Graph Construction

Data Management and Visualization

SoftEng
http://softeng.polito.it

Grammar of Graphics

- Theory behind graphics construction
  - Separation of data from aesthetic
  - Definition of common chart elements
  - Composition of such elements
- Building a graphic involves
  1. Specification
  2. Assembly
  3. Display

Leland Wilkinson, *The grammar of graphics*

Specification

- DATA: a set of data operations that create variables from datasets
  - Link variables (e.g., *by index* or *id*)
- TRANS: variable transformations (*e.g., rank*)
- SCALE: scale transformations (*e.g.*, *log*)
- COORD: a coordinate system (*e.g.*, *polar*)
- ELEMENT: visual objects (*e.g.*, *points*)
- AESTHETIC: attributes (*e.g.*, *color, position*)
- GUIDE: guides (e.g., *axes*, *legends*)

Specification for a scatter plot

- DATA: x, y, group
- TRANS: identity
- SCALE: *linear*(*dim*(1)), *linear*(*dim*(2))
- COORD:*rect*(*dim*(1, 2))
- ELEMENT: *point*()
- AESTHETIC: *position*(x*y)
- GUIDE: *axis*(*dim*(1)), *axis*(*dim*(2))

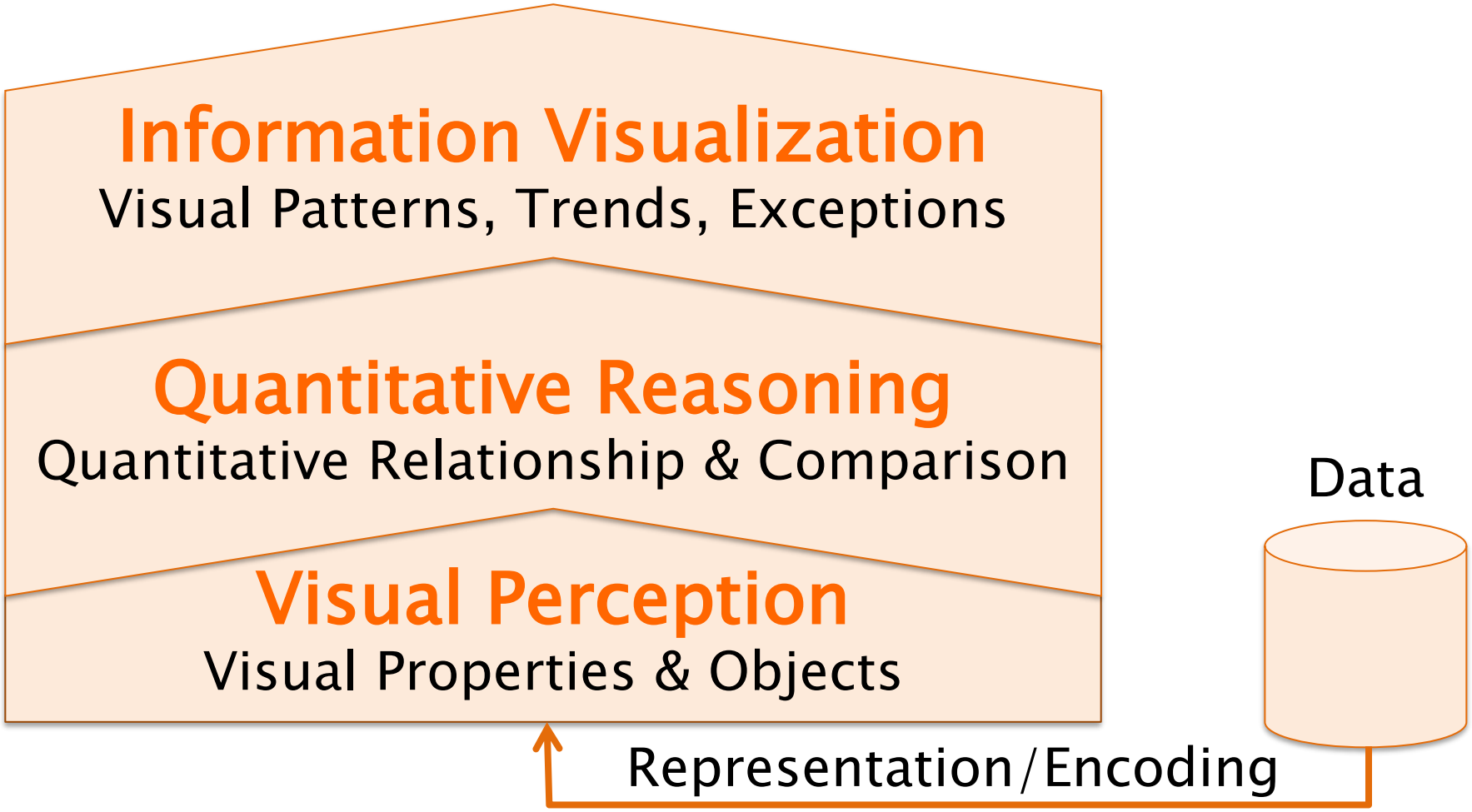
Graph visual components

- Data components
  - Visual objects associated to measures
  - Visual attributes
- Layout
  - Positioning rules (e.g. cartesian coord.)
- Support components
  - Axes
  - Labels
  - Legends

VISUAL RELATIONSHIPS

Data Visualization

Understanding



Visual Encoding

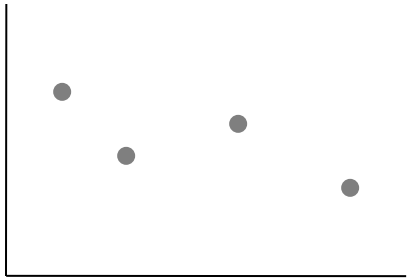
- Given a variable (measure), identify:
  - Visual object
  - Visual attribute

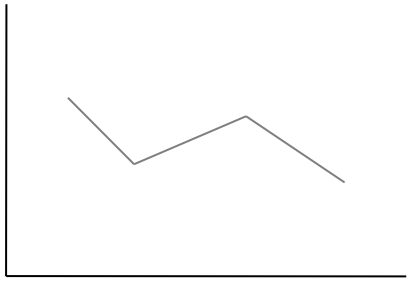
- Main distinction
  - Quantitative (interval, ratio, absolute)
  - Categorical (nominal, ordinal)

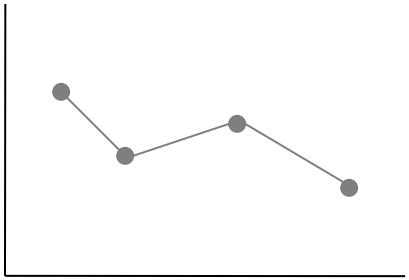
Relationships

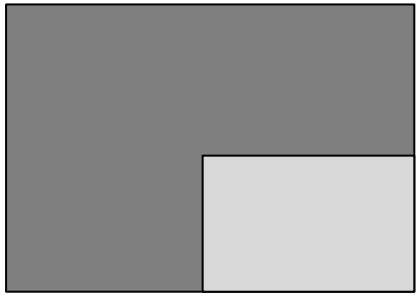
- Within a category
  - Nominal comparison
  - Ranking
  - Part-to-whole
  - Distribution
- Between measures
  - Time series
  - Deviation
  - Correlation

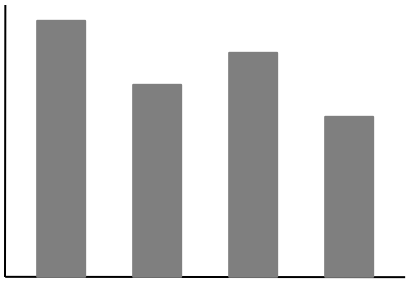
Quantitative encoding











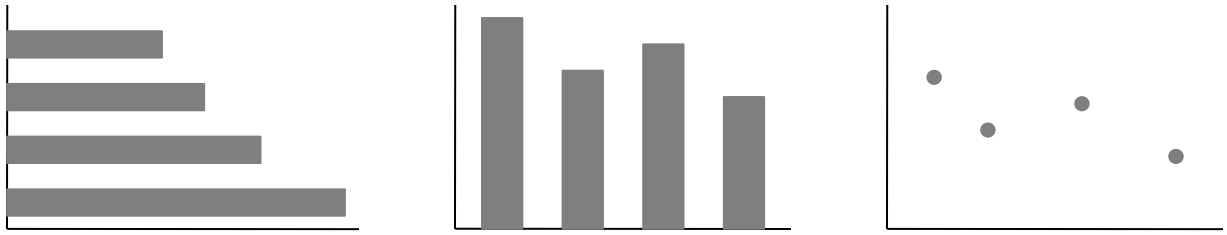
Sample data

Region	turnout (2018)	turnout (2013)
ABRUZZO	75.3%	75.9%
BASILICATA	71.1%	69.5%
CALABRIA	63.6%	63.1%
CAMPANIA	68.2%	67.9%
EMILIA-ROMAGNA	78.3%	82.1%
FRIULI-VENEZIA GIULIA	75.1%	77.2%
LAZIO	72.6%	77.5%
LIGURIA	72.0%	75.1%
LOMBARDIA	76.8%	79.6%
MARCHE	77.3%	79.8%

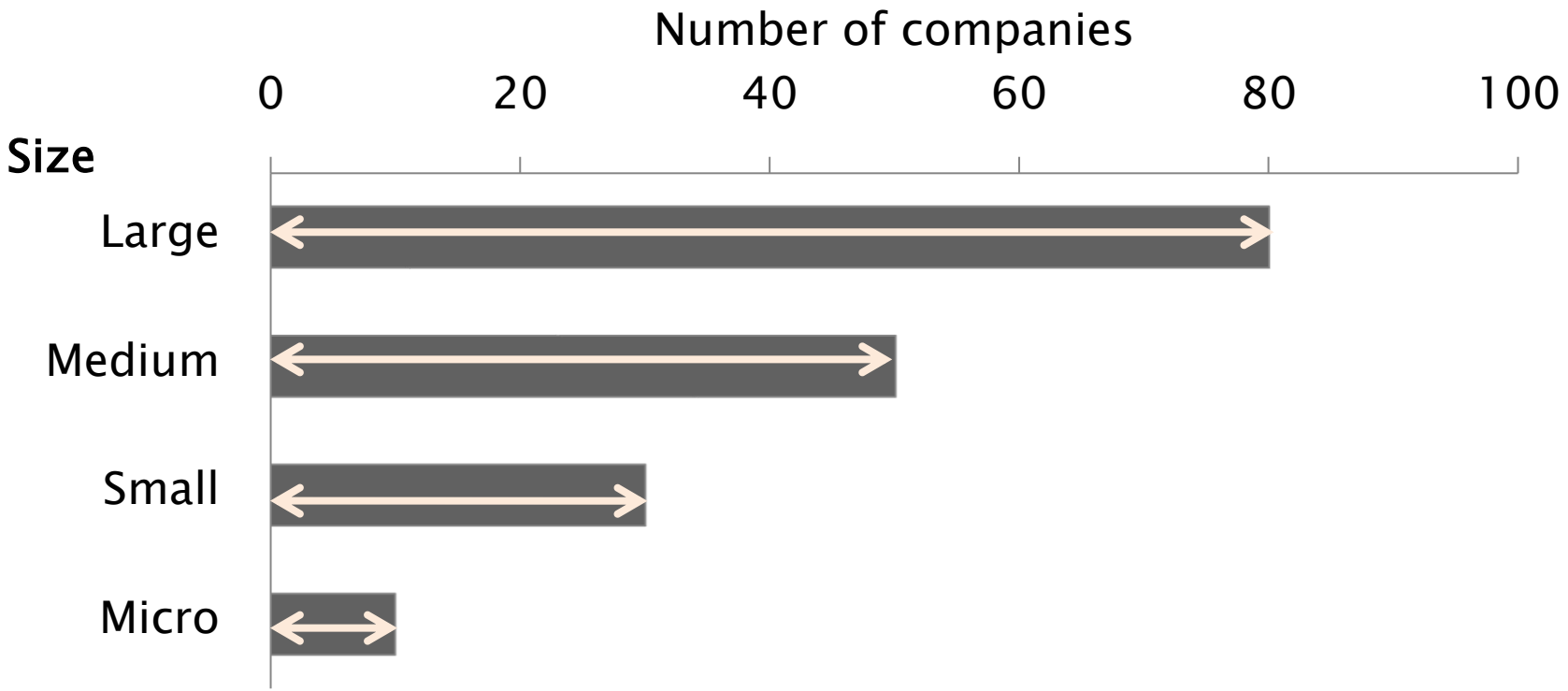
Region	turnout (2018)	turnout (2013)
MOLISE	71.6%	78.1%
PIEMONTE	75.2%	77.3%
PUGLIA	69.1%	69.9%
SARDEGNA	65.5%	68.5%
SICILIA	62.8%	64.6%
TOSCANA	77.5%	79.2%
TRENTINO-ALTO ADIGE	74.3%	81.0%
UMBRIA	78.2%	79.5%
VALLE D'AOSTA	72.3%	77.0%
VENETO	78.7%	81.8%

Nominal comparison

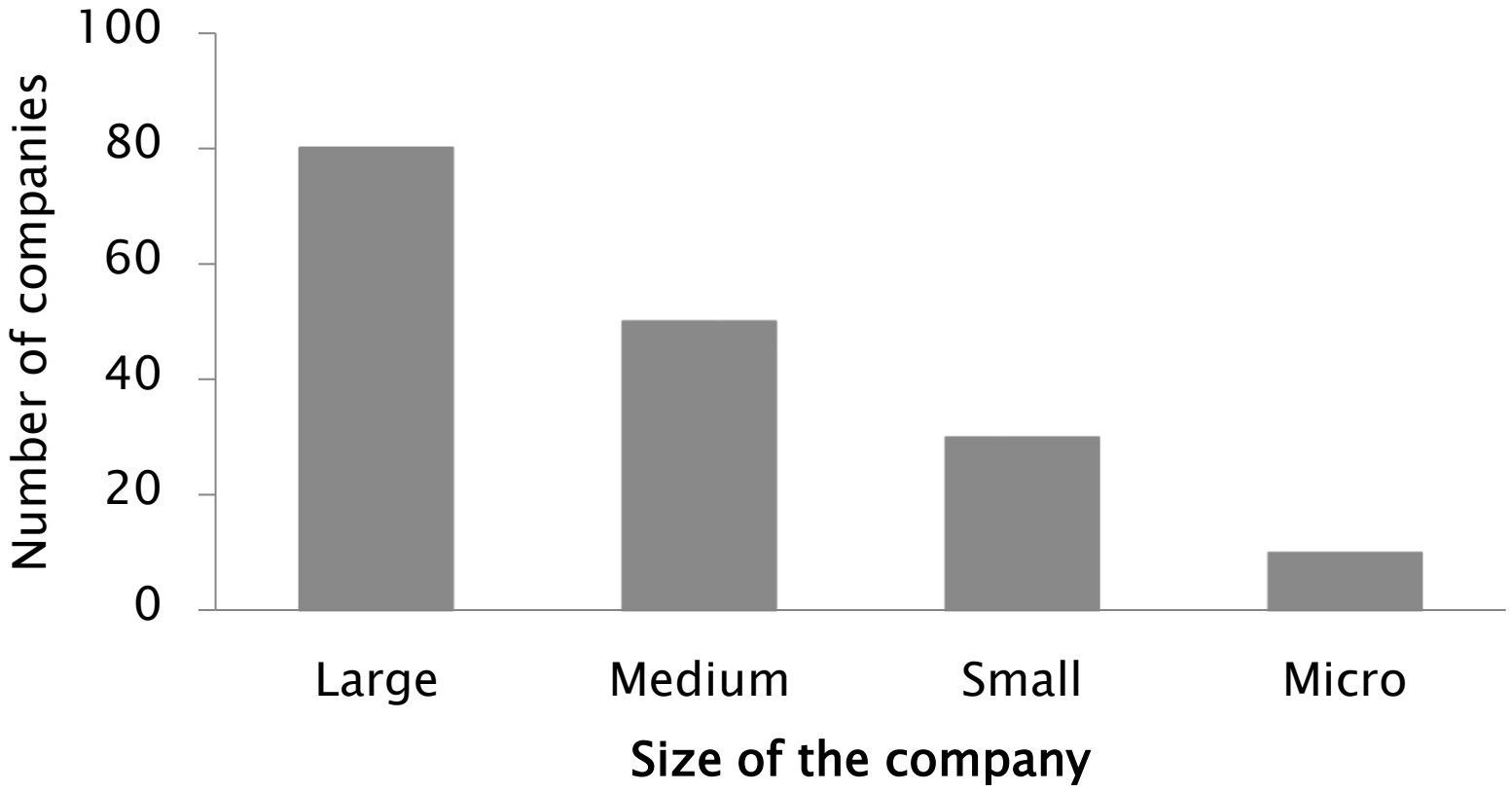
- Compare quantitative values corresponding to categorical levels
  - Small differences are difficult to see
    - Non zero-based scale can emphasize
  - Dot plots can be used for small differences
    - They do not require zero based scale



Line length – Bars chart



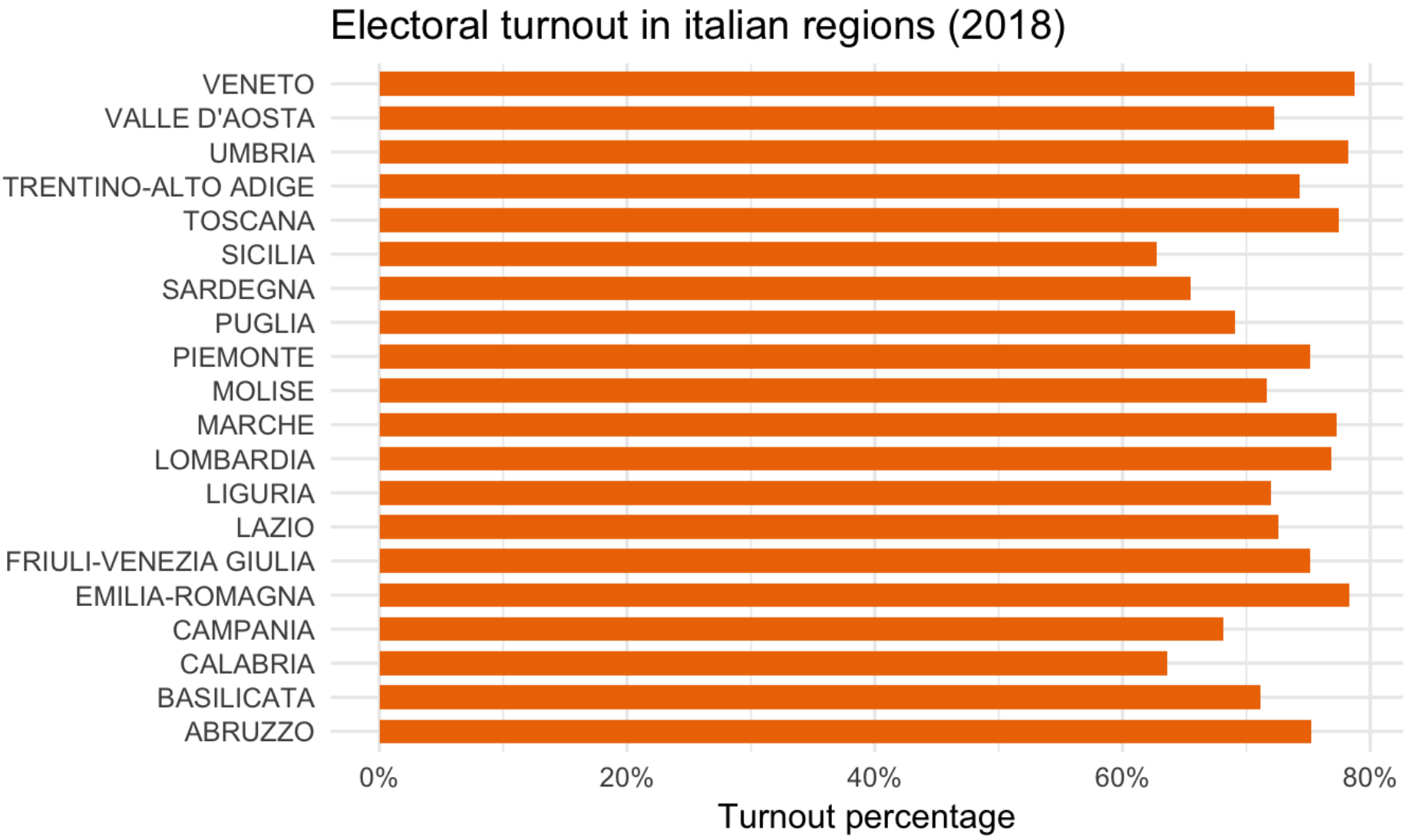
Vertical Bars (aka Columns)



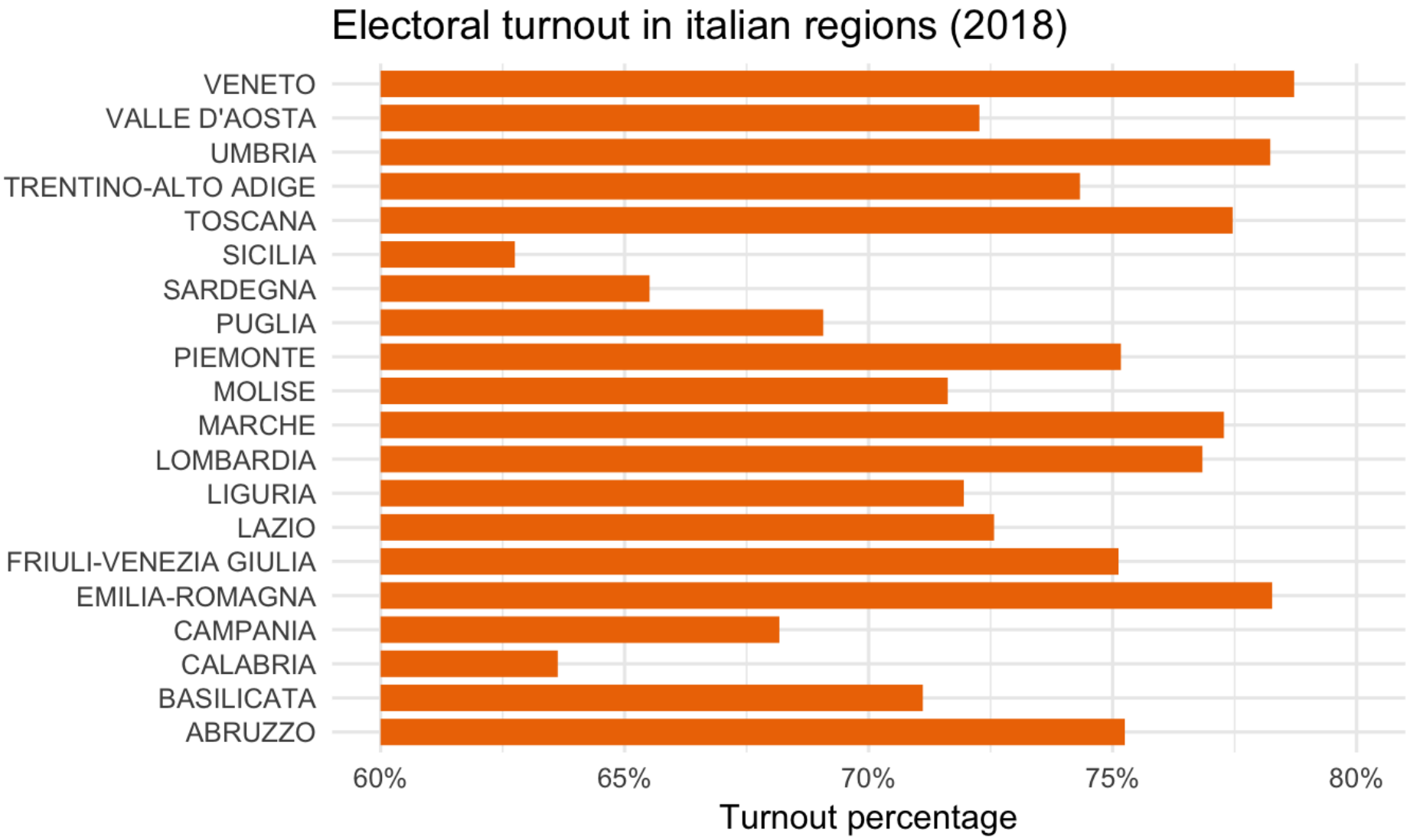
Bar charts

- Categorical values are encoded as position along an axis
- Quantitative values are encoded only as length of the bars
  - The axis is a supporting element
- Width of bars plays no role
  - Bars are just very thick lines
- Bars require a zero-based scale
  - See: Lie factor!

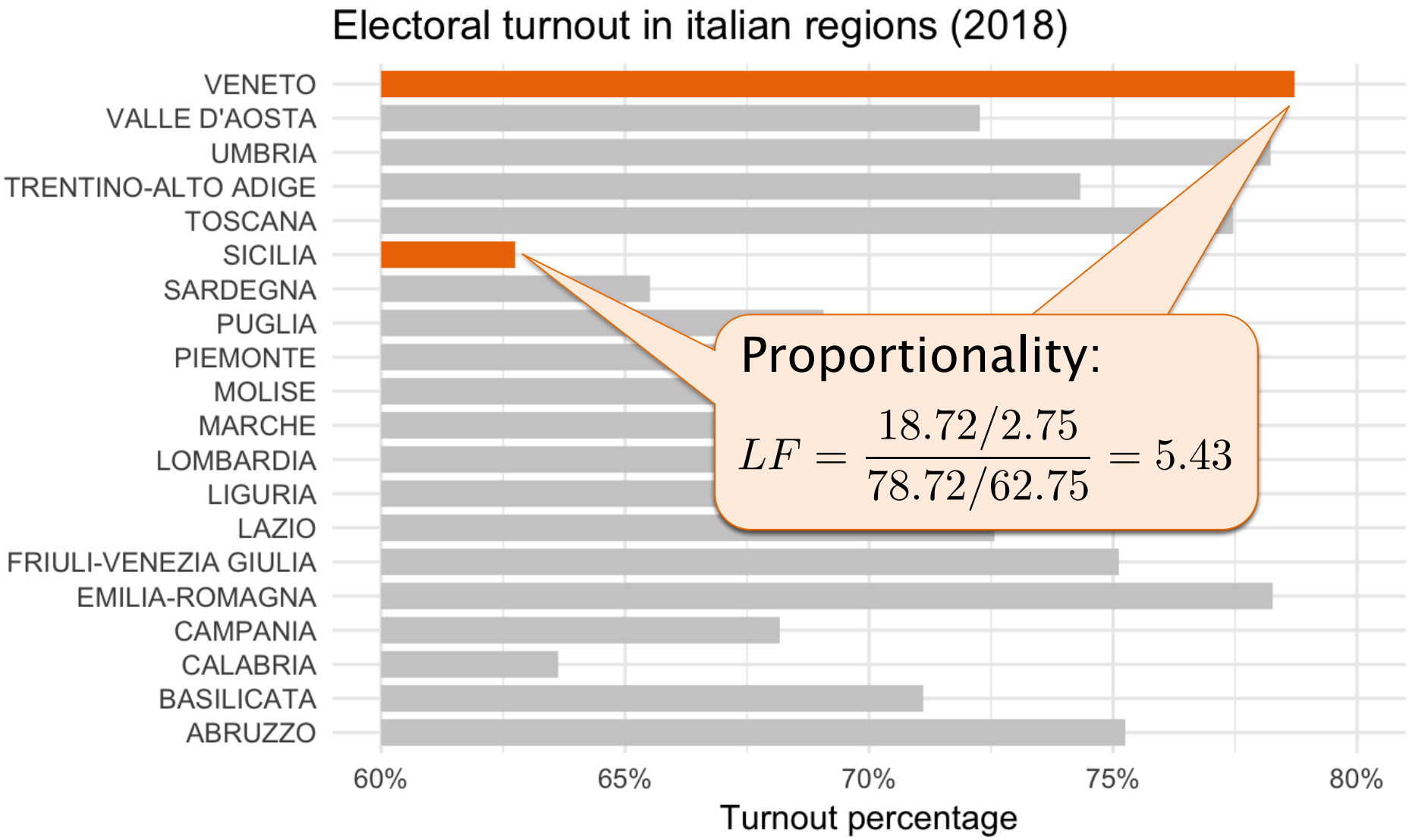
Comparison - Barplot



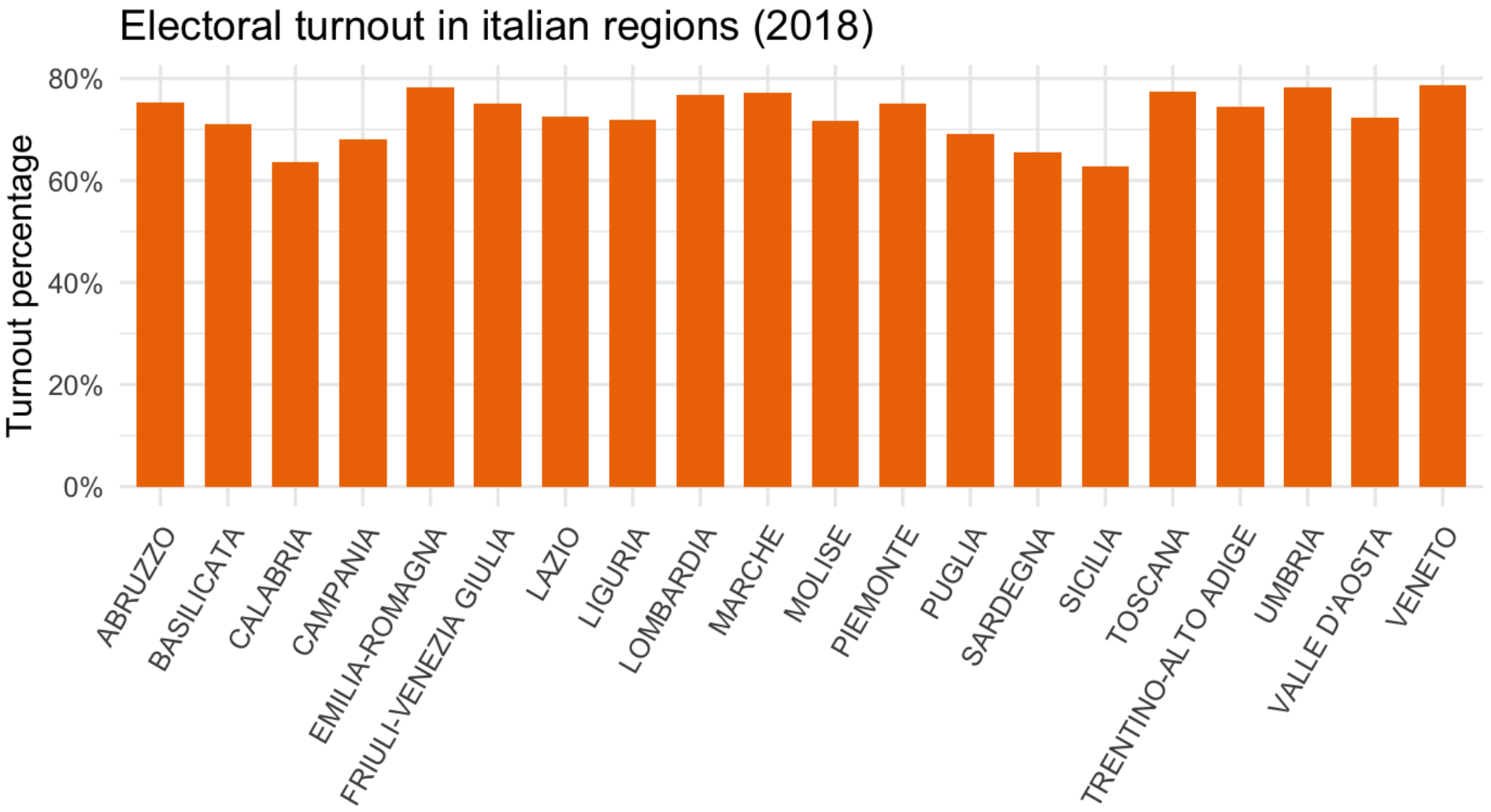
Barplot (non zero based scale)



Barplot (non zero based scale)



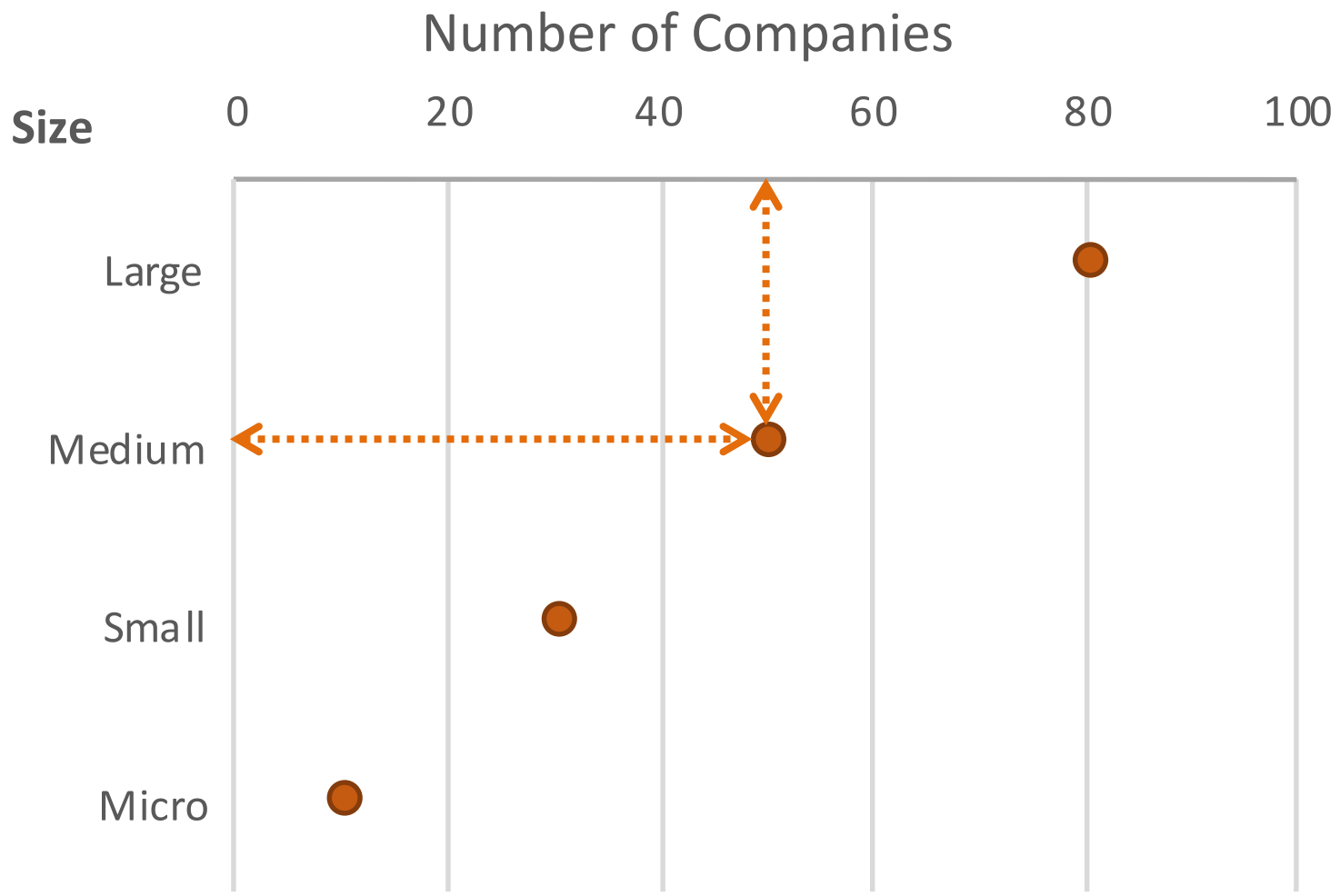
Barplot vertical labels



Bars Guidelines

- Use horizontal bars when
  - A descending order ranking
  - Categorical label don't fit
- Proximity
  - Use a 1:1 bar:spacing ratio ±50%
  - No spacing between bars that are not labeled on the axis (legend categories)
  - No overlapping bars

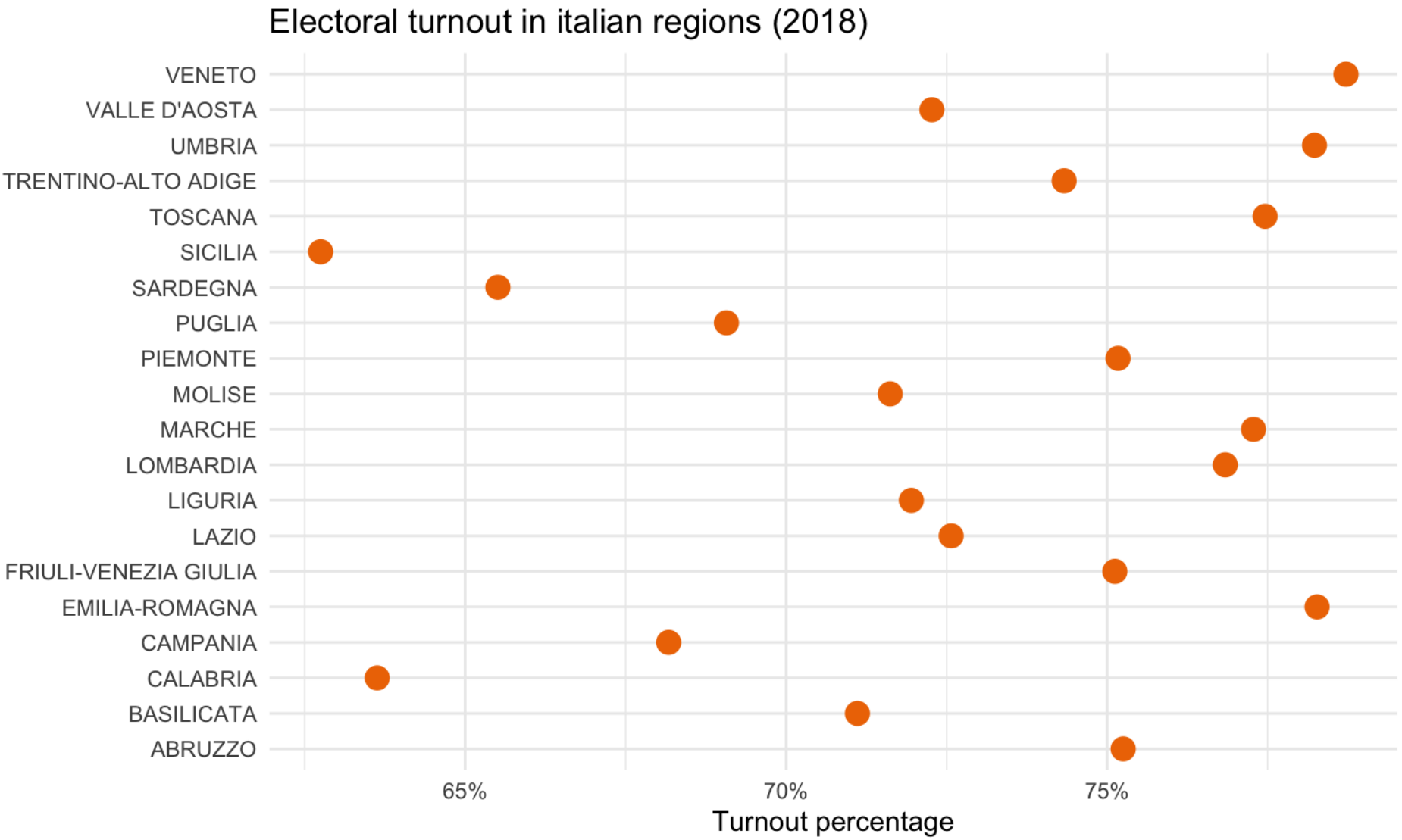
Position – Dots plot



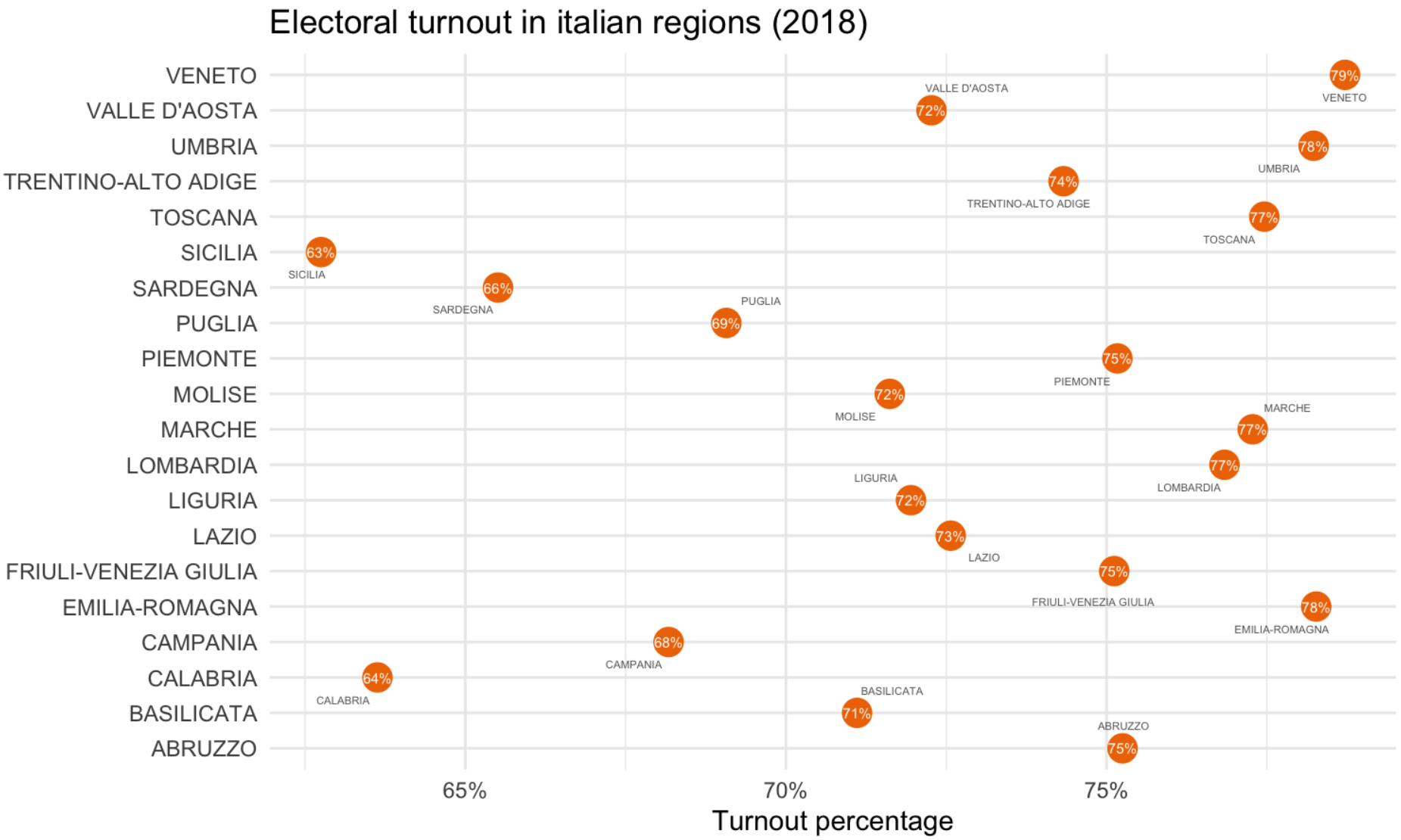
Dot plots

- Categorical values are encoded as position along an axis
- Quantitative values are encoded as position along an axis
  - There is no need to have a zero based axis range

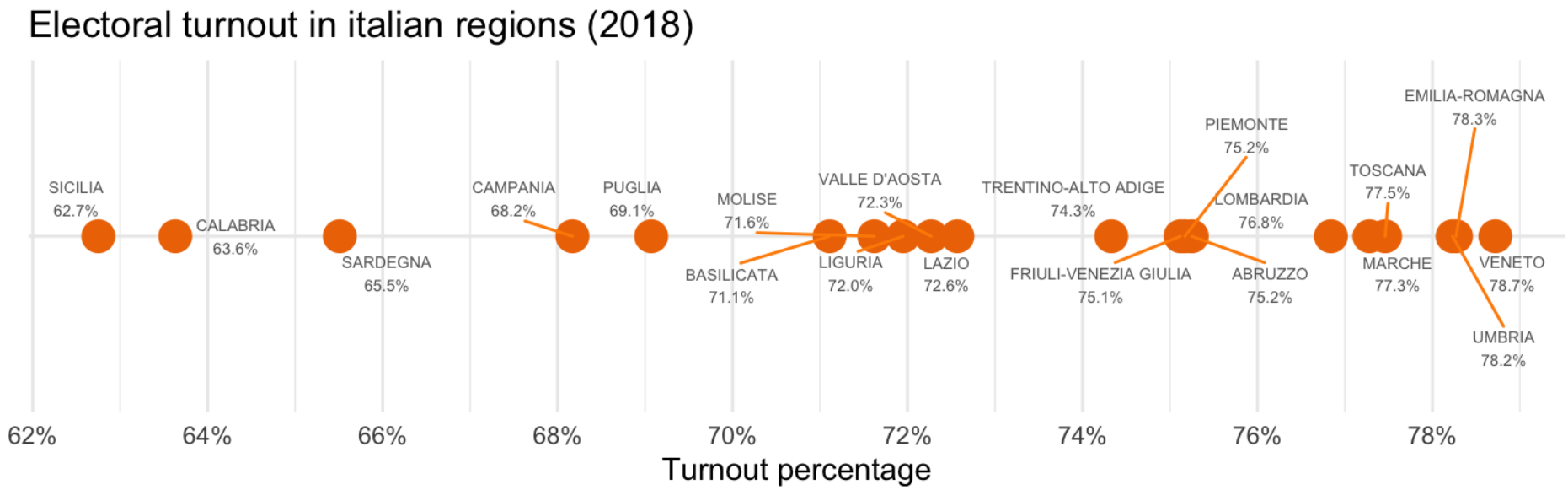
Comparison – Dot plot



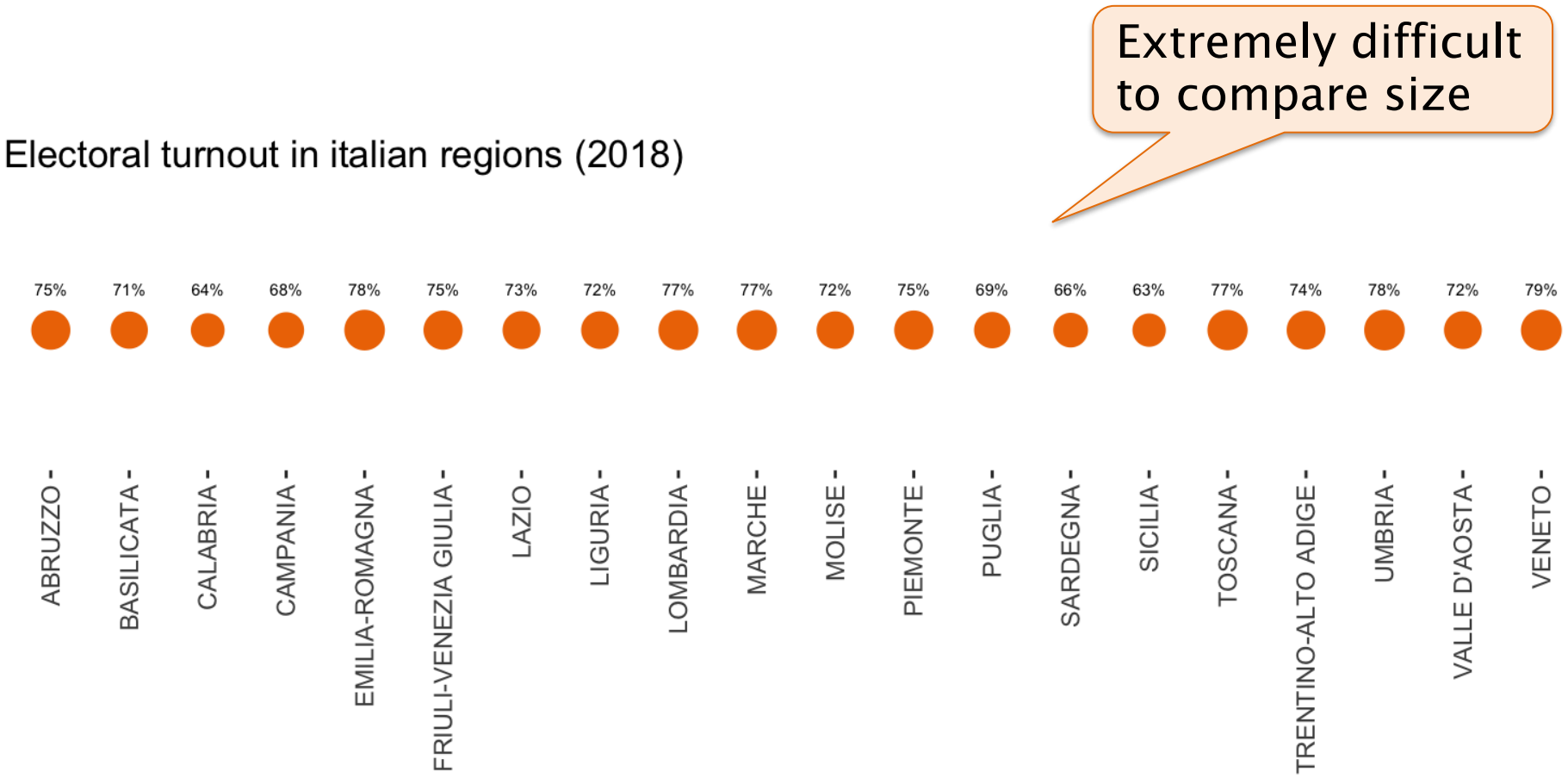
Comparison – Dot plot



Comparison – Strip plot

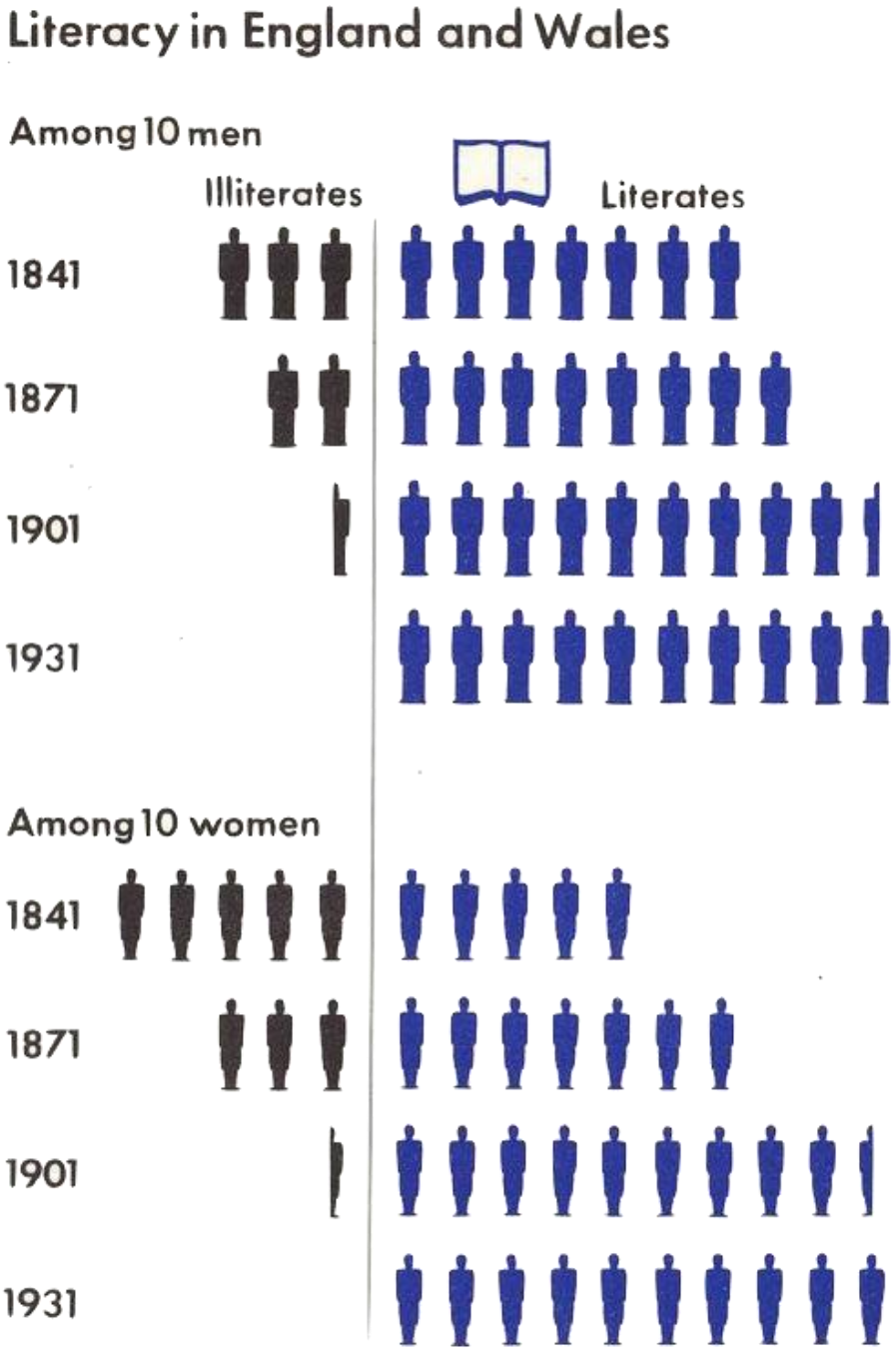


Comparison – Area – Bubbles



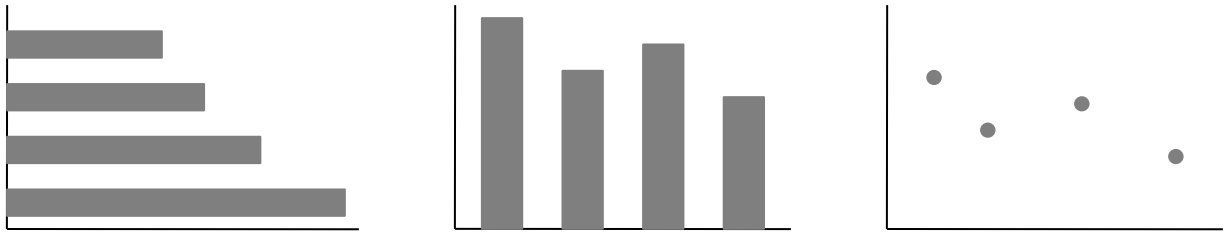
Count – Isotype

- Isotype
  - International System Of Typographic Picture Education
- Marie and Otto Neurath
  - Vienna, 1936



Ranking

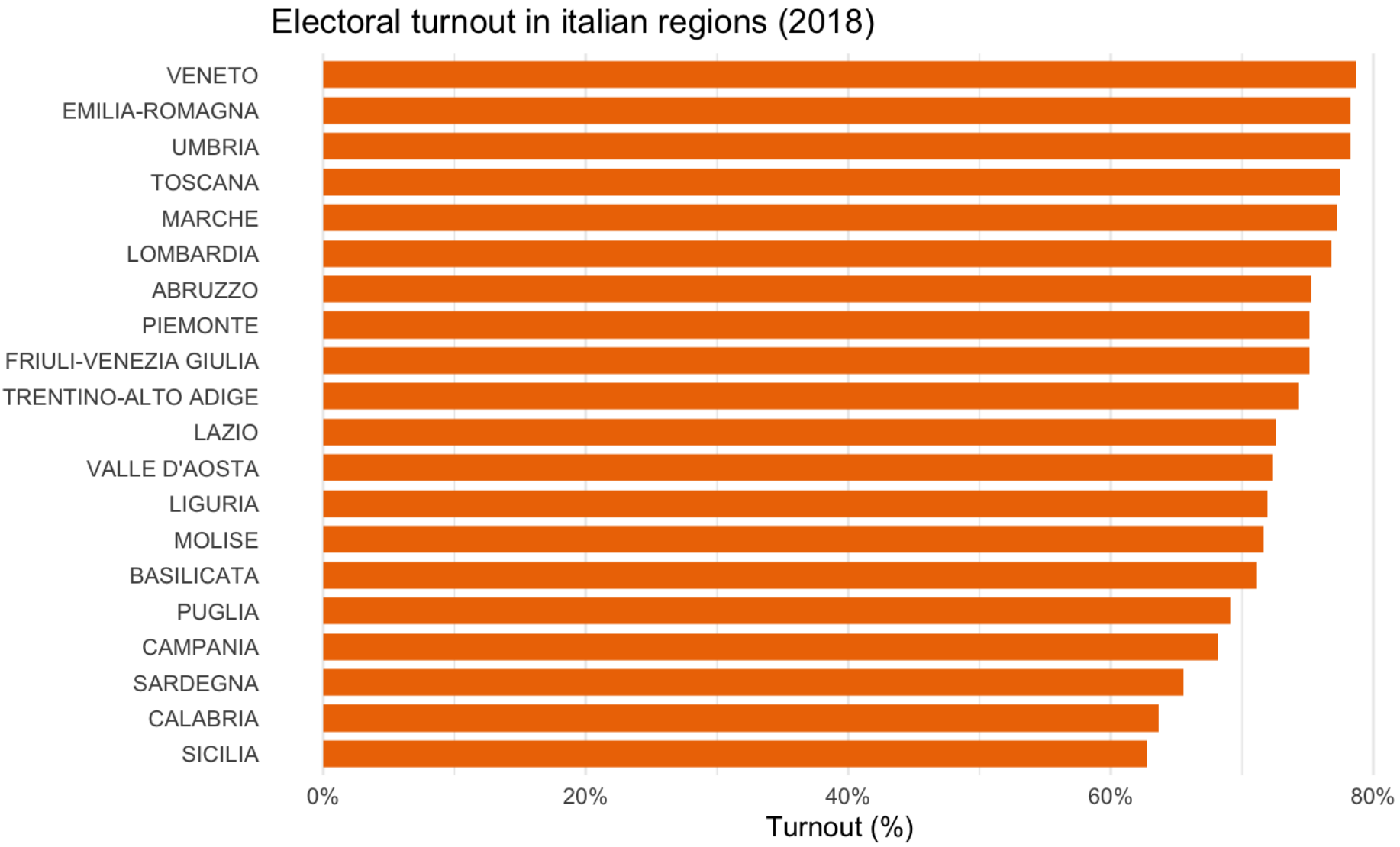
- Same type as nominal comparison
- Pay attention to order
  - Bar graphs
  - Dot plot
    - Allow non zero-based axes



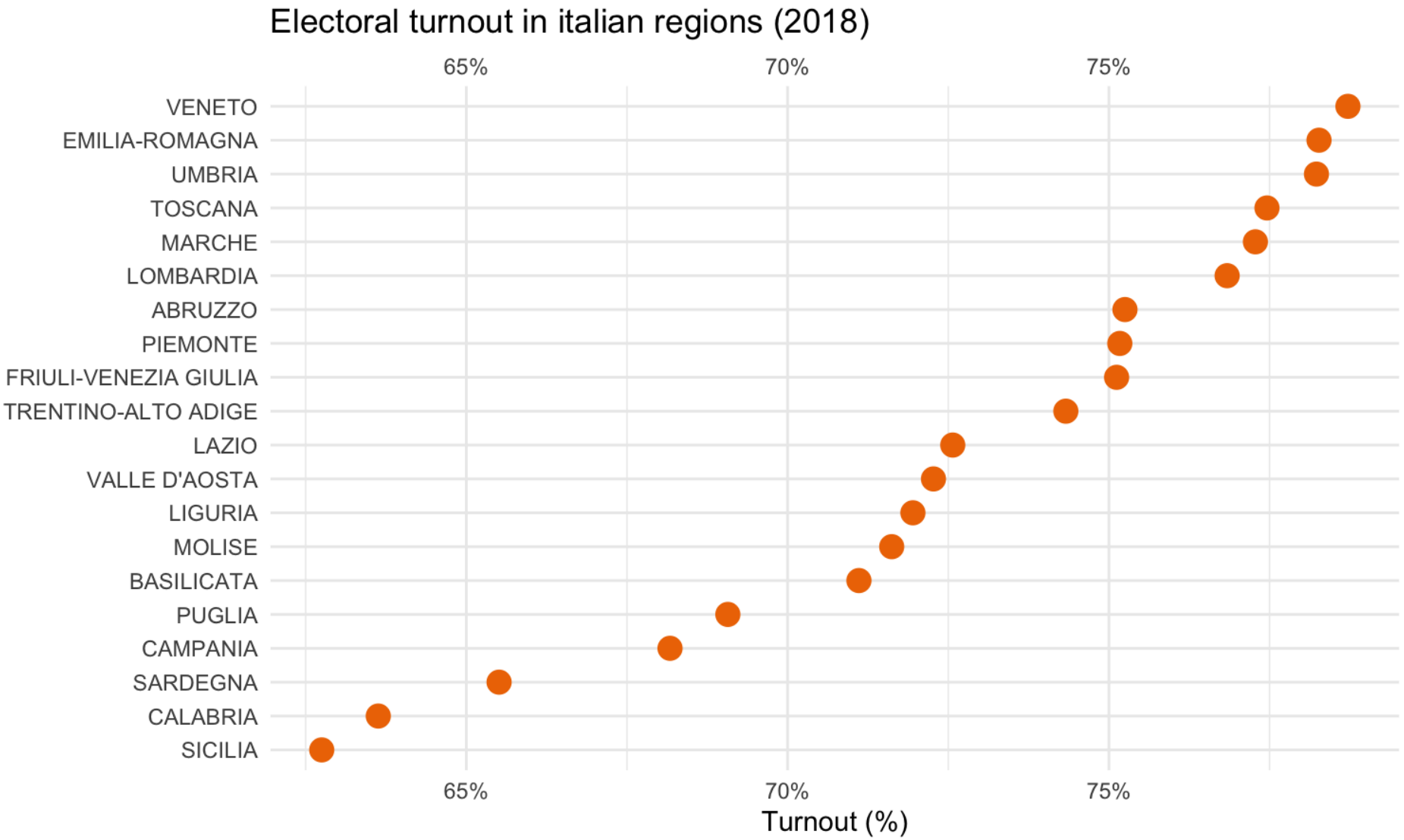
Ranking

Purpose	Sort order	Chart orientation
Highlight the highest value	Descending	H: highest on top V: highest on left
Highlight the lowest value	Ascending	H: lowest on top V: lowest on left

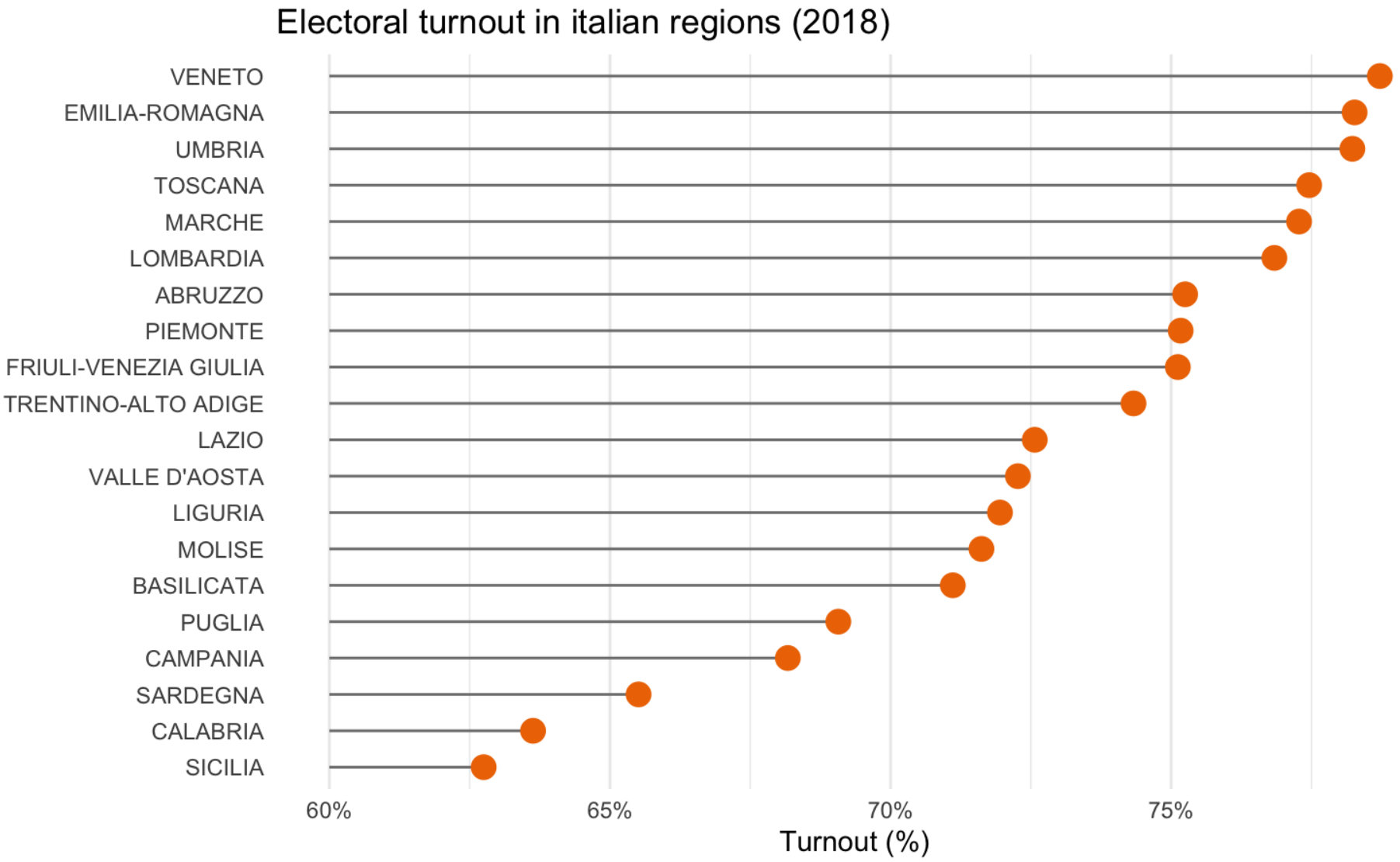
Ranking – Barplot



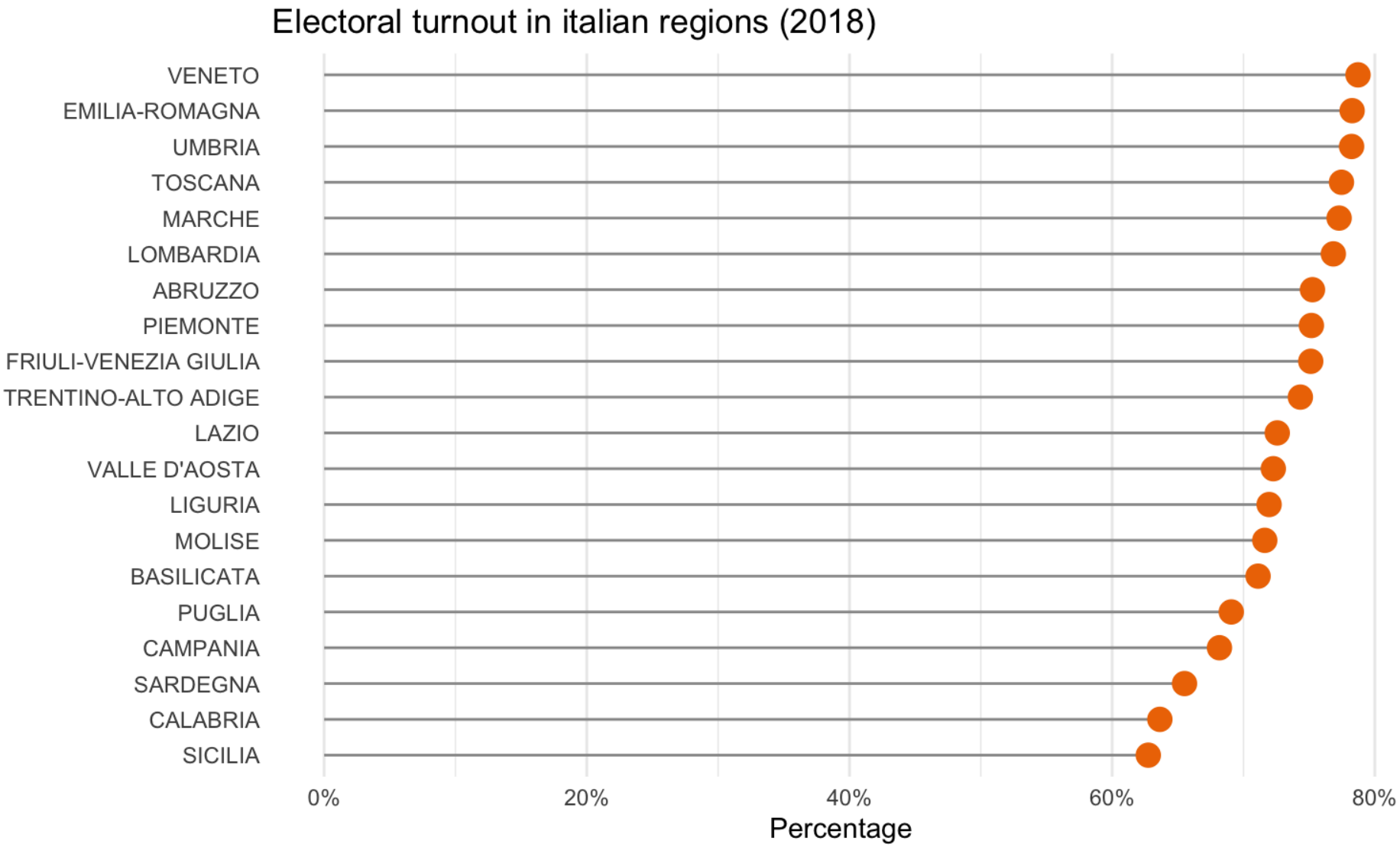
Ranking – Dot plot



Lollypop (nonzero based scale)

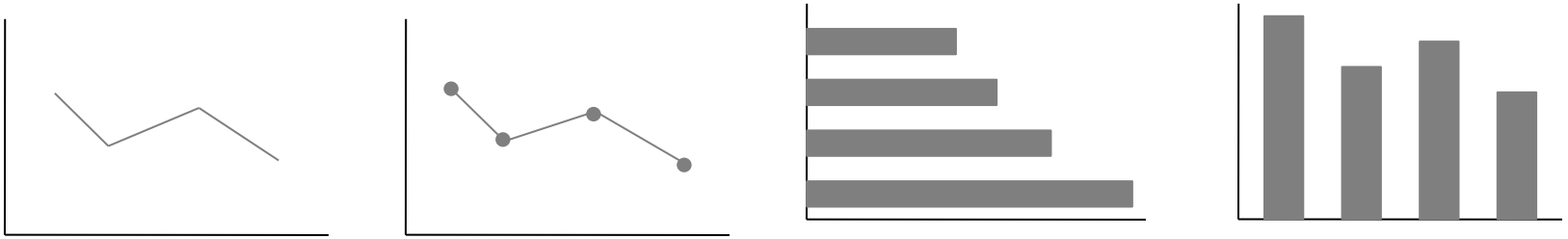


Lollypop (zero based scale)

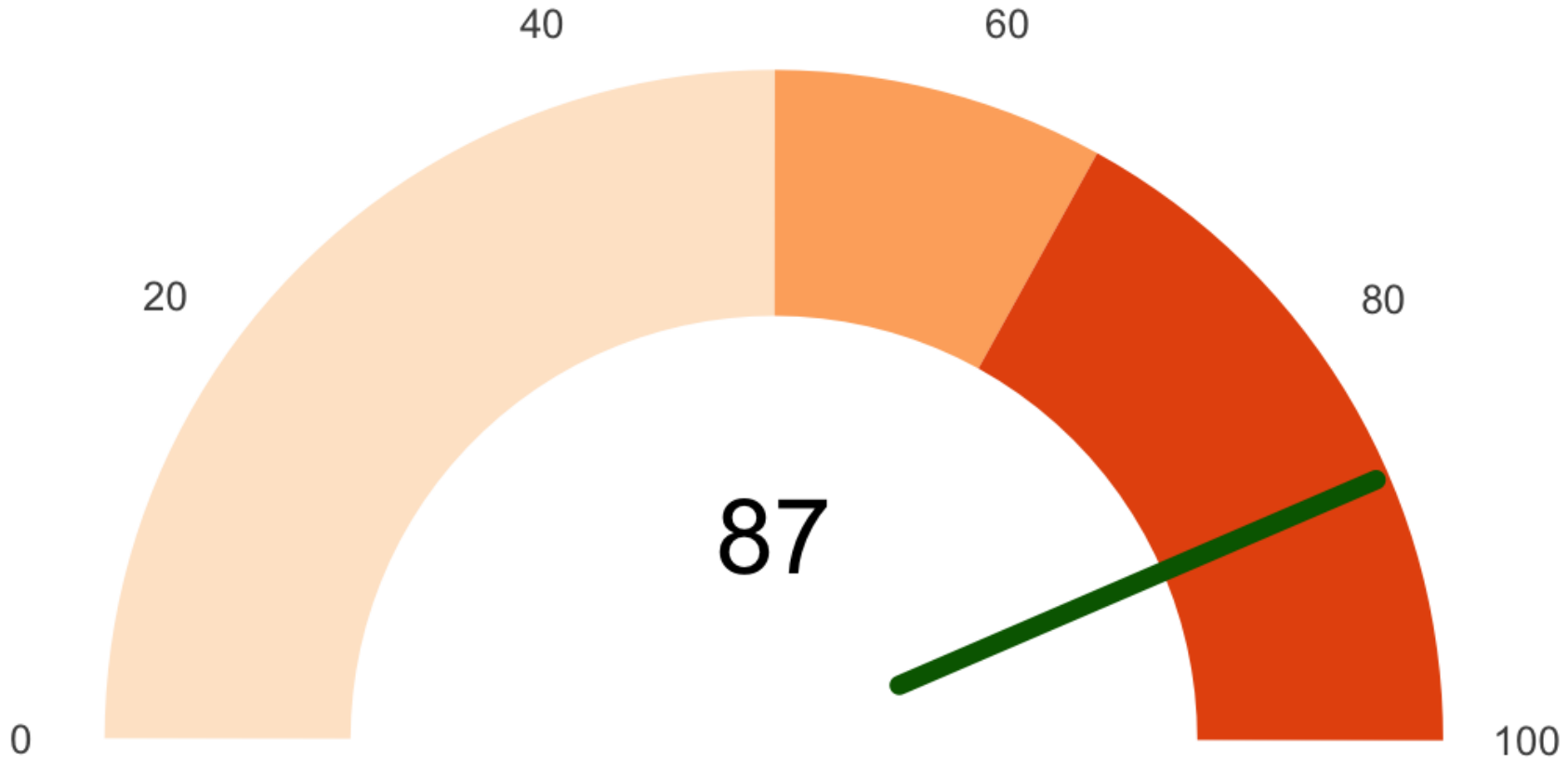


Deviation

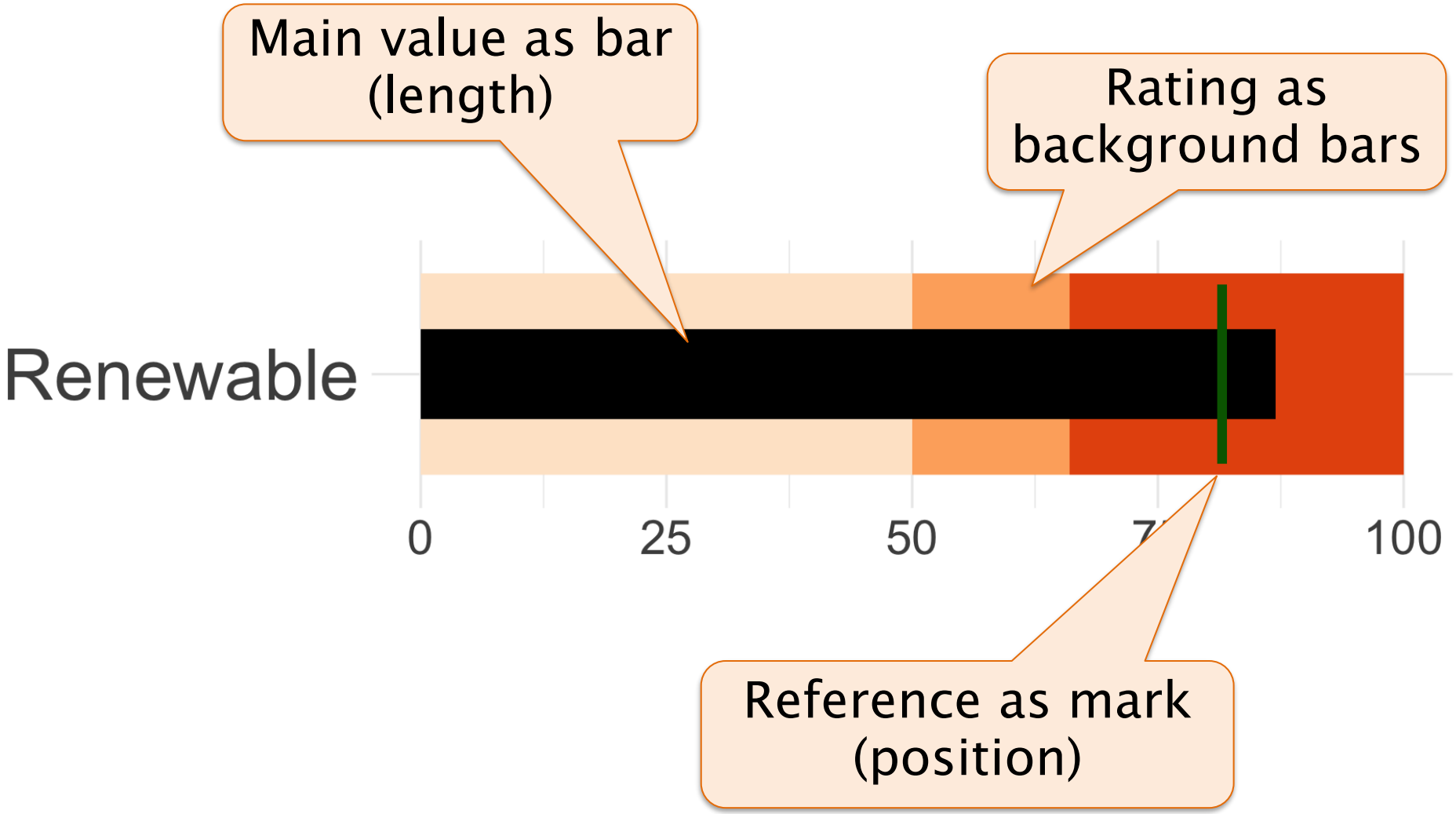
- To what degree one or more sets of values differ in relation to primary values.
  - Points (dots)
  - Gauge
  - Bars
  - Bullet



Angle + Position – Gauge

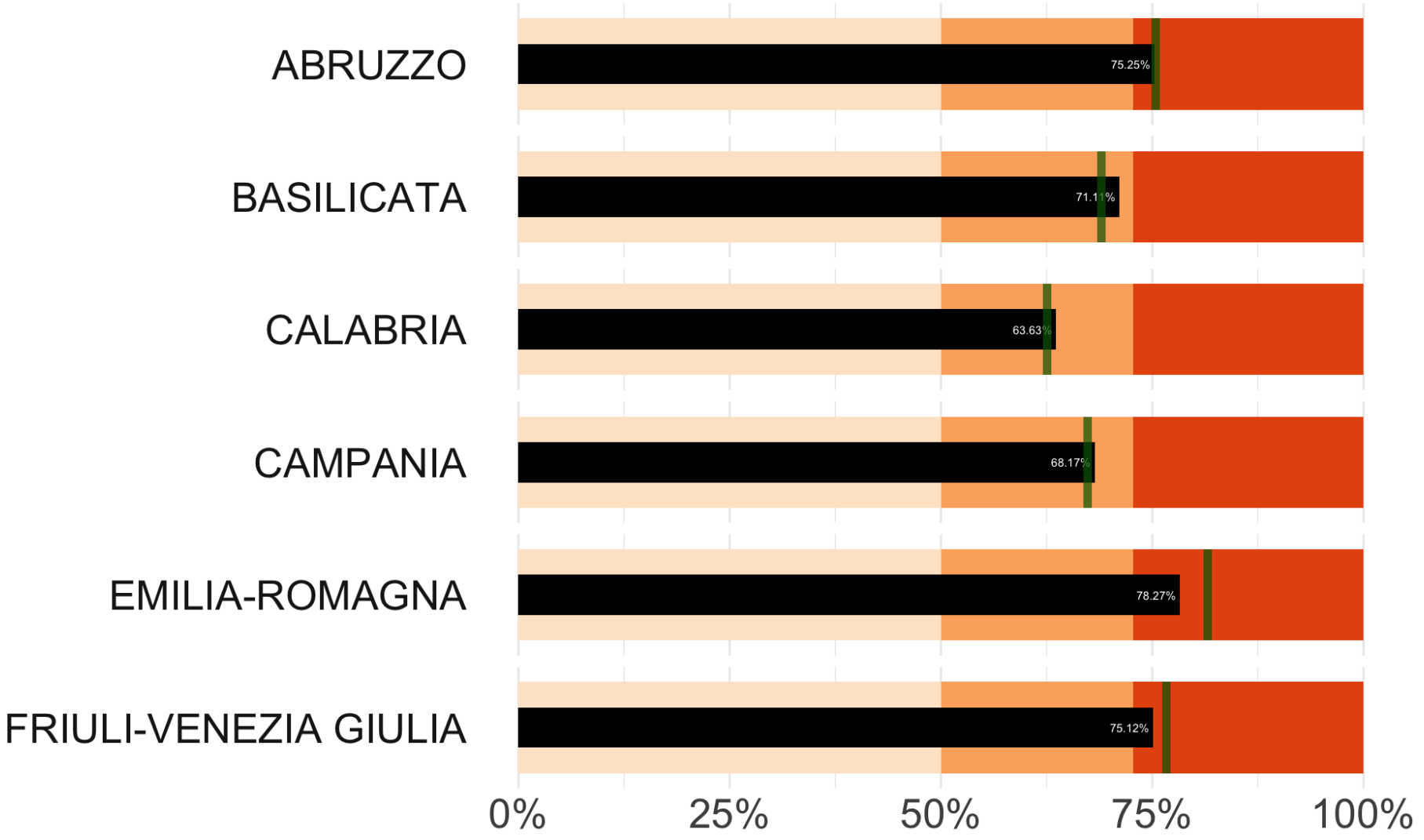


Length+Position- Bullet Graph



See: https://www.perceptualedge.com/articles/misc/Bullet_Graph_Design_Spec.pdf

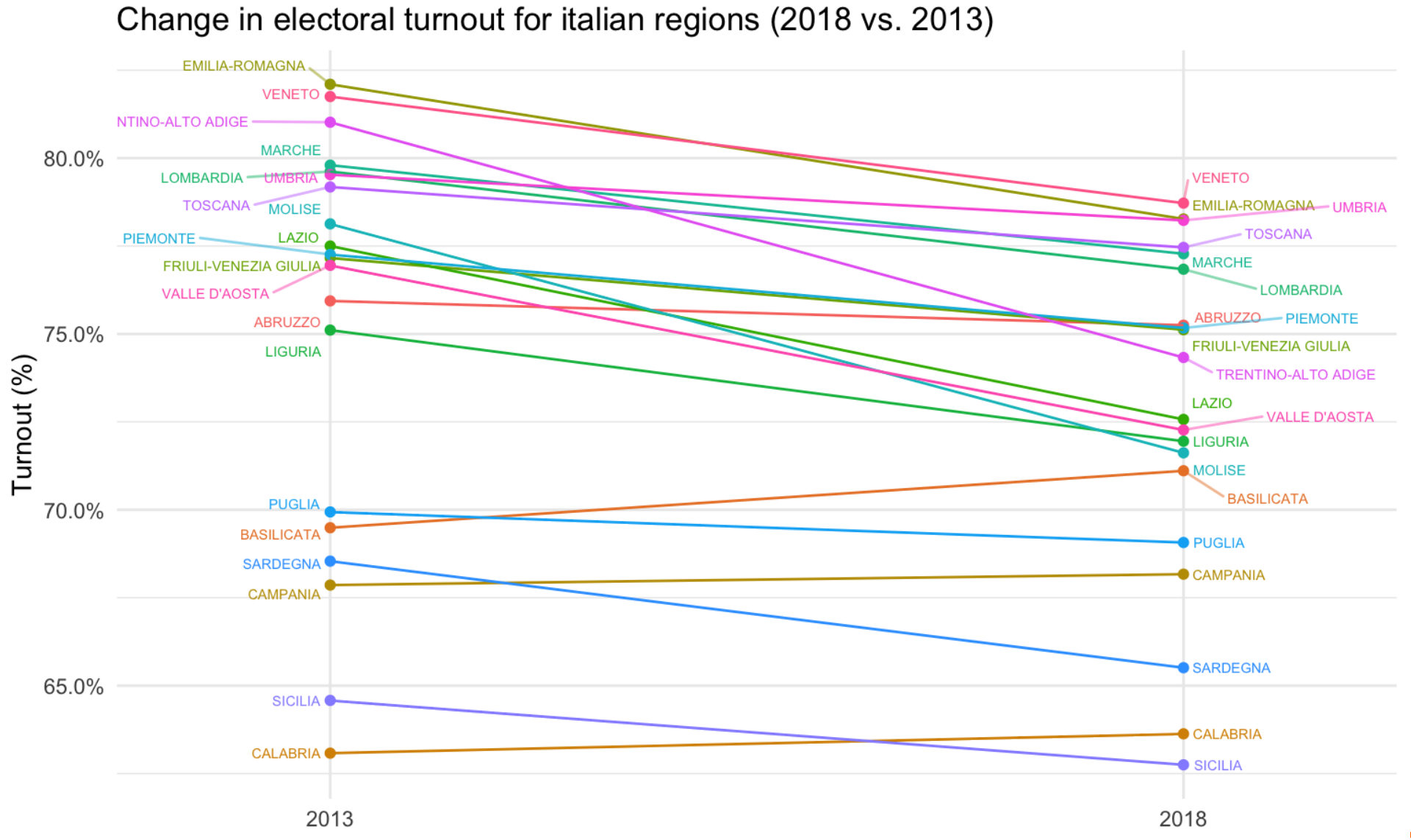
Length+Position- Bullet Graph



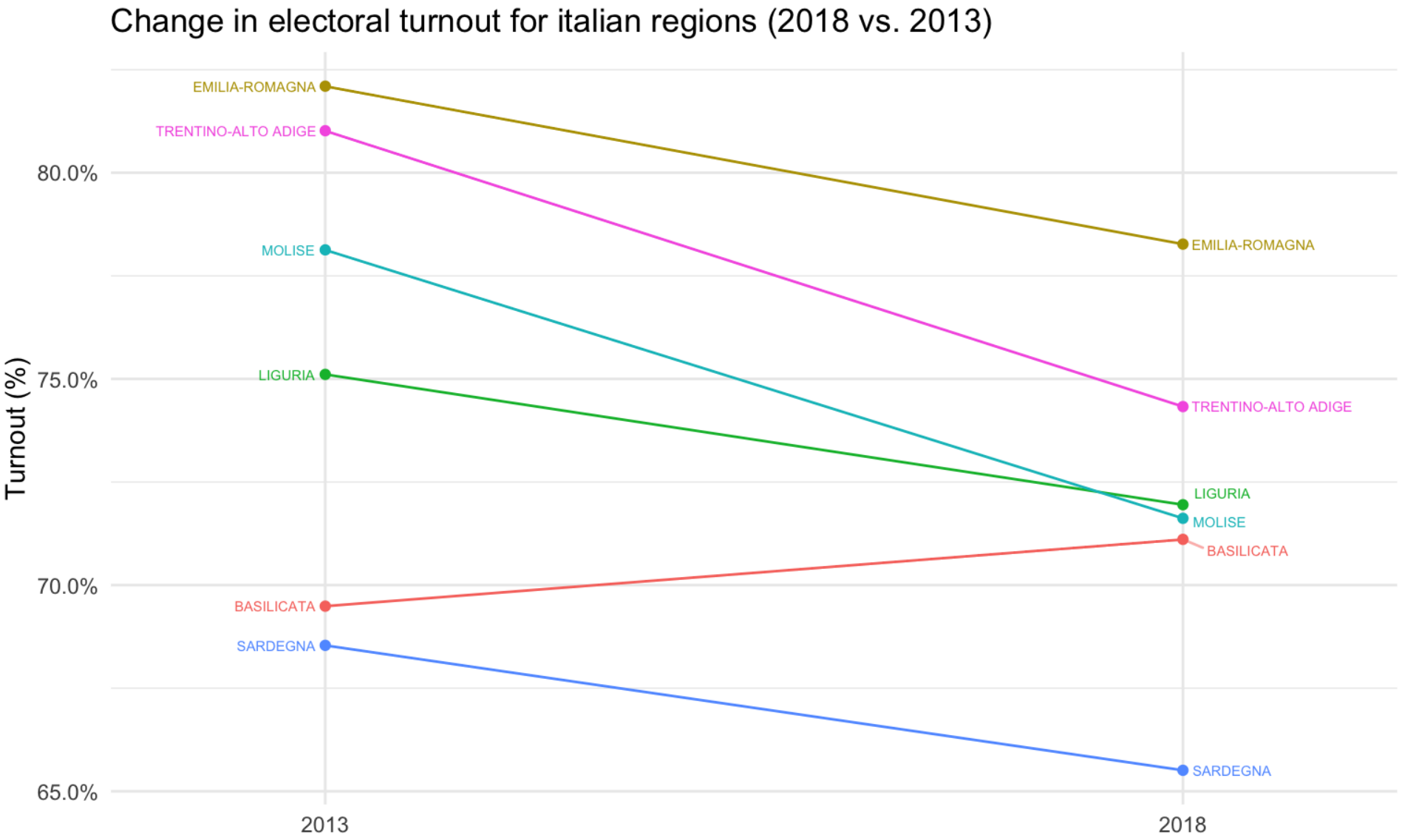
Pre-post variation

- Comparing several categorical values typically two conditions
  - Pre vs. post
  - With vs. without
  - …

Slope chart


Change in electoral turnout for italian regions (2018 vs. 2013)
Turnout (%)
80.0%
75.0%
70.0%
65.0%
2013
2018
EMILIA-ROMAGNA
VENETO
NTINO-ALTO ADIGE
MARCHE
LOMBARDIA
UMBRIA
TOSCANA
MOLISE
PIEMONTE
LAZIO
FRIULI-VENEZIA GIULIA
VALLE D'AOSTA
ABRUZZO
LIGURIA
PUGLIA
BASILICATA
SARDEGNA
CAMPANIA
SICILIA
CALABRIA
VENETO
EMILIA-ROMAGNA
UMBRIA
TOSCANA
MARCHE
LOMBARDIA
ABRUZZO
PIEMONTE
FRIULI-VENEZIA GIULIA
TRENTINO-ALTO ADIGE
LAZIO
VALLE D'AOSTA
LIGURIA
MOLISE
BASILICATA
PUGLIA
CAMPANIA
SARDEGNA
CALABRIA
SICILIA

Slope chart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SARDEGNA
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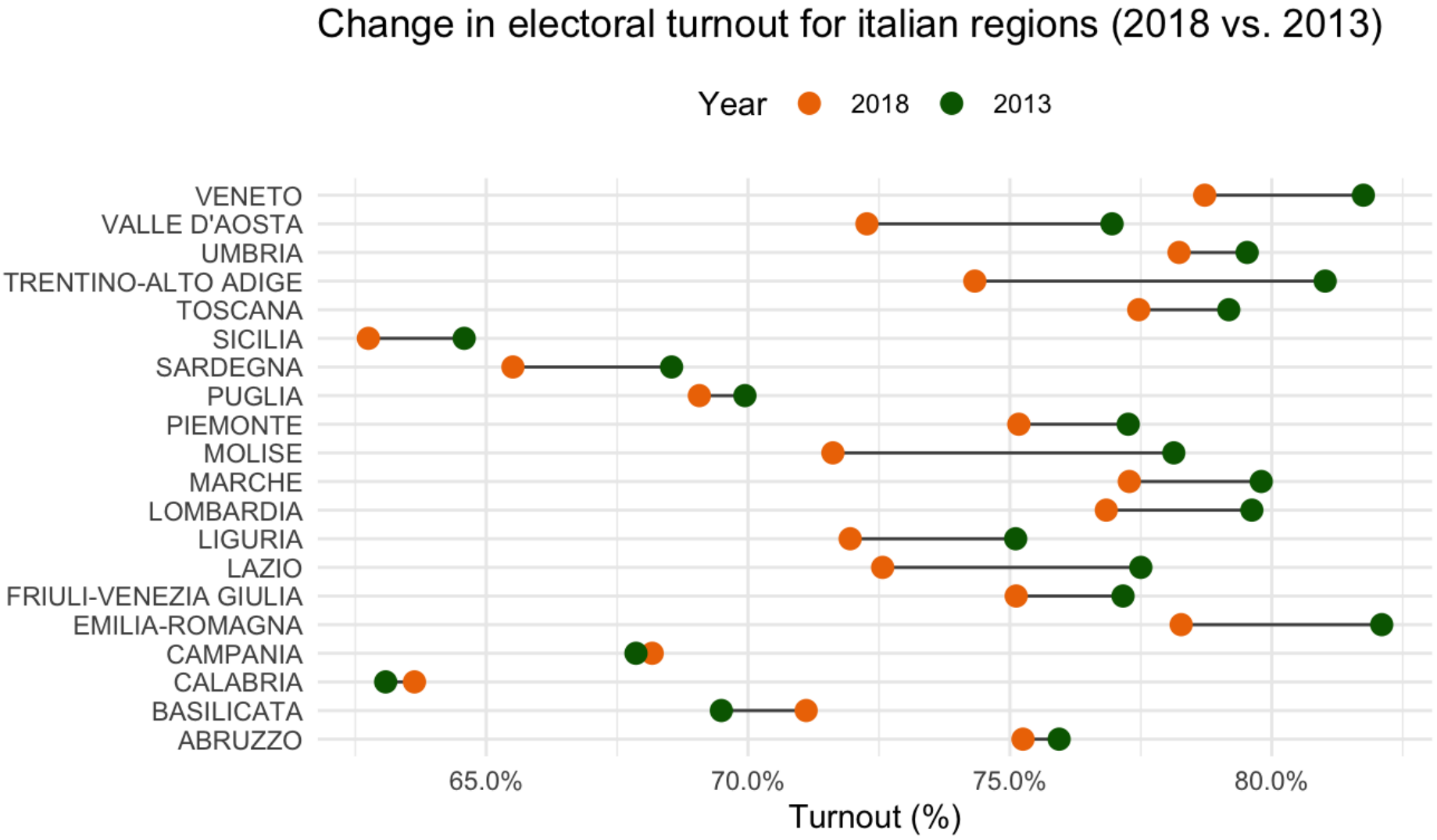
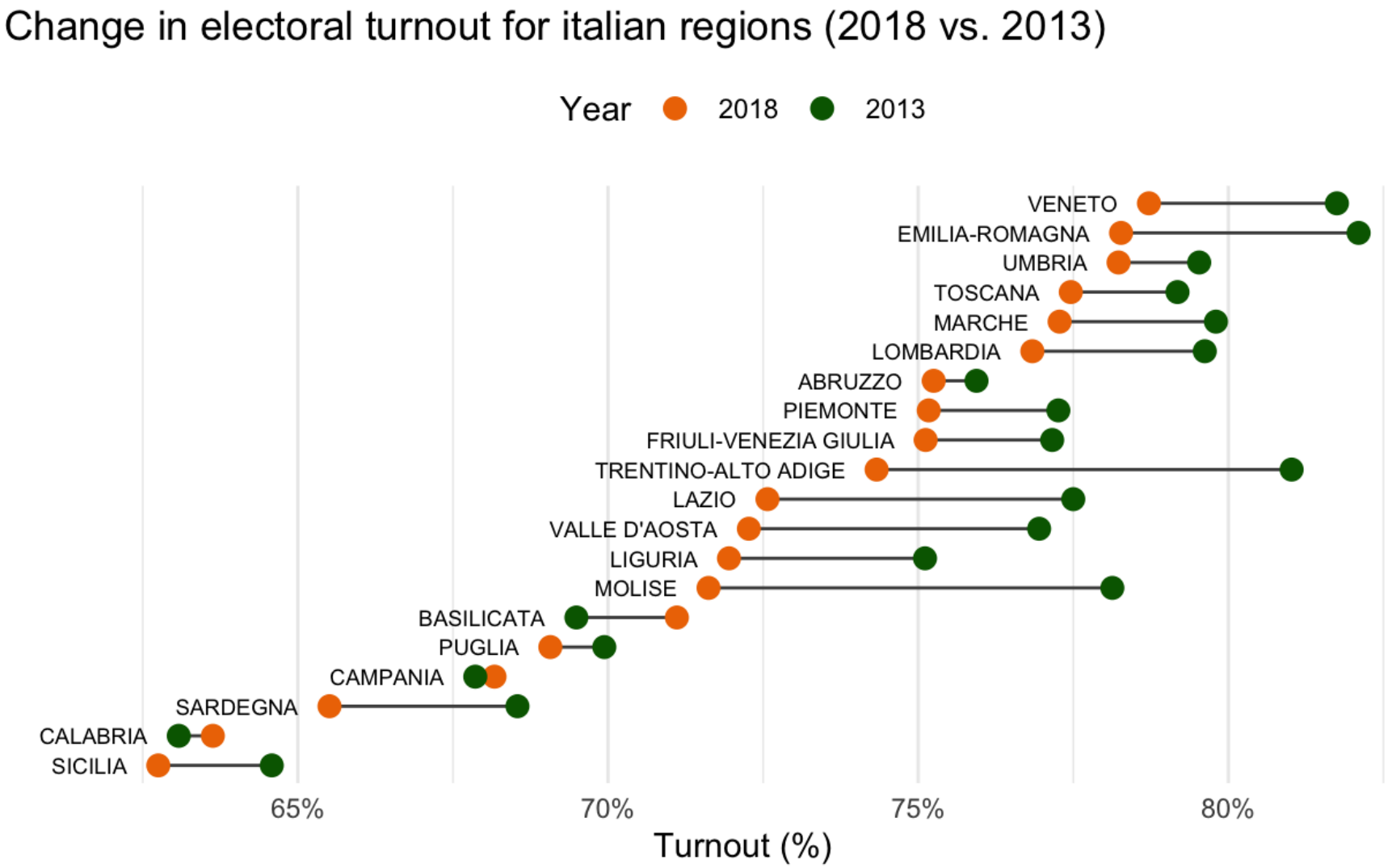
TRENTINO-ALTO ADIGE
LIGURIA
MOLISE
BASILICATA
SARDEGNA

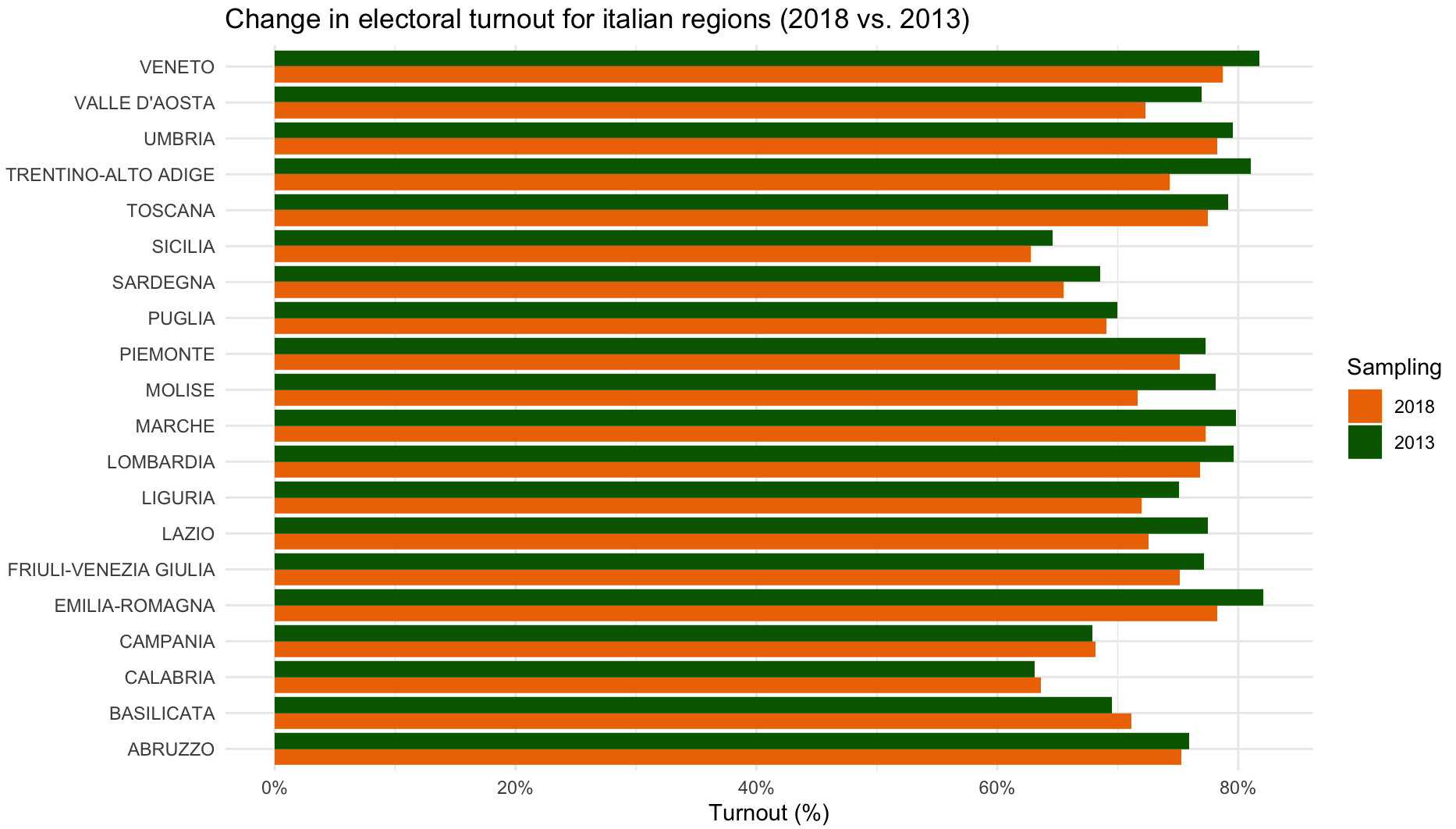
Dumbbell plot



Dumbbell plot (sorted)



Clustered bars

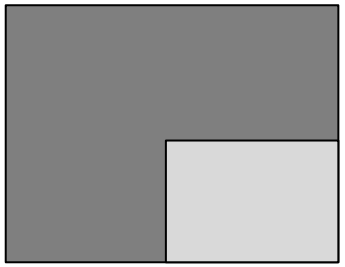


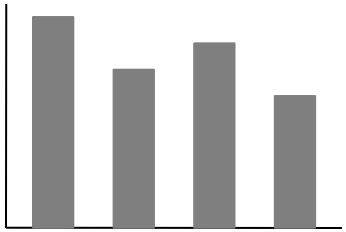
Proportion (Part-to-whole)

- Represent the frequency of different values within a given category
  - Be careful to use all values within the same category
- Can be used to compare frequency distribution across different categories sharing the same levels

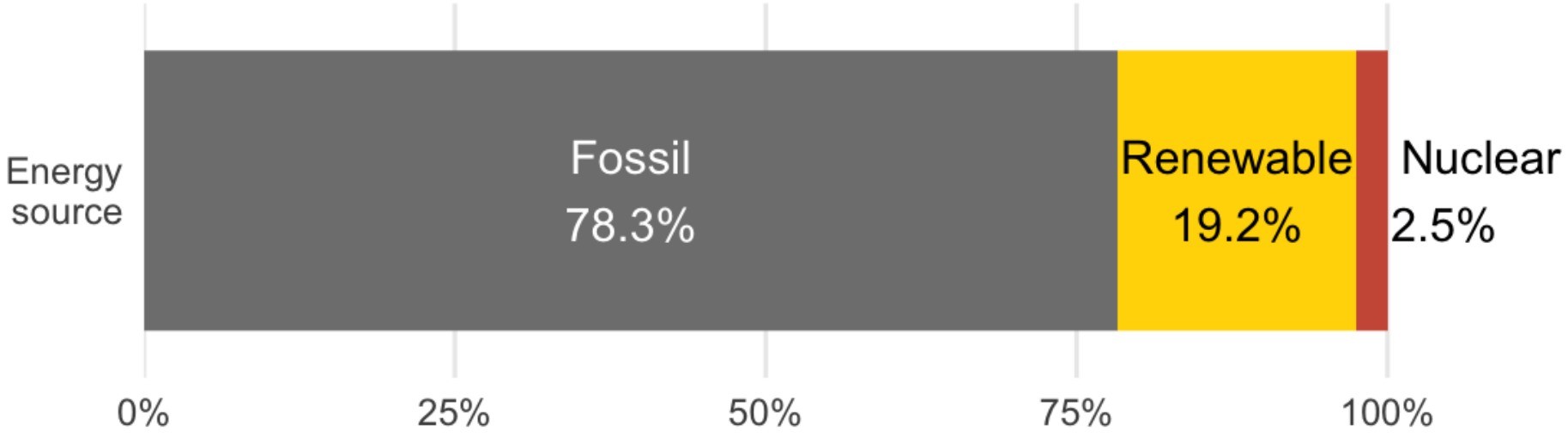
Proportion (Part-to-whole)

- Best unit: percentage
- Stacked bar graph
  - Difficult to read individual values
- Stacked area
- Treemap
- Gridplot
- Pie / Donut
- Marimekko



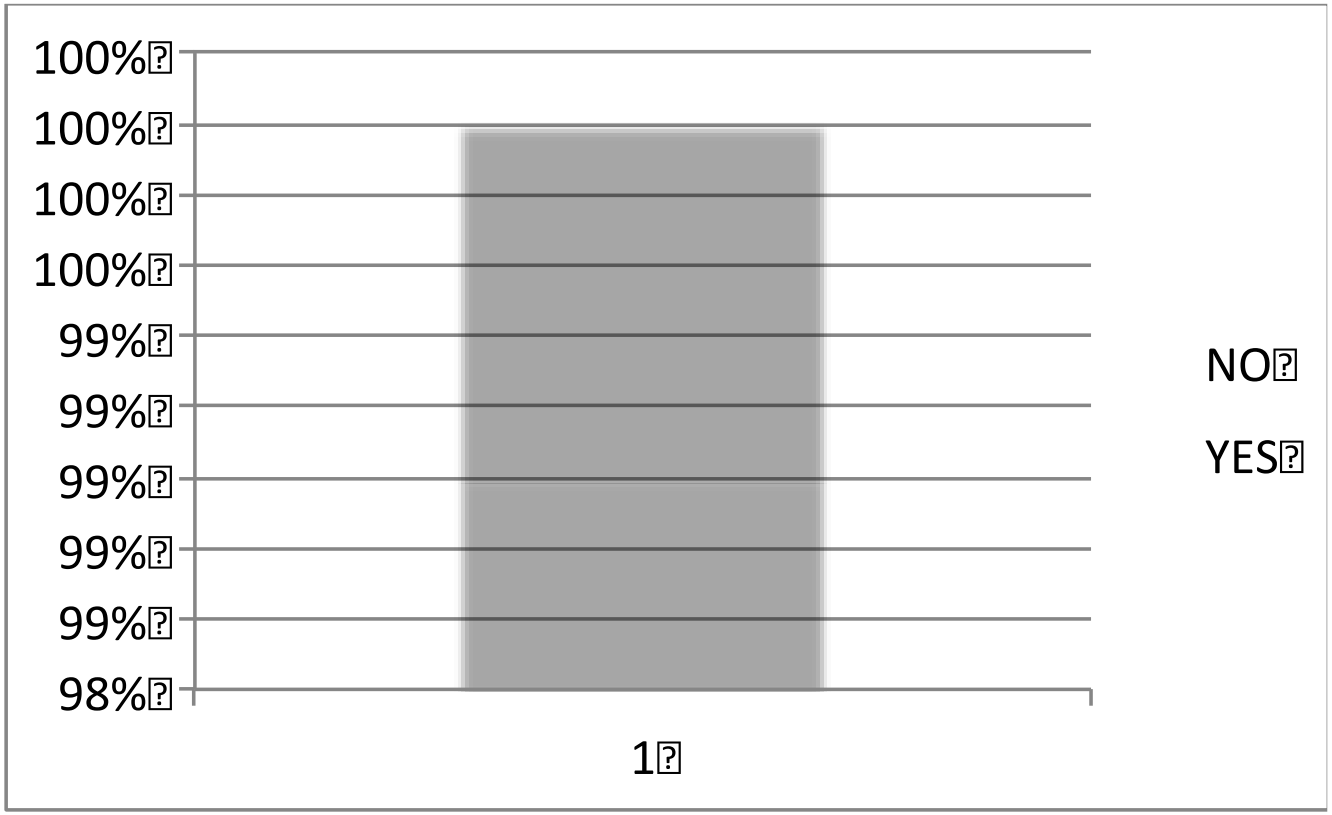


Length – Stacked Bar

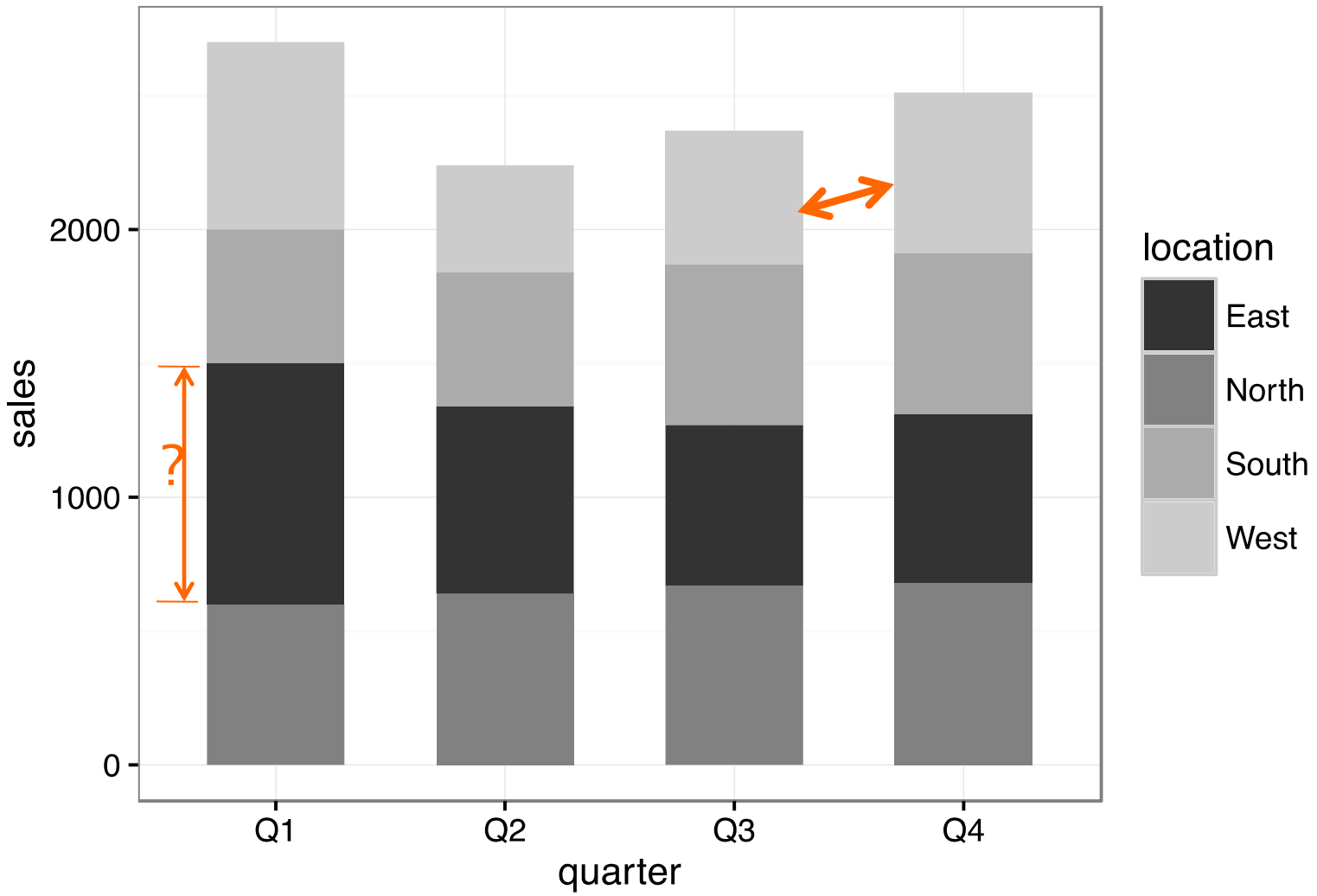


Beware of MS-Excel Defaults

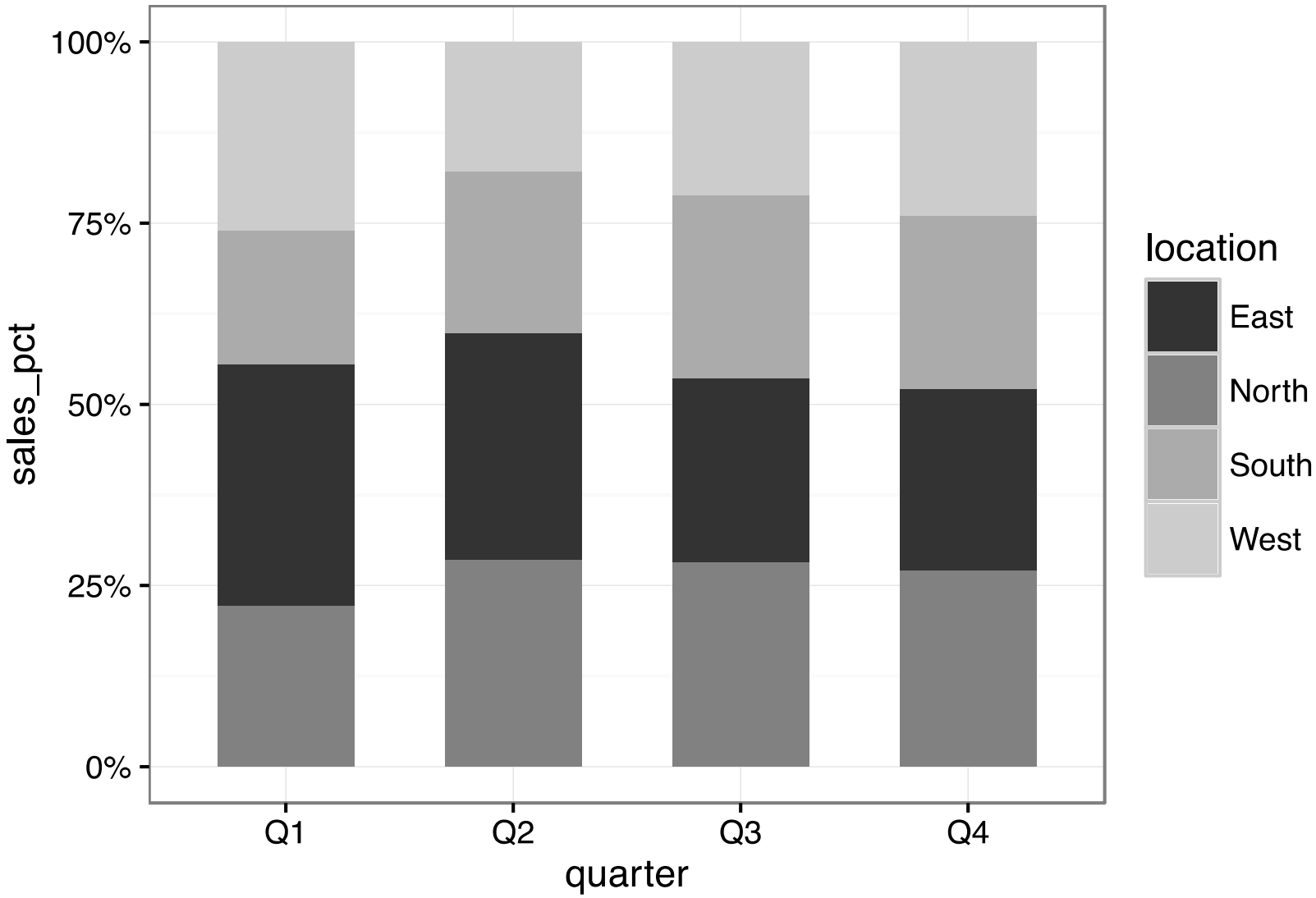
	A	B
1	YES	99%
2	NO	1%



Stacked bar graph

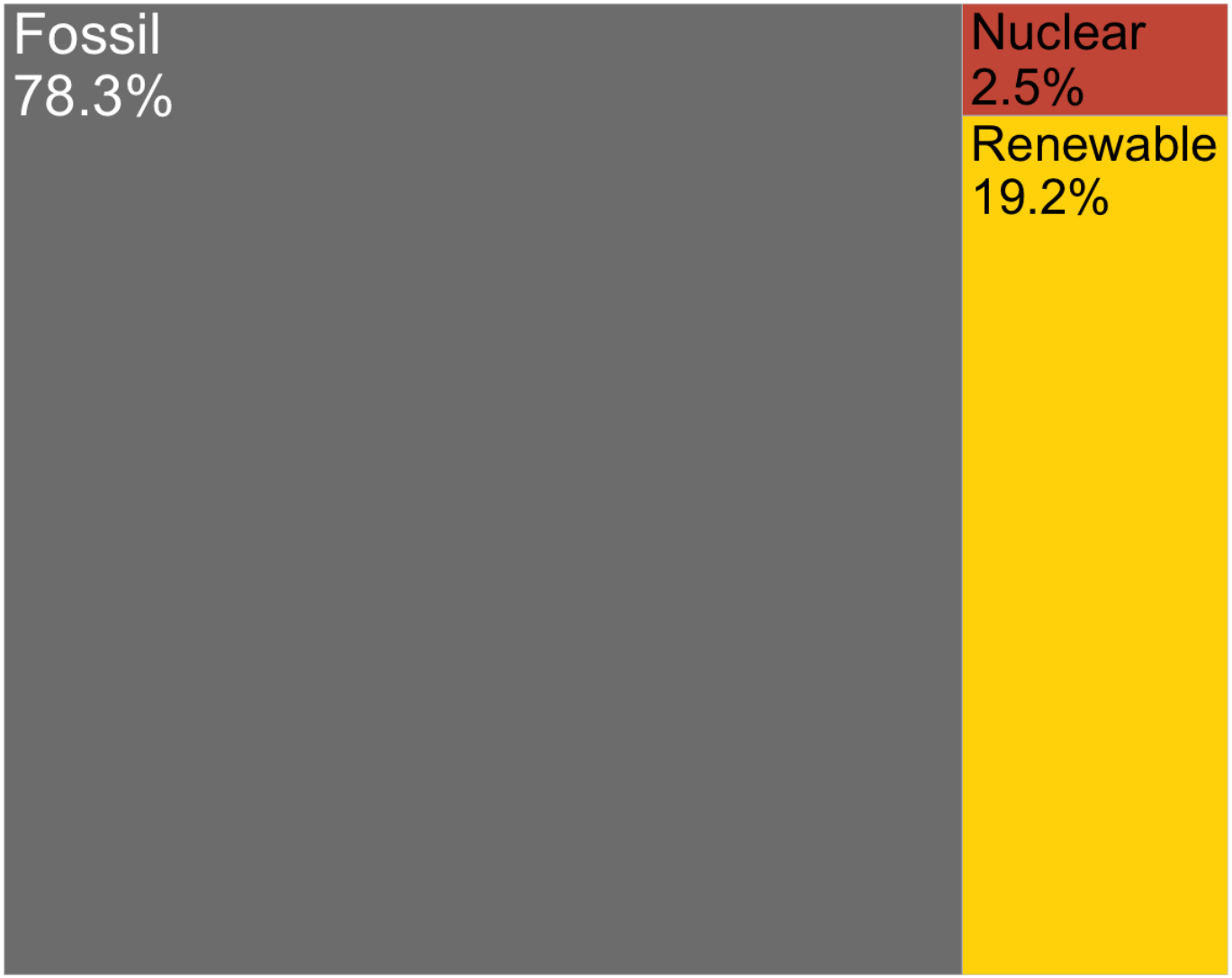


Stacked bars w/percentage

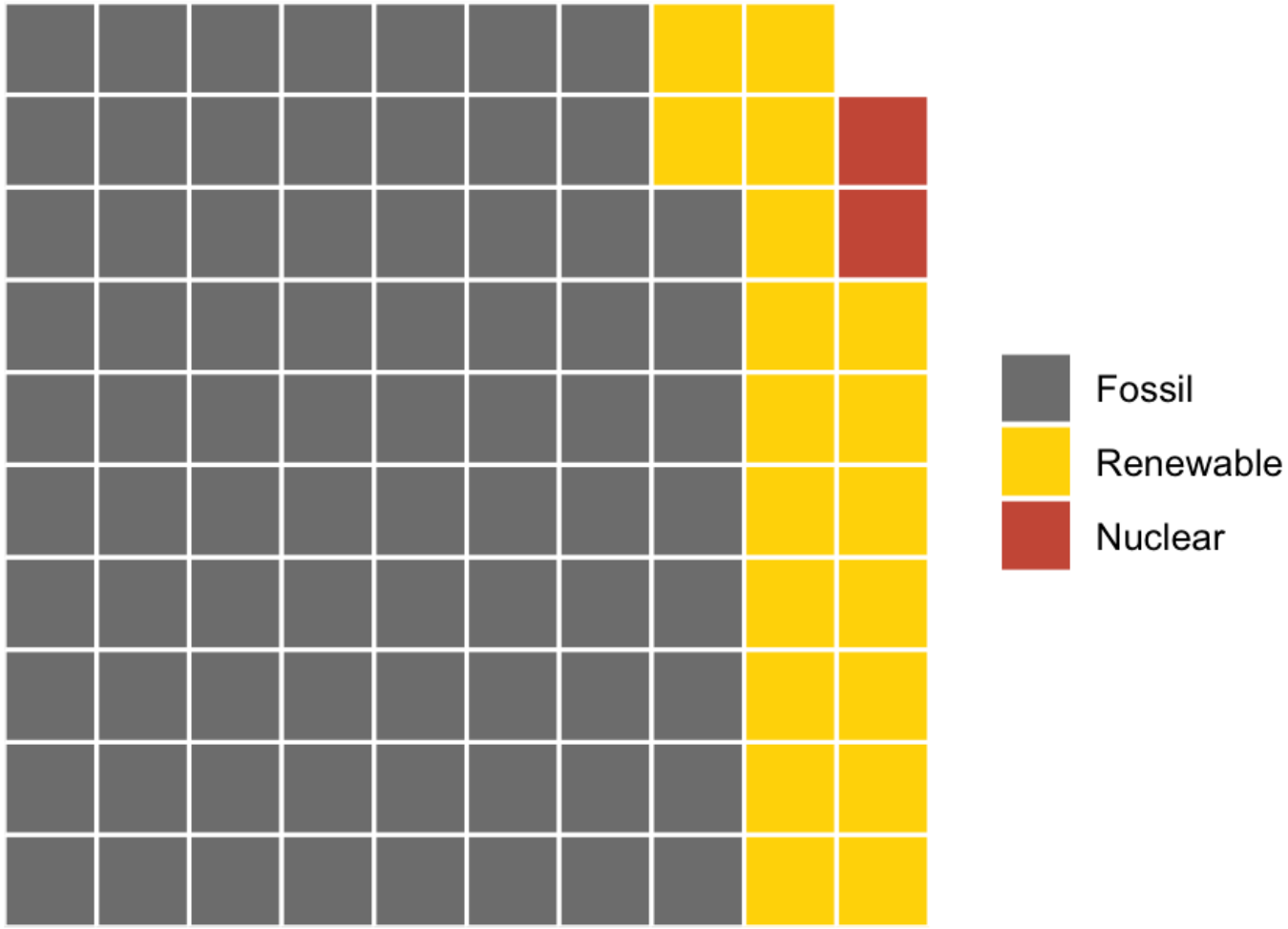


Area – Treemap

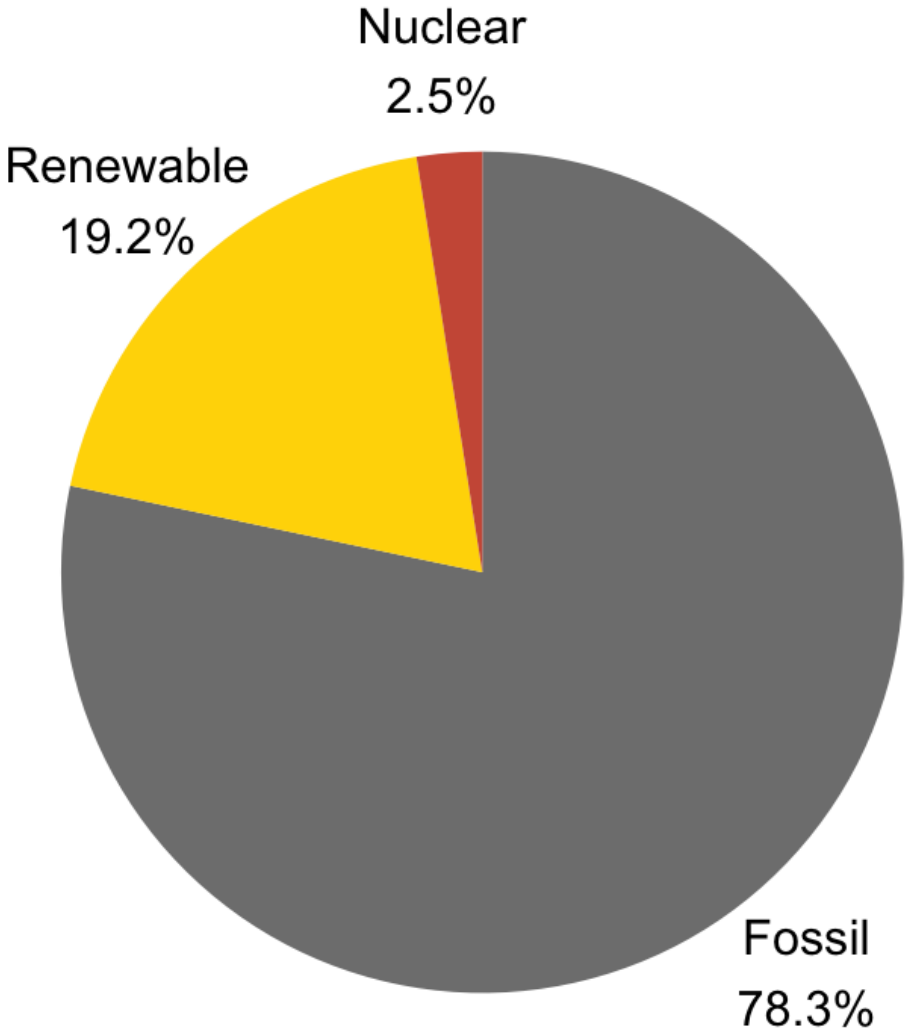
Area – Treemap



Area + Count – Waffle / Grid



Area + Angle – Pie Chart



Pie charts

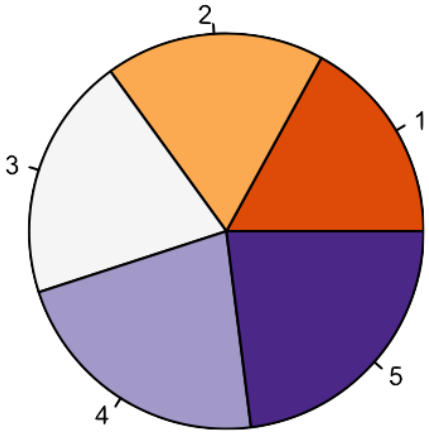
Pie charts

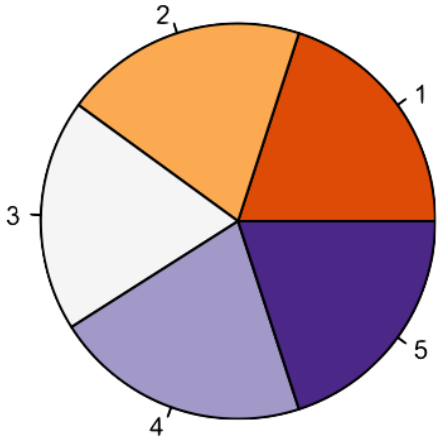
sky

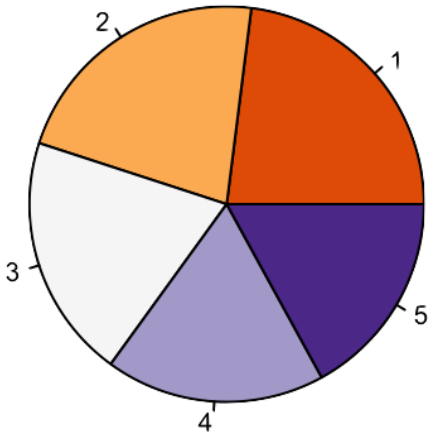
shady side of pyramid

sunny side of pyramid

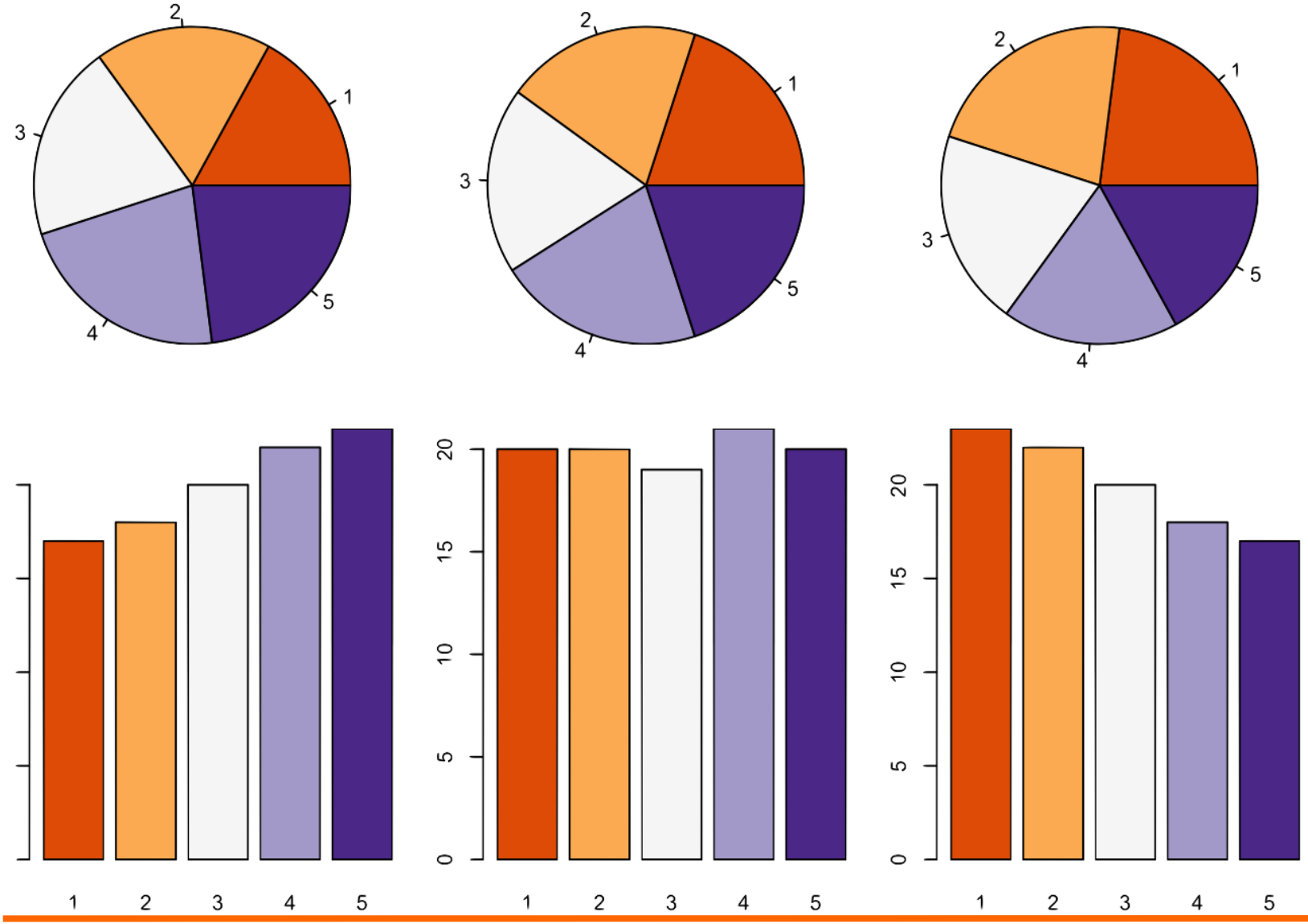
Pies







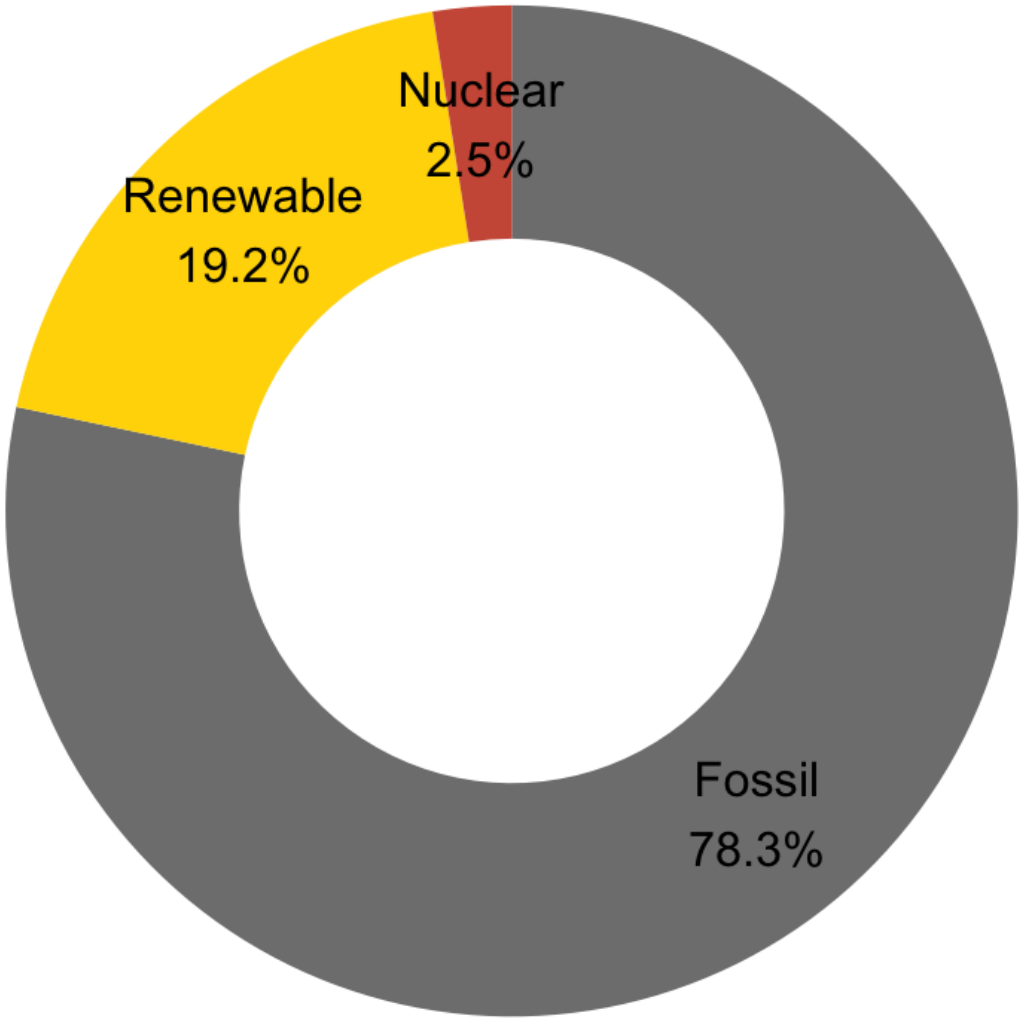
Pies vs. Bars



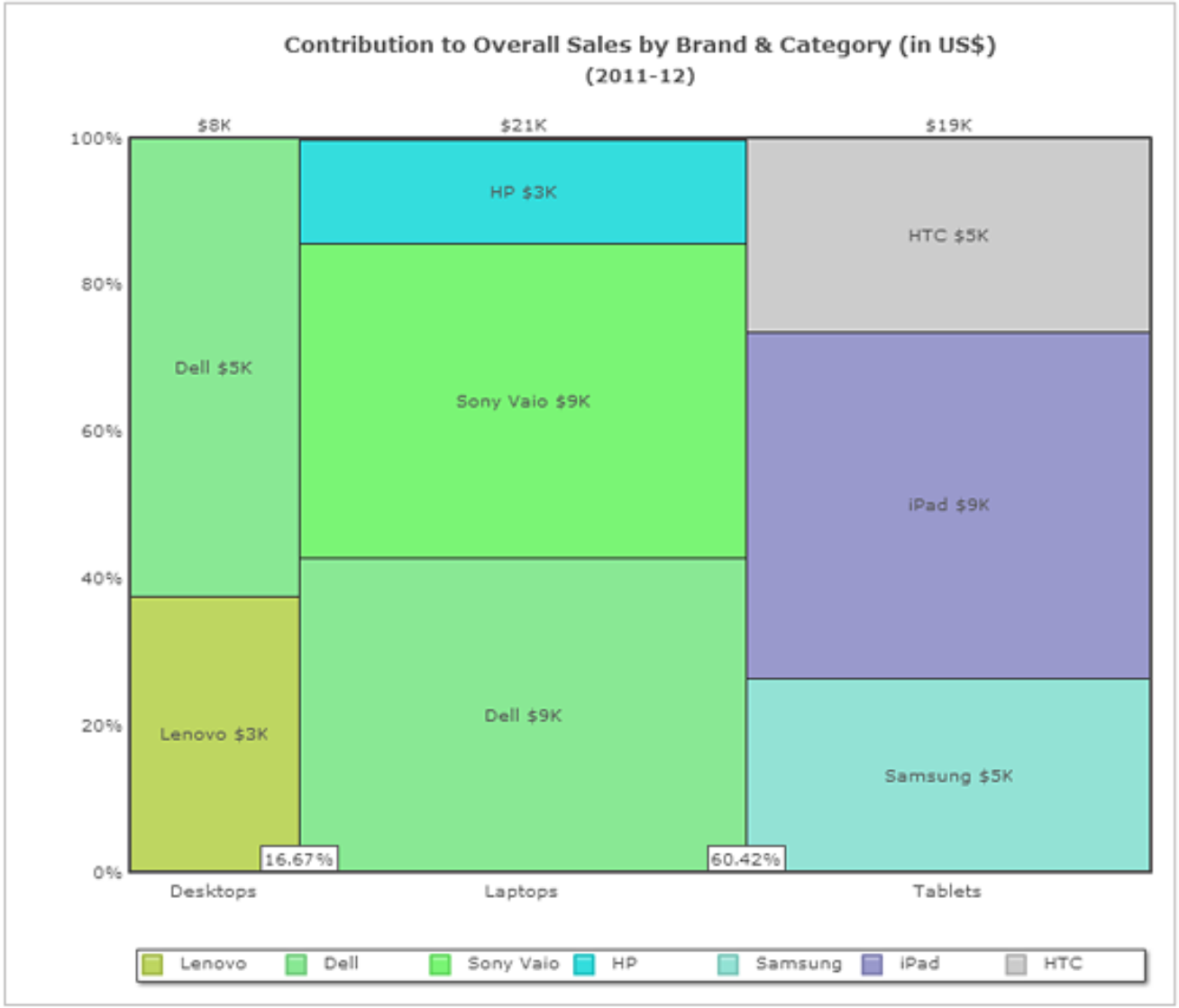
Pie Charts: guidelines

- Have serious limitations
  - To represent part-whole relationship
  - Only with a small number of categories
    - Up to four
    - Avoid rainbow pie
  - When proportions are distinct enough
- Remember to ease reading
  - Labels placed close to slices
  - Labels include values (percentages)

Area+Angle+Length – Donut

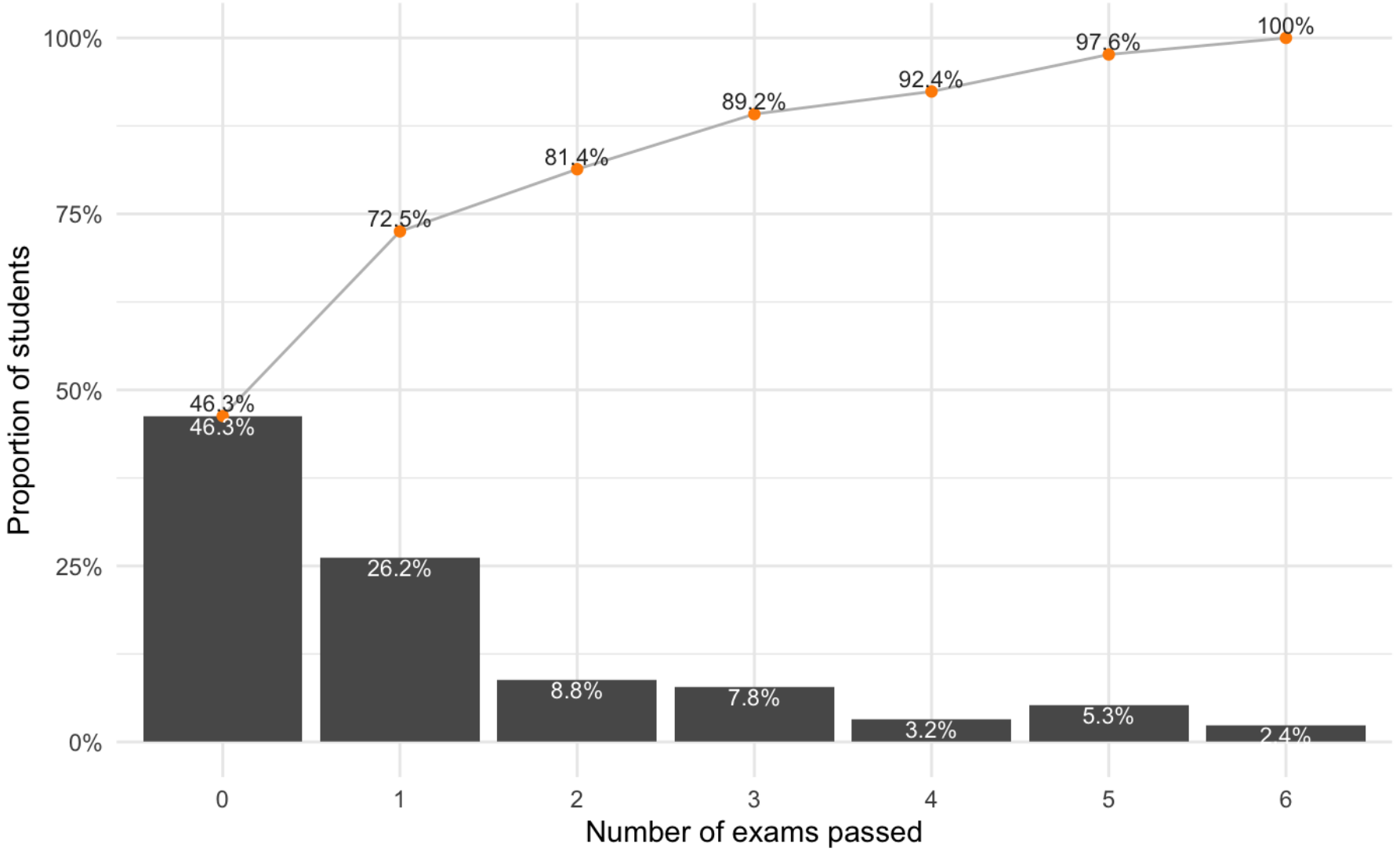


Marimekko Chart



https://www.fusioncharts.com/chart-primers/marimekko-chart/

Pareto chart



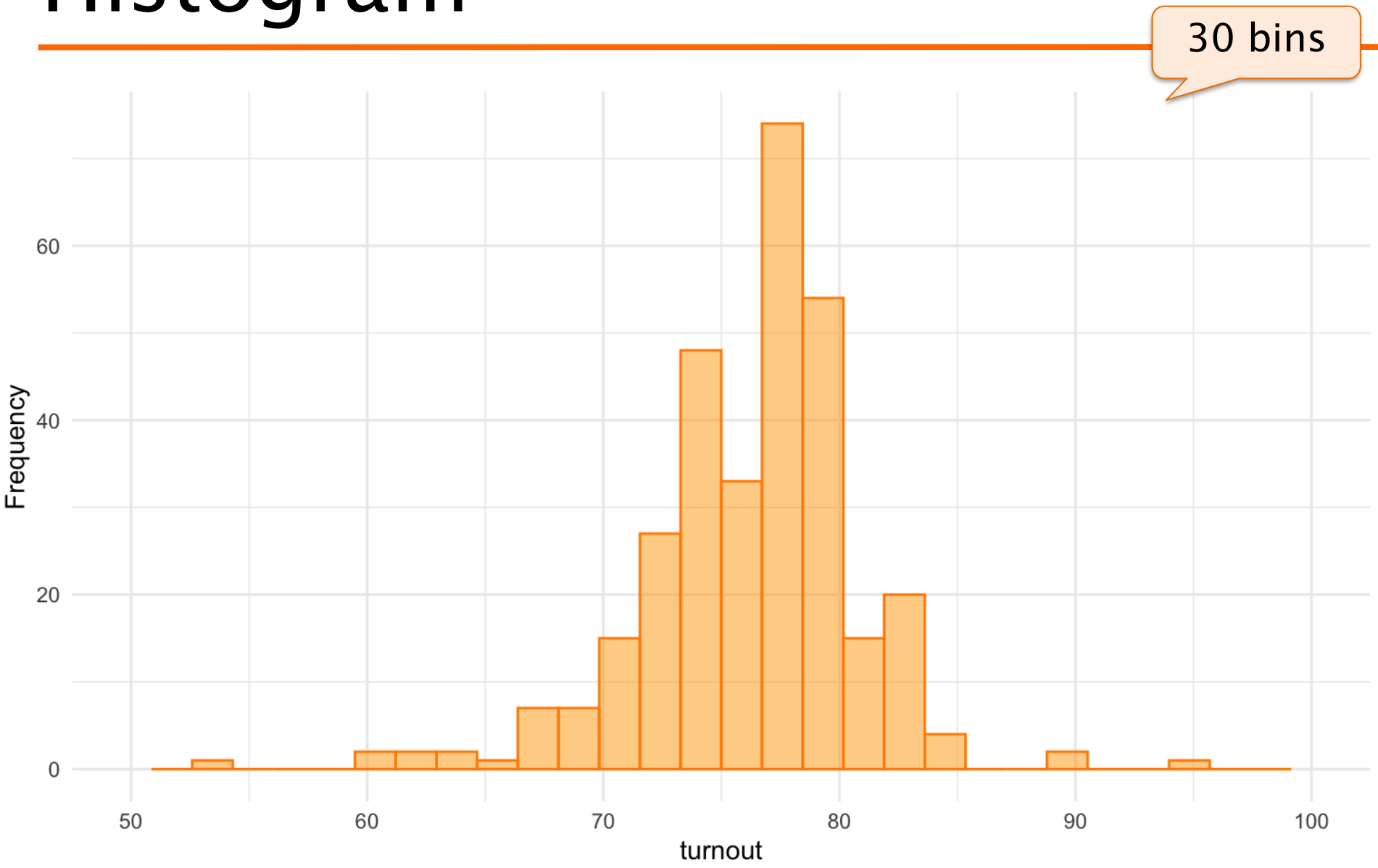
Distribution

- Continuous values
  - Show distribution of single set of values
  - Show and compare two or more distributions

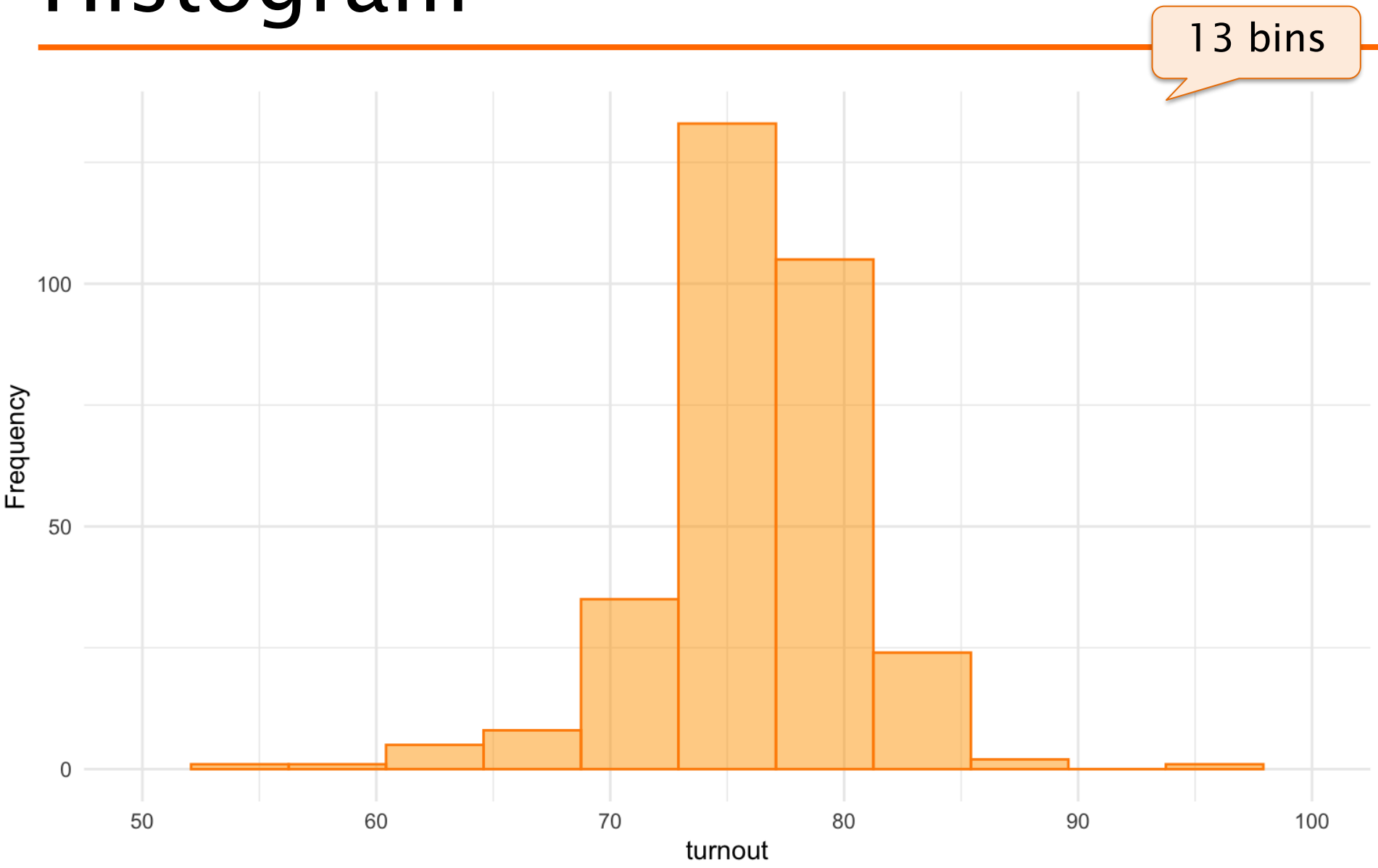
Single distribution

- Histogram
  - Vertical bar graph
  - Frequency for subdivision
    - Quantitative ranges
    - Categories
  - Emphasis on number of occurrences
- Frequency polygon
  - Line graphs
  - Frequency density function
  - Emphasis on the shape of the distribution
- Boxplot
  - Summary

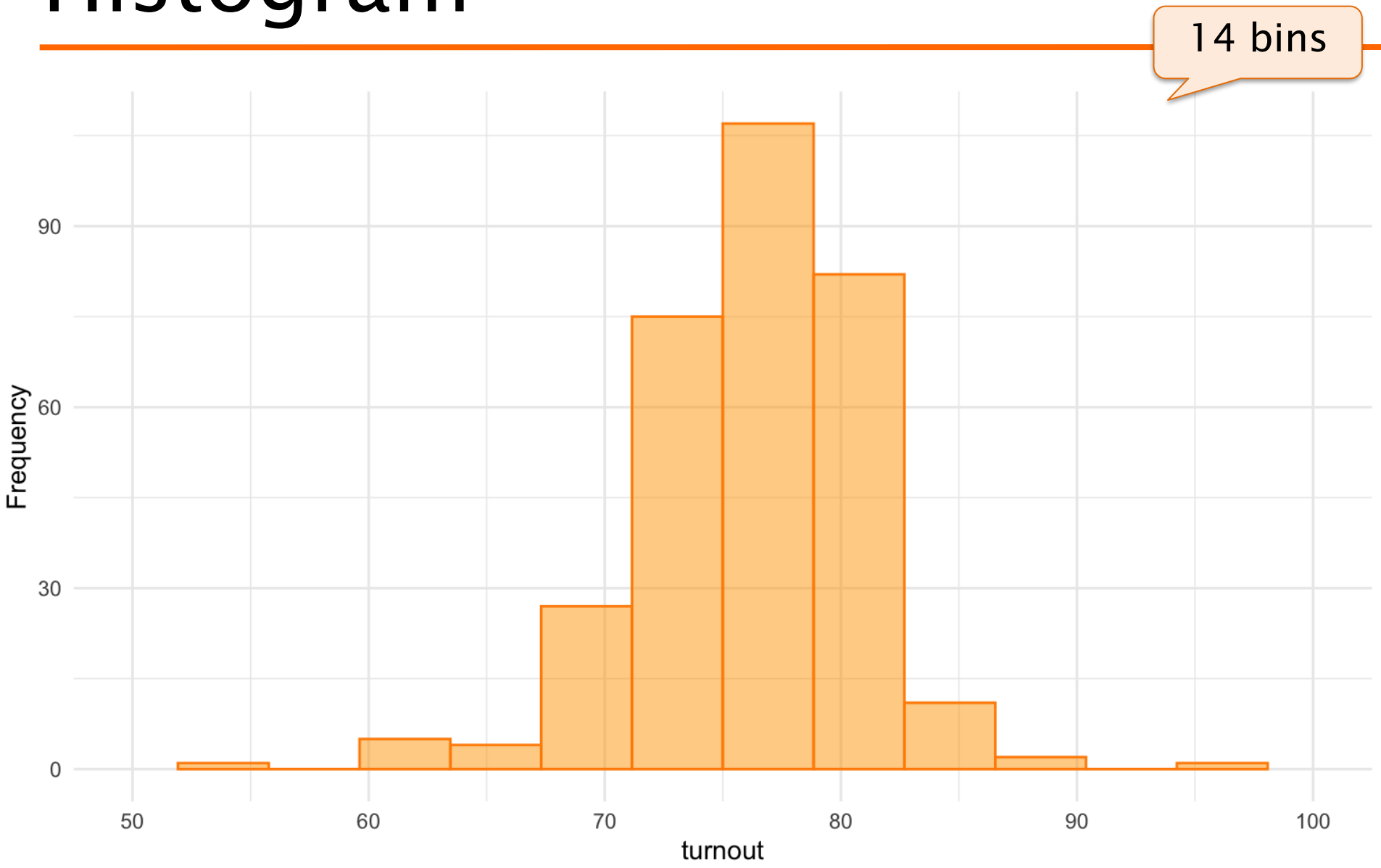
Histogram



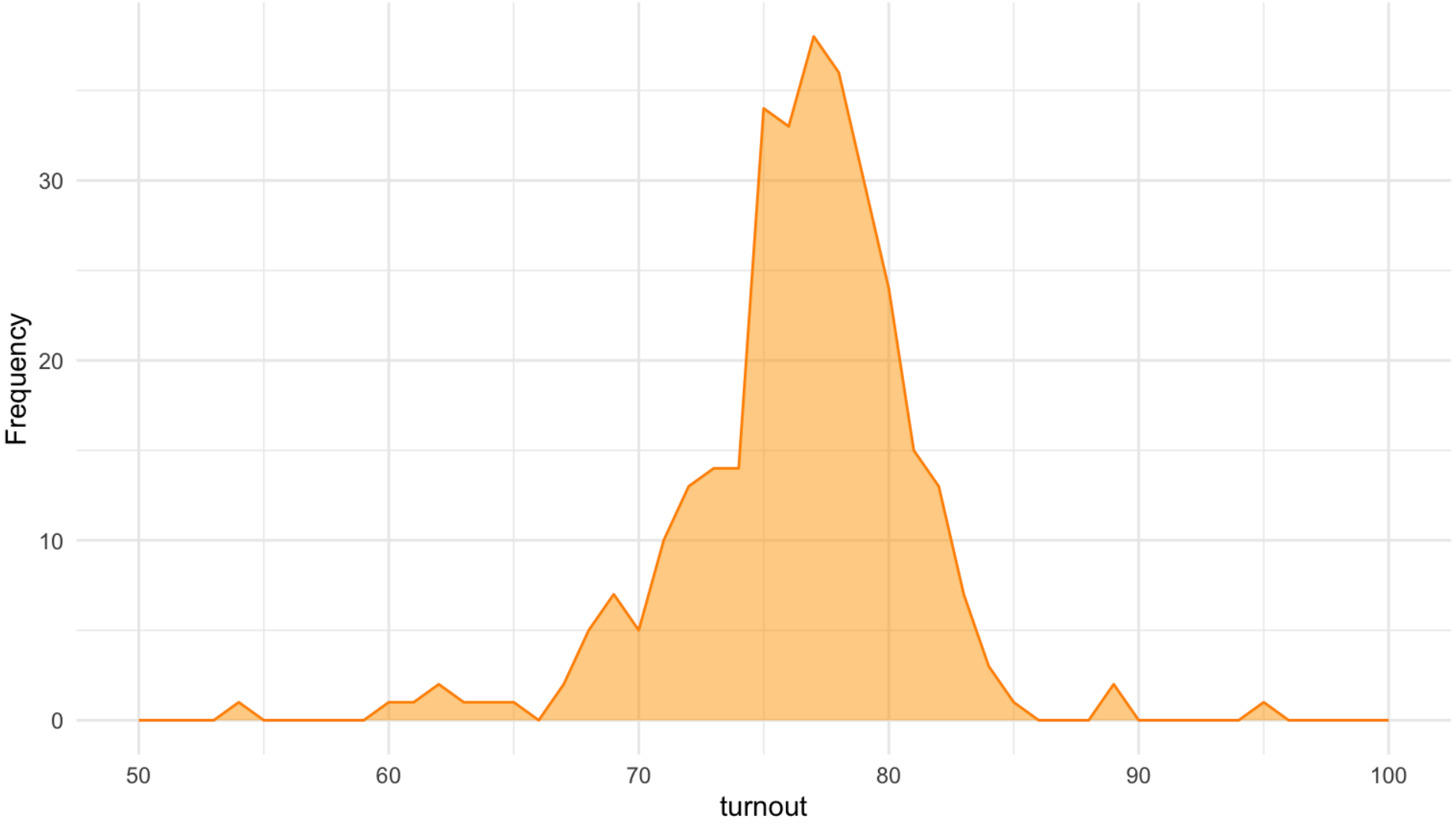
Histogram



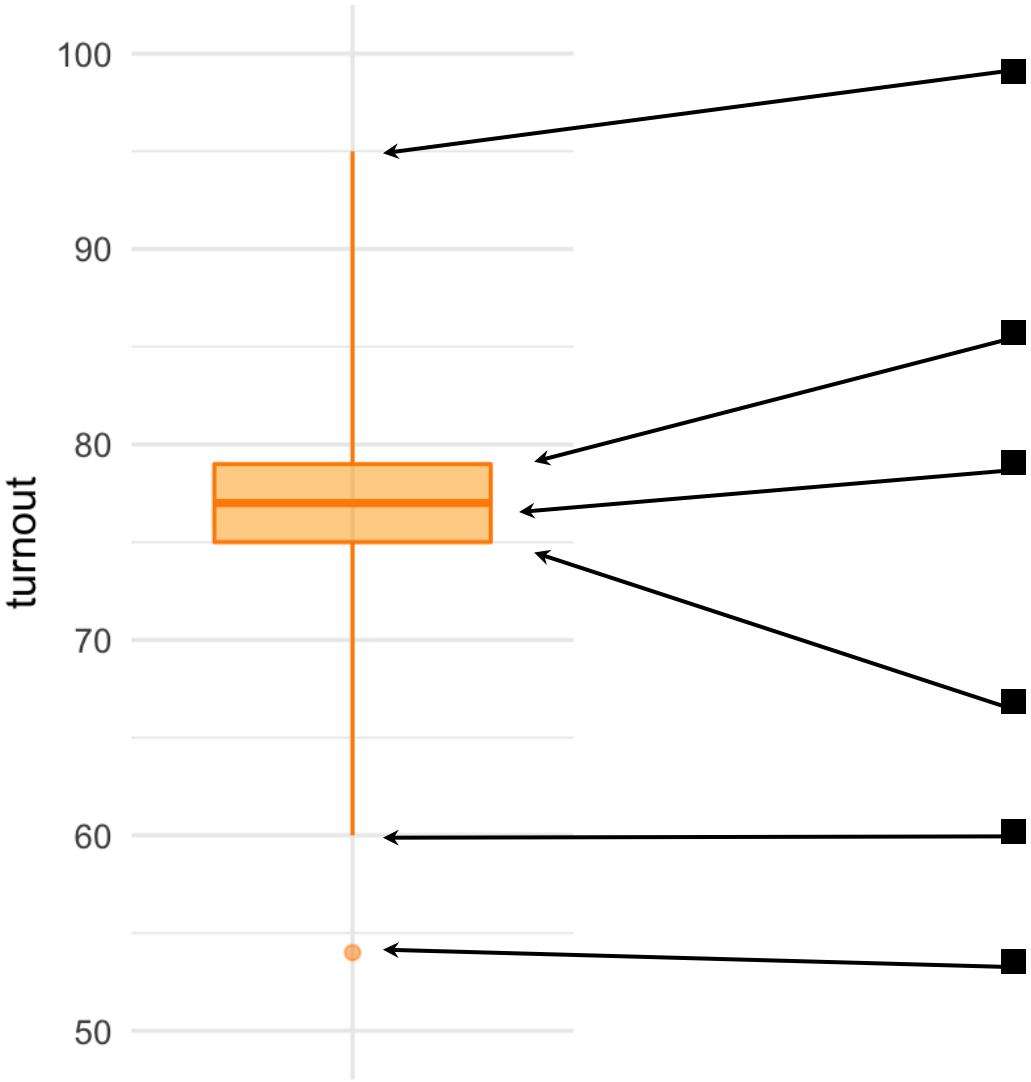
Histogram



Frequency polygon

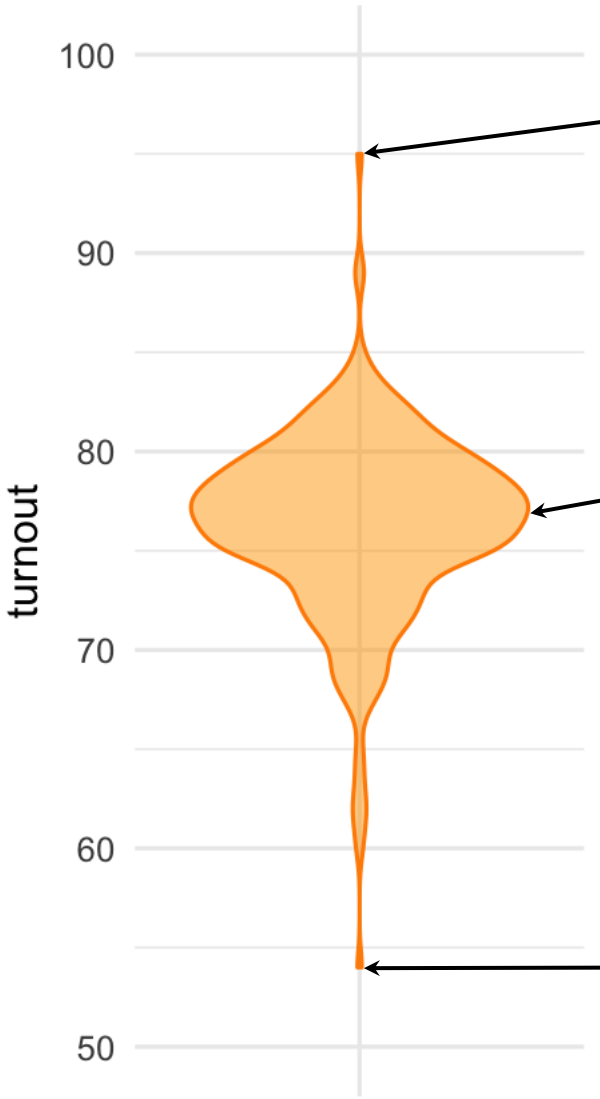


Boxplot



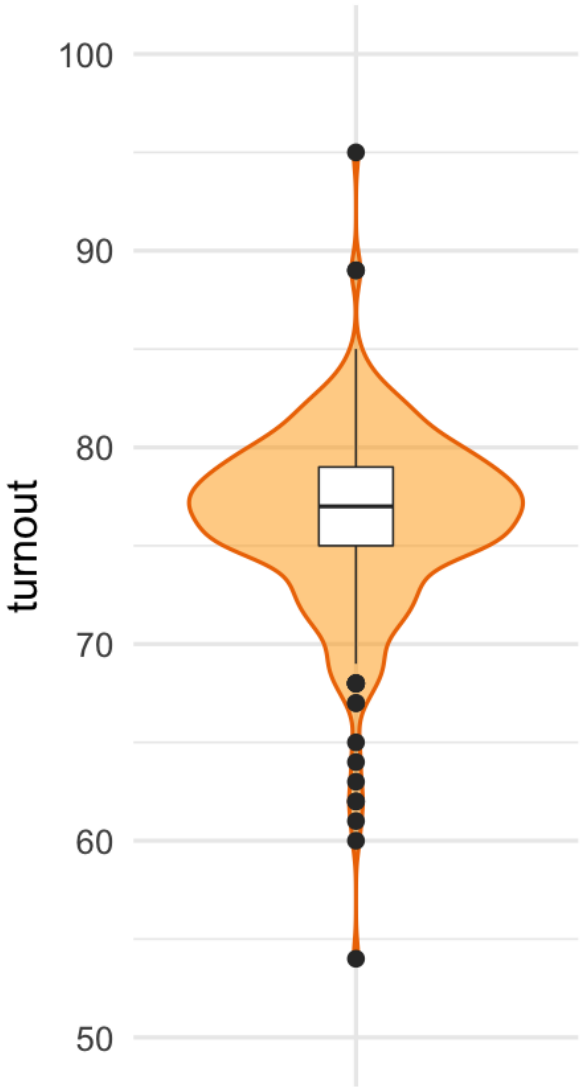
- Max value
- 3rd quartile
- Median
  - 2nd quartile
- 1st quartile
- Min value
- Outlier

Violin plot



- Max value
- Frequency polygon
  - mirrored
- Min value

Violin + Boxplot

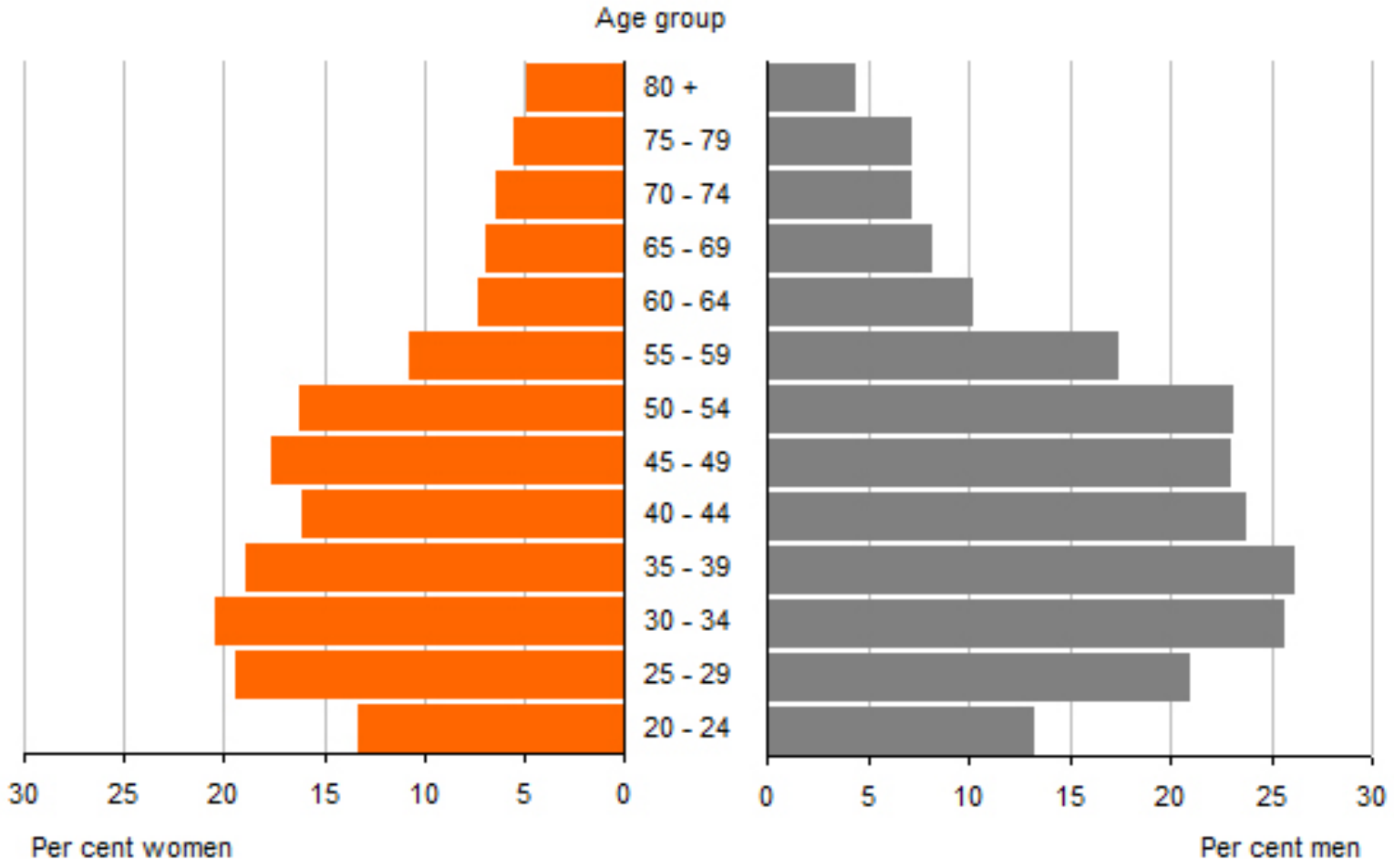


- Overlaying a box plot over the violin provides additional details

Multiple distribution

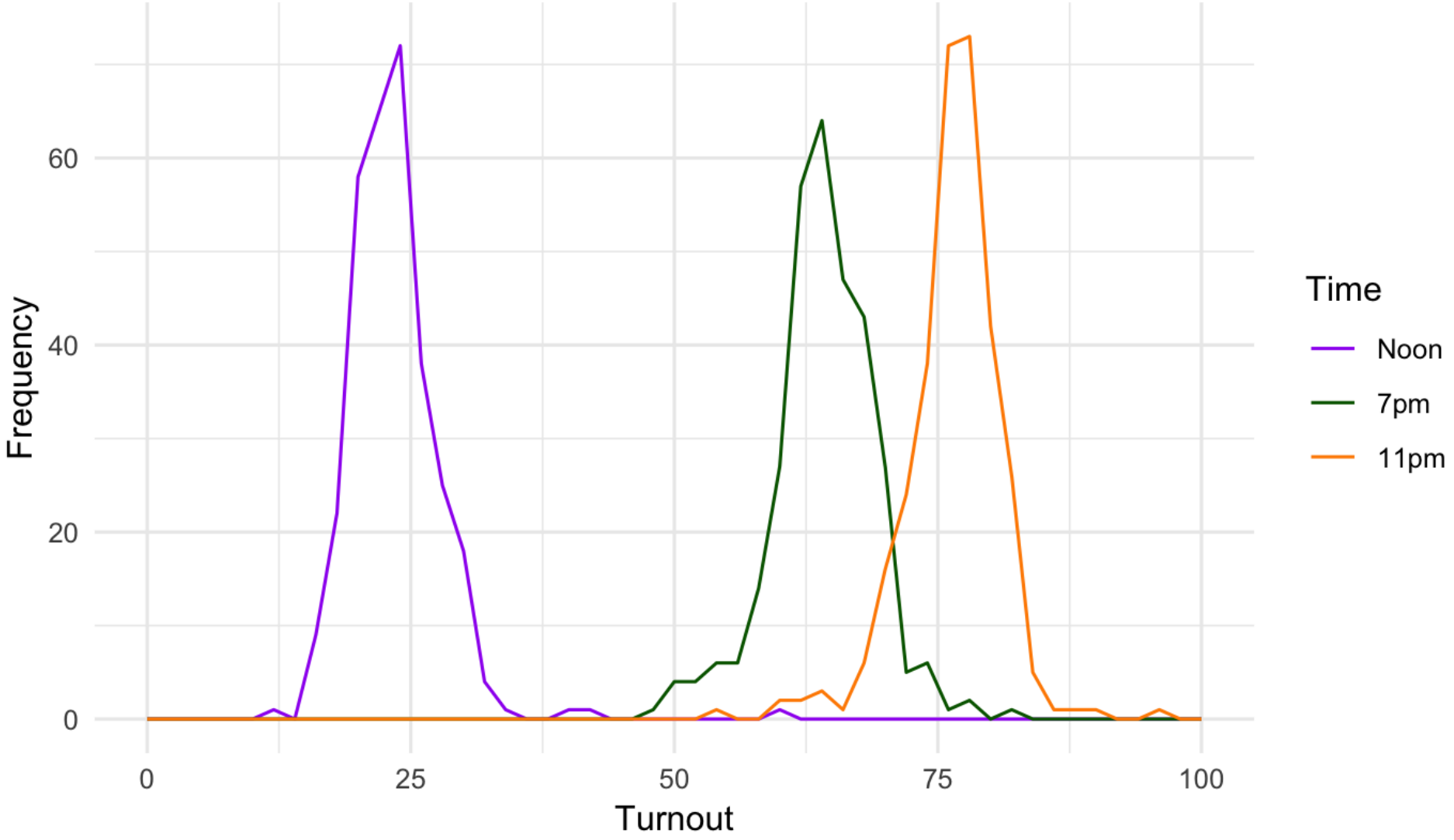
- Histogram is not suitable
- Frequency polygon
  - Line graphs
  - Frequency density function
- Boxplot
  - Summary
  - Less distracting with high number of categories

Paired diverging bargraph

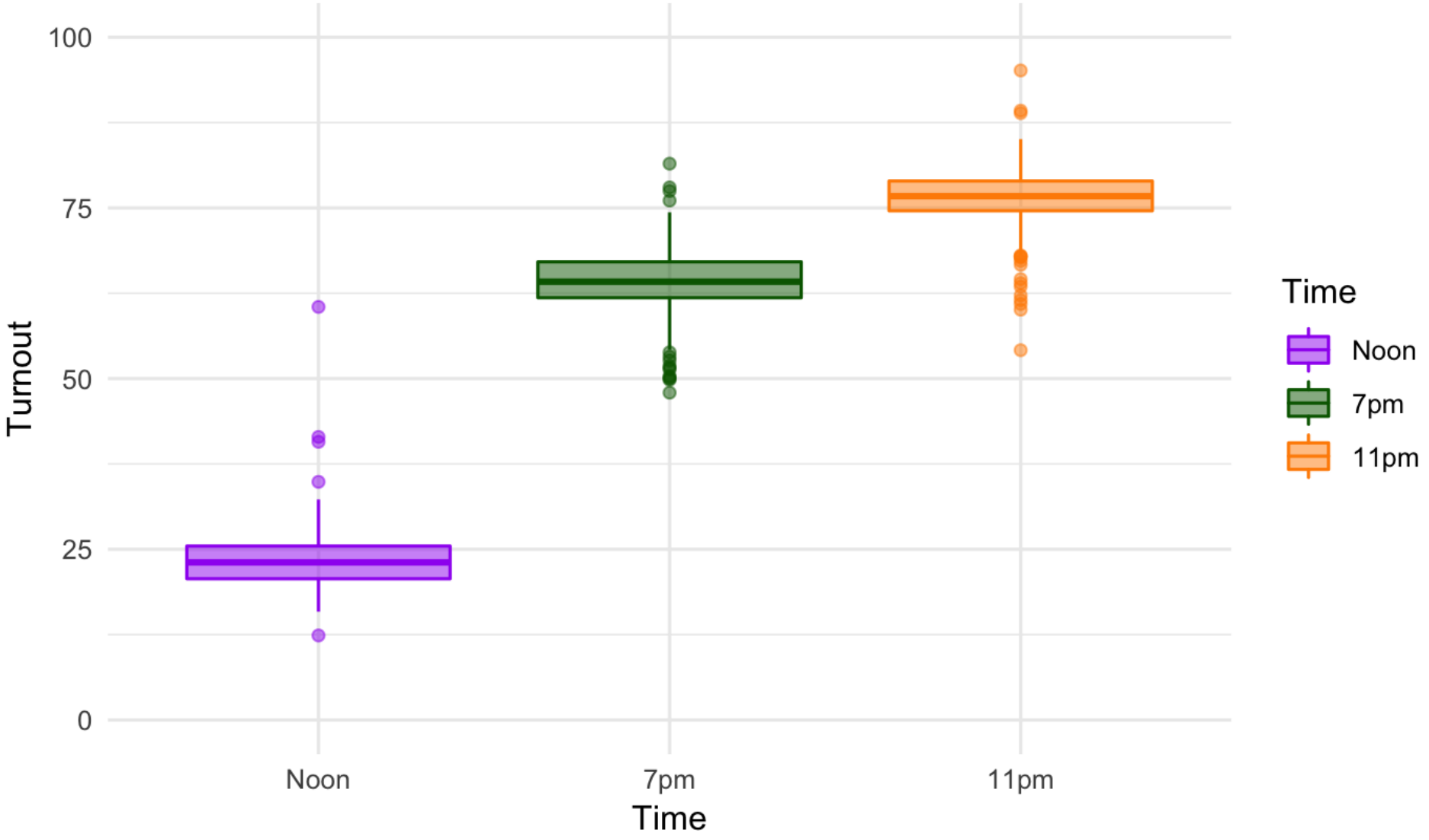


https://unstats.un.org/unsd/genderstatmanual/Print.aspx?Page=Presentation-of-gender-statistics-in-graphs

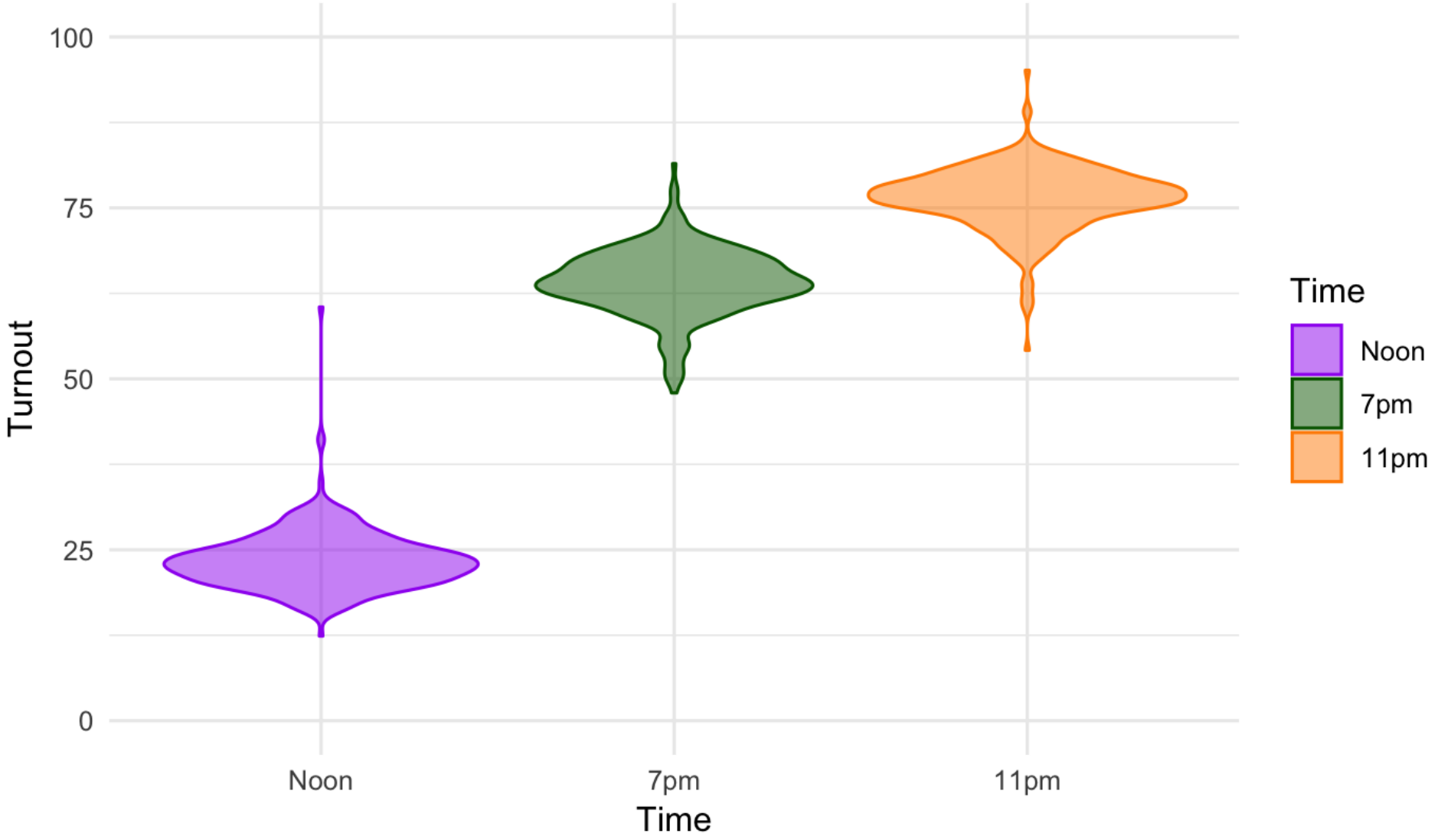
Multiple Frequency polygons



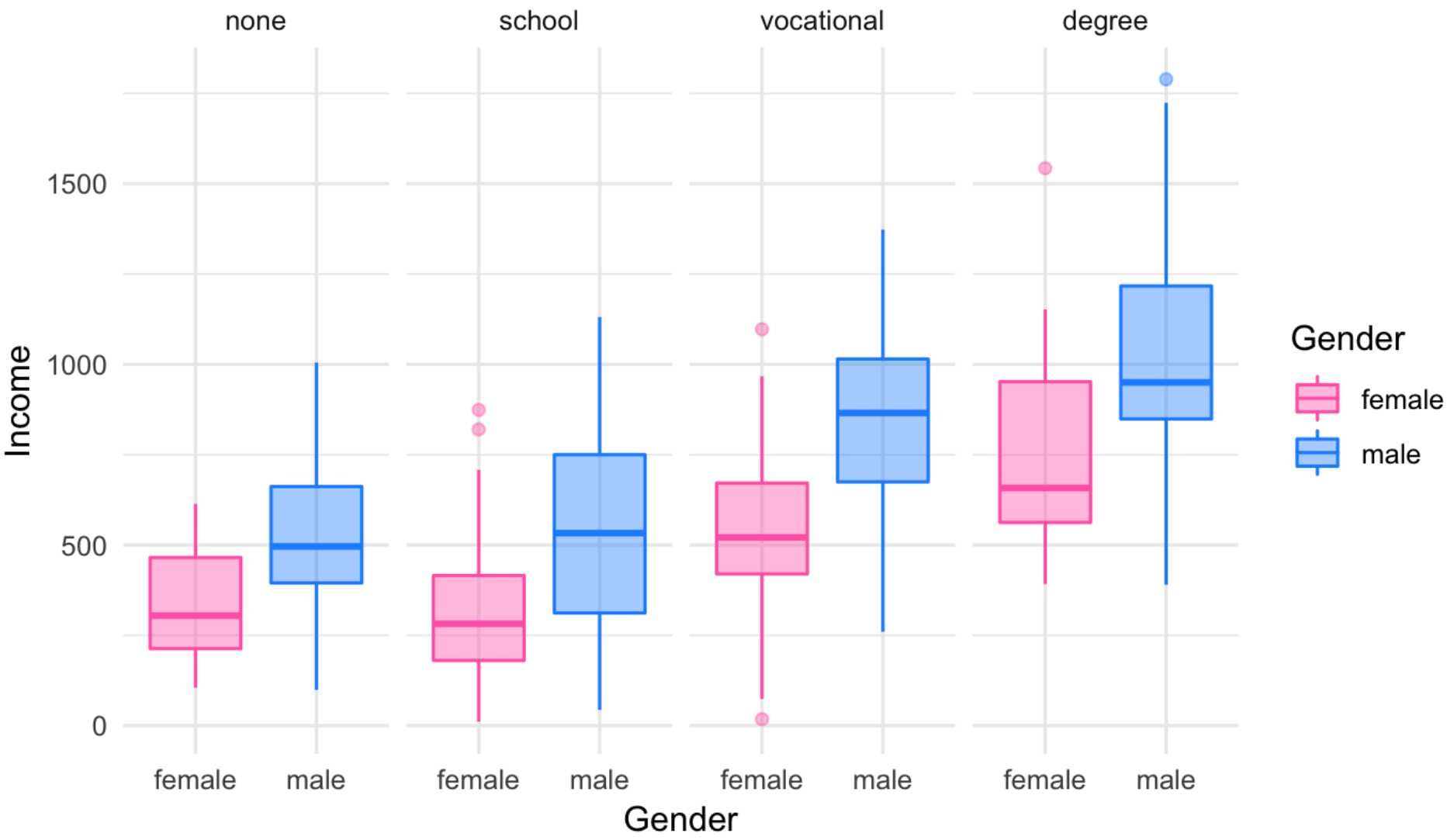
Multiple Box plot



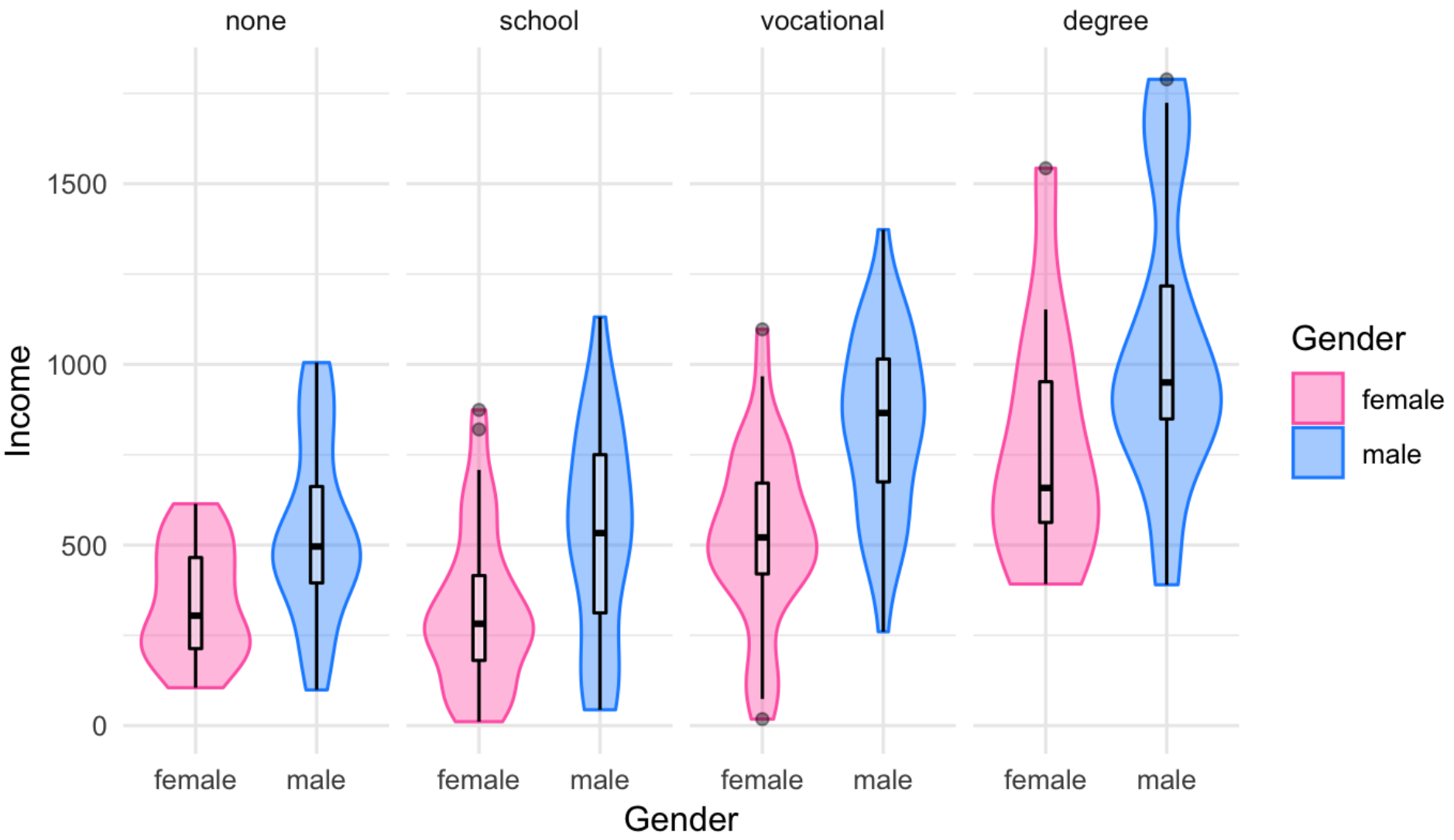
Violin plot



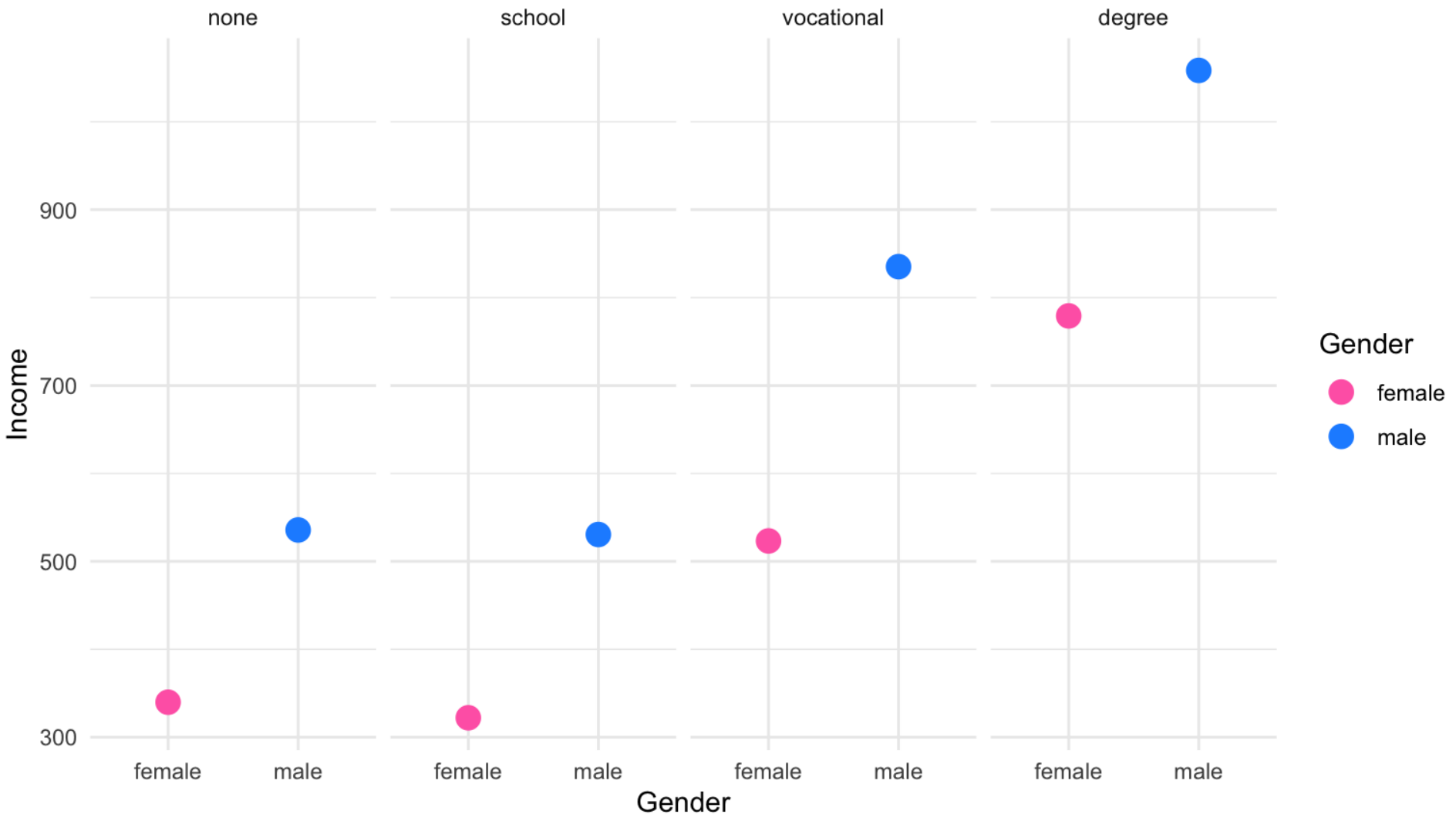
Multiple box plots



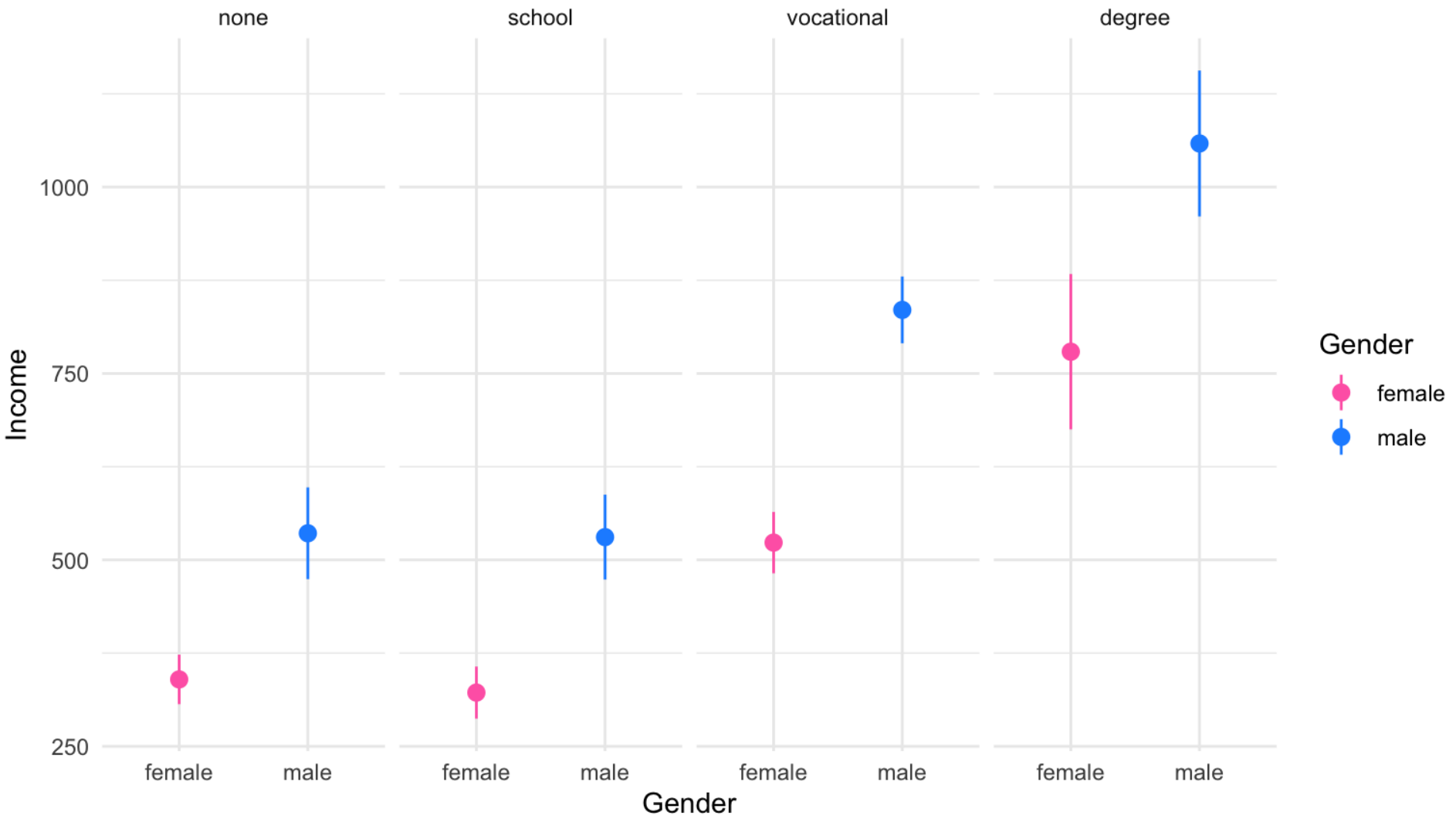
Multiple violin plots



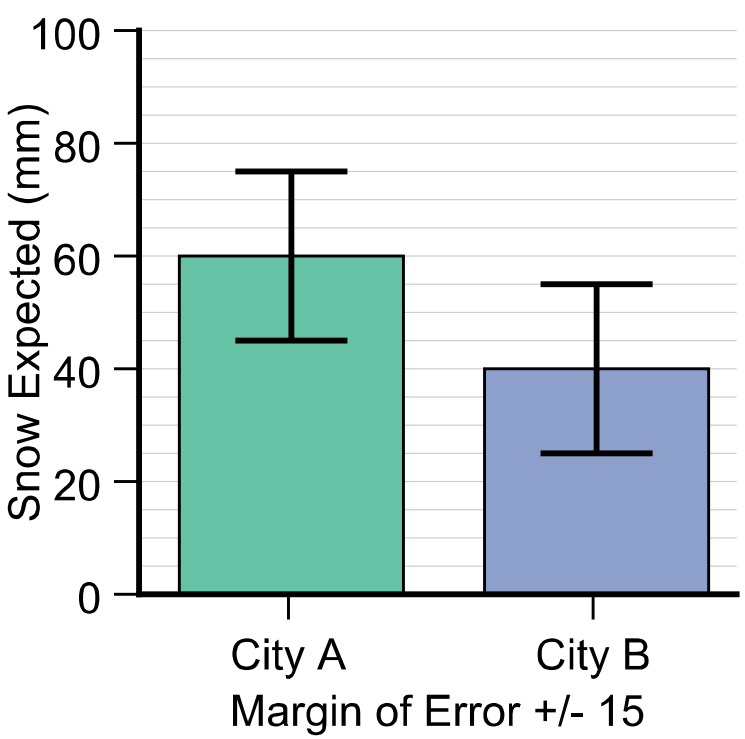
Just dots for mean values

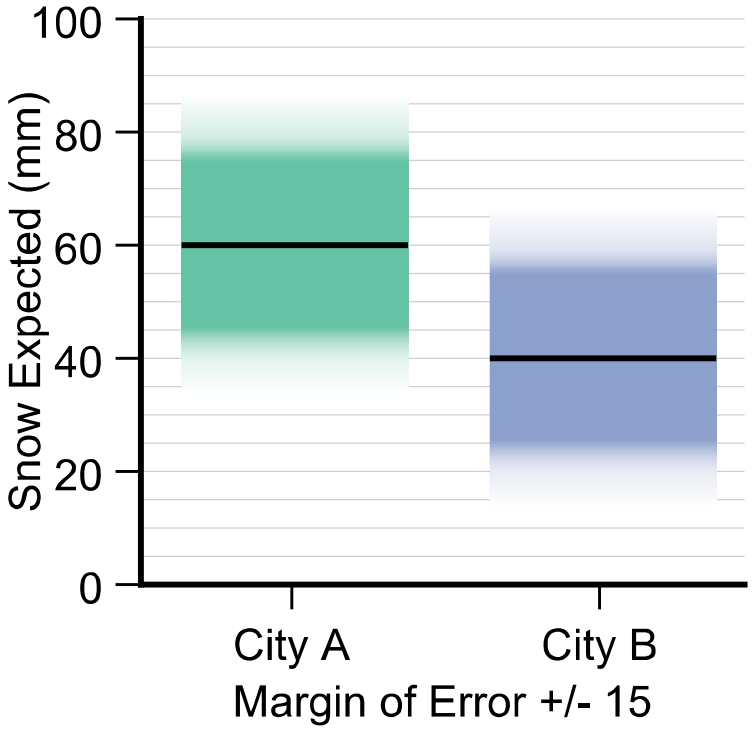


Confidence intervals



Confidence Intervals





Error Bars Considered Harmful: Exploring Alternate Encodings for Mean and Error
Michael Correll, and Michael Gleicher
IEEE Transactions on Visualization and Computer Graphics, Dec. 2014

Interval may be Asymmetric

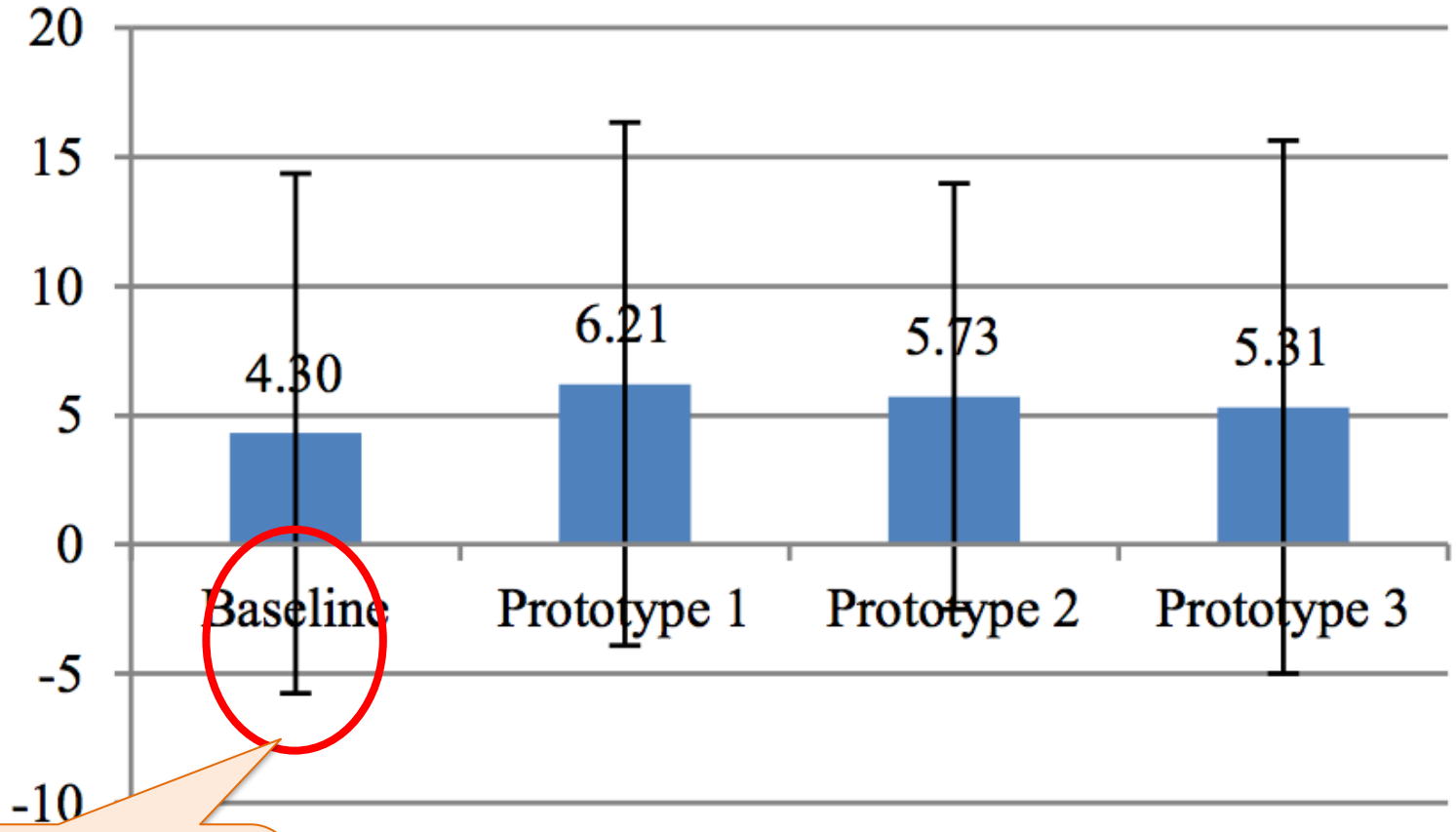


Figure 5. Mean files per changeset.

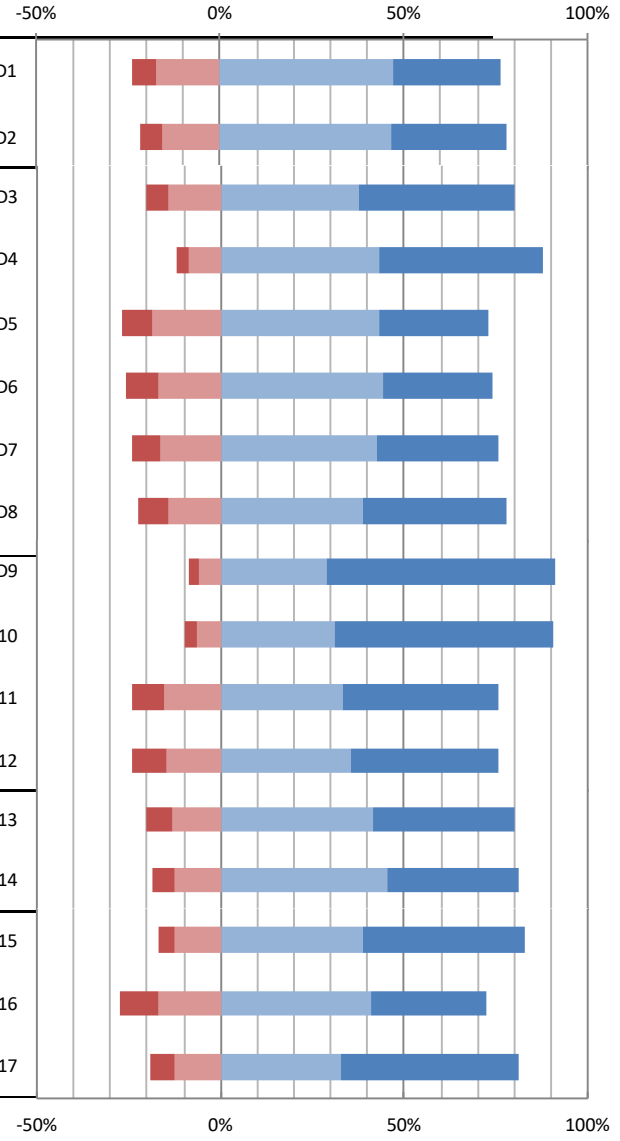
It is physically impossible to modify -6 files

Likert / Agreement

- Likert scale:
  - Measures agreement / disagreement with a given statement
  - Response on an ordinal scale, e.g.
    - Definitely No
    - Mostly No
    - Undecided
    - Mostly Yes
    - Definitely Yes
- Often used to measure positive vs. negative perception

Diverging stacked bars

Macroarea	N°	Domanda	
Organizzazione del periodo didattico	1	Il carico di studio complessivo degli insegnamenti previsti nel periodo didattico è accettabile?	D1
	2	L'orario degli insegnamenti del periodo didattico è ben organizzato?	D2
Organizzazione di questo insegnamento	3	Le regole d'esame, gli obiettivi e il programma dell'insegnamento sono stati resi noti in modo chiaro?	D3
	4	L'insegnamento è stato svolto in maniera coerente con quanto dichiarato sul portale della didattica?	D4
	5	Le conoscenze preliminari da me possedute sono risultate sufficienti per la comprensione della materia ?	D5
	6	Il carico di studio richiesto da questo insegnamento è proporzionato ai crediti assegnati?	D6
	7	Il materiale didattico, indicato o fornito, è adeguato per lo studio della materia?	D7
	8	Le attività didattiche integrative (esercitazioni, lab, seminari, visite, ecc.) sono utili per l'apprendimento della materia?	D8
Efficacia del docente	9	Il docente rispetta gli orari di svolgimento dell'attività didattica?	D9
	10	Il docente è disponibile a fornire chiarimenti e spiegazioni?	D10
	11	Il docente interagisce efficacemente con gli studenti, stimolando l'interesse verso la materia?	D11
	12	Il docente espone gli argomenti in modo chiaro?	D12
Infrastrutture	13	Le aule in cui si svolgono le lezioni sono adeguate?	D13
	14	I locali e le attrezzature per le attività didattiche integrative sono adeguati?	D14
Interesse e soddisfazione	15	Sono interessato agli argomenti di questo insegnamento? (indipendentemente da come è stato svolto)	D15
	16	Sono soddisfatto di come è stato svolto questo insegnamento?	D16
	17	Al fine dell apprendimento, la frequenza alle attività didattiche è utile?	D17

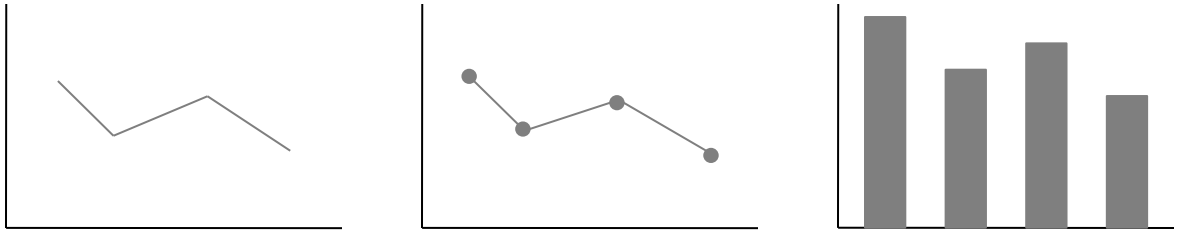


Time series

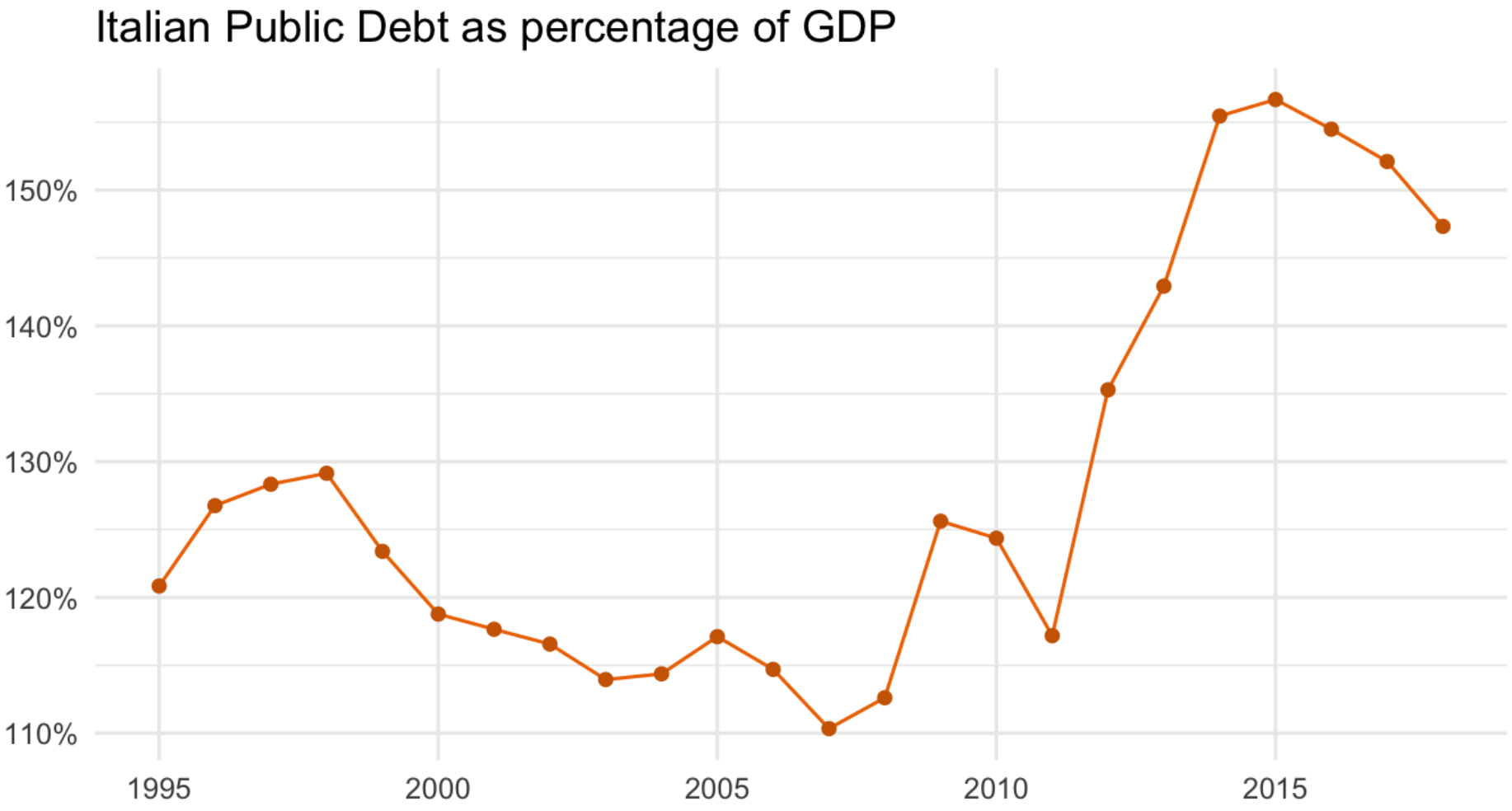
- Series of relationships between quantitative values that are associated with categorical subdivisions of time
- Communicate
  - Change
  - Rise
  - Increase
  - Fluctuate
  - Grow
  - Decline
  - Decrease
  - Trend

Time series

- Time grows from left to right
  - Cultural convention
- Vertical bars
  - highlight individual points in time
  - hide overall trend

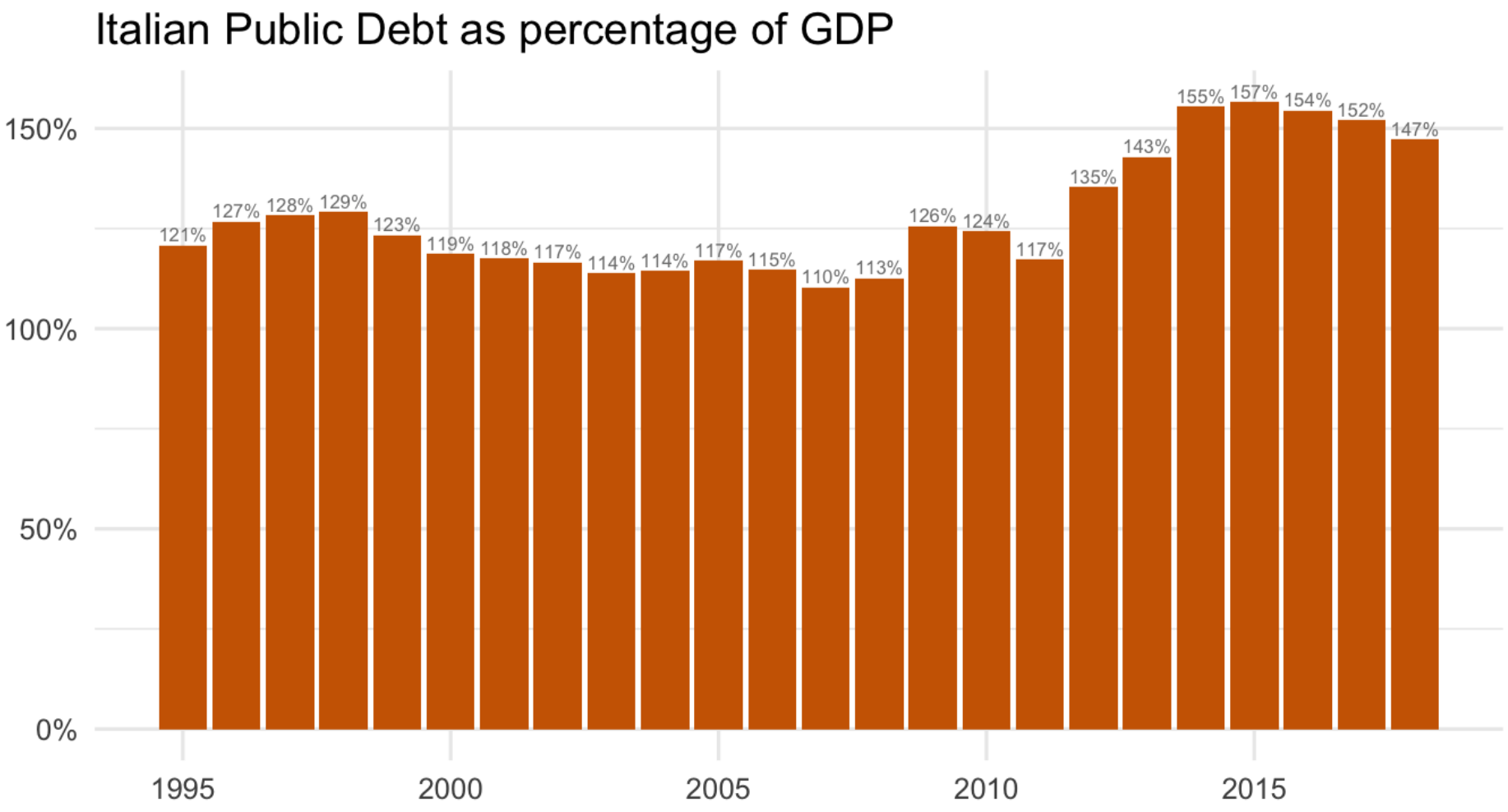


Line plot



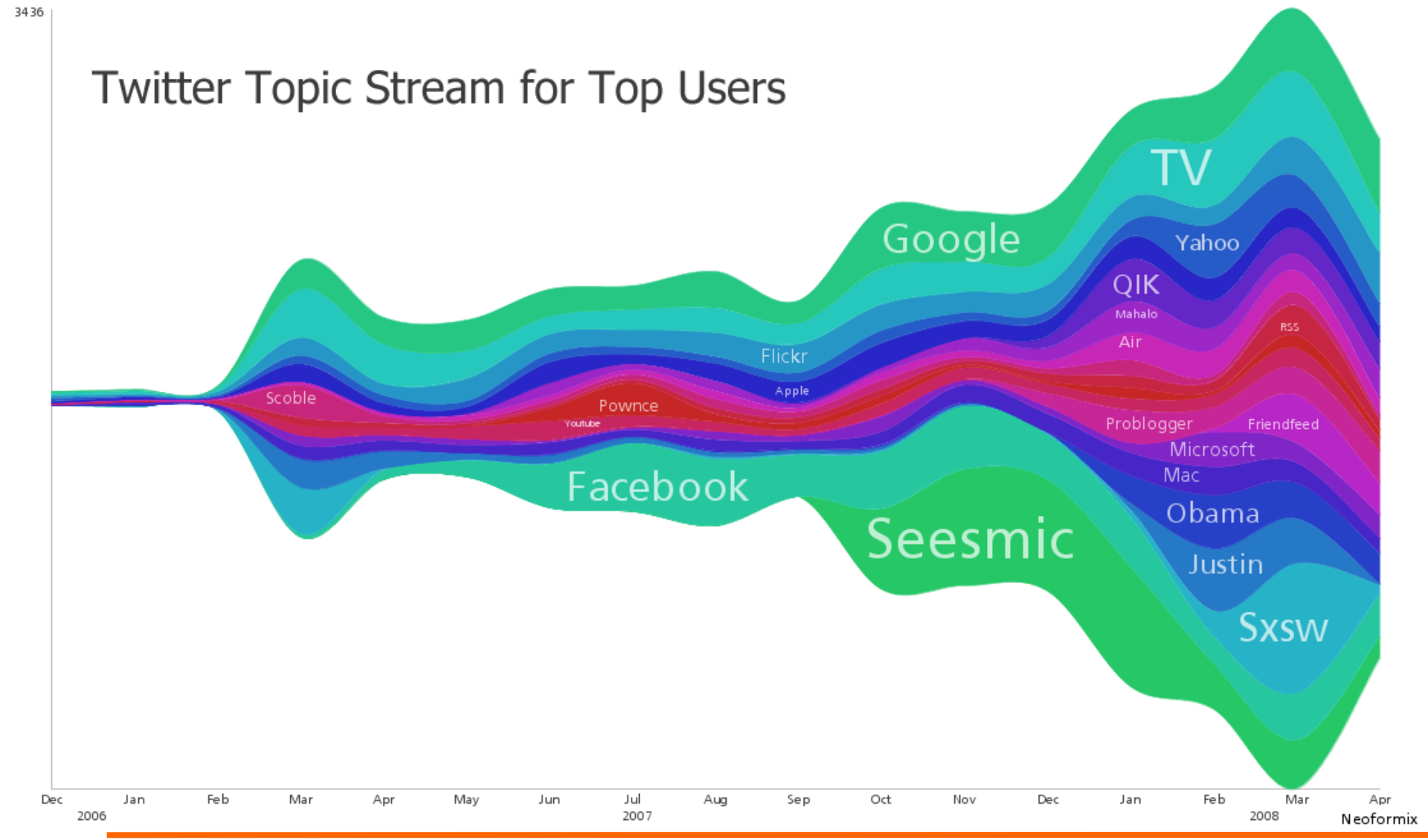
Source: OECD - https://data.oecd.org/chart/5M2J

Bars



Source: OECD - https://data.oecd.org/chart/5M2J

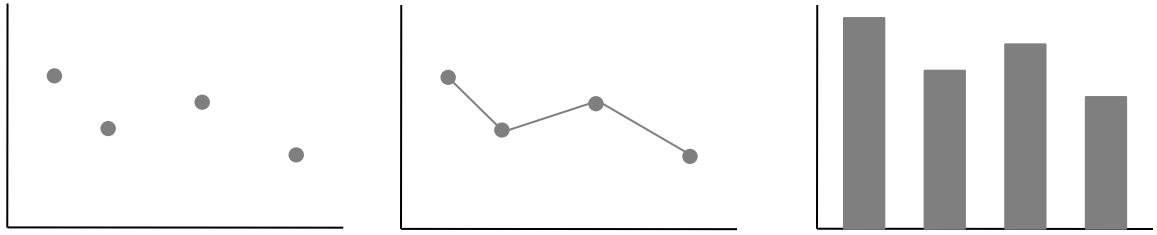
Streamgraph



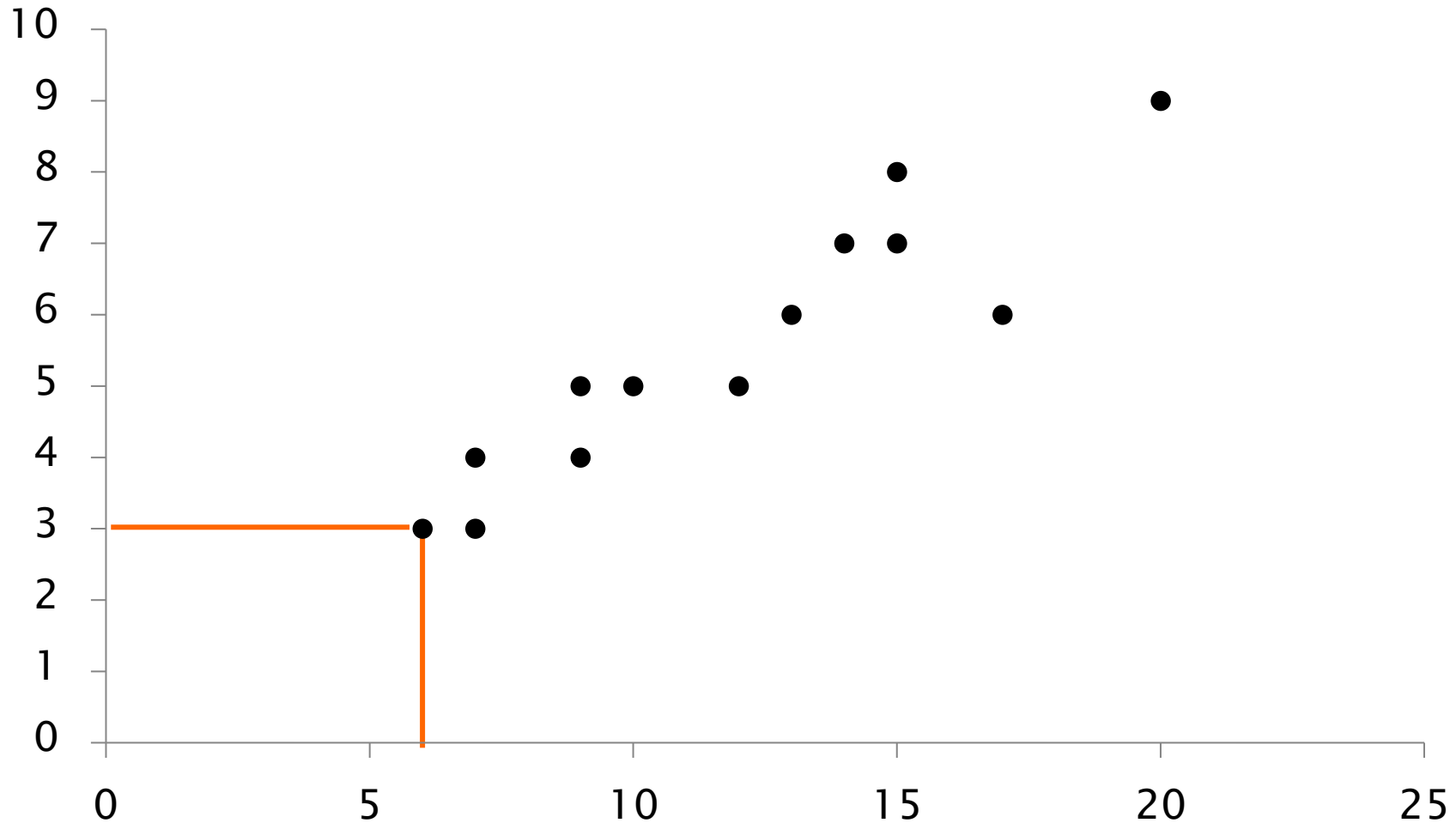
http://www.neoformix.com/2008/TwitterTopicStream.html

Correlation

- Relationships between two paired sets of quantitative values
  - Scatter plot w/possible trend line
    - Ok for educated audience
  - Paired bar graph



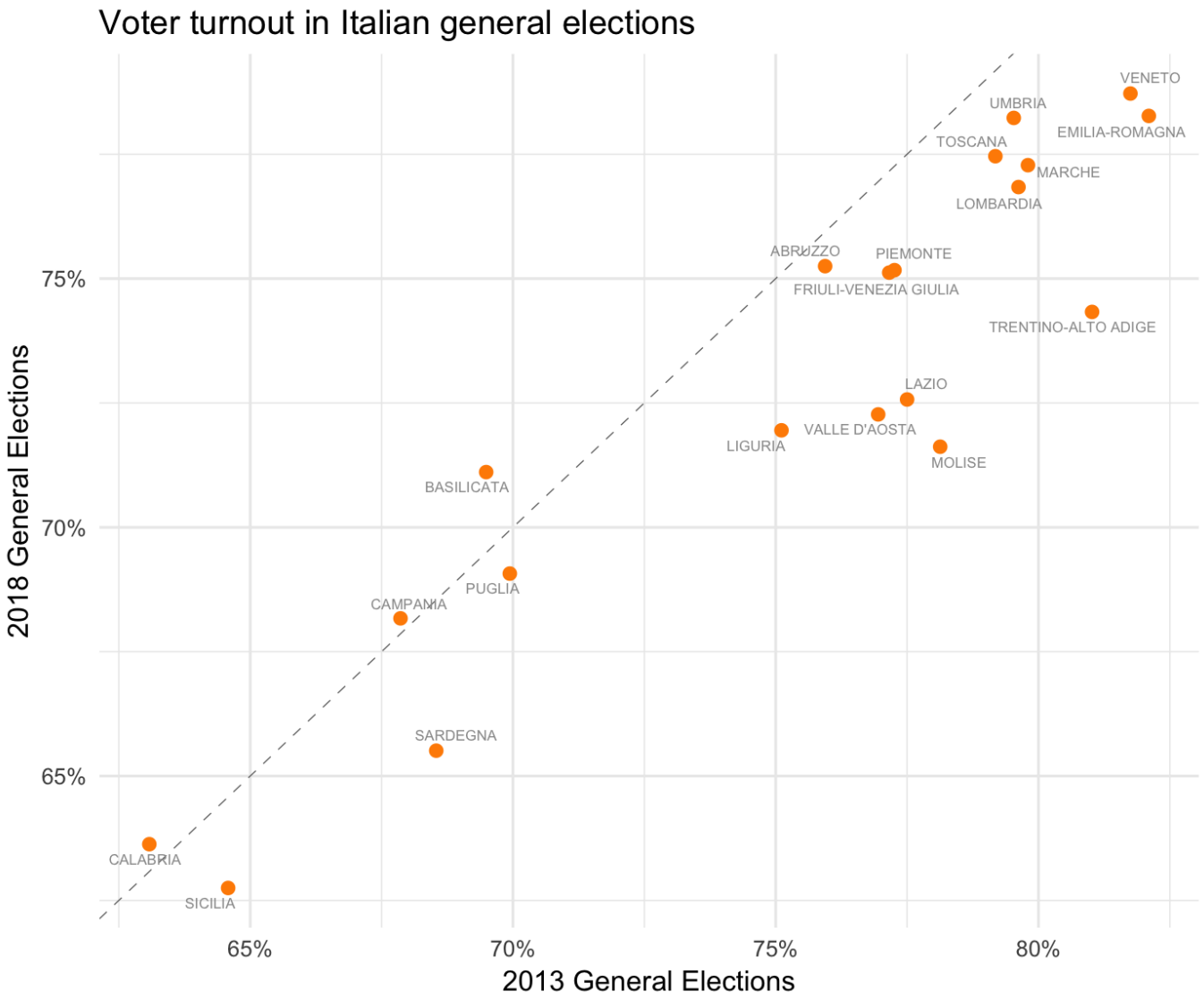
Points



Points Guidelines

- Points must be clearly distinguished
  - Enlarge points
  - Select radically distinct shapes (✚ ○)
  - Balance size of points and graph
  - Use outlined shapes
- Lines must not obscure points

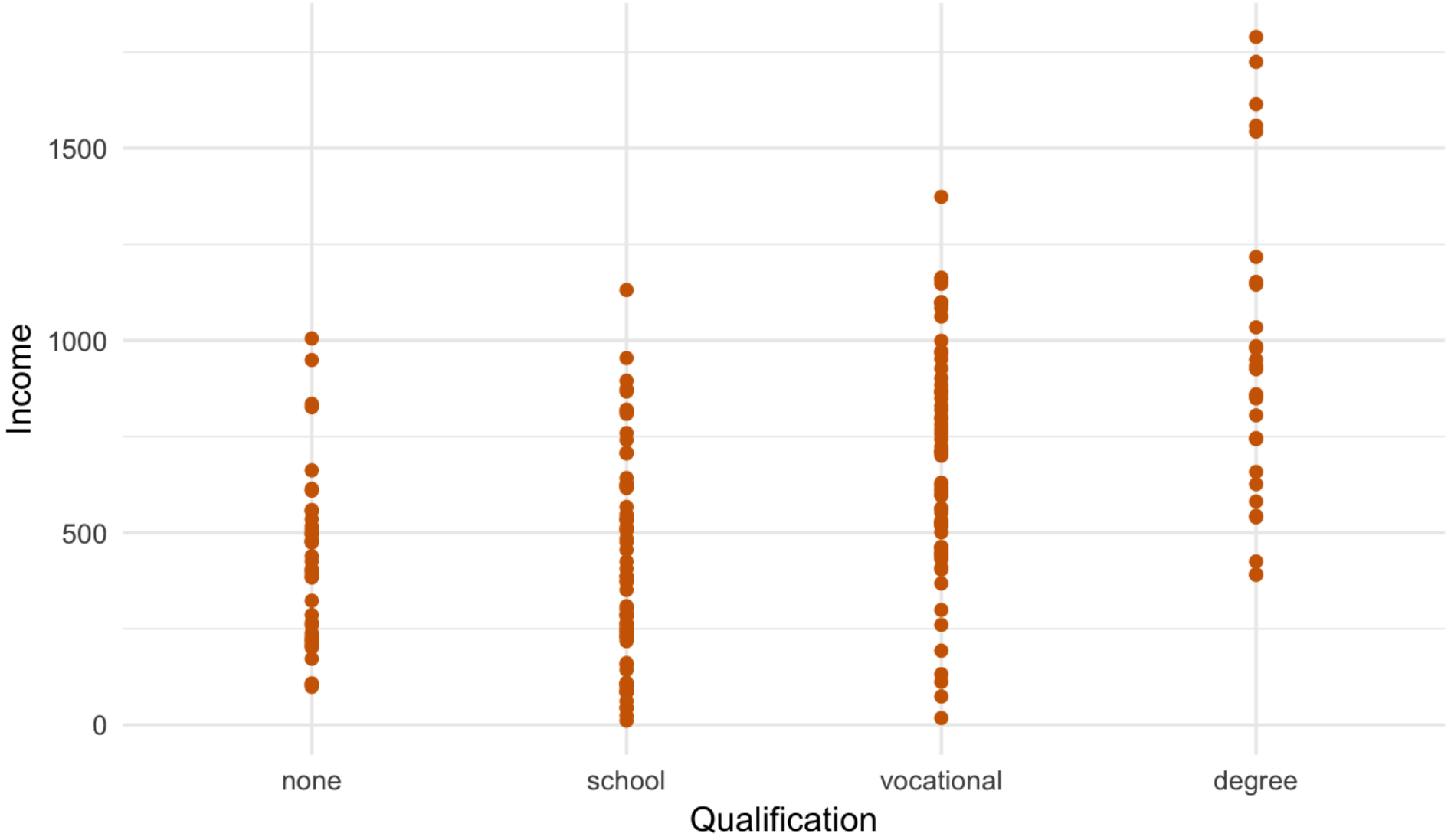
Scatter plot



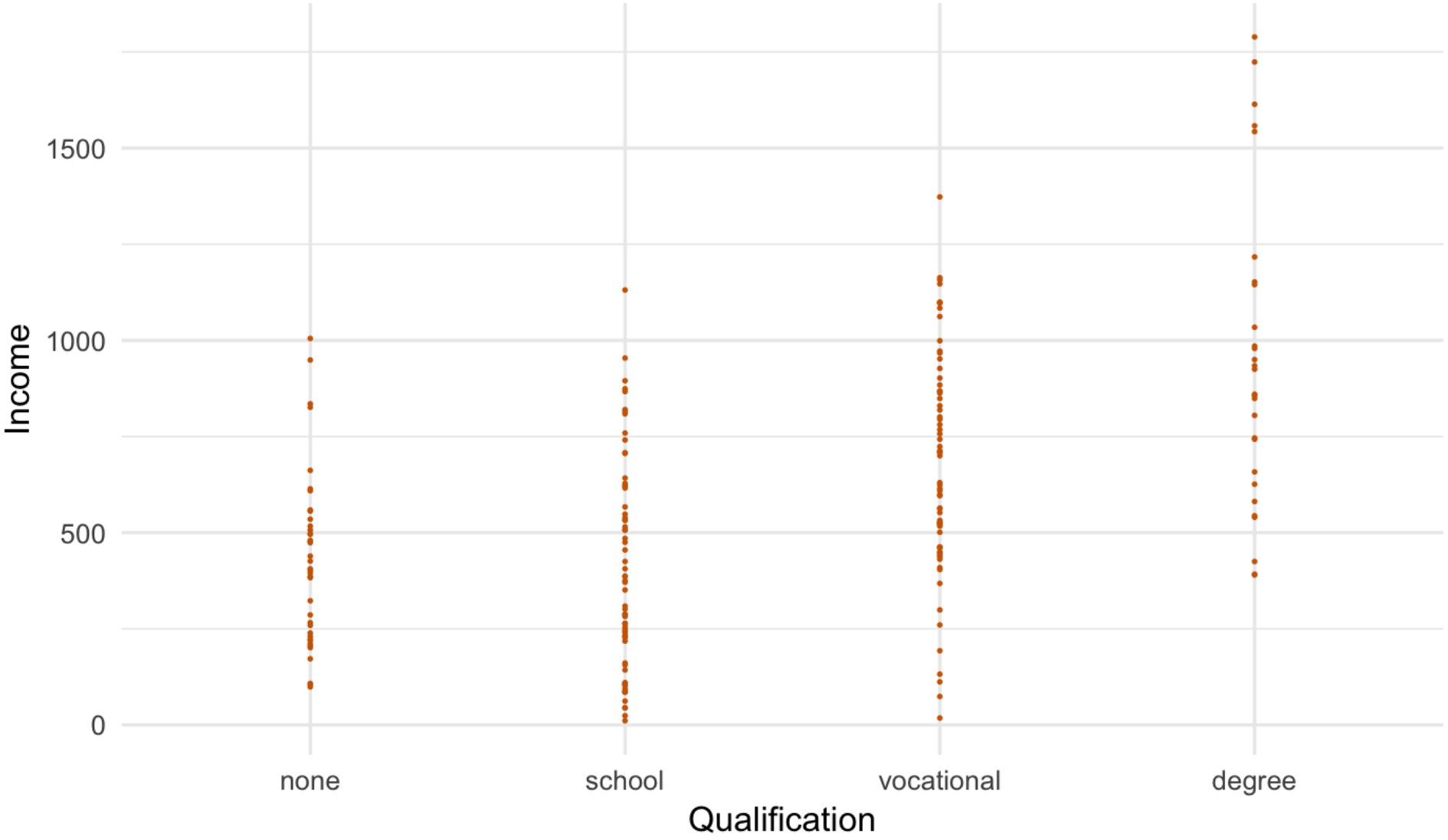
Overplotting

- Phenomenon related to multiple points (or shapes) overlapping
  - Discrete (integer) measure
  - Very large dataset
- Solutions
  - Small shapes
  - Outlined shapes
  - Transparent shapes (alpha)
  - Jittering

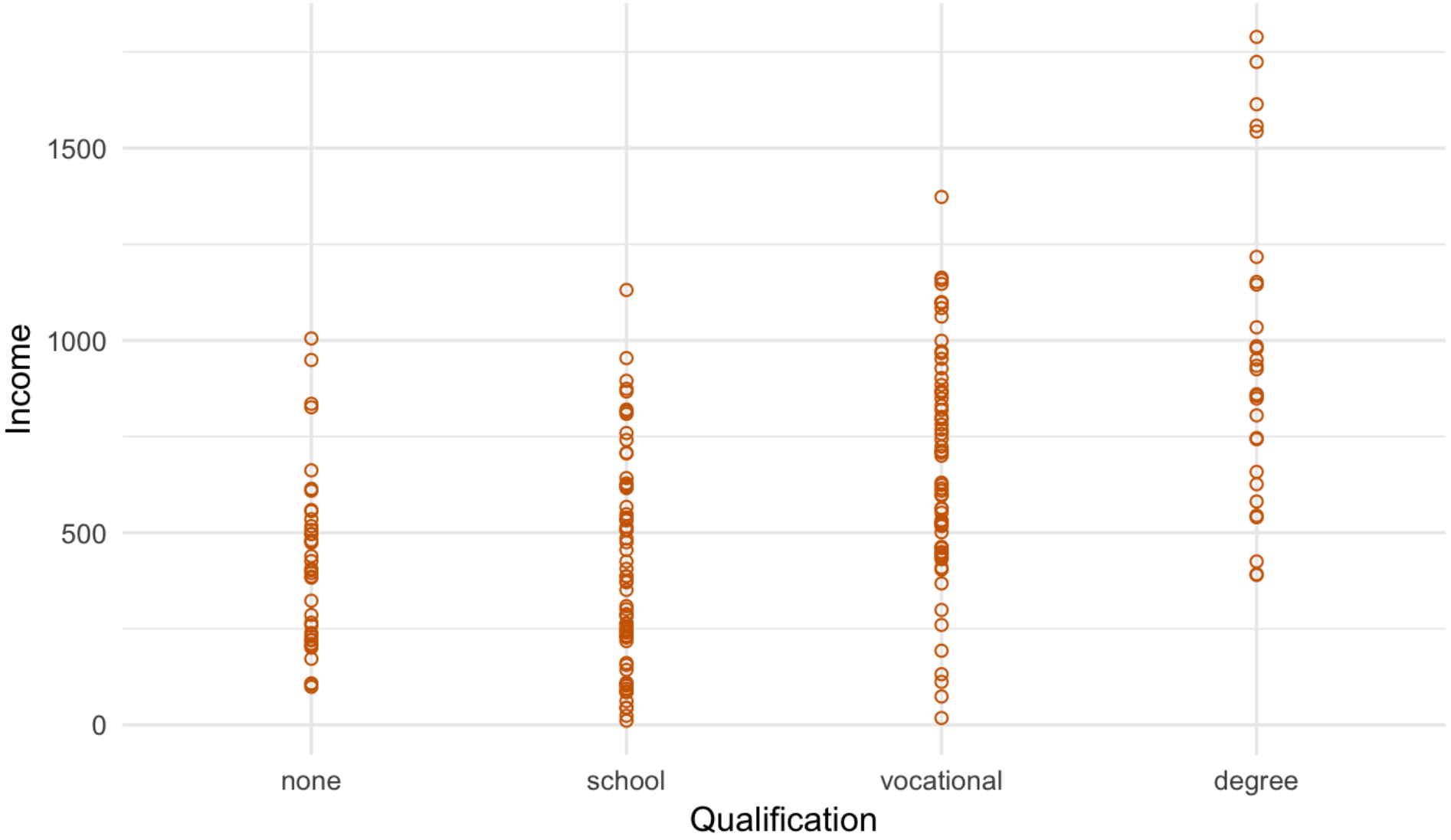
Overplotting example



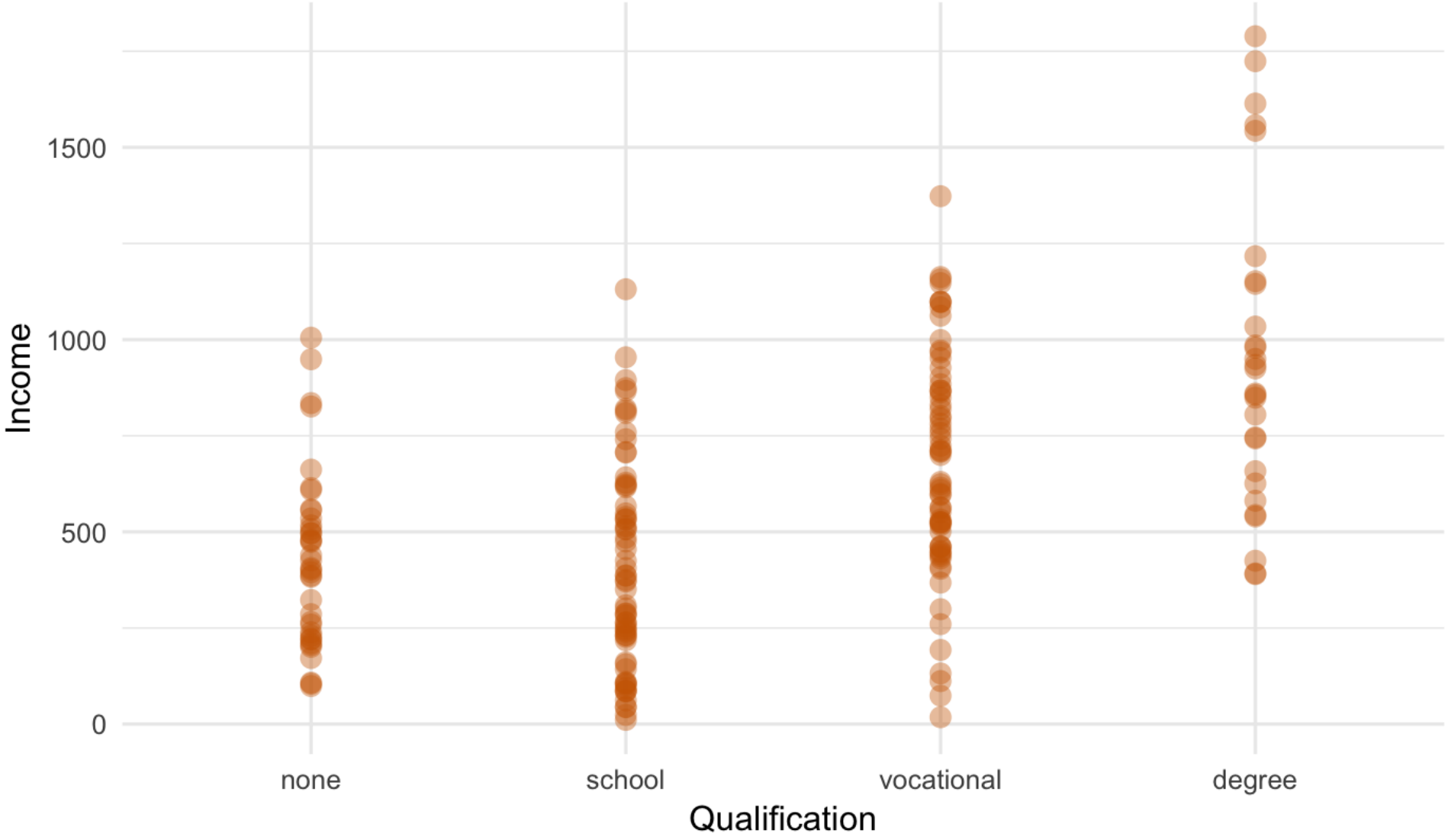
Overplotting – Small



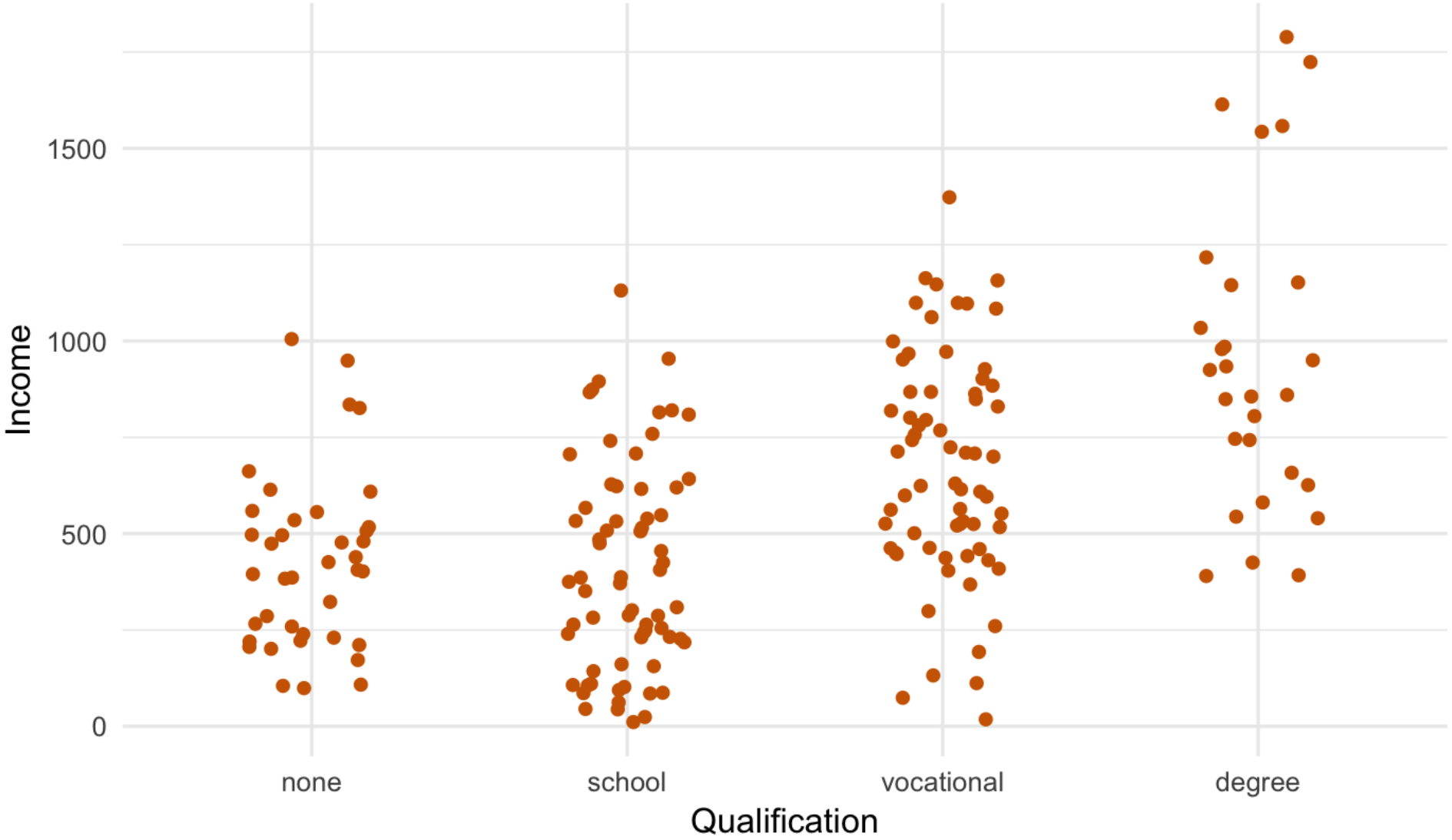
Overplotting – Outlined



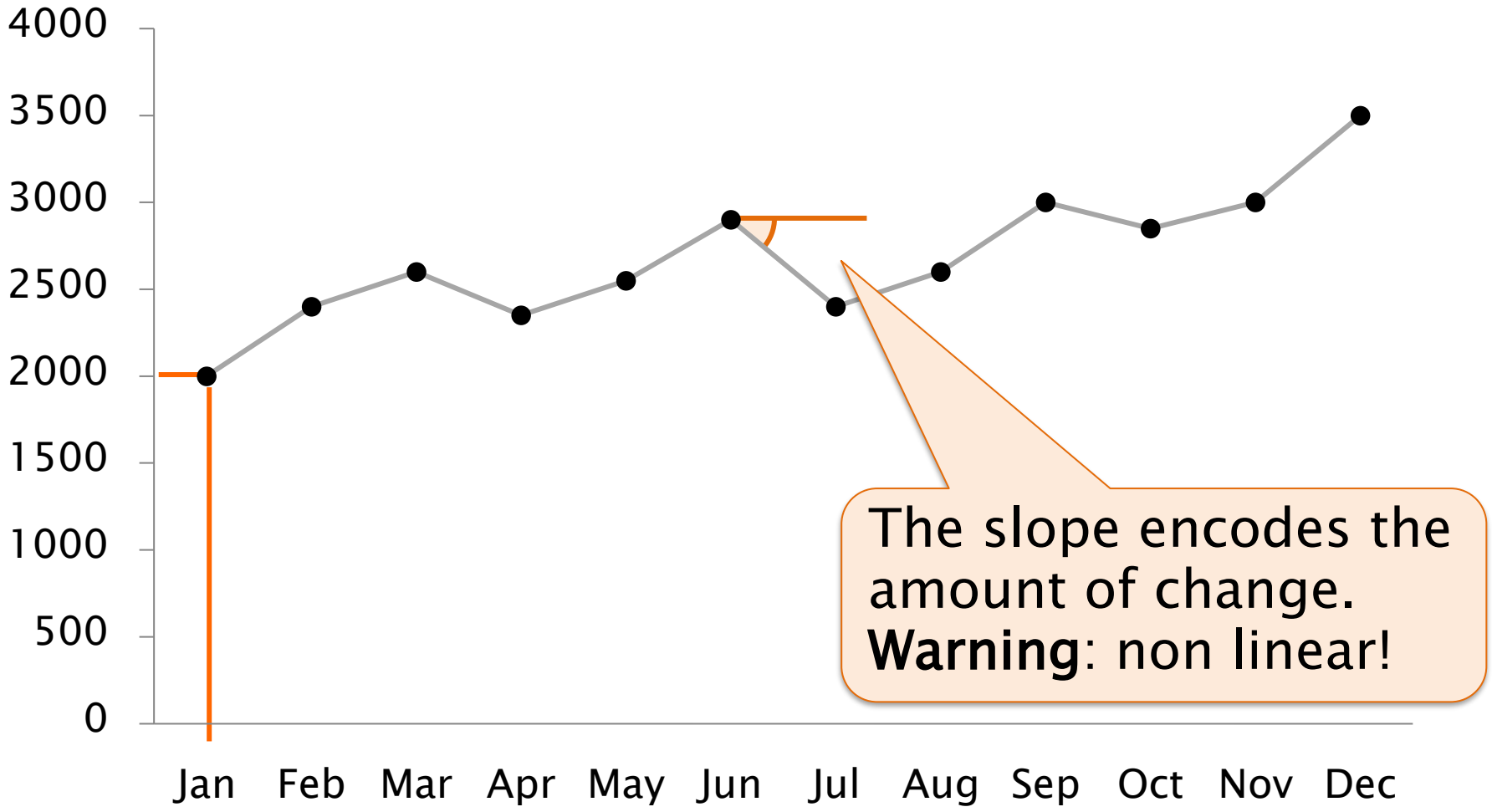
Overplotting – Transparent



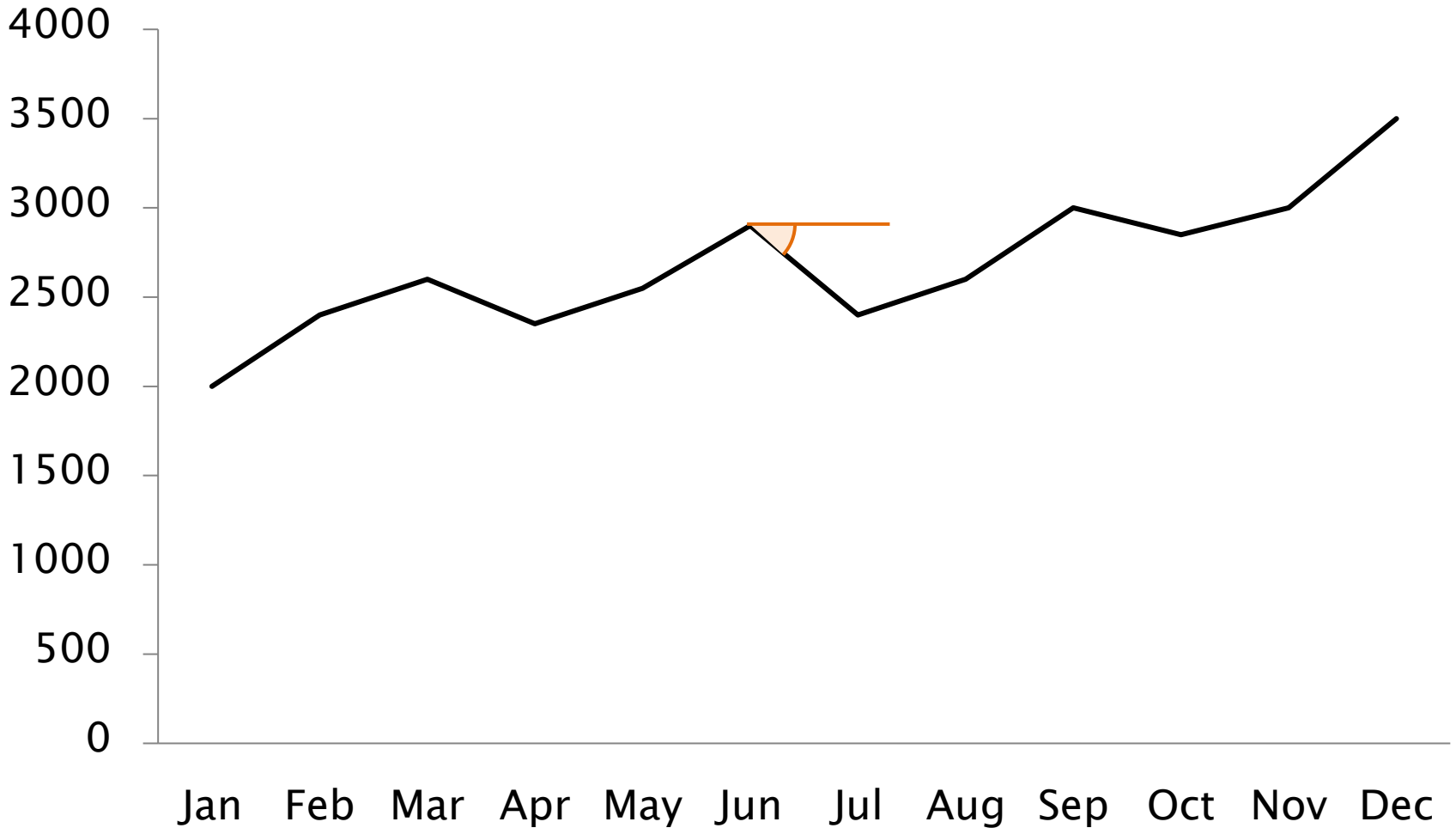
Overplotting – Jittering



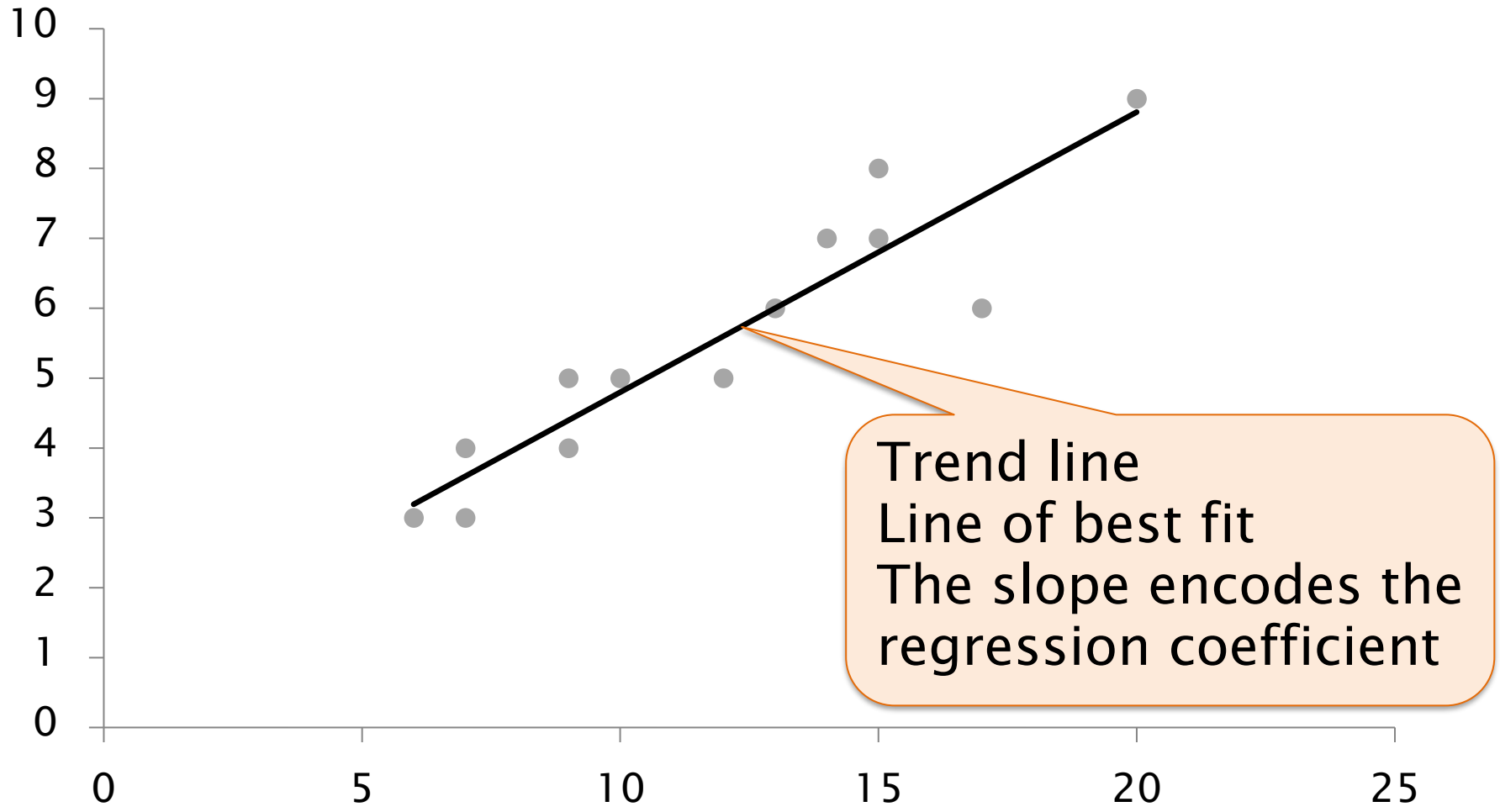
Points and Lines



Slope of lines



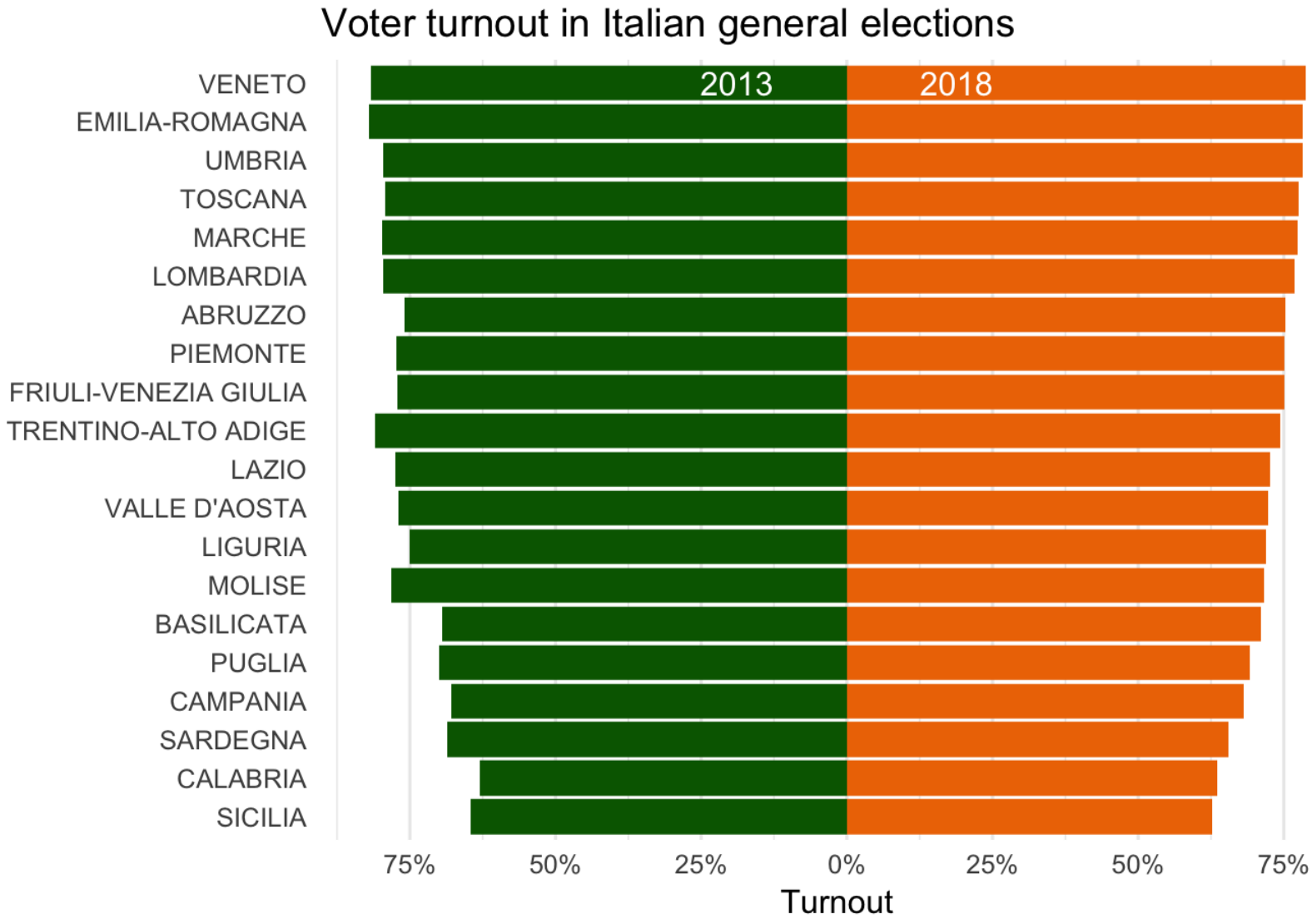
Slope of lines



Lines

- Easy perception of trends and overall shape of data
- Best suited for time series
- Variation encoded as slope
  - Clear direction
  - Approximate magnitude

Paired diverging bars

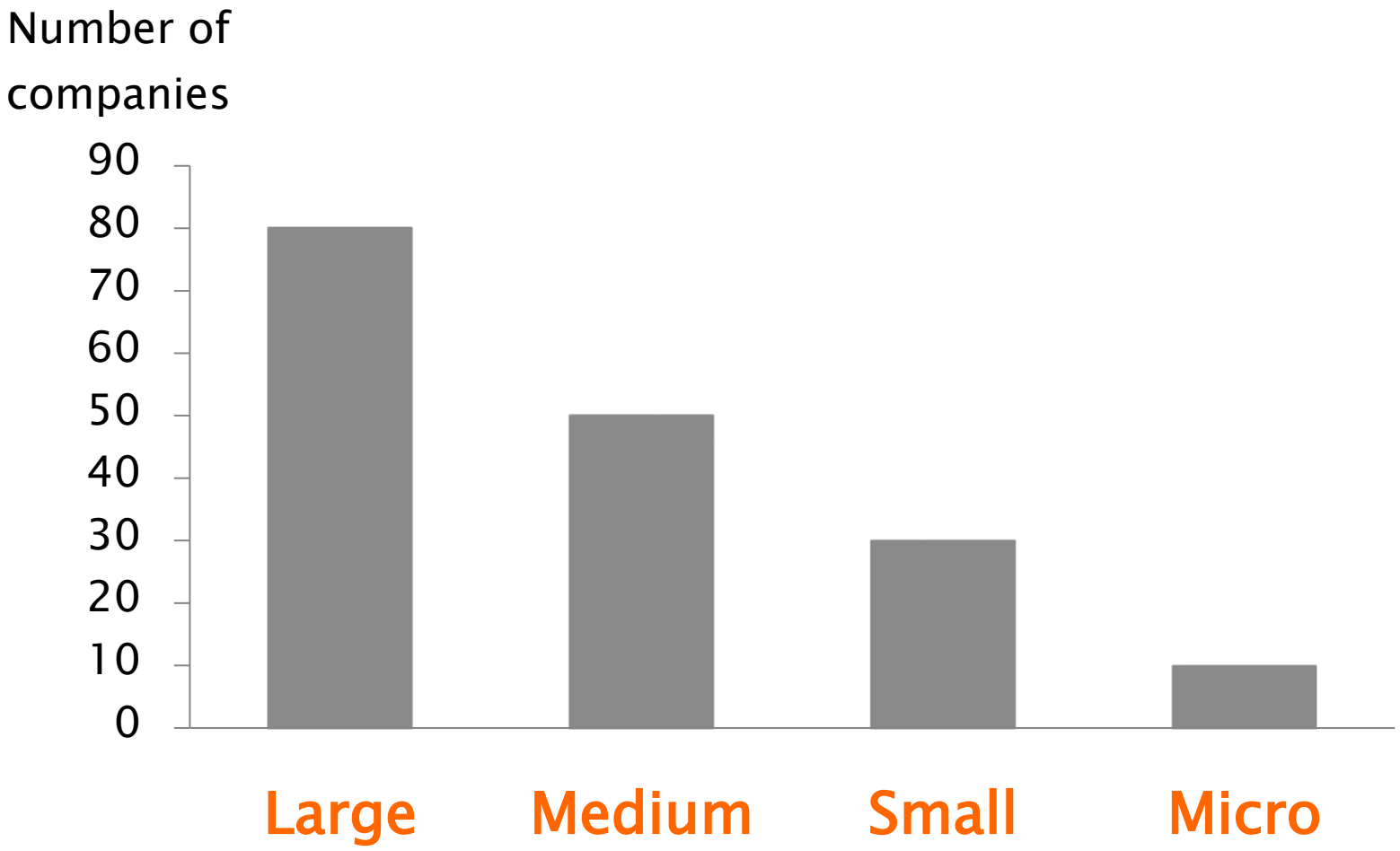


Categorical encoding attributes

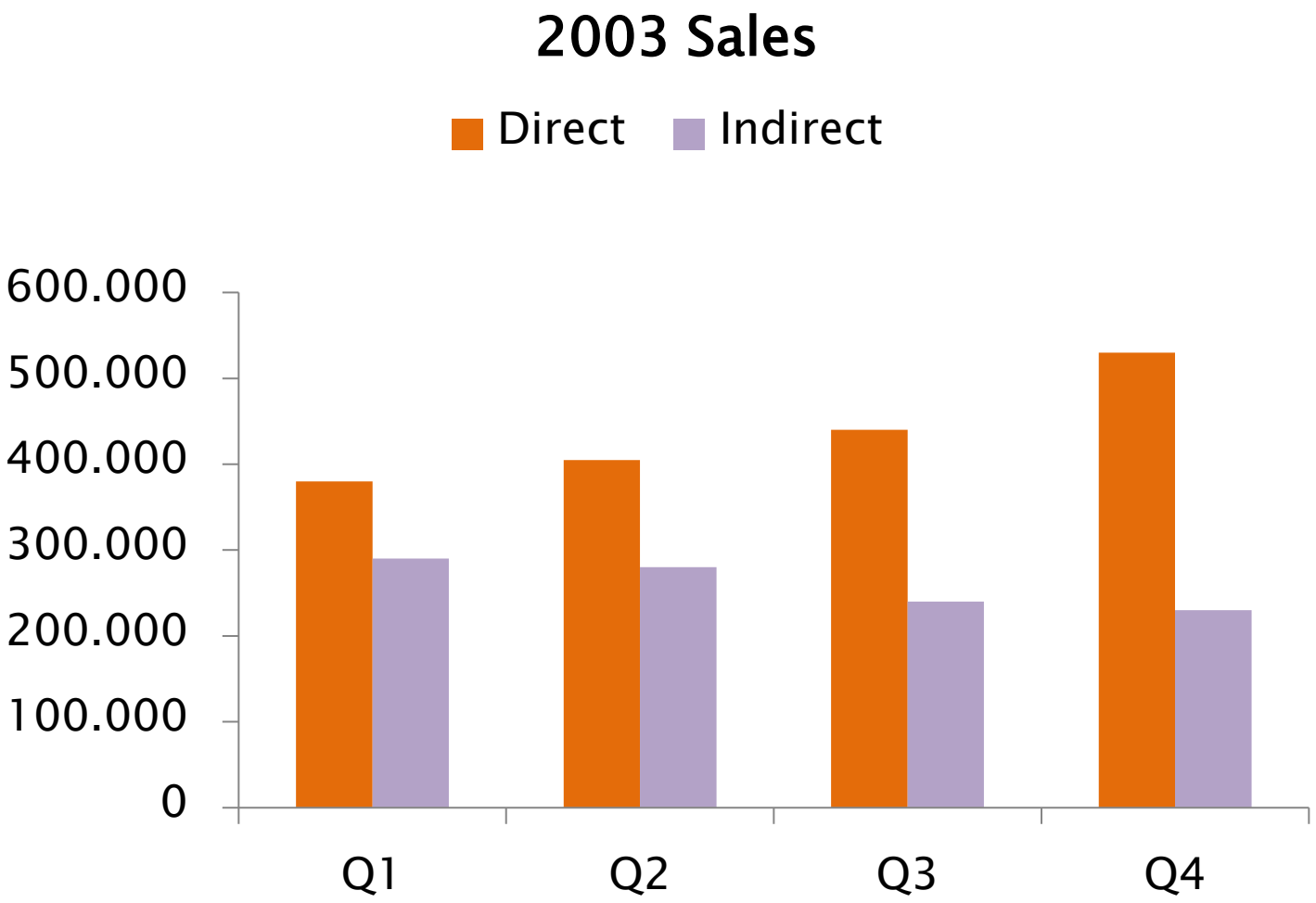
- Encoding of categorical levels
  - Position (along an axis)
  - Size
  - Color
    - Intensity
    - Saturation
    - Hue
  - Shape
  - Fill pattern
  - Line style

Ordinal

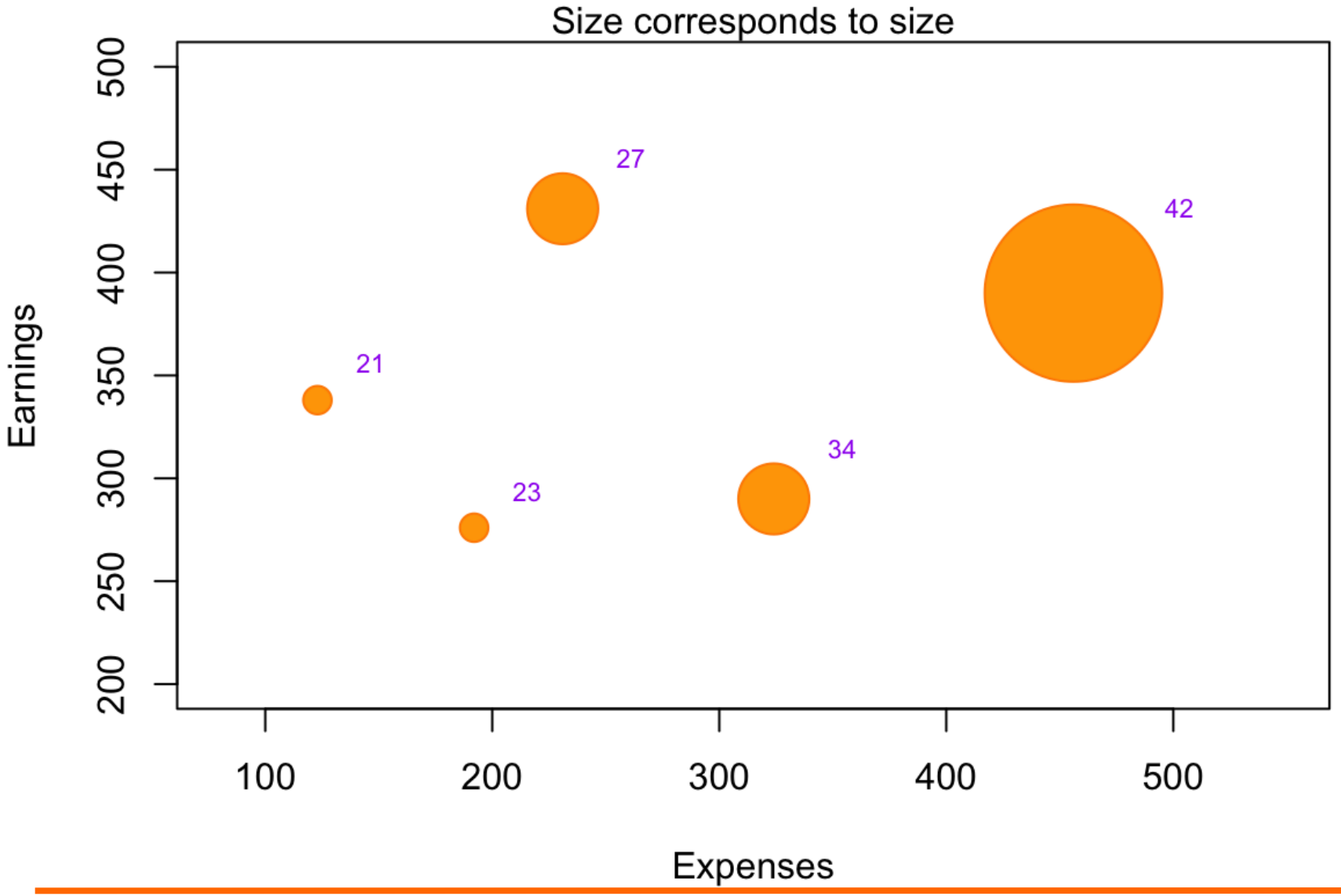
Position


Number of companies
90
80
70
60
50
40
30
20
10
0
Large
Medium
Small
Micro

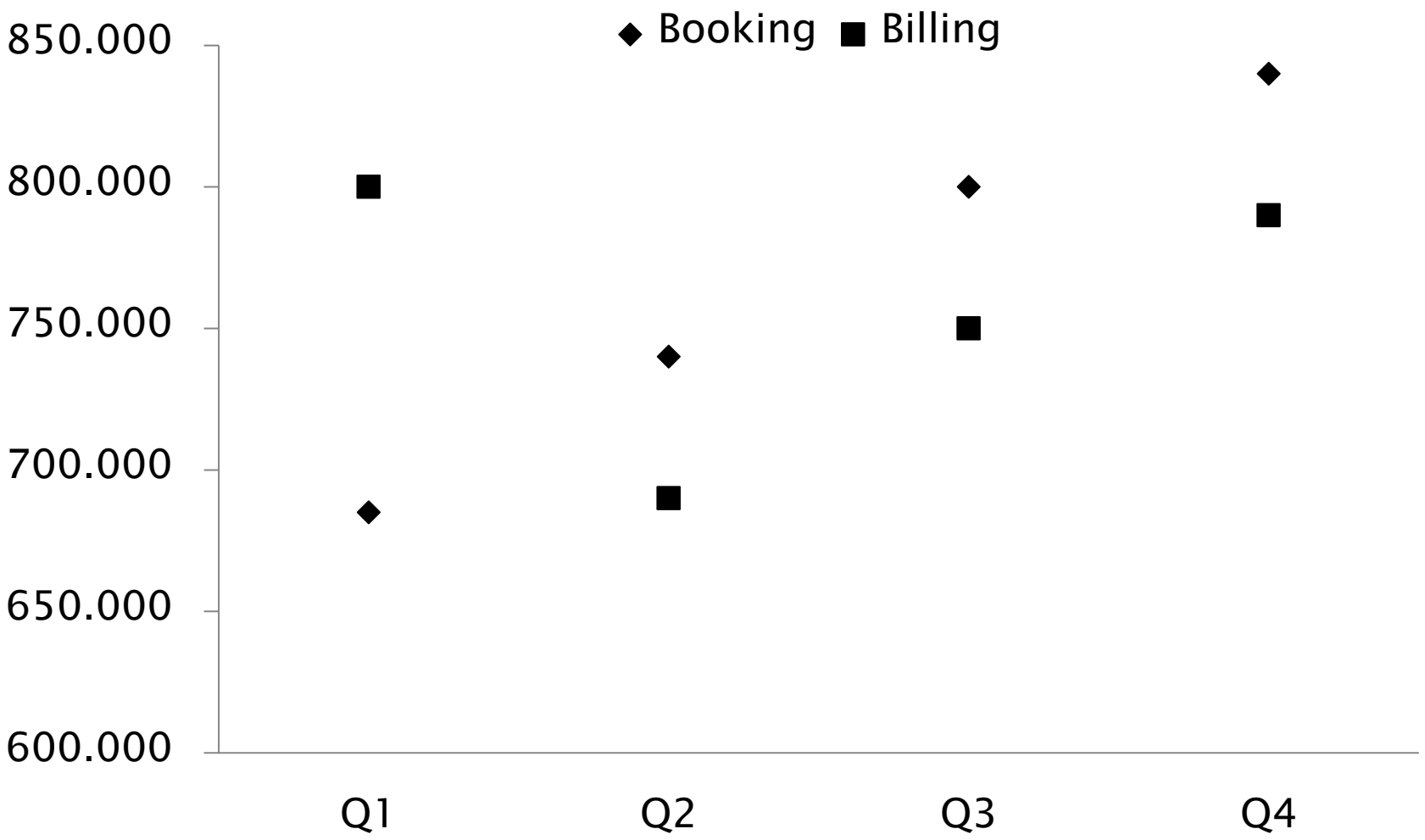
Position × Color (hue)



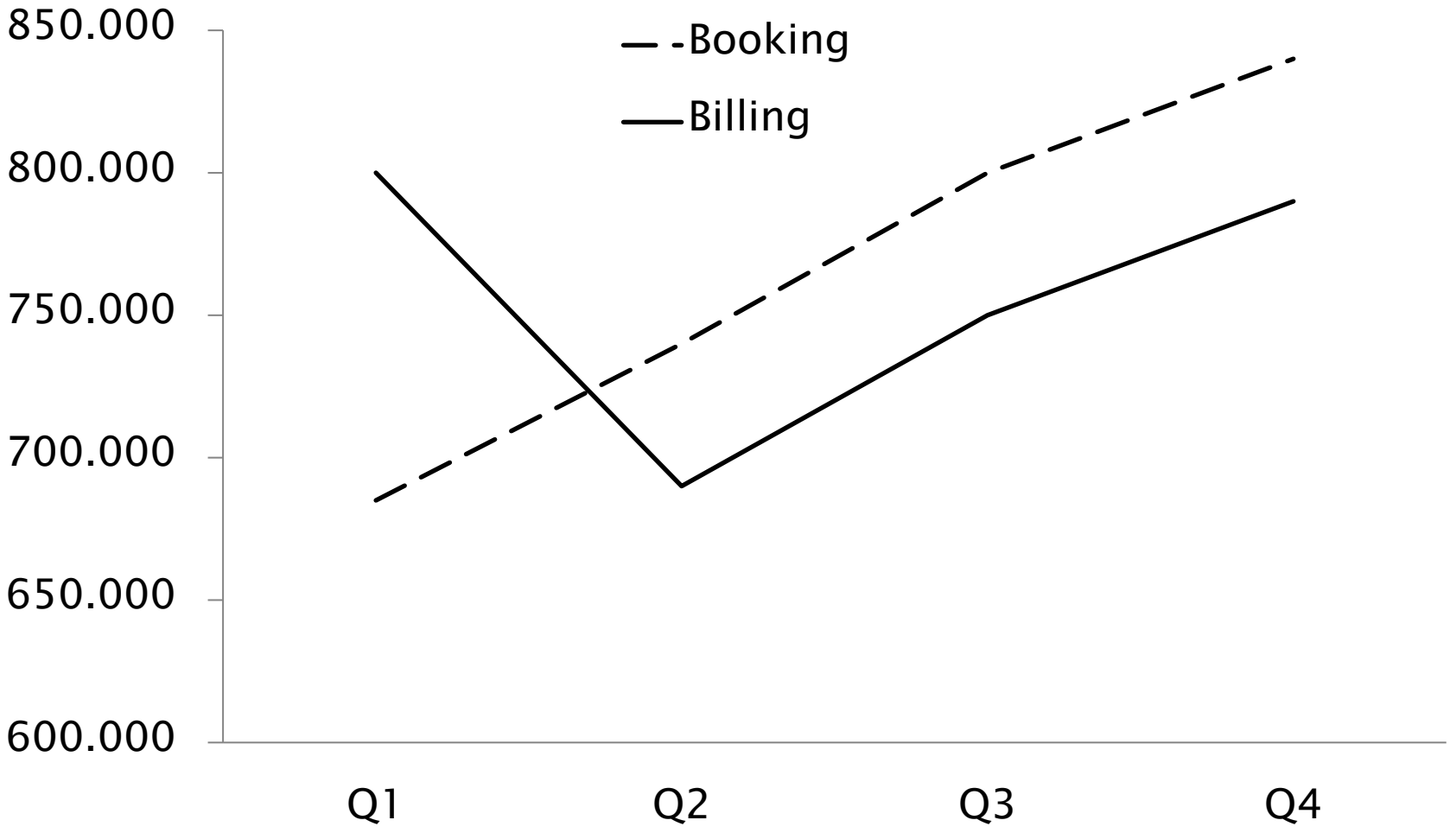
Size


Size corresponds to size
Earnings
Expenses
200
250
300
350
400
450
500
100
200
300
400
500
27
42
21
34
23

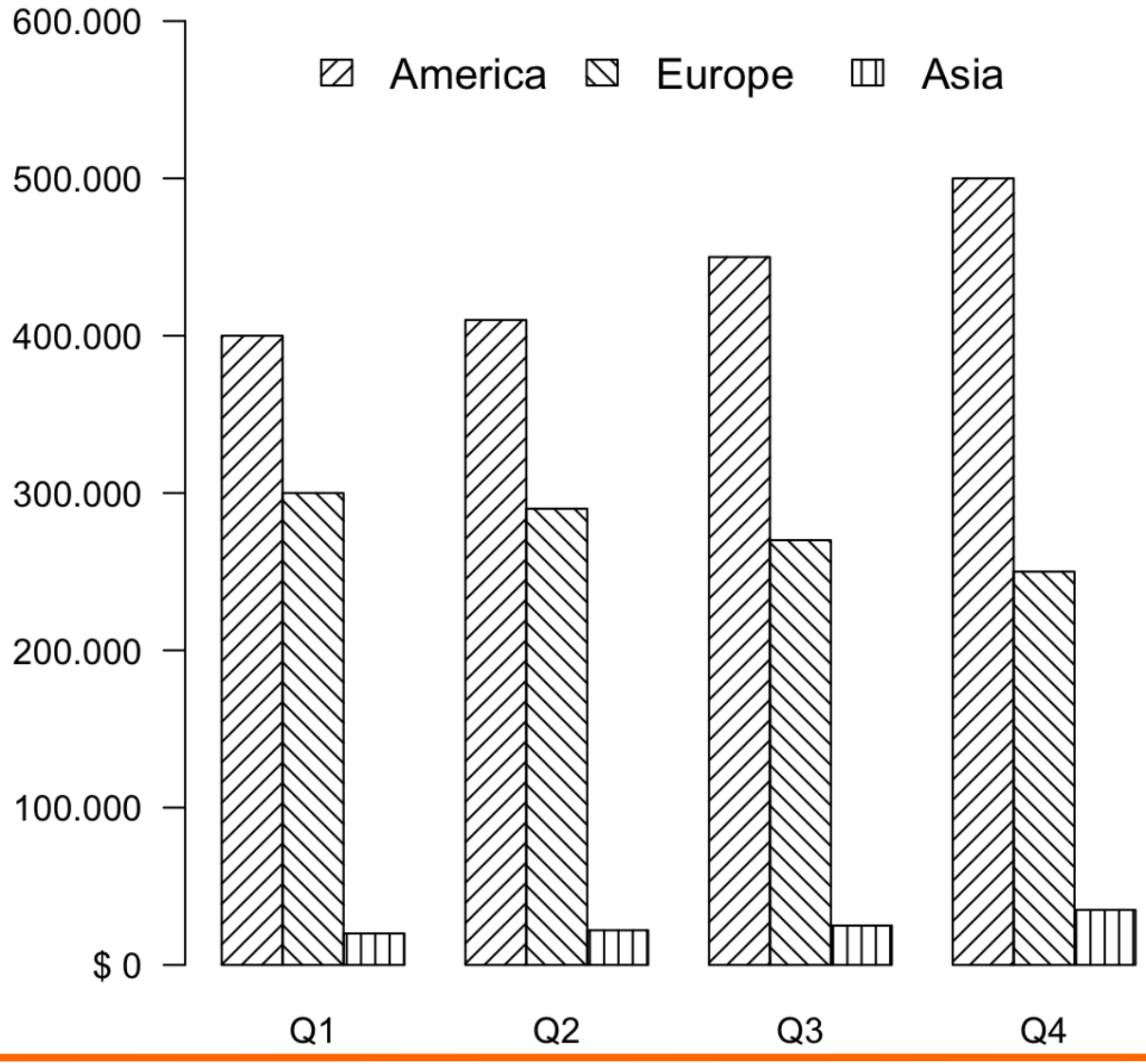
Point shape


Booking
Billing
850.000
800.000
750.000
700.000
650.000
600.000
Q1
Q2
Q3
Q4

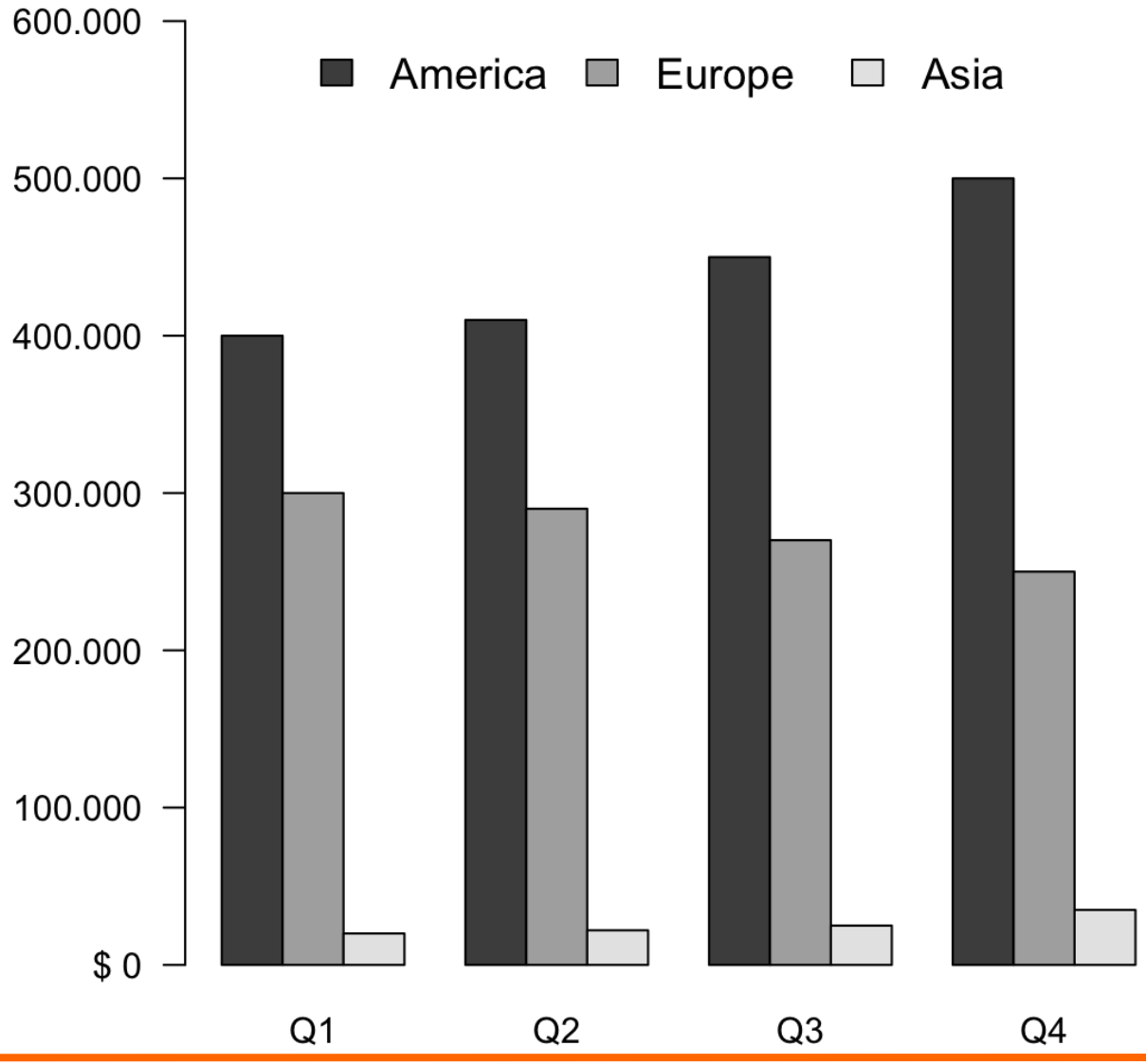
Line style


850.000
800.000
750.000
700.000
650.000
600.000
Booking
Billing
Q1
Q2
Q3
Q4

Fill Texture



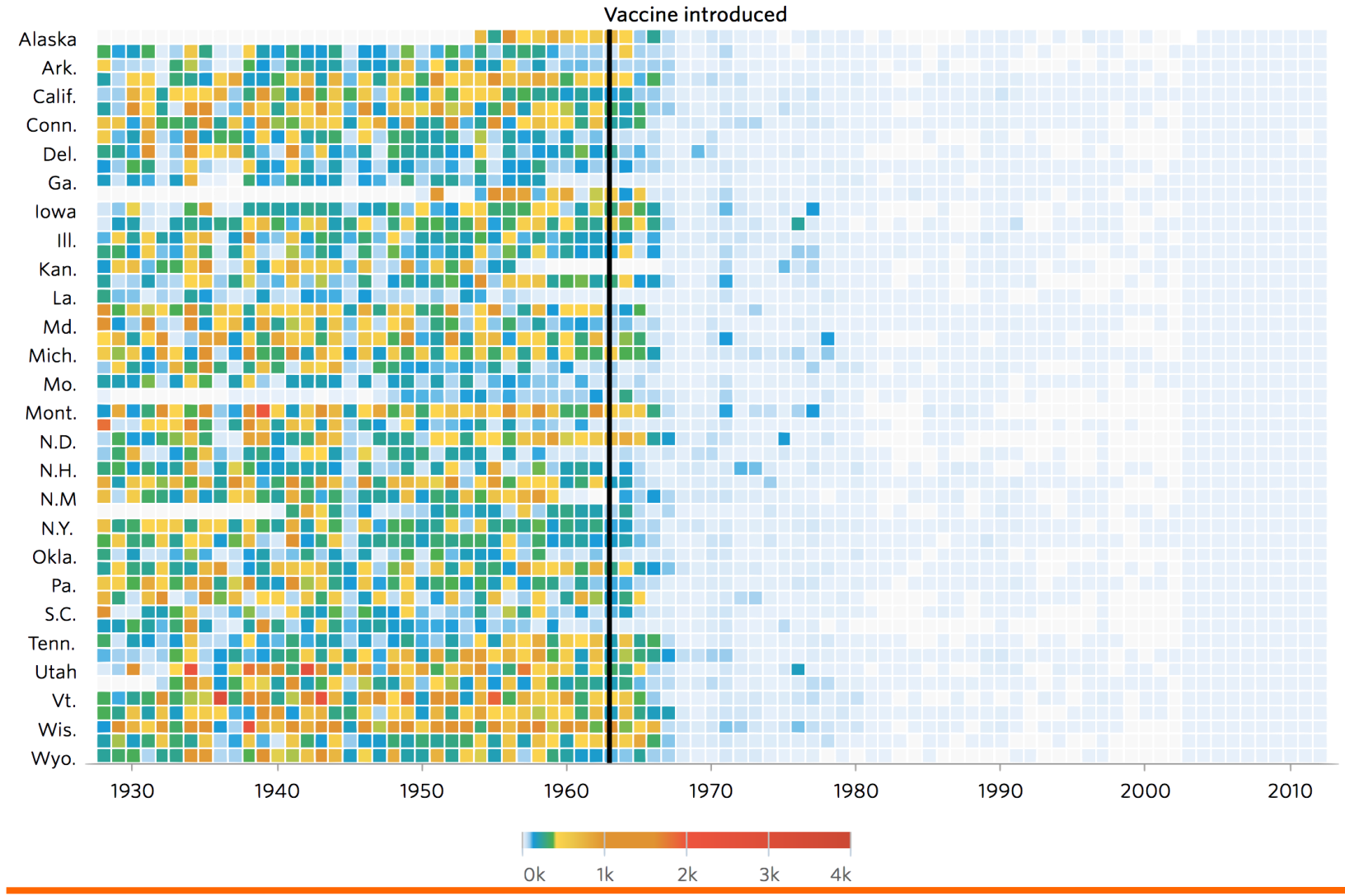
Fill Gray Levels



Discretization / Quantization

- A data transformation that maps a quantitative measure into an ordinal one
  - Based on the definition of intervals
- Discretized measures can be encoded using an ordinal-friendly visual attribute
  - Size
  - Color
- Warning: details are lost in the process

Heatmaps

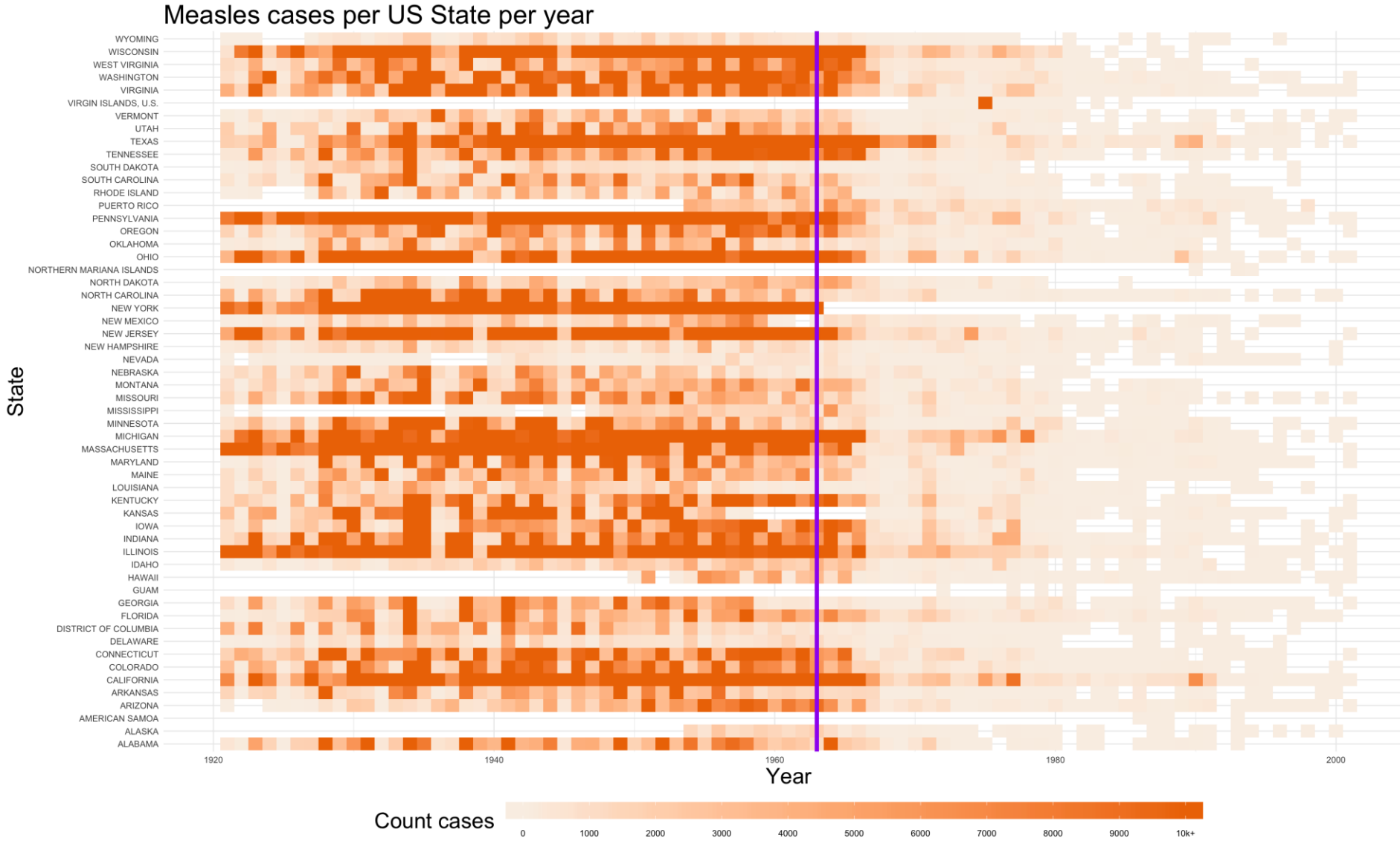


http://graphics.wsj.com/infectious-diseases-and-vaccines/

Heatmaps

- Hues have no unique order semantics
  - Only intensity has one
- Rainbow palette have serious problems for color blinds
  - Roughly 5% of the population

Heatmaps


Measles cases per US State per year
WYOMING
WISCONSIN
WEST VIRGINIA
WASHINGTON
VIRGINIA
VIRGIN ISLANDS, U.S.
VERMONT
UTAH
TEXAS
TENNESSEE
SOUTH DAKOTA
SOUTH CAROLINA
RHODE ISLAND
PUERTO RICO
PENNSYLVANIA
OREGON
OKLAHOMA
OHIO
NORTHERN MARIANA ISLANDS
NORTH DAKOTA
NORTH CAROLINA
NEW YORK
NEW MEXICO
NEW JERSEY
NEW HAMPSHIRE
NEVADA
NEBRASKA
MONTANA
MISSOURI
MISSISSIPPI
MINNESOTA
MICHIGAN
MASSACHUSETTS
MARYLAND
MAINE
LOUISIANA
KENTUCKY
KANSAS
IOWA
INDIANA
ILLINOIS
IDAHO
HAWAII
GUAM
GEORGIA
FLORIDA
DISTRICT OF COLUMBIA
DELAWARE
CONNECTICUT
COLORADO
CALIFORNIA
ARKANSAS
ARIZONA
AMERICAN SAMOA
ALASKA
ALABAMA
State
1920
1940
1960
1980
2000
Year
Count cases
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10k+

SUPPORT ELEMENTS

Support elements

- Axes
  - Ticks
- Graph area
  - Grids
- Labels
- Legends
- References
- Trellies

Axes

- Allow positioning of elements
  - Points
  - Extremes of bars and lines
- Labeled
  - What is the measure?
- Number of axis should be 2
  - 1 is fine for bars
    - continuity gestalt principle

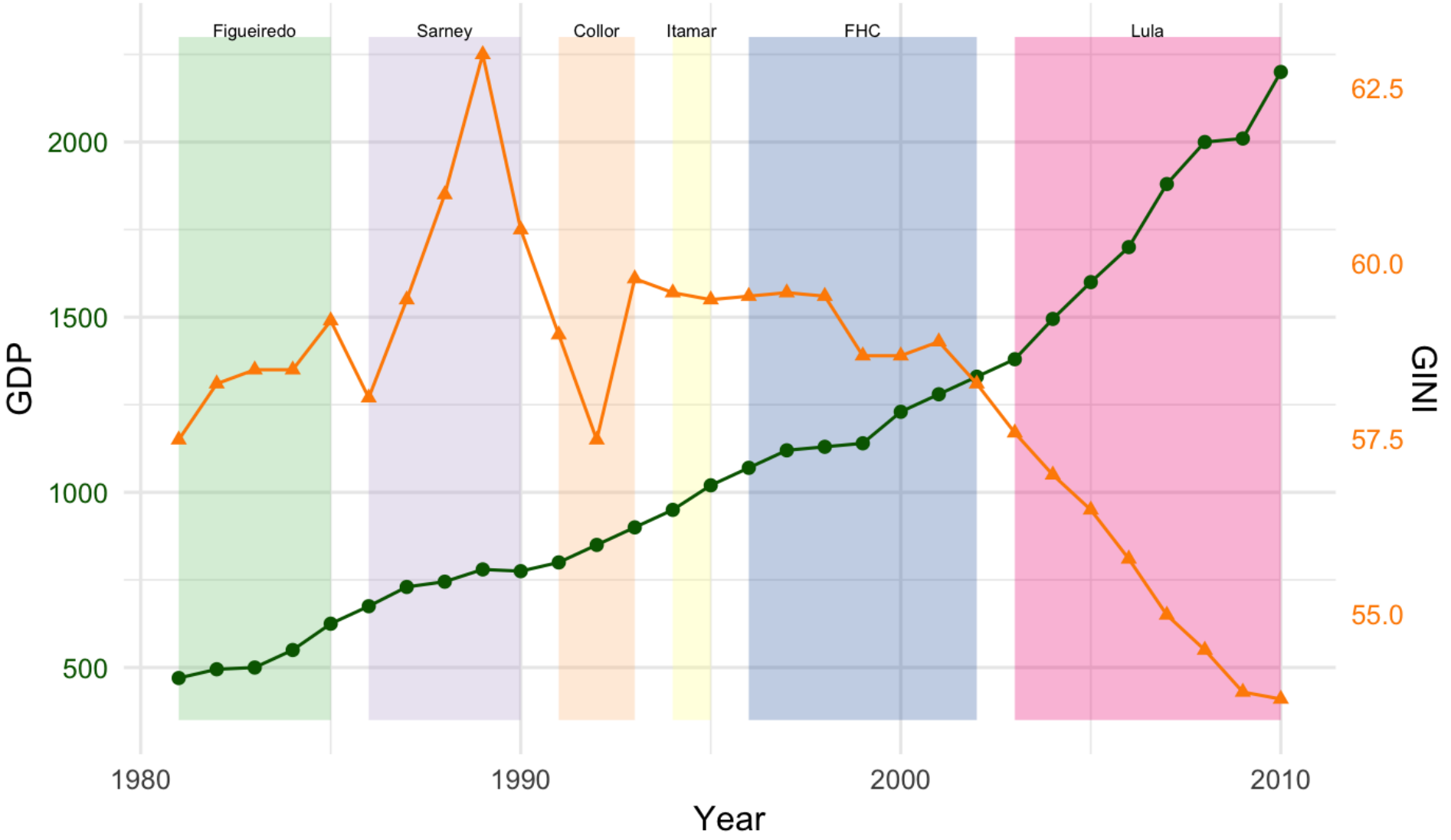
Tick marks

- Must not obscure data objects
- Outside the data region
- Avoid for categorical scales
- Balanced number
  - Too many clutter the graph
  - Too few make difficult to discern reference for data objects
  - Intervals must be equally spaced

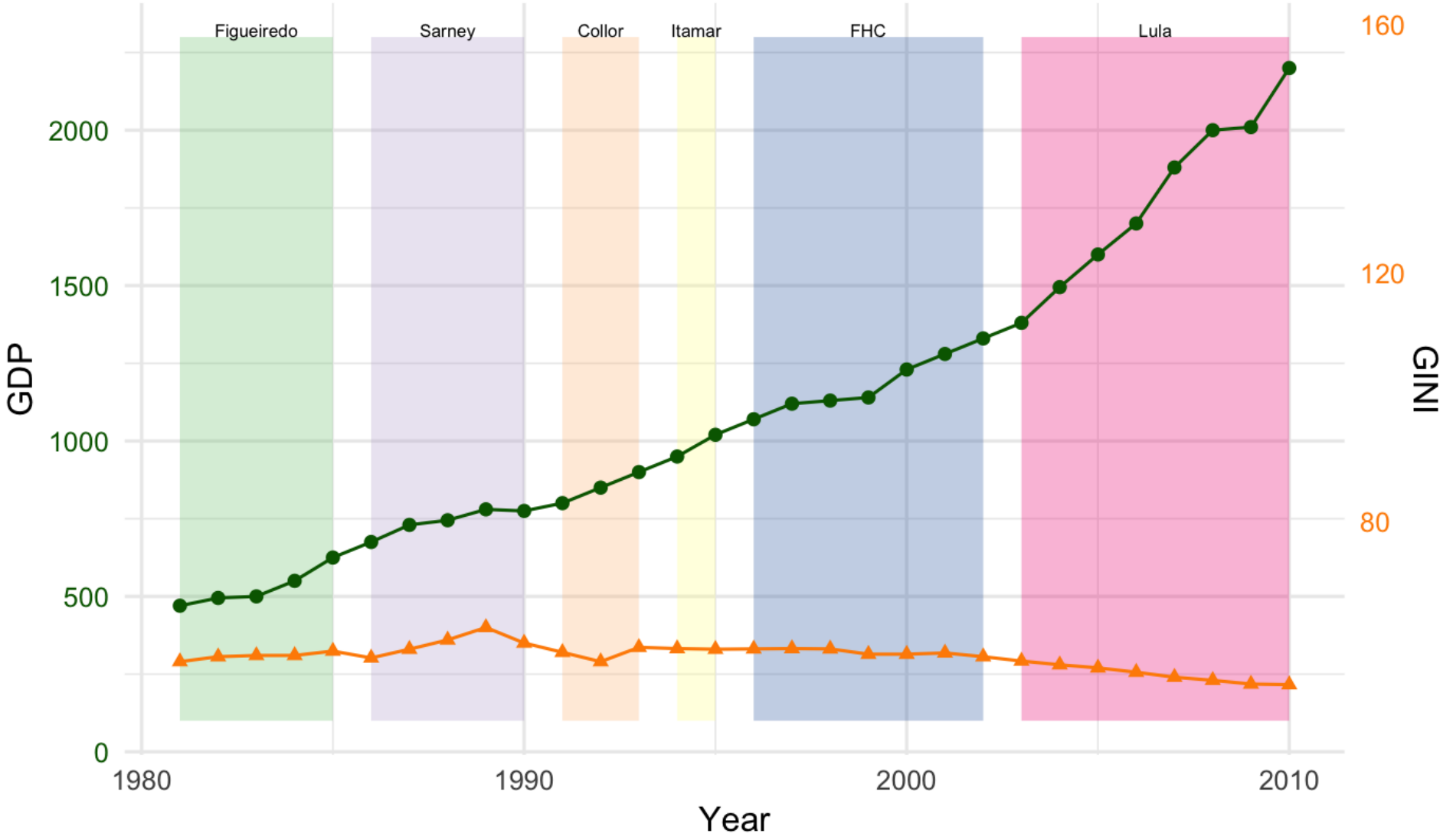
Multiple variables

- Correlation between 3+ variables
  - E.g. two measures in time series
- Multiple units of measure
  - Double quantitative (y) axis
  - Multiple graphs
  - One variable not encoded explicitly

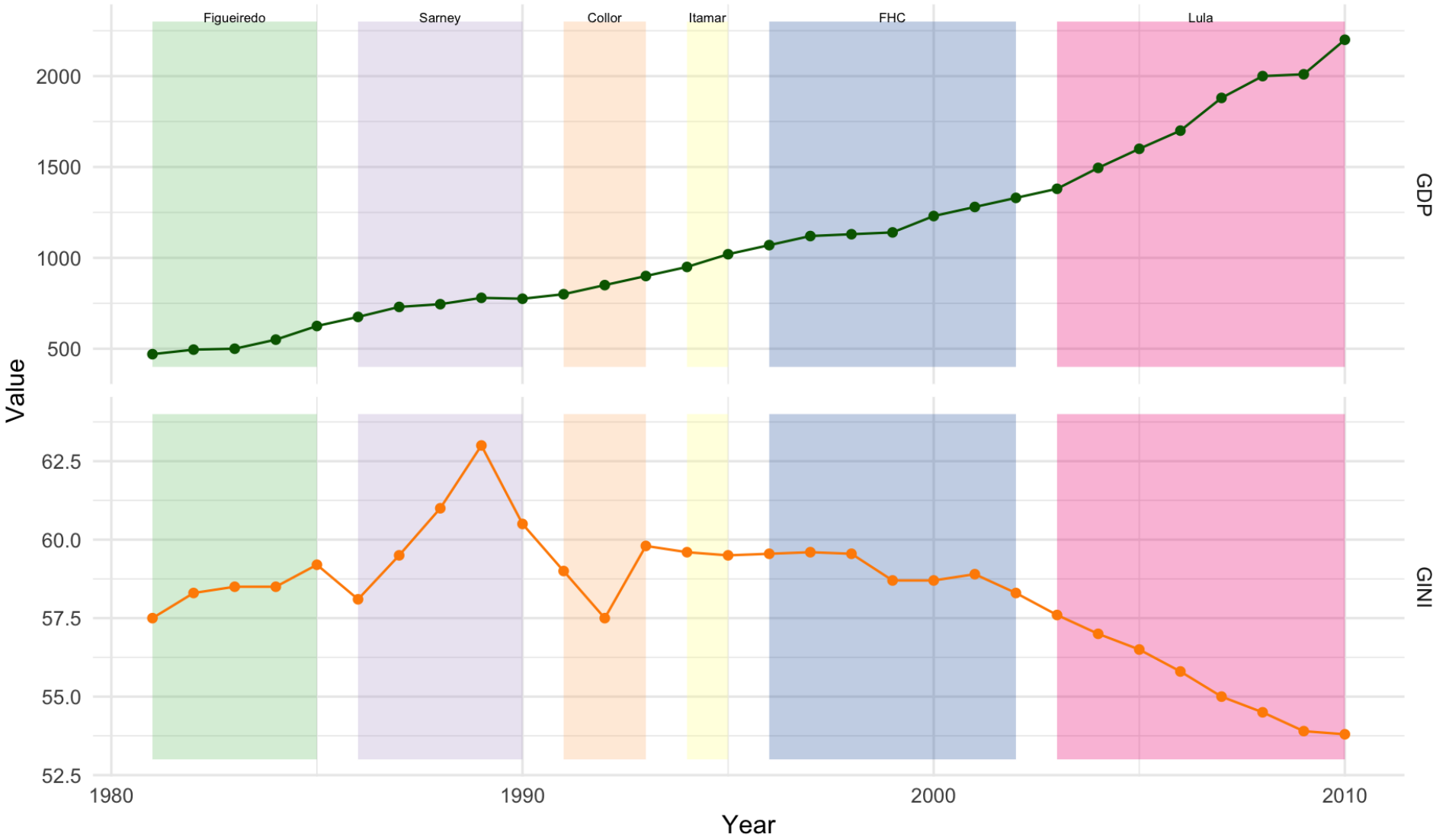
Double scale



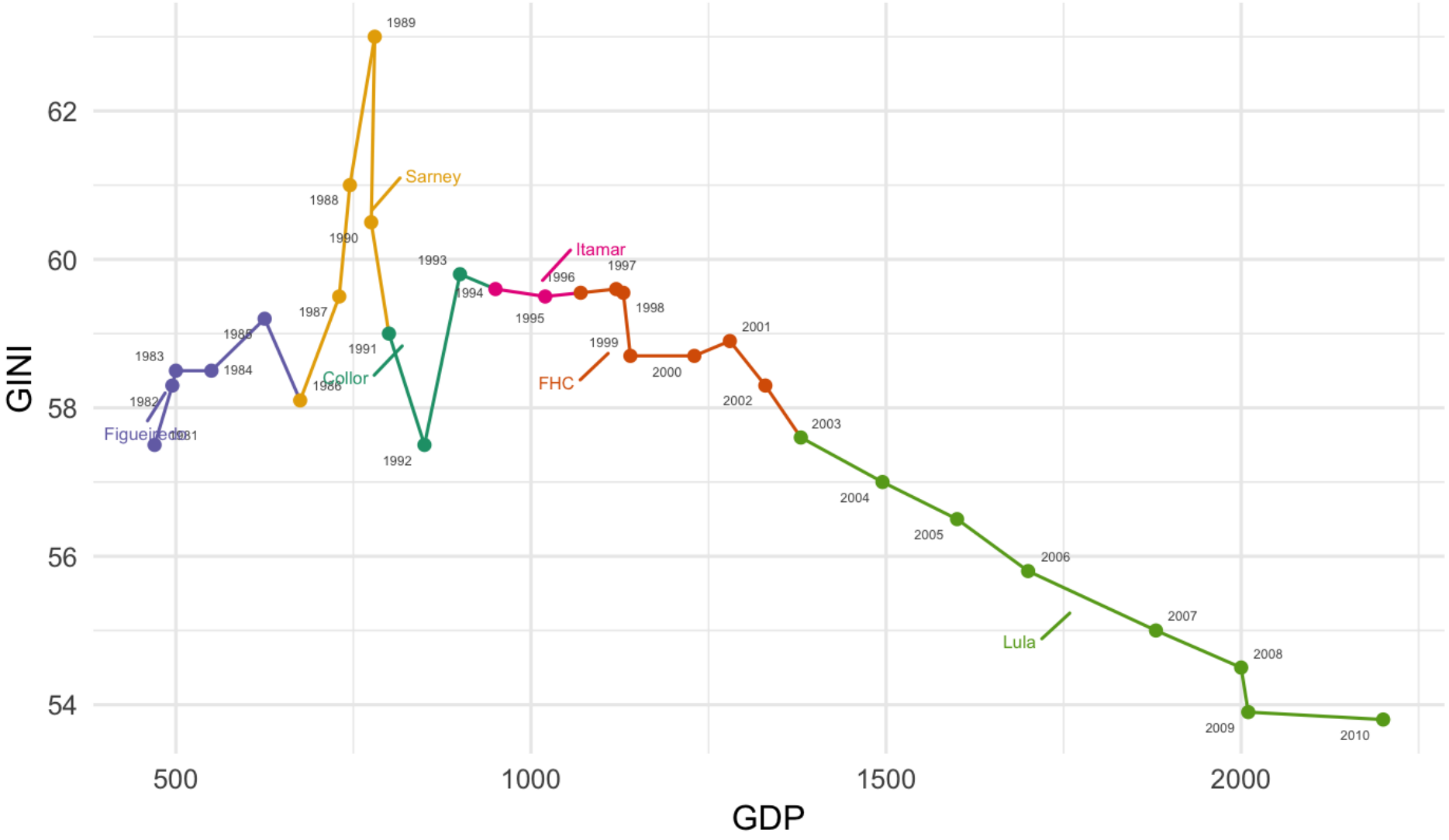
Double scale (alternative)



Multiple graphs



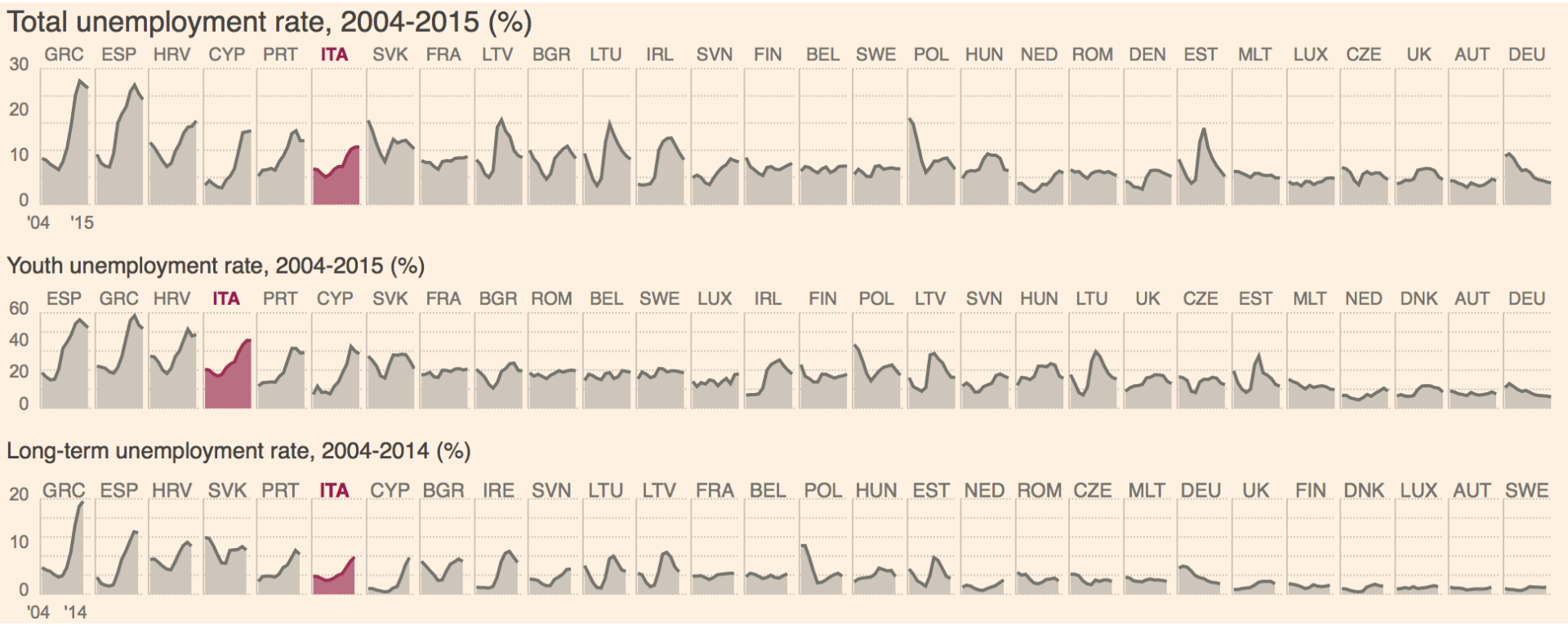
Path


GINI
62
60
58
56
54
500
1000
1500
2000
GDP
1989
Sarney
1988
1990
1993
Itamar
1996
1997
1994
1995
1998
1987
1985
1991
1999
2001
1983
1984
Collor
1986
FHC
2000
1982
2002
Figueiredo
1981
2003
1992
2004
2005
2006
2007
Lula
2008
2009
2010

Small multiples

- A.k.a.
  - Trellis
  - Lattice
  - Grid
- Set of aligned graphs sharing (at least one) scale and axis
  - Enable ease of comparison among different measures

Small multiples



FT EU unemployment tracker
http://blogs.ft.com/ftdata/2015/04/17/eu-unemployment-tracker/

Small multiples

- Consistency
  - Same scale
  - Same categorical levels
  - Same ordering of categorical levels
- Arrangement
  - Align axis that involve comparison
    - Possibly along a matrix

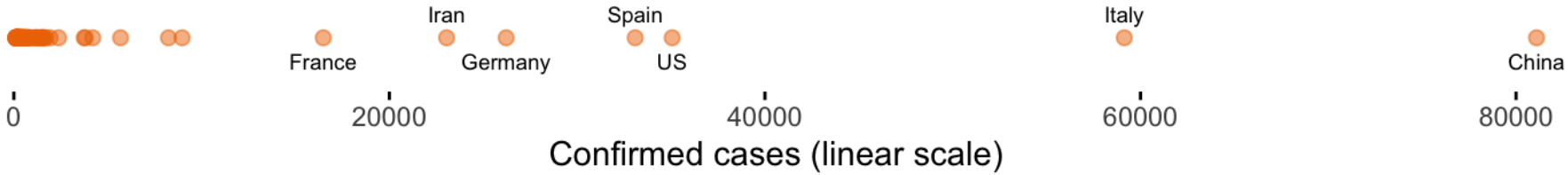
Trellis

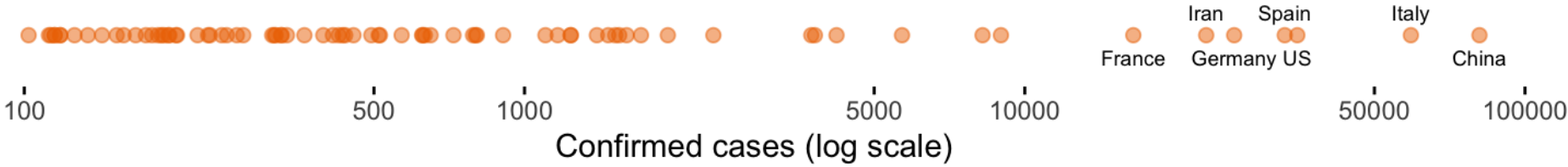
- Sequence
  - Intrinsic order
  - Order of relevance
  - Order by some quantitative attribute
- Rules and grids
  - Use when spacing is not enough
  - Can direct the reader to scan graphs horizontally or vertically

Log scale

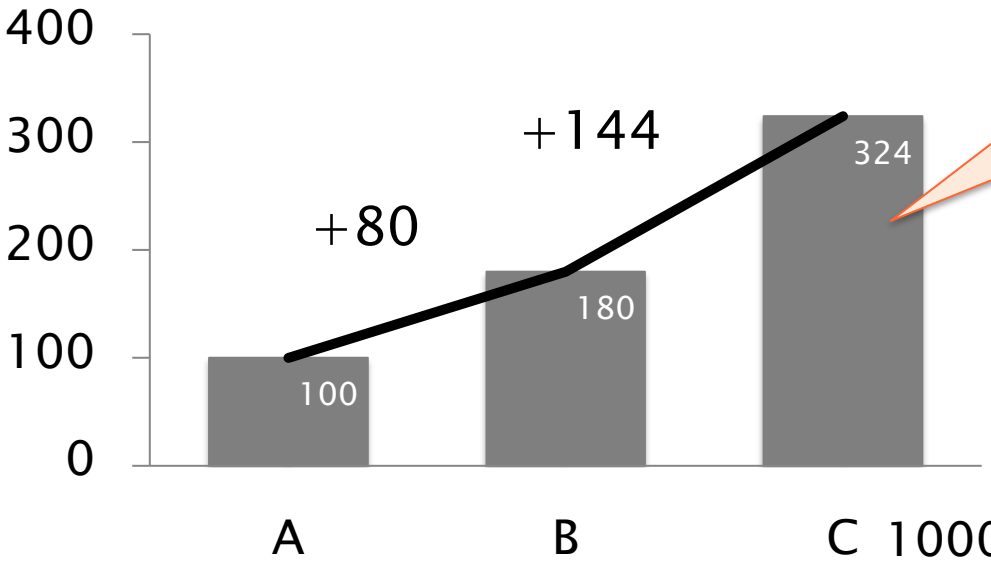
- Reduce visual difference between quantitative data sets with significantly wide ranges
- Differences are proportional to percentages
- Constant percentage increase correspond to a line

Log scale – wide range

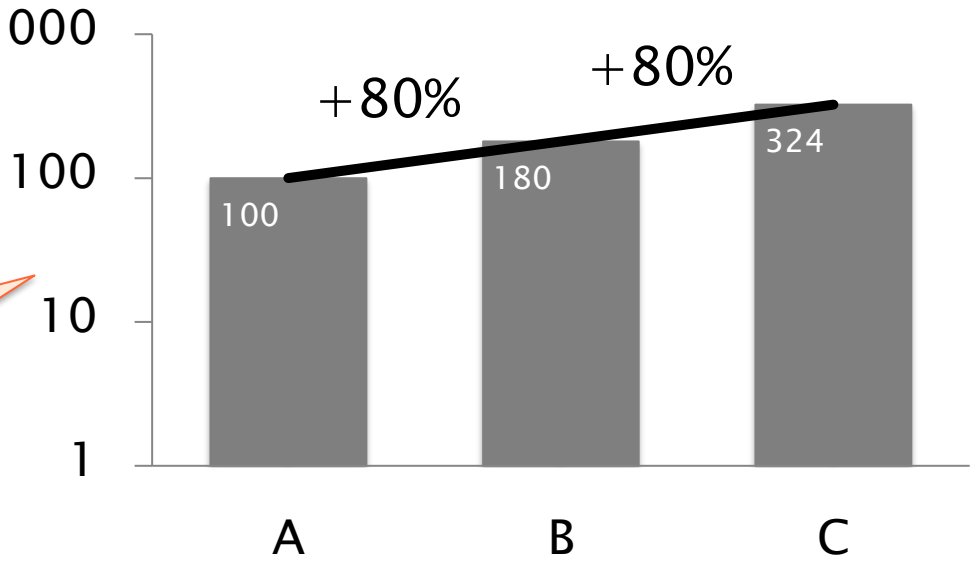




Log scale – differences

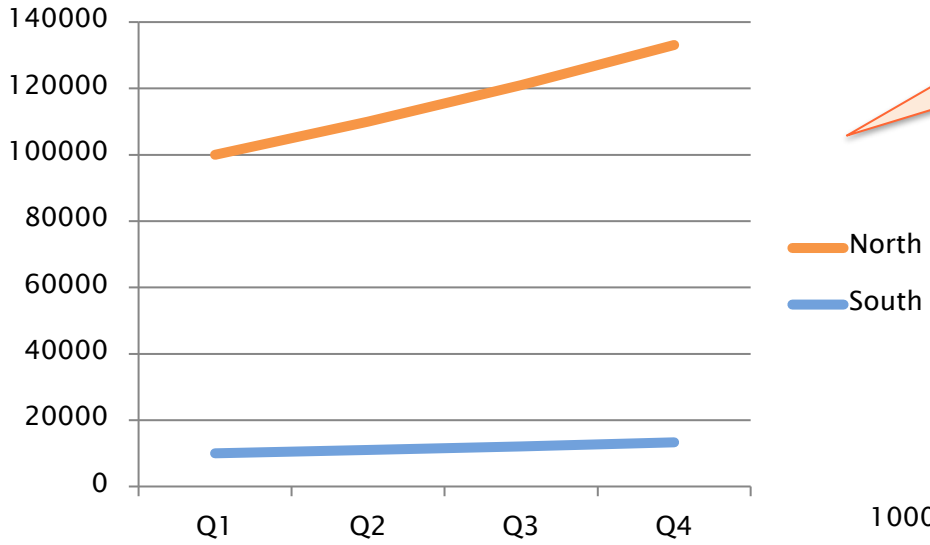


Same absolute gains correspond to same distance

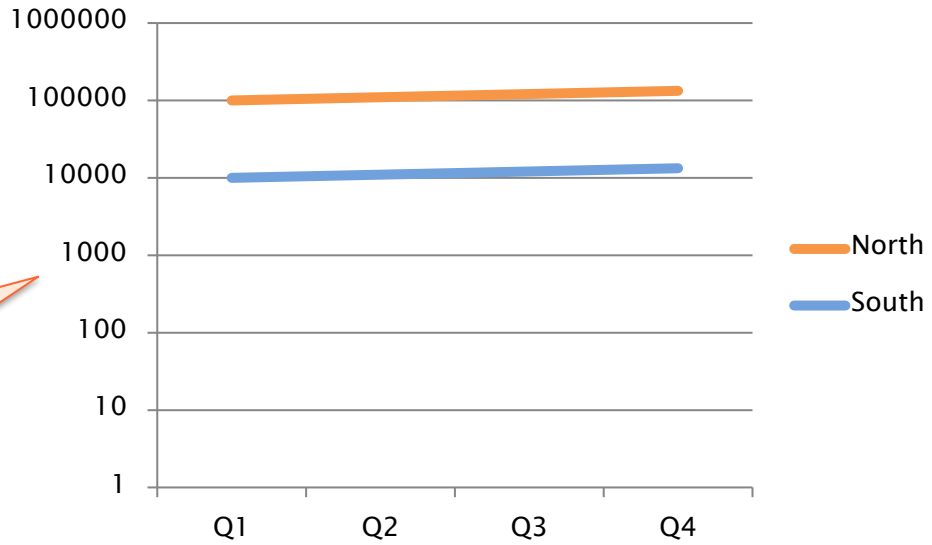


Same percentage gains correspond to same distance

Log scale – variation

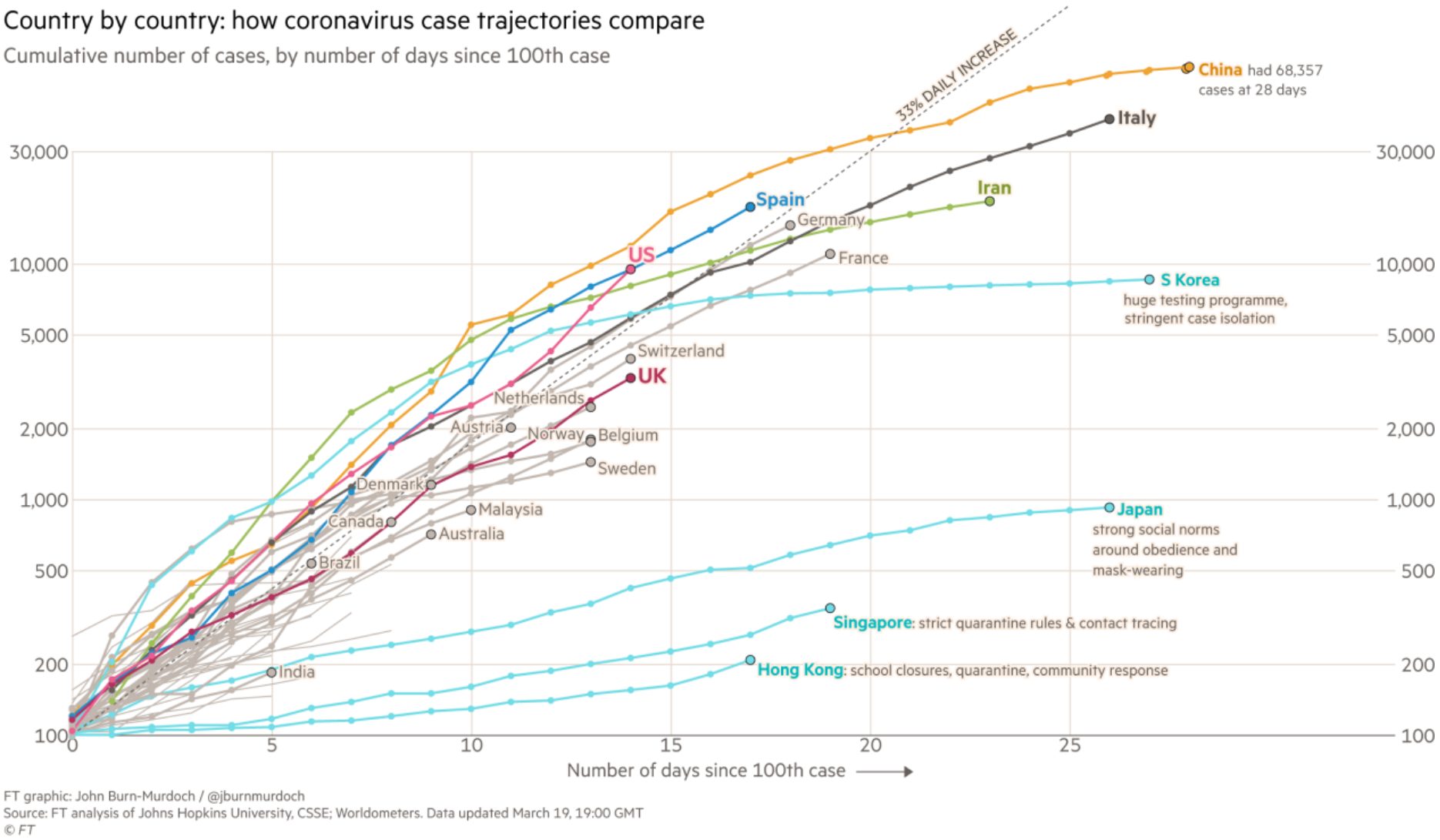


Parallel lines for same absolute gains



Parallel lines for same percentage gains

Log scale



https://www.ft.com/content/a26fbf7e-48f8-11ea-aeb3-955839e06441

Graph area

- Aspect ratio should not distort perception
  - Typically wider than taller
  - Scatter plots may be squared
- Grid lines must be thin and light
  - Useful to look-up values
  - Enhance comparison of values
  - Enhance perception of localized patterns

Labels

- Important elements (e.g. titles) should be prominent
  - Top
  - Larger

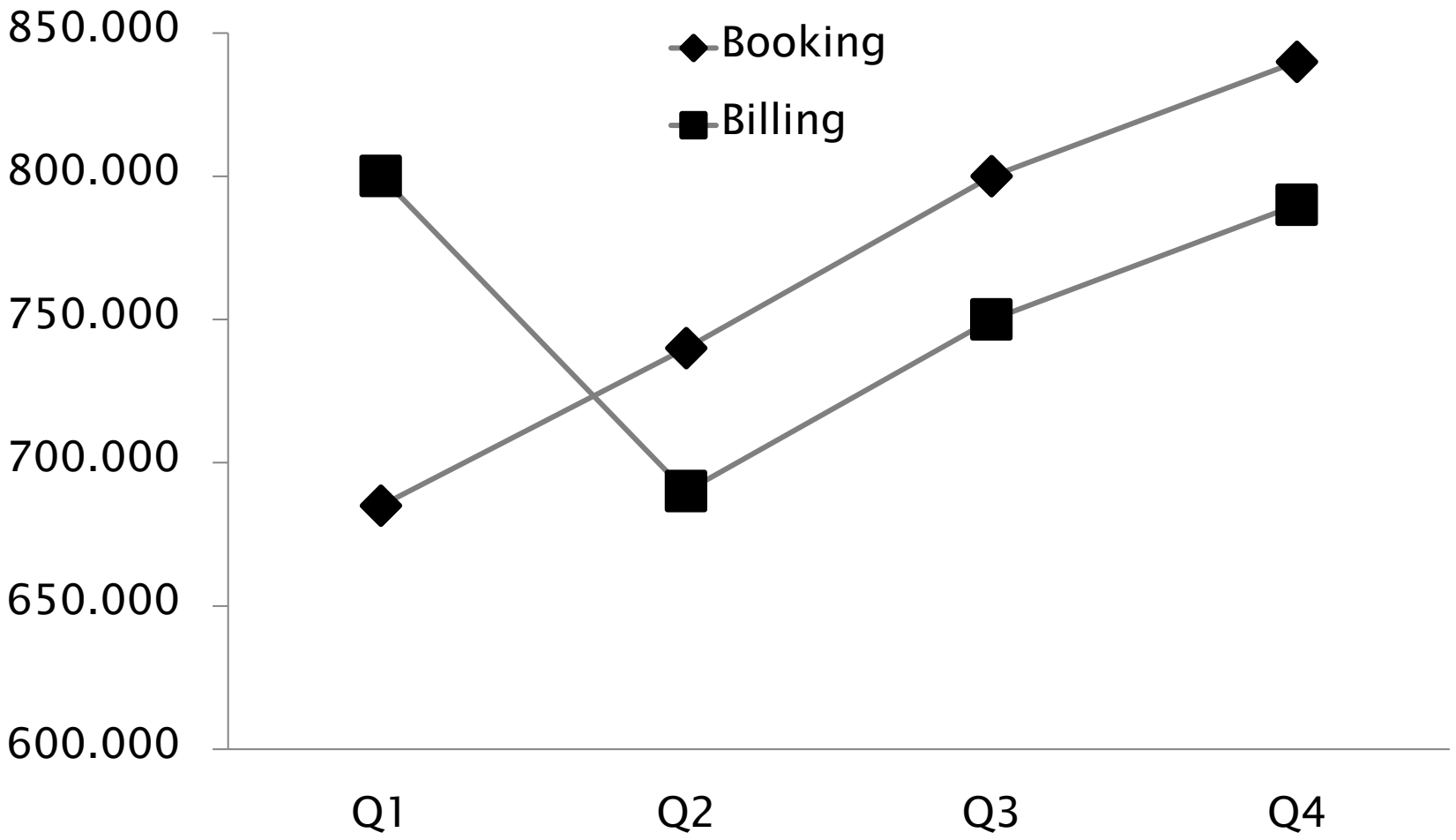
Legends

- Used for categorical attributes not associated to any axis
- As close as possible to the objects
- Less prominent than data objects
- Borders are used only when necessary to separate from other elements

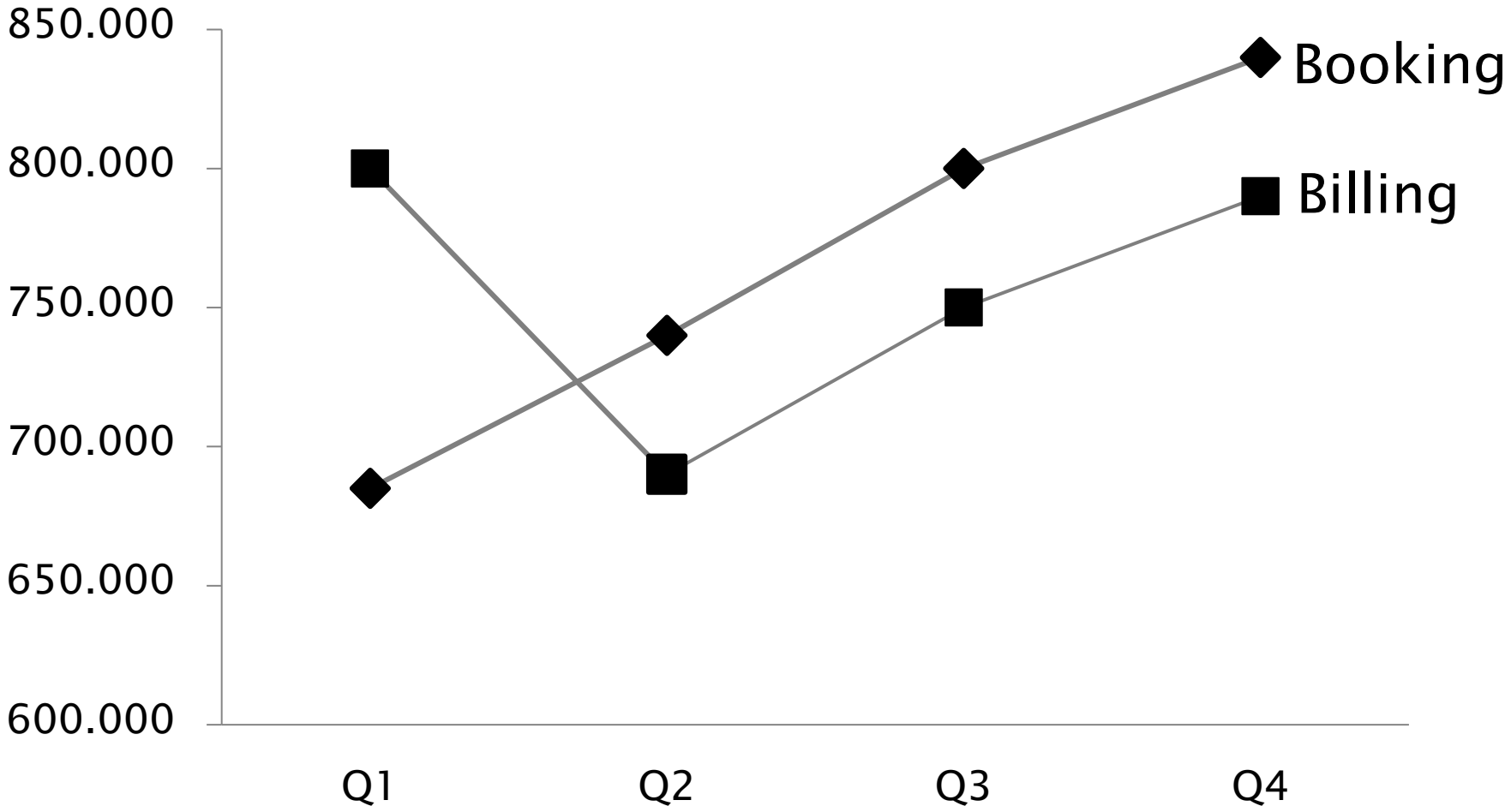
Legends

- Text should be as close as possible to the object it complements
  - Prefer direct labeling to separate legends
- Number of categorical subdivisions
  - Perceptual limit is between 5 and 8
  - Limit is independent of the visual attribute used to encode it
  - Joint use of attributes ease discrimination

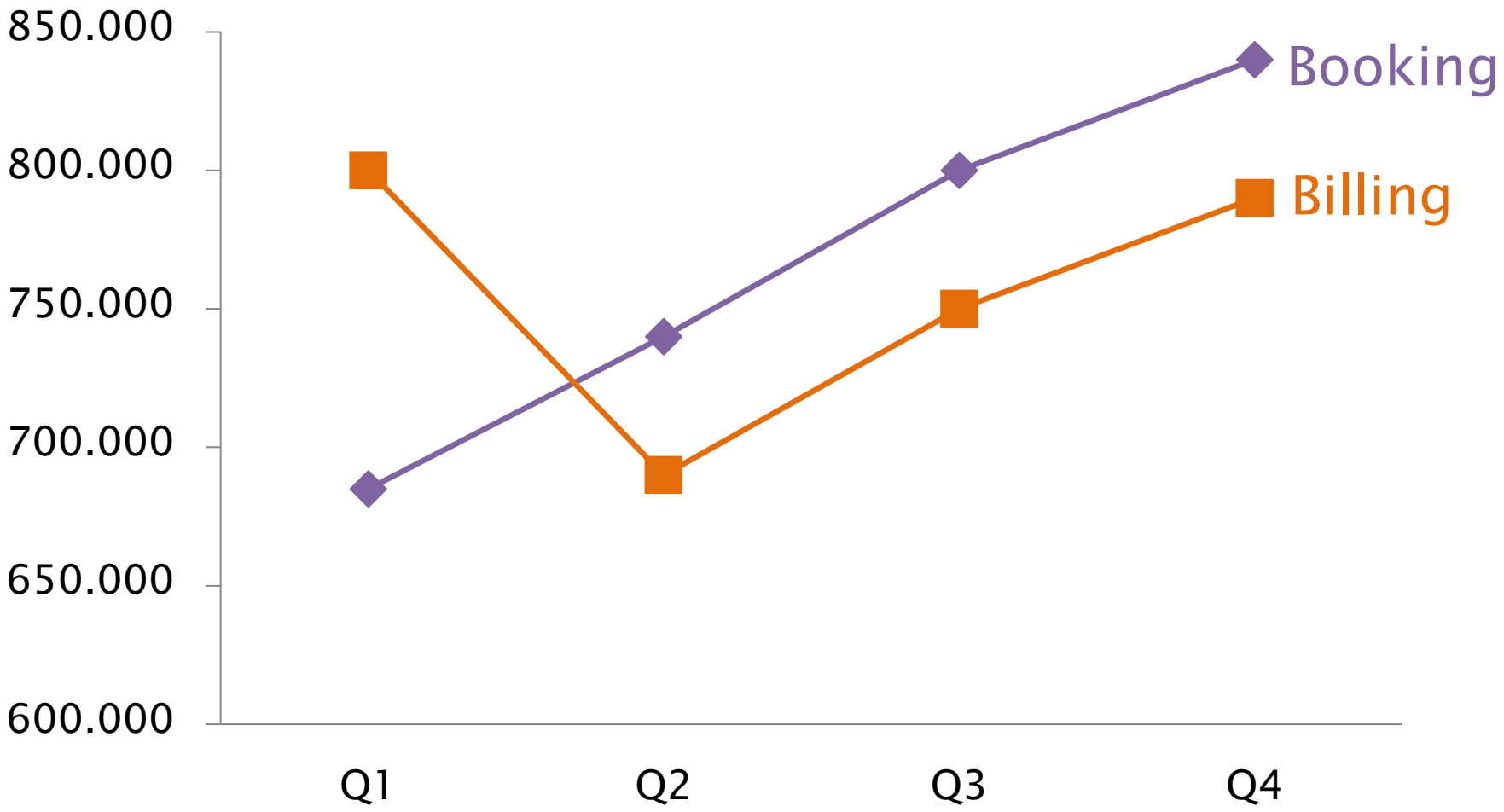
Legend


850.000
800.000
750.000
700.000
650.000
600.000
Booking
Billing
Q1
Q2
Q3
Q4

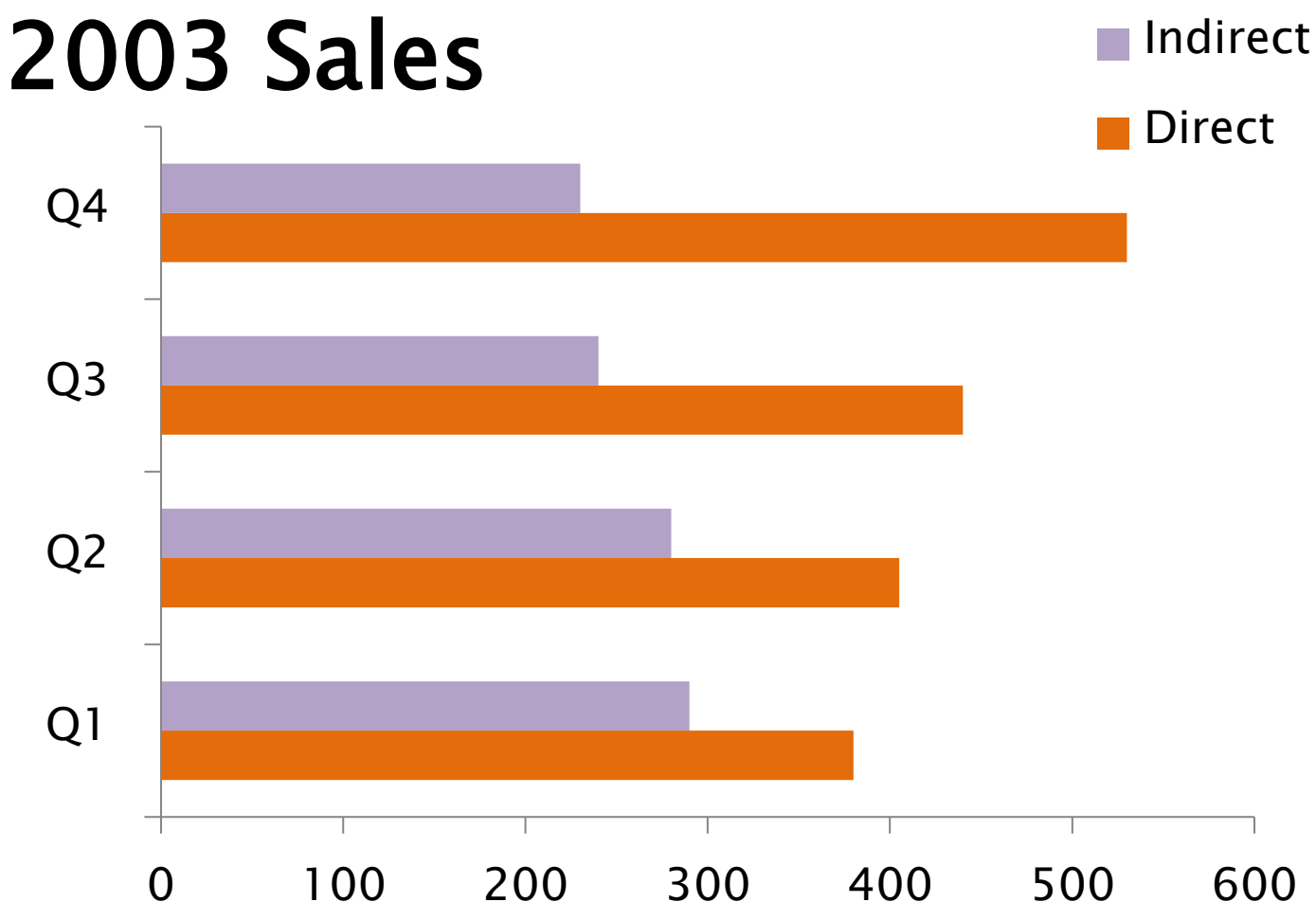
Direct labeling



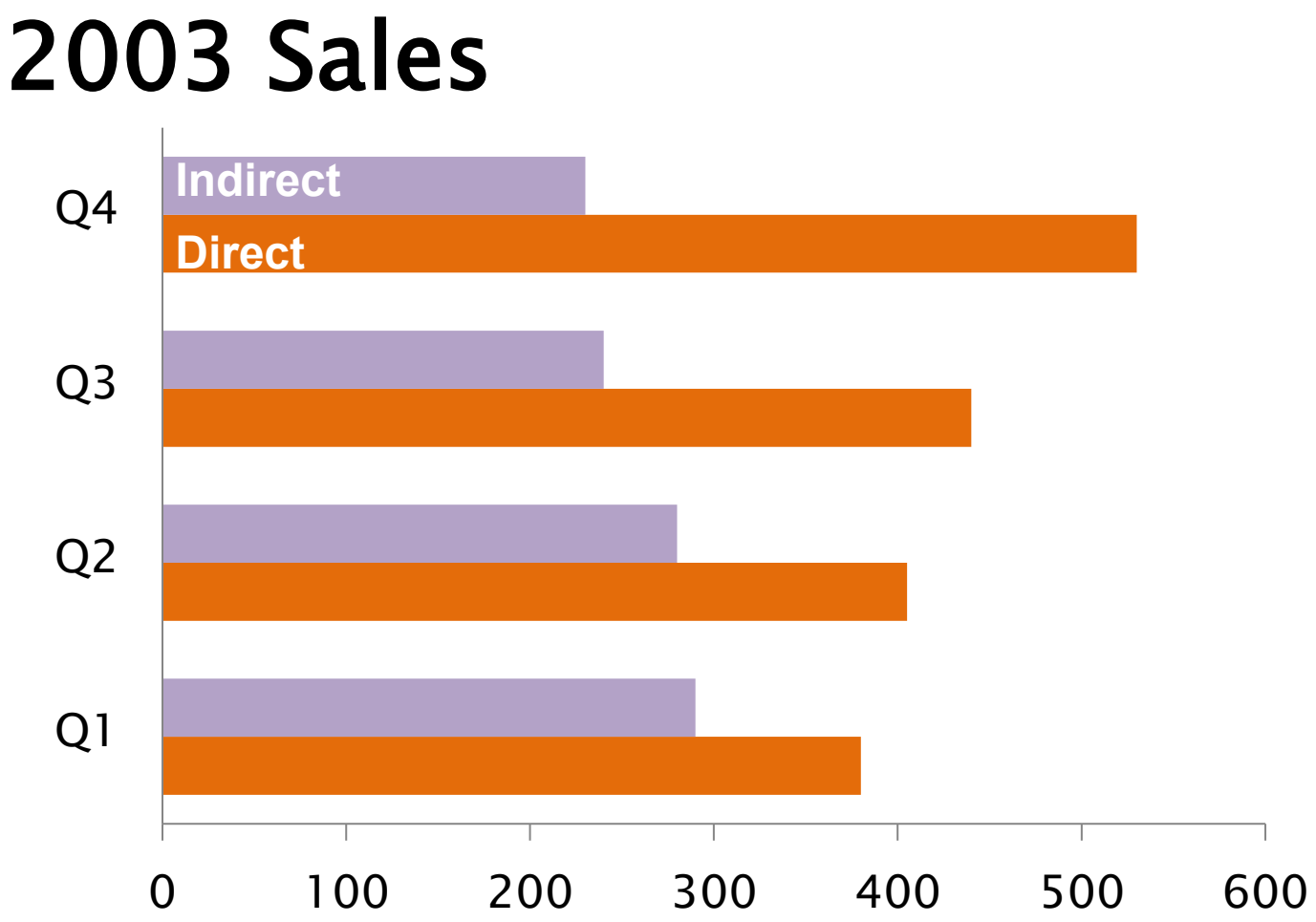
Direct labeling and color



Legend


2003 Sales
Indirect
Direct
Q4
Q3
Q2
Q1
0
100
200
300
400
500
600

Direct labeling



Reference lines and regions

- Reference lines support an easy comparison to a given value
  - Mean
  - Threshold
- Reference regions allow comparison with several values
  - Use background color

DASHBOARD

Dashboard

Visualization of the most relevant information

needed to achieve one or more goals

which fits entirely on a single screen so it can be monitored at a glance

Dashboard

- Dashboards display mechanisms are
  - small
  - concise
  - clear
  - intuitive
- Dashboards are customized
  - To suit the goals of person, group, function

Provide context for data

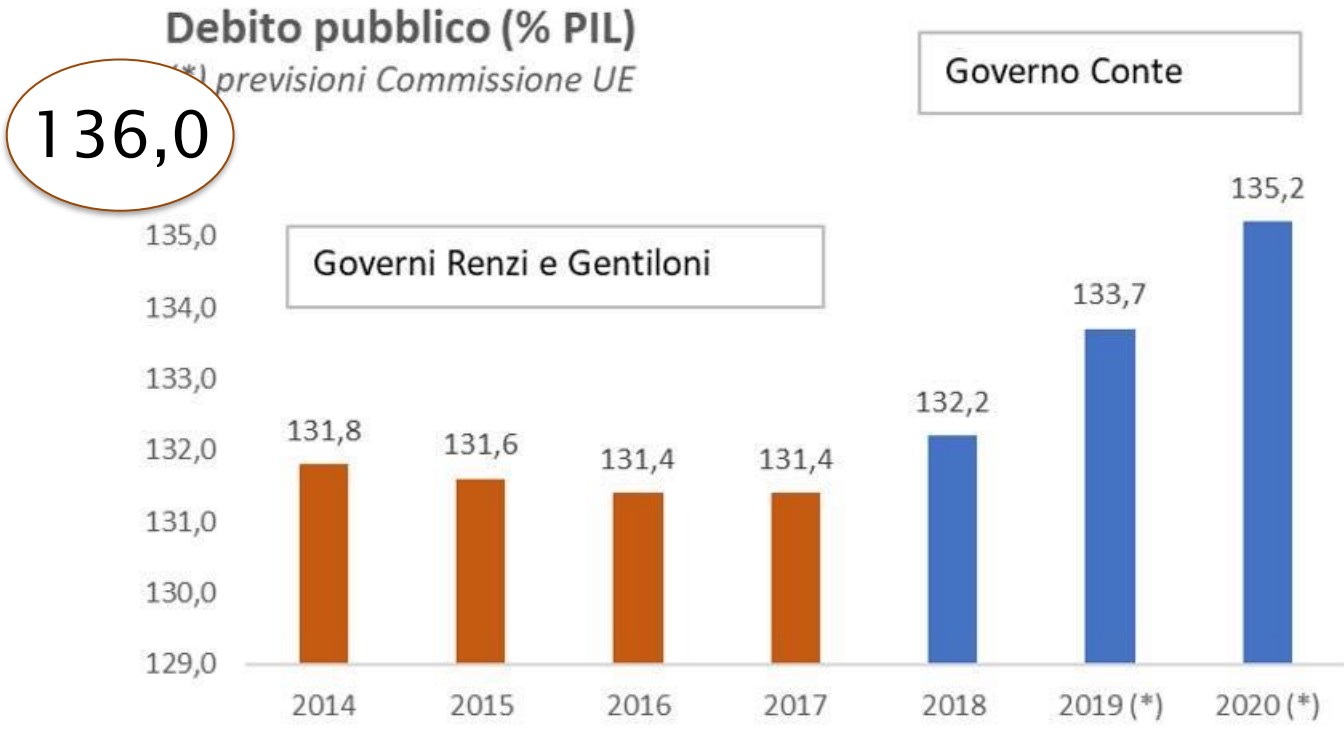
PUC

- References allow judging the data

Use appropriate detail

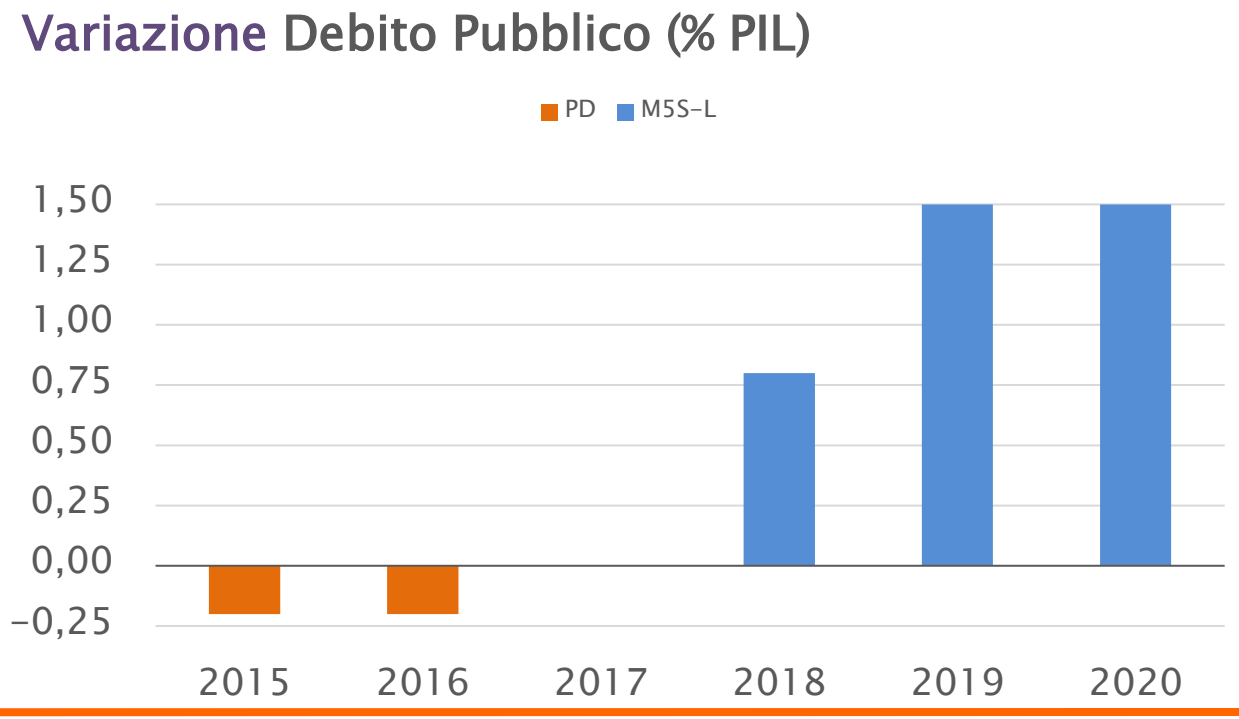
PUC

- Typical counterexamples
  - Dates with seconds detail
  - Decimals



Use the right measures

- If you are interested in e.g. the difference, ratio, variation show such derived measure



Use appropriate visualization

- Typical errors:
  - Any chart when a table would be better
  - Pie-charts not representing part-whole
  - Bubble charts

Visualization instruments

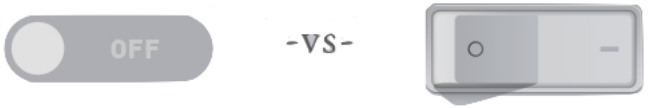
- Tables
  - Textual information
- Graphs
  - Visual information

Avoid decorations

- Skeumorphic design
- Backgrounds motives
- Color gradients
- Variations not encoding any measure
  - Typically color

Avoid decorations

- Skeumorphic design



- Backgrounds motives
- Color gradients
- Variations not encoding any measure
  - Typically color

Avoid decorations

- Skeumorphic design
- Backgrounds motives
- Color gradients
- Variations not encoding any measure
  - Typically color

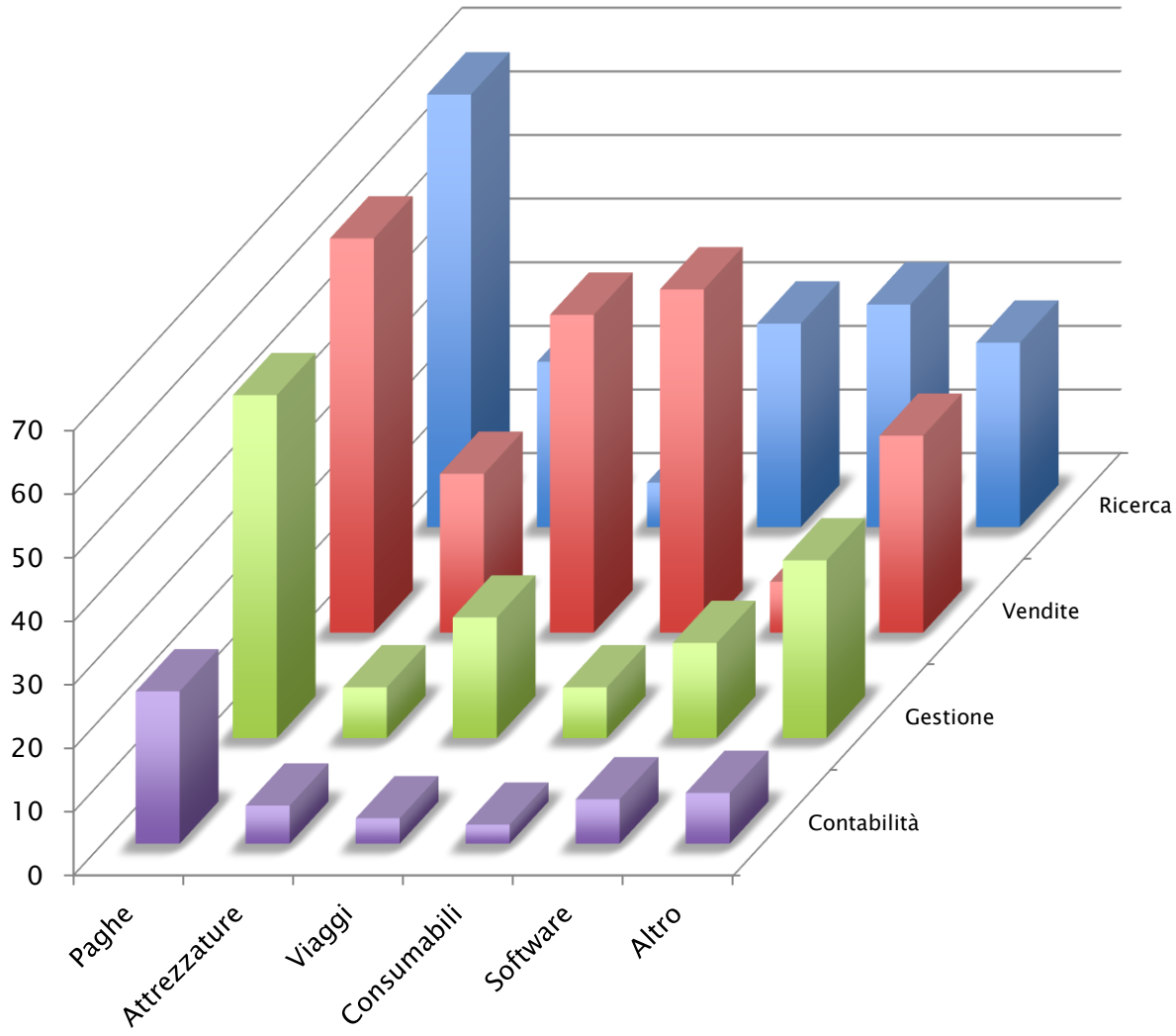
Avoid decorations

- Skeumorphic design
- Backgrounds motives
- Color gradients
- Variations not encoding any measure
  - Typically color

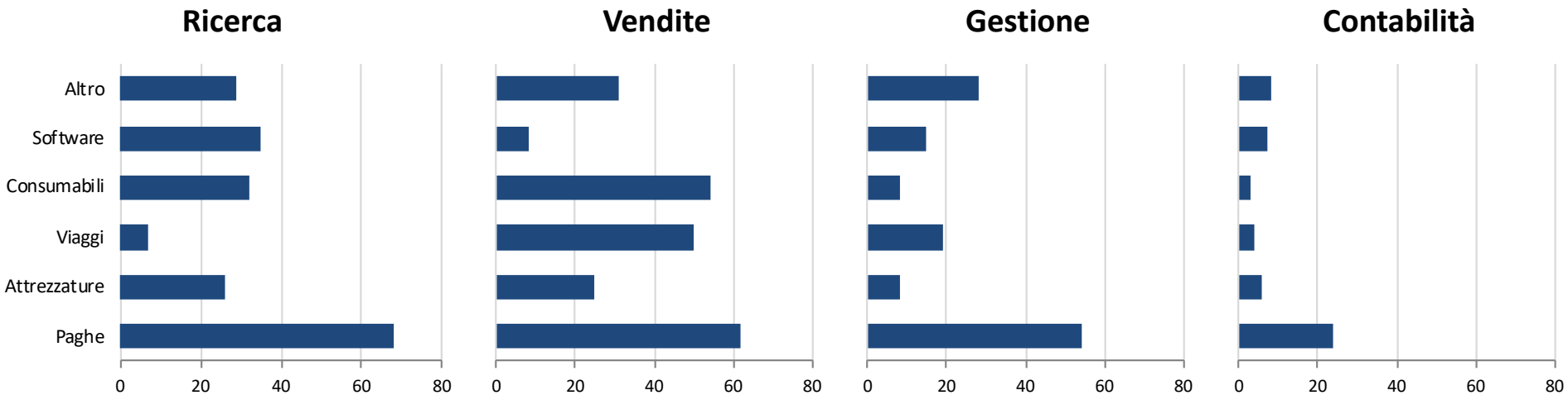
3D diagrams

- Encoding
  - Axonometry typically hides some data and makes comparison hard
- Not encoding
  - Perspective deform dimensions
  - Depth or height distract and make comparison more difficult

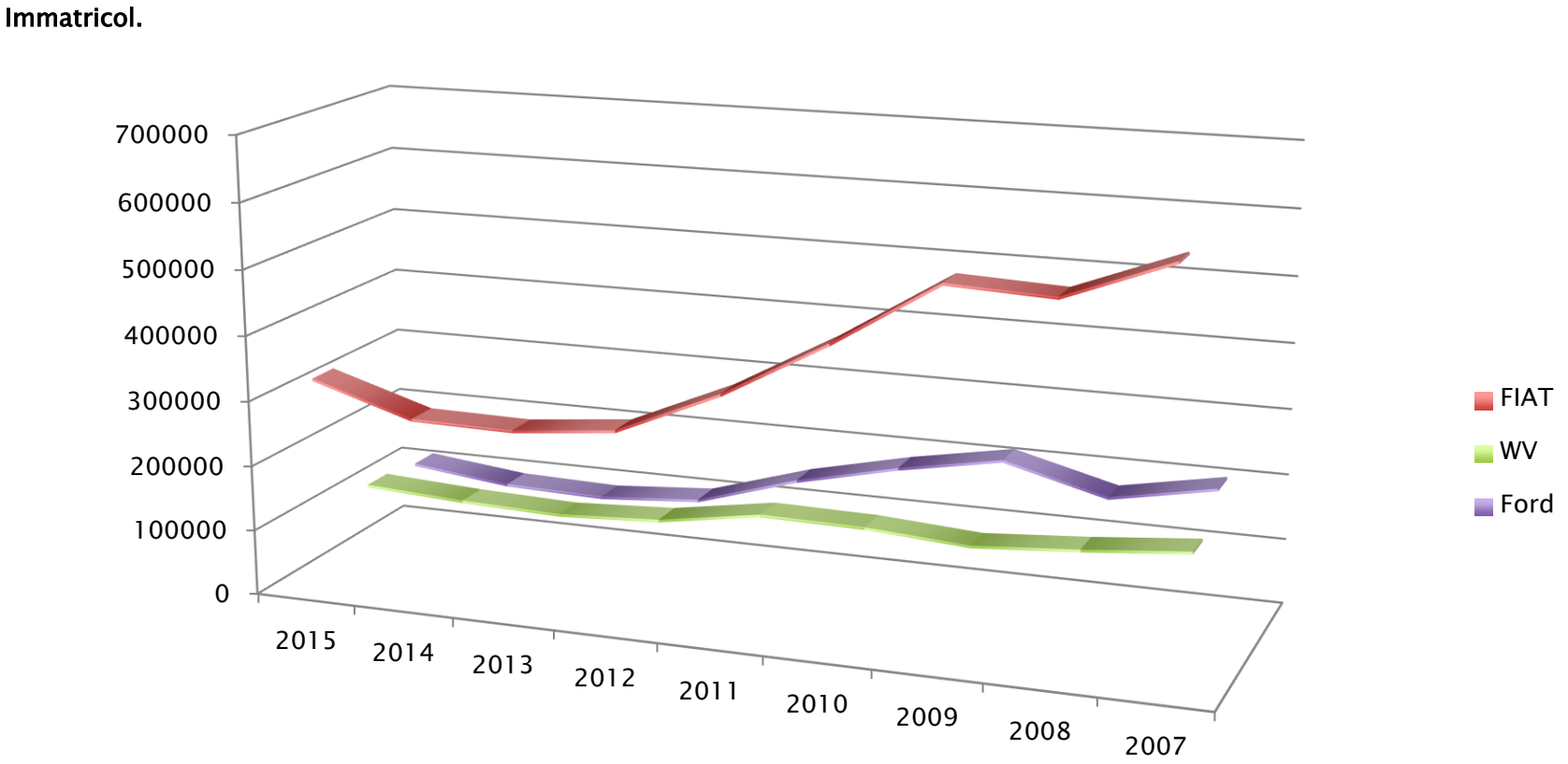
Encoding 3D


70
60
50
40
30
20
10
0
Paghe
Attrezzature
Viaggi
Consumabili
Software
Altro
Contabilità
Gestione
Vendite
Ricerca

Encoding 3D → 2D

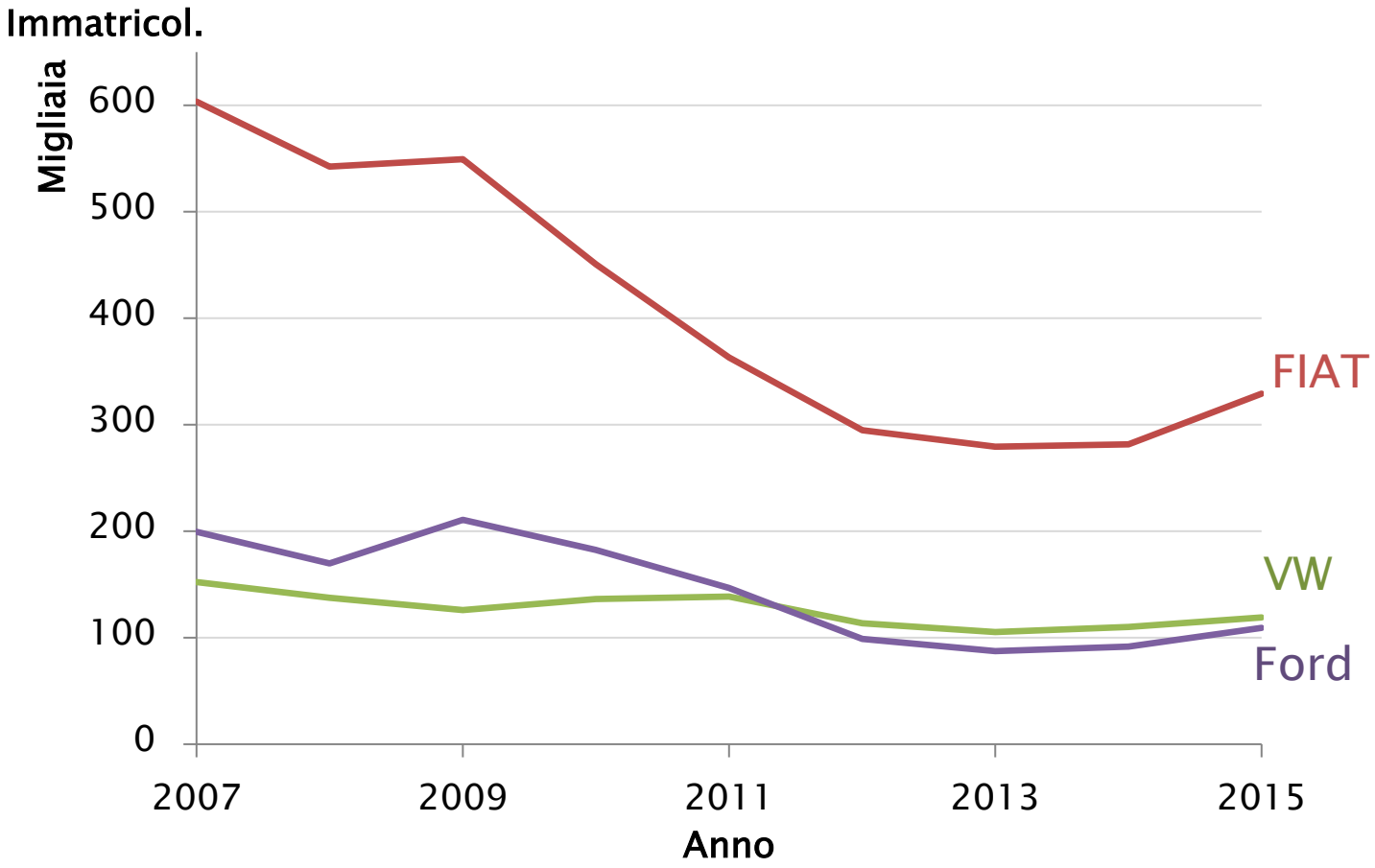


Decorative 3D



Decorative 3D → 2D

Immatricolazioni auto per marchio sul mercato italiano



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  - http://www.perceptualedge.com/blog/

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- Wickham, H. (2010). A layered grammar of graphics. *Journal of Computational and Graphical Statistics*, *19*(1), 3-28.
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- M.Correll, and M.Gleicher. Error Bars Considered Harmful: Exploring Alternate Encodings for Mean and Error *IEEE Transactions on Visualization and Computer Graphics, Dec. 2014*
  - http://graphics.cs.wisc.edu/Papers/2014/CG14/Preprint.pdf