Graph Construction

Data Management and Visualization

SoftEng
http://softeng.polito.it

Version 2.6.0

Grammar of Graphics

- Theory behind graphics construction
  - Separation of data from aesthetic
  - Definition of common plot/chart elements
  - Composition of such common 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*) and their aesthetic attributes (*e.g.*, *color, position*)
- GUIDE: guides (e.g., *axes*, *legends*)

Specification for a scatter plot

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

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 Encoding

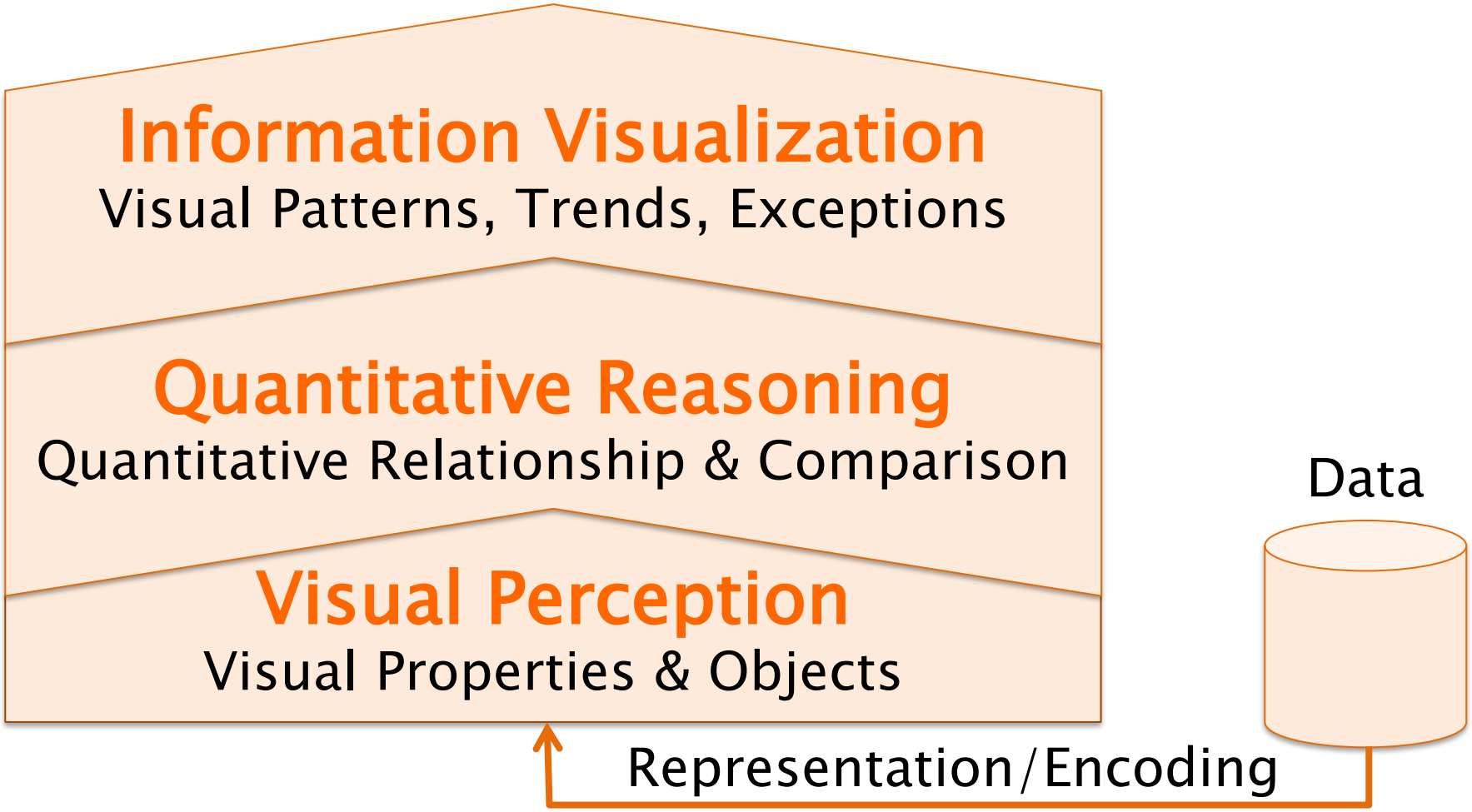
- Given a variable (measure), identify:
  - Visual object
  - Visual attribute

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

VISUAL RELATIONSHIPS

Data Visualization

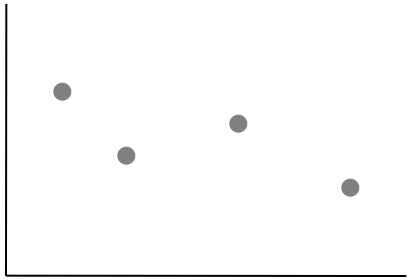
Understanding

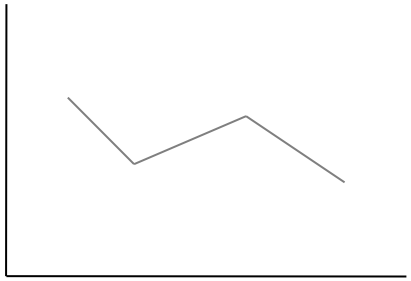


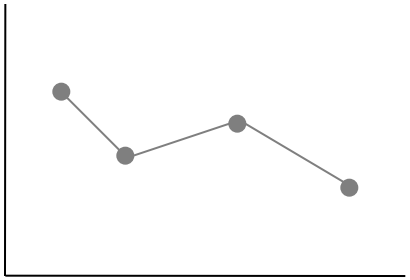
Relationships

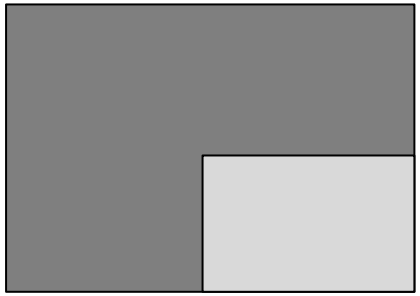
- Within a category
  - Nominal comparison
  - Ranking
  - Part-to-whole
  - Distribution
- Between measures
  - Time series
  - Deviation
  - Correlation

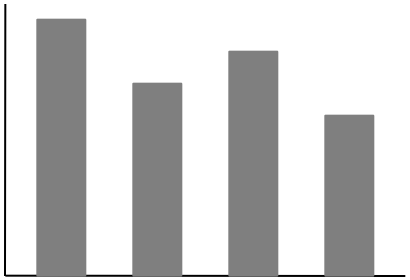
Quantitative encoding





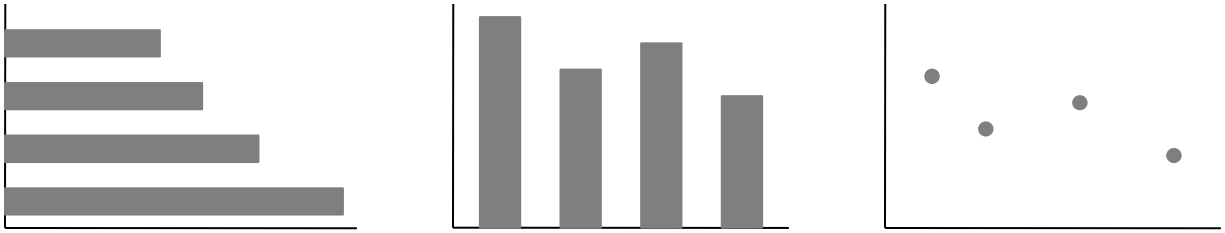




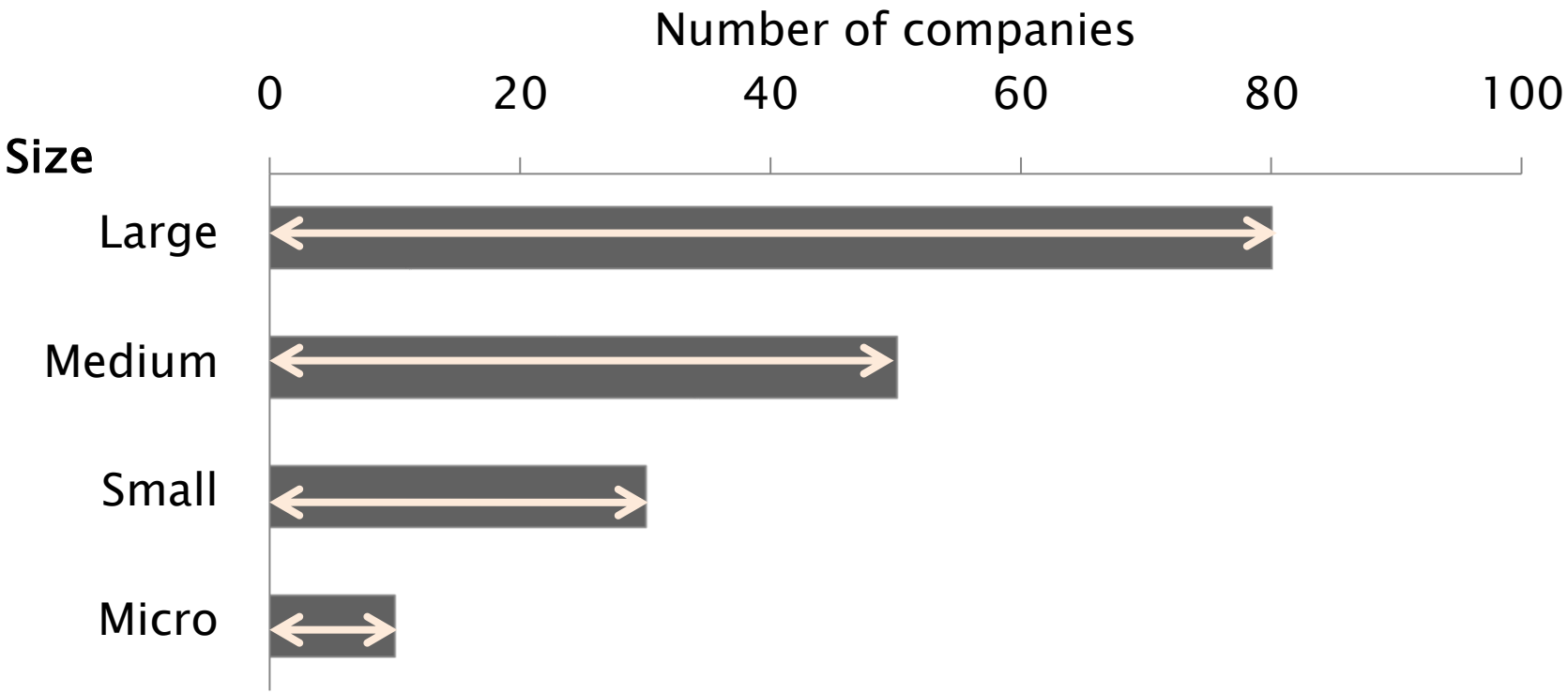


Nominal comparison

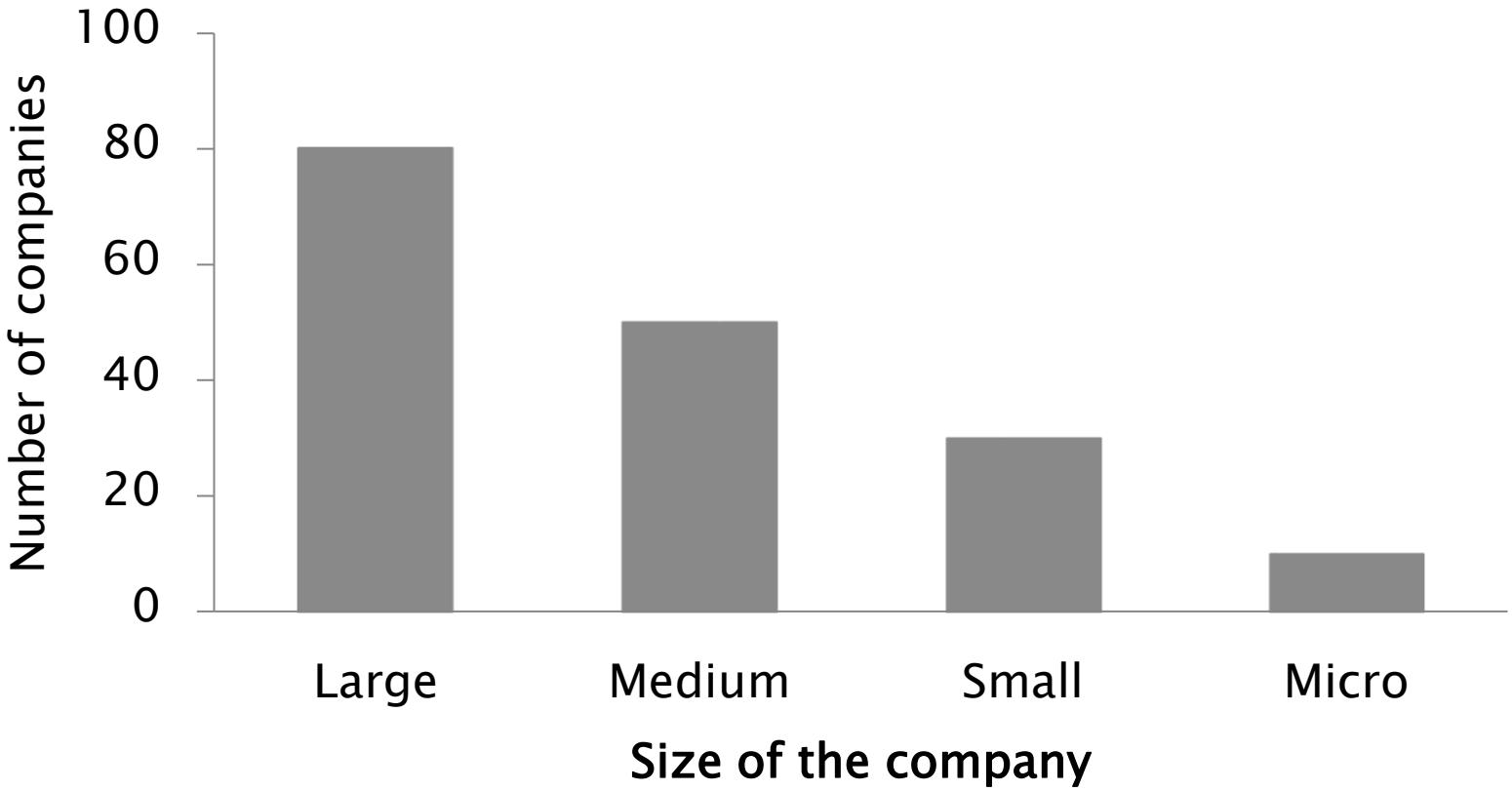
- Compare quantitative values corresponding to categorical levels
  - Small differences are difficult to see
    - Non zero-based scale can emphasize
  - Dot plots can be used for small differences
    - They do not require zero based scale



Line length – Bars chart



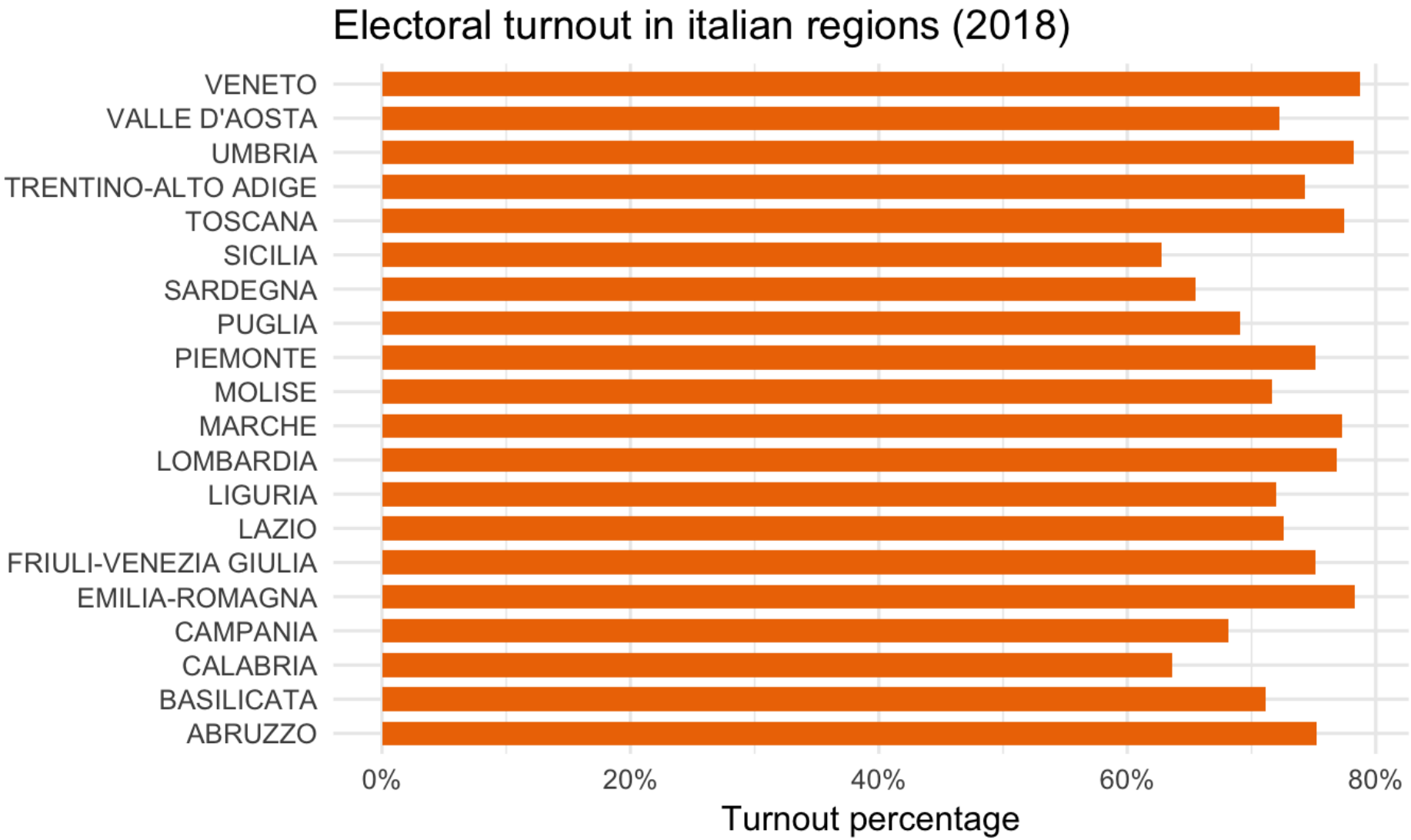
Vertical Bars (aka Columns)



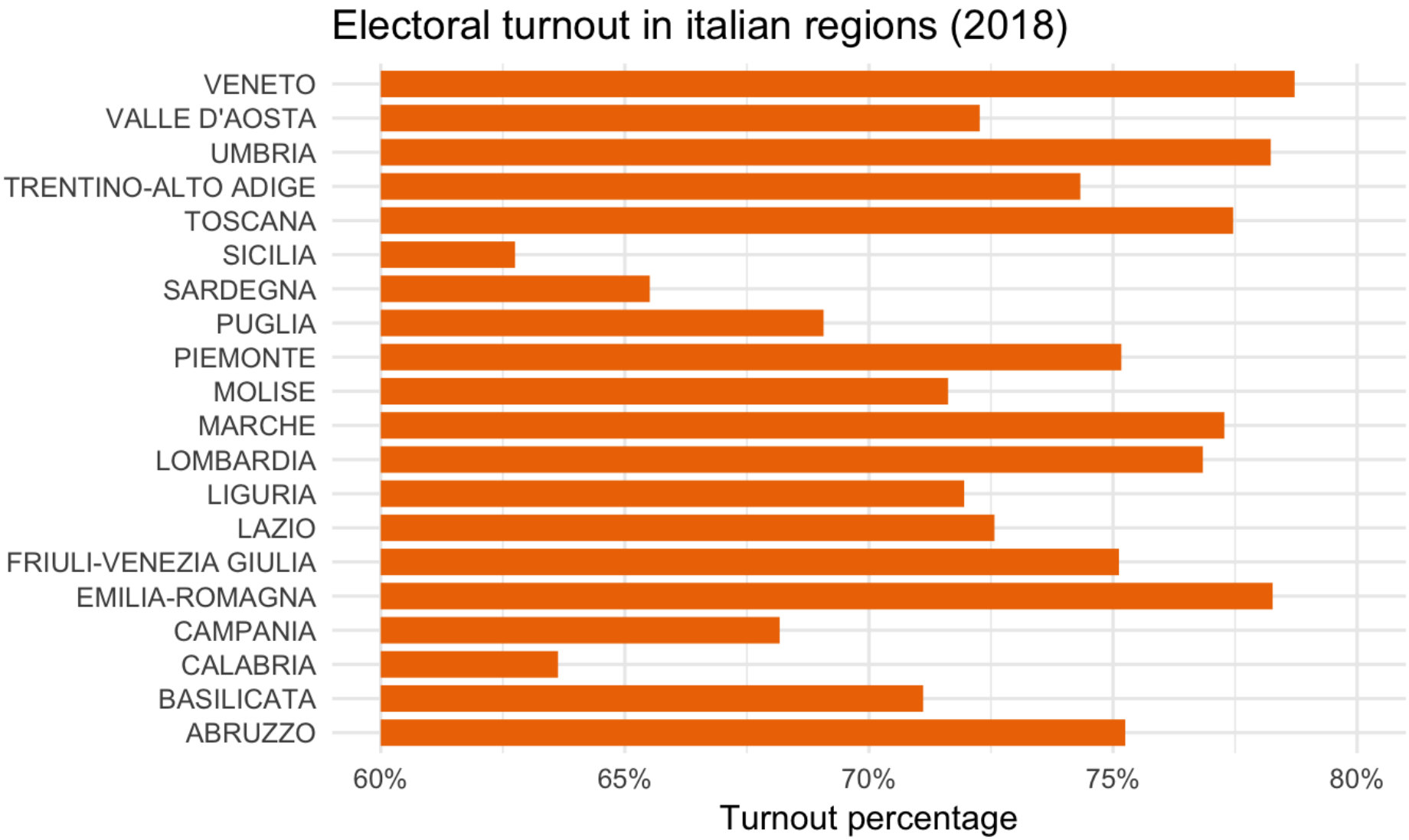
Bar charts

- 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!

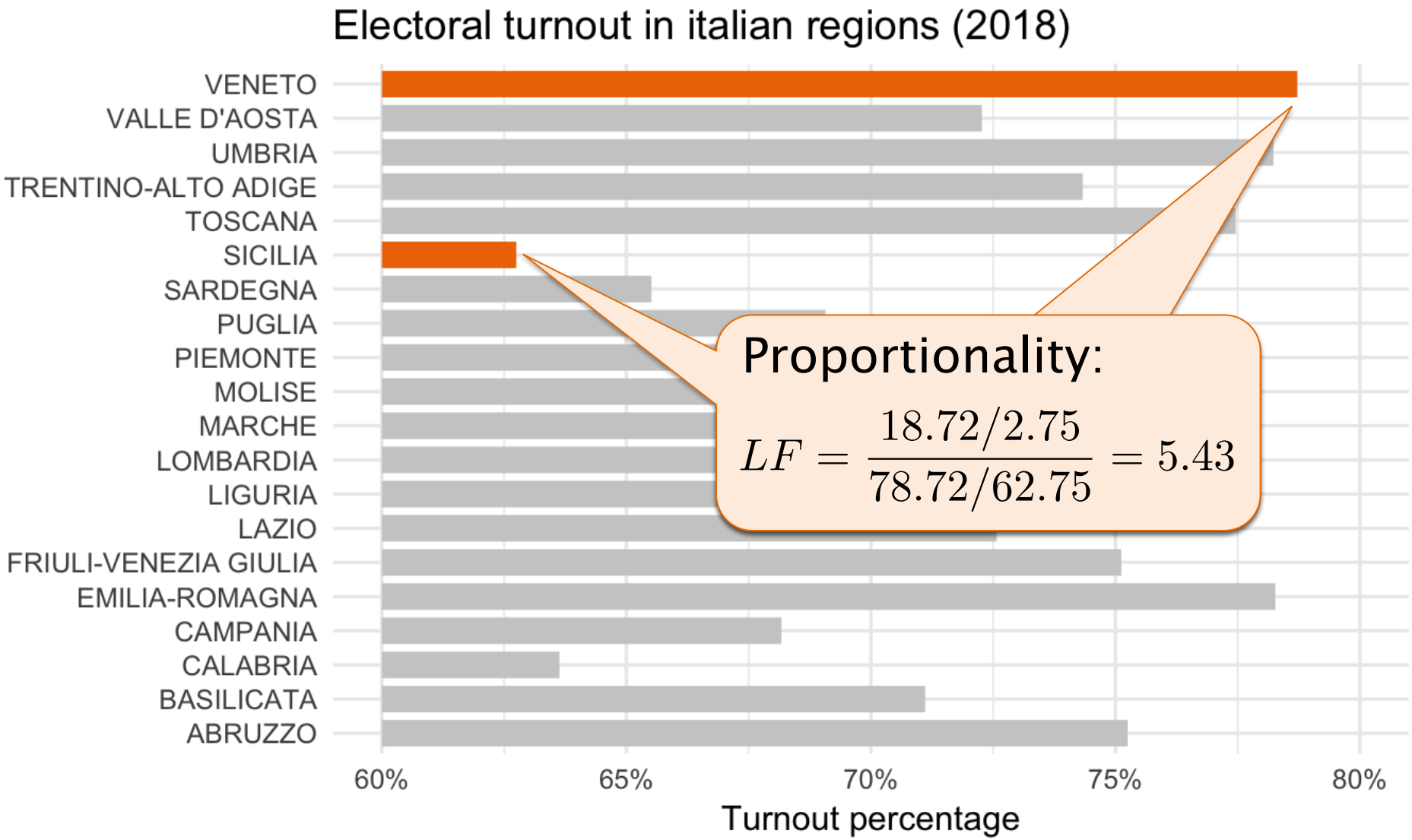
Comparison – Barplot



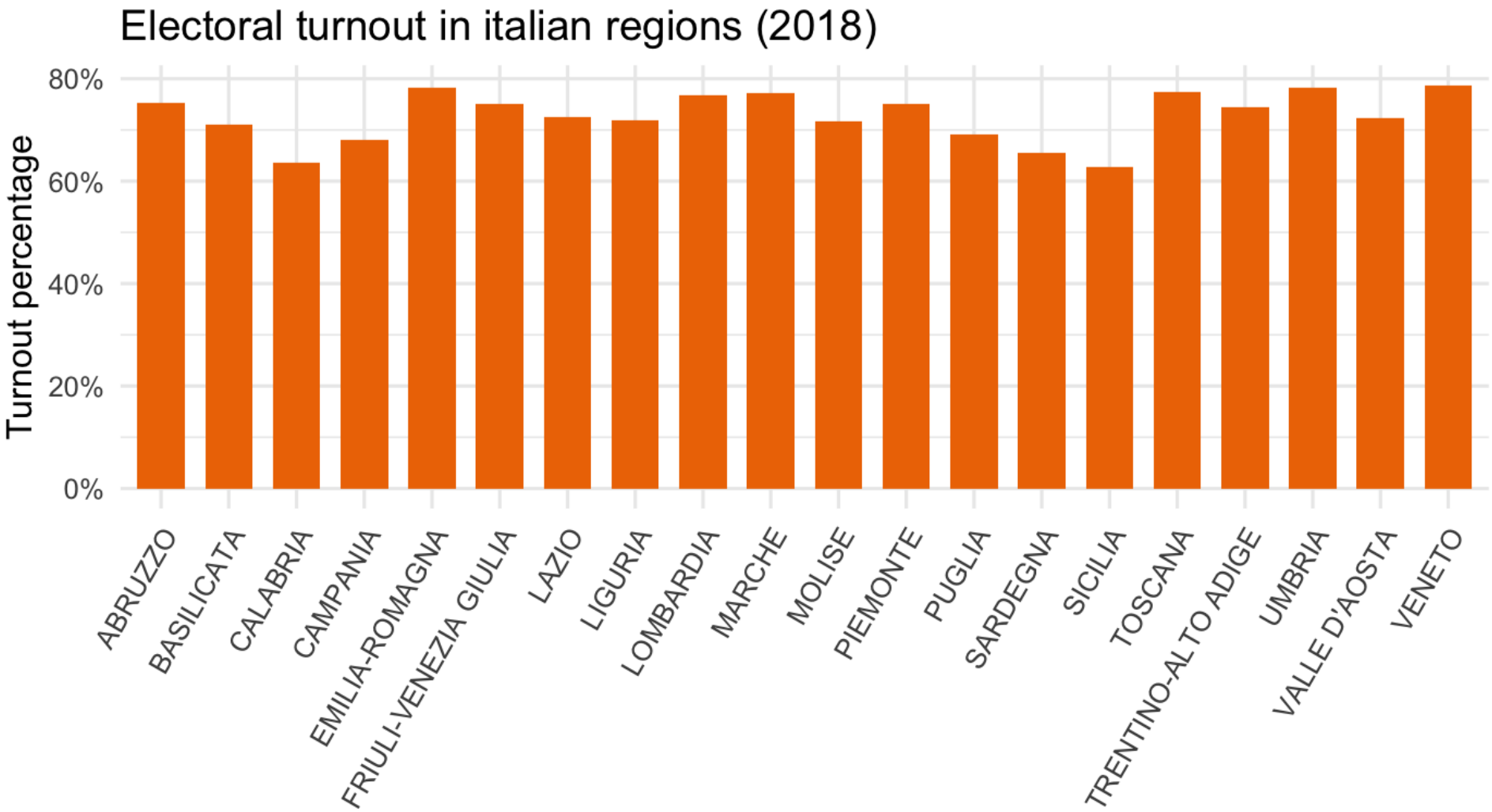
Barplot (non zero based scale)



Barplot (non zero based scale)



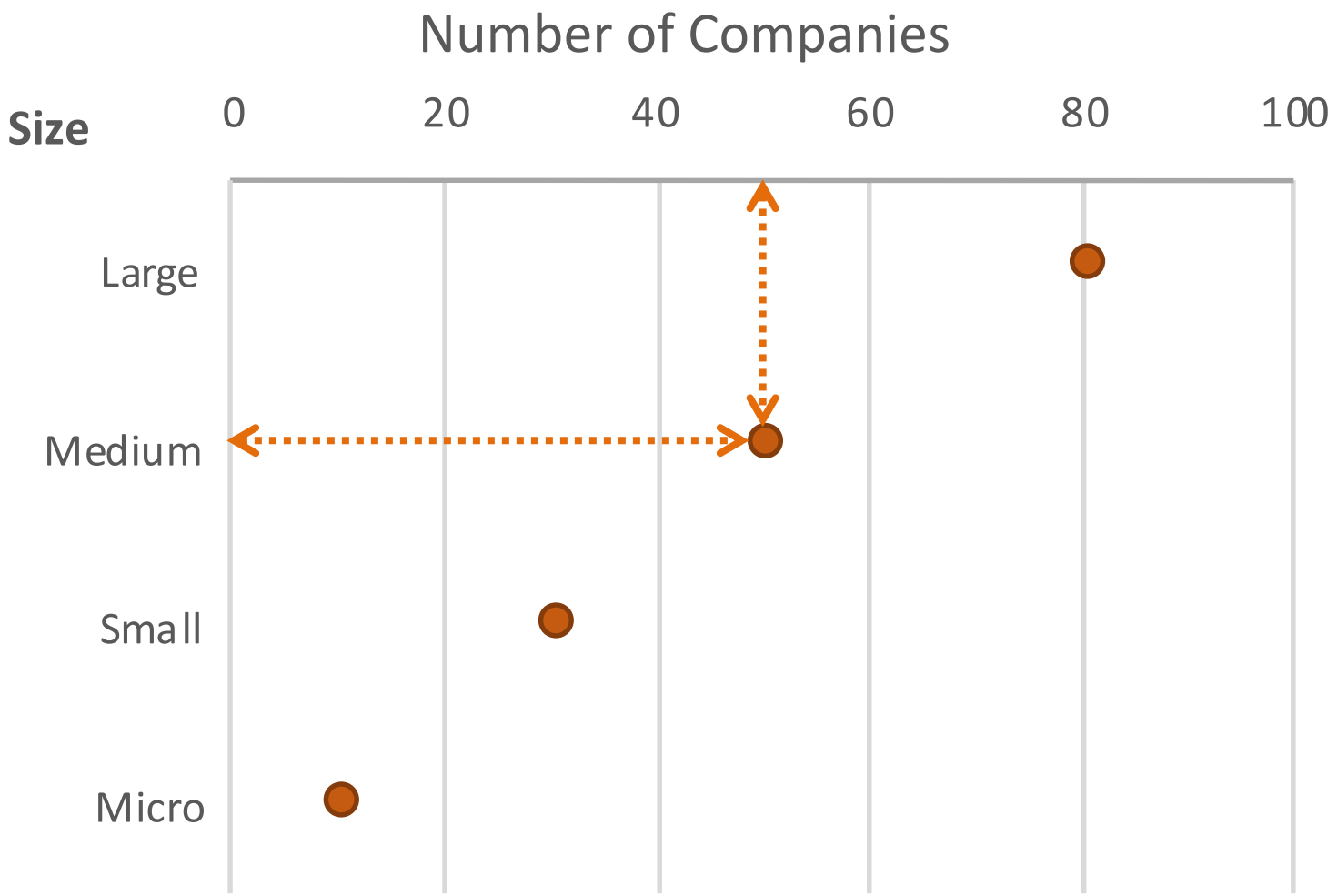
Barplot vertical labels



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

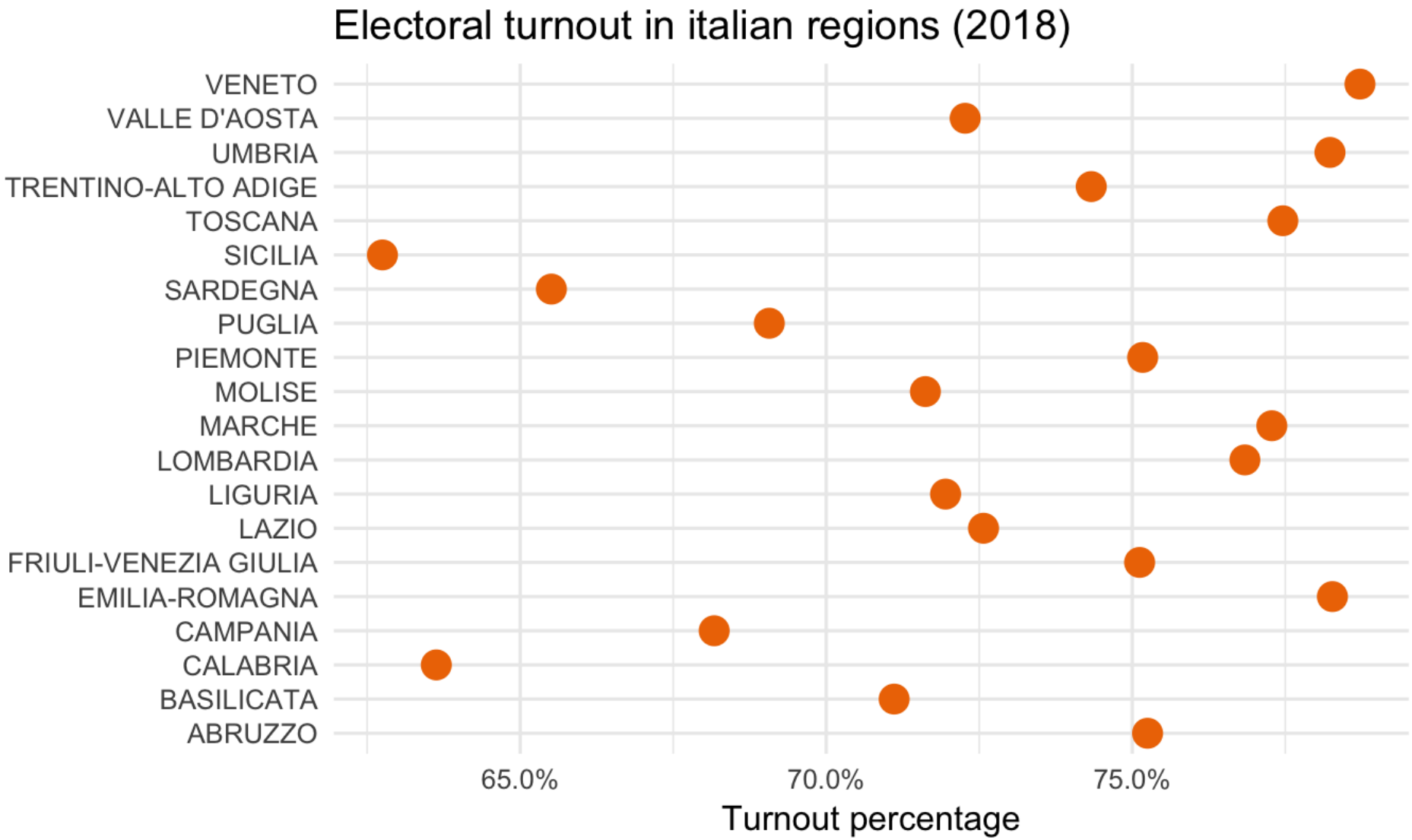
Position – Dots plot



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

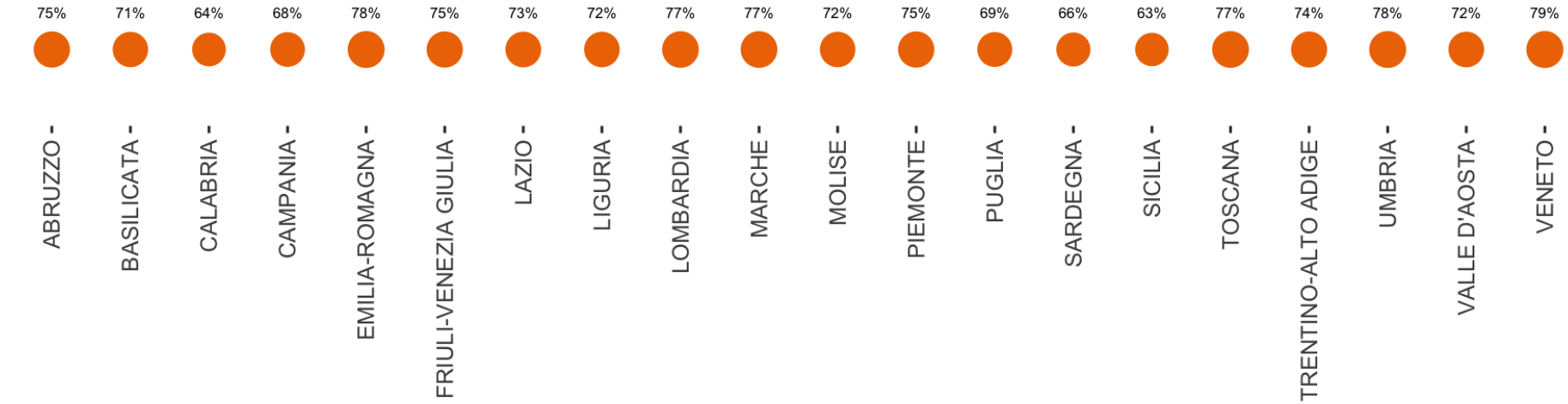
Comparison – Dot plot



Area – Bubble plot

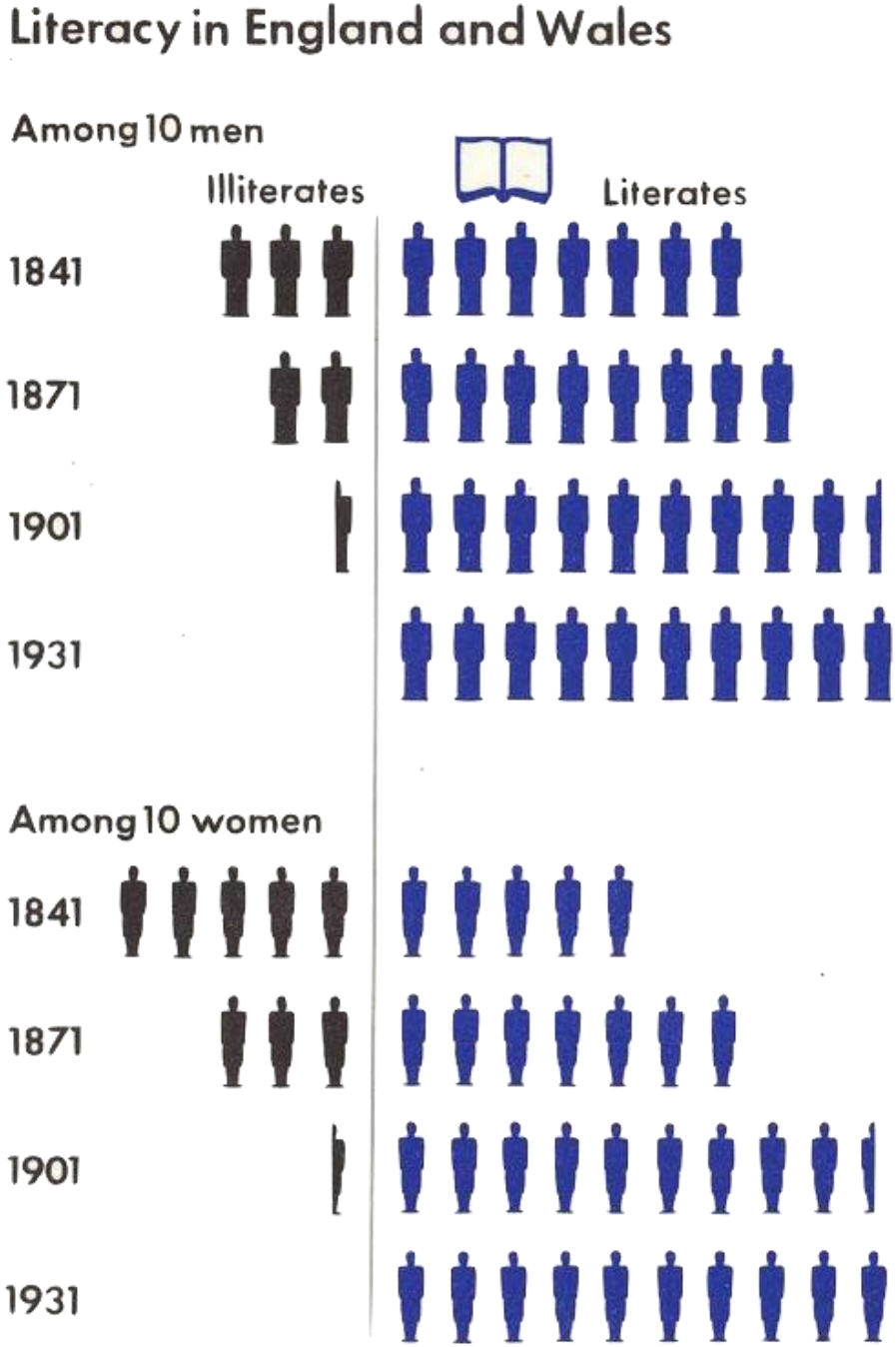
Extremely difficult to compare size

Electoral turnout in italian regions (2018)



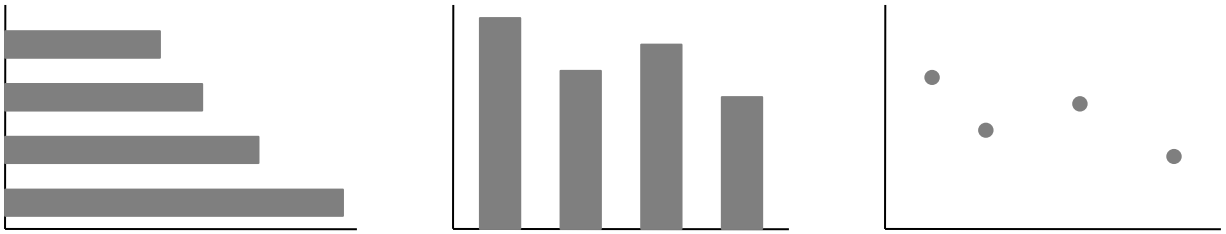
Count – Isotype

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



Ranking

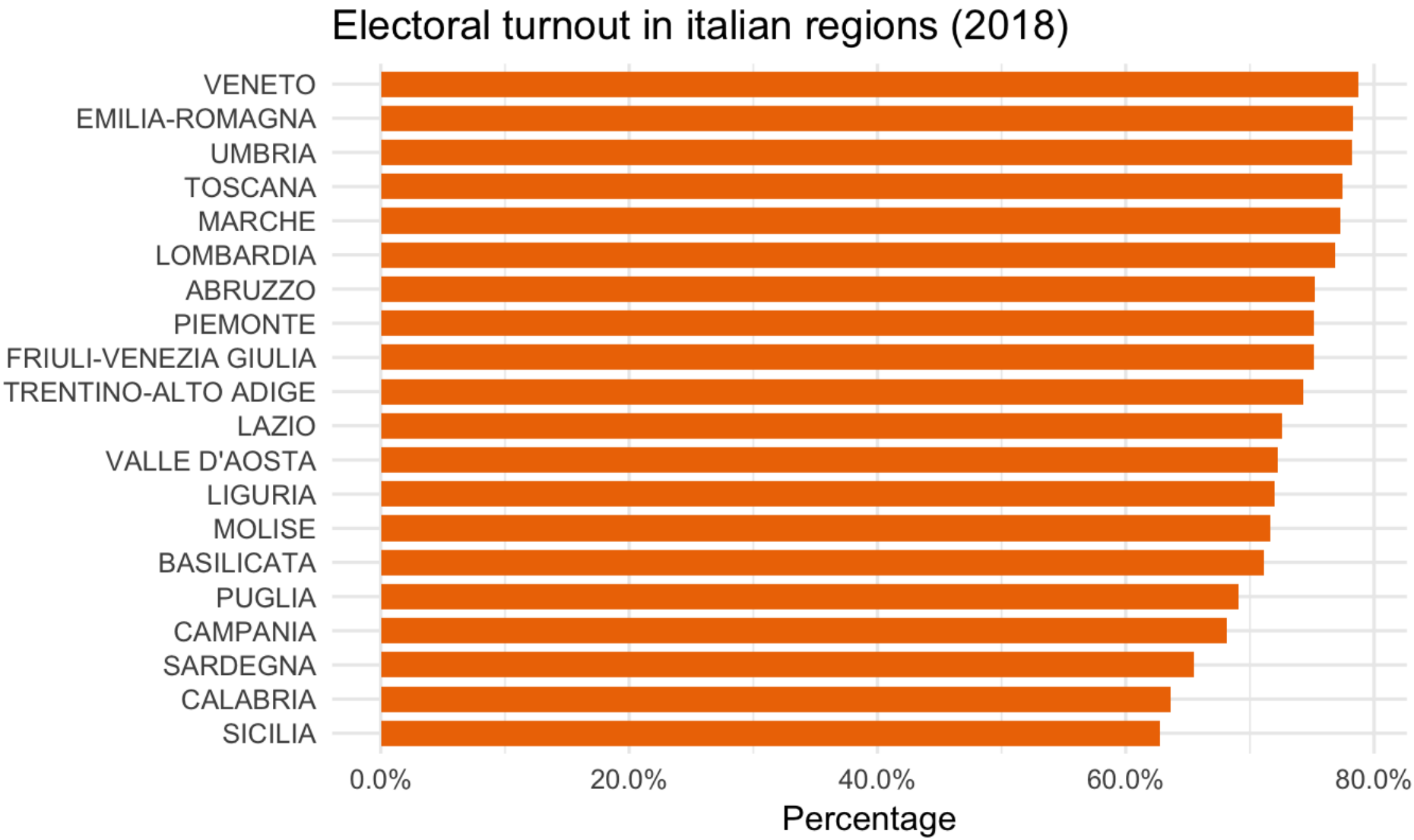
- Same type as nominal comparison
- Pay attention to order
  - Bar graphs
  - Dot plot
    - Allow non zero-based axes



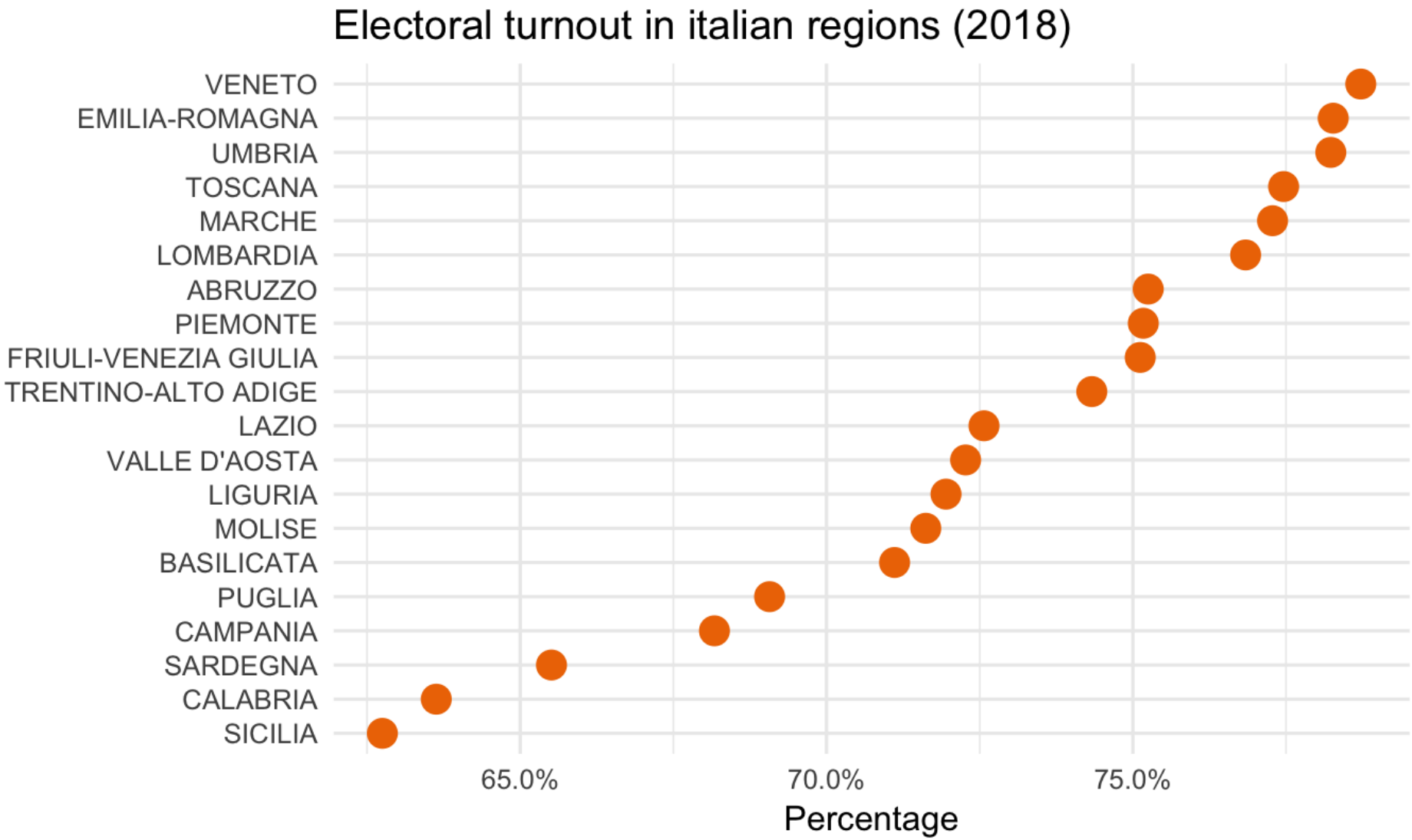
Ranking

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

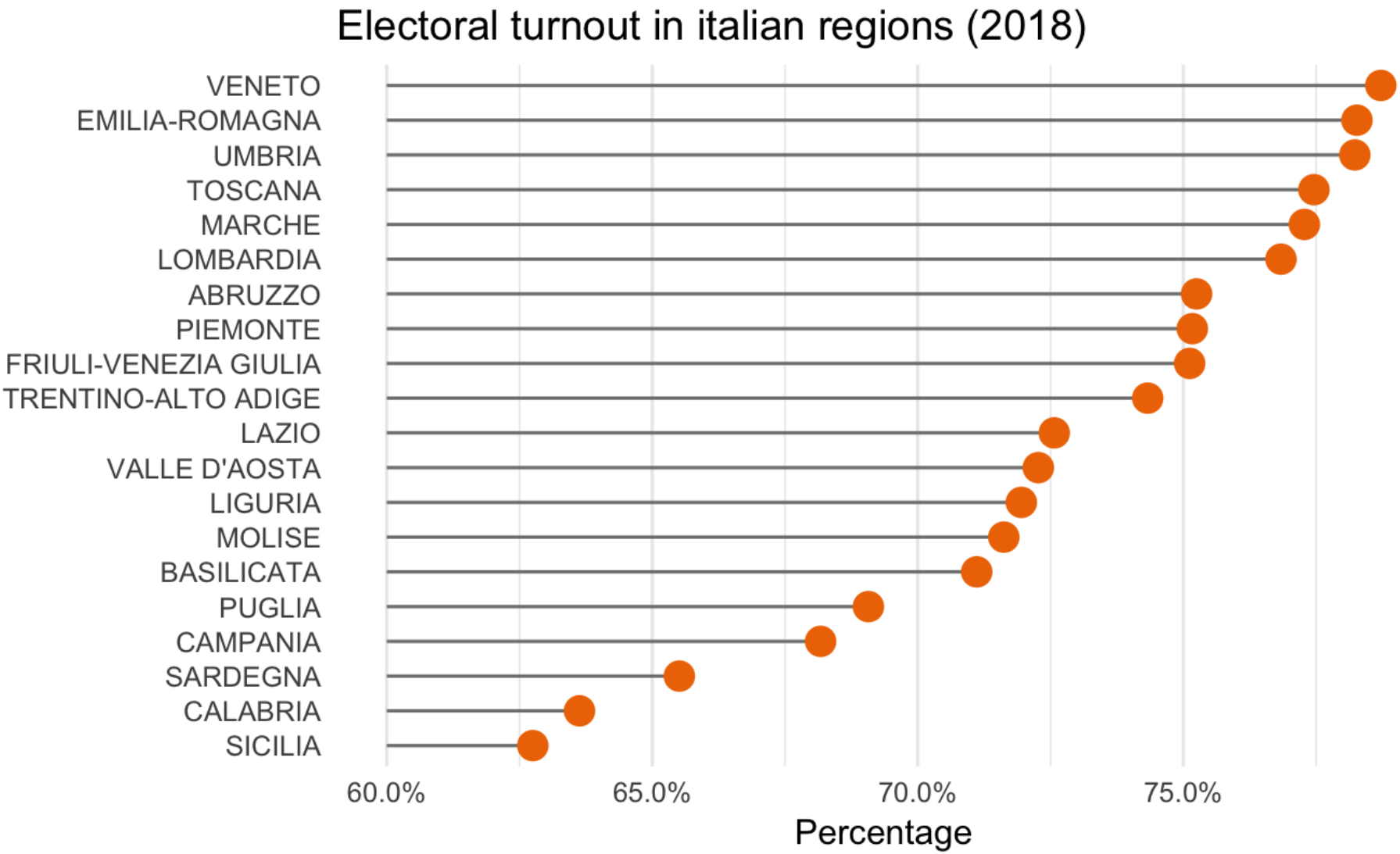
Ranking – Barplot



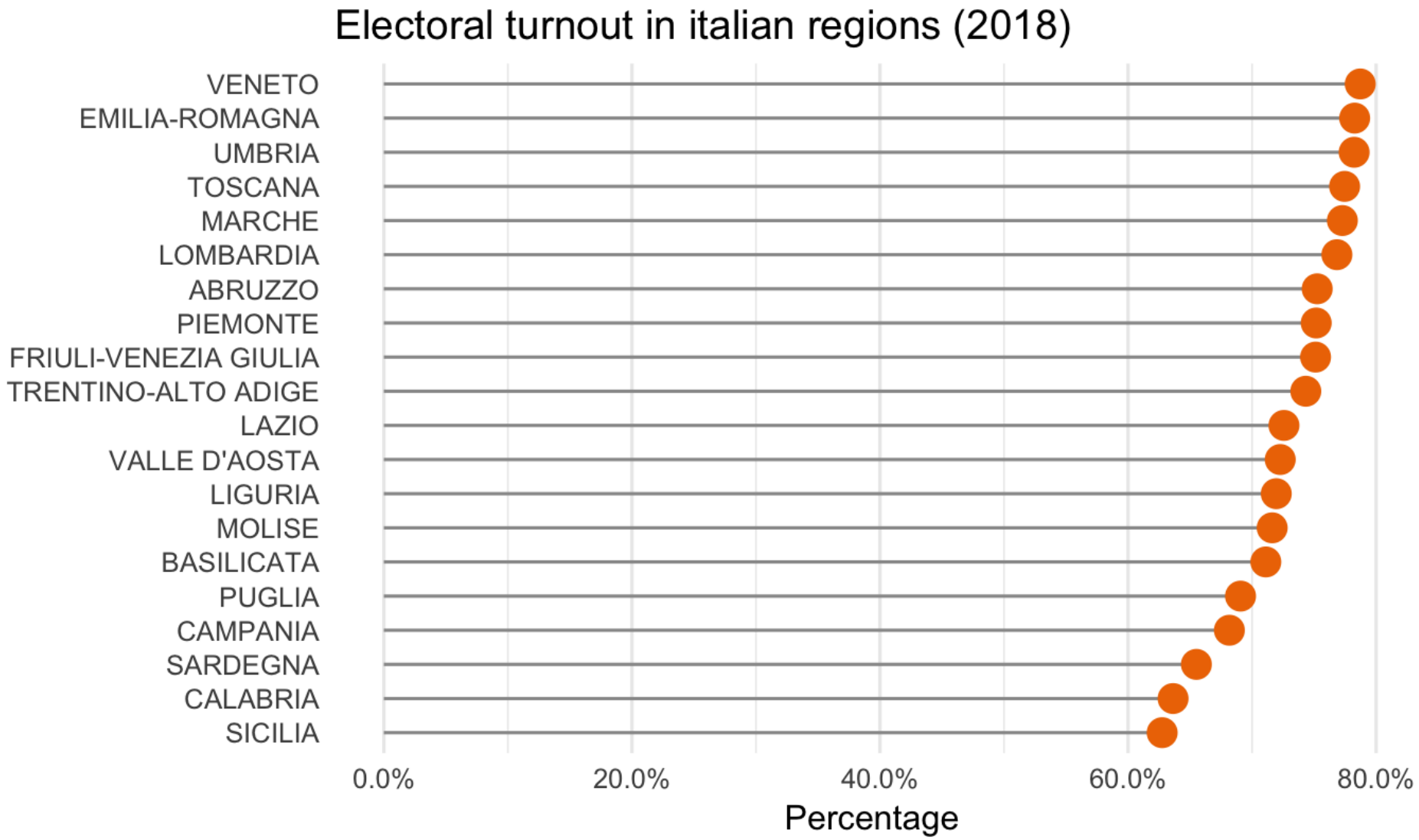
Ranking – Dot plot



Lollypop (non zero based scale)

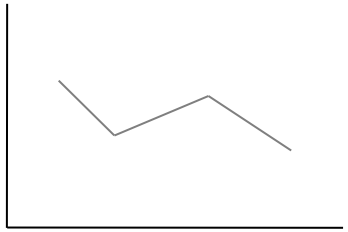
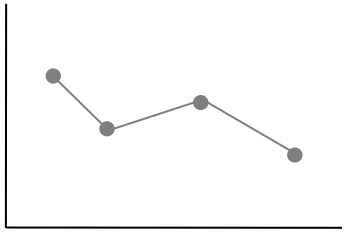


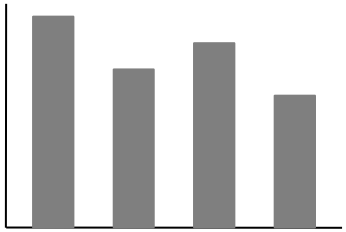
Lollypop (zero based scale)



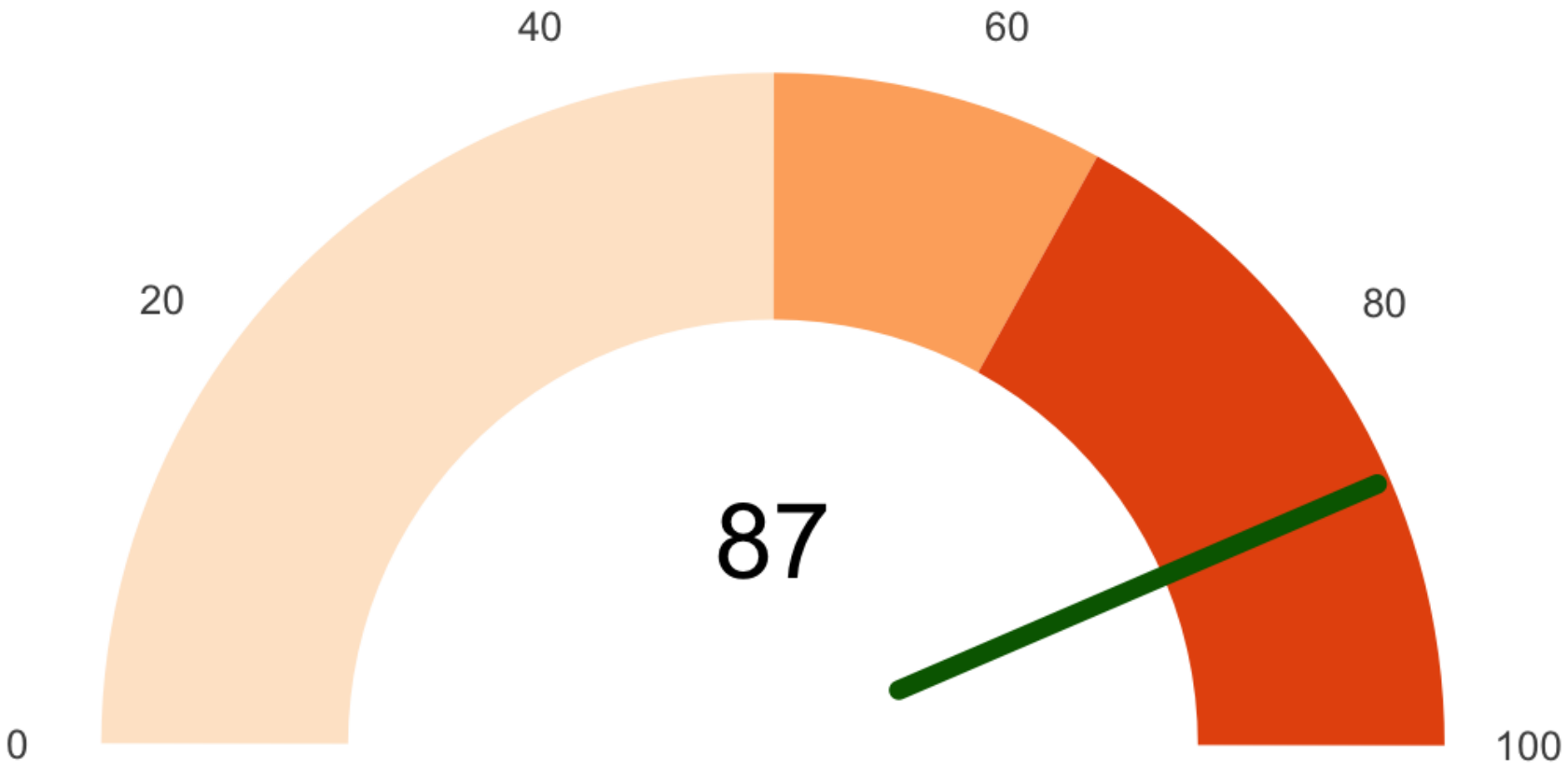
Deviation

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

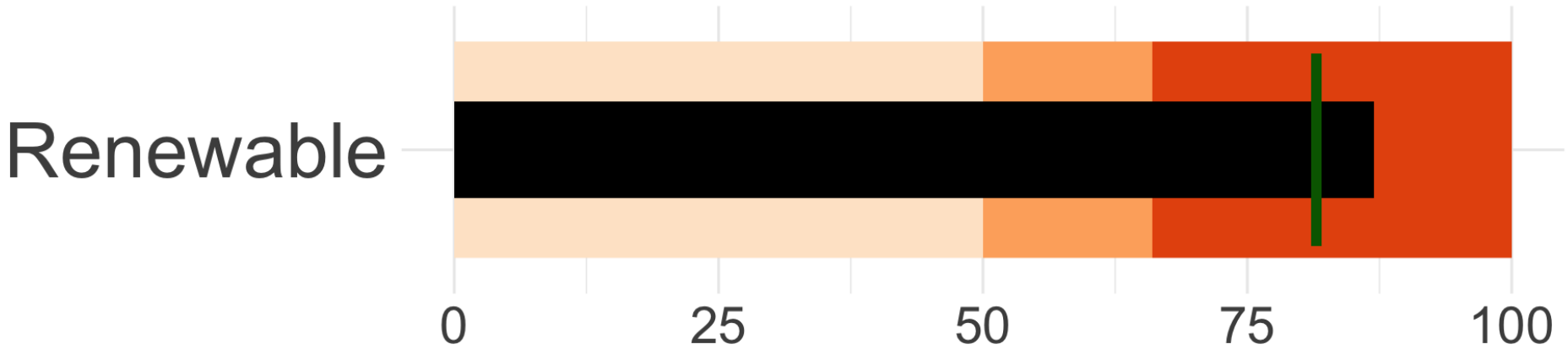





Angle + Position – Gauge



Length+Position- Bullet Graph

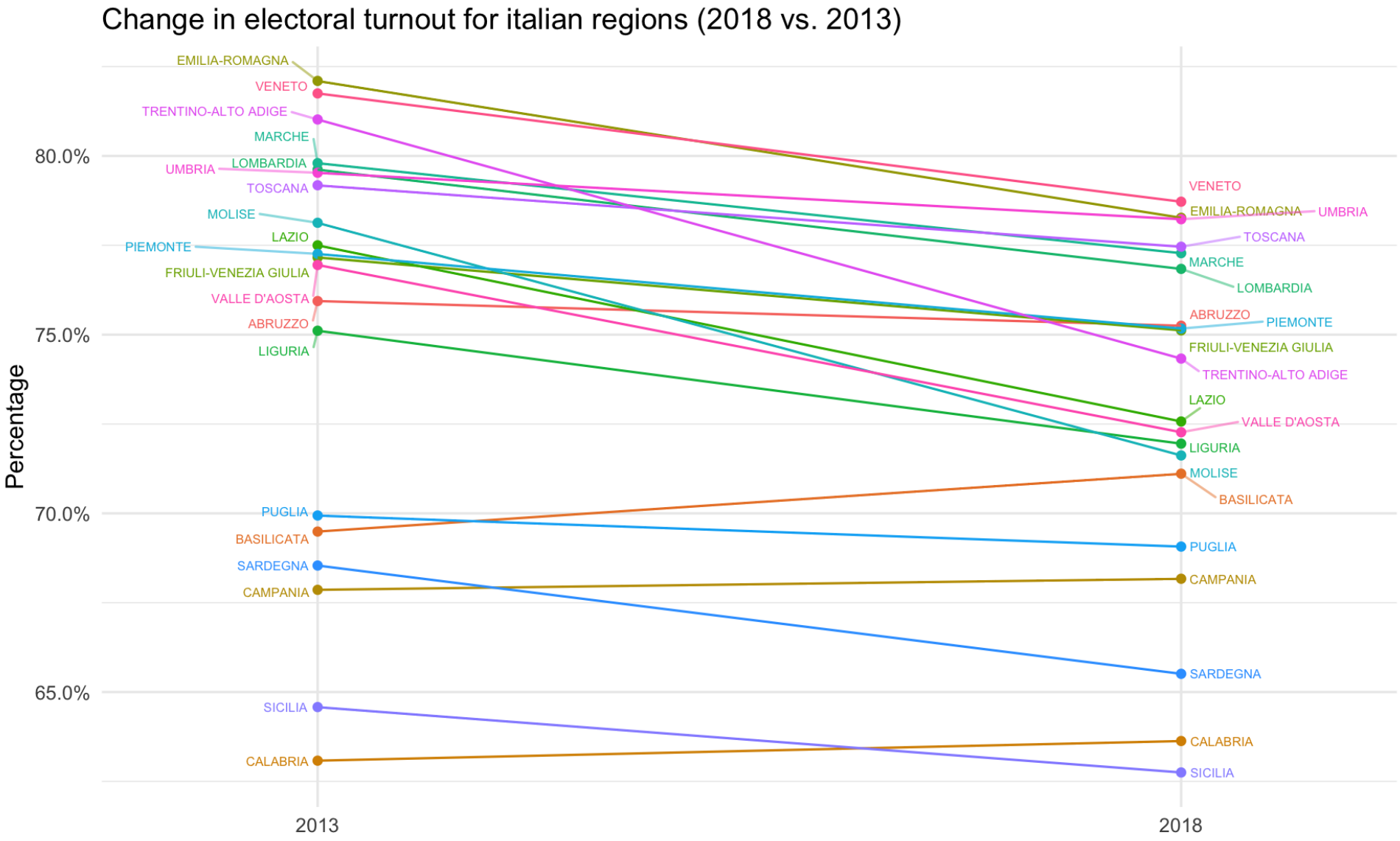


https://www.perceptualedge.com/articles/misc/Bullet_Graph_Design_Spec.pdf

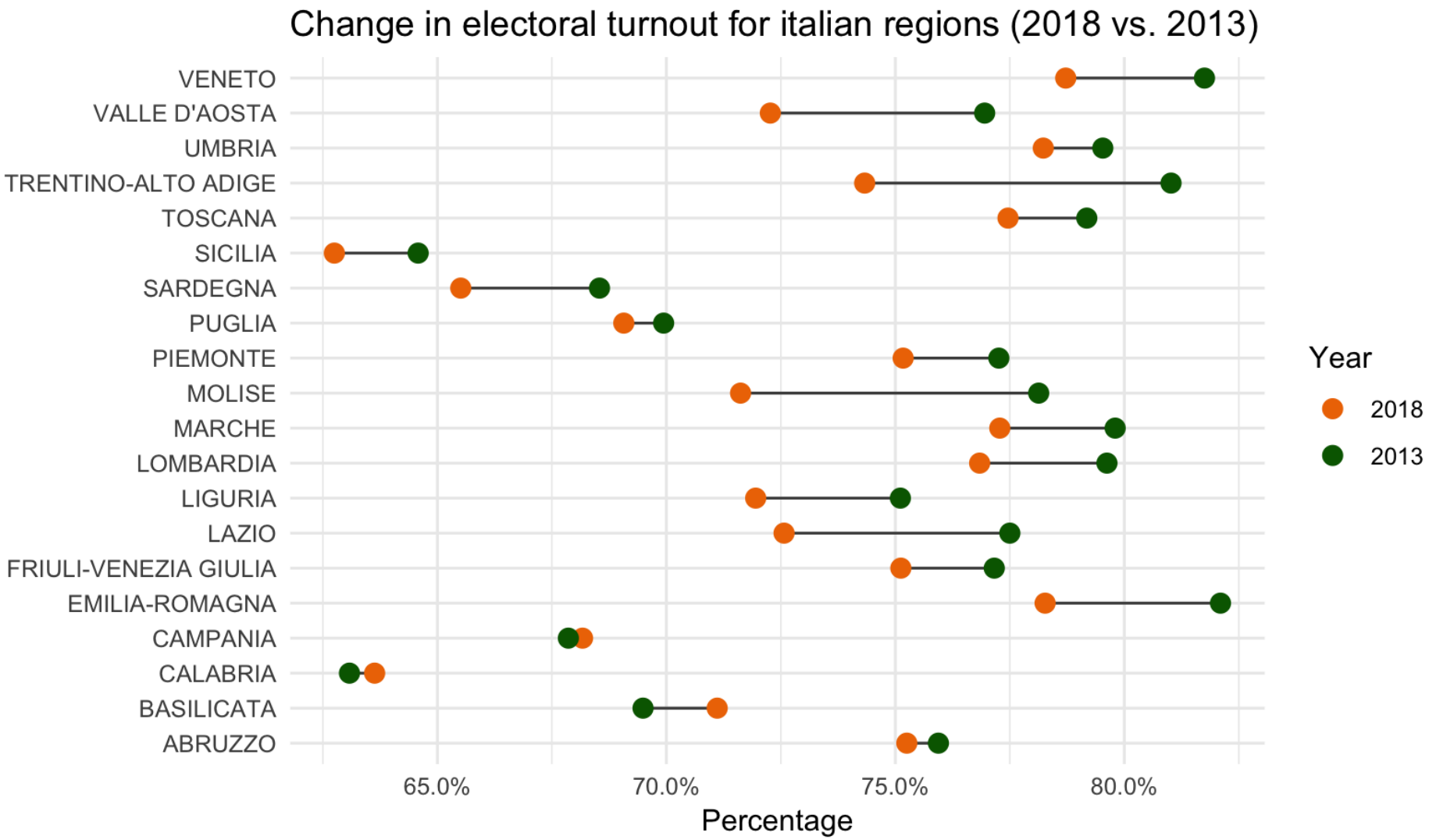
Pre-post variation

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

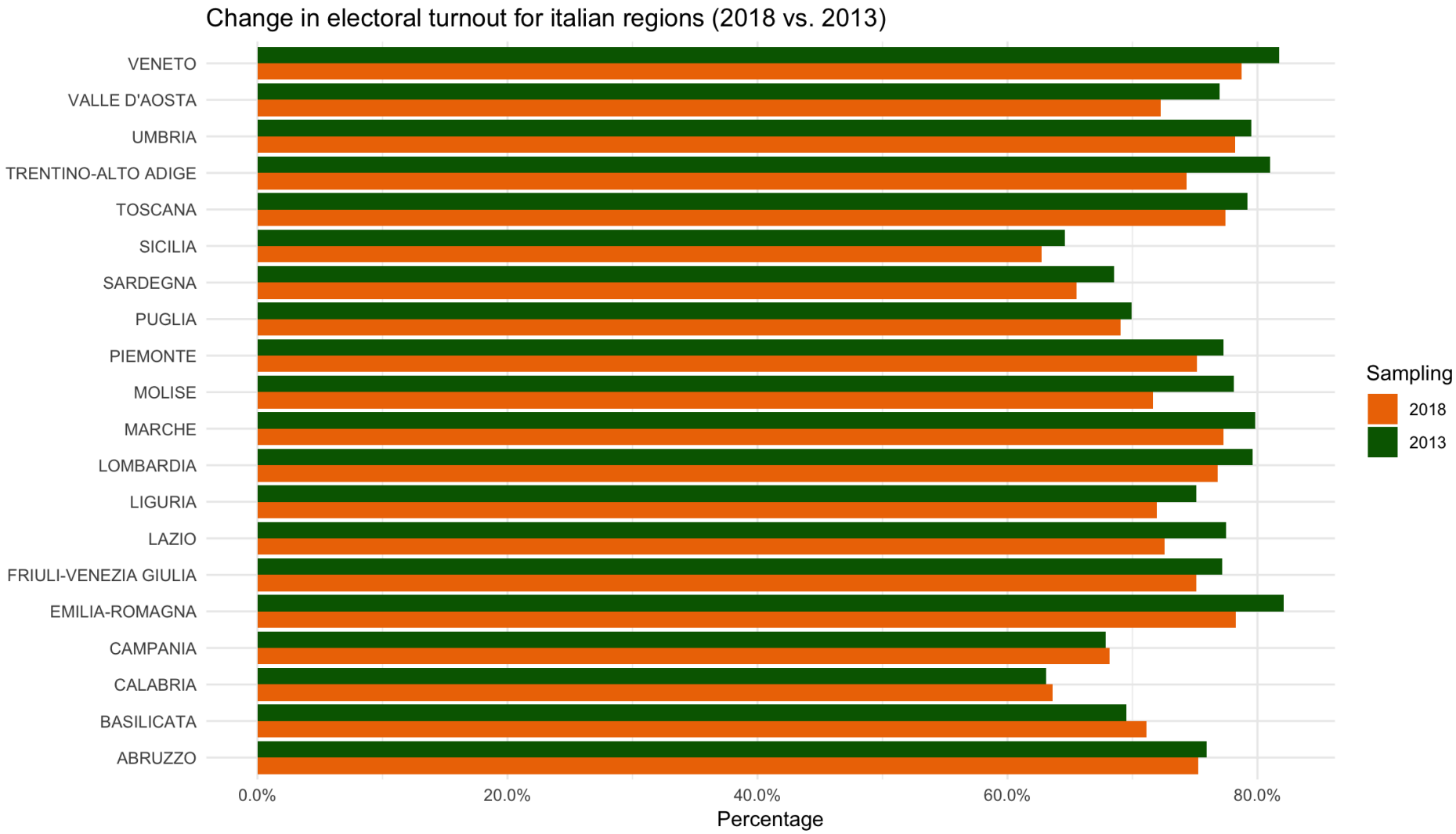
Slope chart


Change in electoral turnout for italian regions (2018 vs. 2013)
Percentage
80.0%
75.0%
70.0%
65.0%
2013
2018
EMILIA-ROMAGNA
VENETO
TRENTINO-ALTO ADIGE
MARCHE
UMBRIA
LOMBARDIA
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

Dumbbell plot

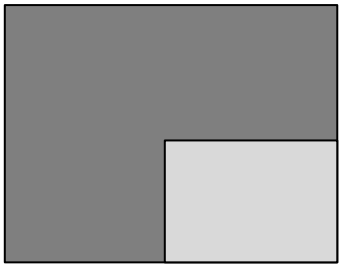


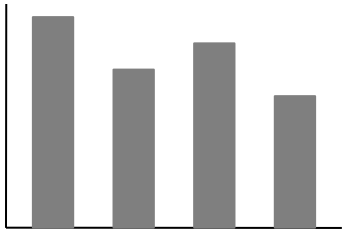
Clustered bars



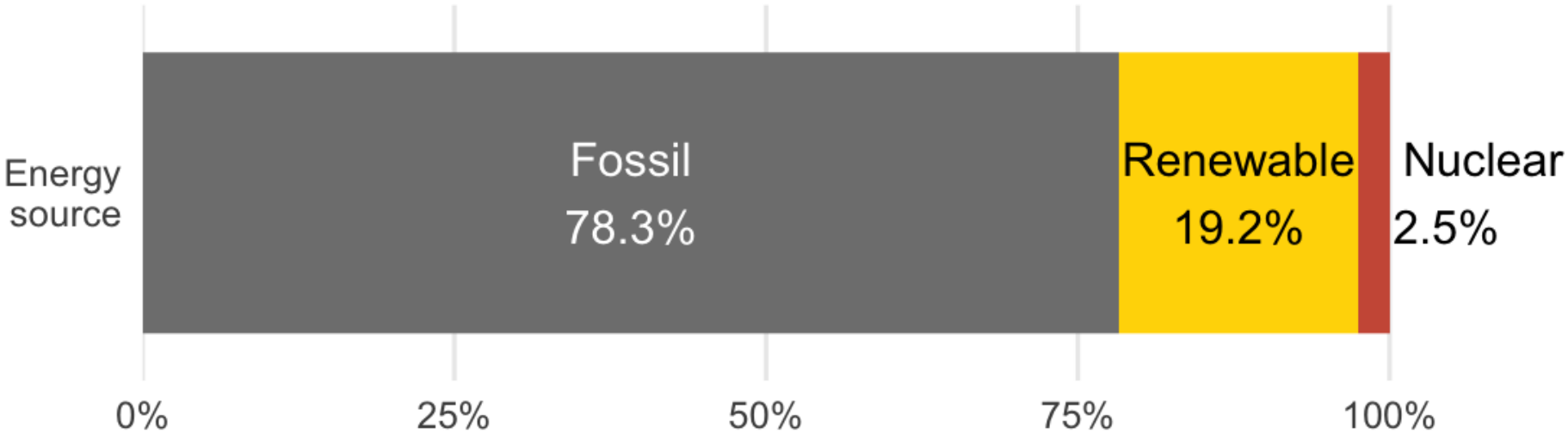
Proportion (Part-to-whole)

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



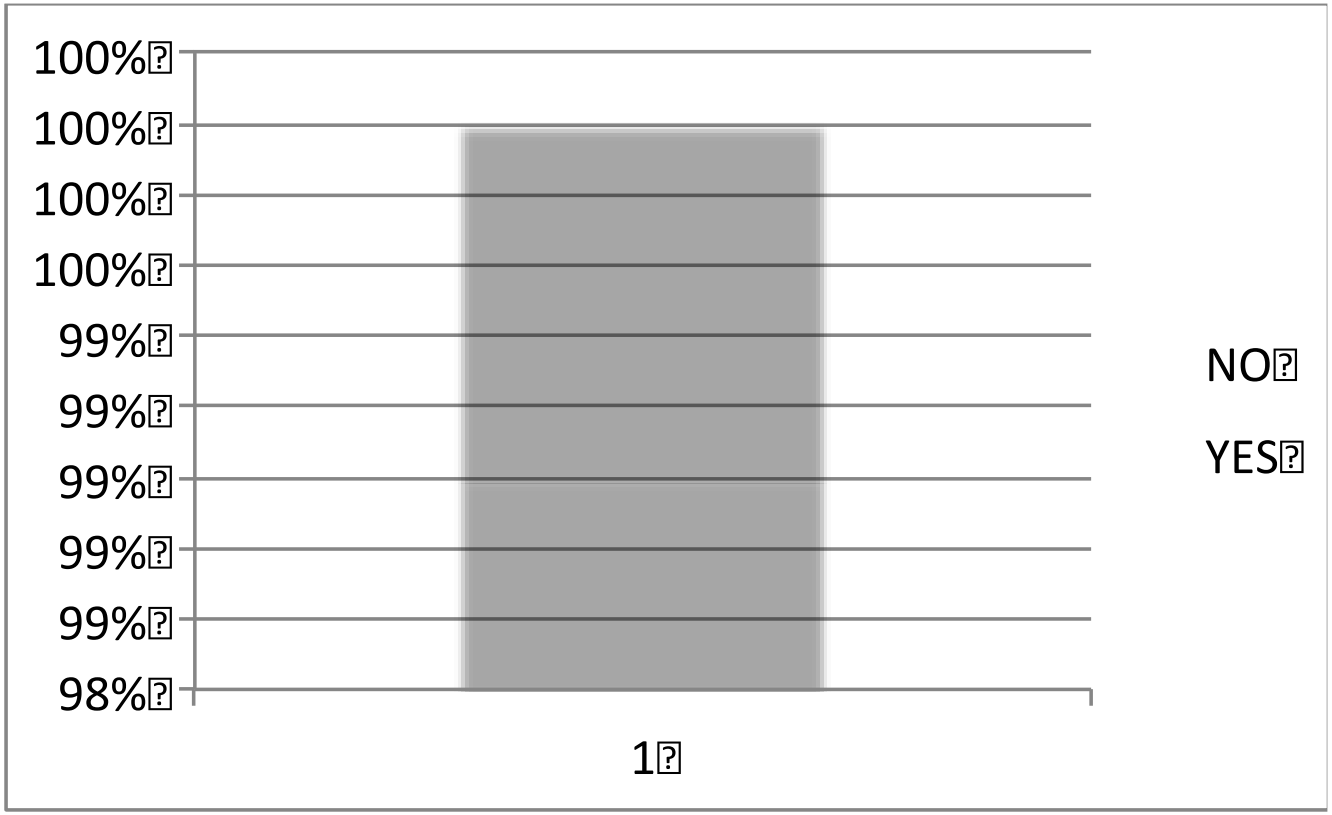


Length – Stacked Bar

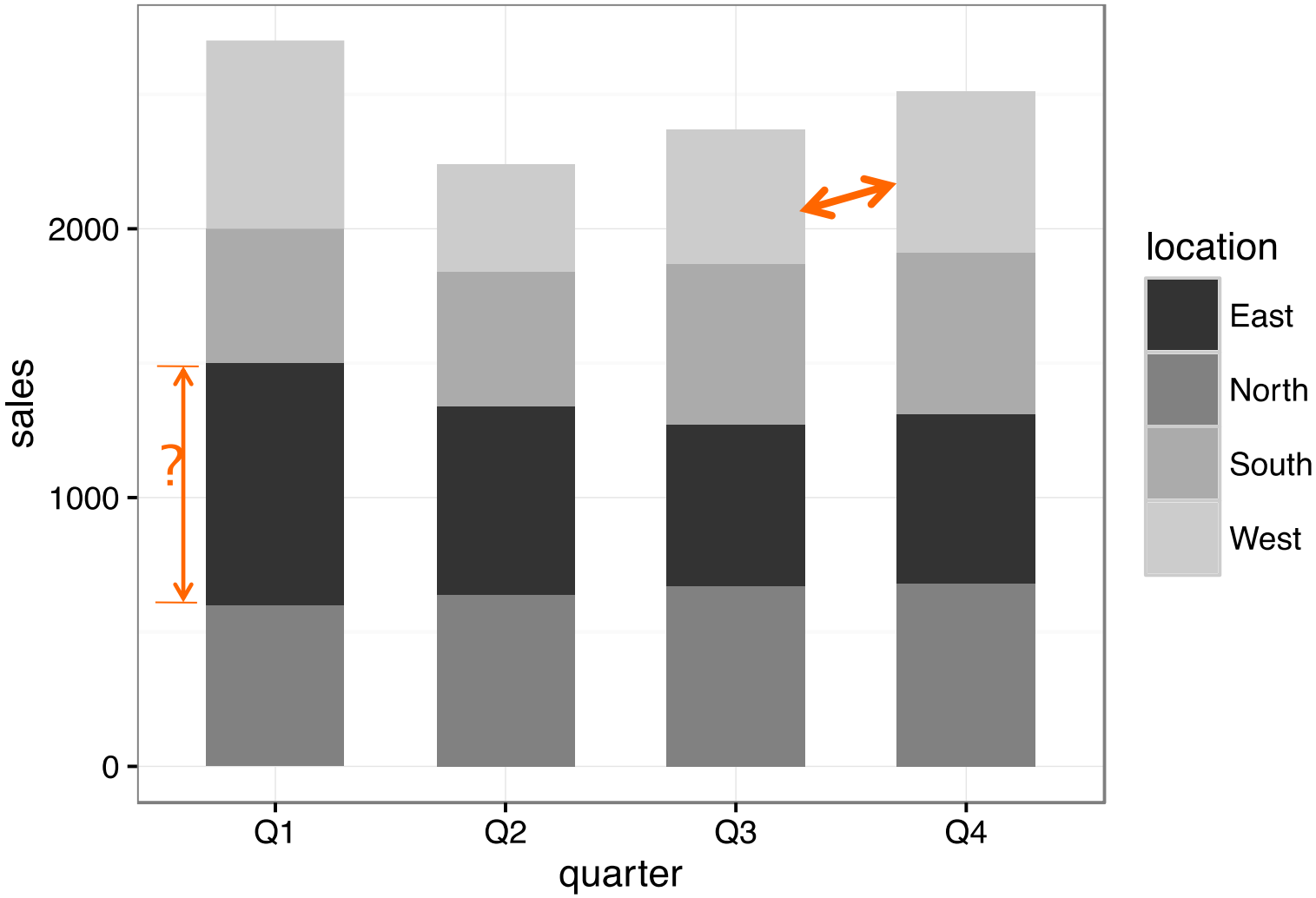


Beware MS-Excel Default

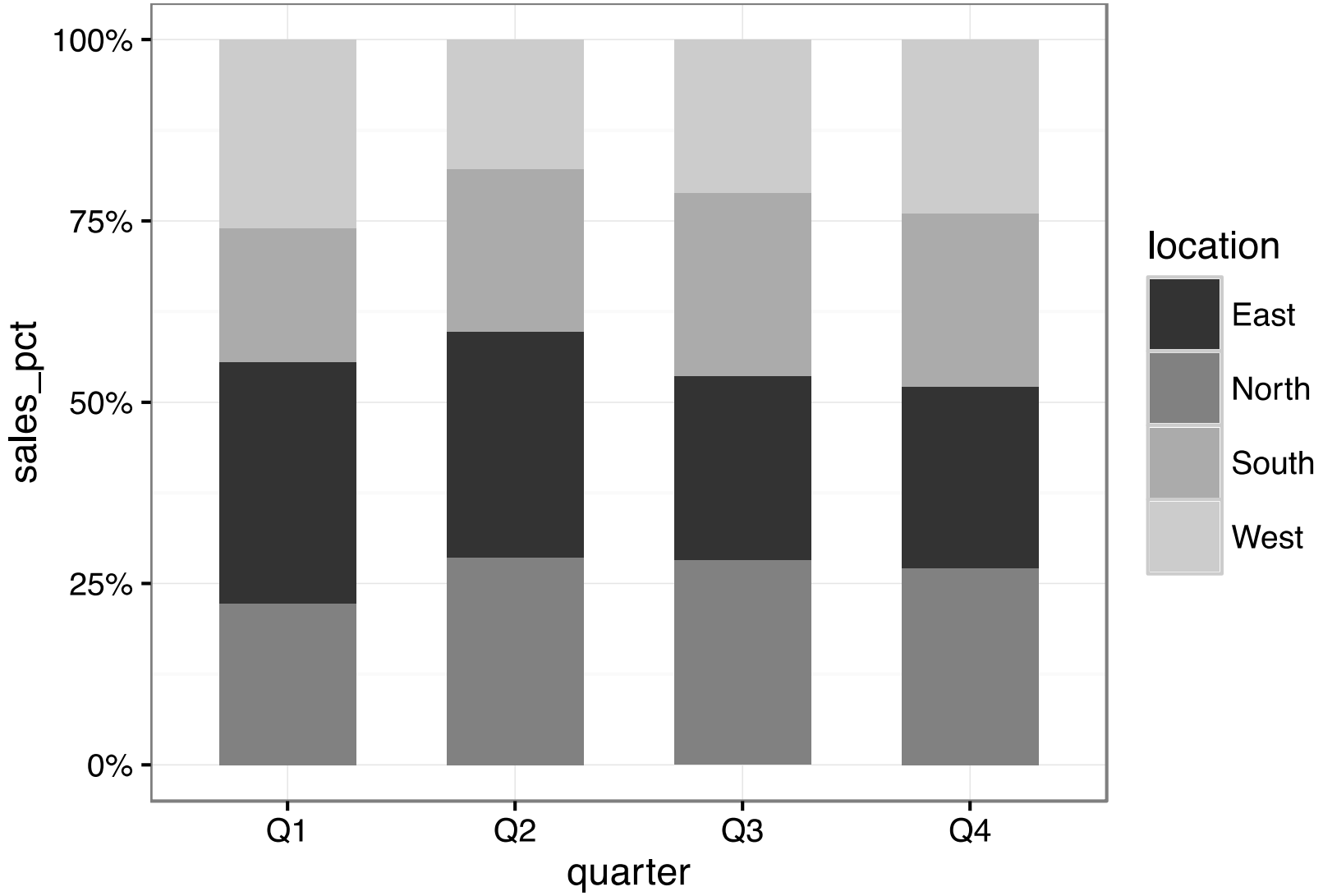
	A	B
1	YES	99%
2	NO	1%



Stacked bar graph

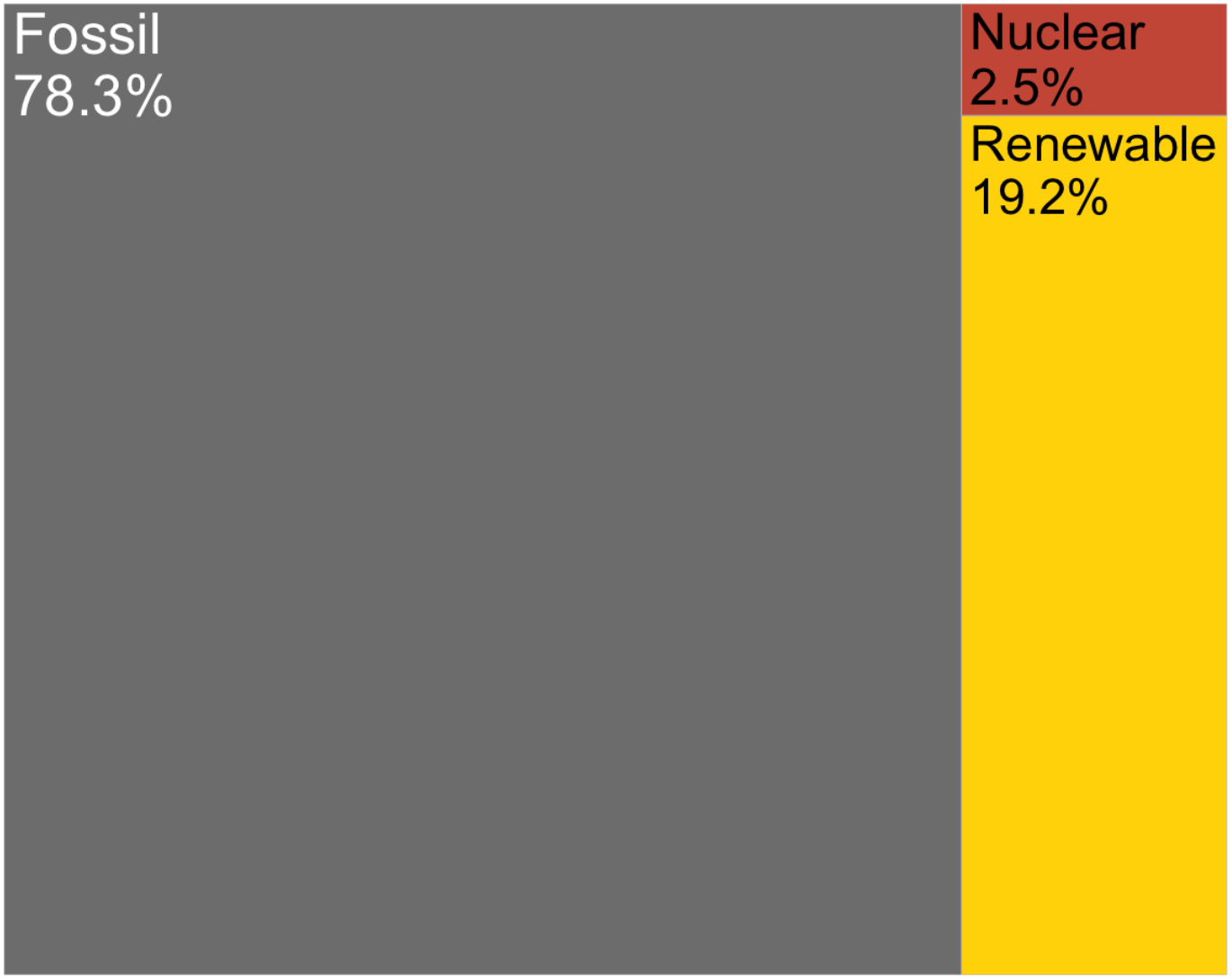


Stacked bars w/percentage

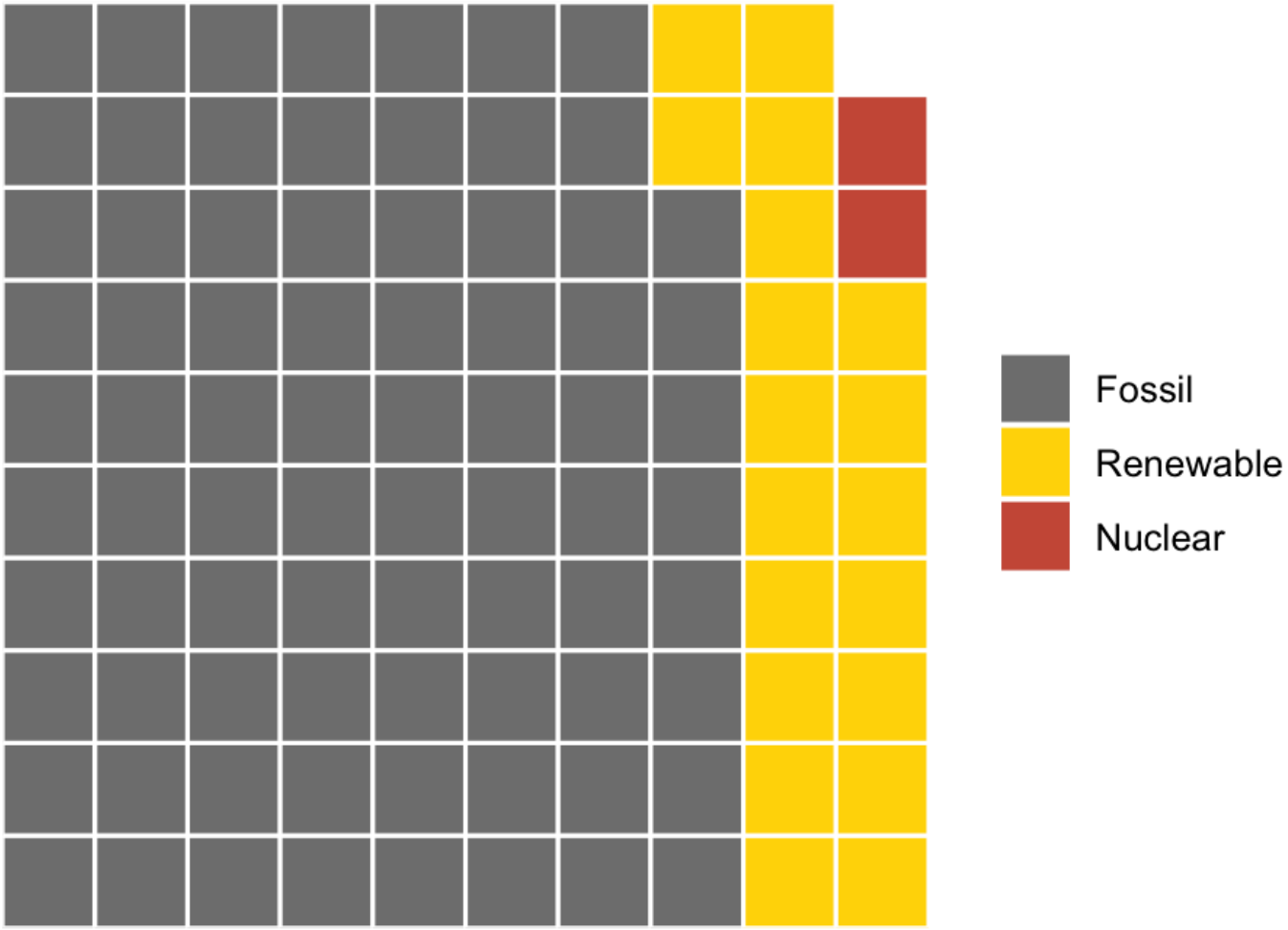


Area – Treemap

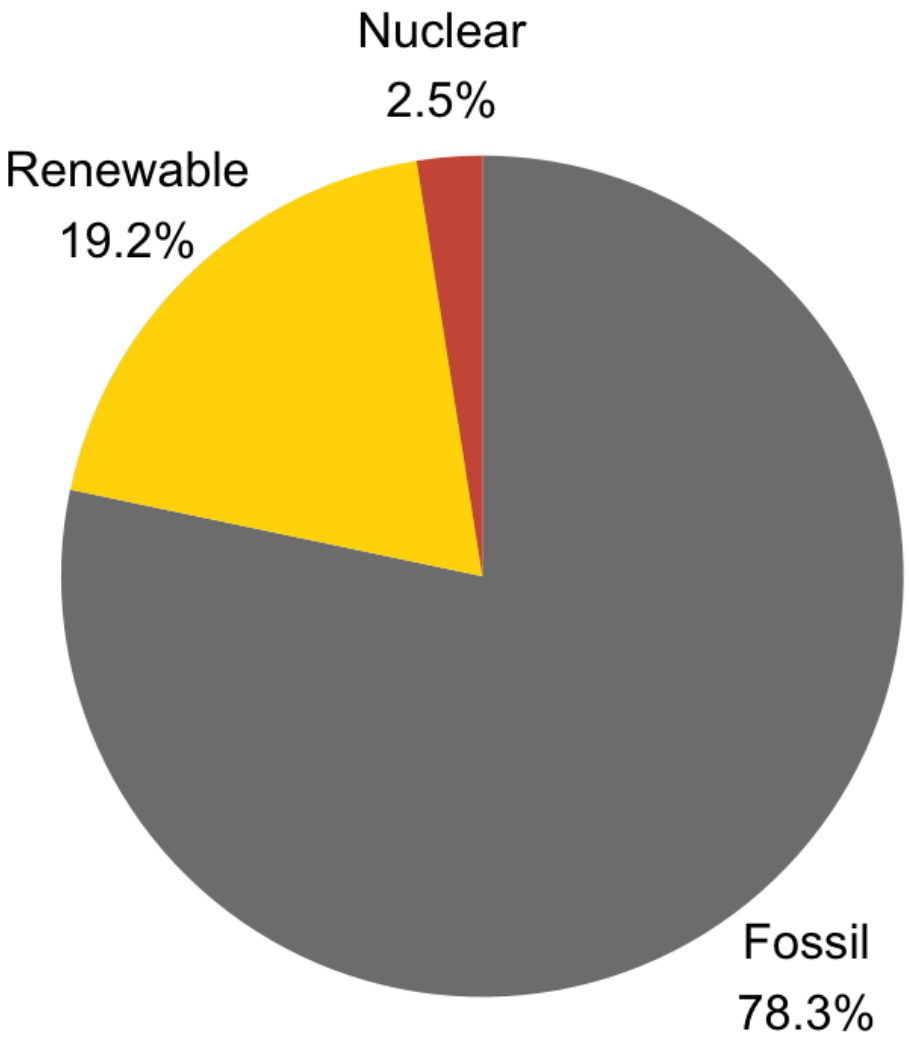
Area – Treemap



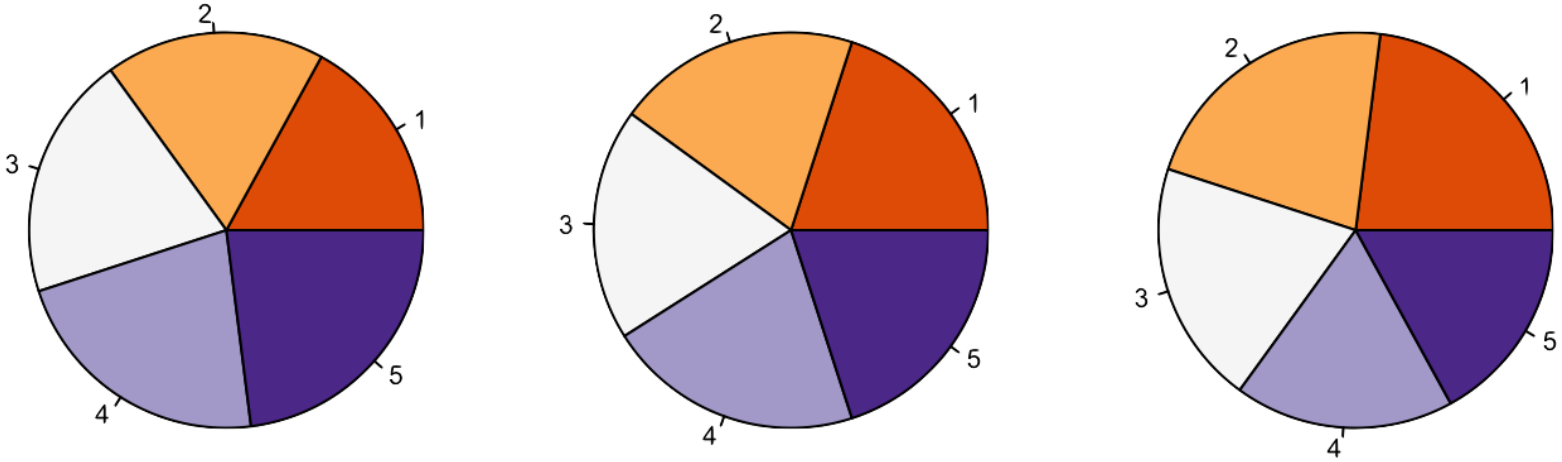
Area + Count – Waffle / Grid



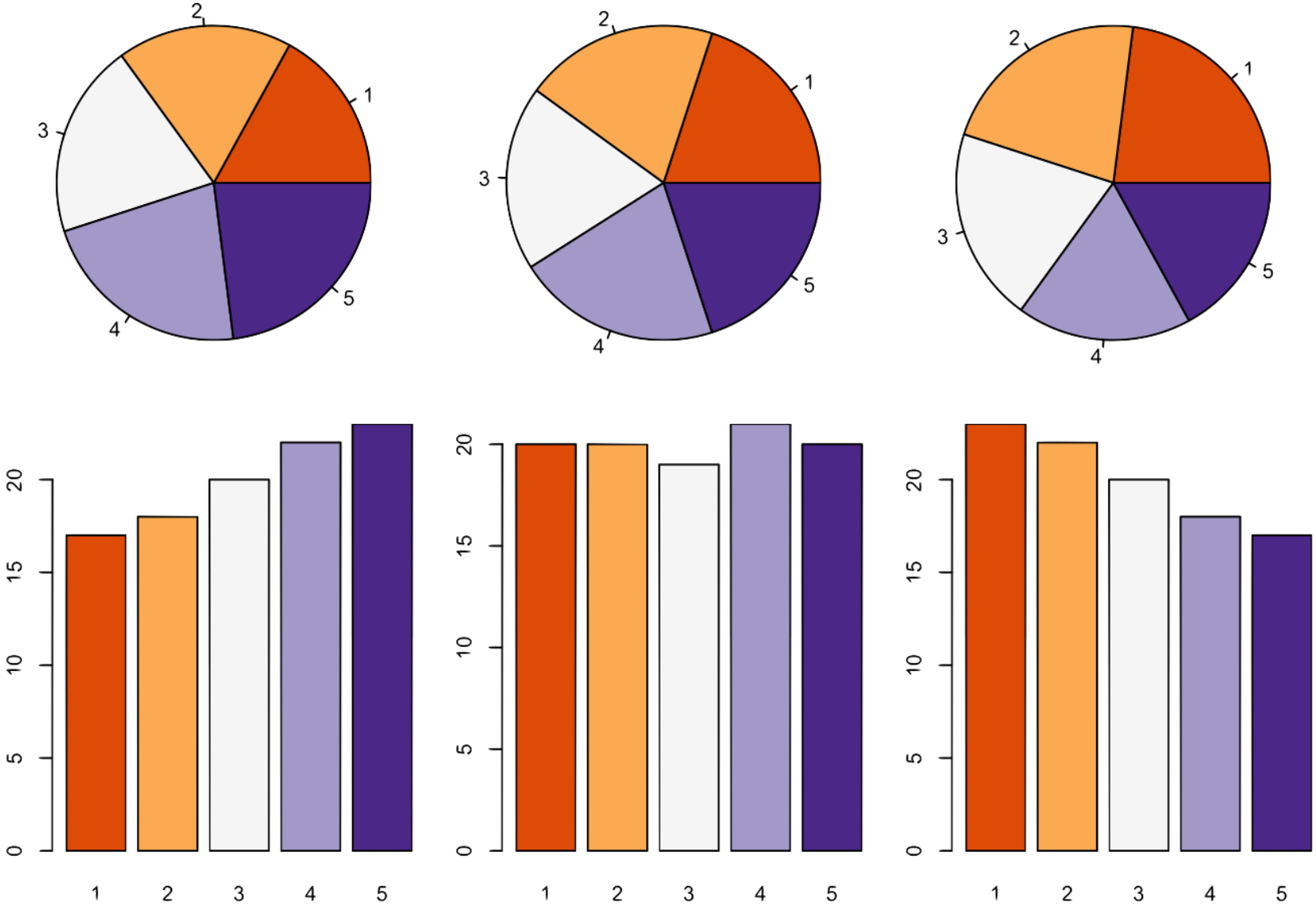
Area + Angle – Pie Chart



Pies



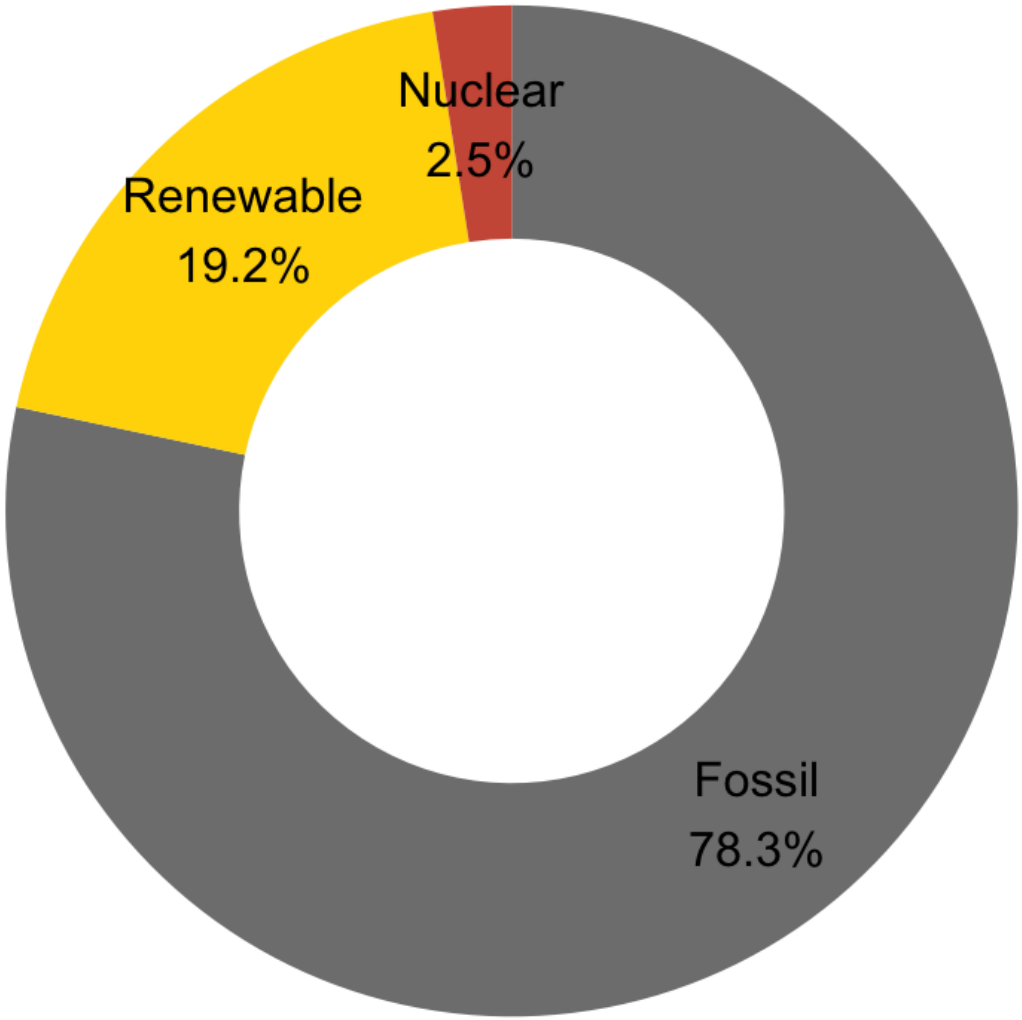
Pies vs. Bars



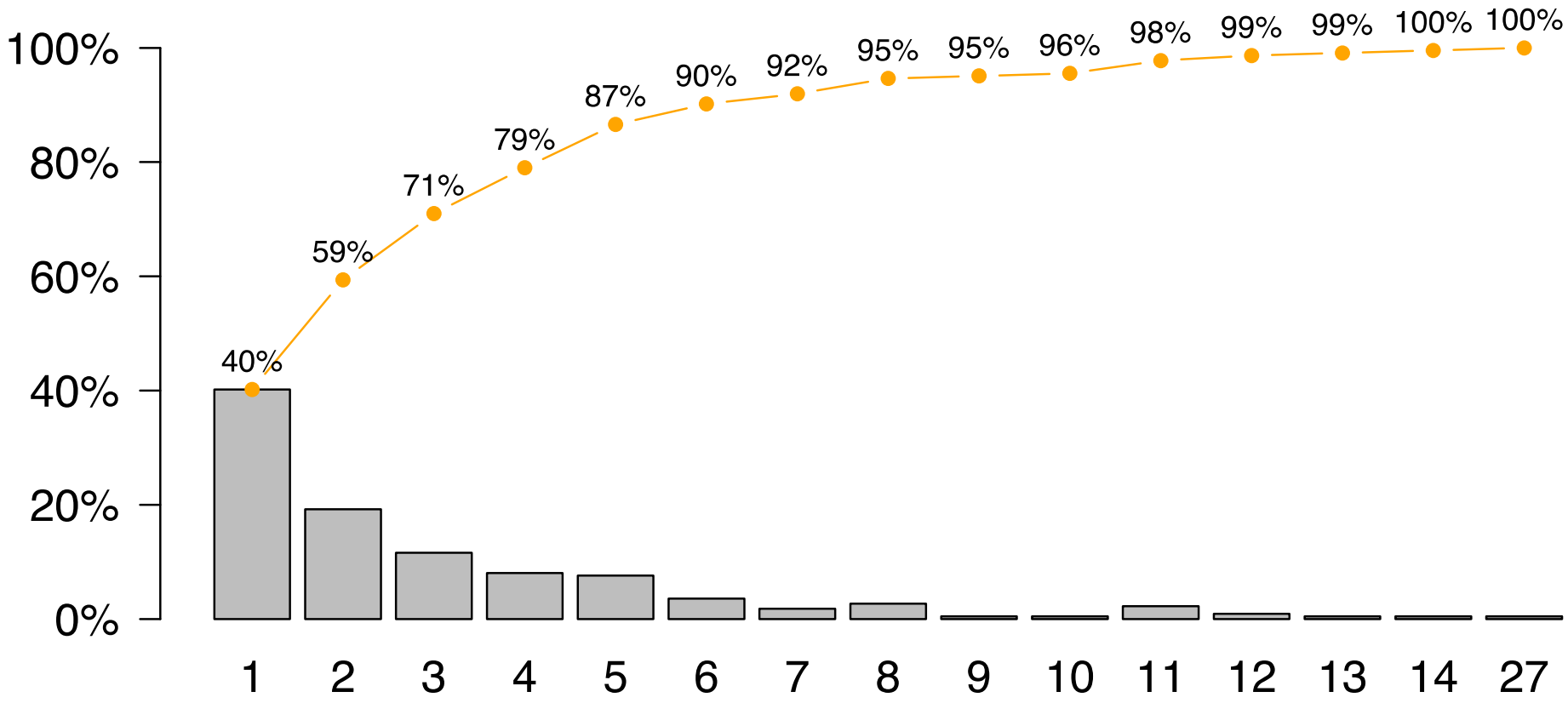
Pie Charts: guidelines

- 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)

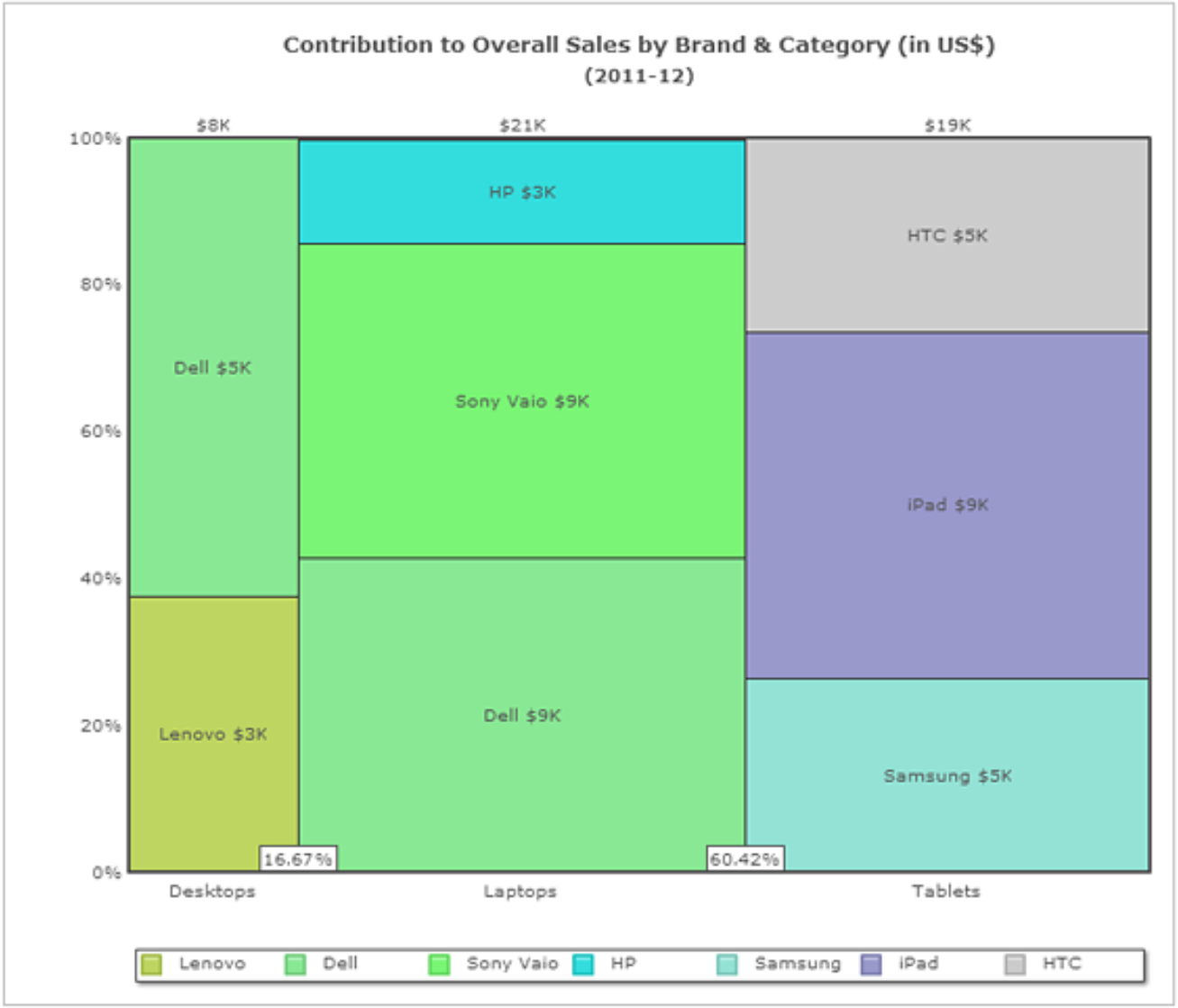
Area/Angle/Length – Donut



Pareto chart



Marimekko Chart



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

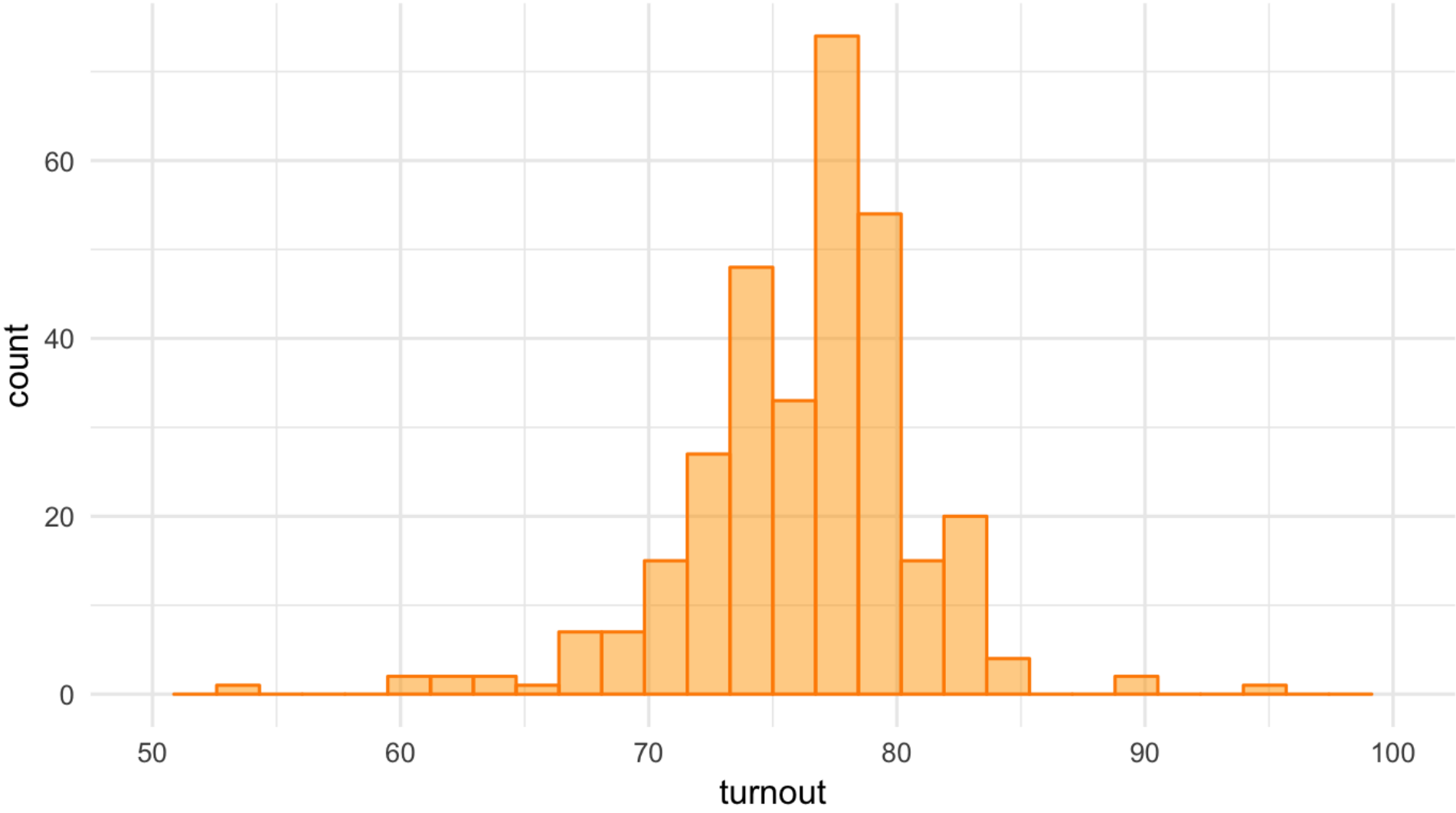
Distribution

- Two main types
  - Show distribution of single set of values
  - Show and compare two or more distributions

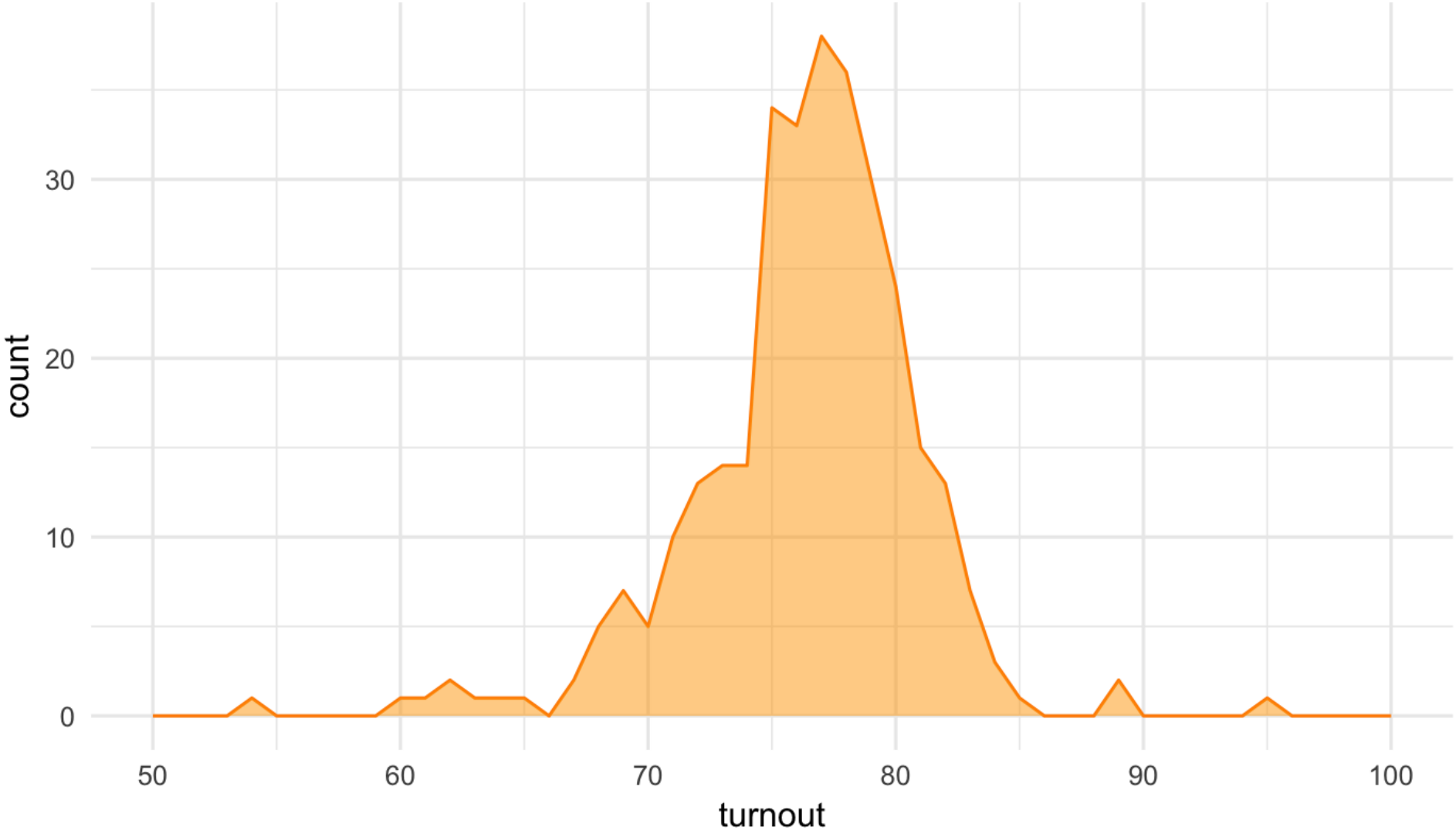
Single distribution

- 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

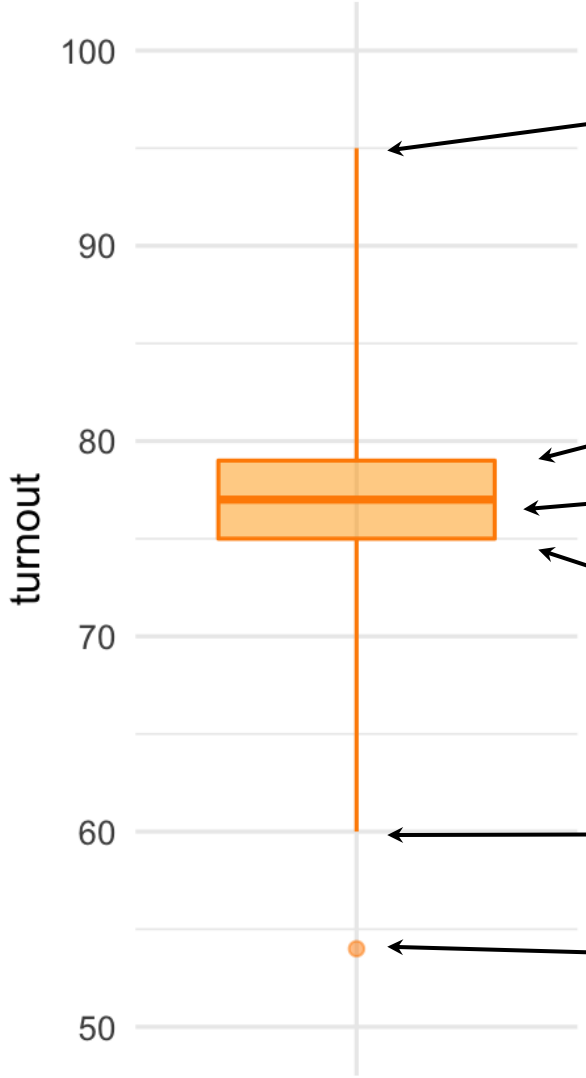
Histogram



Frequency polygon

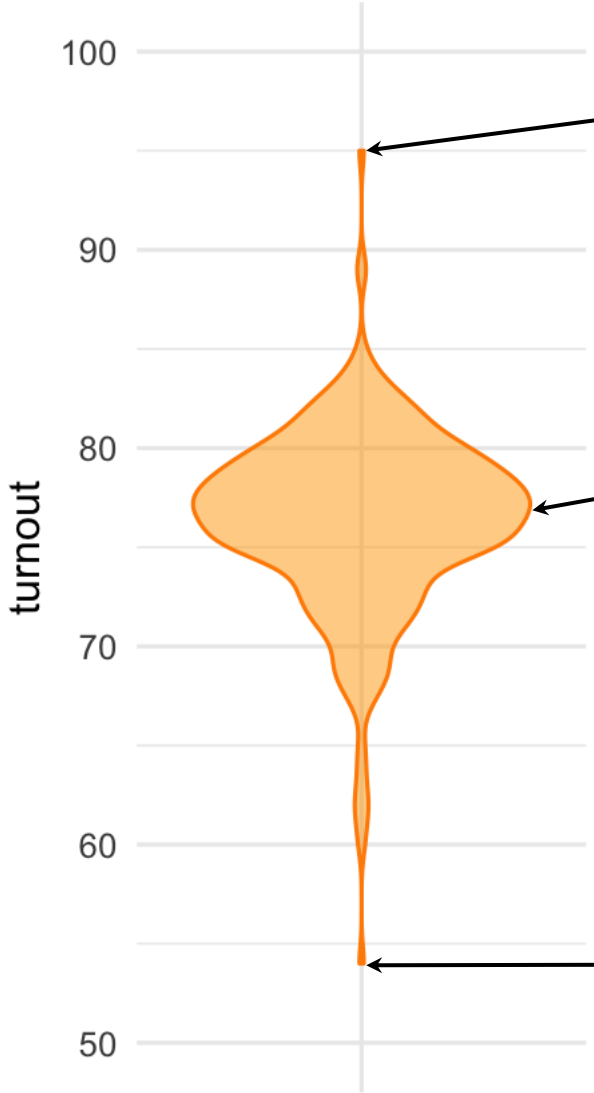


Boxplot



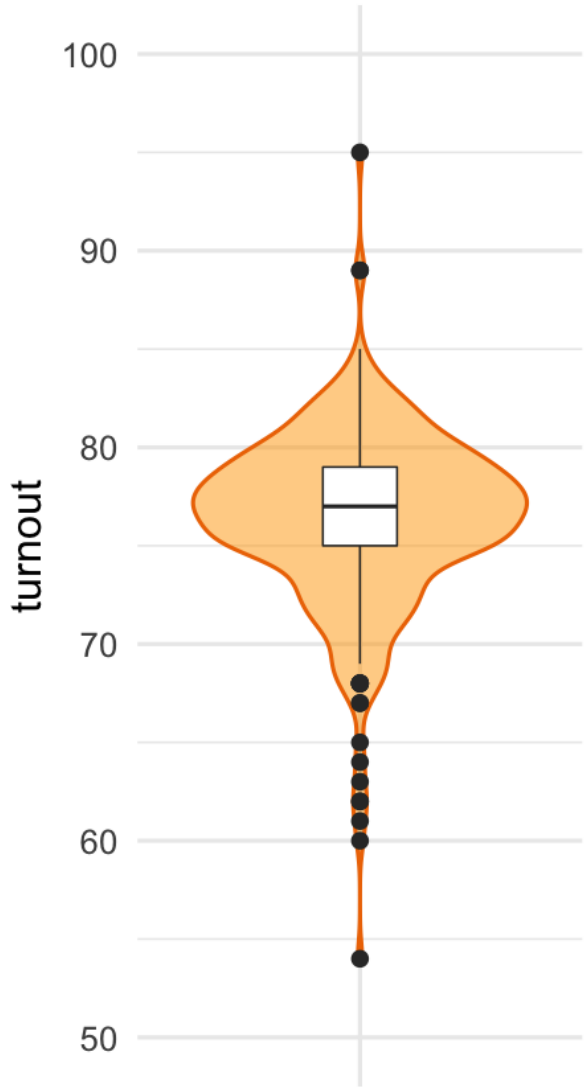
- Max value
- 3rd quartile
- Median
  - 2nd quartile
- 1st quartile
- Min value
- Outlier

Violin plot



- Max value
- Frequency polygon
  - mirrored
- Min value

Violin + Boxplot

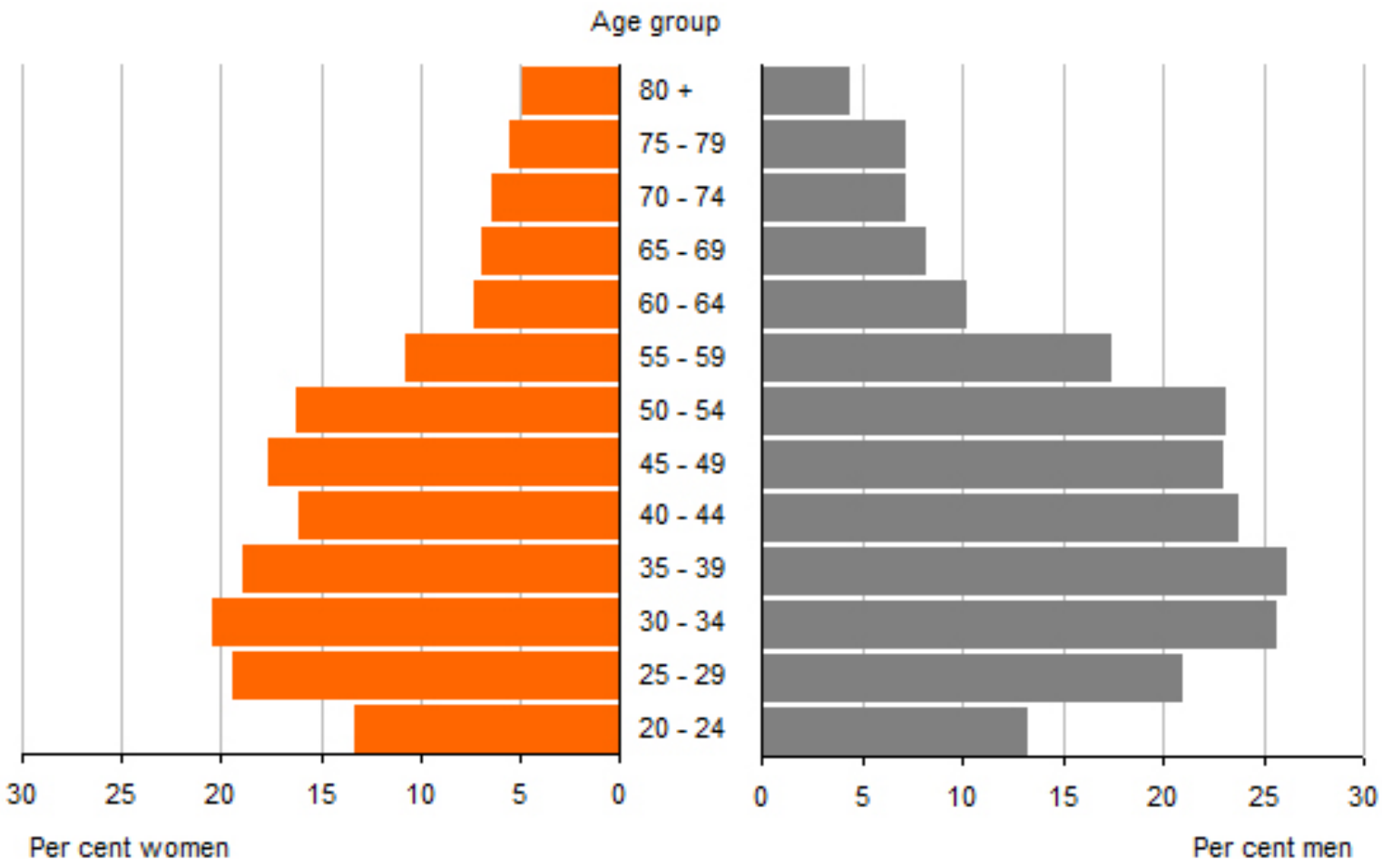


- Overlaying a box plot over the violin provides additional details

Multiple distribution

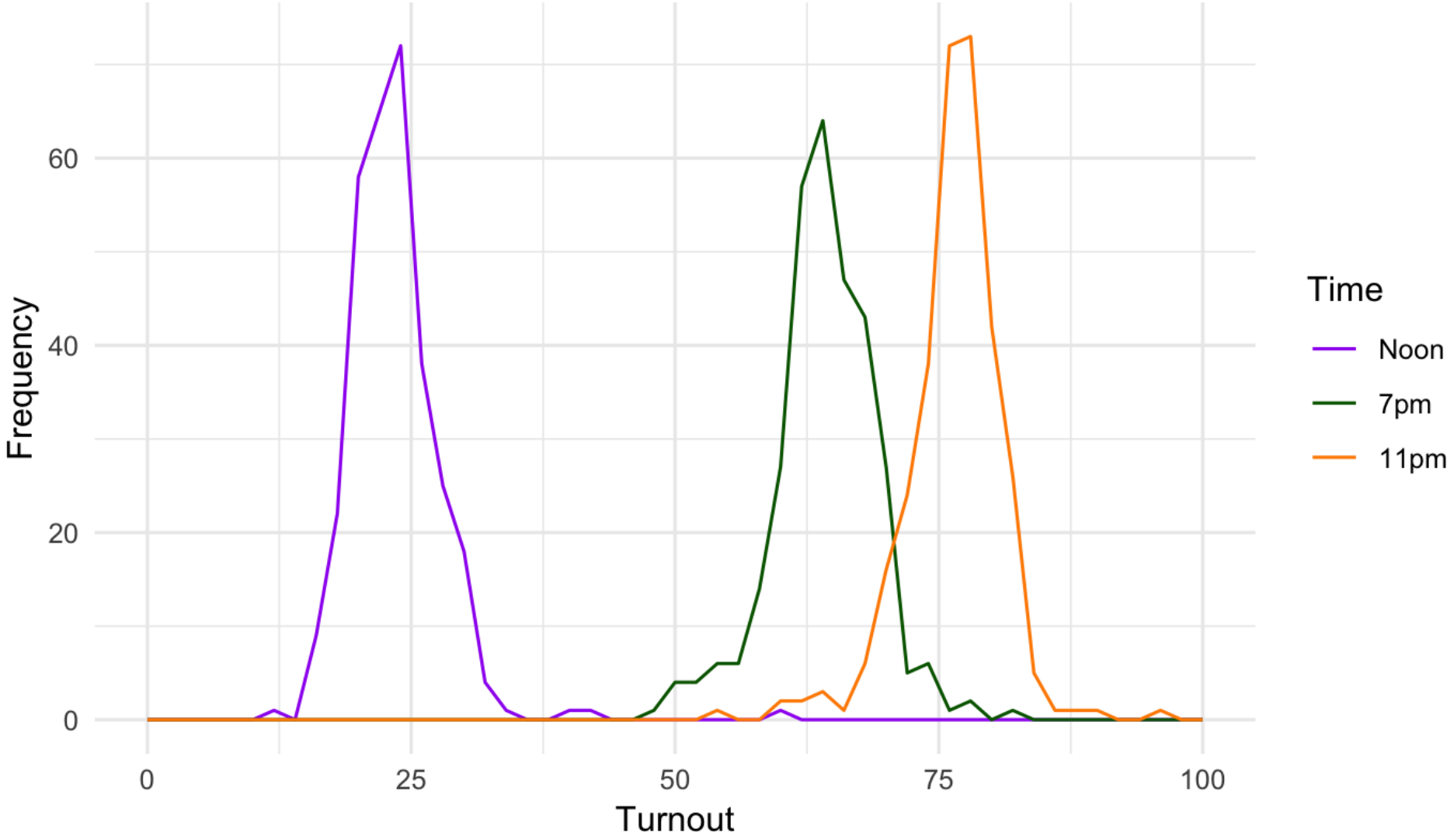
- Histogram is not suitable
- Frequency polygon
  - Line graphs
  - Frequency density function
- Boxplot
  - Summary
  - Less distracting with high number of categories

Paired diverging bargraph

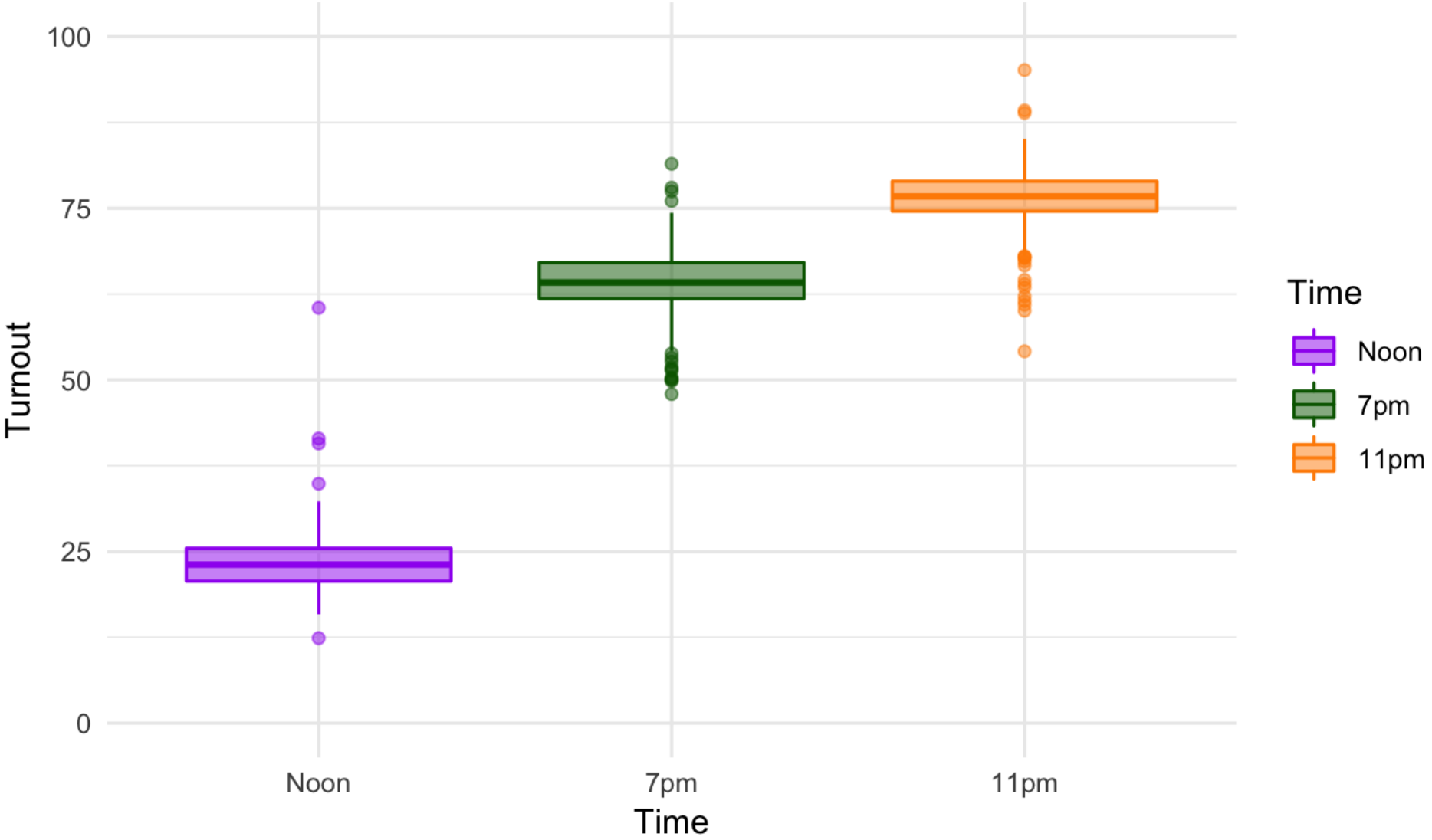


https://unstats.un.org/unsd/genderstatmanual/Print.aspx?Page=Presentation-of-gender-statistics-in-graphs

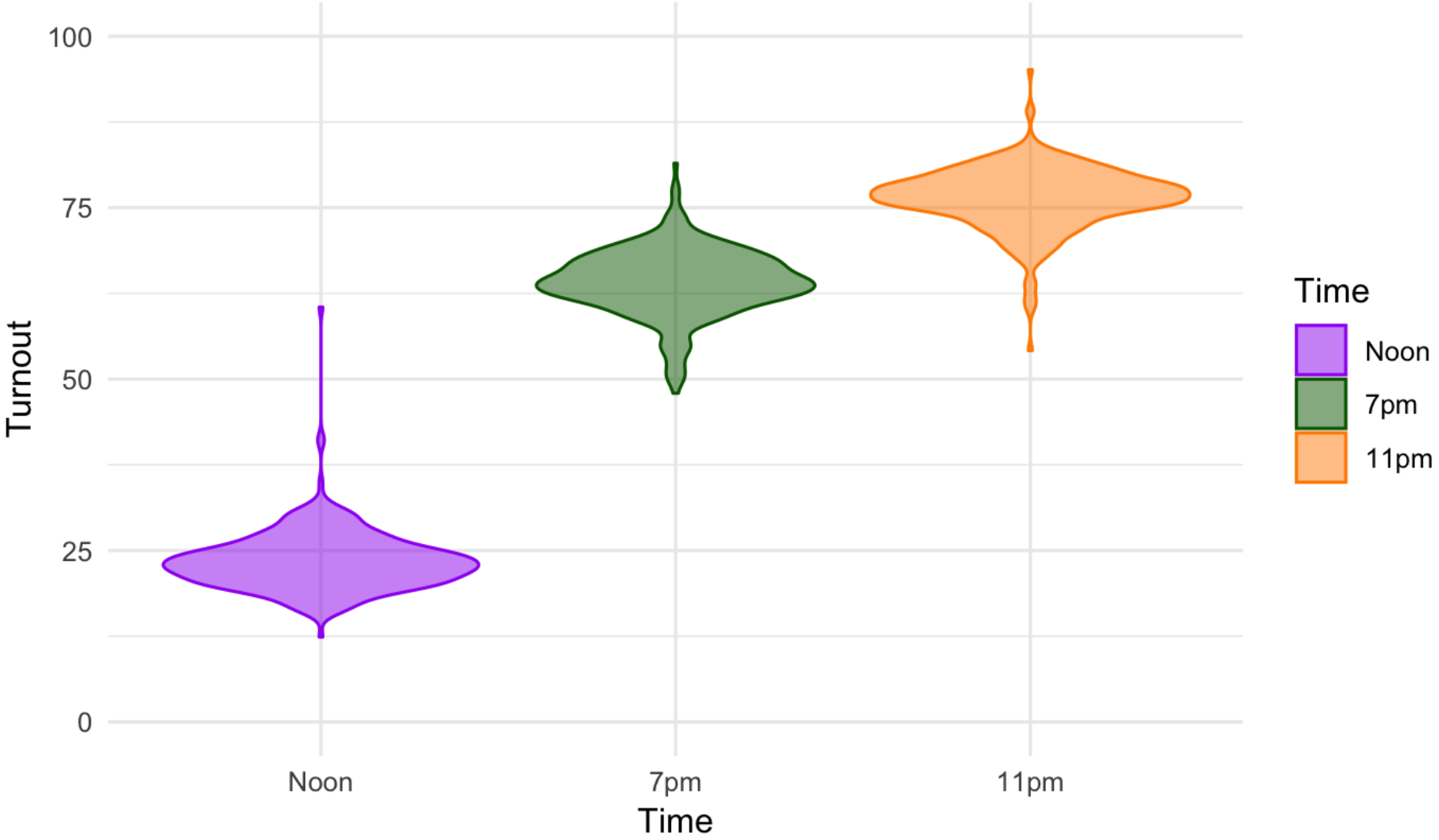
Multiple Frequency polygons



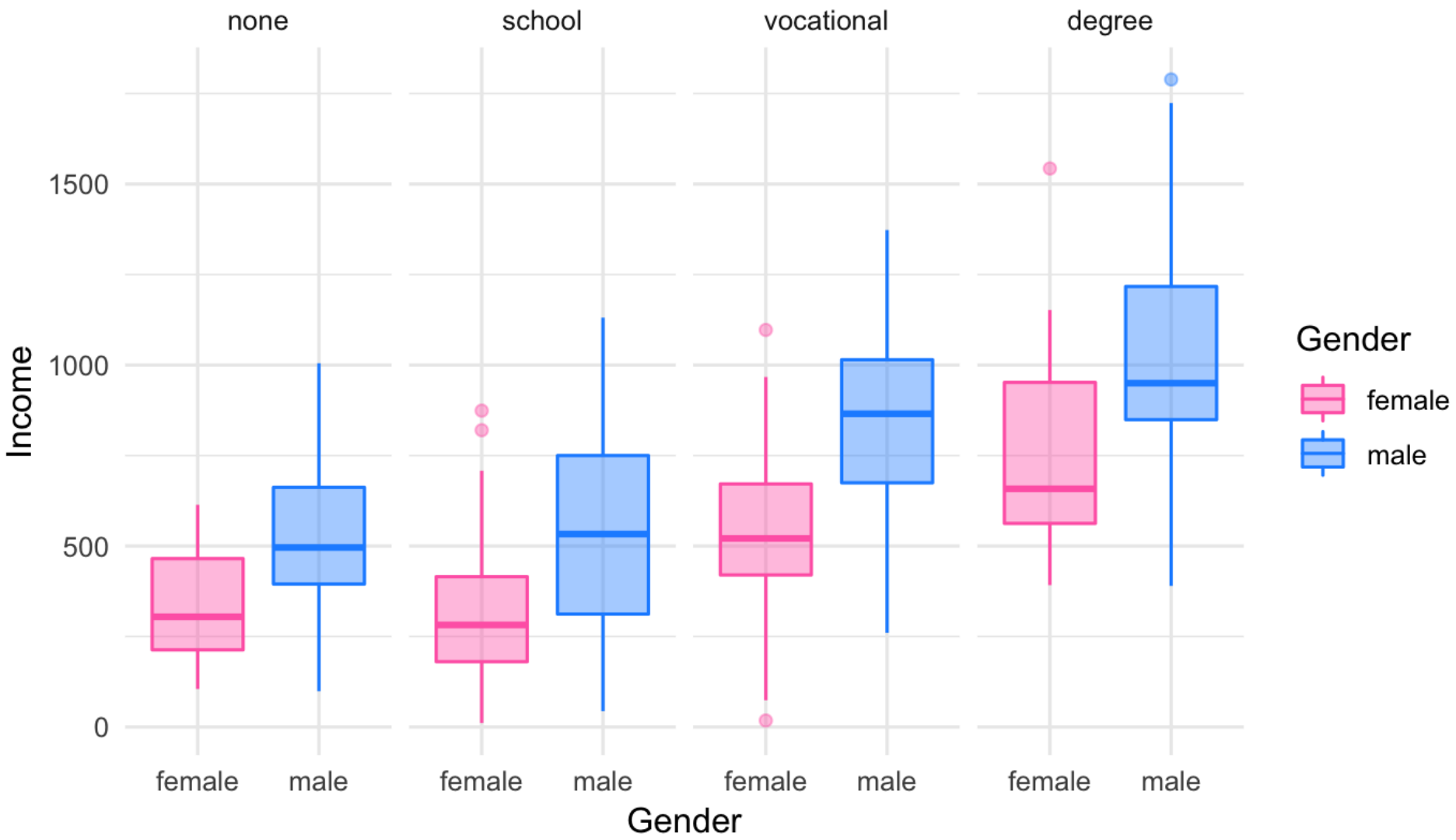
Multiple Box plot



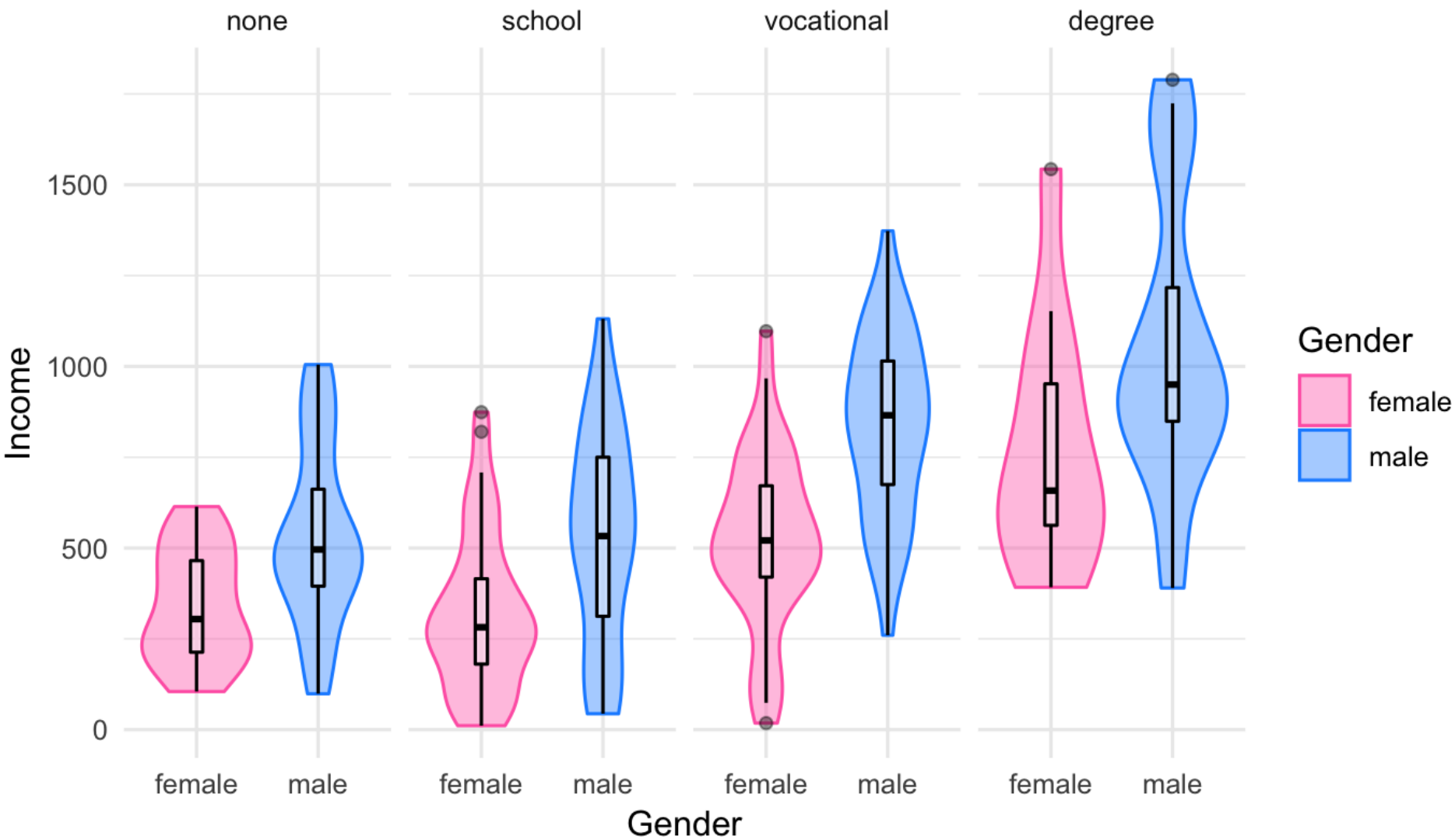
Violin plot



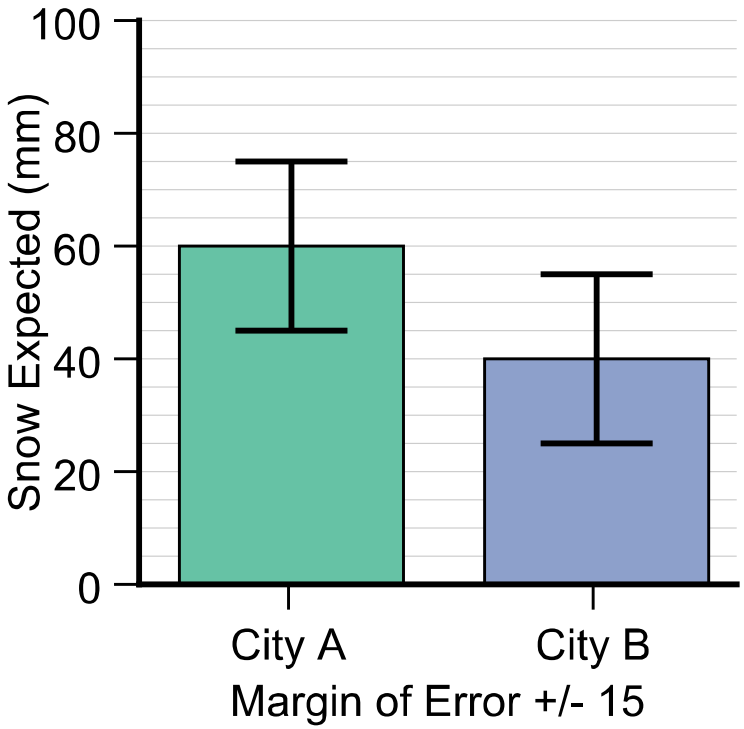
Multiple box plots

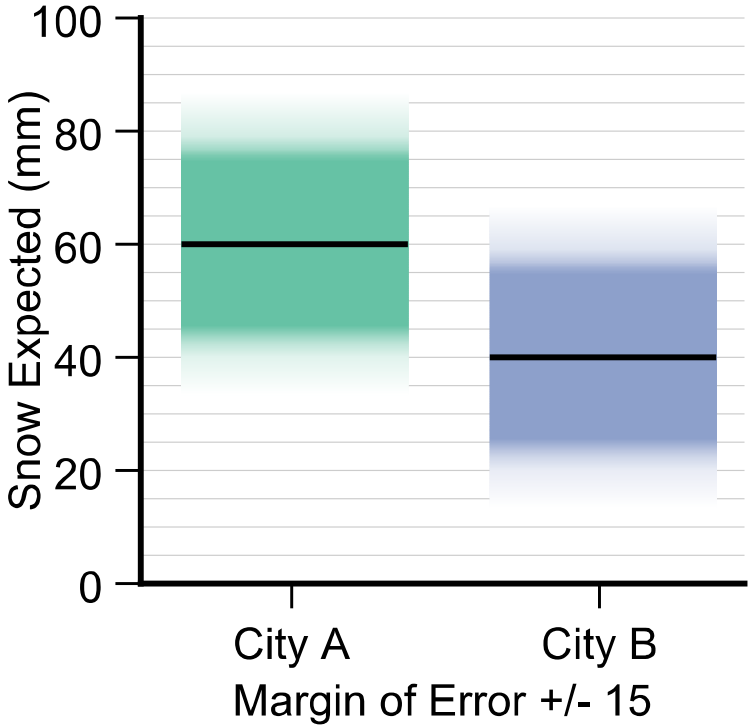


Multiple violin plots



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

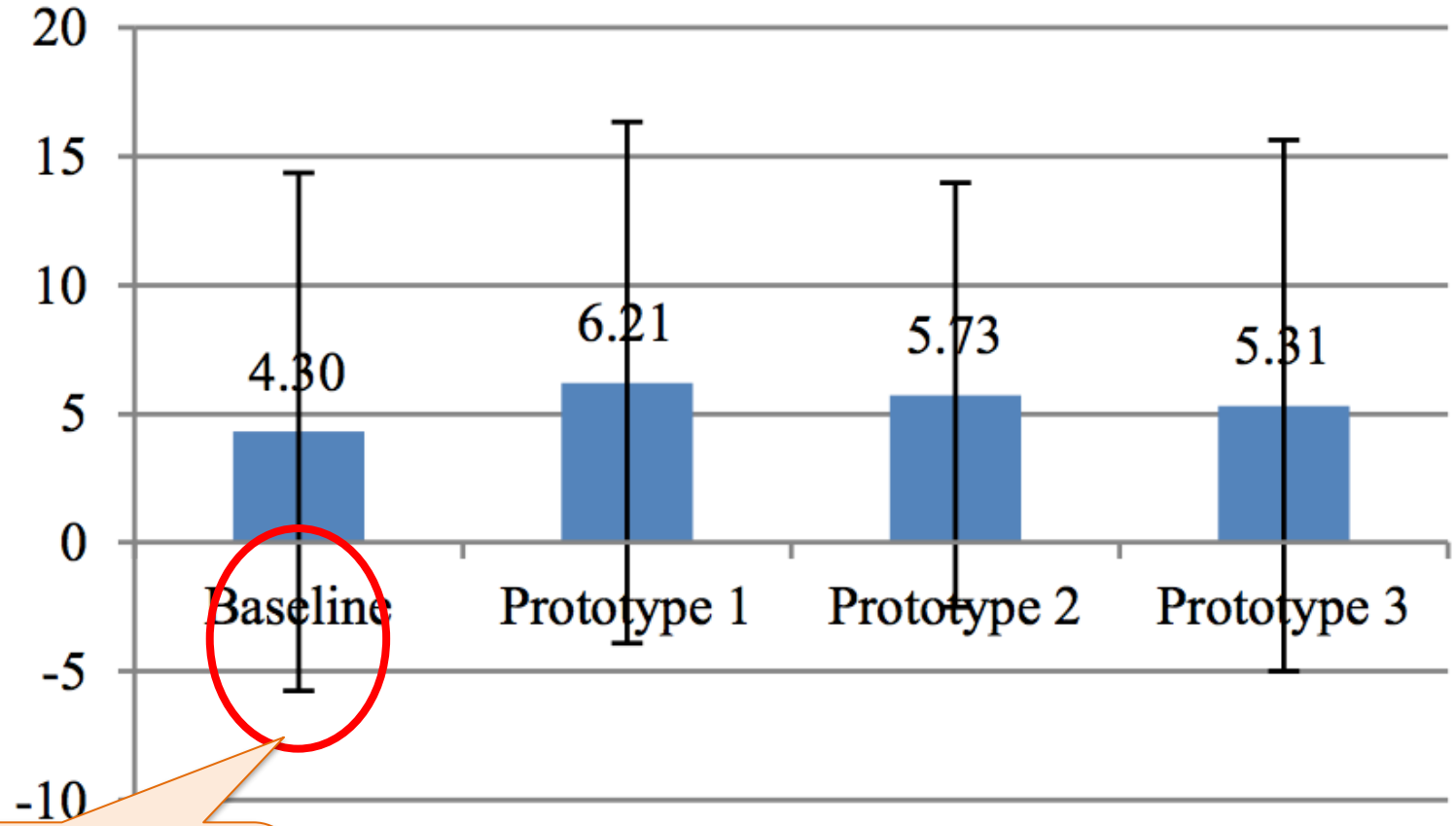


Figure 5. Mean files per changeset.

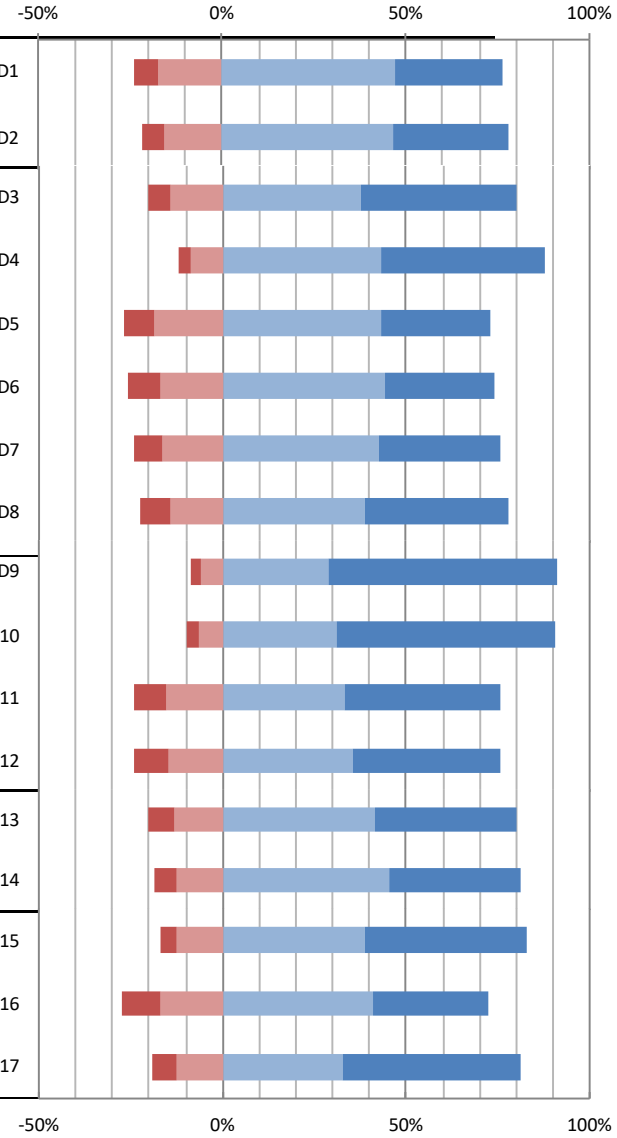
It is physically impossible to modify -6 files

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

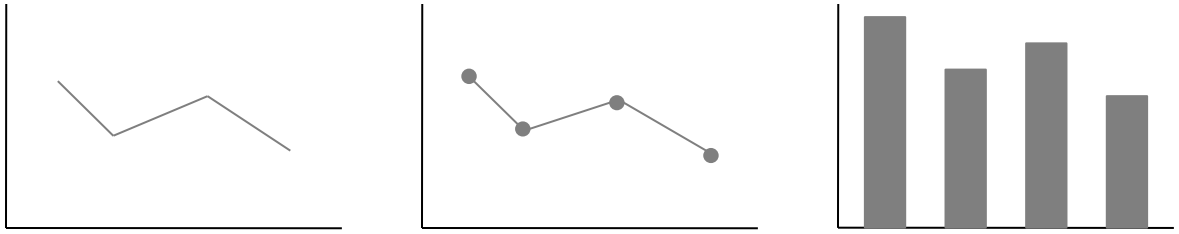


Time series

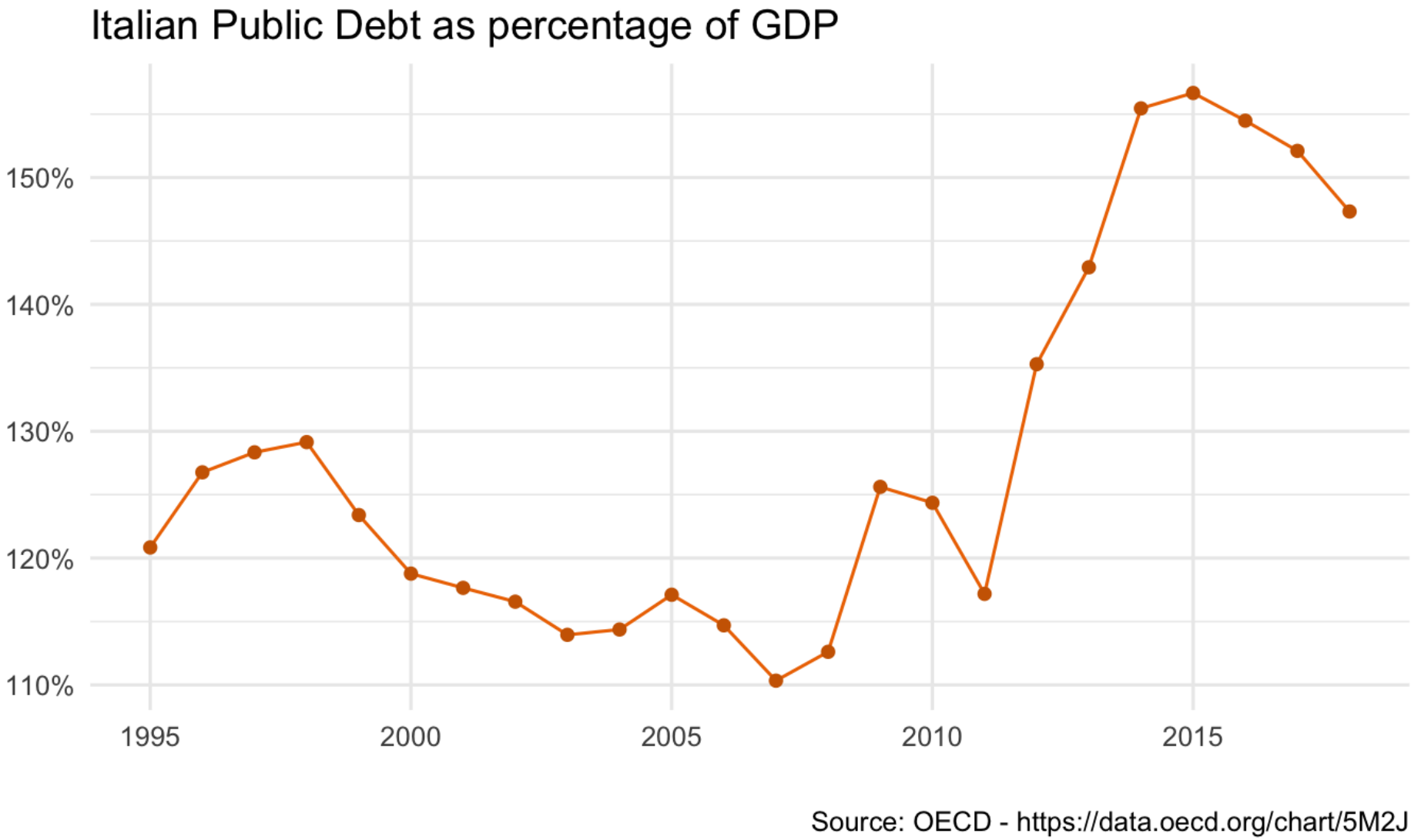
- Series of relationships between quantitative values that are associated with categorical subdivisions of time
- Communicate
  - Change
  - Rise
  - Increase
  - Fluctuate
  - Grow
  - Decline
  - Decrease
  - Trend

Time series

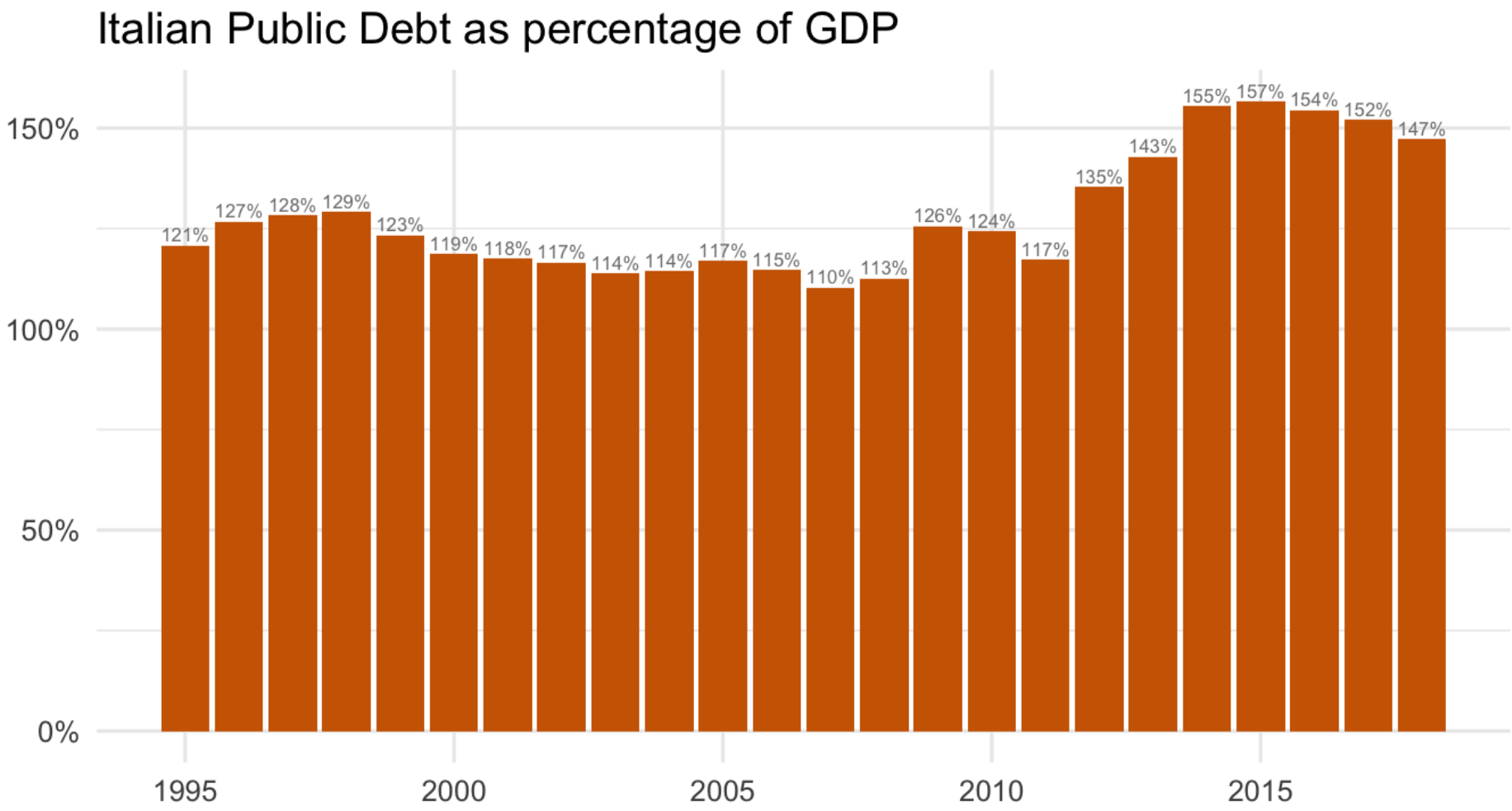
- Time grows from left to right
  - Cultural convention
- Vertical bars
  - highlight individual points in time
  - hide overall trend



Line plot

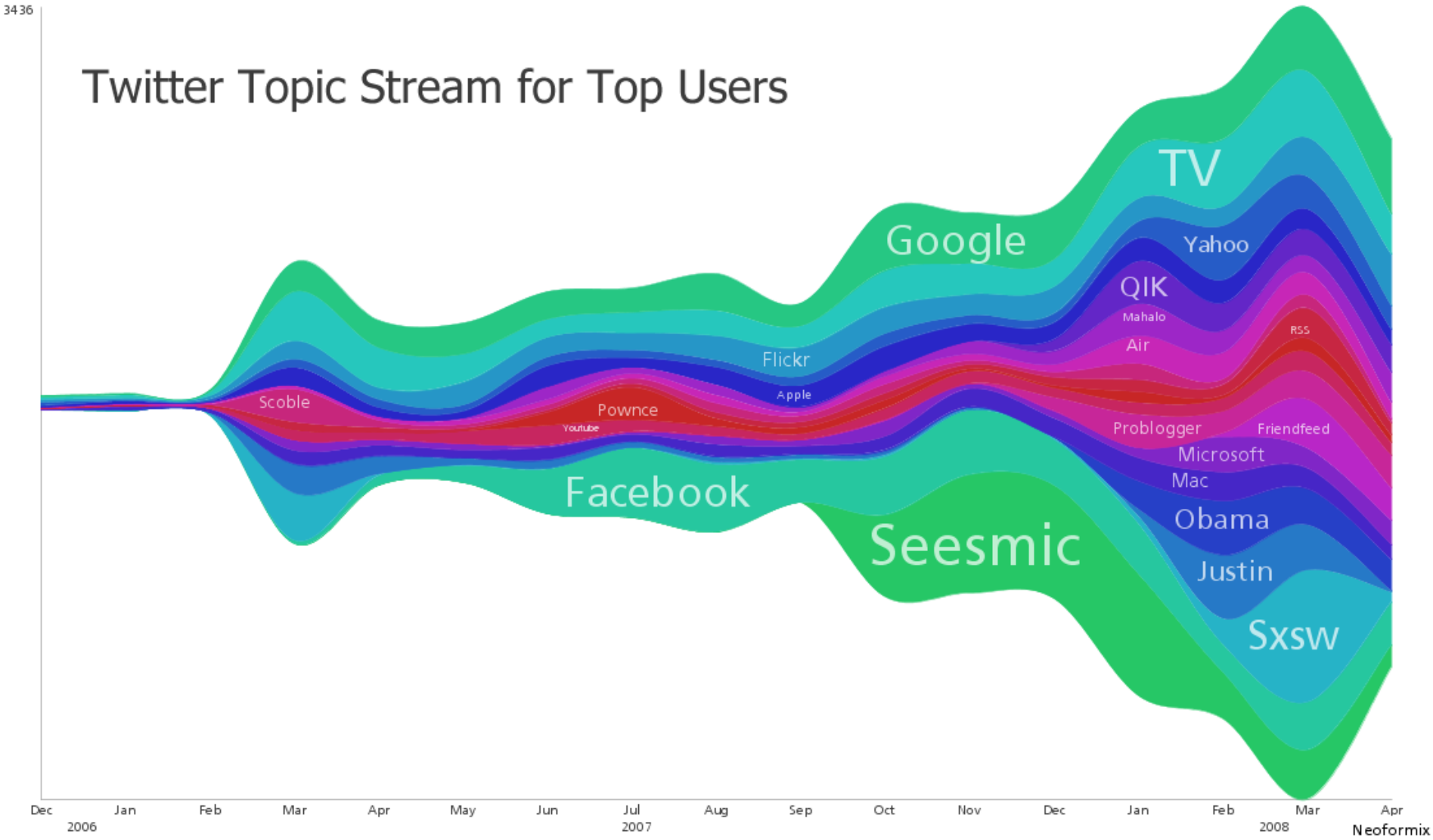

Italian Public Debt as percentage of GDP
150%
140%
130%
120%
110%
1995
2000
2005
2010
2015
Source: OECD - https://data.oecd.org/chart/5M2J

Bars



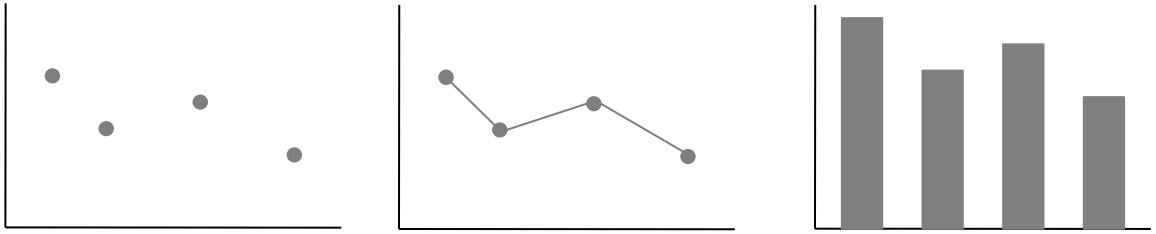
Source: OECD - https://data.oecd.org/chart/5M2J

Streamgraph

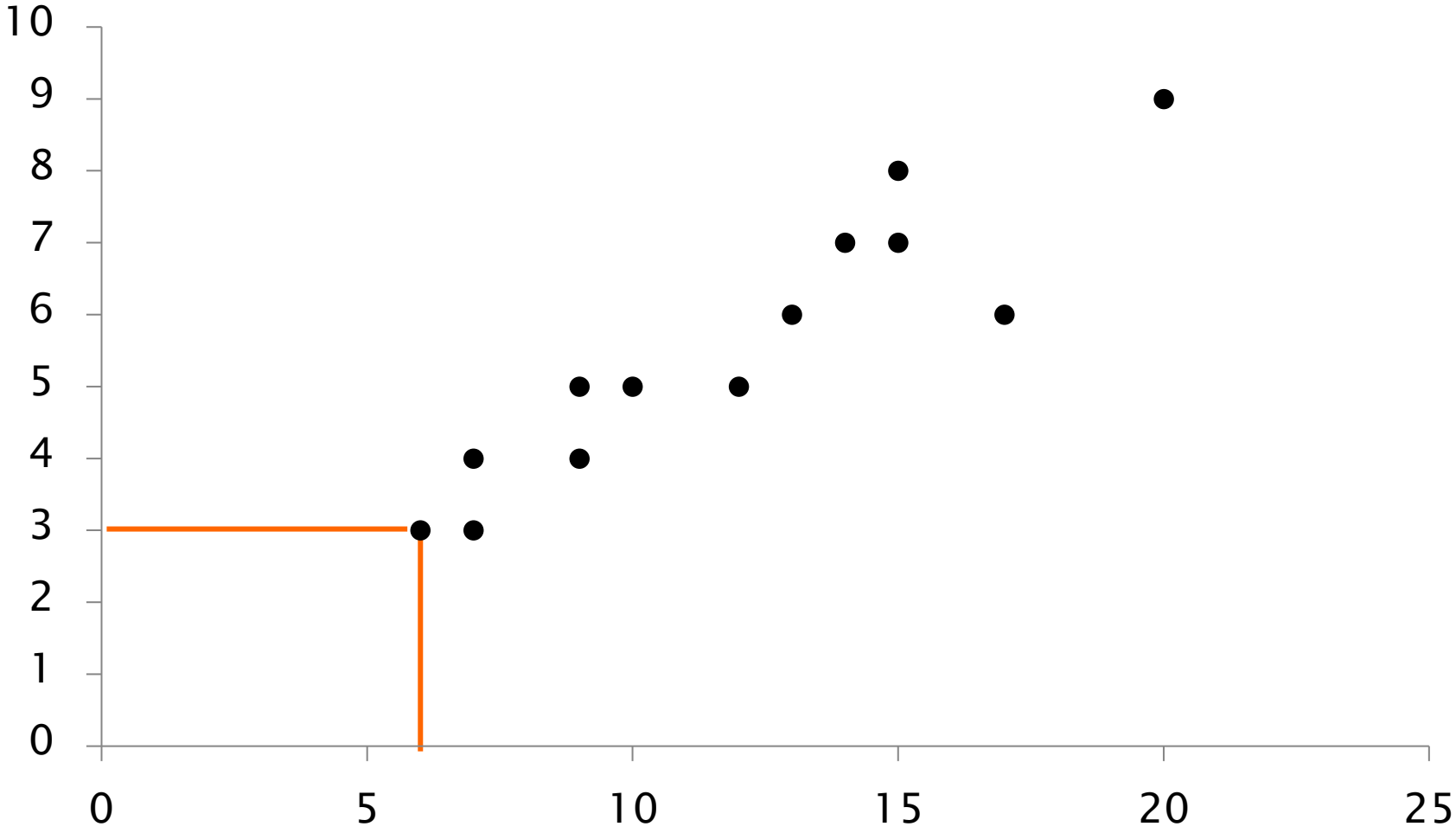


Correlation

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



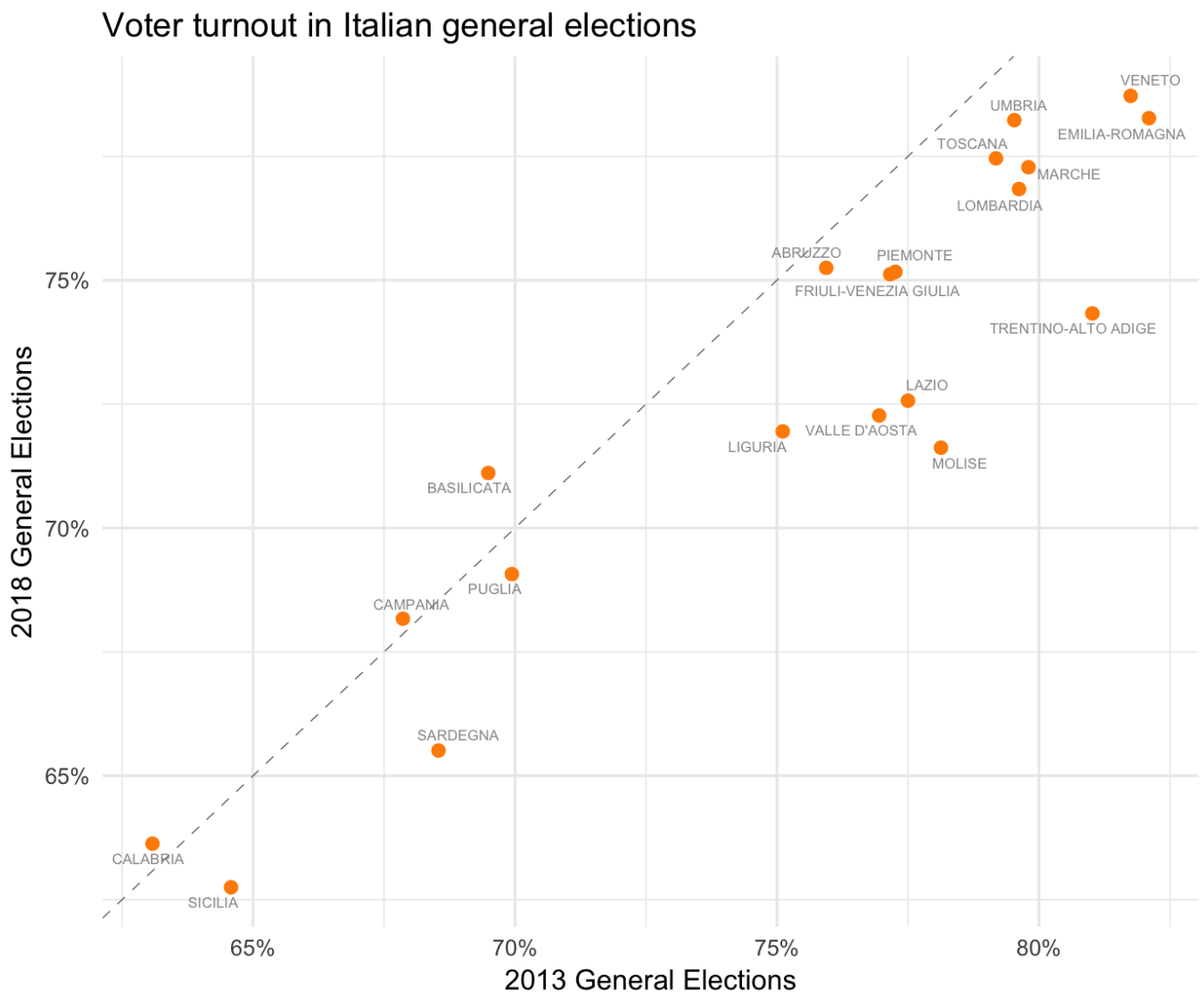
Points



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

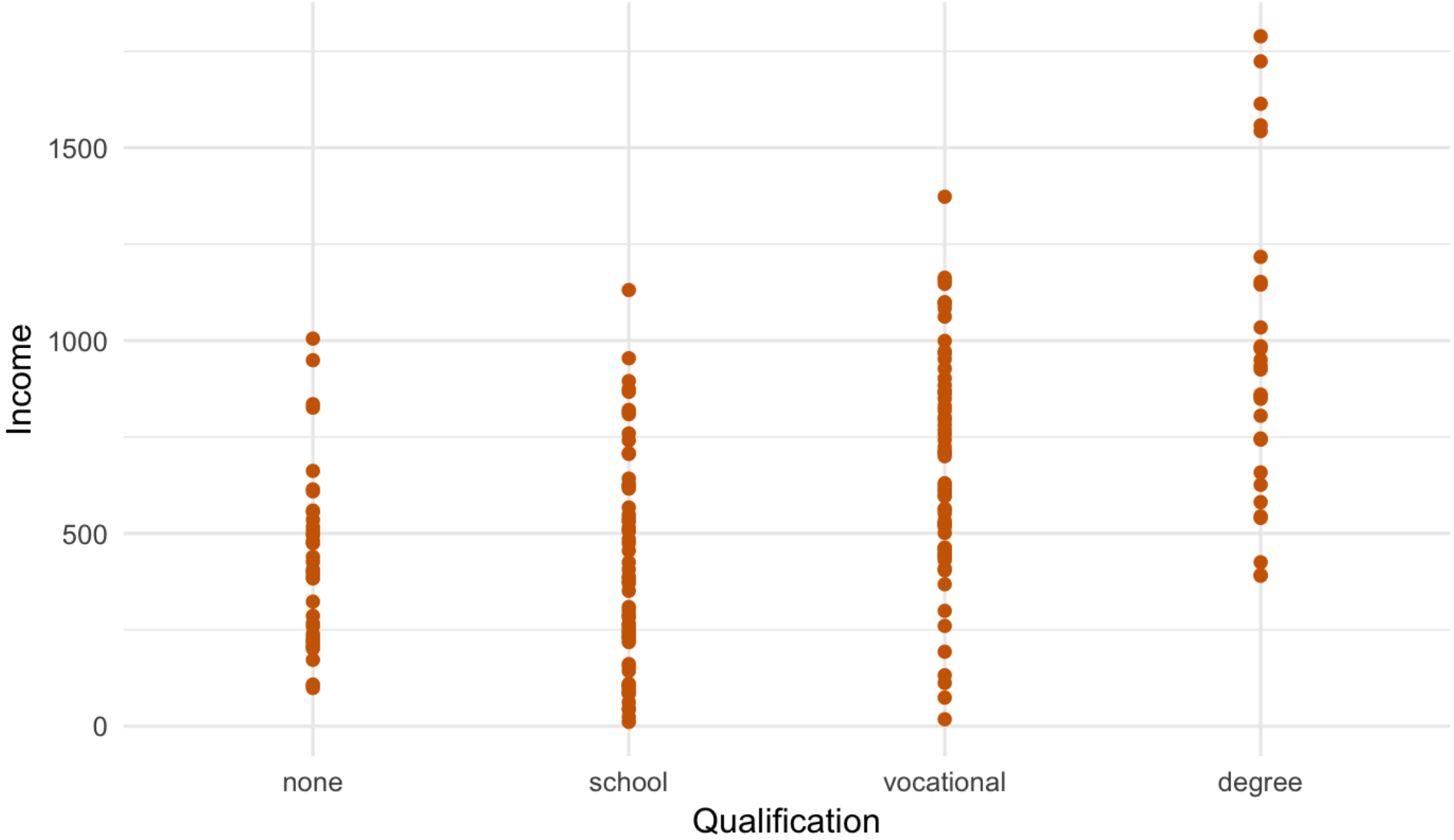
Scatter plot



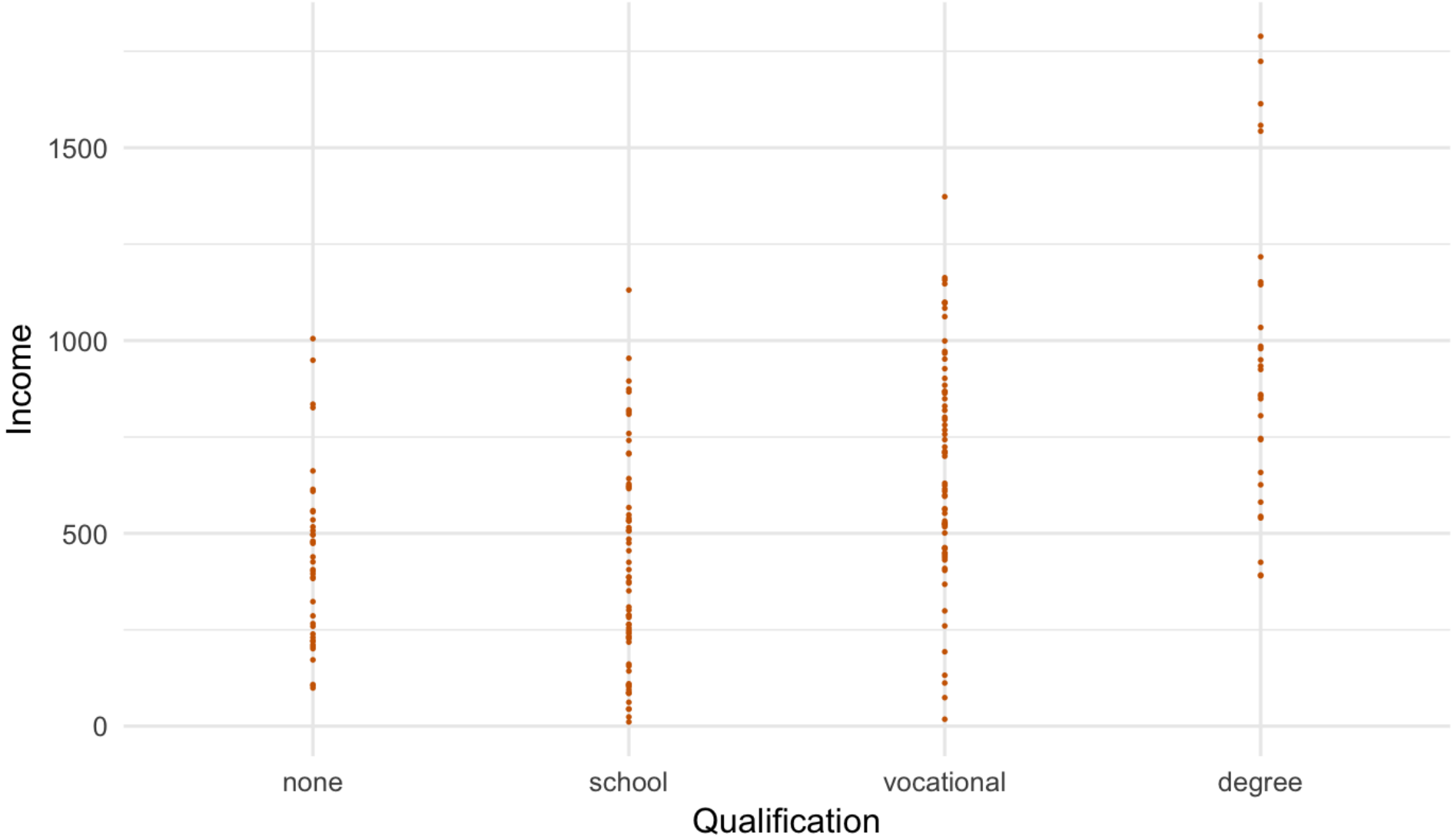
Overplotting

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

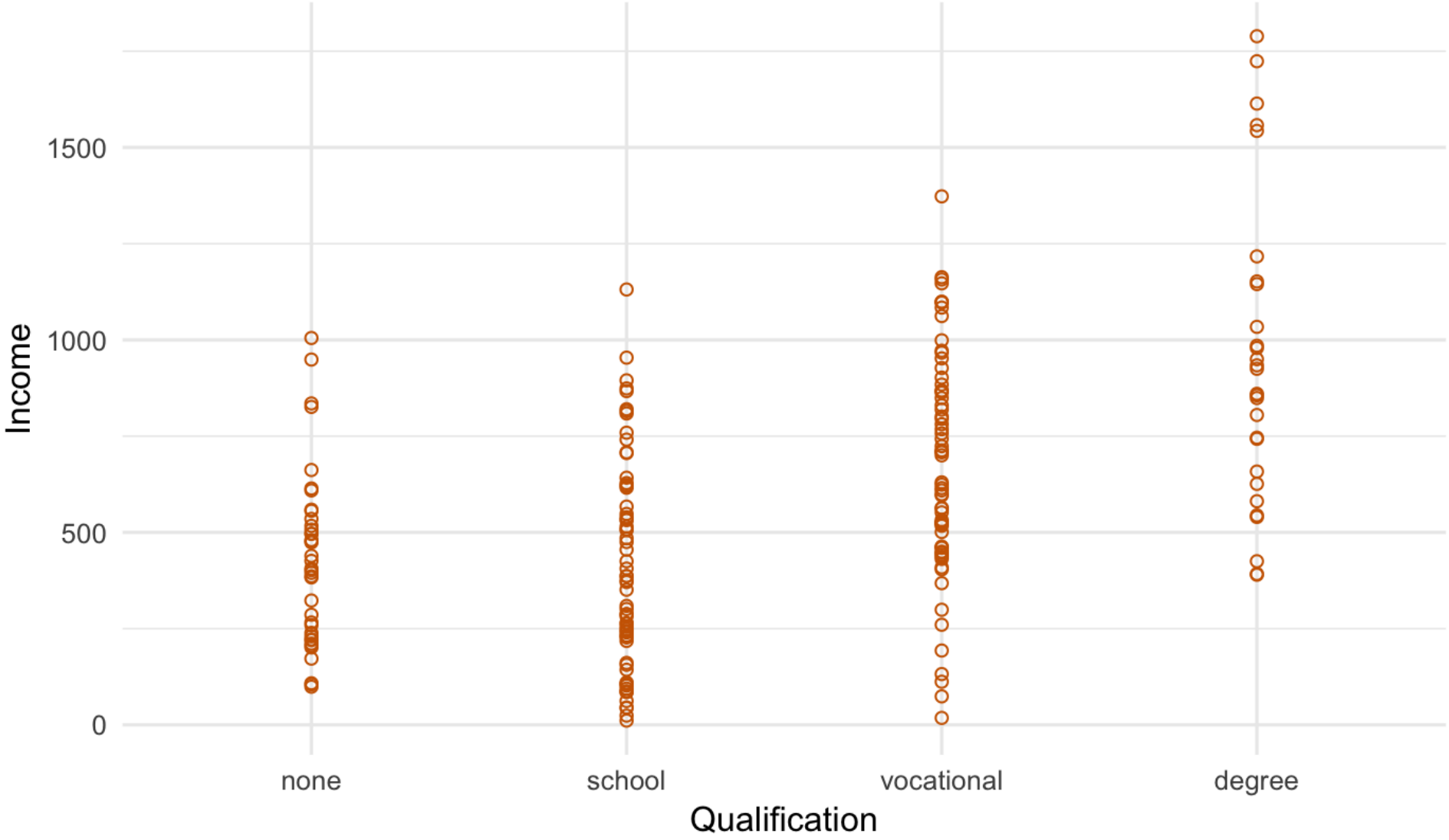
Overplotting example



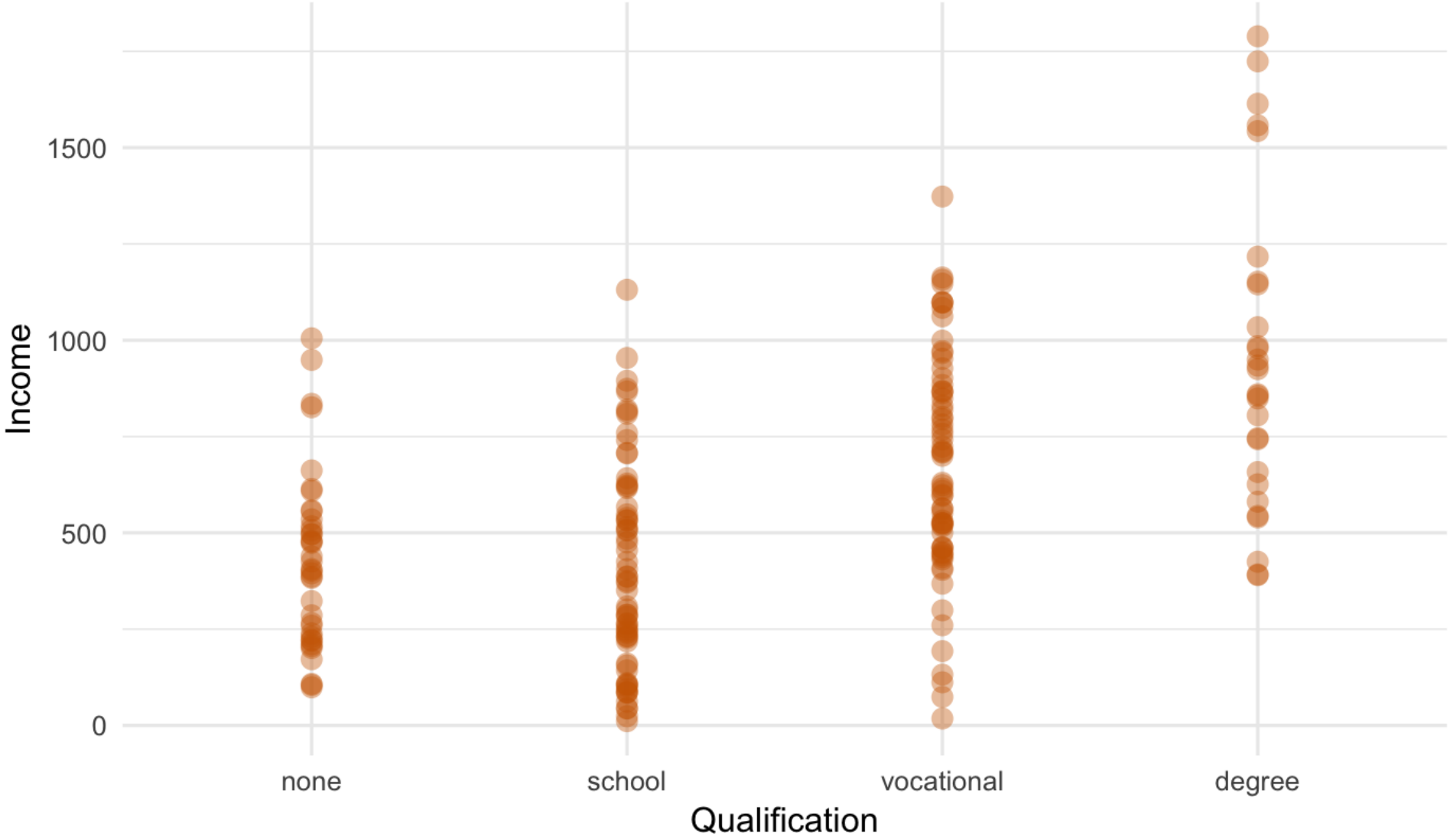
Overplotting – Small



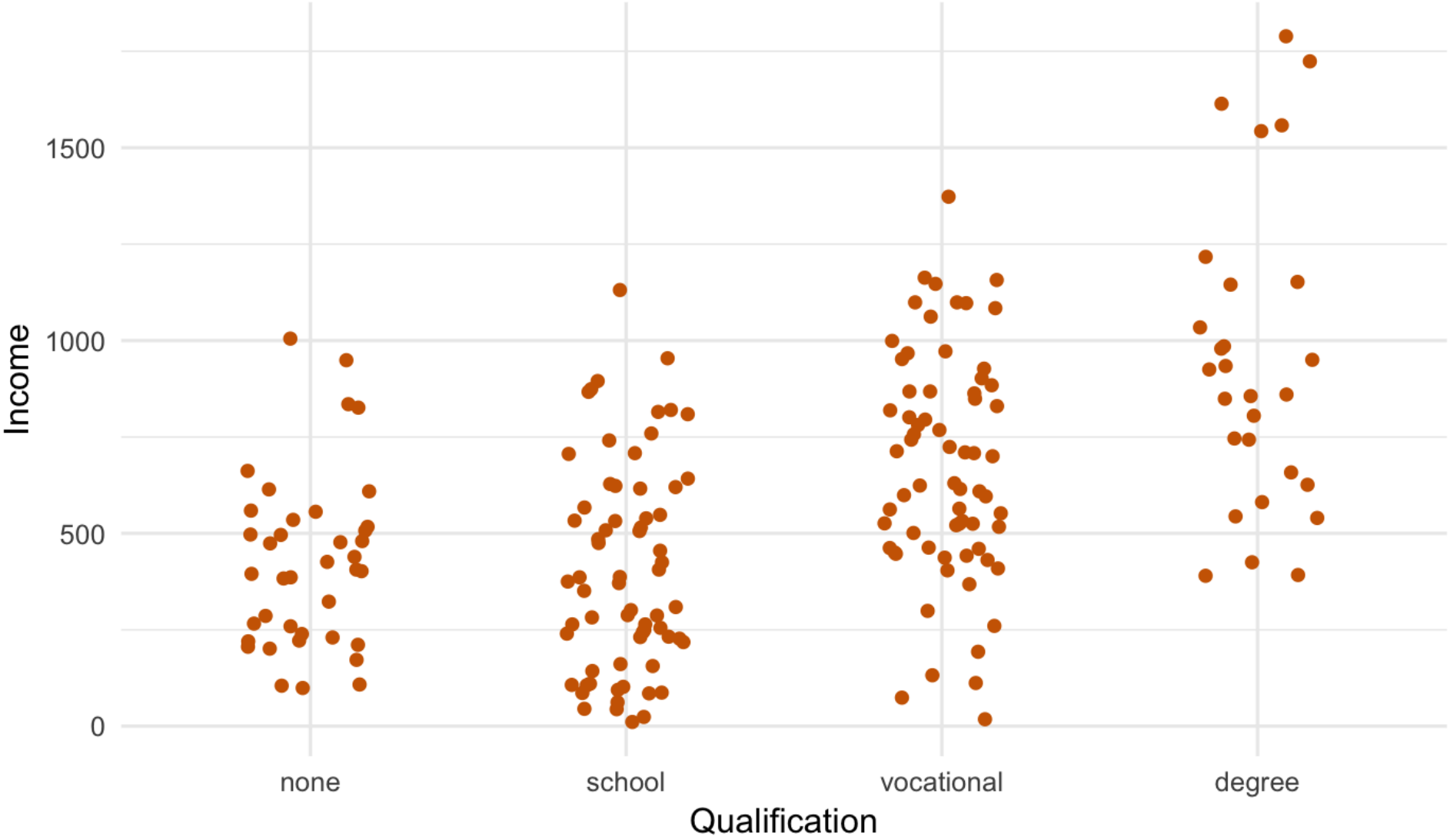
Overplotting – Outlined



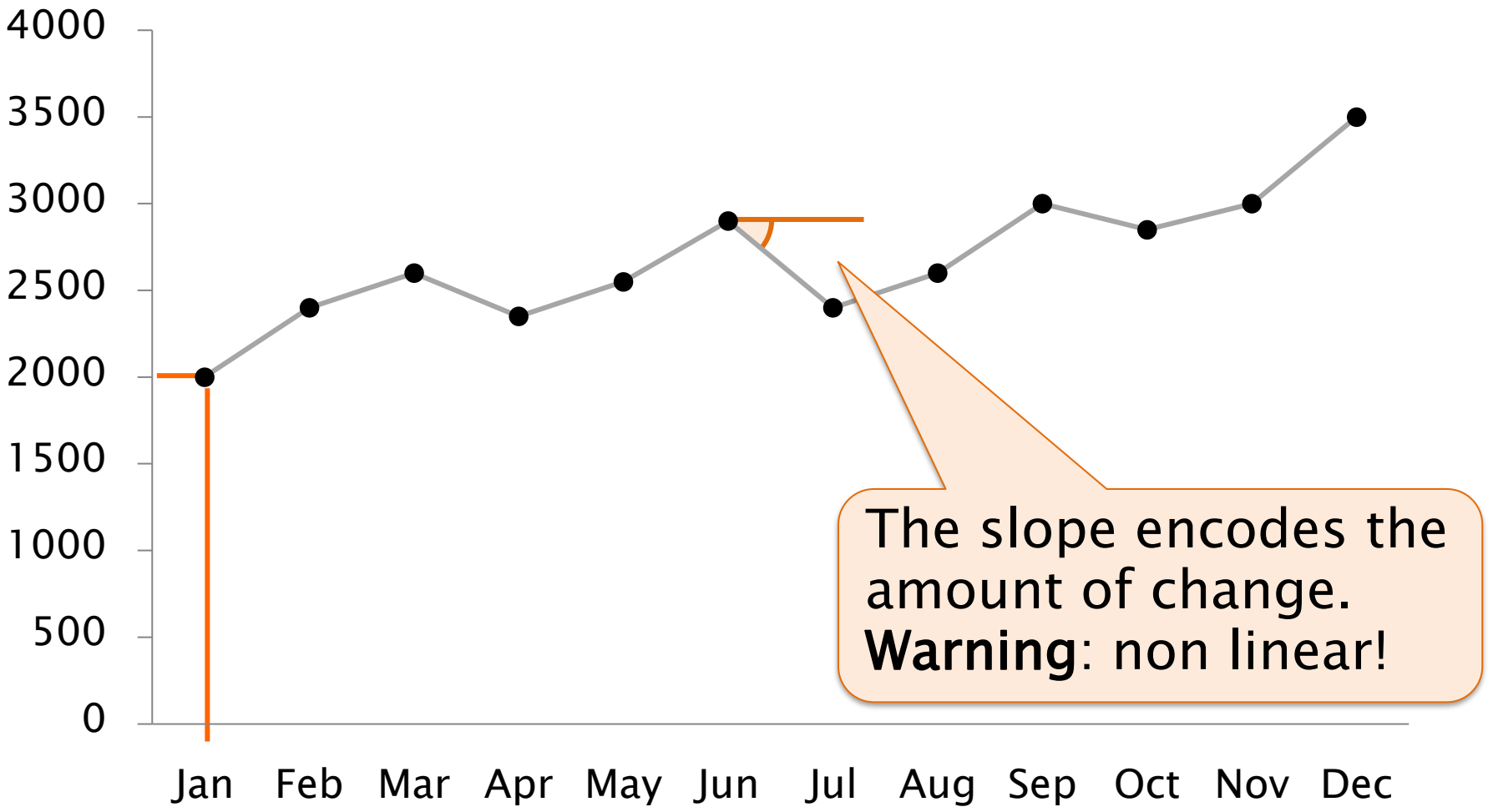
Overplotting – Transparent



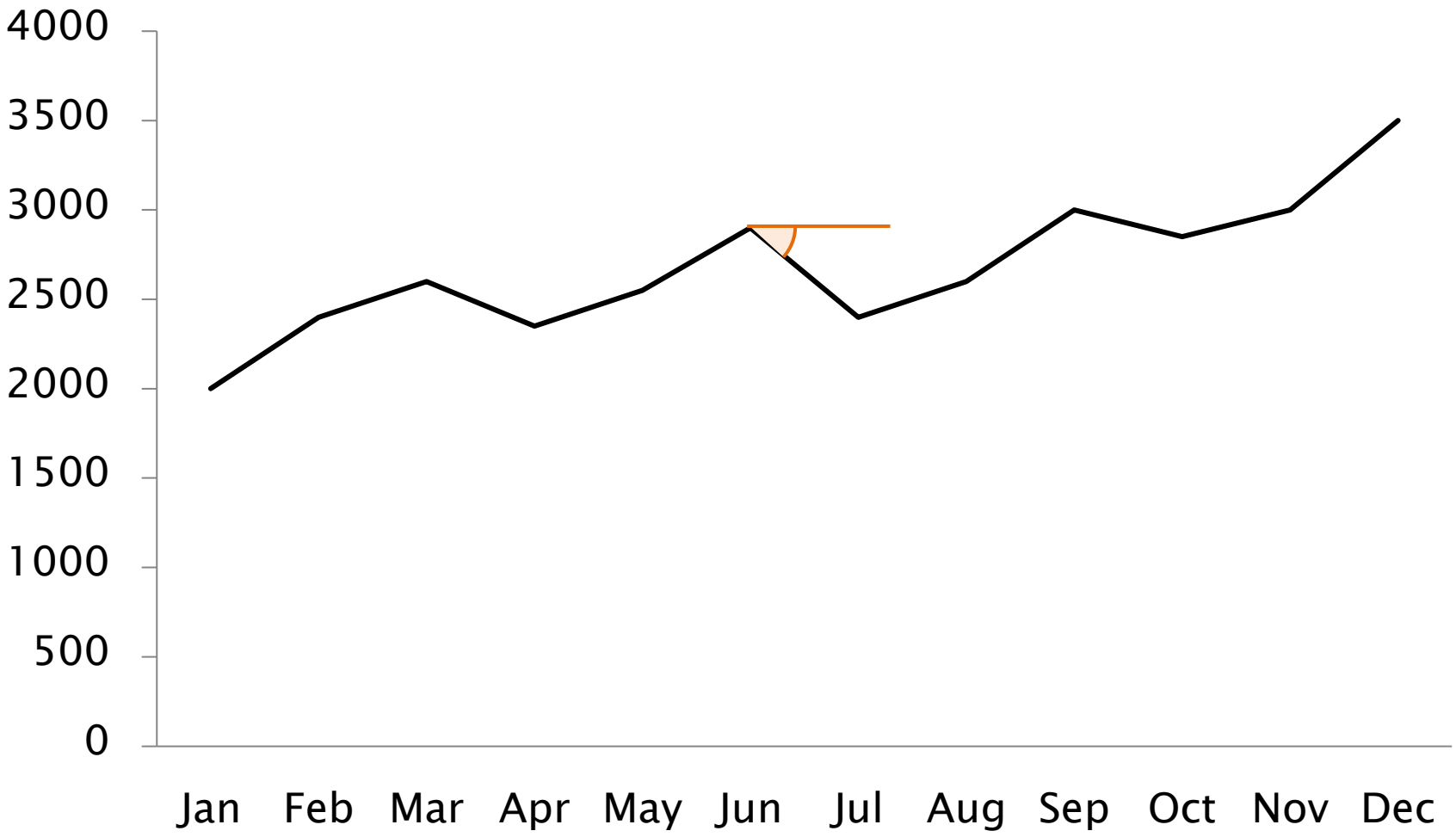
Overplotting – Jittering



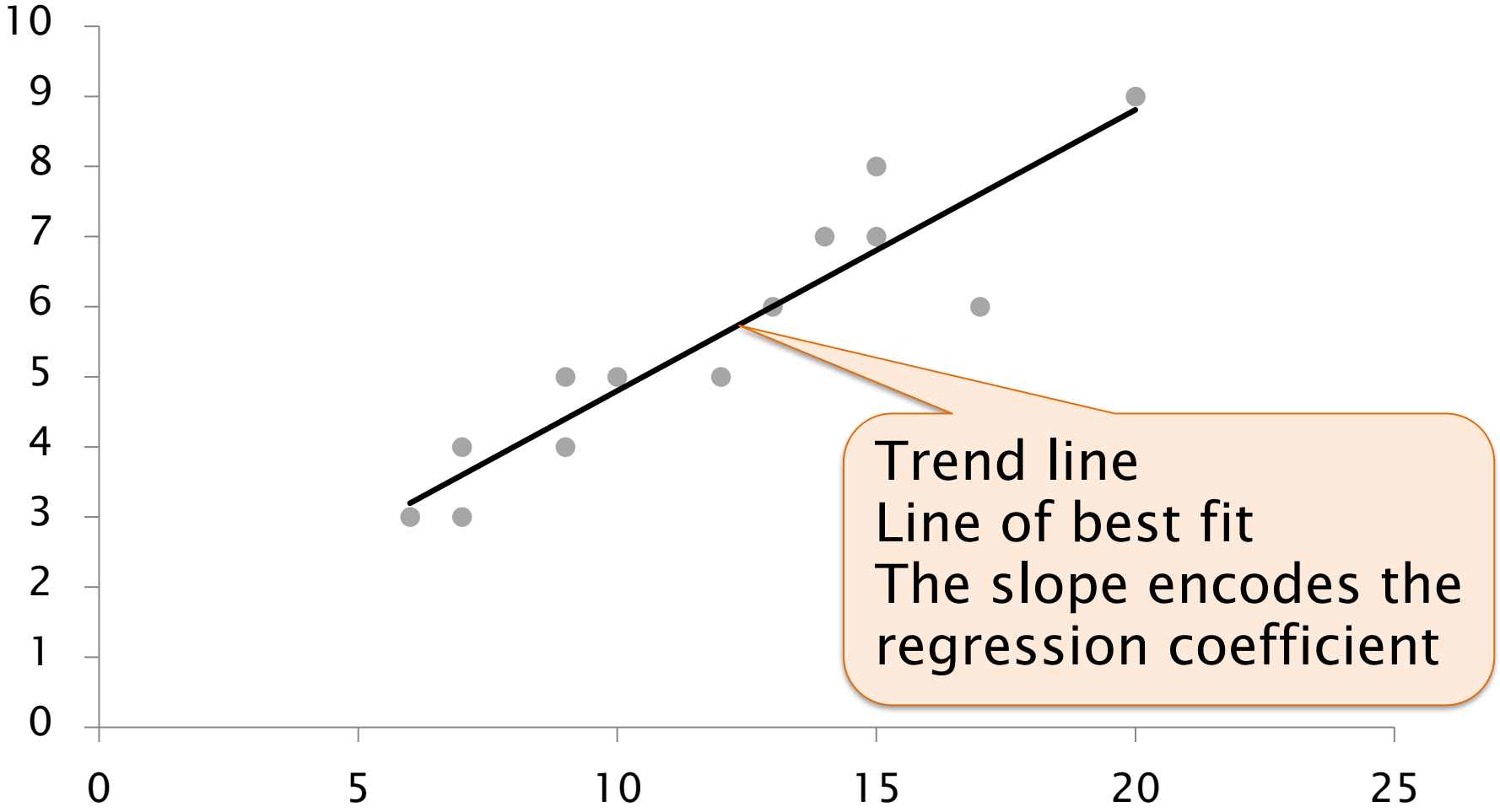
Points and Lines



Slope of lines



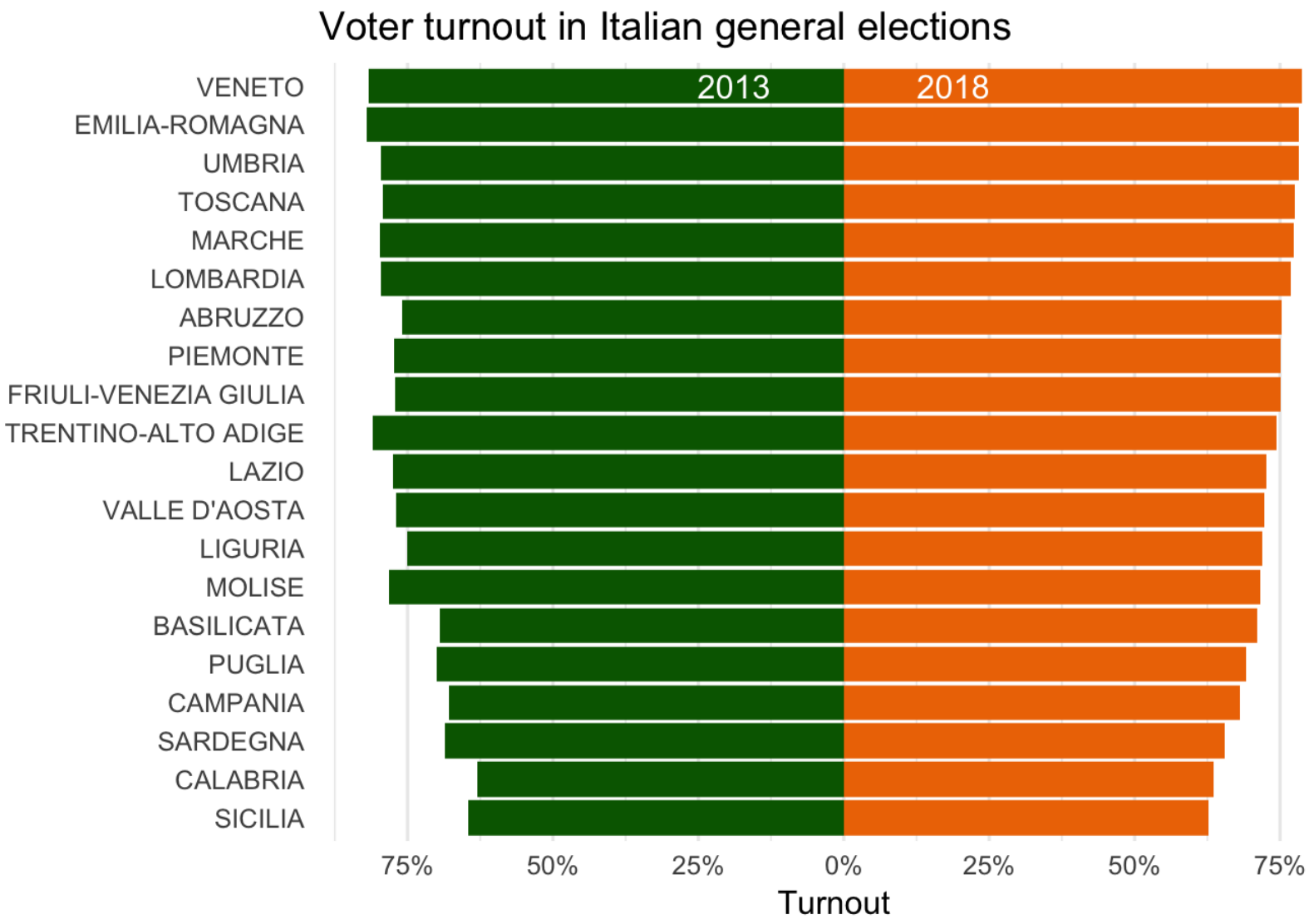
Slope of lines



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

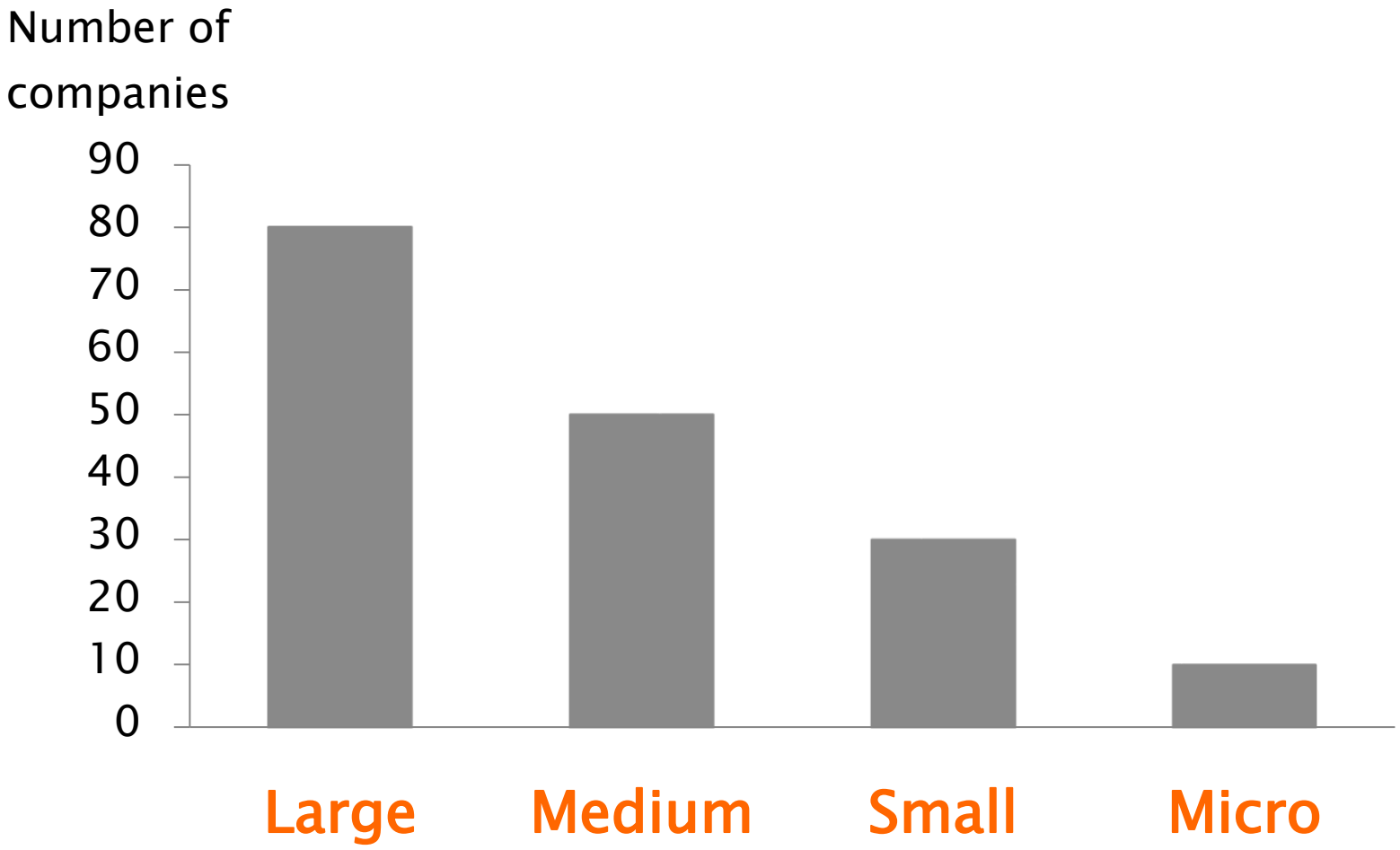


Categorical encoding attributes

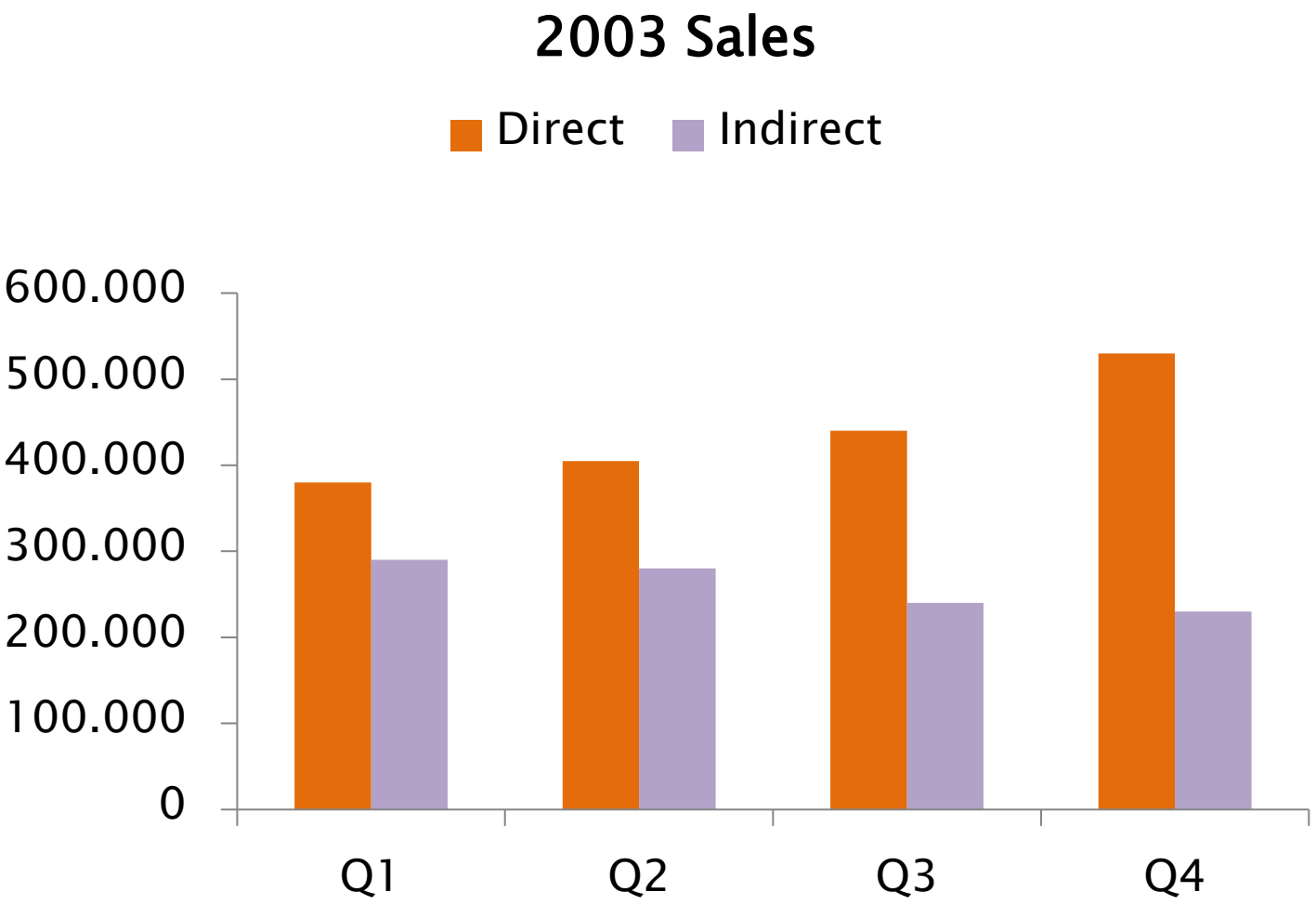
- Encoding of categorical levels
  - Position (along an axis)
  - Size
  - Color
    - Intensity
    - Saturation
    - Hue
  - Shape
  - Fill pattern
  - Line style

Ordinal

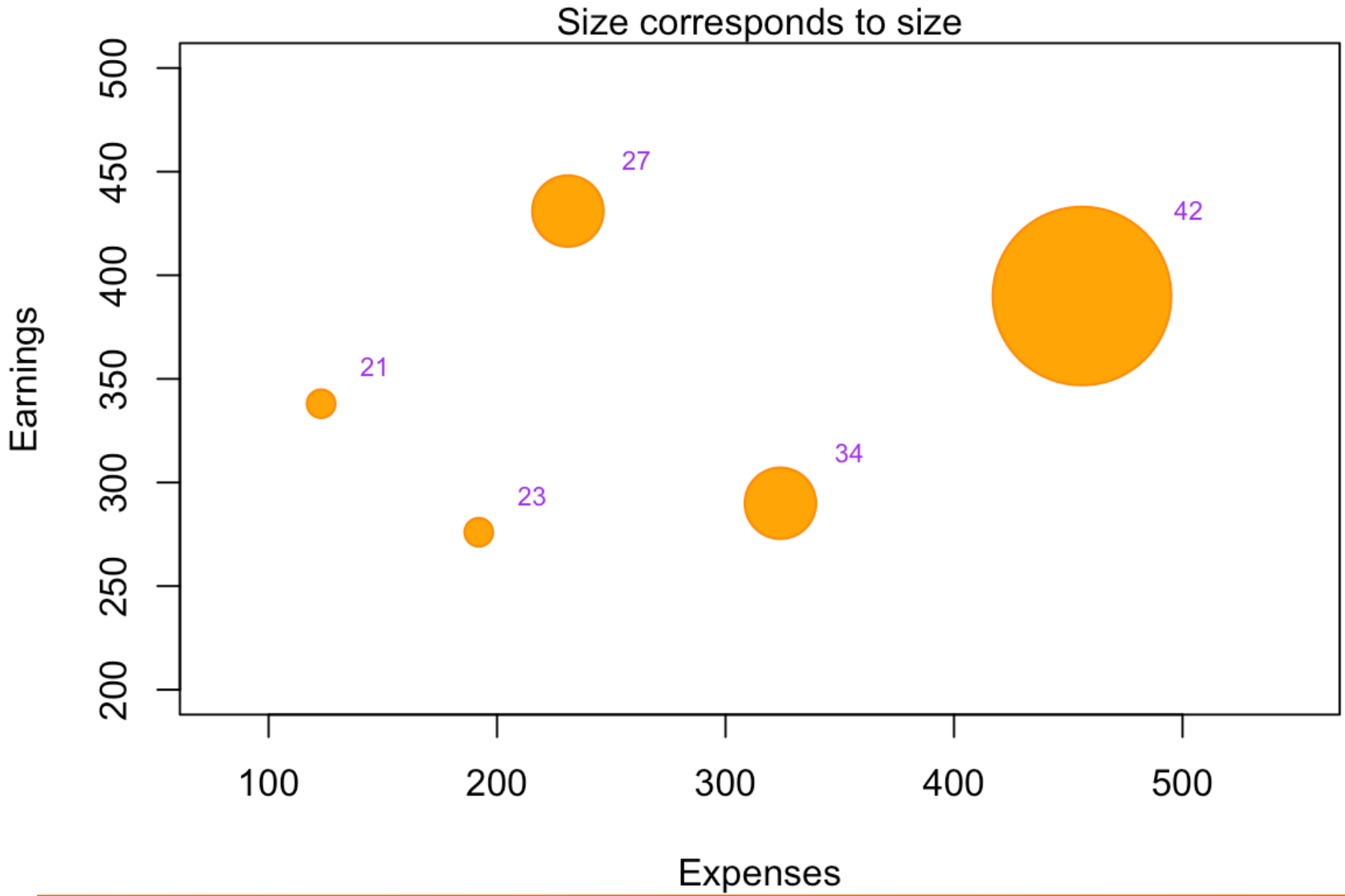
Position


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

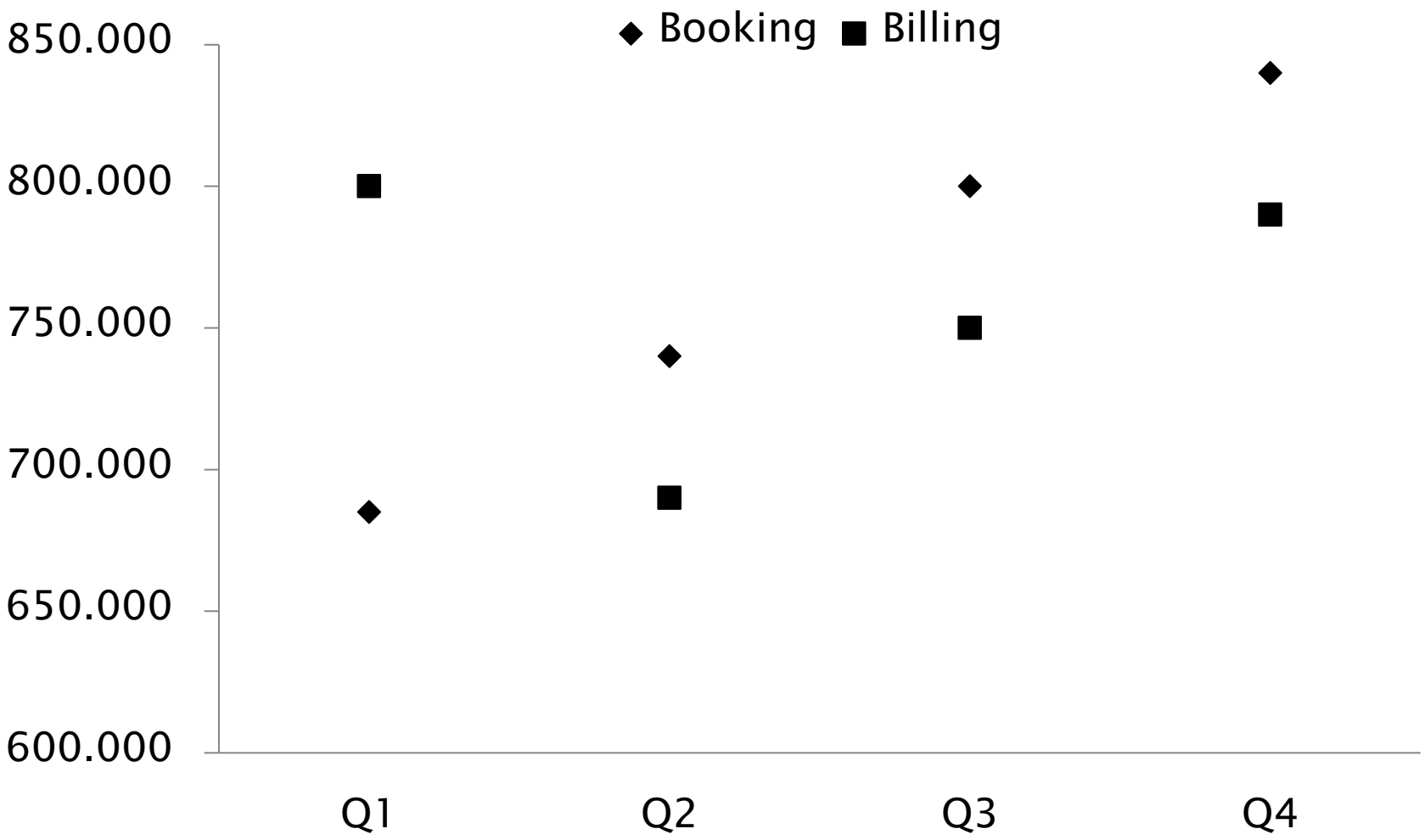
Position × Color (hue)



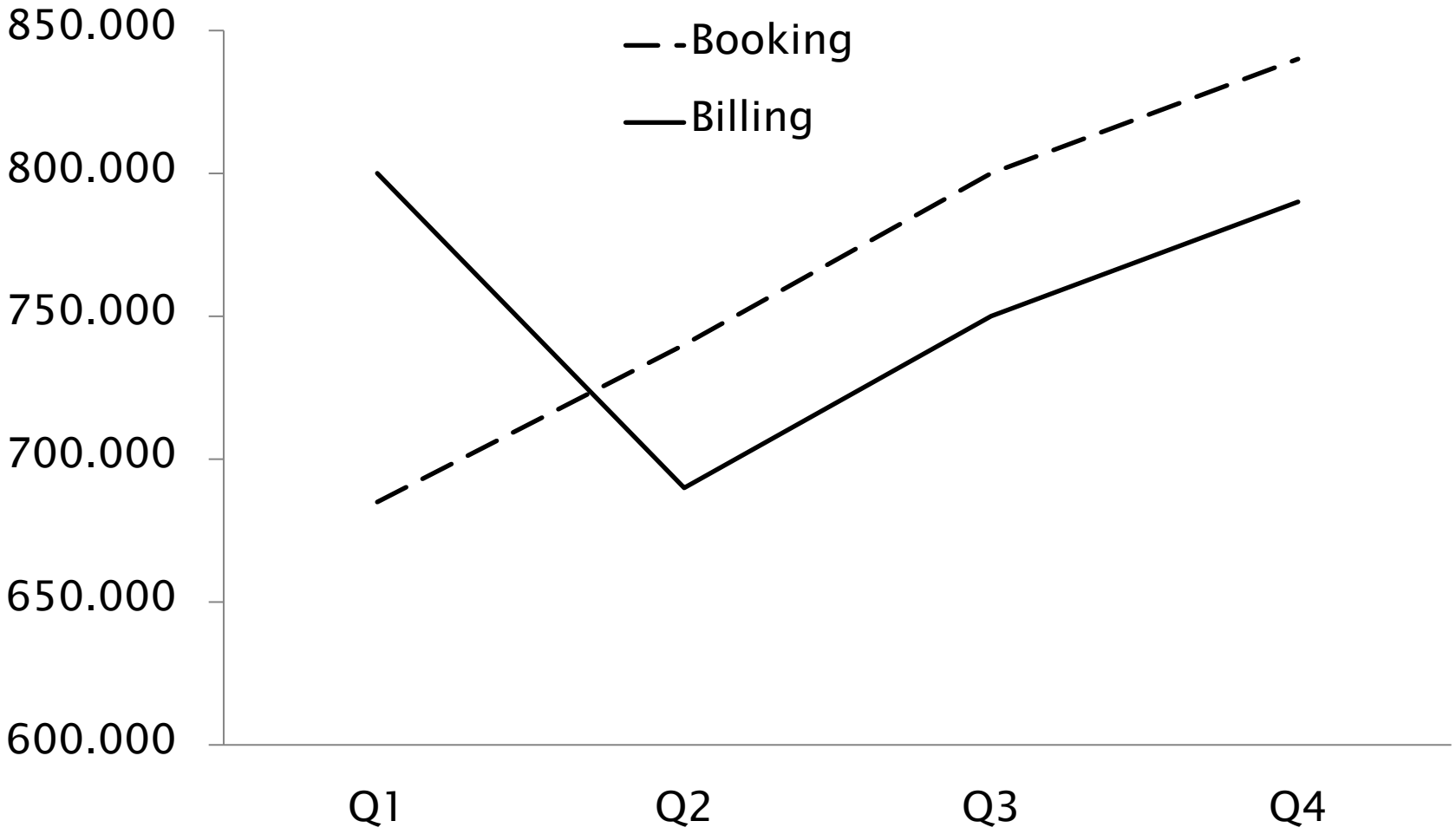
Size


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

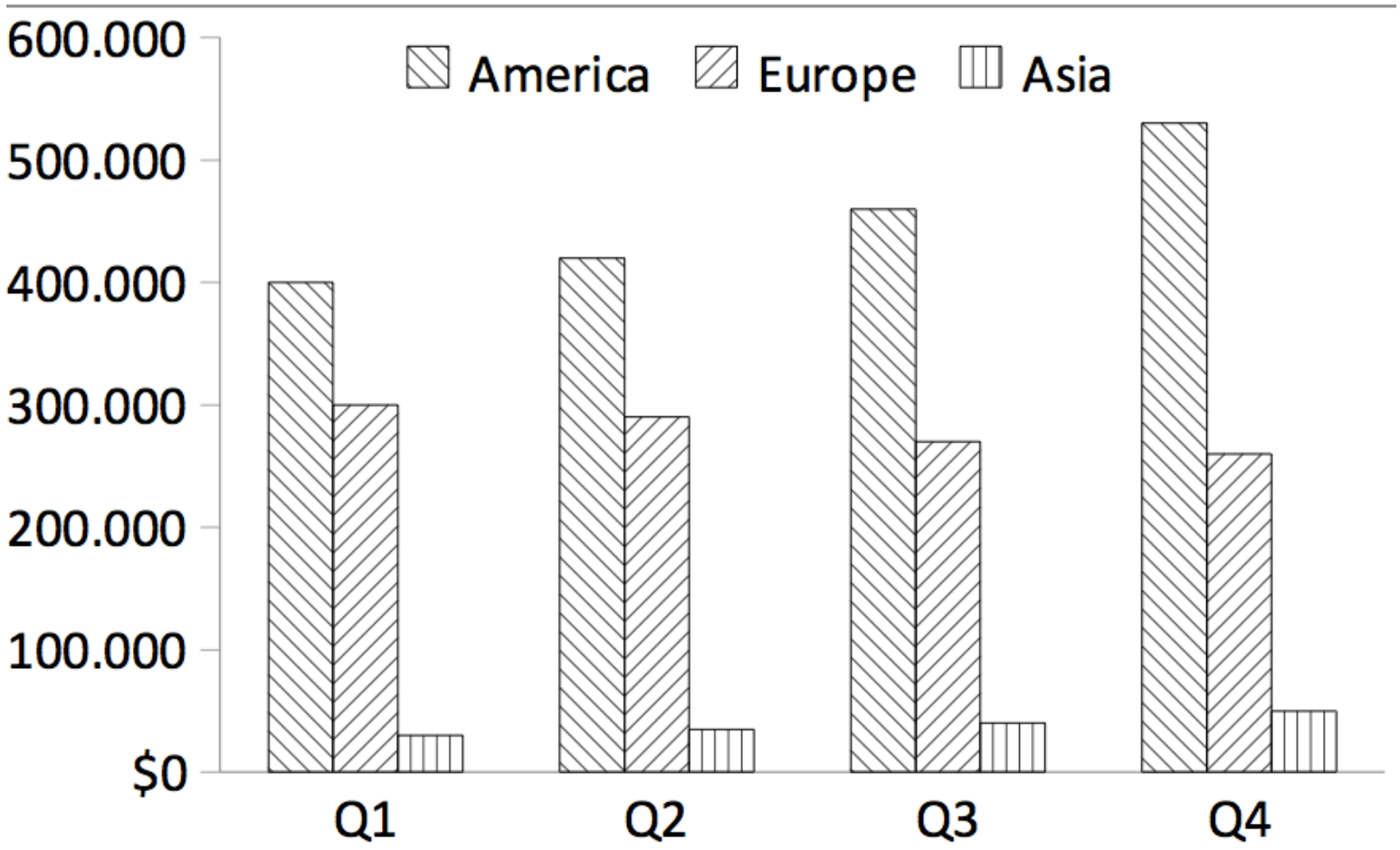
Point shape


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

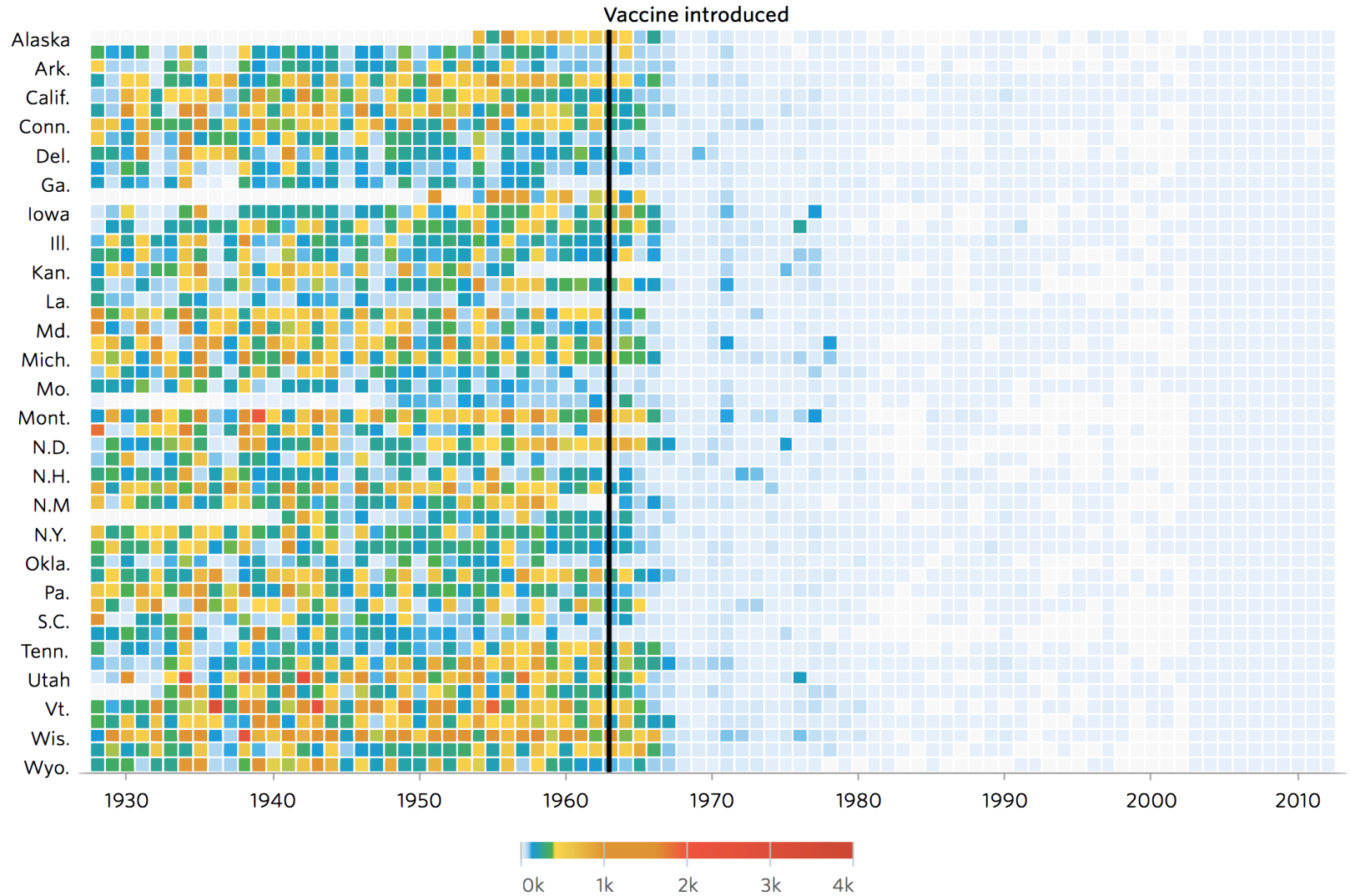


Discretization / Quantization

- 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

Measles

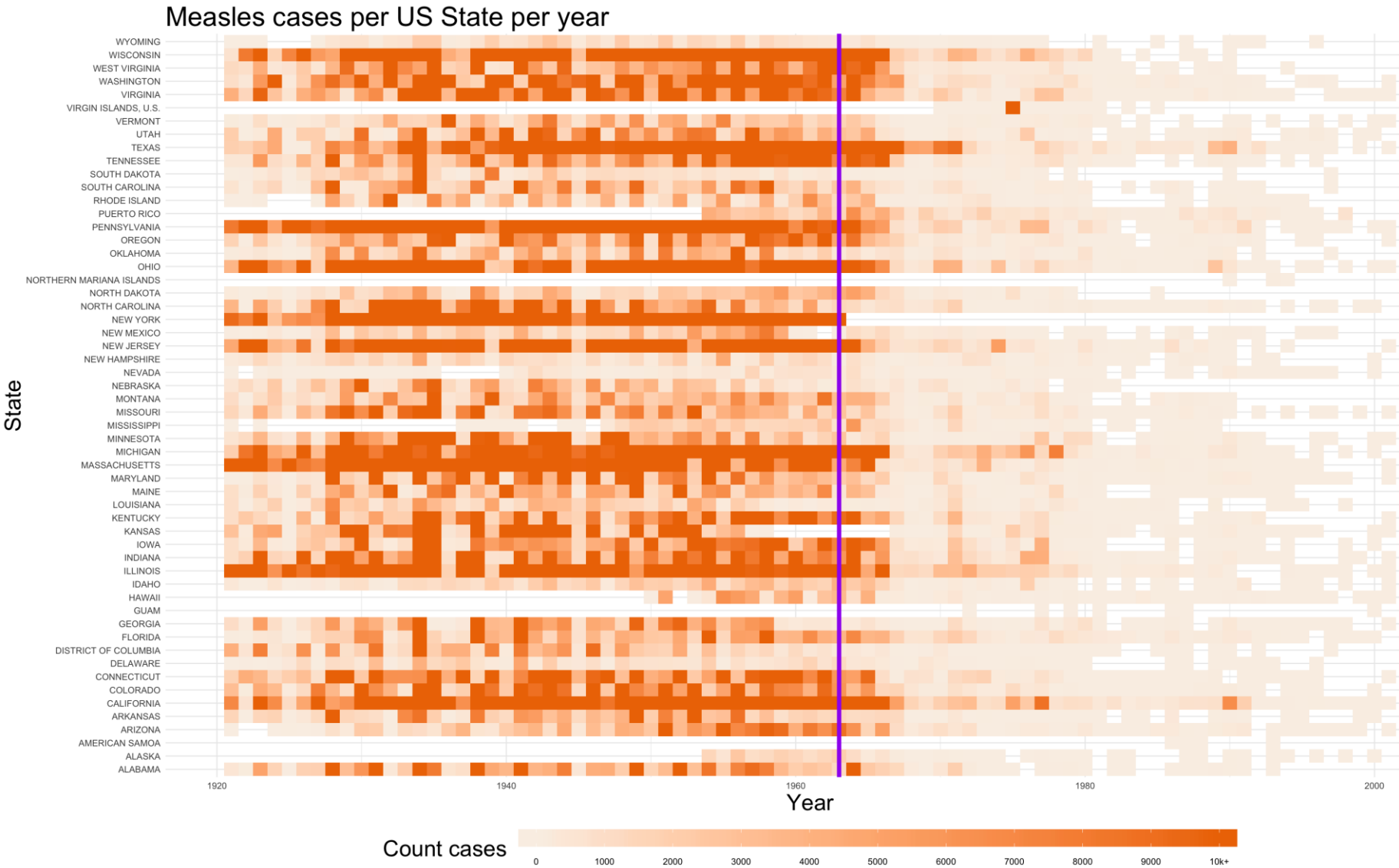


http://graphics.wsj.com/infectious-diseases-and-vaccines/

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
State
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
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

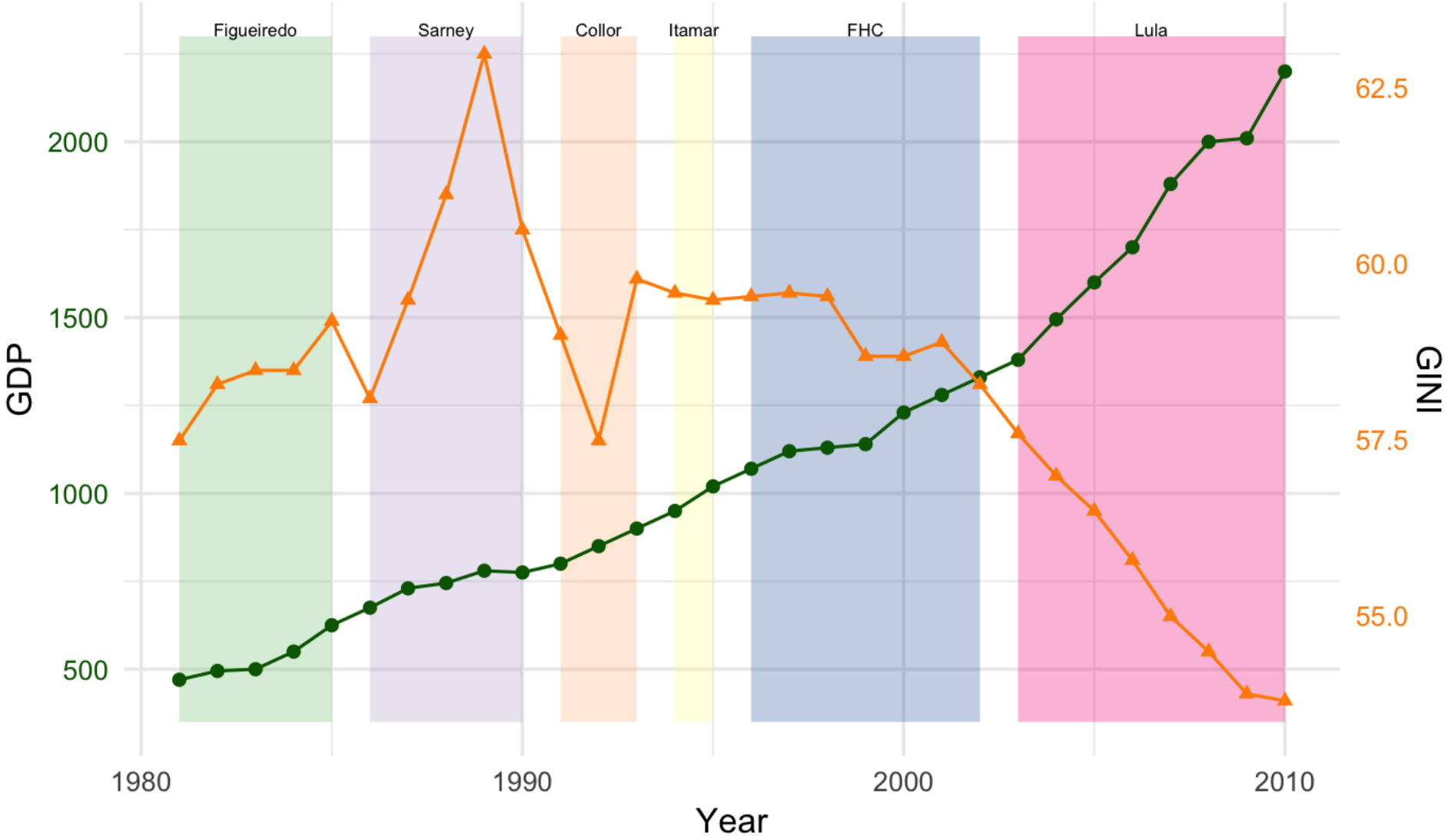
Tick marks

- 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

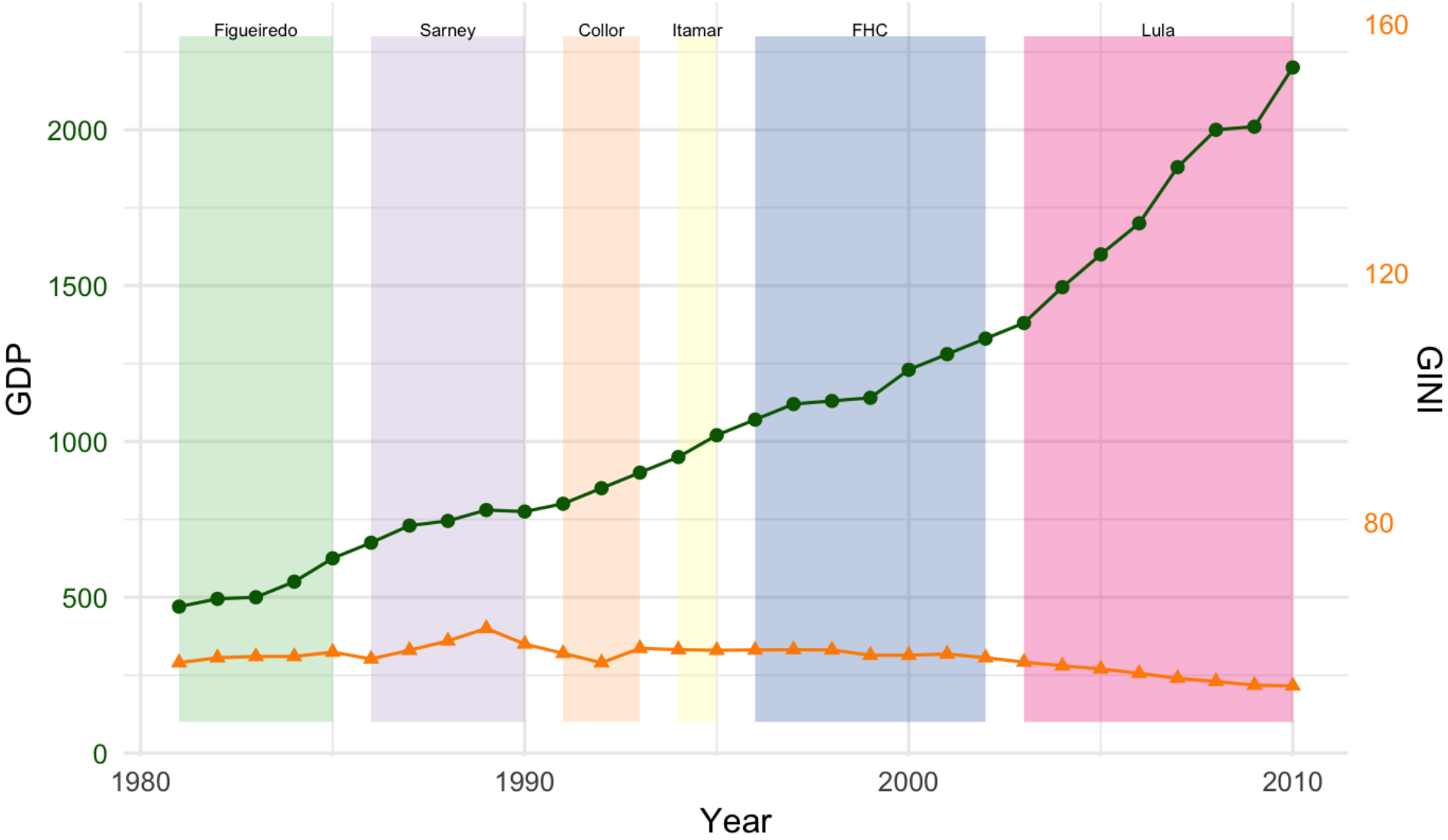
Multiple variables

- 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

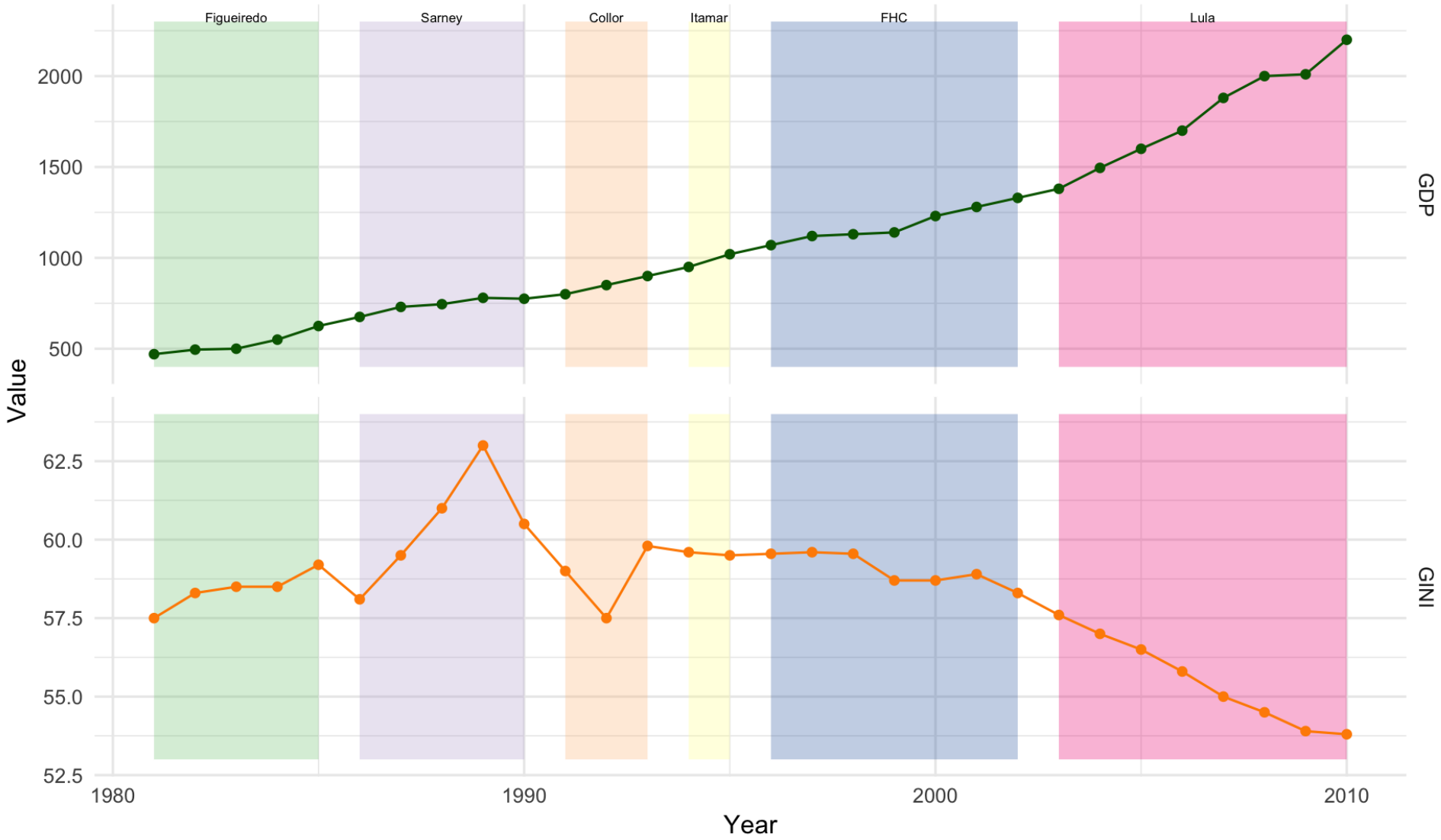
Double scale



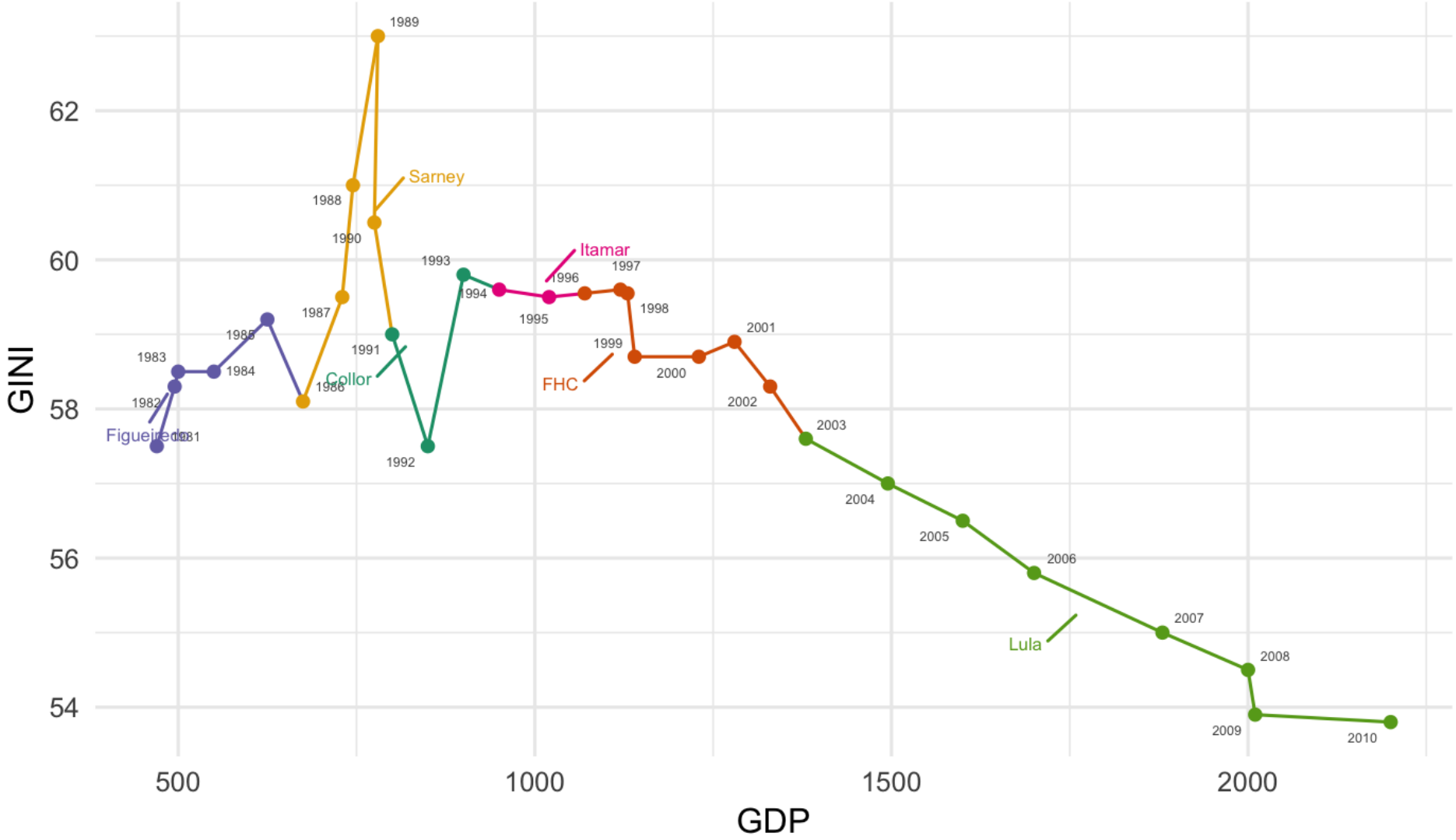
Double scale (alternative)



Multiple graphs



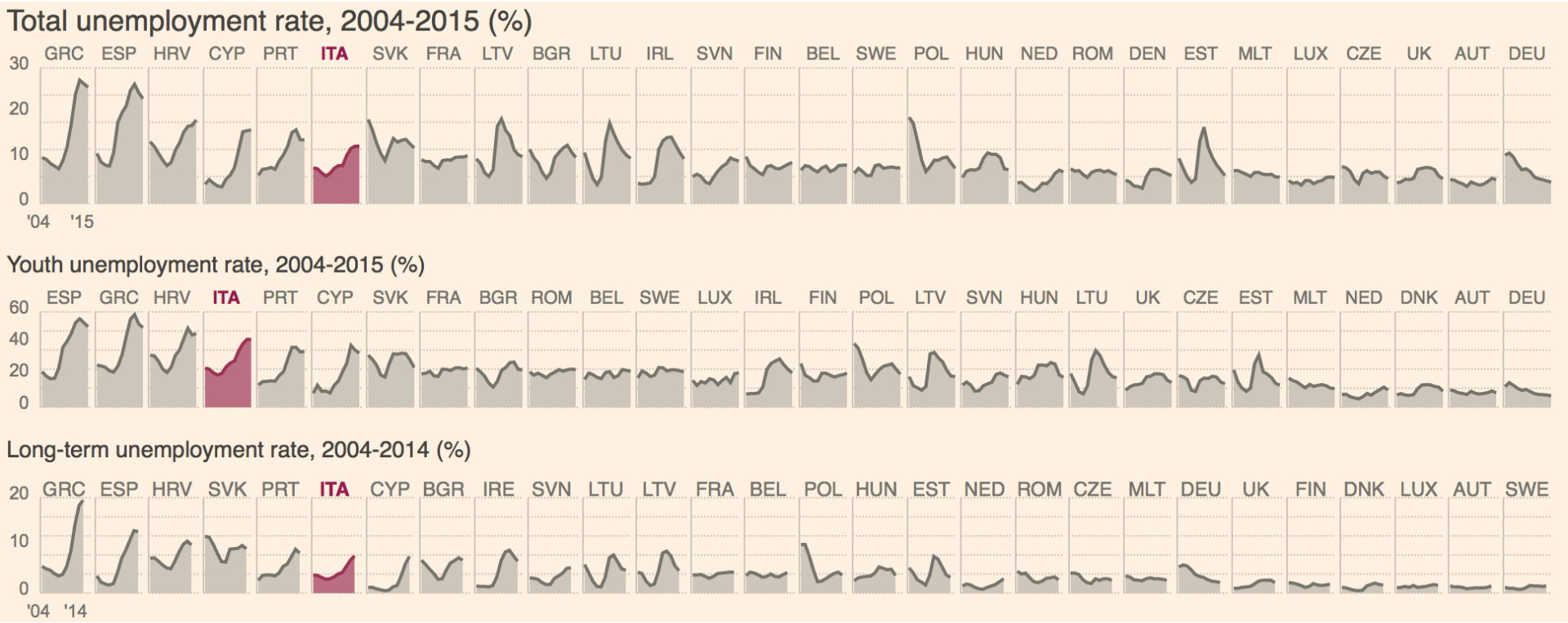
Path


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

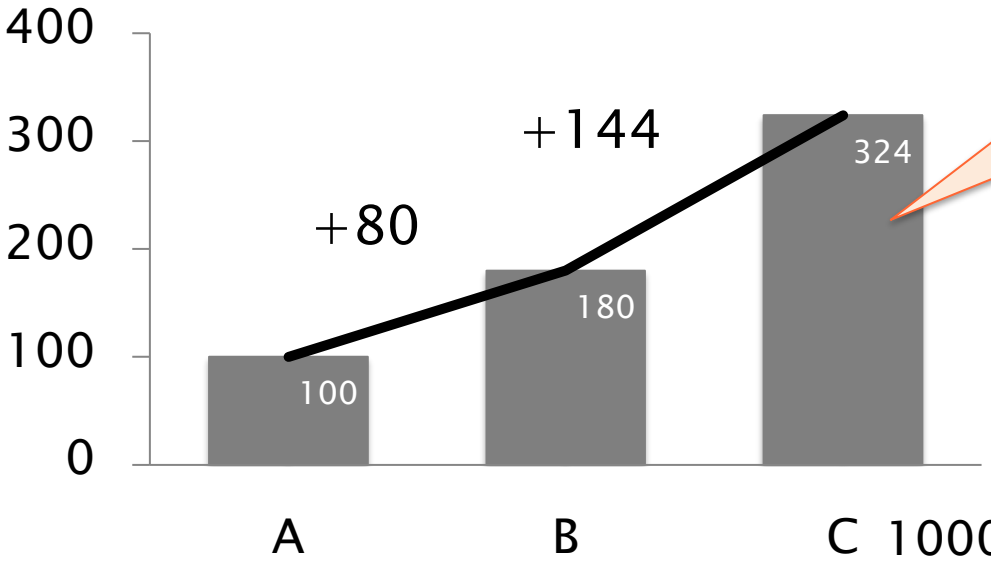
Trellis

- 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

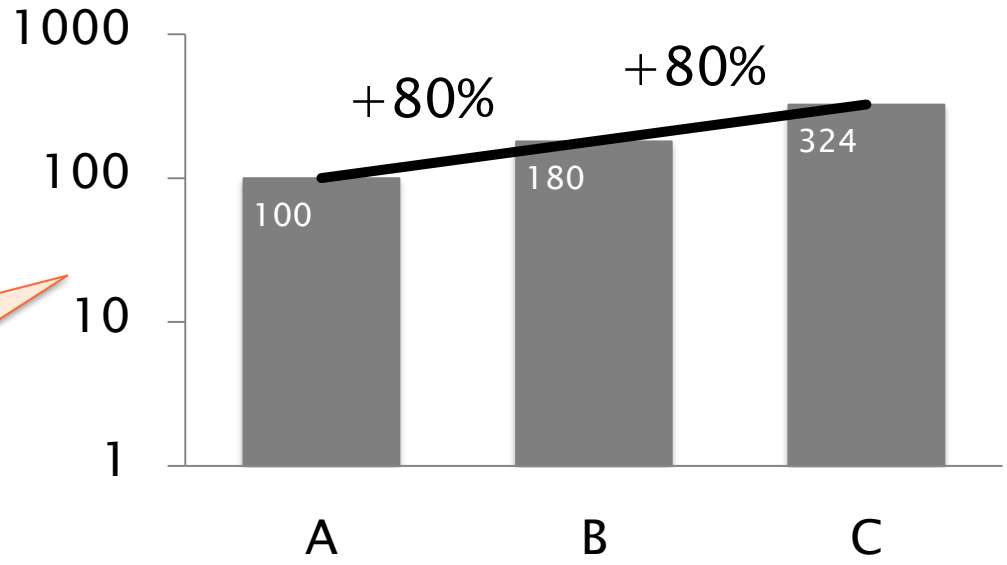
Log scale

- Reduce visual difference between quantitative data sets with significantly wide ranges
- Differences are proportional to percentages

Log scale

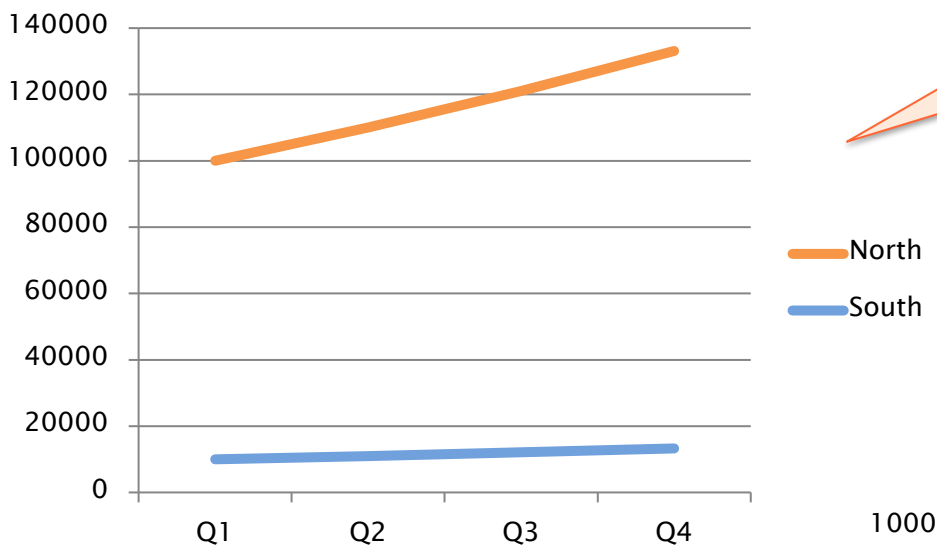


Same absolute gains correspond to same distance

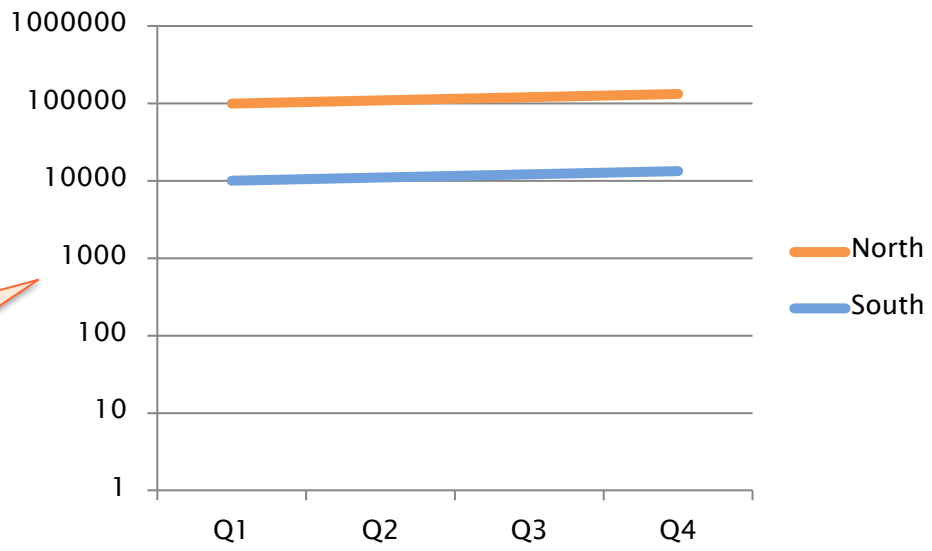


Same percentage gains correspond to same distance

Log scale



Parallel lines for same absolute gains



Parallel lines for same percentage gains

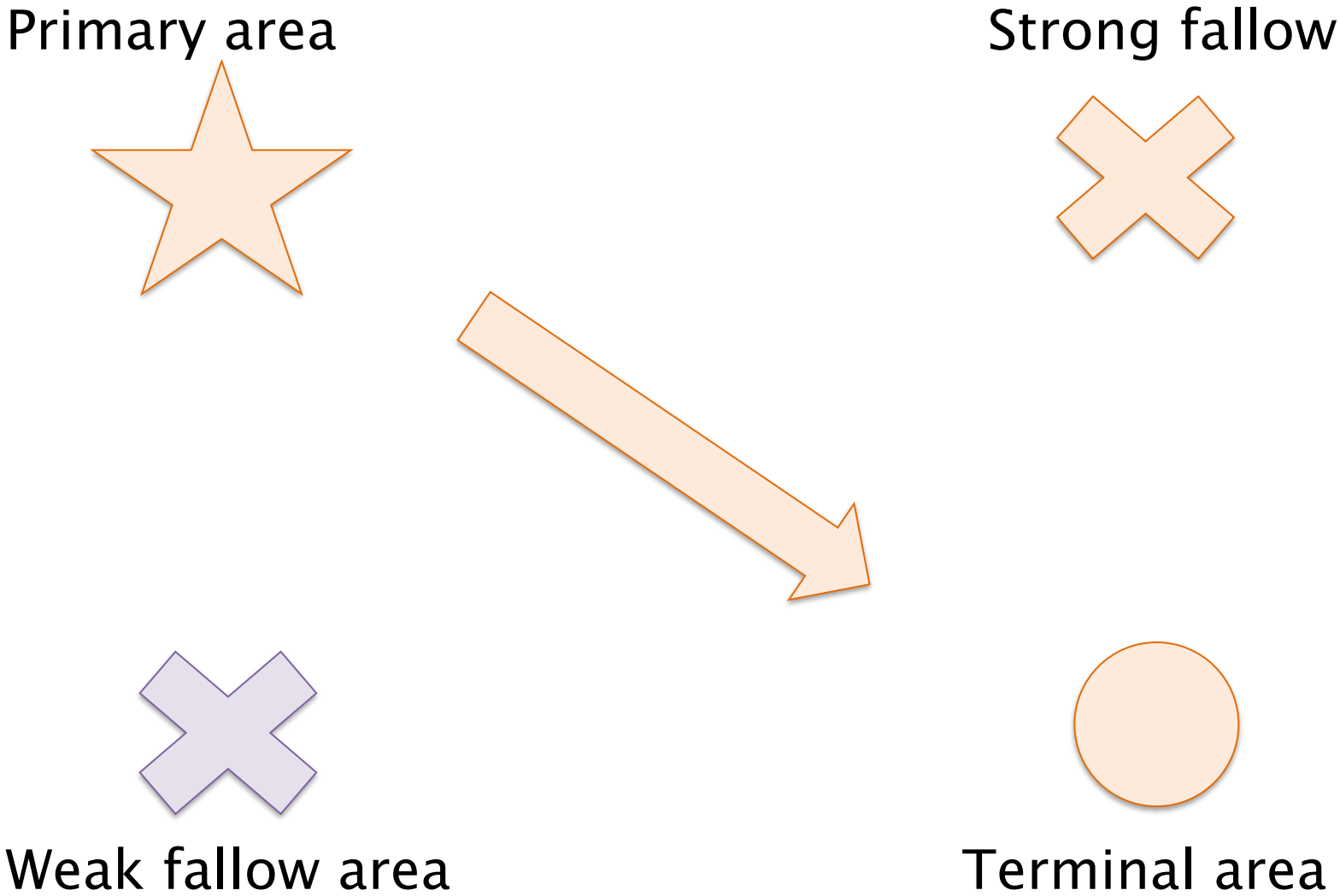
Graph area

- 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

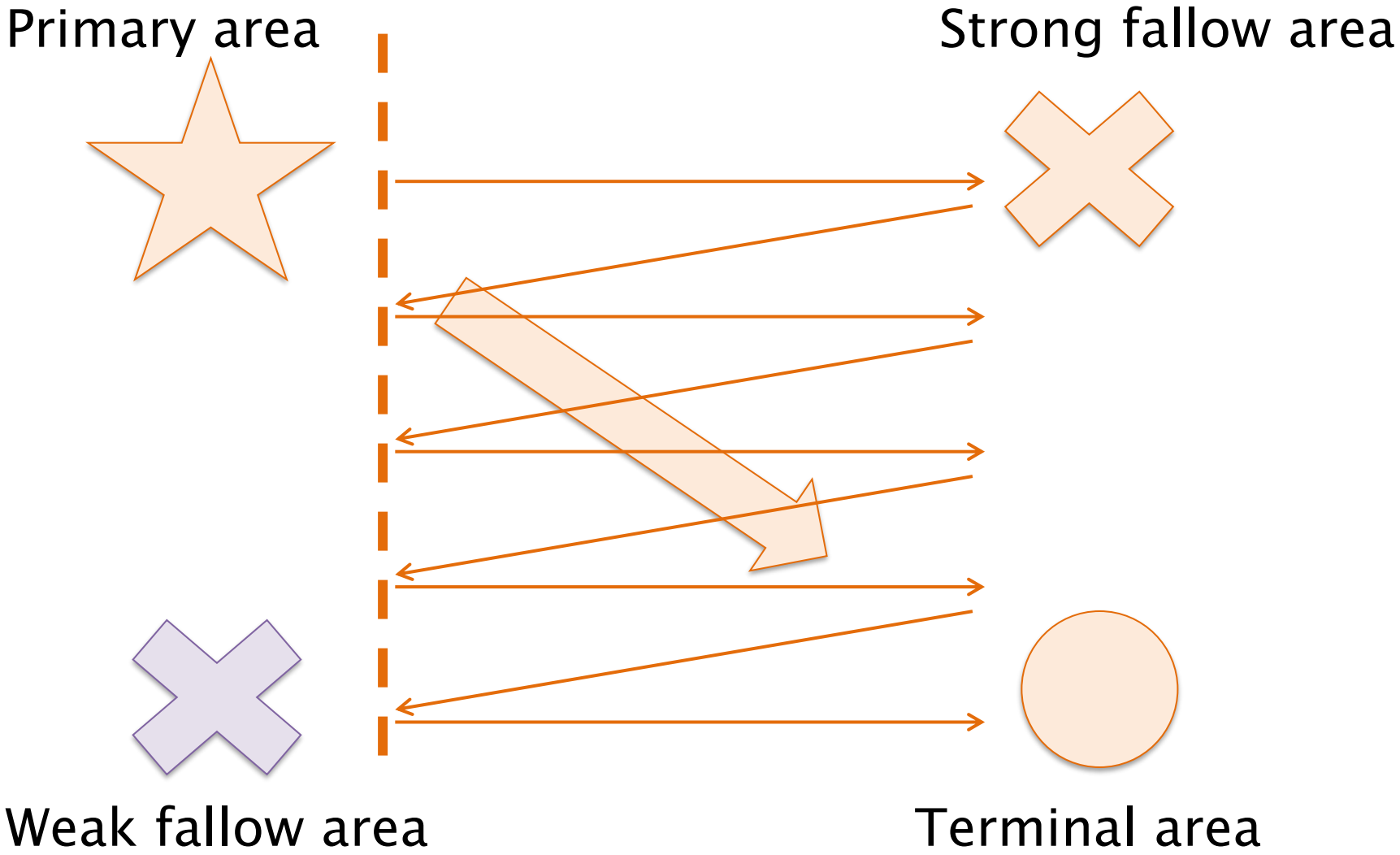
Labels

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

Guthenberg Diagram



Guthenberg Diagram



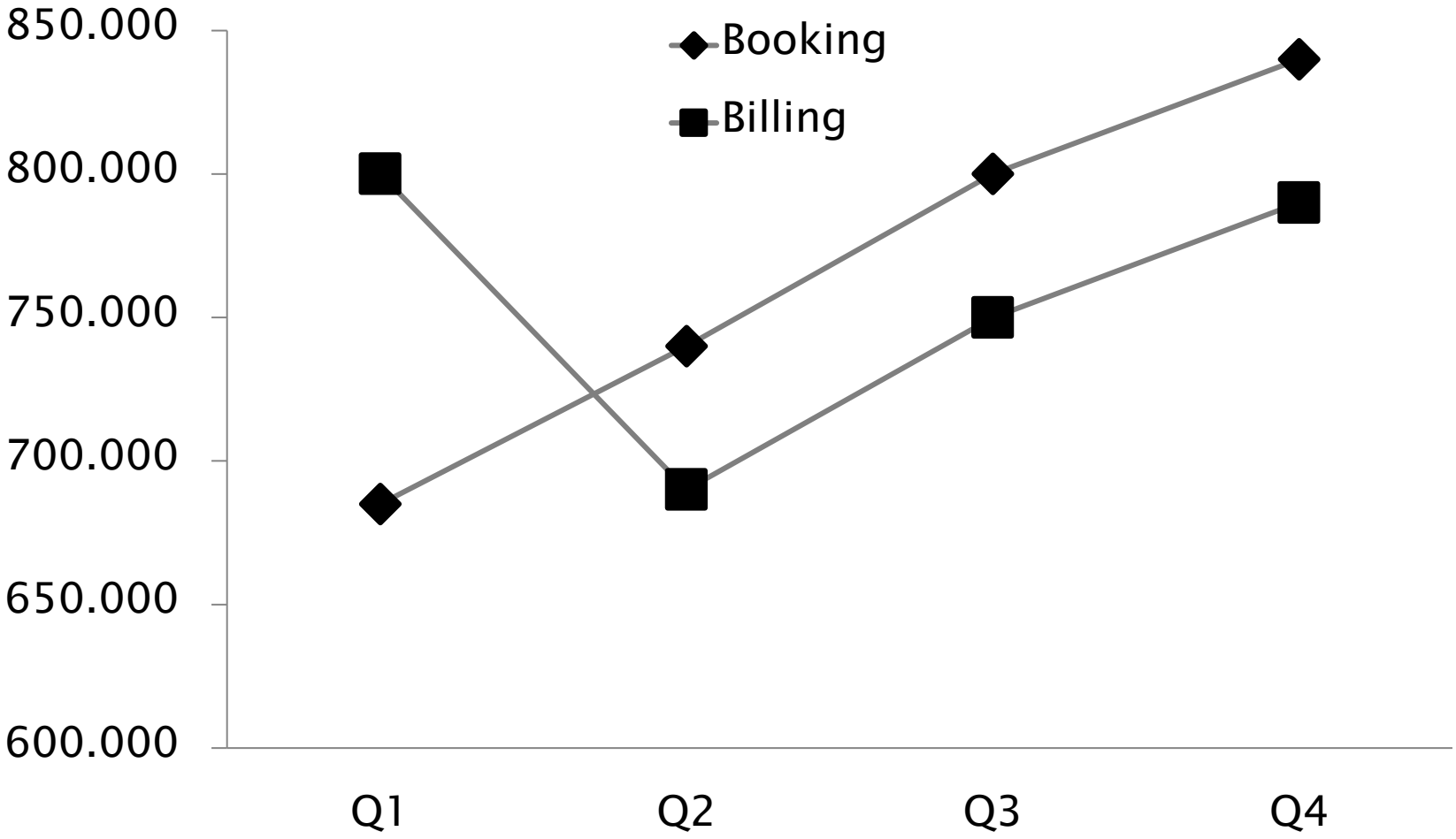
Legends

- 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

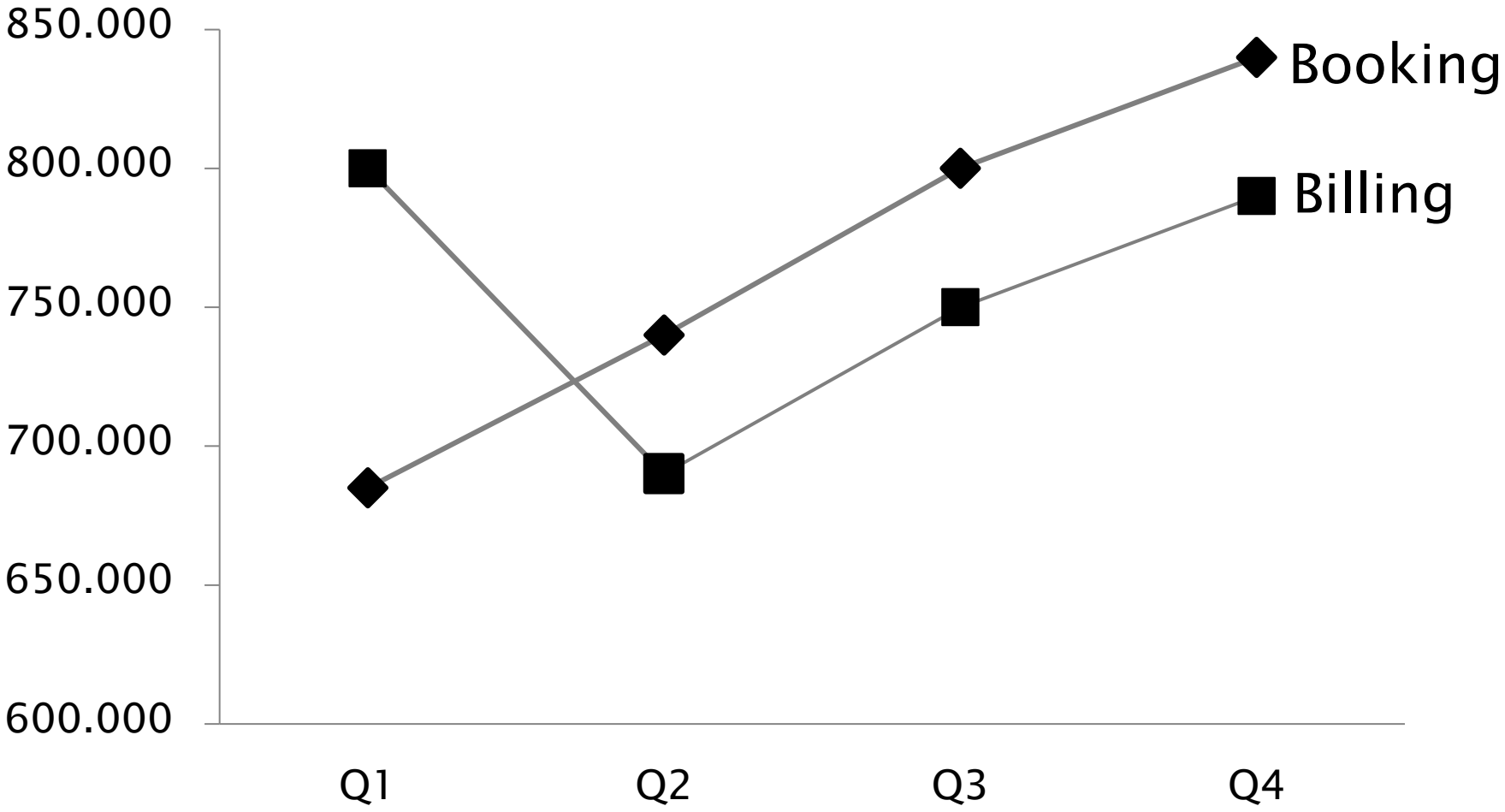
Legends

- 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

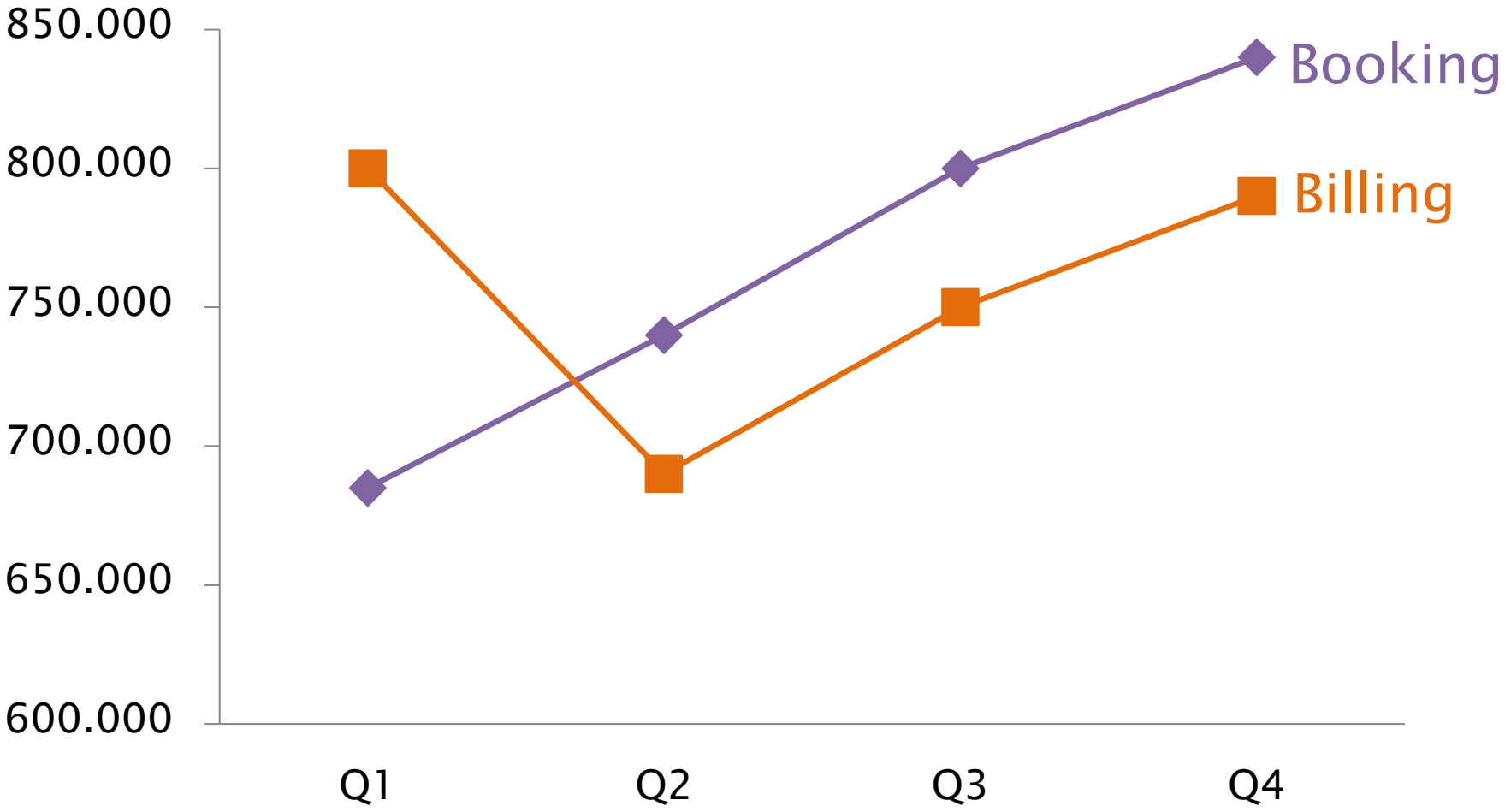
Legend


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

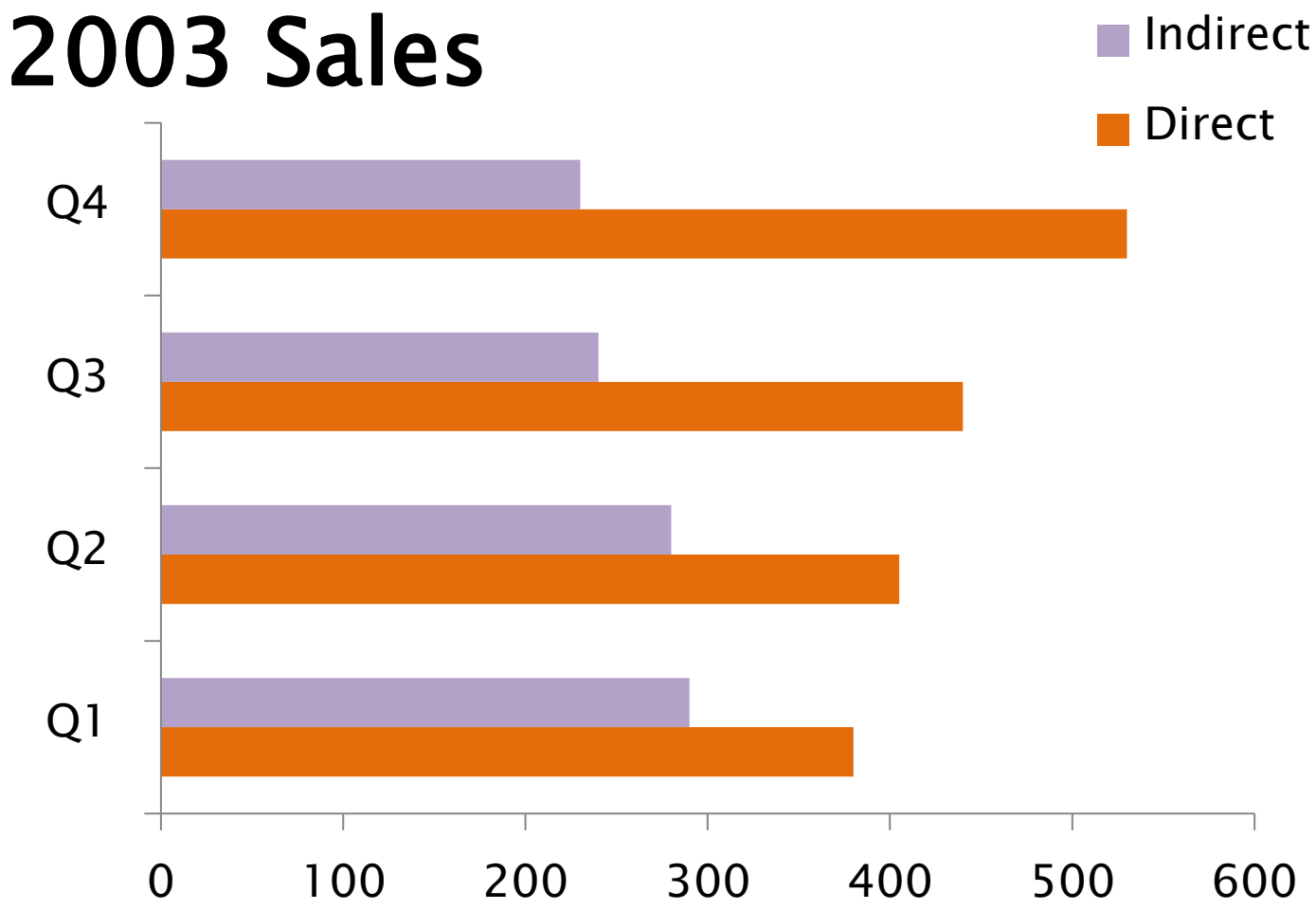
Direct labeling



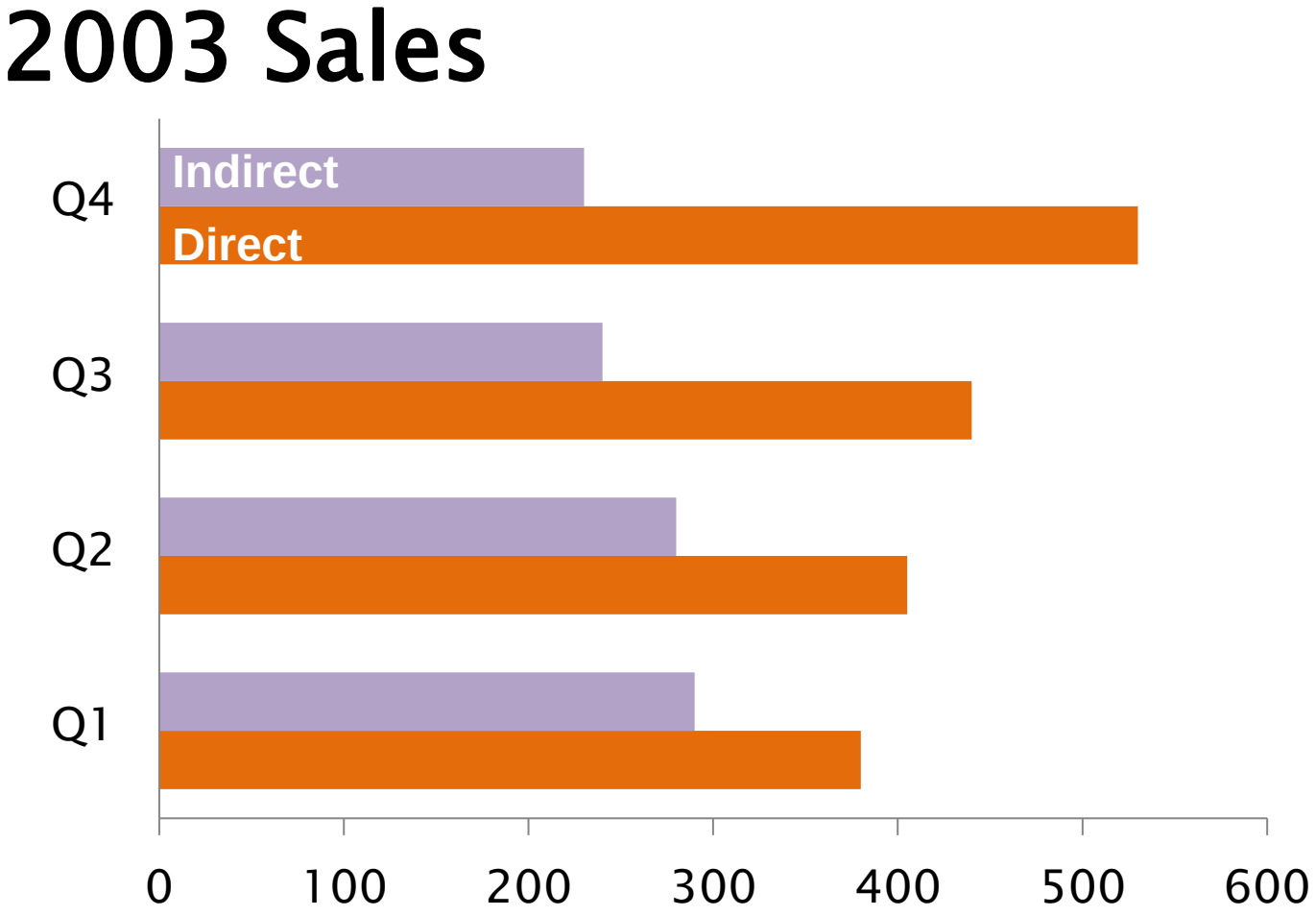
Direct labeling and color



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

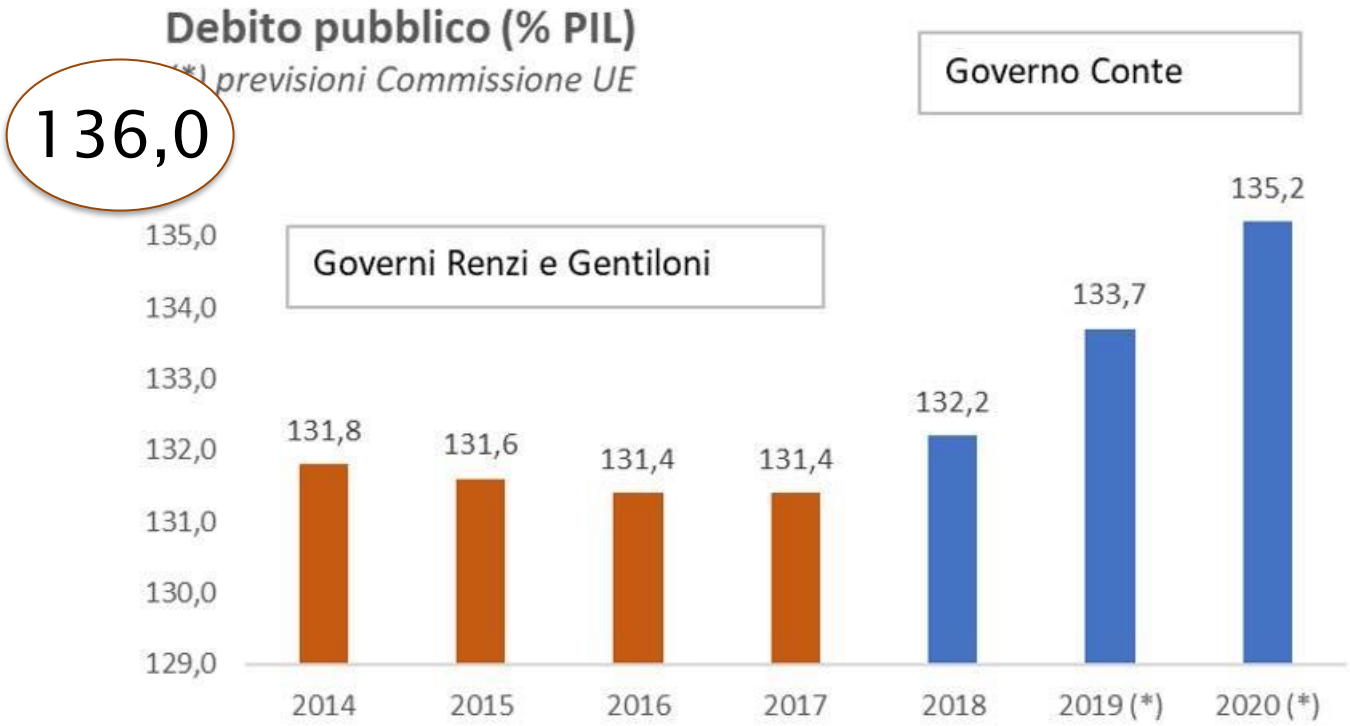
Provide context for data

- References allow judging the data

Use appropriate detail

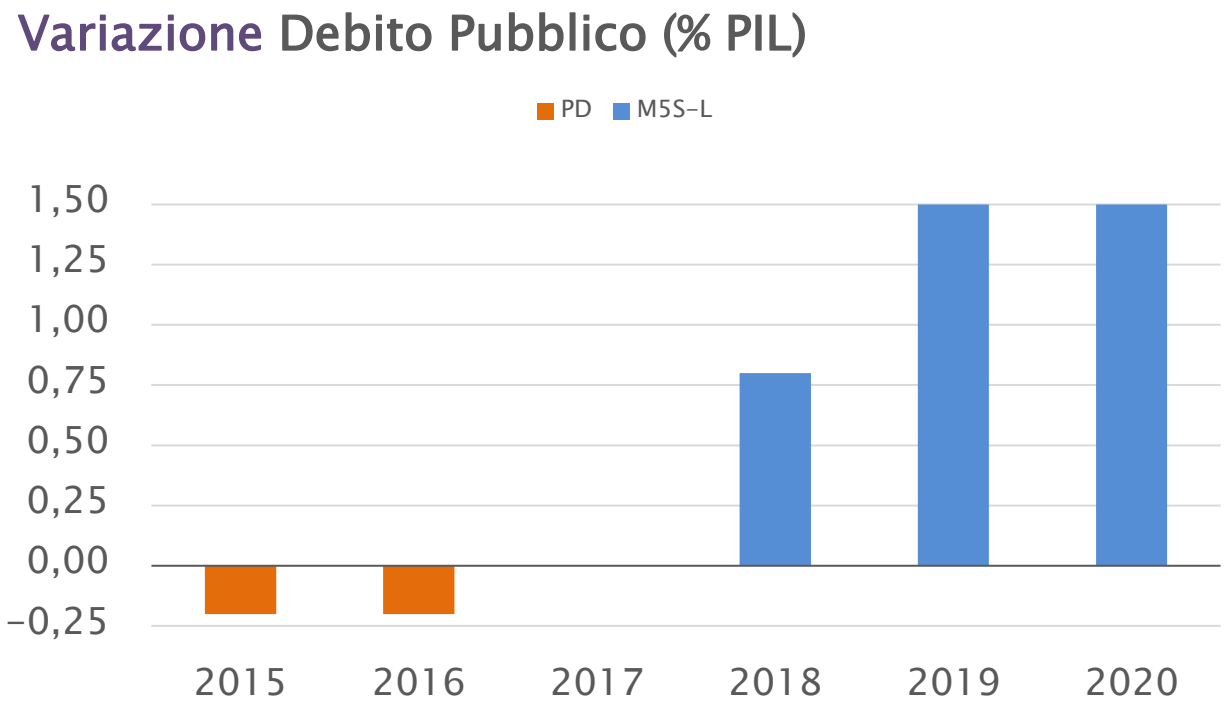
PUC

- Typical counter-examples
  - 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

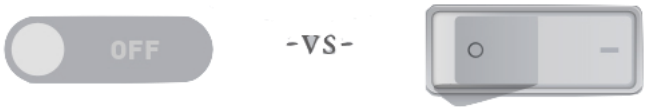
Visualization instruments

- 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

A

B

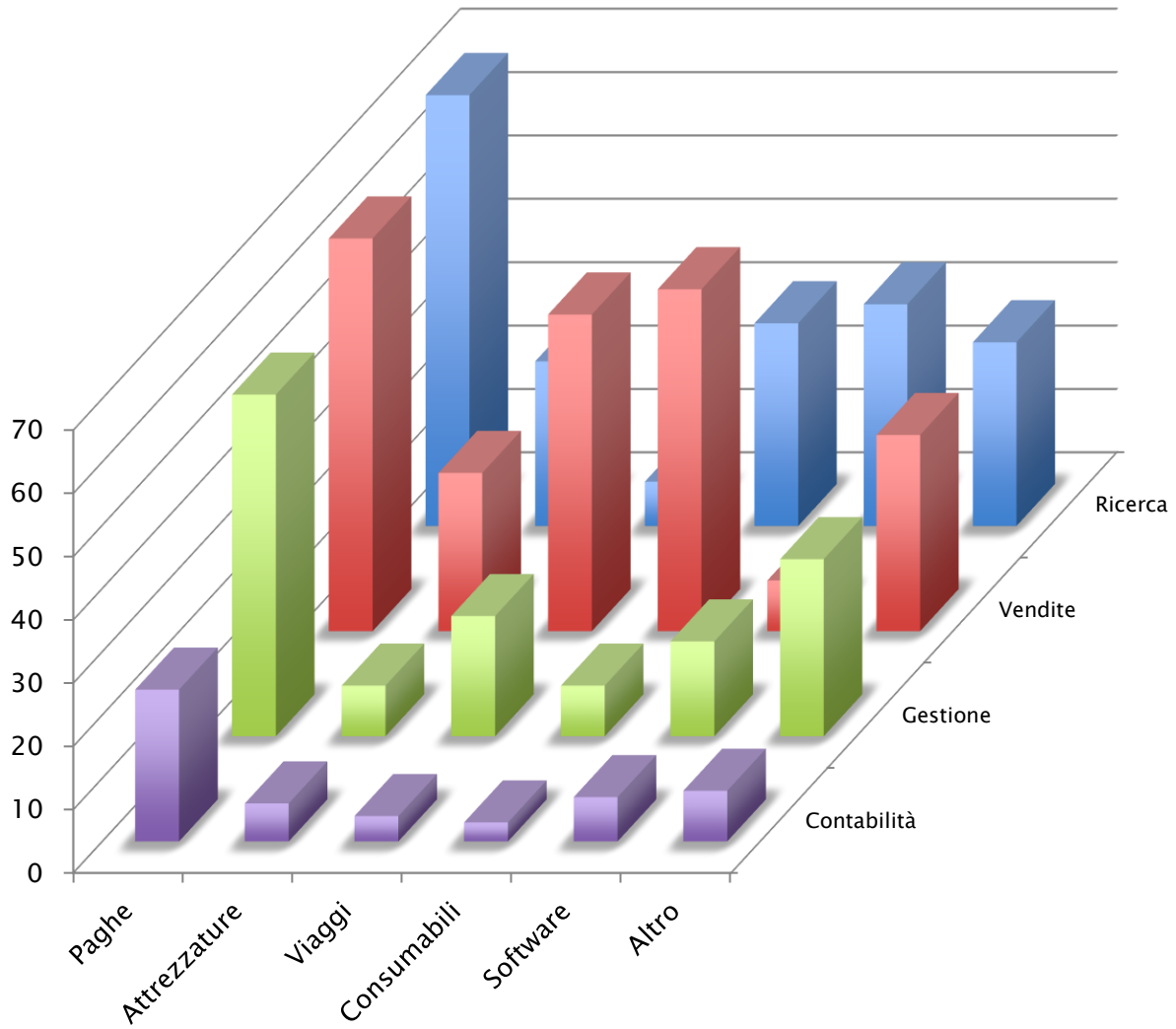
Avoid decorations

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

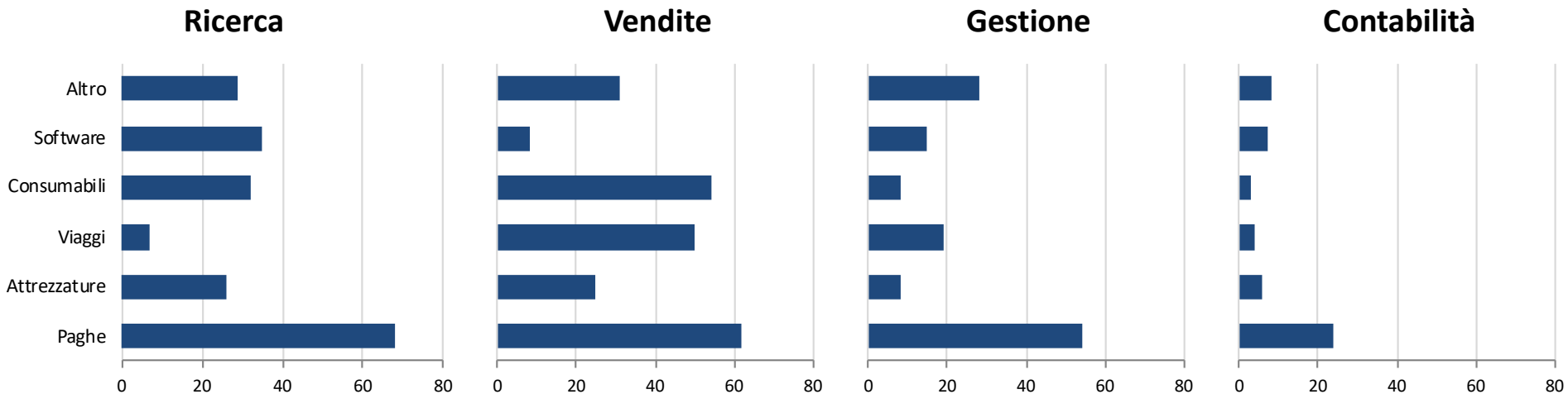
3D diagrams

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

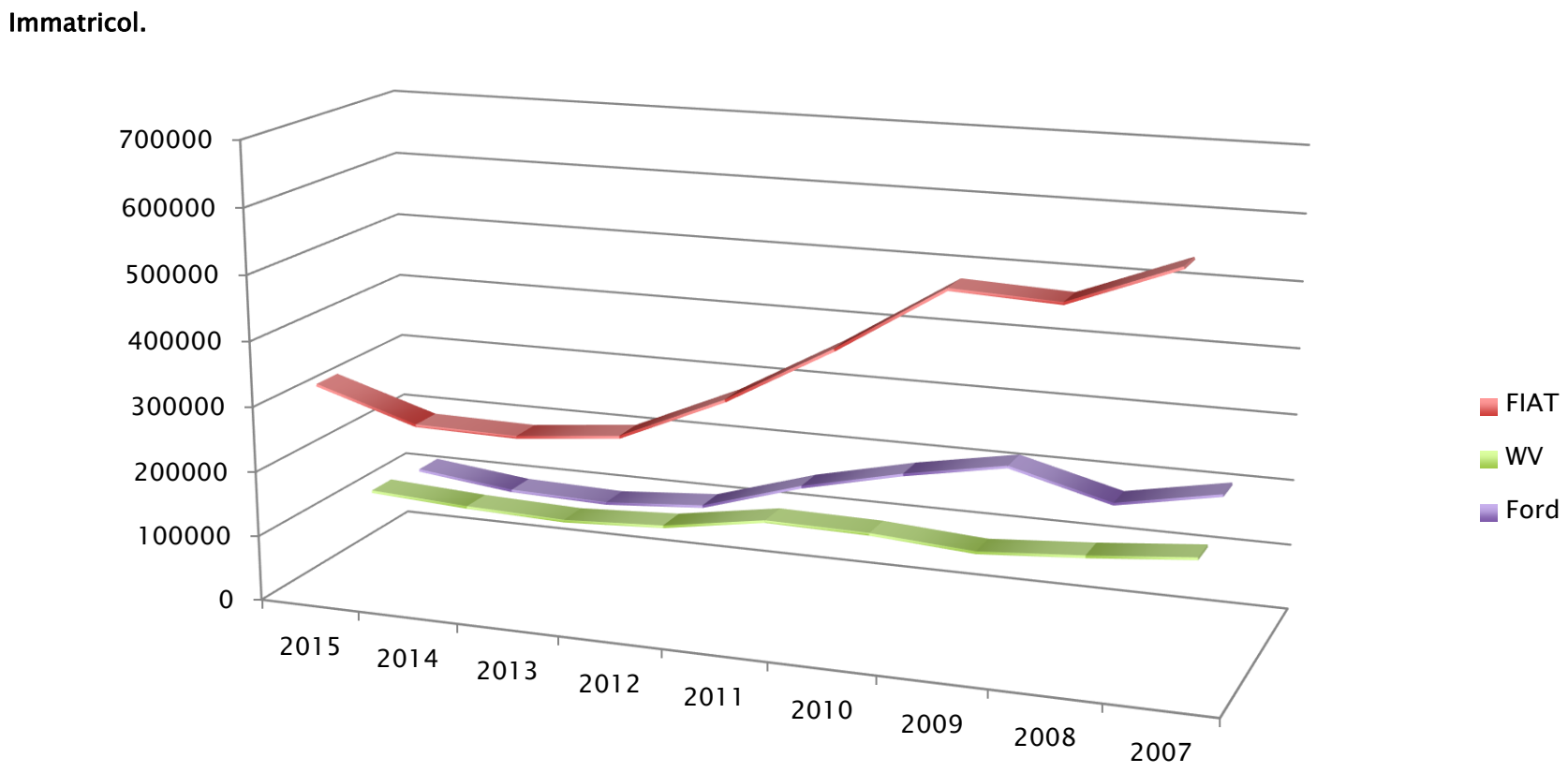
Encoding 3D


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

Encoding 3D → 2D

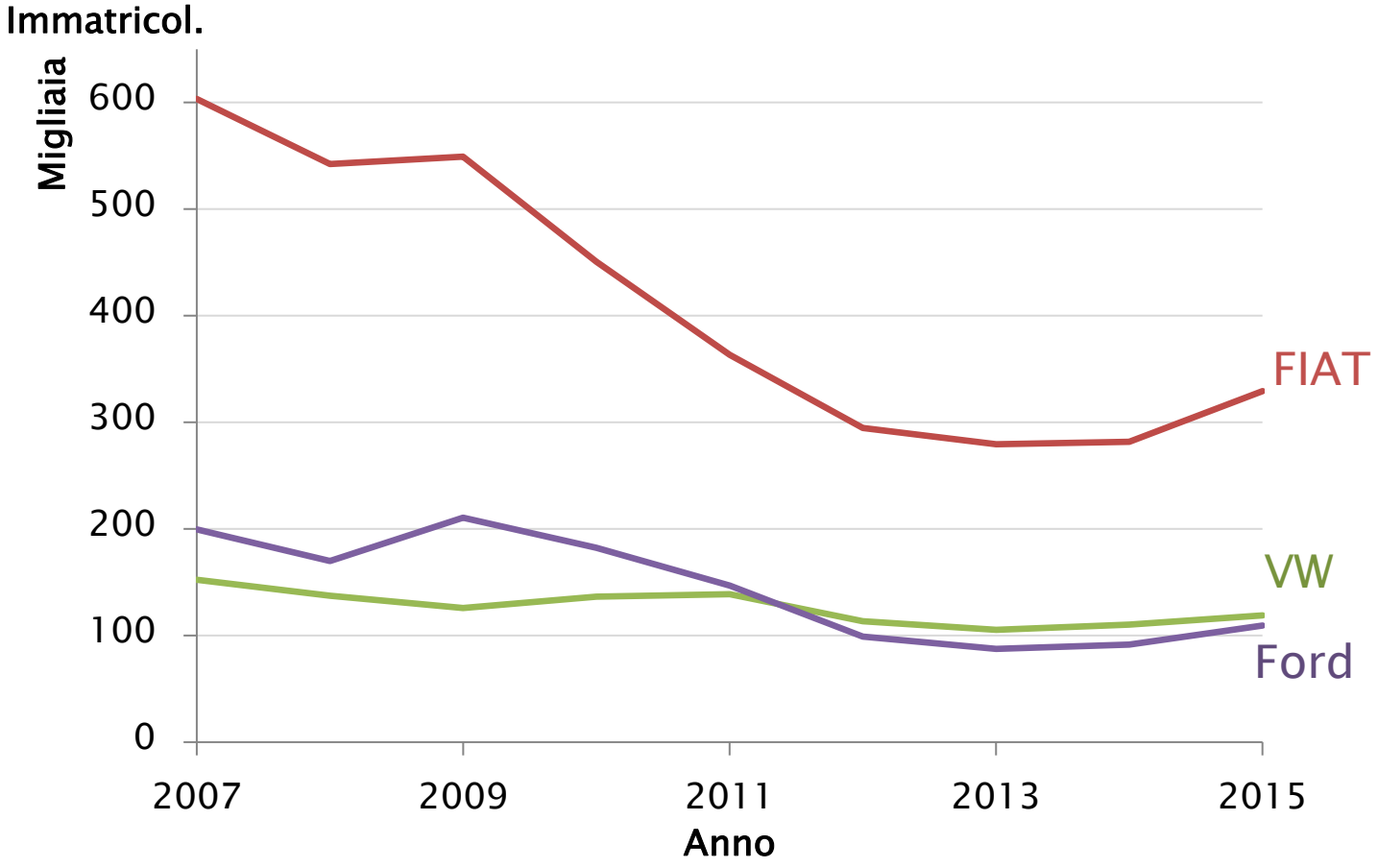


Decorative 3D



Decorative 3D → 2D

Immatricolazioni auto per marchio sul mercato italiano



References

- Stephen Few, 2004. Show me the numbers. Analytics Press.
  - http://www.perceptualedge.com/blog/

- Edward R. Tufte, 1983. The Visual Display of Quantitative Information. Graphics Press.

References

- Wilkinson, L. (2006). *The grammar of graphics*. Springer Science & Business Media.
- Wickham, H. (2010). A layered grammar of graphics. *Journal of Computational and Graphical Statistics*, *19*(1), 3-28.
- Visual Vocabulary http://ft.com/vocabulary

References

- R.Olson. **Revisiting the vaccine visualization**
  - http://www.randalolson.com/2016/03/04/revisiting-the-vaccine-visualizations/
- Nathan Yau. 9 Ways to Visualize Proportions – A Guide
  - http://flowingdata.com/2009/11/25/9-ways-to-visualize-proportions-a-guide/
- 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