Data Visualizations for Effective Exploration and Communication

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School of Informatics, Computing, and Engineering
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Indiana University, Bloomington, IN, USA
+ 2018 Humboldt Fellow, TU Dresden, Germany

IBS Workshop Media Computing
IBS Haus (ehemaliges Verwaltungsgebäude für die Brikettfabrik Erika)
Lauta, Germany

February 5, 2019

8-10a EST

IBS Workshop Media Computing

Dienstag	5. Februar 2019
ab 10 Uhr	Registrierung / Check In
12:00 Uhr	Welcome Lunch
13:30 Uhr	**Session I: Auftakt** Gegenseitige Vorstellung & Ausarbeitung im Duett
15:30 Uhr	Kaffeepause
16:00 Uhr	**Session II:** **Mutual presentations im pitch your project Stil** 1. Folie: Motivation/Anwendungsfall 2. Folie: Methodik 3. Ergebnisse
18:30 Uhr	Dinner for all
21:00 Uhr	**Get together** 2er Team-Fortführung im Entertainment-Format Science Slam: Fail-Session 2. Tag: Methodik
Mittwoch	**6. Februar 2019**
ab 8:00 Uhr	Frühstück
9:00 Uhr	**Session III:** **Methodik & Analytik für Promotionsarbeiten (PIs)** PhD-Struktur Argumentationsstruktur Experimentalsetup & Übertragbarkeit für PhD

Maps of Science & Technology

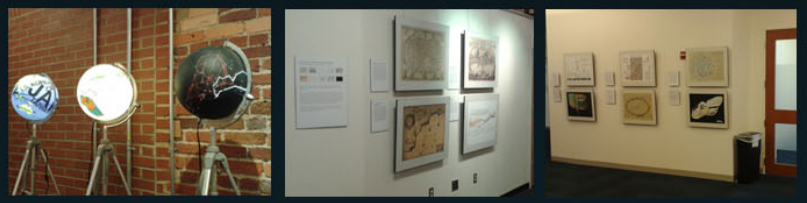
Using large scale datasets, advanced data mining and visualization techniques, and substantial computing resources.

Maps of Science & Technology

http://scimaps.org

101st Annual Meeting of the Association of American Geographers, Denver, CO.
April 5th - 9th, 2005 (First showing of Places & Spaces)

University of Miami, Miami, FL.
September 4 - December 11, 2014.

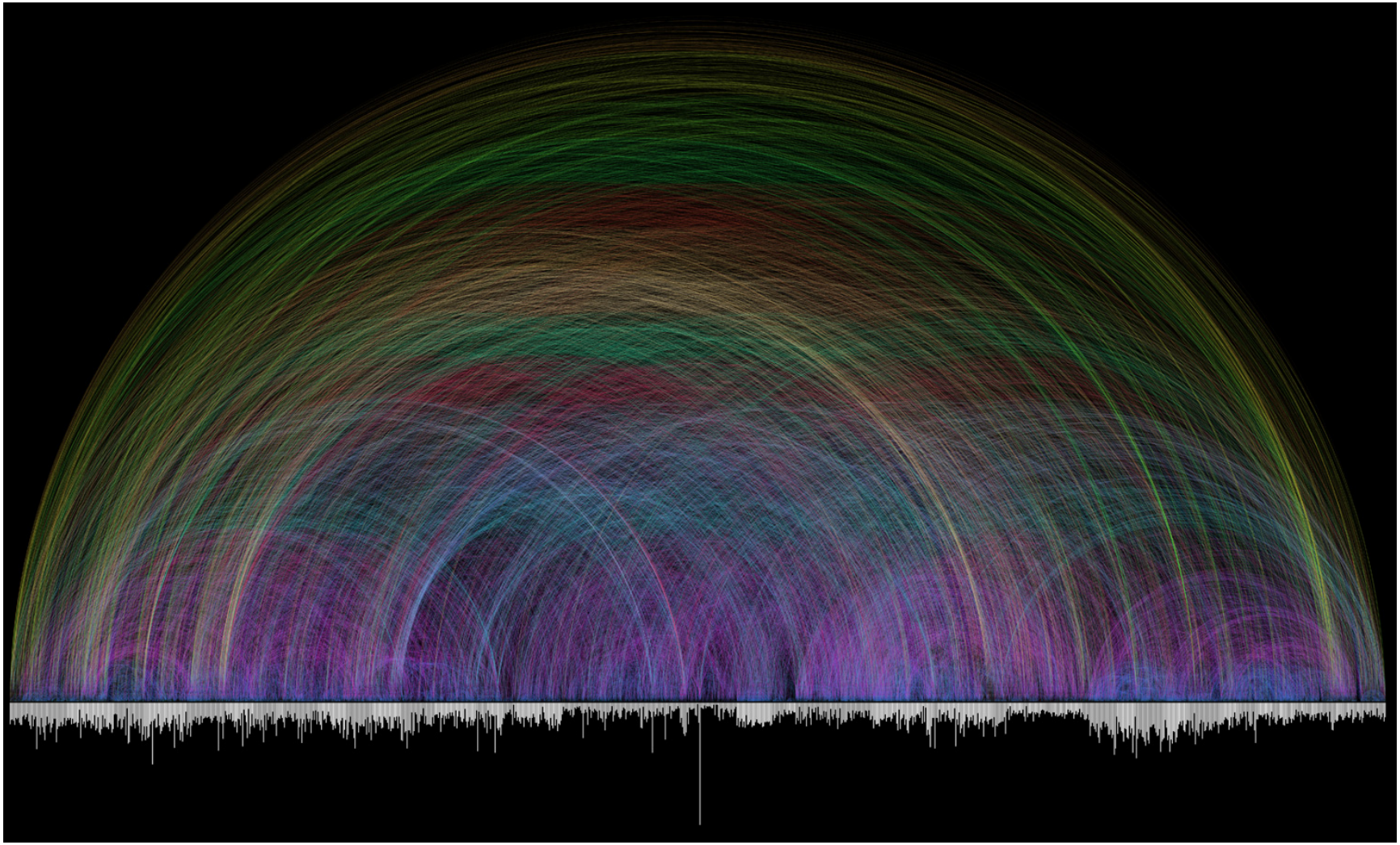


Duke University, Durham, NC.
January 12 - April 10, 2015

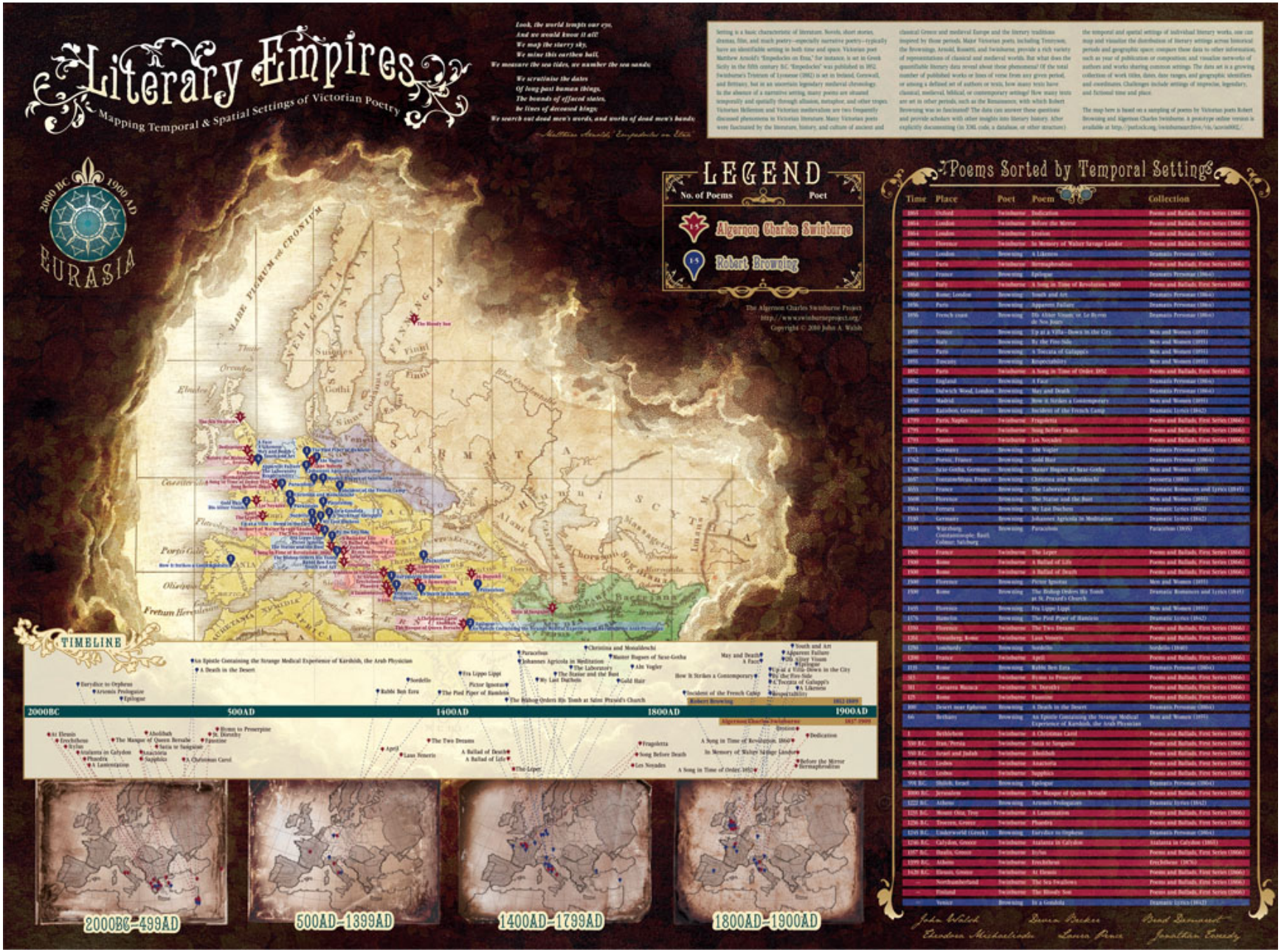
The David J. Sencer CDC Museum, Atlanta, GA.
January 25 - June 17, 2016.

100 maps and 12 macroscopes by 215 experts on display at 354 venues in 28 countries.

I.3 *A New Map of the Whole World with Trade Winds According to the Latest and Most Exact Observations* - Herman Moll - 1736

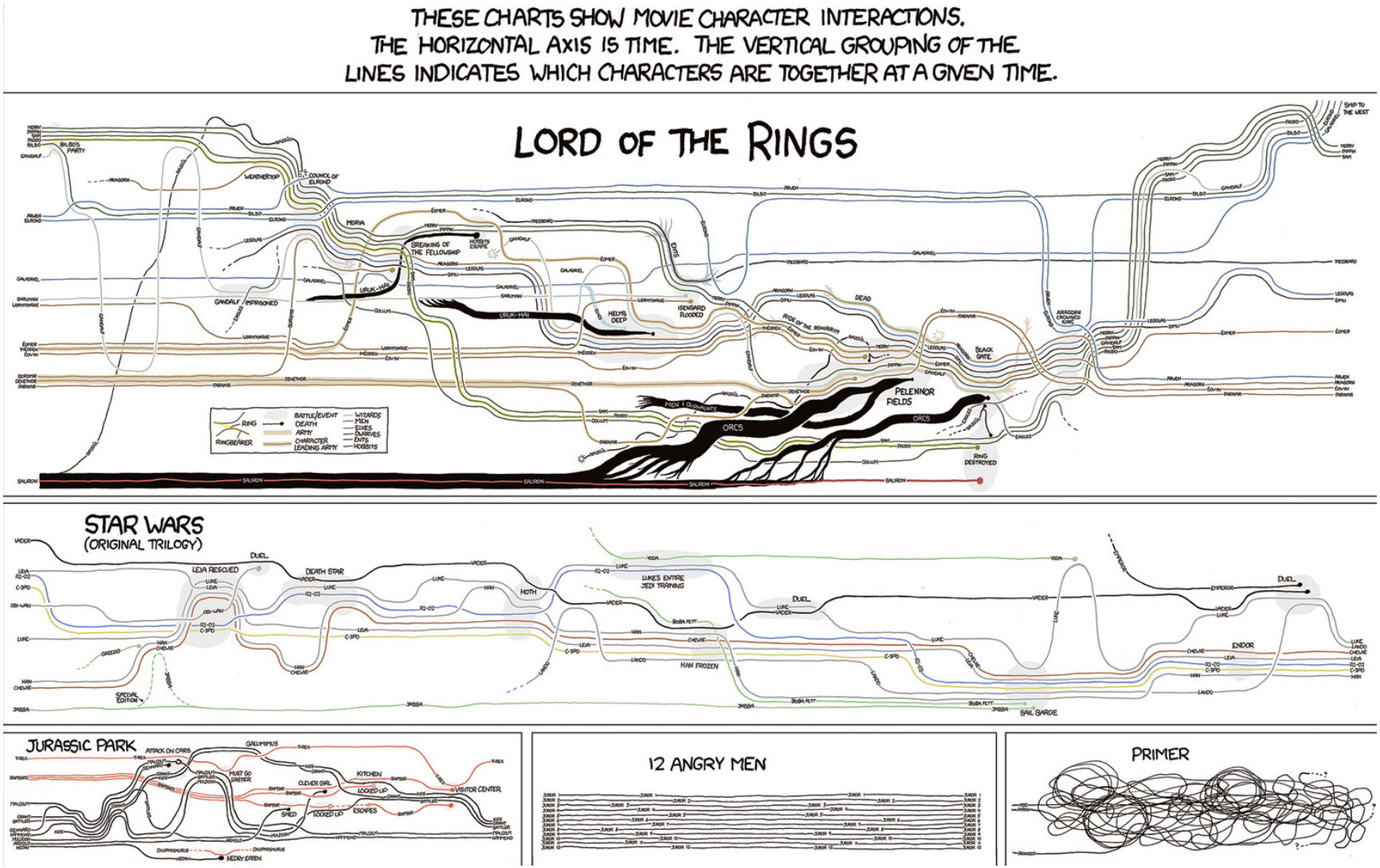


VII.3 *Visualizing Bible Cross-References* - Chris Harrison and Christoph Römhild - 2008

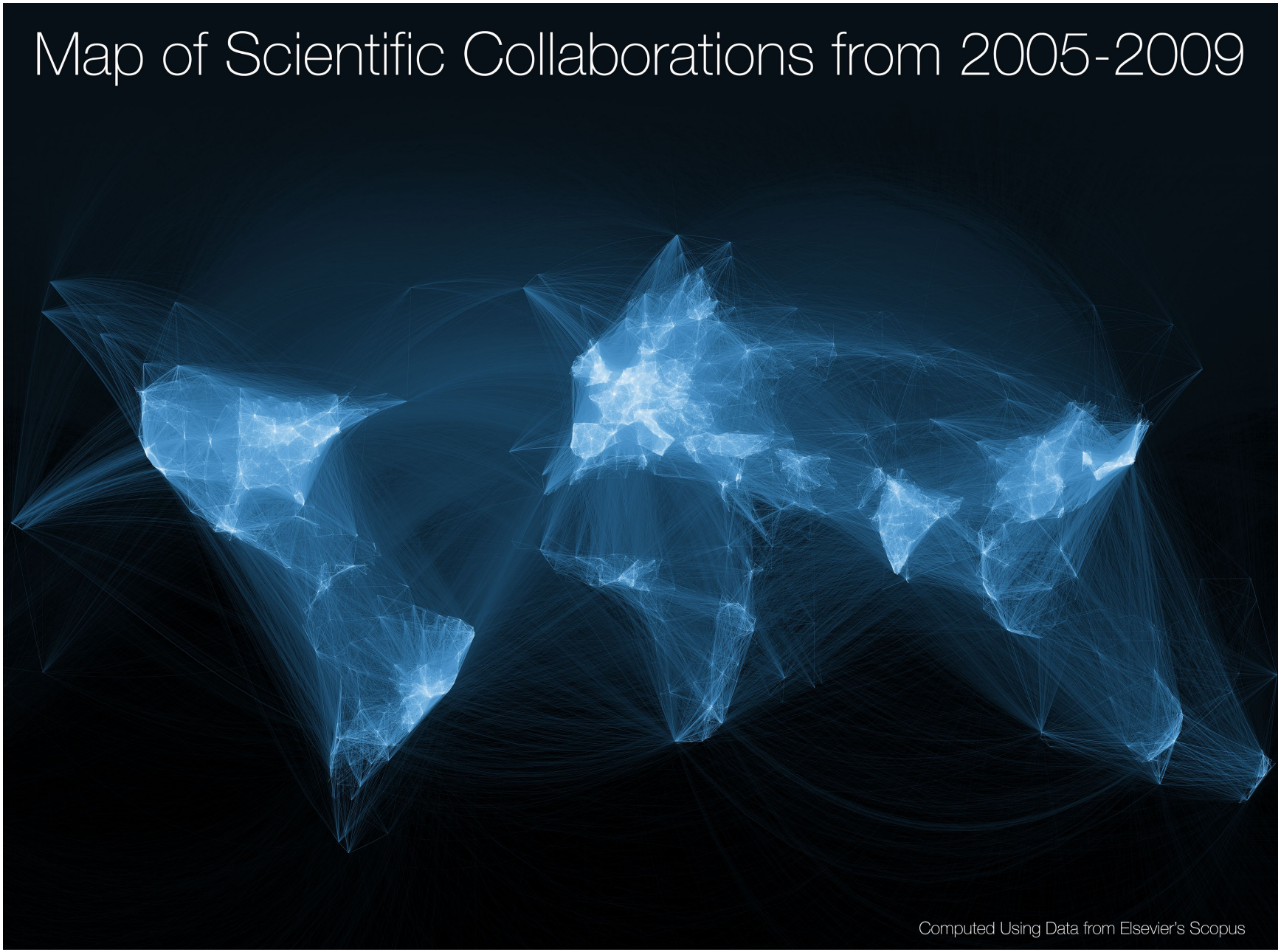


VI.7 *Literary Empires: Mapping Temporal and Spatial Settings of Victorian Poetry*

John A. Walsh, Devin Becker, Bradford Demarest, Jonathan Tweedy, Theodora Michaelidou, and Laura Pence - 2010

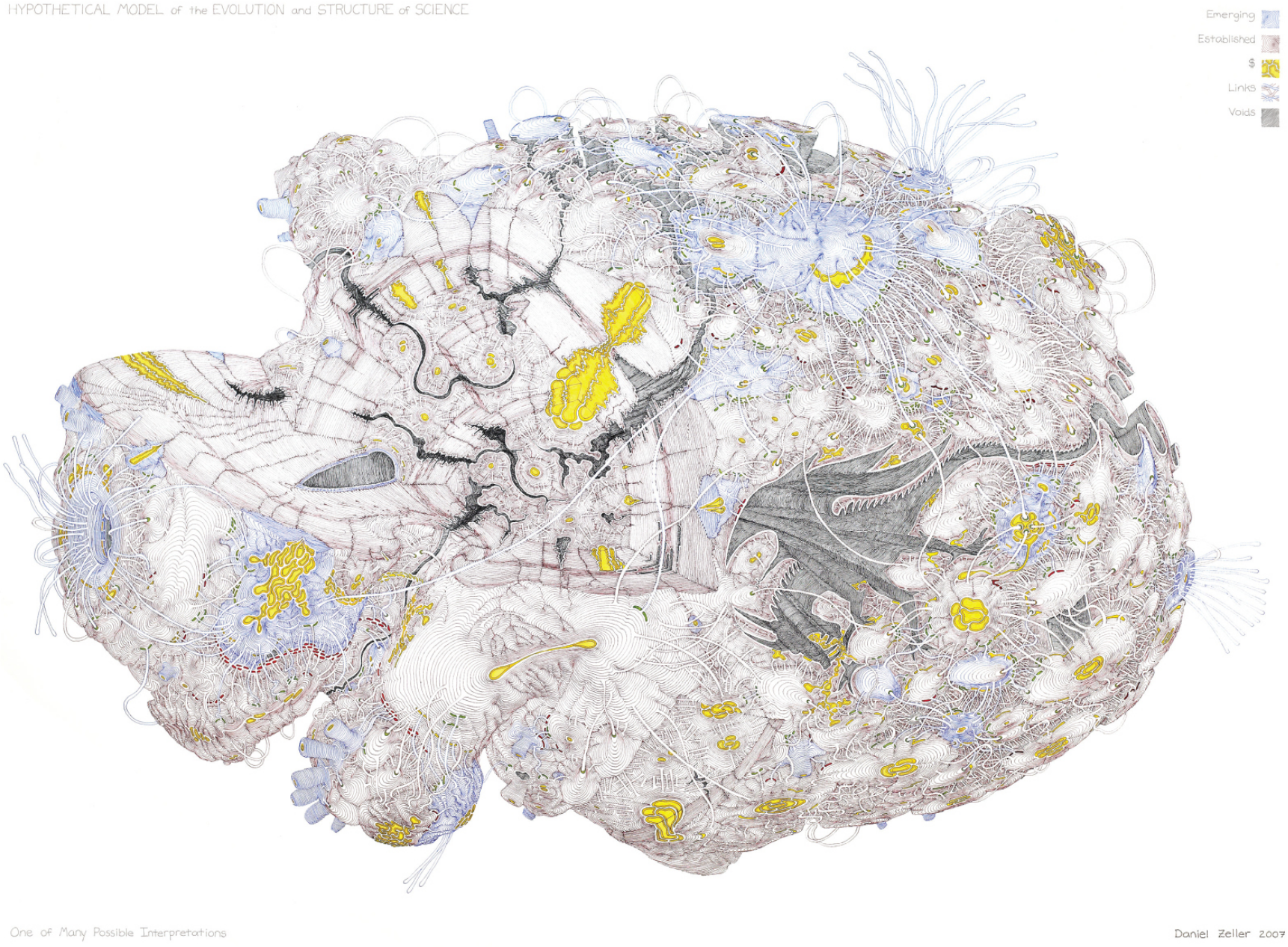


VIII.2 *Movie Narrative Charts (Comic #657)* - Randall Munroe - 2009

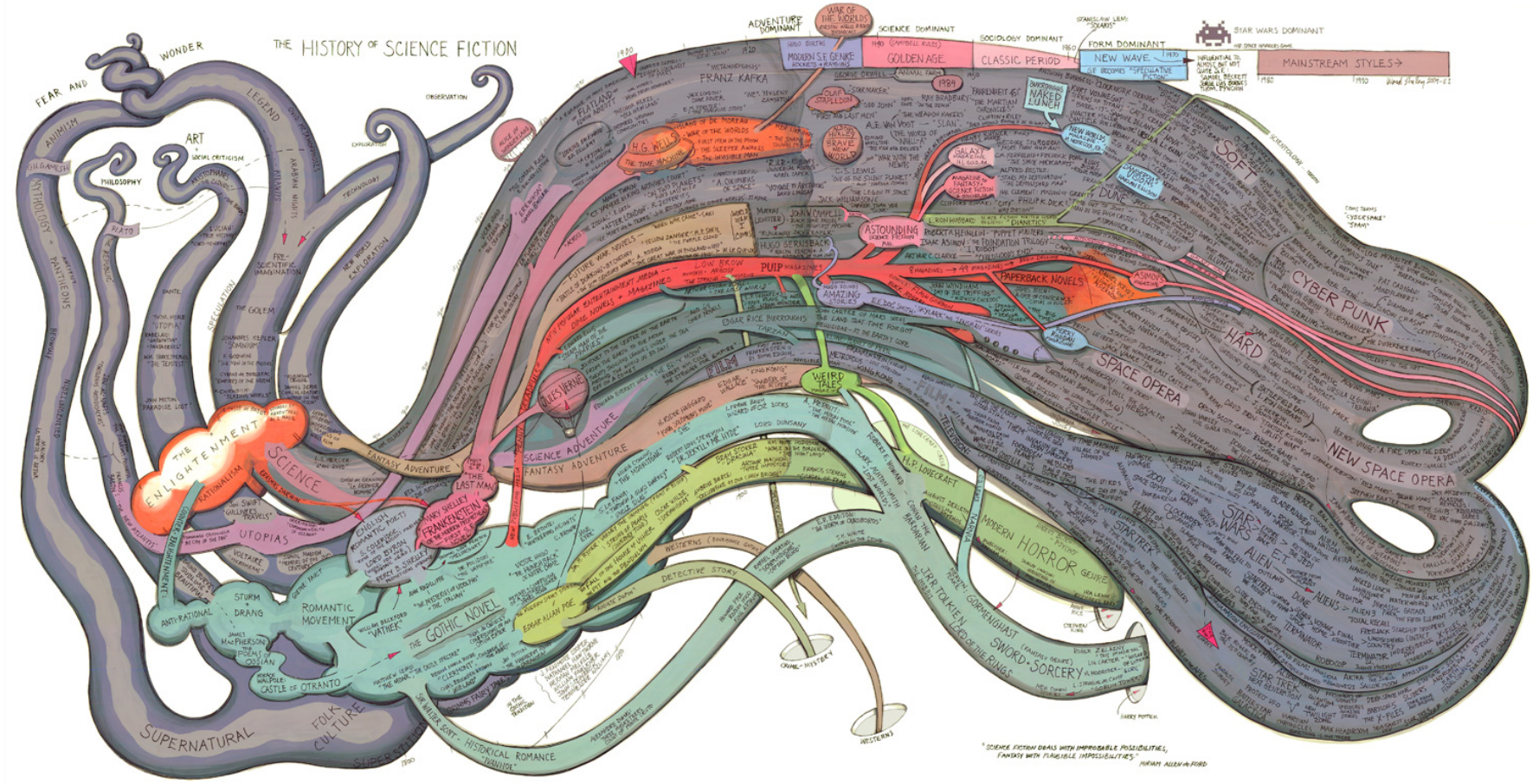


Stream of Scientific Collaborations Between World Cities - Olivier H. Beauchesne - 2012

X.2 *Map of the Internet* - Martin Vargic - 2014

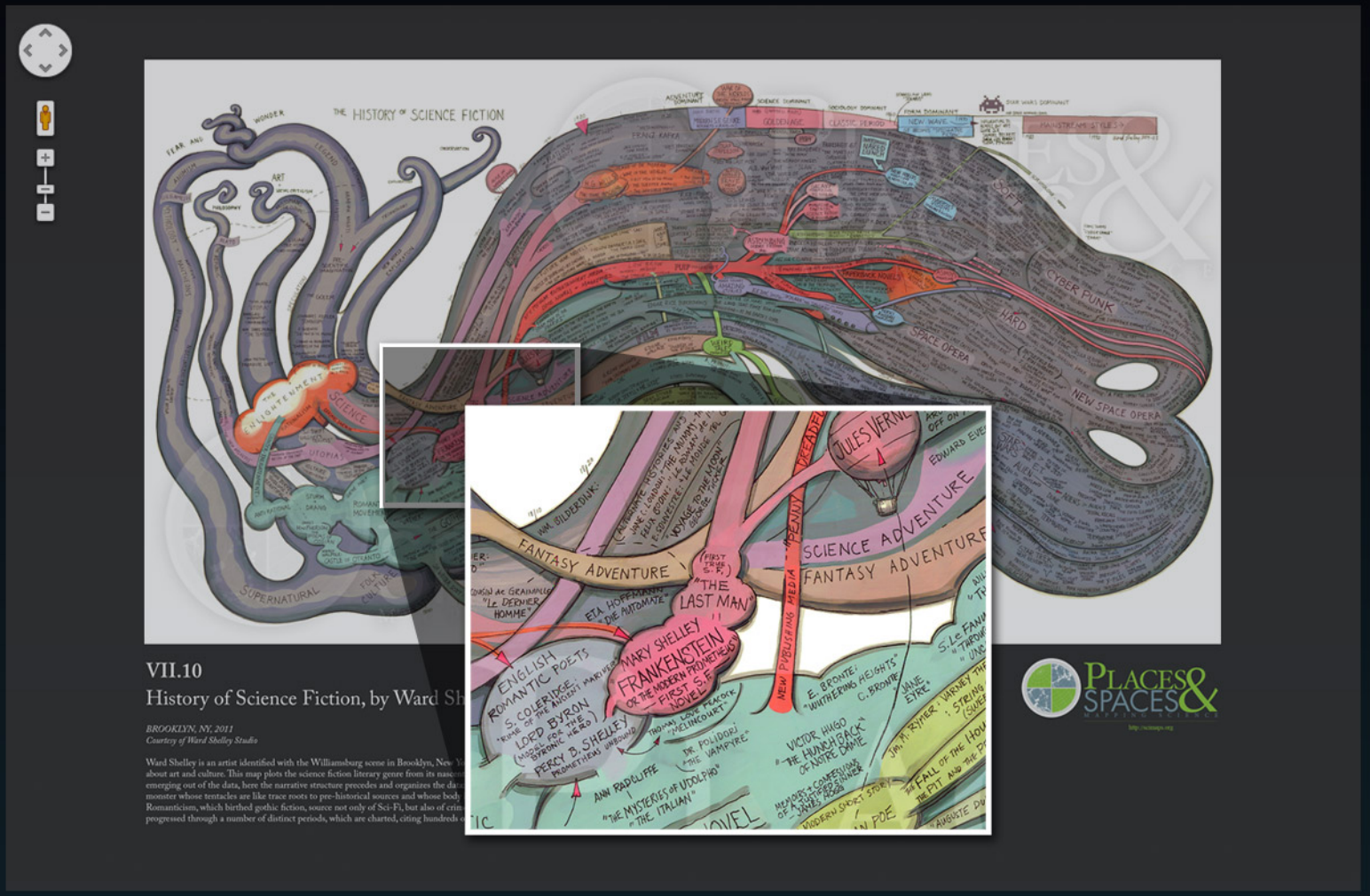


III.10 *Hypothetical Model of the Evolution and Structure of Science* - Daniel Zeller - 2007



VII.10 *History of Science Fiction* - Ward Shelley - 2011

Check out our Zoom Maps online!



VII.10

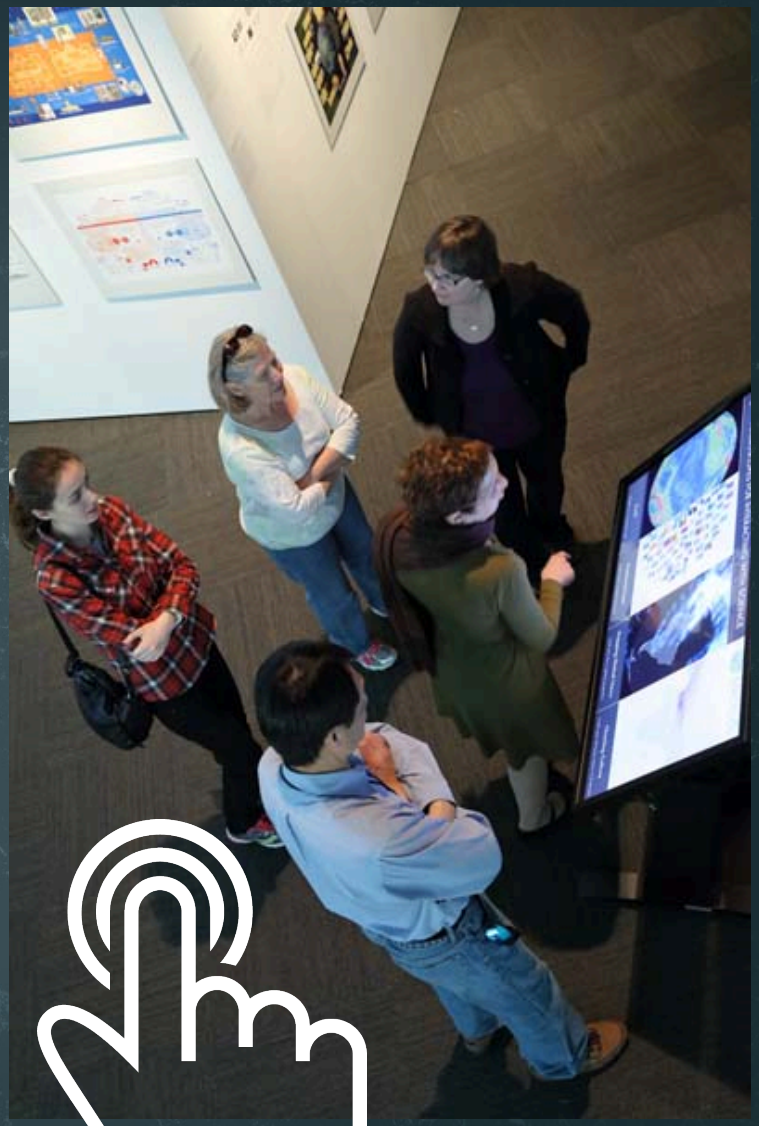
History of Science Fiction, by Ward Sh

BROOKLYN, NY, 2011
Courtesy of Ward Shelley Studio

Ward Shelley is an artist identified with the Williamsburg scene in Brooklyn, New Y
about art and culture. This map plots the science fiction literary genre from its nasc
emerging out of the data, here the narrative structure precedes and organizes the da
monster whose tentacles are like trace roots to pre-historical sources and whose body
Romanticism, which birthed gothic fiction, source not only of Sci-Fi, but also of crim
progressed through a number of distinct periods, which are charted, citing hundreds

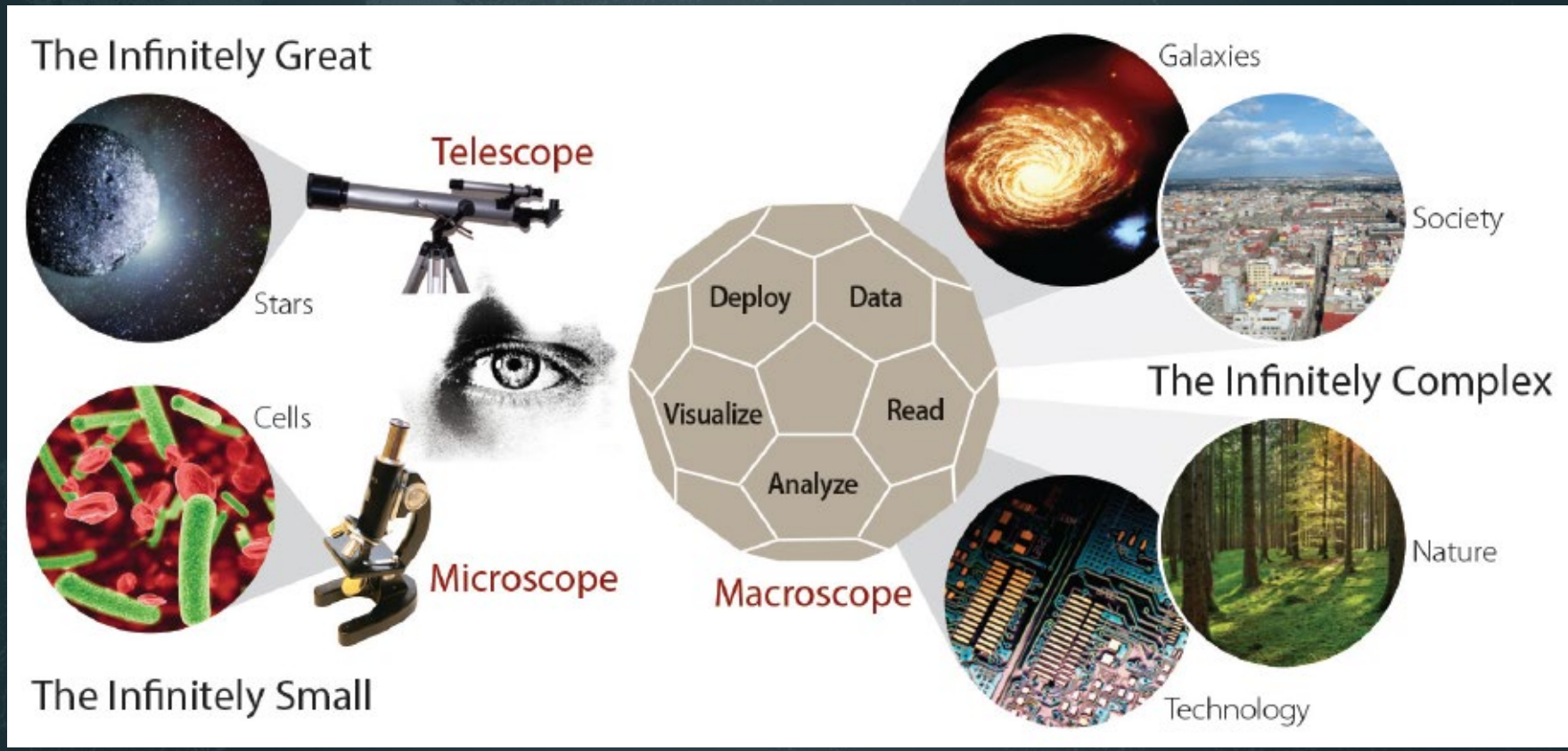
Visit scimaps.org and check out all our maps in stunning detail!

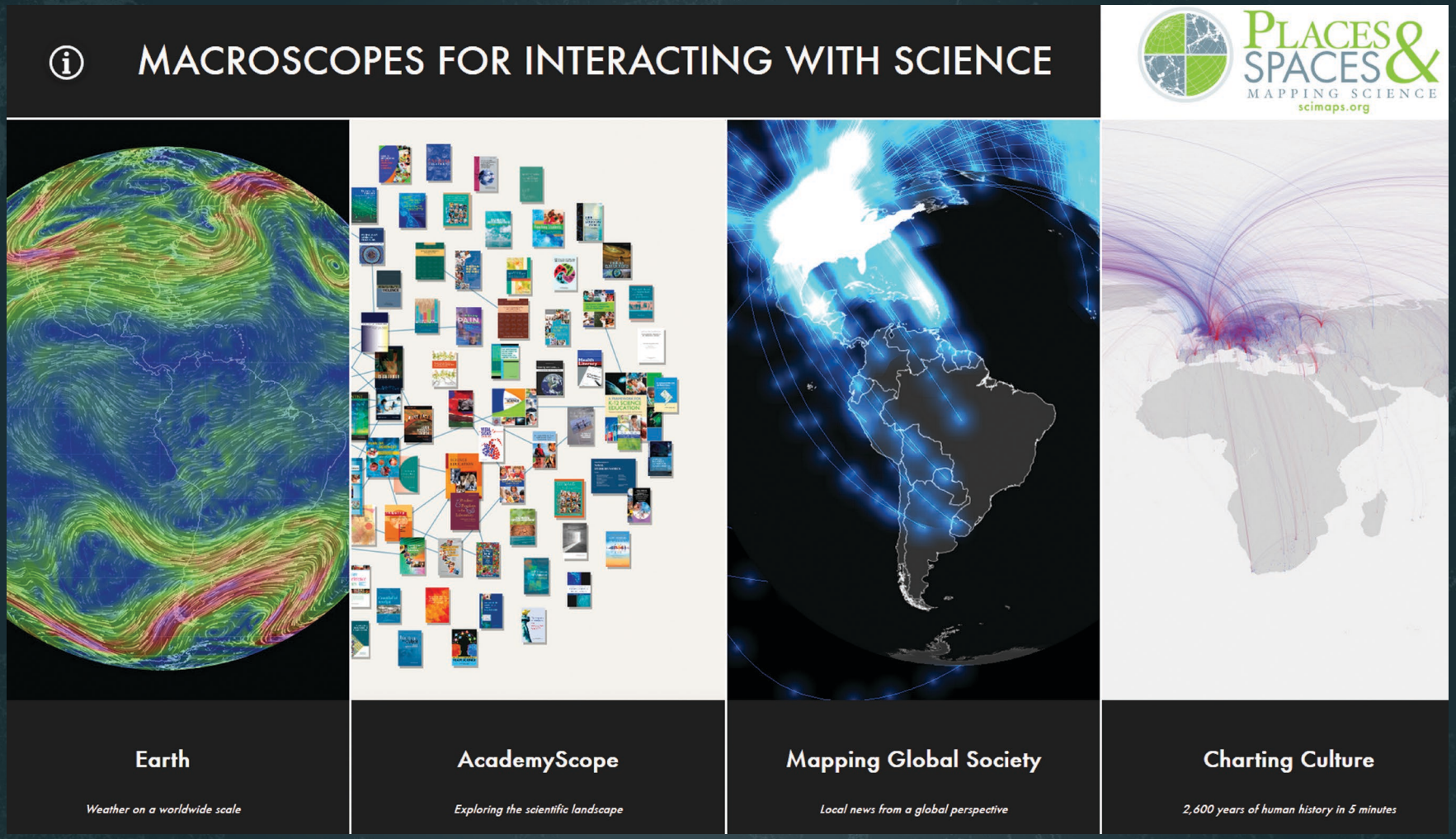
100 Maps of Science on Display in Hörsaalzentrum (Augustusplatz), Uni Leipzig, July 13-30, 2018



MAPS
vs.
MACROSCOPES

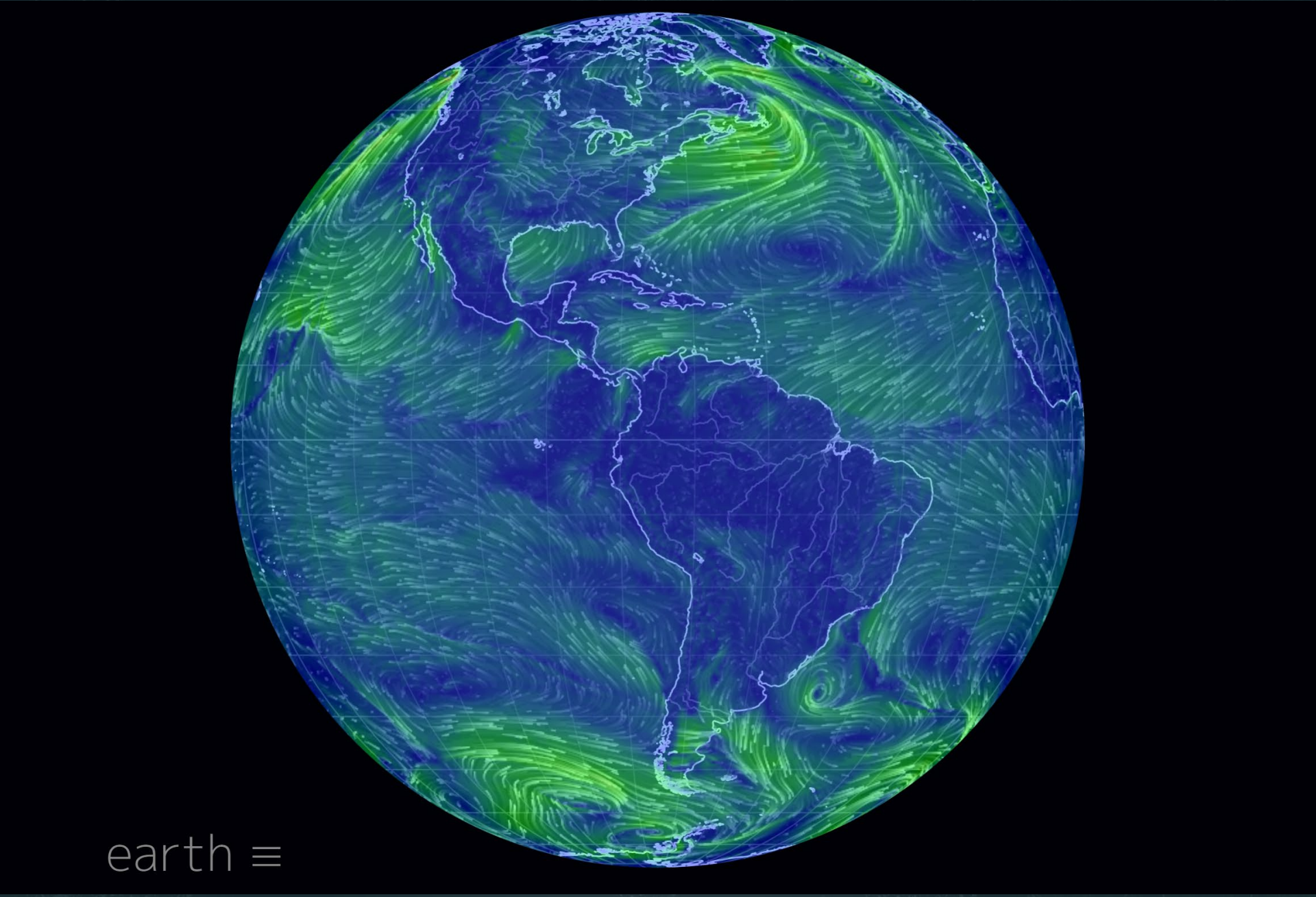
Microscopes & Telescopes vs. MACROSCOPES



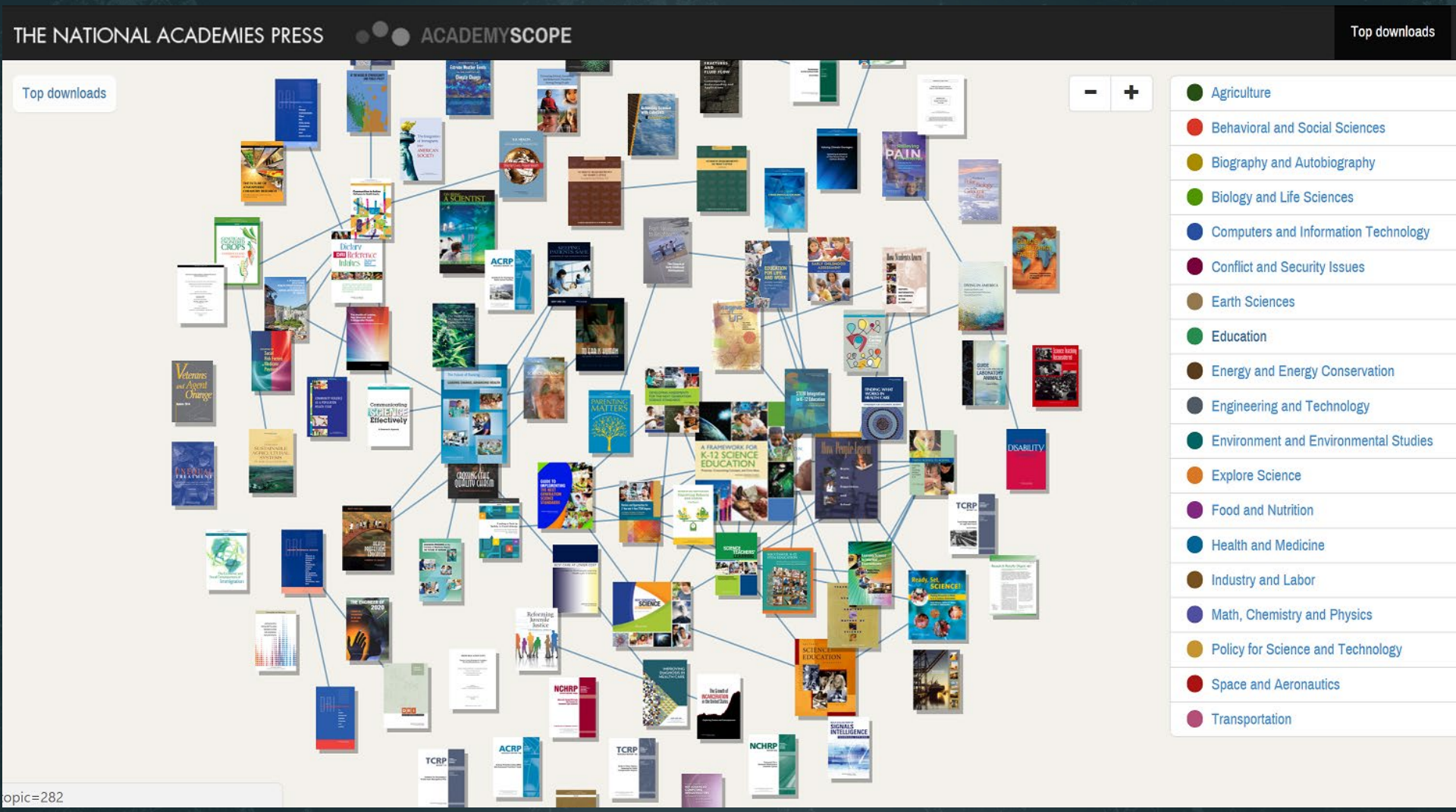


Iteration XI (2015): Macroscopes for Interacting with Science

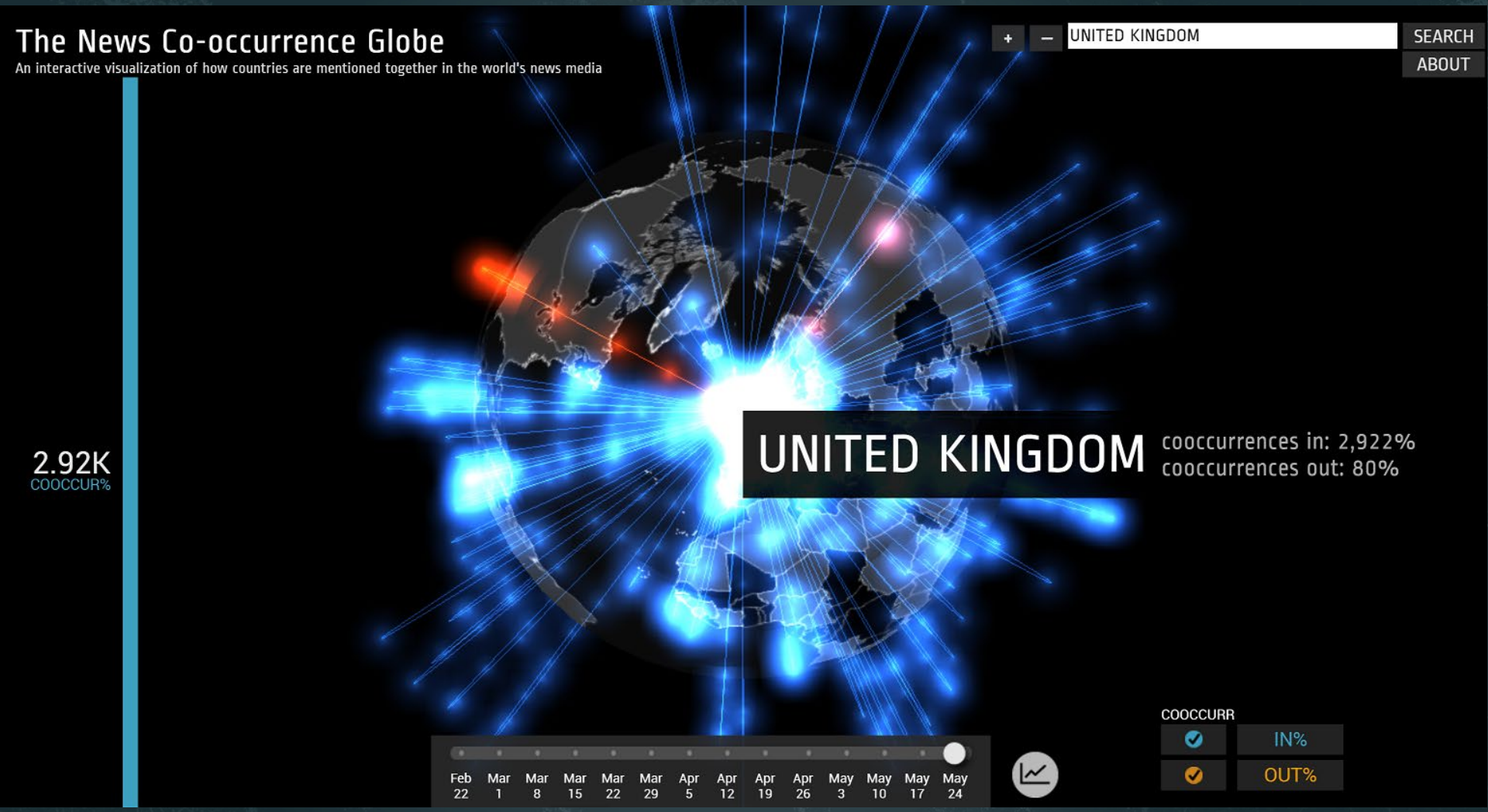
http://scimaps.org/iteration/11



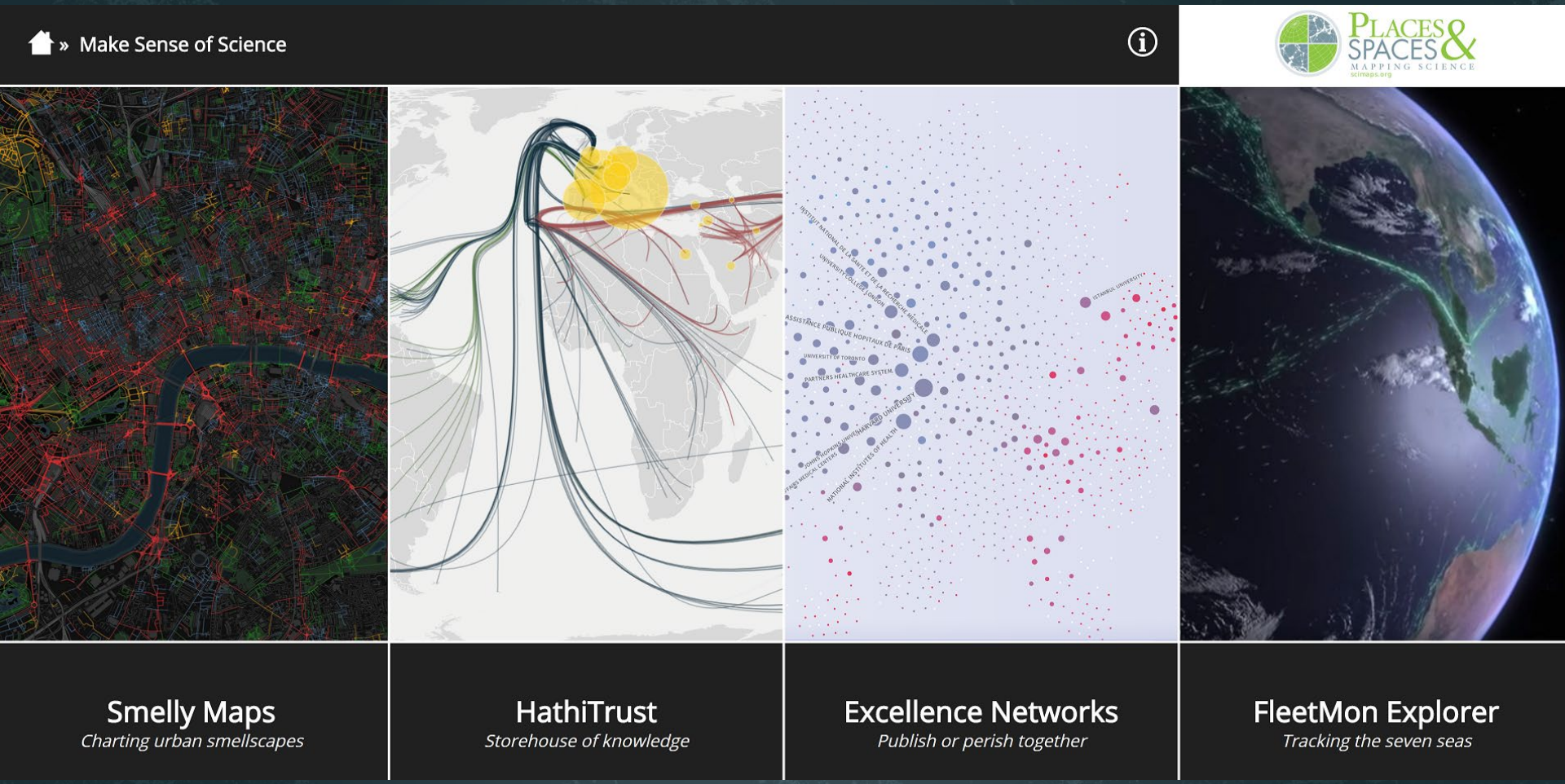
Earth – Cameron Beccario



AcademyScope – National Academy of the Sciences & CNS



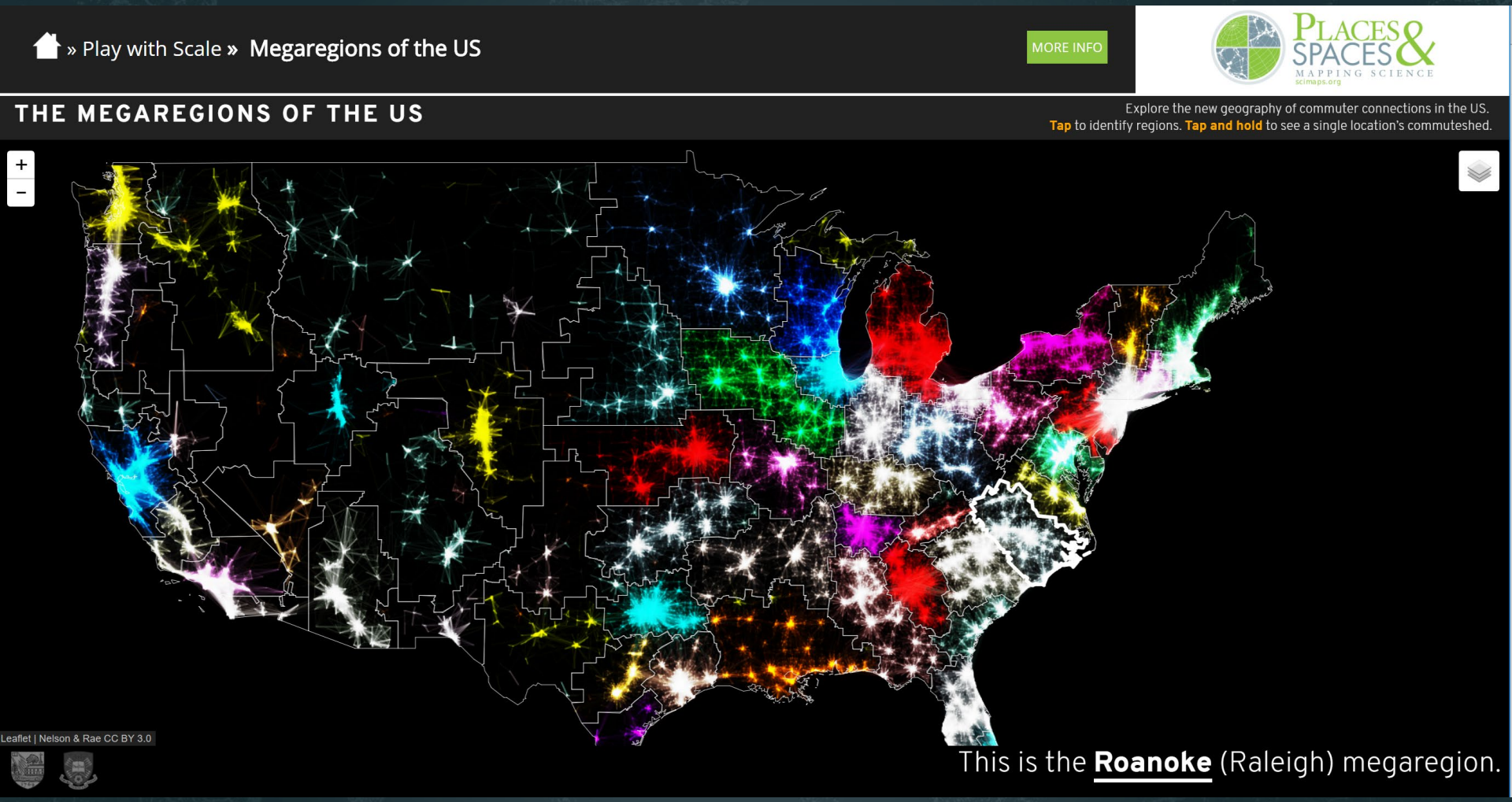
Mapping Global Society –Kalev Leetaru



Iteration XII (2016): Macroscopes for Making Sense of Science

http://scimaps.org/iteration/12

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

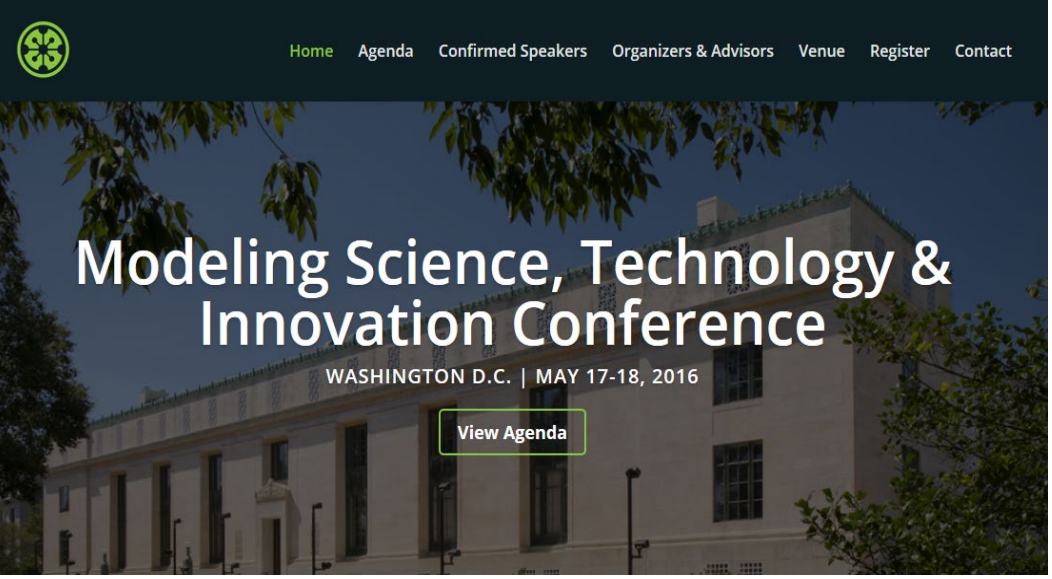


Megaregions of the US –Garrett Dash Nelson and Alasdair Rae – 2016

FleetMon Explorer – FleetMon – 2012

Models of Science & Technology

Using large scale datasets, advanced data mining, modeling, and visualization techniques, and substantial computing resources.

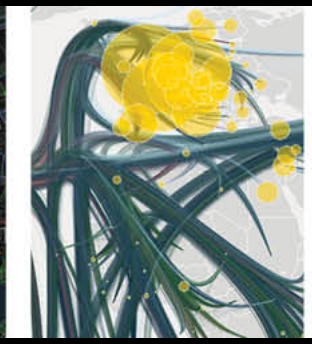
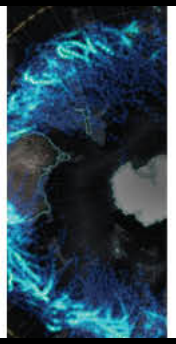


Government, academic, and industry leaders discussed challenges and opportunities associated with using big data, visual analytics, and computational models in STI decision-making.

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

#SacklerModVisST

Arthur M. Sackler COLLOQUIA
OF THE NATIONAL ACADEMY OF SCIENCES

Modeling and Visualizing Science and Technology Developments

National Academy of Sciences Sackler Colloquium, December 4-5, 2017, Irvine, CA

Rankings and the Efficiency of Institutions

H. Eugene Stanley | Albert-László Barabási | Lada Adamic | Marta González | Kaye Husbands Fealing | Brian Uzzi | John V. Lombardi

Higher Education and the Science & Technology Job Market

Katy Börner | Wendy L. Martinez | Michael Richey | William Rouse | Stasa Milojevic | Rob Rubin | David Krakauer

Innovation Diffusion and Technology Adoption

William Rouse | Donna Cox | Jeff Alstott | Ben Shneiderman | Rahul C. Basole | Scott Stern | Cesar Hidalgo

Modeling Needs, Infrastructures, Standards

Paul Trunfio | Sallie Keller | Andrew L. Russell | Guru Madhavan | Azer Bestavros | Jason Owen-Smith

nasonline.org/Sackler-Visualizing-Science

Arthur M. Sackler COLLOQUIA OF THE NATIONAL ACADEMY OF SCIENCES

Clarivate

Microsoft

PROGRAMS

Sackler Colloquia
- About Sackler Colloquia
- Upcoming Colloquia
- Completed Colloquia
- Sackler Lectures
- Video Gallery
- Connect with Sackler Colloquia
- Give to Sackler Colloquia

Cultural Programs
Distinctive Voices
Kavli Frontiers of Science
Keck Futures Initiative
LabX
Sackler Forum
Science & Entertainment Exchange

Arthur M. Sackler COLLOQUIA

Modeling and Visualizing Science and Technology Developments

December 4-5, 2017; Irvine, CA
Organized by Katy Börner, H. Eugene Stanley, William Rouse and Paul Trunfio

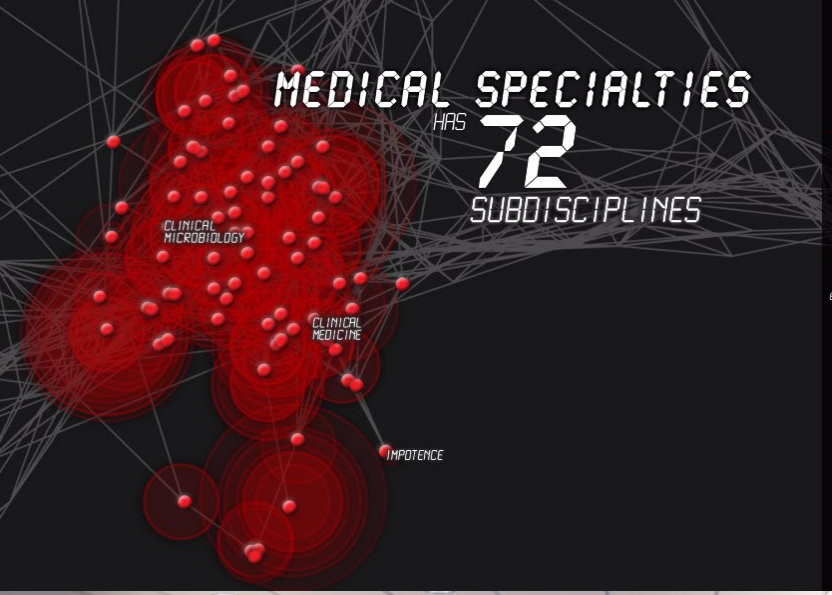
Overview

This colloquium was held in Irvine, CA on December 4-5, 2017.

This colloquium brought together researchers and practitioners from multiple disciplines to present, discuss, and advance computational models and visualizations of science and technology (S&T). Existing computational models are being applied by academia, government, and industry to explore questions such as: What jobs will exist in ten years and what career paths lead to success? Which types of institutions will likely be most innovative in the future? How will the higher education cost bubble burst affect these institutions? What funding strategies have the highest return on investment? How will changing demographics, alternative economic growth trajectories, and relationships among nations impact answers to these and other questions? Large-scale datasets (e.g., publications, patents, funding, clinical trials, stock market, social media data) can now be utilized to simulate the structure and evolution of S&T. Advances in computational power have created the possibility of implementing scalable, empirically validated computational models. However, because the databases are massive and multidimensional, both the data and the models tend to exceed human comprehension. How can advances in data visualizations be effectively employed to communicate the data, the models, and the model results to diverse stakeholder groups? Who will be the users of next generation models and visualizations and what decisions will they be addressing.

Videos of the talks are available on the **Sackler YouTube Channel**.

http://www.nasonline.org/programs/sackler-colloquia/completed_colloquia/modeling-and-visualizing.html



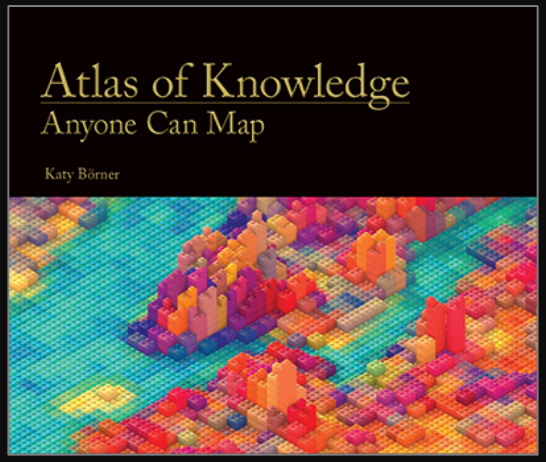
Science Forecast S1:E1

Science Forecast
S1:E1

https://www.youtube.com/watch?v=lByX2_eb_QQ

Making Science & Technology Visualizations

Using a theoretically grounded visualization framework that defines key terminology and processes together with valid workflows and data mappings.



Places & Spaces: Mapping Science Exhibit, online at http://scimaps.org

How to Classify (Name & Make) Different Visualizations?

By

- User insight needs?
- User task types?

- Data to be visualized?
- Data transformation?

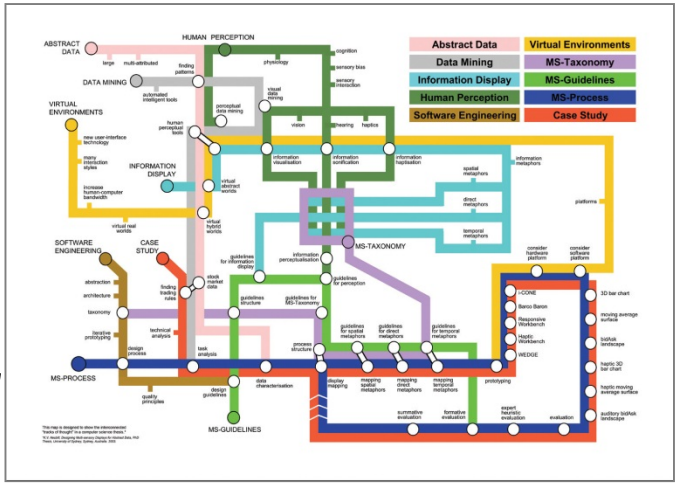
- Visualization technique?
- Visual mapping transformation?
- Interaction techniques?

- Or ?

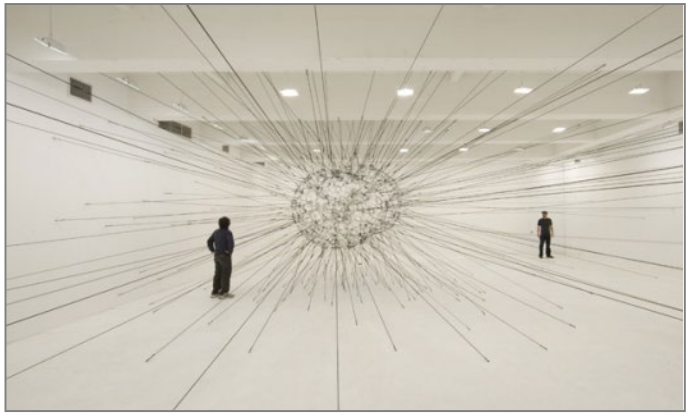
Different Question Types

Terabytes of data

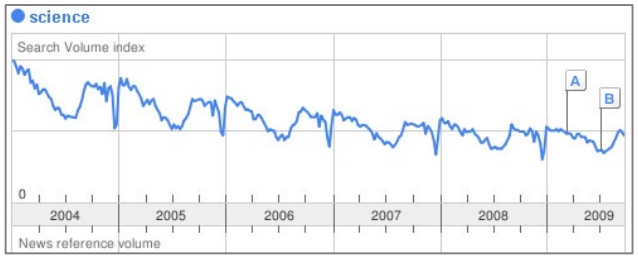
Descriptive & Predictive Models



Find your way



Find collaborators, friends



Identify trends

Different Question Types

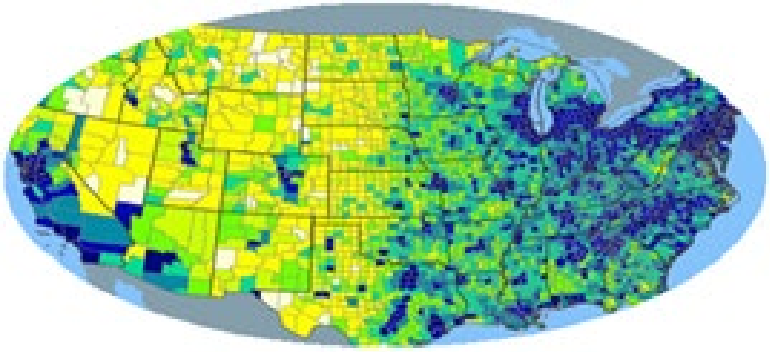
- Monitor Data Quality
- Customer Complaints
- Customer/Supplier/Learner Churn
- Optimizing Supplier Chains
- Improving (Traffic/Communication) Network Resilience
- Optimizing Traffic/Communication Flows
- Optimizing Work Cells/Built Process
- Workforce Development

And other WHEN, WHERE, WHAT, WITH WHOM questions.

Different Levels of Abstraction/Analysis

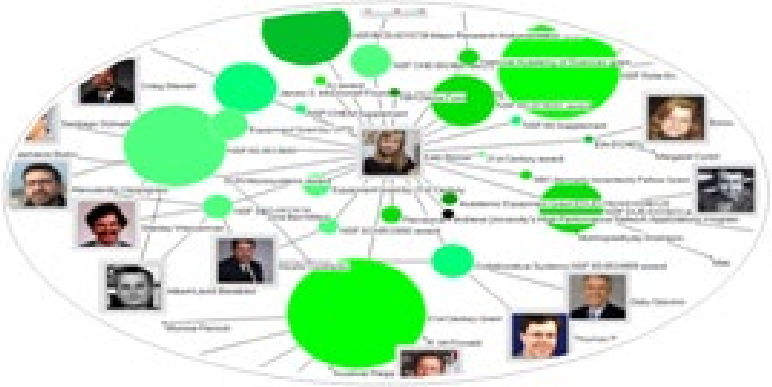
Macro/Global

Population Level



Meso/Local

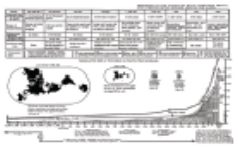
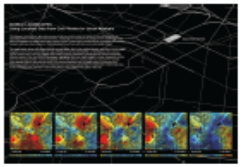
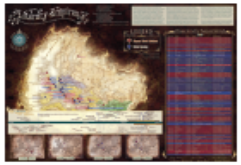
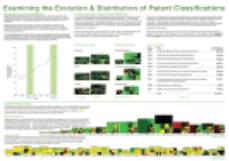
Group Level

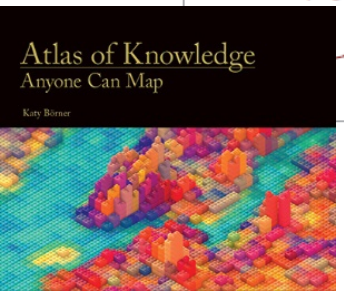


Micro

Individual Level

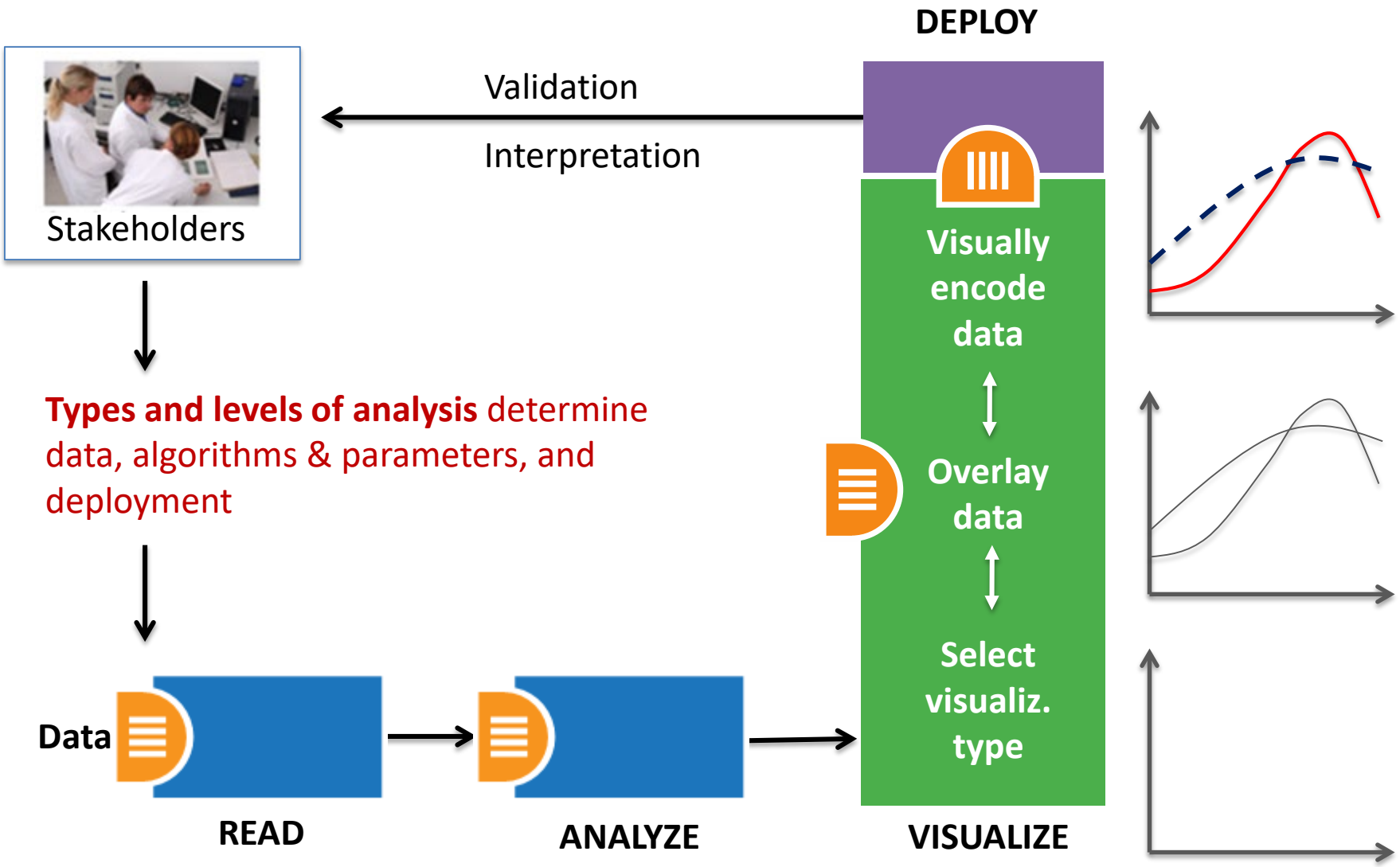
Tasks

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

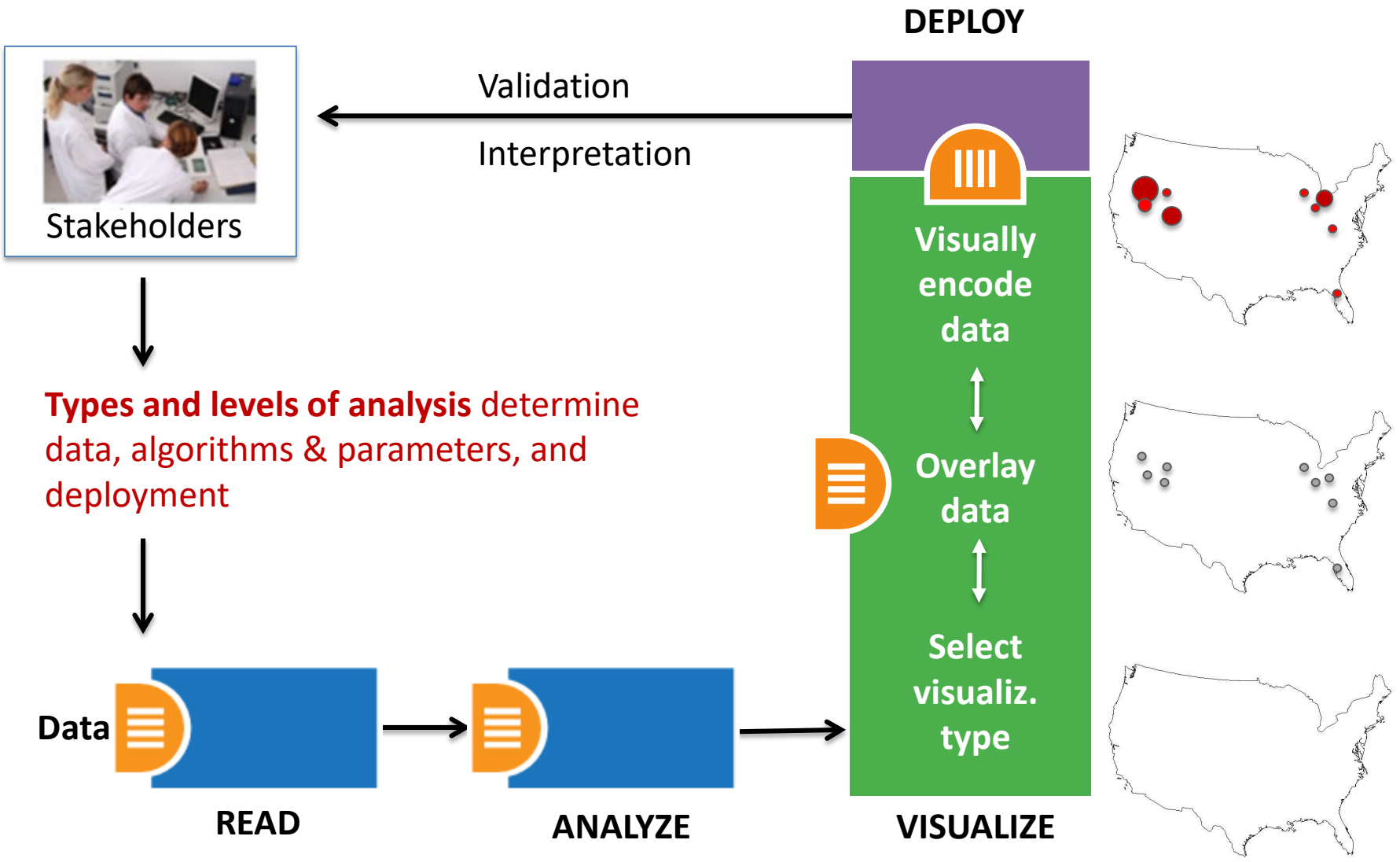


See *Atlas of Science: Anyone Can Map*, page 5

Needs-Driven Workflow Design

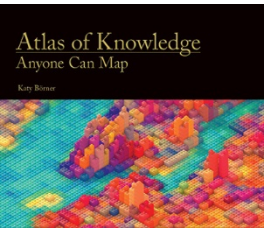


Needs-Driven Workflow Design



Visualization Framework (Vis-FW)

Insight Need Types page 26	Data Scale Types page 28	Visualization Types page 30	Graphic Symbol Types page 32	Graphic Variable Types page 34	Interaction Types page 26
• categorize/cluster • order/rank/sort • distributions (also outliers, gaps) • comparisons • trends (process and time) • geospatial • compositions (also of text) • correlations/relationships	• nominal • ordinal • interval • ratio	• table • chart • graph • map • network layout	• geometric symbols point line area surface volume • linguistic symbols text numerals punctuation marks • pictorial symbols images icons statistical glyphs	• spatial position • retinal form color optics motion	• overview • zoom • search and locate • filter • details-on-demand • history • extract • link and brush • projection • distortion



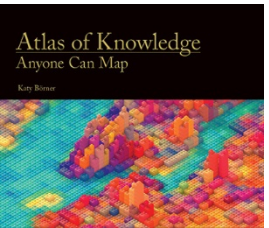
See page 24

Visualization Framework

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

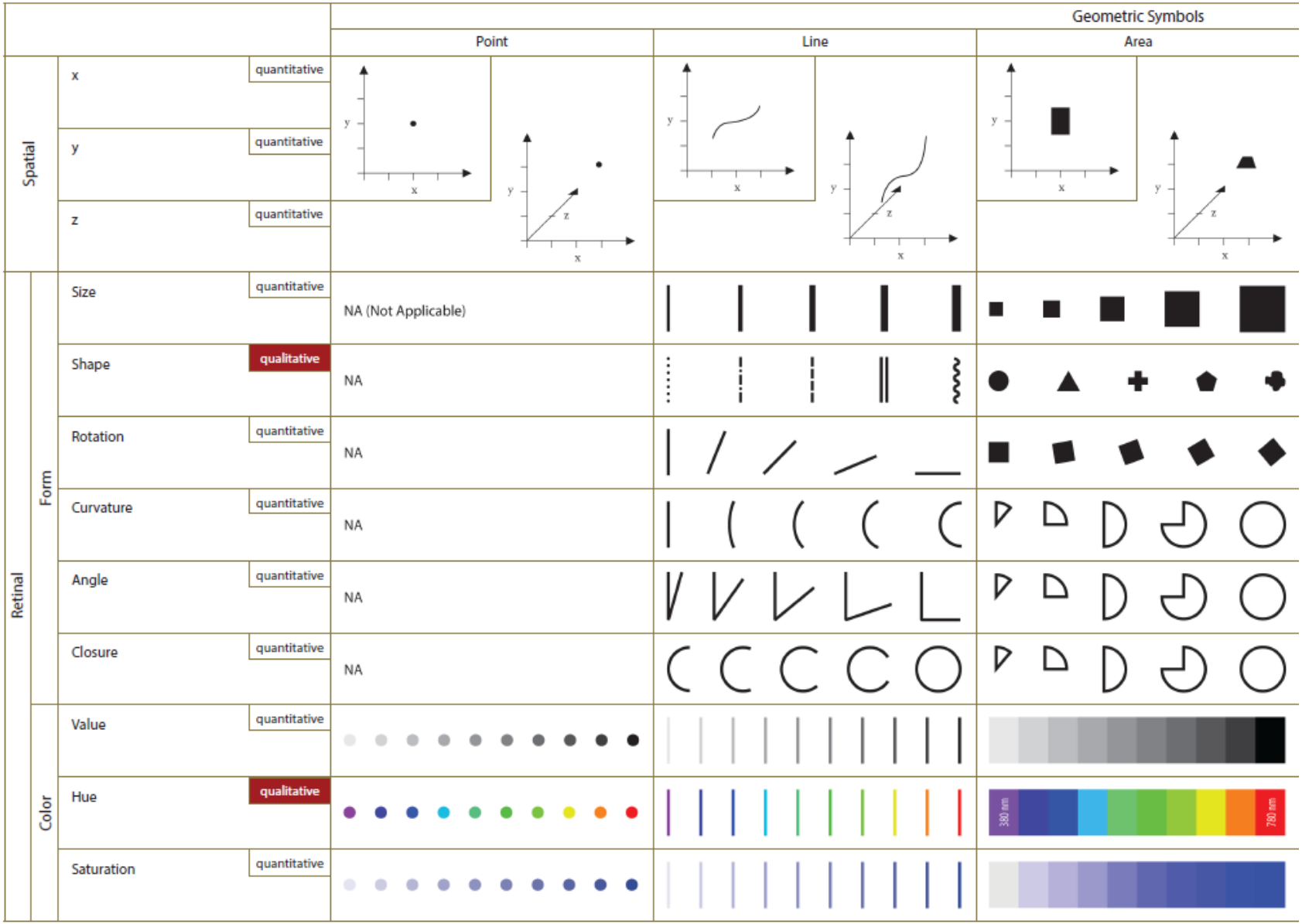
Visualization Framework

Insight Need Types page 26	Data Scale Types page 28	Visualization Types page 30	Graphic Symbol Types page 32	Graphic Variable Types page 34	Interaction Types page 26
• categorize/cluster • order/rank/sort • distributions (also outliers, gaps) • comparisons • trends (process and time) • geospatial • compositions (also of text) • correlations/relationships	• nominal • ordinal • interval • ratio	• table • chart • graph • map • network layout	• geometric symbols point line area surface volume • linguistic symbols text numerals punctuation marks • pictorial symbols images icons statistical glyphs	• spatial position • retinal form color optics motion	• overview • zoom • search and locate • filter • details-on-demand • history • extract • link and brush • projection • distortion

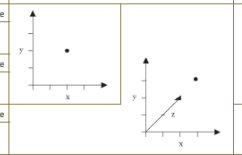


See page 24

Graphic Variable Types Versus Graphic Symbol Types

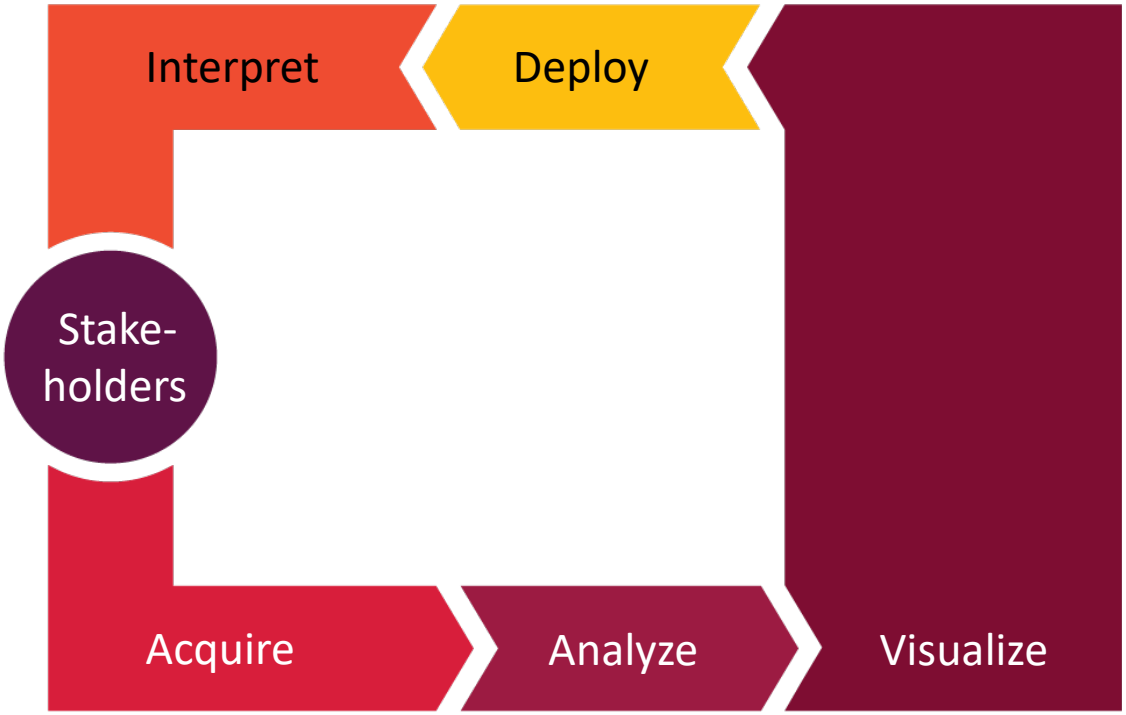


Graphic Variable Types Versus Graphic Symbol Types

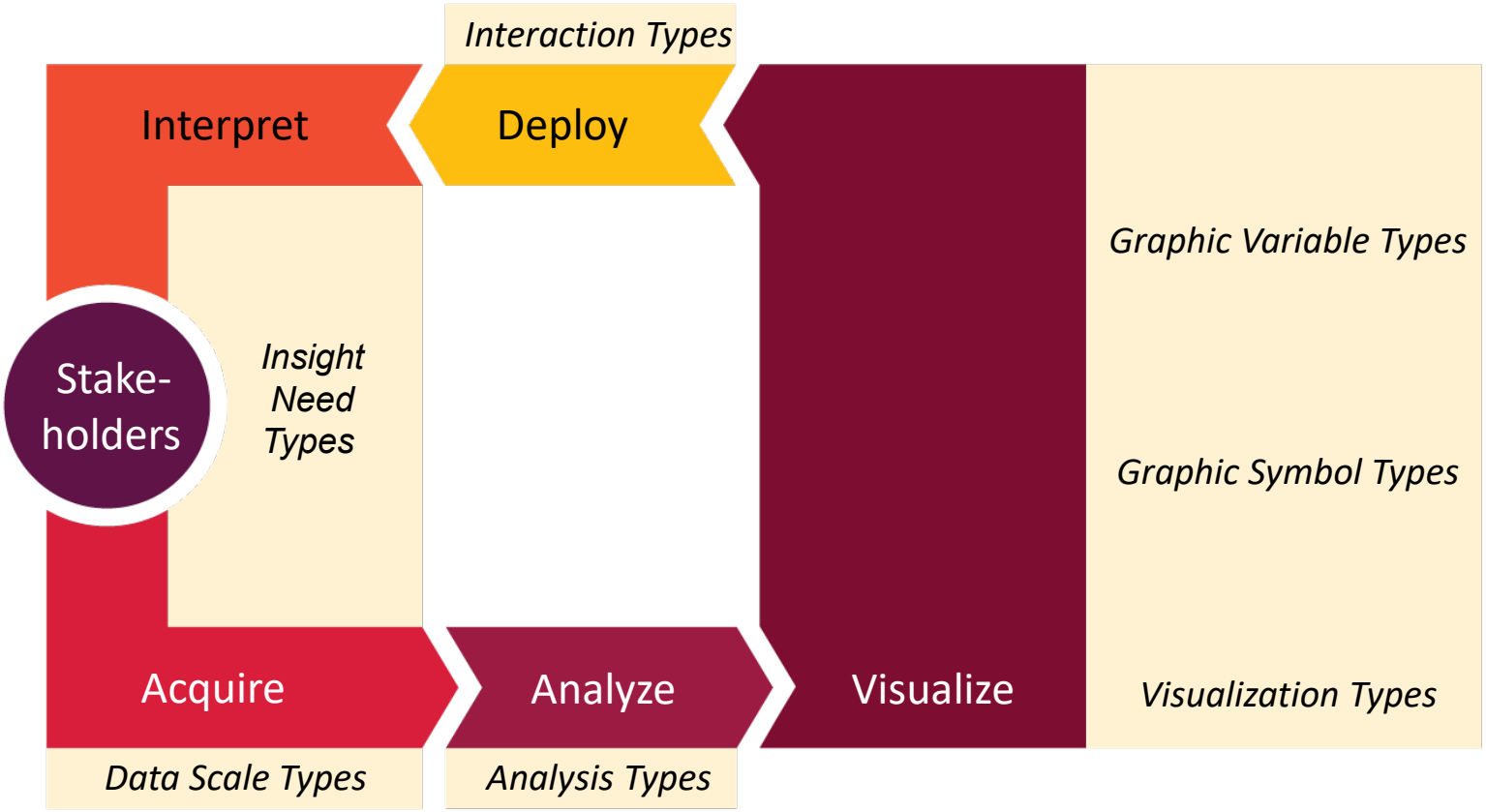
			Geometric Symbols: Point	Geometric Symbols: Line	Geometric Symbols: Area	Geometric Symbols: Surface	Geometric Symbols: Volume	Linguistic Symbols: Text, Numerals, Punctuation Marks	Pictorial Symbols: Images, Icons, Statistical Glyphs
Spatial	x	quantitative							
Spatial	y	quantitative							
Spatial	z	quantitative							
Retinal / Form	Size	quantitative	NA (Not Applicable)			See **Elevation Map, page 55**	See **Stepped Relief Map, pages 53-54**	See **Proportional Symbol Map, page 54**	See *Heights of the Principal Mountains ...*, **page 67**
Retinal / Form	Shape	qualitative	NA					Text Text Text Text Text	See also *Life in Los Angeles* **page 32**
Retinal / Form	Rotation	quantitative	NA					Text Text Text Text Text	(alive) (dead)
Retinal / Form	Curvature	quantitative	NA					Text Text Text Text Text	
Retinal / Form	Angle	quantitative	NA				Some table cells are left blank to encourage future exploration of combinations.	Text Text Text Text Text	
Retinal / Form	Closure	quantitative	NA					Text Text Text Text Text	
Retinal / Color	Value	quantitative						Text Text Text Text Text	
Retinal / Color	Hue	qualitative			280 nm 720 nm			Text Text Text Text Text	(alive) (dead)
Retinal / Color	Saturation	quantitative						Text Text Text Text Text	(shallow water) (deep water)

			Geometric Symbols: Point	Geometric Symbols: Line	Geometric Symbols: Area	Geometric Symbols: Surface	Geometric Symbols: Volume	Linguistic Symbols: Text, Numerals, Punctuation Marks	Pictorial Symbols: Images, Icons, Statistical Glyphs
Retinal / Texture	Spacing	quantitative							
Retinal / Texture	Granularity	quantitative							
Retinal / Texture	Pattern	qualitative							
Retinal / Texture	Orientation	quantitative	NA						See *Field Vectors at Random Positions*, **page 51**
Retinal / Texture	Gradient	quantitative							
Retinal / Optics	Blur	quantitative						Text Text Text Text Text	
Retinal / Optics	Transparency	quantitative						Text Text Text Text Text	
Retinal / Optics	Shading	quantitative						Text Text Text Text Text	
Retinal / Optics	Stereoscopic Depth	quantitative	Point in foreground ... background	Line in foreground ... background	Area in foreground ... background	Surface in foreground ... background	Volume in foreground ... background	Text in foreground ... background	Icons in foreground ... background
Motion	Speed	quantitative							
Motion	Velocity	quantitative							
Motion	Rhythm	quantitative	Blinking point slow ... fast	Blinking line slow ... fast	Blinking area slow ... fast	Blinking surface slow ... fast	Blinking volume slow ... fast	Blinking text slow ... fast	Blinking icons slow ... fast

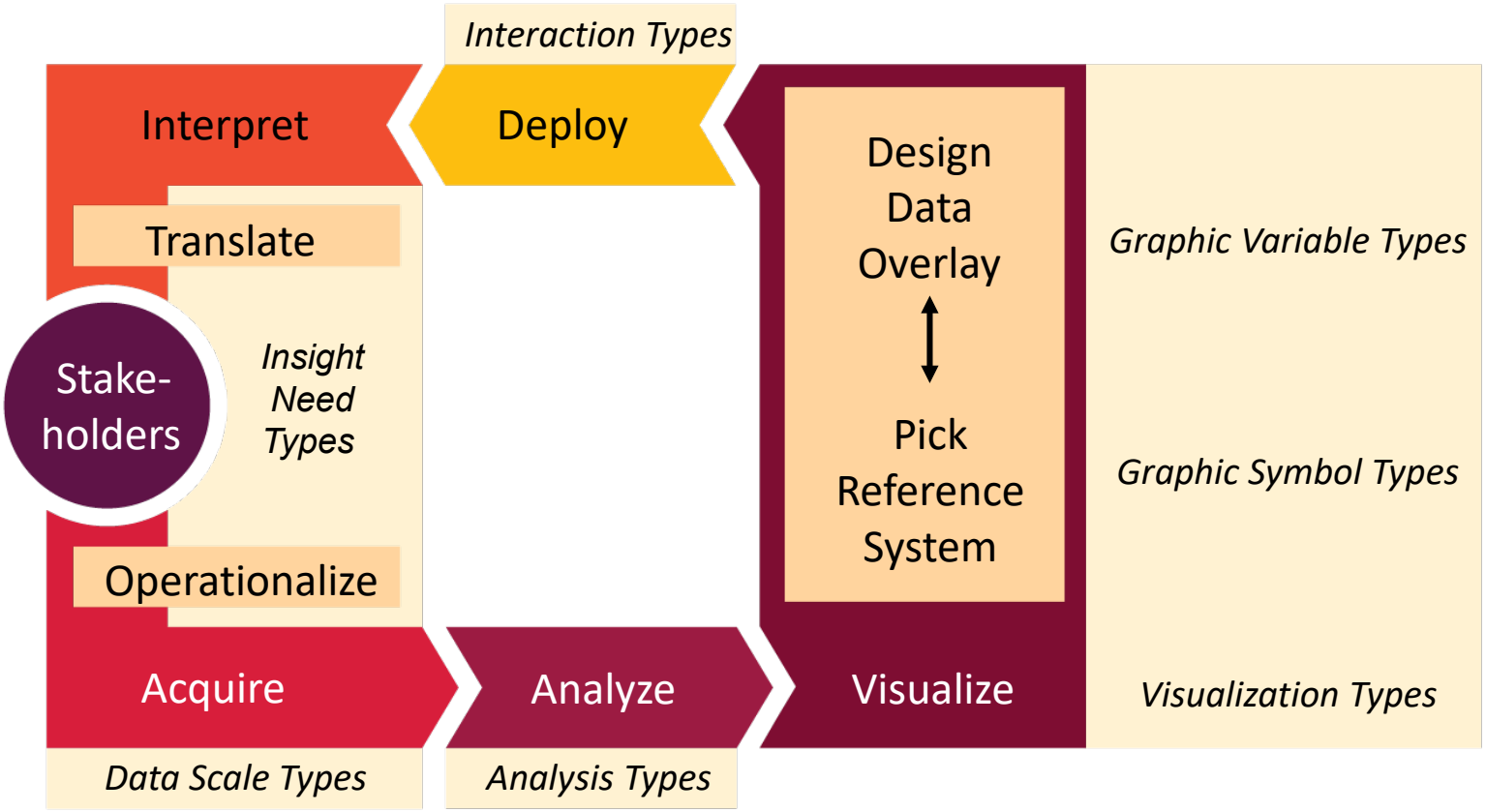
Workflow Design



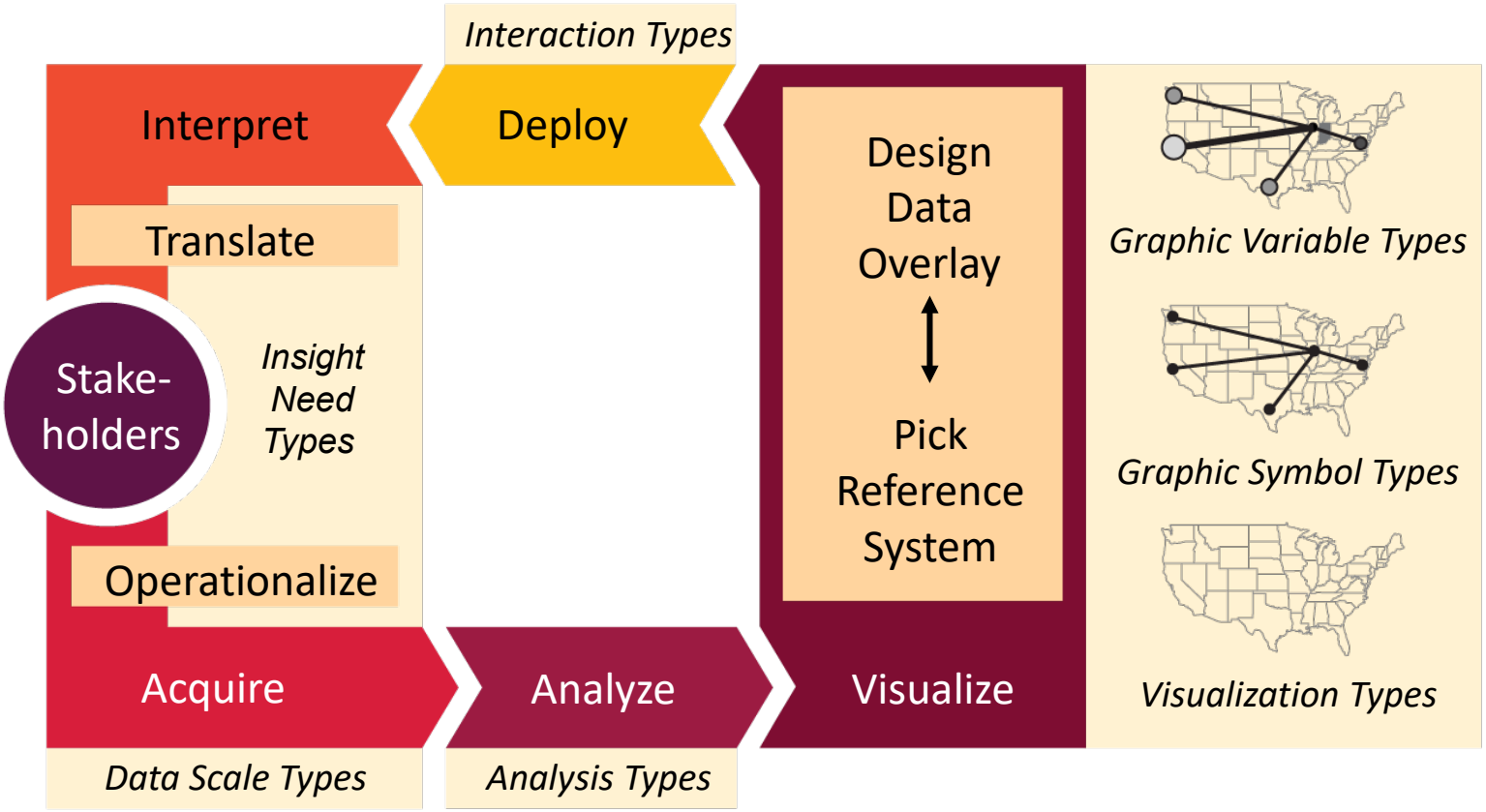
Workflow Design + Visualization Framework



Workflow Design + Visualization Framework



Workflow Design + Visualization Framework



Data Visualization Literacy: Definitions, Conceptual Frameworks, Exercises, and Assessments

Katy Börner[1], Andreas Bueckle[1], Michael Ginda[1]

[1]Indiana University

Submitted to Proceedings of the National Academy of Sciences of the United States of America

In the information age, the ability to read and construct data visualizations becomes as important as the ability to read and write text. However, while standard definitions and theoretical frameworks to teach and assess textual, mathematical, and visual literacy exist, current data visualization literacy (DVL) definitions and frameworks are not comprehensive enough to guide the design of DVL teaching and assessment. This paper introduces a conceptual framework (DVL-FW) that was specifically developed to define, teach, and assess DVL. The holistic DVL-FW promotes both the *reading and construction* of data visualizations, a pairing analogous to that of both *reading and writing* in textual literacy and *understanding and applying* in mathematical literacy. Specifically, the DVL-FW defines a hierarchical typology of core concepts and details the process steps that are required to extract insights from data. Advancing the state of the art, the DVL-FW interlinks theoretical and procedural knowledge and showcases how both can be combined to design curricula and assessment measures for DVL. Earlier versions of the DVL-FW have been used to teach DVL to more than 8,500 residential and online students, and results from this effort have helped revise and validate the DVL-FW presented here.

Data visualization | literacy | assessment | learning sciences

measurement, and estimation," as well as an "understanding of ratio concepts, notably fractions, proportions, percentages, and probabilities" (6). PISA defines it as "an individual's capacity to formulate, employ, and interpret mathematics in a variety of contexts," including "reasoning mathematically and using mathematical concepts, procedures, facts and tools to describe, explain and predict phenomena." PISA administers standardized tests for math, problem-solving, and financial literacy (7). The *PISA 2015 Draft Mathematics Framework* (8) explains the *theoretical underpinnings* of the assessment, the formal *definition* of mathematical literacy, the mathematical *processes* which students undertake when using mathematical literacy, and the fundamental mathematical *capabilities* that underlie those processes.

Visual literacy was initially defined as a person's ability to "discriminate and interpret the visible actions, objects, and symbols natural or man-made, that he encounters in his environment" (9). In 1978, it was defined "as a group of skills which enable an individual to understand and use visuals for intentionally communicating with others" (10). More recently, the Association of College and Research Libraries (ACRL) defined standards, performance indicators, and learning outcomes for visual literacy (11, 12). In the academic setting, Avgerinou (13) developed and validated a visual literacy index by running focus groups of visual

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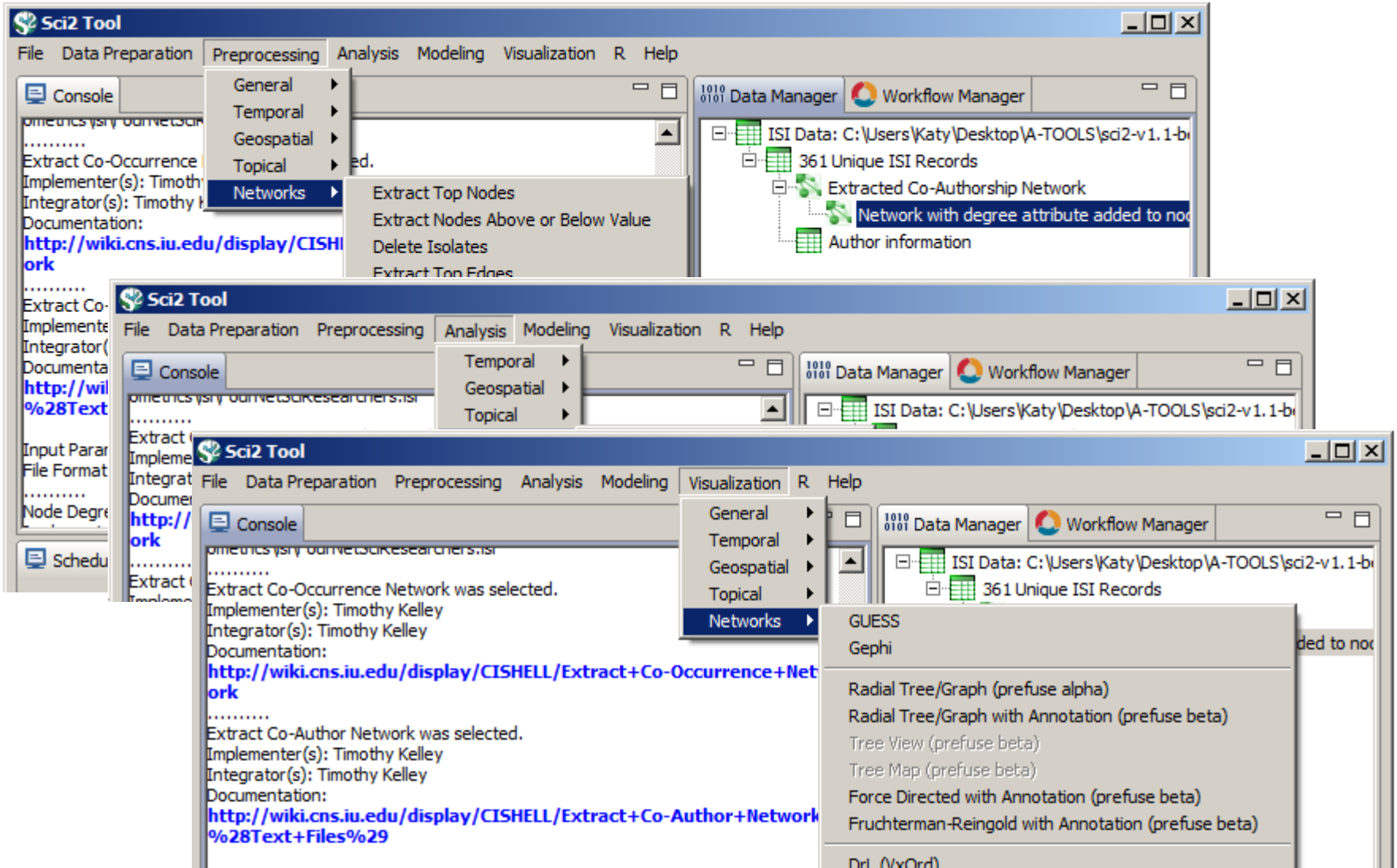

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Times Cited	Publication Year	City of Publisher	Country	Journal Title (Full)	Title	Subject Category	Authors
12	2011	NEW YORK	USA	COMMUNICATIONS OF THE ACM	Plug-and-Play Macroscopes	Computer Science	Borner, K
18	2010	MALDEN	USA	CTS-CLINICAL AND TRANSLATIONAL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

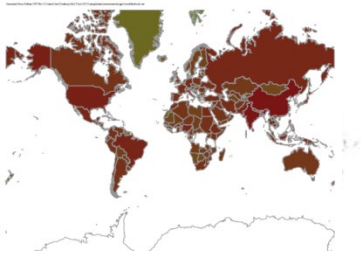
Statistical Analysis–p. 44

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

Temporal Burst Analysis–p. 48

Geospatial Analysis–p. 52

Geospatial Analysis–p. 52



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

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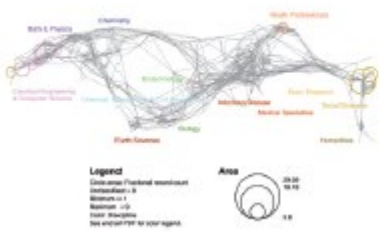
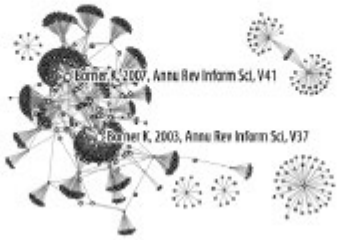
13	2010	WASHINGTON	USA	SCIENCE TRANSLATIONAL MEDICINE	A Multi-Level Systems Perspective for the Science of Team Science	Cell Biology |Research & Experimental Medicine	Borner, K|Contractor, N|Falk-Krzesinski, HJ|Fiore, SM|Hall, KL|Keyton, J|Spring, B|Stokols, D|Trochim, W|Uzzi, B

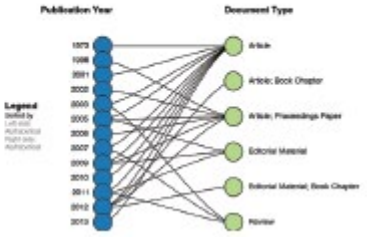
Topical Analysis–p. 56



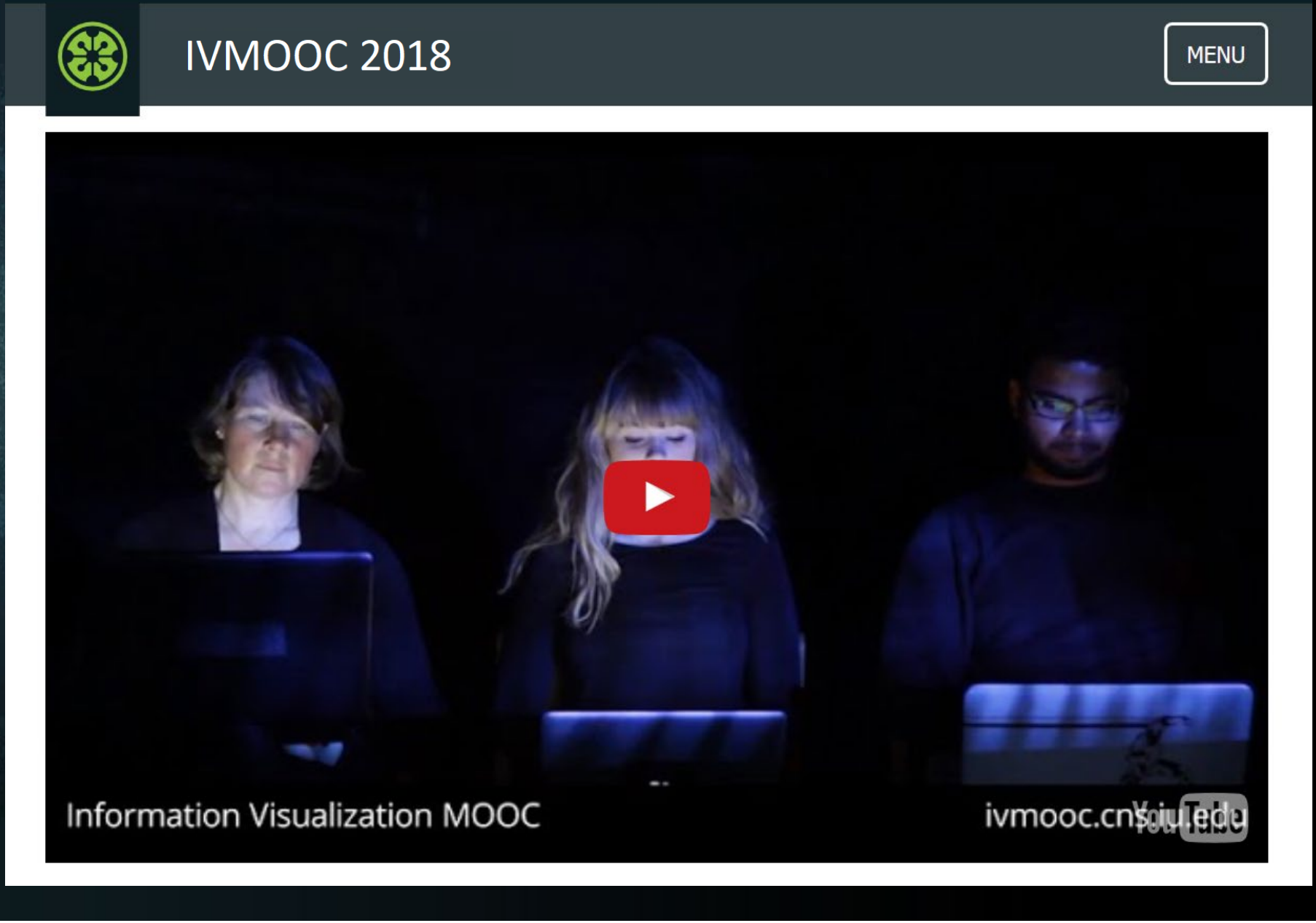
Paper Citation Network–p. 60



Bi-Modal Network–p. 60



Co-author and many other bi-modal networks.



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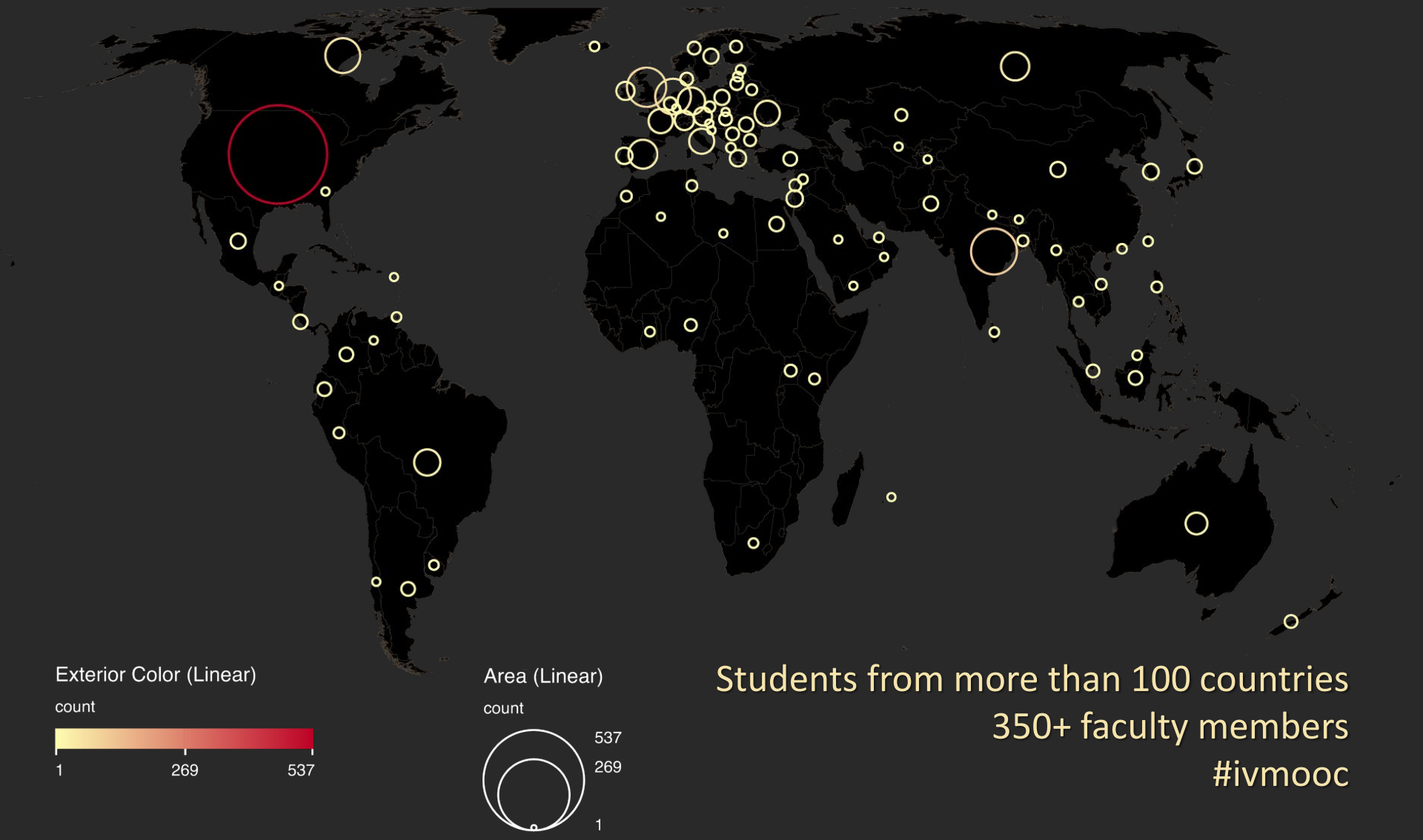

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Course Schedule

Part 1: Theory and Hands-On

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

Mid-Term

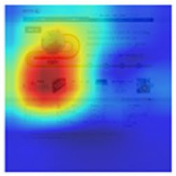
- **Session 5** – "With Whom:" Trees
- **Session 6** – "With Whom:" Networks
- **Session 7** – Dynamic Visualizations and Deployment

Final Exam

Part 2: Students work in teams on client projects.

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

Client Projects



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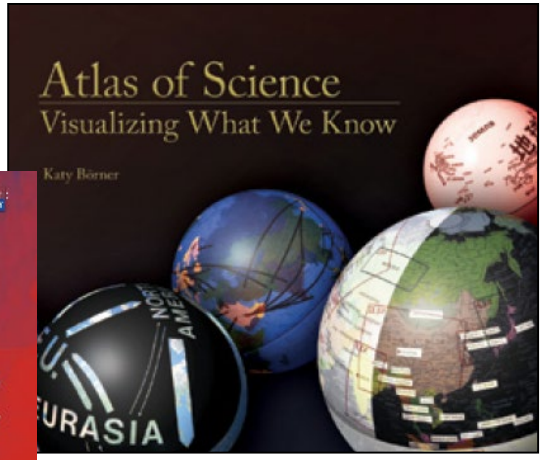

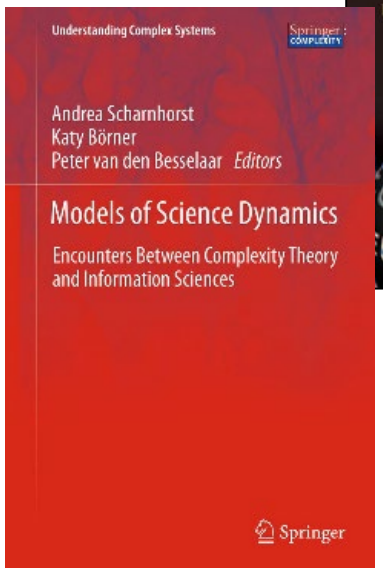

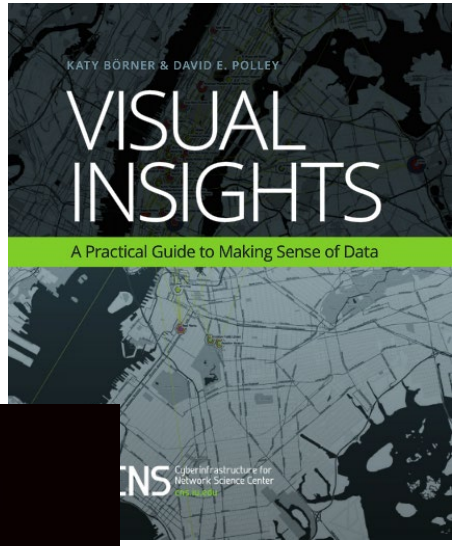

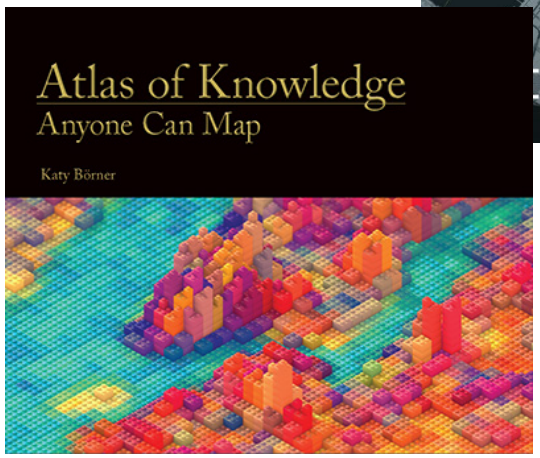

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