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Saliency Prediction in the Data Visualization Design Process

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Dan Witzner Hansen

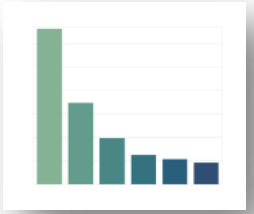
Politecnico di Torino

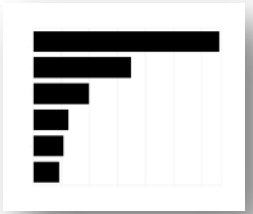
DAUN

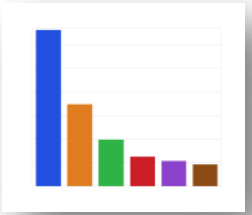
*"Design graphic representations of data by taking into account **human sensory capabilities** in such a way that important data elements and data patterns can be quickly perceived."* by Colin Ware [1]

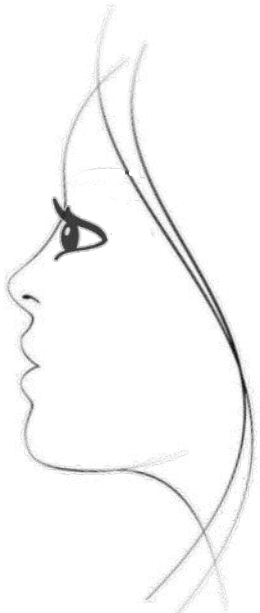
DataViz

Graph Designers









Human Sensory Capabilities

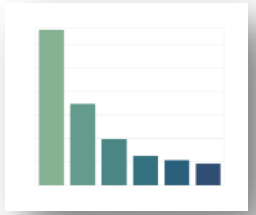
Observer

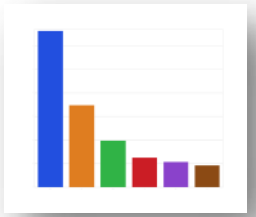
Human Vision Attention

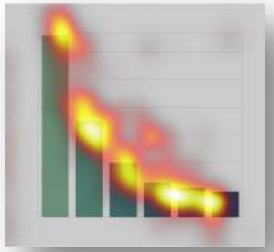
DataViz Images

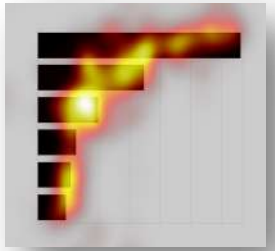
Observers Focus Attention

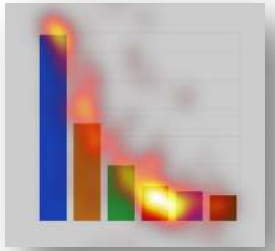
Same data, different visual elements

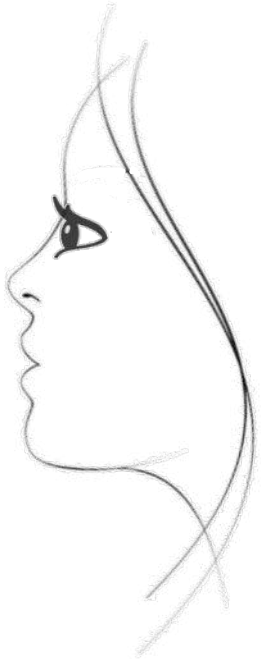












Research Aim

Integrate **visual-cognitive concepts** into the **Data Visualization Design Process and tools**. We intend to bring those concepts to the **graph designer's** context and provide insight into how their design choices might affect the **observer's perception**.

Research Development Process

- InfoVis and Human Attention
- Saliency Prediction Models
- Saliency Prediction for DataViz Design Process
- Conclusions

Research Development Process

InfoVis and Human Attention

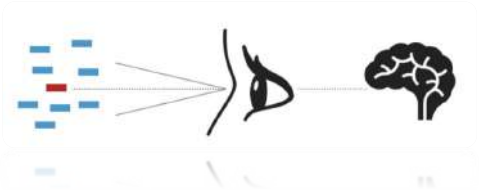
- Key Concepts
- Literature Review

Saliency Prediction Models

Saliency Prediction for DataViz Design Process

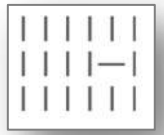
Conclusions

Preattentive Process

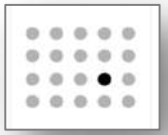


Decides what visual attributes are ***offered up*** to our attention and easy to find in the next fixation " [21]

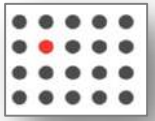
Preattentive Attributes



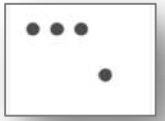
Orientation



Color Intensity

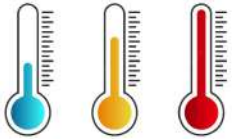


Color Hue



Position

Saliency



The degree to which a target stimulus "***pops out***" in a set of stimuli." [22]

Heat Map

Eye-Tracker

Saliency Prediction

*Computer Models that **imitate** human attention process*

Saliency Map

How is the preattentive visual process used in information visualization? (RQ)

Oriented to improve the observer's cognitive process in graph comprehension

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Sources

- IEEExplore
- ACM
- SpringerLink
- ScienceDirect

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Key Words

- Preattentive
- Pre-attentive
- Data Highlighting
- InfoVis
- DataViz

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Range of Years

From 2010 to 2021

4

Filtering Topics

- Computer Sciences
- HCI
- InfoVis
- DataViz

4

Filtering Questions

- Improve understanding?
- Draw observer attention
- Cognitive influence
- Saliency models

Literature Review II

Preattentive Uses in InfoVis:

1. For **Design**
   - Design elements manipulation to achieve different goals (*e.g., identifying relevant data*).

2. For **Measurement**
   - Assess attention on portions of a graph or determine the impact of preattentive attributes.

Insights

- Highlighting and Data enhancement
- Implicit and Unconscious design decisions
- Graph designer oblivion
- Saliency Models

Research Development Process

InfoVis and Human Attention

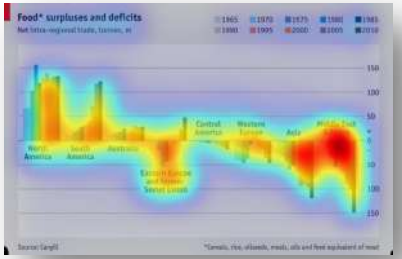
Saliency Prediction Models

- Saliency Models Fundamentals
- Saliency Models + DataViz
- Saliency Model Validation

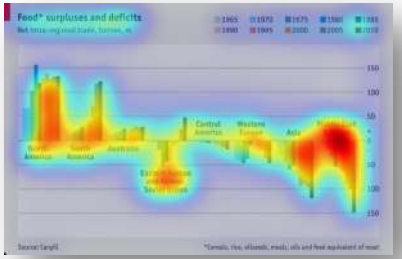
Saliency Prediction for DataViz Design Process

Conclusions

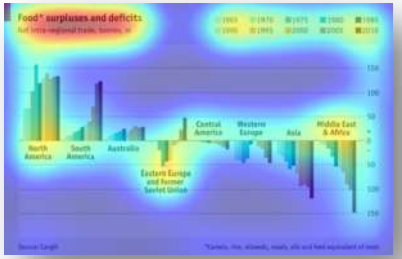
Saliency Models in DataViz



Itti-Koch
(2001)



Matzen
(2018)



Bylinskii
(2017)

Classical Models

Deep Learning

Itti-Koch
2001

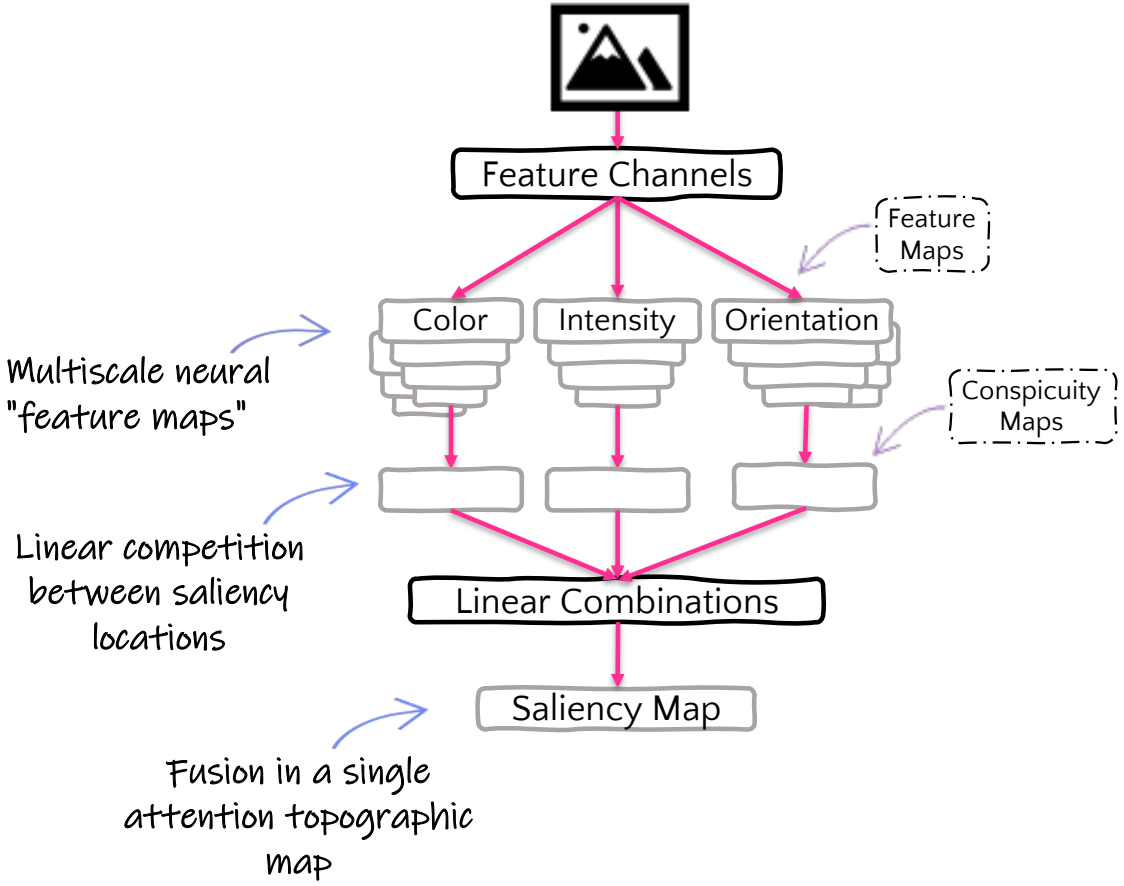
Biologically
conceivable

Bottom-up
Classical Model

Natural Images
Root Data Set

Markov Chains
Strategy

Matlab
Code Language



Matzen
2018

Biologically
conceivable

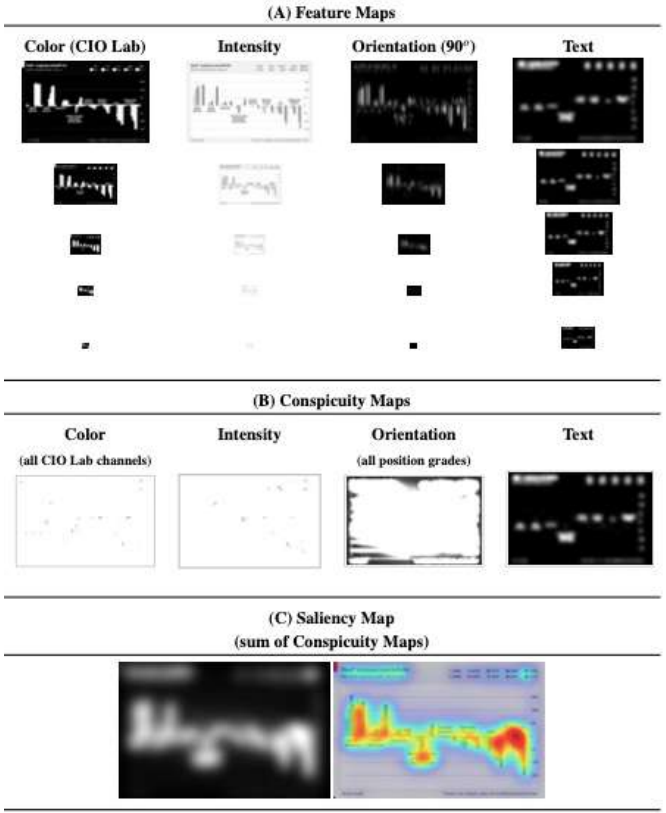
Bottom-up + Top-down
Classical Model

MASSVIS + Natural Images
Root Data Set

Modified Itti-Koch + Text Detection
Strategy

Matlab
Code Language

Saliency Prediction Process



Bylinskii
2017

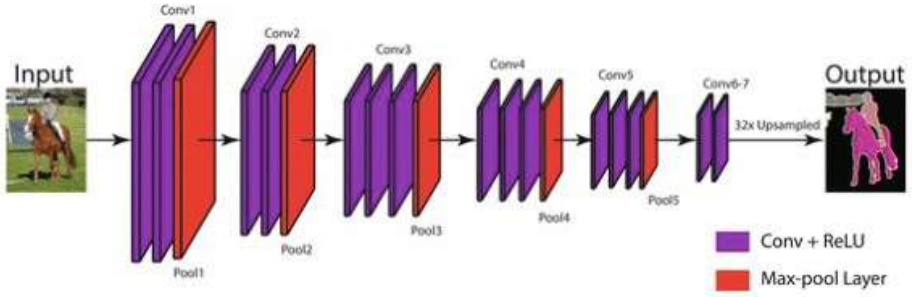
Computational
conceivable

Deep Learning
Model Classification

MASSVIS
Root Data Set

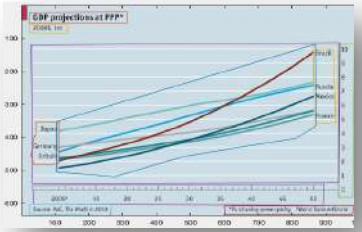
Fully Convolutional Networks
Strategy

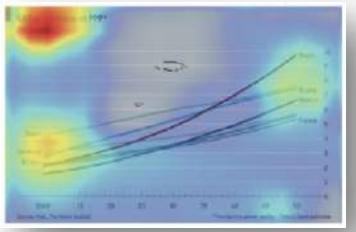
Python + Caffe DL
Code Language



Fully Convolutional Networks
(FCN32)

Relative Importance
(Higher-level Features)





Saliency Models Analysis

Concerns about the Saliency Models' behavior:

1. Significant imbalance in the attention given to Text elements.
2. Suitability of the dataset for training DataViz models (*e.g.,* several context elements).
3. Some representative features, such as position, are not considered in DataViz saliency models.

Which is the best-performing model?

Even if the graph's visual elements are varied (or removed).

Research Development Process

InfoVis and Human Attention

Saliency Prediction Models

- Saliency Models Fundamentals
- Saliency Models + DataViz
- Saliency Model Validation

Saliency Prediction for DataViz Design Process

Conclusions

First Experiment

Scopes

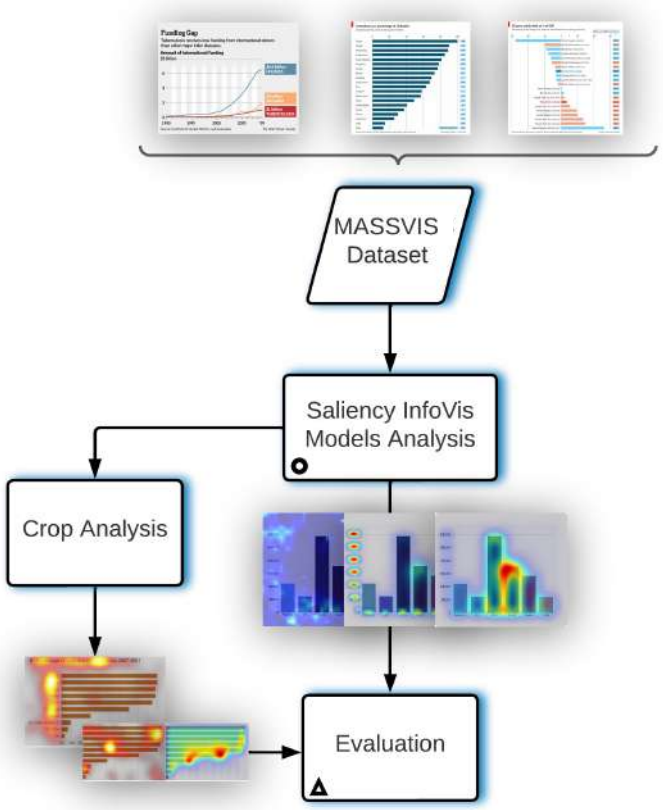
- Confirming the model's performance with the frequently used dataset.
- Detailing how the models behaved by predicting the graph saliency.

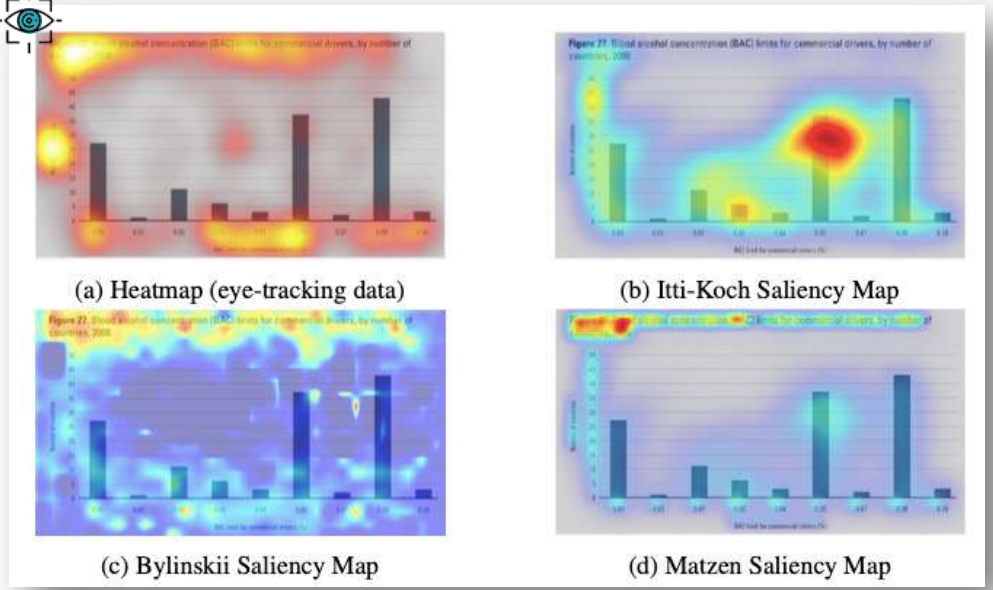
Dataset

- MASSVIS: Massachusetts (Massive) Visualization Dataset

Metrics typically used in the Saliency Prediction:

- AUC (Area Under the ROC –Receive Operating Characteristics–)
- CC (Pearson's Correlation Coefficient)
- NSS (Normalized Scanpath Saliency)





(a) Heatmap (eye-tracking data)

(b) Itti-Koch Saliency Map

(c) Bylinskii Saliency Map

(d) Matzen Saliency Map

Insights:

- The results were **consistent** with previous studies.
- Matzen model had the **highest** score of the three metrics.
- Most of the attention goes to the **textual elements**, and Matzen and Bylinskii models accurately address this.

Second Experiment

Scope

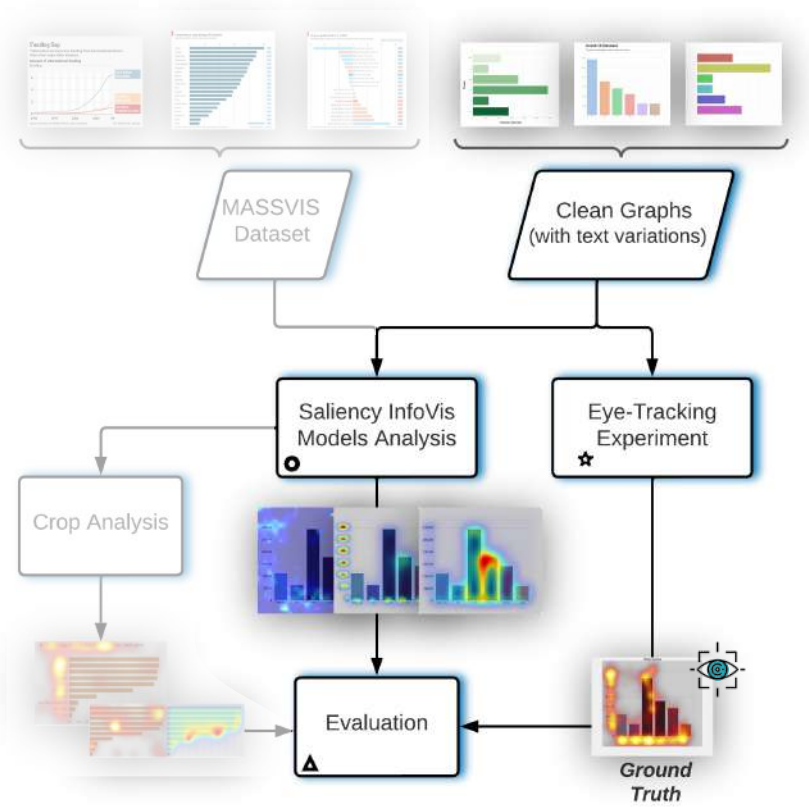
- Validate the model's performance with graphs without design elements distractions (e.g., logos, icons) and varying some design elements.

Images

- Clean Graphs dataset

Metrics for Saliency

- AUC , CC and NSS



Clean Graphs Dataset

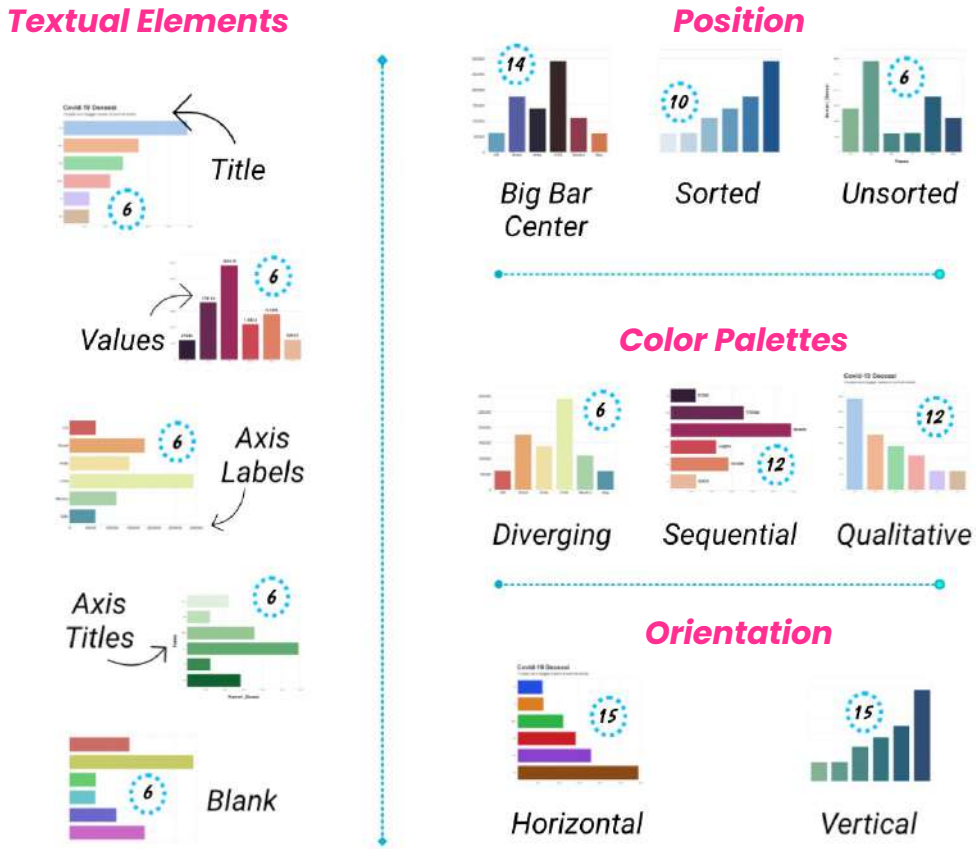
30 images

Bar Charts
DataViz Technique

Covid-19
Dataset

Position, Color, Orientation and Textual Elements.
Variations

Python
Seaborn library



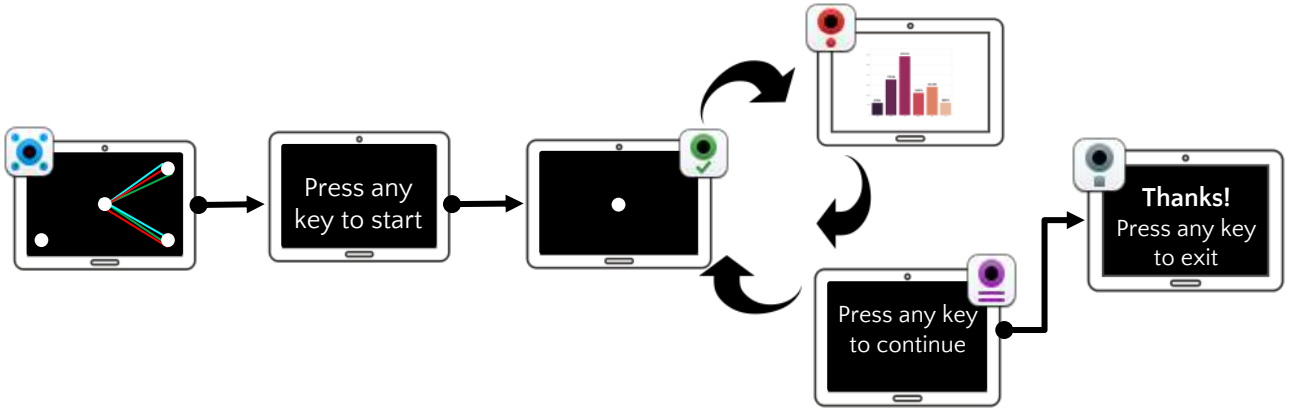
Eye-Tracking Data Acquisition

General Data

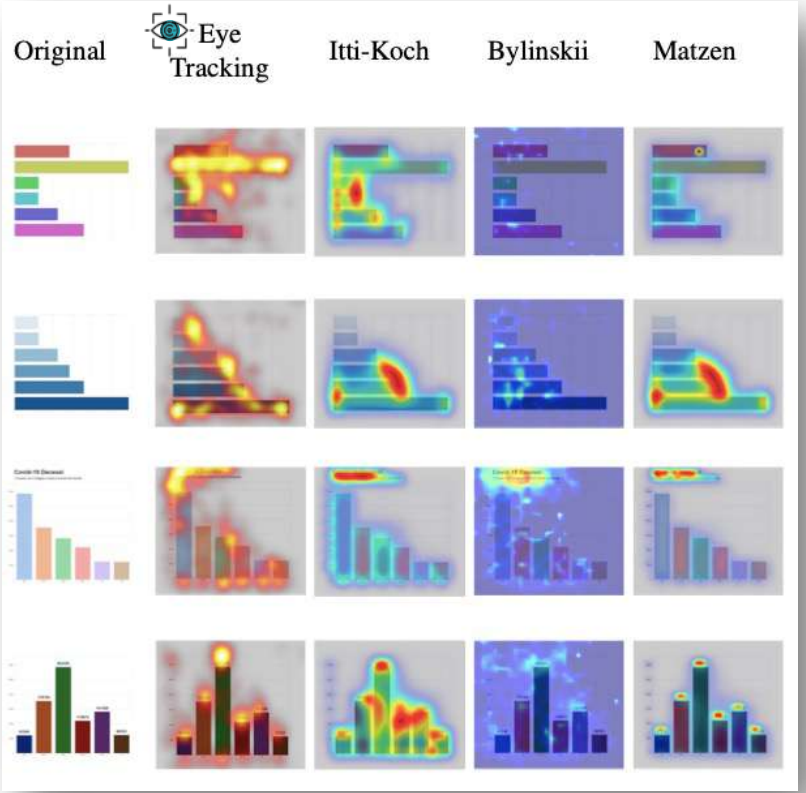
Clean Graphs Dataset

30	62	14 - 50	Exploratory	5 sec.
Images	Observers	Age rate	Visual observer task	Data recording

Data Collection Process



Example Saliency Maps



Insights

- Text is a visual component that is **highly influential**, for better or worse, in all three model's performance.
- Orientation, position and Color **influence the model's** accuracy, but less than text elements.
- Blank graph (no text), was where the models had the **lowest scores**.

Third Experiment

Scope

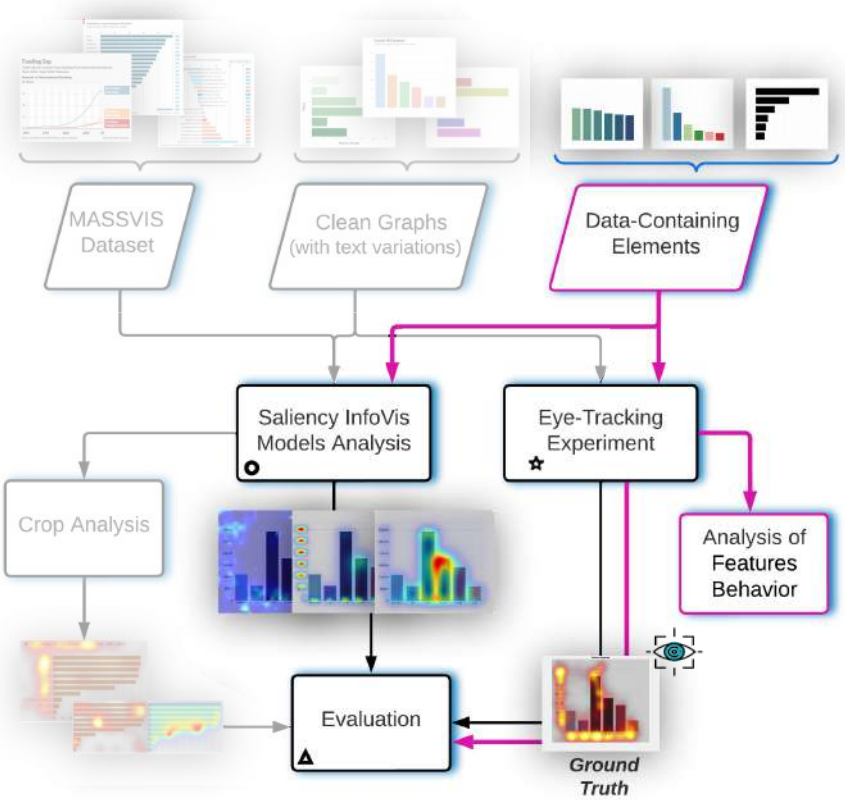
- Deepen the behavior of the models only in the elements that represent the data (no textual elements).

Images

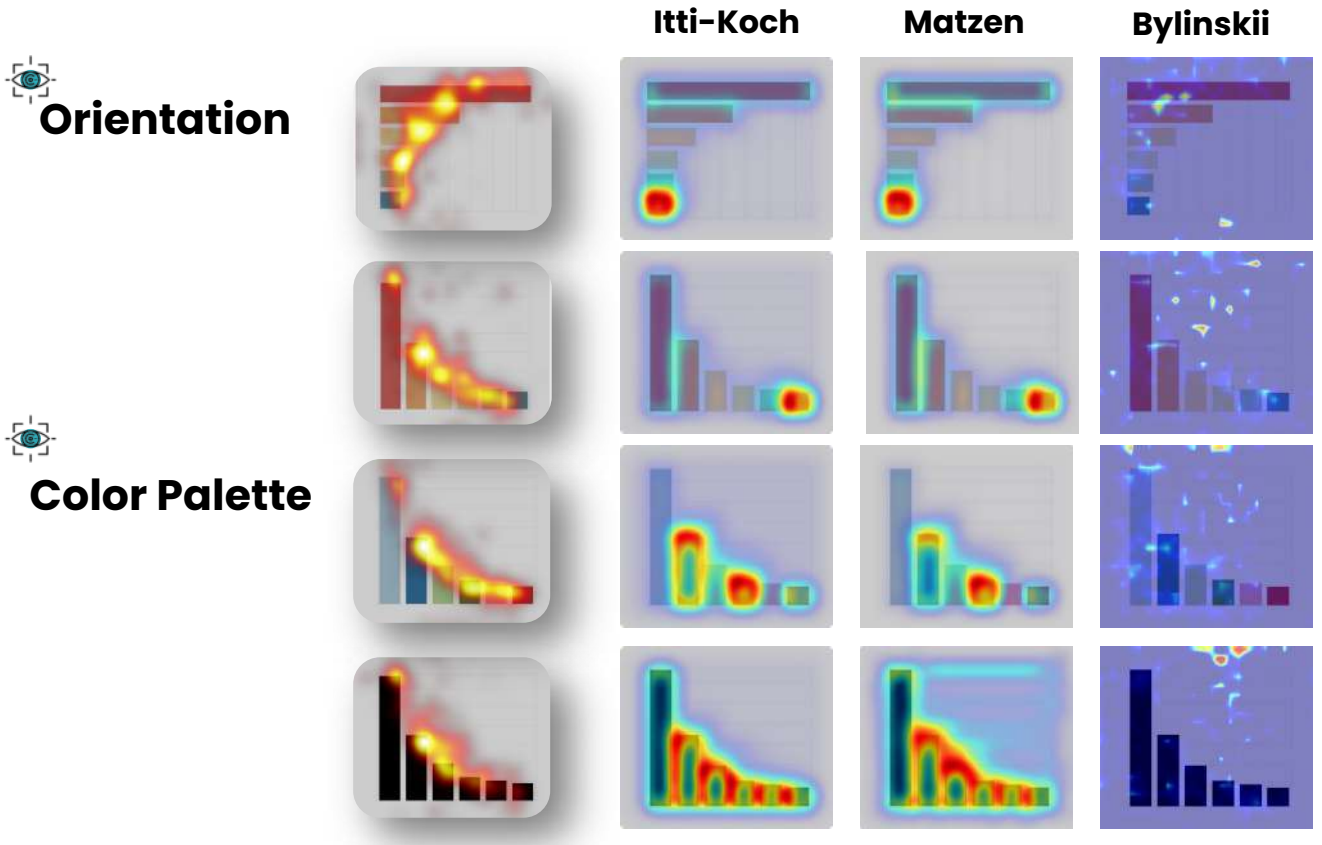
- Clean Graph (without text)

Metrics for Saliency

- AUC, CC and NSS



Third Experiment Results



Models Comparison

Model	Experiments	CC		NSS		AUC	
		t	p	t	p	t	p
Bylinskii	*MASSVIS vs. Clean Graph*	7.50	1.06e-09	5.26	2.30e-06	6.13	9.81e-08
	Clean Graph vs. Data-Contained	6.28	9.31e-08	5.94	7.44e-07	5.60	3.08e-06
Matzen	*MASSVIS vs. Clean Graph*	0.66	0.51	0.49	0.63	2.74	0.008
	Clean Graph vs. Data-Contained	0.097	0.92	0.74	0.46	-1.24	0.23
Itti-Koch	*MASSVIS vs. Clean Graph*	-1.90	0.063	-2.40	0.020	-2.70	0.01
	Clean Graph vs. Data-Contained	-3.12	0.003	-2.03	0.052	-1.05	0.30

t-test

- Bylinskii is strongly attached to the training images.
- Itti-Koch, the less context information (distractors), the better the saliency prediction.
- Matzen is the model that demonstrated the most stable behavior during the three experiments.

Research Development Process

InfoVis and Human Attention

Saliency Prediction Models

Saliency Prediction for DataViz Design Process

- Saliency as Design Tool
- Saliency as Measurement Tool
- Experts Validation

Conclusions

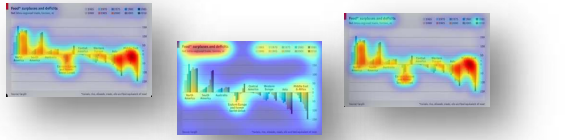
Human Sensory Capabilities in Graph Design

Sight

For Design

For Measure

Literature Review



Saliency Models for DataViz

Matzen Model

How do we integrate **saliency models** into the **DataViz design process** to support **Graph Designer** decision-making?

Development Tools

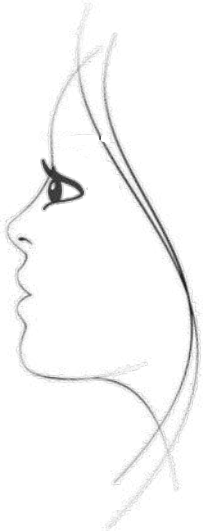
Graph Designers

Design Tool

Systematic variation of Visual Elements to highlight relevant data.

Measurement Tool

Saliency Maps into graph design commonly process to validate design decisions.



Observer

Design Tool

1. Inputs:

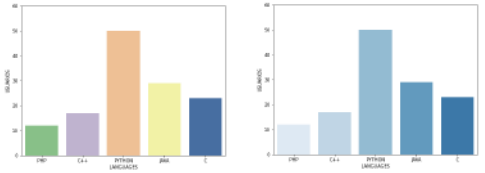
Dataset

Focus Data

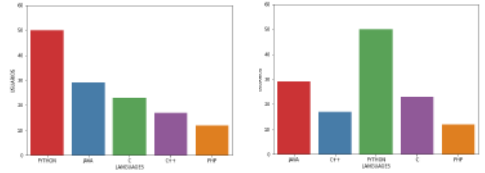
Preferred
Color Palettes

2. Systematic Variations:

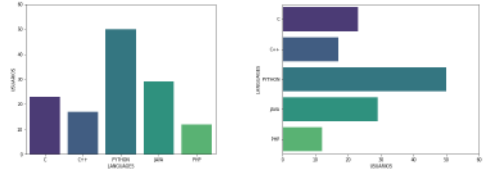
Color Palette



Data Position

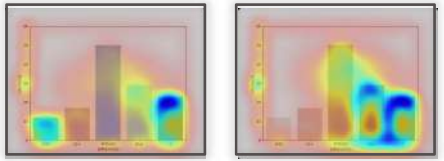


Data Orientation

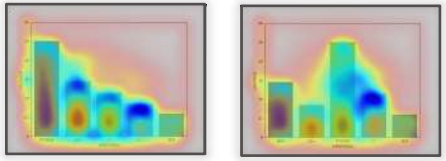


3. Saliency Map Generation:

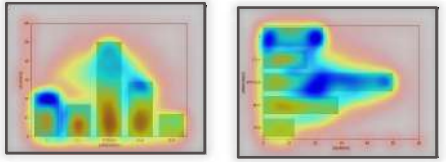
Color Palette



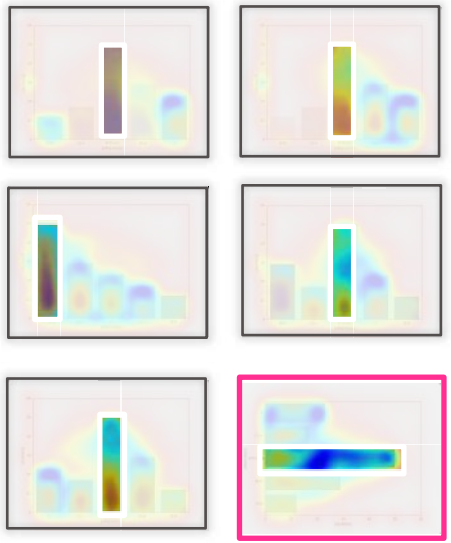
Data Position



Data Orientation

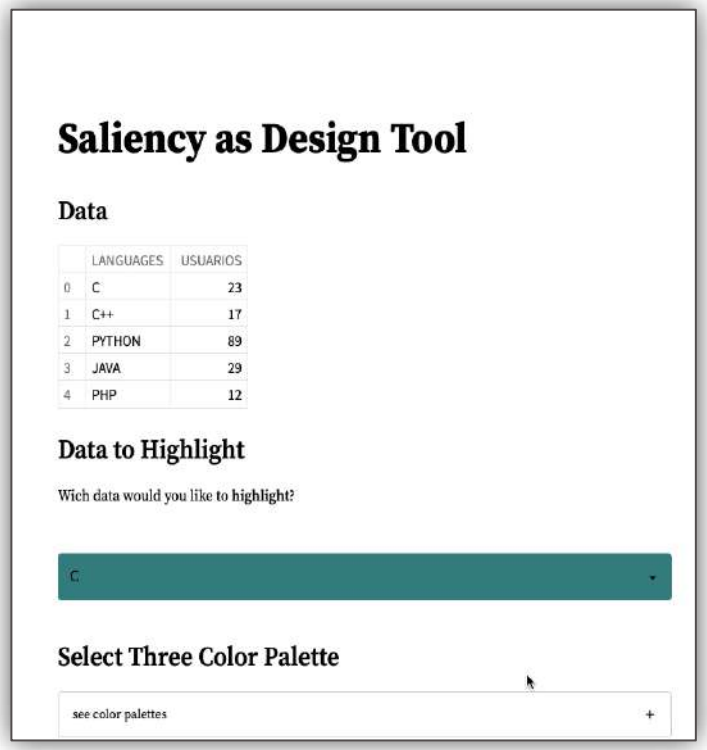


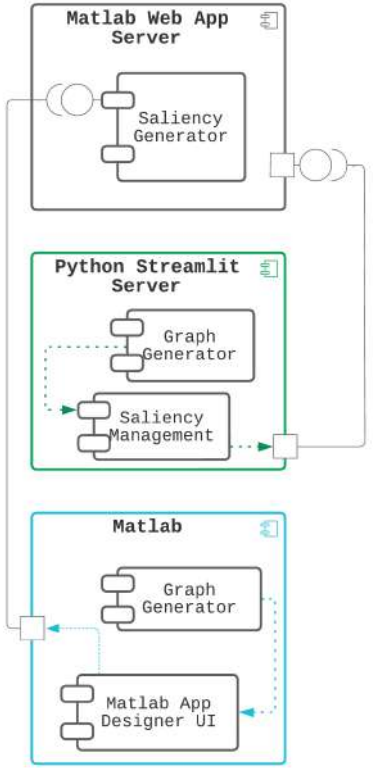
3. Graph Selection



Winner

4. Show Results





Components Diagram

Development Tools

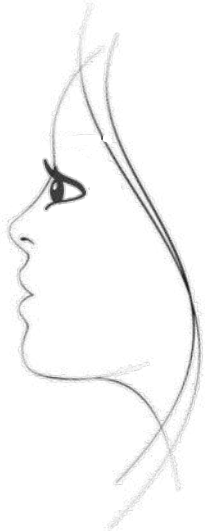
Graph Designers

Design Tool

Systematic variation of Visual Elements to highlight relevant data.

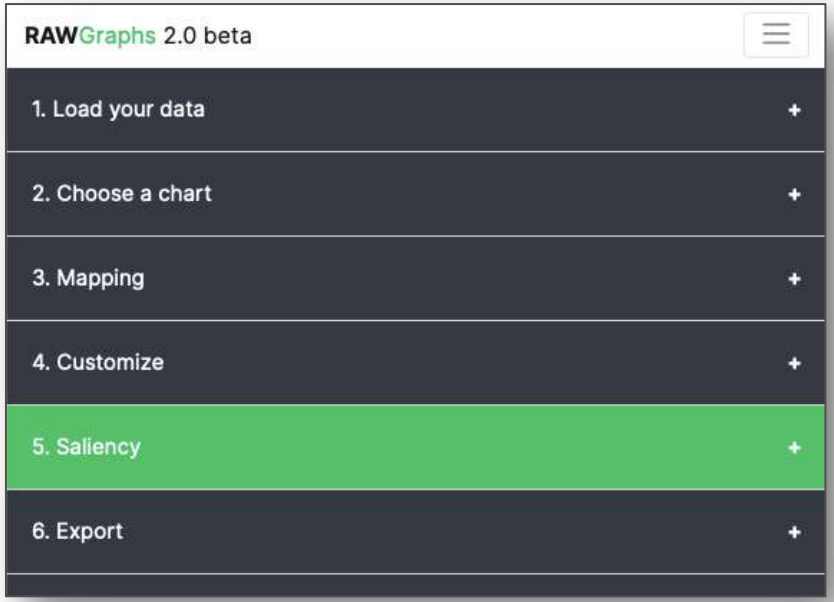
Measurement Tool

Saliency Maps into graph design common process to validate design decisions.



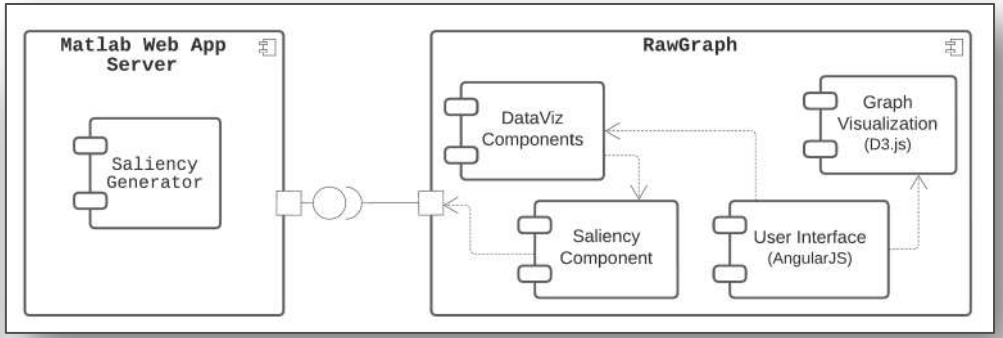
Observer

Measurement Tool



New Function

Components Diagram

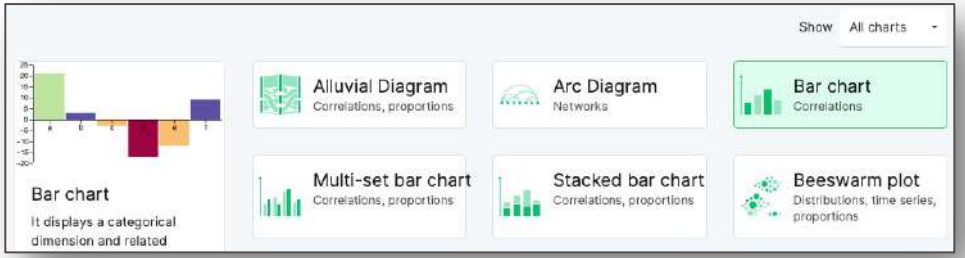


Measurement Tool

1. Input

Dataset

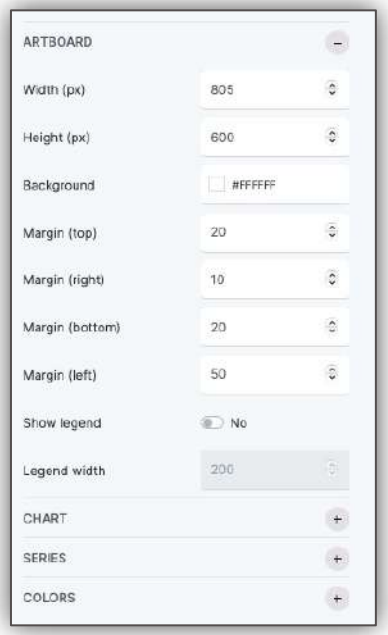
2. Graph Selection



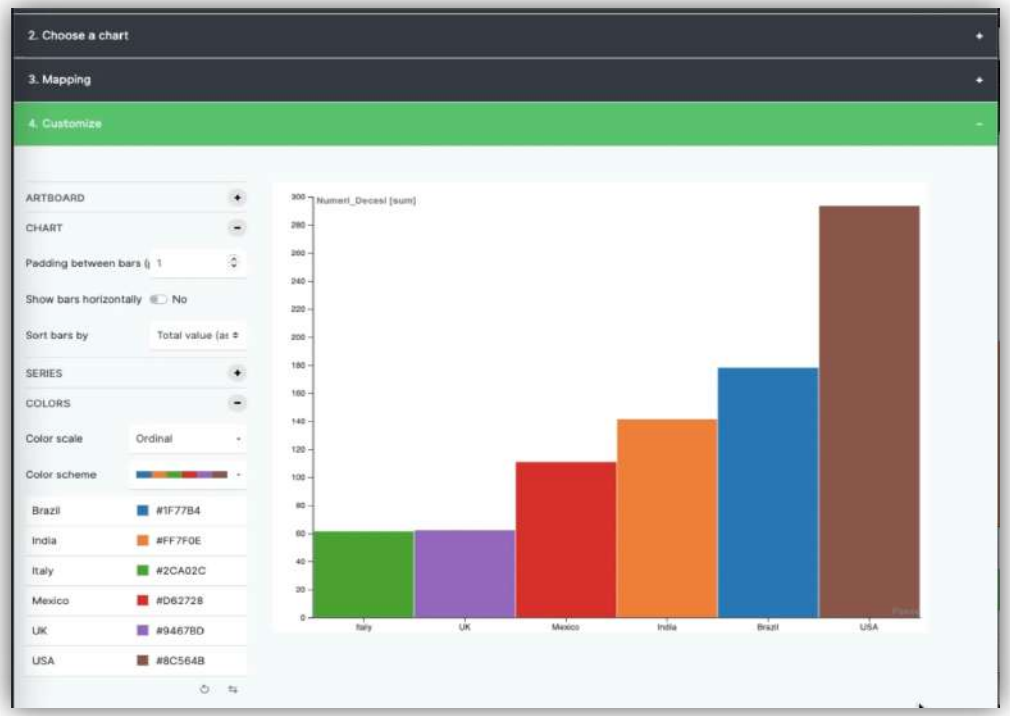
3. Mapping

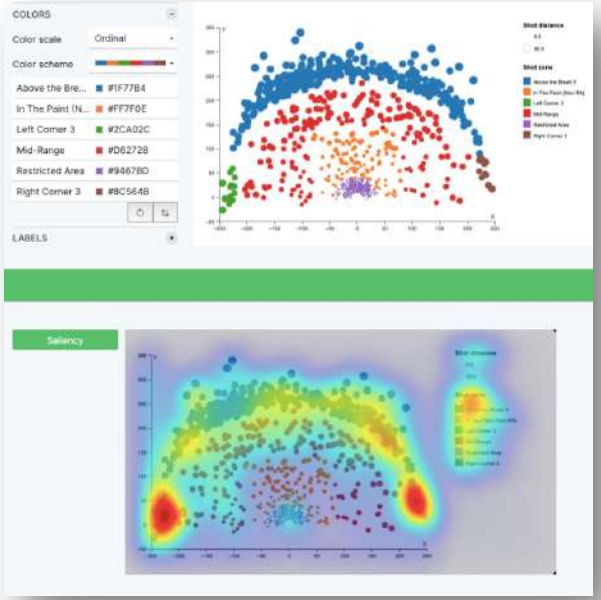
Measurement Tool

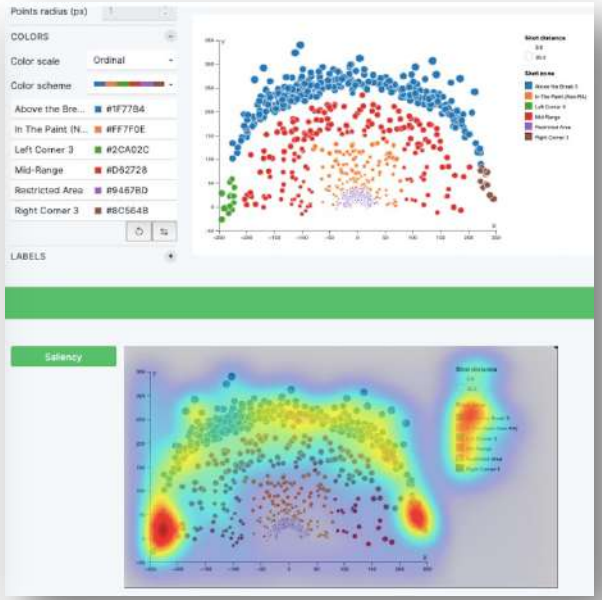
4. Customize



5. Saliency Map Generation




COLORS
Color scale
Ordinal
Color scheme
Above the Bre...
#1F77B4
In The Paint (N...
#FF7F0E
Left Corner 3
#2CA02C
Mid-Range
#D62728
Restricted Area
#9467BD
Right Corner 3
#8C564B
LABELS
Saliency


Points radius (px)
COLORS
Color scale
Ordinal
Color scheme
Above the Bre...
#1F77B4
In The Paint (N...
#FF7F0E
Left Corner 3
#2CA02C
Mid-Range
#D62728
Restricted Area
#9467BD
Right Corner 3
#8C564B
LABELS
Saliency


Points radius (px)
COLORS
Color scale
Ordinal
Color scheme
Above the Bre...
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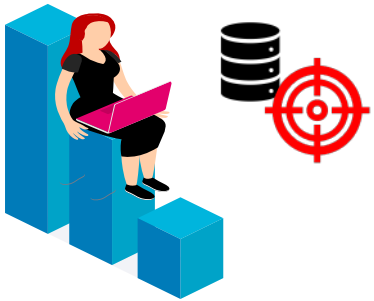
#FF7F0E
Left Corner 3
#2CA02C
Mid-Range
#D62728
Restricted Area
#9467BD
Right Corner 3
#8C564B
LABELS
Saliency

Examples

Development Tools



Graph Designers

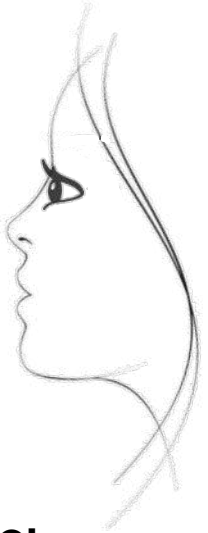
Experts Validation

Design Tool

Systematic variation of Visual Elements to highlight relevant data.

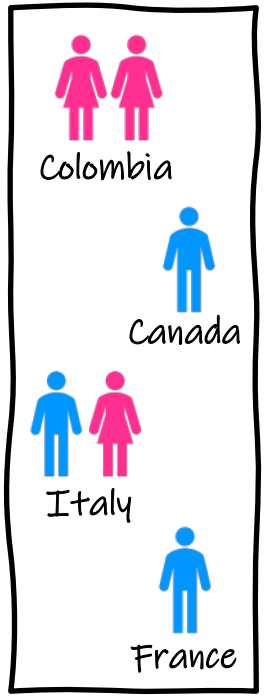
Measurement Tool

Saliency Maps into graph design commonly process to validate design decisions.



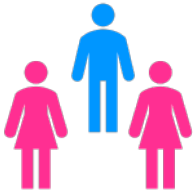
Observer

Experts Profiles



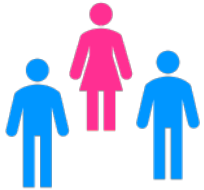
6
Experts

30 – 45
Age Range



ACADEMIA

- Higher Education/Research Information Visualization, HCI
- Computational Biology
- Informatics



INDUSTRY

- Data Visualization Expert
- Software Development/Data Visualization
- Project Manager in Business Intelligence

Evaluation Protocol

Design Tool

1. Open Questions (relevant data highlighting)

2. Tool Demo (both versions)

3. Evaluation using Heuristics instruments:

- **USE** (Usefulness, Satisfaction, and Ease of use)
- **QUIS** (Questionnaire for User Interface Satisfaction)

Measurement Tool

1. Open Questions (area attention detection)

2. Tool Demo

3. Evaluation using Heuristics instrument:

- **TAM** (Perceived Usefulness and Ease of Use)

Experts Evaluation - Discussion

- ” Tools with much **potential** and would be very useful”
- Attention behavior (patterns) could be **learned** if the tools are used for an extended period.
- The second benefit is expert-oriented since there may be an acquired data **visualization bias** over time

- Measurement Tool should provide **more information** about saliency
- Extend Design Tool with **other visualization** types.

*Results demonstrated that both tools are a **relevant** and **valuable** approaches.*

Research Development Process

InfoVis and Human Attention

Saliency Prediction Models

Saliency Prediction for DataViz Design Process

Conclusions

- Contributions
- Future Works

Contributions

Matzen

Saliency Prediction Models

Literature Review

Design and Measurement

Integrate visual-cognitive concepts into the Data Visualization Design Process and tools. We intend to bring those concepts to the graph designer's context and provide insights into how her design choices might affect the observer's perception.

Consciousness about visual impact.

Oblivion in research

Measurement Tool.

Design Tool

" Tools with much potential and would be very useful"

Future Works

More observation Tasks

1. Improve saliency Prediction Models

Local Saliency for data-contained elements

Graph profile

2. Extend graph types

3. Saliency Details for graph designer

Saliency percentage per by zones

Thanks!

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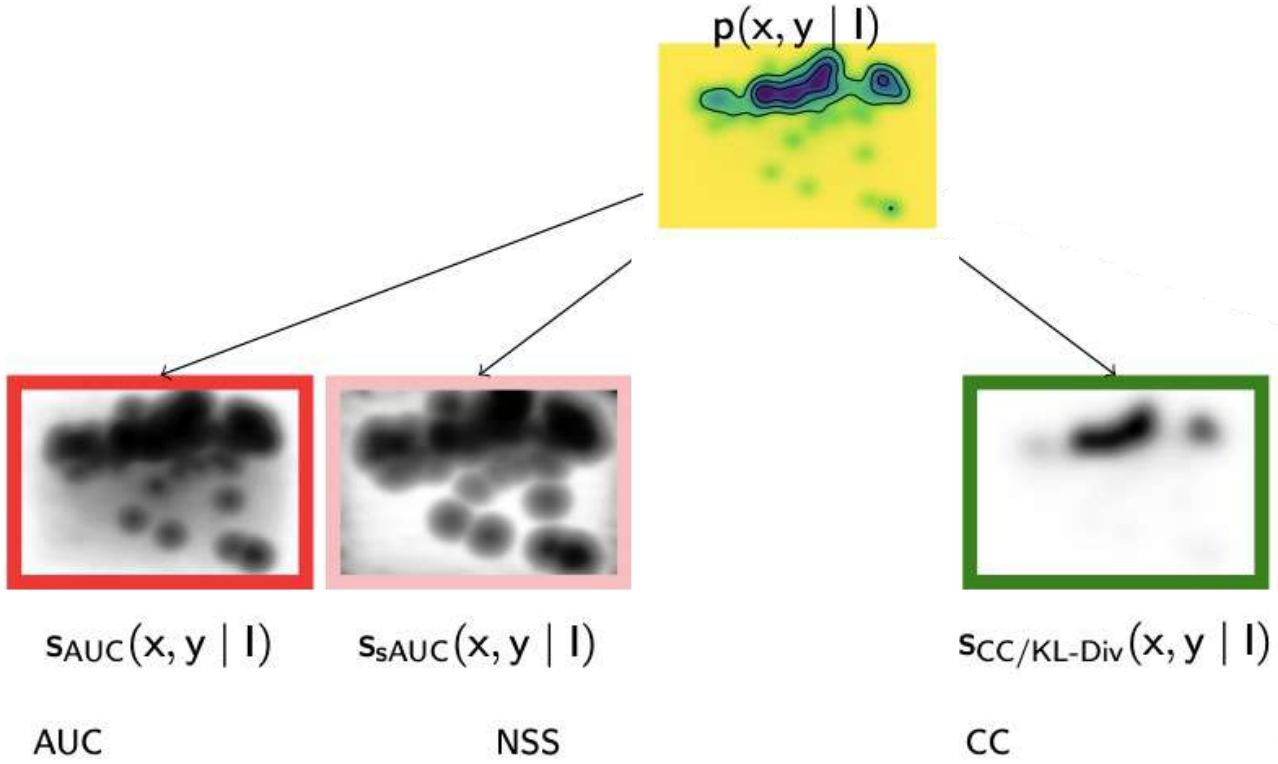
Fulvio Corno
Advisor

fulvio.corno@polito.it

Supplemental Material

Feature Integration Model
Evaluation Metrics

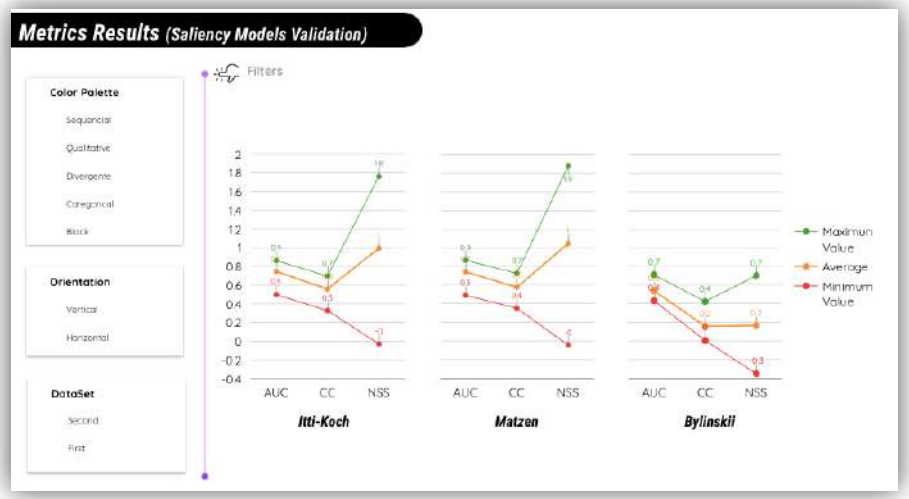
Metrics



Dashboards

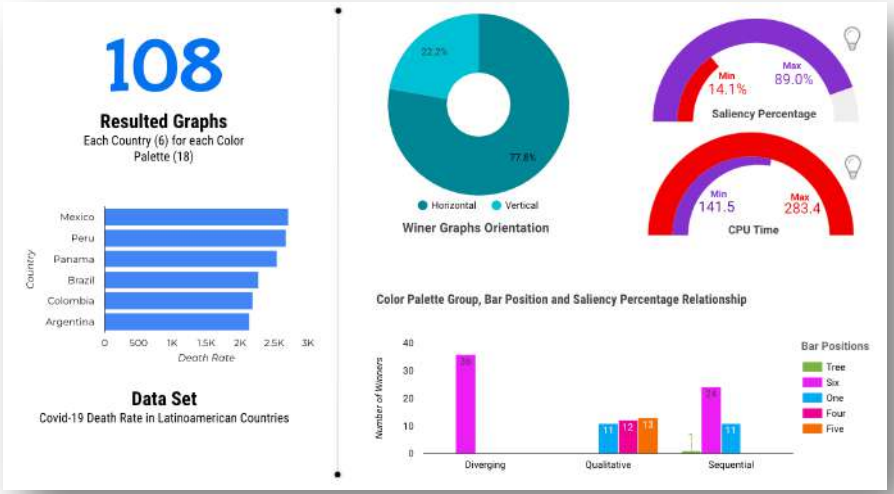
https://bit.ly/2sdExpe_Dashboard

https://bit.ly/data-elements_results



Design Tool - tests

https://bit.ly/DesignTool_CovidResutls



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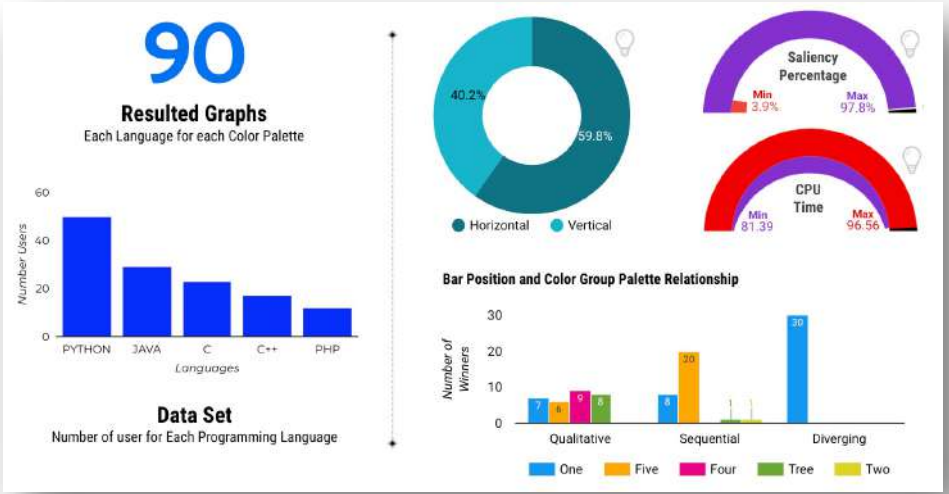


Usability Heuristics

Design Tool

3. Evaluation using Heuristics instruments:

- **USE** (Usefulness, Satisfaction, and Ease of use): measures the subjective usability of a product or service. Questions: Perceived Usefulness, Perceived Easy to Use, and Perceived Satisfaction.

- **QUIS** (Questionnaire for User Interface Satisfaction): focuses on how an interface is evaluated, and it was created based on Shneiderman's list of five different types of dependent measures. Questions: Overall Reaction to the Software.

Measurement Tool

3. Evaluation using Heuristics instrument:

- **TAM** (Perceived Usefulness and Ease of Use): the model intends to forecast the future use of a product (expected usefulness and ease-of-use as viewed before any use) rather than to rate the actual user experience.

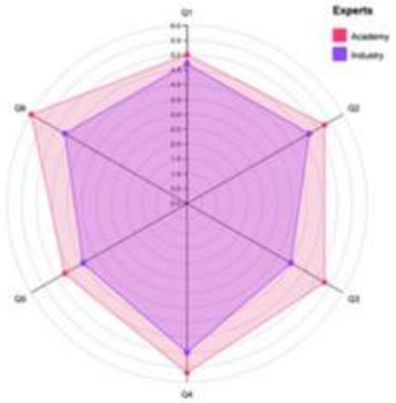
Experts Validation - Results

Table 8.2 QUIS Academia Experts

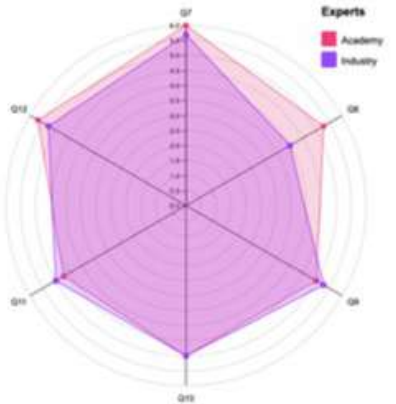
Scale	Average Rating	Median Score
Terrible *0* ... *9* Wonderful	8,3	8,0
Difficult 0 ... 9 Easy	7,3	7,0
Frustrating 0 ... 9 Satisfying	8,3	8,0
Inadequate 0 ... 9 Adequate	7	8,0
Dull 0 ... 9 Stimulating	7,7	9,0
Rigid 0 ... 9 Flexible	5,3	8,0

Table 8.3 QUIS Industrial Experts results for Design Tool validation

Scale	Average Rating	Median Score
Terrible 0 ... 9 Wonderful	7,3	8
Difficult 0 ... 9 Easy	6	7
Frustrating 0 ... 9 Satisfying	6,3	8
Inadequate 0 ... 9 Adequate	6,3	8
Dull 0 ... 9 Stimulating	7	9
Rigid 0 ... 9 Flexible	7,3	8



(a) TAM Perceived Usefulness (PU)



(b) TAM Perceived Ease of Use (PEU)