

Keeping Multiple Views Consistent

Constraints, **Validations**, **Exceptions**

in Visualization Authoring



@ZeningQu



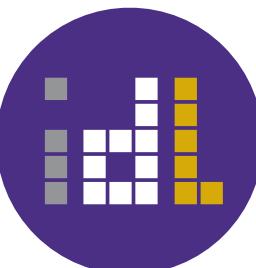
@JessicaHullman



@UW



@uwdub



@uwdata

Keeping Multiple Views Consistent

Constraints, **Validations**, **Exceptions**

in Visualization Authoring



Dashboards, Narrative Stories,
Coordinated Views...



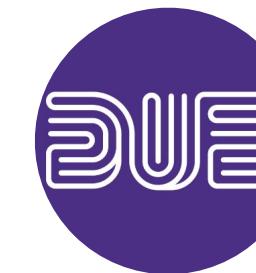
@ZeningQu



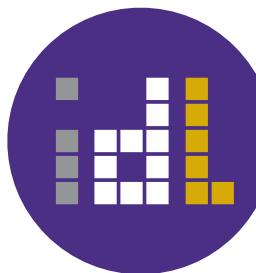
@JessicaHullman



W@UW



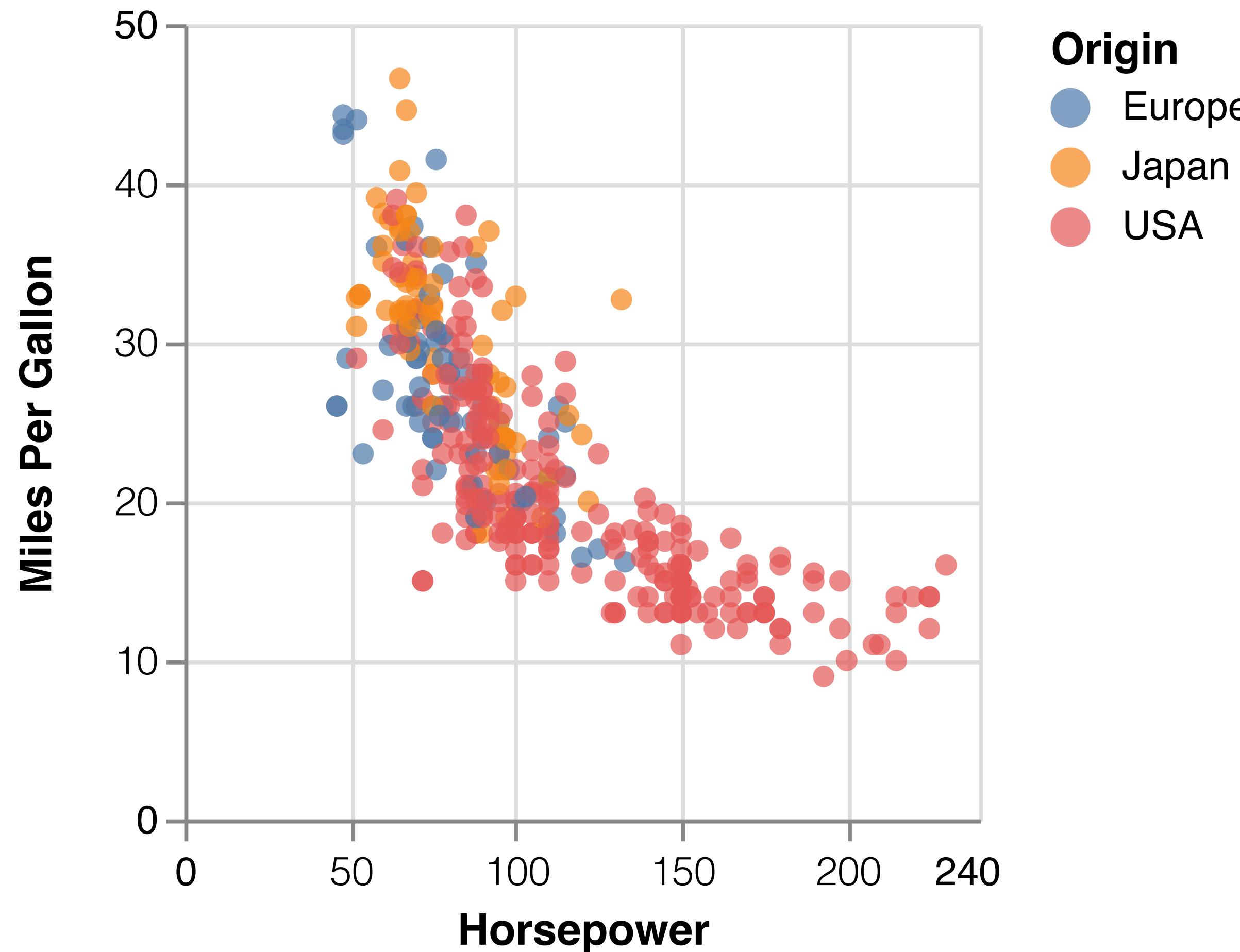
DUB @uwdub



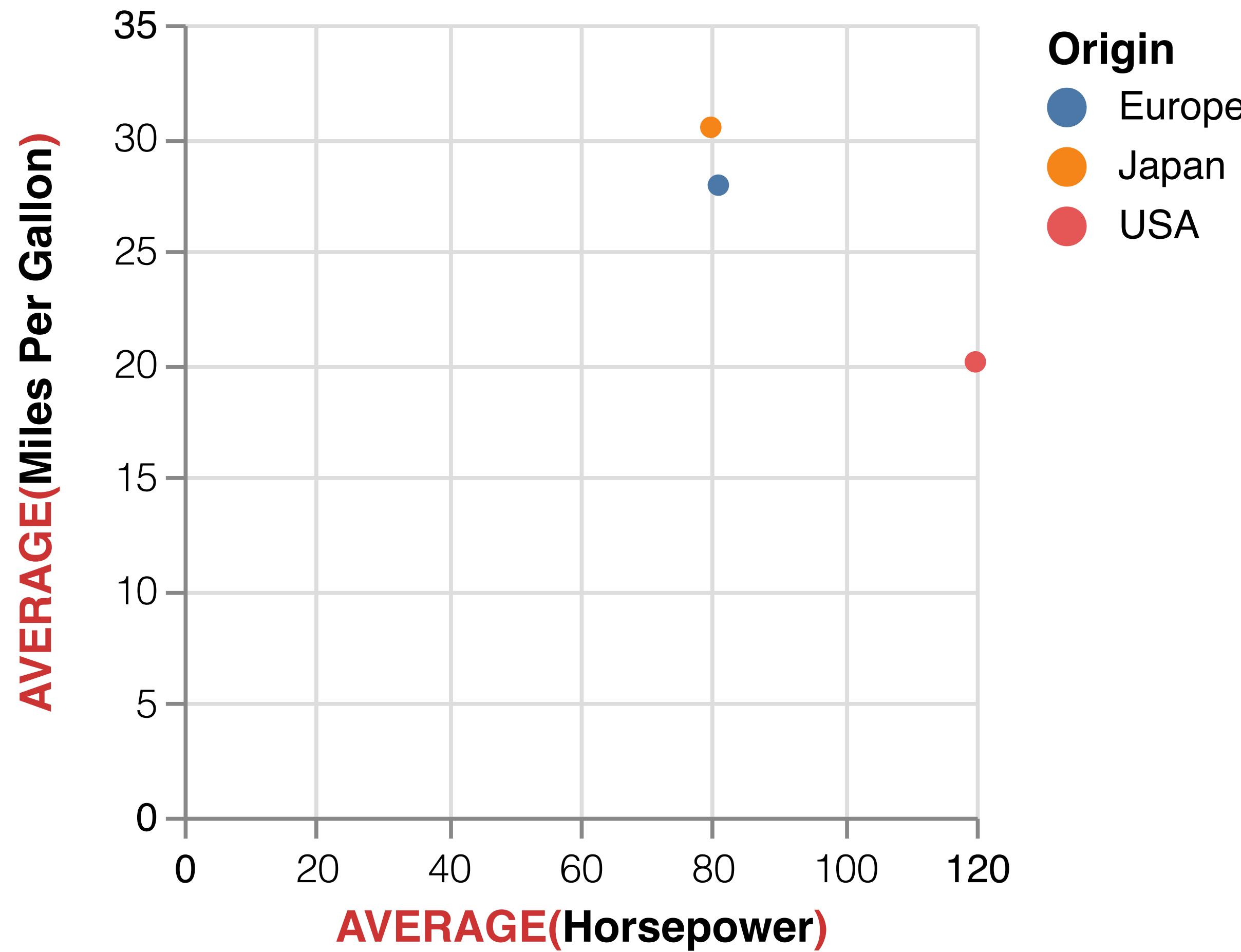
UW Data @uwdata

The Consistency Problem

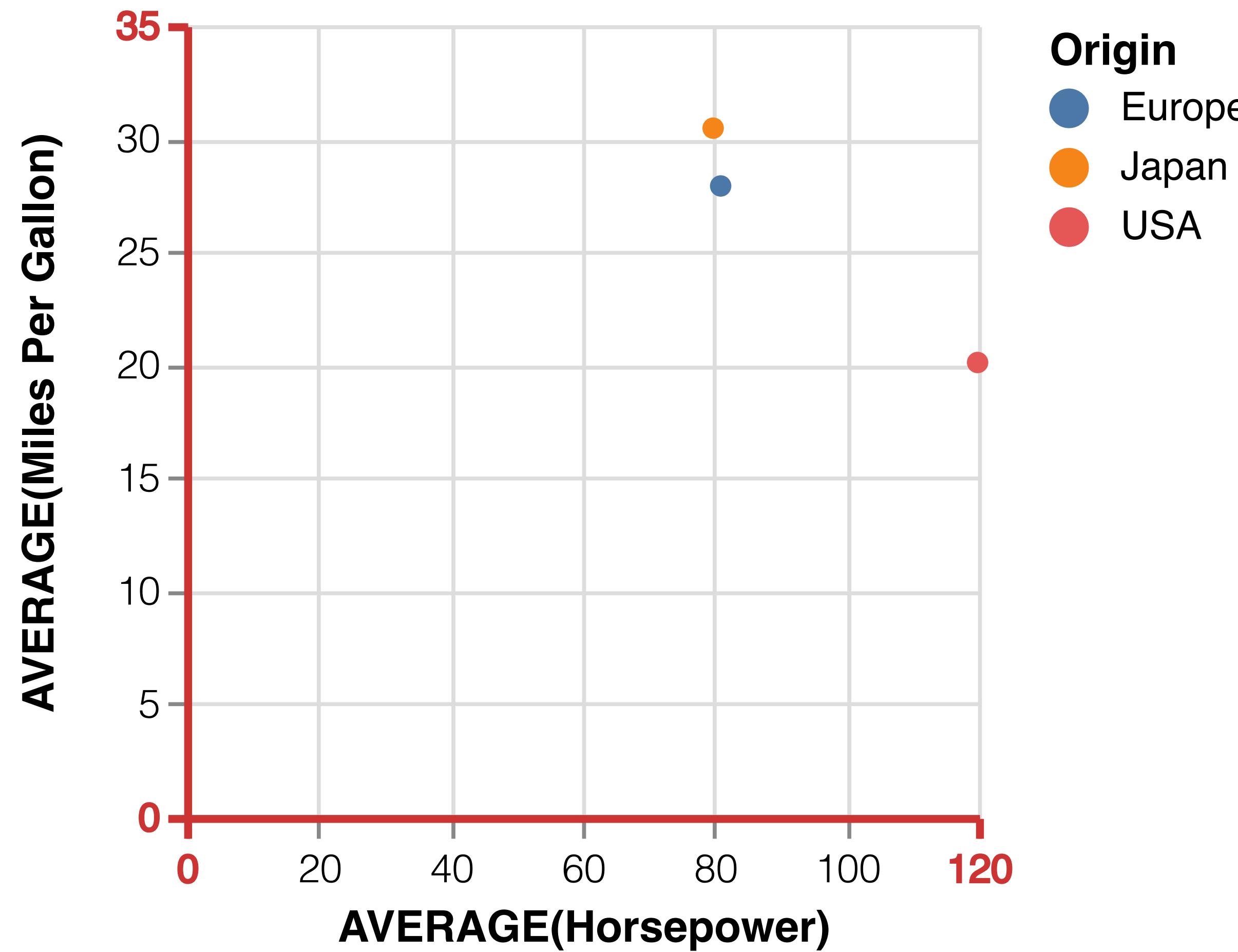
Creating Single Views



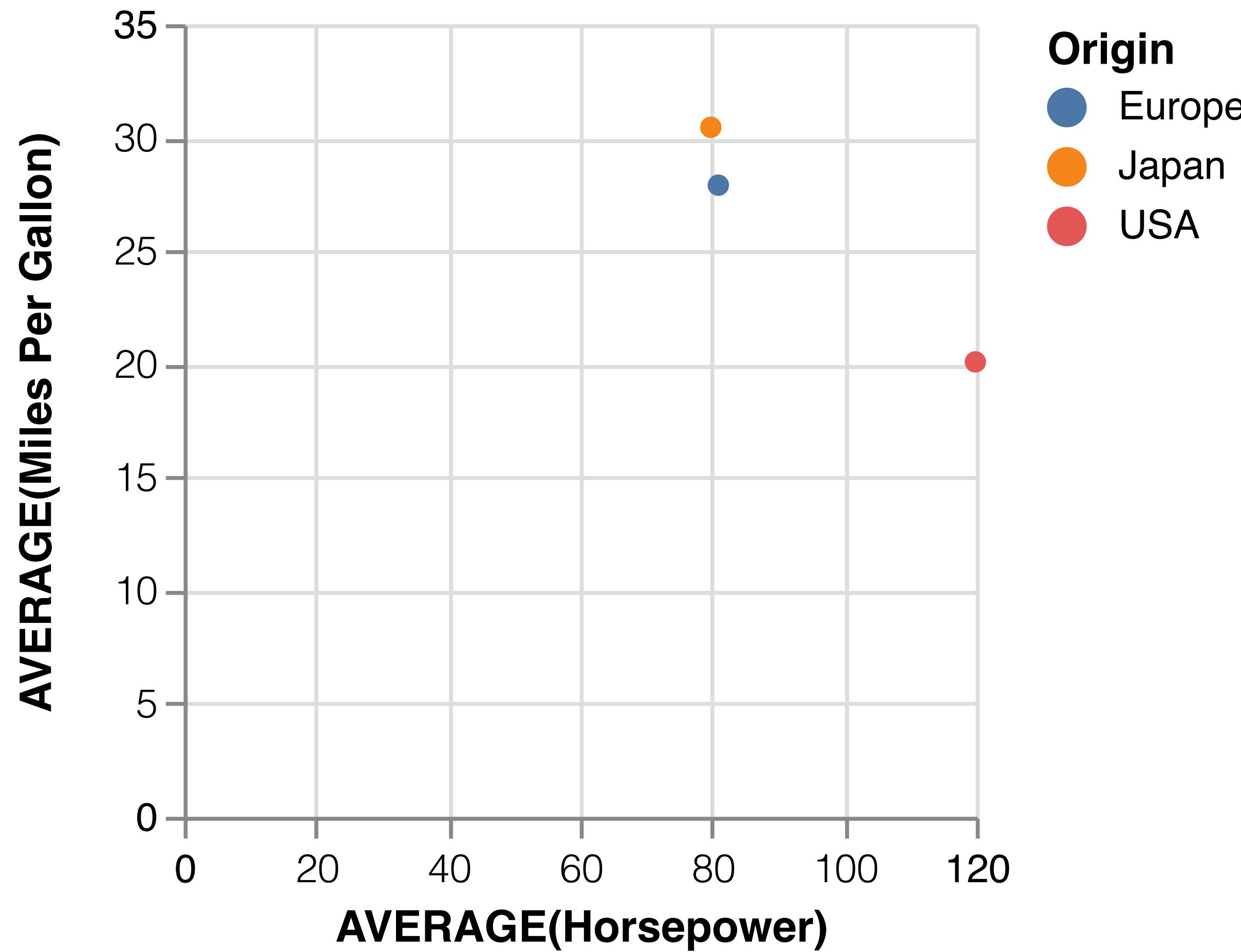
Creating Single Views



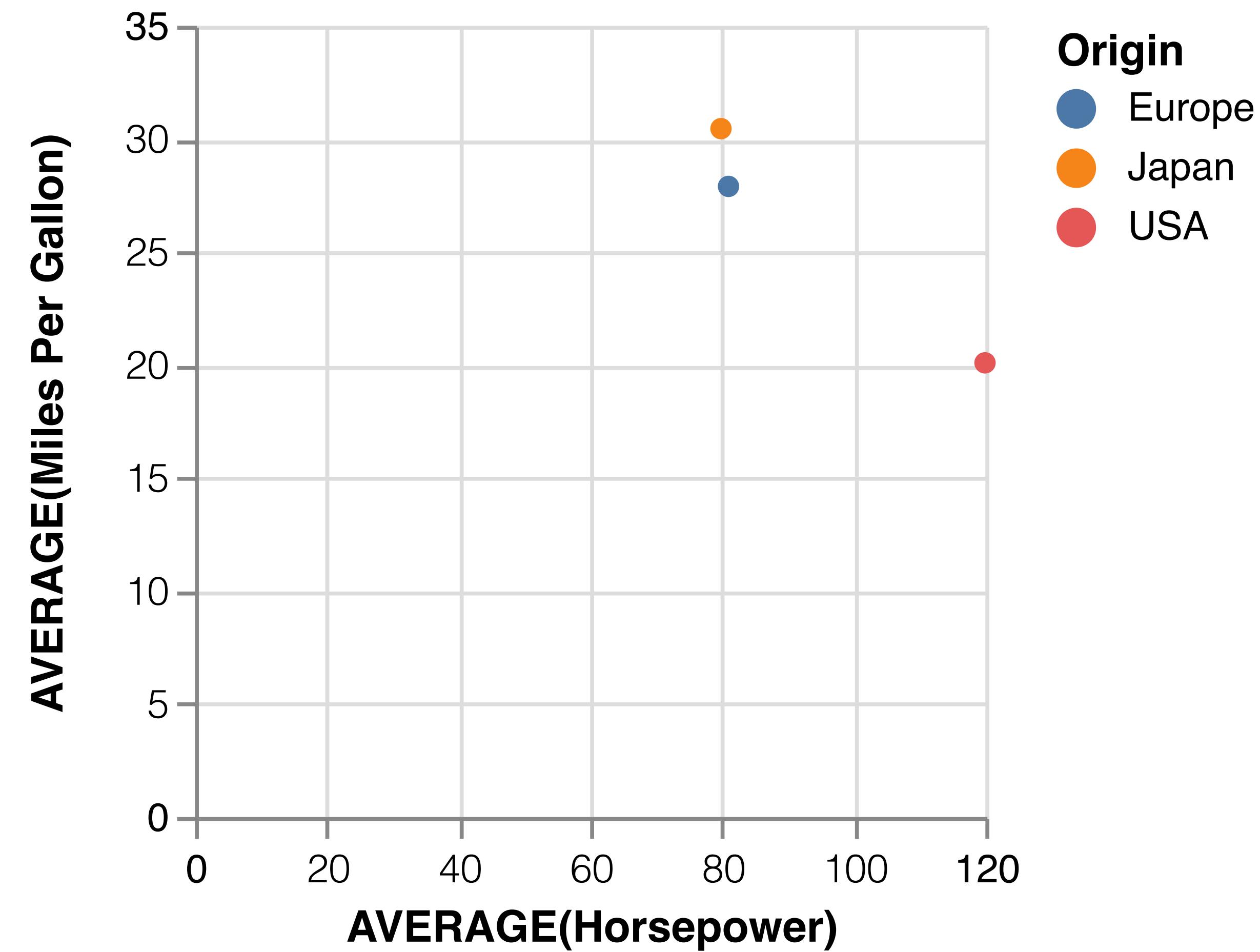
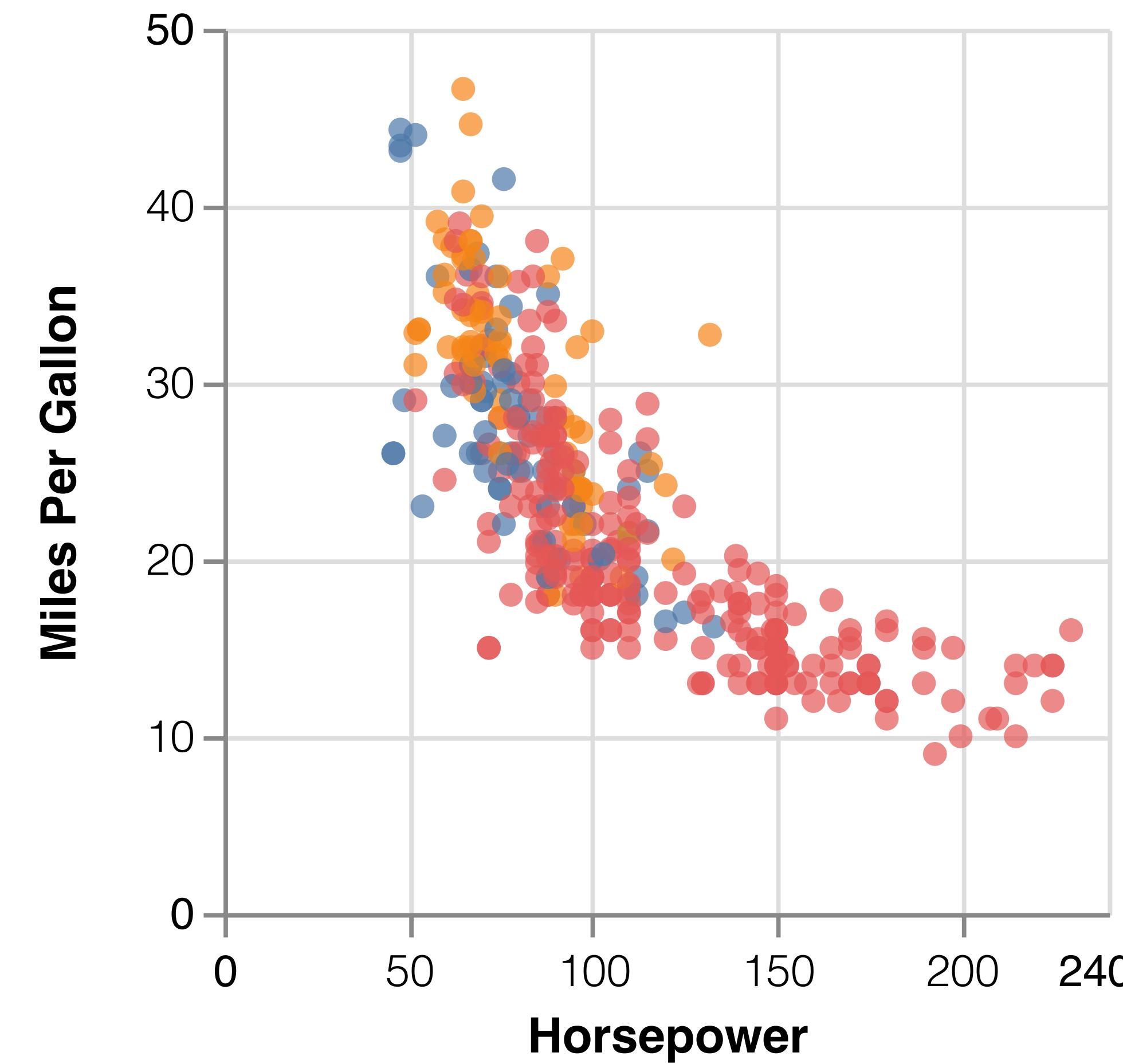
Creating Single Views



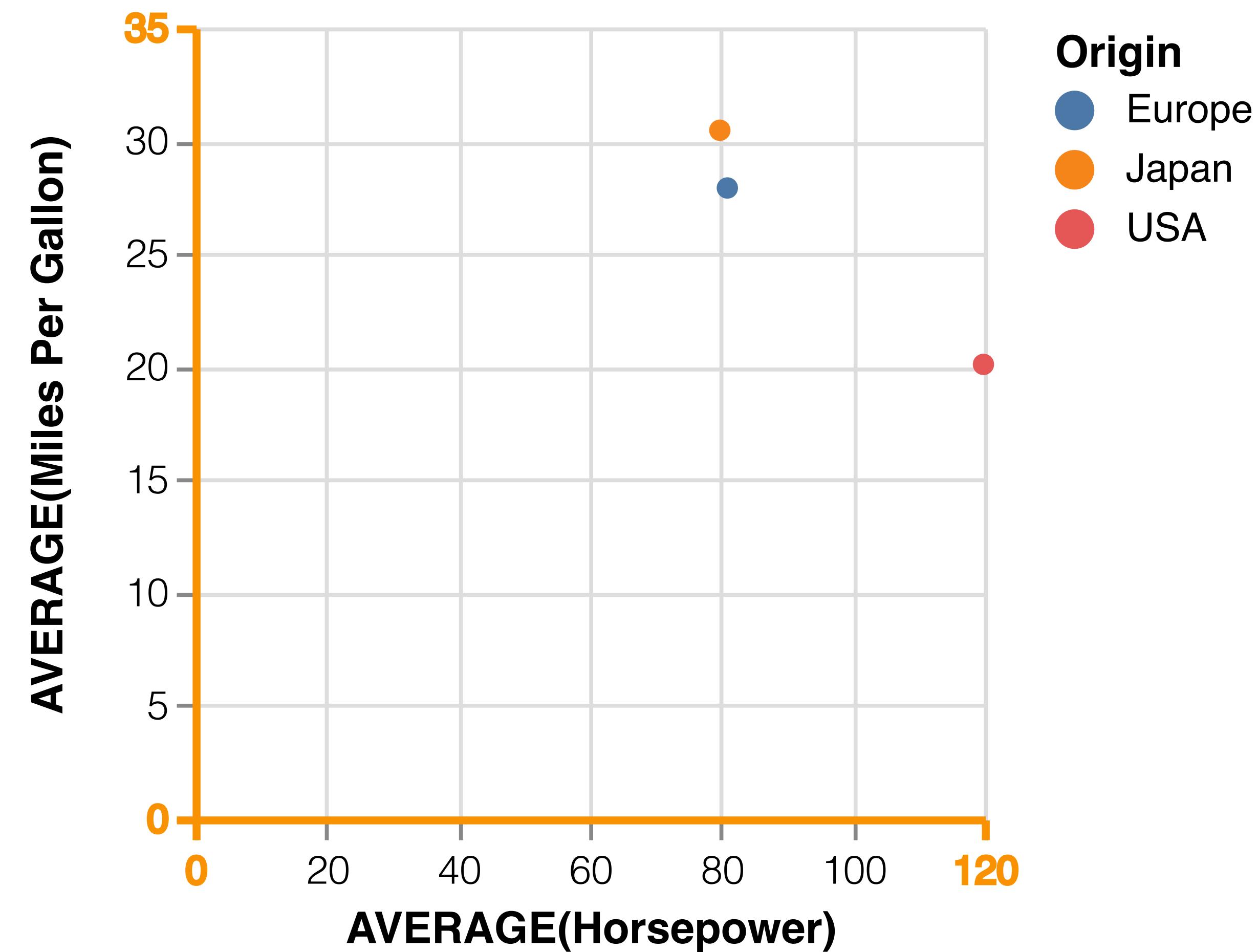
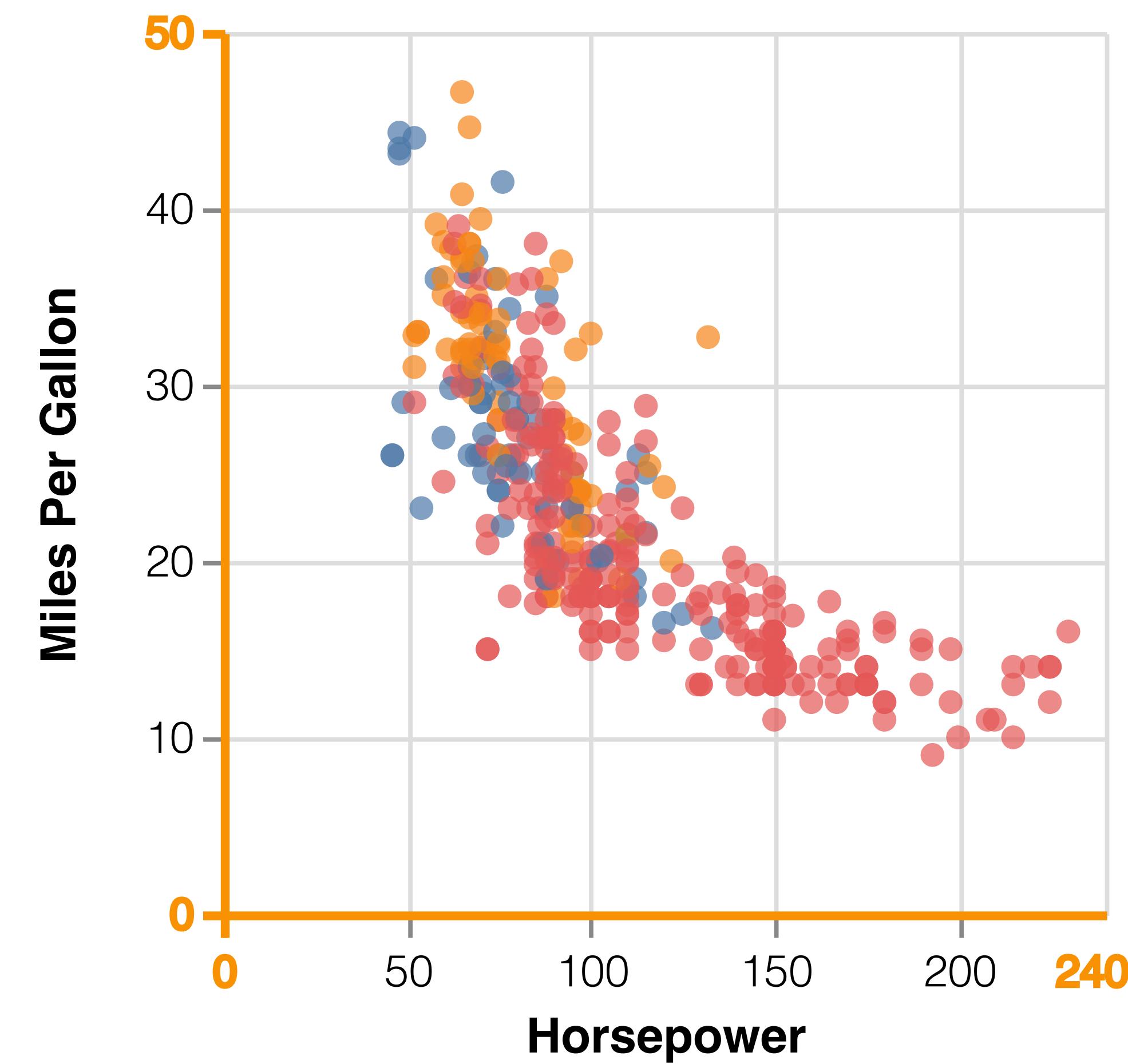
Creating Single Views



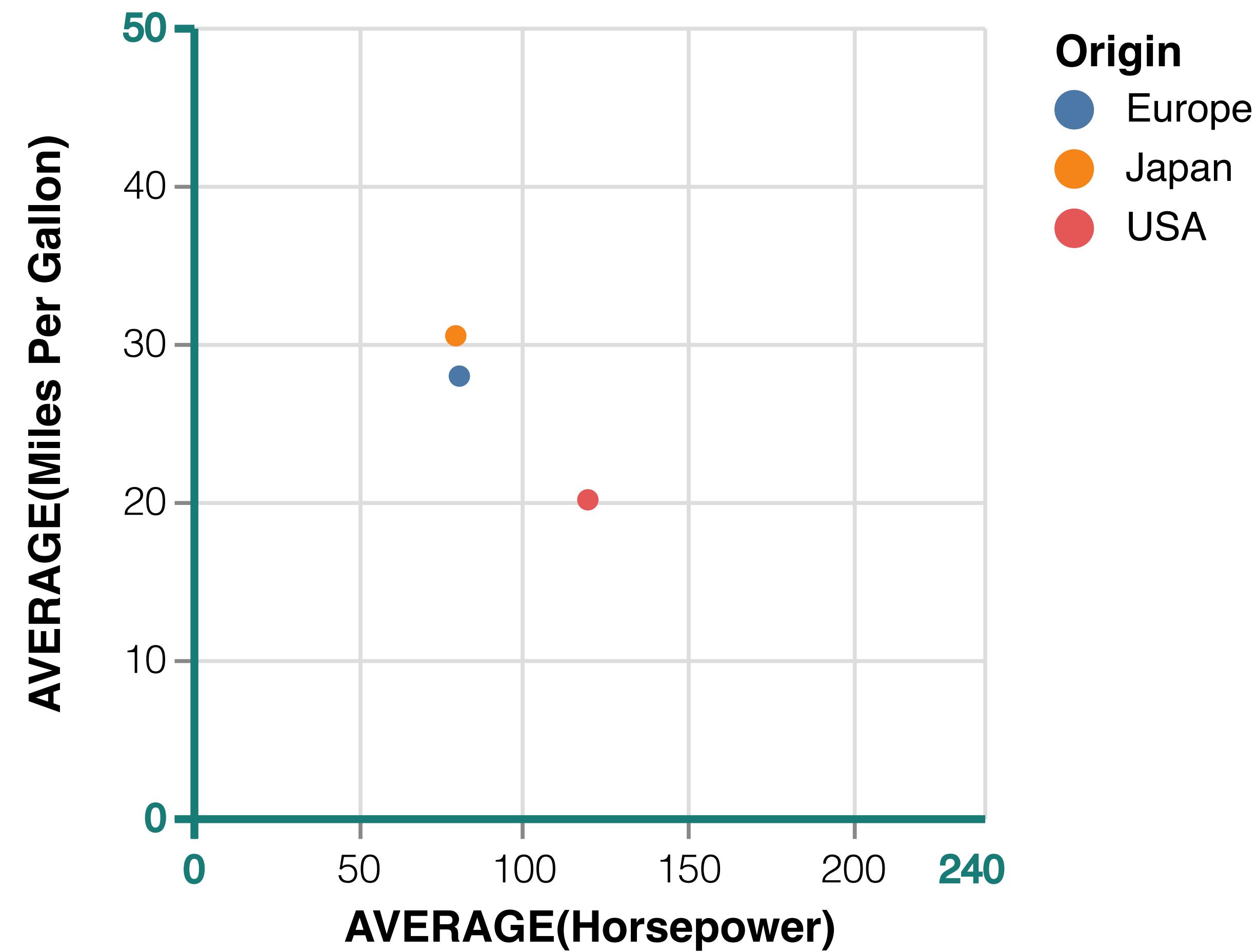
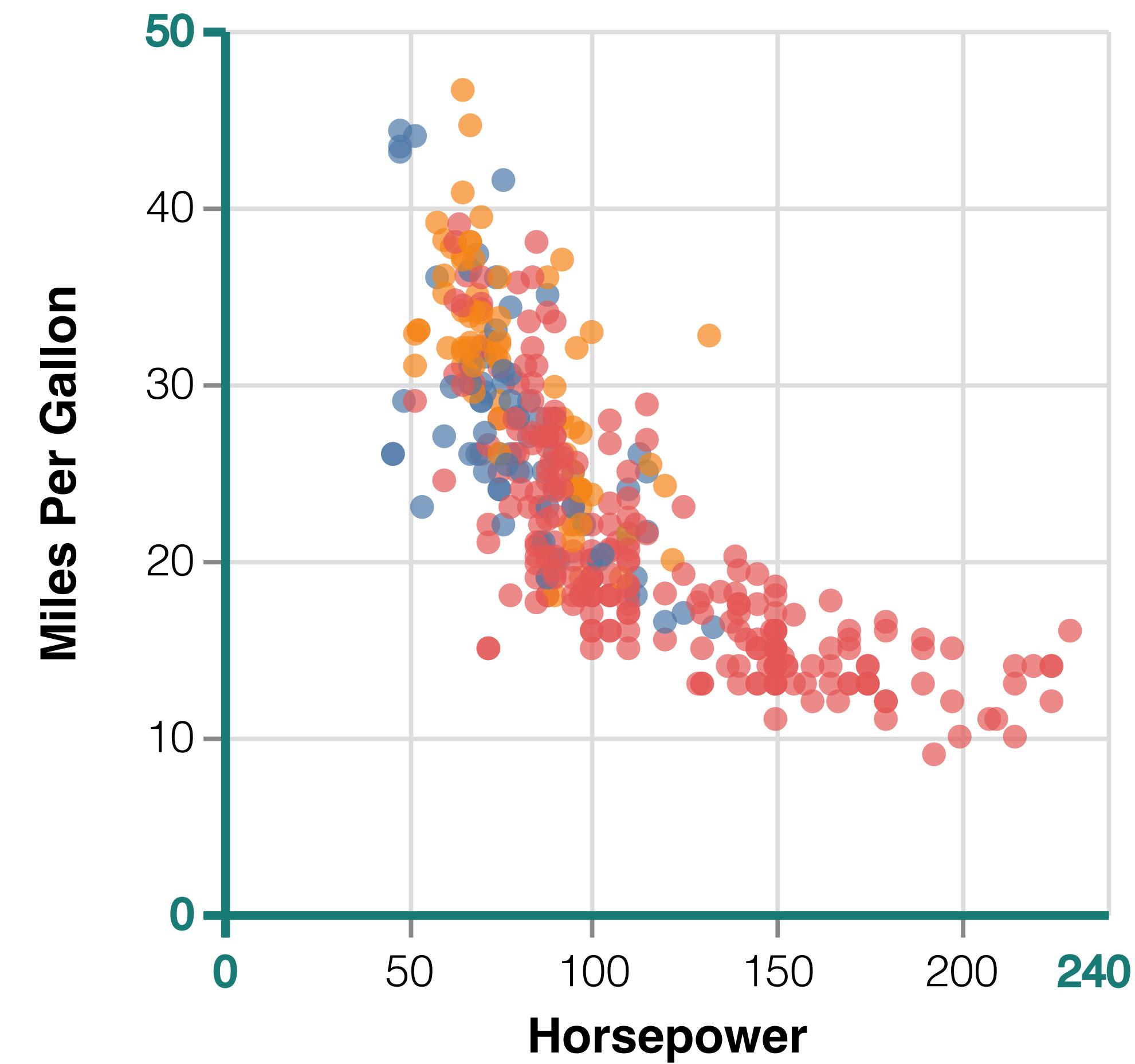
Presenting Multiple Inconsistent Views



Presenting Multiple Inconsistent Views



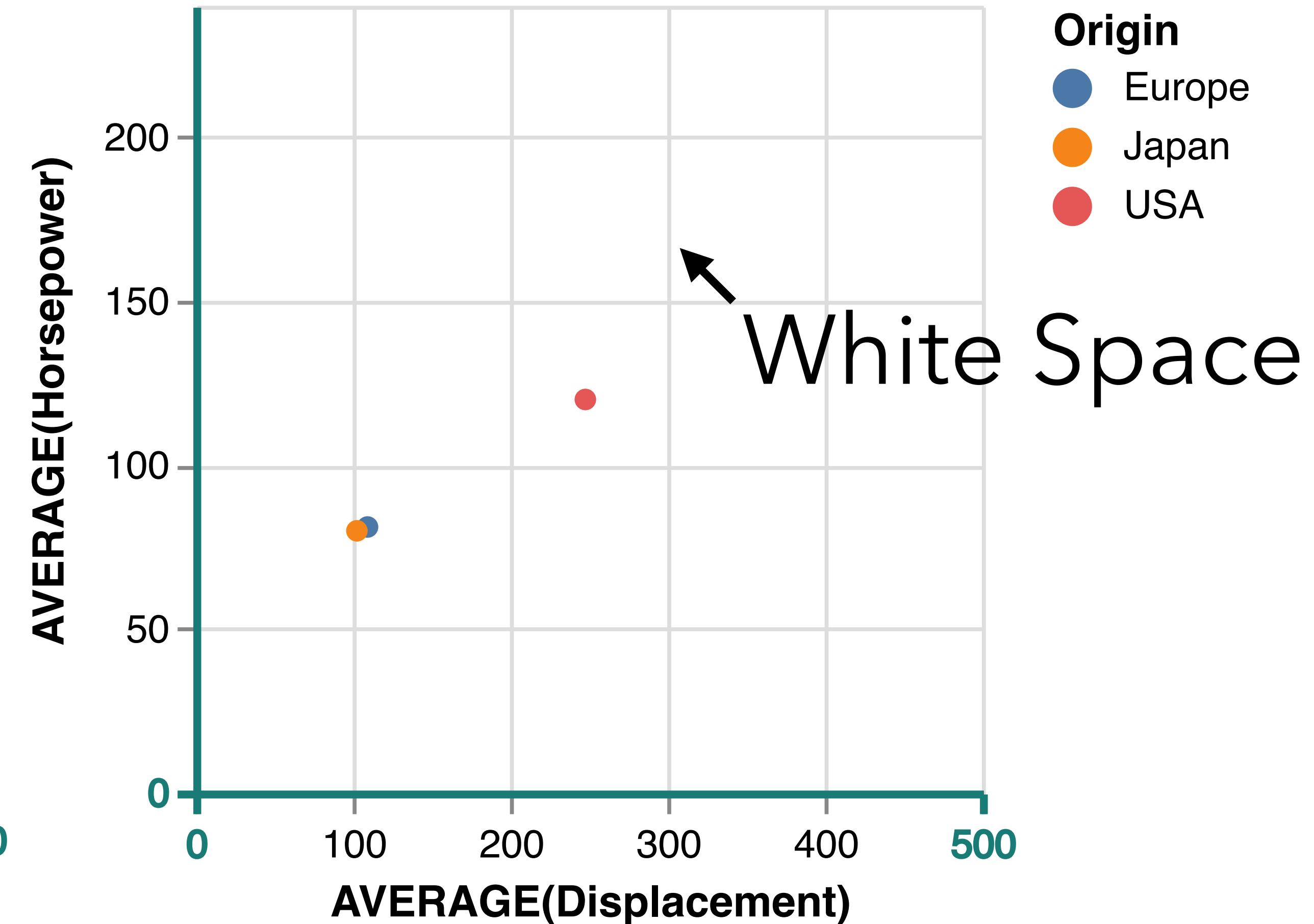
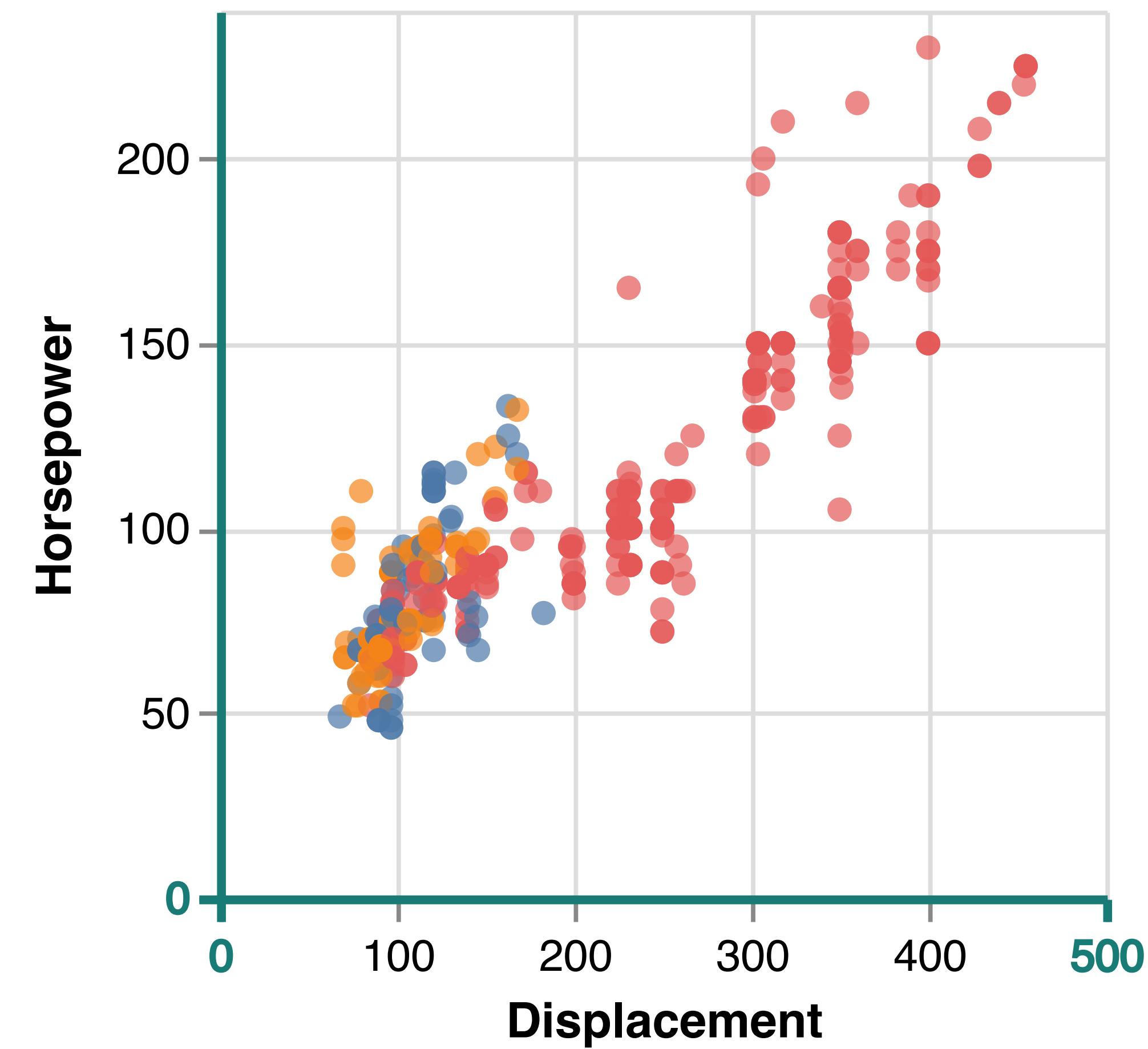
Presenting Multiple Inconsistent Views



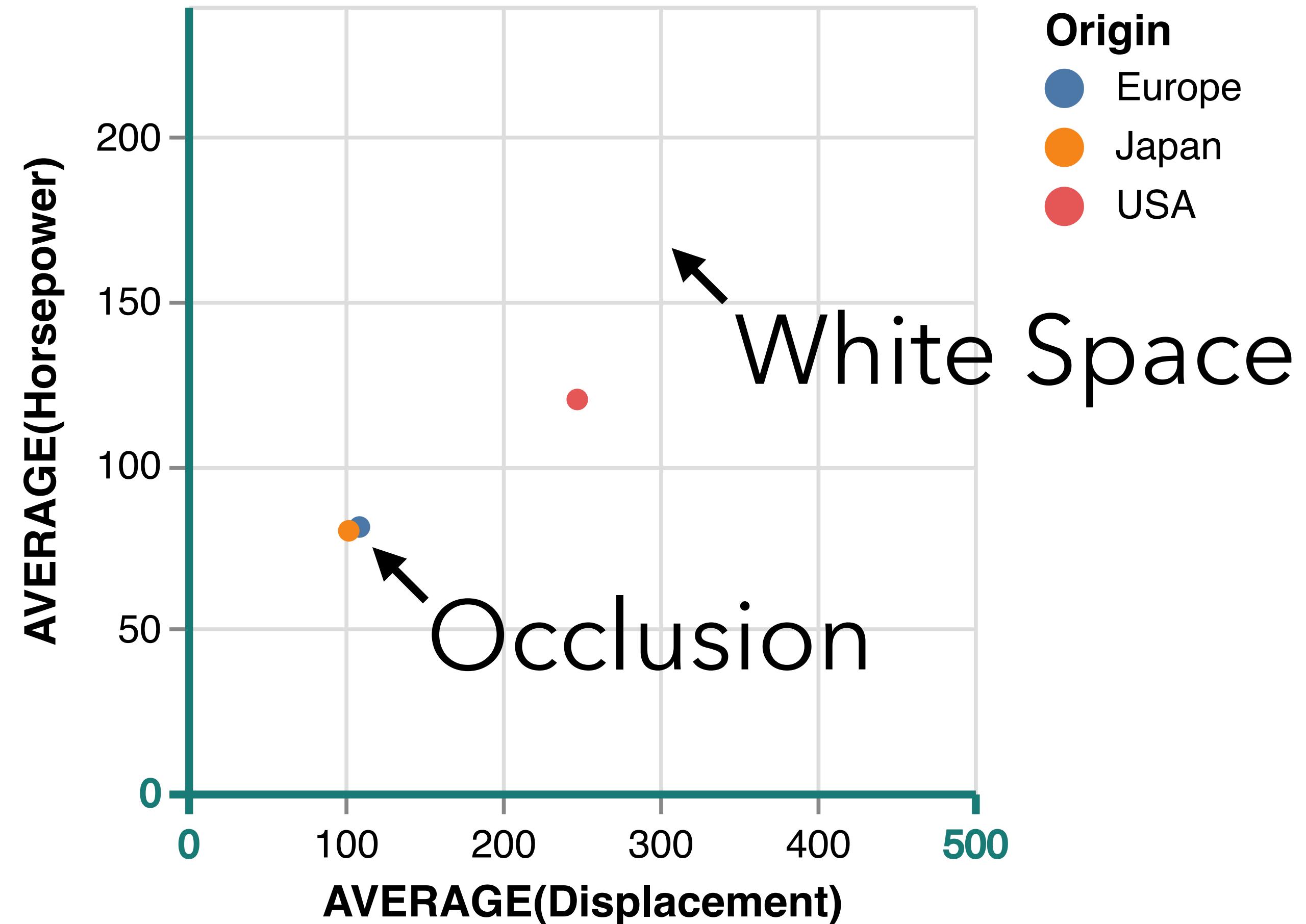
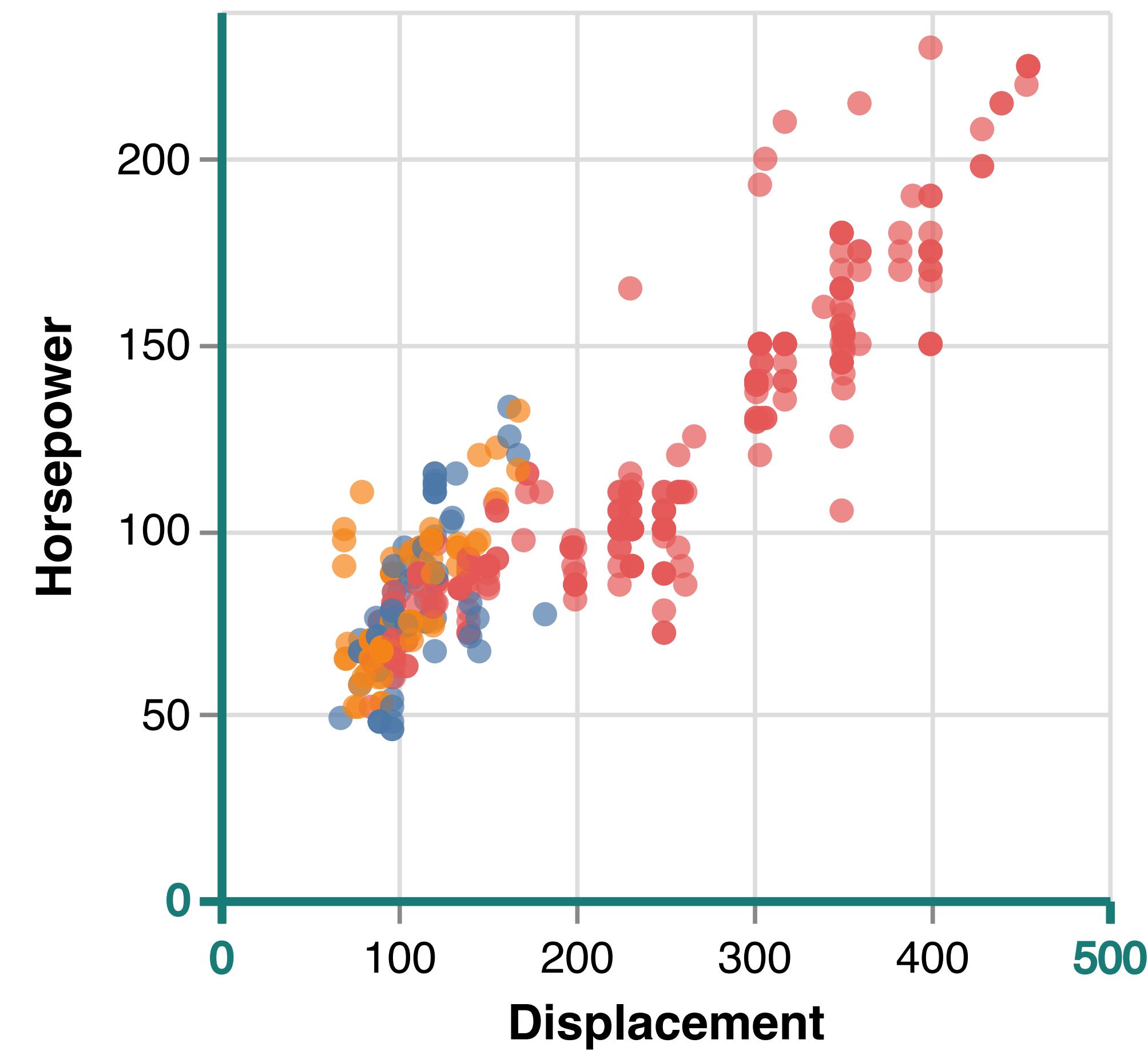
Having consistency can help audience
see view relations, avoid misinterpretations...

Why don't we always achieve consistency?

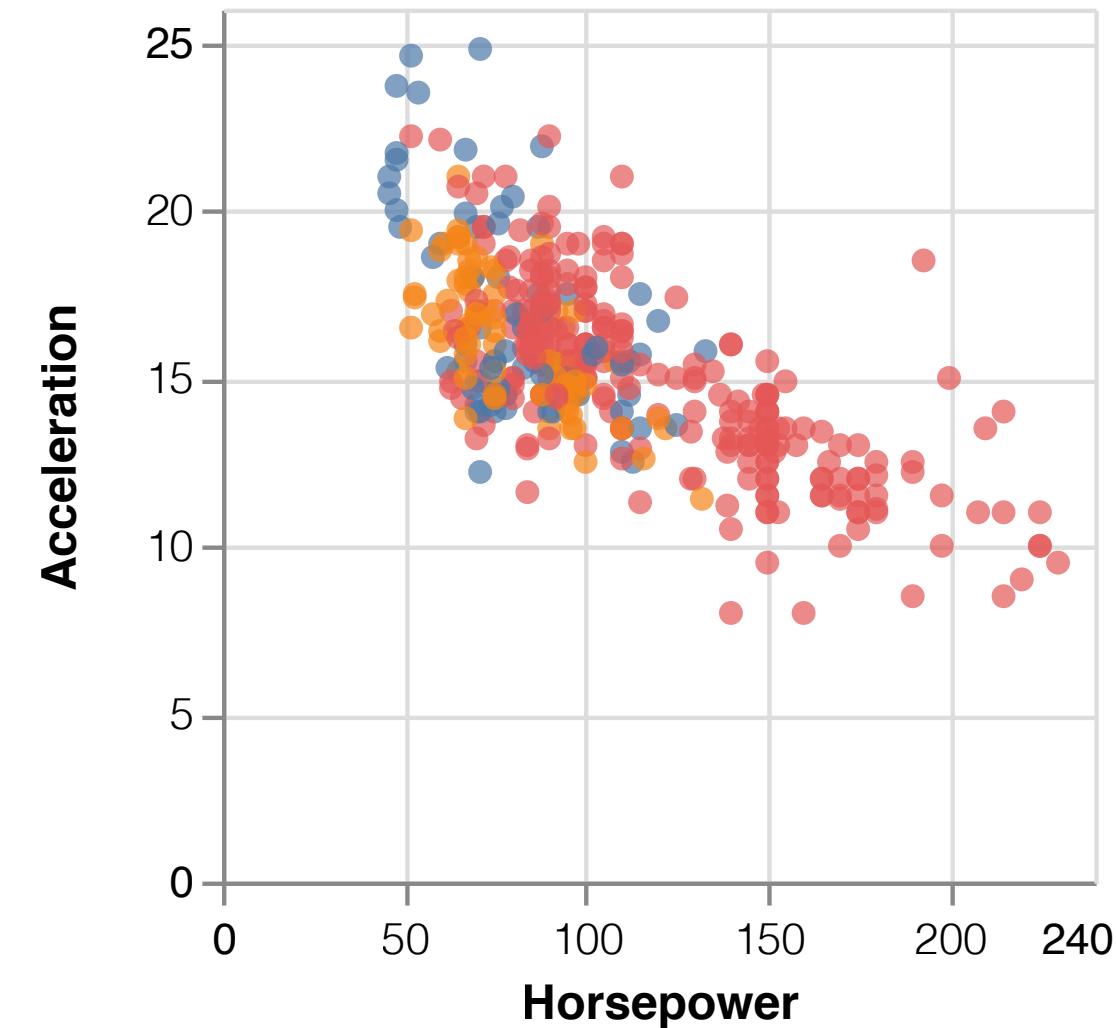
Multiple Views Consistency vs. Single View Effectiveness



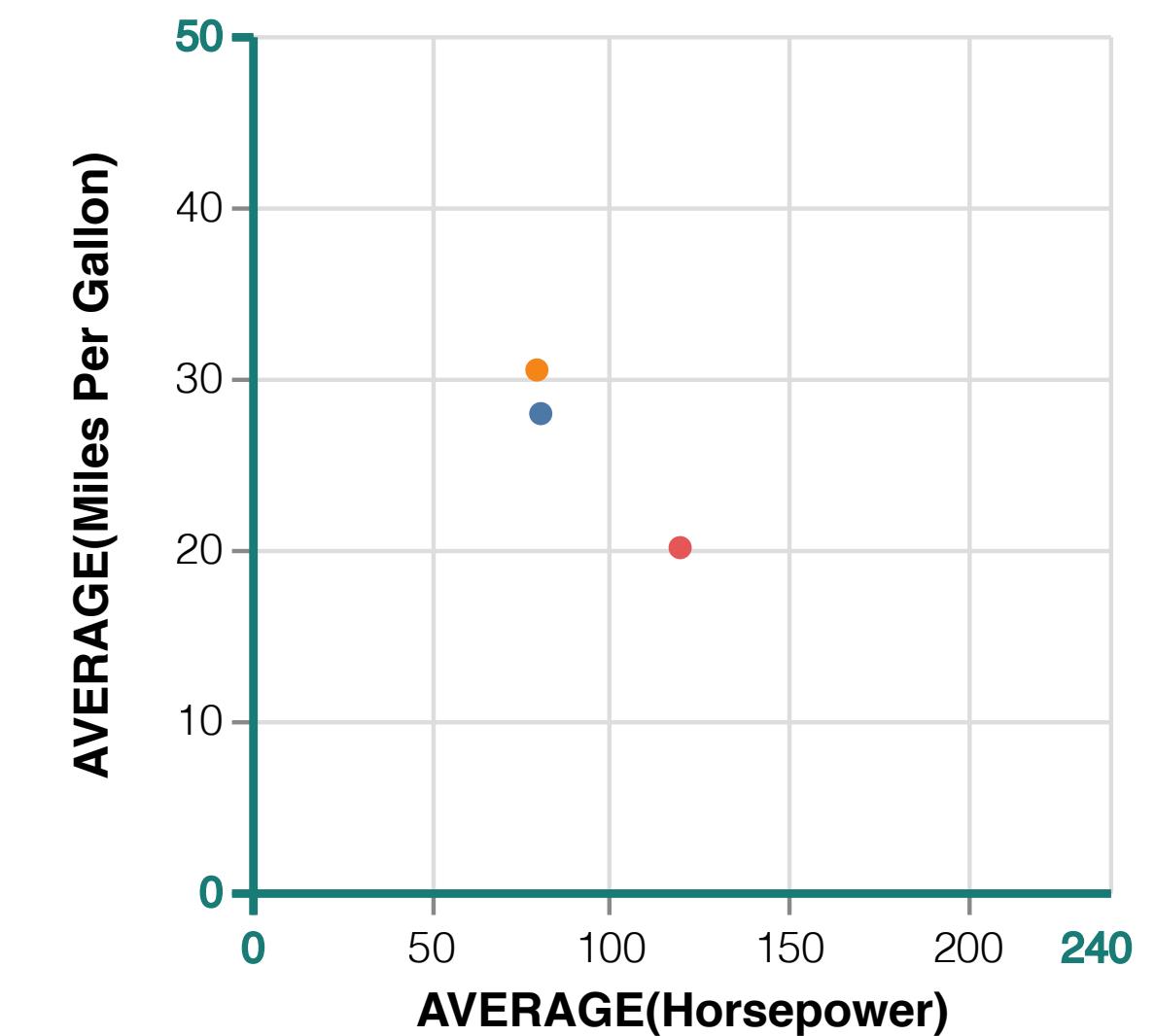
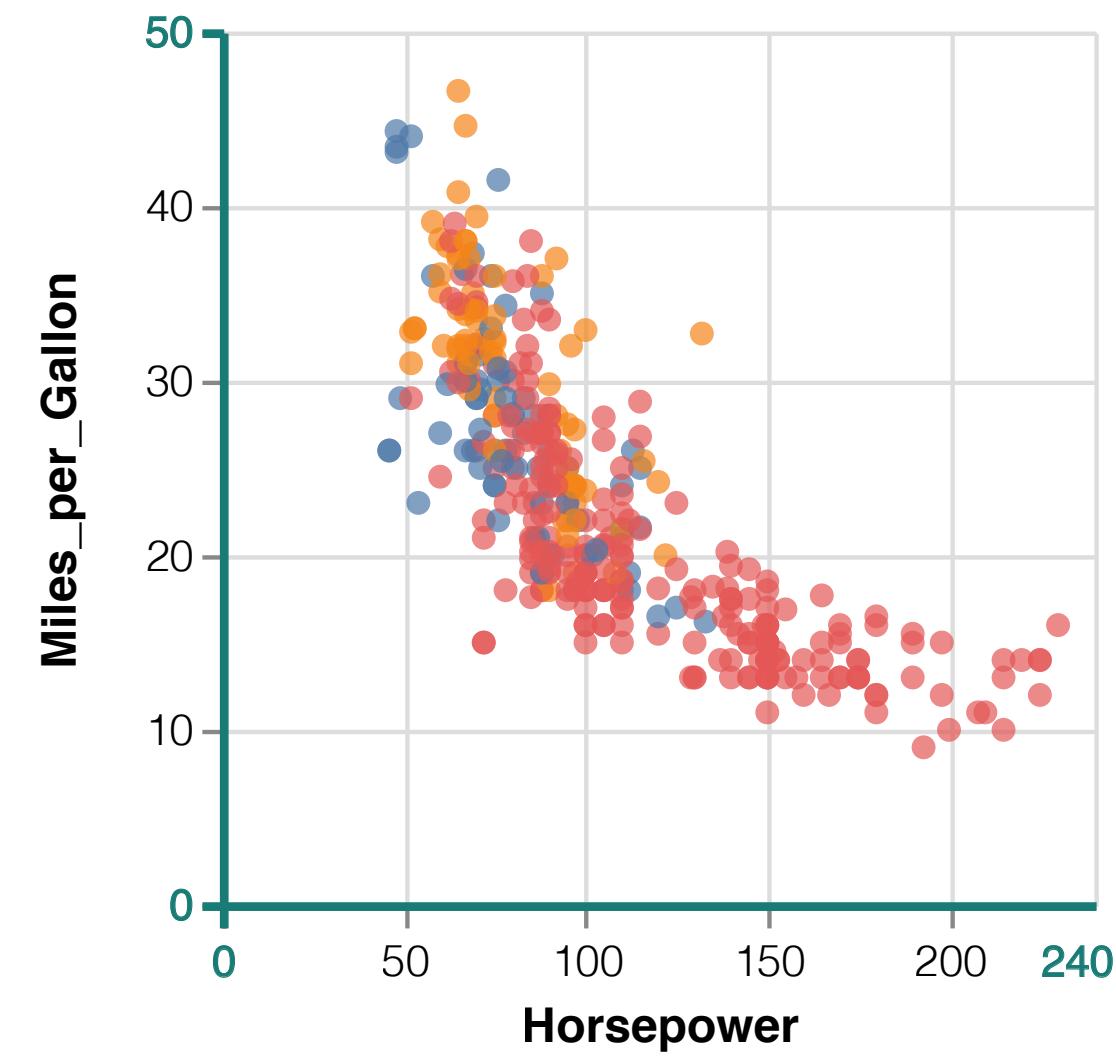
Multiple Views Consistency vs. Single View Effectiveness



What's the Scope of Consistency?



← Separated →



3 Research Questions to Understand Trade-offs

Q1

Q2

Q3

3 Research Questions to Understand Trade-offs

Q2

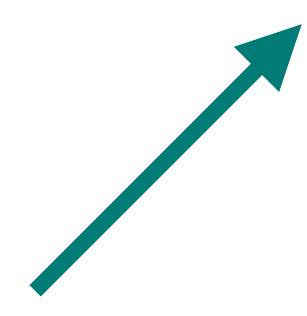
Q1: What is Multiple View
Consistency?

Q3

3 Research Questions to Understand Trade-offs

Q1: What is Multiple View Consistency?

Q2: **When** do authors achieve it and **how**?

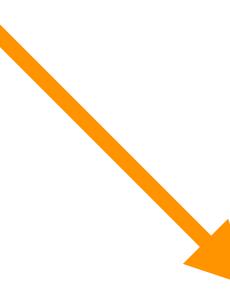


Q3

3 Research Questions to Understand Trade-offs

Q1: What is Multiple View Consistency?

Q2: **When** do authors achieve it and **how**?



Q3: When do they **trade-off** Consistency for other goals?

3 Contributions

Q1: What is Multiple View Consistency?

A: **Constraints**

Q2: **When** do authors achieve it and **how**?



Q3: When do they **trade-off** Consistency for other goals?

3 Contributions

Q1: What is Multiple View Consistency?

A: Constraints

Q2: **When** do authors achieve it and **how**?

A: **Validations**

Q3: When do they **trade-off** Consistency for other goals?



3 Contributions

Q1: What is Multiple View Consistency?

A: Constraints

Q2: When do authors achieve it and how?

A: Validations

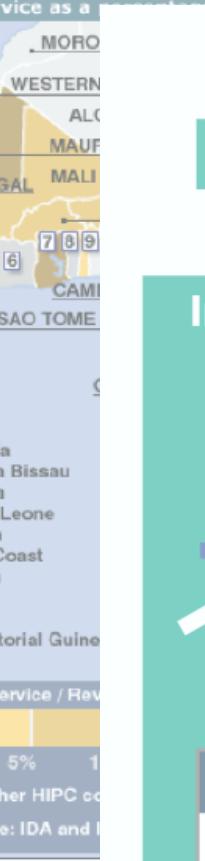
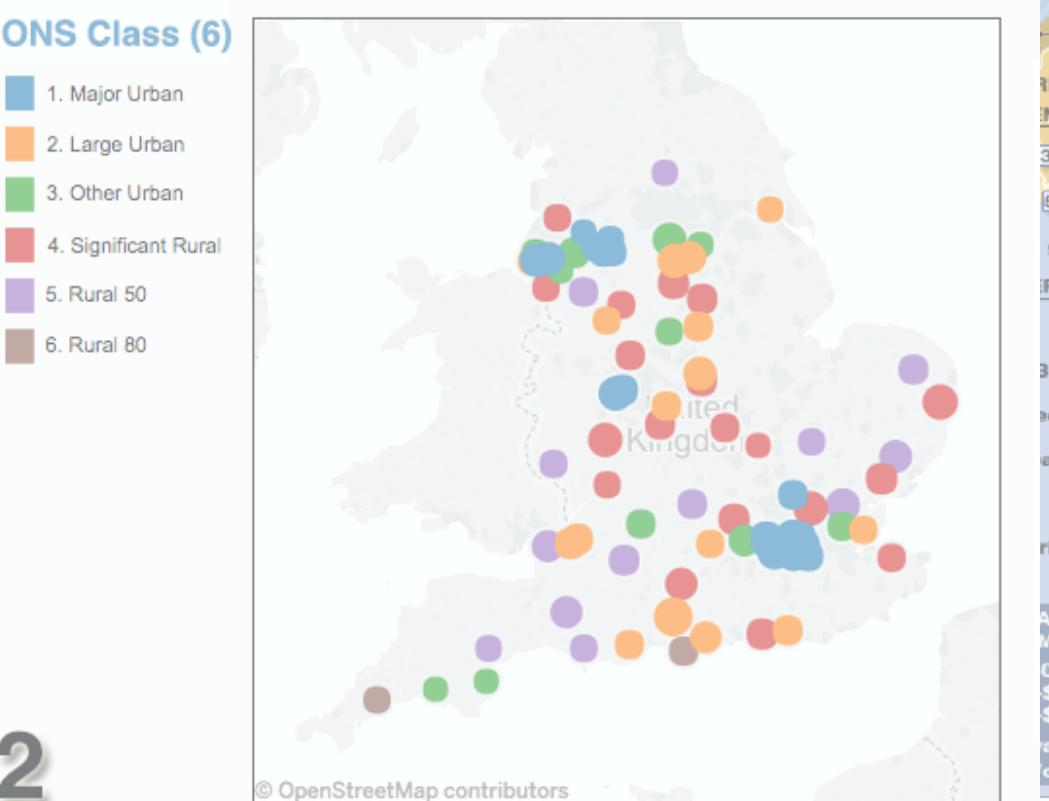
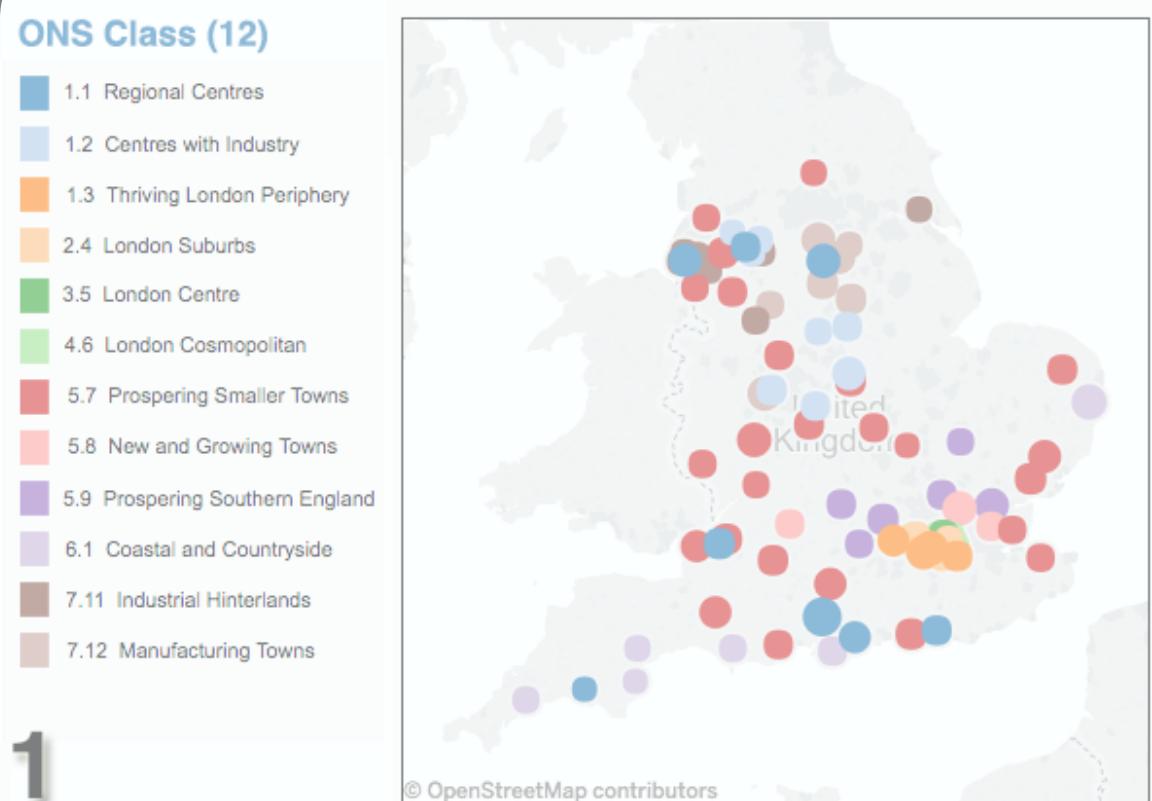
Q3: When do they trade-off Consistency for other goals?

A: Exceptions

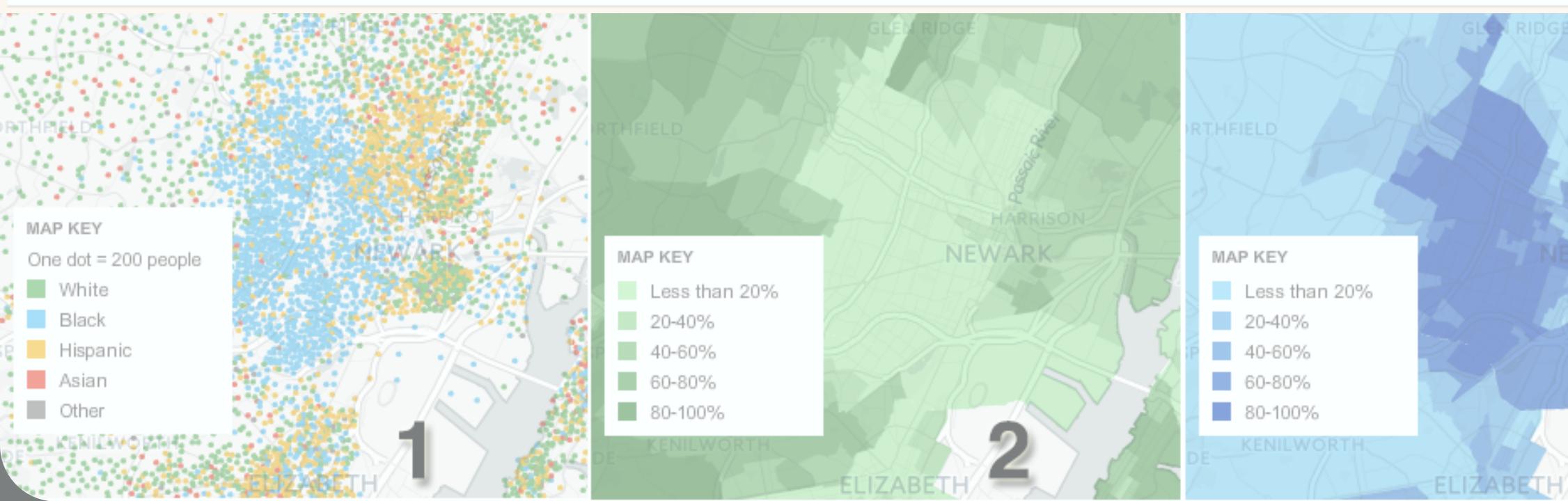


**Q1: What is Multiple View
Consistency?**

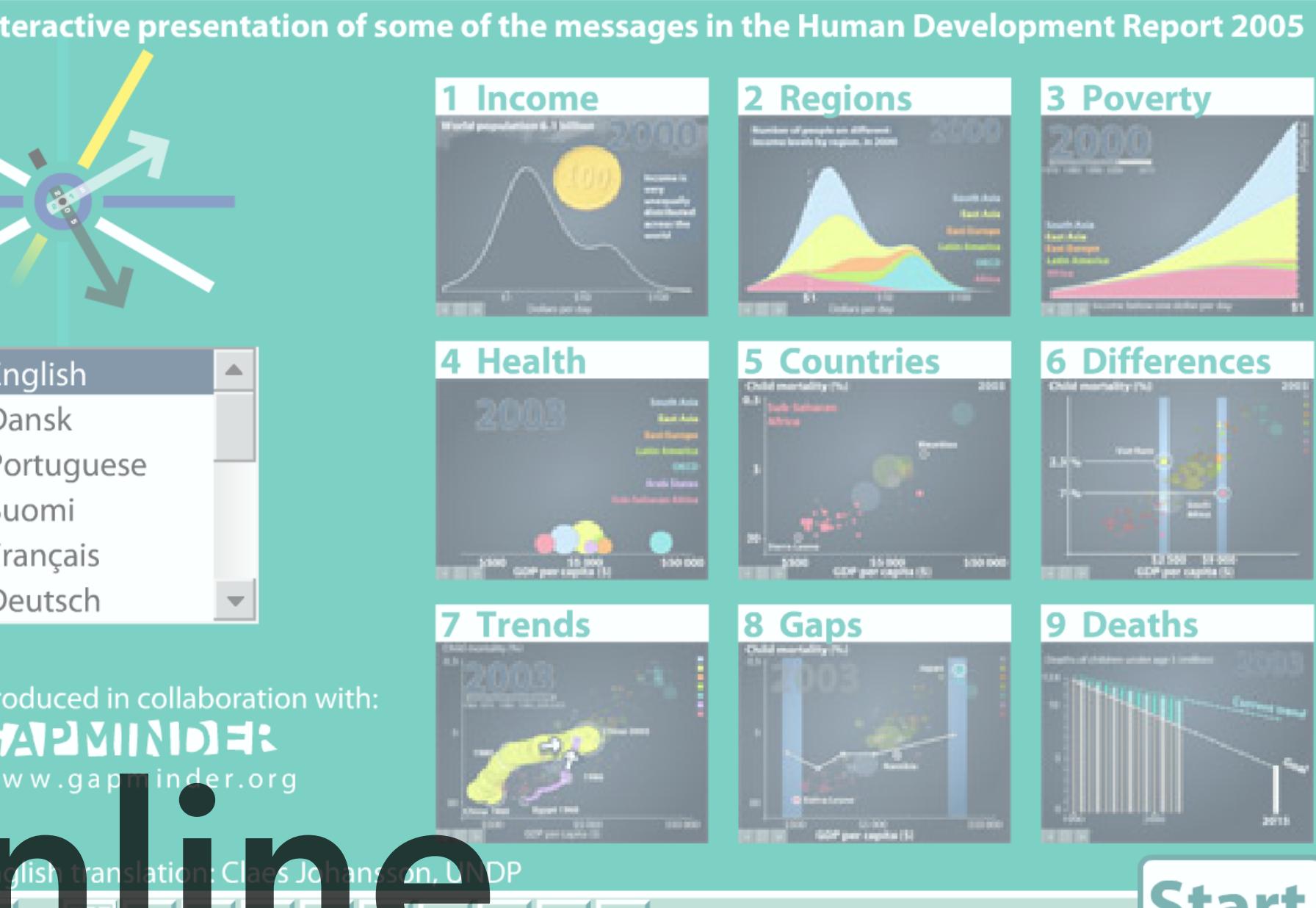
A: Constraints



	Citi	BoA Merrill Lynch	Goldman Sachs	Morgan Stanley	JPMorgan Chase
Total pay	\$28.43bn	\$35.15bn	\$15.38bn	\$16.01bn	\$28.1bn
Revenue	\$86.6bn	\$110.2bn	\$39.16bn	\$31.62bn	\$102.7bn
Profit/loss	\$10.6bn	-\$2.24bn	\$8.35bn	\$4.46bn	\$17.37bn
Pay per employee	\$109,346	\$122,495	\$430,812	\$255,988	\$117,165
Pay to revenue ratio	33%	32%	39%	51%	27%

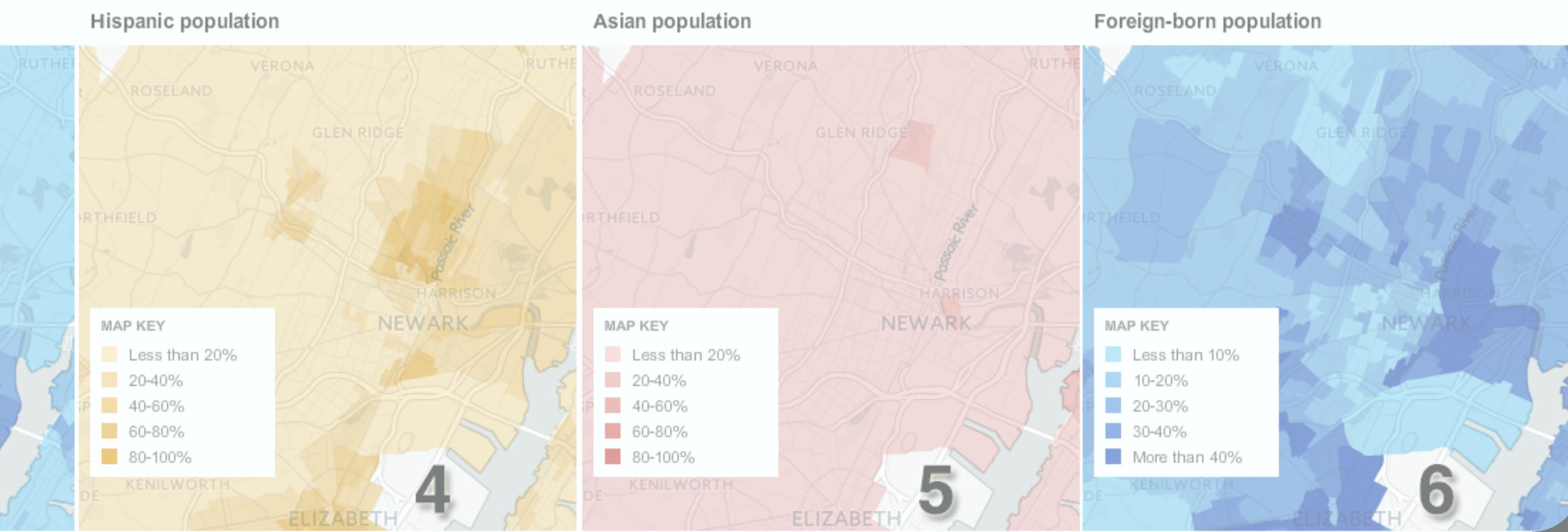


Human Development Trends 2005



Examples Online...

Evaluating Visualization Sets,
Qu, Hullman, BELIV 2016



High Level Constraints

Same Rule

Different Rule

High Level Constraints

If two views contain
the **same** data field,
that field should be
encoded in the **same** way

Different Rule

High Level Constraints

If two views contain the **same** data field, that field should be encoded in the **same** way

If two views contain **different** data fields, the two fields should be encoded **differently**

High Level Constraints

If two views contain the **same** data field, that field should be encoded in the **same** way

If two views contain **different** data fields, the two fields should be encoded **differently**

In paper: heuristics for classifying **same/different fields**.

High Level Constraints

Same

Different

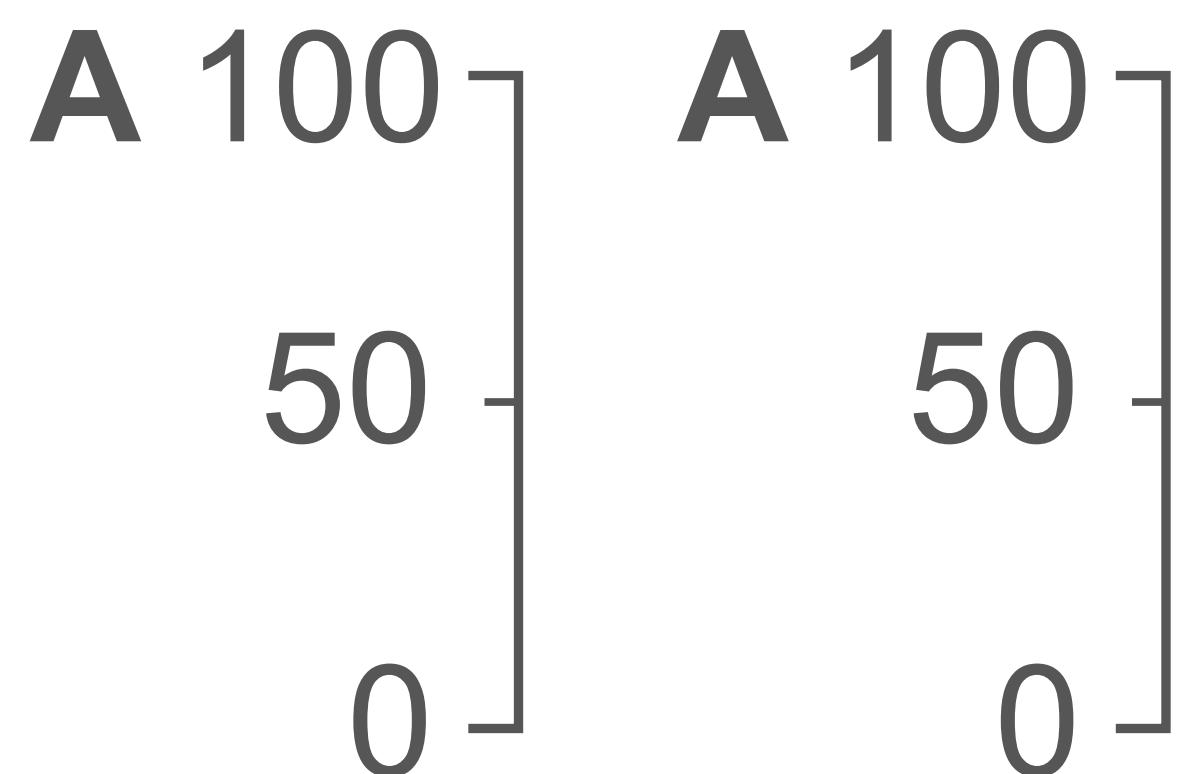
Specific Constraints: XY

Same

Different

Specific Constraints: XY

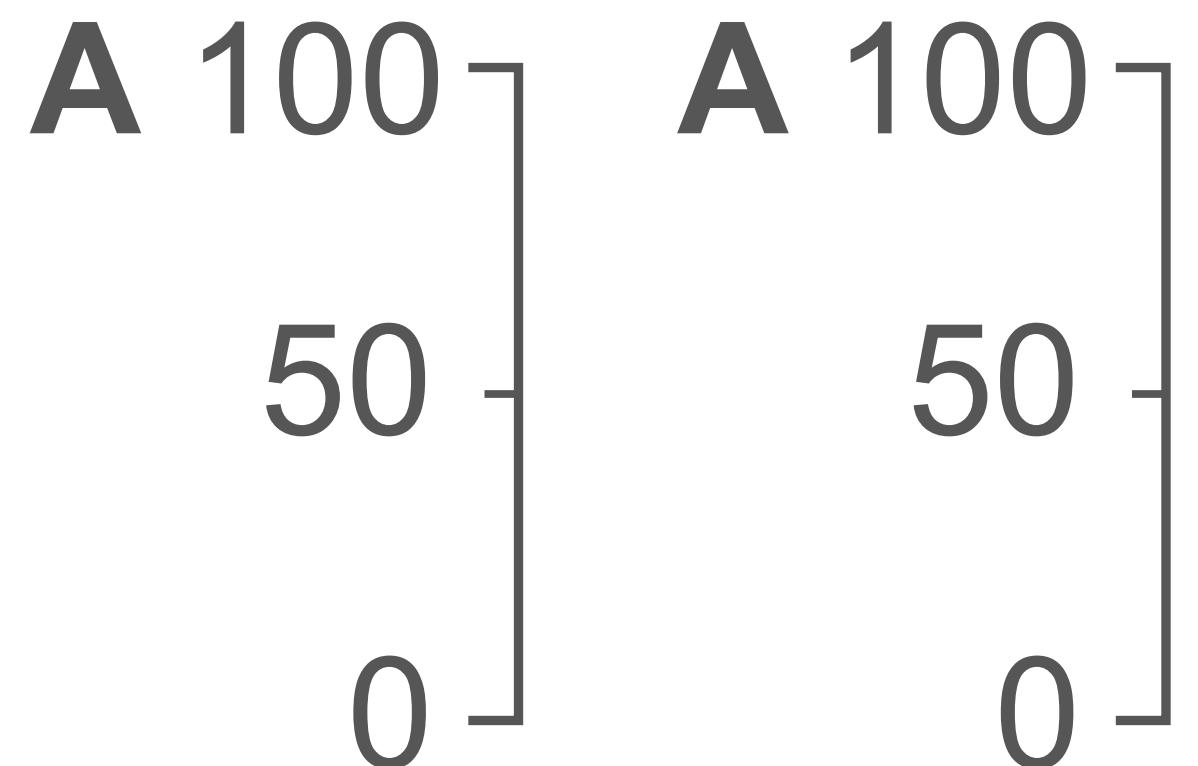
C1.1 Same Field,
Same XY Scale



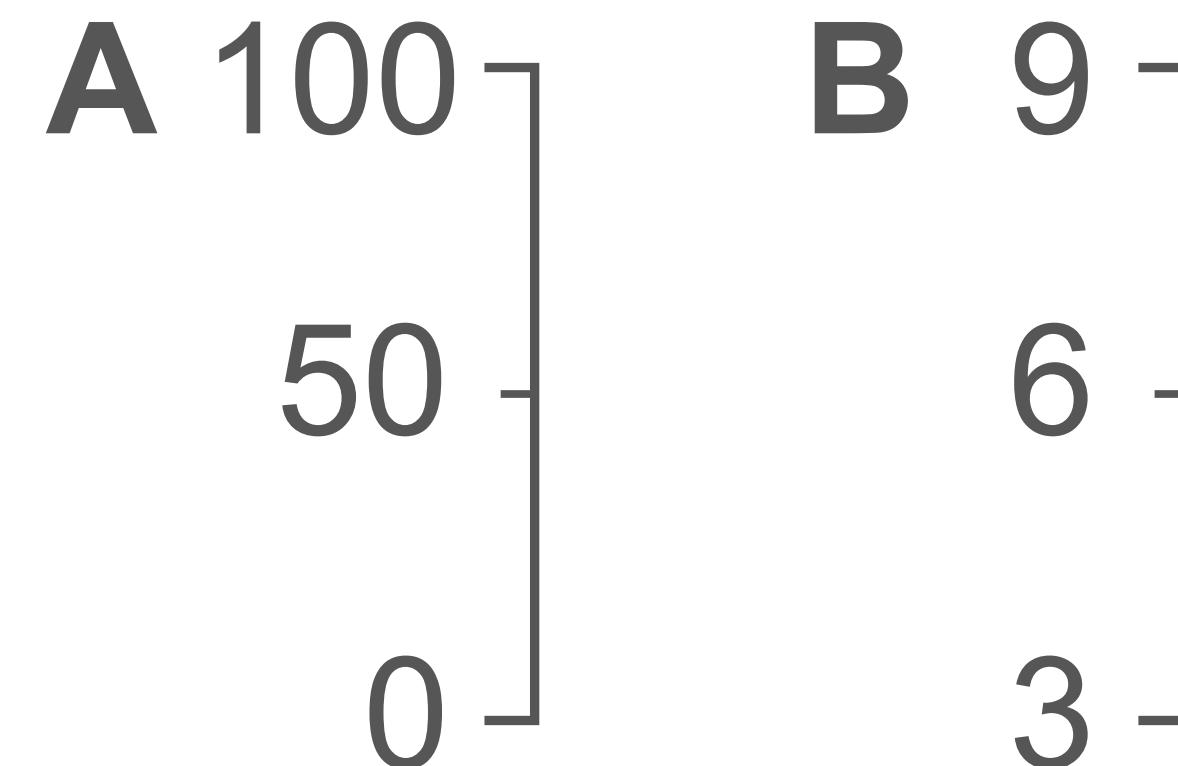
Different

Specific Constraints: XY

C1.1 Same Field,
Same XY Scale



C2.1 Different Fields,
Different XY Domains

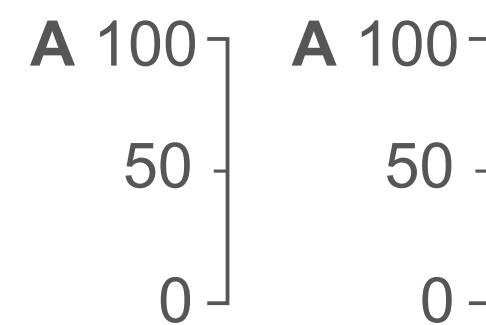


Specific Constraints

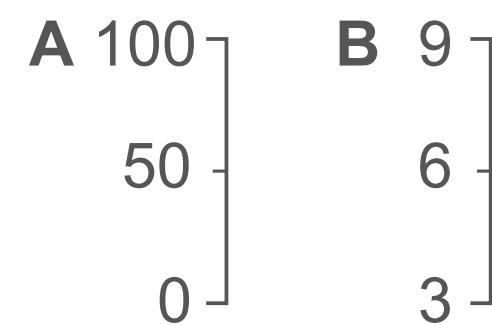
Quantitative

X & Y

C1.1 Same Field,
Same XY Scale



C2.1 Different Fields,
Different XY Domains



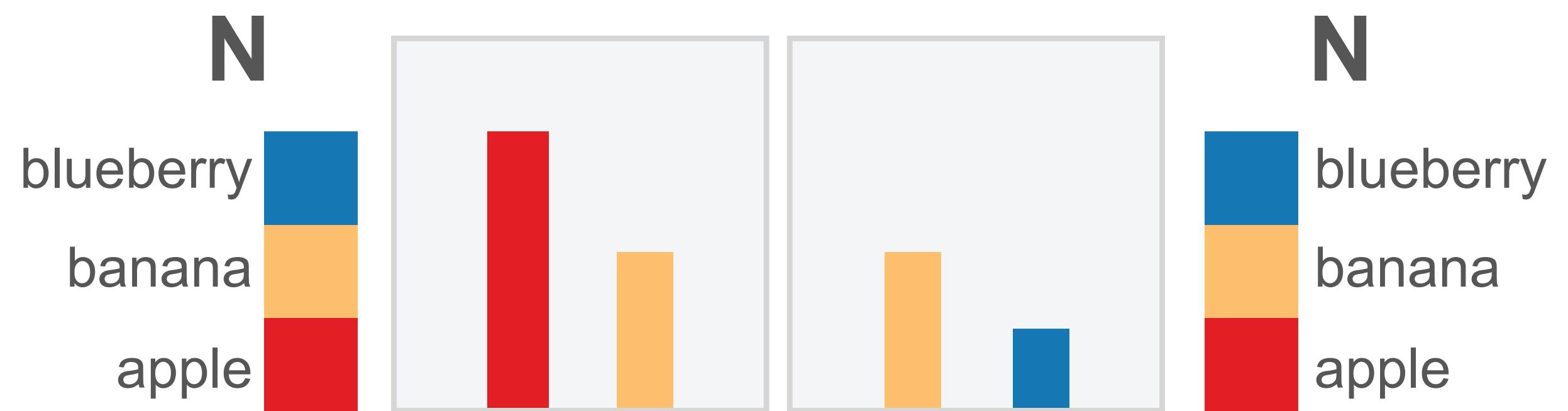
Specific Constraints: Color

Same

Different

Specific Constraints: Color

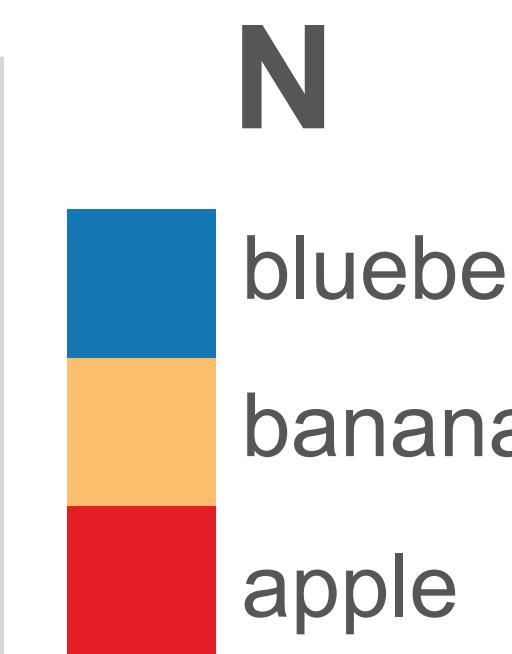
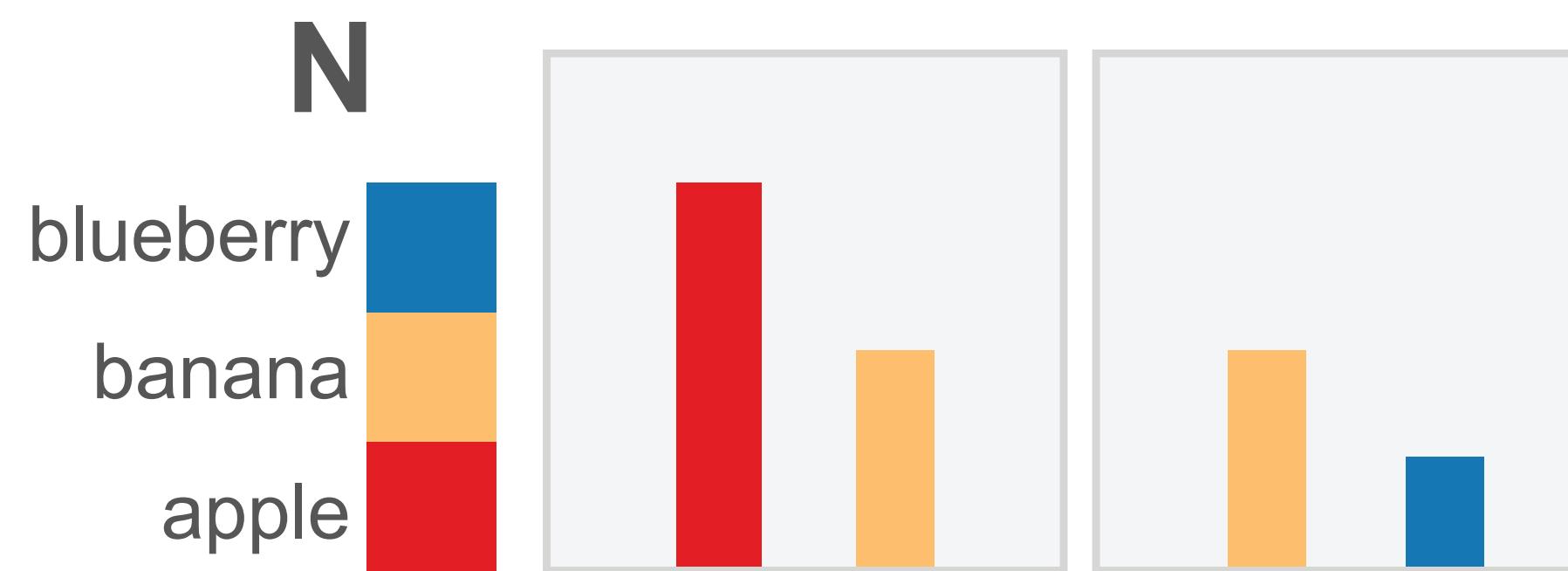
C1.4 Same Field, Same Value-Color Mapping



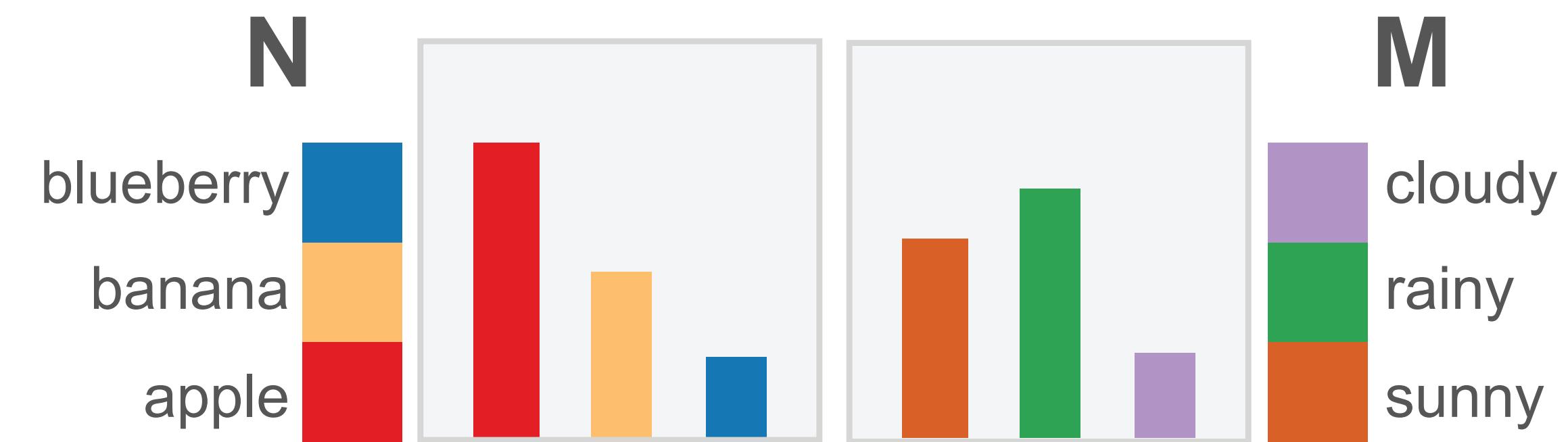
Different

Specific Constraints: Color

C1.4 Same Field, Same
Value-Color Mapping



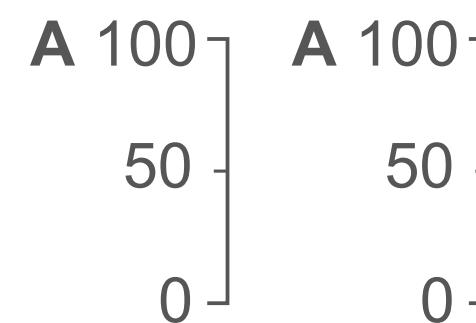
C2.4 Different Fields,
Non-overlapping Palettes



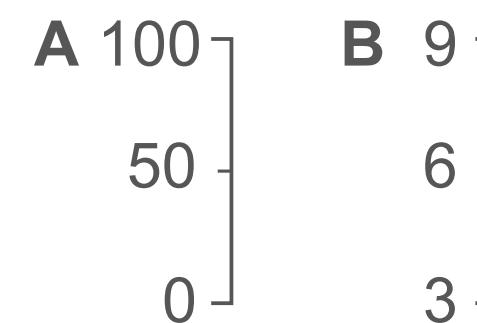
Specific Constraints

Quantitative
X & Y

C1.1 Same Field,
Same XY Scale



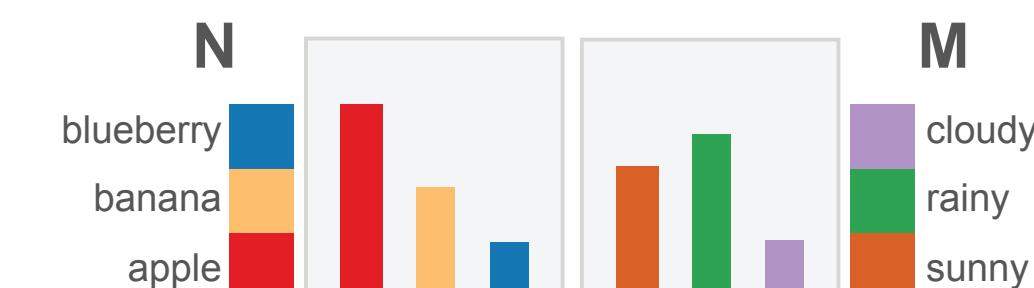
C2.1 Different Fields,
Different XY Domains



C1.4 Same Field, Same
Value-Color Mapping



C2.4 Different Fields,
Non-overlapping Palettes

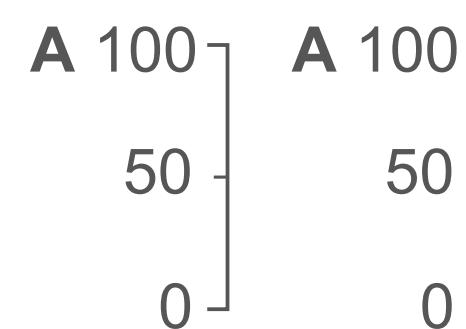


Nominal
Color

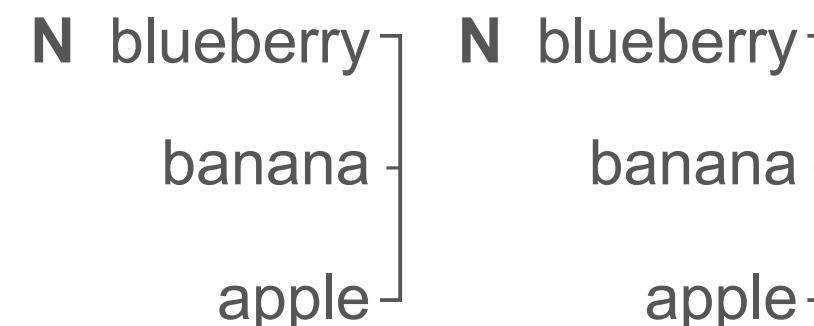
Specific Constraints

Quantitative
X & Y

C1.1 Same Field,
Same XY Scale

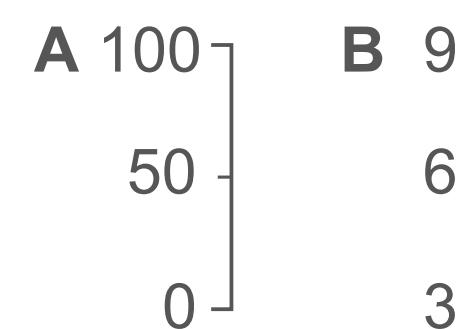


C1.2 Same Field, Same
Values in Same Order

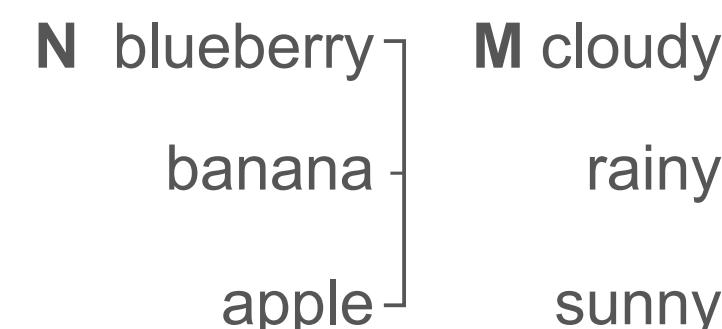


Nominal
X & Y

C2.1 Different Fields,
Different XY Domains

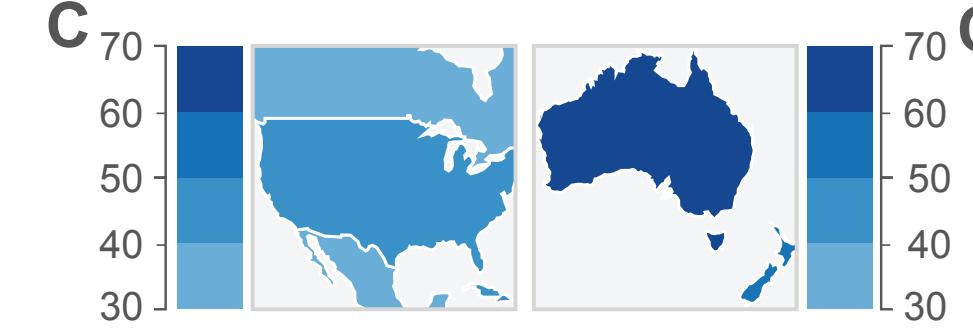


C2.2 Different Fields,
Different Nominal Values

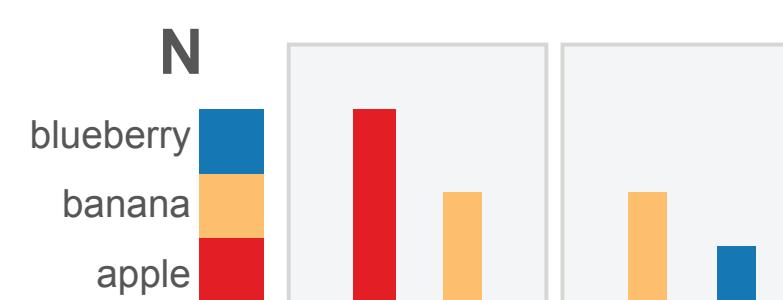


Quantitative
Color

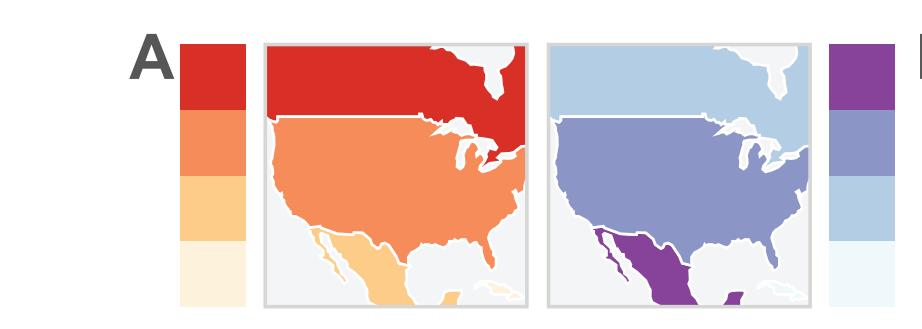
C1.3 Same Field, Same
Quantitative Color Scale



C1.4 Same Field, Same
Value-Color Mapping



C2.3 Different Fields,
Non-Overlapping Hues

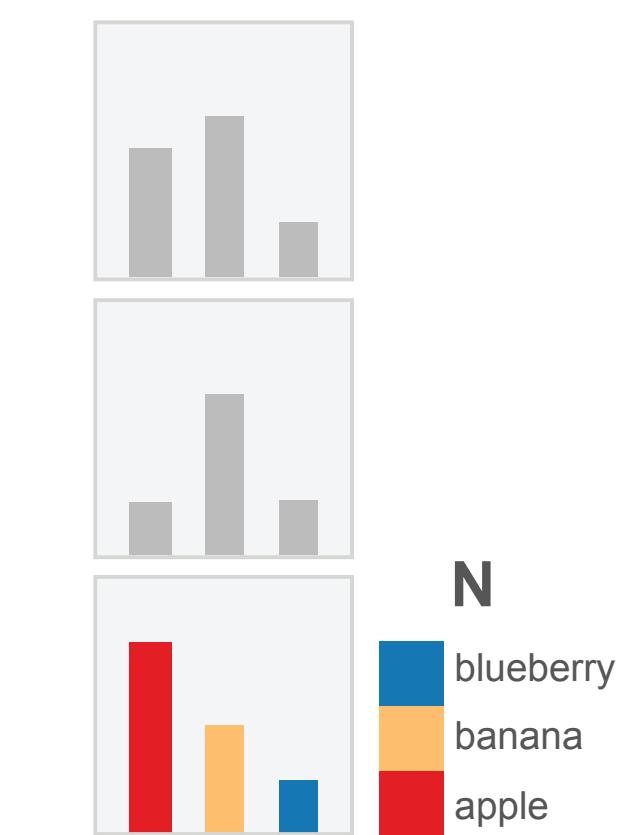


C2.4 Different Fields,
Non-overlapping Palettes

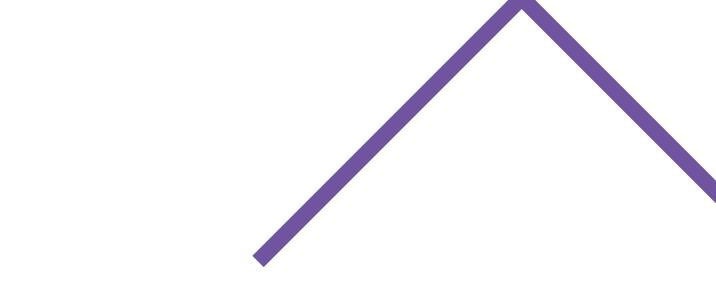


Constant
Color

C2.5 Non-overlapping
Nominal and
Constant Colors



Qualitative Study



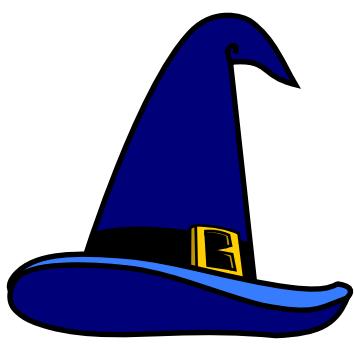
Wizard of Oz

Q2: How do authors achieve consistency? A: Validations

Q3: When do they trade-off consistency for other goals?

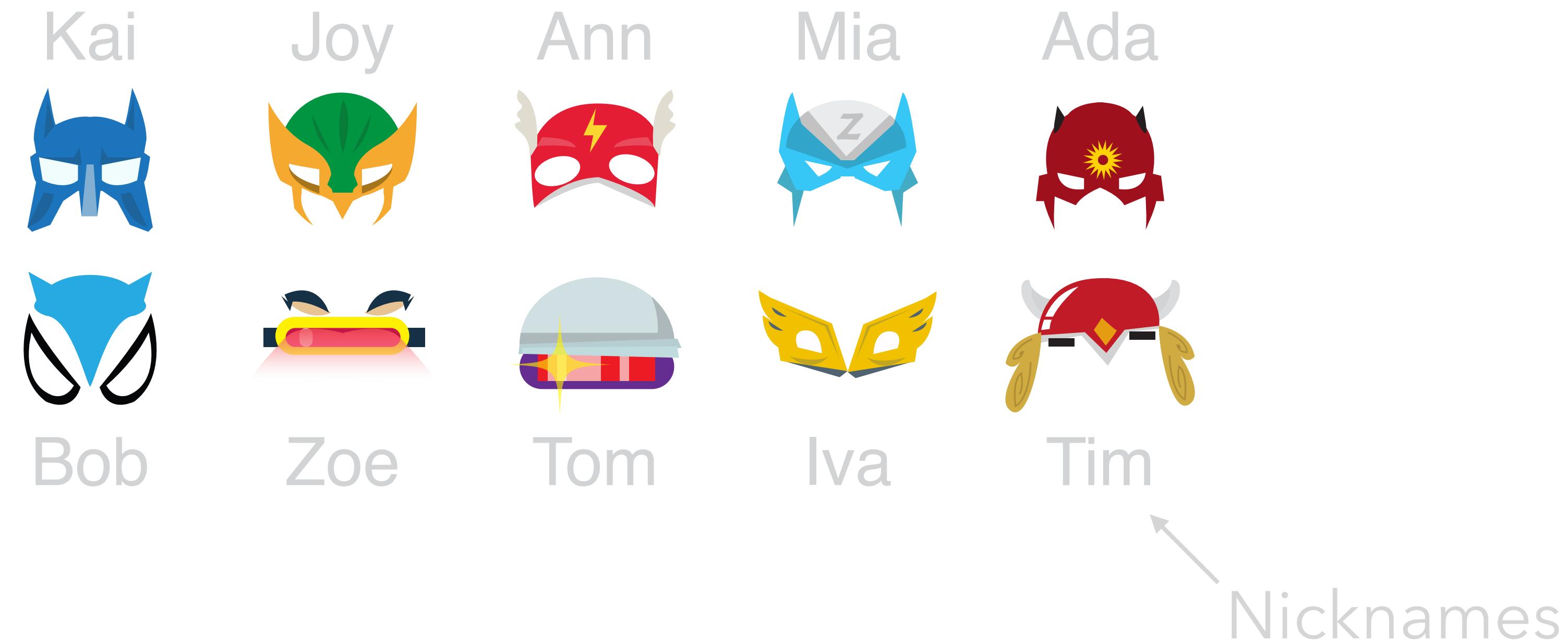
A: Exceptions

Experimenter



Wizard

Participants



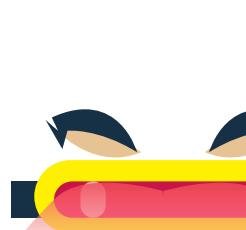
Participants

Kai



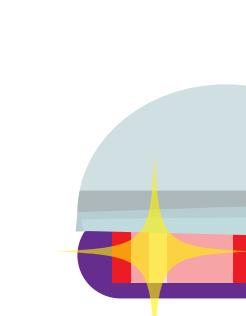
Bob

Joy



Zoe

Ann



Tom

Mia



Iva

Ada



Tim

4 Males, 6 Females

Age 18-56

Expertise:

(Class/Work)

Professions:

Graduate Student, Data Librarian, Market Research Consultant, IT Service Representative

Qualitative Study

1 h

Explore



1 h

Present

Datasets: cameras, cereals,
country development, films,
seat belts, speed dating

Imaginary
Online Audience

Qualitative Study

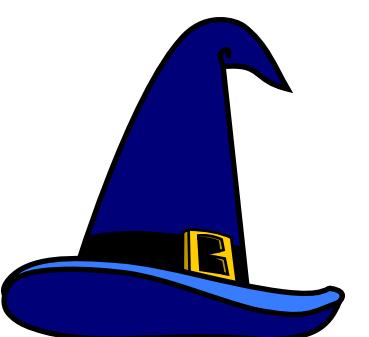


Hero

Explore

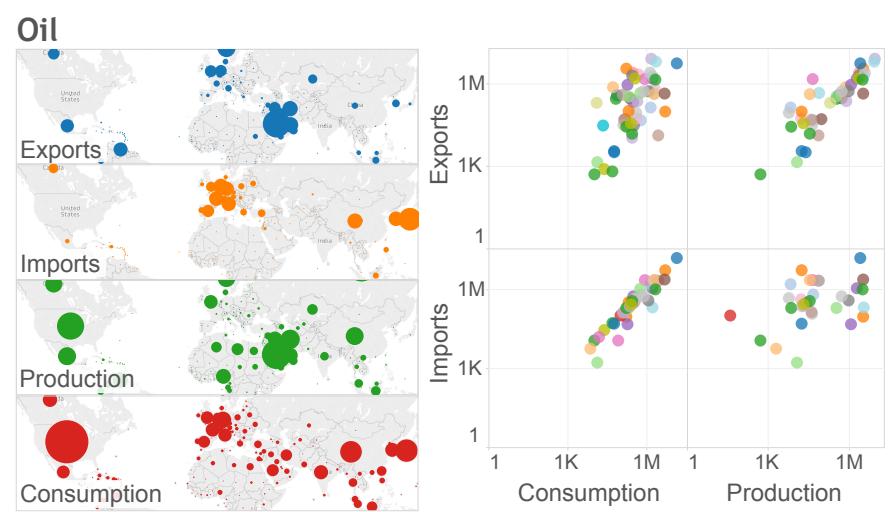


Present



Wizard

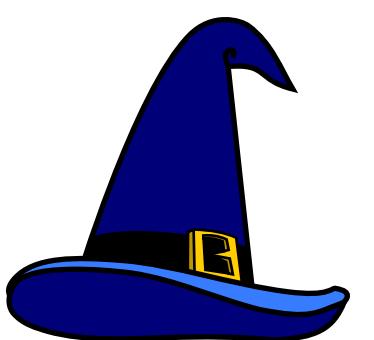
Qualitative Study



Explore

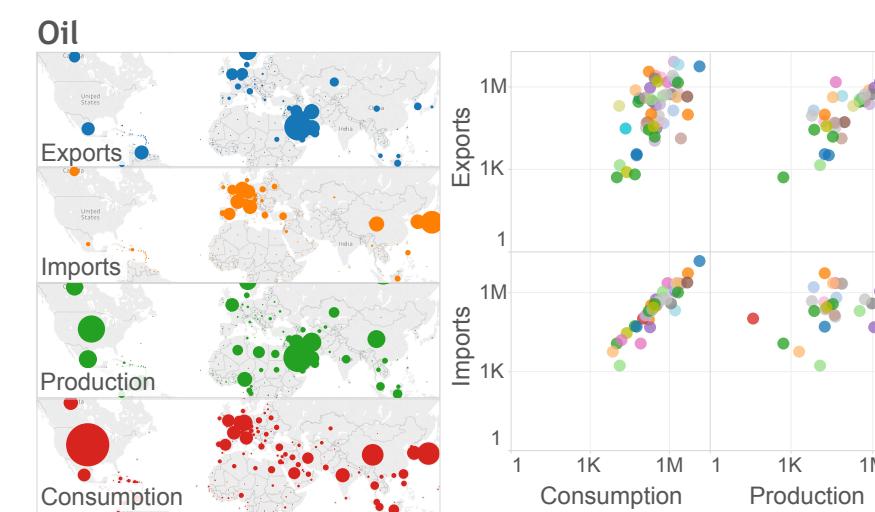


Present



Wizard

Qualitative Study



Explore



Present



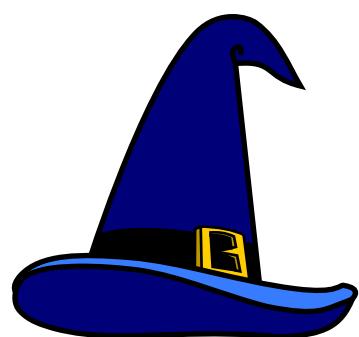
Wizard

Qualitative Study

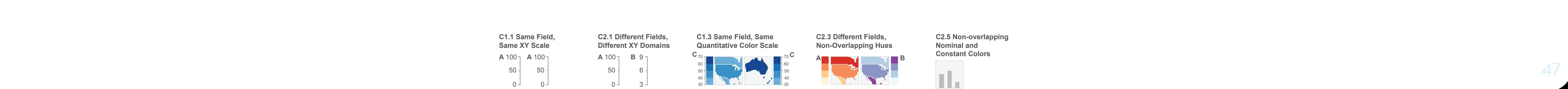
Explore



Present



Wizard

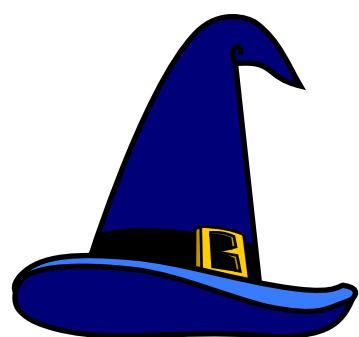


Qualitative Study

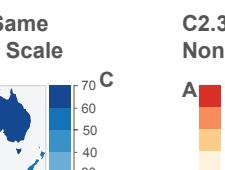
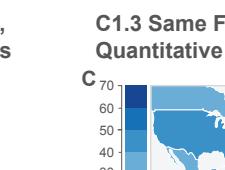
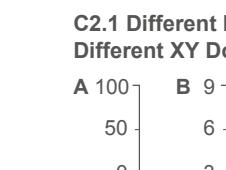
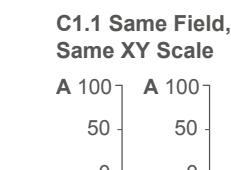
Explore



Present



Wizard

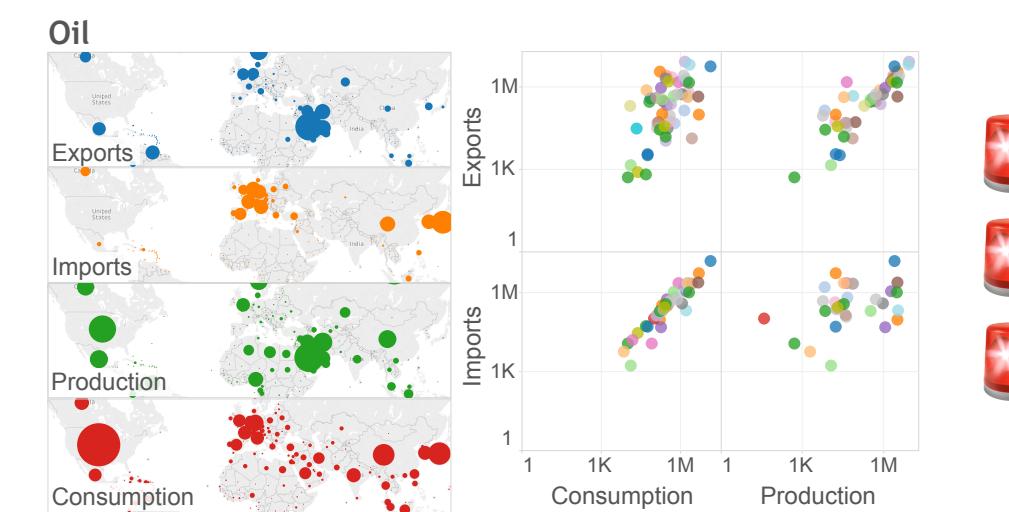


Qualitative Study

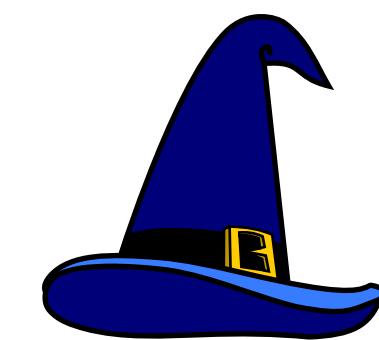
Explore



Present



Hero



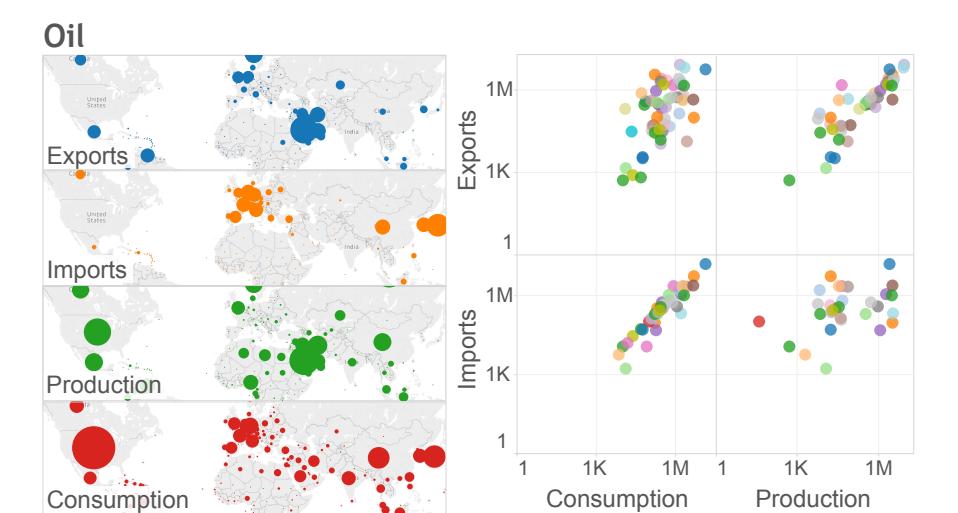
Wizard

Qualitative Study

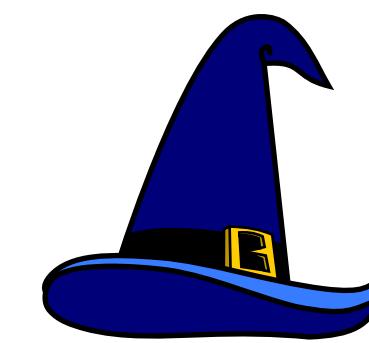
Explore



Present



Validations
&
Exceptions



Wizard

Qualitative Study

20 Hrs+ Screen Recording

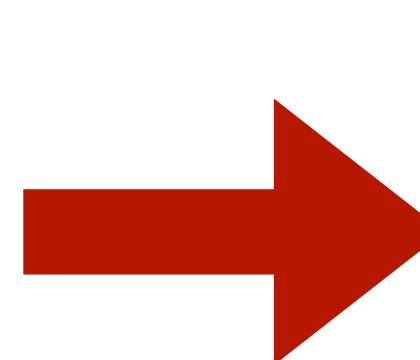
15 presentations: 4 storyboards, 11 dashboards

88 basic views

Validations: 90 instances

Exceptions: 49 instances

Counting Method: number of revisions/verifications



Constraints

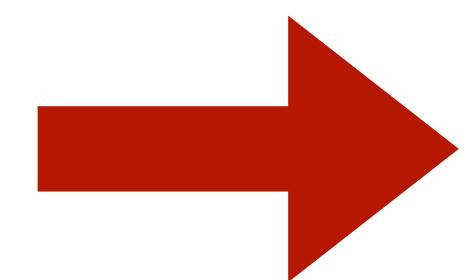
Validations

&

Exceptions

Implications

Constraints



Validations

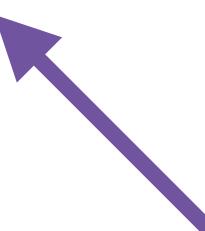
&

Exceptions

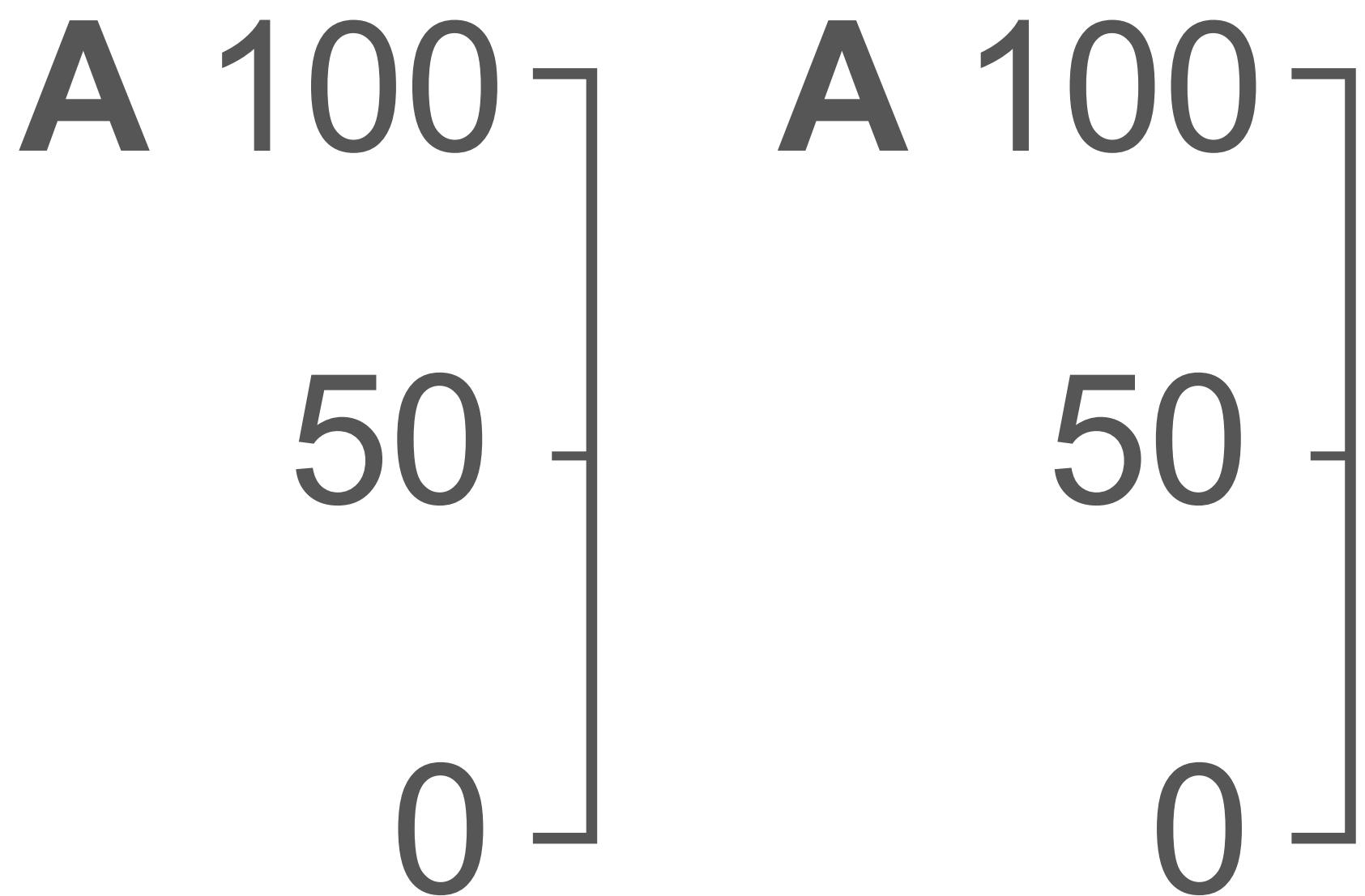
Implications

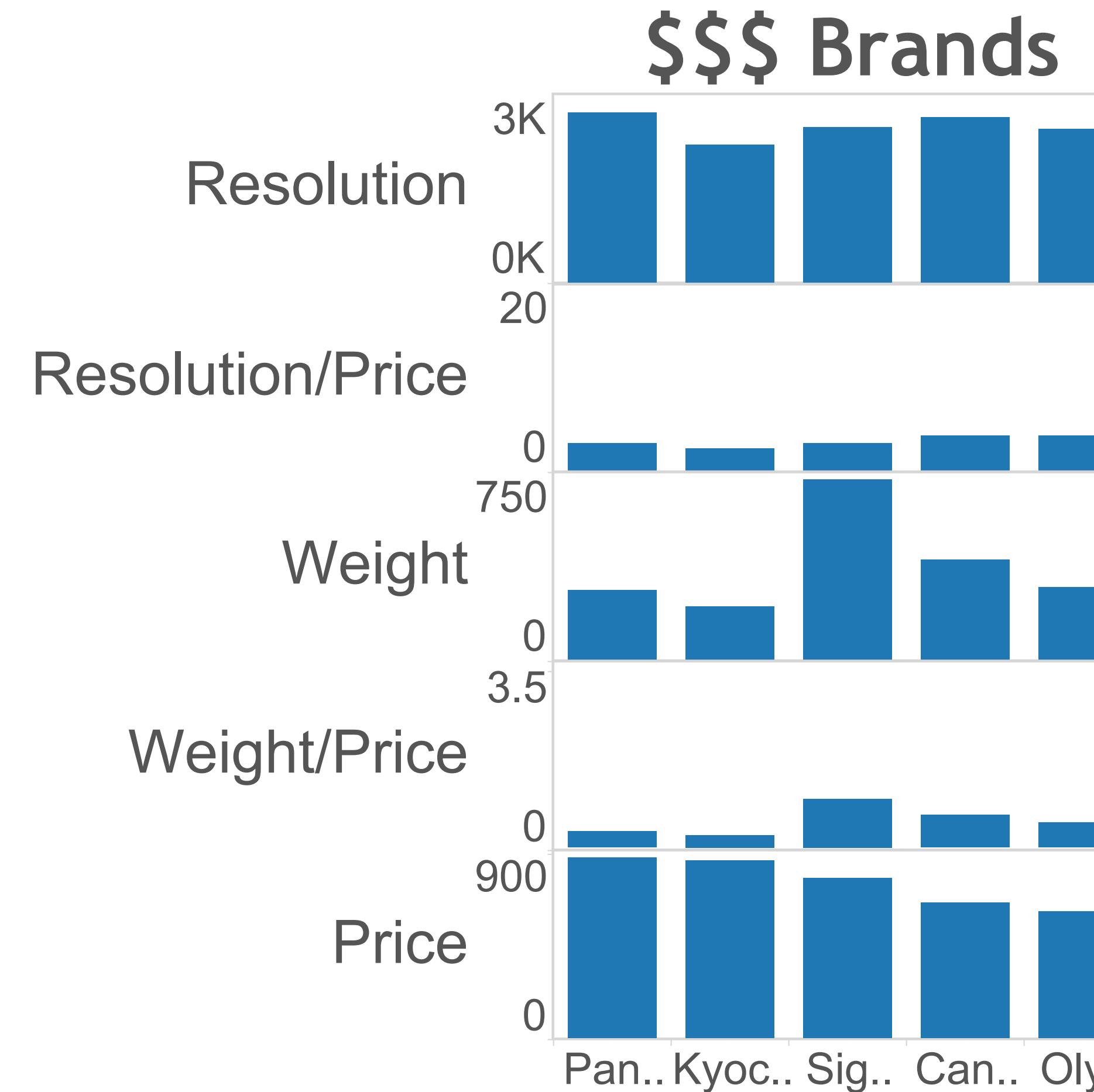
Validations & Exceptions

Real Stories



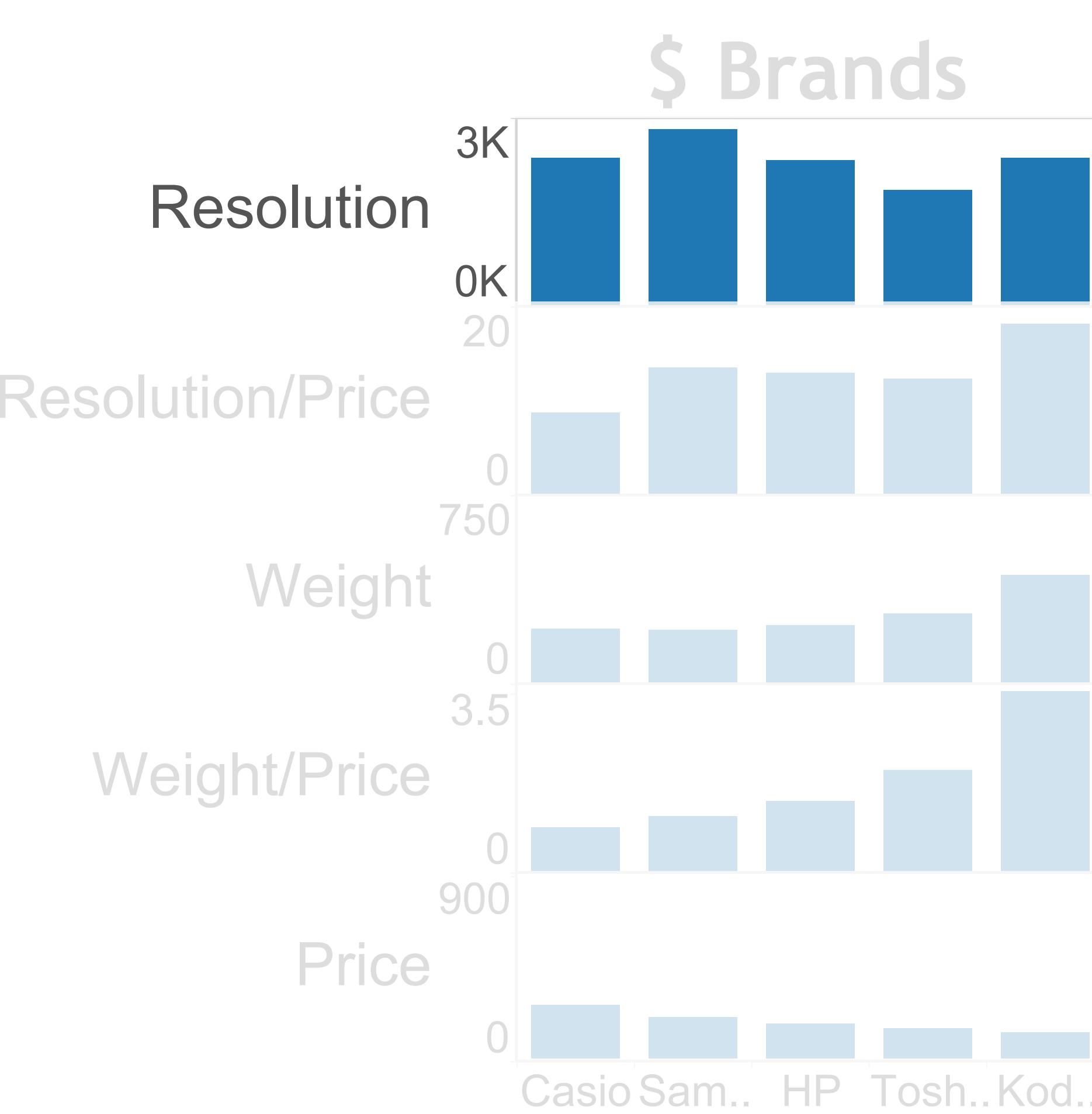
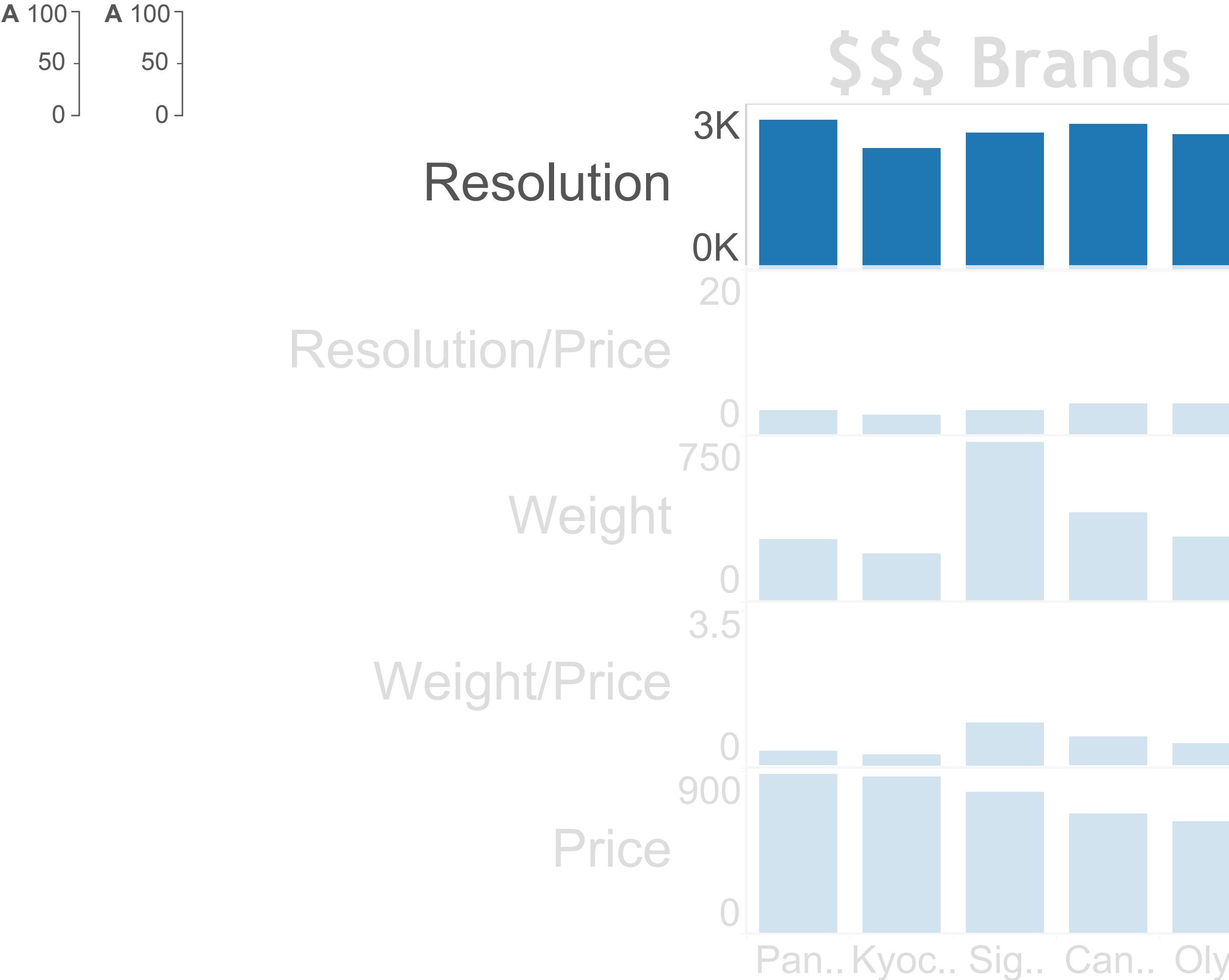
C1.1 Same Field, Same XY Scale





Validation: Manually Align Domains

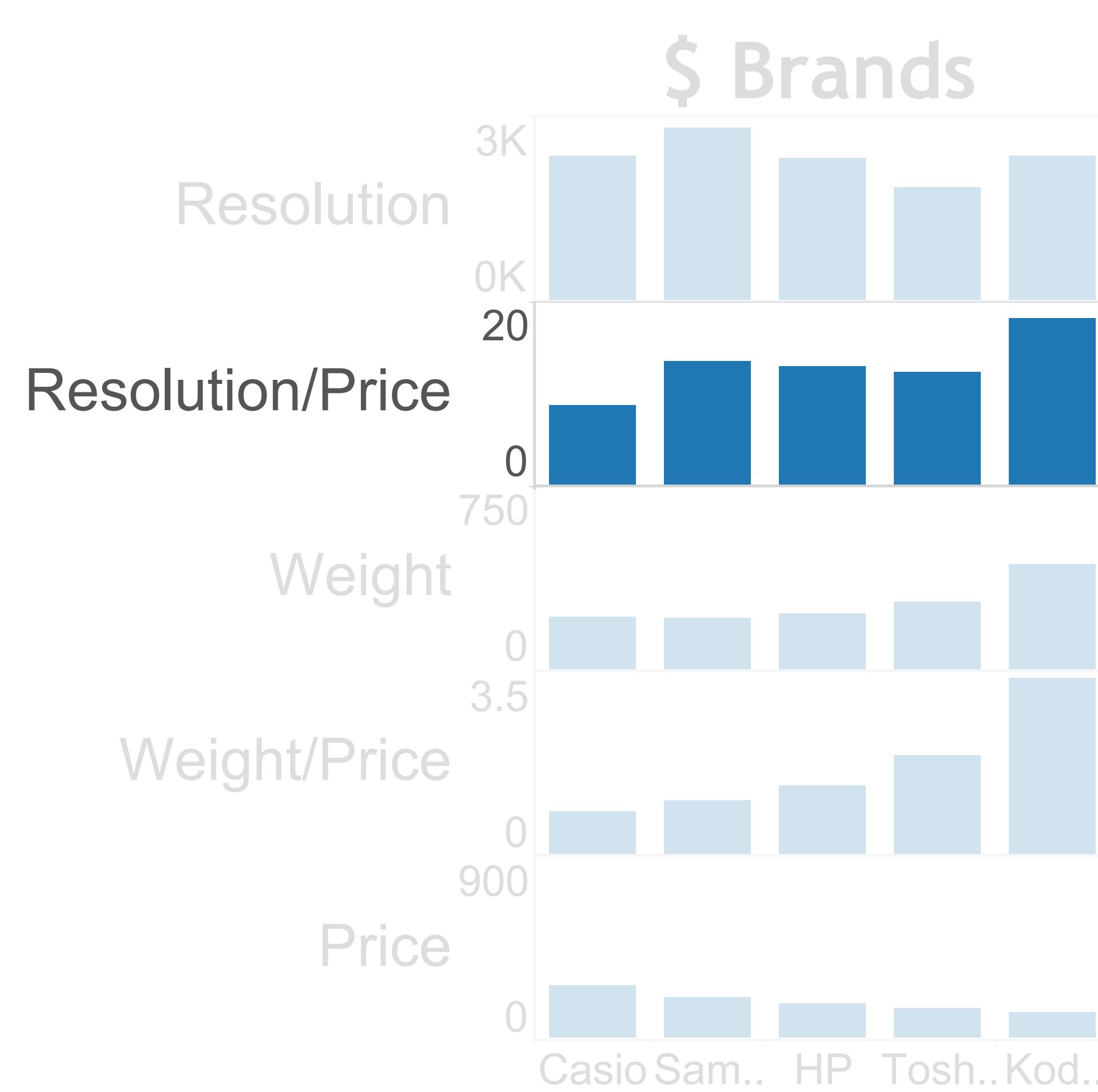
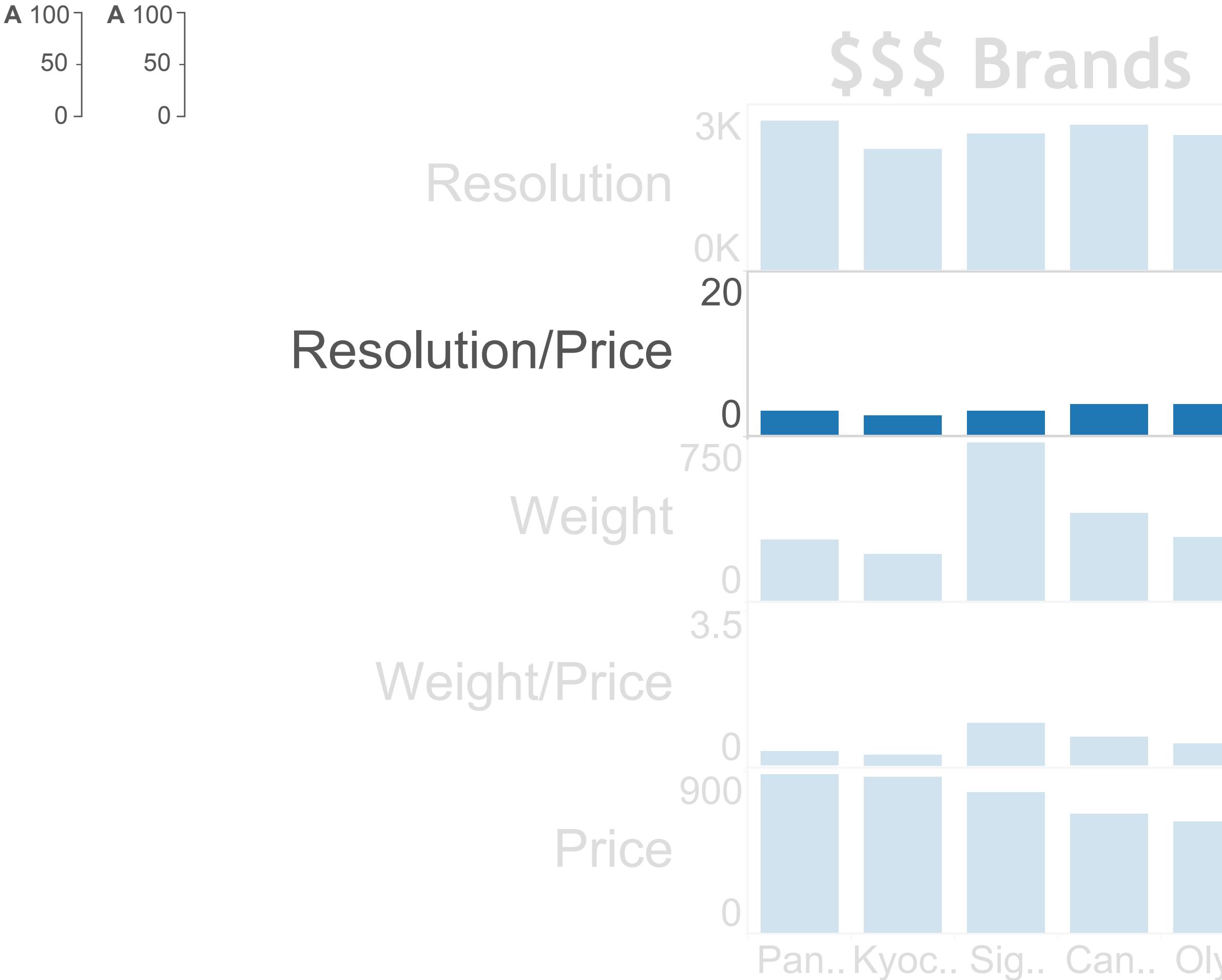
C1.1 Same Field,
Same XY Scale



Bob

Validation: Manually Align Domains

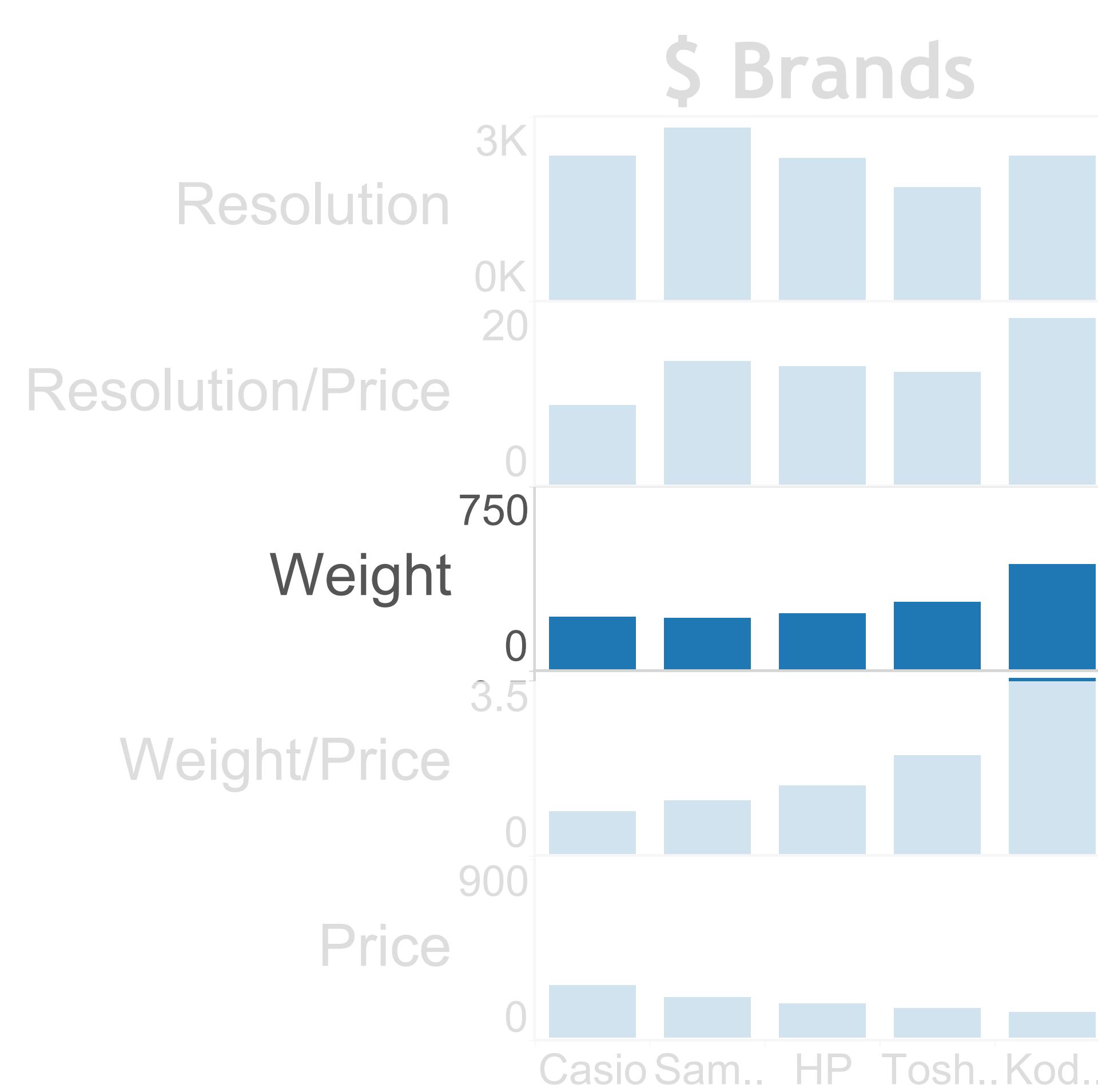
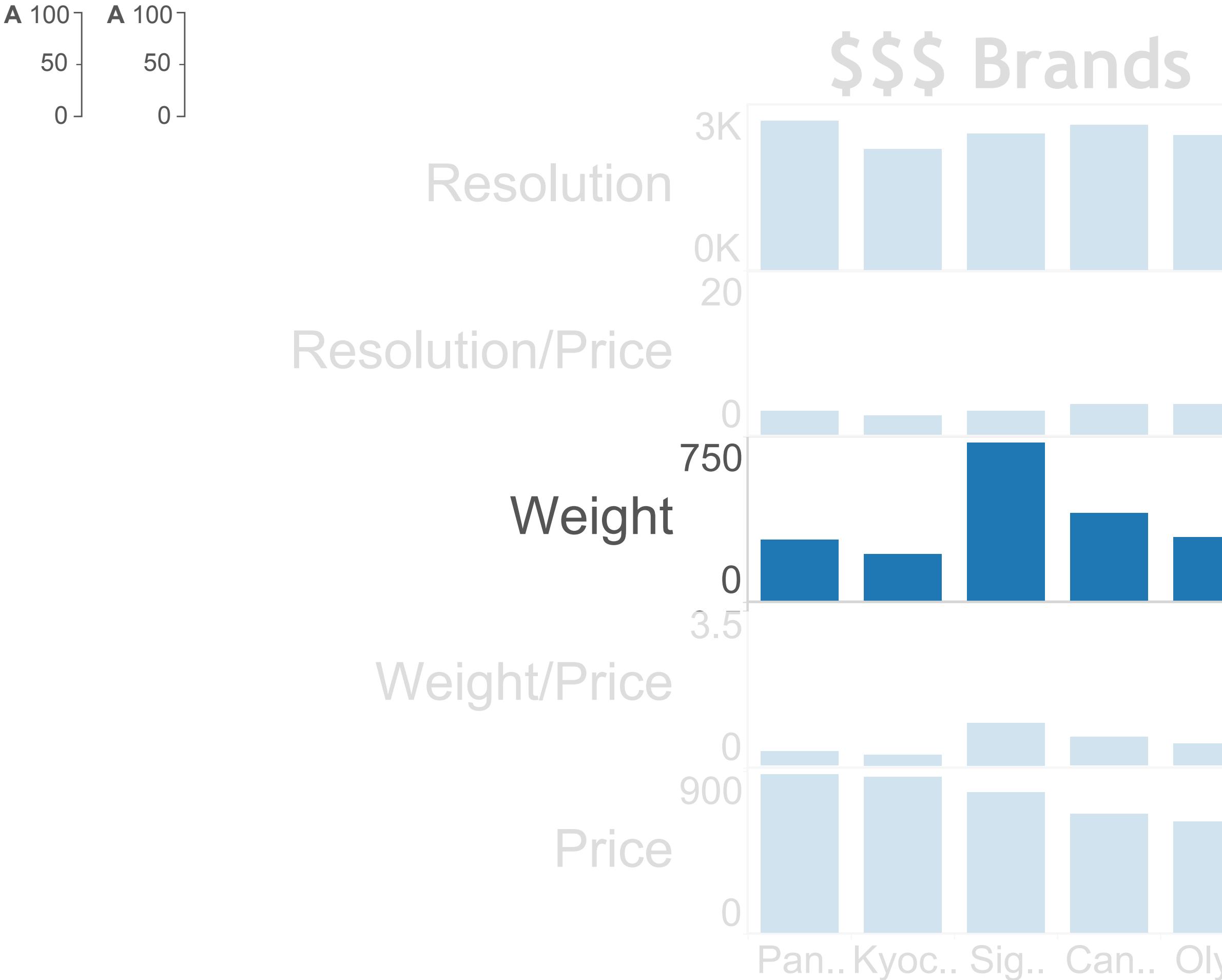
C1.1 Same Field,
Same XY Scale



Bob

Validation: Manually Align Domains

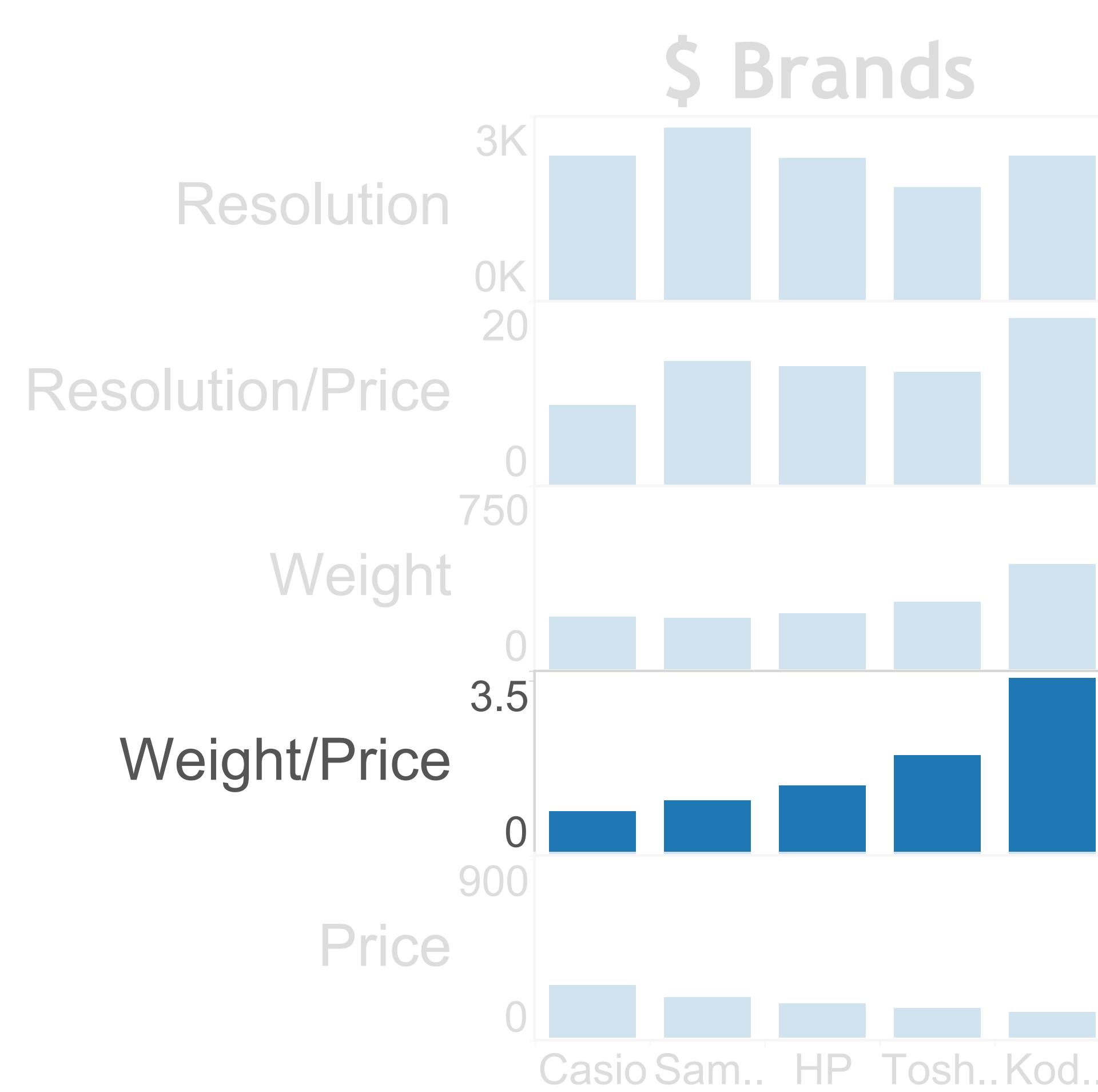
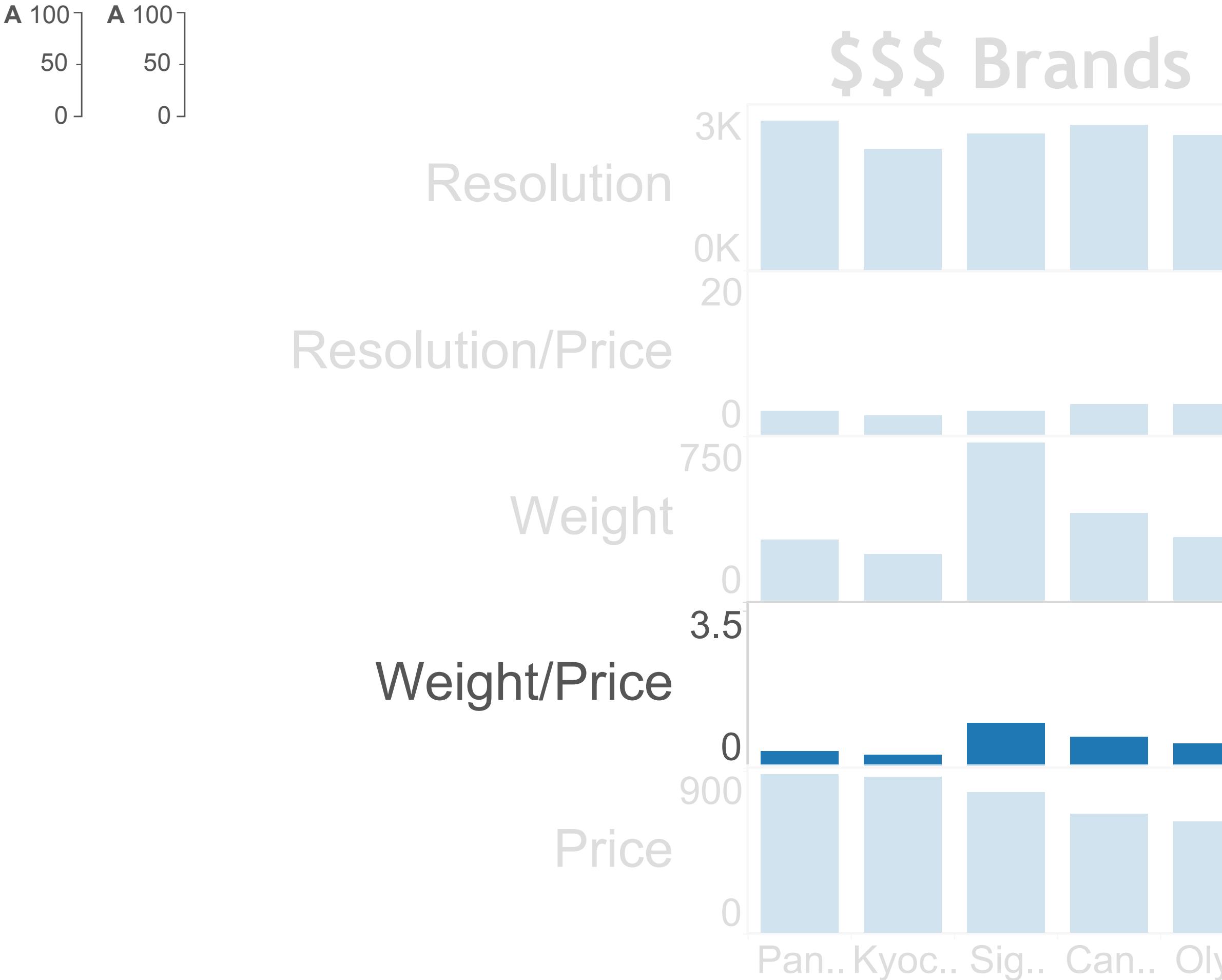
C1.1 Same Field,
Same XY Scale



Bob

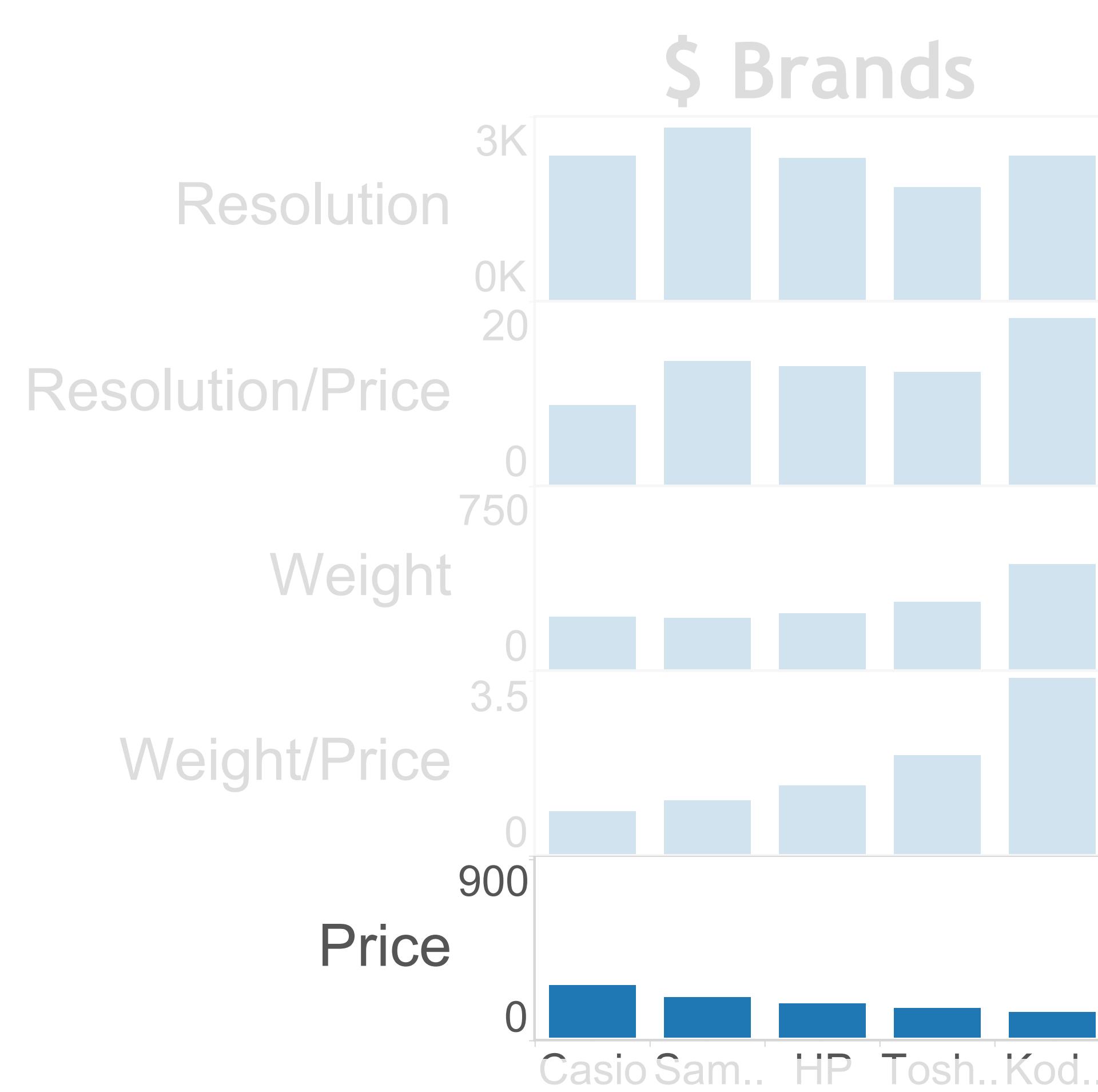
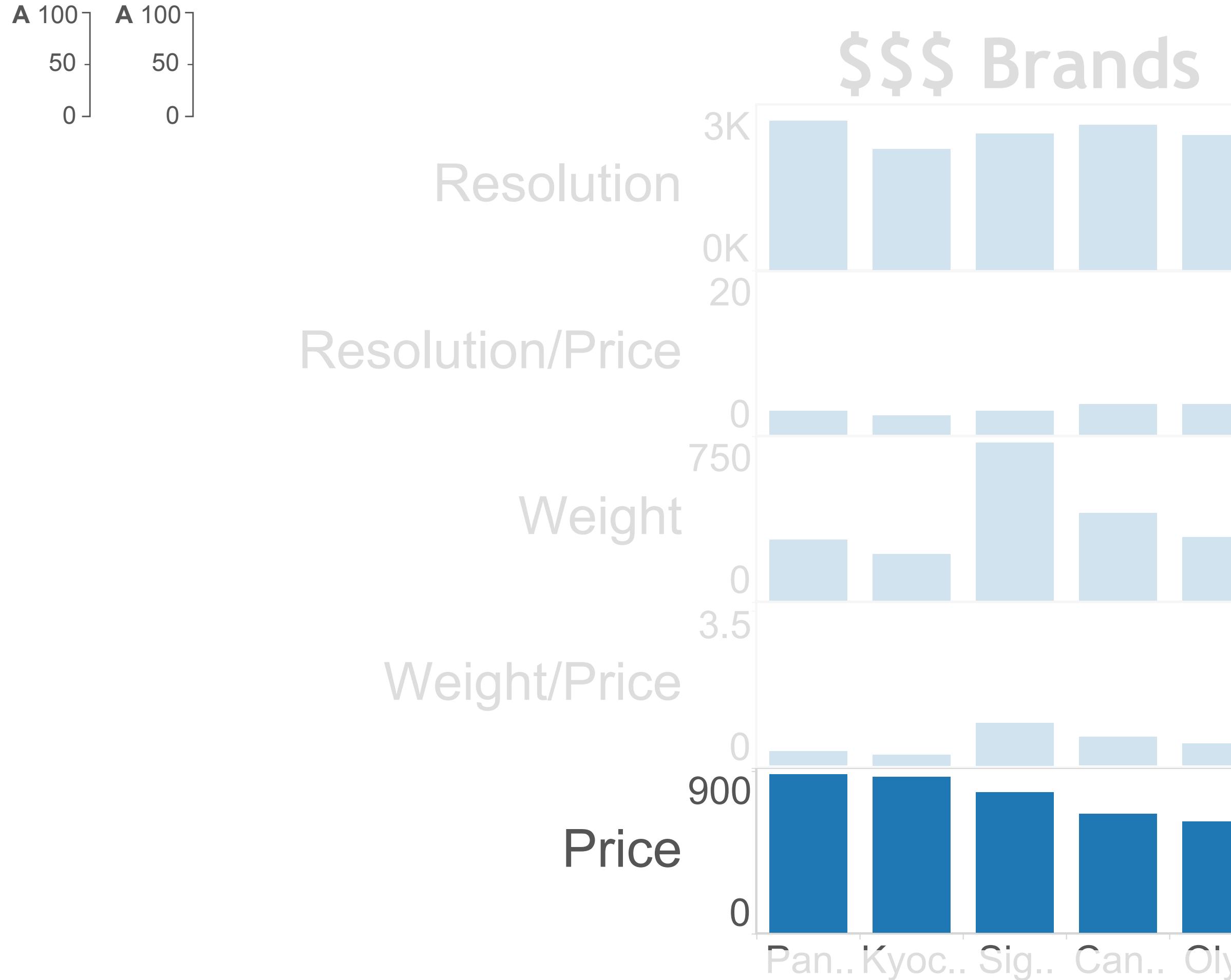
Validation: Manually Align Domains

C1.1 Same Field,
Same XY Scale



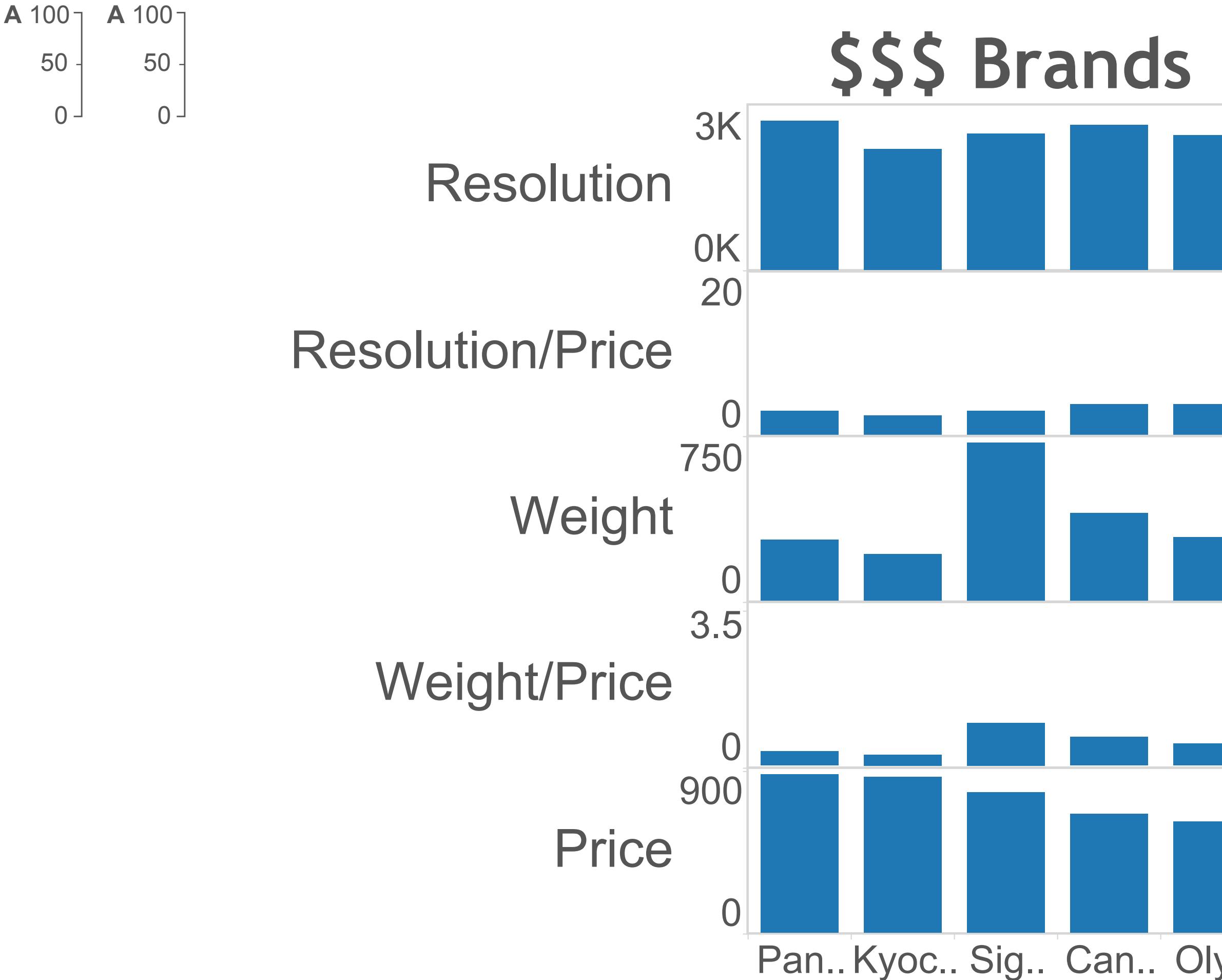
Validation: Manually Align Domains

C1.1 Same Field,
Same XY Scale

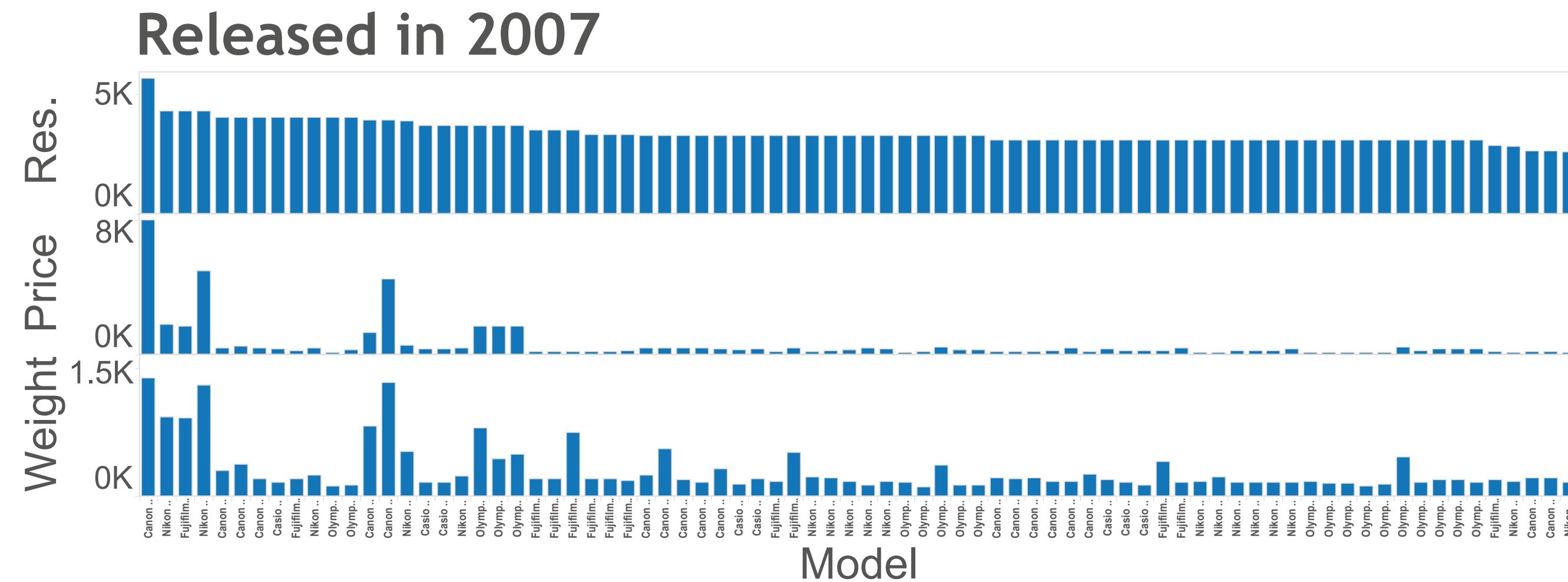
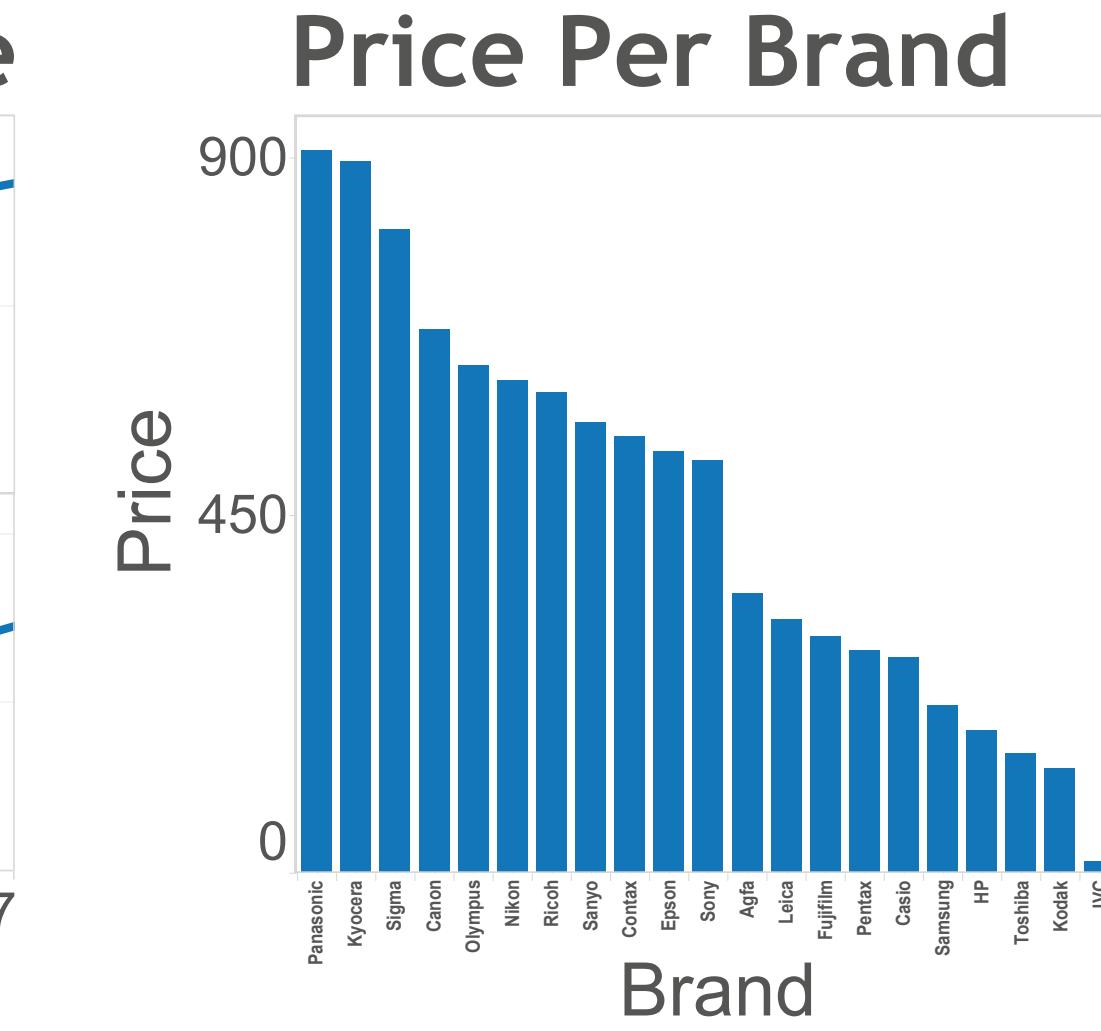
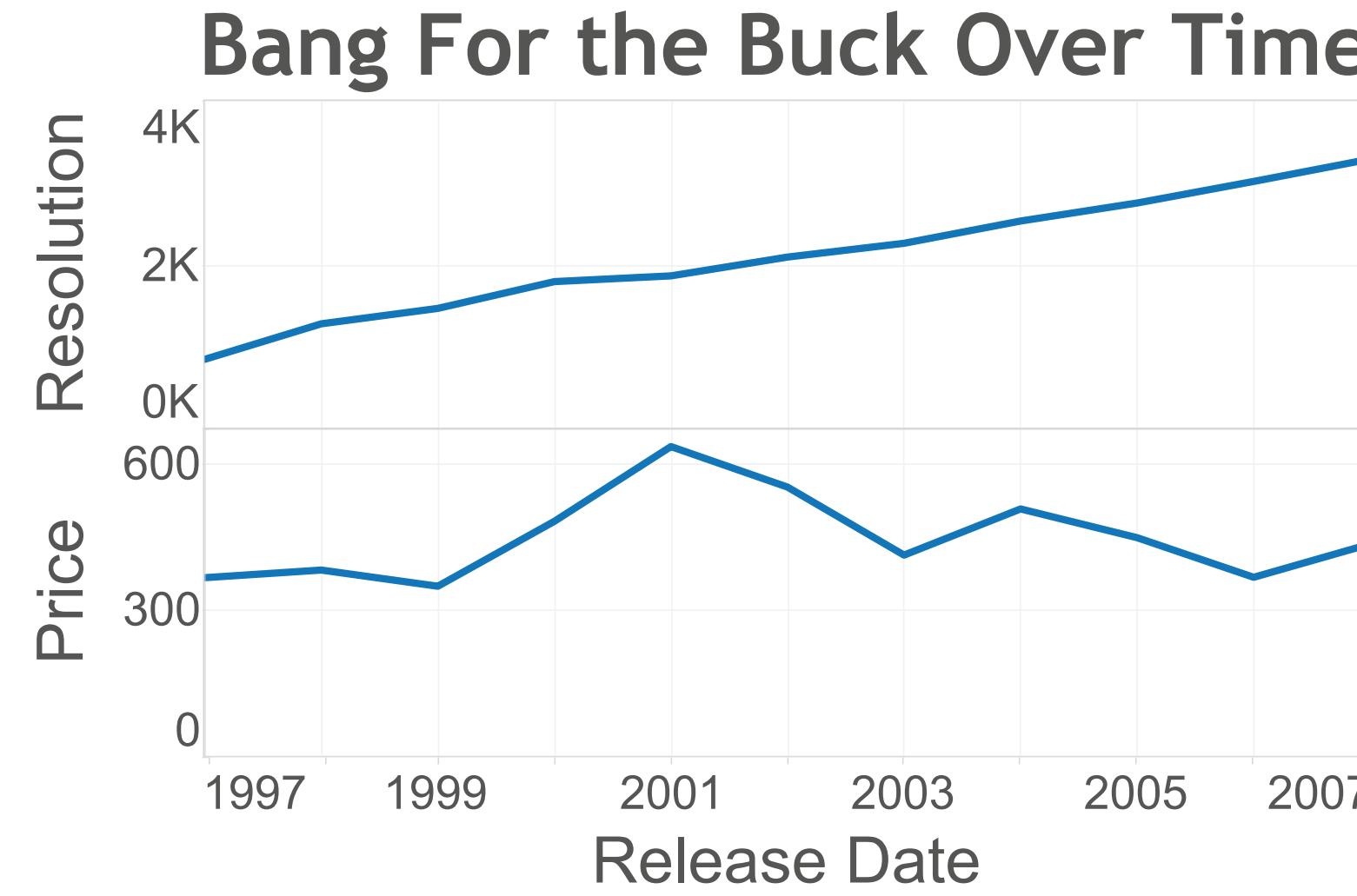


Validation: Manually Align Domains

C1.1 Same Field,
Same XY Scale



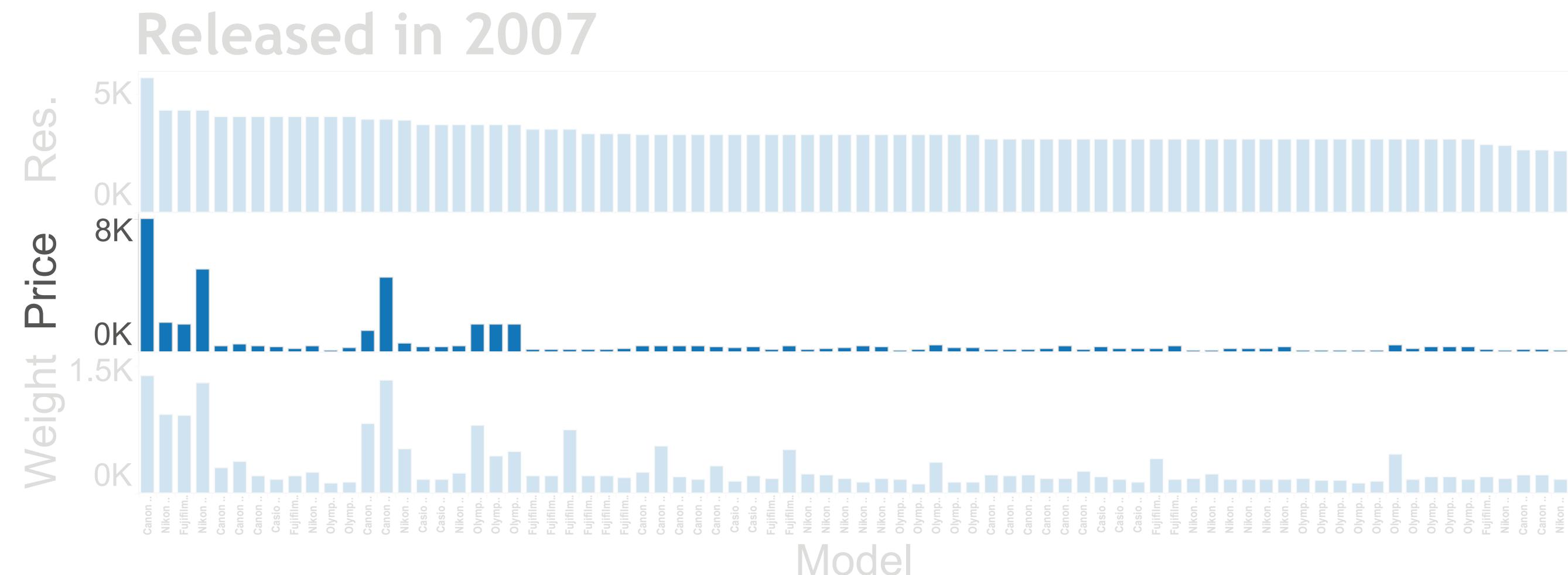
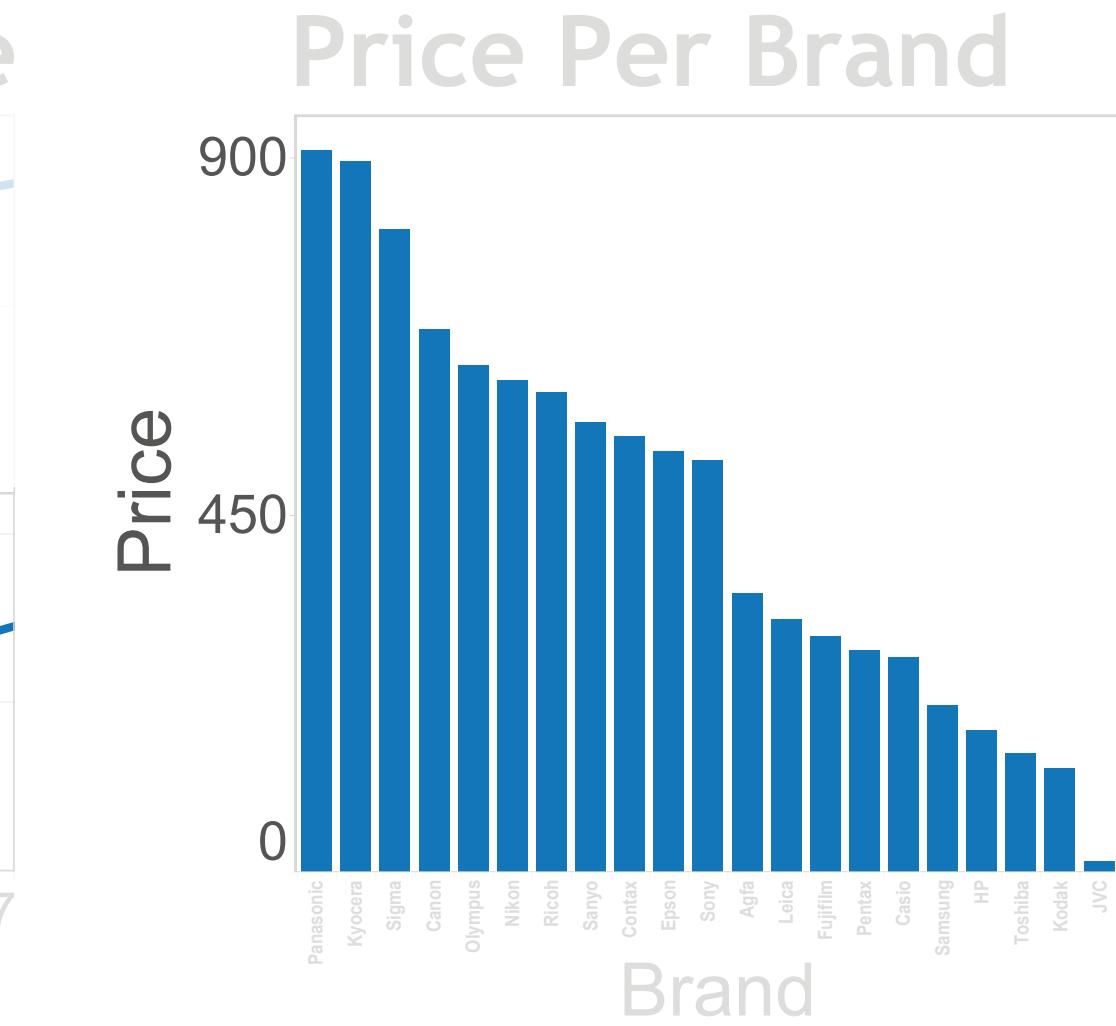
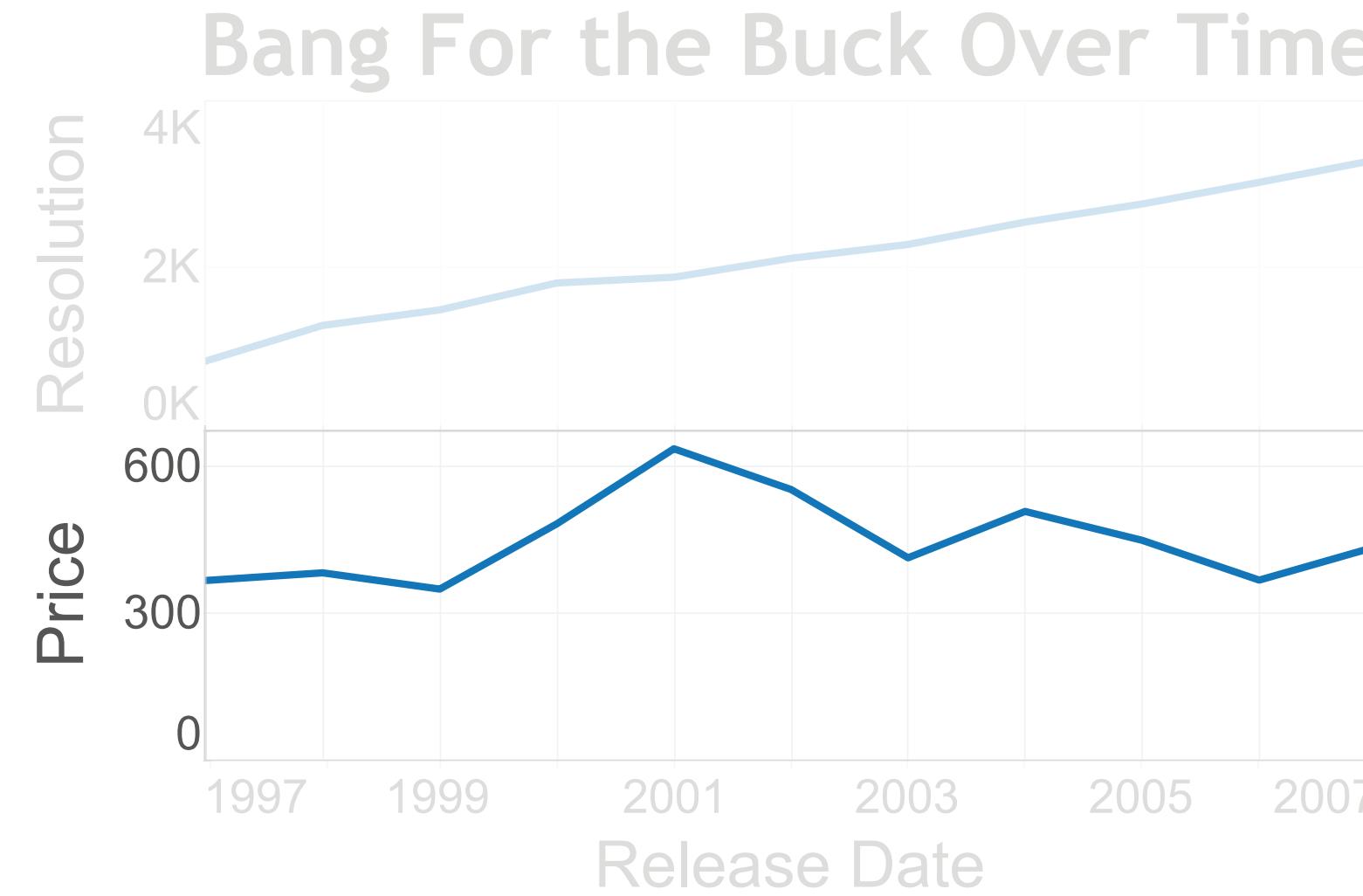
Validation: Manually Align Domains



Bob

Exception: Not Juxtaposed, Too Much White Space

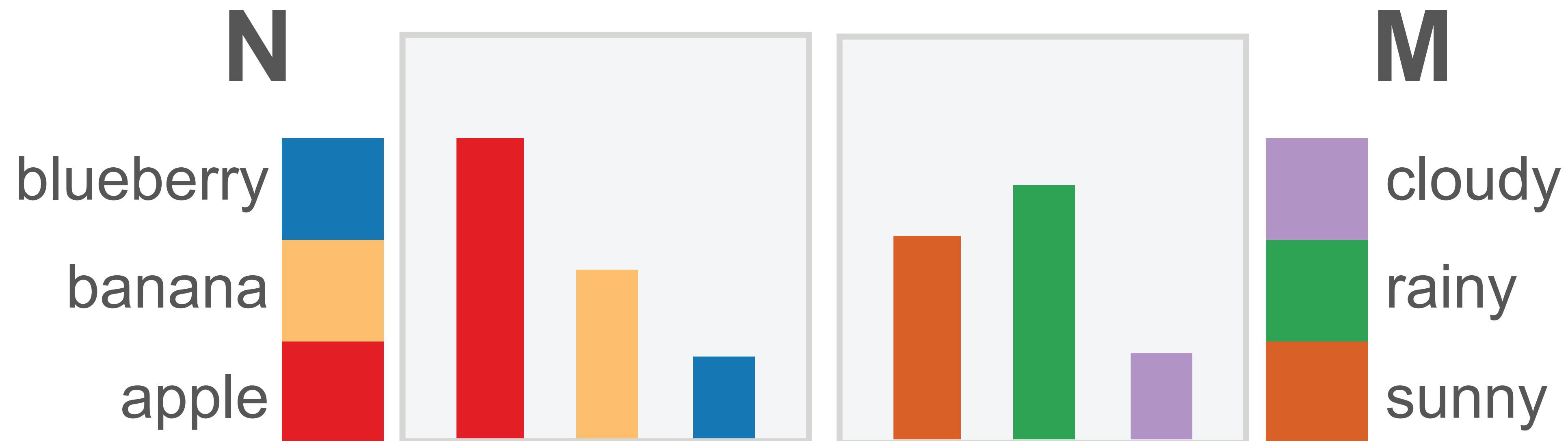
C1.1 Same Field, Same XY Scale



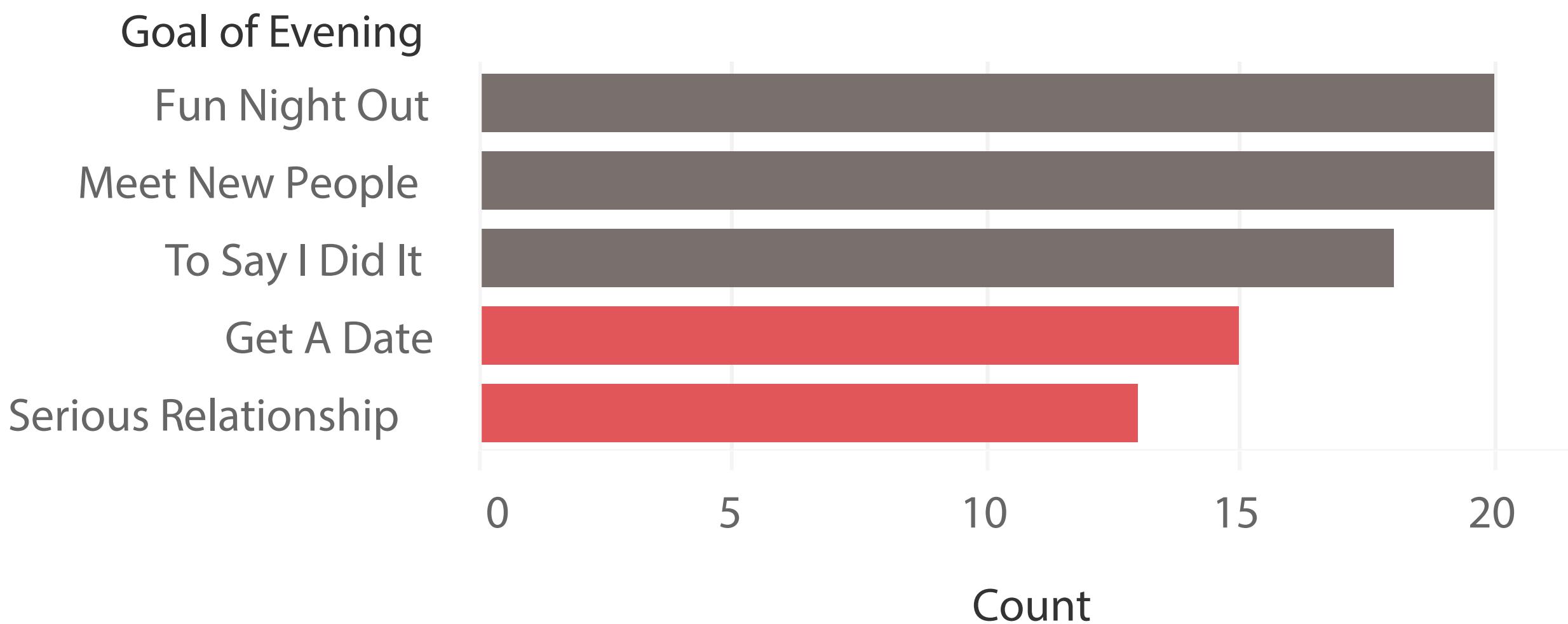
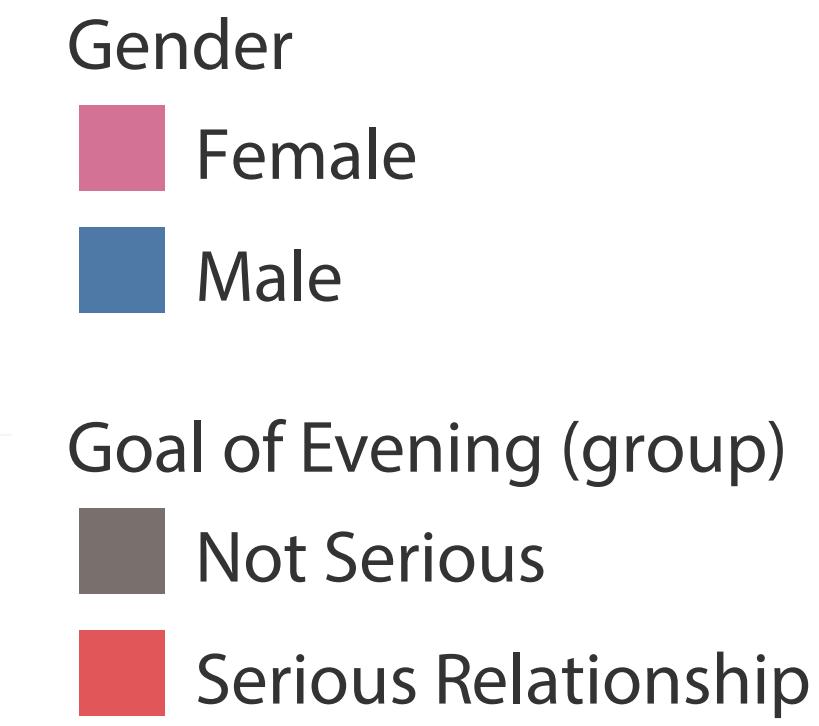
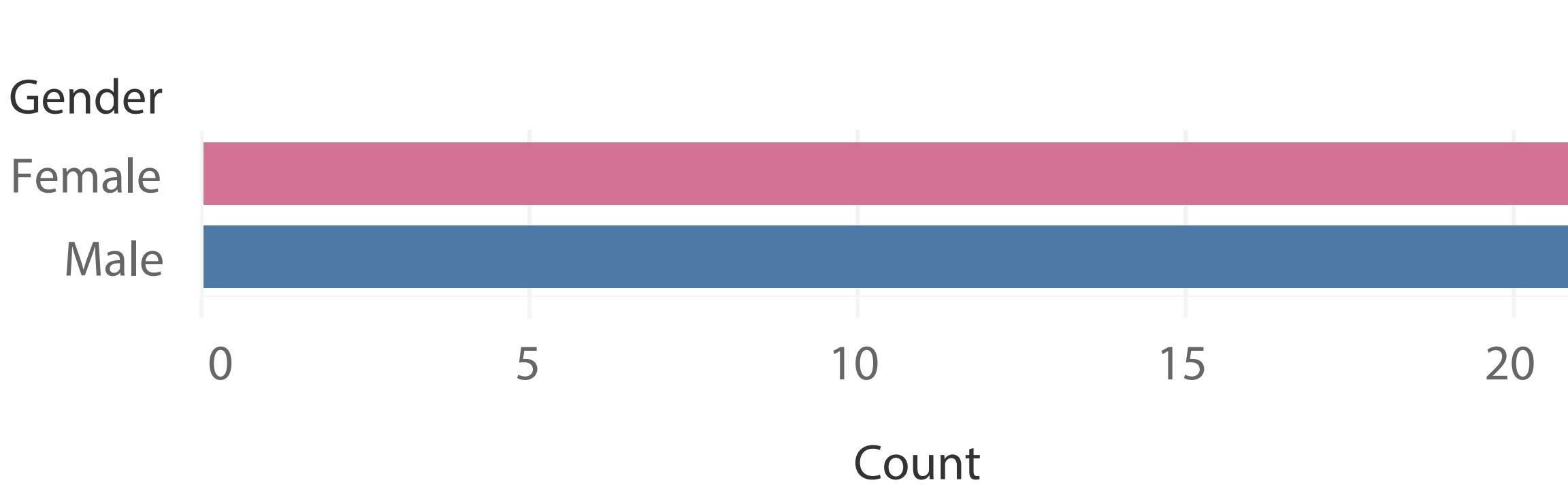
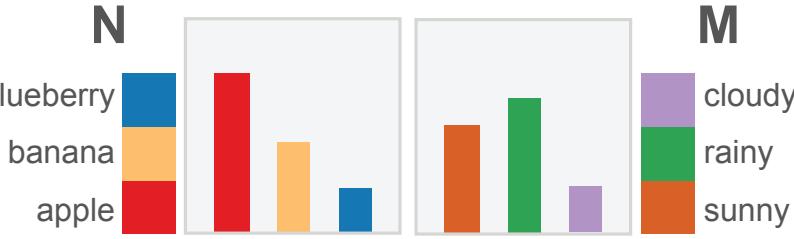
Bob

Exception: Not Juxtaposed, Too Much White Space

C2.4 Different Fields, Non-overlapping Palettes



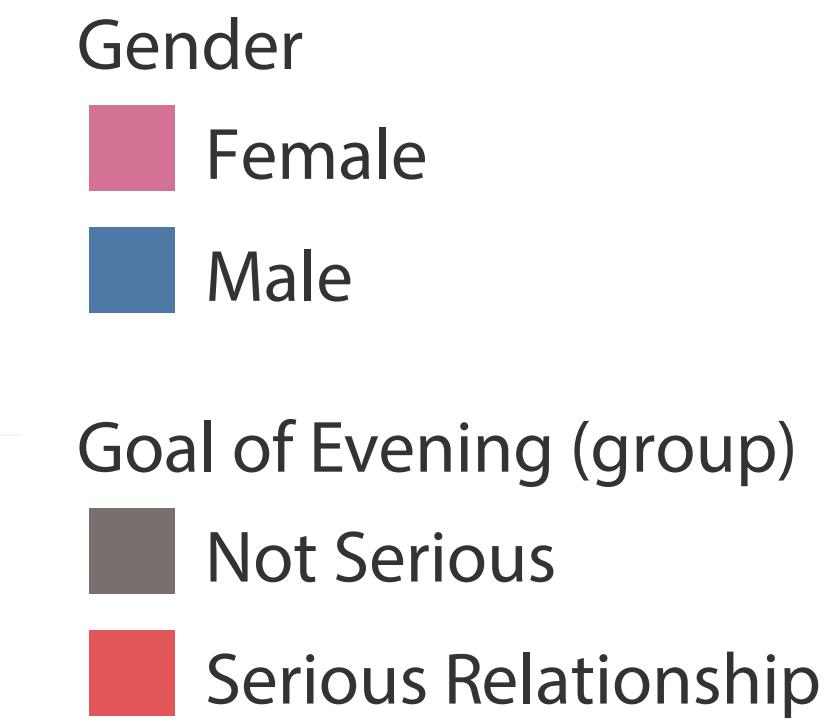
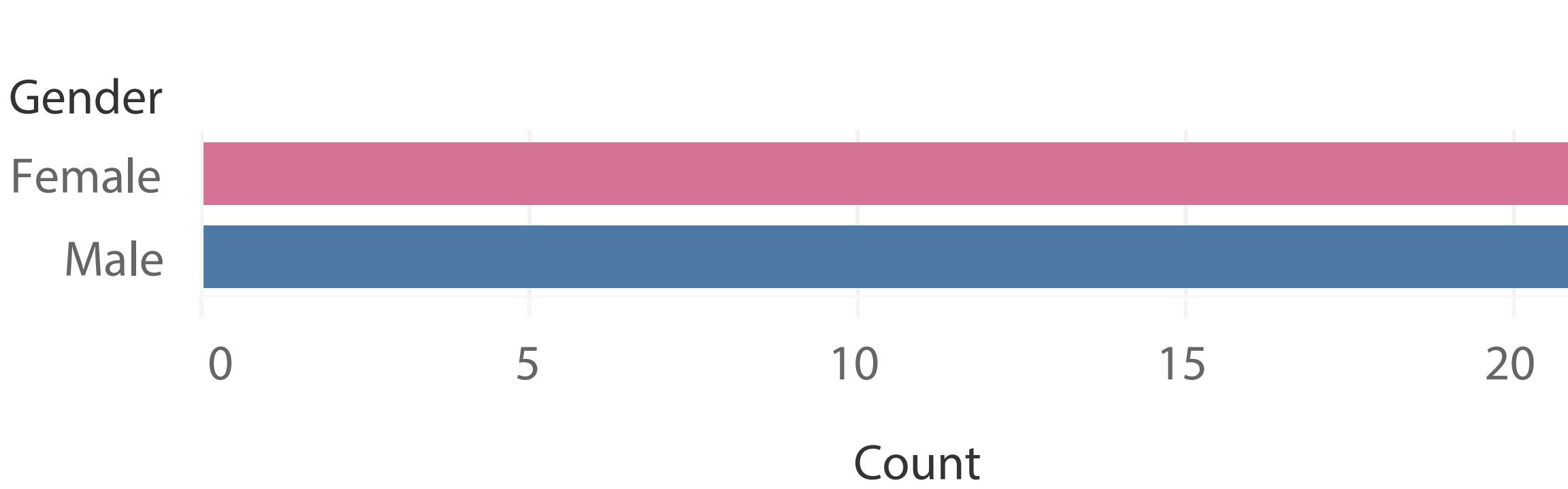
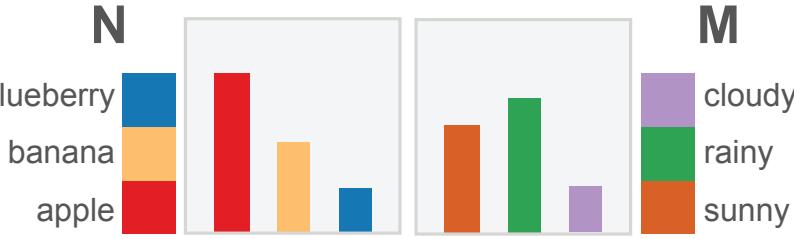
C2.4 Different Fields, Non-overlapping Palettes



Iva

Validation: Avoid Multiple Meanings
for the Same Color

C2.4 Different Fields, Non-overlapping Palettes



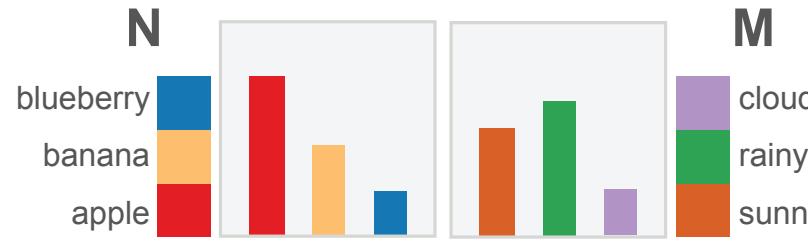
"I wouldn't use this (pink) color (for serious relationship)
because that's the girl color that I used."



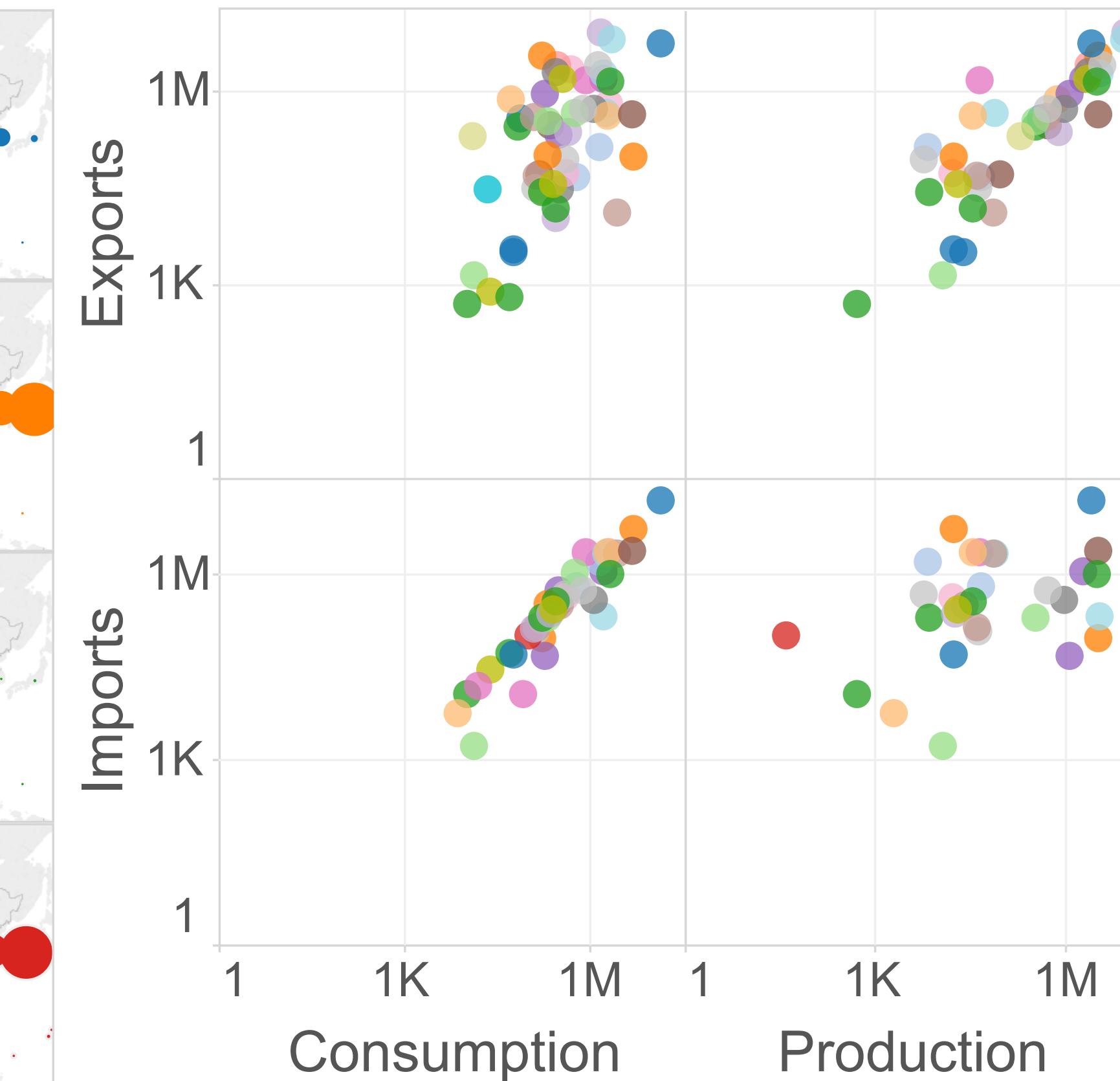
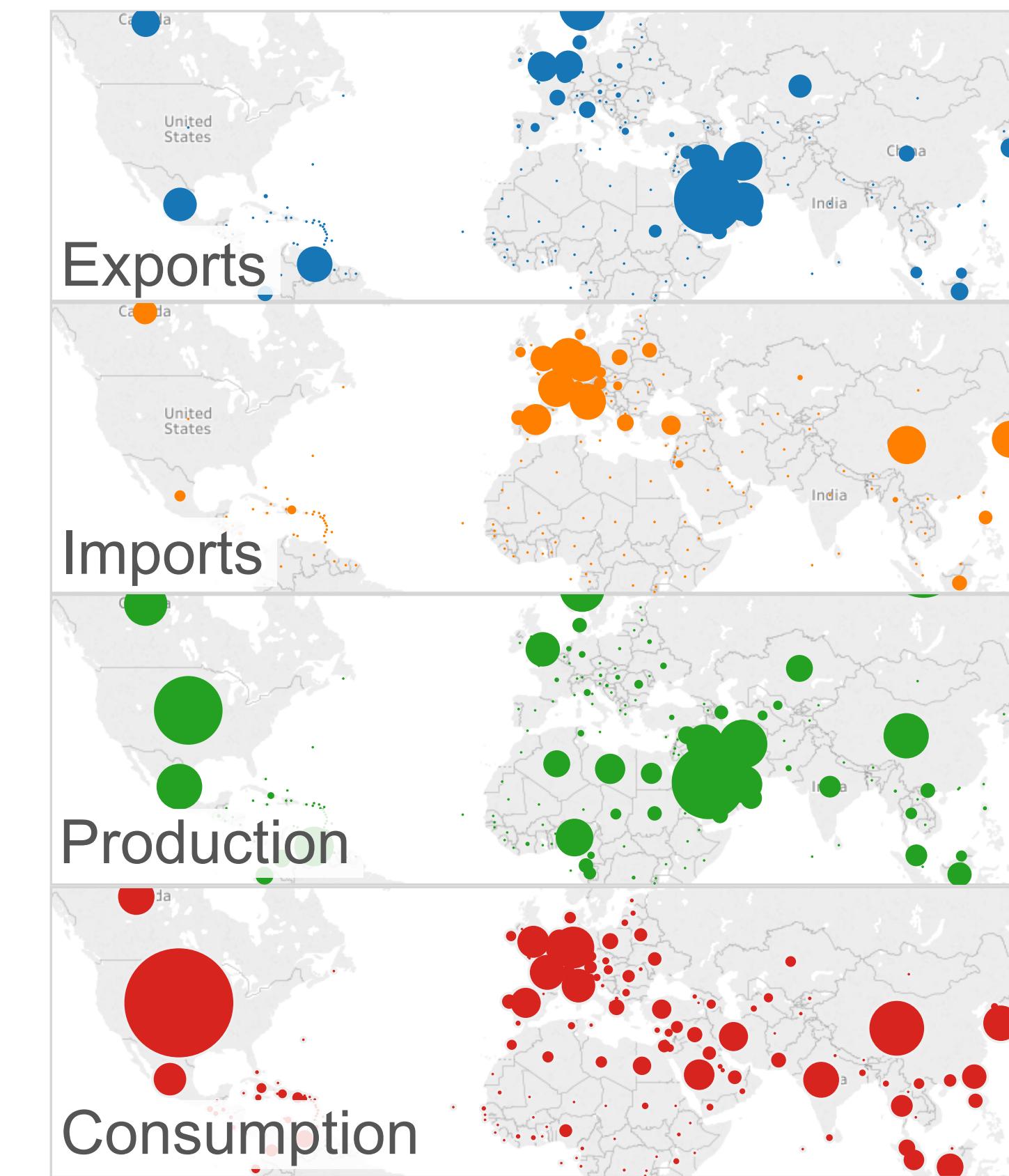
Iva

Validation: Avoid Multiple Meanings
for the Same Color

C2.4 Different Fields, Non-overlapping Palettes

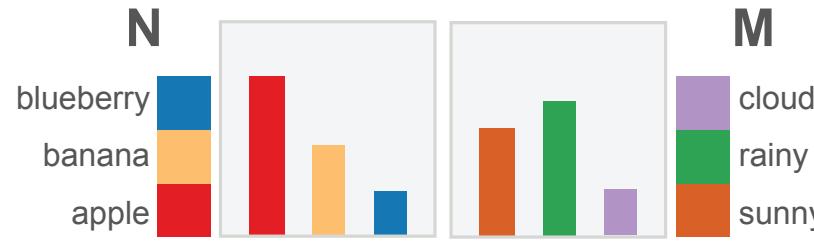


Oil

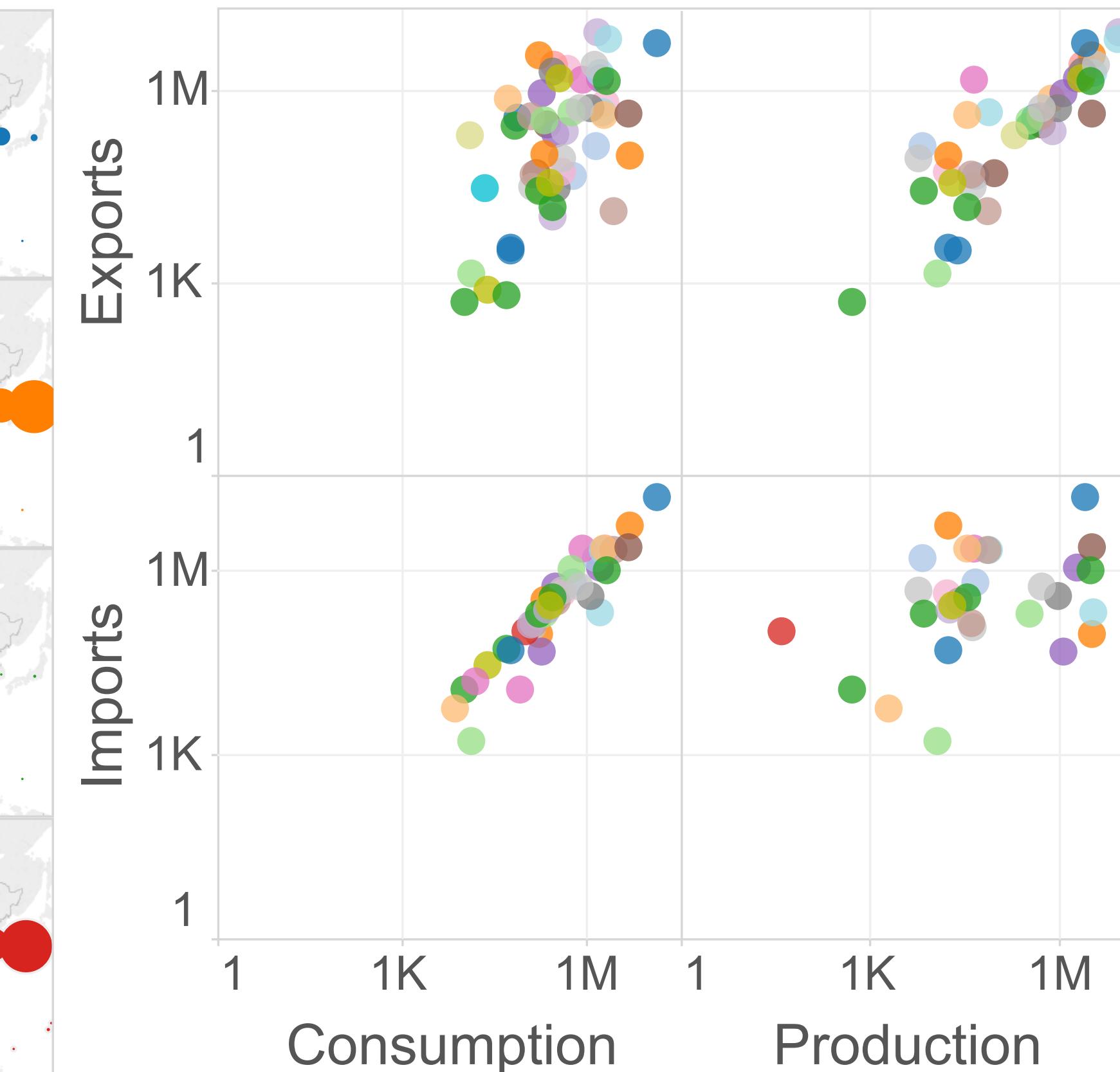
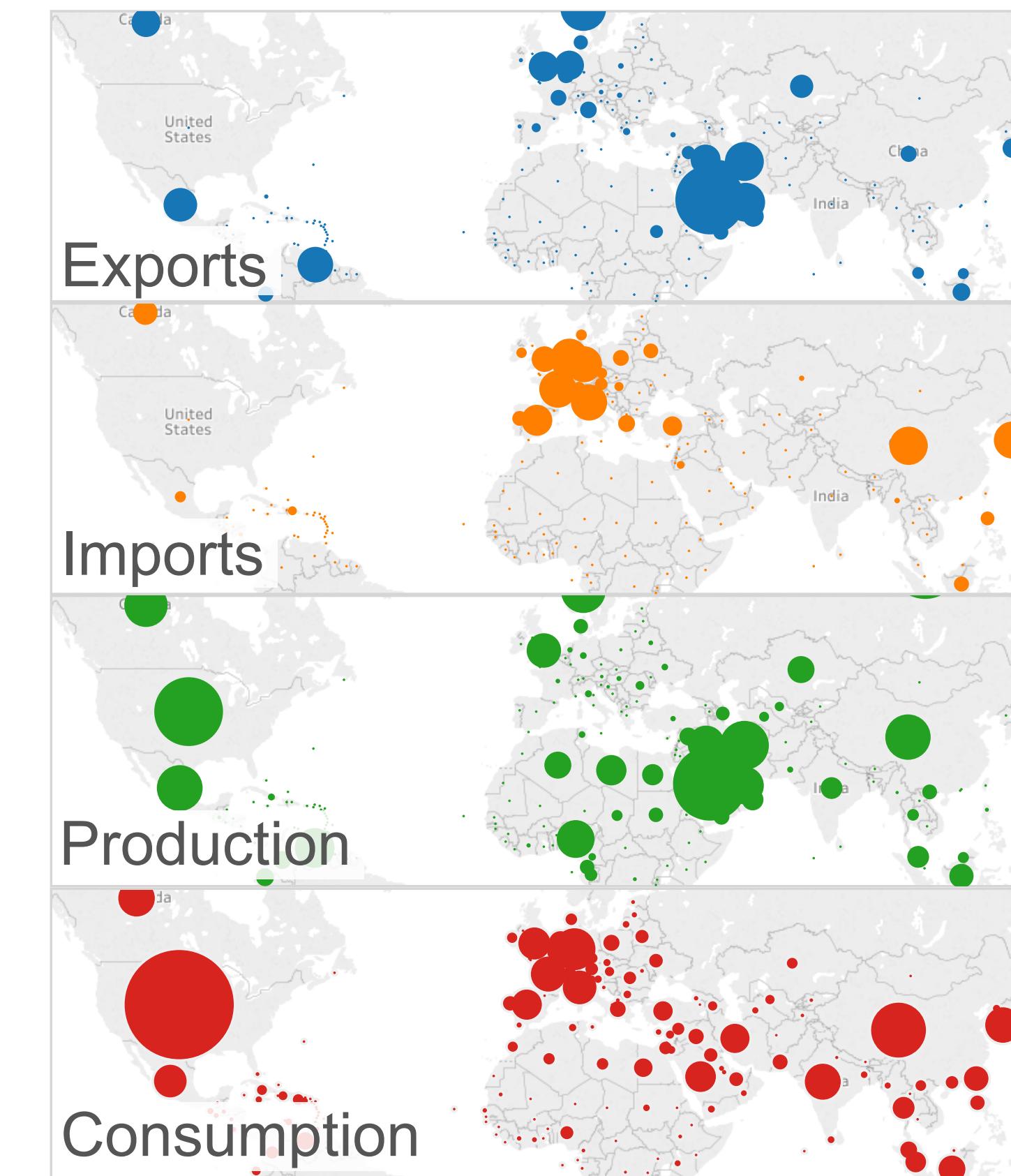


Exception: Forgive High Cardinality

C2.4 Different Fields, Non-overlapping Palettes



Oil



Mia



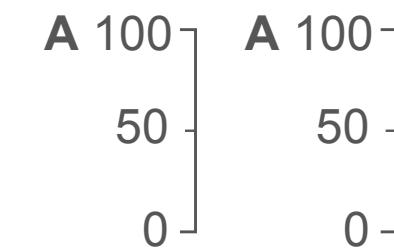
"High cardinality color encoding isn't useful"

Tim

Exception: Forgive High Cardinality

Validations Exceptions

C1.1 Same Field,
Same XY Scale



Manually Align Domains

Not Juxtaposed

C2.4 Different Fields,
Non-overlapping Palettes



Avoid Multiple Meanings

Forgive High-Cardinality

Validations

Exceptions

C1.2 Special Case: Same Measure Order



Manually Order Fields

Validations Exceptions

C1.2 Special Case: Same Measure Order



Manually Order Fields

C1.4 Special Case: Same Measure, Same Color



One Color per Field

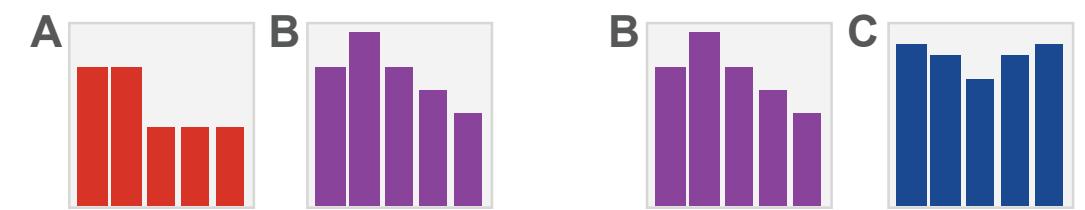
Validations Exceptions

C1.2 Special Case: Same Measure Order



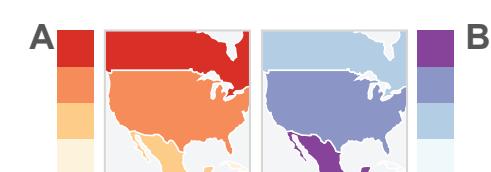
Manually Order Fields

C1.4 Special Case: Same Measure, Same Color



One Color per Field

C2.3 Different Fields,
Non-Overlapping Hues



Hues for Quantitative Fields

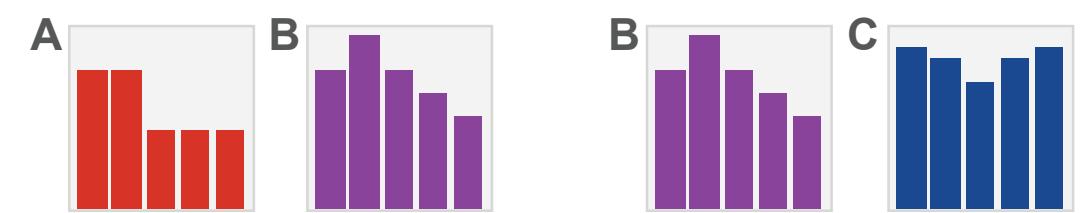
Hues for High-Low, Good-Bad

Validations Exceptions

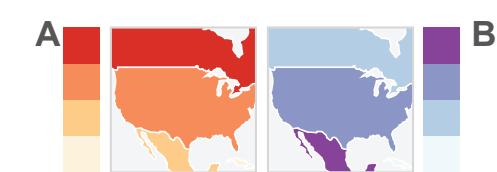
C1.2 Special Case: Same Measure Order



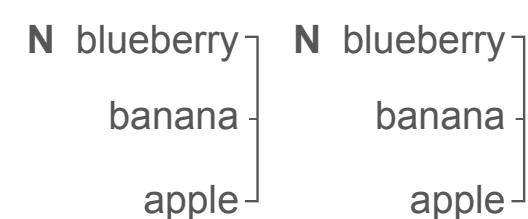
C1.4 Special Case: Same Measure, Same Color



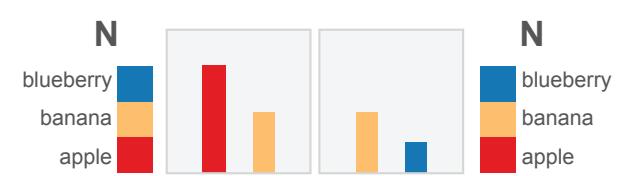
C2.3 Different Fields,
Non-Overlapping Hues



C1.2 Same Field, Same
Values in Same Order



C1.4 Same Field, Same
Value-Color Mapping



Manually Order Fields

One Color per Field

Hues for Quantitative Fields

Check Filter & Sort

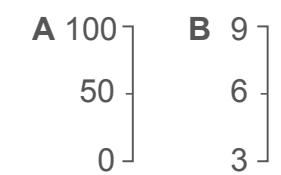
Assign & Reuse

Hues for High-Low, Good-Bad

Sorted By Different Metrics

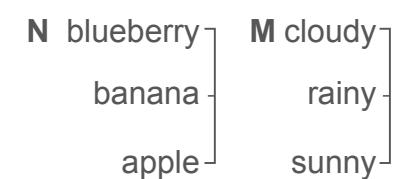
Validations Exceptions

C2.1 Different Fields,
Different XY Domains



Naturally Differed

C2.2 Different Fields,
Different Nominal Values



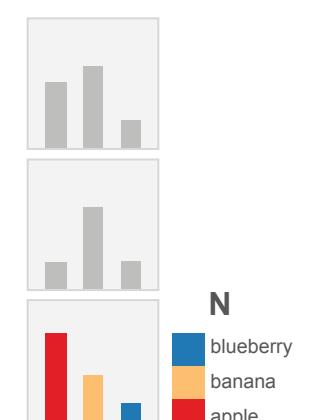
Naturally Differed

C1.3 Same Field, Same
Quantitative Color Scale



Reuse Color Scales

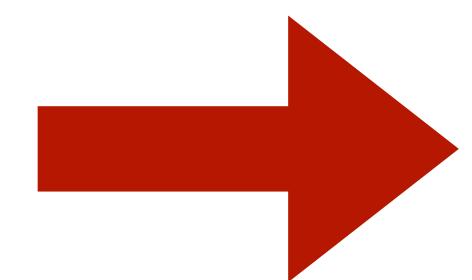
C2.5 Non-overlapping
Nominal and
Constant Colors



Change Constant Color

Forgive High-Cardinality

Constraints



Validations

&

Exceptions

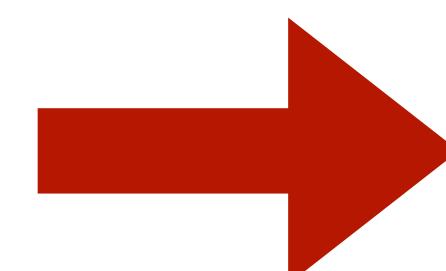
Implications

Constraints

Validations

&

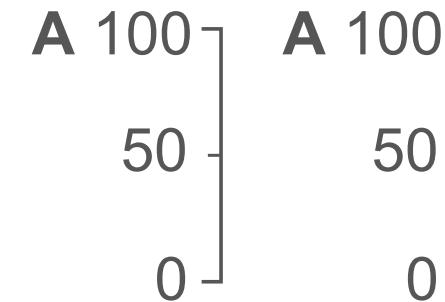
Exceptions



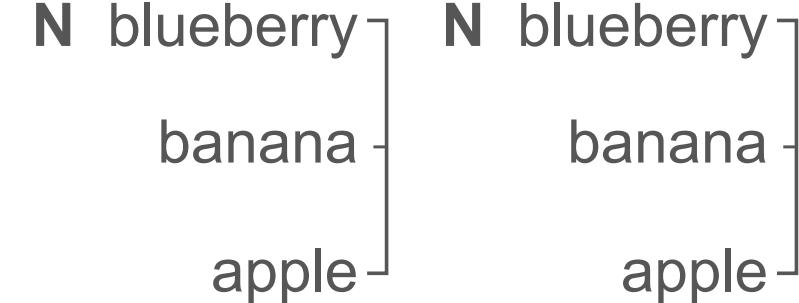
Implications

Design Implications

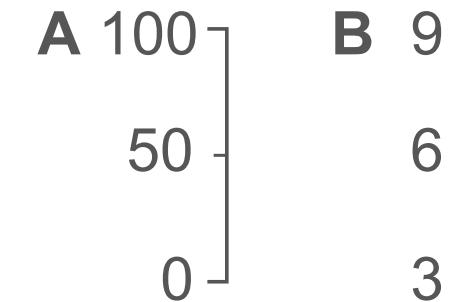
C1.1 Same Field,
Same XY Scale



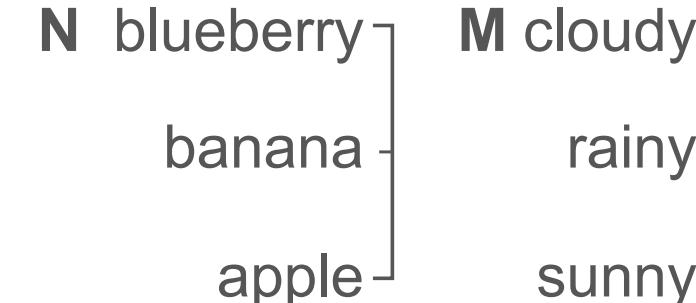
C1.2 Same Field, Same
Values in Same Order



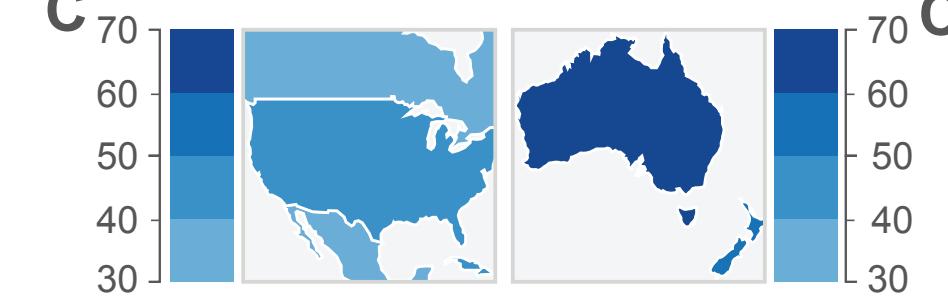
C2.1 Different Fields,
Different XY Domains



C2.2 Different Fields,
Different Nominal Values



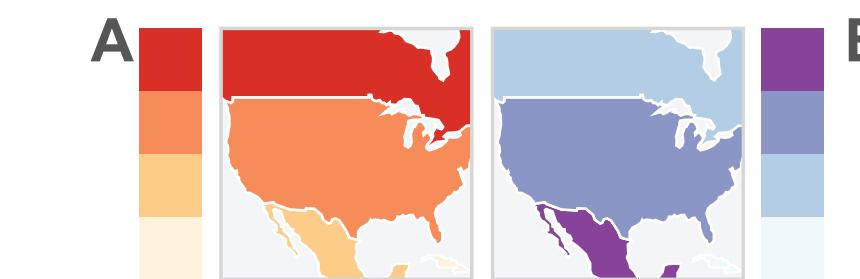
C1.3 Same Field, Same
Quantitative Color Scale



C1.4 Same Field, Same
Value-Color Mapping



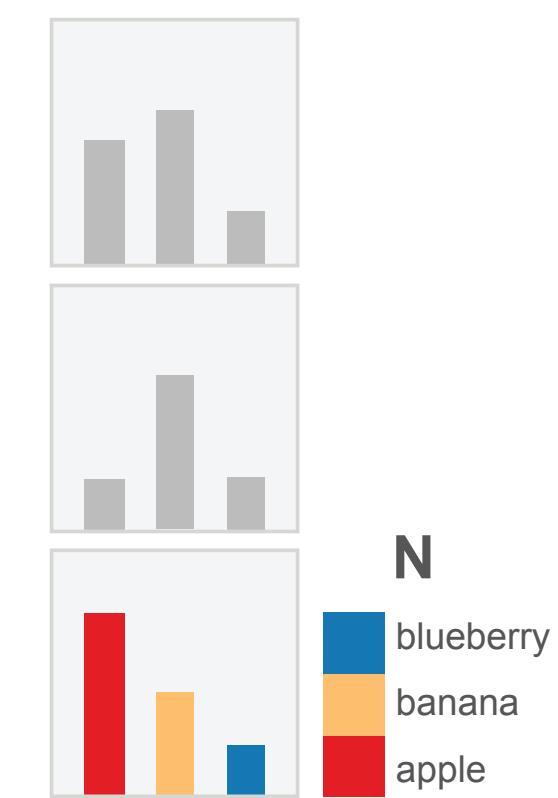
C2.3 Different Fields,
Non-Overlapping Hues



C2.4 Different Fields,
Non-overlapping Palettes



C2.5 Non-overlapping
Nominal and
Constant Colors



Constraints can be automatically detected during visualization authoring to generate warnings

Design Implications

Validations

Reuse Color Scales

Change Constant Color

Assign & Reuse

Manually Align Domains

Manually Order Fields

One Color per Field

Avoid Multiple Meanings

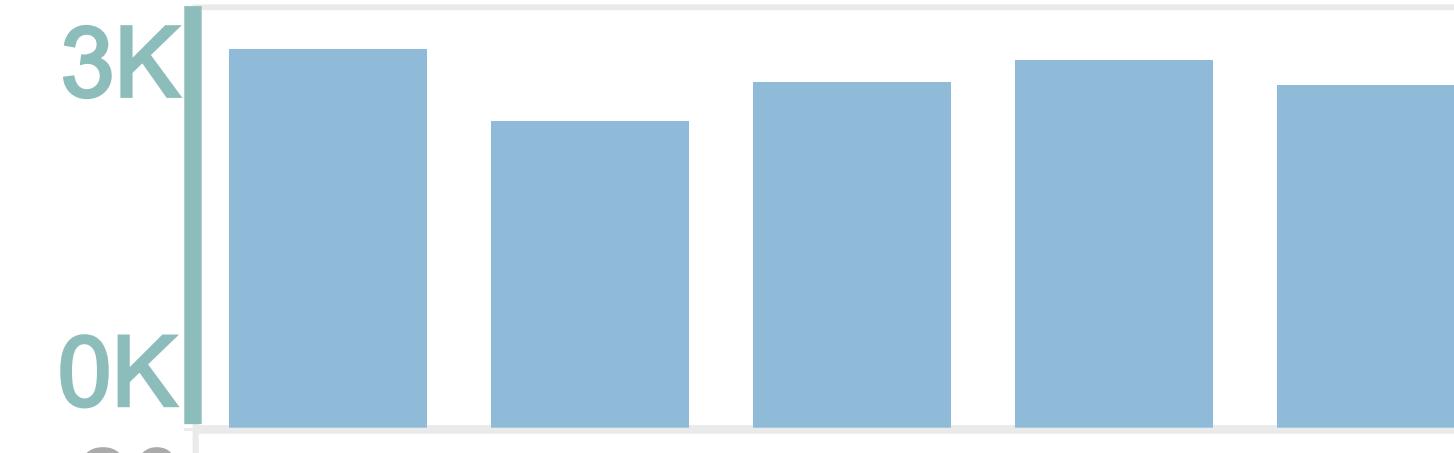
Check Filter & Sort

Hues for Fields

Validations suggest consistency strategies
that authoring systems can help enact

\$\$\$ Brands

Resolution



Resolution



Manual Effort 💧

Align Axes, Check Filters & Sort

Weight/Price



Weight/Price



Price

Pan.. Kyoc.. Sig.. Can.. Oly..

Casio Sam.. HP Tosh.. Kod..

Design Implications

Exceptions

Not Juxtaposed, Too Much Whitespace

Sorted By Different Metrics

Forgive High-Cardinality

Hues for High-Low, Good-Bad

Exceptions are trade-offs that tools should be aware of

Future Work

Can we **rank** consistency constraints by importance?

What are the **boundaries** for various constraints?

How to **express** inconsistency to authors?

What to do if **no solution exists** for resolving an inconsistency? What to do if **multiple solutions exist**?

A Bold Question

Many tools that we use today like Tableau treat single views as first-class-citizens.

Is it possible to adapt these tools to also prioritize consistency without requiring **a new paradigm** for visualization authoring?

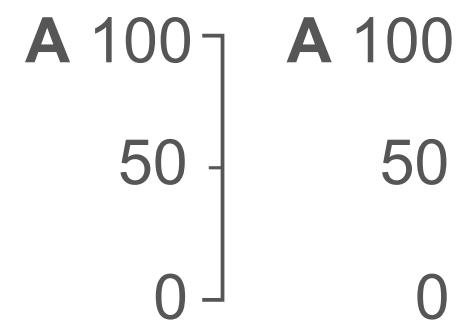
Thank You!

Keeping Multiple Views Consistent

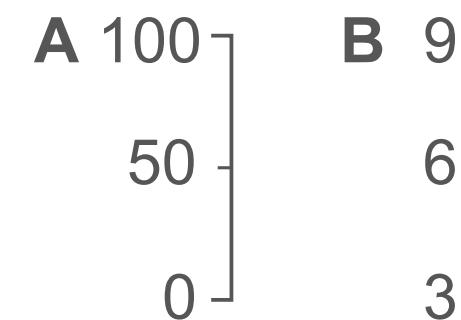
Constraints, **Validations**, **Exceptions**

Quantitative
X & Y

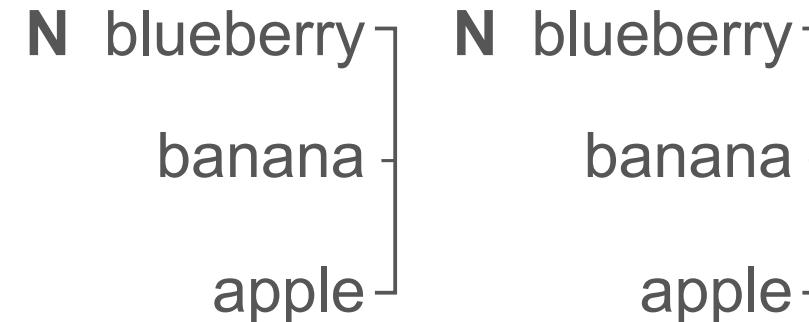
C1.1 Same Field,
Same XY Scale



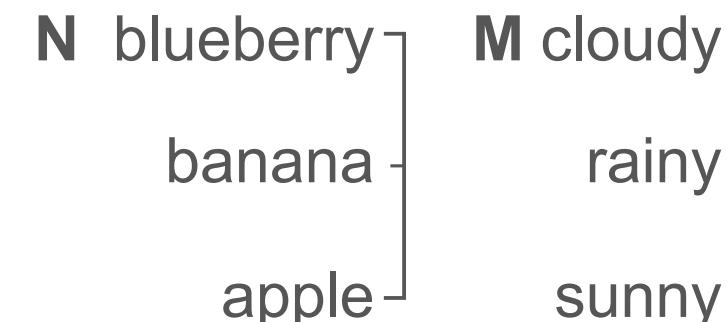
C2.1 Different Fields,
Different XY Domains



C1.2 Same Field, Same
Values in Same Order



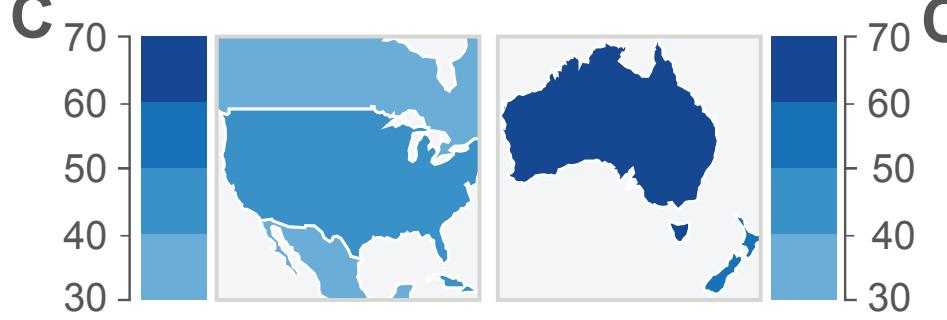
C2.2 Different Fields,
Different Nominal Values



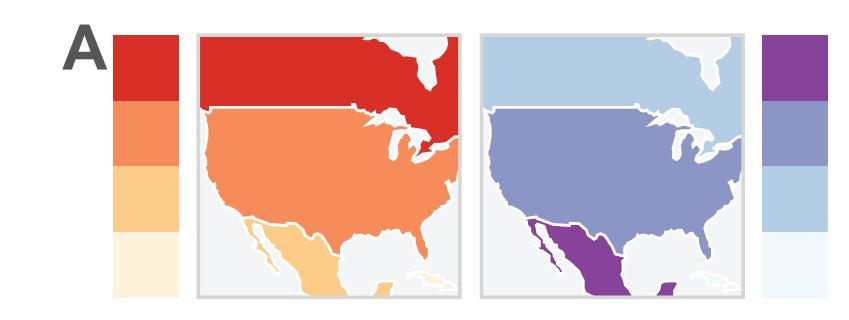
Nominal
X & Y

Quantitative
Color

C1.3 Same Field, Same
Quantitative Color Scale

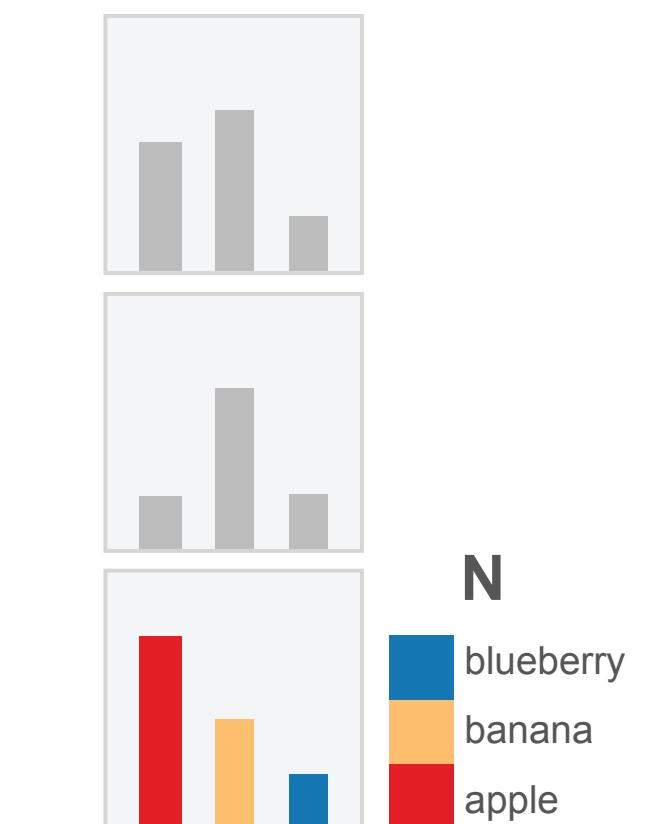


C2.3 Different Fields,
Non-Overlapping Hues



Constant
Color

C2.5 Non-overlapping
Nominal and
Constant Colors



Nominal
Color



@ZeningQu



@JessicaHullman



@uwdata



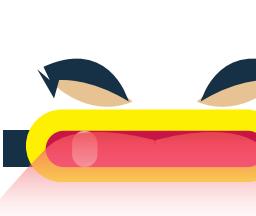
4/10

Kai



Bob

Joy



Zoe

Ann



Tom

Mia



Iva

Ada

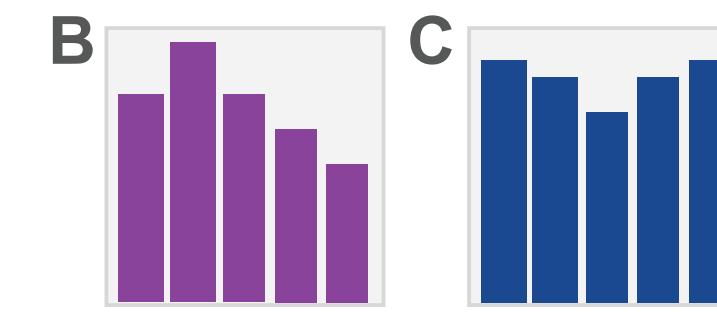
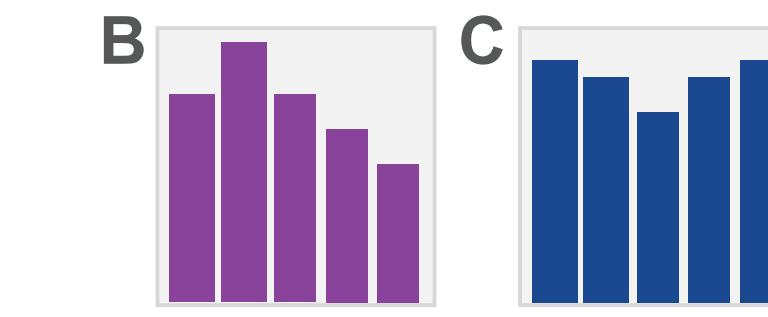
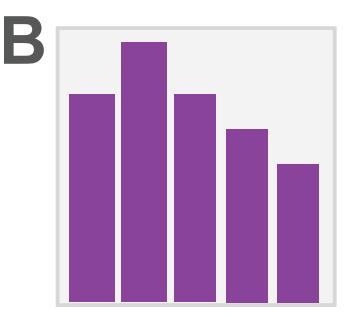
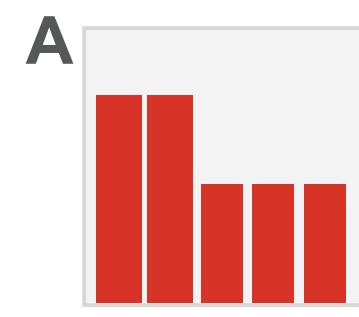


Tim

Joy

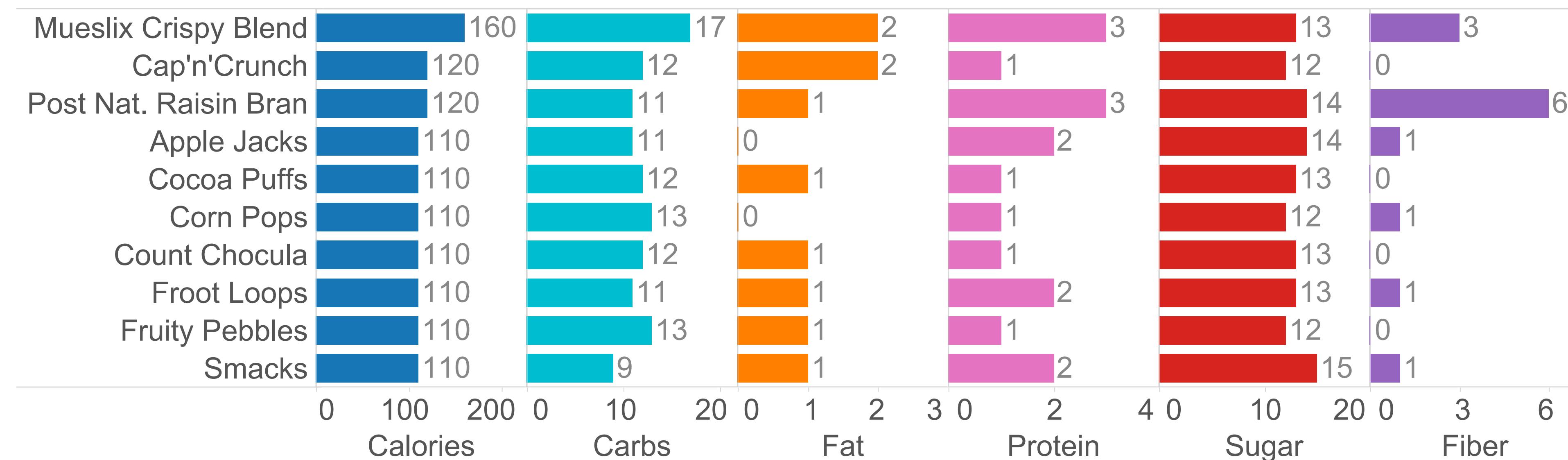


C1.4 Special Case: Same Measure, Same Color

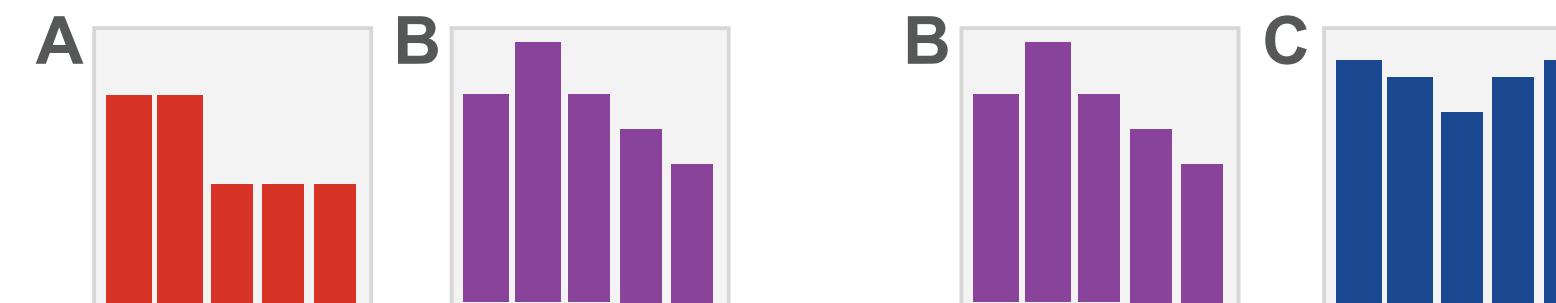


Validation: One Hue per Field

Nutrition Information



C1.4 Special Case: Same Measure, Same Color



Validation: One Hue per Field





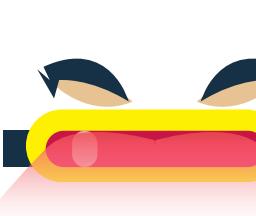
4/10

Kai



Bob

Joy



Zoe

Ann



Tom

Mia



Iva

Ada

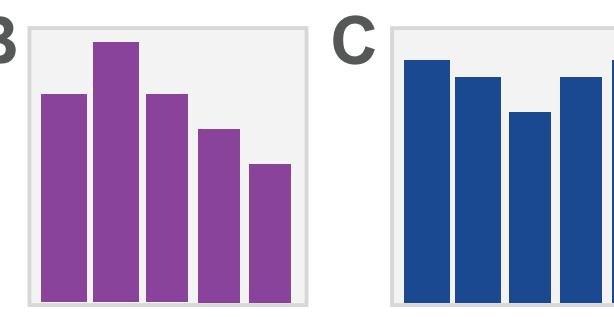
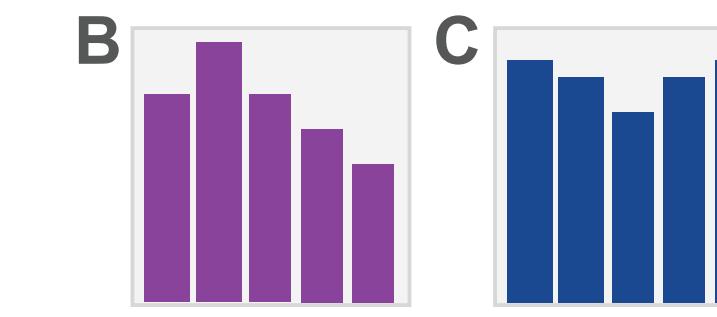
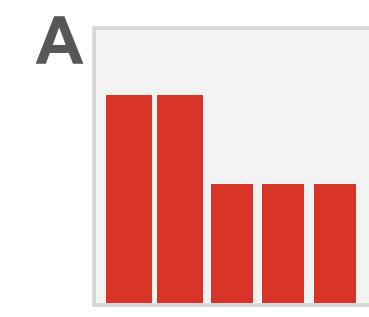


Tim

Joy



C1.4 Special Case: Same Measure, Same Color



Validation: One Hue per Field



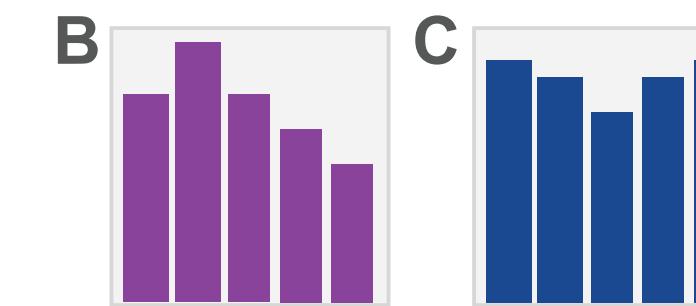
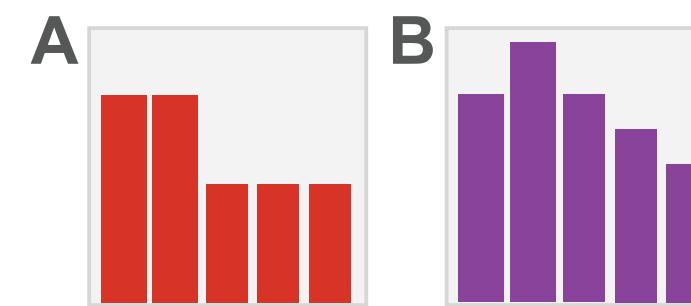
1/10



Joy



C1.4 Special Case: Same Measure, Same Color



Validation: One Hue per Field



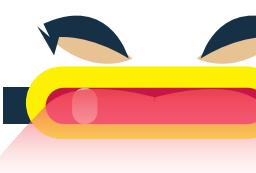
3/10

Kai



Bob

Joy



Zoe

Ann



Tom

Mia



Iva

Ada

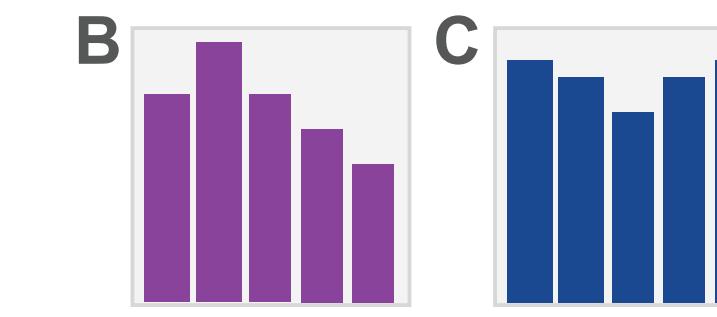
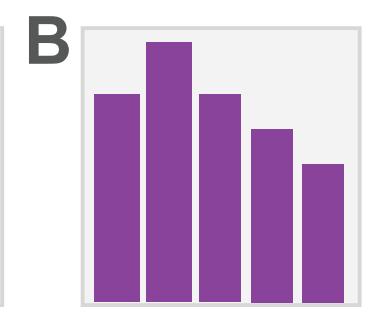
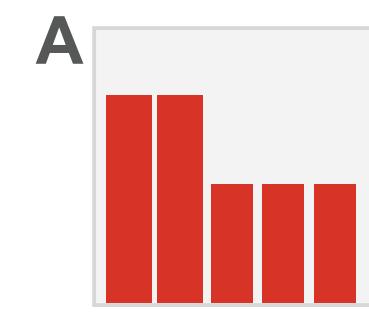


Tim

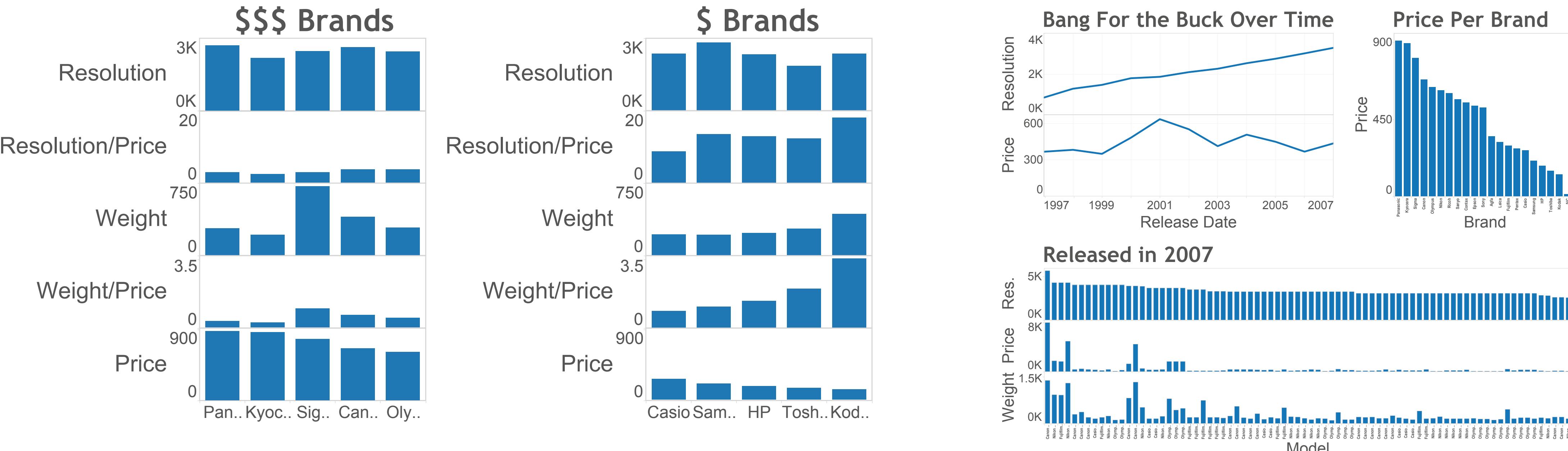
Joy



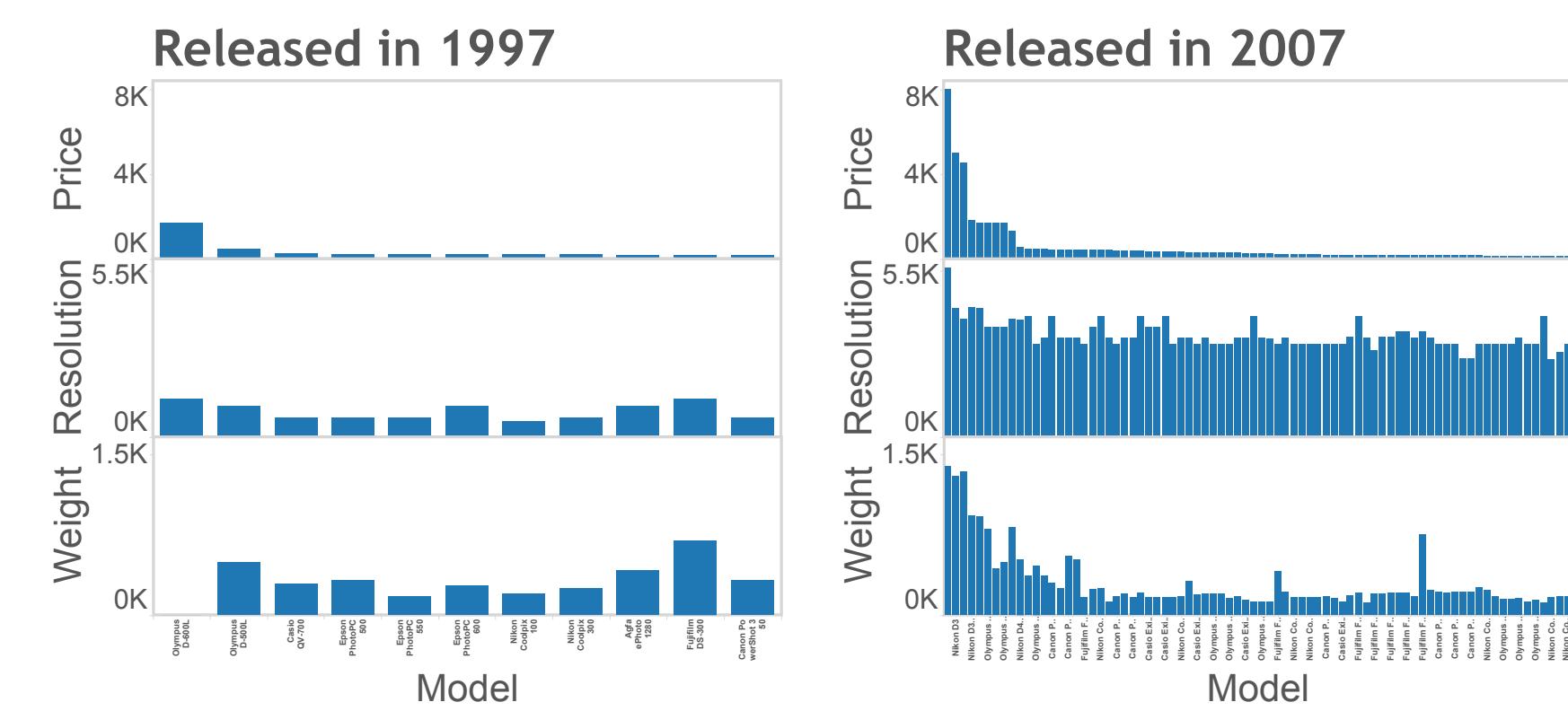
C1.4 Special Case: Same Measure, Same Color

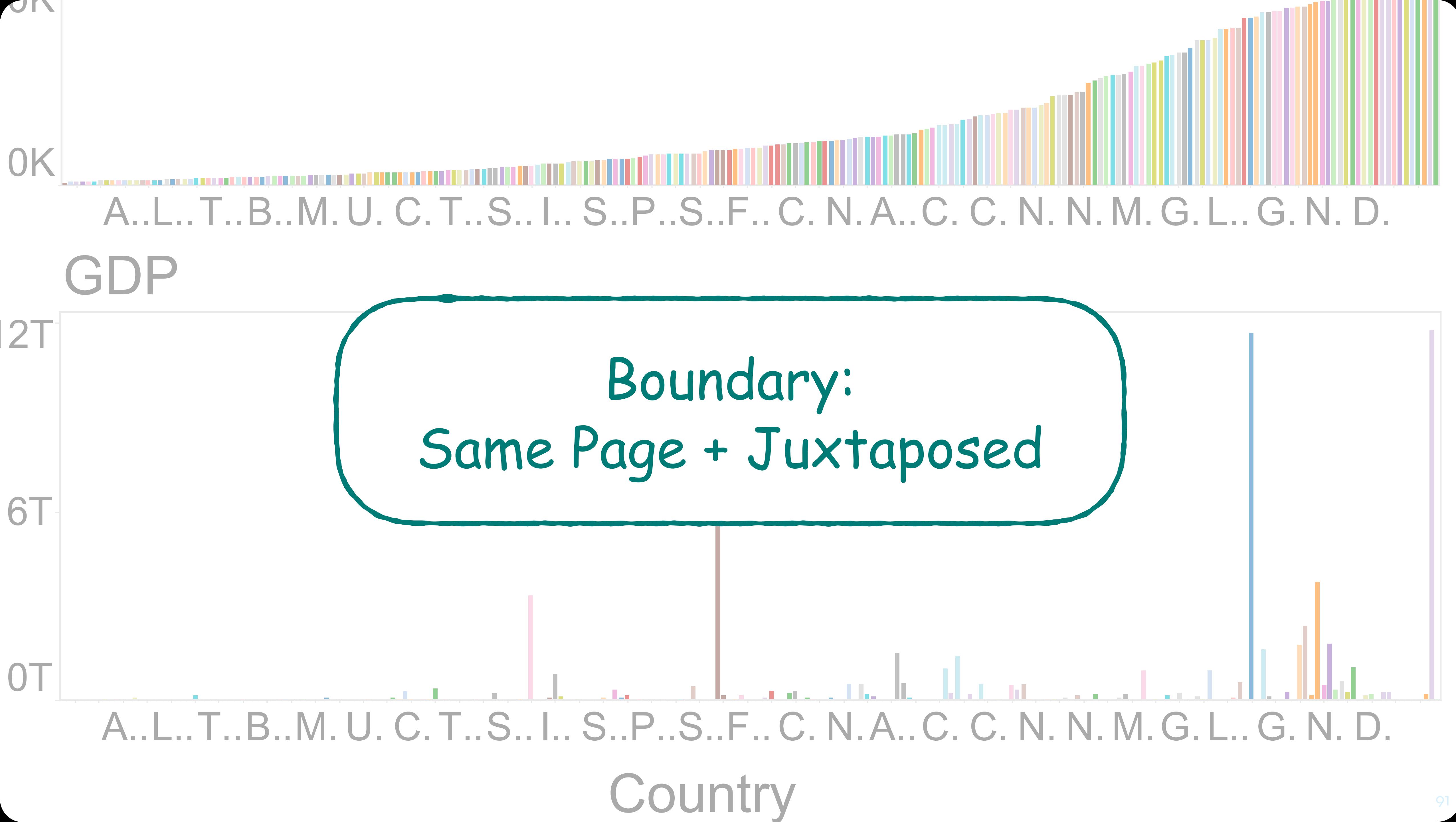


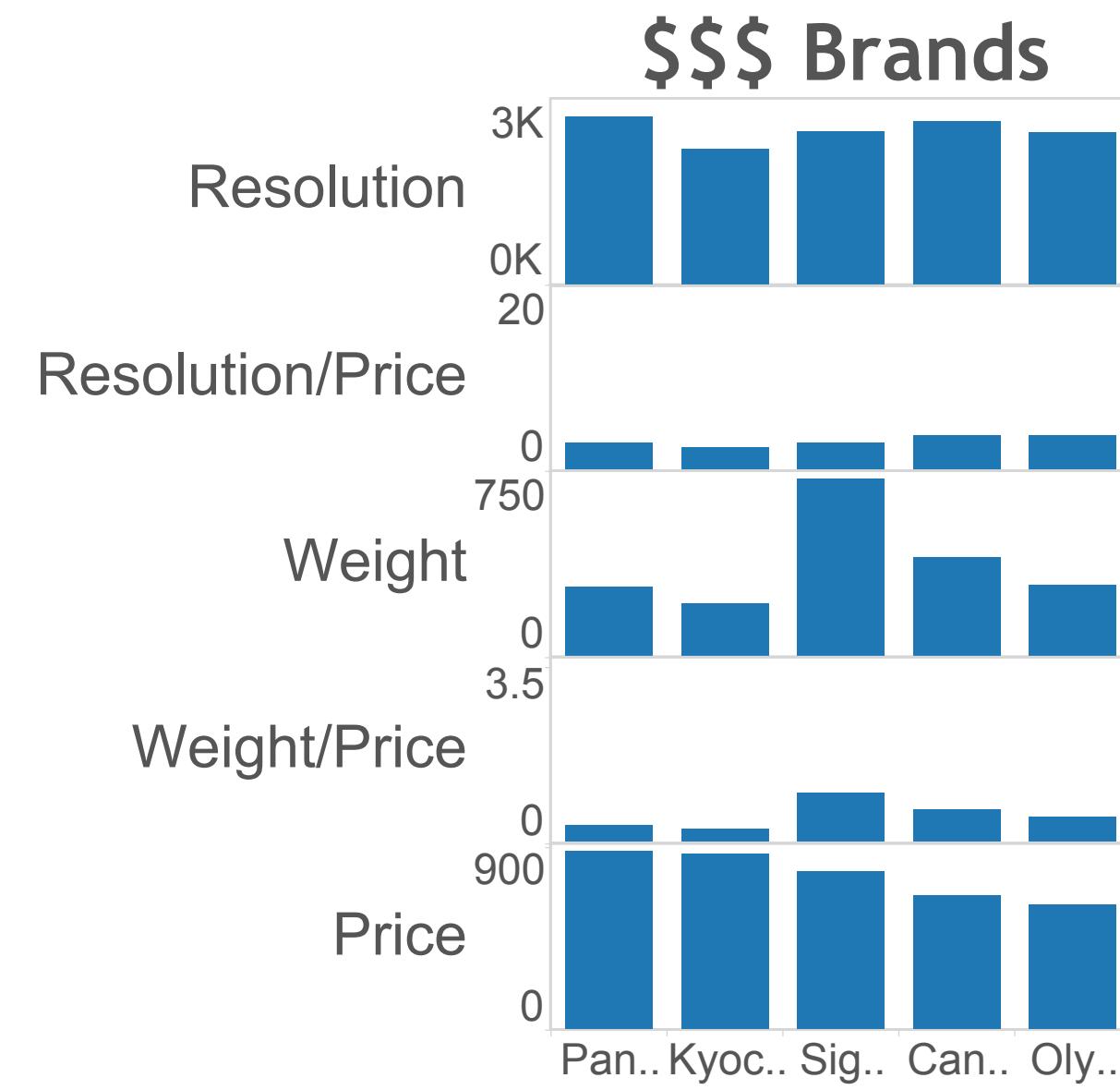
Validation: One Hue per Field



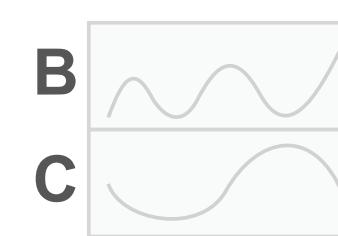
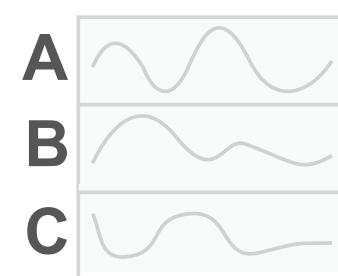
Boundary:
Across Pages



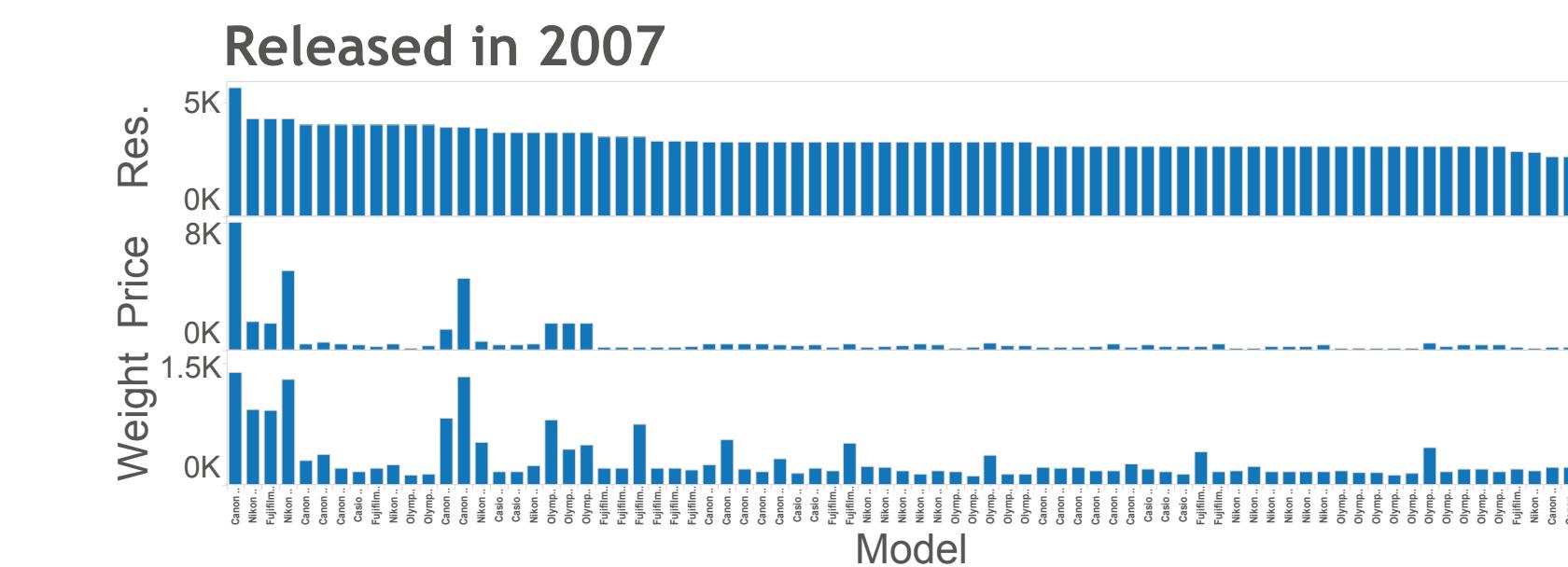
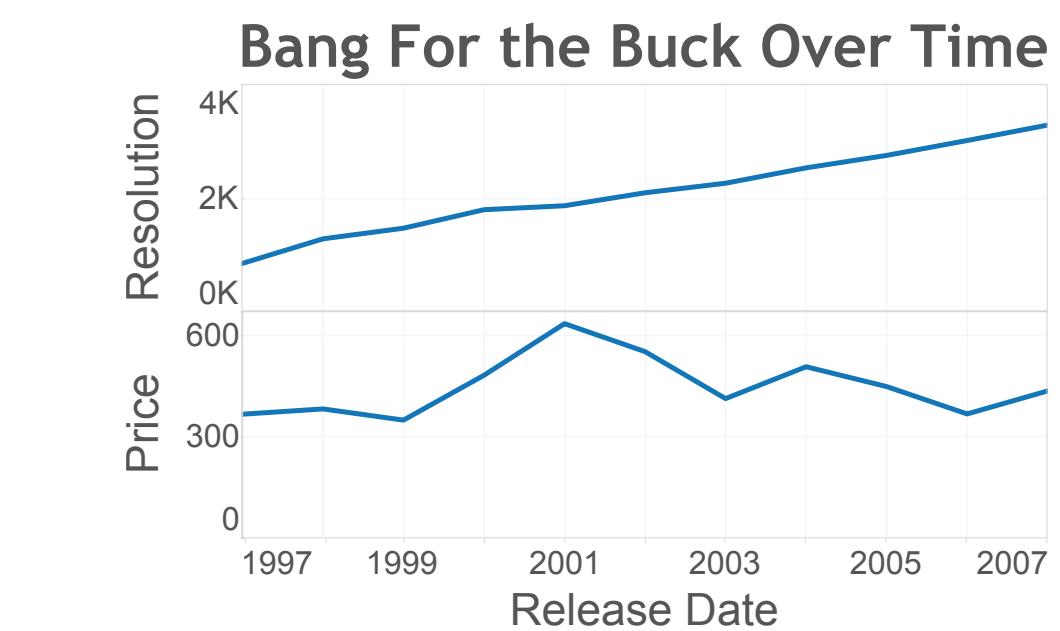




C1.2 Special Case: Same Measure Order



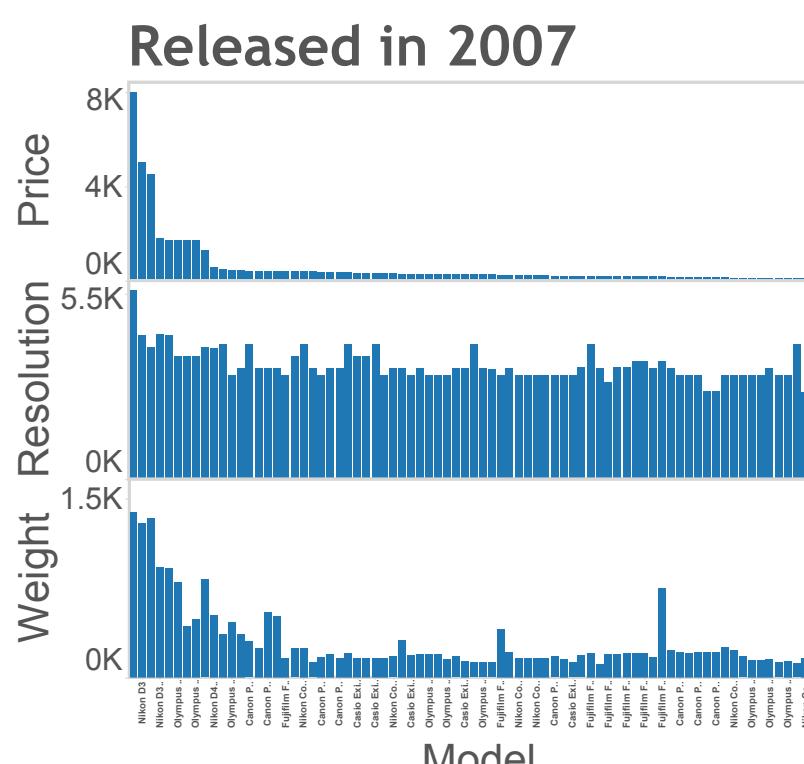
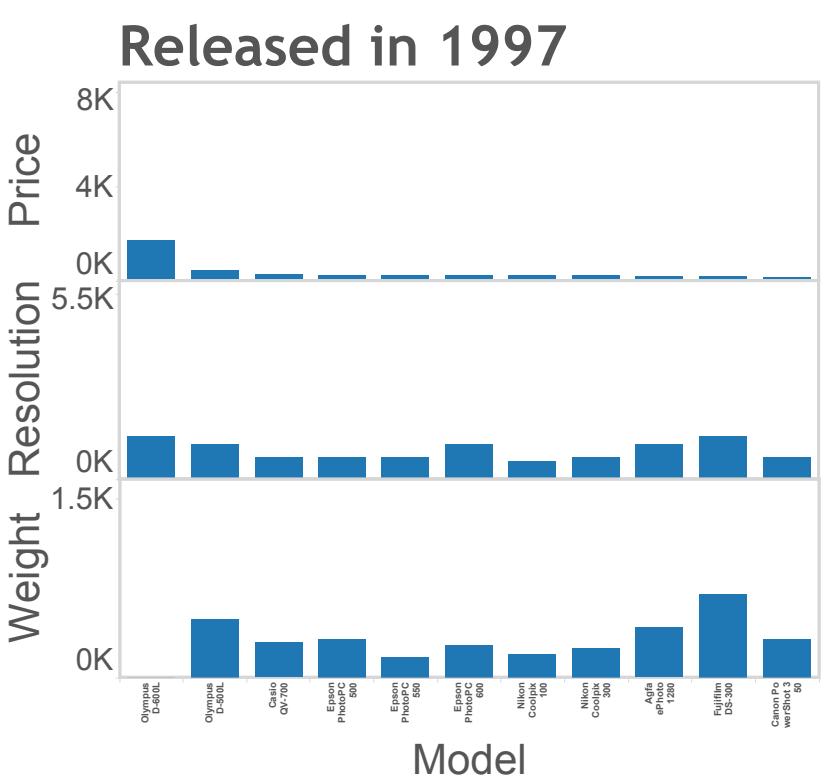
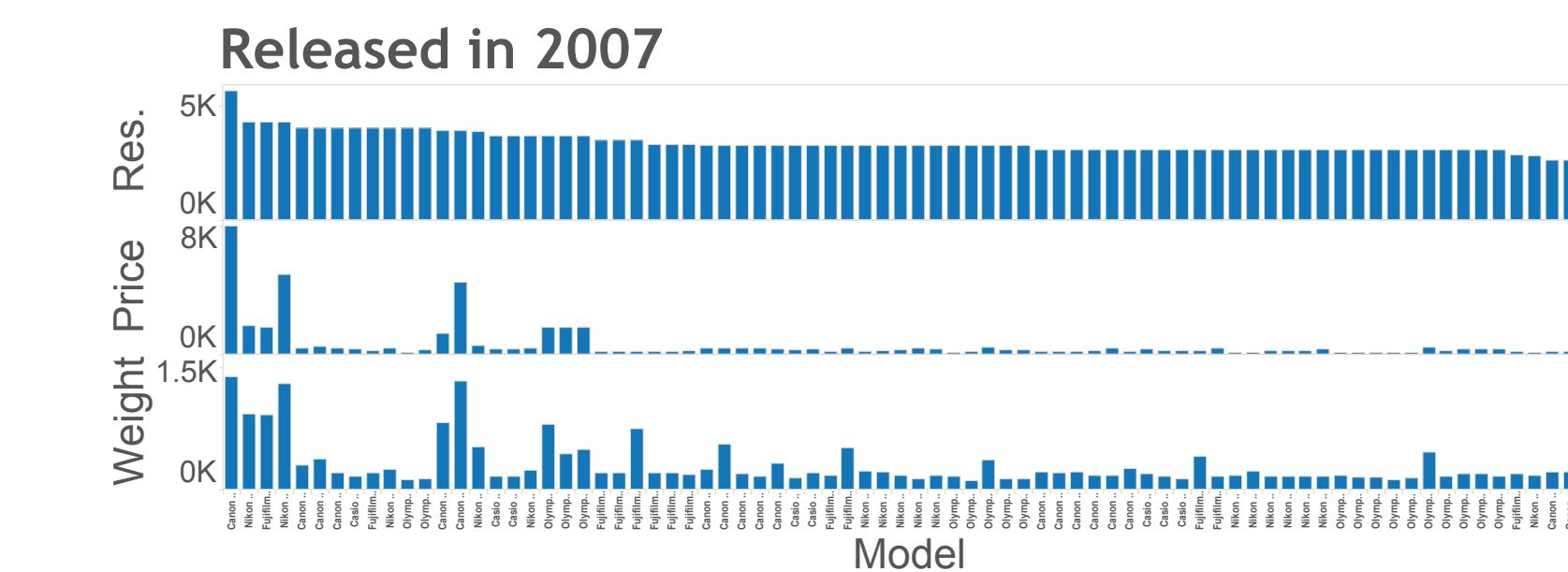
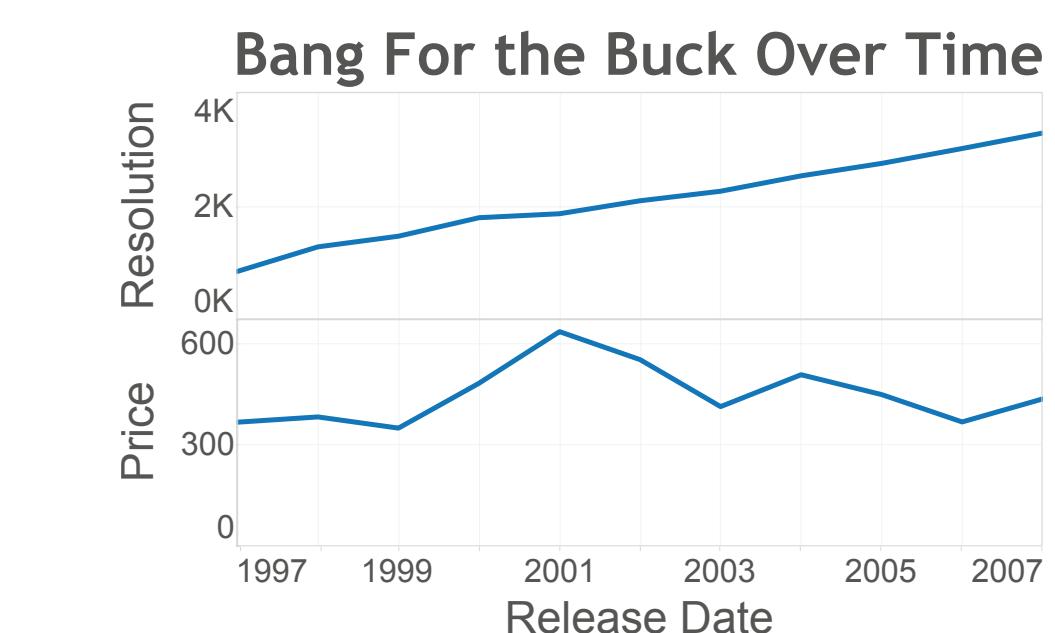
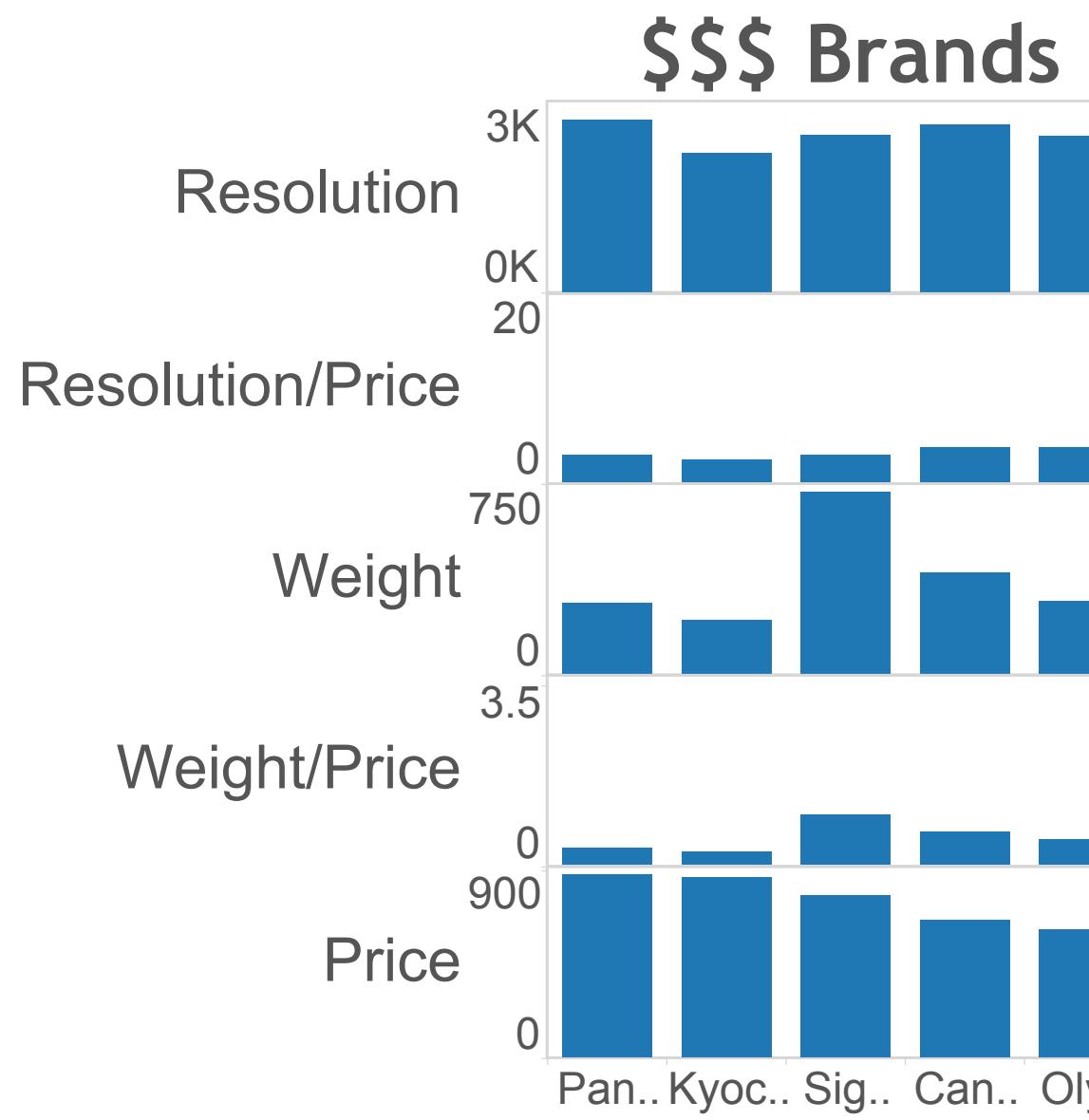
Validation: Manually Order Fields



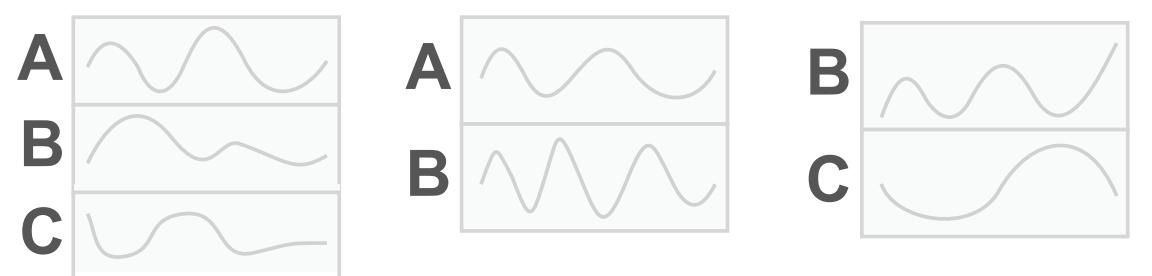
C1.2 Special Case: Same Measure Order



Validation: Manually Order Fields



C1.2 Special Case: Same Measure Order



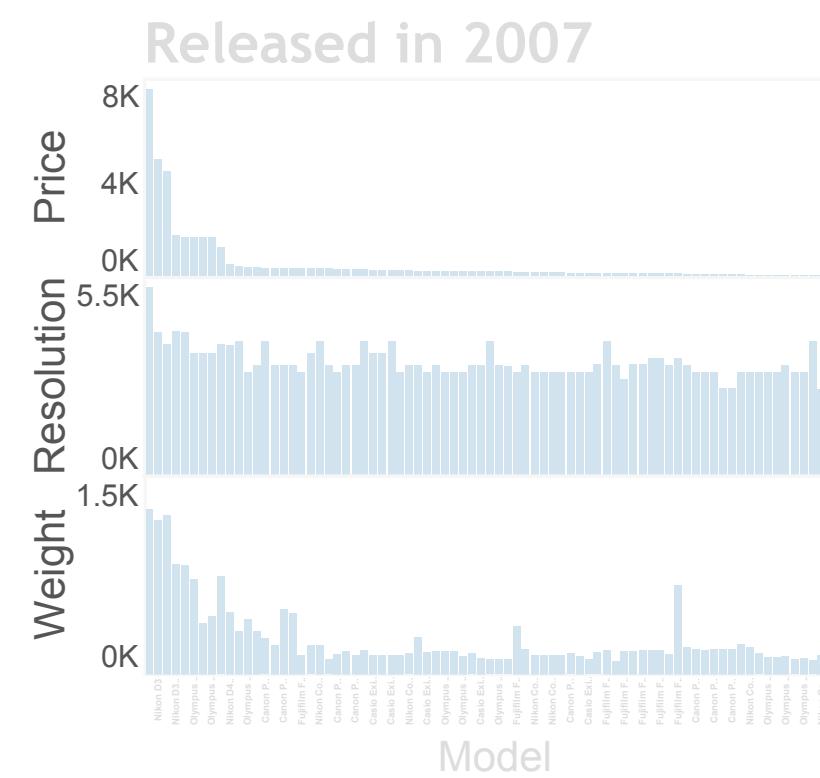
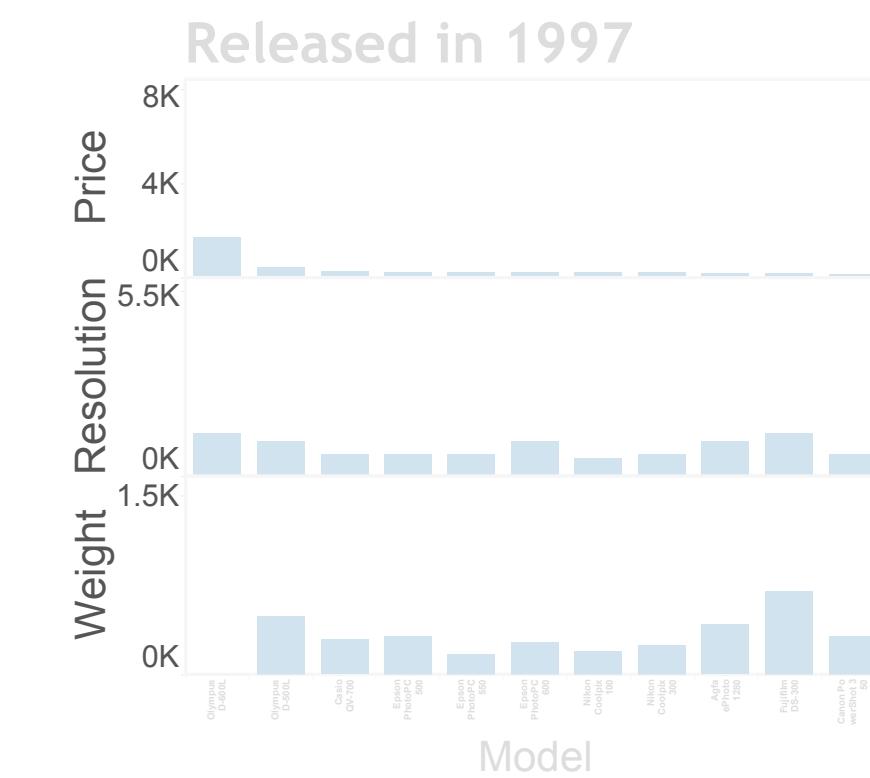
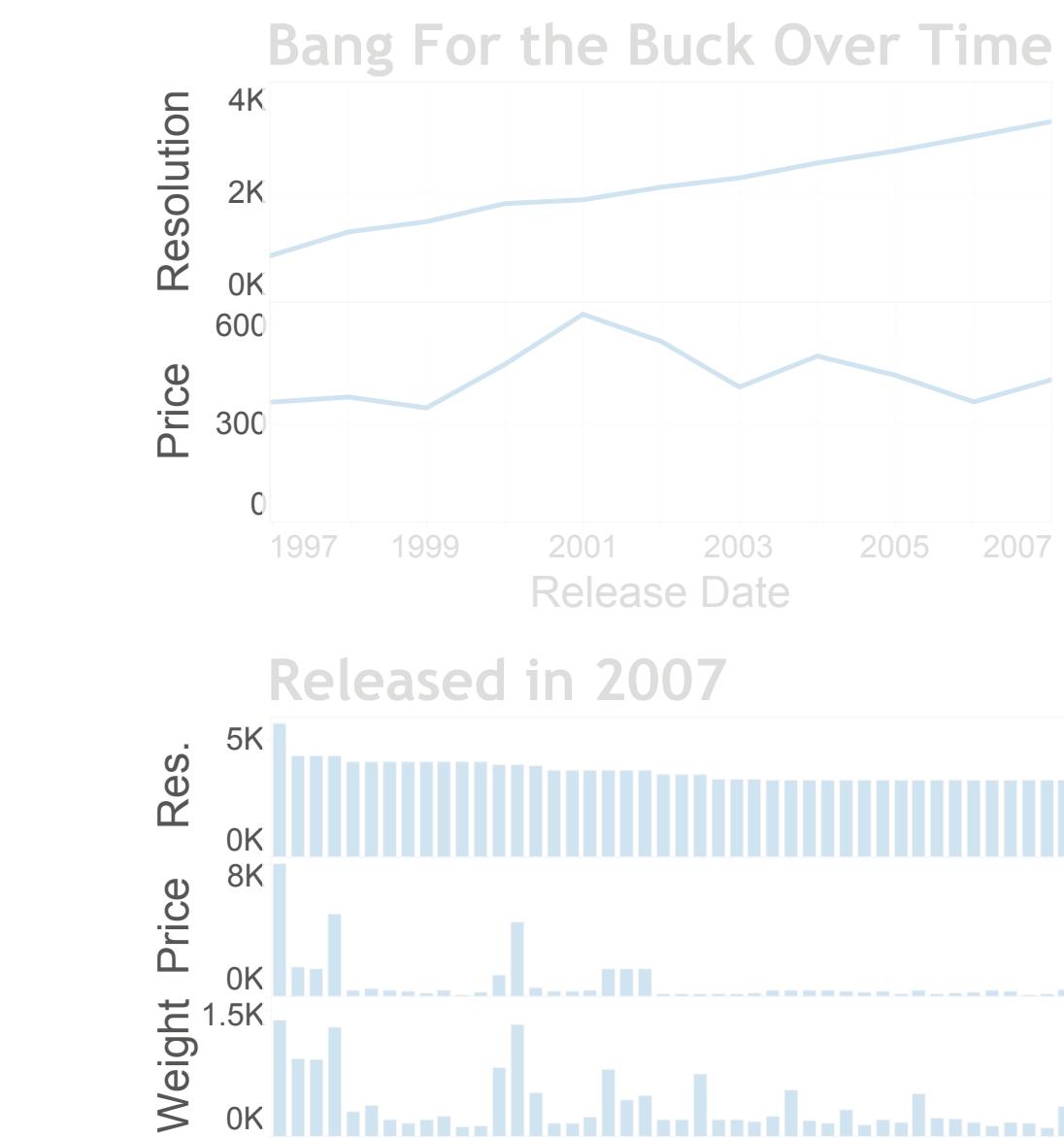
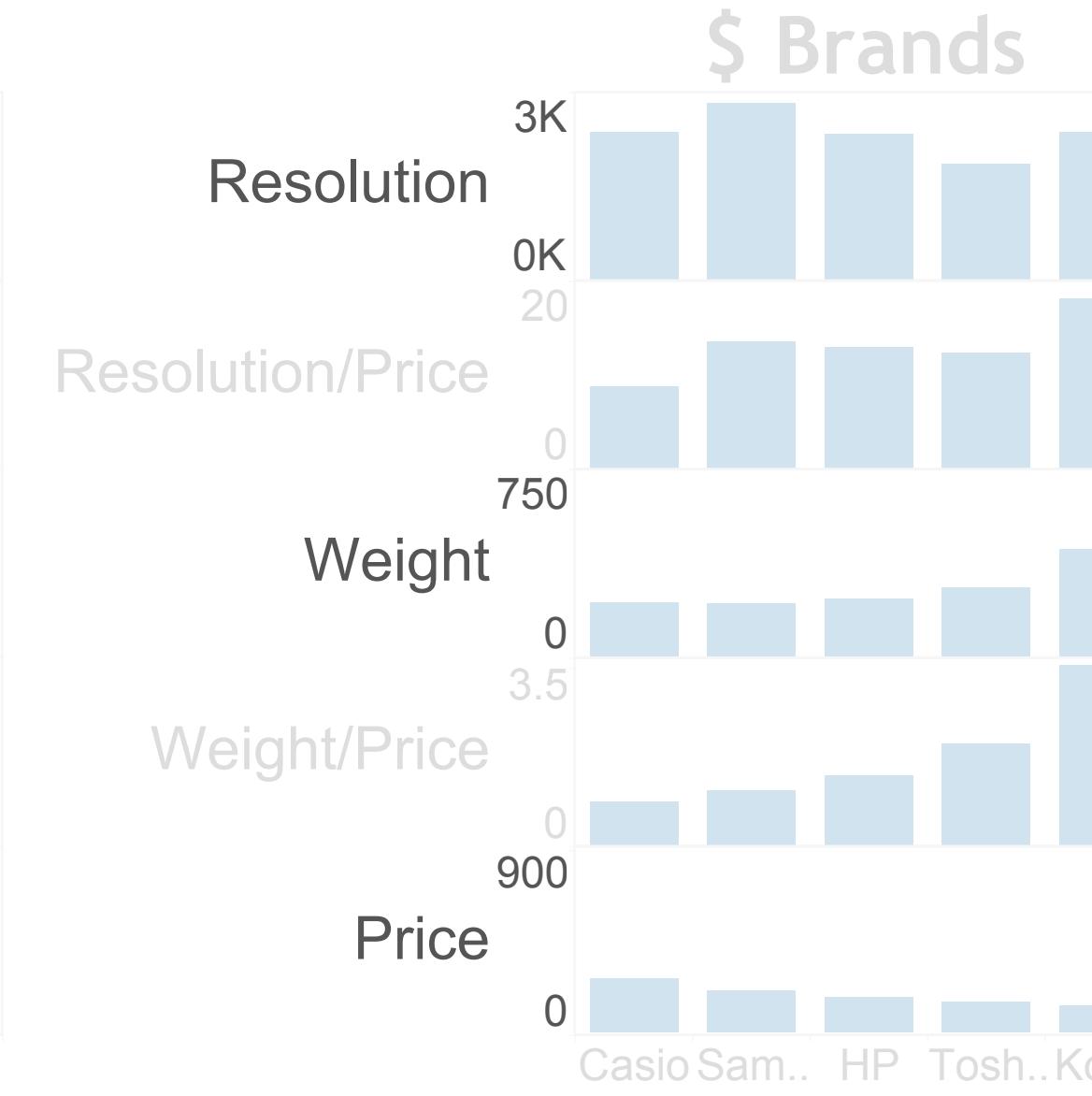
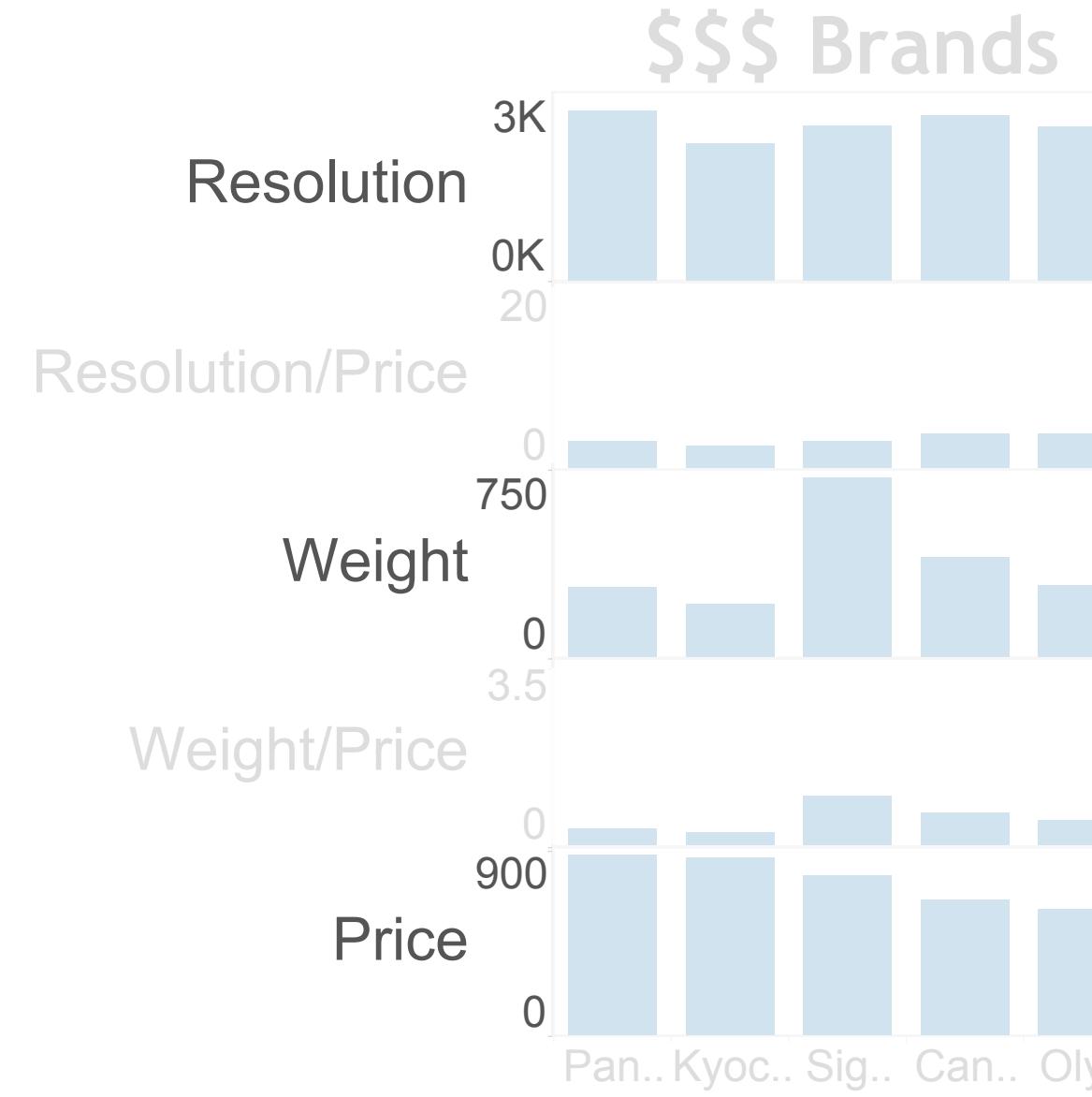
Validation: Manually Order Fields



Bob



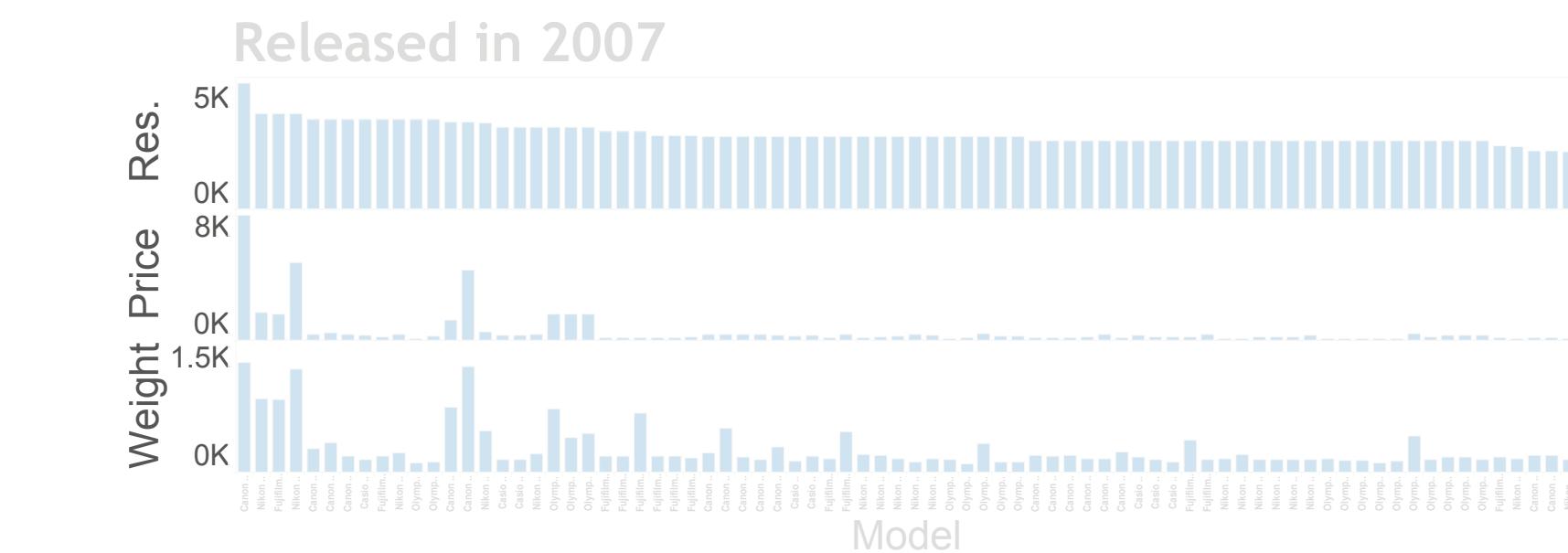
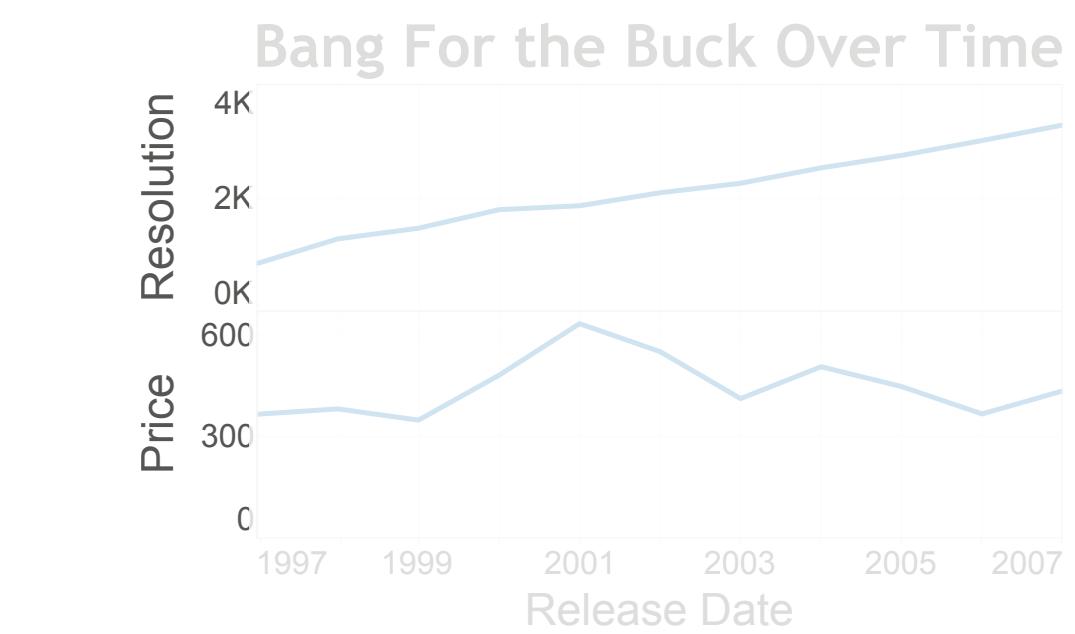
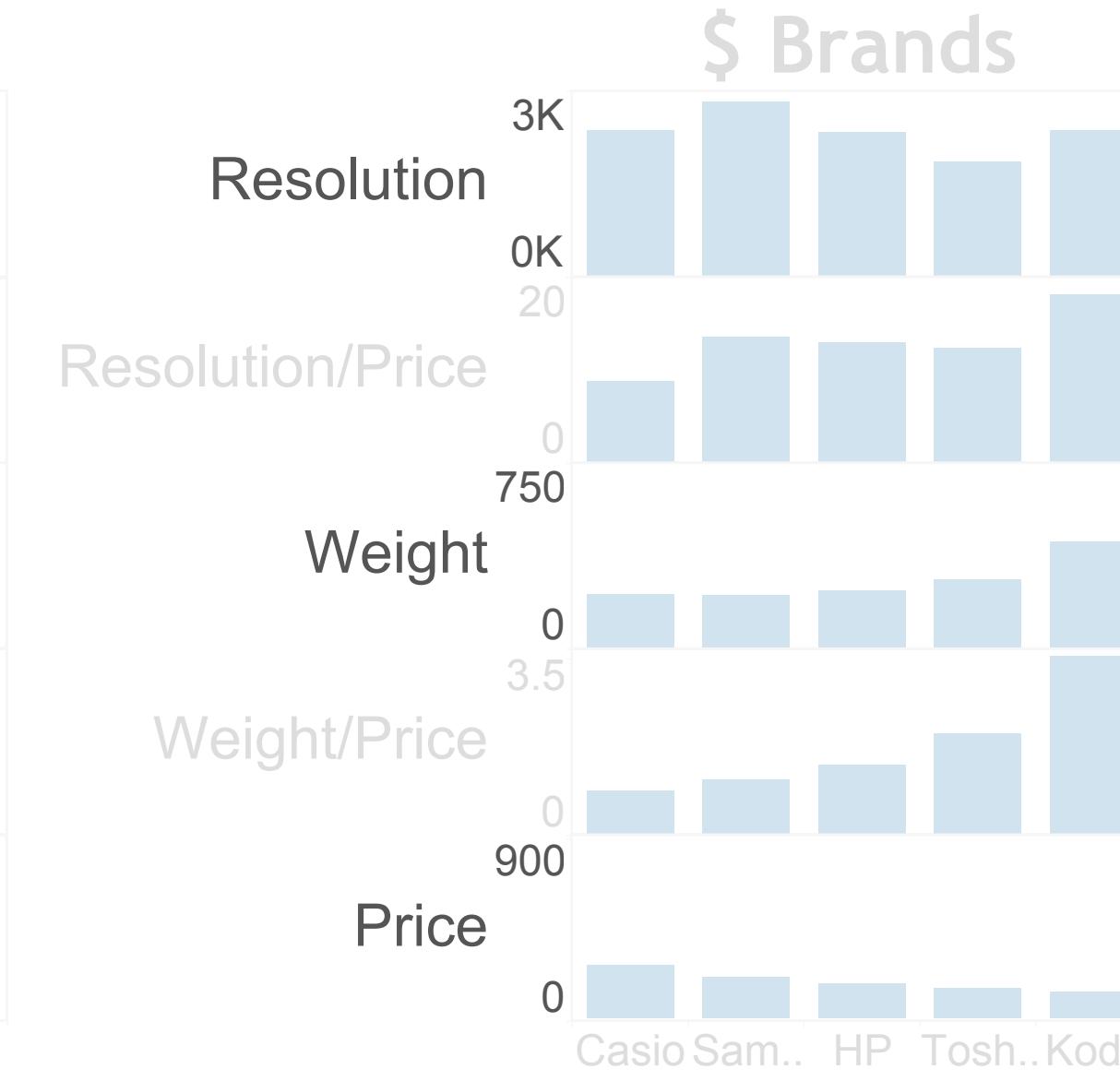
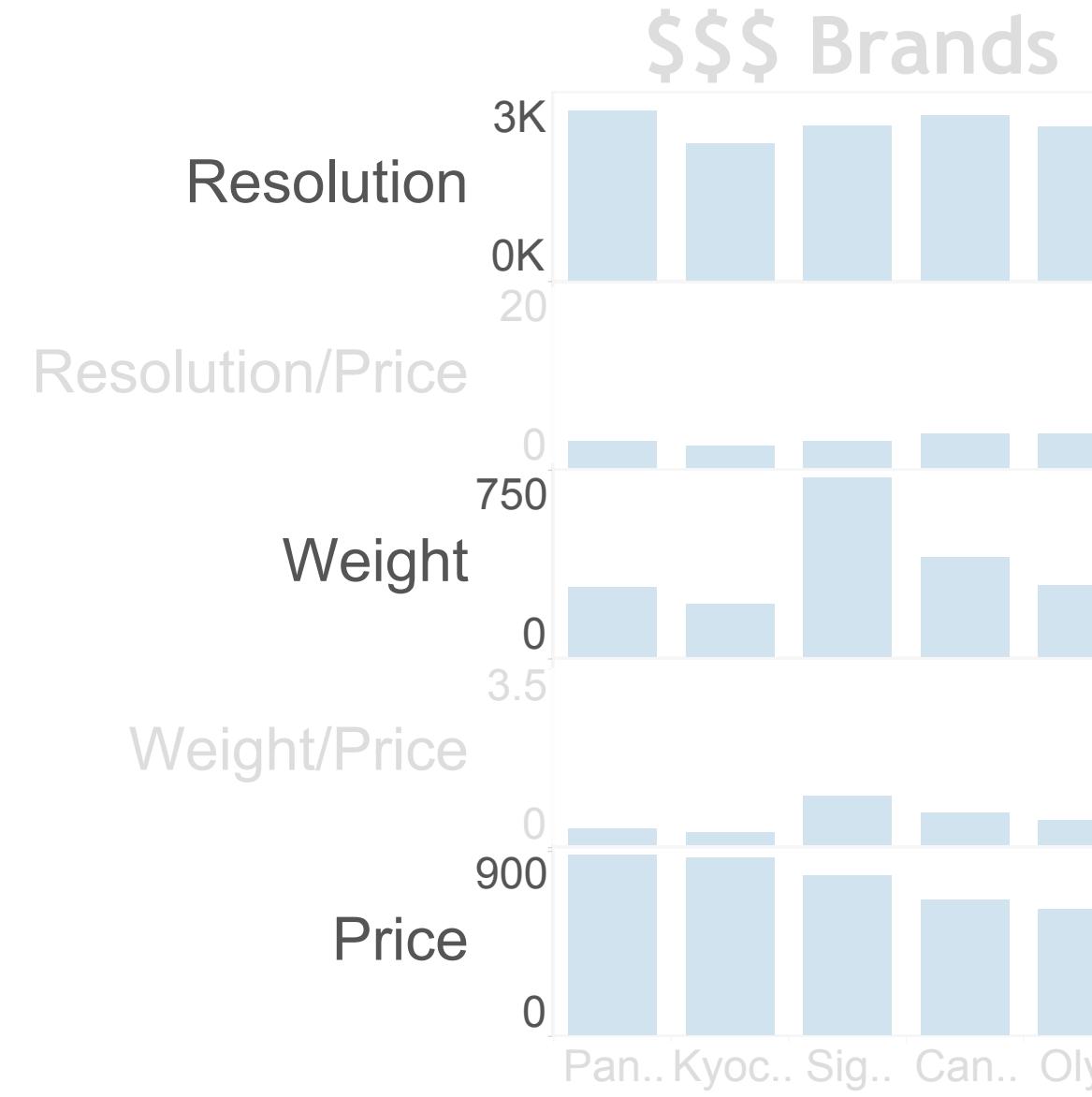
Bob



C1.2 Special Case: Same Measure Order



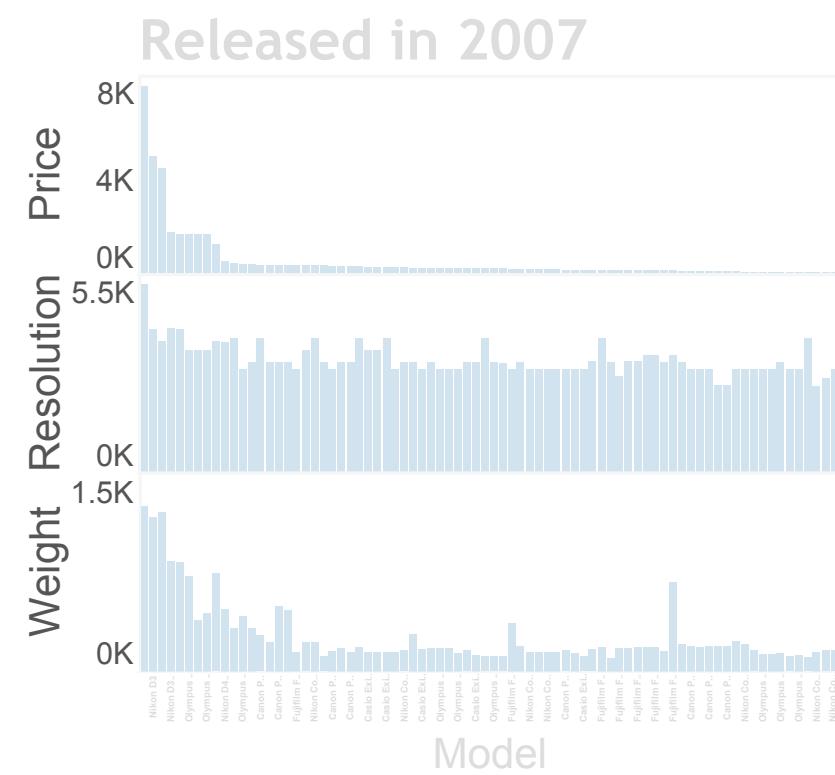
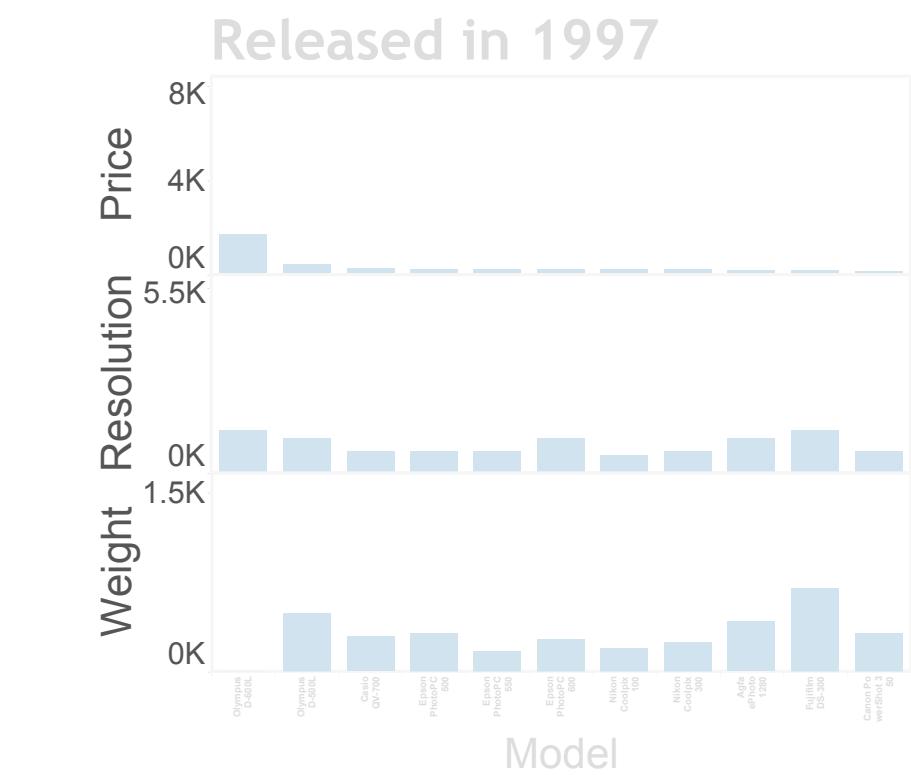
Validation: Manually Order Fields



"I'd definitely take a warning for that.
And I'll have to think about it **pretty hard**."



C1.2 Special Case: Same Measure Order



Validation: Manually Order Fields