Foreword

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

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

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

...
Early Maps of the World VERSUS Early Maps of Science

3D
Physically-based
Accuracy is measurable
Trade-offs have more to do with granularity
2-D projections are very accurate at local levels
Centuries of experience
Geo-maps can be a template for other data

n-D
Abstract space
Accuracy is difficult
Trade-offs indirectly affect accuracy
2-D projections neglect a great deal of data
Decades of experience
Science maps can be a template for other data

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

Black Box

Find your way
Find collaborators, friends
Identify trends

Take terra bytes of data
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Part 1: Introduction

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

Ray Kurzweil

The Rise of Science and Technology

Papers & Wikipedia Entries
2005 World Population
The population map uses a quarter degree box resolution. Boxes with zero people are given in white. Darker shades of red indicate higher population counts per box using a logarithmic interpolation. The highest density boxes appear in Mumbai, with 11,687,850 people in the quarter degree block, Calcutta (10,816,010), and Shanghai (8,628,088).

2007 IP Address Ownership
This map shows IP address ownership by location. Each owner is represented by a circle and the area size of the circle corresponds to the number of IP addresses owned. The large circle denotes MIT’s holdings of an entire class A subnet, which equates to 16,581,375 IP addresses. The countries that own the most IP addresses are US (560 million), Japan (130 million), Great Britain (47 million).
**2003 Scientific Productivity**
Shown is where science is performed today. Each circle indicates a geographic location at which scholarly papers are published. The larger the circle the more papers are produced. Boston, MA, London, England, and New York, NY are the top three paper production areas. Note the strong resemblance with the Night on Earth and the IP Ownership maps and the striking differences to the world population map.

**2000 Night on Earth**
This image shows city lights at night. It was composed from hundreds of pictures made by orbiting satellites. The seaboards of Europe, the eastern United States, and Japan are particularly well lit. Many cities exist near rivers or oceans so that goods can be exchanged cheaply by boat. The central parts of South America, Africa, Asia, and Australia are rather dark despite their high population density, see map to the left.
In 1870, Captain George Everest embarked to map India by triangulation. For generations, a vast network of repeating sightline triangles was meticulously measured and recorded (see map below). What resembles a pattern of eyelashes on the northern border represents the sightlines to stations built above treetops. While analyzing the triangles in the calculating offices of Calcutta, the mapmakers discovered the highest peak in the world: Mount Everest.

---

Part 2: The History of Science Maps

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

George Santayana
Part 3: Toward a Science of Science

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

George Santayana
Temporal Analysis
Science evolves over time. Attributing values of scholarly activity and their diverse aggregations increase and decrease at different rates and respond with different latency to internal and external events. Temporal analysis aims to identify the nature of phenomena represented by a sequence of observations, such as processes, trends, seasonality, cycles, and inertia of activity.

Data
A time series is a sequence of events or observations that are ordered in time. Time series data can be time-ordered time series, an observation at any instant of time (e.g., figure to the right) or data (observations) that are not regularly or irregularly spaced intervals. Temporal aggregations, such as annual, monthly, quarterly, or daily data, are common.

Algorithms
Frequently, some forms of filtering are applied to reduce noise and make patterns more salient. Seasonal filtering can be using a smoothing window at a certain width and time approximation might be applied. The number of scholarly records can often be plotted to give an idea of the temporal distribution of a data set. It might be shown in total revenue or as a percentage of them. One may find out how long a scholarly entity was active, how old it was at a certain point, what growth, decay rates, peaks, or dips are, or what trends are observable. Data models such as the square root model (Bibby, 1969;听听 that’s a bit unusual), or other time series models, are used. Time series data are usually visualized using a line graph, displaying the number of records over time with a title and axis labels, and a legend that explains the data points.

Topical Analysis
The topic coverage and topical similarity of basic and aggregate units of science (journals, conferences, institutions, or researchers) can be derived from the data associated with them (papers, patents, organizations).

Data
The data in a geographic area or a unit of science can be derived from the data annotated or indexed. Topical papers, such as those related to journals, conference, organizations, or researchers, can be used to identify the topics that are covered.

Algorithms
Topic analysis extracts the set of unique words or phrases and their frequency from a set corpus. These words, such as “big” and “small,” are removed. Remaining can be applied to identify the set of unique words or phrases from a set corpus. The stops are an occurring word or phrase, allowing a unique set of topics for each document. Similarly, topics can be used to group according to the number of words that are common. In addition, topics are used to create documents based on the common words that are common.

Interpretation
Study I: Mapping Knowledge Disruption and the Importance of Space
This study aimed to determine whether the internet leads to more global citation patterns that include more citations between papers presented at geographically distant research institutions. The study used the dataset of scholarly publications in the field of computer science to analyze the impact of disruptions on the citation networks. The study found that disruptions led to more citations between papers presented at geographically distant research institutions, indicating that the internet leads to more global citation patterns.

Study II: Identifying Research Topics and Trends
Scientific research is highly dynamic. New areas of science are continually evolving and shifting in importance, driven by new discoveries and applications. Because of the study’s focus on the number of scholarly publications, it can be challenging to identify the scientific subfields related to the study. The study used a dataset of scholarly publications to identify the major research topics and trends in the field of computer science. The study found that the number of publications in each research topic increased over time, indicating that the field is growing in importance.

Study III: Modeling the Correlation of Author-Paper Networks
Models of scientific structure and evolution can be used to understand the interactions and information flows in scholarly communities. The study used a dataset of scholarly publications to identify the major research topics and trends in the field of computer science. The study found that the number of publications in each research topic increased over time, indicating that the field is growing in importance.

Symposium
The symposium aims to bring together researchers from diverse fields to discuss the latest developments and challenges in the field of computer science. The symposium includes a series of invited talks, presentations, and discussions that cover a wide range of topics, including research topics, trends, and models of scientific structure and evolution. The symposium provides a platform for researchers to share their latest findings and to network with others in the field.
Part 4: Science Maps in Action

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

Jacob L. Moreno

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

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

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

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

Maps of science today are based on limited knowledge and therefore imperfect. In order to generate comprehensive maps that are entirely accurate and reliable, we must first have proper coverage and interpretative technologies.

Maps of science will increase our appreciation and application of scientific thought processes in educational and public presentation.

The Power of Maps features four cartographic maps: an early statistical graph by Charles Joseph Minard, a flow diagram, an early statistical graph by Charles Joseph Minard, and early maps of our world by medieval and 17th-century cartographers. The exhibit employs a different metaphor: a node-link diagram; a topological map rendered using geographic information systems; a network map; and a galaxy view. Which metaphor is best? It depends on the visual index of our collective science and technology.
The Structure of Science

Mathematics is our starting point, the seeds of all sciences. It lies at the core of the map of science, becoming the foundation for all scientific disciplines. Mathematics underpins the work of all other sciences, including the physical sciences, life sciences, and social sciences. It is the language of science, allowing us to describe and understand the world around us.

Nanoscience

Nanotechnology has revolutionized science, enabling us to see things on a molecular level. We can now manipulate matter at the atomic scale, opening up new possibilities in medicine, materials science, and more.

Proteomics

Proteomics is the study of proteins, which are essential for all life processes. By understanding protein structures, we can gain insights into how cells function and develop new drugs to treat diseases.

Pharmacogenomics

Pharmacogenomics is the study of how genes influence an individual's response to a drug. This knowledge can help us personalize treatment, ensuring it is effective for each individual.

The Life Sciences include Biology and Medicine. In Biology, we study the fundamental processes of life, from molecules to ecosystems. Medicine is the practice of diagnosing and treating diseases, improving human health.


Four Existing Reference Systems Versus Six Potential Reference Systems

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

Results include the description of the electromagnetic periodic table of elements, geographic projections, data systems, shown here. Note that the geographic maps from paper to geographic information systems (GIS) for public use and consumption.

In comparison to these four existing systems are four potential reference systems for scholarly knowledge. Each reference system is based on a functional timeline and the geographic system to the schedule to identify the location of an author, paper, priority, or contribution.
The Visual Elements Periodic Table

The Visual Elements Periodic Table is an arrangement of all known elements in order of increasing atomic number. The elements are depicted using images that reflect their physical and chemical properties, creating a visual representation of the periodic table. This unique approach makes it easier to understand the relationships between elements.

Evening Stars

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

How to Use a Sky Map

1. **Check the date and time:*** Use the map that matches the night you are observing. The sky changes from night to night as the Earth rotates on its axis.

2. **Find the star constellations:*** Use the constellation names and symbols to help you locate the stars. The constellations are like road signs in the sky, helping you navigate your way through the stars.

3. **Locate the stars:*** Use the stars as markers on the map to find other stars and objects in the sky. The stars are our guideposts in the vastness of space.

Tips

- **A couple of tips:*** Use the map to identify constellations, bright stars, and other interesting objects in the sky.

- **When to use this map:*** Use the map to get a general idea of what you'll see in the sky on a clear night.

- **Sky & Telescope:** Check out the Sky & Telescope website for more information and resources on astronomy.
Writing the History of Science

In their book "The Genius Code," authors Kate优于 and Creswell discuss the impact of science on human history and culture. They draw on a wide range of historical examples, including ancient civilizations and modern scientific breakthroughs, to illustrate how scientific ideas have shaped our understanding of the world.

The authors argue that scientific progress is not linear but rather a series of bursts of activity followed by periods of consolidation. They trace the development of scientific thought from ancient Greece to the present day, highlighting key innovations and discoveries along the way.

The diagram above represents the timeline of scientific development, with major breakthroughs marked by significant events. The timeline covers the period from ancient Greece to the present day, with a focus on the scientific contributions of major figures and institutions.

The authors also discuss the role of science in shaping society, pointing out how scientific knowledge has been used to solve problems and improve lives. They argue that science is not just a body of knowledge, but a way of thinking and a set of tools that can be used to address a wide range of challenges.

Science Education and Personal Discovery

Science education and personal discovery can be fostered through hands-on learning and inquiry-based instruction. By engaging students in the scientific process of observation, hypothesis testing, and data analysis, educators can help students develop critical thinking skills and a deeper understanding of the scientific method.

The authors also suggest that personal discovery is a key component of scientific development, as individuals who are passionate about science are more likely to make important contributions to the field.

In conclusion, the authors of "The Genius Code" provide a comprehensive overview of the history of science, highlighting the key figures and institutions that have shaped our understanding of the world. They argue that science is a dynamic and ever-evolving field, and that by fostering a culture of curiosity and inquiry, we can continue to make progress towards a better understanding of the natural world.
Map of Scientific Paradigms

By Kevin W. Boyack and Richard Klavans
ALBUQUERQUE, NEW MEXICO, AND BERWYN, PENNSYLVANIA, 2006
Courtesy of Kevin W. Boyack and Richard Klavans, SoTeaR Strategies, Inc.

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

Interpretation
This map was generated by nearest neighbor clustering the 8,200,000 most important papers referenced in 2003 using the processing pipeline described on page 12. Toward a Reference System for Science. The result is a map of 776 paradigms, which are shown as circles on the map. Although each paradigm contains an average of 1,000 papers, they range to sixes, as shown by the various size circles on the map. The most dominant relationships between paradigms were also calculated and are shown as lines between paradigms. A reference system was added for means of navigation and communication.

Color-coding indicates the vitality of a research topic—the darker the red, the younger the average reference age and the more vital and faster moving the topic. The white circles represent paradigms where consensus is reached relatively slowly. This is a common phenomenon in the social sciences, ecological sciences, computer sciences, and mathematics disciplines. The red circles represent communities of researchers where consensus is reached relatively quickly. This is more common in physics, chemistry, biochemistry, and many medical disciplines. Very dark circles (such as those in quantum physics) represent communities where consensus is reached most quickly.

Countries, industries, companies, and individual researchers can all locate themselves within the map, either as single points or as a specific collection of paradigms. Science education and discovery can also be enhanced by linking to the map stories and facts that highlight content and relationships between scientific paradigms.
Third Iteration of Exhibit (2007): The Power of Forecasts

Four Existing Forecasts
Versus
Six Science Forecasts

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

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

Daily science and technology forecasts would serve a broad audience of experts/institutions/countries, major activity frontiers, augmenting our knowledge and decision-making available on TV, in the press, and online?
Impact of Air Travel on the Global Spread of Infectious Diseases

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

In pre-industrial times, disease spread was mostly in limited adjacent areas. During the 18th-century Europe, only few traveling areas were available and travel took place by foot, leaving low numbers of people exposed. In the 20th century, the number of people traveling increased rapidly, and the speed and distance traveled increased significantly. The average travel time for a person traveling on a continuous wave through the continent increased approximately 200-400 miles per year.

The SARS outbreak on the other hand was characterized by a much lower, non-seasonal transport network, which had a smaller impact on the spread of the disease. The SARS outbreak was a new disease, which resulted in the immediate and efficient identification of infected patients and the much more rapid rate of progression of the disease. On the contrary, seasonal outbreaks are more difficult to control and require a more detailed approach to prevent their spread.

Forecasts of the Next Pandemic Influenza

Seasonal forecasts are obtained with a stochastic, computational model which simulates the stochastic nature of the disease. The model incorporates a range of factors such as the rate of transmission, the rate of recovery, and the rate of infection. The result is a set of forecasts that can be used to predict the likelihood of a pandemic outbreak.

Geographical forecasts are obtained by simulating the stochastic nature of the disease. The model incorporates a range of factors such as the rate of transmission, the rate of recovery, and the rate of infection. The result is a set of forecasts that can be used to predict the likelihood of a pandemic outbreak.

Reproductive Number (R0) forecasts are obtained by simulating the stochastic nature of the disease. The model incorporates a range of factors such as the rate of transmission, the rate of recovery, and the rate of infection. The result is a set of forecasts that can be used to predict the likelihood of a pandemic outbreak.

Intervention strategies are obtained by simulating the stochastic nature of the disease. The model incorporates a range of factors such as the rate of transmission, the rate of recovery, and the rate of infection. The result is a set of forecasts that can be used to predict the likelihood of a pandemic outbreak.

Science & Technology Outlook: 2005–2055

A look at the future suggests a world of possibilities. In terms of science and technology, the world is moving faster than ever before. New technologies are emerging at a rate never seen before. Innovation is key to unlocking the potential of these technologies. Technologies such as artificial intelligence, blockchain, and quantum computing are changing the way we live and work. These technologies will continue to evolve and shape the future of society.

The future is bright, but there are also challenges. The world faces a range of issues such as climate change, global health, and economic inequality. These challenges require innovative solutions. Technology can play a role in addressing these challenges. For example, renewable energy technologies can help mitigate climate change.

As we look to the future, we can see a world that is both exciting and full of possibilities. The key is to harness the power of technology to build a better future for all.
Illuminated Diagram Display


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

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

This overlay shows the distribution of nanotechnology within the paradigms of science. The majority of current work in nanotechnology takes place 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 at the tiny scale of molecules

Sustainability
- The science behind our long-term hopes

Biology & Chemistry
- The interface between these two vital fields

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

Albert EINSTEIN
- Renalized physics with relativity theories

Michael E. FISHER
- Models critical phase transitions of matter

Susan T. FISKE
- Connects perception and priorities

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

TOPIC MAP: HOW SCIENTIFIC PARADIGMS RELATE
Activities:
Solve the puzzle.
Navigate to ‘Earth Science’.
Identify major inventions.
Place major inventors.
Find your dream job on the map.
Why is mathematics important?

Part 5: The Future of Science Maps

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

Joshua L. Chamberlain
Part 5: The Future of Science Maps

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210 Growing a “Global Brain and Heart”

Mapping Science Exhibit – 10 Iterations in 10 years

http://scimaps.org/

The Power of Maps (2005)


The Power of Forecasts (2007)

Science Maps for Economic Decision Makers (2008)

Science Maps for Science Policy Makers (2009)

Science Maps for Scholars (2010)

Science Maps as Visual Interfaces to Digital Libraries (2011)

Science Maps for Kids (2012)

Science Forecasts (2013)

How to Lie with Science Maps (2014)

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

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

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

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

References

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

Part 4: Science Maps in Action

References


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

All world and science map overlays for each of the 33 maps: 2002 Base Map, see Boyack et al. 2009: Science location of map significance by Elisha F. Hardy (design), Katy Borner (concept). World Map by Russell J. Dubin, overlay of geographical influence and significance by Elisha F. Hardy (design), Katy Borner (concept).

Image Credit

We would like to thank the map makers
References


Scharnhorst, Andrea, Börner, Katy, van den Besselaar, Peter (2011) Models of Science Dynamics. Springer Verlag
All papers, maps, tools, talks, press are linked from http://cns.iu.edu

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