Overview

Theoretical data visualization framework (DVL) meant to empower anyone to systematically render data into insights.


Data Visualization Literacy (DVL)

Data visualization literacy (ability to read, make, and explain data visualizations) requires:

• literacy (ability to read and write text in titles, axis labels, legends, etc.),
• visual literacy (ability to find, interpret, evaluate, use, and create images and visual media), and
• mathematical literacy (ability to formulate, employ, and interpret math in a variety of contexts).

Being able to “read and write” data visualizations is becoming as important as being able to read and write text. Understanding, measuring, and improving data and visualization literacy is important to strategically approach local and global issues.
Places & Spaces: Mapping Science Exhibit

1st Decade (2005-2014)
Maps

2nd Decade (2015-2024)
Macrosopes

100
MAPS
In large format, full color, and high resolution.

248
MAPMAKERS
from fields as disparate as art, urban planning, engineering, and the history of science.

100
MACROSCOPE MAKERS
including one whose job title is “Truth and Beauty Operator.”

20
MACROSCOPES
for touching all kinds of data.

382
DISPLAY VENUES
from the Cannes Film Festival to the World Economic Forum.

354
PRESS ITEMS

http://scimaps.org

Map of Scientific Collaborations from 2005-2009

VII.6 Stream of Scientific Collaborations Between World Cities - Olivier H. Beauchesne - 2012

Check out our **Zoom Maps** online!

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

Smelly Maps – Daniele Quercia, Rossano Schifanella, and Luca Maria Aiello – 2015
Stop by VISAP in South Foyer tonight at 6:30pm for a grand tour!

https://visap.net
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](http://modsti.cns.iu.edu/report)
Acknowledgments

Exhibit Curators

http://scimaps.org

Plus, we thank the more than 250 authors of the 100 maps and 16 interactive macroscopes.
Data Visualization Literacy Framework


Data Visualization Literacy (DVL)

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Being able to “read and write” data visualizations is becoming as important as being able to read and write text. Understanding, measuring, and improving data and visualization literacy is important to strategically approach local and global issues.
Visualization Frameworks

MANY frameworks and taxonomies have been proposed to

• help organize and manage the evolving zoo of 500+ different data visualization types,
• provide guidance when designing data visualizations, and
• facilitate teaching.

Existing Visualization Frameworks

Organize data visualizations by

• User insight needs
• User task types
• Data to be visualized
• Data transformations
• Visualization technique
• Visual mapping transformations
• Interaction techniques
• Deployment options
• and other features ...
DVL Framework: Desirable Properties

• Most existing frameworks focus on **READING**. We believe that much expertise is gained from also **CONSTRUCTING** data visualizations.
• Reading and constructing data visualizations needs to take human perception and cognition into account.
• Frameworks should build on and consolidate prior work in cartography, psychology, cognitive science, statistics, scientific visualization, data visualization, learning sciences, etc. in support of a de facto standard.
• Theoretically grounded + practically useful + easy to learn/use.
• Highly modular and extendable.

DVL Framework: Development Process

• The initial DVL-FW was developed via an extensive literature review.
• The resulting DVL-FW typology, process model, exercises, and assessments were then tested in the **Information Visualization** course taught for more than 17 years at Indiana University. More than 8,500 students enrolled in the IVMOOC version ([http://ivmooc.cns.iu.edu](http://ivmooc.cns.iu.edu)) over the last six years.
• The FW was further refined using feedback gained from constructing and interpreting data visualizations for 100+ real-world client projects.
• Data on student engagement, performance, and feedback guided the continuous improvement of the DVL-FW typology, process model, and exercises for defining, teaching, and assessing DVL.
• The DVL-FW used in this course supports the systematic construction and interpretation of data visualizations.
Data Visualization Literacy Framework (DVL-FW)

Consists of two parts:

**DVL Typology**
Defines 7 types with 4-17 members each.

**DVL Workflow Process**
Defines 5 steps required to render data into insights.

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Data Visualization Literacy Framework (DVL-FW)

Consists of two parts that are interlinked:

**DVL Typology + DVL Workflow Process**

1. **Stakeholders**
2. **Data Scale Types**
3. **Analysis Types**
4. **Visualization Types**
5. **Graphic Symbol Types**
6. **Graphic Variable Types**
7. **Interaction Types**

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**Data Visualization Literacy Framework (DVL-FW)**

Implemented in Make-A-Vis (MAV) to support learning via horizontal transfer, scaffolding, hands-on learning, etc.

![Make-A-Vis](image)

**Typology of the Data Visualization Literacy Framework**

<table>
<thead>
<tr>
<th>Insight Needs</th>
<th>Data Scales</th>
<th>Analyses</th>
<th>Visualizations</th>
<th>Graphic Symbols</th>
<th>Graphic Variables</th>
<th>Interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>• categorize/cluster</td>
<td>• nominal</td>
<td>• statistical</td>
<td>• table</td>
<td>• geometric symbols</td>
<td>• spatial position</td>
<td>• zoom</td>
</tr>
<tr>
<td>• order/rank/sort</td>
<td>• ordinal</td>
<td>• temporal</td>
<td>• chart</td>
<td>point</td>
<td>position</td>
<td>search and locate</td>
</tr>
<tr>
<td>• distributions (also outliers, gaps)</td>
<td>• interval</td>
<td>• geospatial</td>
<td>• graph</td>
<td>line</td>
<td>form</td>
<td>filter</td>
</tr>
<tr>
<td>• comparisons</td>
<td>• ratio</td>
<td>• topological</td>
<td>• map</td>
<td>area</td>
<td>color</td>
<td>details-on-demand</td>
</tr>
<tr>
<td>• trends (process and time)</td>
<td></td>
<td>• relational</td>
<td>• tree</td>
<td>surface</td>
<td>optics</td>
<td>history</td>
</tr>
<tr>
<td>• geospatial</td>
<td></td>
<td></td>
<td>• network</td>
<td>volume</td>
<td>motion</td>
<td>extract</td>
</tr>
<tr>
<td>• compositions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>link and brush</td>
</tr>
<tr>
<td>(also of text)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>projection</td>
</tr>
<tr>
<td>• correlations/relationships</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>distortion</td>
</tr>
</tbody>
</table>

## Typology of the Data Visualization Literacy Framework


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<th>Visualizations</th>
<th>Graphic Symbols</th>
<th>Graphic Variables</th>
<th>Interactions</th>
</tr>
</thead>
<tbody>
<tr>
<td>- categorize/cluster&lt;br&gt;- order/rank/sort&lt;br&gt;- distributions (also outliers, gaps)&lt;br&gt;- comparisons&lt;br&gt;- trends (process and time)&lt;br&gt;- geospatial&lt;br&gt;- compositions (also of text)&lt;br&gt;- correlations/relationships</td>
<td>- nominal&lt;br&gt;- ordinal&lt;br&gt;- interval&lt;br&gt;- ratio</td>
<td>- statistical&lt;br&gt;- temporal&lt;br&gt;- geospatial&lt;br&gt;- topical&lt;br&gt;- relational</td>
<td>- table&lt;br&gt;- chart&lt;br&gt;- graph&lt;br&gt;- map&lt;br&gt;- tree&lt;br&gt;- network</td>
<td>- geometric symbols&lt;br&gt;- linguistic symbols&lt;br&gt;- text numerals&lt;br&gt;- punctuation marks&lt;br&gt;- pictorial symbols&lt;br&gt;- images&lt;br&gt;- icons&lt;br&gt;- statistical glyphs</td>
<td>- spatial position&lt;br&gt;- retinal&lt;br&gt;- form&lt;br&gt;- color&lt;br&gt;- optics&lt;br&gt;- motion</td>
<td>- zoom&lt;br&gt;- search and locate&lt;br&gt;- filter&lt;br&gt;- details-on-demand&lt;br&gt;- history&lt;br&gt;- extract&lt;br&gt;- link and brush&lt;br&gt;- projection&lt;br&gt;- distortion</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tool: Many Eyes</th>
<th>Tool: Chart Chooser</th>
<th>Börner, 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>selection</td>
<td>compare</td>
<td>tool: many eyes</td>
</tr>
<tr>
<td>order</td>
<td>comparison</td>
<td>table</td>
</tr>
<tr>
<td>distribution</td>
<td>differences</td>
<td>distribution</td>
</tr>
<tr>
<td>compare</td>
<td>compare data values</td>
<td>comparison</td>
</tr>
<tr>
<td>time series</td>
<td>time</td>
<td>tool: many eyes</td>
</tr>
<tr>
<td>geospatial</td>
<td>spatial relations</td>
<td>tool: many eyes</td>
</tr>
<tr>
<td>quantity</td>
<td>part-to-whole</td>
<td>tool: many eyes</td>
</tr>
<tr>
<td>association</td>
<td>correlate</td>
<td>tool: many eyes</td>
</tr>
</tbody>
</table>

Bérzin, 1967  
Wehrend & Lewis, 1996  
Few, 2004  
Yau, 2011  
Rendgen & Wiedemann, 2012  
Frankel, 2012  
Börner, 2014
Typology of the Data Visualization Literacy Framework

Data Scale Types

**Nominal:** A categorical scale, also called a nominal or category scale, is **qualitative.** Categories are assumed to be non-overlapping.

**Ordinal:** An ordinal scale, also called sequence or ordered, is **quantitative.** It rank-orders values representing categories based on some intrinsic ranking, but not at measurable intervals.

**Interval:** An interval scale, also called a value scale, is a **quantitative** numerical scale of measurement where the distance between any two adjacent values (or intervals) is equal, but the zero point is arbitrary.

**Ratio:** A ratio scale, also called a proportional scale, is a **quantitative** numerical scale. It represents values organized as an ordered sequence, with meaningful uniform spacing, and a true zero point.
Data Scale Types - Examples

**Nominal:** Words or numbers constituting the "categorical" names and descriptions of people, places, things, or events.

**Ordinal:** Days of the week, degree of satisfaction and preference rating scores (e.g., using a Likert scale), or rankings such as low, medium, high.

**Interval:** Temperature in degrees or time in hours. Spatial variables such as latitude and longitude are interval.

**Ratio:** Physical measures such as height, weight, (reaction) time, or intensity of light; number of published papers, co-authors, citations.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>nominal</td>
<td>quantitative</td>
<td>category</td>
<td>categorical/nominal</td>
<td>nominal</td>
<td>nominal</td>
</tr>
<tr>
<td>ordinal</td>
<td>ordered</td>
<td>sequence</td>
<td>ordinal</td>
<td>ordinal</td>
<td>ordinal</td>
</tr>
<tr>
<td>interval</td>
<td>quantitative</td>
<td>quantitative</td>
<td>quantitative</td>
<td>interval</td>
<td>interval</td>
</tr>
<tr>
<td>ratio</td>
<td>quantitative</td>
<td>quantitative</td>
<td>quantitative</td>
<td>ratio</td>
<td>ratio</td>
</tr>
</tbody>
</table>

Qualitative

Quantitative
Data Scale Types - Mathematical Operations

This table shows the logical mathematical operations permissible, the measure of central tendency, and examples for the different data scale types.

<table>
<thead>
<tr>
<th>Data Scale Types</th>
<th>Logical Mathematical Operations</th>
<th>Measure of Central Tendency</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal</td>
<td>$\neq \leq \geq \pm \mp$</td>
<td>mode</td>
<td>![example1]</td>
</tr>
<tr>
<td>Ordinal</td>
<td>$\neq \leq \geq \pm \mp$</td>
<td>median</td>
<td>![example2]</td>
</tr>
<tr>
<td>Interval</td>
<td>$\neq \leq \geq \pm \mp$</td>
<td>arithmetic mean</td>
<td>0–6 7–12 13–18</td>
</tr>
<tr>
<td>Ratio</td>
<td>$\neq \leq \geq \pm \mp$</td>
<td>geometric mean</td>
<td>0 1 2 3</td>
</tr>
</tbody>
</table>

Typology of the Data Visualization Literacy Framework

Analysis Types

- When: Temporal Data Analysis + Statistical
- Where: Geospatial Data Analysis
- What: Topical Data Analysis
- With Whom: Network Analysis

Data Hierarchy by Tamara Munzner distinguishes
tabular, relational, and spatial data.

Typology of the Data Visualization Literacy Framework

Insight Needs
- categorize/cluster
- order/rank/sort
- distributions (also outliers, gaps)
- comparisons
- trends (process and time)
- geospatial
- compositions (also of text)
- correlations/relationships

Data Scales
- nominal
- ordinal
- interval
- ratio

Analyses
- statistical
- temporal
- geospatial
- topical
- relational

Visualizations
- table
- chart
- graph
- map
- tree
- network

Graphic Symbols
- geometric symbols
- point
- line
- area
- surface
- volume
- linguistic symbols
- text
- numerals
- punctuation marks
- pictorial symbols
- images
- icons
- statistical glyphs

Graphic Variables
- spatial
- position
- retinal
- form
- color
- optics
- motion

Interactions
- zoom
- search and locate
- filter
- details-on-demand
- history
- extract
- link and brush
- projection
- distortion

Visualization Types

Chart
- Pie Chart
- Bubble Chart

Tree
- Dendrogram
- Tree Map

Graph
- Scatter Graph
- Temporal Bar Graph

Map
- Choropleth Map
- Proportional Symbol Map

Visualize: Reference Systems

Table
- columns by rows

Graph
- x-y coordinates

Map
- latitude/longitude

Network
- local similarity

Visualization Types
- table
- chart
- graph
- map
- network layout
Visualize: Reference Systems, Graphic Symbols and Variables

Typology of the Data Visualization Literacy Framework

Typology of the Data Visualization Literacy Framework

**Graphic Variable Types**

**Position:** x, y; possibly z  
**Form:**  
- Size  
- Shape  
- Rotation (Orientation)  
**Color:**  
- Value (Lightness)  
- Hue (Tint)  
- Saturation (Intensity)  
**Optics:** Blur, Transparency, Shading, Stereoscopic Depth  
**Texture:** Spacing, Granularity, Pattern, Orientation, Gradient  
**Motion:** Speed, Velocity, Rhythm

Graphic Variable Types

Position: \( x, y; \) possibly \( z \)

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Typology of the Data Visualization Literacy Framework

Data Visualization Literacy Framework (DVL-FW)

Consists of two parts that are interlinked:

DVL Typology + DVL Workflow Process

- Stakeholders
- Interpret
- Acquire
- Analyze
- Visualize
- Deploy
- Insight Need Types
- Data Scale Types
- Analysis Types

Interaction Types

Graphic Variable Types
Graphic Symbol Types
Visualization Types
Scaling Up:
Teaching Data Visualization Literacy

MAV in Science Museums
Information Visualization MOOC (IVMOOC) + Visual Analytics Certificate (VAC)

xMacroscopes in Science Museums

Data Visualization Literacy: Research and Tools that Advance Public Understanding of Scientific Data.
NSF AISL #1713567
Data Visualization Literacy
NSF AISL #1713567

E583 | Z637 | Information Visualization MOOC

This graduate level course provides an overview of the art of information visualization. The course teaches visualization theory and the process of producing effective and actionable visualizations that take the needs of users into account. Students apply the visualization knowledge and skills that they gain in the course by working in teams on real-world client projects.

Among other topics, the course covers:
- Stakeholder needs acquisition & project specification
- Data mining algorithms and visualization tools
- Temporal, geospatial, topical, and network visualization techniques

Data Visualization Literacy

In the information age, being able to create and interpret data visualizations is as important as being able to read and write text. This course introduces a theoretical visualization framework to define, measure, and advance student ability in data visualization literacy, discussed in part two in the Atlas of Knowledge, published by The MIT Press. The framework is used to organize course content and exams; support the design of effective workflows; to guide visual design, i.e., the mapping of data variables to graphic valuable types and graphic symbol types; and to effectively communicate using proper terminology.

https://ivmooc.cns.iu.edu
Client Projects

Visualizing the Evolution of Website Design
With over 15 years of history, the web itself has become a significant cultural artifact. We are studying how website design has changed over time, and how those changes reflect history.

Visualizing Research Silos in Ecological Interaction datasets

ChaCha Menopause queries
The ChaCha menopause query data is the foundation for building intervention modules to improve patient knowledge and reduce patient risk related to menopause. For the latest updates, visit the website.

Text-Mining of User-Generated Queries on Menstrual Pain

BioSimmer
BioSim is a participatory simulation where young students grade it to locate the role of arts and biological evidence of the importance of educational and social practices in healthcare.

https://ivmooc.cns.iu.edu/clients.html

Visual Analytics Certificate
Advance your skills in one of the most in-demand careers through this innovative and cutting-edge online course focused on understanding and creating data visualizations that translate complex data into actionable insights.

Learn from Experts
Connect with industry professionals and leading researchers.

Evolve Yourself
Gain forever knowledge and skill-up in powerful data visualization tools.

Make a Difference
Embrace data-driven decision-making in your personal and professional life.

https://visanalytics.cns.iu.edu
NSF RAISE: C-Accel Pilot - Track B1: Analytics-Driven Accessible Pathways To Impacts-Validated Education (ADAPTIVE)

**Goal:** Development of data-driven tools to support the tens of millions of US workers whose jobs are being transformed by Artificial Intelligence (AI) and automation.

The project will demonstrate how labor market and course syllabi data, learning analytics, and insights on transferability of learned skills can be combined and visualized in novel ways to support a learner’s decision-making about, sustained engagement in, and application to their job of professional skills acquired through education and job-related training.

**Team B-6656:** Katy Börner, Indiana University, Ariel Anbar, Arizona State University, Kemi Jona, Northeastern University, Martin Storksdieck and Heather Fischer, Oregon State University
Marvelous Visualization Opportunity:

HuBMAP: Mapping 37 Trillion Cells


HuBMAP

**Vision**
Catalyze the development of an open, global framework for comprehensively mapping the human body at cellular resolution.

**Goals**
1. Accelerate the development of the next generation of tools and techniques for constructing high resolution spatial tissue maps
2. Generate foundational 3D tissue maps
3. Establish an open data platform
4. Coordinate and collaborate with other funding agencies, programs, and the biomedical research community
5. Support projects that demonstrate the value of the resources developed by the program

https://commonfund.nih.gov/HuBMAP
The Human Body at Cellular Resolution:  
The NIH Human Biomolecular Atlas Program.  

**Fig. 1** | **The HubMAP consortium.** The TMCs will collect tissue samples and generate spatially resolved, single-cell data. Groups involved in TTD and RTI initiatives will develop emerging and more developed technologies, respectively; in later years, these will be implemented at scale. Data from all groups will be rendered useable for the biomedical community by the HuBMAP integration, visualization and engagement (HIVE) teams. The groups will collaborate closely to iteratively refine the atlas as it is gradually realized.

The Human Body at Cellular Resolution:  
The NIH Human Biomolecular Atlas Program.  

**Fig. 2** | **Key tissues and organs initially analysed by the consortium.** Using innovative, production-grade (‘shovel ready’) technologies, HubMAP TMCs will generate data for single-cell, three-dimensional maps of various human tissues. In parallel, TTD projects (and later RTI projects) will refine assays and analysis tools on a largely distinct set of human tissues. Samples from individuals of both sexes and different ages will be studied. The range of tissues will be expanded throughout the program.

**Map assembly and data query**

- Single cell and ‘omics assays
  - Genomics
  - Epigenomics
  - Transcriptomics
- Multiplexed spatial assays
  - Protein
  - RNA
  - Lipids / metabolites

**Fig. 3** | Map generation and assembly across cellular and spatial scales. The Human Body at Cellular Resolution: The NIH Human Biomolecular Atlas Program. Snyder et al. *Nature* 574, p. 187-192.


**Acknowledgments**

- Patients that agreed to volunteer healthy tissue and to use their data openly.
- TC-Harvard Team lead by Nils Gehlenborg
- https://hubmapconsortium.org
- MC-IU HIVE Team at IU

Plus, patients that agreed to volunteer healthy tissue and to use their data openly.
References


