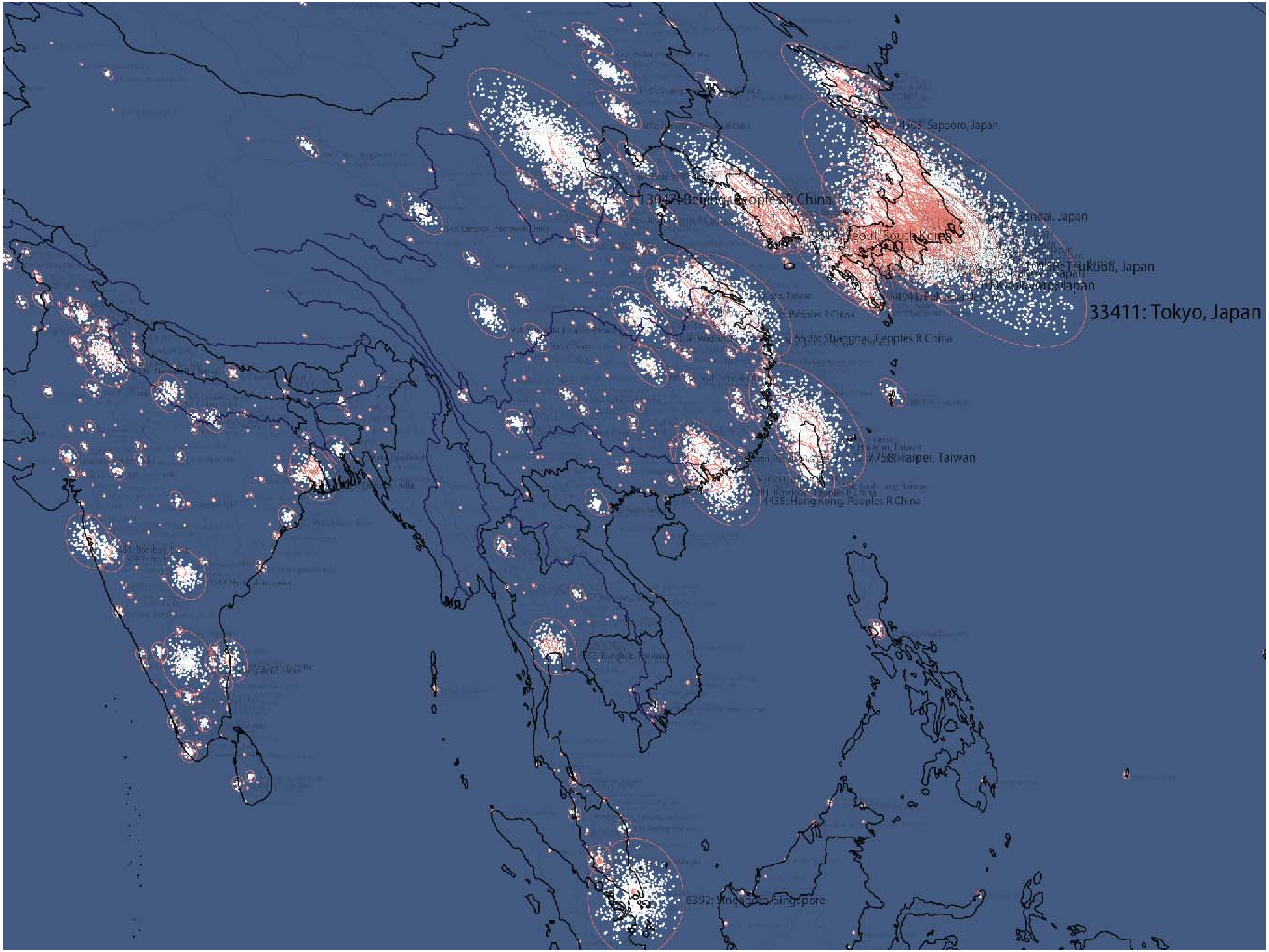

periodic mesoporous, stable mesoporous, hydrotreating catalysts, deep hydrodesulfuriz
edible films, 6 clay, polypropylene nanocomposites
fluorene based, electrophosphorescent, organic electroluminescence, exciton form
hydrothermal syntheses, heteropoly acid, [uo2, decavanadate, heteropoly
12 acetate, 2 fecl4, bedt tsf, tsf 2, lambda bedt, molecular ma
dissociative electron, kinetic method, dot pi, rotational spectrum, cente
vibrational assignment, ferrierite, ligand field, dft analysis, disso
femo, ethylene catalyzed, mgcl2 suppor
cheddar cheese, dry cured, bar, milk cheese, microextraction
ground acceleration, vogtland nw
bismuth triflate, micro
samarium diiodide

Geographic Map: Where Science Gets Done




5028: Edmonton, Canada
18439: Seattle, WA, USA
2350: Winnipeg, Canada
8773: Minneapolis, MN, USA
17756: Toronto, Canada
44537: Boston, MA, USA
New York, NY, USA
12543: Pittsburgh, PA, USA
Bethesda, MD, USA
Washington, DC, USA
5118: Salt Lake City, UT, USA
12820: San Francisco, CA, USA
10226: St Louis, MO, USA
20414: Los Angeles, CA, USA
La Jolla, CA, USA
13001: Atlanta, GA, USA
15020: Houston, TX, USA
5047: Gainesville, FL, USA
5012: Mexico City, Mexico

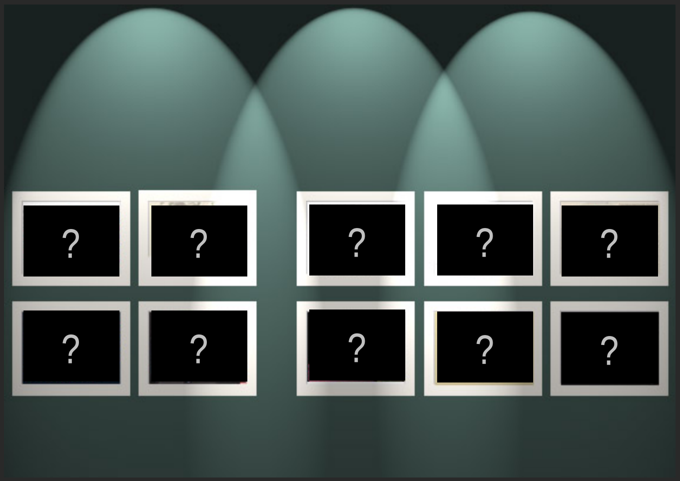

15076: Moscow, Russia
43143: London, England
27545: Paris, France
11810: Madrid, Spain
9014: Barcelona, Spain
1181: Iraklion, Greece
4528: Jerusalem, Israel


Beijing, Peoples R China
Sapporo, Japan
Sendai, Japan
Tsukuba, Japan
33411: Tokyo, Japan
Shanghai, Peoples R China
Taipei, Taiwan
4435: Hong Kong, Peoples R China
Singapore

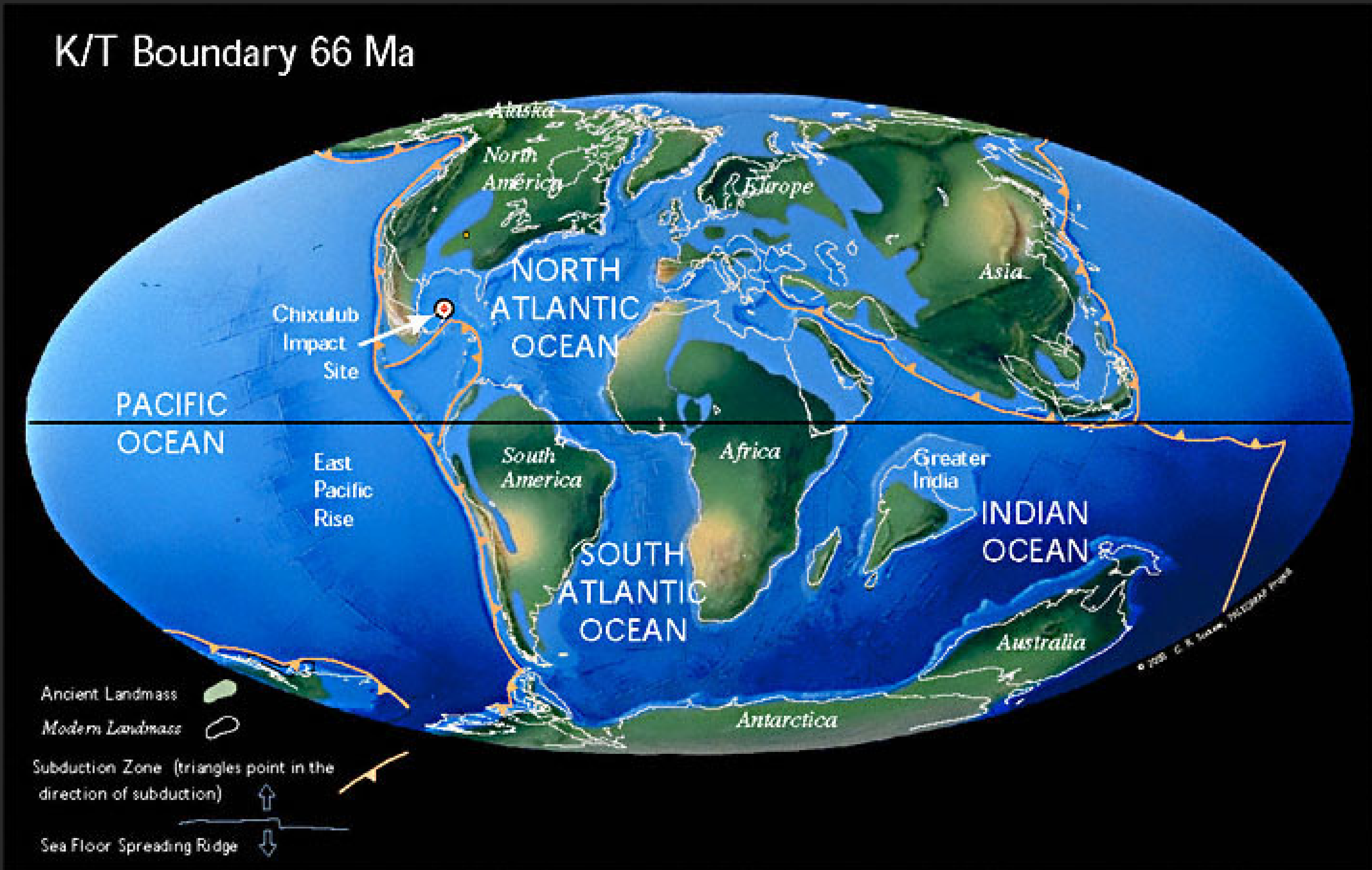
"Places & Spaces: Mapping Science"
on display at the NYPL Science, Industry, and Business Library
Madison/34th, New York City
April 3rd - August 31st, 2006.

The Power of Forecasts

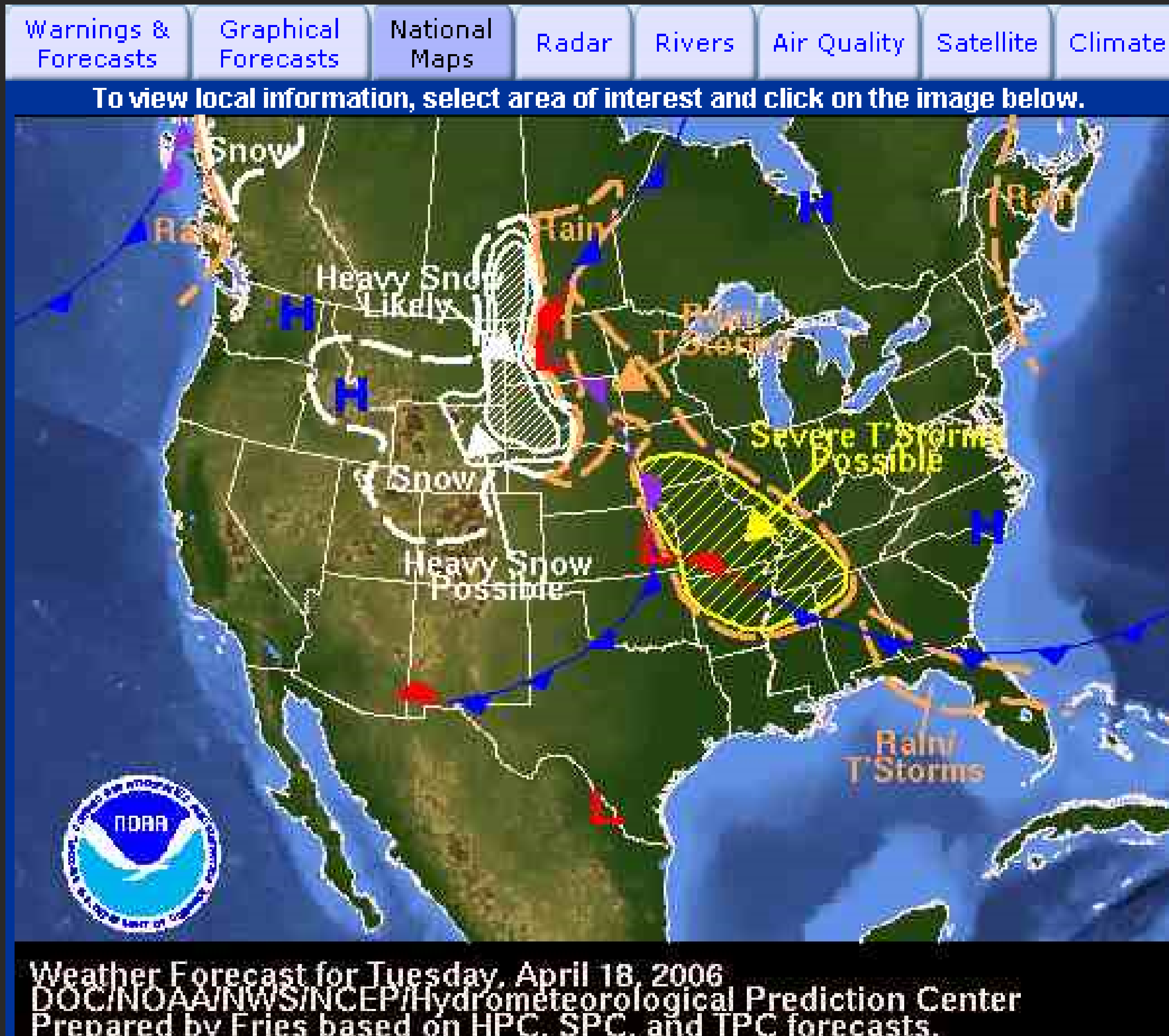
Four Existing Forecasts
VERSUS
Six Potential Science 'Weather' Forecasts



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



http://www.scotese.com/



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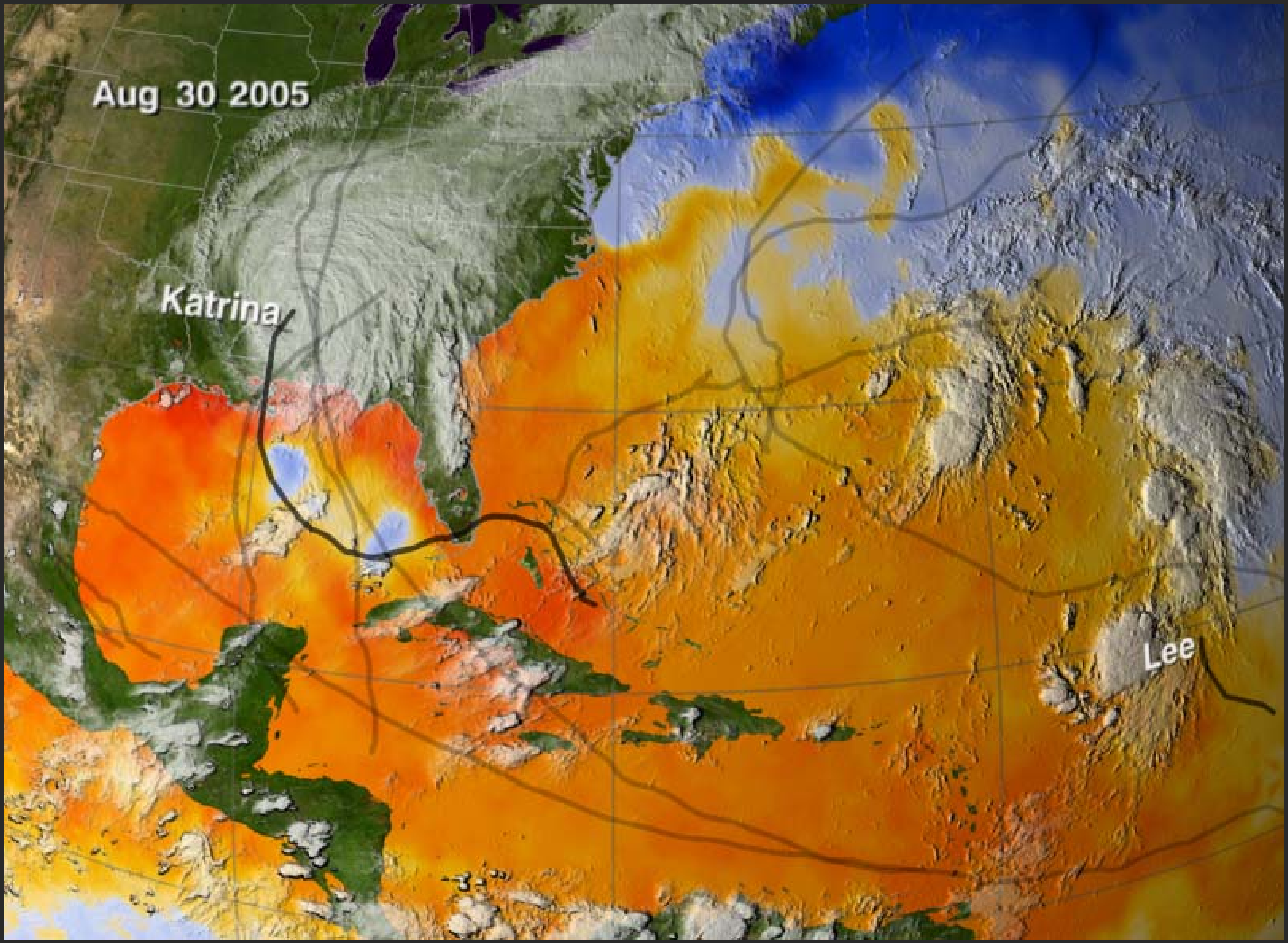


Named Storms, available online at http://svs.gsfc.nasa.gov/vis/a000000/a003200/a003279

A Potential Future:

Science Maps in Action

KIDS first …

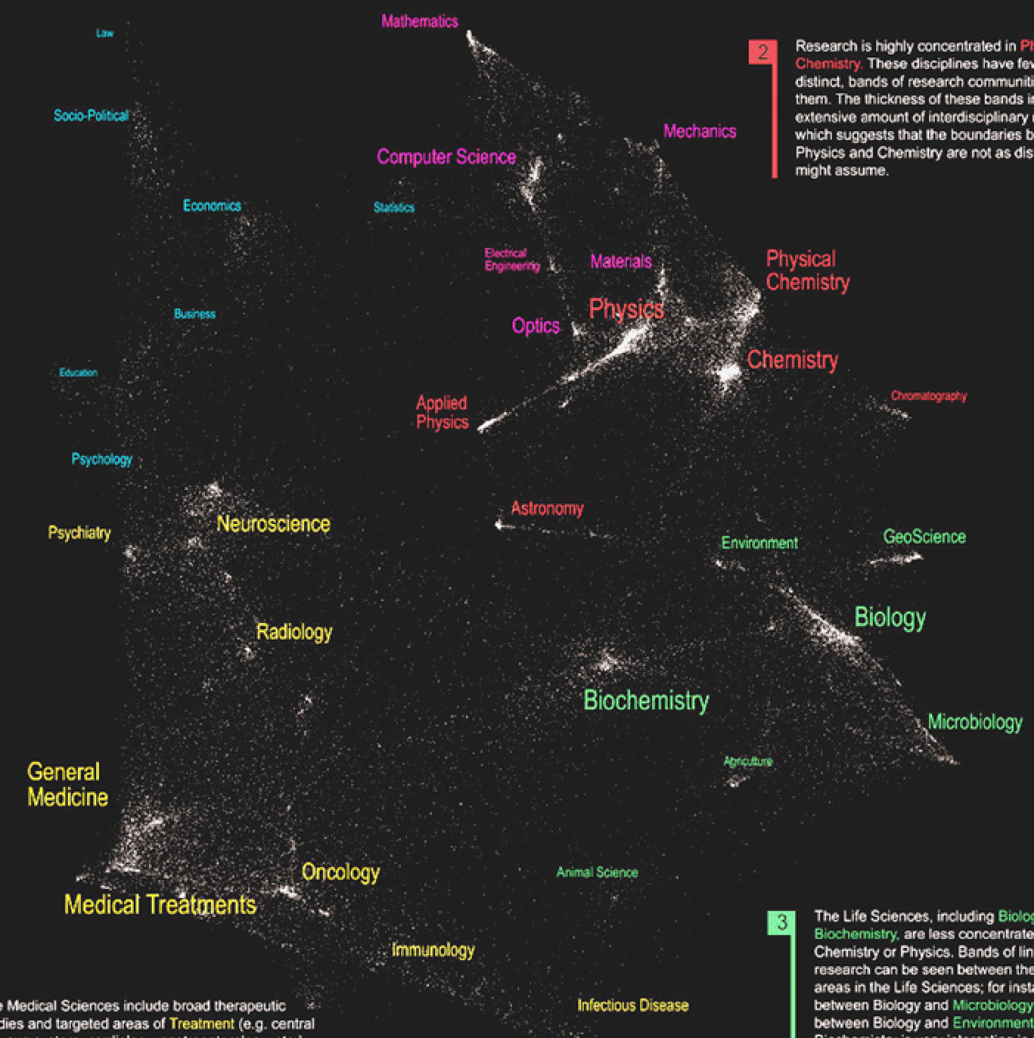
All maps of science & the video are on sale via
http://vw.indiana.edu/places&spaces

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.



4 The Medical Sciences include broad therapeutic studies and targeted areas of Treatment (e.g. central nervous system, cardiology, gastroenterology, etc.) Unlike Physics and Chemistry, the medical disciplines are more spread out, suggesting a more multi-disciplinary approach to research. The transition into Life Sciences (via Animal Science and Biochemistry) is gradual.

3 The Life Sciences, including Biology and Biochemistry, are less concentrated than Chemistry or Physics. Bands of linking research can be seen between the larger areas in the Life Sciences; for instance between Biology and Microbiology, and between Biology and Environmental Science. Biochemistry is very interesting in that it is a large discipline that has visible links to disciplines in many areas of the map, including Biology, Chemistry, Neuroscience, and General Medicine. It is perhaps the most interdisciplinary of the sciences.

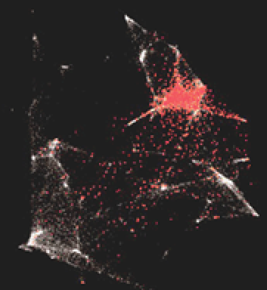
We are all familiar with traditional maps that show the relationships between countries, provinces, states, and cities. Similar relationships exist between the various disciplines and research topics in science. This allows us to map the structure of science.

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

Things are different today. We have enormous computing power and advanced visualization software that make mapping of the structure of science possible. This galaxy-like map of science (left) was generated at Sandia National Laboratories using an advanced graph layout routine (VxOrd from the citation patterns in 800,000 scientific papers published in 2002. Each dot in the galaxy represents one of the 96,000 research communities active in science in 2002. A research community is a group of papers (9 on average) that are written on the same research topic in a given year. Over time, communities can be born, continue, split, merge, or die.

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

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



Nanotechnology

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

Proteomics

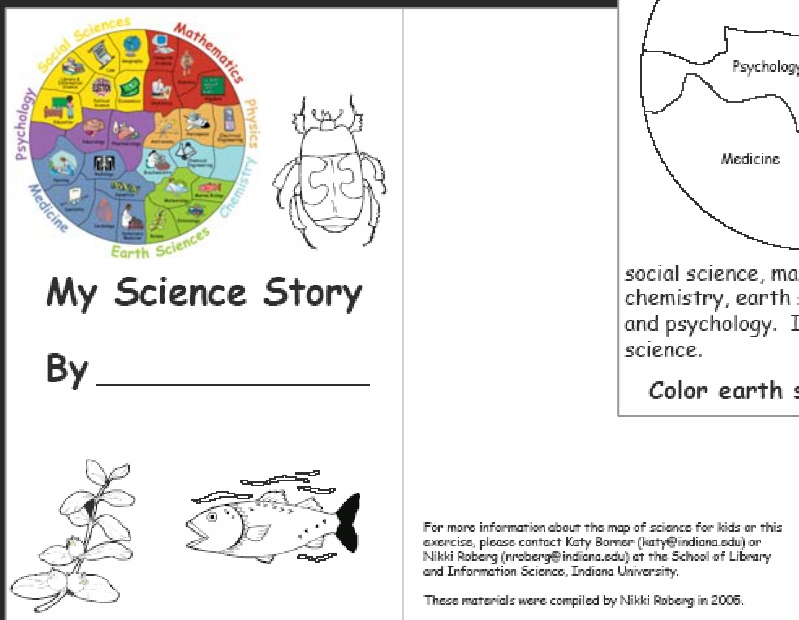
Research communities in proteomics are centered in Biochemistry. In addition, there is a heavy focus in the tools section of chemistry, such as Chromatography. The balance of the proteomics communities are widely dispersed among the Life and Medical Sciences.

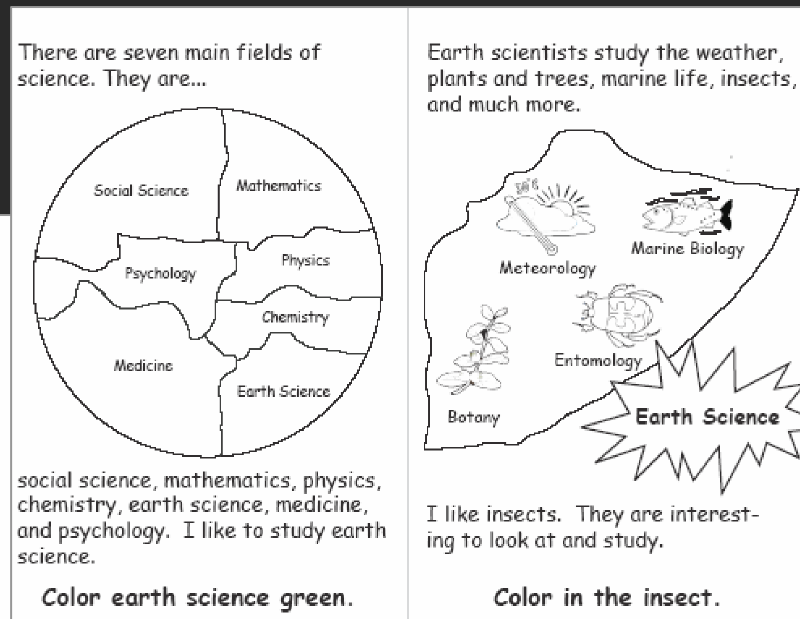
Pharmacogenomics

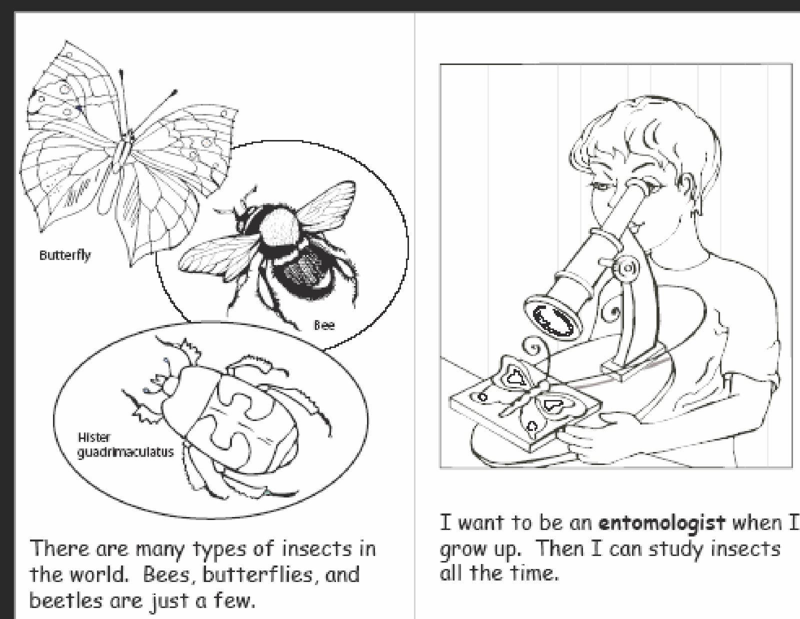
Pharmacogenomics is a relatively new field with most of its activity in Medicine. It also has many communities in Biochemistry and two communities in the Social Sciences.

Social Sciences
Mathematics
Physics
Chemistry
Earth Sciences
Medicine
Psychology
Library & Information Science
Law
Geography
Computer Science
Robotics
Political Science
Economics
Statistics
Algebra
Education
Neurology
Pharmacology
Astronomy
Aerospace
Electrical Engineering
Nursing
Radiology
Biochemistry
Chemical Engineering
Genetics
Meteorology
Marine Biology
Dentistry
Cardiology
Veterinary Medicine
Entomology
Botany
ELECTION

12\8\05
Going
RATTY
THE WORLD
Morning Meeting
Thursday
Trip to Art Museum
Lunch and Recess
54
SOCCER
CO
AZ
TX
AR
LA







Activities:

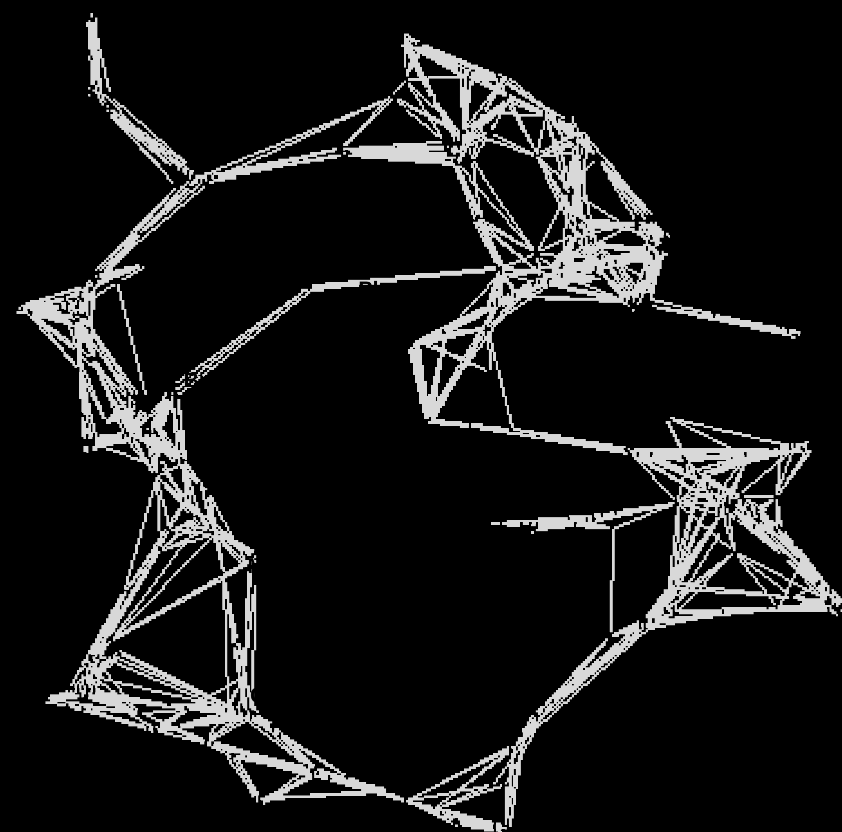
- Solve the puzzle.
- Navigate to 'Earth Science'.
- Identify major inventions.
- Place major inventors.
- Find your dream job on the map.
- Why is mathematics important?

… my SPONSORS next …

Latest 'Base Map' of Science

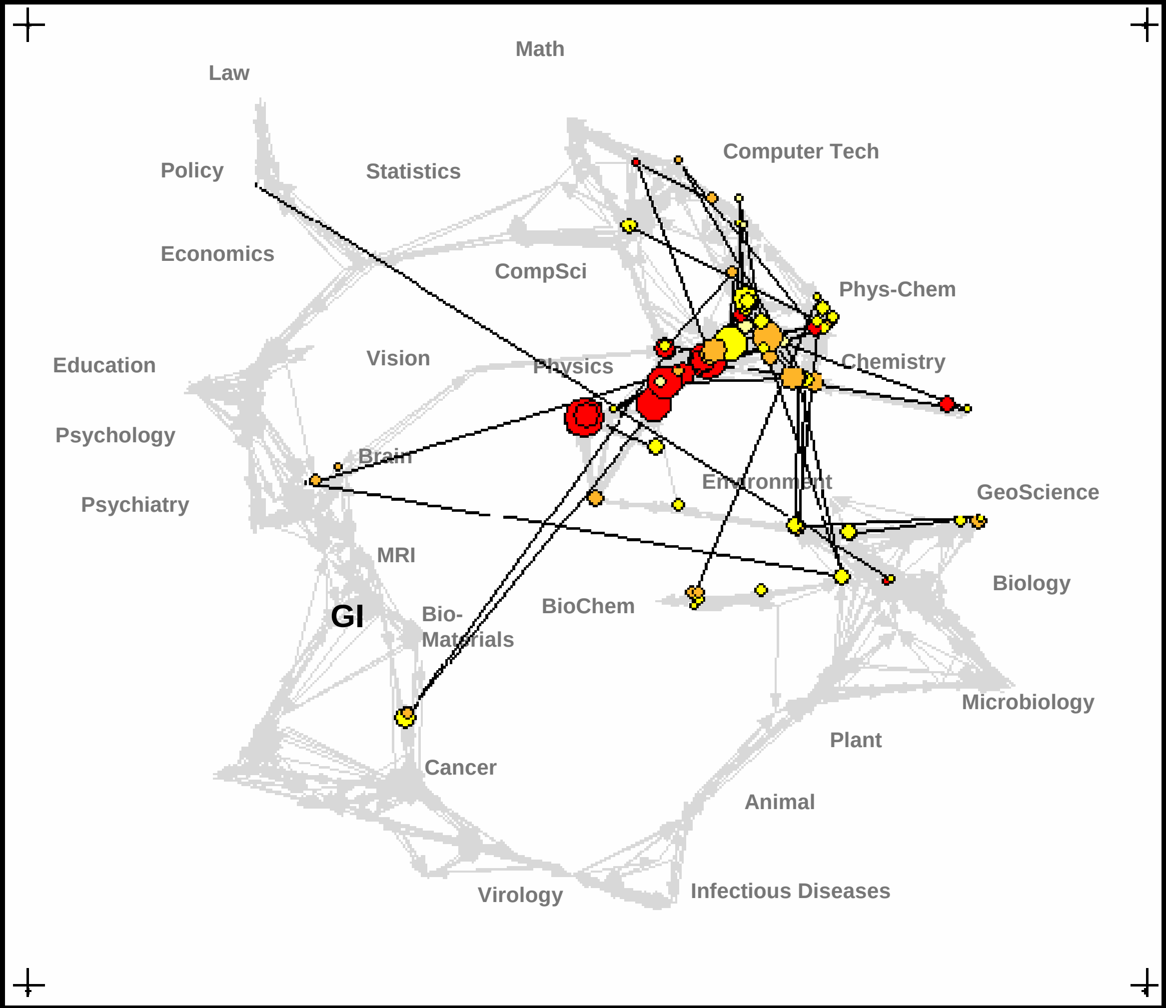
Kevin W. Boyack & Richard Klavans, unpublished work.

- Uses combined SCI/SSCI from 2002
  - 1.07M papers, 24.5M references, 7,300 journals
  - Bibliographic coupling of papers, aggregated to journals
- Initial ordination and clustering of journals gave 671 clusters
- Coupling counts were reaggregated at the journal cluster level to calculate the
  - (x,y) positions for each journal cluster
  - by association, (x,y) positions for each journal

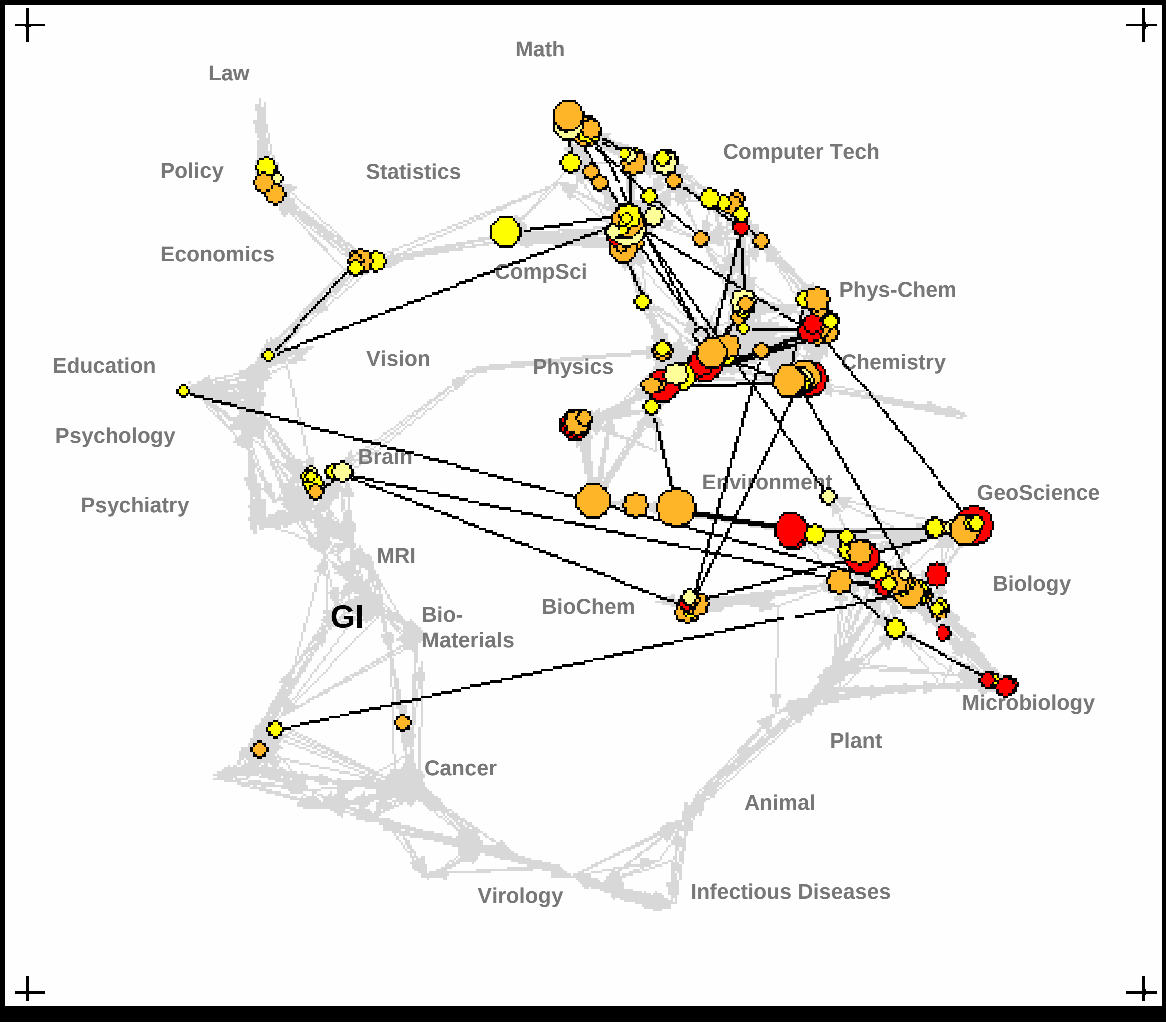


Science map applications: Identifying core competency

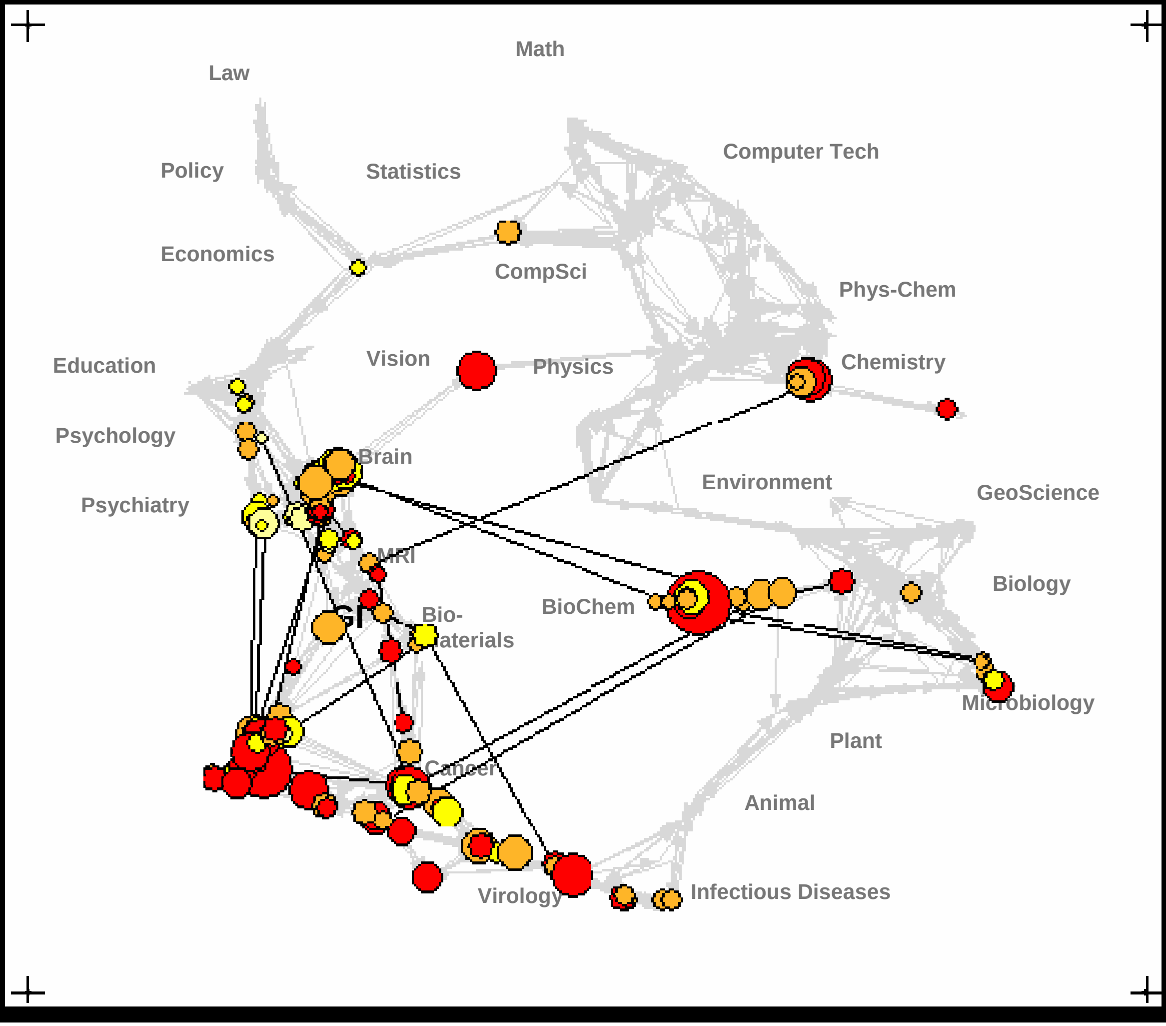
Kevin W. Boyack & Richard Klavans, unpublished work.



Kevin W. Boyack & Richard Klavans, unpublished work.

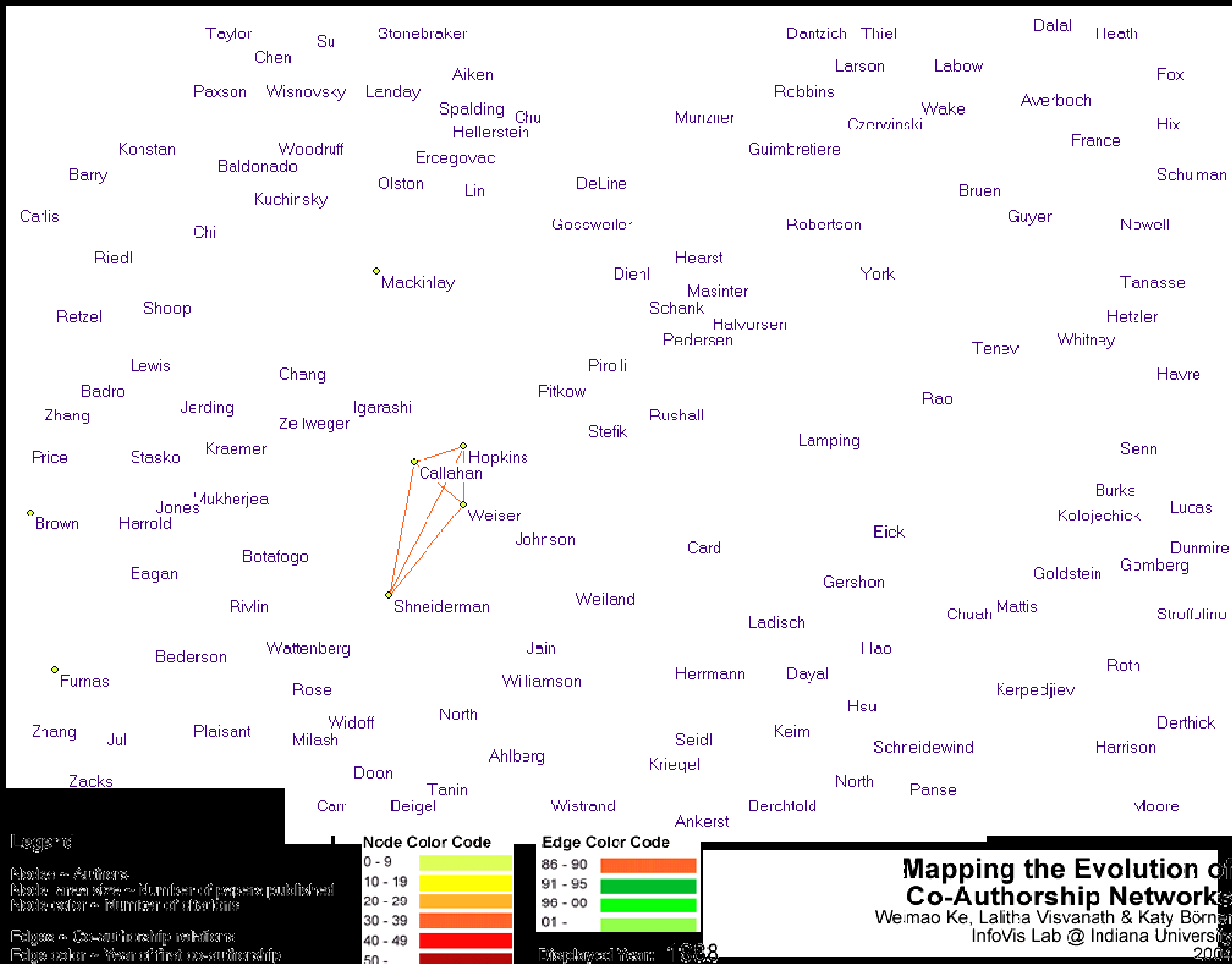


Kevin W. Boyack & Richard Klavans, unpublished work.



… then SCIENTISTS …

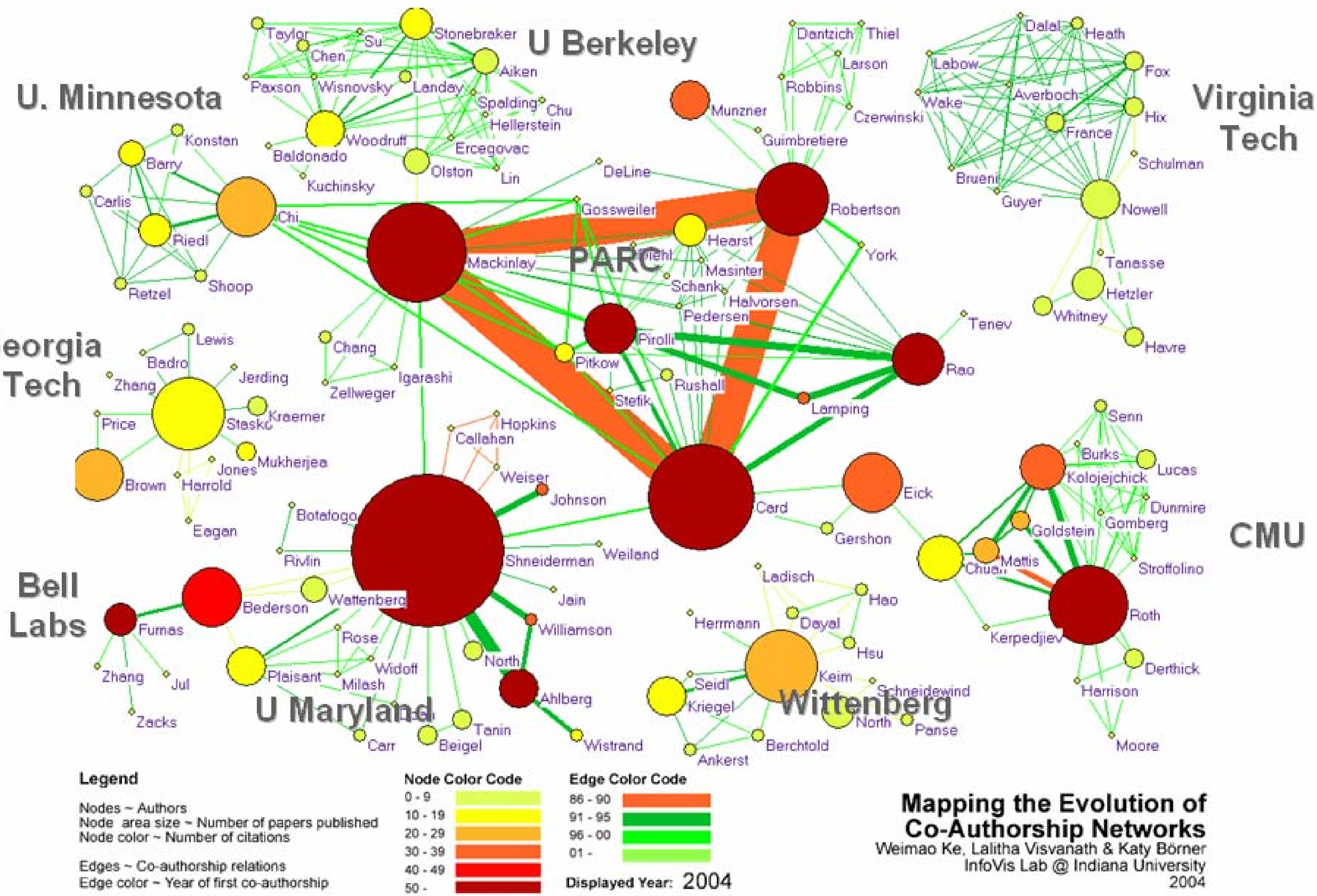
Ke, Visvanath & Börner, (2004) Won 1st price at the IEEE InfoVis Contest.



[redacted]

Mapping the Evolution of Co-Authorship Networks

Ke, Visvanath & Börner, (2004) Won 1st price at the IEEE InfoVis Contest.



… and INDUSTRY too.

Examining the Evolution and Distribution of Patent Classifications

1 Patents Granted Over the Last 20 Years

Top Classes 1978 - 1982		
Class	Title	Patents
260	Chemistry of Carbon Compounds	15,599
424	Drug, Bio Affecting and Body Treating Compositions	9,621
252	Compositions	5,858
128	Surgery	5,404
428	Stock Material or Miscellaneous Articles	4,984
73	Measuring and Testing	4,875
123	Internal-Combustion Engines	4,142
340	Communications: Electrical	4,043
364	Electrical Computers and Data Processing Systems	3,700
29	Metal Working	3,684
	Total	59,705

Top Classes 1998 - 2002		
Class	Title	Patents
514	Drug, Bio-Affecting and Body Treating Compositions	18,778
438	Semiconductor Device Manufacturing: Process	17,775
435	Chemistry: Molecular Biology and Microbiology	17,474
424	Drug, Bio-Affecting and Body Treating Compositions	13,637
428	Stock Material or Miscellaneous Articles	13,314
257	Active Solid-State Devices (e.g., Transistors, Solid-state Diodes	12,924
395	Information Processing System Organization	9,955
345	Computer Graphics Processing, Operator Interface Processing, and Selective Visual Display Systems	9,510
359	Optical Systems and Elements	9,151
365	Static Information Storage and Retrieval	8,392
	Total	130,910

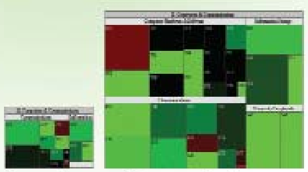
In the United States, each patent gets assigned to one out of more than 450 classes covering broad application domains. An examination of the size and growth of patent classes provides insight about patenting trends.

Treemaps, a space filling technique developed in the HCI Lab at the University of Maryland, are used to communicate major results. Treemaps represent a tree structure as nested rectangles with each rectangle representing a node. A rectangular area is first allocated to hold the representation of the tree, and this area is then subdivided into a set of rectangles that represent the top level of the tree. This process continues recursively on the resulting rectangles to represent each lower level of the tree. The parent-child relationship is indicated by enclosing the child rectangle by its parent rectangle. Typically, the size of each rectangle corresponds to the size of the node. Additional information about a node, e.g., its age or value, can be represented by the color of the respective rectangle.

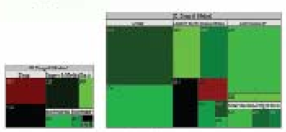
2 Fast Growth Domains

1983 - 1987 / 1998 - 2002

Electrical and Electronic



Computers and Communications



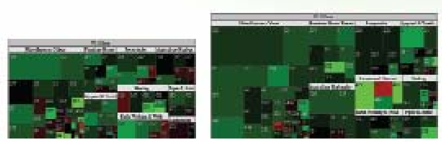
Drugs and Medical

Slow Growth Domains

1983 - 1987 / 1998 - 2002

Mechanical

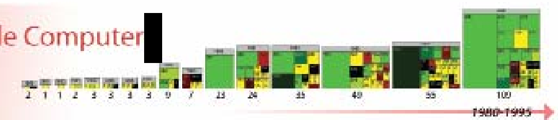
Chemical

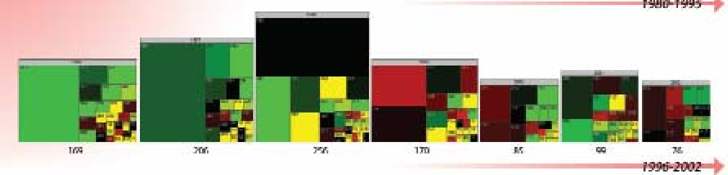


Others

Shown is a comparison of the patent class space for 1983 to 1987 and 1998 to 2002. There is a predominance of growth in the 1998 to 2002 patent space, which correlates to the increase in patent grants during this period. By comparing the growth in categories, one can distinguish between domains that have been receiving a larger amount of patent grants.

3 Apple Computer

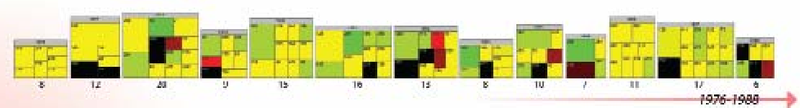


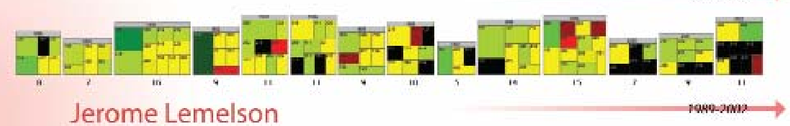


Depicted above is how Apple Computers' portfolio has changed in yearly increments from 1980 to 2002.

Lemelson's patent holdings below show a more even distribution over multiple classes. No class dominates over a majority of the years for granted patents; instead they are distributed more broadly over the intellectual space.

Legend:
Green = Increase in number of patent grants in particular class.
Red = Decrease in number of patent grants in particular class.
Yellow = No patents granted in that class in the past five years.
Size = Number of patent grants in a particular class.



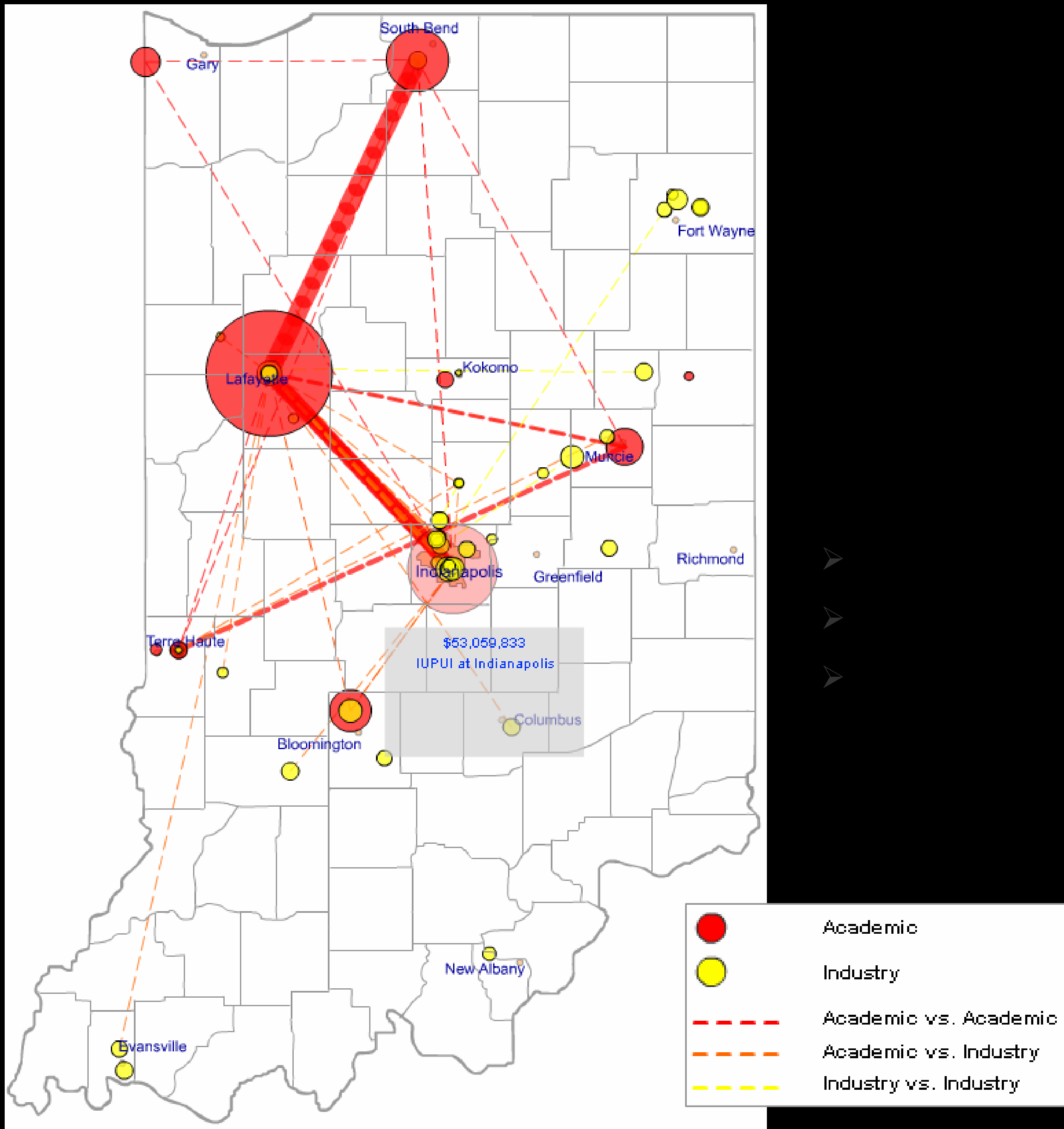


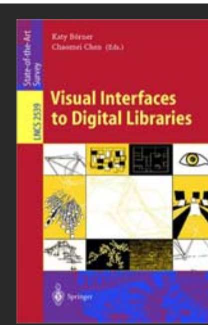
Jerome Lemelson

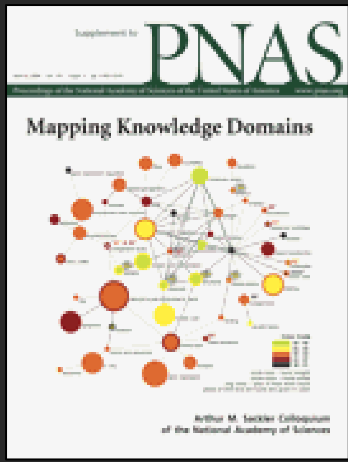
Kutz, Daniel O. Examining the Evolution and Distribution of Patent Classifications. Accepted for the Information Visualization Conference, London, UK, July 2004.

The material is based upon work supported bythe National Science Foundation under Grant No. IIS-0238261.

For more information, contact Katy Borner at katy@indiana.edu.


South Bend
Gary
Fort Wayne
Kokomo
Lafayette
Muncie
Richmond
Greenfield
Indianapolis
Terre Haute
$53,059,833
IUPUI at Indianapolis
Columbus
Bloomington
New Albany
Evansville
Academic
Industry
Academic vs. Academic
Academic vs. Industry
Industry vs. Industry

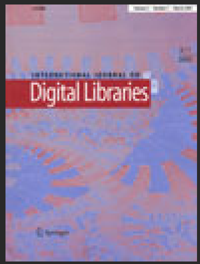


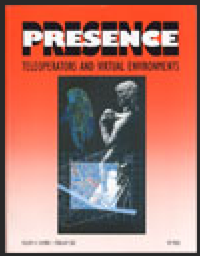


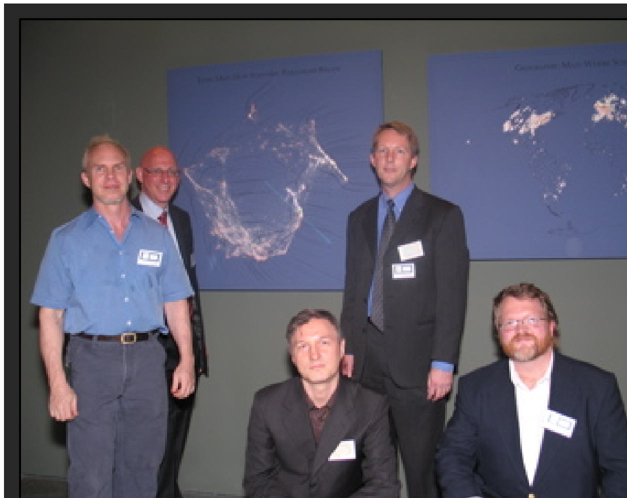
Computational Scientometrics

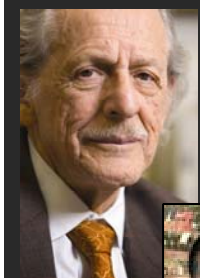
&

Macroscopes







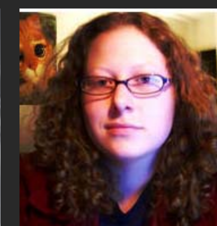



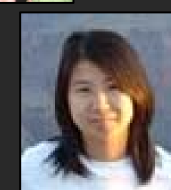
Interested to get your own science map?

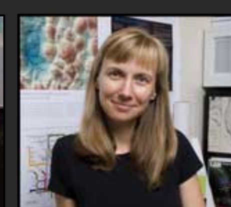
Contact the map makers!

katy@indiana.edu





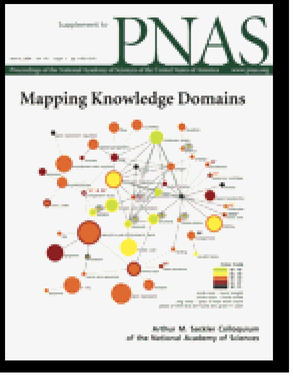
The End.

How to Make a Science Map

DATA EXTRACTION	UNIT OF ANALYSIS	MEASURES	LAYOUT (often one code does both similarity and ordination steps)		DISPLAY
			SIMILARITY	ORDINATION	
SEARCHES	COMMON CHOICES	COUNTS/FREQUENCIES	SCALAR (unit by unit matrix)	DIMENSIONALITY REDUCTION	INTERACTION
ISI	Journal	Attributes (e.g. terms)	Direct citation	Eigenvector/ Eigenvalue solutions	Browse
INSPEC	Document	Author citations	Co-citation	Factor Analysis (FA) and Principal Components Analysis (PCA)	Pan
Eng Index	Author	Co-citations	Combined linkage	Multi-dimensional scaling (MDS)	Zoom
Medline	Term	By year	Co-word / co-term	LSA	Filter
ResearchIndex			Co-classification	Pathfinder networks (PFNet)	Query
Patents		THRESHOLDS		Self-organizing maps (SOM) includes SOM, ET-maps, etc.	Detail on demand
etc.		By counts	VECTOR (unit by attribute matrix)		
			Vector space model (words/terms)		ANALYSIS
BROADENING			Latent Semantic Analysis (words/terms) incl. Singular Value Decomp (SVD)	CLUSTER ANALYSIS	
By citation					
By terms					
			CORRELATION (if desired)	SCALAR	
			Pearson's R on any of above	Triangulation	
				Force-directed placement (FDP)	

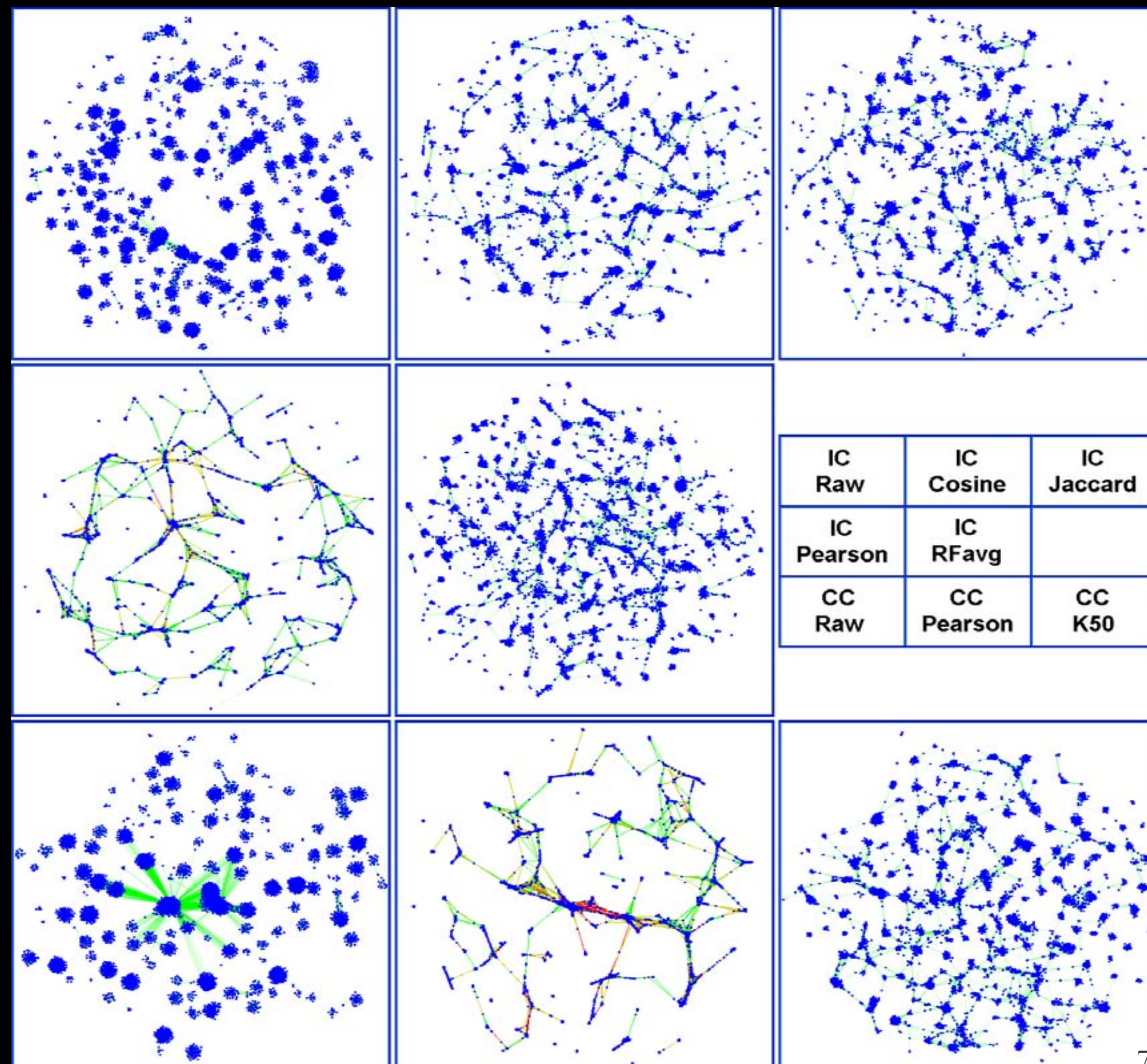
Shiffrin, Richard M. and Börner, Katy (Eds.) (2004). Mapping Knowledge Domains. Proceedings of the National Academy of Sciences of the United States of America, 101(Suppl_1).

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

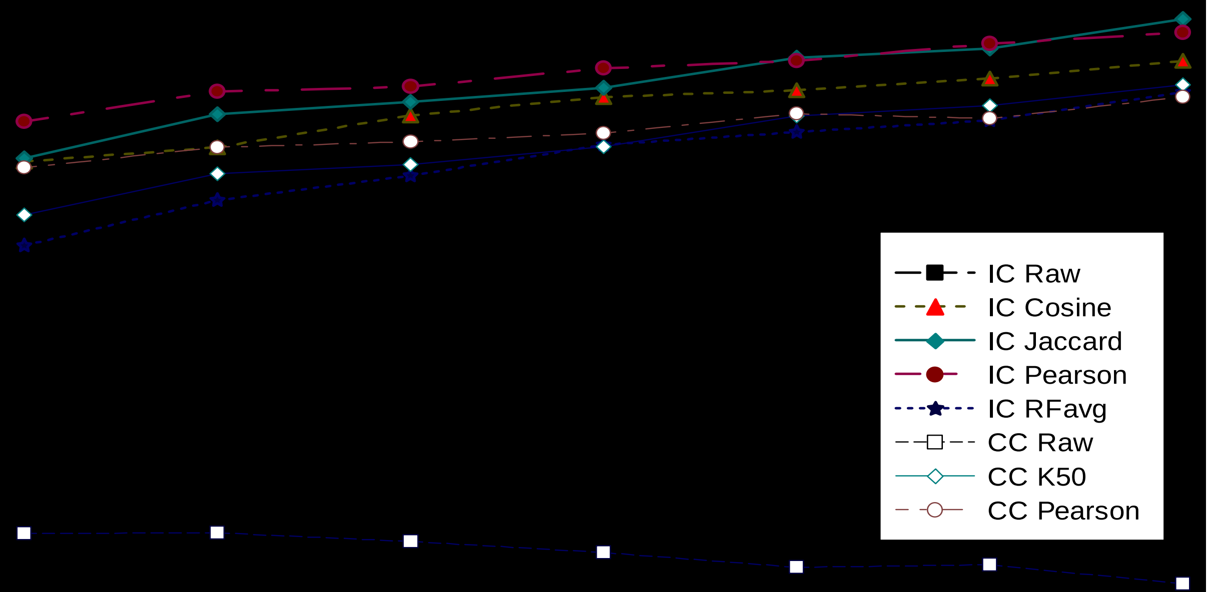


Comparison of Similarity Metrics

- ISI file year 2000, SCI and SSCI: 7,121 journals.
- Different similarity metrics
  - Inter-citation (raw counts, cosine, modified cosine, Jaccard, RF, Pearson)
  - Co-citation (raw counts, cosine, modified cosine, Pearson)
- Maps were compared based on
  - regional accuracy,
  - the scalability of the similarity algorithm, and
  - the readability of the layouts.



Boyack, Kevin W., Klavans, R. and Börner, Katy. (2005). Mapping the Backbone of Science. Scientometrics. 64(3), 351-374.



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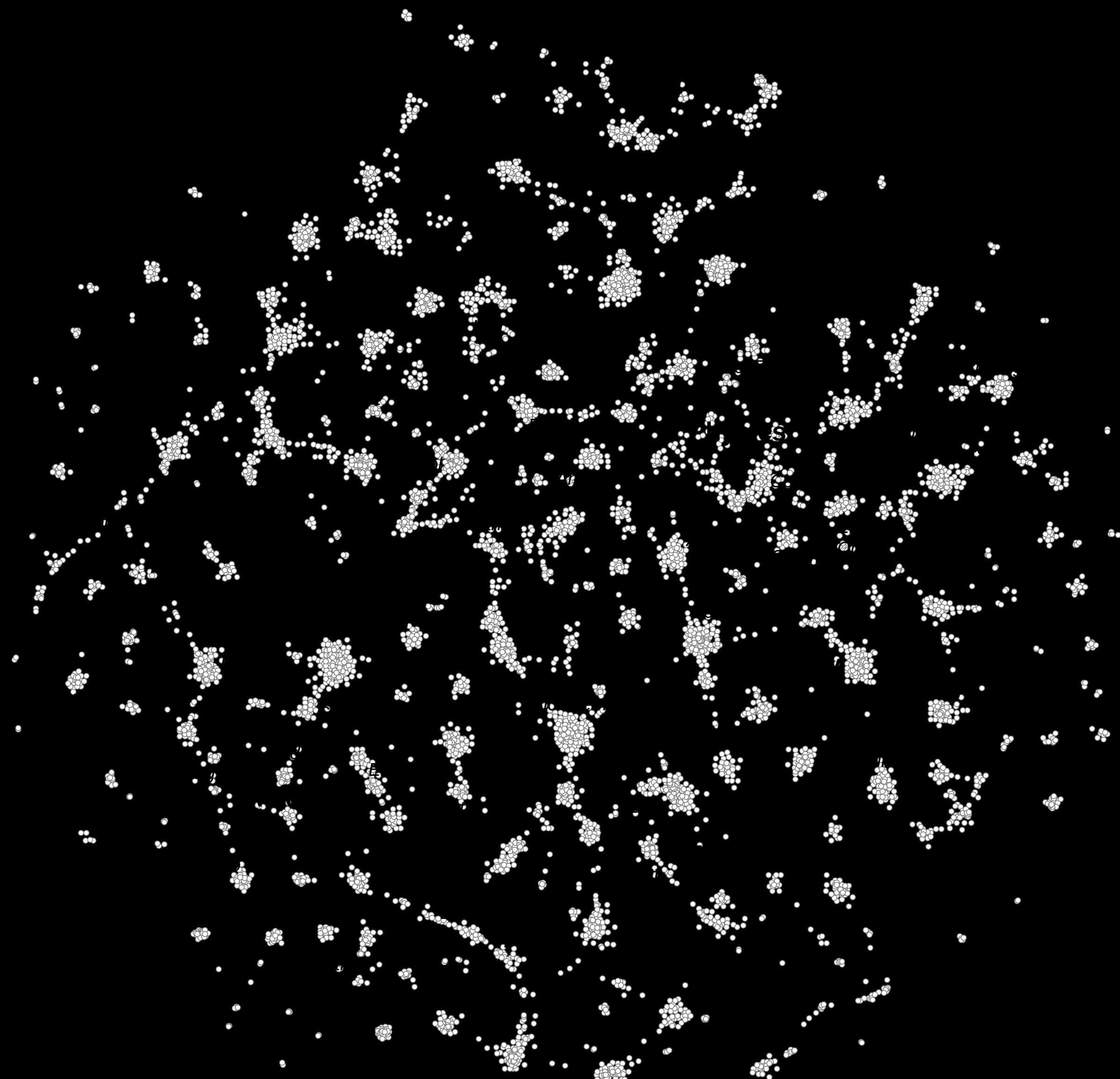
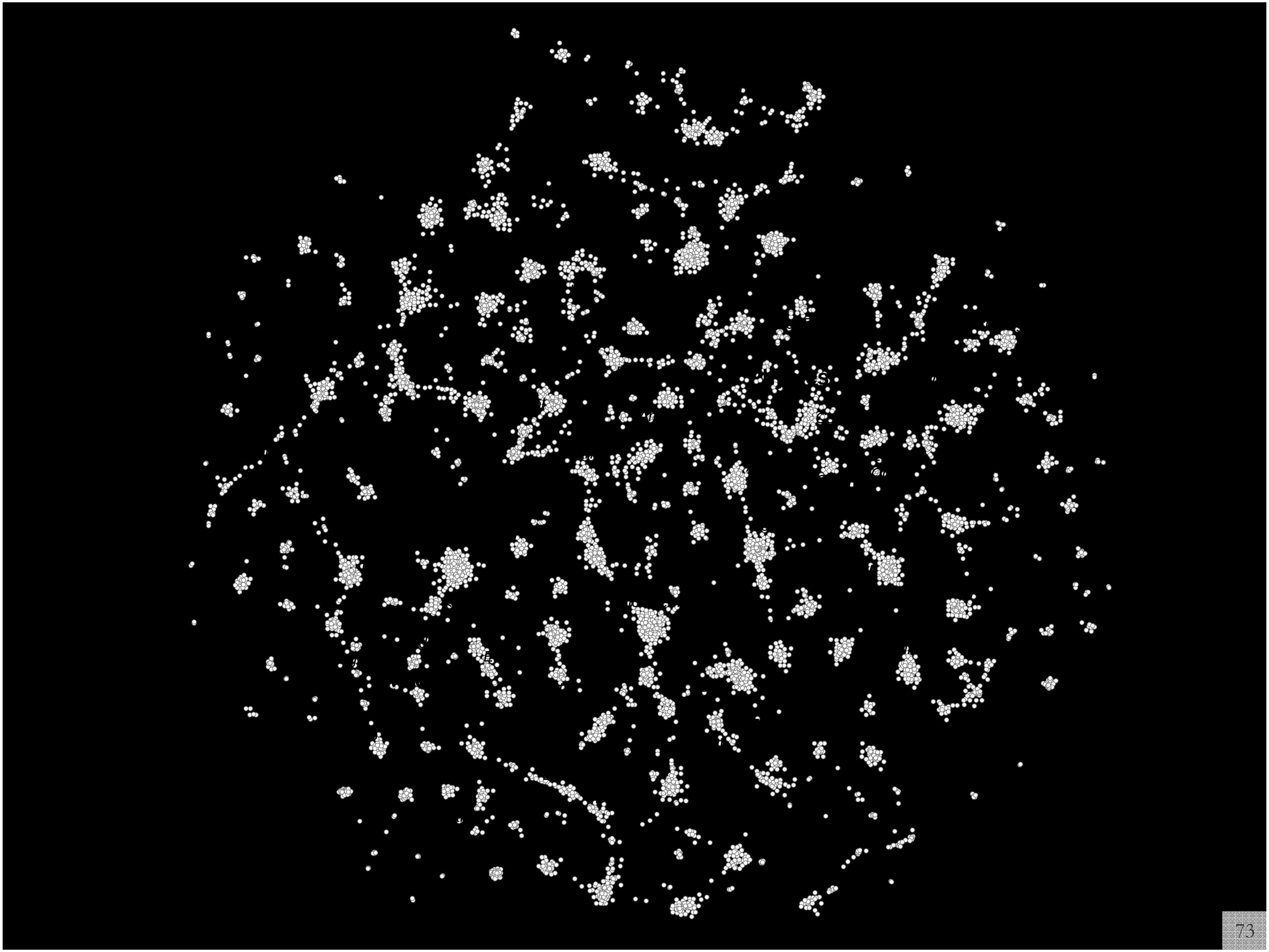
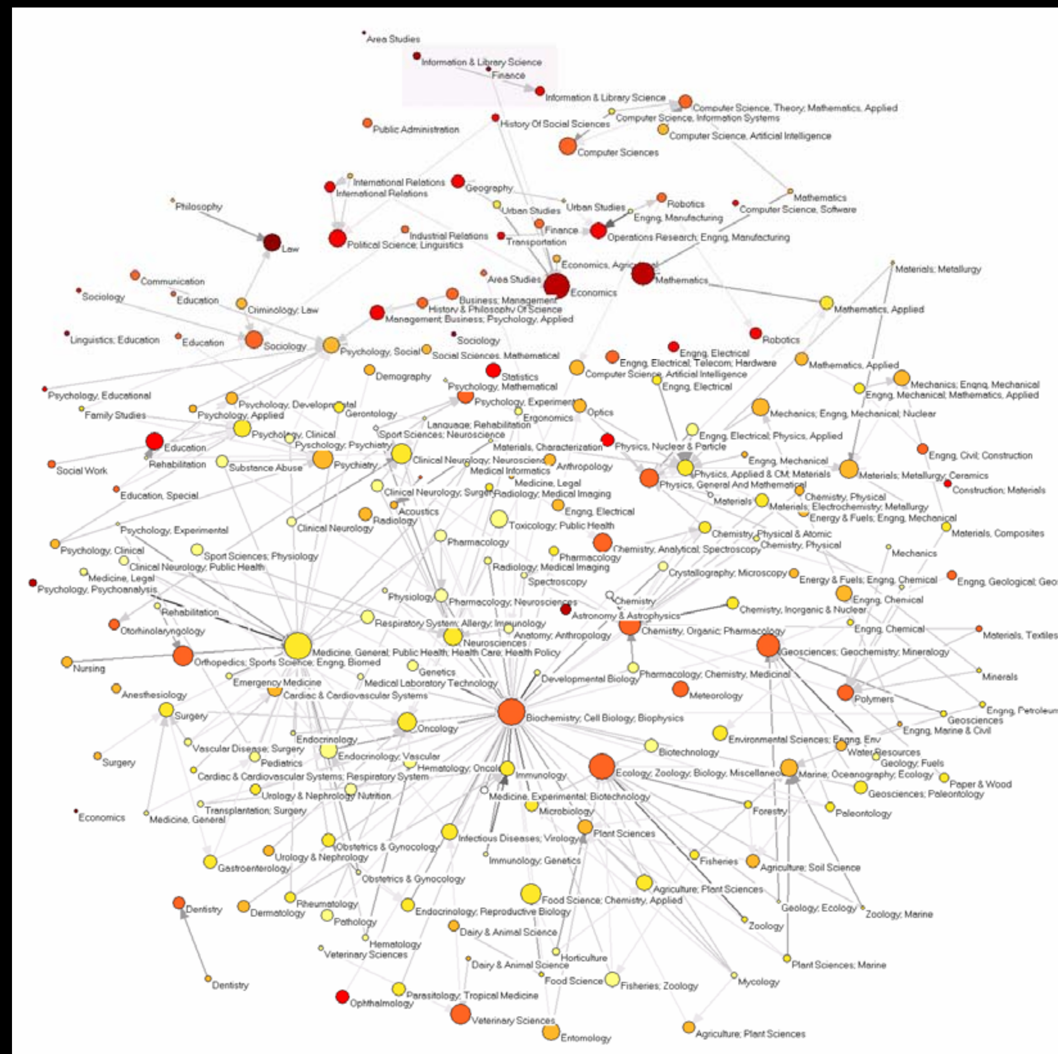
A ‘Backbone’ Map of Science & Social Science






Area Studies
Information & Library Science
Finance
Computer Science, Theory, Mathematics, Applied
Computer Science, Information Systems
History Of Social Sciences
Public Administration
Computer Science, Artificial Intelligence
Computer Sciences
International Relations
Geography
Urban Studies
Robotics
Mathematics
Computer Science, Software
Philosophy
Engng, Manufacturing
Industrial Relations
Political Science; Linguistics
Transportation
Operations Research; Engng, Manufacturing
Law
Economics
Materials; Metallurgy
Communication
Sociology
Education
Criminology; Law
Business; Management
History & Philosophy Of Science
Management; Business; Psychology, Applied
Mathematics, Applied
Linguistics; Education
Psychology, Social
Social Sciences, Mathematical
Statistics
Demography
Engng, Electrical; Telecom; Hardware
Computer Science, Artificial Intelligence
Psychology, Educational
Family Studies
Psychology, Developmental
Psychology, Applied
Gerontology
Psychology, Mathematical
Psychology, Experimental
Ergonomics
Optics
Mechanics; Engng, Mechanical
Engng, Mechanical; Mathematics, Applied
Mechanics; Engng, Mechanical; Nuclear
Psychology, Clinical
Psychology; Psychiatry
Language; Rehabilitation
Sport Sciences; Neuroscience
Engng, Electrical; Physics, Applied
Physics, Nuclear & Particle
Materials, Characterization
Engng, Civil; Construction
Social Work
Rehabilitation
Substance Abuse
Psychiatry
Clinical Neurology; Neuroscience
Medical Informatics
Anthropology
Engng, Mechanical
Materials; Metallurgy; Ceramics
Physics, Applied & CM; Materials
Physics, General And Mathematical
Construction; Materials
Education, Special
Clinical Neurology; Surgery
Radiology; Medical Imaging
Medicine, Legal
Chemistry, Physical
Materials; Electrochemistry; Metallurgy
Energy & Fuels; Engng, Mechanical
Acoustics
Engng, Electrical
Clinical Neurology
Toxicology; Public Health
Chemistry, Physical & Atomic
Materials, Composites
Psychology, Experimental
Pharmacology
Chemistry, Analytical; Spectroscopy
Mechanics
Psychology, Clinical
Sport Sciences; Physiology
Clinical Neurology; Public Health
Crystallography; Microscopy
Energy & Fuels; Engng, Chemical
Engng, Geological; Geosci
Psychology, Psychoanalysis
Physiology
Pharmacology; Neurosciences
Chemistry
Engng, Chemical
Astronomy & Astrophysics
Chemistry, Inorganic & Nuclear
Otorhinolaryngology
Respiratory System; Allergy; Immunology
Anatomy; Anthropology
Chemistry, Organic; Pharmacology
Materials, Textiles
Neurosciences
Medicine, General; Public Health; Health Care; Health Policy
Geosciences; Geochemistry; Mineralogy
Nursing
Orthopedics; Sports Science; Engng, Biomed
Genetics
Developmental Biology
Pharmacology; Chemistry, Medicinal
Minerals
Emergency Medicine
Medical Laboratory Technology
Anesthesiology
Cardiac & Cardiovascular Systems
Meteorology
Polymers
Engng, Petroleum
Surgery
Biochemistry; Cell Biology; Biophysics
Geosciences
Oncology
Engng, Marine & Civil
Endocrinology
Environmental Sciences; Engng, Env
Vascular Disease; Surgery
Biotechnology
Water Resources
Pediatrics
Endocrinology; Vascular
Geology; Fuels
Hematology; Oncology
Immunology
Ecology; Zoology; Biology, Miscellaneous
Marine; Oceanography; Ecology
Paper & Wood
Cardiac & Cardiovascular Systems; Respiratory System
Geosciences; Paleontology
Urology & Nephrology
Nutrition
Medicine, Experimental; Biotechnology
Transplantation; Surgery
Microbiology
Forestry
Economics
Medicine, General
Paleontology
Infectious Diseases; Virology
Plant Sciences
Obstetrics & Gynecology
Urology & Nephrology
Immunology; Genetics
Fisheries
Agriculture; Soil Science
Gastroenterology
Obstetrics & Gynecology
Agriculture; Plant Sciences
Rheumatology
Food Science; Chemistry, Applied
Geology; Ecology
Zoology, Marine
Dentistry
Dermatology
Pathology
Endocrinology; Reproductive Biology
Zoology
Dairy & Animal Science
Hematology
Veterinary Sciences
Horticulture
Dairy & Animal Science
Plant Sciences; Marine
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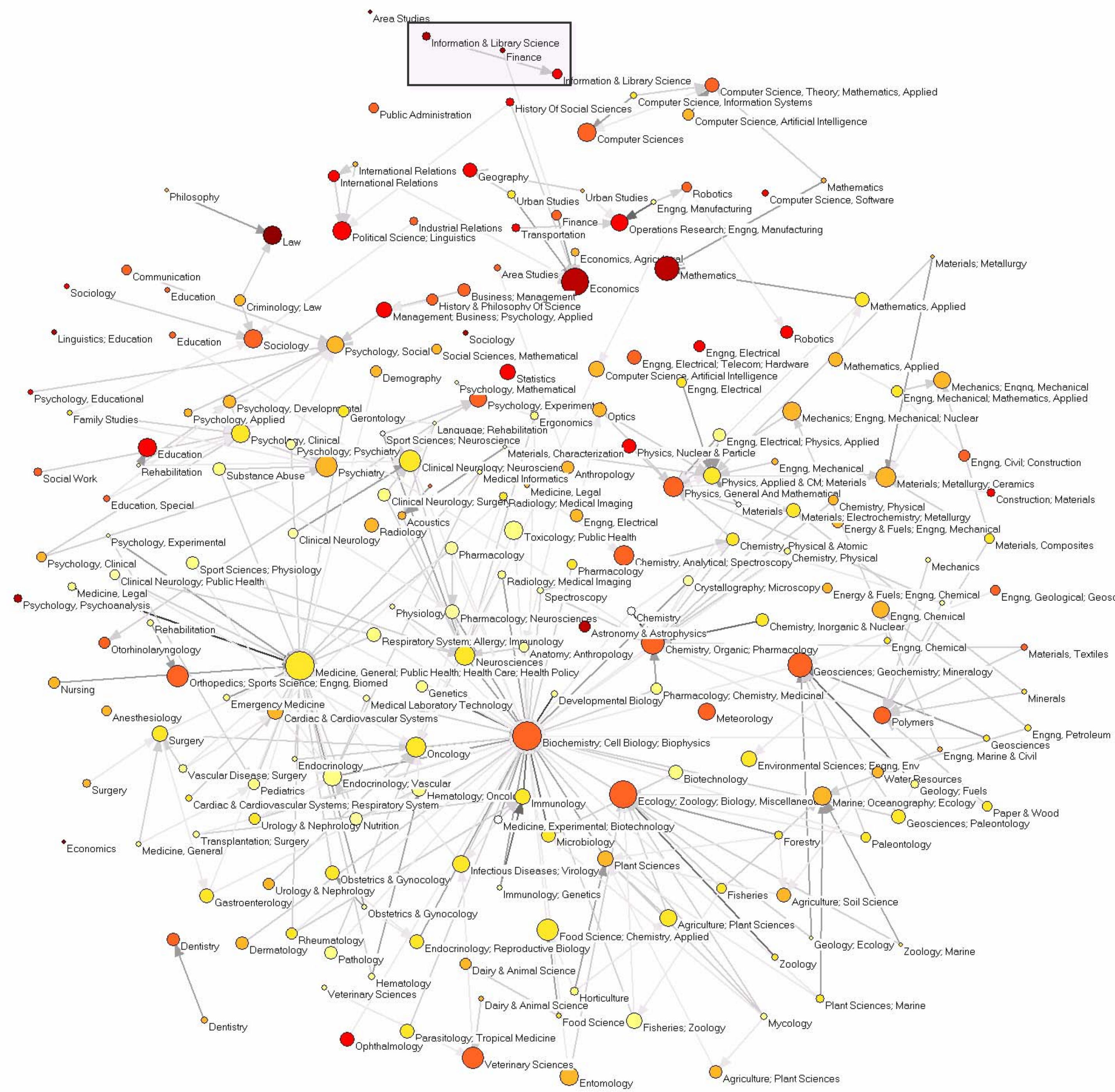
Fisheries; Zoology
Mycology
Dentistry
Ophthalmology
Parasitology; Tropical Medicine
Veterinary Sciences
Entomology
Agriculture; Plant Sciences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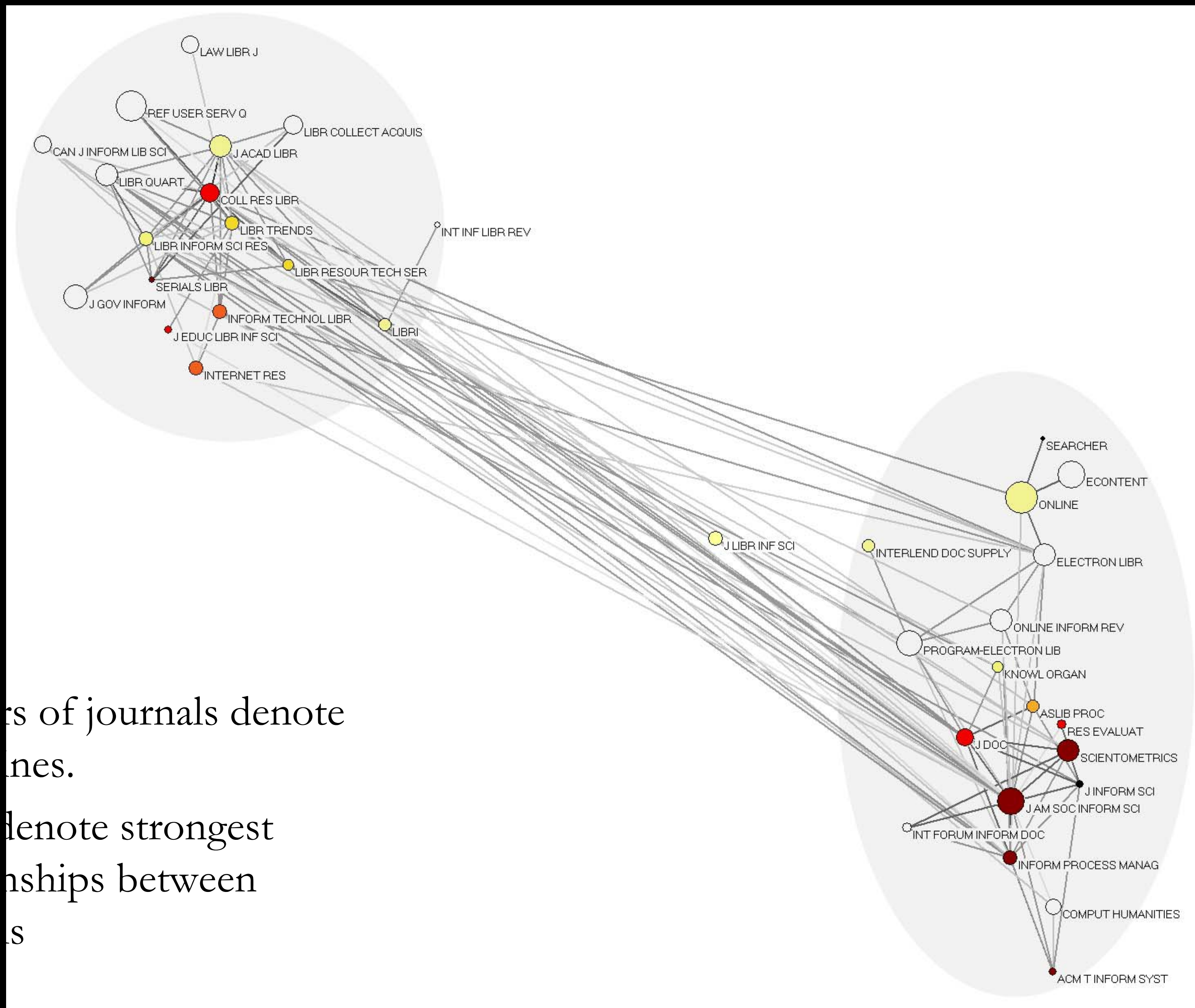
Criminology; Law
Business; Management
History & Philosophy Of Science
Management; Business; Psychology, Applied
Mathematics, Applied
Linguistics; Education
Education
Sociology
Psychology, Social
Sociology
Social Sciences, Mathematical
Robotics
Engng, Electrical
Engng, Electrical; Telecom; Hardware
Computer Science, Artificial Intelligence
Mathematics, Applied
Demography
Statistics
Engng, Electrical
Mechanics; Engng, Mechanical
Engng, Mechanical; Mathematics, Applied
Psychology, Educational
Psychology, Mathematical
Psychology, Developmental
Psychology, Experimental
Gerontology
Family Studies
Psychology, Applied
Optics
Ergonomics
Mechanics; Engng, Mechanical; Nuclear
Language; Rehabilitation
Psychology, Clinical
Sport Sciences; Neuroscience
Engng, Electrical; Physics, Applied
Education
Psychology; Psychiatry
Materials, Characterization
Physics, Nuclear & Particle
Engng, Civil; Construction
Rehabilitation
Substance Abuse
Psychiatry
Clinical Neurology; Neuroscience
Anthropology
Engng, Mechanical
Social Work
Medical Informatics
Physics, Applied & CM; Materials
Materials; Metallurgy; Ceramics
Medicine, Legal
Physics, General And Mathematical
Construction; Materials
Education, Special
Clinical Neurology; Surgery
Radiology; Medical Imaging
Materials
Chemistry, Physical
Acoustics
Materials; Electrochemistry; Metallurgy
Radiology
Engng, Electrical
Energy & Fuels; Engng, Mechanical
Psychology, Experimental
Clinical Neurology
Toxicology; Public Health
Materials, Composites
Chemistry, Physical & Atomic
Pharmacology
Chemistry, Physical
Psychology, Clinical
Chemistry, Analytical; Spectroscopy
Sport Sciences; Physiology
Pharmacology
Mechanics
Clinical Neurology; Public Health
Radiology; Medical Imaging
Crystallography; Microscopy
Energy & Fuels; Engng, Chemical
Medicine, Legal
Spectroscopy
Engng, Geological; Geosci
Psychology, Psychoanalysis
Engng, Chemical
Physiology
Pharmacology; Neurosciences
Chemistry
Rehabilitation
Astronomy & Astrophysics
Chemistry, Inorganic & Nuclear
Respiratory System; Allergy; Immunology
Engng, Chemical
Otorhinolaryngology
Chemistry, Organic; Pharmacology
Materials, Textiles
Anatomy; Anthropology
Neurosciences
Geosciences; Geochemistry; Mineralogy
Medicine, General; Public Health; Health Care; Health Policy
Nursing
Orthopedics; Sports Science; Engng, Biomed
Genetics
Developmental Biology
Minerals
Pharmacology; Chemistry, Medicinal
Emergency Medicine
Medical Laboratory Technology
Anesthesiology
Cardiac & Cardiovascular Systems
Meteorology
Polymers
Engng, Petroleum
Geosciences
Surgery
Biochemistry; Cell Biology; Biophysics
Oncology
Engng, Marine & Civil
Endocrinology
Environmental Sciences; Engng, Env
Water Resources
Vascular Disease; Surgery
Biotechnology
Geology; Fuels
Pediatrics
Endocrinology; Vascular
Surgery
Hematology; Oncology
Ecology; Zoology; Biology, Miscellaneous
Marine; Oceanography; Ecology
Paper & Wood
Cardiac & Cardiovascular Systems; Respiratory System
Immunology
Geosciences; Paleontology
Urology & Nephrology
Nutrition
Medicine, Experimental; Biotechnology
Transplantation; Surgery
Microbiology
Forestry
Paleontology
Economics
Medicine, General
Infectious Diseases; Virology
Plant Sciences
Obstetrics & Gynocology
Fisheries
Urology & Nephrology
Immunology; Genetics
Agriculture; Soil Science
Gastroenterology
Obstetrics & Gynocology
Agriculture; Plant Sciences
Food Science; Chemistry, Applied
Dentistry
Rheumatology
Geology; Ecology
Zoology; Marine
Dermatology
Endocrinology; Reproductive Biology
Pathology
Zoology
Dairy & Animal Science
Hematology
Veterinary Sciences
Horticulture
Dairy & Animal Science
Plant Sciences; Marine
Food Science
Dentistry
Fisheries; Zoology
Mycology
Parasitology; Tropical Medicine
Ophthalmology
Veterinary Sciences
Entomology
Agriculture; Plant Sciences



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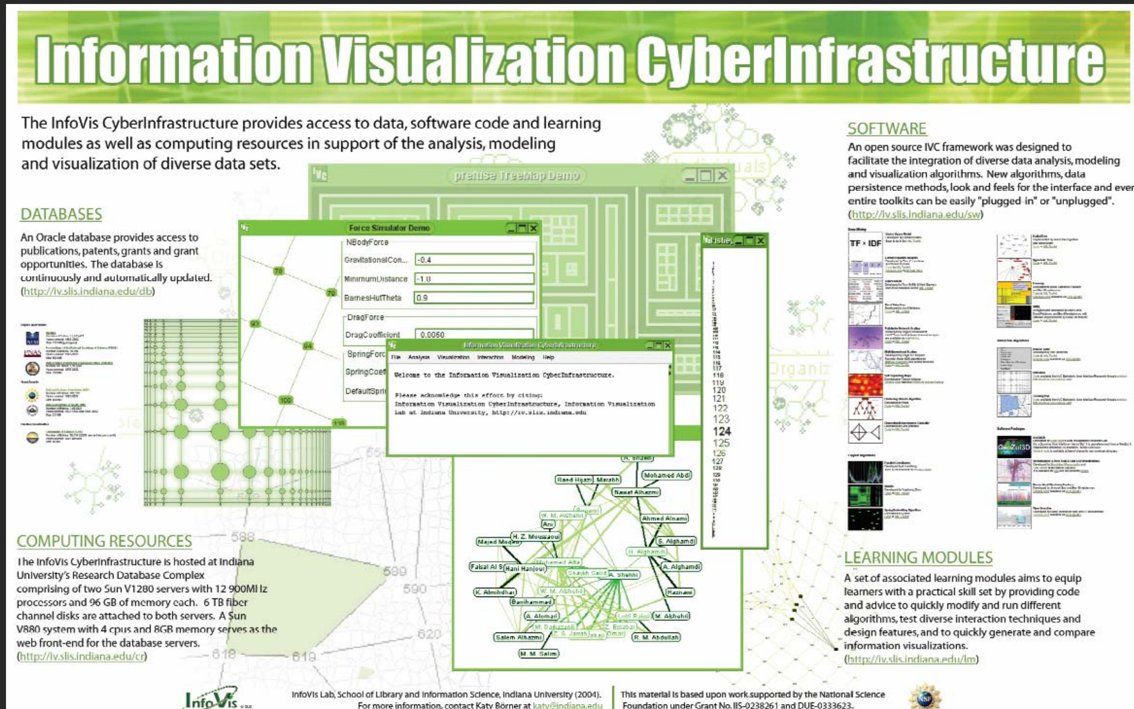

CAREER: Visualizing Knowledge Domains. NSF IIS-0238261 award (Katy Börner, $440,000) Sept. 03-Aug. 08.
http://iv.slis.indiana.edu/

SEI: Network Workbench: A Large-Scale Network Analysis, Modeling and Visualization Toolkit for Biomedical, Social Science and Physics Research. NSF IIS-0513650 award (Katy Börner, Albert-Laszlo Barabasi, Santiago Schnell, Alessandro Vespignani & Stanley Wasserman, Craig Stewart (Senior Personnel), $1,120,926) Sept. 05 - Aug. 08. http://nwb.slis.indiana.edu