Looks Good To Me: Visualizations As Sanity Checks

Michael Correll
Mingwei Li
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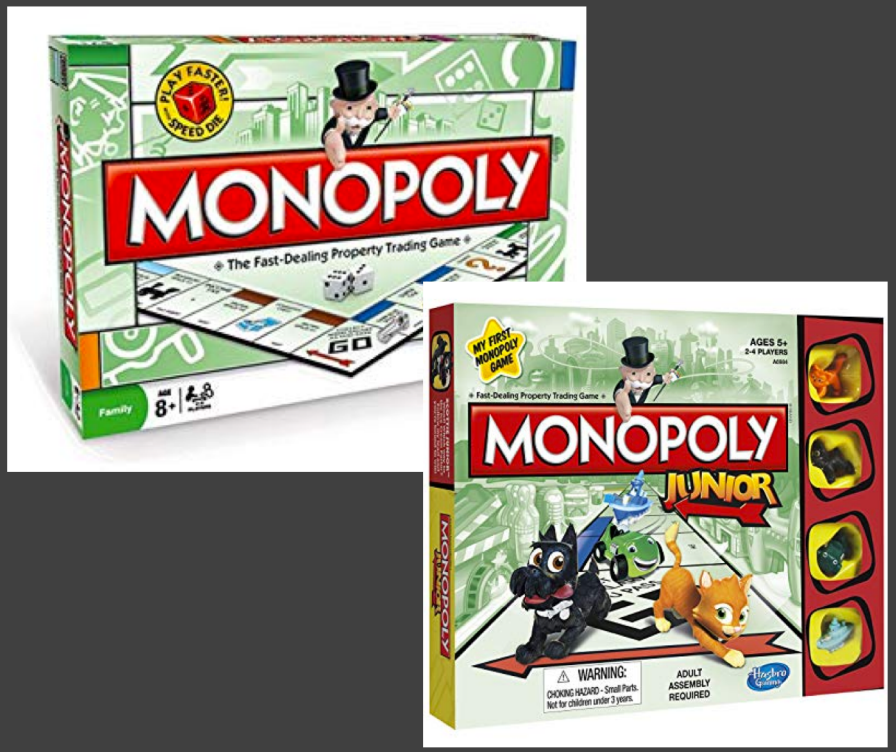
Research Questions

Do data quality issues we care about have **characteristic visual patterns** in our visualizations?

Are these characteristic patterns **robustly detectable** across design parameters?

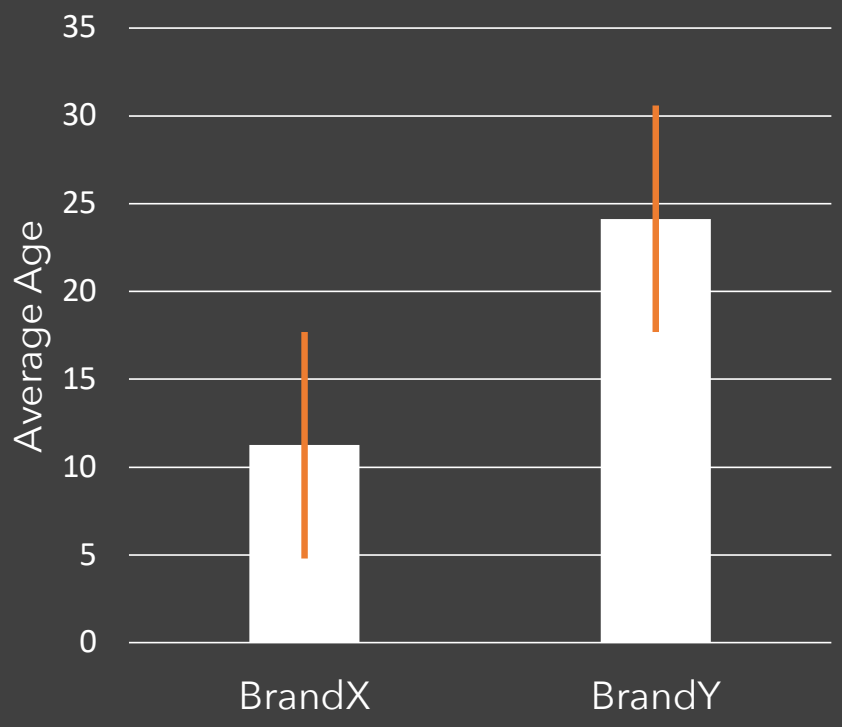
The Focus Test



We recruited 100 children. We gave each child toys from both Brands X and Y. We then asked which brand they preferred.

Does **age** have an affect on **brand preference**?

The Focus Test



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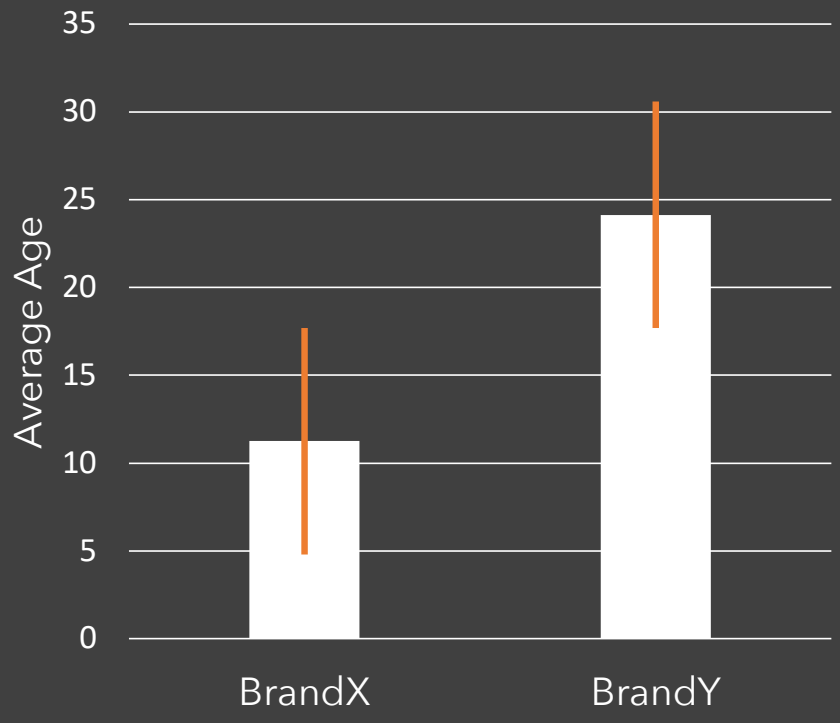
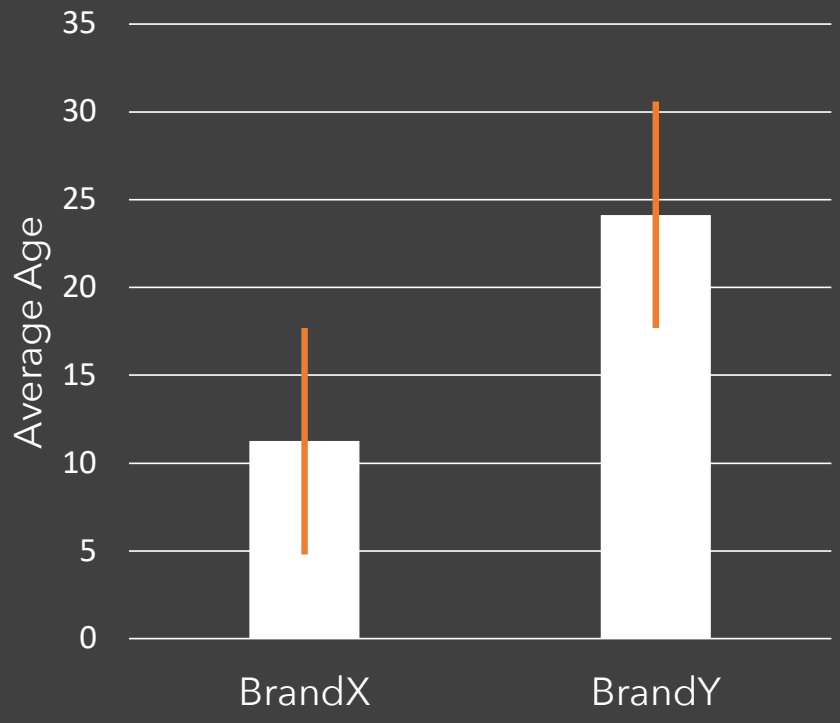
Distribution of Age



Age	Prefers
99	BrandX
99	BrandX
99	BrandY
99	BrandY
99	BrandY
99	BrandY
99	BrandY
99	BrandY
99	BrandY
16	BrandX
4	BrandX
10	BrandX
16	BrandX
10	BrandY



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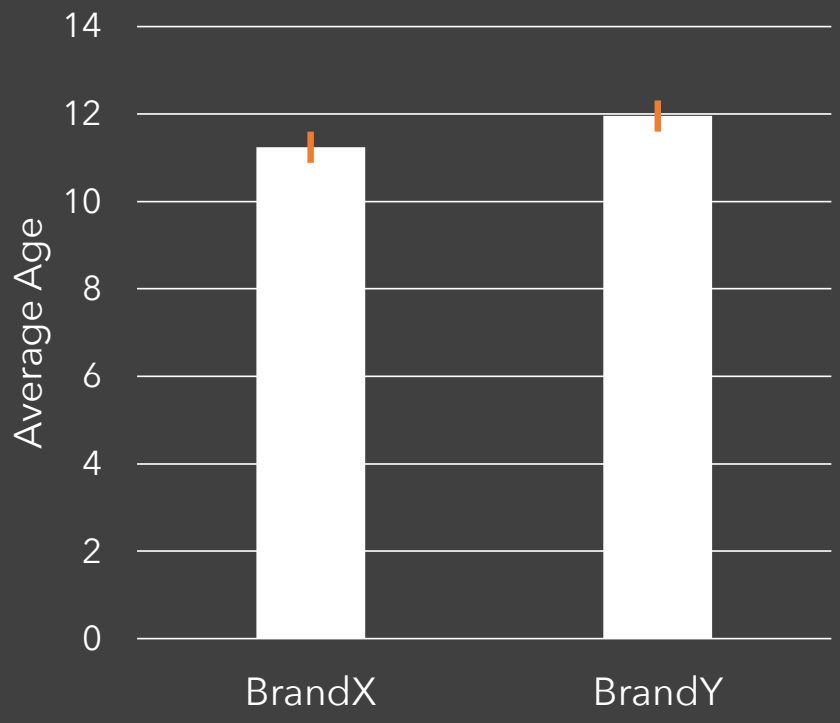
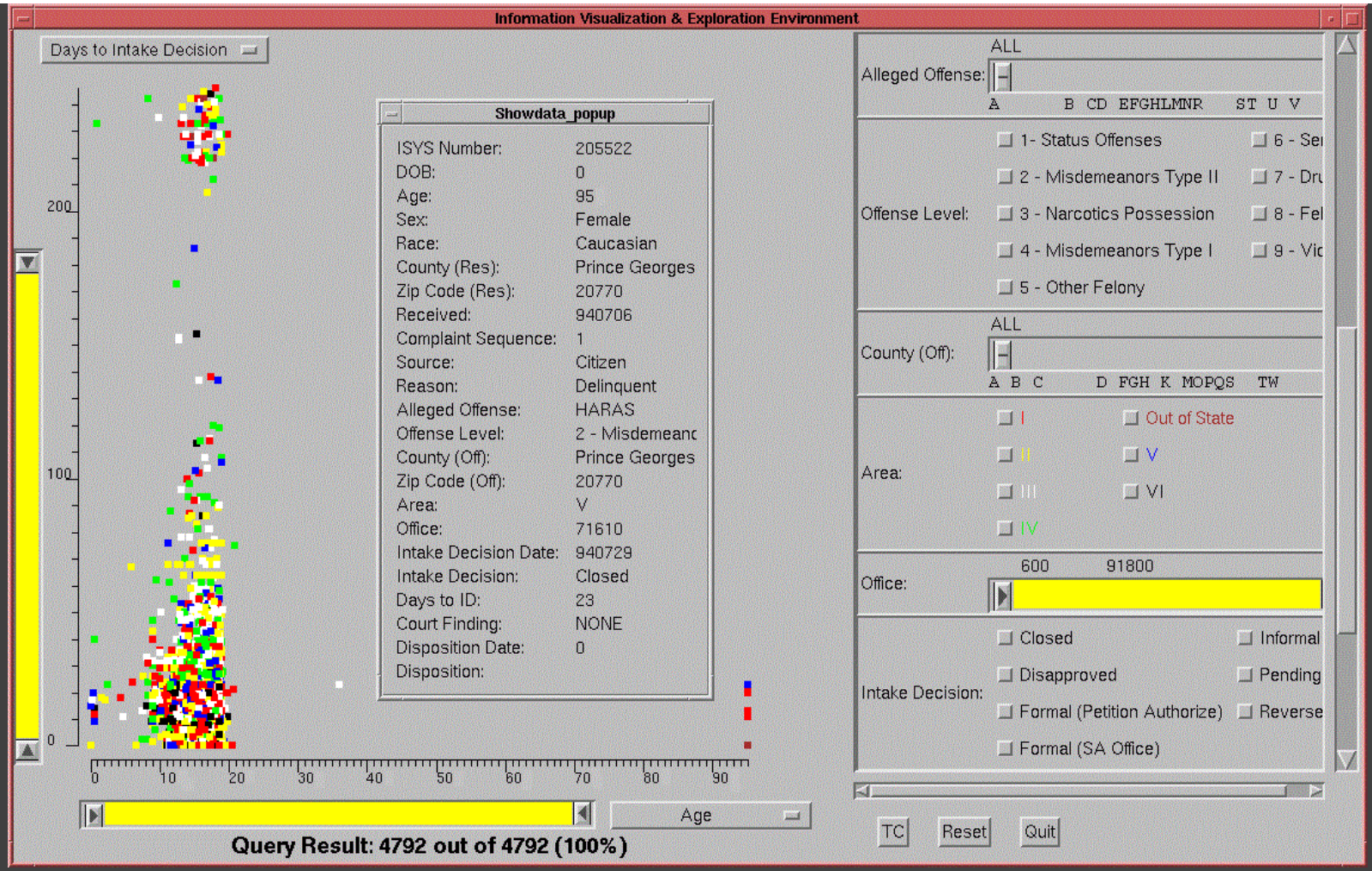
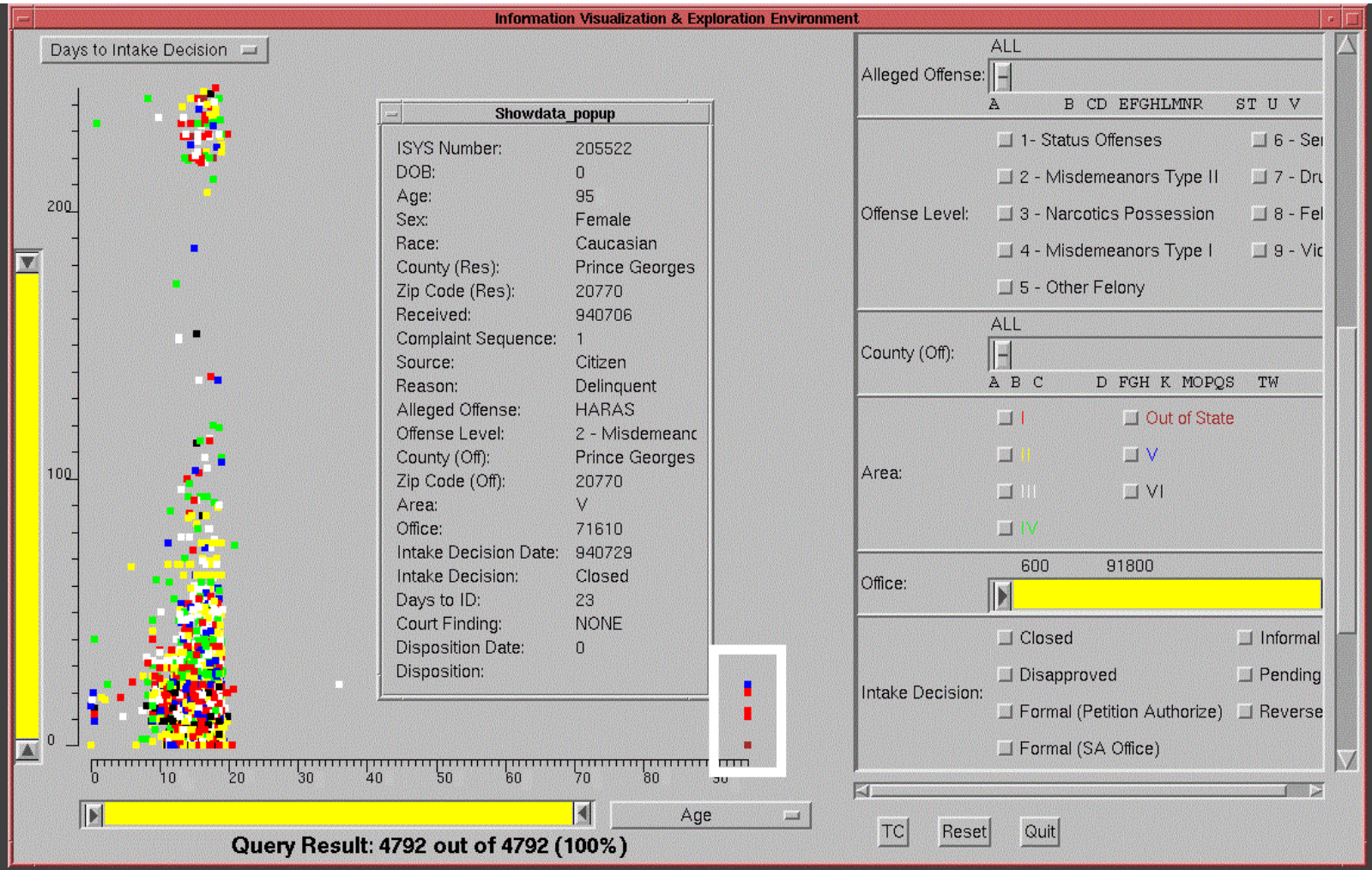
99	BrandY
16	BrandX
4	BrandX
10	BrandX
16	BrandX
10	BrandY


14
12
10
8
6
4
2
0
Average Age
BrandX
BrandY


Information Visualization & Exploration Environment
Days to Intake Decision
Showdata_popup
ISYS Number: 205522
DOB: 0
Age: 95
Sex: Female
Race: Caucasian
County (Res): Prince Georges
Zip Code (Res): 20770
Received: 940706
Complaint Sequence: 1
Source: Citizen
Reason: Delinquent
Alleged Offense: HARAS
Offense Level: 2 - Misdemeanc
County (Off): Prince Georges
Zip Code (Off): 20770
Area: V
Office: 71610
Intake Decision Date: 940729
Intake Decision: Closed
Days to ID: 23
Court Finding: NONE
Disposition Date: 0
Disposition:
200
100
0
0 10 20 30 40 50 60 70 80 90
Age
Query Result: 4792 out of 4792 (100%)
Alleged Offense:
ALL
A B CD EFGHLMNR ST U V
Offense Level:
1- Status Offenses
2 - Misdemeanors Type II
3 - Narcotics Possession
4 - Misdemeanors Type I
5 - Other Felony
6 - Se
7 - Dru
8 - Fel
9 - Vic
County (Off):
ALL
A B C D FGH K MOPQS TW
Area:
I
II
III
IV
Out of State
V
VI
Office:
600 91800
Intake Decision:
Closed
Disapproved
Formal (Petition Authorize)
Formal (SA Office)
Informal
Pending
Reverse
TC
Reset
Quit

[Plaisant96]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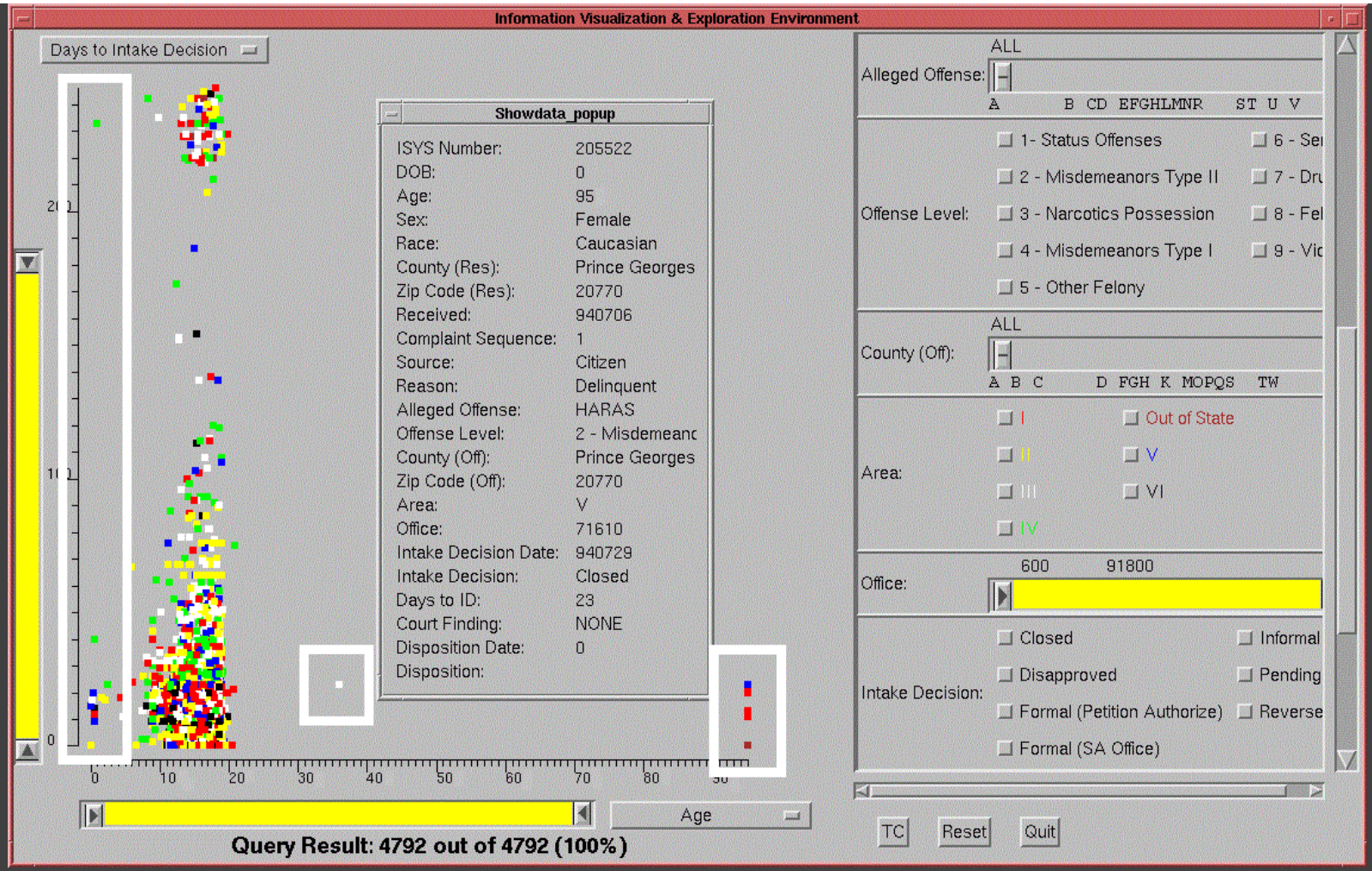
[Plaisant96]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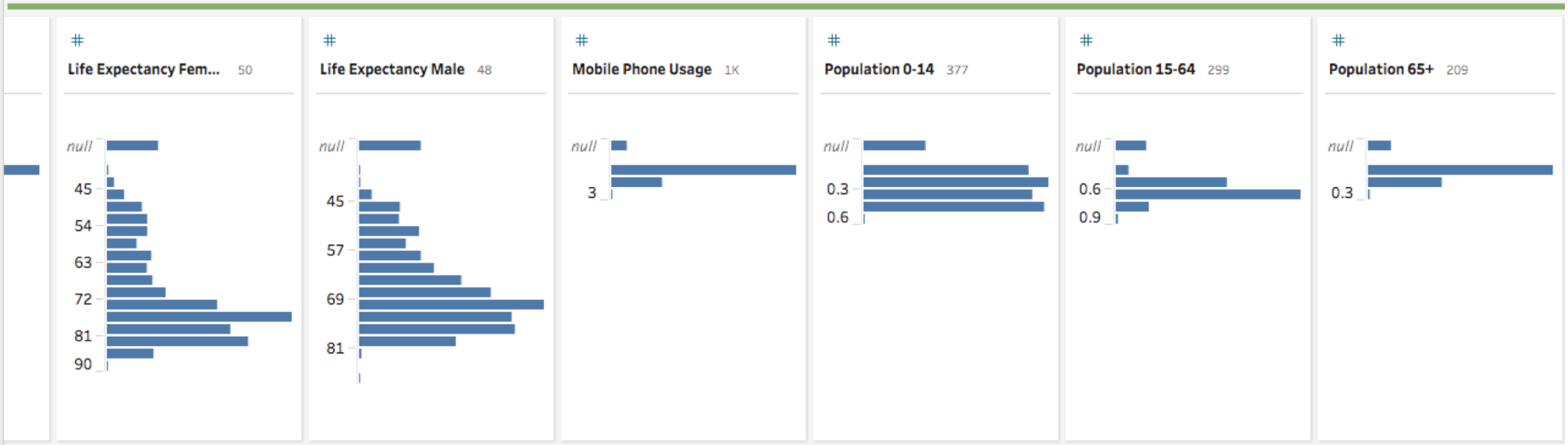
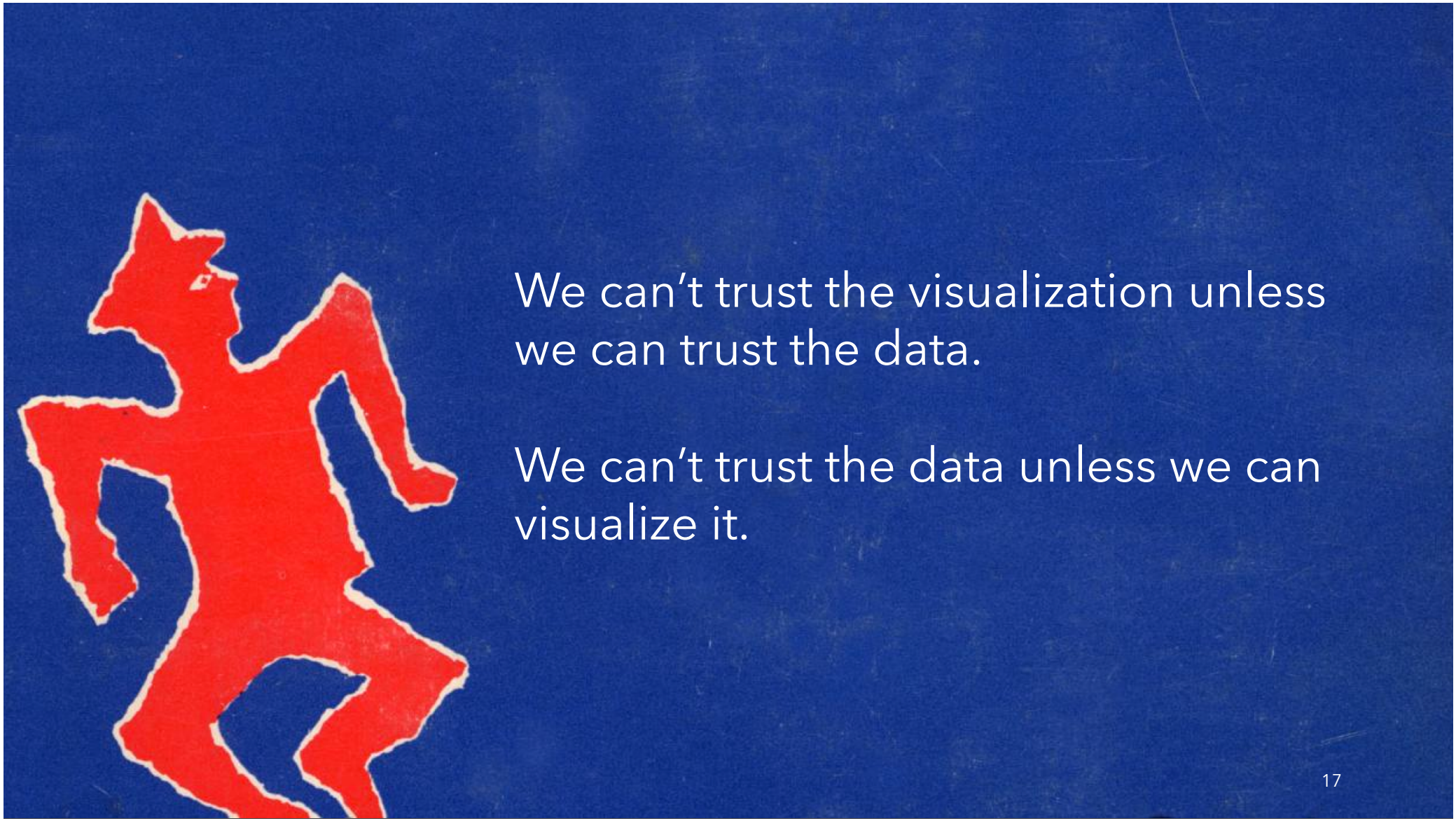
[Plaisant96]

Field Clean Up 27 Fields 3K Rows | Filter Values... | Create Calculated Field... | Search

Changes (5)



CPI	Year	Country	Birth Rate	Business Tax Rate	CO2 Emissions	Ease of Business (clusters)	Ease of Business	Energy Usage	GDP
null	*null*	*null*	0.02	*null*	87,931	Low	*null*	26,998	54,790,058,957


We can’t trust the visualization unless we can trust the data.
We can’t trust the data unless we can visualize it.

Research Question

Do data quality issues we care about have **characteristic visual patterns** in our visualizations?

Are these characteristic patterns **robustly detectable** across design parameters?

Outline

Framework

Study

Outline

Framework

Study

Algebraic Vis

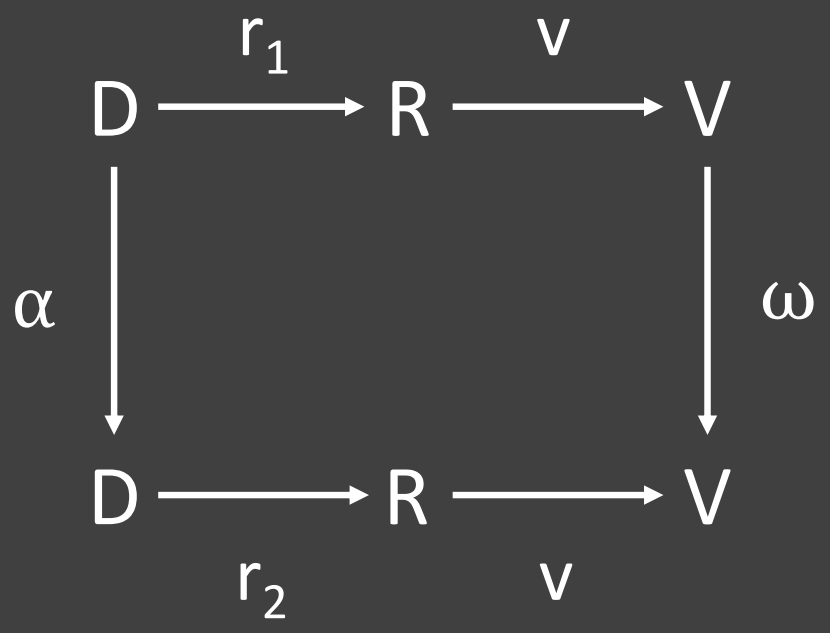
http://algebraicvis.net/

[Kindlmann14]

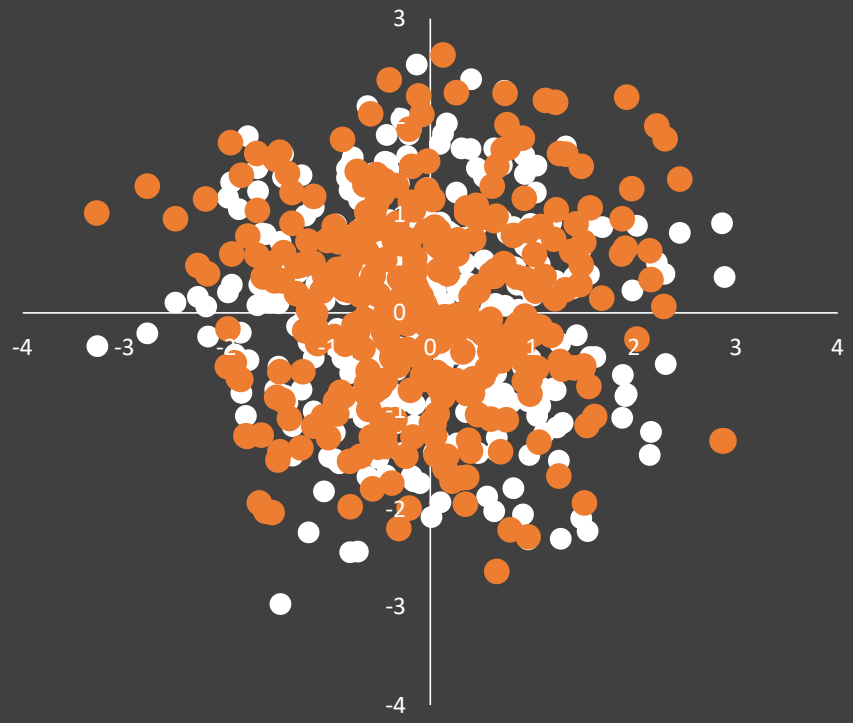
Commutative Diagram

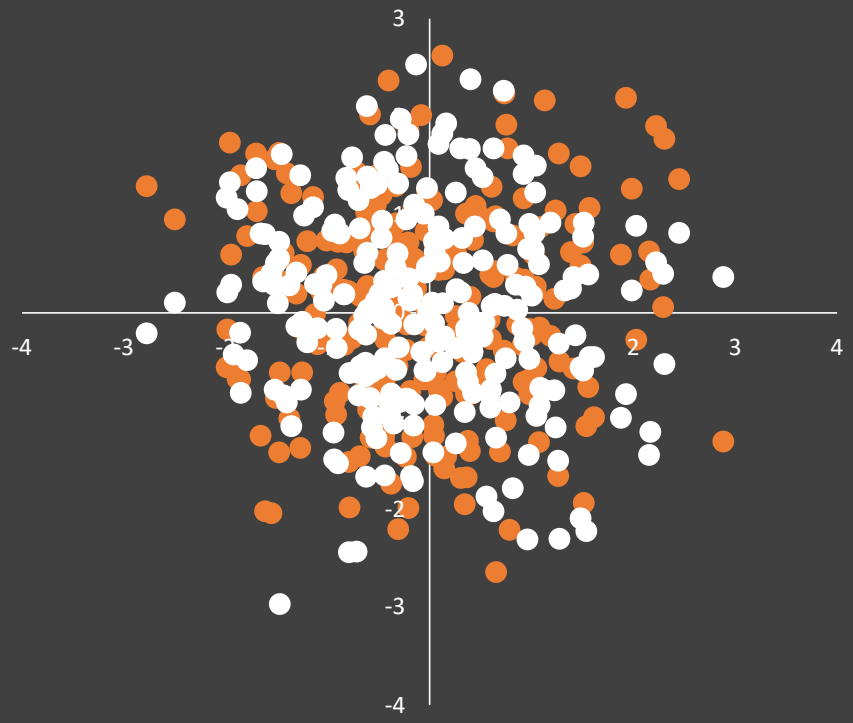
Data: D
Data Representations: R
Visualizations: V
α: data operation
ω: design operation

We want stuff to *commute*.



Algebraic Violations: Different Vizzes!





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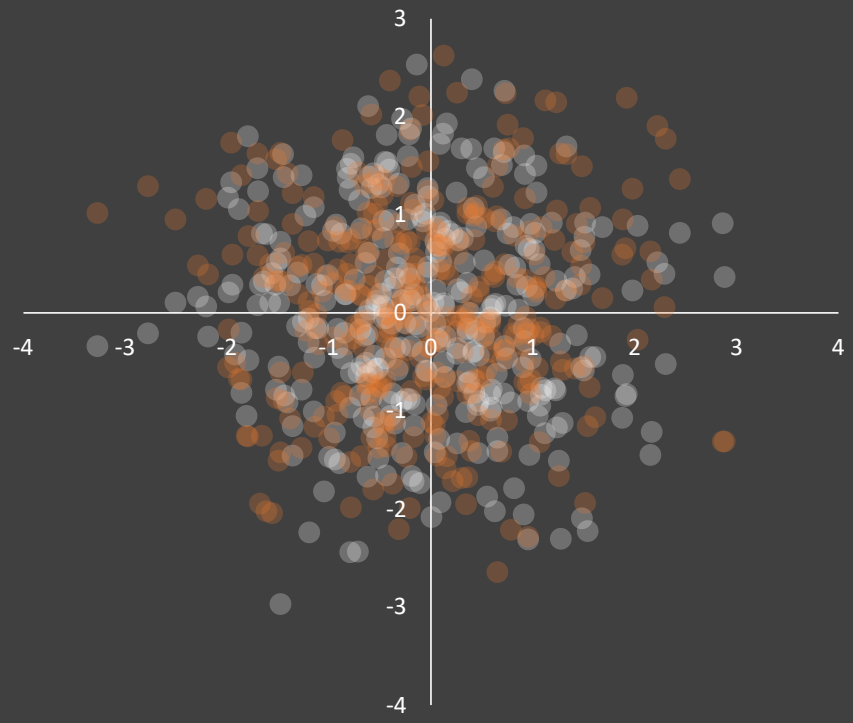
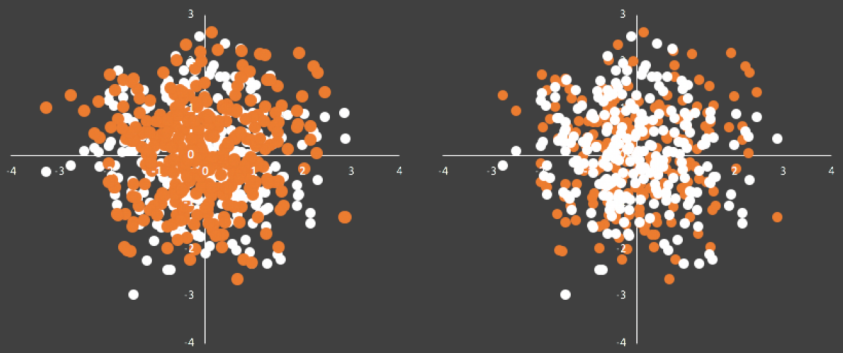


Algebraic Violations

Hallucinator



A **difference** in the **visualization** should only occur when there's a **difference** in the **data**.

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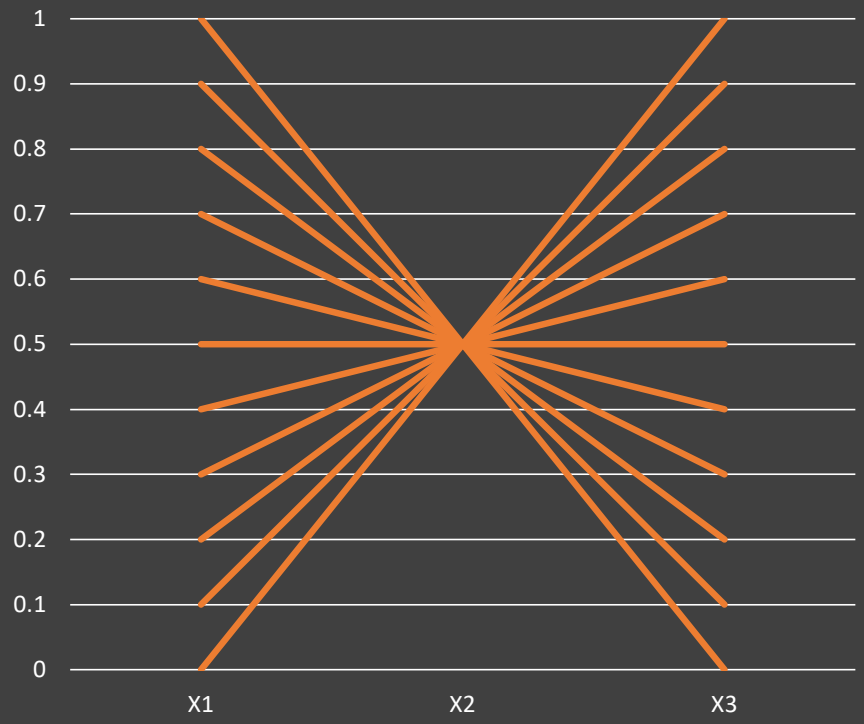

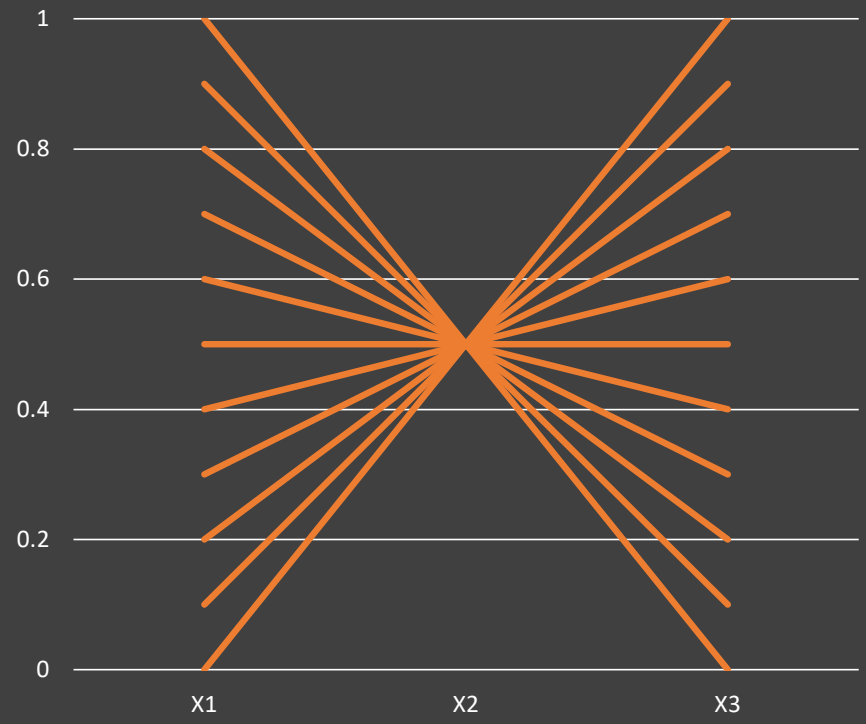

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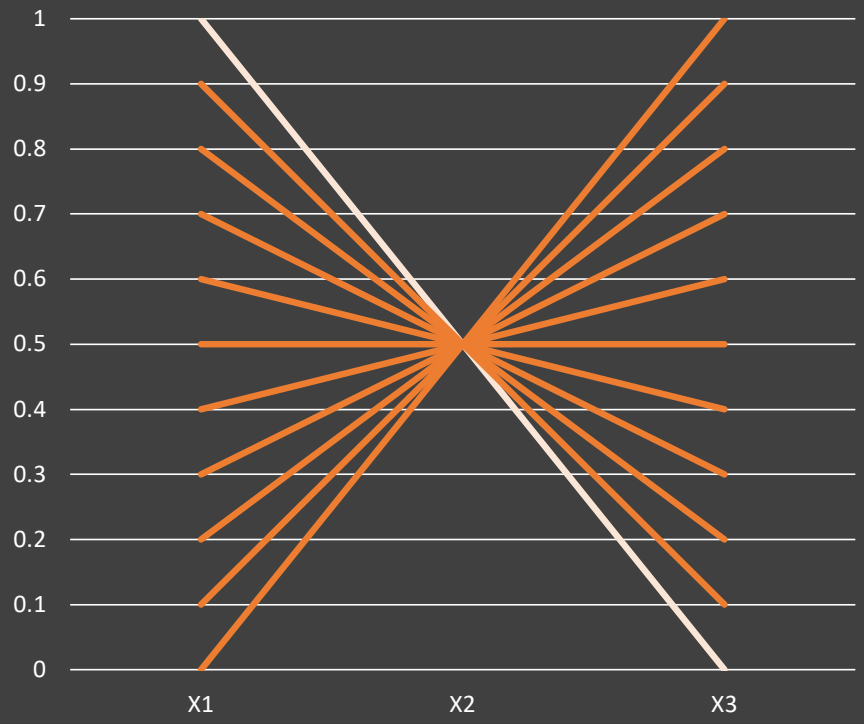

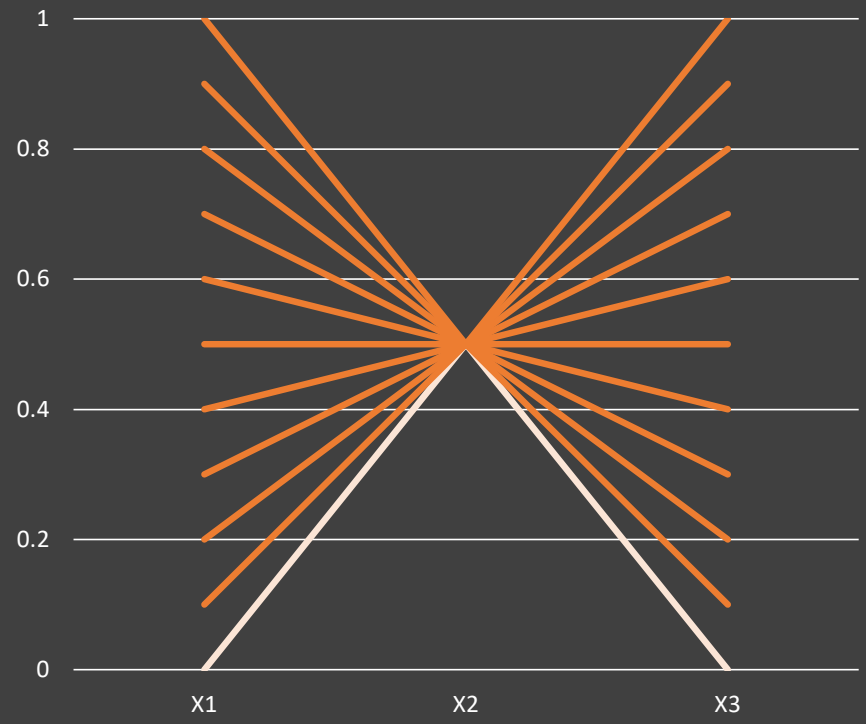

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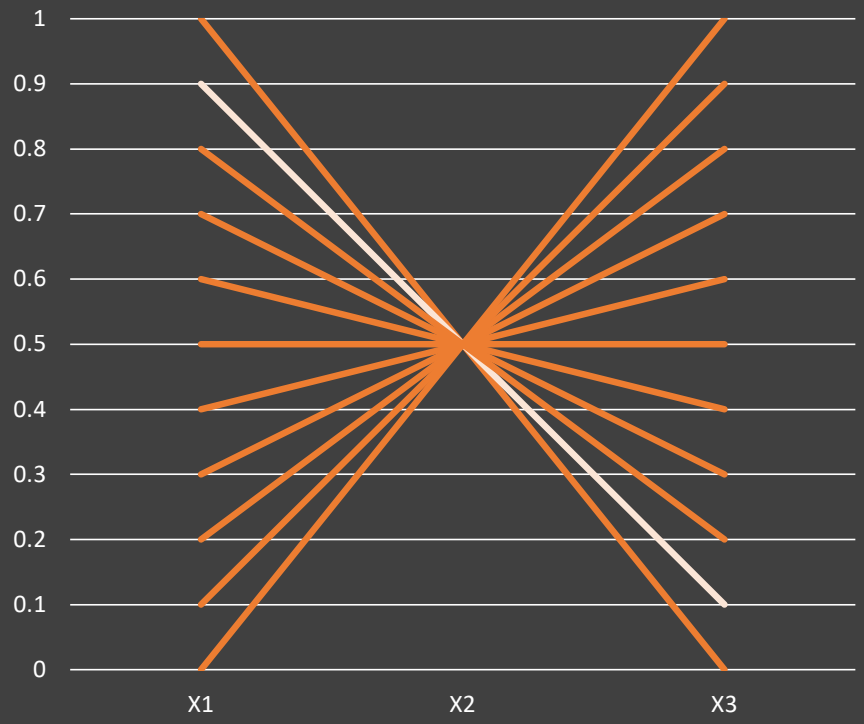

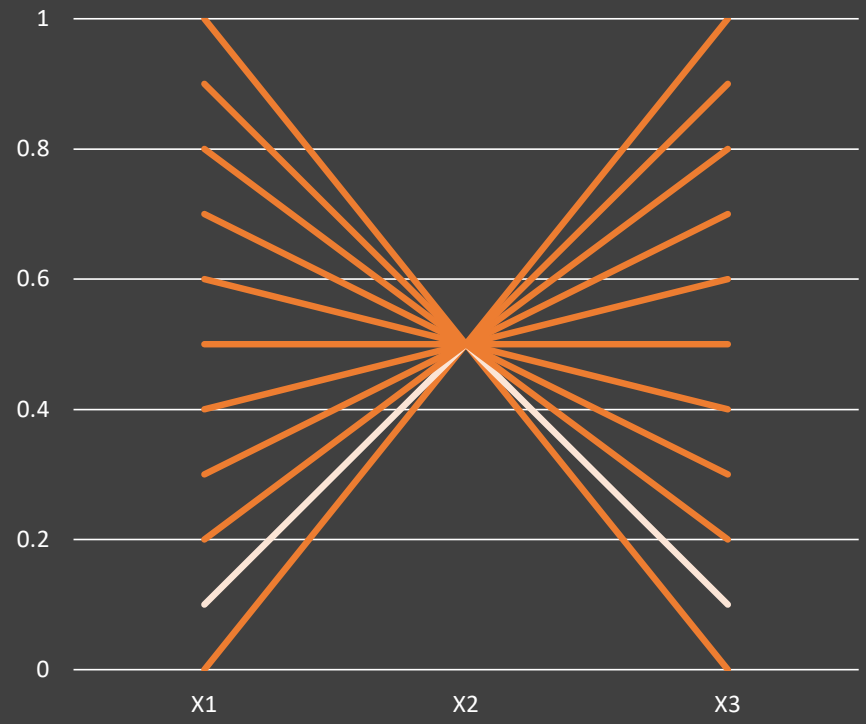

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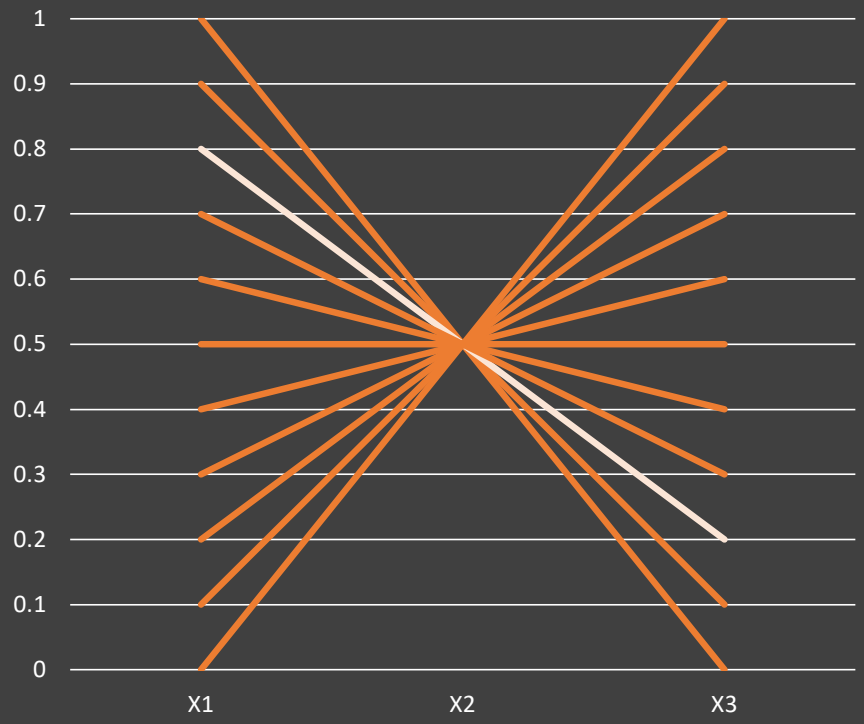

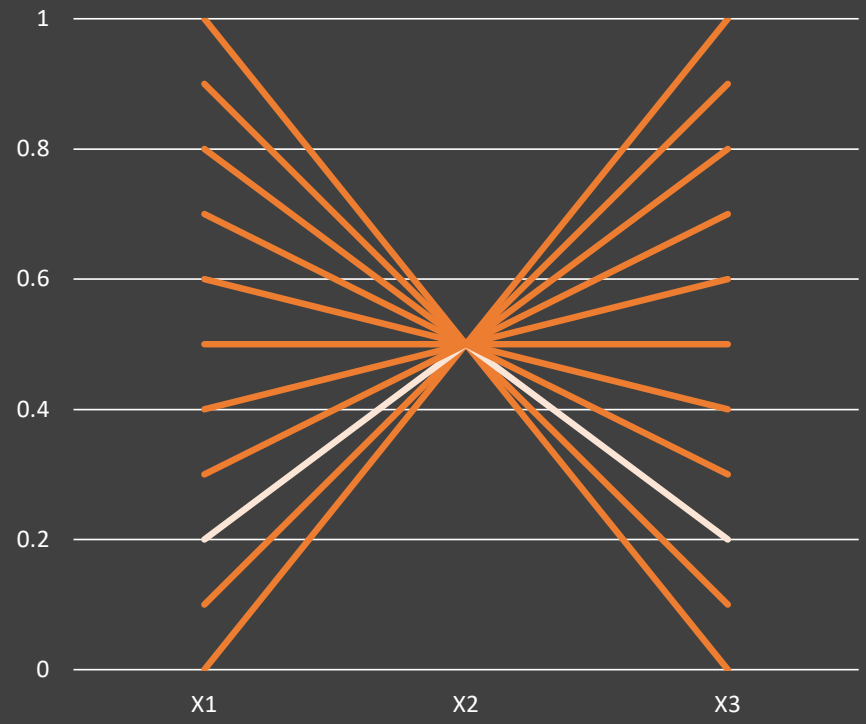

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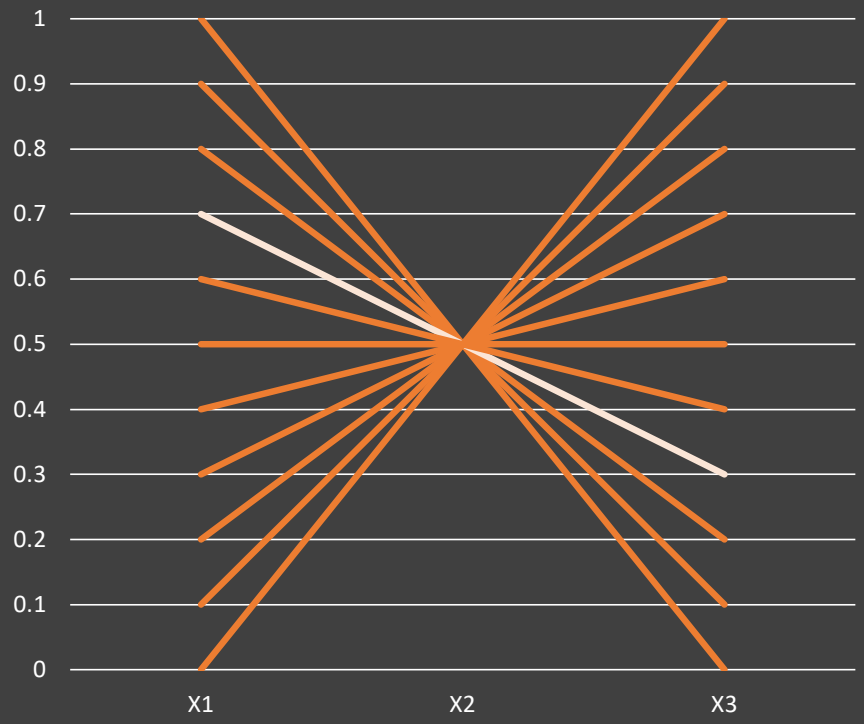

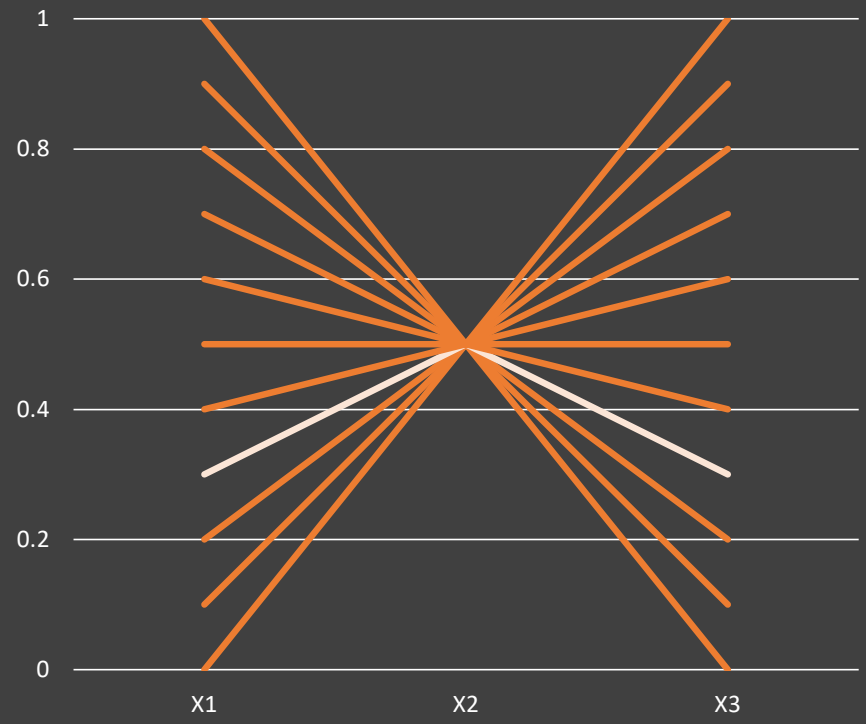

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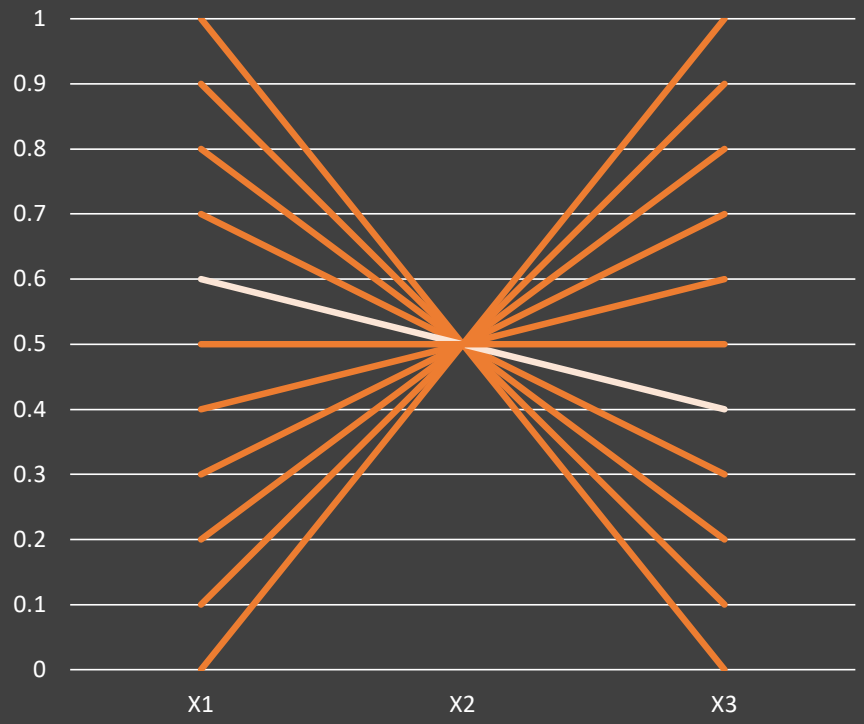

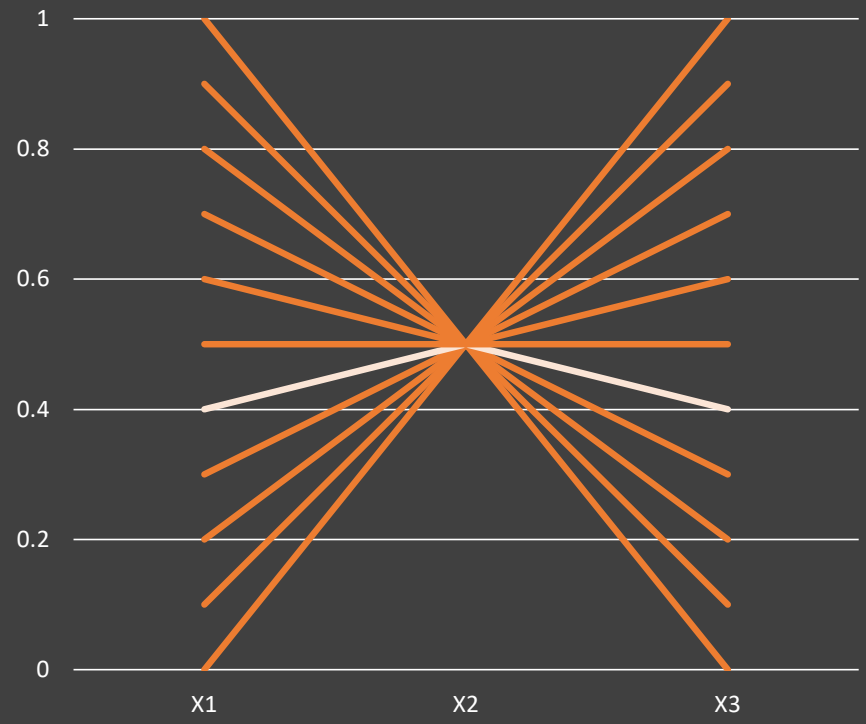

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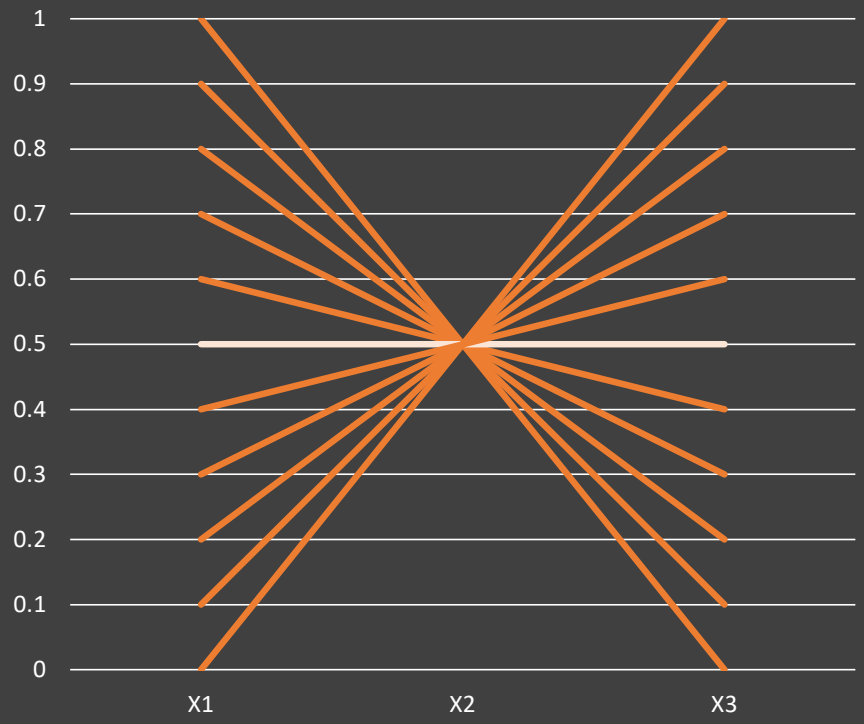

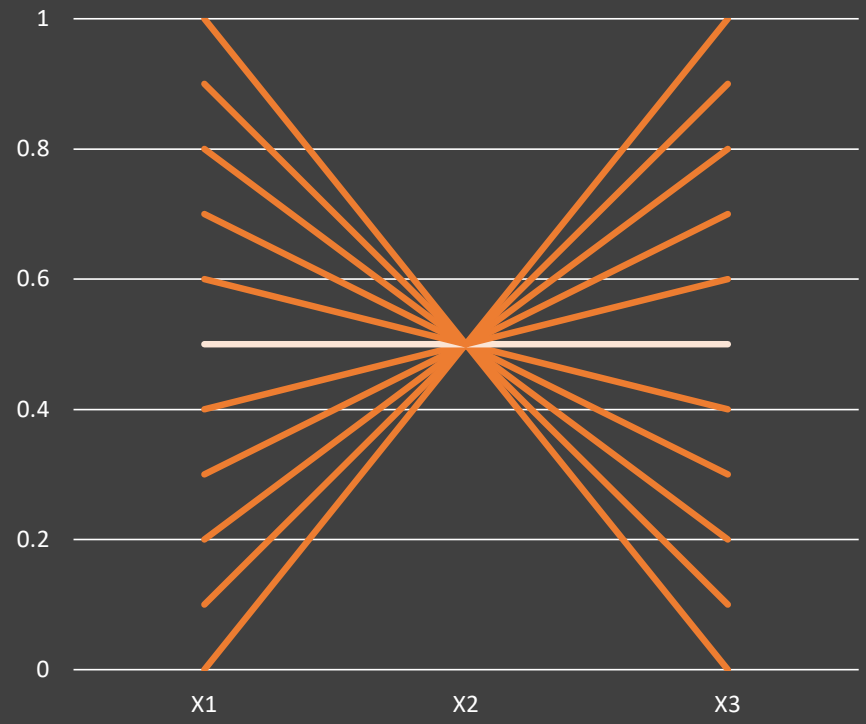

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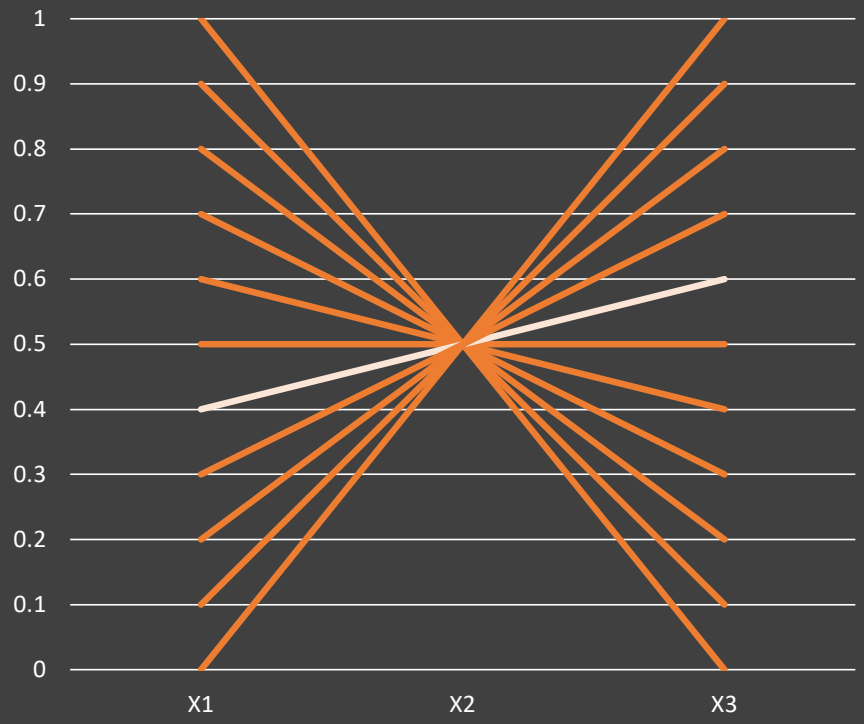

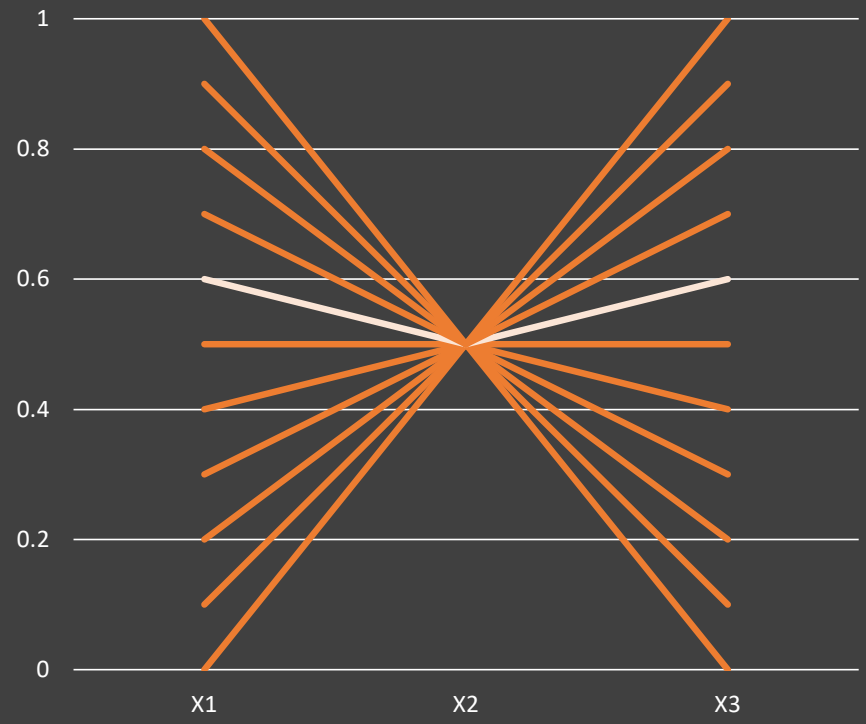

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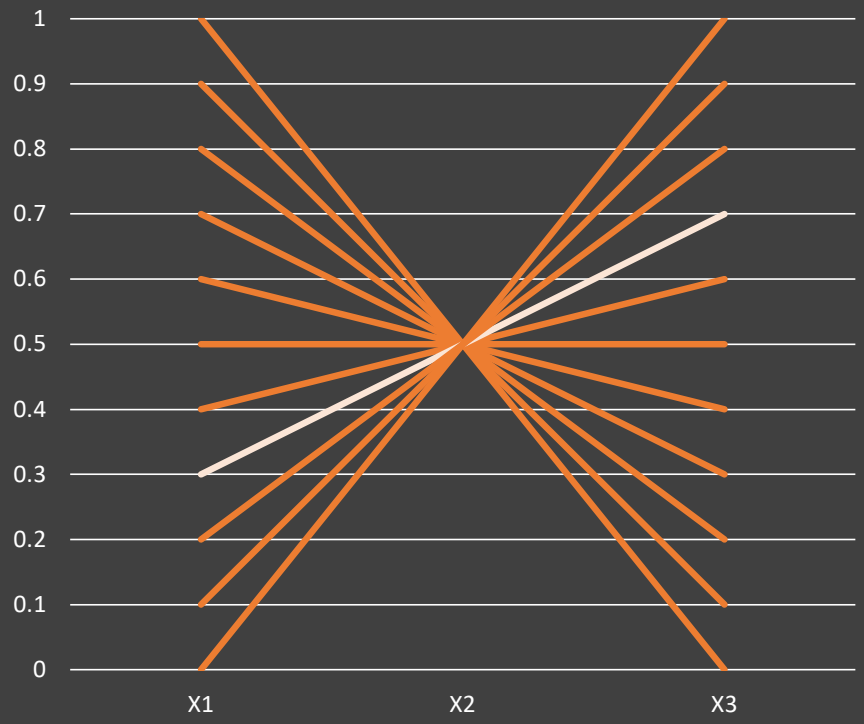

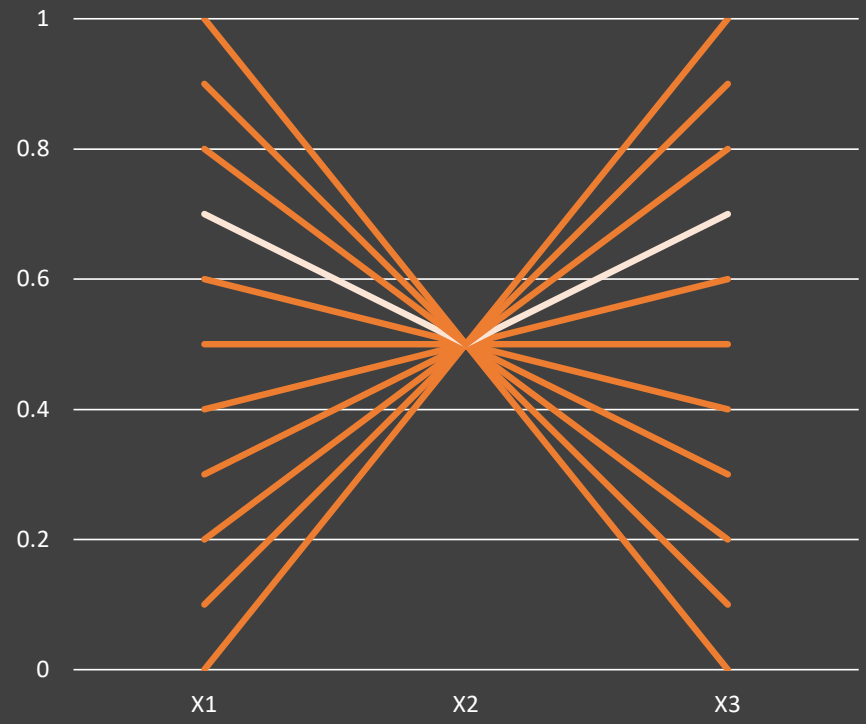

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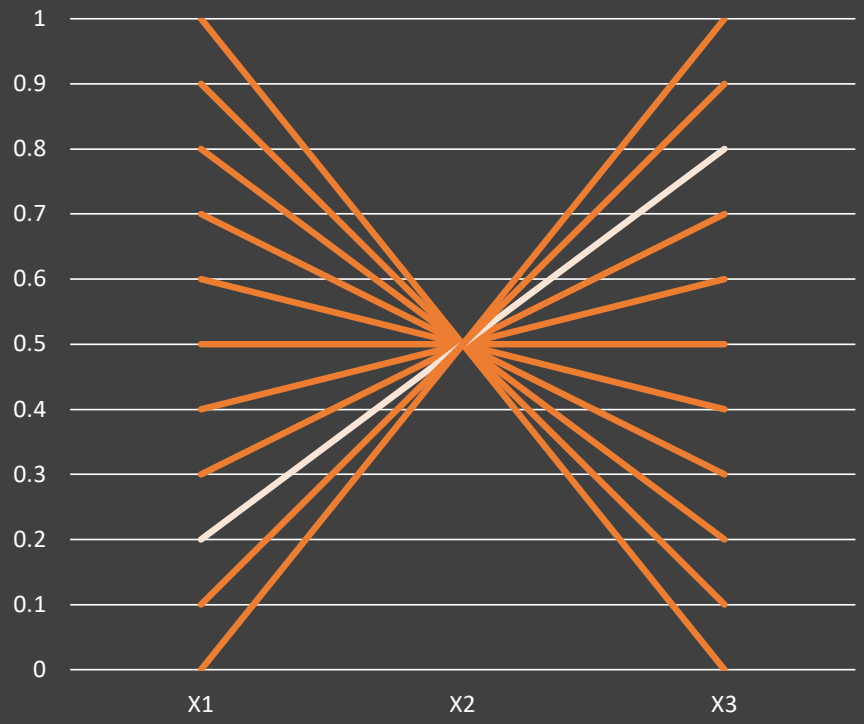

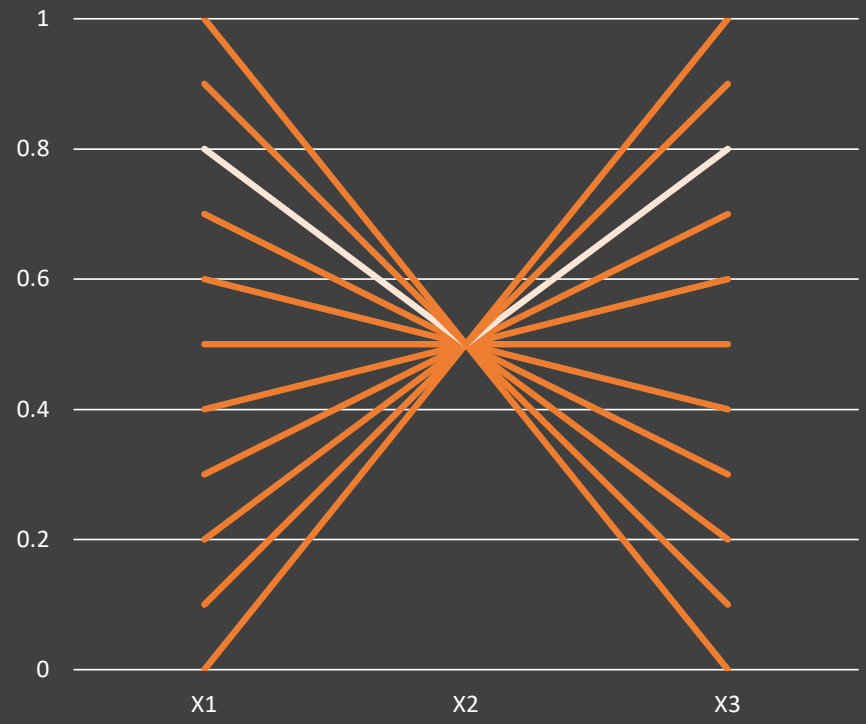

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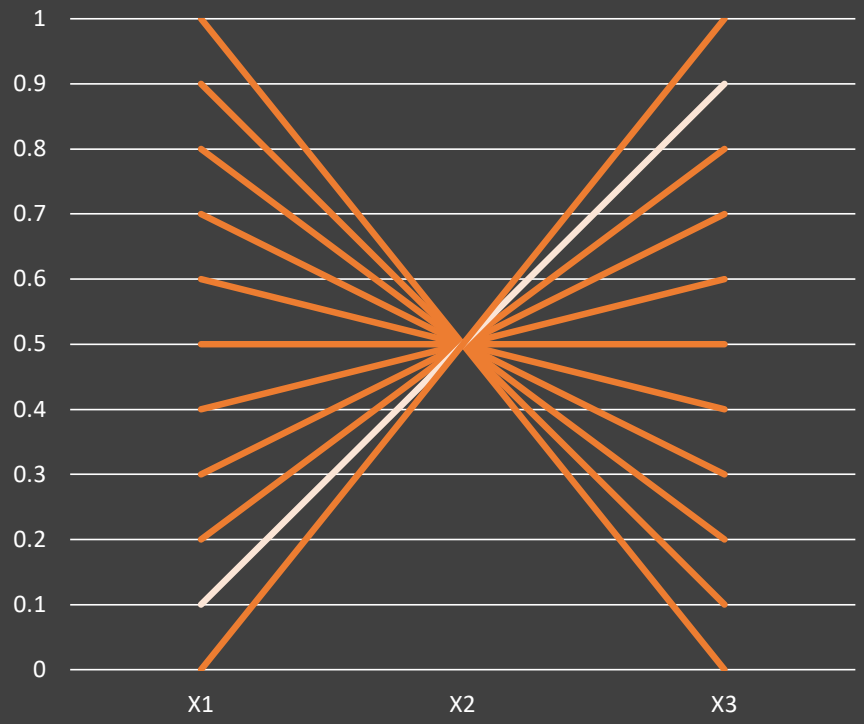

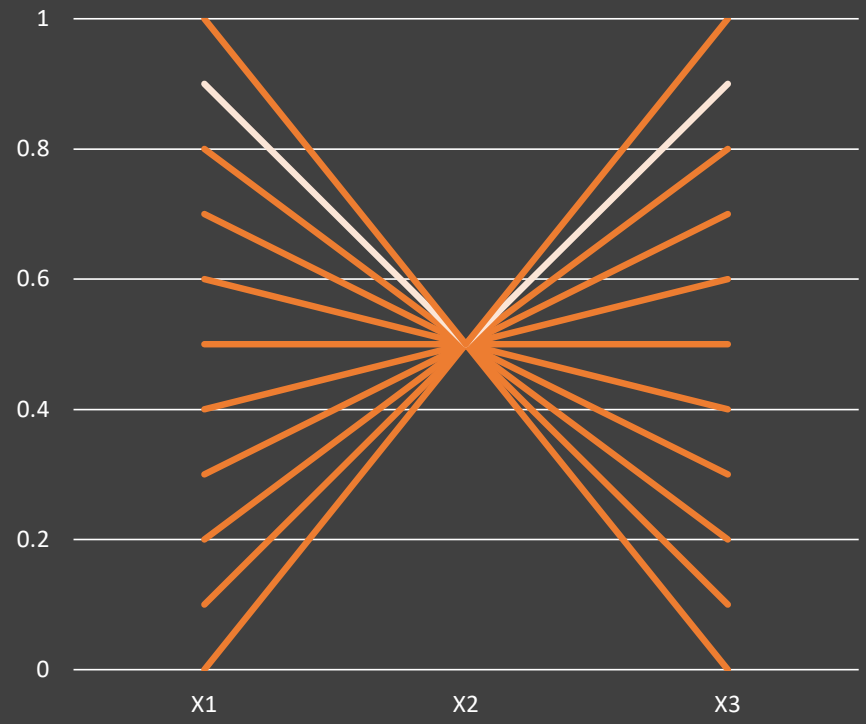

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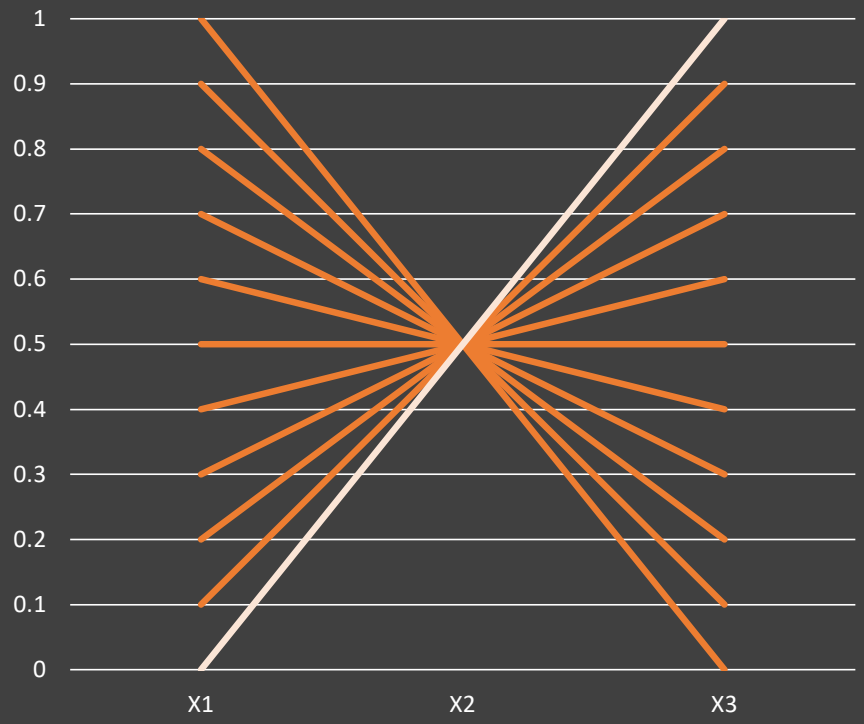
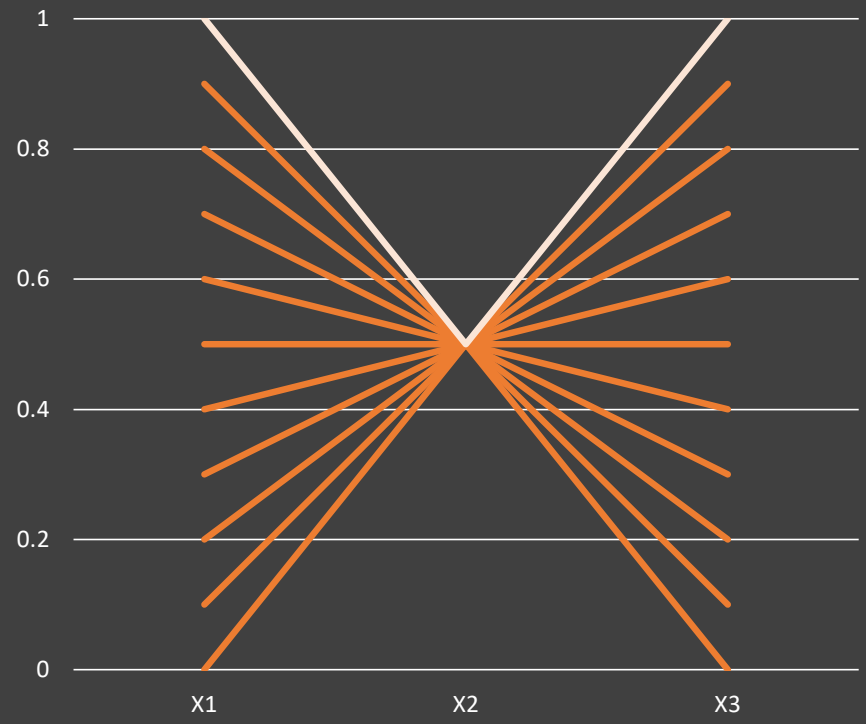
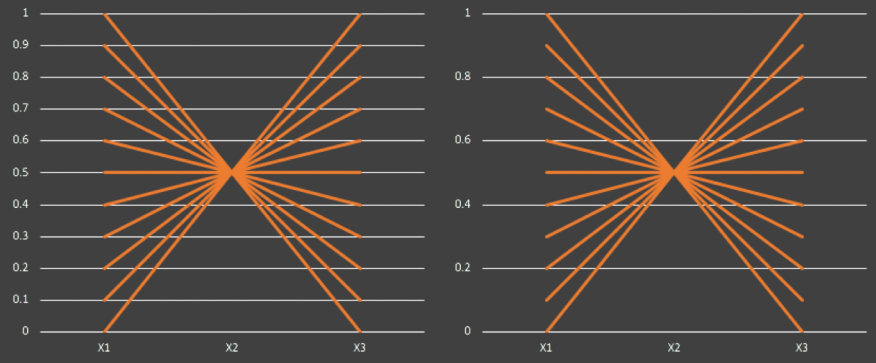




Algebraic Violations

A **similarity** in the **visualization** should only occur when there's a **similarity** in the **data**.

Confuser



Algebraic Violations

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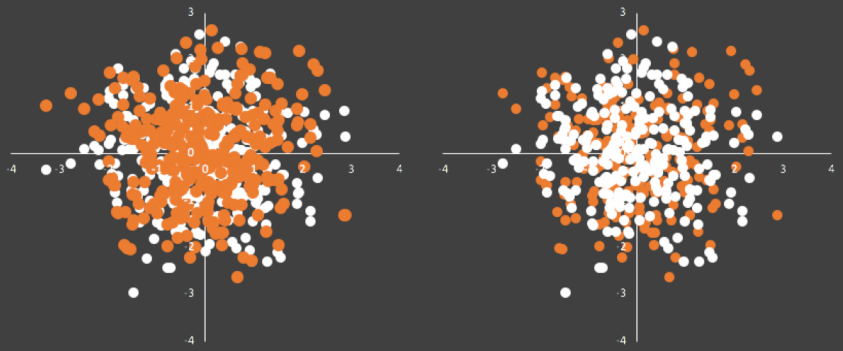
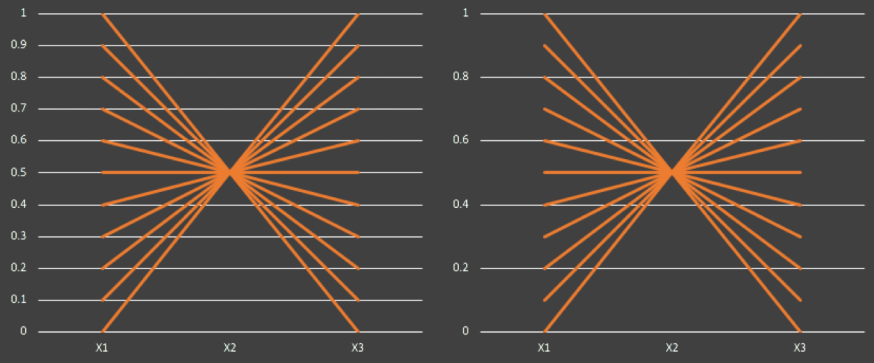
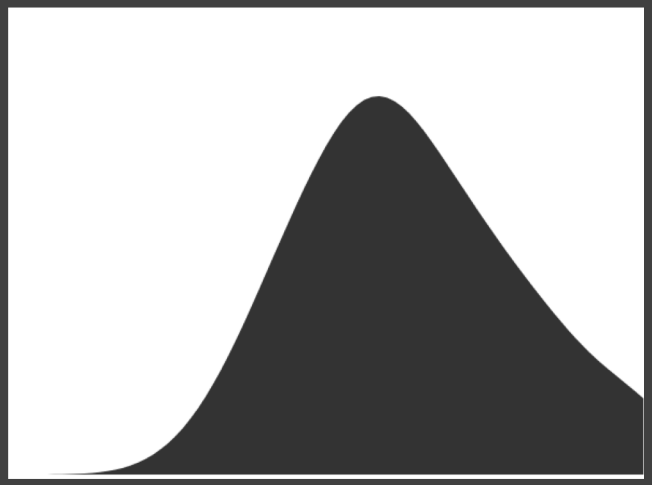


Confuser



Outliers

"Good" Data

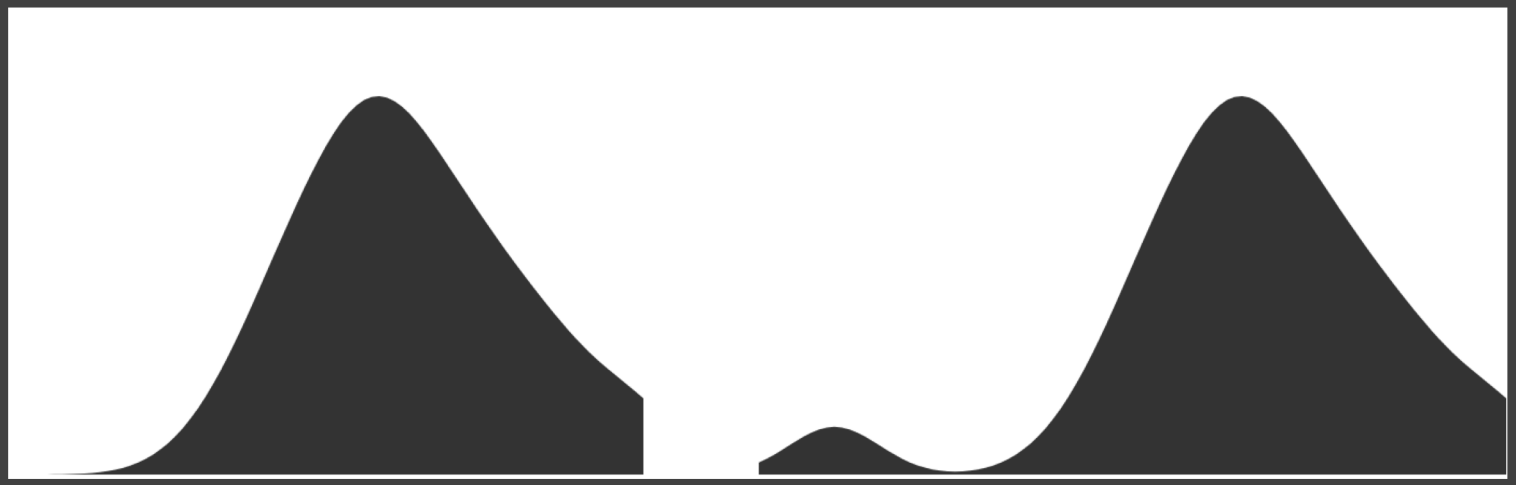


"Bad" Data

Outliers

"Good" Data

"Bad" Data



Outliers

"Good" Data

"Bad" Data

Confusers

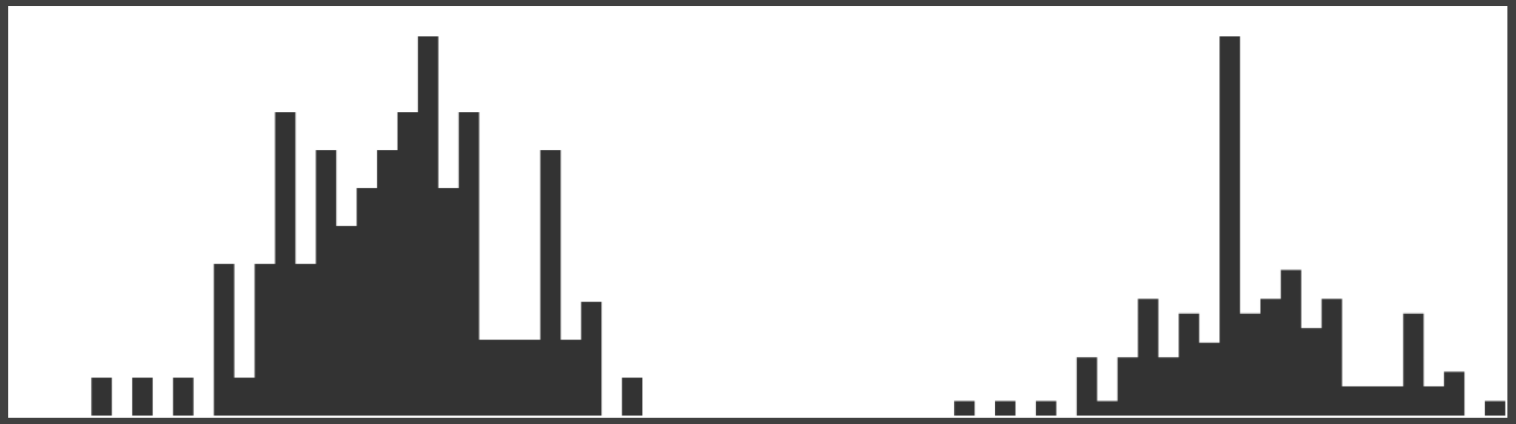
"Good" Data

"Bad" Data

Confusers

“Good” Data

“Bad” Data



Hallucinators

"Good" Data

Also "Good" Data

Hallucinators

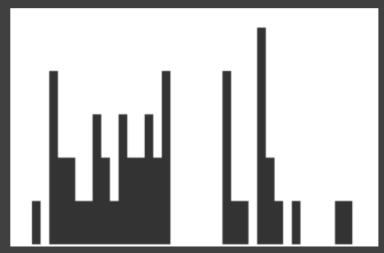
"Good" Data

Also "Good" Data

Setting Parameters

🐻🔥

👩👍

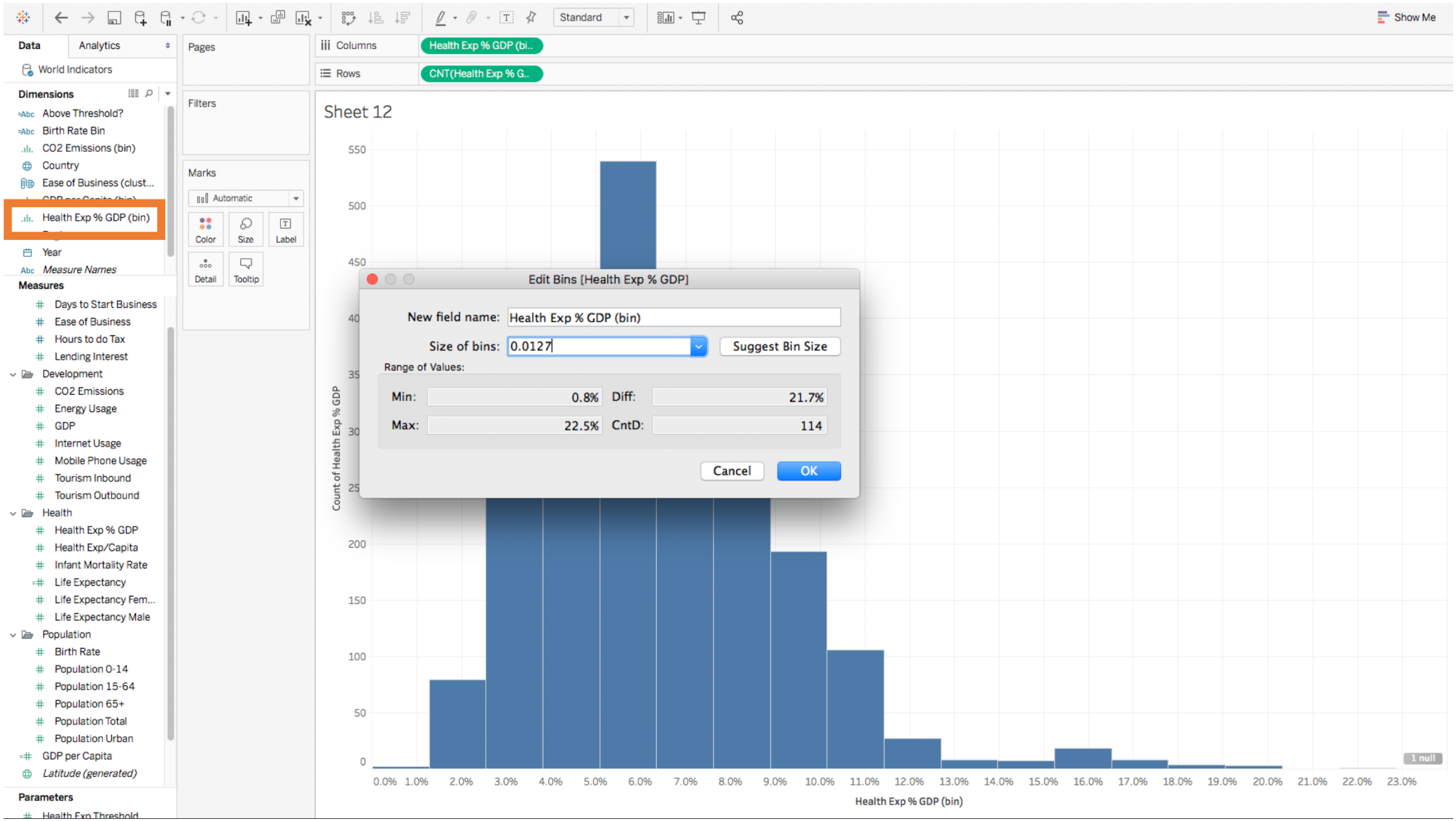


🐻❄️

Skim summary statistics
 n obs: 32
 n variables: 11

── Variable type:numeric ──

variable	missing	complete	n	mean	sd	p0	p25	p50	p75	p100	hist
am	0	32	32	0.41	0.5	0	0	0	1	1	
carb	0	32	32	2.81	1.62	1	2	2	4	8	
cyl	0	32	32	6.19	1.79	4	4	6	8	8	
disp	0	32	32	230.72	123.94	71.1	120.83	196.3	326	472	
drat	0	32	32	3.6	0.53	2.76	3.08	3.7	3.92	4.93	
gear	0	32	32	3.69	0.74	3	3	4	4	5	
hp	0	32	32	146.69	68.56	52	96.5	123	180	335	
mpg	0	32	32	20.09	6.03	10.4	15.43	19.2	22.8	33.9	
qsec	0	32	32	17.85	1.79	14.5	16.89	17.71	18.9	22.9	
vs	0	32	32	0.44	0.5	0	0	0	1	1	
wt	0	32	32	3.22	0.98	1.51	2.58	3.33	3.61	5.42	


Standard
Show Me
Data
Analytics
World Indicators
Dimensions
Above Threshold?
Birth Rate Bin
CO2 Emissions (bin)
Country
Ease of Business (clust...
Health Exp % GDP (bin)
Year
Measure Names
Measures
Days to Start Business
Ease of Business
Hours to do Tax
Lending Interest
Development
CO2 Emissions
Energy Usage
GDP
Internet Usage
Mobile Phone Usage
Tourism Inbound
Tourism Outbound
Health
Health Exp % GDP
Health Exp/Capita
Infant Mortality Rate
Life Expectancy
Life Expectancy Fem...
Life Expectancy Male
Population
Birth Rate
Population 0-14
Population 15-64
Population 65+
Population Total
Population Urban
GDP per Capita
Latitude (generated)
Parameters
Pages
Filters
Marks
Automatic
Color
Size
Label
Detail
Tooltip
Columns
Health Exp % GDP (bi..
Rows
CNT(Health Exp % G..
Sheet 12
Edit Bins [Health Exp % GDP]
New field name:
Health Exp % GDP (bin)
Size of bins:
0.0127
Suggest Bin Size
Range of Values:
Min:
0.8%
Diff:
21.7%
Max:
22.5%
CntD:
114
Cancel
OK
Count of Health Exp % GDP
Health Exp % GDP (bin)
1 null

Problems

We **rely on univariate summaries** to detect data quality issues

The **choice of design parameters** determine how visible these problems are.

Parameters are often **hidden** from the user or **difficult to adjust**

Outline

Framework

Study

Measuring Sanity Checkability?

Can people find whether or not a data flaw exists?

Is the visual pattern of the data flaw robust enough to hold up against sampling variability?

Lineups Protocol!

[Buja09],[Wickham10]

Lineups Protocol!

[Buja09],[Wickham10]

Lineups Protocol!

[Buja09],[Wickham10]

Methods

Lineup study on prolific.ac

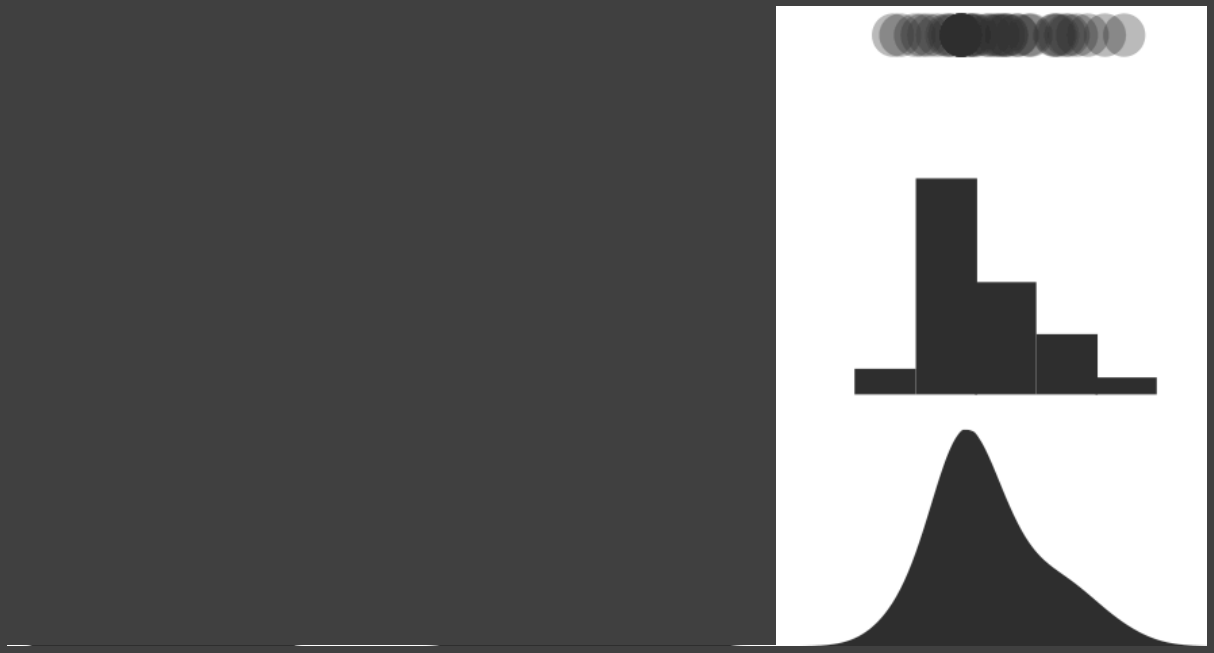
32 participants

288 training lineups

2592 trial lineups

Data Flaws

Visualization Types

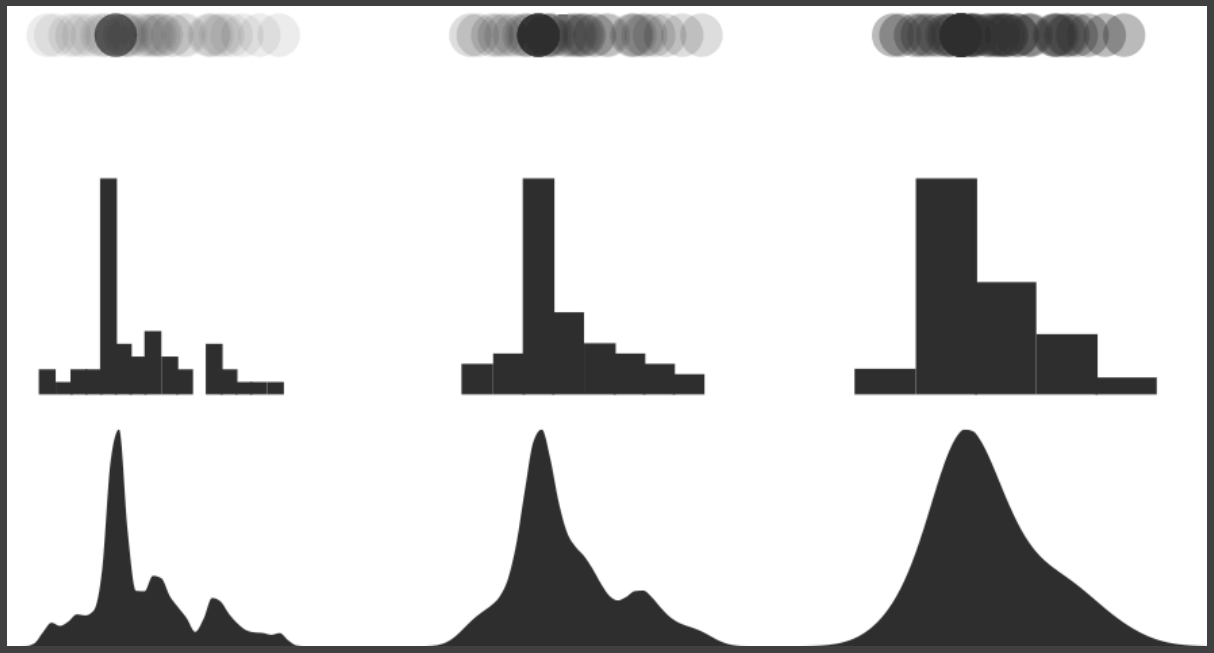


Dot Plots

Histograms

Density Plots

Parameter Types

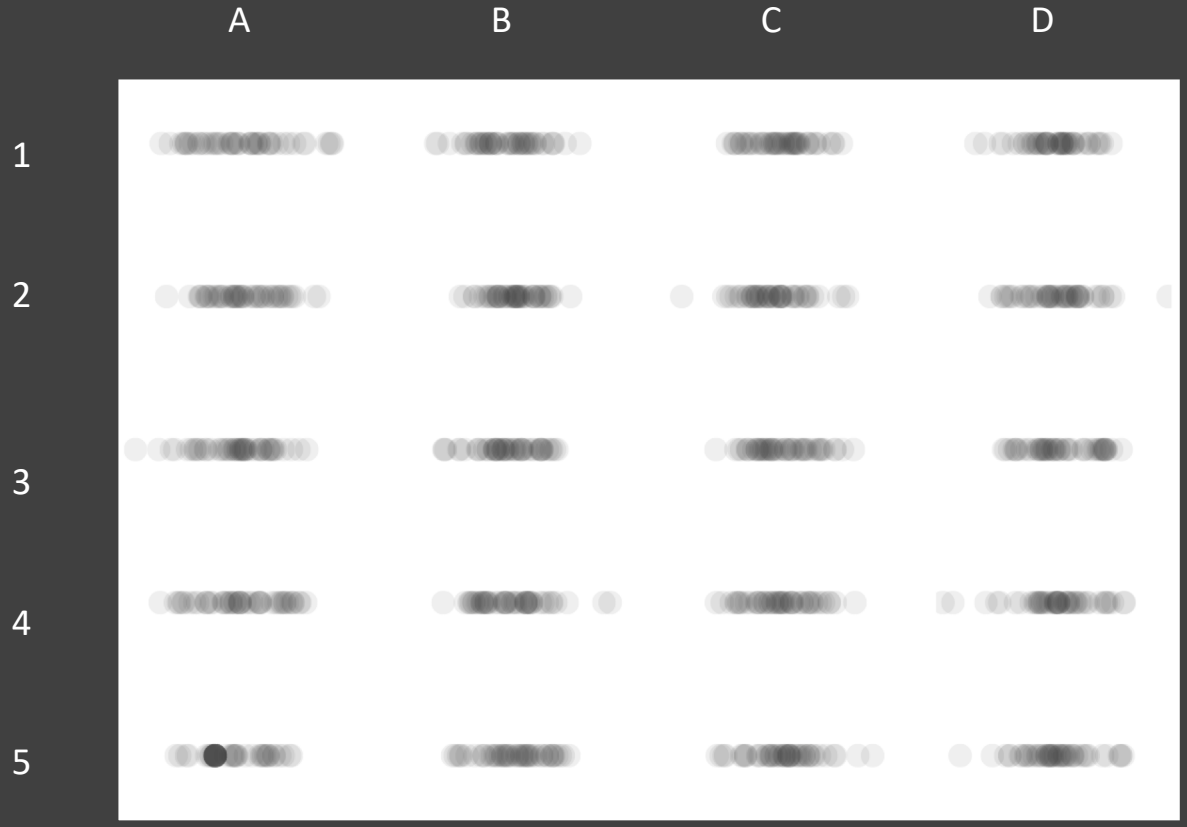


Mark Opacity

Bin Count

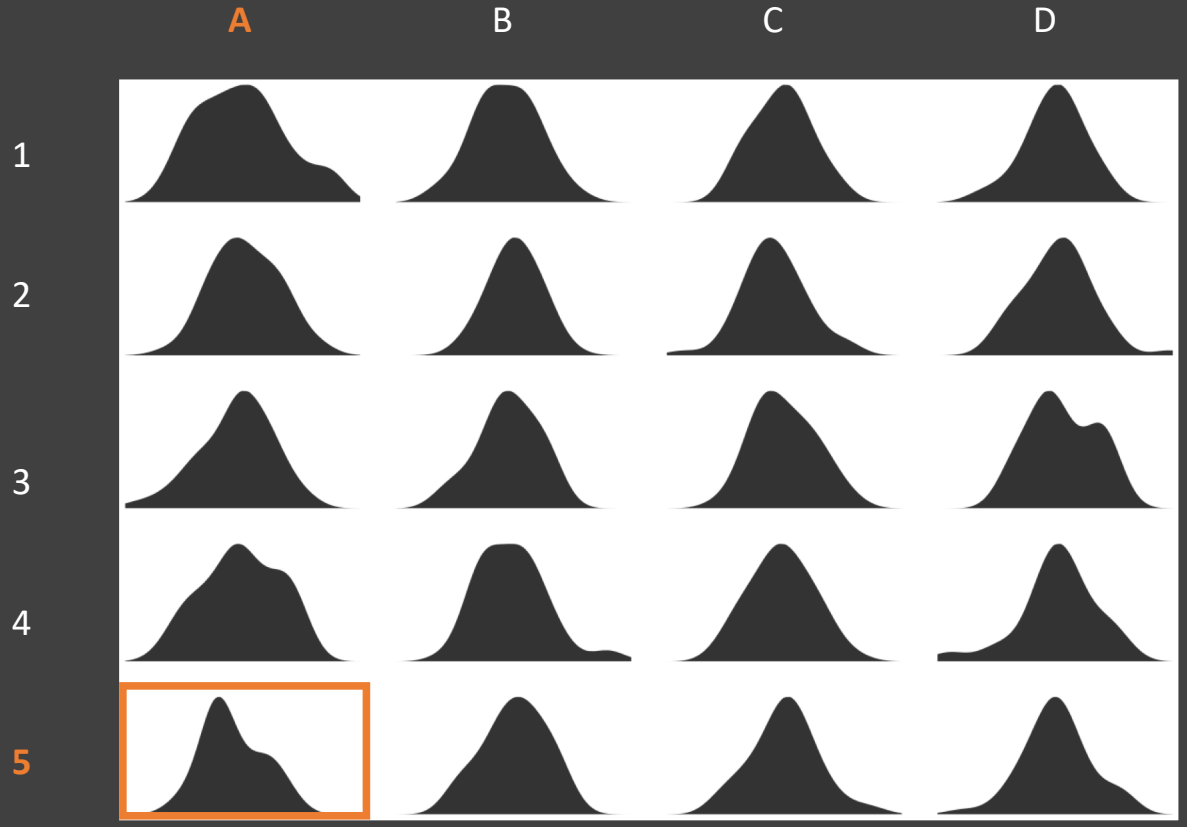
Kernel Bandwidth

Where's the Spike?



Where's the Spike?

Where's the Spike?



Results

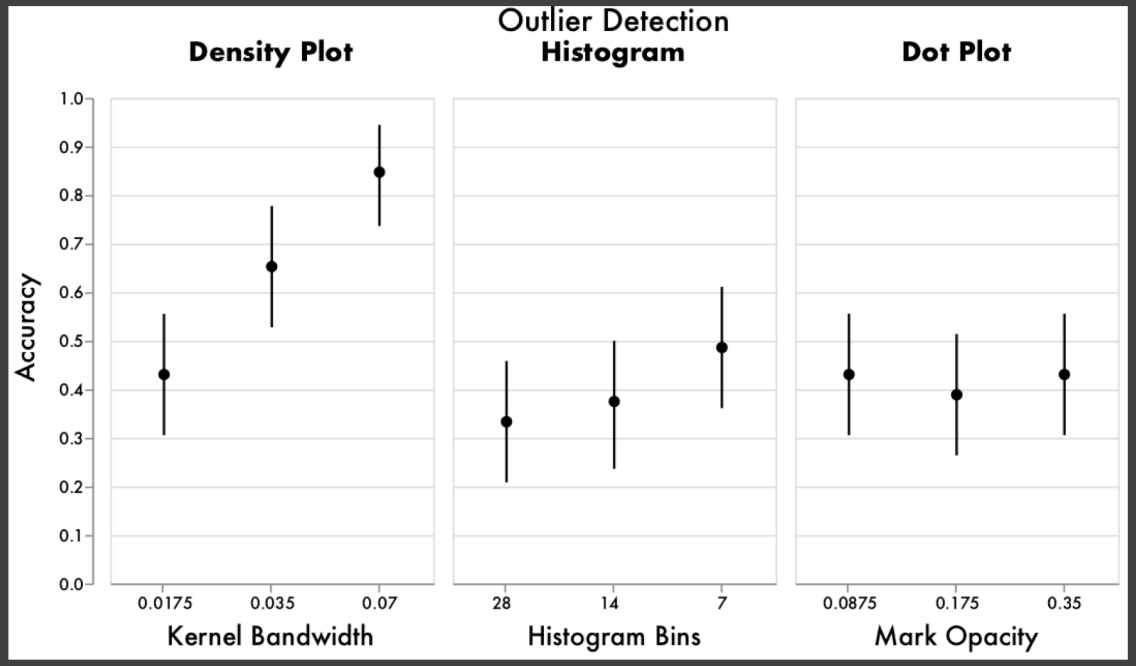
Outliers Are Tough To Hide

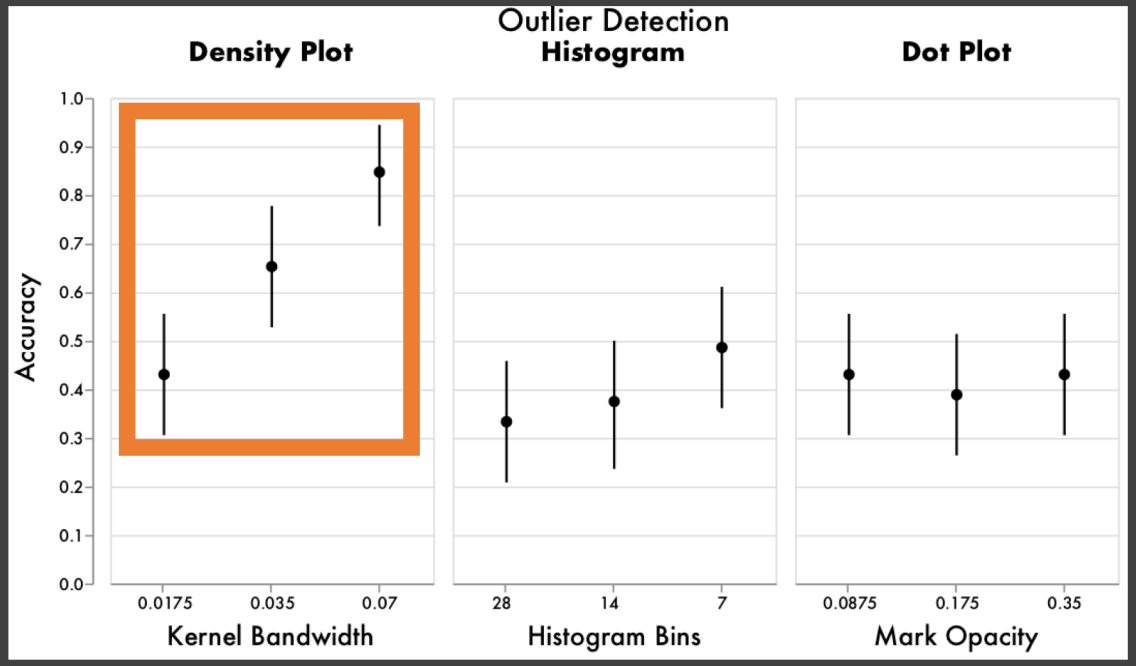
Gaps Are Easy To Hide

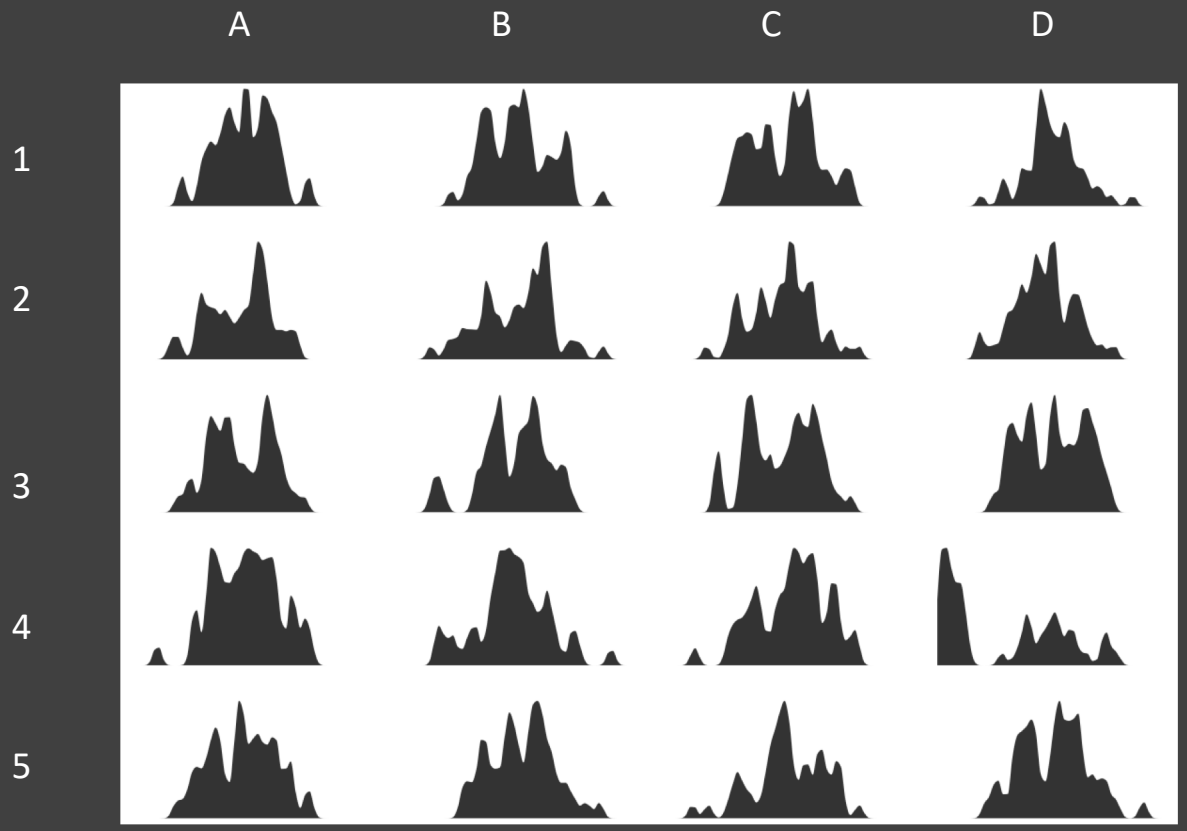
Results

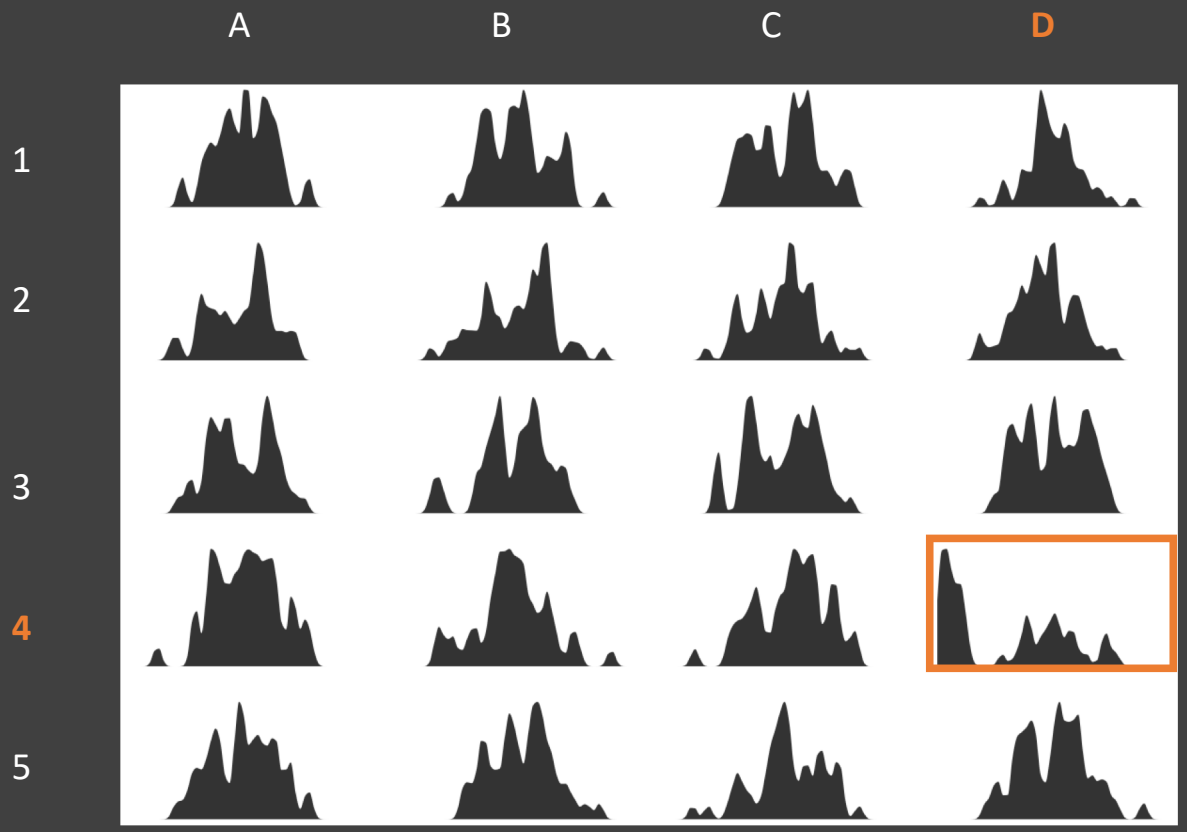
Outliers Are Tough To Hide

Gaps Are Easy To Hide


Outlier Detection
Density Plot
Histogram
Dot Plot
Accuracy
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0175
0.035
0.07
Kernel Bandwidth
28
14
7
Histogram Bins
0.0875
0.175
0.35
Mark Opacity


Outlier Detection
Density Plot
Histogram
Dot Plot
Accuracy
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0175
0.035
0.07
Kernel Bandwidth
28
14
7
Histogram Bins
0.0875
0.175
0.35
Mark Opacity

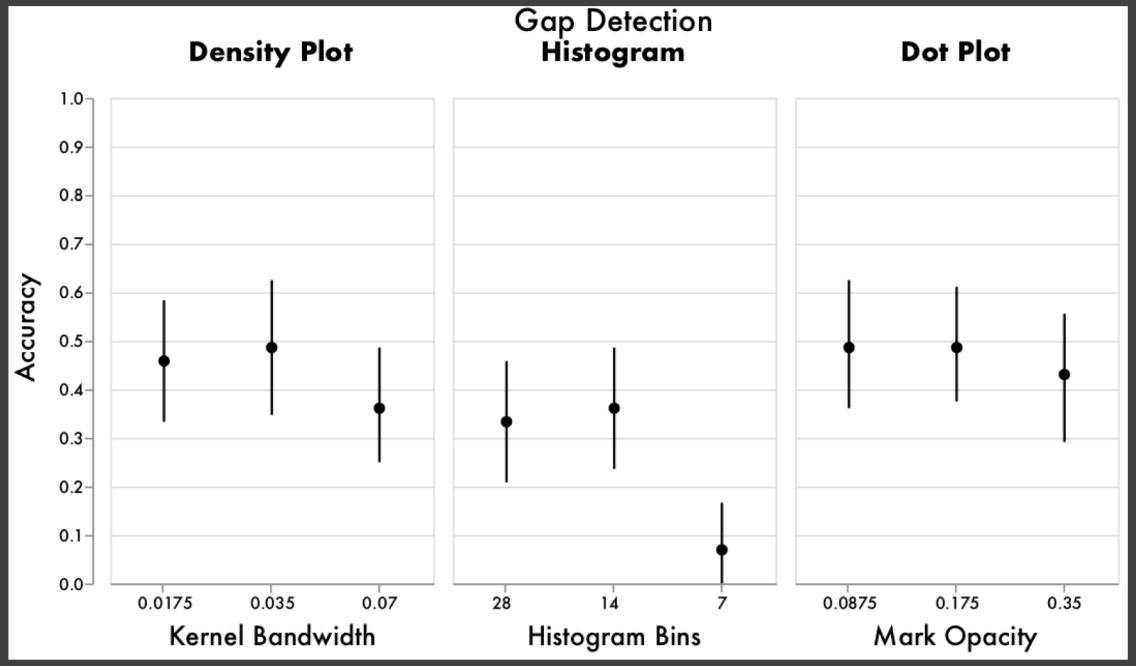

A
B
C
D
1
2
3
4
5

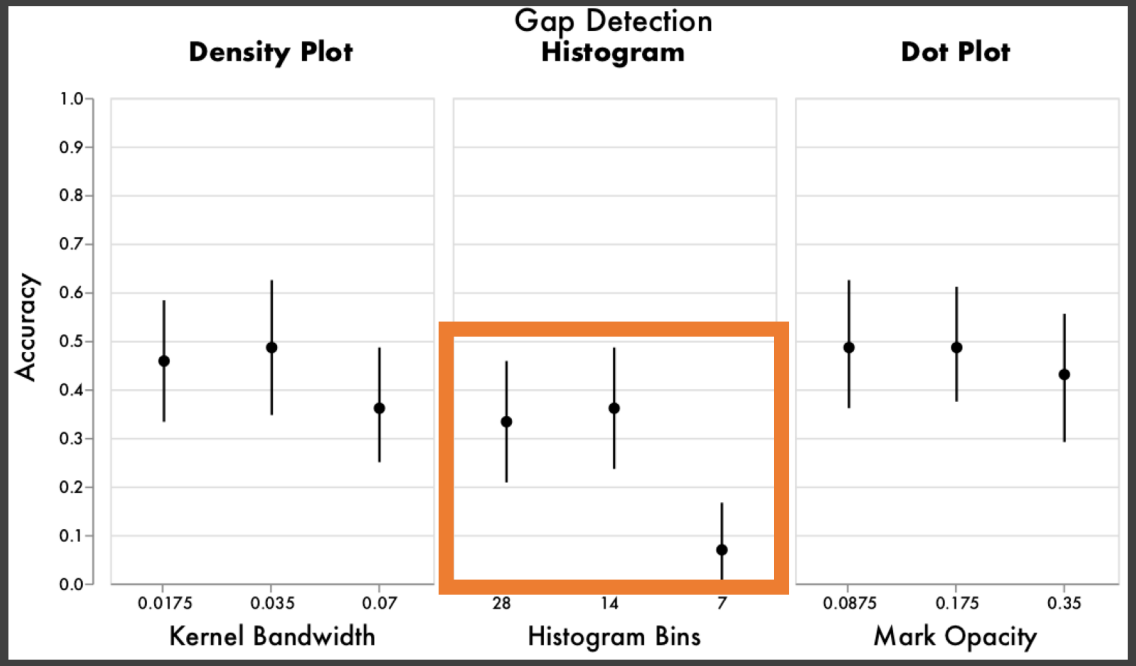

A
B
C
D
1
2
3
4
5

Results

Outliers Are Tough To Hide

Gaps Are Easy To Hide


Gap Detection
Density Plot
Histogram
Dot Plot
Accuracy
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
0.0175
0.035
0.07
Kernel Bandwidth
28
14
7
Histogram Bins
0.0875
0.175
0.35
Mark Opacity


Gap Detection
Density Plot
Histogram
Dot Plot
Accuracy
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
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0.0
0.0175
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14
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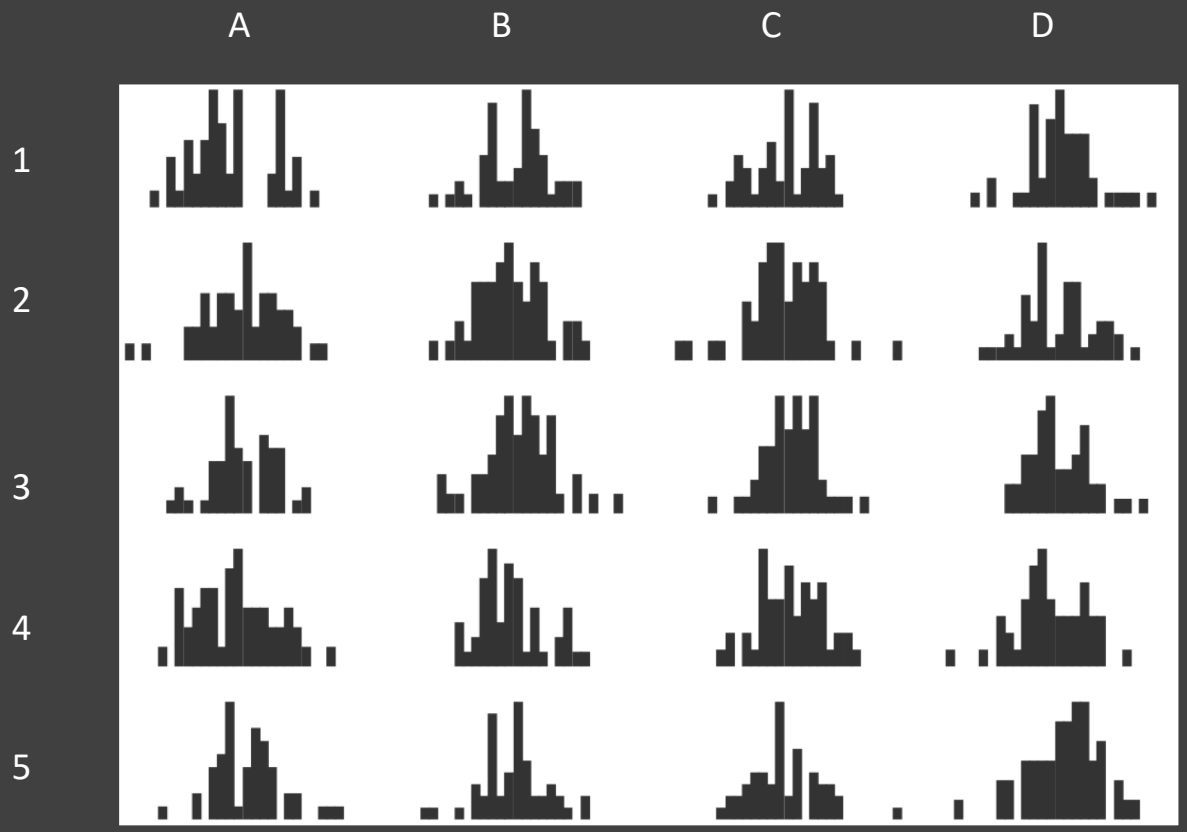
0.35
Kernel Bandwidth
Histogram Bins
Mark Opacity


A
B
C
D
1
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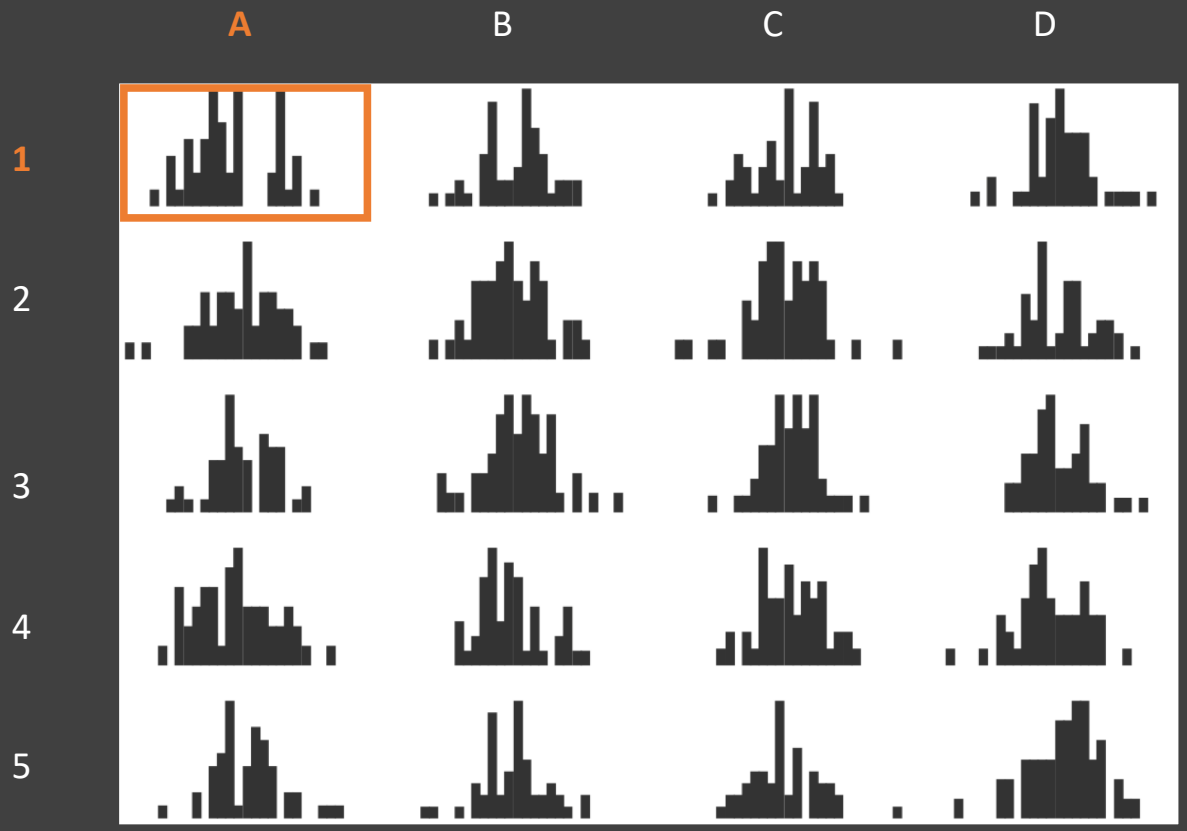
A
B
C
D
1
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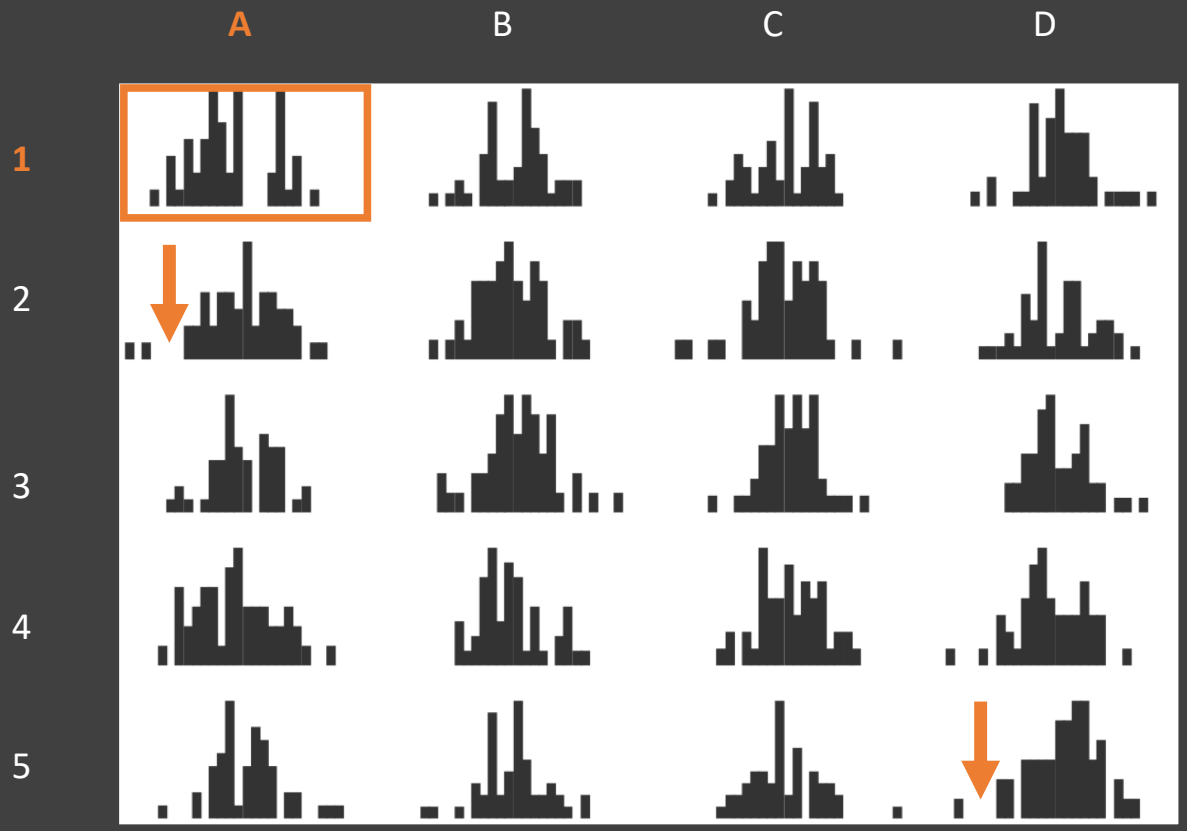
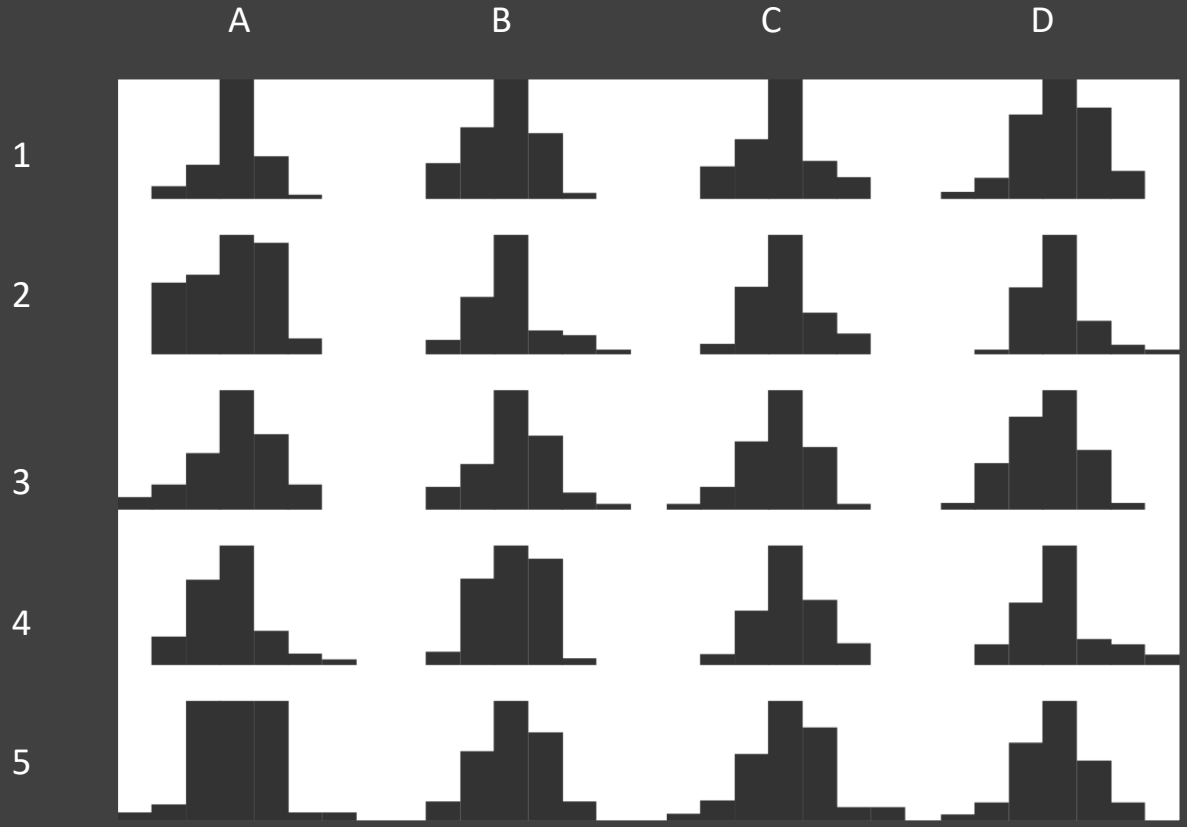
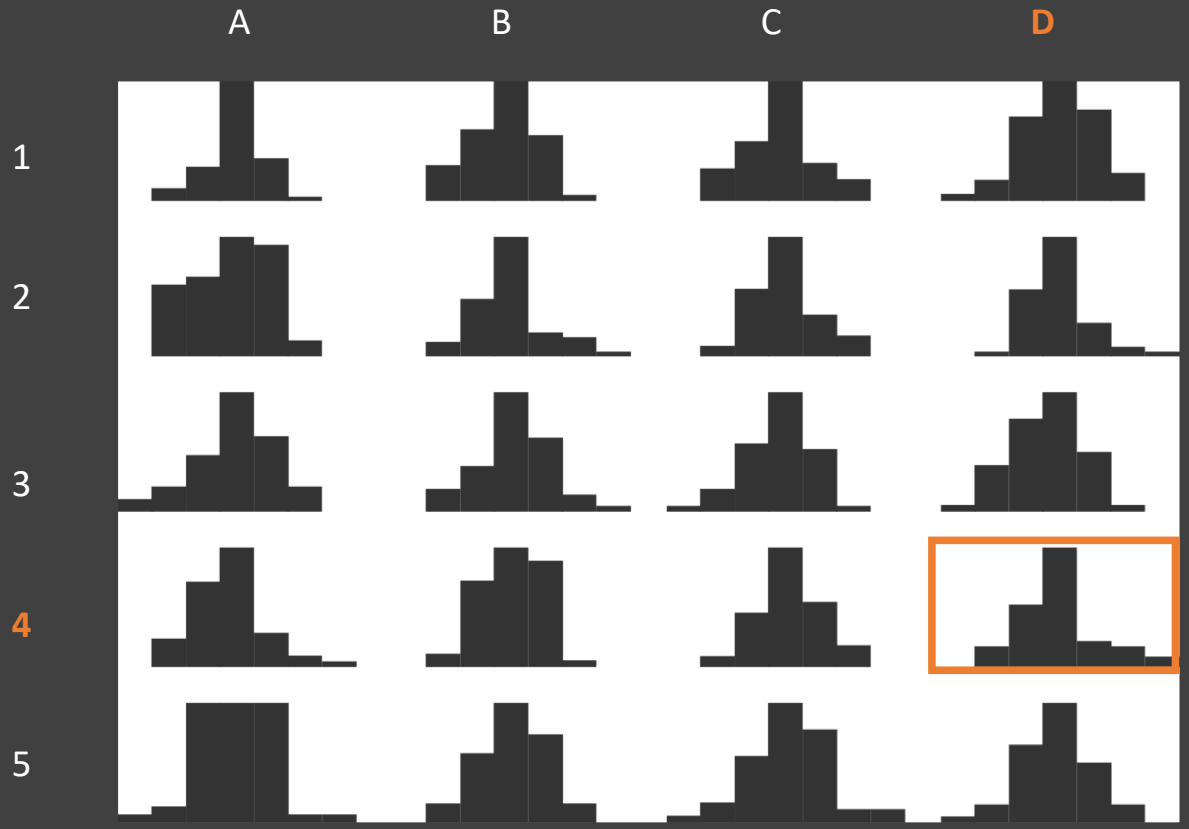
3
4
5


A
B
C
D
1
2
3
4
5


A
B
C
D
1
2
3
4
5


A
B
C
D
1
2
3
4
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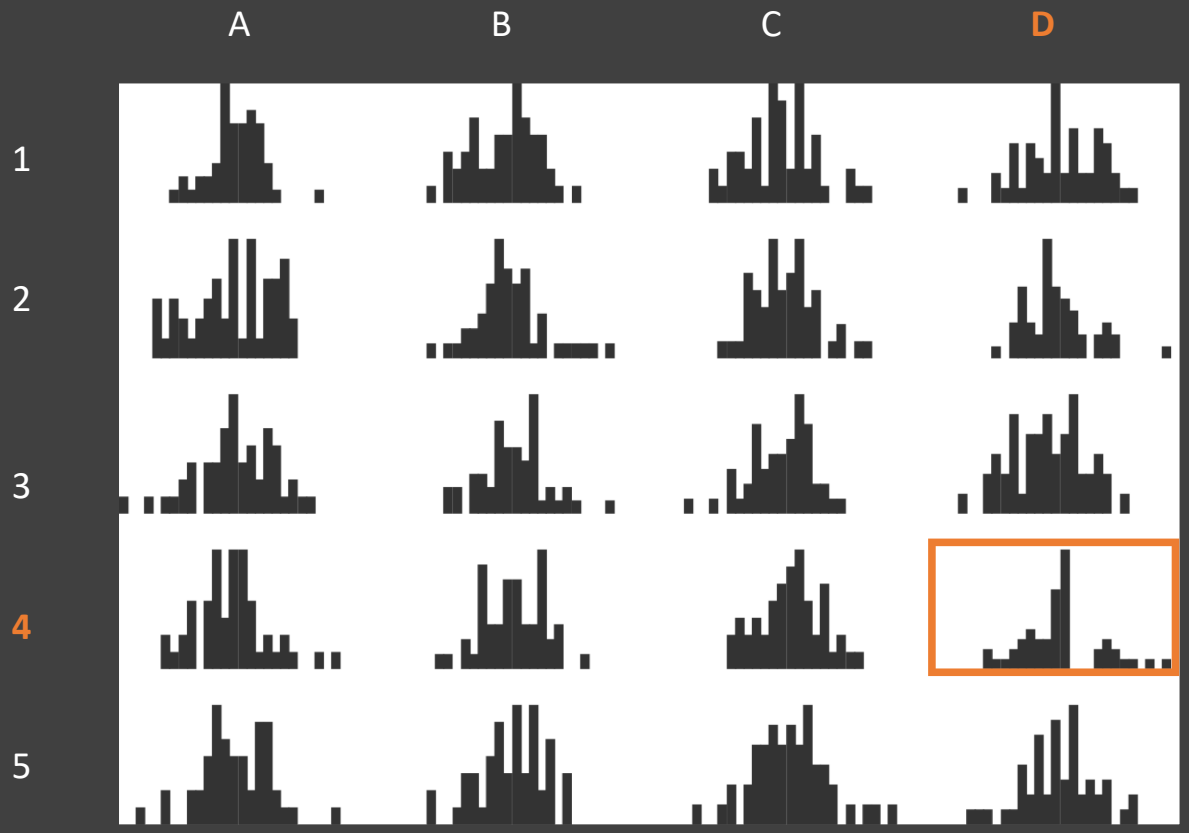

A
B
C
D
1
2
3
4
5


A
B
C
D
1
2
3
4
5

What should we do next?

Intervene!

Supplement!

What should we do next?

🚨Speculation Alert🚨

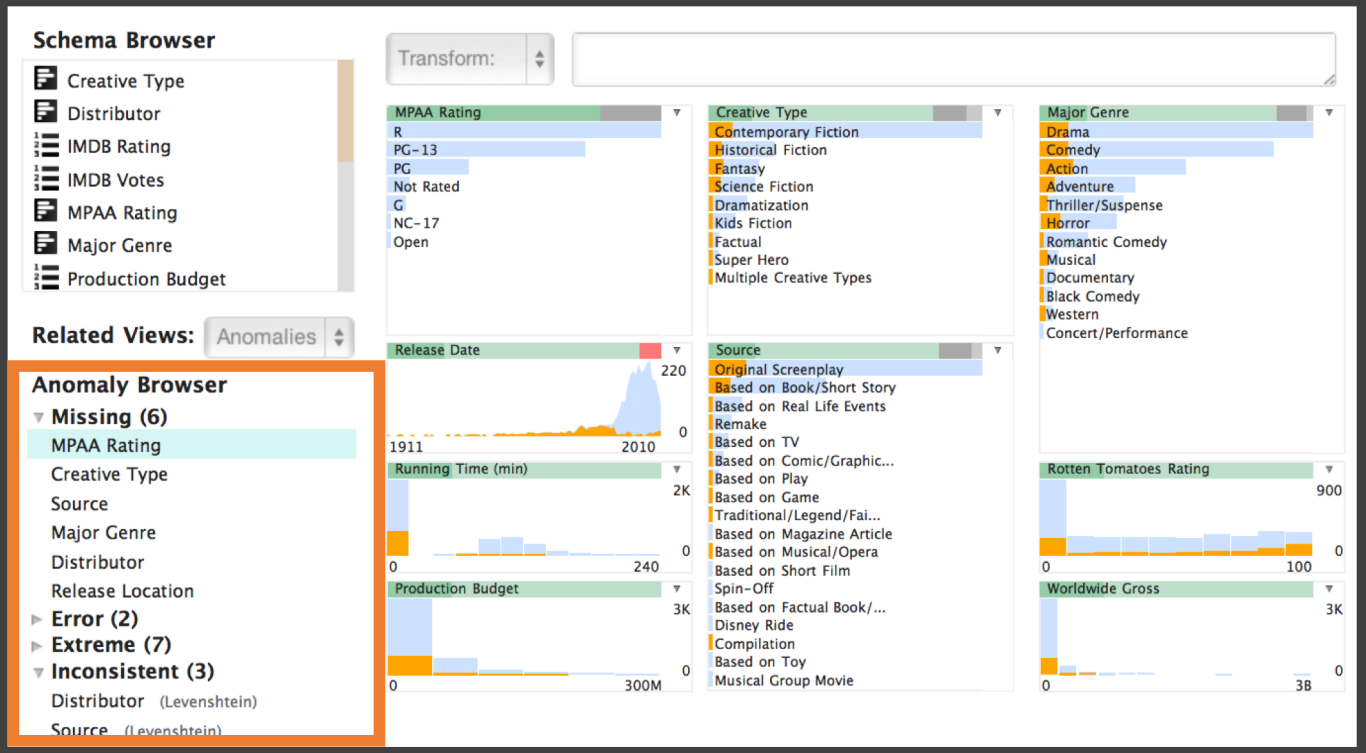
Intervene!

Supplement!

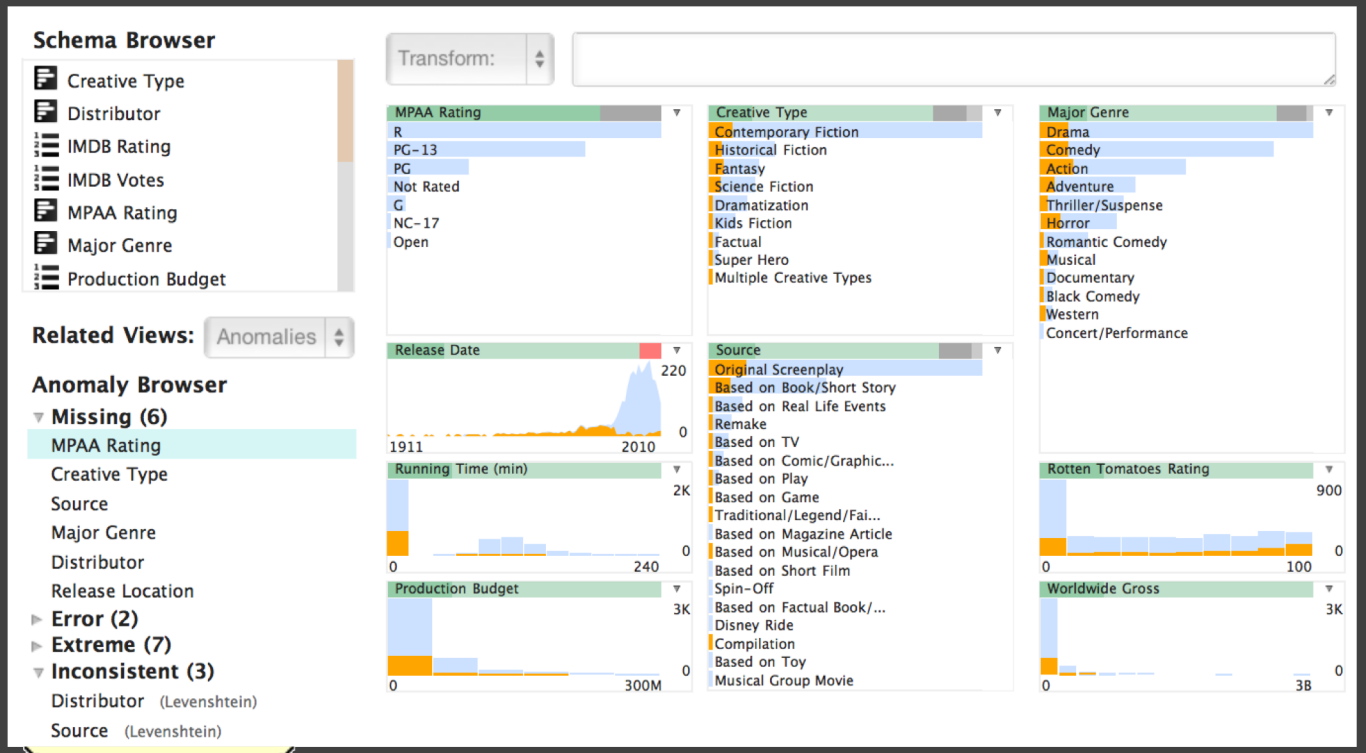
What should we do next?

Intervene!

Supplement!


Schema Browser
Creative Type
Distributor
IMDB Rating
IMDB Votes
MPAA Rating
Major Genre
Production Budget
Related Views:
Anomalies
Anomaly Browser
Missing (6)
MPAA Rating
Creative Type
Source
Major Genre
Distributor
Release Location
Error (2)
Extreme (7)
Inconsistent (3)
Distributor (Levenshtein)
Source (Levenshtein)
Transform:
MPAA Rating
R
PG-13
PG
Not Rated
G
NC-17
Open
Creative Type
Contemporary Fiction
Historical Fiction
Fantasy
Science Fiction
Dramatization
Kids Fiction
Factual
Super Hero
Multiple Creative Types
Major Genre
Drama
Comedy
Action
Adventure
Thriller/Suspense
Horror
Romantic Comedy
Musical
Documentary
Black Comedy
Western
Concert/Performance
Release Date
220
0
1911
2010
Source
Original Screenplay
Based on Book/Short Story
Based on Real Life Events
Remake
Based on TV
Based on Comic/Graphic...
Based on Play
Based on Game
Traditional/Legend/Fai...
Based on Magazine Article
Based on Musical/Opera
Based on Short Film
Spin-Off
Based on Factual Book/...
Disney Ride
Compilation
Based on Toy
Musical Group Movie
Running Time (min)
2K
0
0
240
Rotten Tomatoes Rating
900
0
0
100
Production Budget
3K
0
0
300M
Worldwide Gross
3K
0
0
3B

[Kandel12]


Schema Browser
Creative Type
Distributor
IMDB Rating
IMDB Votes
MPAA Rating
Major Genre
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Missing (6)
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0
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[Kandel12]

What should we do next?

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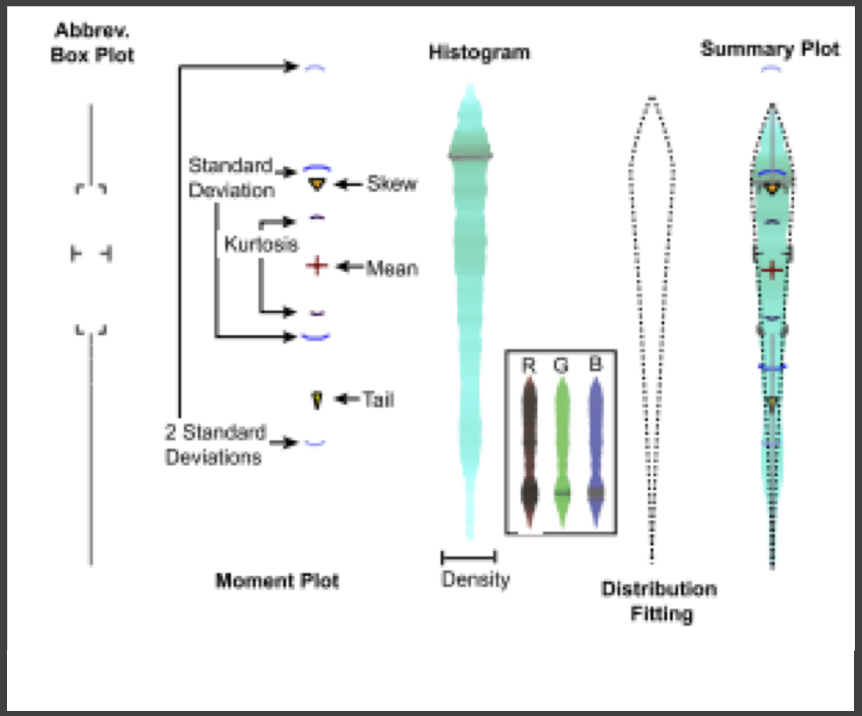
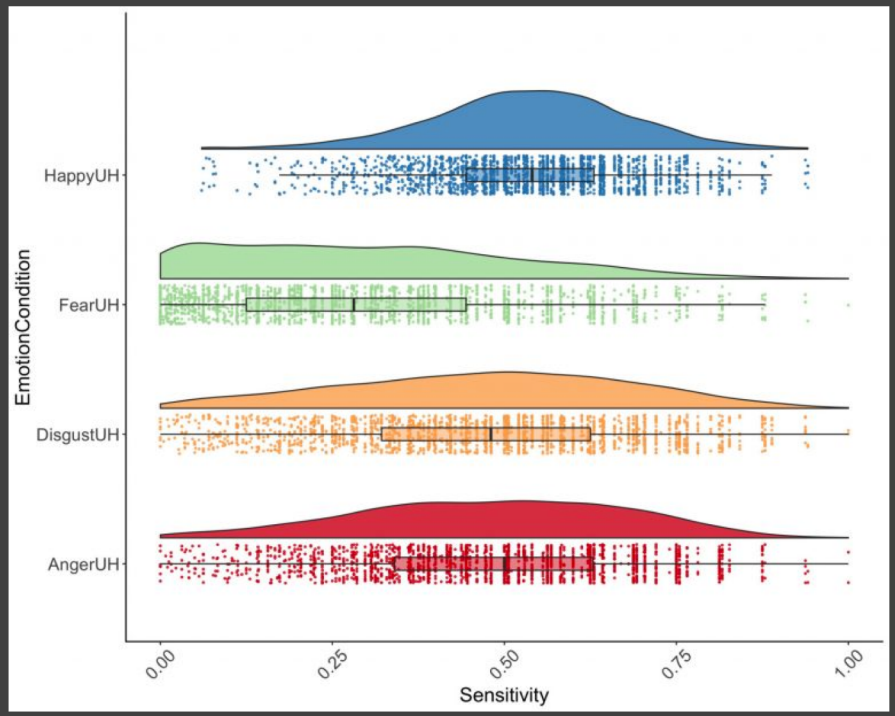
Supplement!

Supplement!





[Potter10], xeno.graphics

Research Questions

Do data quality issues we care about have **characteristic visual patterns** in our visualizations?

Are these characteristic patterns **robustly detectable** across design parameters?

Thanks!







Work partially supported by NSF award IIS-1513651 and the Arizona Board of Regents

Data, code, and study materials at: **http://bit.ly/sanityvis**

[Anscombe73] Anscombe, F. "Graphs in Statistical Analysis." *American Statistician*, 1973.

[Buja09] Buja, A. et al. "Statistical inference for exploratory data analysis and model diagnostics." *The Royal Society*, 2009.

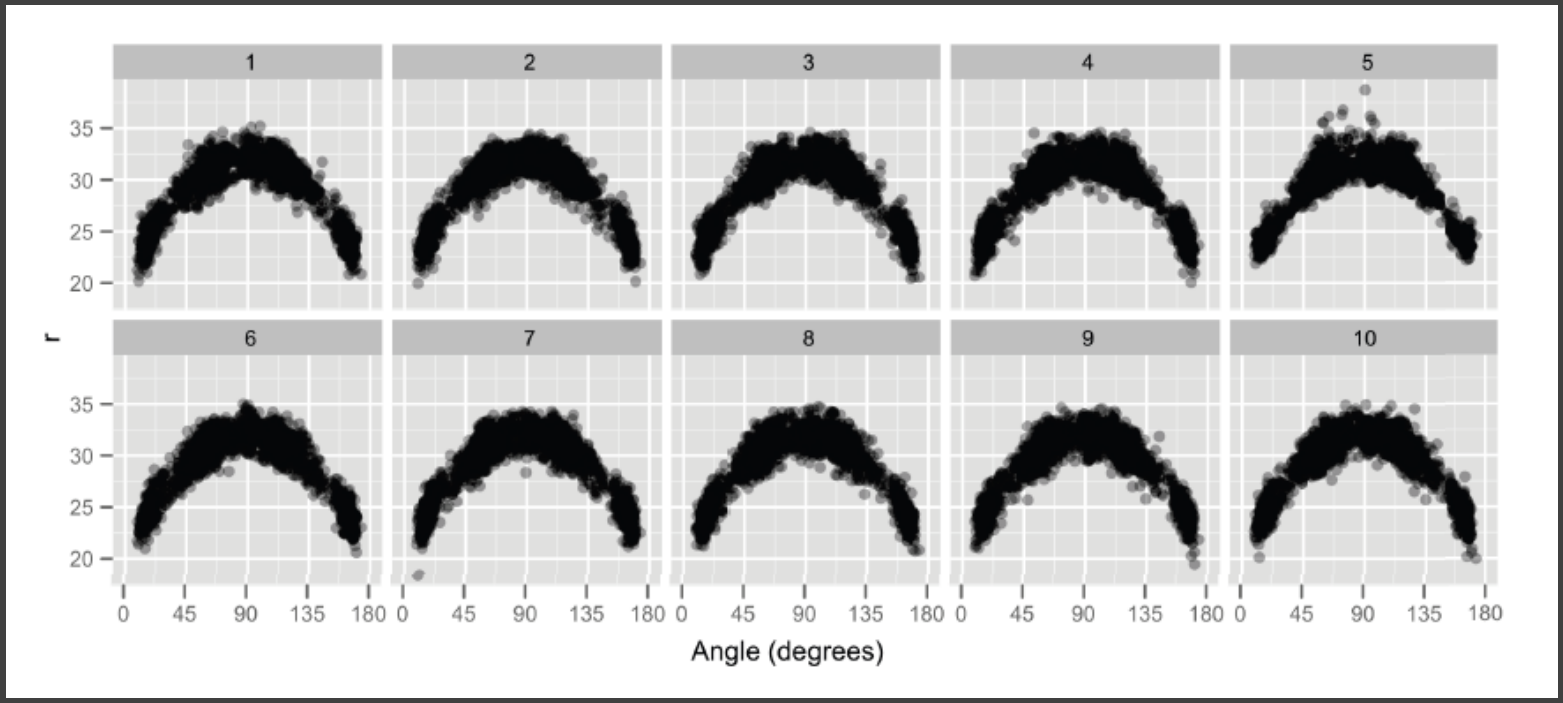
[Correll17] Correll, M. and Heer, J. "Black Hat Visualization." DECISIVe, 2017.

[Kindlmann14] Kindlmann, G. and Scheidegger, C. "An algebraic process for visualization design." *TVCG*, 2014.

[Plaisant96] Plaisant, C. et al. "Life Lines: Visualizing personal histories." *CHI,* 1996.

[Potter10] Potter, K. et al. "Visualizing summary statistics and uncertainty. *CGF,* 2010.

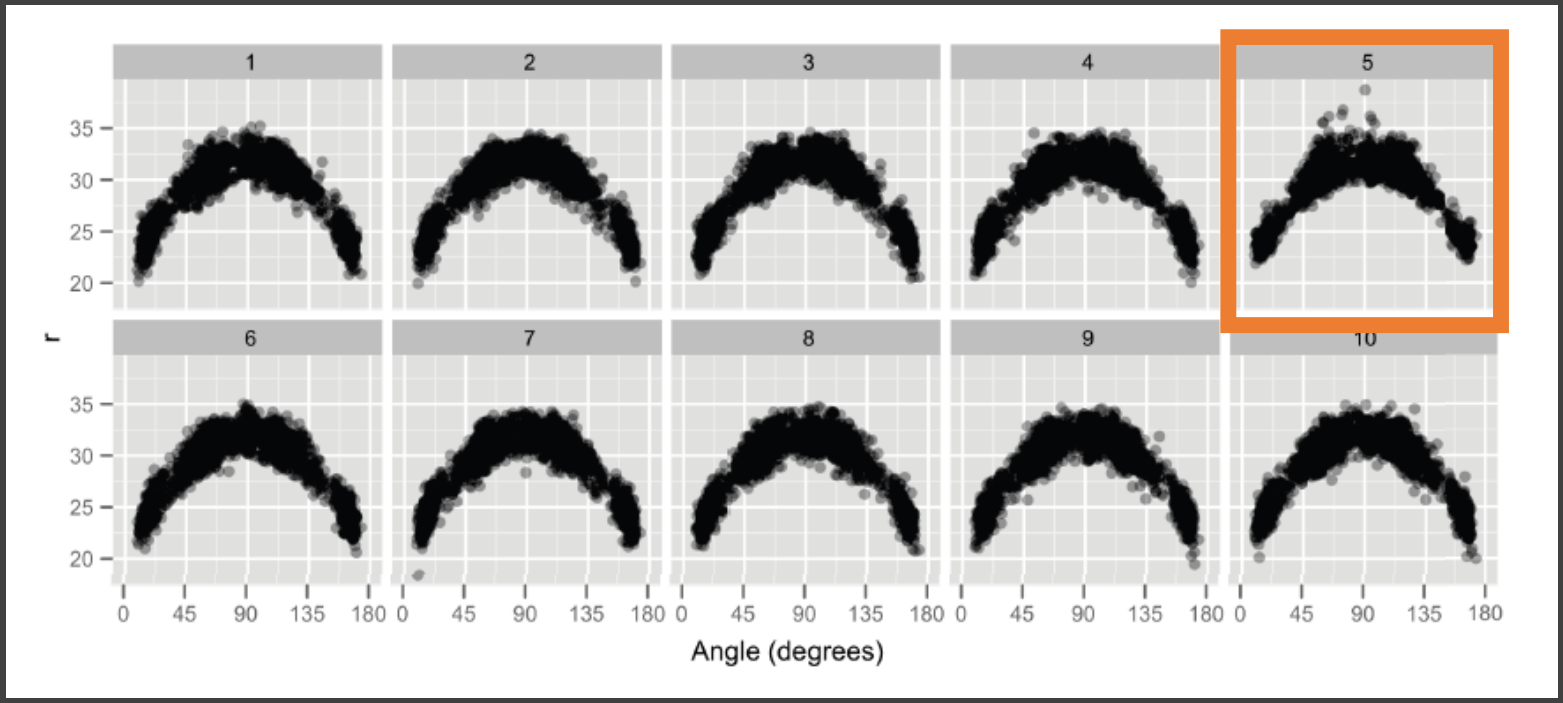
[Wickham10] Wickham, H et al. "Graphical Inference for InfoVis." *TVCG*, 2010.



Distance vs. angle for 3 point shots by the LA Lakers.

One plot is the real data. The others are generated according to a null hypothesis of quadratic relationship.

[Wickham10]



Distance vs. angle for 3 point shots by the LA Lakers.

One plot is the real data. The others are generated according to a null hypothesis of quadratic relationship.

[Wickham10]

Extra Slides

Data Oddities

Outliers
Trends
“Insights”
…

Data Oddities

Outliers
Trends
“Insights”
…

Visual Oddities

Patterns
Gestalts
…

Statistical Oddities

$p<0.05$
$x_i > Q_3 + 1.5\times IQR$
…

Data Oddities

Outliers
Trends
“Insights”
…

Visual Oddities

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Statistical Oddities

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$x_i > Q_3 + 1.5\times IQR$
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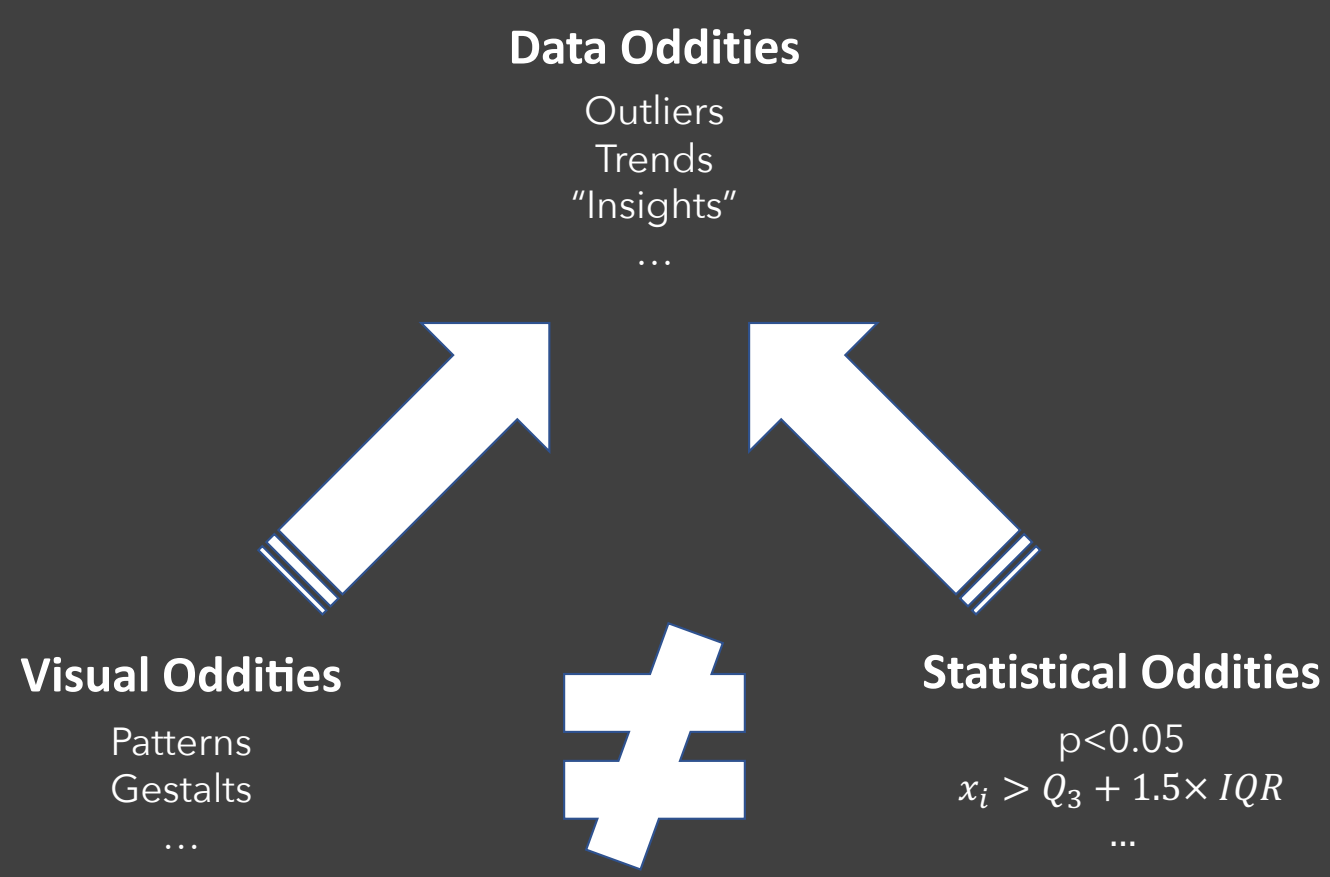
Data Oddities
Outliers
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"Insights"
…
Visual Oddities
Patterns
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Statistical Oddities
p<0.05
$x_i > Q_3 + 1.5\times IQR$
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Data Oddities

Outliers
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≠

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…

Data Oddities

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…

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…

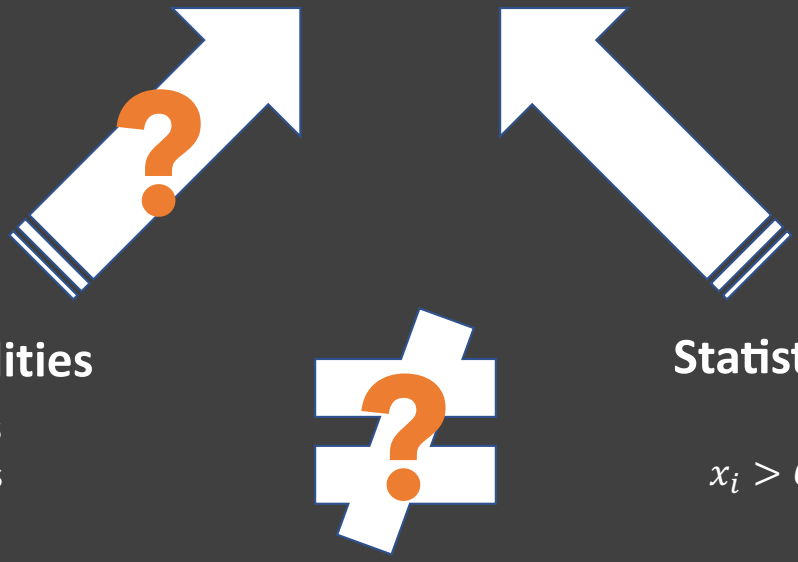
≠

Statistical Oddities

p<0.05
$x_i > Q_3 + 1.5 \times IQR$
…

Data Oddities

Outliers
Trends
"Insights"
…



Visual Oddities

Patterns
Gestalts
…

Statistical Oddities

p<0.05
$x_i > Q_3 + 1.5 \times IQR$
…

Set I		Set II		Set III		Set IV	
X	Y	X	Y	X	Y	X	Y
10	8.04	10	9.14	10	7.46	8	6.58
8	6.95	8	8.14	8	6.77	8	5.76
13	7.58	13	8.74	13	12.74	8	7.71
9	8.81	9	8.77	9	7.11	8	8.84
11	8.33	11	9.26	11	7.81	8	8.47
14	9.96	14	8.1	14	8.84	8	7.04
6	7.24	6	6.13	6	6.08	8	5.25
4	4.26	4	3.1	4	5.39	19	12.5
12	10.84	12	9.11	12	8.15	8	5.56
7	4.82	7	7.26	7	6.42	8	7.91
5	5.68	5	4.74	5	5.73	8	6.89

Summary Statistics
$u_X = 9.0$ $\sigma_X = 3.317$
$u_Y = 7.5$ $\sigma_Y = 2.03$

Linear Regression
$Y = 3 + 0.5\ X$
$R^2 = 0.67$

[Anscombe73]

Set I		Set II		Set III		Set IV	
X	Y	X	Y	X	Y	X	Y
10	8.04	10	9.14	10	7.46	8	6.58
8	6.95	8	8.14	8	6.77	8	5.76
13	7.58	13	8.74	13	12.74	8	7.71
9	8.81	9	8.77	9	7.11		
11	8.33	11	9.26	11			
14	9.96	14	8.1			8	7.04
6	7.24				6.08	8	5.25
4	4.26			4	5.39	19	12.5
12		12	9.11	12	8.15	8	5.56
7		7	7.26	7	6.42	8	7.91
5	5.68	5	4.74	5	5.73	8	6.89

🚨 Don't Turn Off Your Brain Yet 🚨

Summary Statistics
$u_X = 9.0$ $\sigma_X = 3.317$
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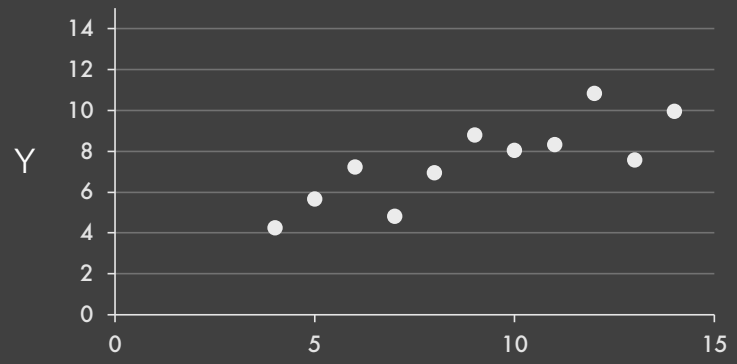
[Anscombe73]

Set I



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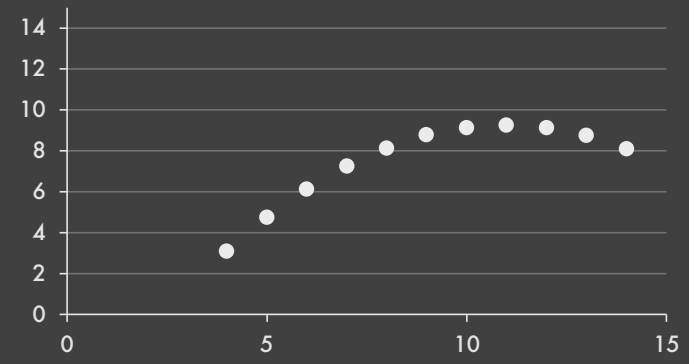

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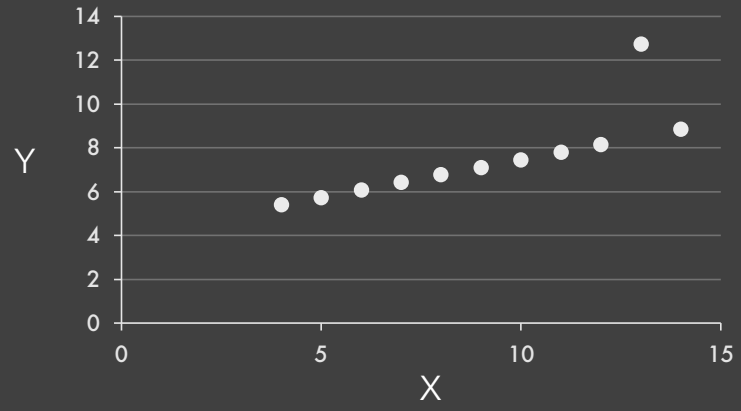

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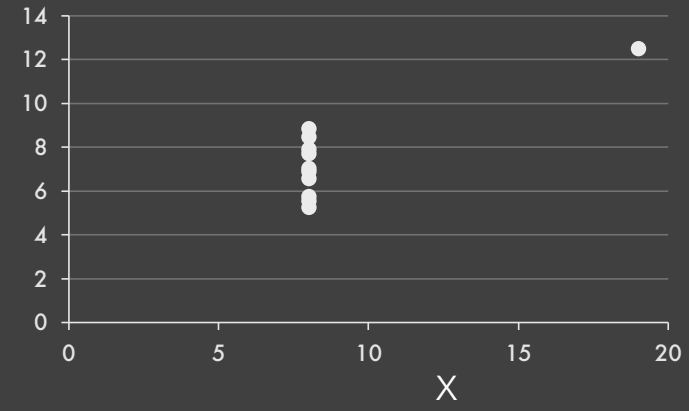


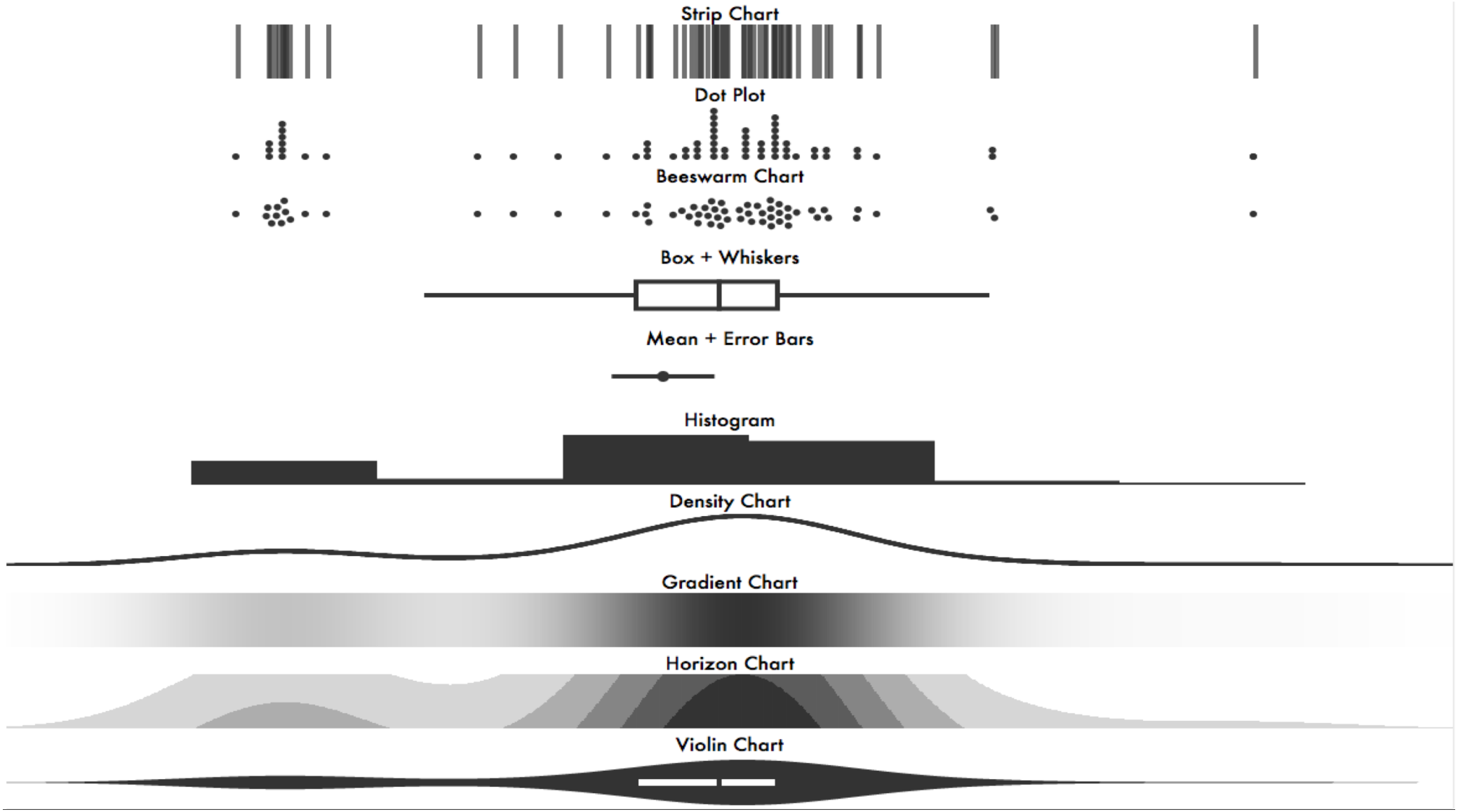
Research Questions

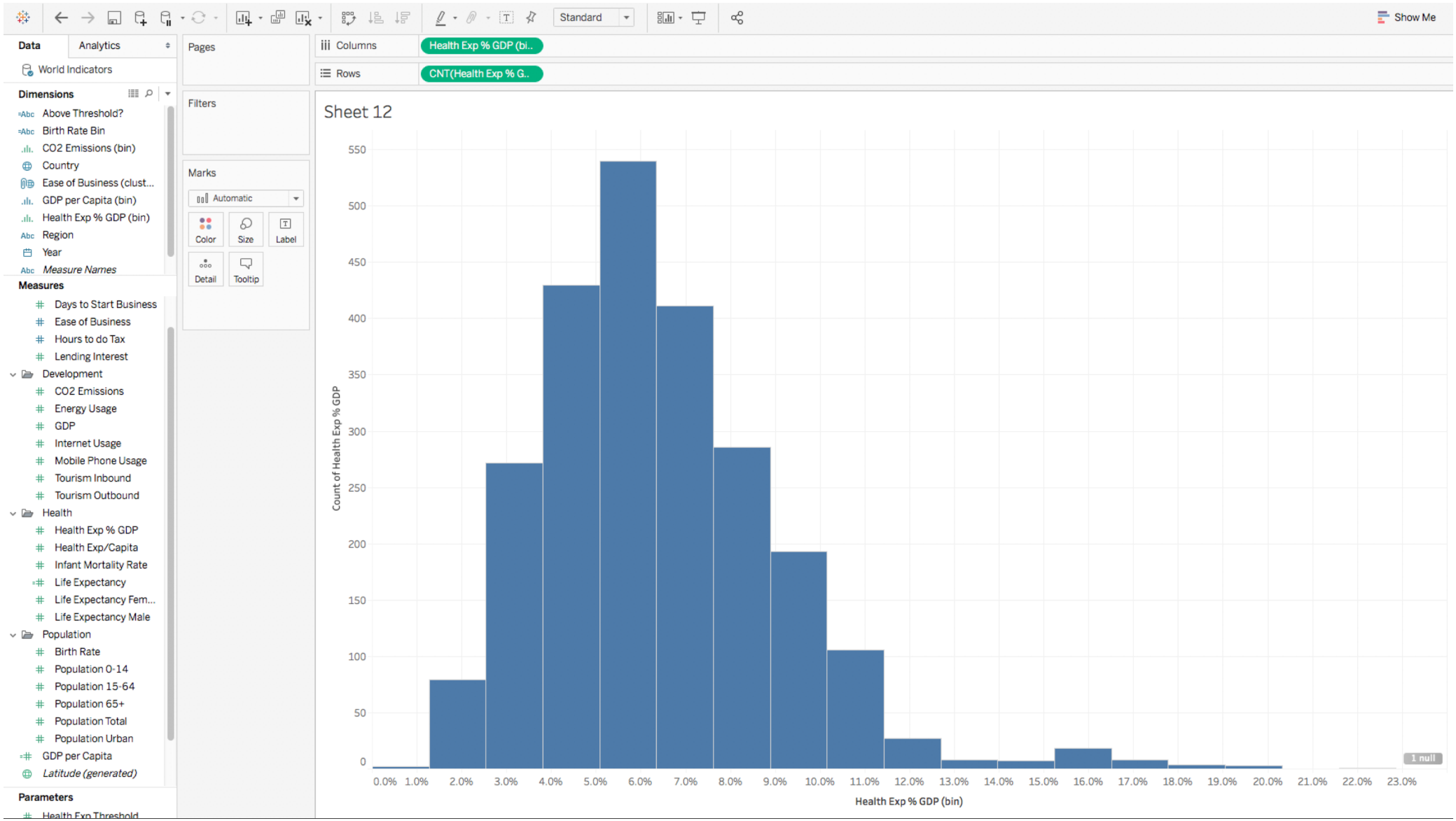
Do data quality issues we care about have **characteristic visual patterns** in our visualizations?

Are these characteristic patterns **robustly detectable**?

tl;dr: **we did a penetration test on univariate summaries**


Penetration Testing
user01
ACCESS GRANTED
EUROPE
AMERICA
AFRICA
SEARCH
PASSWORD


Strip Chart
Dot Plot
Beeswarm Chart
Box + Whiskers
Mean + Error Bars
Histogram
Density Chart
Gradient Chart
Horizon Chart
Violin Chart


Standard
Show Me
Data
Analytics
World Indicators
Dimensions
Above Threshold?
Birth Rate Bin
CO2 Emissions (bin)
Country
Ease of Business (clust...
GDP per Capita (bin)
Health Exp % GDP (bin)
Region
Year
Measure Names
Measures
Days to Start Business
Ease of Business
Hours to do Tax
Lending Interest
Development
CO2 Emissions
Energy Usage
GDP
Internet Usage
Mobile Phone Usage
Tourism Inbound
Tourism Outbound
Health
Health Exp % GDP
Health Exp/Capita
Infant Mortality Rate
Life Expectancy
Life Expectancy Fem...
Life Expectancy Male
Population
Birth Rate
Population 0-14
Population 15-64
Population 65+
Population Total
Population Urban
GDP per Capita
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Detail
Tooltip
Columns
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Sheet 12
Count of Health Exp % GDP
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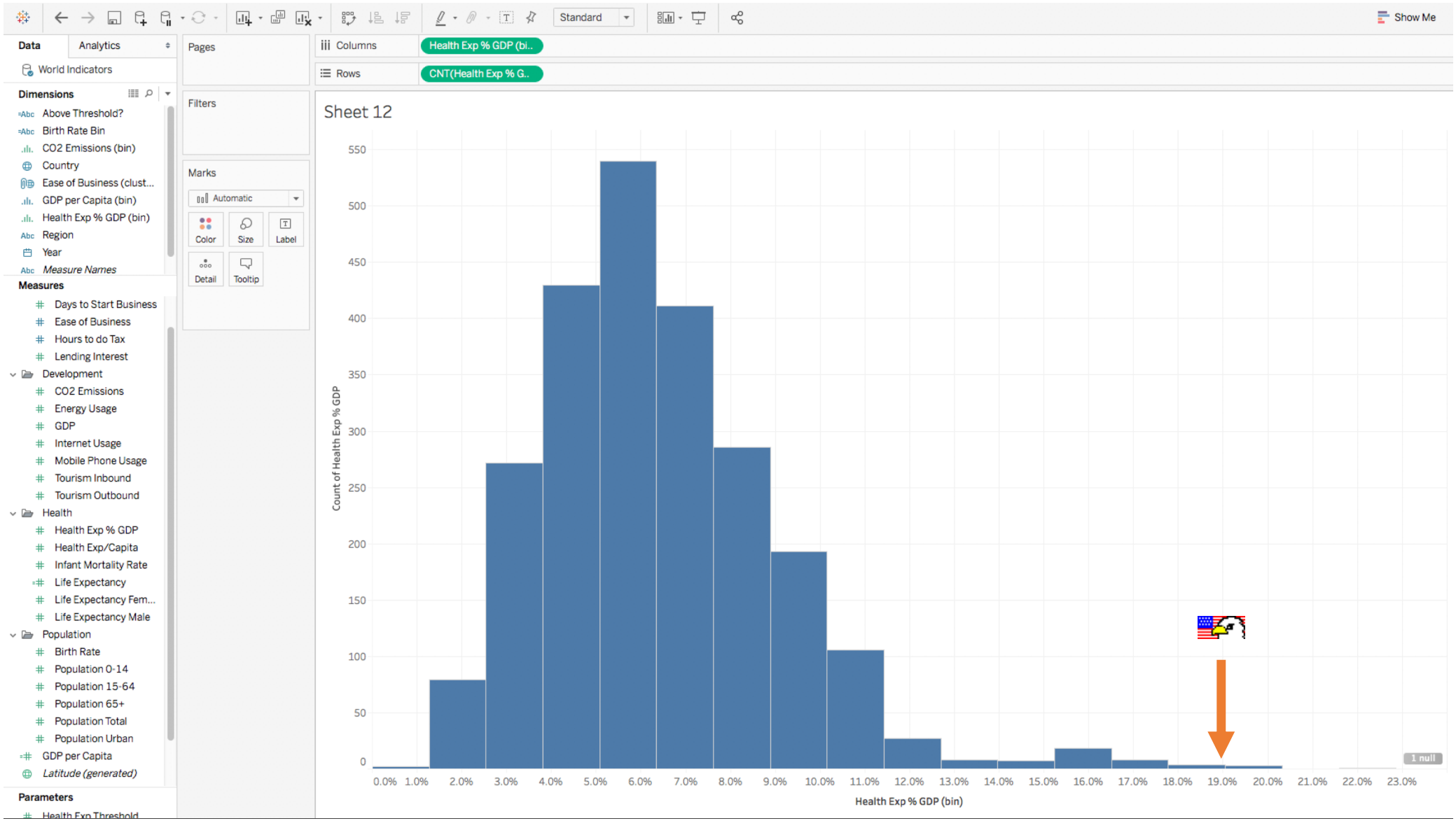
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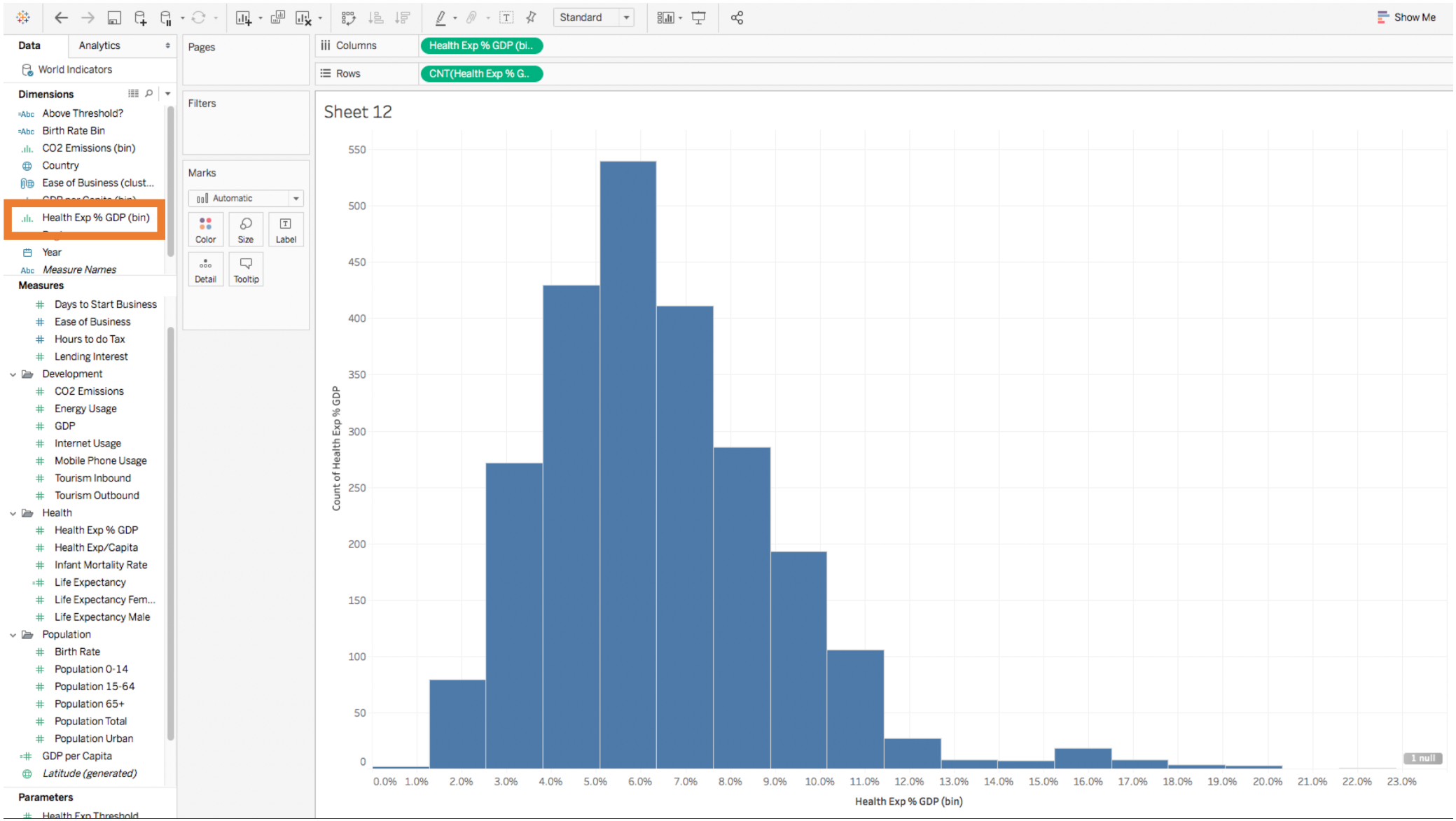
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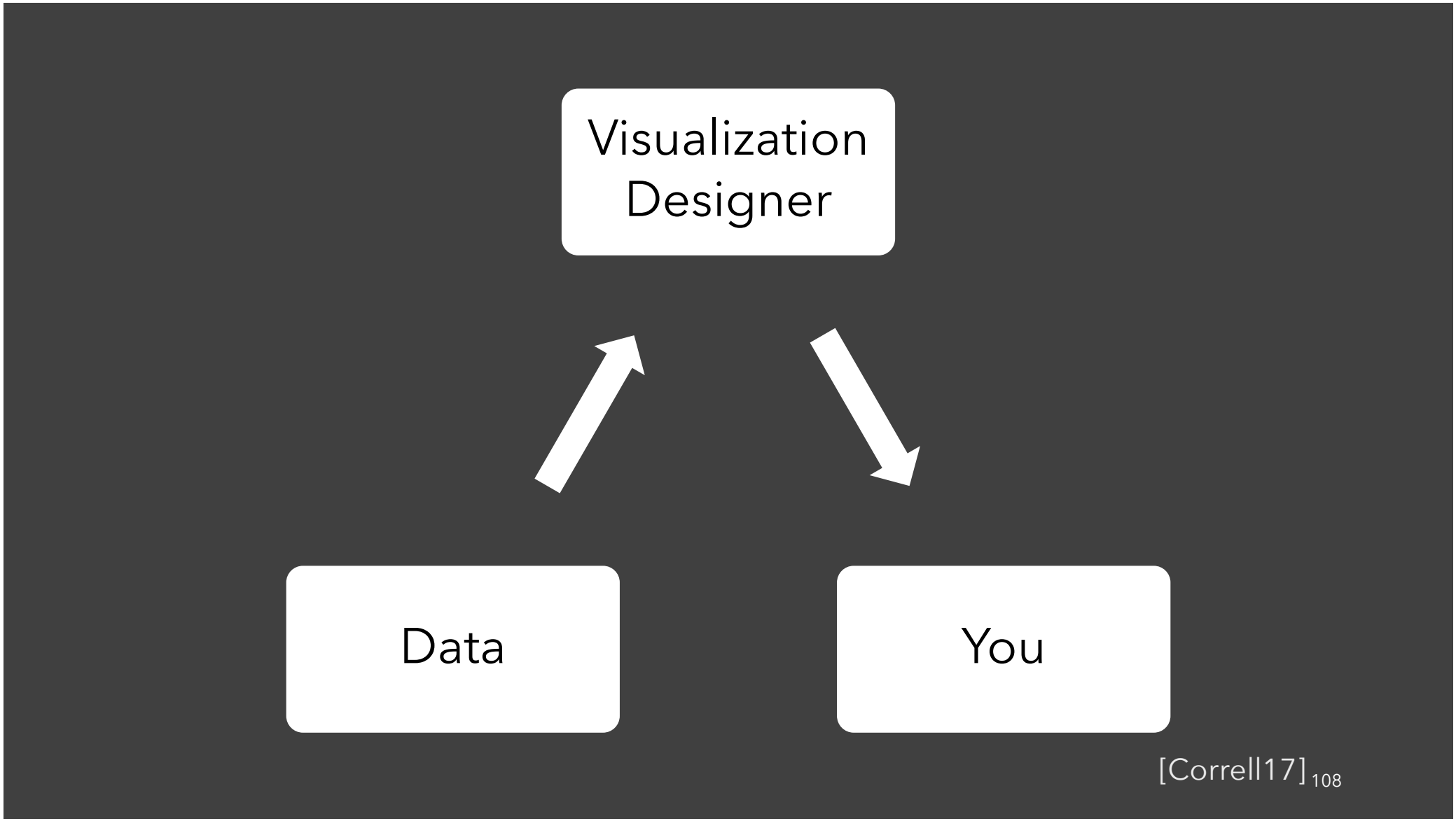
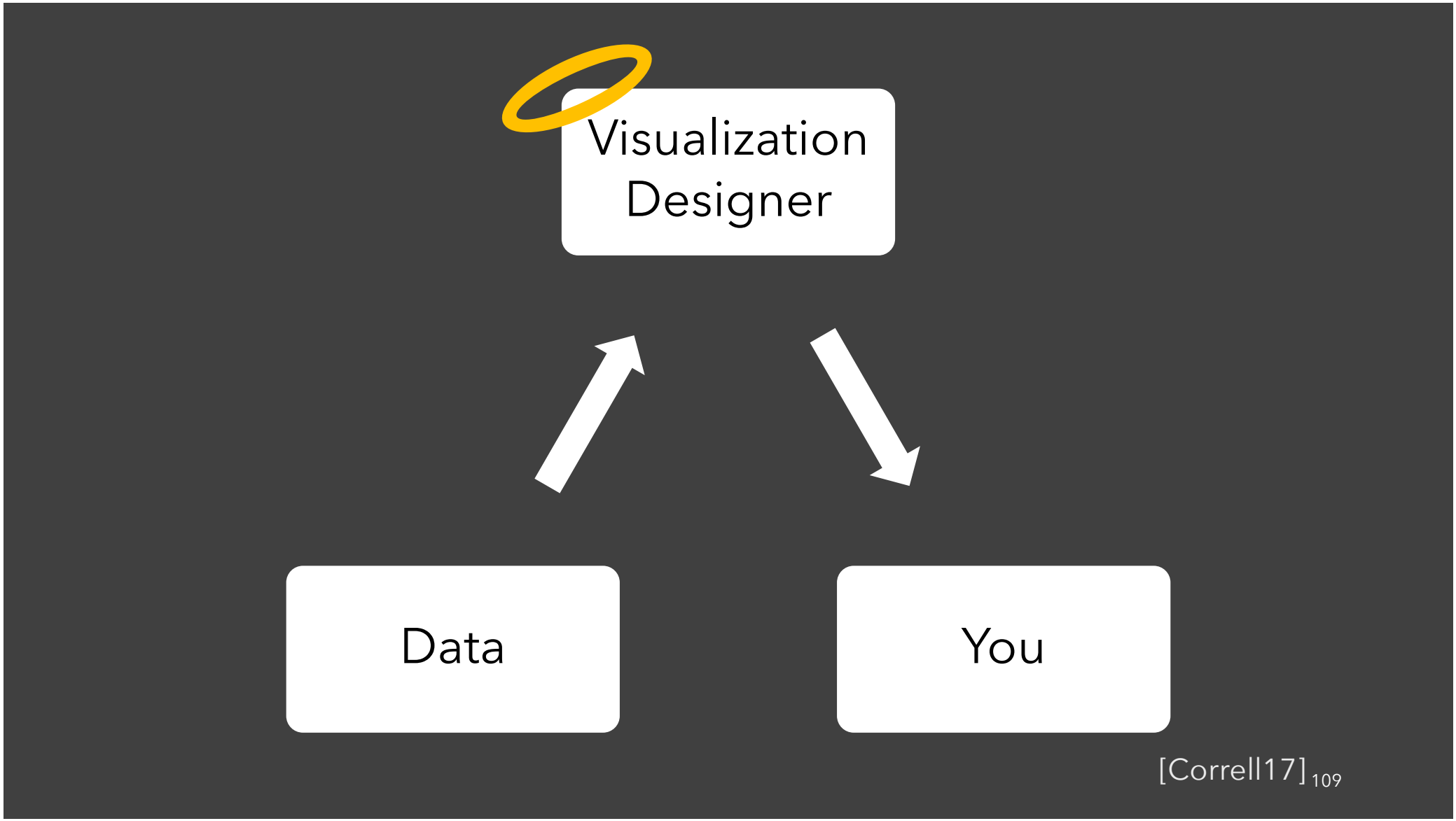
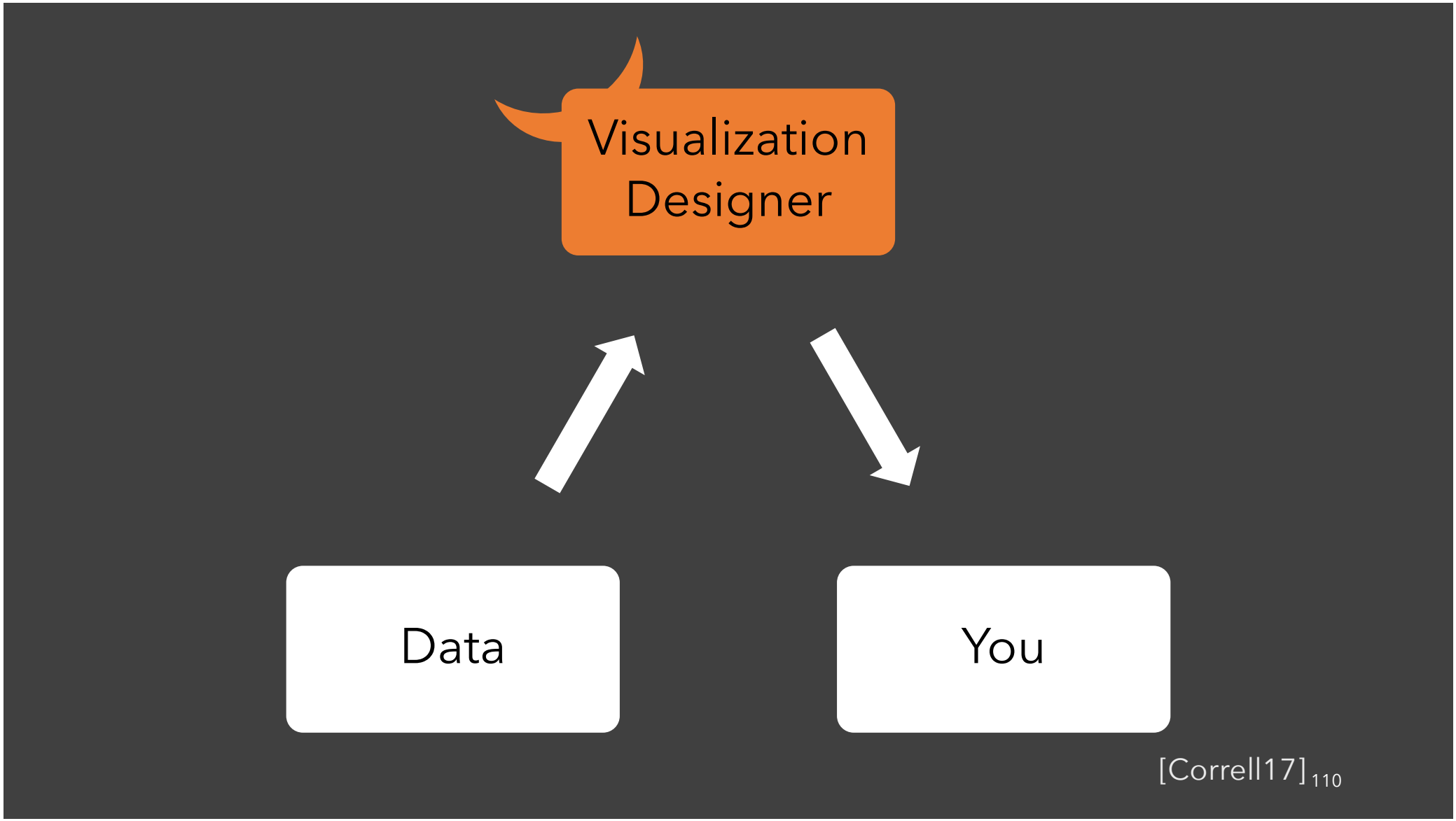


[Correll17]

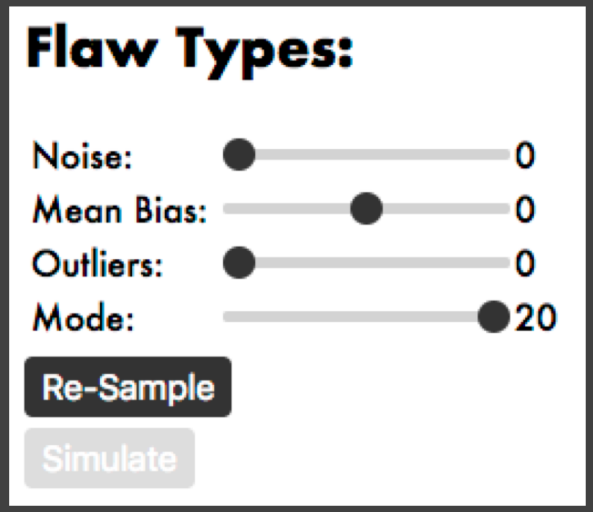


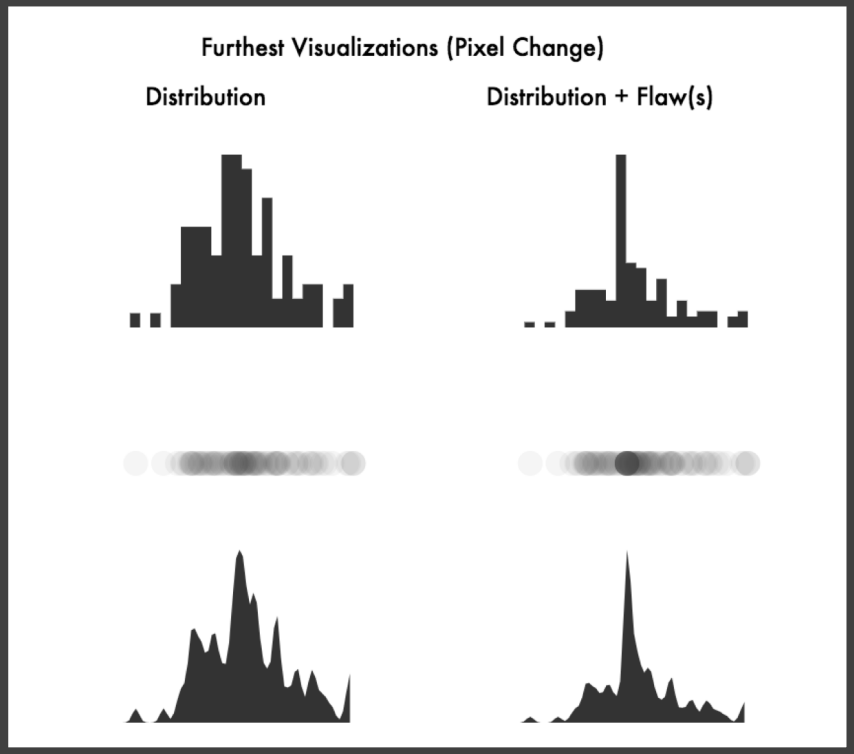
[Correll17]



[Correll17]

Visualization Attack





Visualization Attack