CNS Cyberinfrastructure for Network Science Center

INDIANA UNIVERSITY SCHOOL OF INFORMATICS, COMPUTING, AND ENGINEERING

Envisioning the Internet of Things

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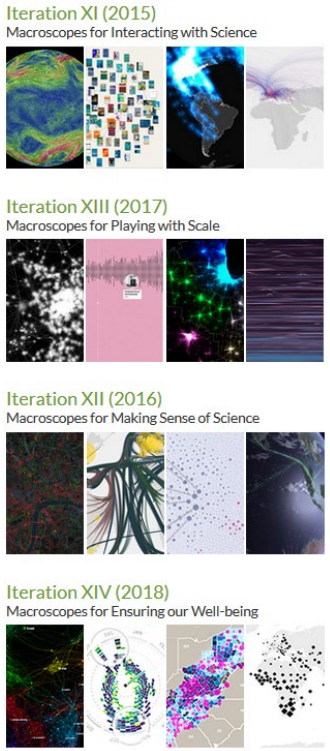
Places & Spaces: Mapping Science Exhibit

1st Decade (2005-2014)

Maps

2nd Decade (2015-2024)

Macroscopes



3rd Decade (2015-2034)

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http://scimaps.org

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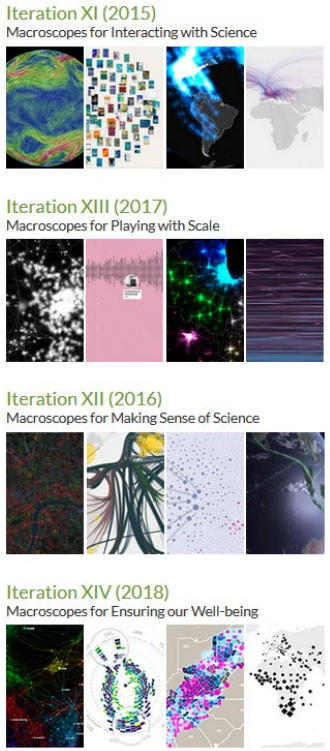

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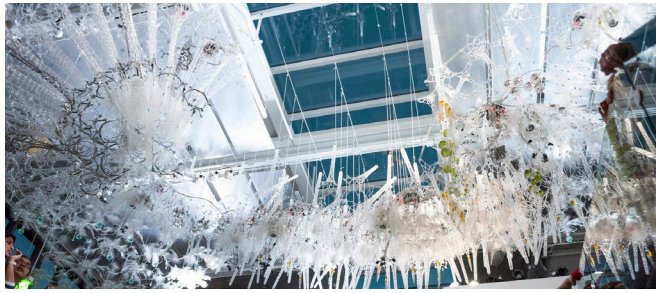
3rd Decade (2015-2034)

Experiences



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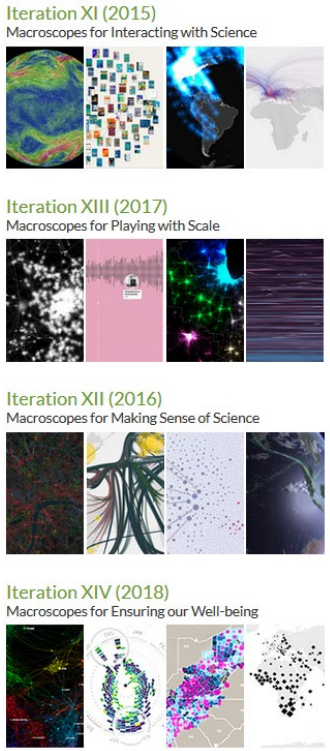

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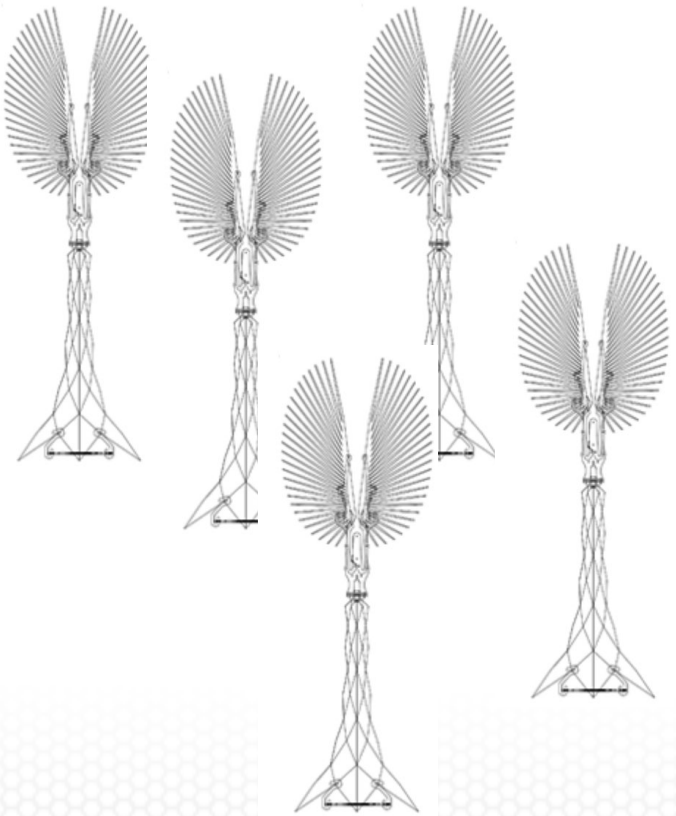

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INDIANA UNIVERSITY SCHOOL OF INFORMATICS, COMPUTING, AND ENGINEERING

Data Visualization Literacy Framework

Data Visualization Literacy (DVL)

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

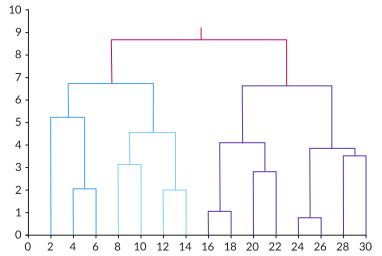
- literacy (ability to read and write text in titles, axis labels, legends, etc.),
- visual literacy (ability to find, interpret, evaluate, use, and create images and visual media), and
- mathematical literacy (ability to formulate, employ, and interpret math in a variety of contexts).

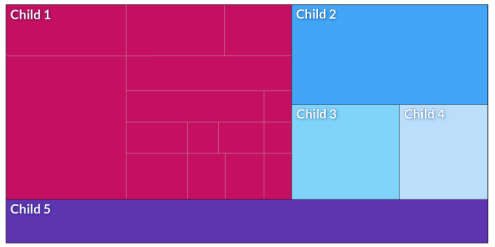
Being able to “read and write” data visualizations is becoming as important as being able to read and write text. Understanding, measuring, and improving data and visualization literacy is important to strategically approach local and global issues.

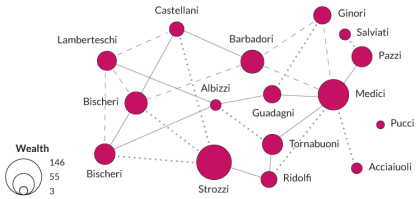
Visualization Frameworks

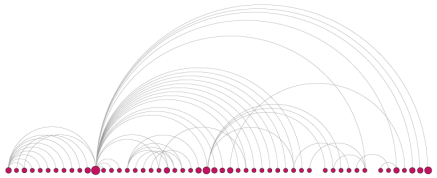
MANY frameworks and taxonomies have been proposed to

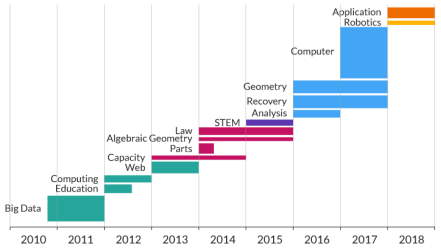
- help organize and manage the evolving zoo of 500+ different data visualization types,
- provide guidance when designing data visualizations, and
- facilitate teaching.

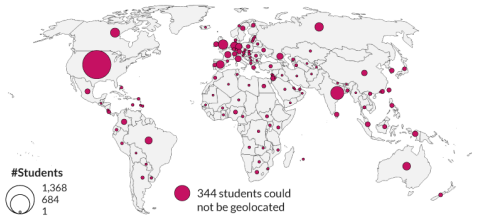


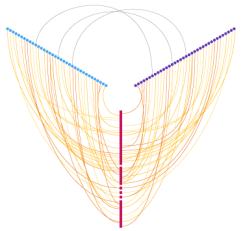


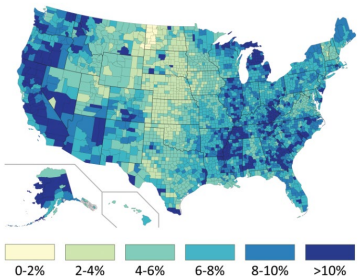


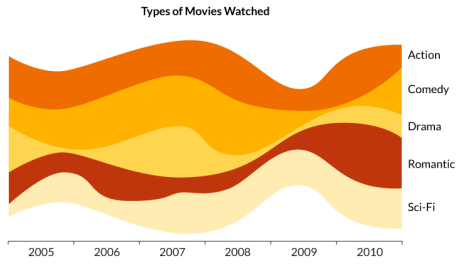








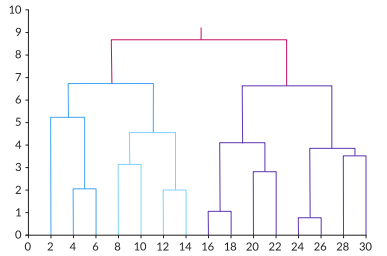


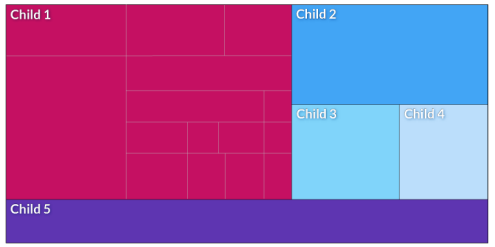


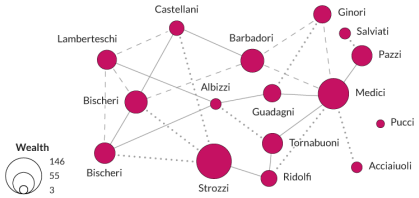
Existing Visualization Frameworks

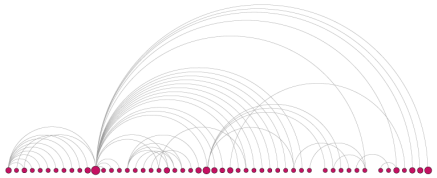
Organize data visualizations by

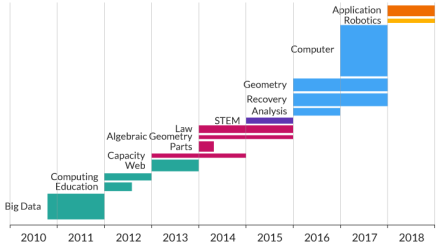
- User insight needs
- User task types
- Data to be visualized
- Data transformations
- Visualization technique
- Visual mapping transformations
- Interaction techniques
- Deployment options
- and other features …

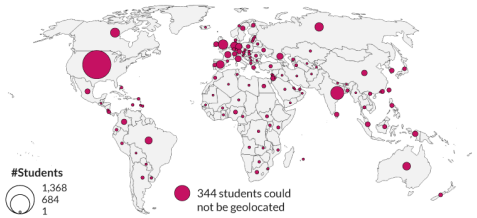


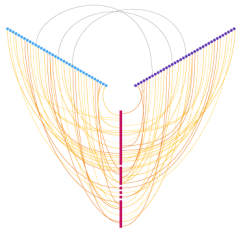


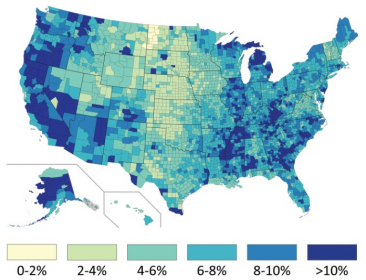


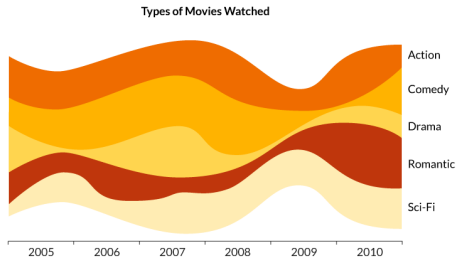












DVL Framework: Desirable Properties

- 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 15 years at Indiana University. More than 8,500 students enrolled in the IVMOOC version (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.

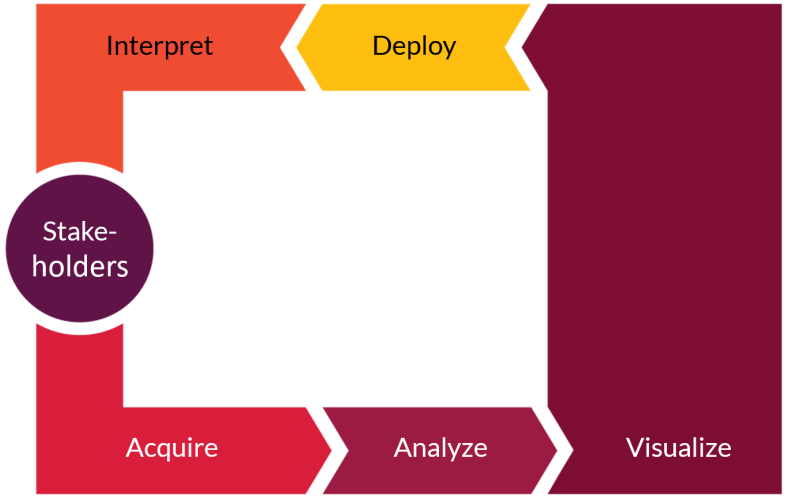
Data Visualization Literacy Framework (DVL-FW)

Consists of two parts:

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

1	2	3	4	5	6	7
Insight Needs	**Data Scales**	**Analyses**	**Visualizations**	**Graphic Symbols**	**Graphic Variables**	**Interactions**
• 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	• statistical • temporal • geospatial • topical • relational	• table • chart • graph • map • tree • network	• 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	• zoom • search and locate • filter • details-on-demand • history • extract • link and brush • projection • distortion

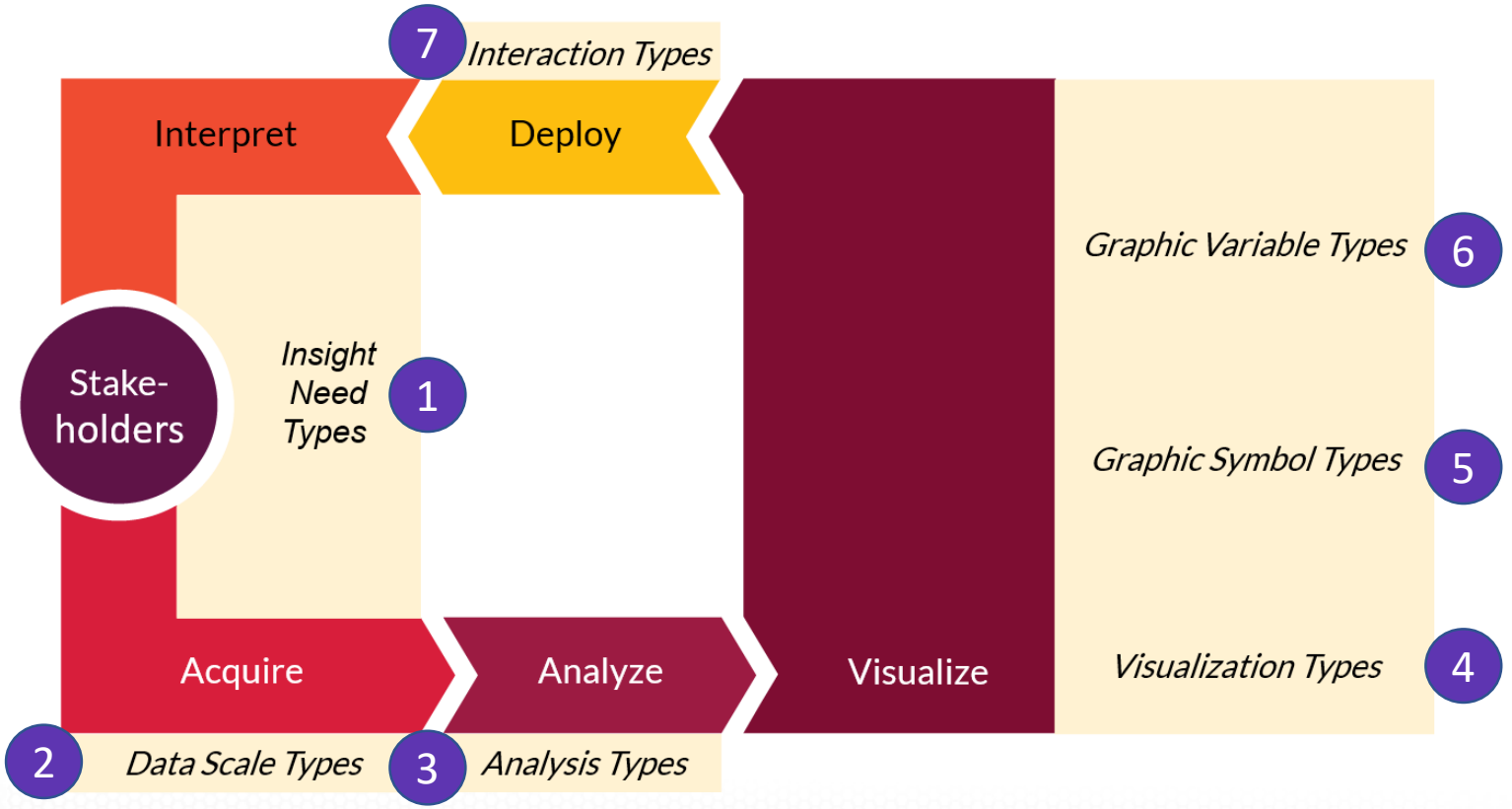
DVL Workflow Process
Defines 5 steps required to render data into insights.



Data Visualization Literacy Framework (DVL-FW)

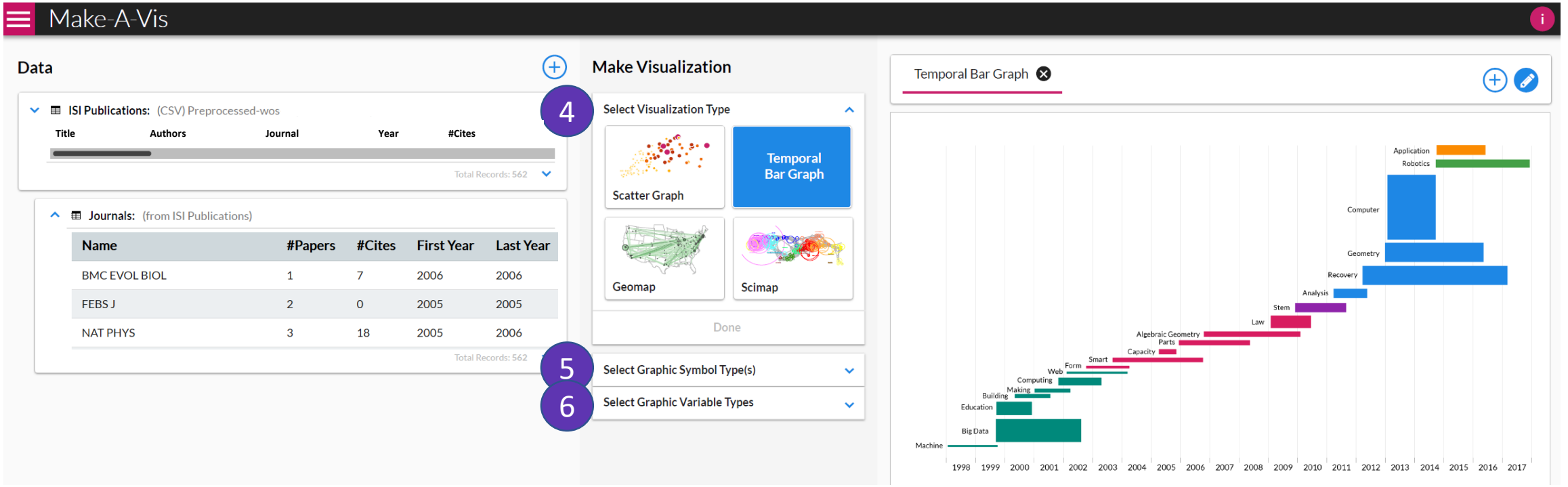
Consists of two parts that are interlinked:

DVL Typology +
DVL Workflow Process



Data Visualization Literacy Framework (DVL-FW)

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



Typology of the Data Visualization Literacy Framework

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

2 **Data Scales**
- nominal
- ordinal
- interval
- ratio

3 **Analyses**
- statistical
- temporal
- geospatial
- topical
- relational

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

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

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

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

Börner, Katy. 2015. *Atlas of Knowledge: Anyone Can Map*. Cambridge, MA: The MIT Press. 25.

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Börner, Katy. 2015. *Atlas of Knowledge: Anyone Can Map*. Cambridge, MA: The MIT Press. 26-27.

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

Example: MAV Scatter Graph

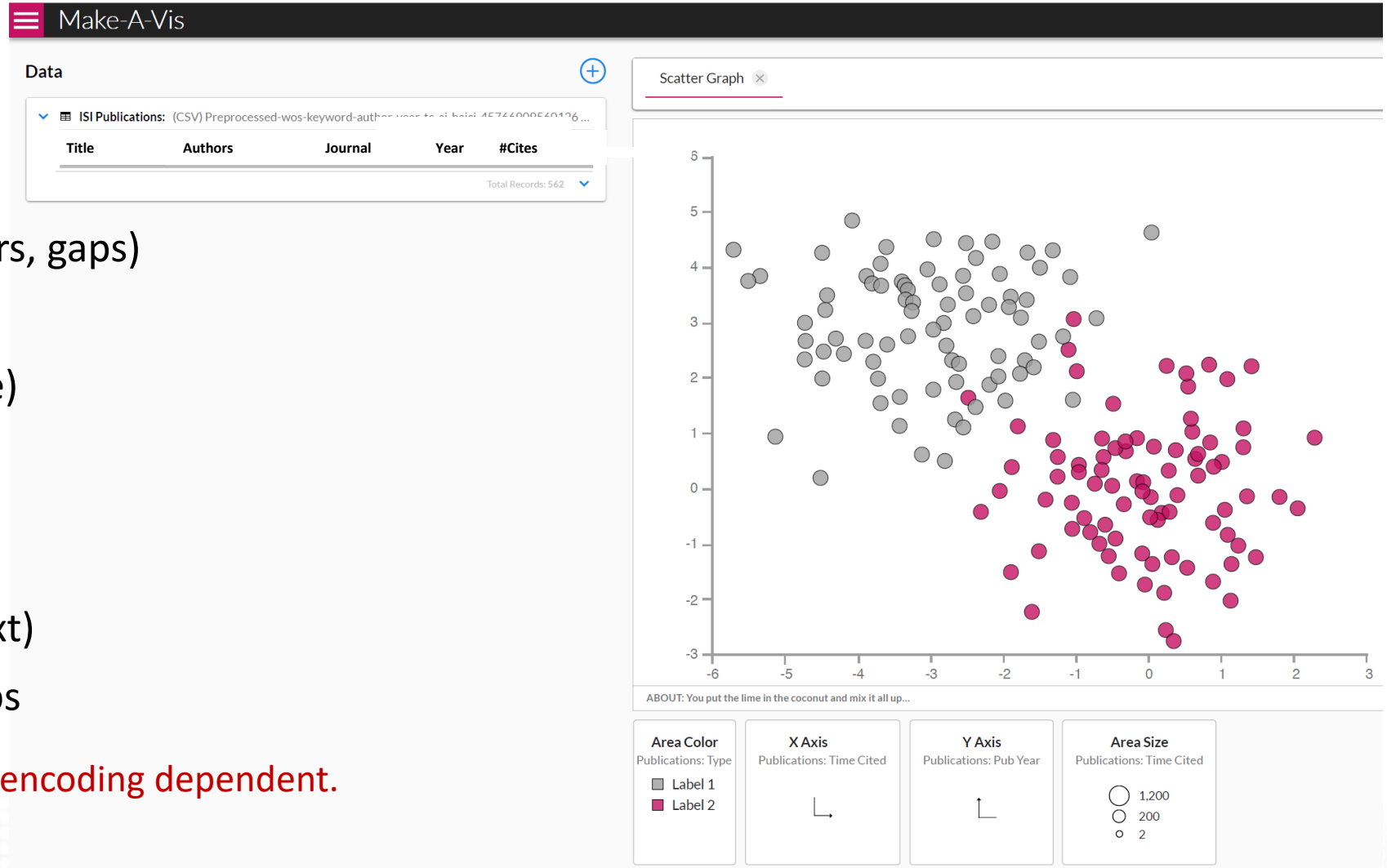
Supports:

- Categorize/cluster
- Order, rank, sort
- Distributions (also outliers, gaps)
- Comparisons
- Trends (process and time)

But NOT:

- Geospatial
- Compositions (also of text)
- Correlations/relationships

Note: Insight is data and data-encoding dependent.



Typology of the Data Visualization Literacy Framework

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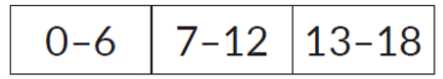
Börner, Katy. 2015. *Atlas of Knowledge: Anyone Can Map*. Cambridge, MA: The MIT Press. 28-29.

Data Scale Types

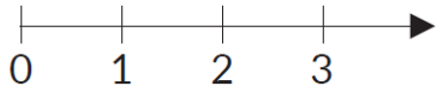
Nominal: A categorical scale, also called a nominal or category scale, is qualitative. Categories are assumed to be non-overlapping.

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.

Data Scale Types - Examples

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

Qualitative

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.

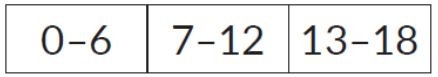
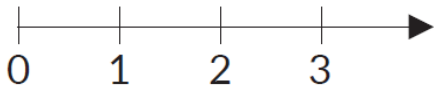
Quantitative

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

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

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.

Data Scale Types	Logical Mathematical Operations				Measure of Central Tendency	Examples
	= ≠	< >	+ -	x ÷		
Nominal	y				mode	
Ordinal	y	y			median	
Interval	y	y	y		arithmetic mean	
Ratio	y	y	y	y	geometric mean	

Qualitative

Quantitative

Typology of the Data Visualization Literacy Framework

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Börner, Katy. 2015. *Atlas of Knowledge: Anyone Can Map*. Cambridge, MA: The MIT Press. 25.

Analysis Types

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

Typology of the Data Visualization Literacy Framework

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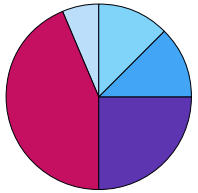
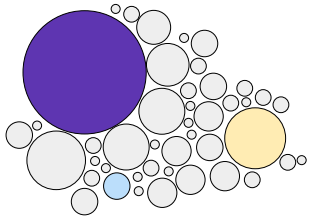
Börner, Katy. 2015. *Atlas of Knowledge: Anyone Can Map*. Cambridge, MA: The MIT Press. 30-31.

Visualization Types

Chart

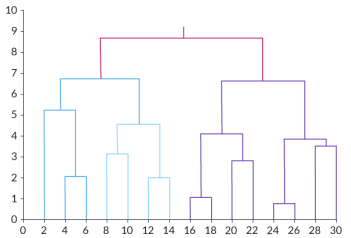


Pie Chart

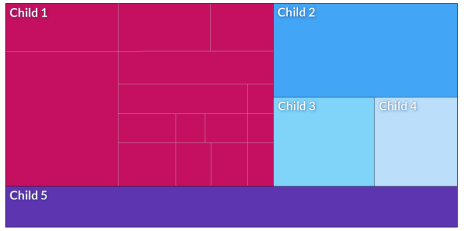


Bubble Chart

Tree

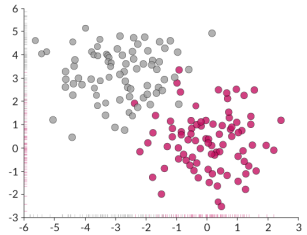


Dendrogram

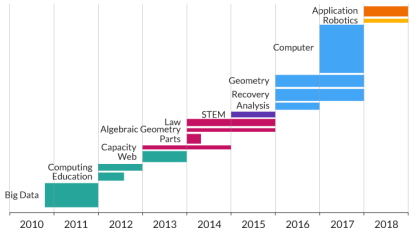


Tree Map

Graph

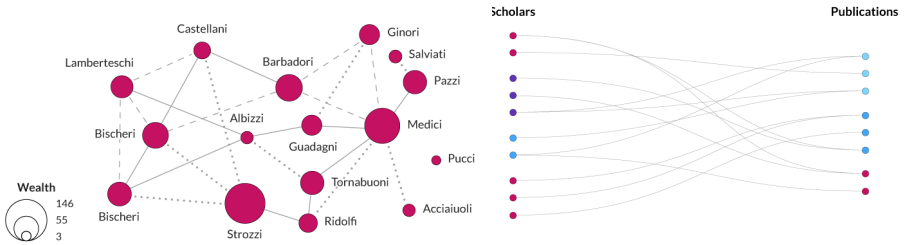


Scatter Graph



Temporal Bar Graph

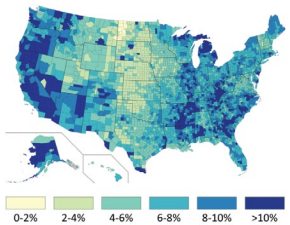
Network



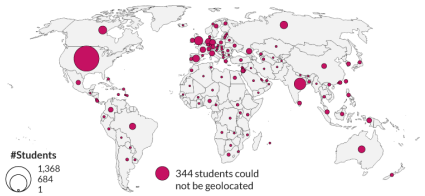
Dendrogram

Tree Map

Map



Choropleth Map



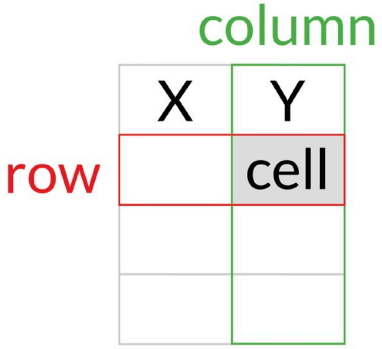
Proportional Symbol Map

Visualize: Reference Systems

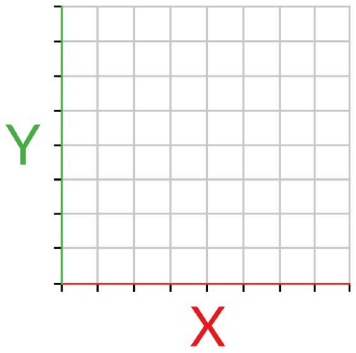
4

Visualization Types
- table
- chart
- graph
- map
- network layout

Table
columns by rows

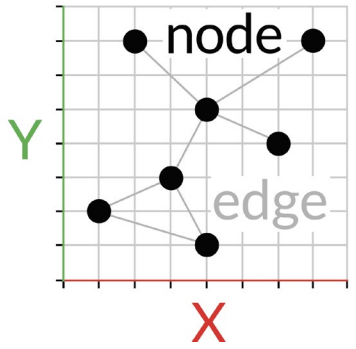


Graph
x-y coordinates

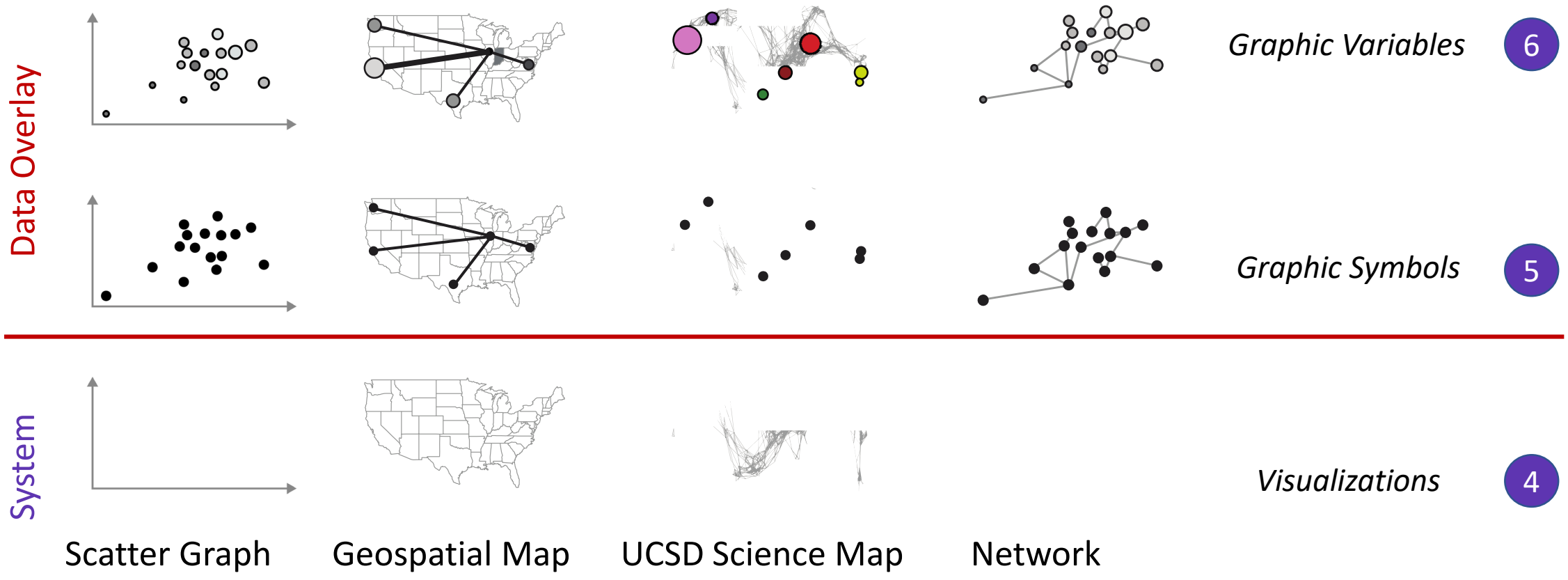


Map
latitude/
longitude

Network
local similarity



Visualize: Reference Systems, Graphic Symbols and Variables



Typology of the Data Visualization Literacy Framework

5

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

Börner, Katy. 2015. *Atlas of Knowledge: Anyone Can Map*. Cambridge, MA: The MIT Press. 32-33.

Typology of the Data Visualization Literacy Framework

6

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  - surface
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  - numerals
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- pictorial symbols
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  - icons
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- extract
- link and brush
- projection
- distortion

Börner, Katy. 2015. *Atlas of Knowledge: Anyone Can Map*. Cambridge, MA: The MIT Press. 34-35.

Graphic Variable Types

Position: x, y; possibly z — Quantitative

Form:

- Size — Quantitative
- Shape — Qualitative
- Rotation (Orientation) — Quantitative

Color:

- Value (Lightness)  ntitative
- Hue (Tint)  Qualitative
- Saturation (Intensity)  Quantitative

Optics: Blur, Transparency, Shading, Stereoscopic Depth

Texture: Spacing, Granularity, Pattern, Orientation, Gradient

Motion: Speed, Velocity, Rhythm

Graphic Variable Types

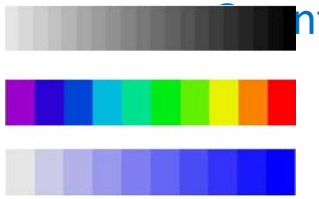
Position: x, y; possibly z

Form:

- Size
- Shape
- Rotation (Orientation)

Color:

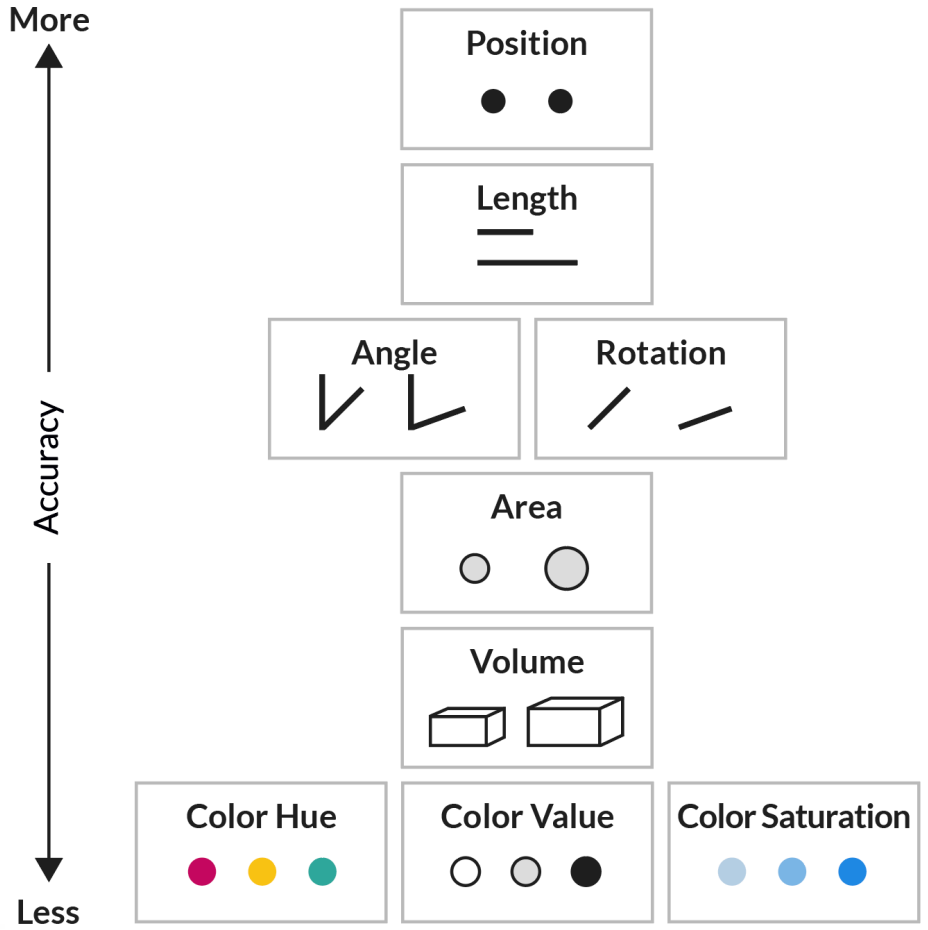
- Value (Lightness)
- Hue (Tint)
- Saturation (Intensity)



Optics: Blur, Transparency, Shading, Stereoscopic Depth

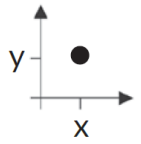
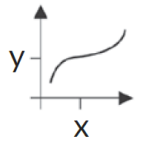
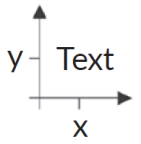
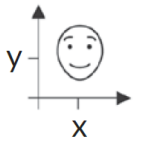
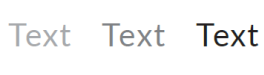
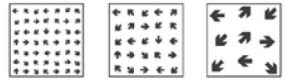
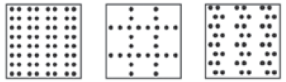
Texture: Spacing, Granularity, Pattern, Orientation, Gradient

Motion: Speed, Velocity, Rhythm



Graphic Symbol Types

Graphic Variable Types

			Geometric Symbols		Linguistic Symbols	Pictorial Symbols
			Point	Line		
Spatial	Position	X Y				
Retinal	Form	Size				
		Shape				
	Color	Value				
		Hue				
		Saturation				
	Texture	Granularity				
		Pattern				
	Optics	Blur				
	Motion	Speed				

See *Atlas of Knowledge* pages 36-39 for complete table.

Qualitative

Also called:

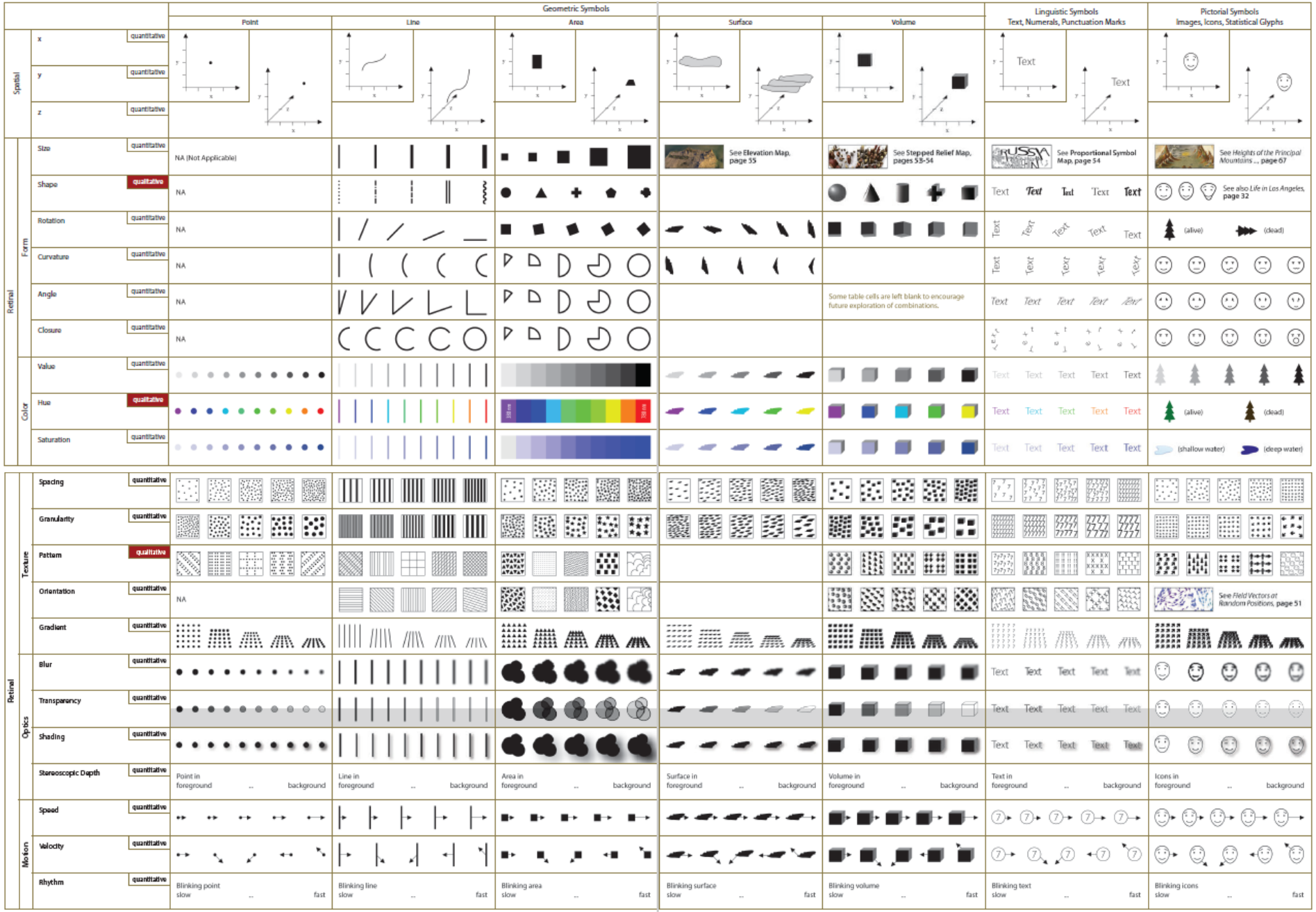
Categorical Attributes
Identity Channels

Quantitative

Also called:

Ordered Attributes
Magnitude Channels

Graphic Variable Types Versus Graphic Symbol Types



See *Atlas of Knowledge* pages 36-39 for complete table.

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  - statistical glyphs

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  - form
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  - optics
  - motion

7

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

Börner, Katy. 2015. *Atlas of Knowledge: Anyone Can Map*. Cambridge, MA: The MIT Press. 26, 68-69.

Example: MAV Scatter Graph

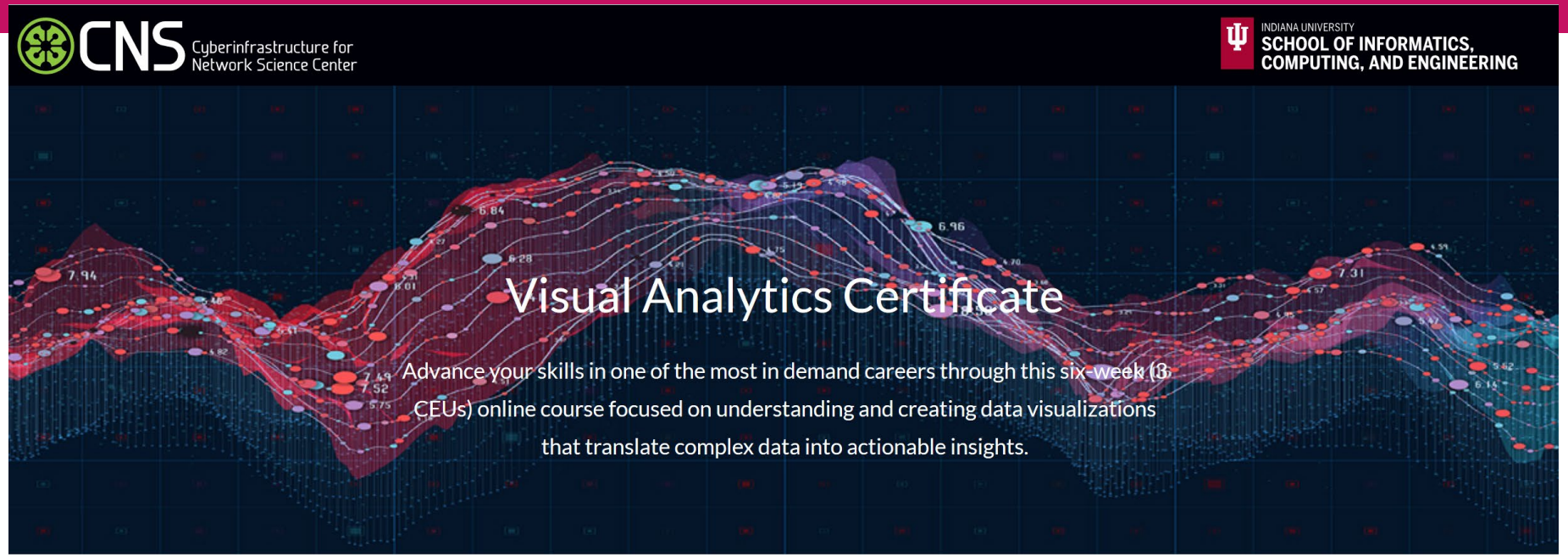
Supports:

- Zoom
- Search and locate

But NOT:

- Filter
- Details on demand
- History
- Extract
- Link and brush
- Projection
- Distortion

Note: Interactivity is data, software, and hardware dependent.



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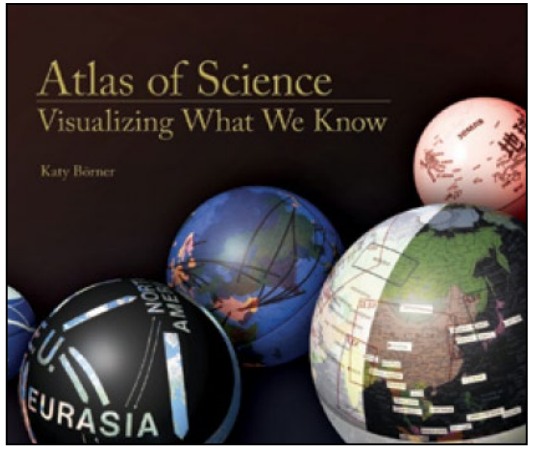
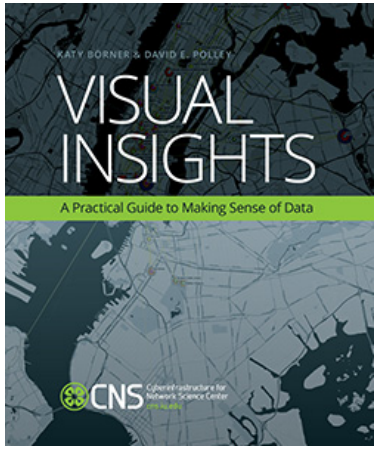
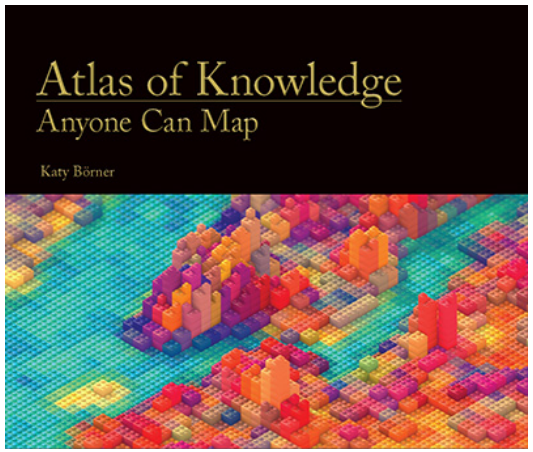
Resources

- Börner, Katy. 2010. *Atlas of Science*. Cambridge, MA: The MIT Press. http://scimaps.org/atlas1.
- Börner, Katy and David E. Polley. 2014. *Visual Insights.* Cambridge, MA: The MIT Press. http://cns.iu.edu/ivmoocbook14.html.
- Börner, Katy. 2015. *Atlas of Knowledge*. Cambridge, MA: The MIT Press. http://scimaps.org/atlas2.







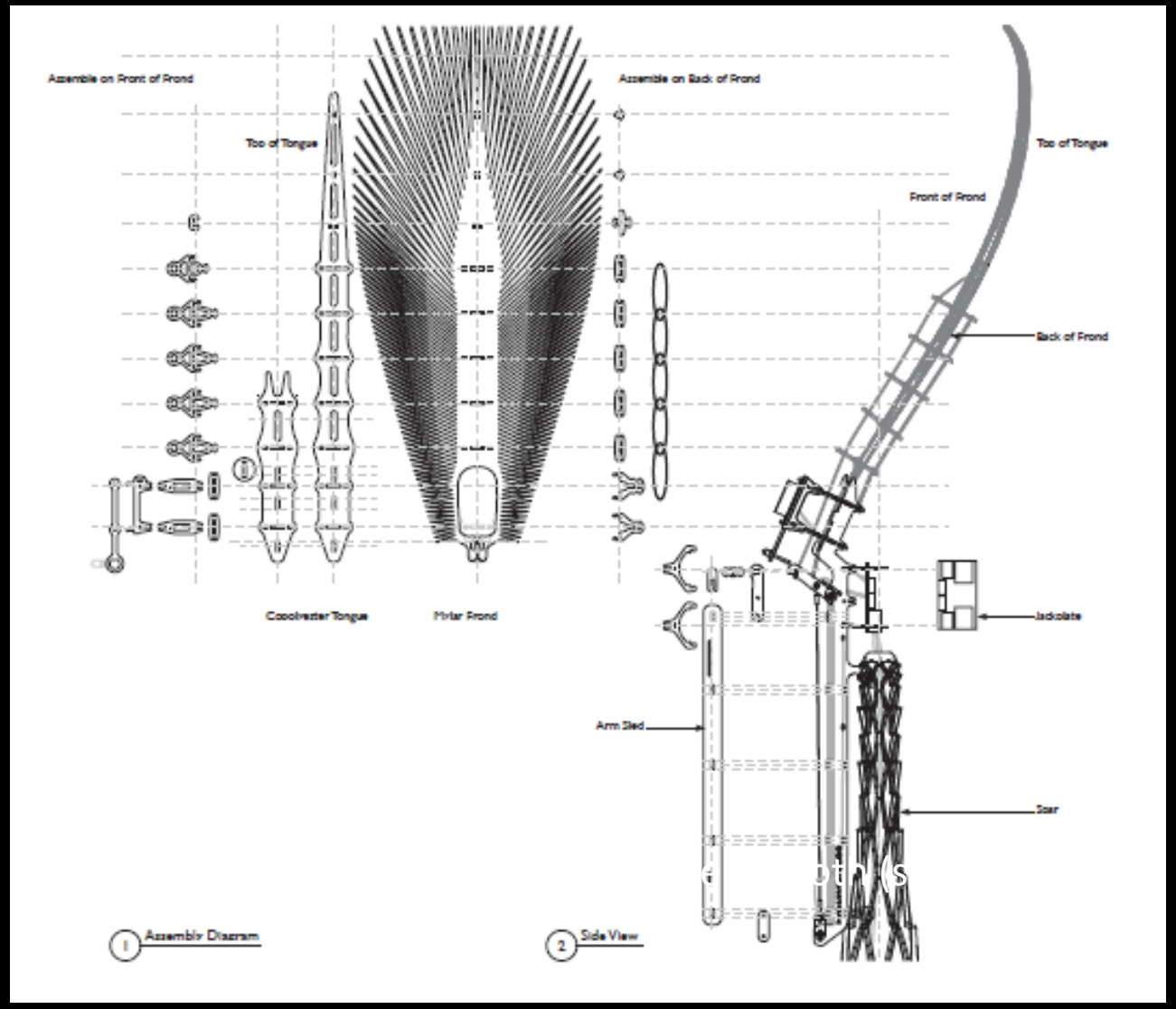
CNS Cyberinfrastructure for Network Science Center

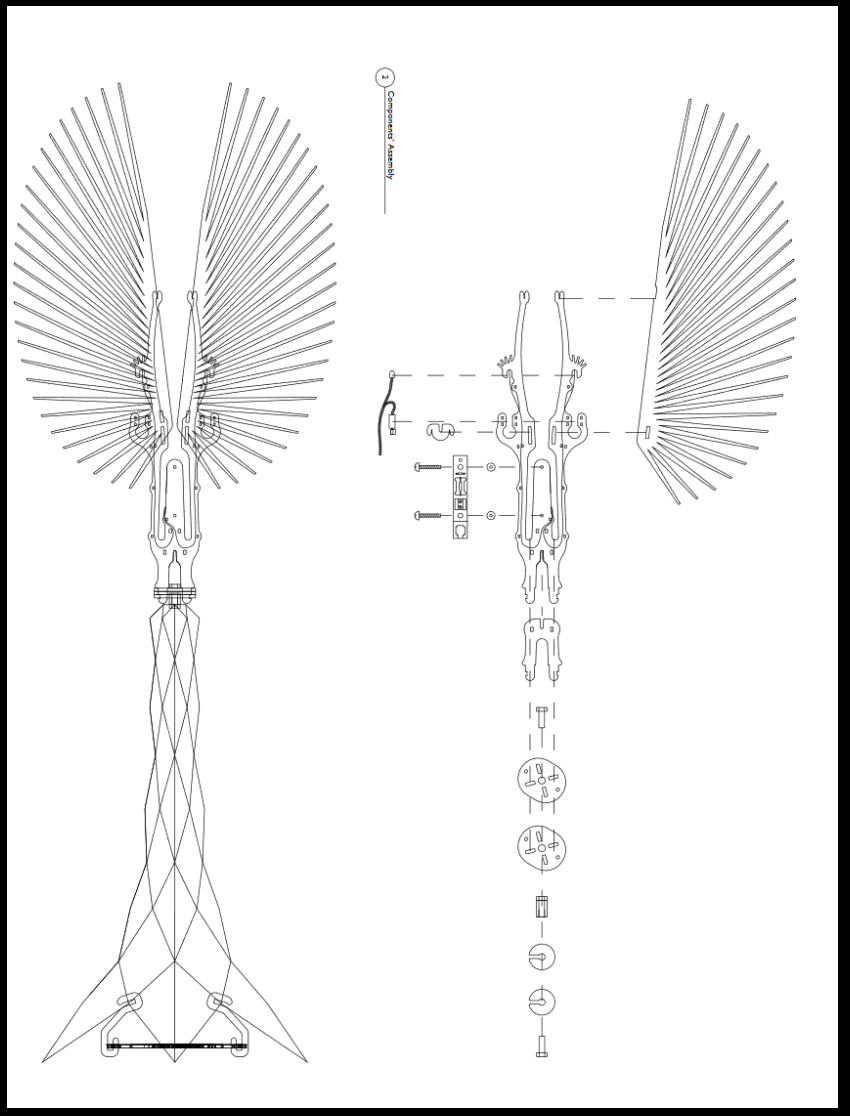
INDIANA UNIVERSITY SCHOOL OF INFORMATICS, COMPUTING, AND ENGINEERING

Visualizing Sentient Architecture

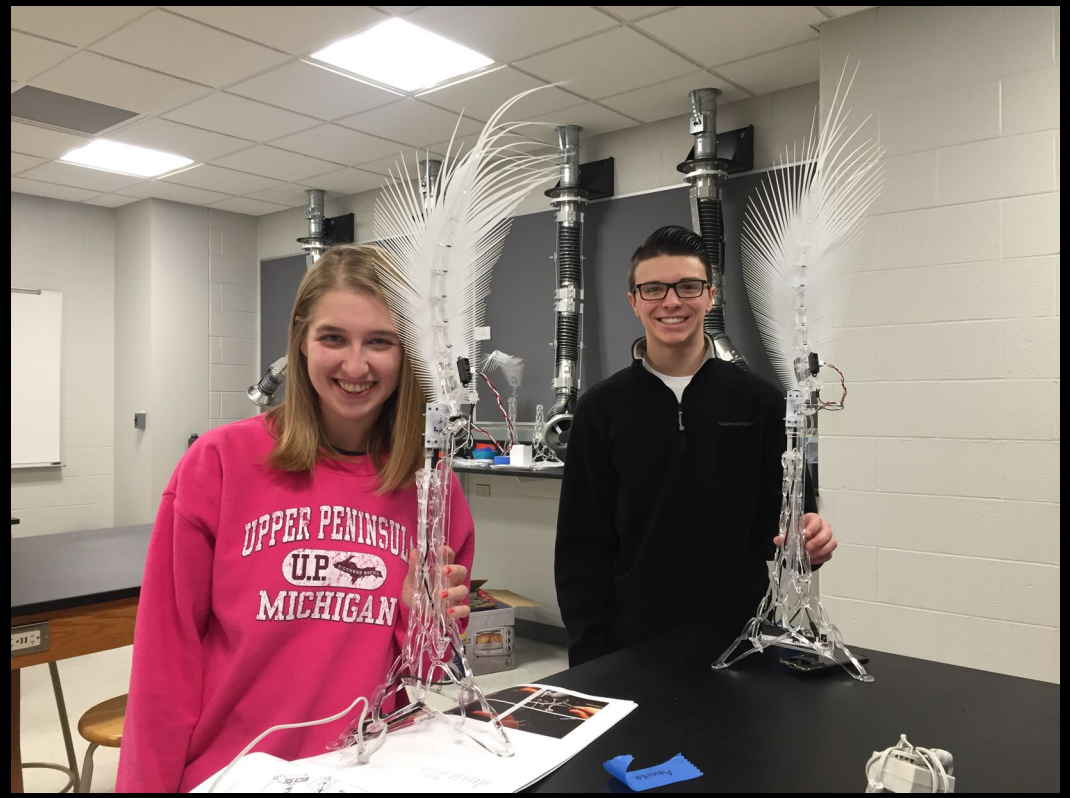
Dendrites and Moths

Bueckle, A., & Börner, K. (2019). **Envisioning Intelligent Interactive Systems: Data Visualizations for Sentient Architecture.** In P. Beesley, S. Bonnemaison, & S. Hastings (Eds.), *White Papers 2019. Toronto, ON: Riverside Architectural Press.*

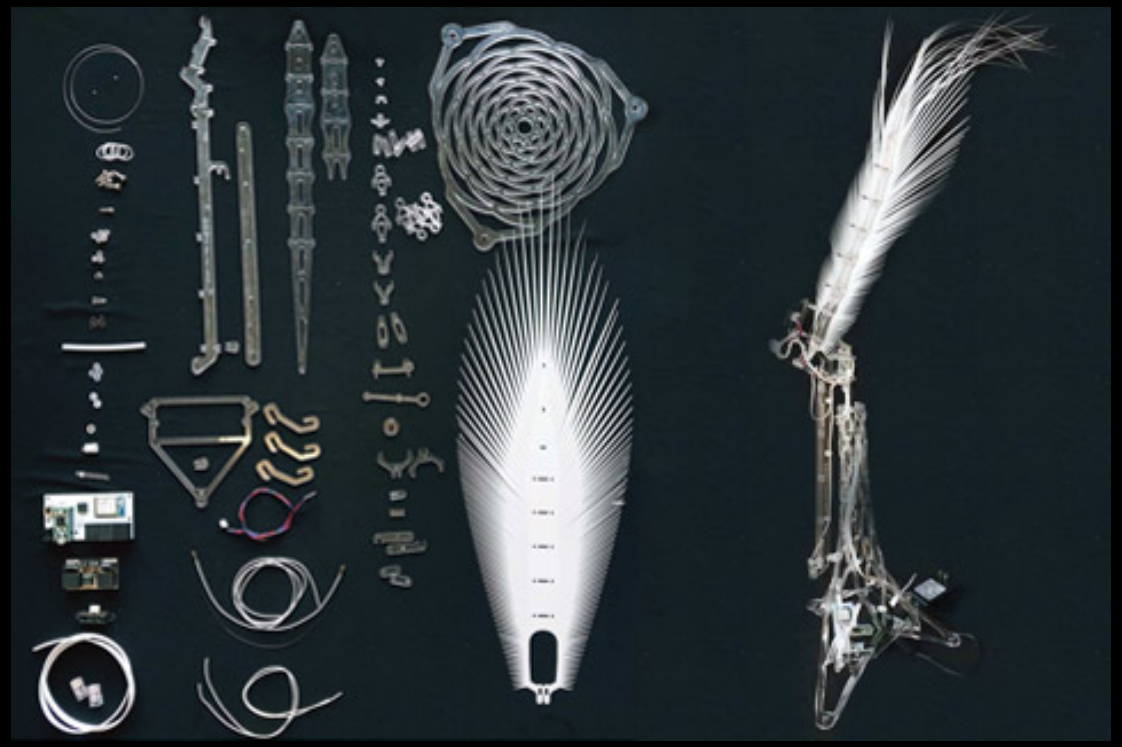




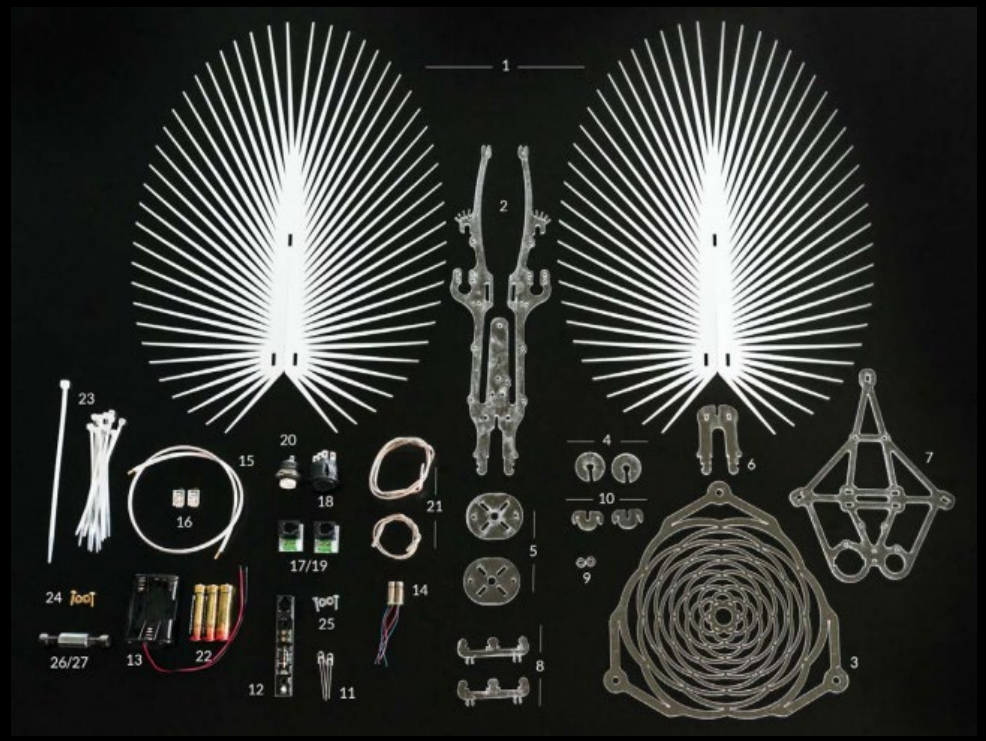
IoT Sculptural Kit
Dendrites & Moths (since 2017/2018)



Students interacting with Dendrites
2017 Summer Camp



Dendrite



Moth

HelloResearch workshop for undergraduate women in computer science
October, 2018

CNS Cyberinfrastructure for Network Science Center

INDIANA UNIVERSITY SCHOOL OF INFORMATICS, COMPUTING, AND ENGINEERING

Visualizing Sentient Architecture

Amatria

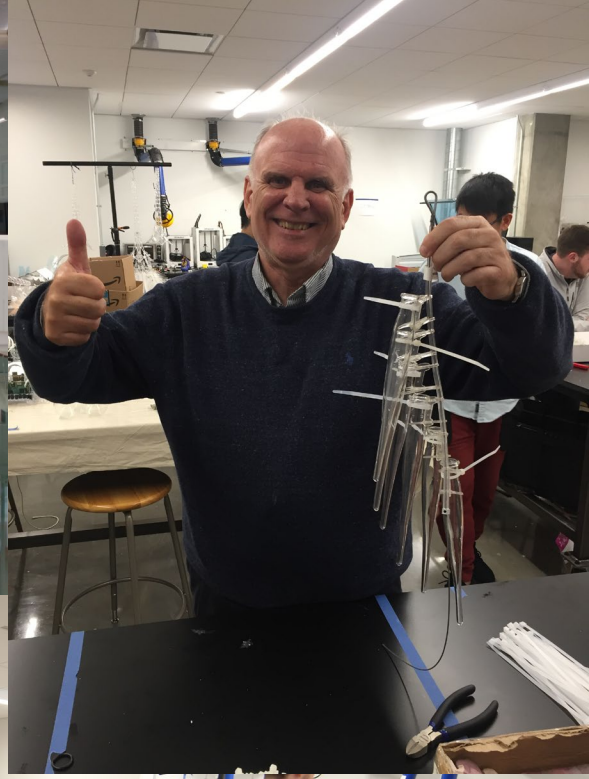
Bueckle, A., & Börner, K. (2019). **Envisioning Intelligent Interactive Systems: Data Visualizations for Sentient Architecture.** In P. Beesley, S. Bonnemaison, & S. Hastings (Eds.), *White Papers 2019. Toronto, ON: Riverside Architectural Press.*

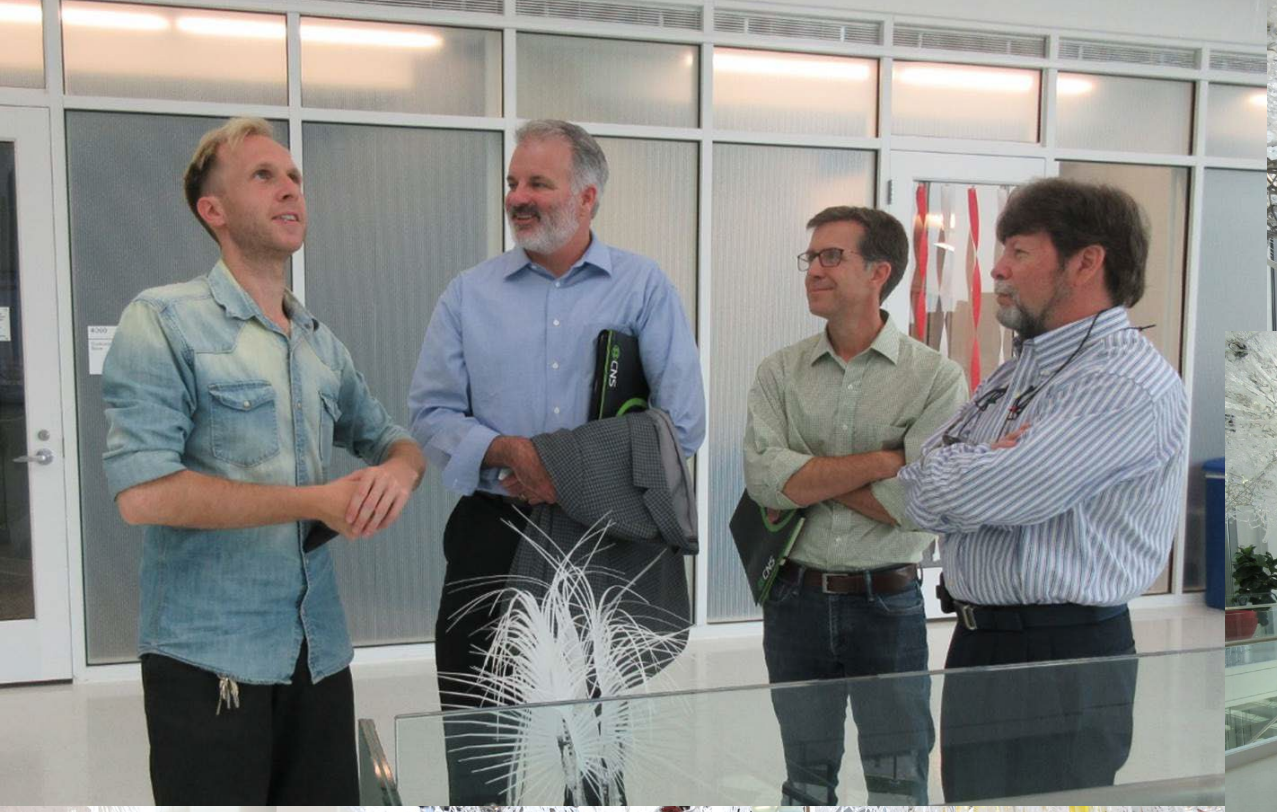
Amatria (2018)

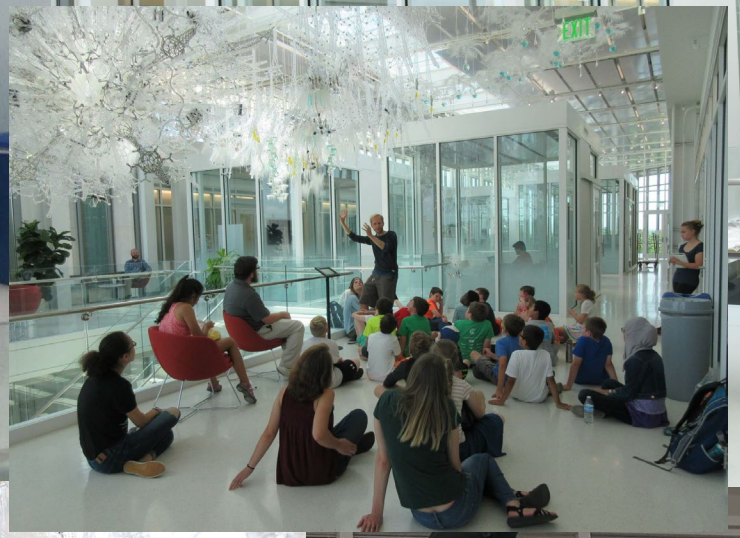
Luddy Hall, SICE, IU

Photo: Ann Schertz






EXIT


How can we use data visualization to enhance the visitor's *understanding* of Amatria?

We started Tavola.

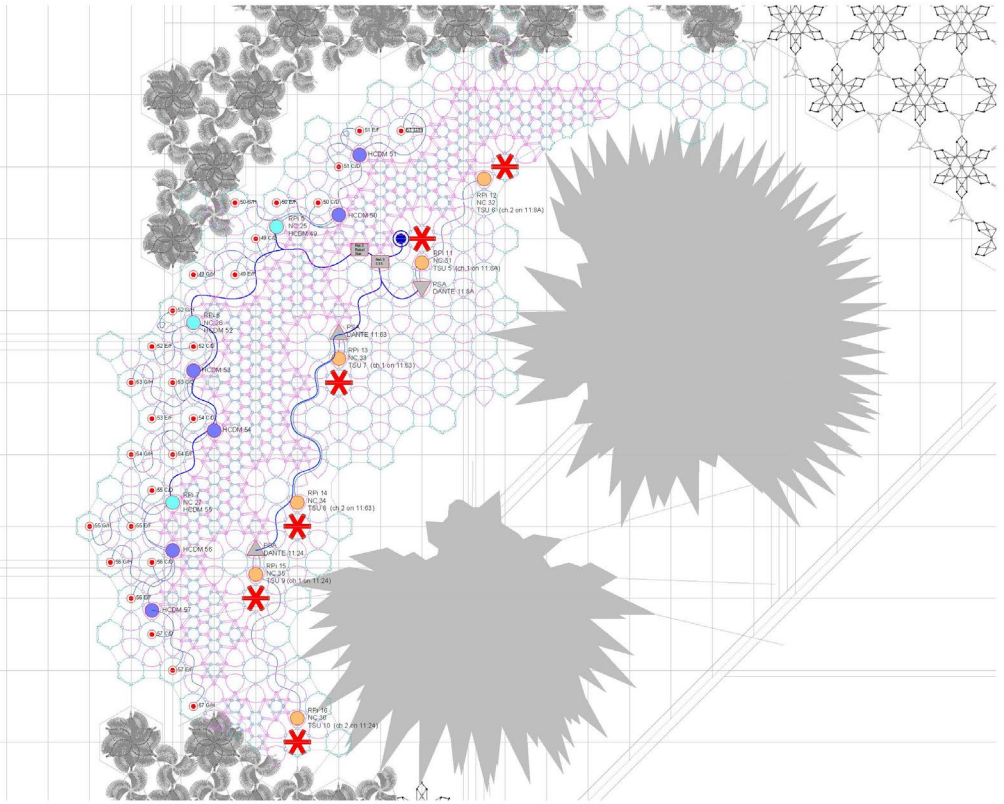
That’s Italian for “tablet”.
Somehow, the name stuck.

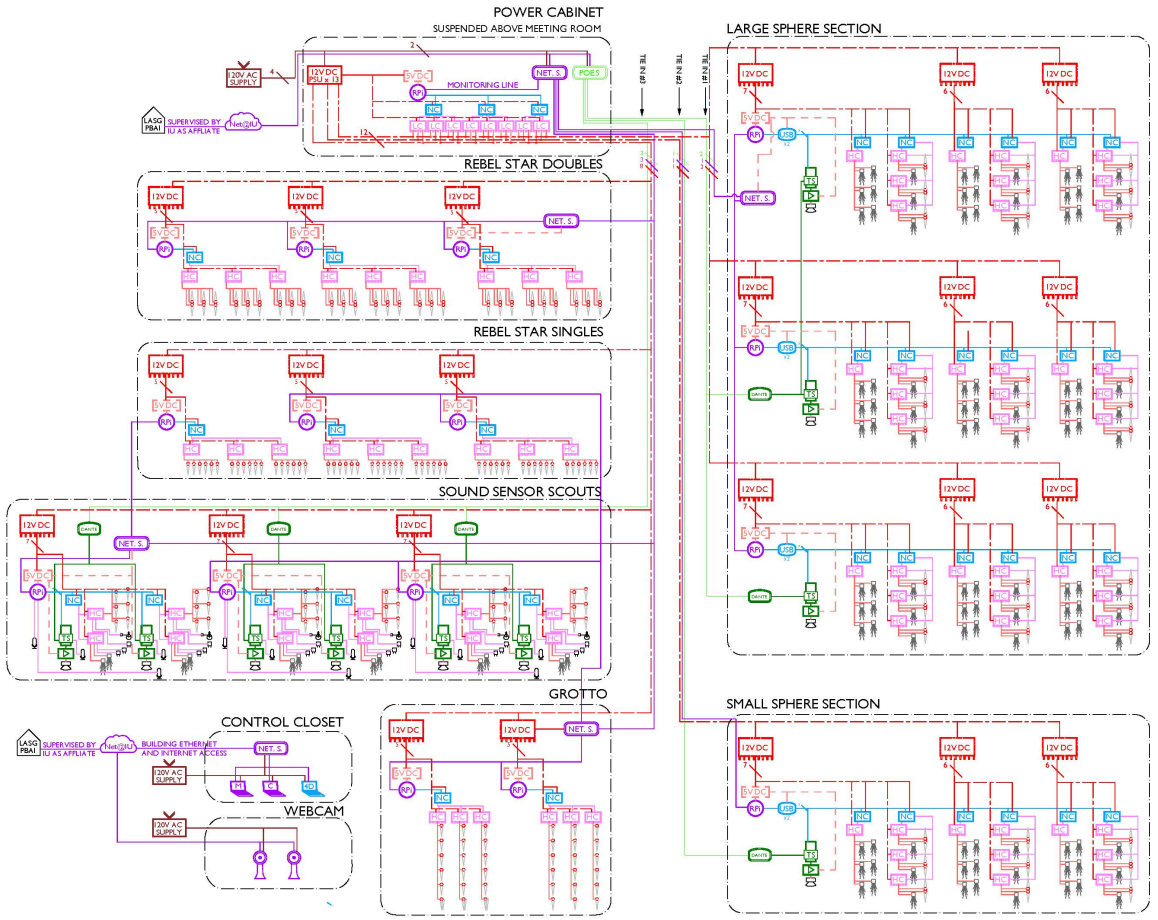
CNS Cyberinfrastructure for Network Science Center

INDIANA UNIVERSITY SCHOOL OF INFORMATICS, COMPUTING, AND ENGINEERING

Step 1

Identify insight needs





Living Architecture Systems Group/
Philip Beesley Architect Inc.

213 Sterling Road Suite 200
Toronto, Canada
M6R2B2
web: lasg.ca
tel: 416 766 8284

By	Date	Status	Rev By	Rev Date
MH	01/03/08	Draft		

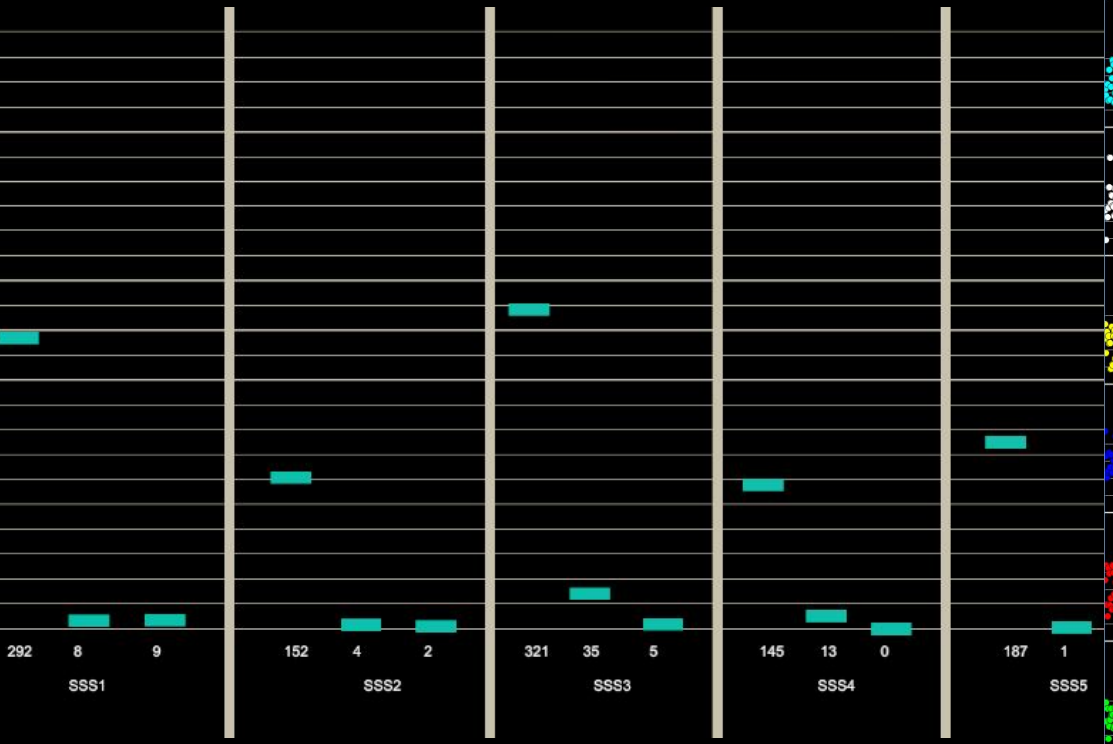
DRAWING LEGEND

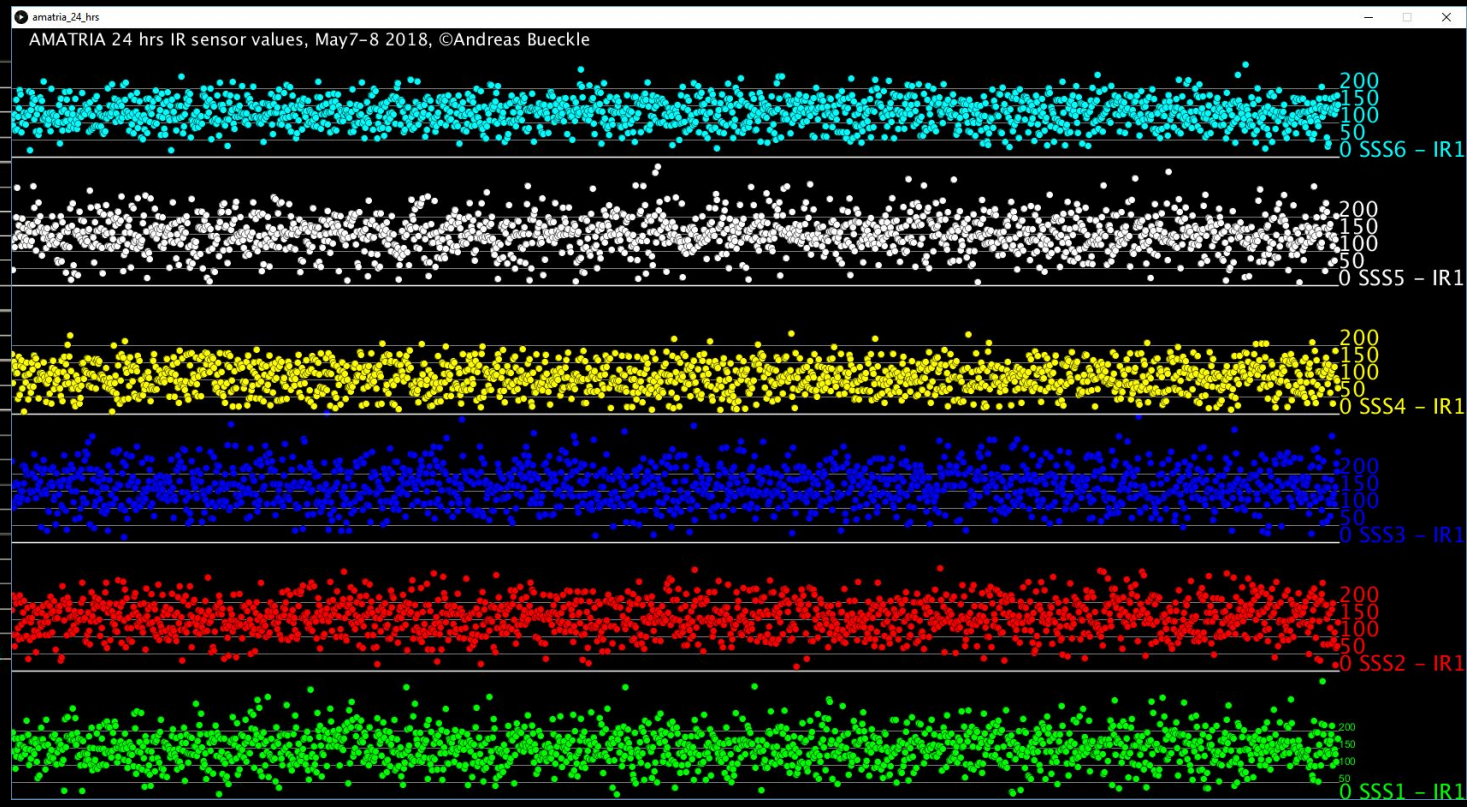
Phase
Design Development

Project
17540 Luddy Hall

Drawing Title
Electronic Schematic

Sheet
IS103





What works for engineers does not always work for *visitors*.

Insight Need Analysis

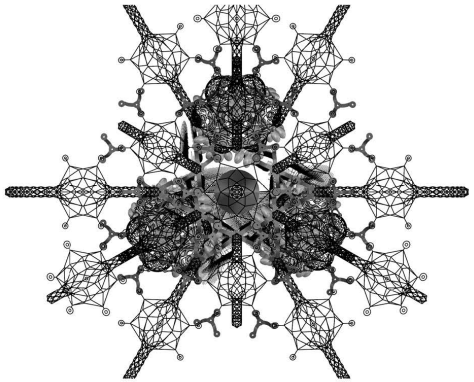
Geospatial insights into structure

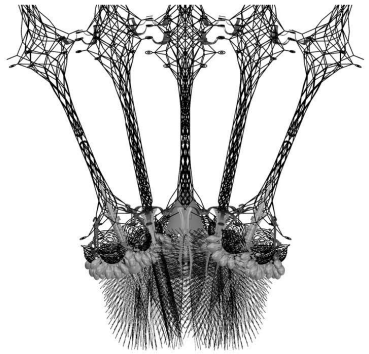
Visualize location and type of sensors & actuators

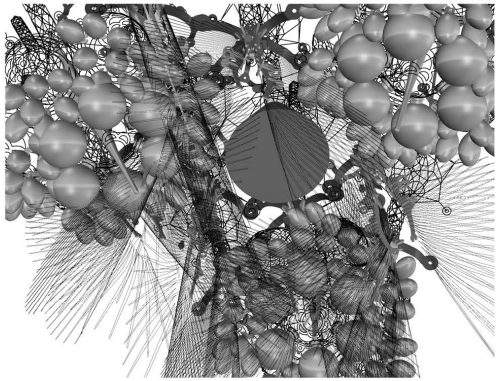
Compare states of sculpture via IR sensor values

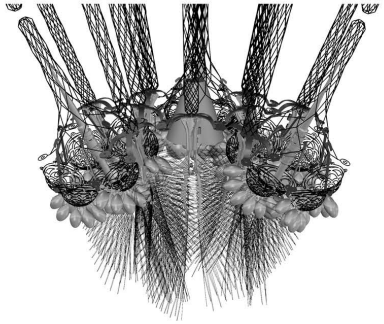
Step 2

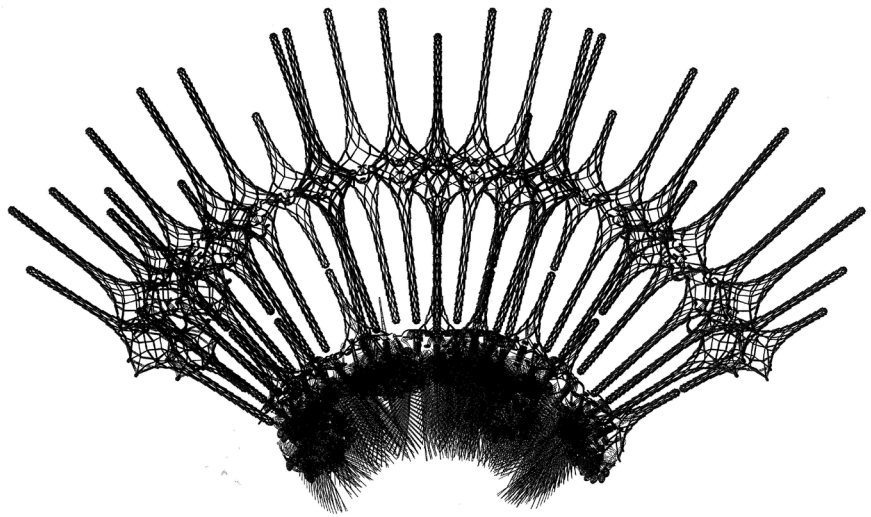
Data acquisition











Living Architecture
Systems Group/
Philip Beesley
Architect Inc.

213 Sterling Road Suite 200
Toronto, Canada
M6R2B2

web: lasg.ca
tel: 416 766 8284

By	Date	Status	Rev By	Rev Date
MA	18/03/05	DRAFT	PB	18/03/05

Notes

Phase
Design Development

Project
17540 Luddy Hall

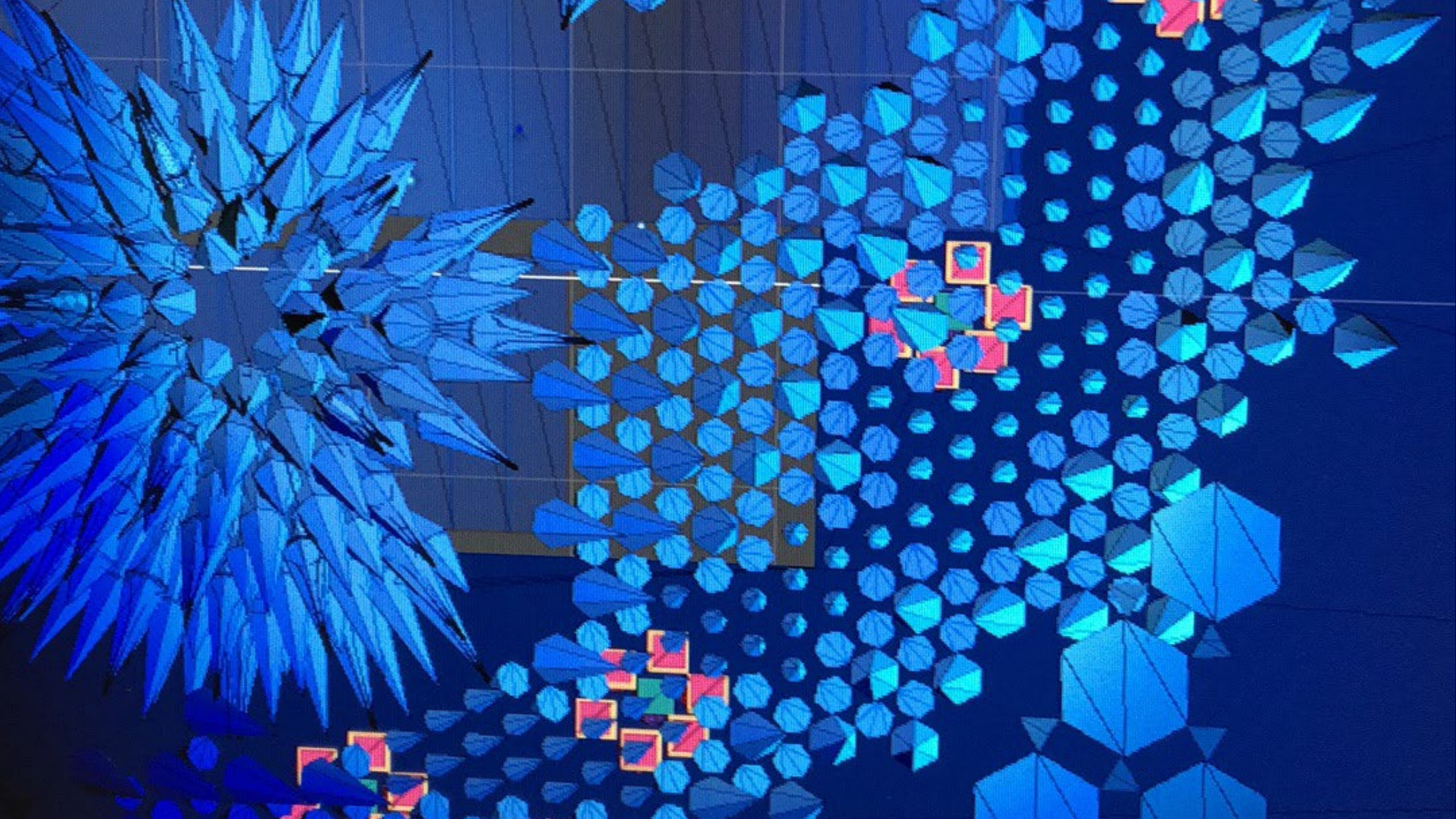
Drawing Title
Sphere Unit

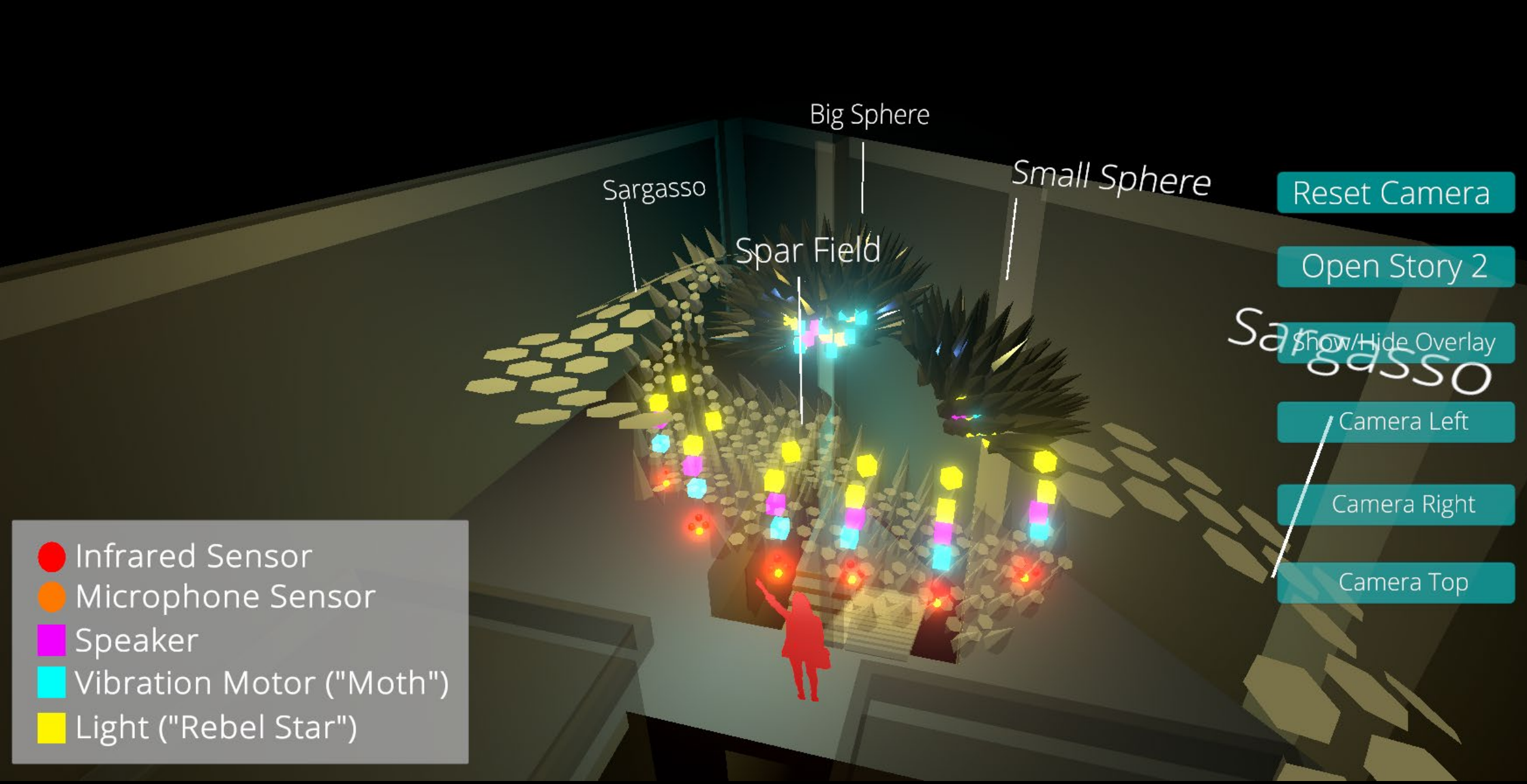
Sheet
X000

Original 3D model *straight out of* Rhino

Your PC ran into a problem and needs to restart. We're just collecting some error info, and then we'll restart for you. (0% complete)

If you'd like to know more, you can search online later for this error: CRITICAL_PROCESS_DIED




Big Sphere
Sargasso
Small Sphere
Spar Field
Reset Camera
Open Story 2
Show/Hide Overlay
Sargasso
Camera Left
Camera Right
Camera Top
Infrared Sensor
Microphone Sensor
Speaker
Vibration Motor ("Moth")
Light ("Rebel Star")

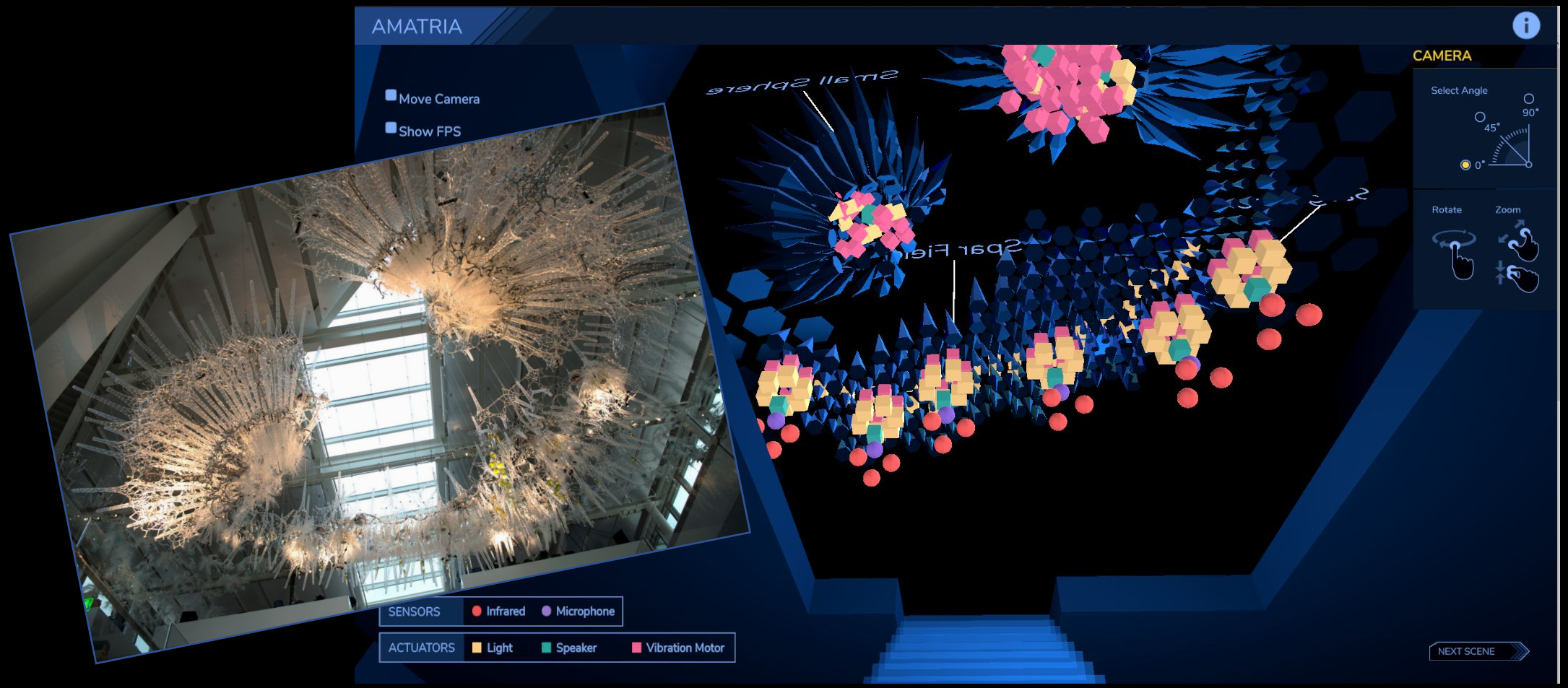
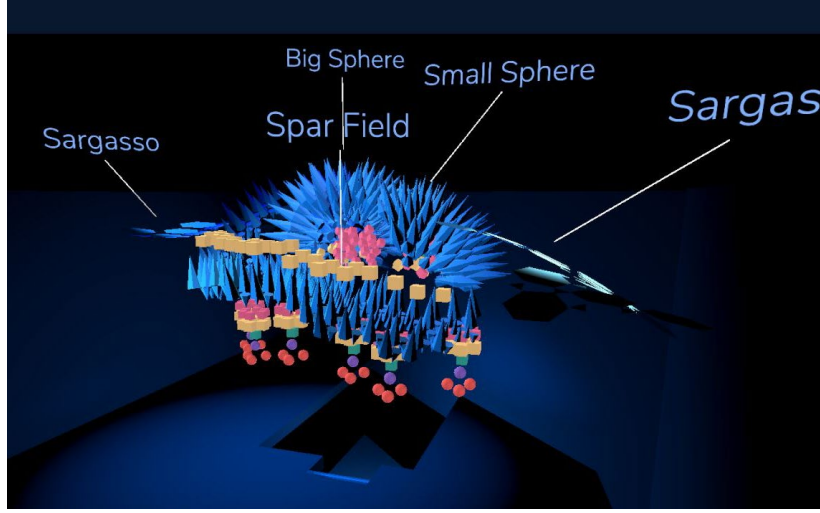
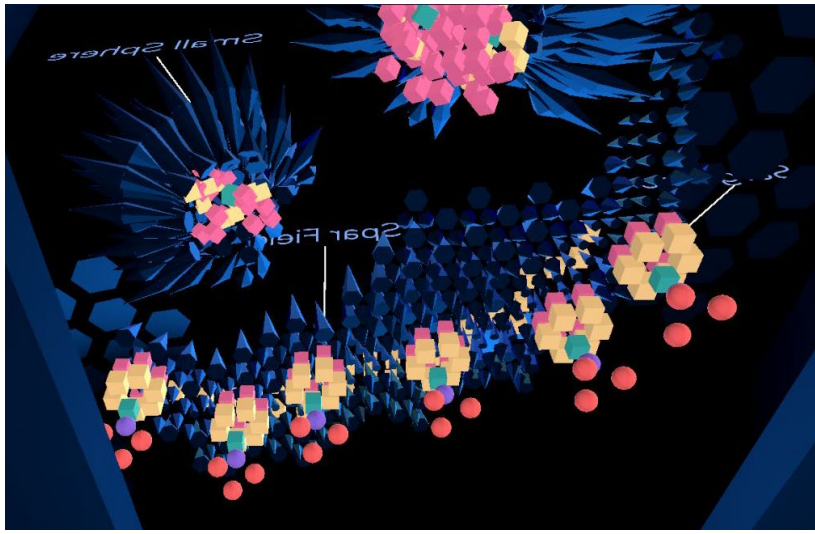
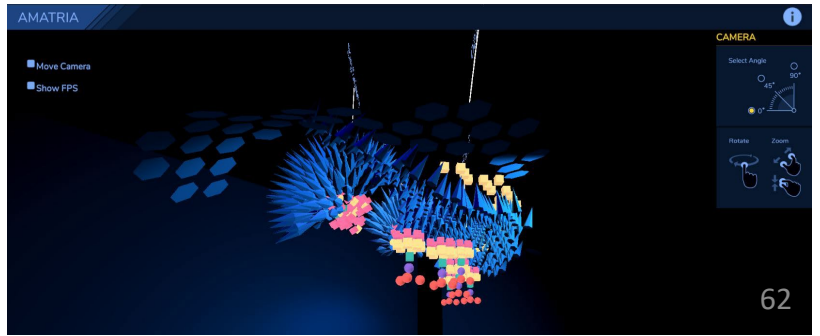

AMATRIA
Move Camera
Show FPS
CAMERA
Select Angle
90°
45°
0°
Rotate
Zoom
SENSORS
Infrared
Microphone
ACTUATORS
Light
Speaker
Vibration Motor
NEXT SCENE

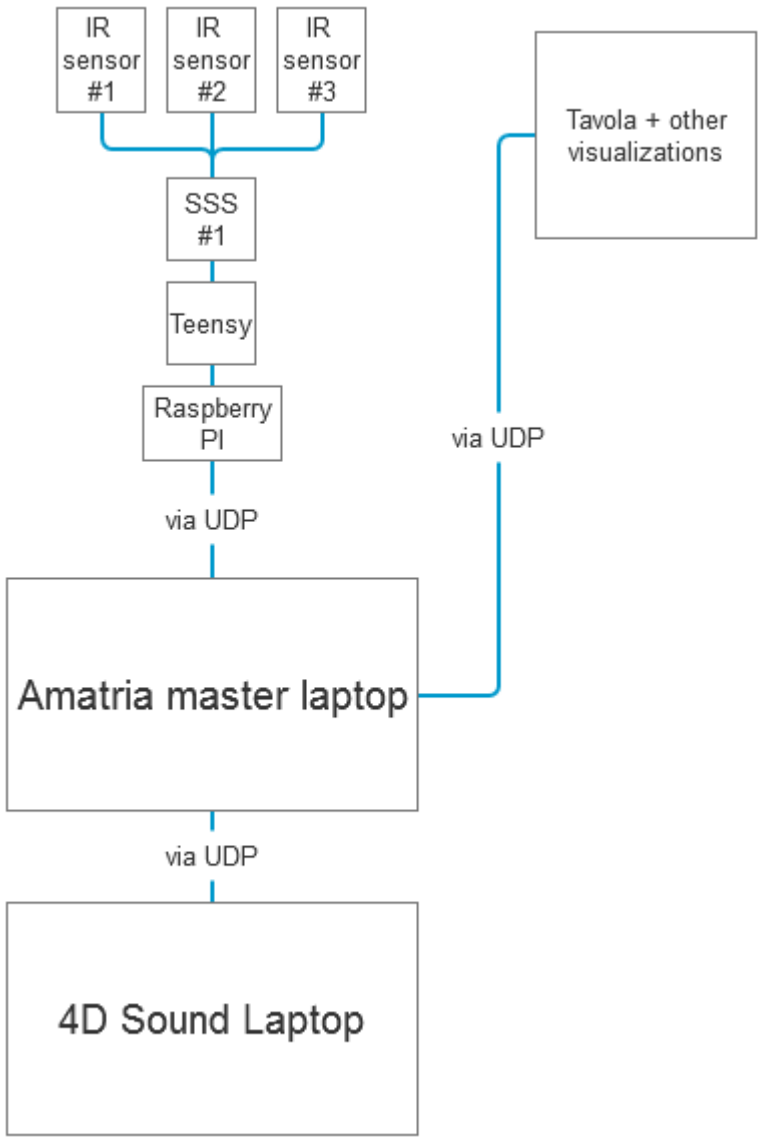
Table 1. Graphic symbol types vs. graphic variable types in scene 1 of Tavola.
*** qualitative**
**** quantitative**

		Graphic symbol types				
		Volume				
Graphic variable types	Shape*	Sphere: sensor		Cube: actuator		
	Color hue*	#EF5350 (red): IR sensor	#9575CD (purple): microphone sensor	#FFCC 80 (yellow) : light	#26A69A (green): speaker	#f06292 (pink): vibration motor
	Color intensity*	Opacity: 0%: graphic symbol turned off Opacity: 100%: graphic symbol turned off				
	x-position**	Location of sensor or actuator in 3D space				
	y-position**					
	z-position**					










```
b'TV/TRIGGER/SSS2/105/4/1'
b'TV/TRIGGER/SSS5/207/1/1'
b'TV/TRIGGER/SSS4/163/0/0'
b'TV/TRIGGER/SSS3/142/36/2'
b'TV/TRIGGER/SSS6/198/4/2'
b'TV/TRIGGER/SSS1/199/1/3'
b'TV/TRIGGER/SSS2/86/4/6'
b'TV/TRIGGER/SSS5/213/1/1'
b'TV/TRIGGER/SSS4/154/0/0'
b'TV/TRIGGER/SSS3/198/31/2'
b'TV/TRIGGER/SSS6/200/15/17'
b'TV/TRIGGER/SSS1/258/1/4'
b'TV/TRIGGER/SSS2/62/2/4'
b'TV/TRIGGER/SSS5/126/1/1'
b'TV/TRIGGER/SSS4/132/0/0'
b'TV/TRIGGER/SSS3/192/37/6'
b'TV/TRIGGER/SSS6/155/1/3'
b'TV/TRIGGER/SSS1/308/24/10'
b'TV/TRIGGER/SSS2/237/0/2'
b'TV/TRIGGER/SSS5/221/1/1'
b'TV/TRIGGER/SSS4/45/0/0'
b'TV/TRIGGER/SSS3/196/27/5'
b'TV/TRIGGER/SSS6/162/3/1'
b'TV/TRIGGER/SSS1/257/2/4'
b'TV/TRIGGER/SSS2/177/7/0'
b'TV/TRIGGER/SSS5/246/1/1'
b'TV/TRIGGER/SSS4/83/4/0'
b'TV/TRIGGER/SSS3/255/24/5'
b'TV/TRIGGER/SSS6/256/1/1'
b'TV/TRIGGER/SSS1/226/7/12'
b'TV/TRIGGER/SSS2/200/8/4'
b'TV/TRIGGER/SSS5/201/1/1'
b'TV/TRIGGER/SSS4/38/0/0'
b'TV/TRIGGER/SSS3/204/26/1'
b'TV/TRIGGER/SSS6/205/1/3'
b'TV/TRIGGER/SSS1/217/8/11'
b'TV/TRIGGER/SSS2/115/0/5'
b'TV/TRIGGER/SSS5/203/1/1'
b'TV/TRIGGER/SSS4/52/0/0'
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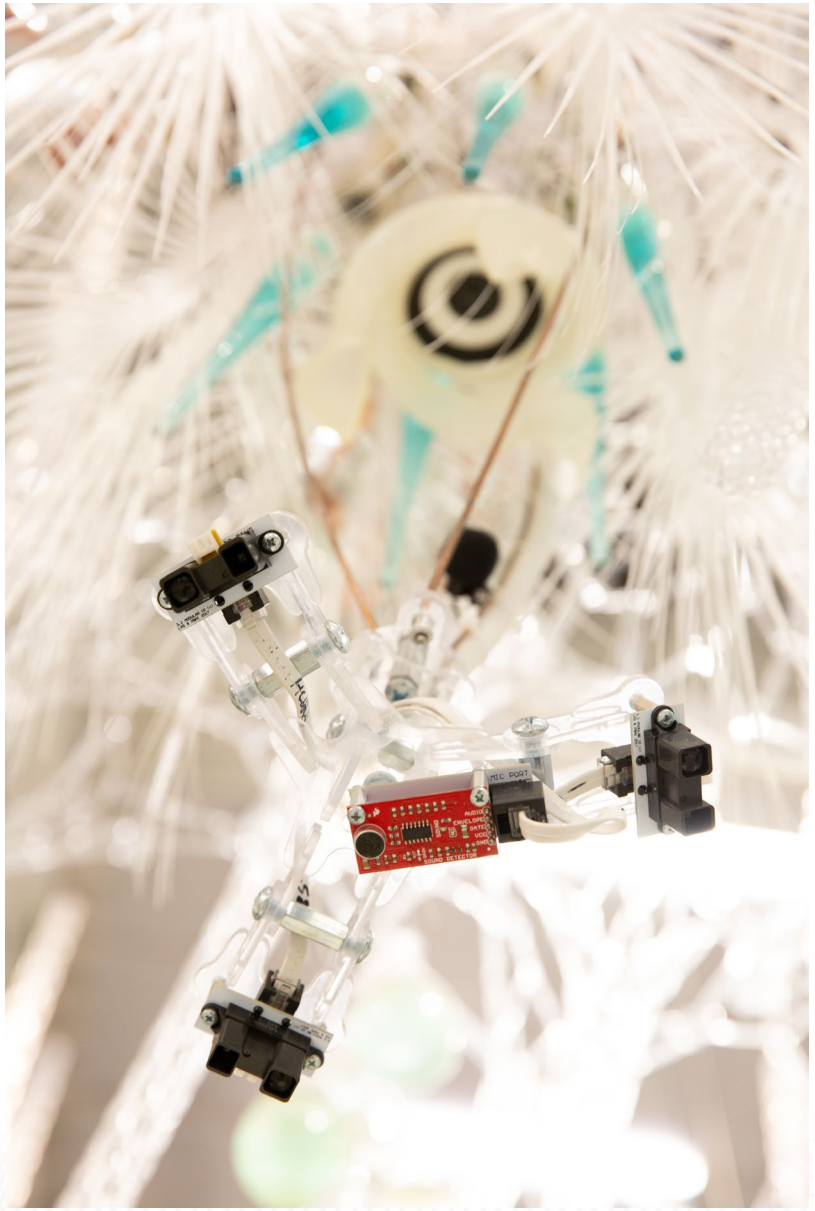
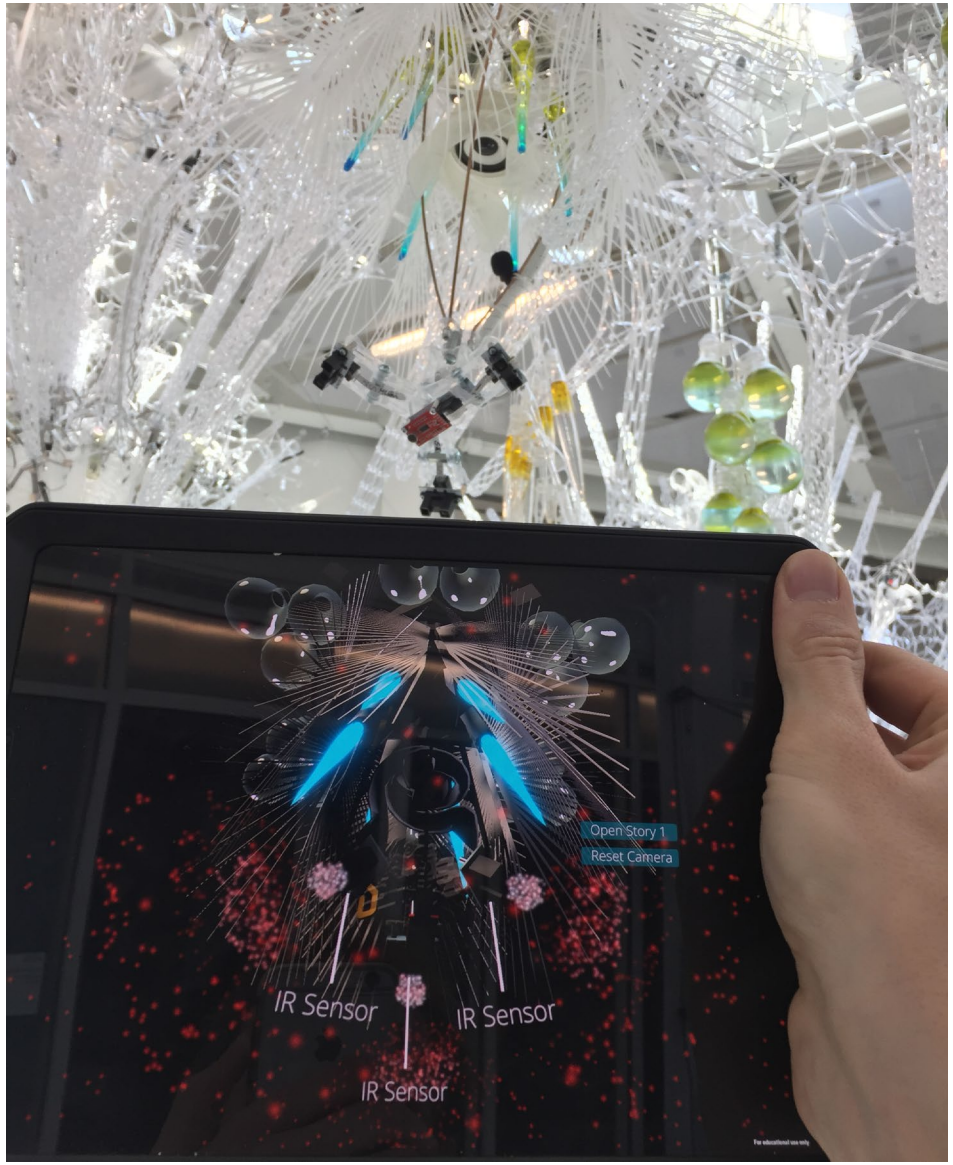
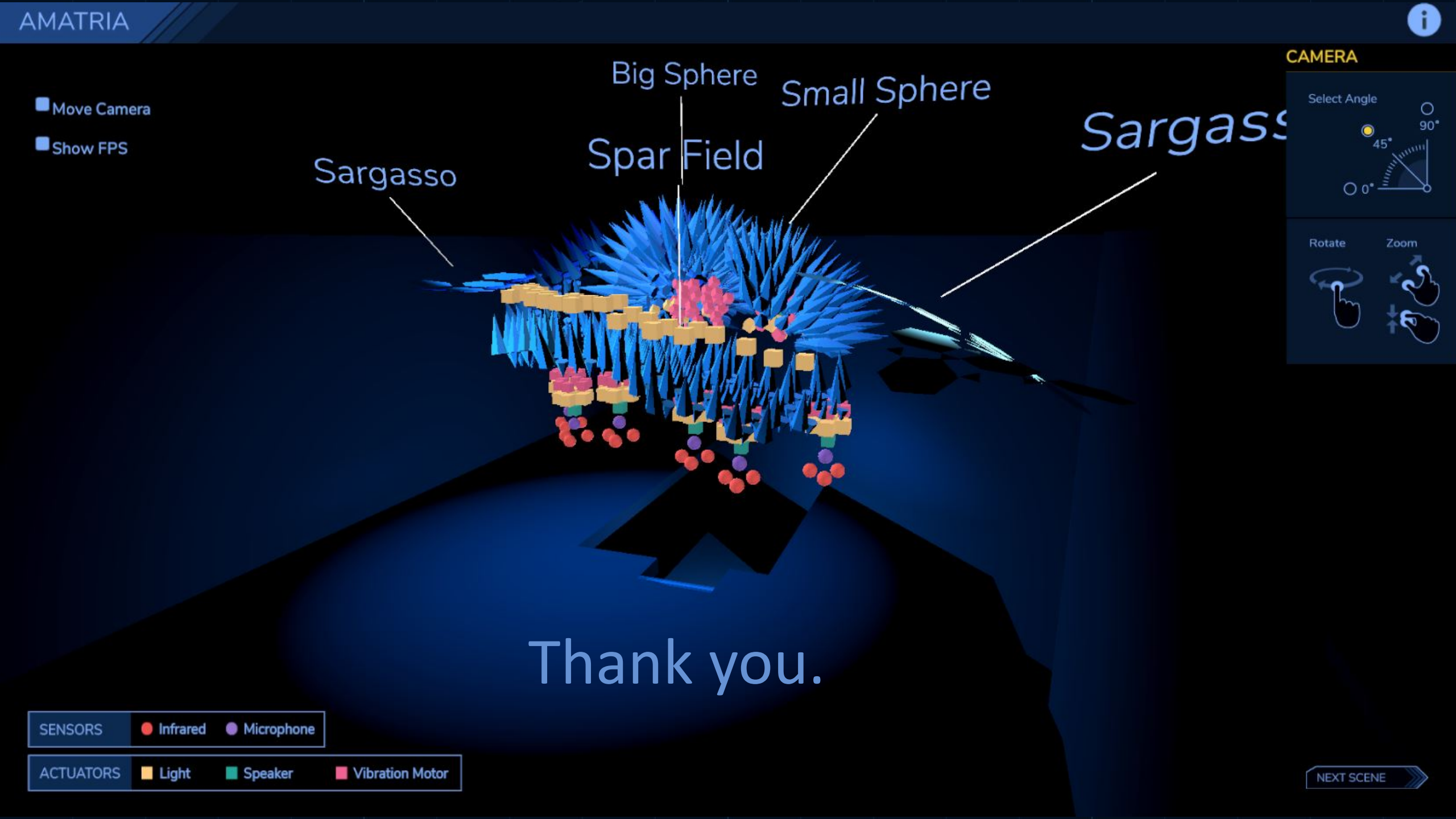



Open Story 1
Reset Camera
IR Sensor
IR Sensor
IR Sensor

Outlook & Future Work

- Perform user studies to
  - test insight need satisfaction
  - validate use of graphic symbols & graphic variables
- Deployment planned via 32” touch screen
- To be installed for Amatria’s 1st birthday in April 2019


AMATRIA
Move Camera
Show FPS
Big Sphere
Small Sphere
Spar Field
Sargasso
Sargass
CAMERA
Select Angle
90°
45°
0°
Rotate
Zoom
Thank you.
SENSORS
Infrared
Microphone
ACTUATORS
Light
Speaker
Vibration Motor
NEXT SCENE