



Lesson 2: Designing Graphs to Enlighten

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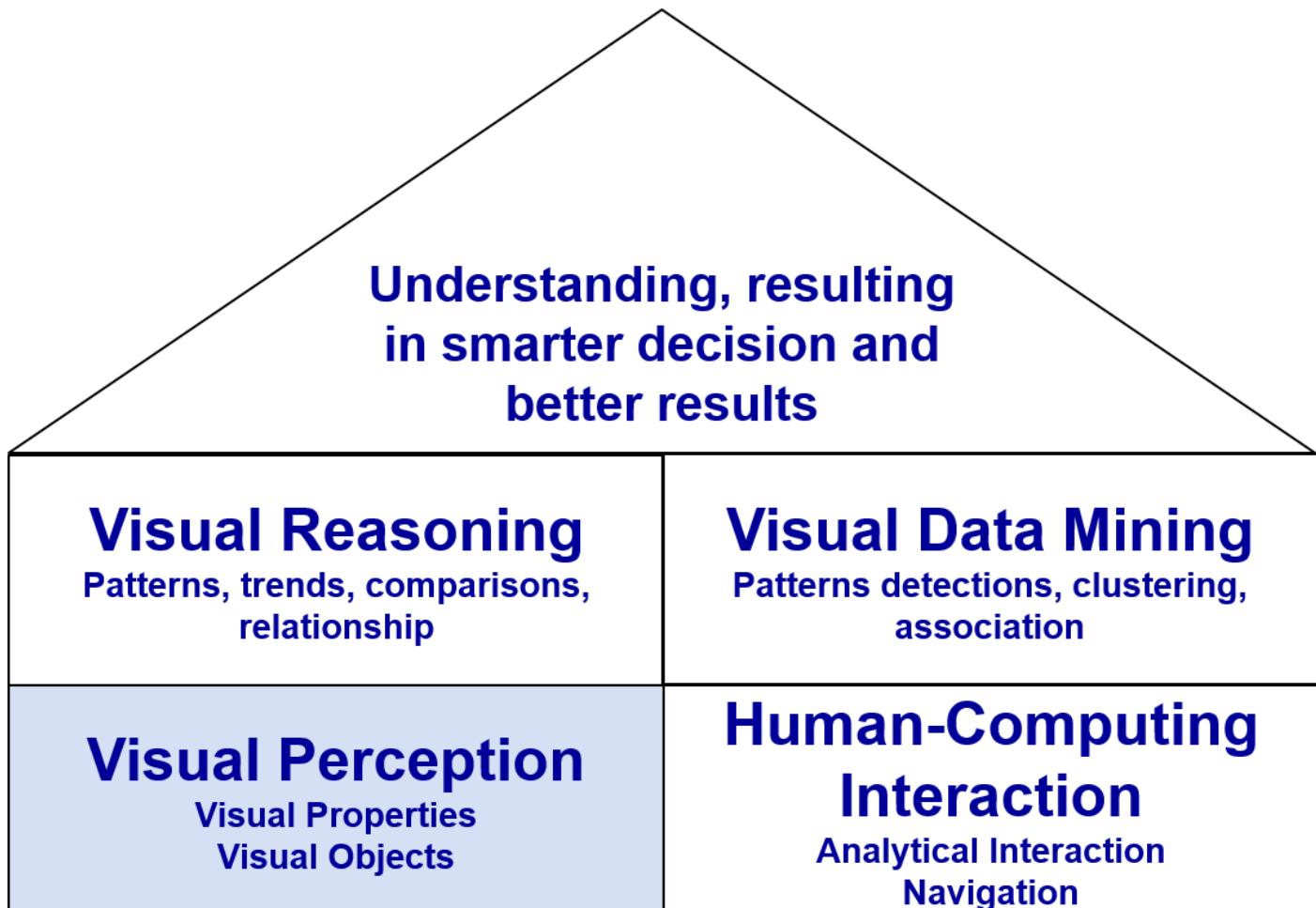
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What will you learn from this lesson?

- Data visualisation design process
- The Devil is in the data
- Human perception and information processing
- Components of a graph
- Principles and practical guides for data visualisation design
- Data visualisation critics framework

In this lesson, I am going to share with you the basic principles and best practices of Data Visualisation Design. The discussion consists of five sections. First, I will provide an overview of data visualisation design process. Next, by using appropriate examples, I will share with you the importance of data selection and preparation in building enlightening graphs. In section three, the principles of visual perception will be introduce. In section four, the practical guides of data visualisation design will be discussed. Lastly, a framework for evaluating and criticising data visualisation design will be introduced.

Building Block of Visual Analytics



This slide shows the building block of visual analytics. Today, we will focus our attention on the lower left corner of the building block, namely Visual Perception.

DataVis design process

- Start with a clear message
- Select the right data
- Use the right visualisations
- Express and explain
- Review and seek feedback from experts and casual readers

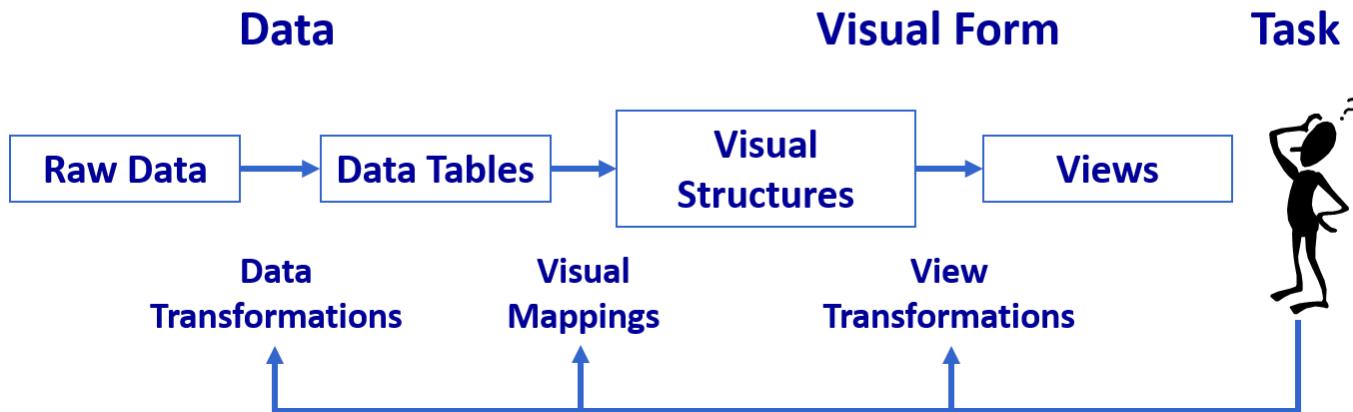
In general, a data visualisation design process consists of five major steps.

DataViz design process: Start with a clear message

Data Management
Select data source
Clean data
Categorise data
Moderate data

Visualisation
Information design
Visual encoding
Interface design

Visual Analytics
Observations
Hypothesis
Evidence (+/-)
Summarise
Communicate



In data visualisation design, it is important to be clear and explicit about what you want to achieve. Is it to explore some data, to convey an inferential analysis, to deliver a message, convince an audience, or support a decision? It may be a mixture of these—for example, even seemingly simple exploratory plots should serve some (perhaps implicit) decision (e.g., on how to explore further). Every graph, and, more generally, every communication, must be tailored to its specific purpose.

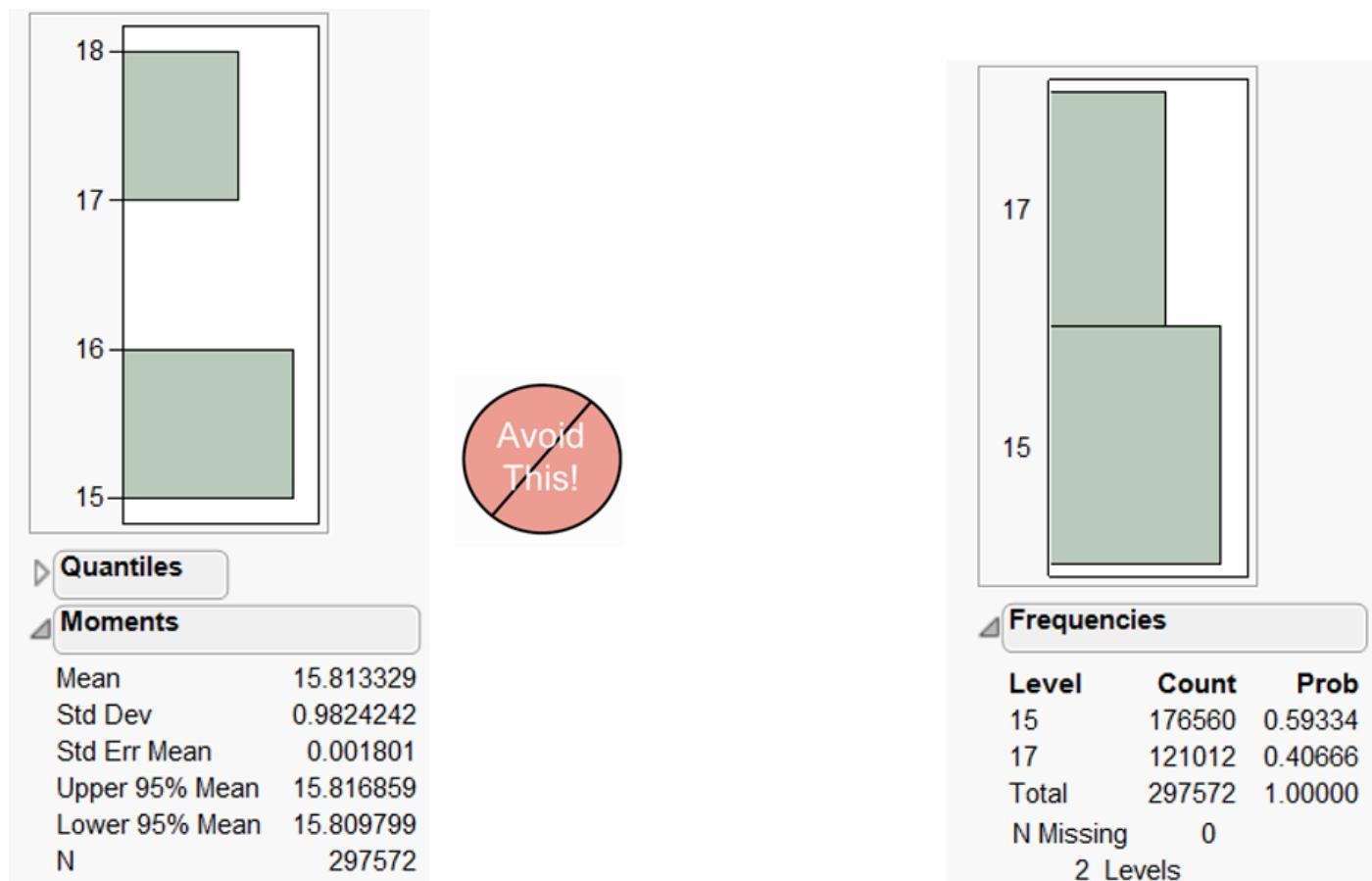
The Devil is in the Data



Clean and tidy data are needed to build truthful data visualisation. But beside clean and tidy data, there are at least two considerations related to data require our attention.

Numbers Worth Knowing

Not all numerical data are continuous!

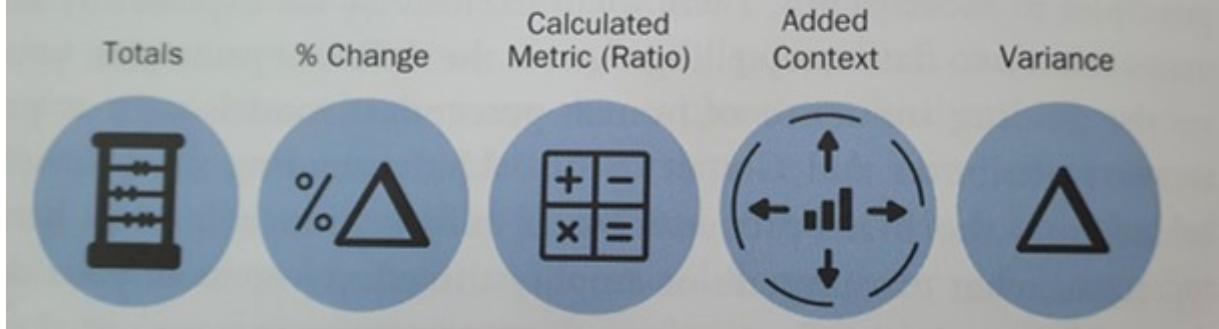


First, it is important to note that not all numerical data are continuous. There are two types of numerical data. They are discrete and continuous. Discrete data can only assume specific values that you cannot subdivide. Typically, you count discrete values, and the results are in frequency count or in per cent. For example, display size should be classified as discrete (i.e. nominal or ordinal scales) instead of continuous., a mean of 15.81 in monitor is no meaning. Continuous data can assume any numeric value and can be meaningfully split into smaller parts. Consequently, they have valid fractional and decimal values. In fact, continuous variables have an infinite number of potential values between any two points. Generally, you measure them using a scale.

Visualising the Right Data

- There are more than one way to present the data.

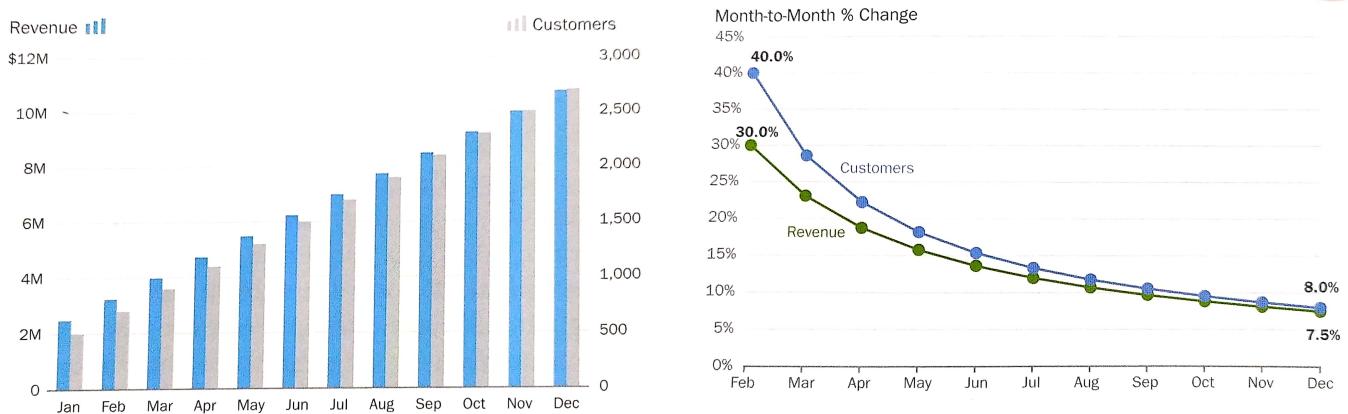
FIVE DATA VARIATIONS TO CONSIDER



Secondly, there are more than one way to present the data. It is not unusual by presenting derived data reveal more aha surprises than the raw data.

Visualising the Right Data

- Derived values reveal more interesting patterns than absolute values.

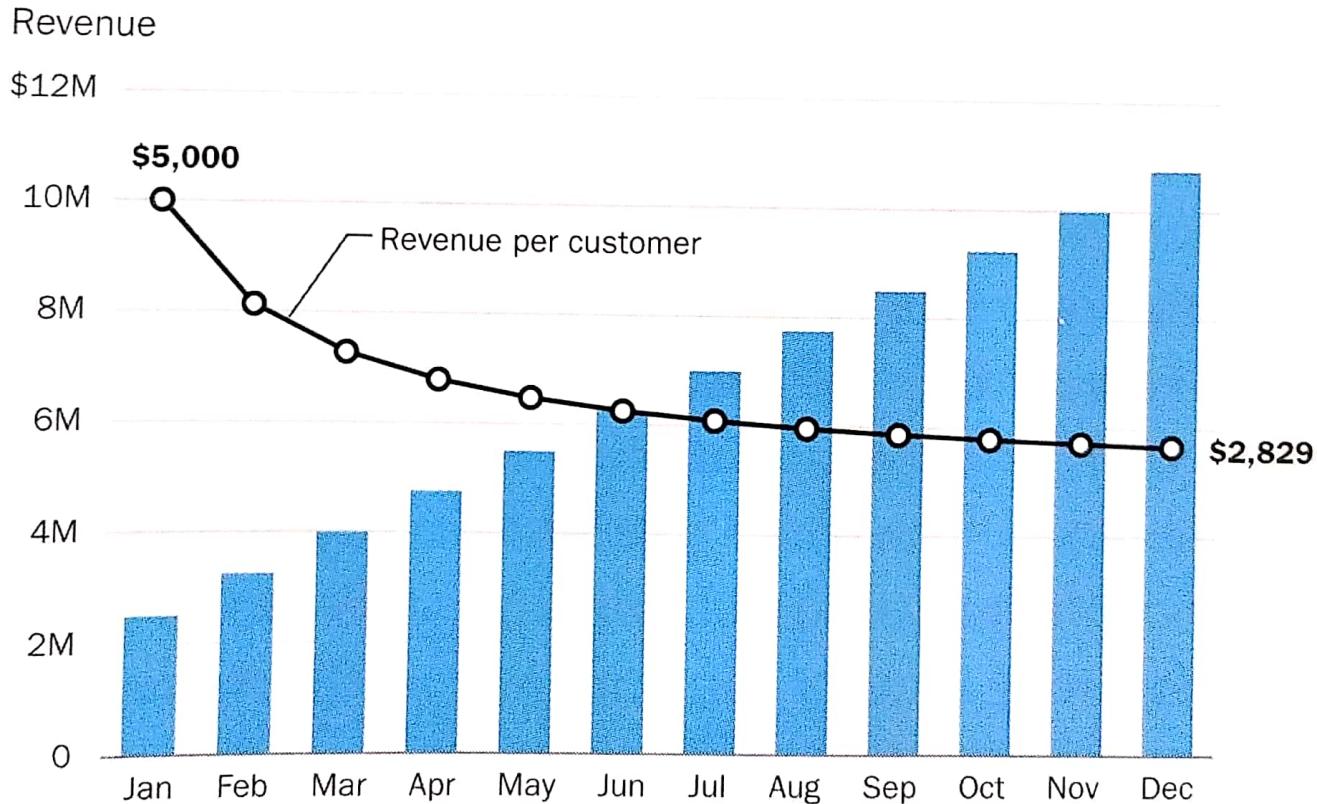


The data visualisation on the left is a dual y-axis bar graph. The y-axis on the left shows revenue and the y-axis on right shows customers. From the graph, you can see how both the monthly revenue and number of customers are growing for this company.

The data visualisation on the right shows the differences between the month-to-month % change of revenue and customers. By showing the data in percent change, the data visualisation allows us to discover that the month-to-month customers and revenue growth rate are reducing in the financial year.

Visualising the Right Data

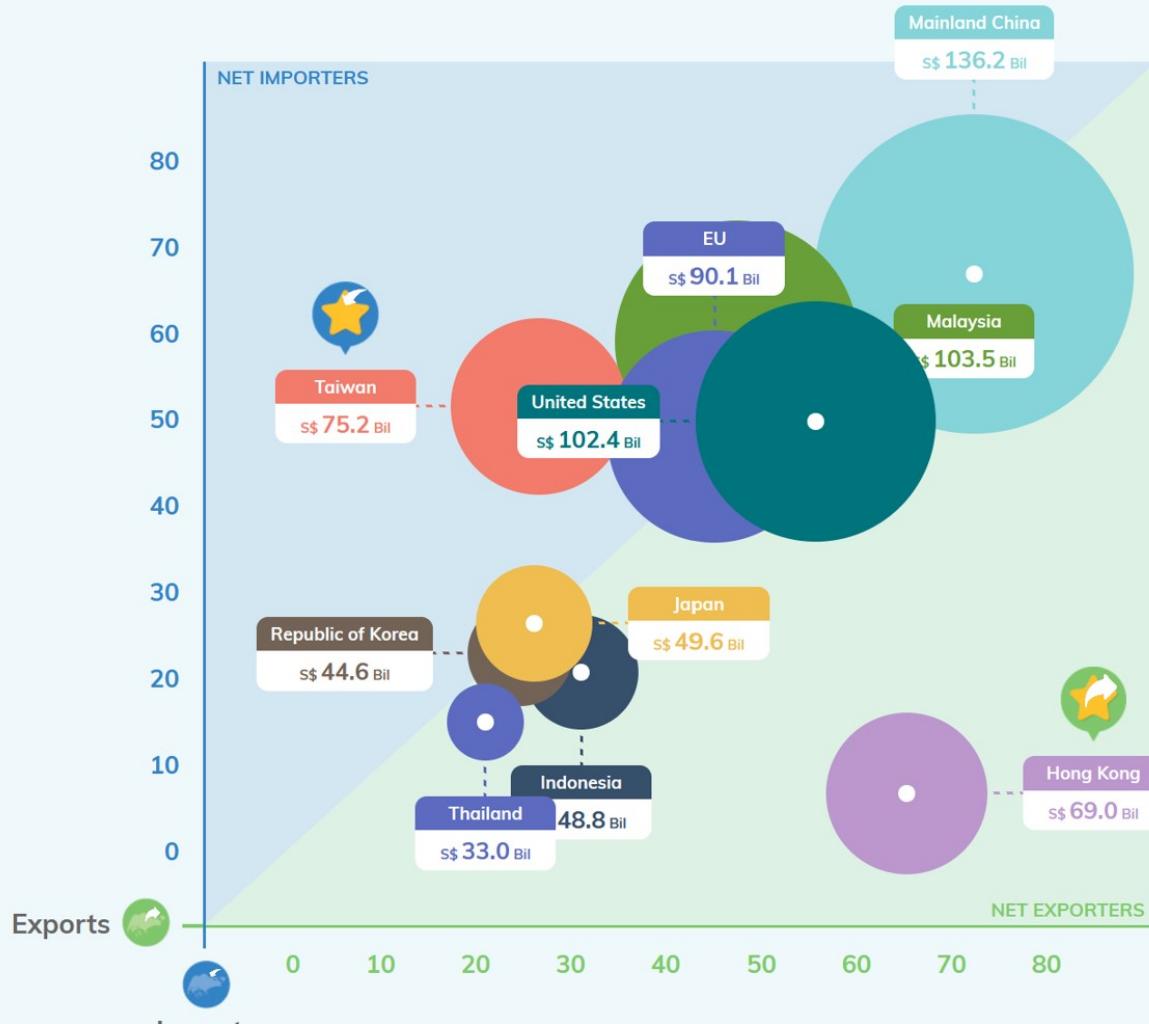
- Derived values reveal more interesting patterns than absolute values.



By deriving revenue per customer and plot them as a line graph, the data visualisation allows us to tell a more compelling data story. In the figure, we can see that revenue per customer has decreased significantly during the year, even though the monthly revenue has risen steadily. The important take away from this case study is that select the right data to prepare the data visualisation and be mindful that the raw data might not always be the right choice.

Graphical Integrity: Show Me the Truth

MERCHANDISE TRADE PERFORMANCE WITH MAJOR TRADING PARTNERS, 2020



Note: The size of the bubble reflects the total merchandise trade value with the trading partner. If the value of imports exceeds exports, the centre point (white circle) of the bubble falls in the 'Net Importers' section marked by the blue region in the chart. Similarly, if the value of exports exceeds imports, the centre point of the bubble falls in the 'Net Exporters' section marked by the green region.

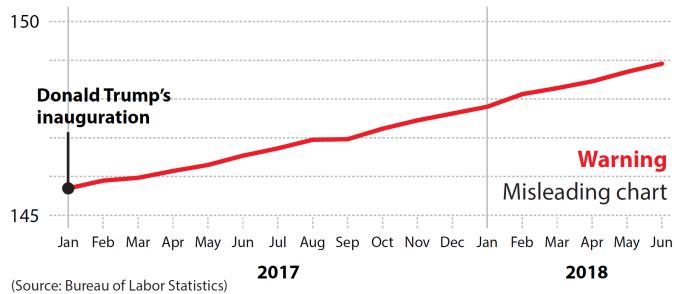
Source: [Department of Statistics](#)

Let us take a good look at the data visualisation on the slide. Can you spot any graphical integrity issue? Yes, the issue of inconsistent data aggregation. On the figure, the major trading partners are at the country level except EU.

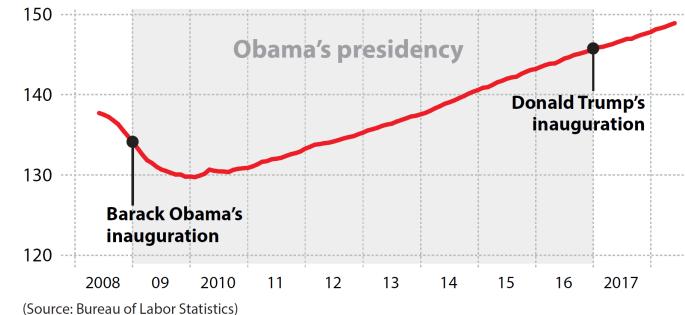
Graphical Integrity: Show Me the Truth

Snapshot can be misleading!

All employees: millions of nonfarm payrolls



All employees: millions of nonfarm payrolls (Bureau of Labor Statistics)



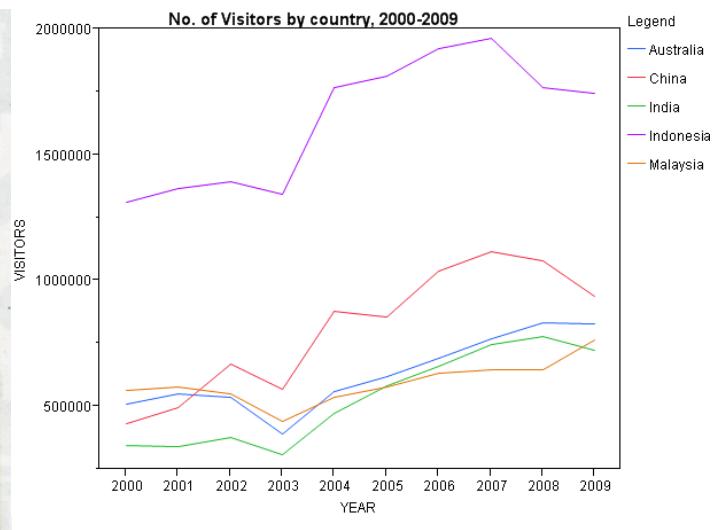
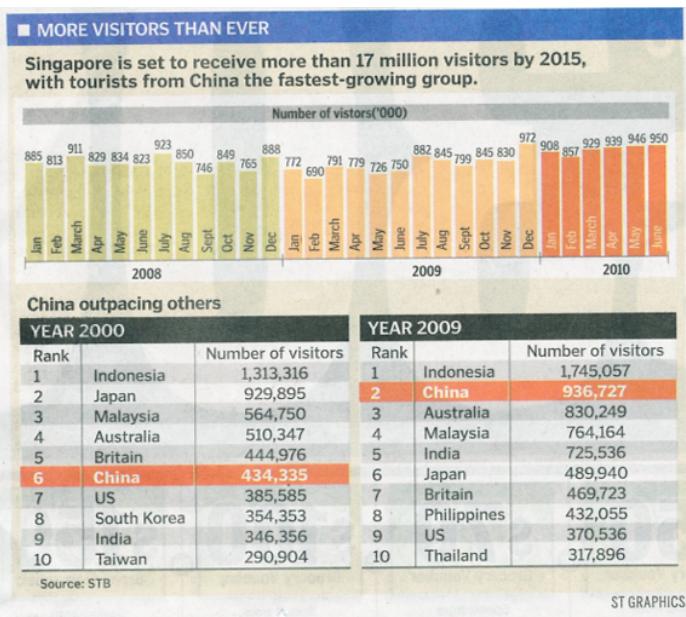
Source: Cairo, Alberto (2019) **How Charts Lie**, W.W. Norton & Company, USA. pg 168.

Donald Trump liked to claim that the job market was a “disaster” before he was sworn in but recovered right after, and he used charts that cropped the horizontal axis in a convenient place.

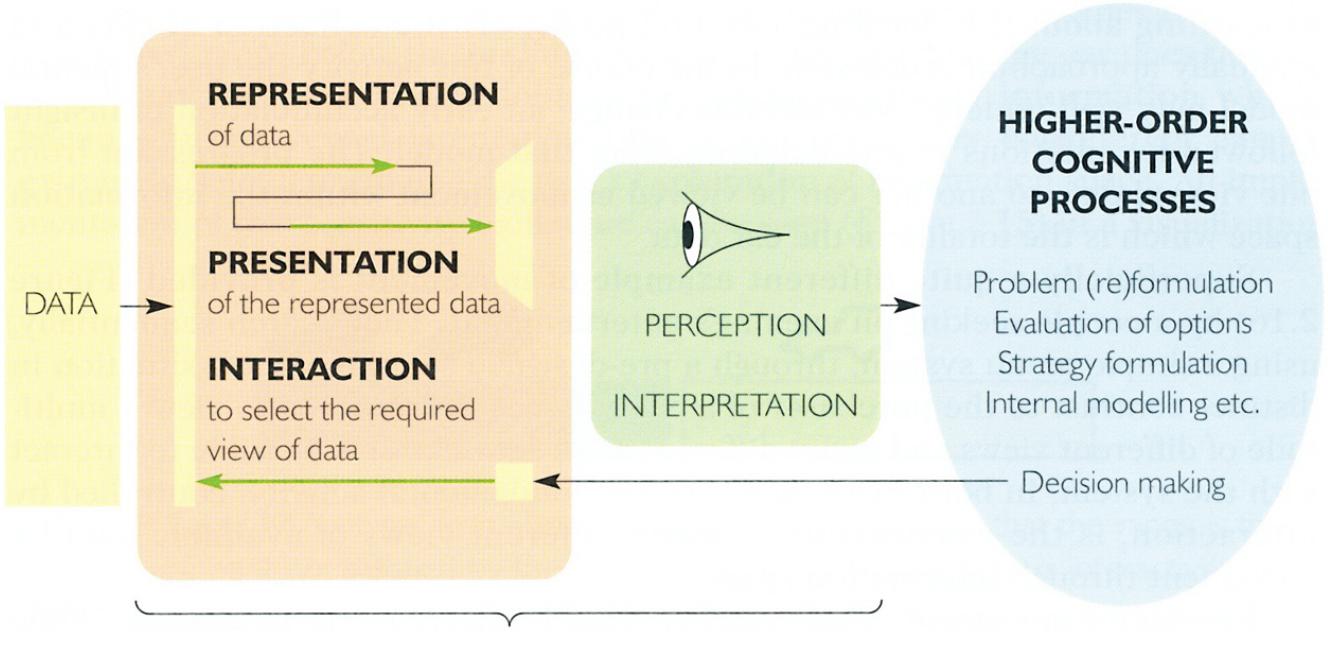
But if we go back in time and mark the point when Trump became president, we’ll see that there’s no remarkable change in the trajectory and slope of the line. Jobs began recovering in 2010.

Graphical Integrity: Show Me the Truth

Do not miss-out what had happened in between.



Human Perception and Information Processing



Pre-attentive Processing

- A limited set of visual properties are processed preattentively (without need for focusing attention).
- This is important for design of visualizations
 - What can be perceived immediately?
 - Which properties are good discriminators?
 - What can mislead viewers?

How Visual Sensing Works?

(i) Fact 1:

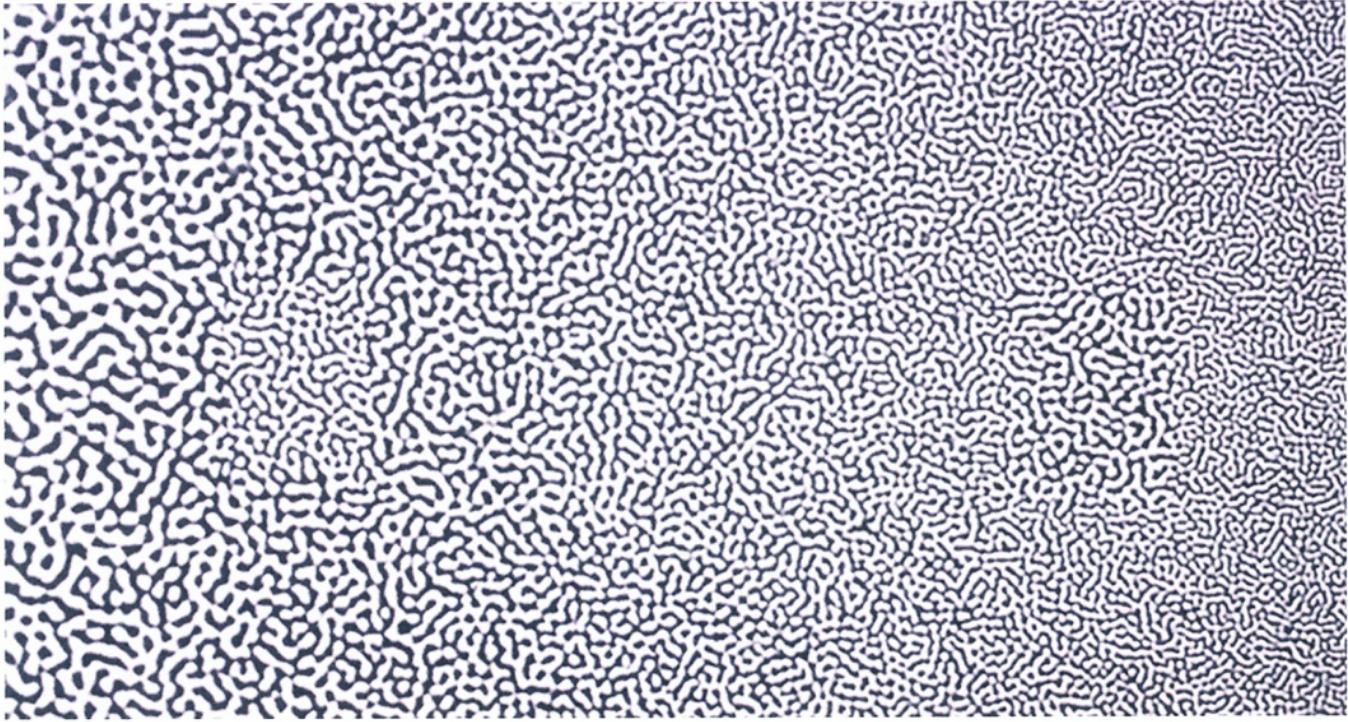
We see what we know and expect.



How Visual Sensing Works?

 **Fact 2:**

We do not attend to everything we see.



How Visual Sensing Works?

 **Fact 3:**

We don't remember everything we see.



How Visual Sensing Works?

Fact 3:

We don't remember everything we see.



How Visual Sensing Works?

How Many 3's?

**1281768756138976546984506985604982826762
9809858458224509856458945098450980943585
9091030209905959595772564675050678904567
8845789809821677654876364908560912949686**

How Visual Sensing Works?

Now you see them!

12817687561**3**8976546984506985604982826762
 980985845822450985645894509845098094**3**585
 90910**3**02099059595772564675050678904567
 8845789809821677654876**3**64908560912949686

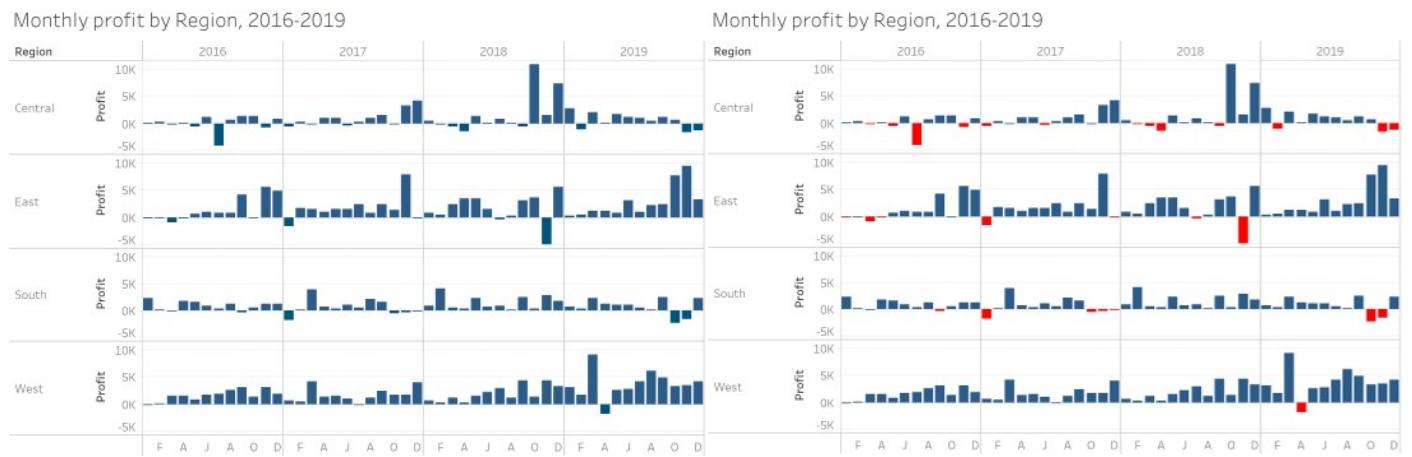
As you can see, by applying pre-attentive principle, we can count the number 3 easily now.

Application of pre-attentive principle in data visualisation design



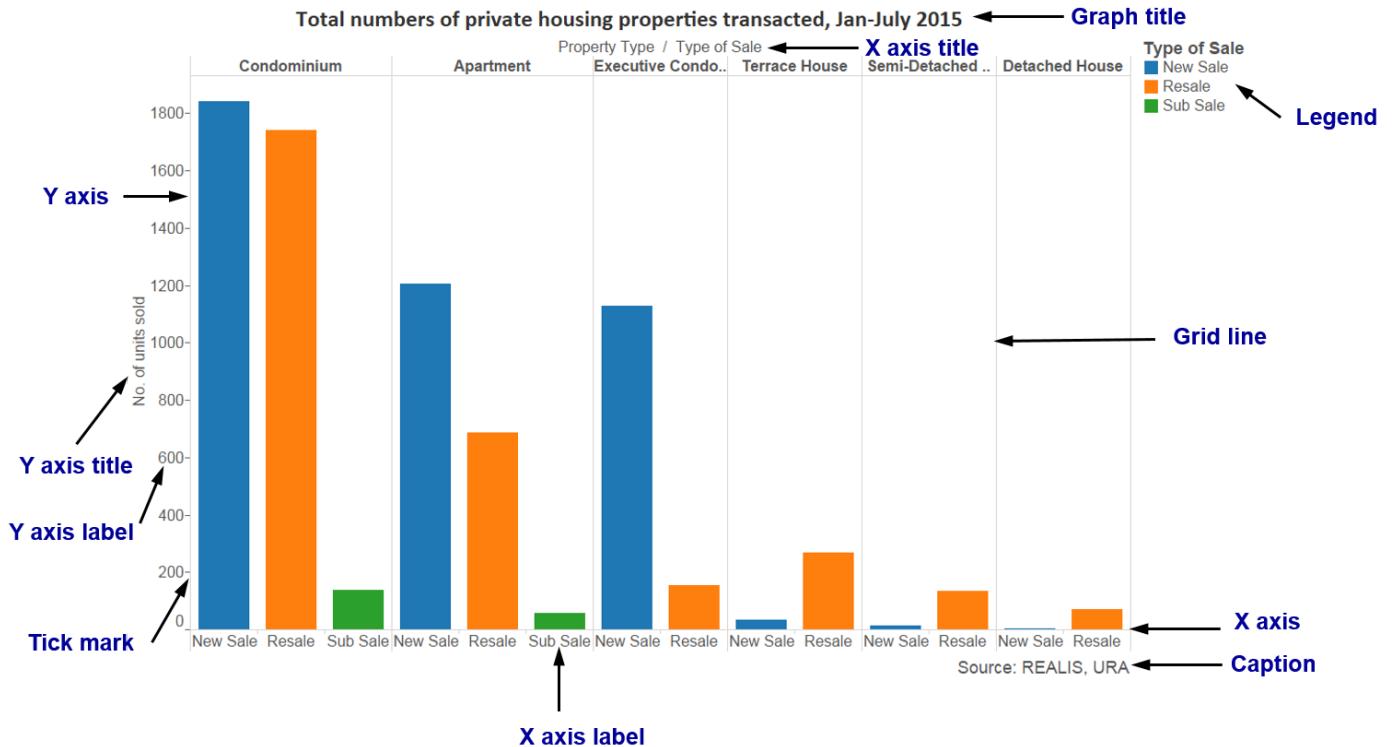
In last Saturday class, I had shown the reference line feature of Tableau. By understanding the principle of pre-attentive, reference line feature is useful for providing context to the data visualisation.

Application of pre-attentive principle in data visualisation design



In the data visualisation of the right, bright red is used to show the month running at a lot. This is another example whereby pre-attentive principle is put to good use.

Components of a graph



Bertin's Semiology of graphics

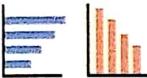
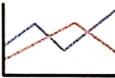
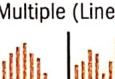
Bertin's Original Visual Variables								
Position changes in the x, y location								
Size change in length, area or repetition								
Shape infinite number of shapes								
Value changes from light to dark								
Colour changes in hue at a given value								
Orientation changes in alignment								
Texture variation in 'grain'								



Jacques Bertin

Choosing the Right Visualisation

MAJOR CHART TYPE CATEGORIES FOR BUSINESS PROFESSIONALS

Comparison	Trend	Composition	Relationship	Distribution	Spatial	Flow
						
						
						
						

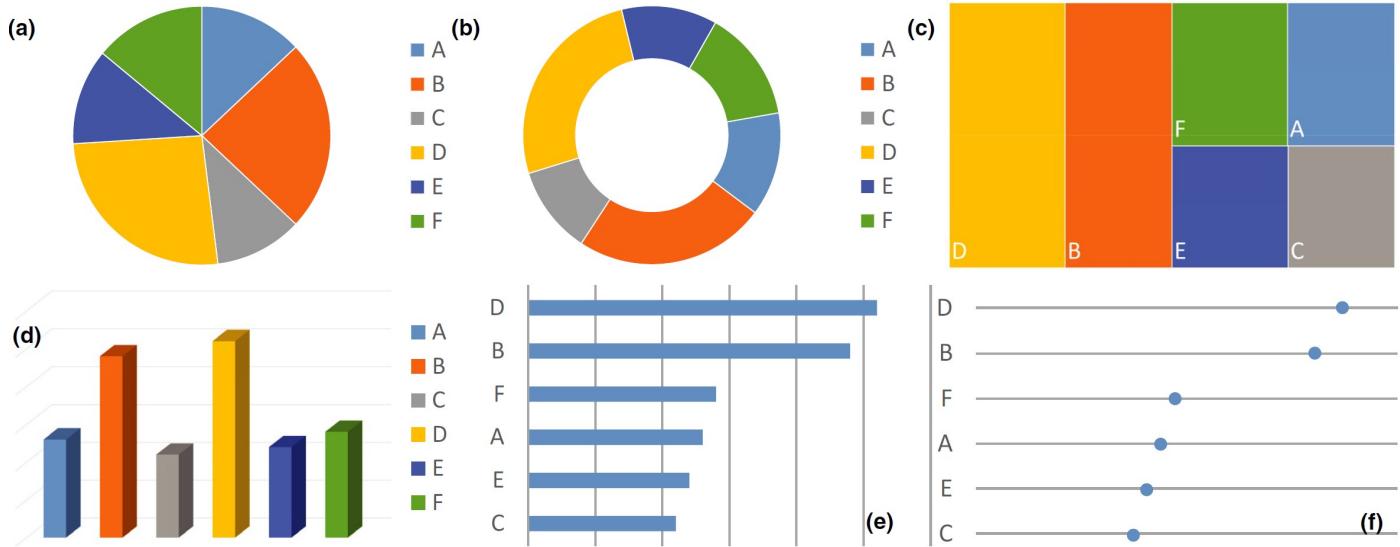
Design principles for effective visual presentation

- Guides for Encoding Values in Graph
- JunkCharts
- Practical Guides for Using Colour in Charts
- Data-ink

Design principles for effective visual presentation

- **Guides for Encoding Values in Graph**
- JunkCharts
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General Guide: Show the Data Clearly

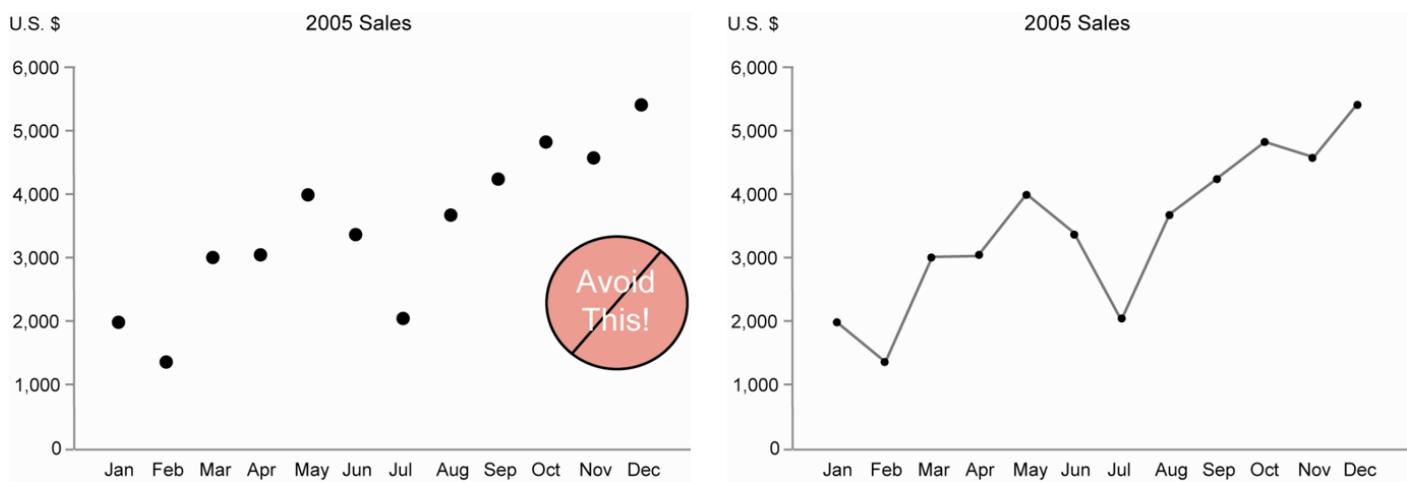


The pie and donut charts in panels (a) and (b) make it difficult to see the order of magnitude of some of the segments. The eye needs to compare areas, bent lengths (of the contour), or angles, – graphical attributes that are not easily decoded. The donut chart even omits the angles. The mosaic plot in panel (c) only relies on areas; again, it is hard to tell the order of magnitude. It is better to use lengths with a common baseline or positions on a common scale, such as in a bar chart or dot plot (see Cleveland-McGill effectiveness ranking in Law 3). The bar chart in panel (d), however, introduces a fake dimension, which is unnecessary and makes it hard to decode the numerical values from the height of the bars. Panels (e) and (f) are appropriately simple and show the data clearly. They also order the data by magnitude to aid comparison even further. The dot plot in panel (f) uses minimal amount of ink and draws the eye to the position of the dots; it is the most effective way of displaying these data.

Guides for Encoding Values in Graph

(i) Guide 1:

Avoid using point alone to display time-series data.

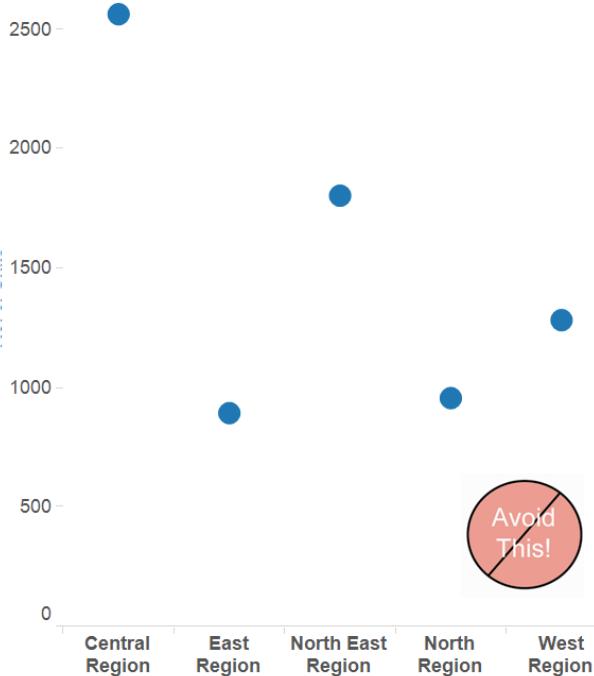


Guides for Encoding Values in Graph

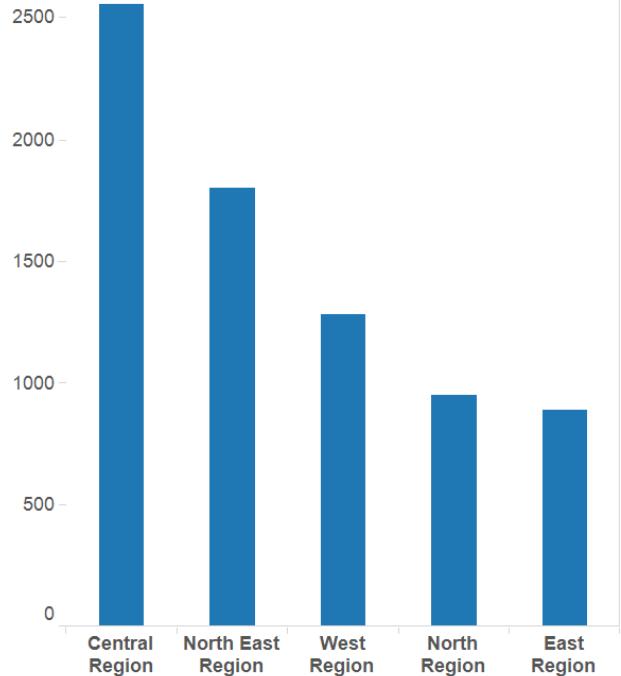
(i) Guide 2:

Avoid using points to represent discrete values

Sum(No. of Units)



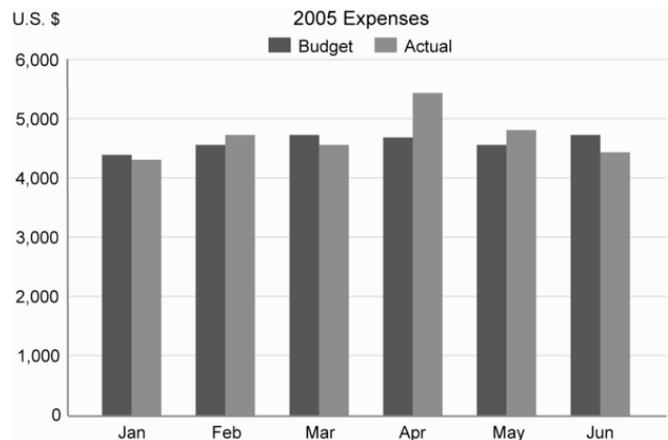
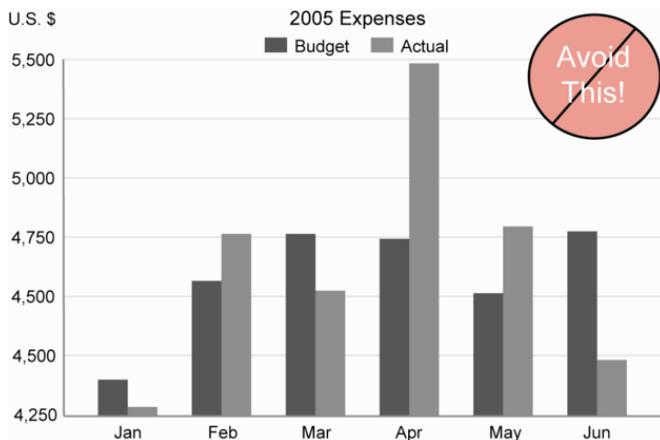
Sum(No. of Units)



Guides for Encoding Values in Graph

(i) Guide 3:

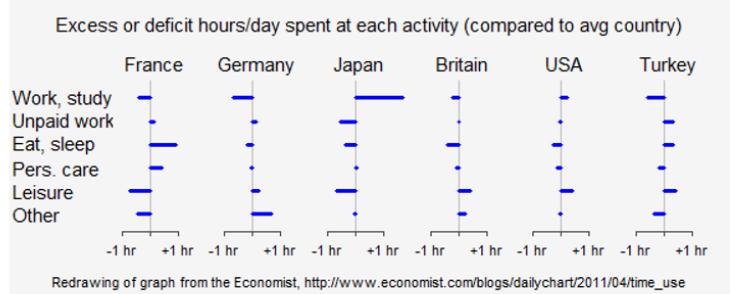
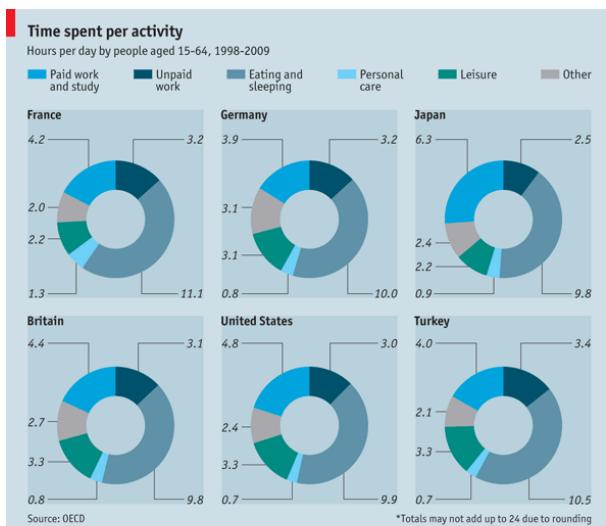
Bars don't work unless the quantitative scale begins at zero



Guide for Encoding Values in Graph

(i) Guide 4:

Avoid pie chart if possible because our eyes are not good in reading areas



Source: Time use: A day in the life, Apr 19th 2011, 15:00 by The Economist online

Reference: [JunkCharts](#)

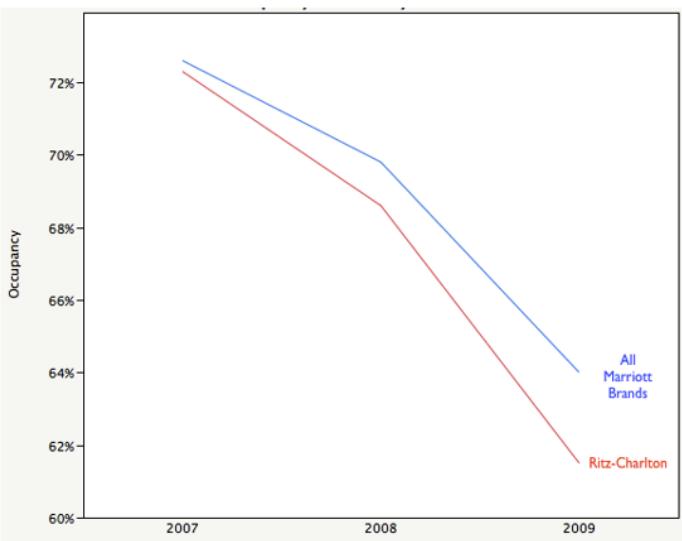
Guide for Encoding Values in Graph

(i) Guide 5:

Avoid pie chart if you are comparing changes over time



The Ritz-Charlton Brand Was Hit Worse Than Other Marriott Brands During the Downturn



:scale 80%

Design principles for effective visual presentation

- Guides for Encoding Values in Graph
- **Chartjunk**

- Practical Guides for Using Colour in Charts
- Data-ink

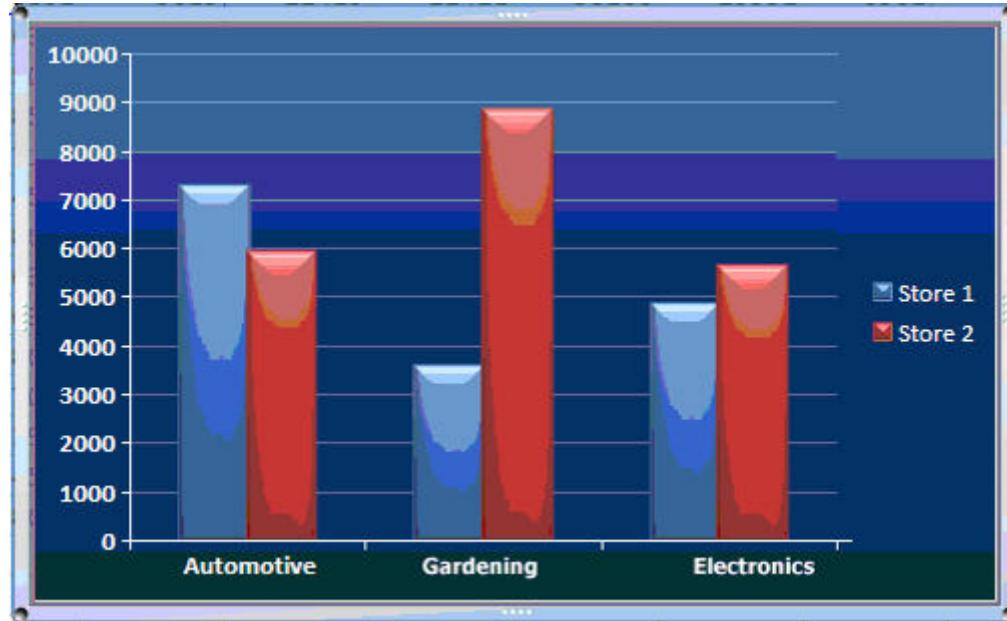
Chartjunk refers to all visual elements in charts and graphs that are not necessary to comprehend the information represented on the graph, or that distract the viewer from this information.

It was first introduced by Edward Tufte in his 1983 book *The Visual Display of Quantitative Information*.

There is an interesting blog called Junk Charts by Kaiser Fung. The blog link is available on the last slide.

ChartJunk I

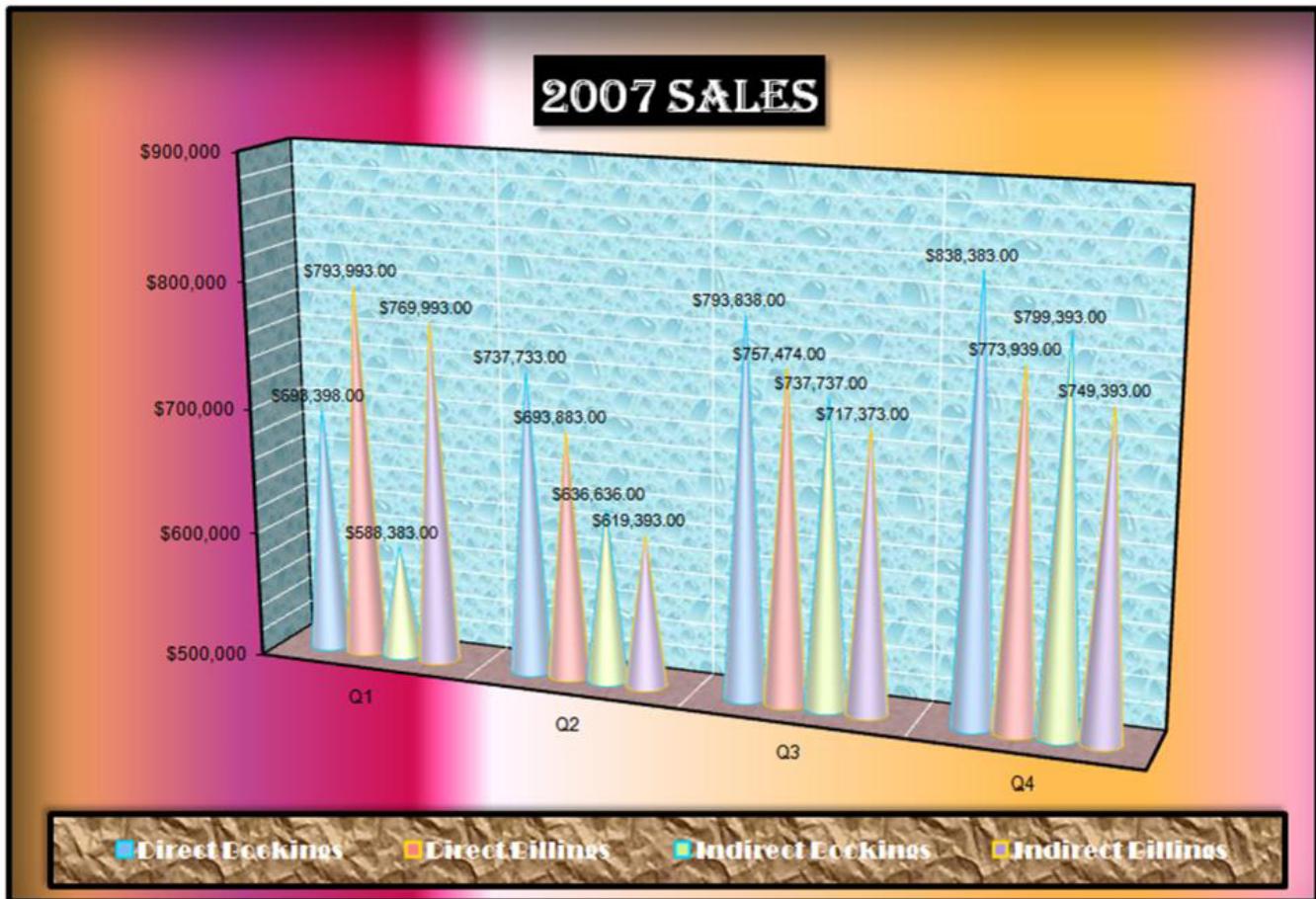
Avoid using unnecessary colour shading for the bar.



In this data visualisation, it is very obvious that the different intensity colours shading used on the bars and background are not map to any meaningful variables. These are junk that should be avoid in our graphs.

ChartJunk II

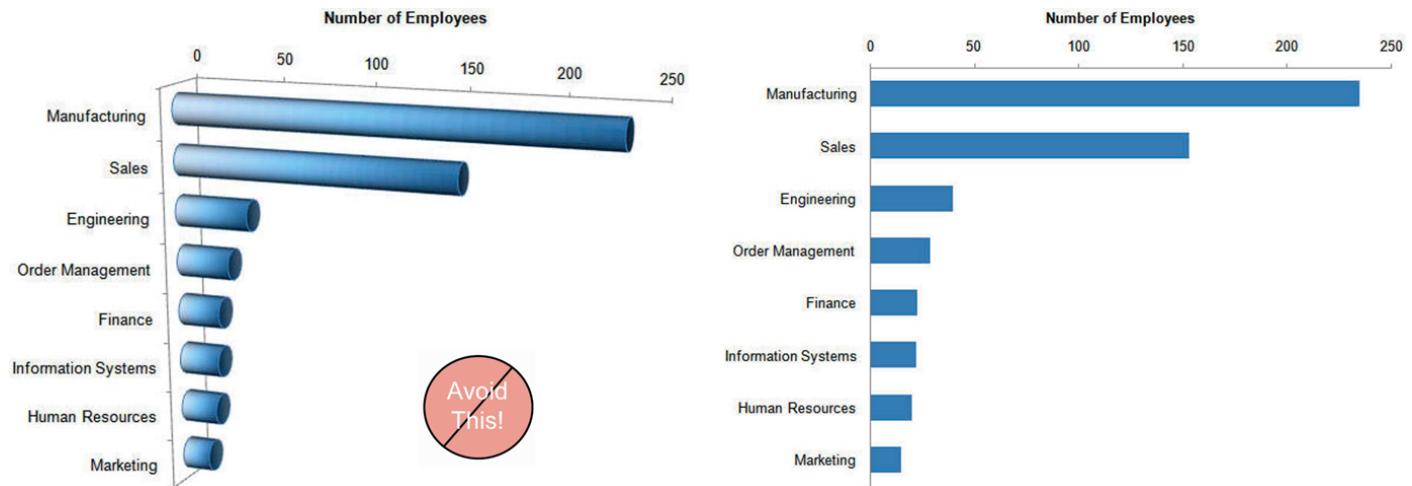
Avoid colourful or wallpaper background.



In this data visualisation, the background patterns make it impossible for us to read the words in the legend. Likewise the watermarks used as the background of the graph is redundant. Again, these are junk that we should be avoided.

ChartJunk III

Avoid using 3D effects in graphics.

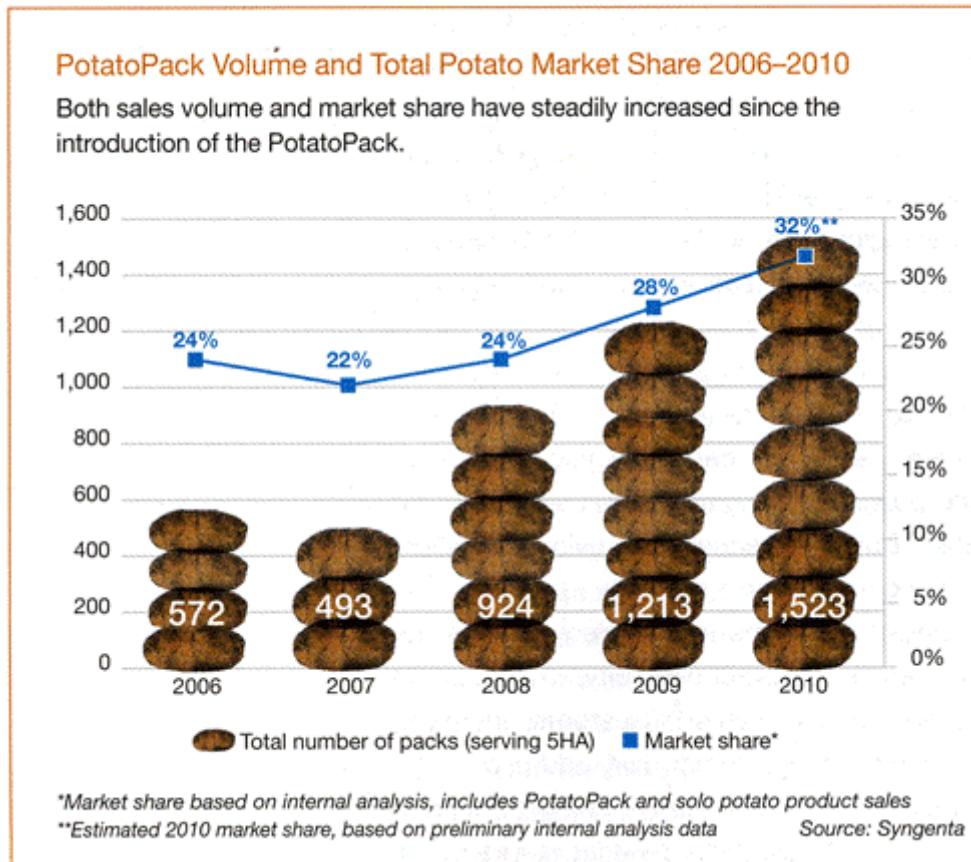


It is very common for us to see 3D bar chart was used to present frequency distribution of a categorical variable like the data visualisation on the left of the slide. In fact, the fancy 3D bar chart is less effective to read as compared

to the simple bar chart on the right of the slide. The key take away is avoid using 3D object to display univariate data.

ChartJunk IV

Avoid using misleading graphical representation.

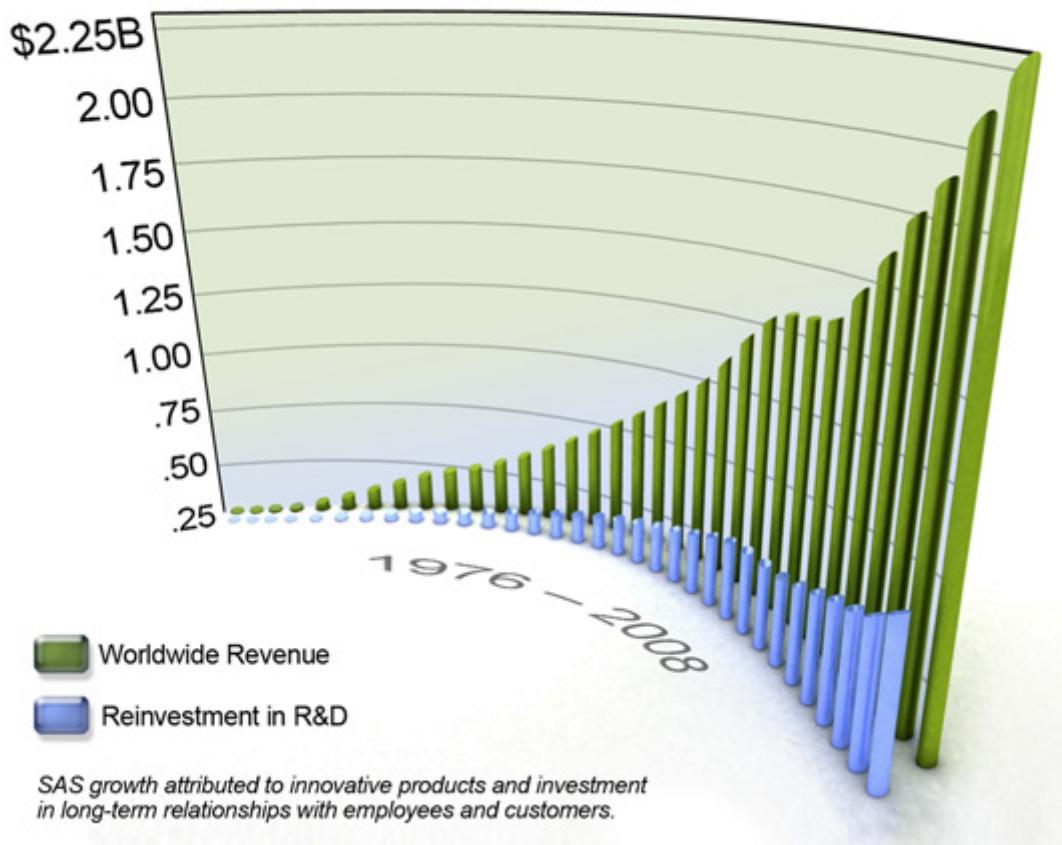


In this data visualisation, there is no way for us to know what is the sales volume represented by one potato because their ratio varies from one year to another.

ChartJunk V

Avoid using artistic design which is difficult to visualise.

SAS Clears \$2.26 Billion



Although the visualisation is very appealing visually. However, it is not functional because the curve 3D bar chart make it very difficult to do a proper comparison.

ChartJunk VI

Designing graph to enlighten people – not to entertain them.



This is another good example of JunkChart. In this data visualisation, the author distorts the sequence of the age-cohort intentionally in order to show the ladder-like view. But this design easily lead to misinterpretation by the graph users.

Design principles for effective visual presentation

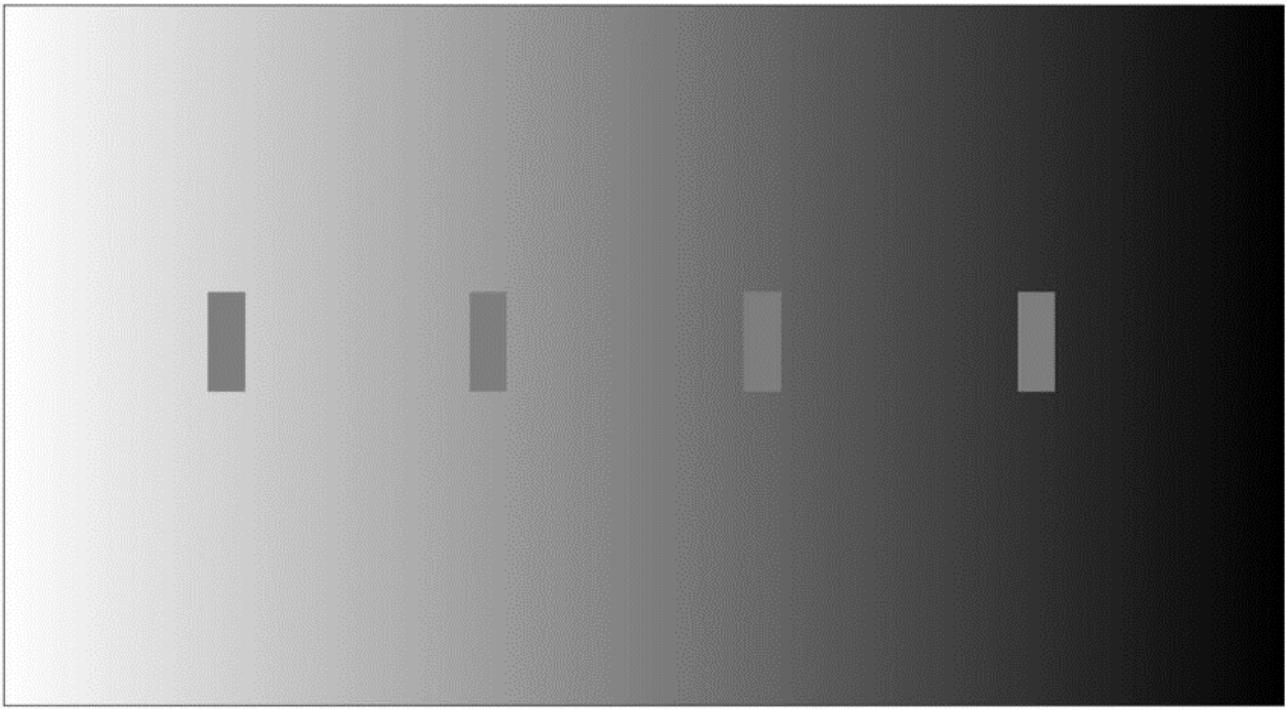
- Guides for Encoding Values in Graph
- JunkCharts
- **Practical Guides for Using Colour in Charts**
- Data-ink

In this topic, I am going to share with the practical guides for using colour in data visualisation.

Practical Guides for Using Colour in Charts

i Guide 1:

If you want different objects of the same colour in a graph to look the same, make sure that the background- the colour that surrounds them – is consistent.



The guide practice If you want different objects of the same colour in a graph to look the same, make sure that the background- the colour that surrounds them – is consistent. We should avoid using background with different colour intensity.

Practical Guides for Using Colour in Charts

Guide 2:

If you want objects in a graph to be easily seen, use a background colour that contrasts sufficiently with the object.

name	age	sex	height	weight
KATIE				
LOUISE				
JANE				
JACLYN				
LILLIE				
TIM				
JAMES				
ROBERT				
BARBARA				
ALICE				
SUSAN				
JOHN				
JOE				
MICHAEL				
DAVID				
JUDY				
ELIZABETH				
LESLIE				
CAROL				
PATTY				
FREDERICK				
ALFRED				
HENRY				
LEWIS				
EDWARD				
CHRIS				
JEFFREY				
MARY				
AMY				
ROBERT				
WILLIAM				
CLAY				
MARK				
DANNY				
MARTHA				
MARION				
PHILLIP				
LINDA				
KIRK				
LAWRENCE				

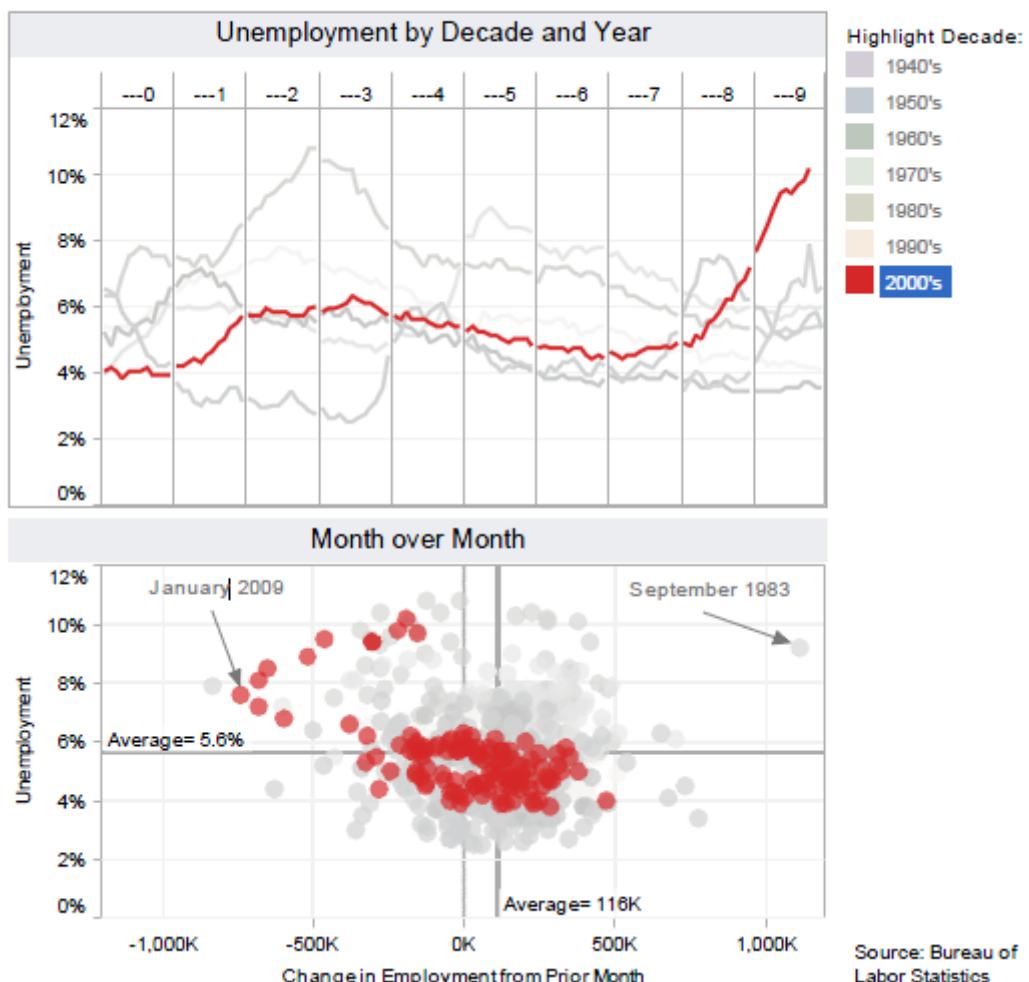
		name	age	sex	height	weight	mean weight by age
1	KATIE		12	F	59	95	99.000
2	LOUISE		12	F	61	123	99.000
3	JANE		12	F	55	74	99.000
4	JACLYN		12	F	66	145	99.000
5	LILLIE		12	F	52	64	99.000
6	TIM		12	M	60	84	99.000
7	JAMES		12	M	61	128	99.000
8	ROBERT		12	M	51	79	99.000
9	BARBARA		13	F	60	112	94.714
10	ALICE		13	F	61	107	94.714
11	SUSAN		13	F	56	67	94.714
12	JOHN		13	M	65	98	94.714
13	JOE		13	M	63	105	94.714
14	MICHAEL		13	M	58	95	94.714
15	DAVID		13	M	59	79	94.714
16	JUDY		14	F	61	81	100.833
17	ELIZABETH		14	F	62	91	100.833
18	LESLIE		14	F	65	142	100.833
19	CAROL		14	F	63	84	100.833
20	PATTY		14	F	62	85	100.833
21	FREDERICK		14	M	63	93	100.833
22	ALFRED		14	M	64	99	100.833
23	HENRY		14	M	65	119	100.833
24	LEWIS		14	M	64	92	100.833
25	EDWARD		14	M	68	112	100.833
26	CHRIS		14	M	64	99	100.833
27	JEFFREY		14	M	69	113	100.833
28	MARY		15	F	62	92	108.286
29	AMY		15	F	64	112	108.286
30	ROBERT		15	M	67	128	108.286
31	WILLIAM		15	M	65	111	108.286

Practical Guides for Using Colour in Charts

(i) Guide 3:

Use color only when needed to serve a particular communication goal.

60 Years of Unemployment

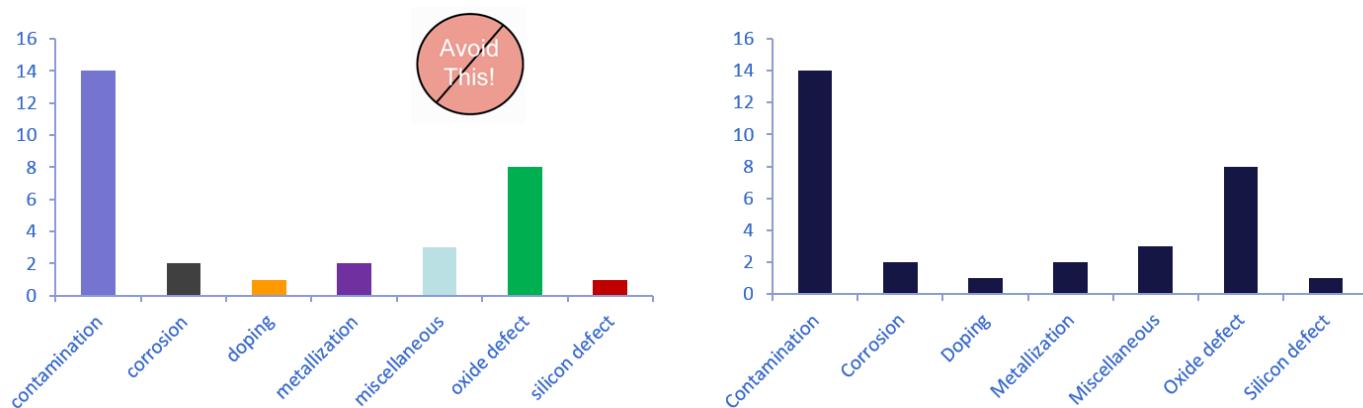


The power of pre-attentive processing.

Practical Guides for Using Colour in Charts

(i) Guide 4:

Use different colours when they correspond to differences of meaning in the data.

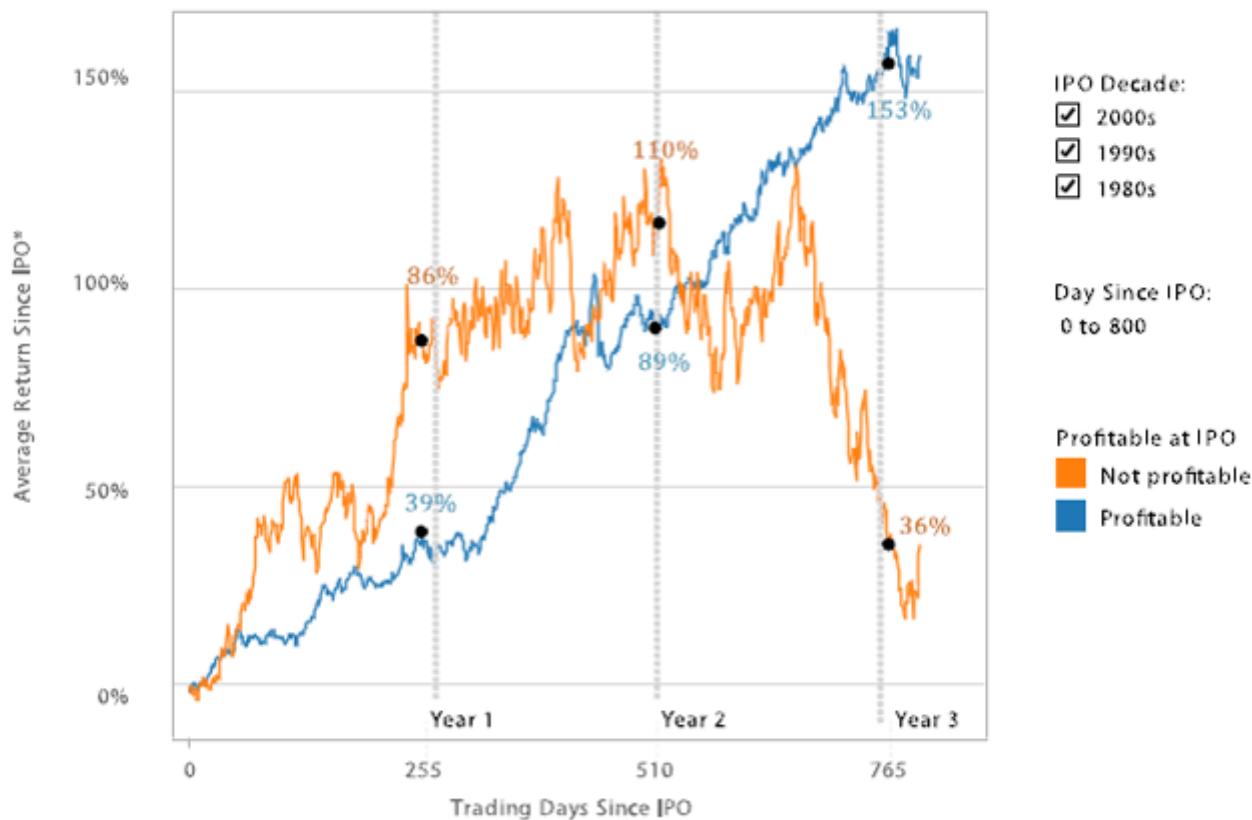


Practical Guides for Using Colour in Charts

(i) Guide 5:

Use soft, natural colours to display most information and bright and/or dark colours to highlight information that requires greater attention.

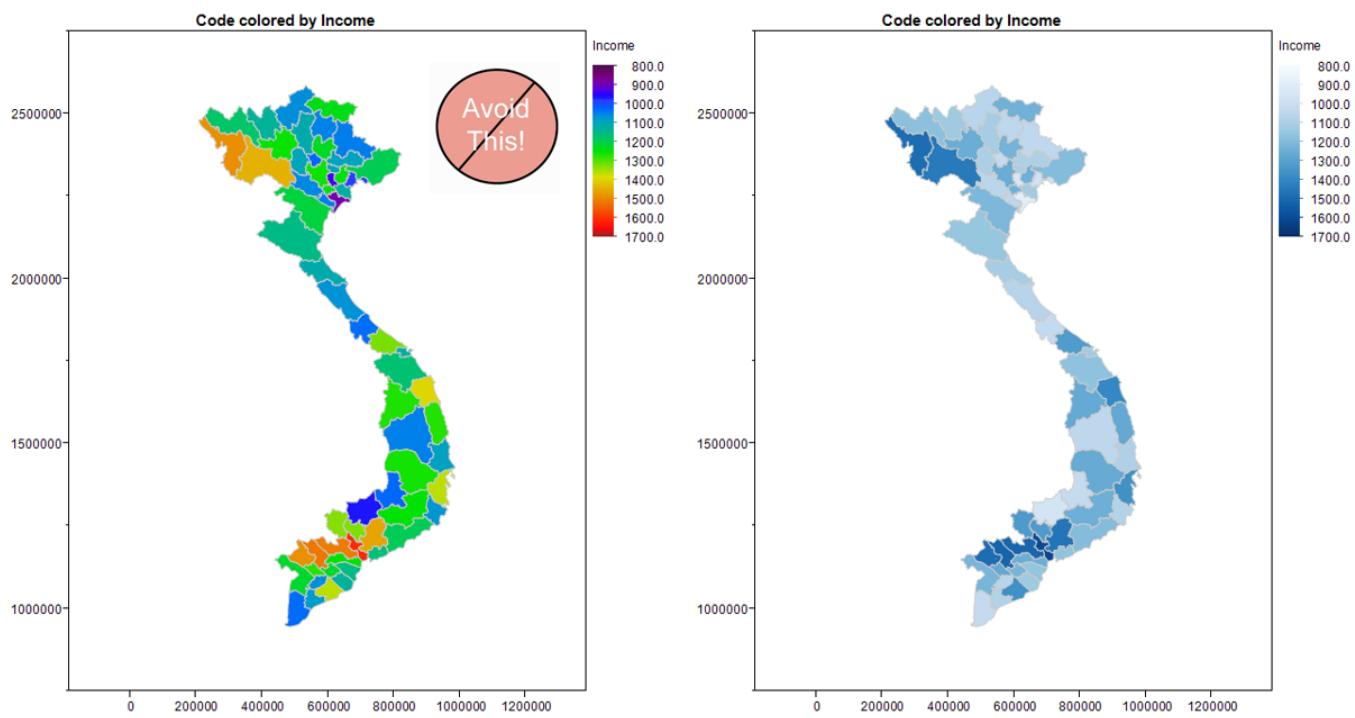
Profitable vs. Unprofitable IPOs



Practical Guides for Using Colour in Charts

(i) Guide 6:

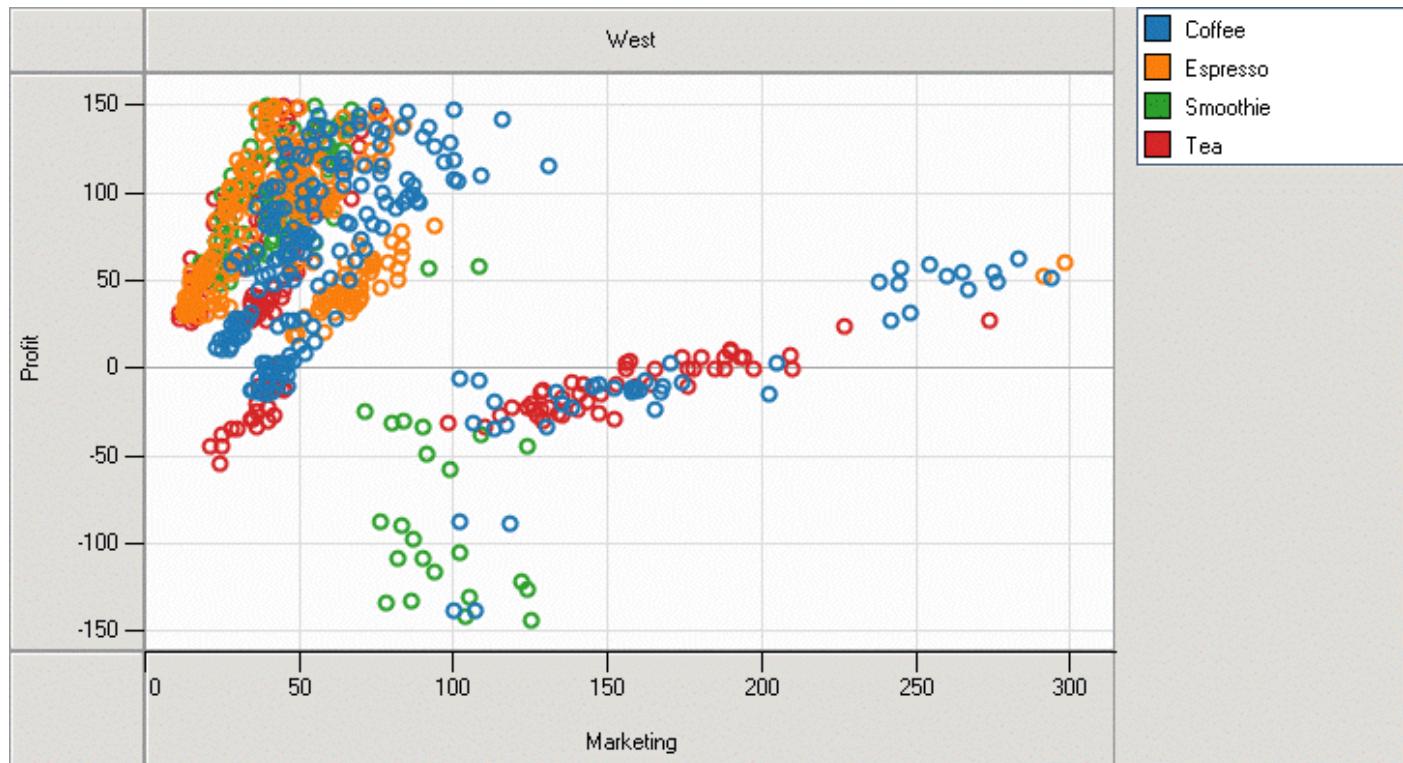
When using colour to encode a sequential range of quantitative values, stick with a single hue (or a small set of closely related hues) and vary intensity from pale colours for low values to increasingly darker and brighter colours for high values.



Practical Guides for Using Colour in Charts

(i) Guide 7:

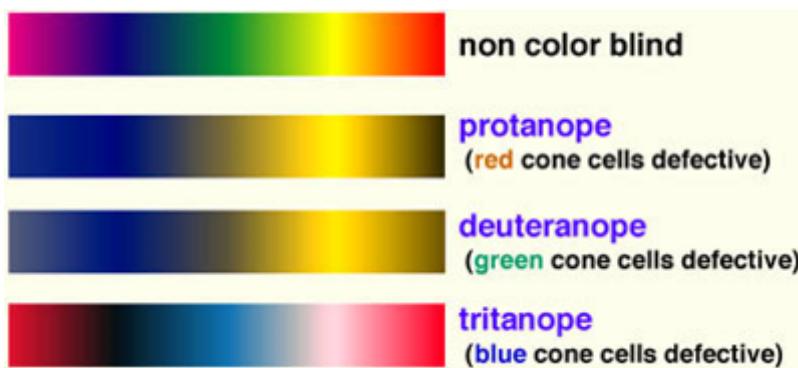
Non-data components of a graph should be displayed just visibly enough to perform their role, but not more so, for excessive salience could cause them to distract attention from the data.



Practical Guides for Using Colour in Charts

Guide 8:

To guarantee that most people who are colourblind can distinguish groups of data that are colour coded, avoid using a combination of red and green in the same display.

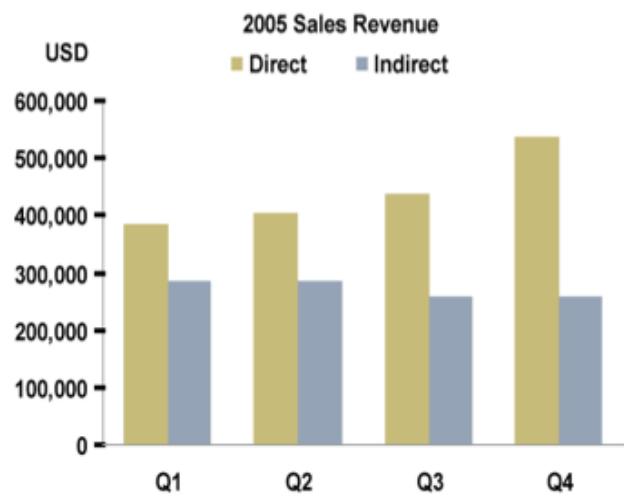
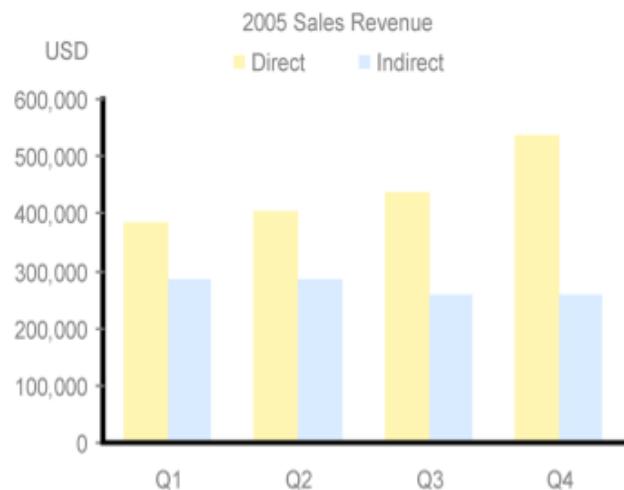


Design principles for effective visual presentation

- Guides for Encoding Values in Graph
 - JunkCharts
 - Practical Guides for Using Colour in Charts
 - **Data-ink**
-

Data-ink

- Reduce the non data-ink
 - Removed unnecessary non data-ink
 - De-emphasise or regularise the remaining non data-ink
- Enhance the data-ink
 - Remove unnecessary data-ink
 - Emphasise the remaining data-ink



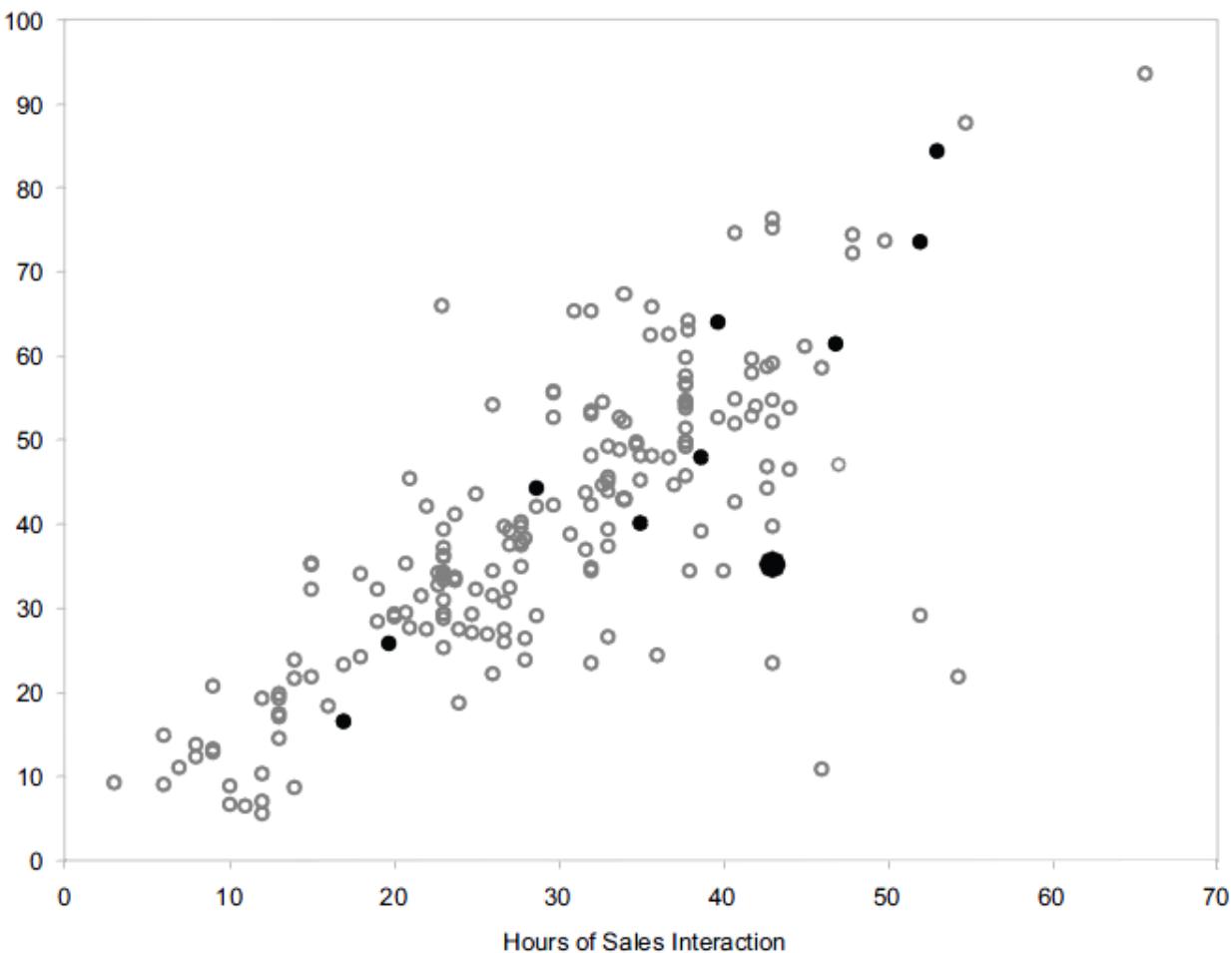
The term, 'data-ink', is defined as the total ink on a graph that represents data. Tufte claims that good graphical representations maximize data-ink and erase as much non-data-ink as possible. Thus, he defines the data-ink ratio is the proportion of a graphic's ink devoted to the non-redundant display of data-information. It should equal to $(1 - \text{the proportion of graphics that can be erased without loss of data-information})$.

Practical used of data-ink

Shouting to emphasize what's interesting

Number of Orders

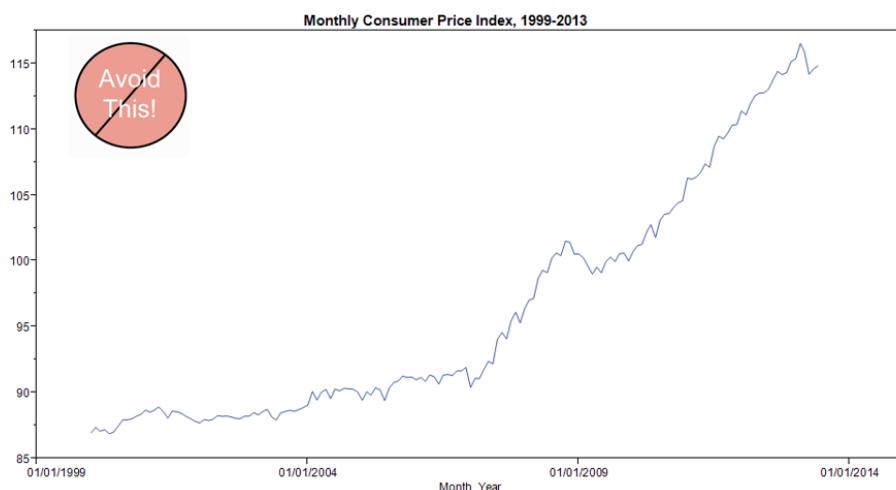
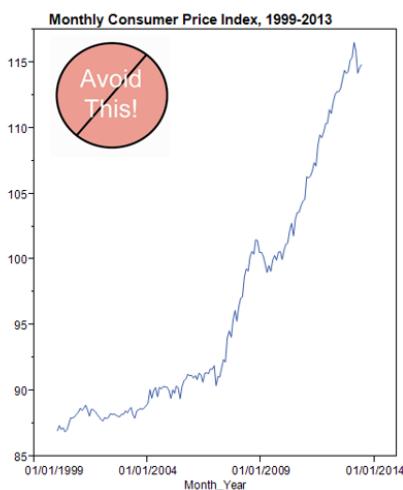
There is a strong correlation between the amount of time salespeople interact with customers and the number of orders that customers place.



(Dark data points ● represent last year's top 10 customers based on the number of orders placed.
The largest data point represents last year's top customer.)

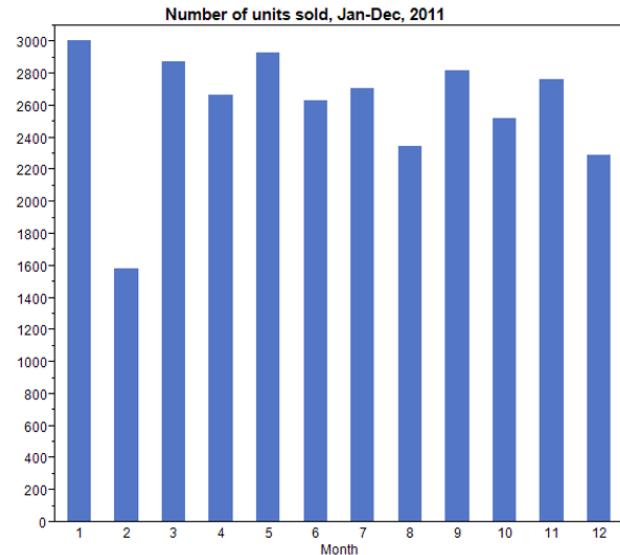
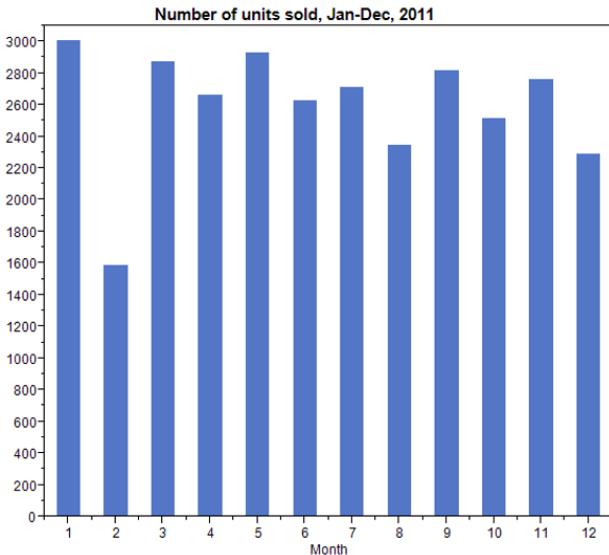
What should the relative lengths of the axis be?

- Should not manipulate the aspect ratio to intentionally exaggerate or downplay the rate of change.
- Stick to the convention of making your graphs wider than being tall.



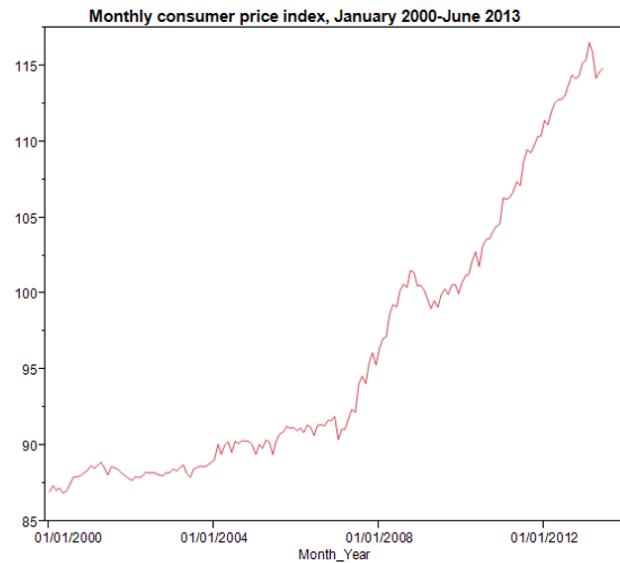
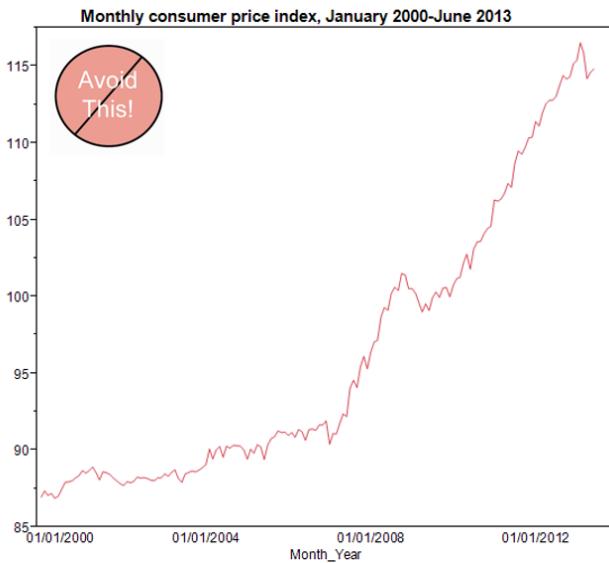
When can you eliminate tick mark?

Tick marks are superfluous on categorical scale.



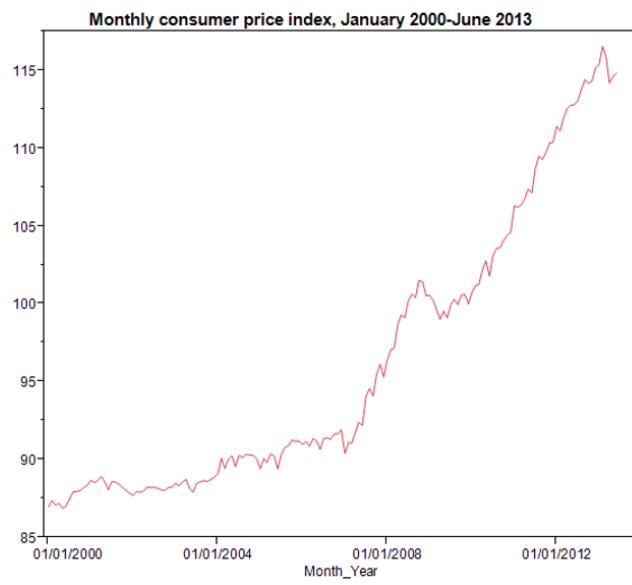
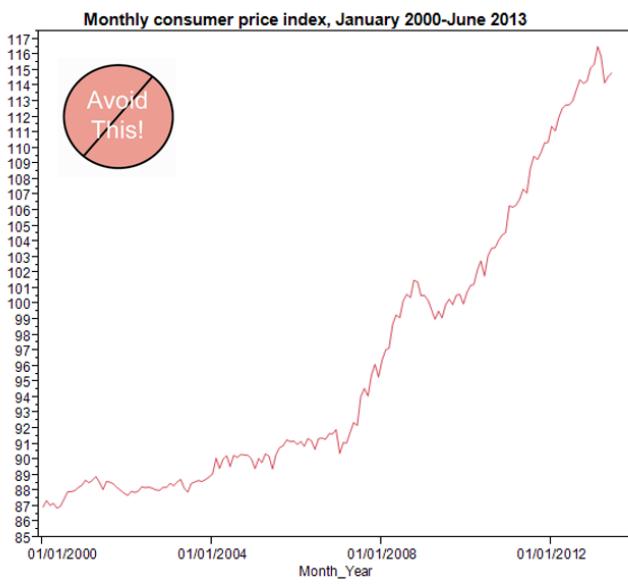
When you shouldn't eliminate tick mark?

Tick marks are necessary on continuous scale.



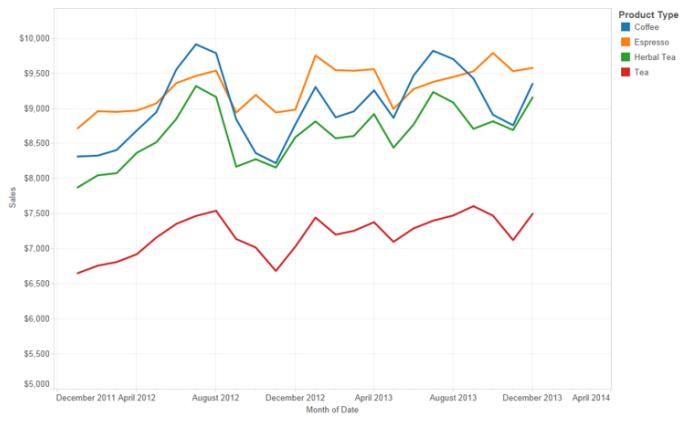
How many tick marks should you use?

- There is no exact number that works best in all circumstances, and the size of the graph is a factor that must be considered: the longer the scale line, the more tick marks it should contain.

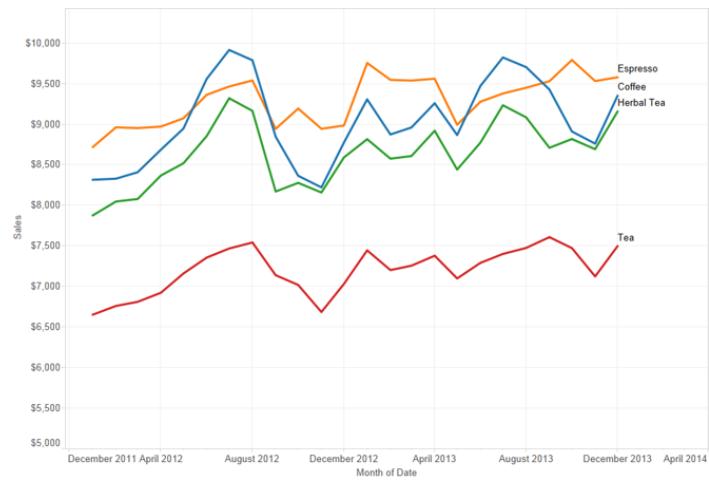


When can you eliminate legends?

- In this graph, a legend is used to indicate product types.



- In this graph, product types are labeled directly.



An enlightening data visualisation will be incomplete without a well worded title

Mid-to-low paid workers are doing more weekend work

Change in share of workers who work at the weekend, 2009 to 2019 (% points), by income decile



Source: FT analysis of Labour Force Survey

© FT

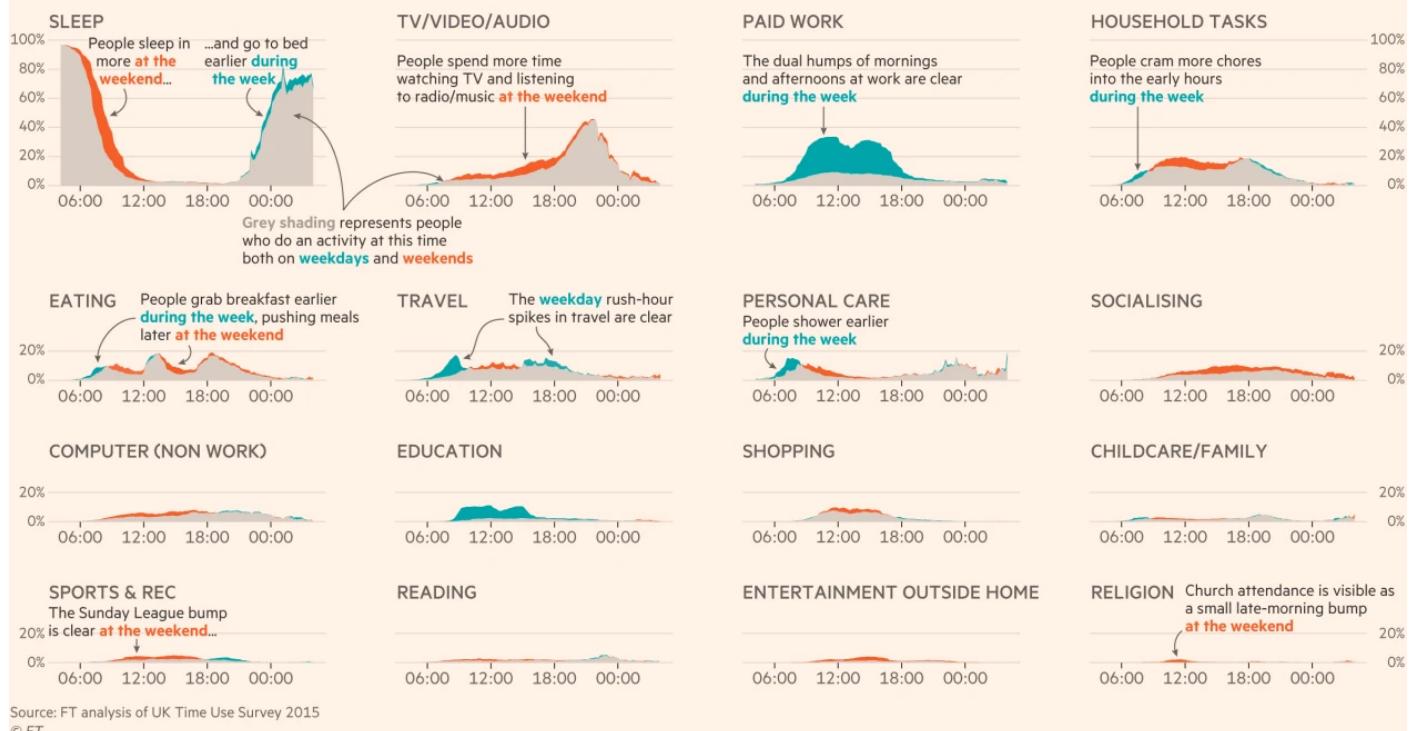
Source: [The truth about weekend working](#), Financial Times, January 23 2020.

- More example can be found [here](#)

Using Annotation to tell data story

How Britons spend their time at weekends vs weekdays

Share of people doing specific activities during **weekends** vs **weekdays**, by time of day (%)



Source: [The truth about weekend working](#), Financial Times, January 23 2020.

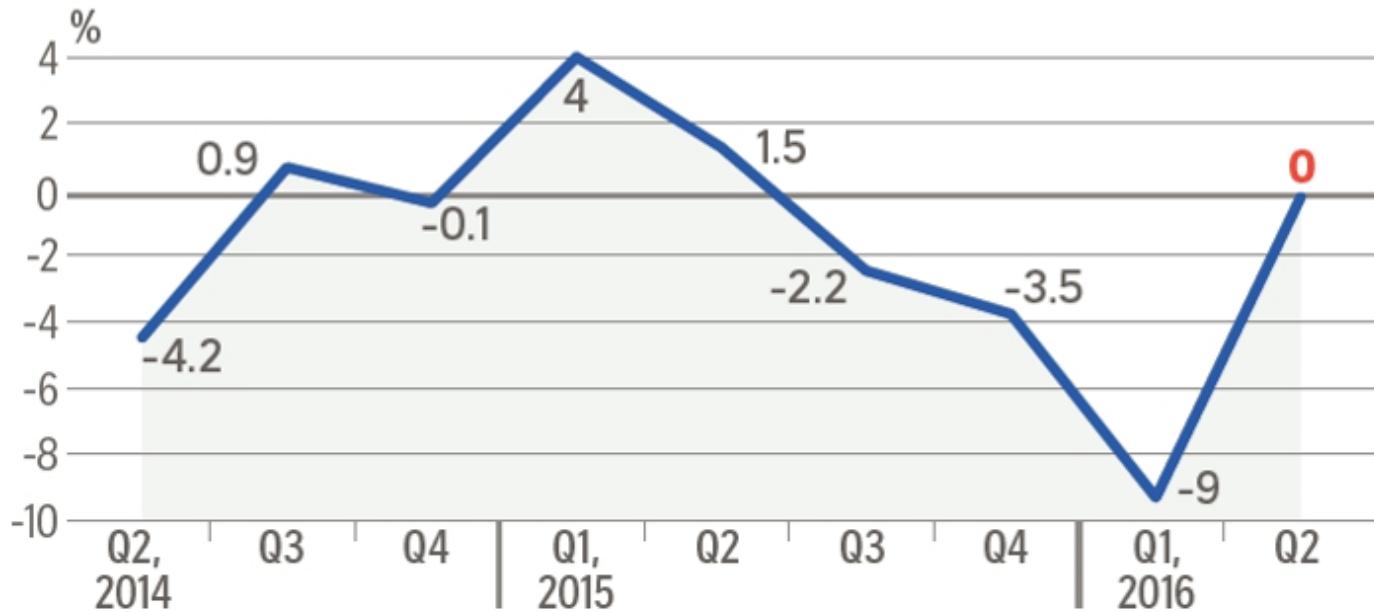
Graphical Integrity: Show Me the Truth

Don't lie to yourself (or to others) with charts



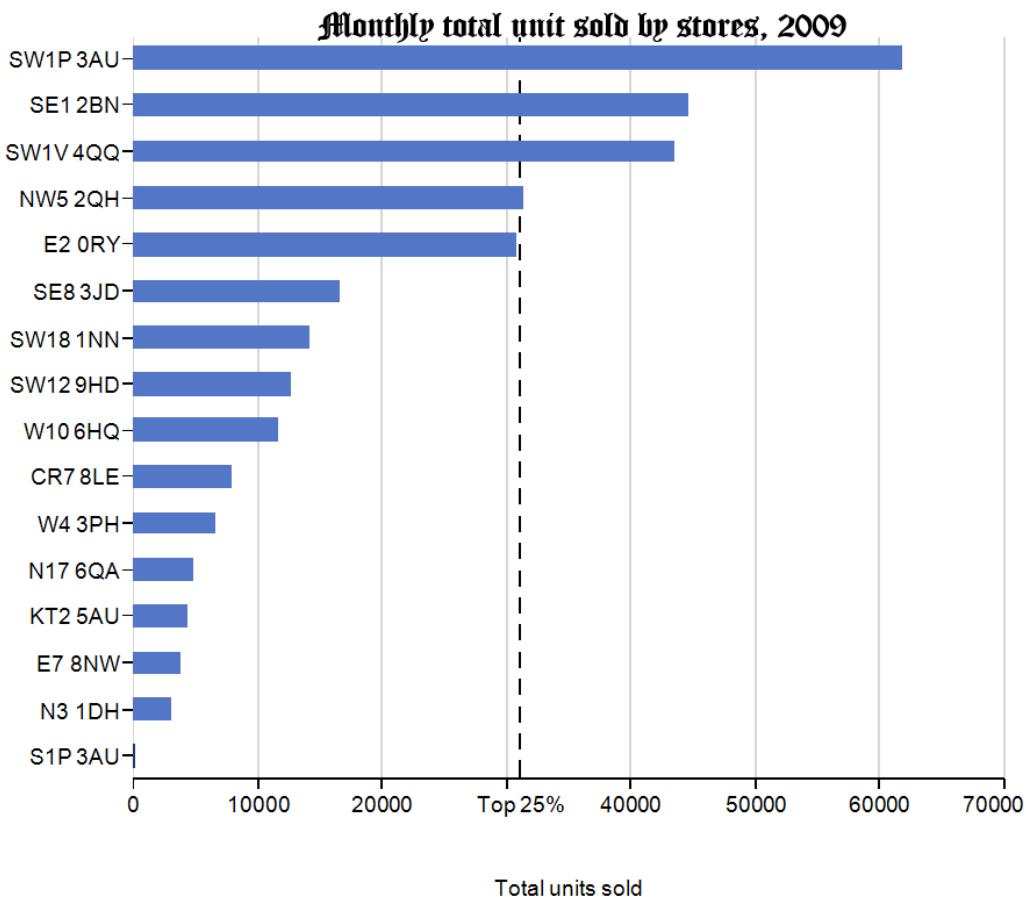
Non-oil domestic exports (Nodx) growth was flat in the second quarter. For the first half this year, **Nodx fell 4.5 per cent** compared with the same period last year.

Stuttering Nodx performance



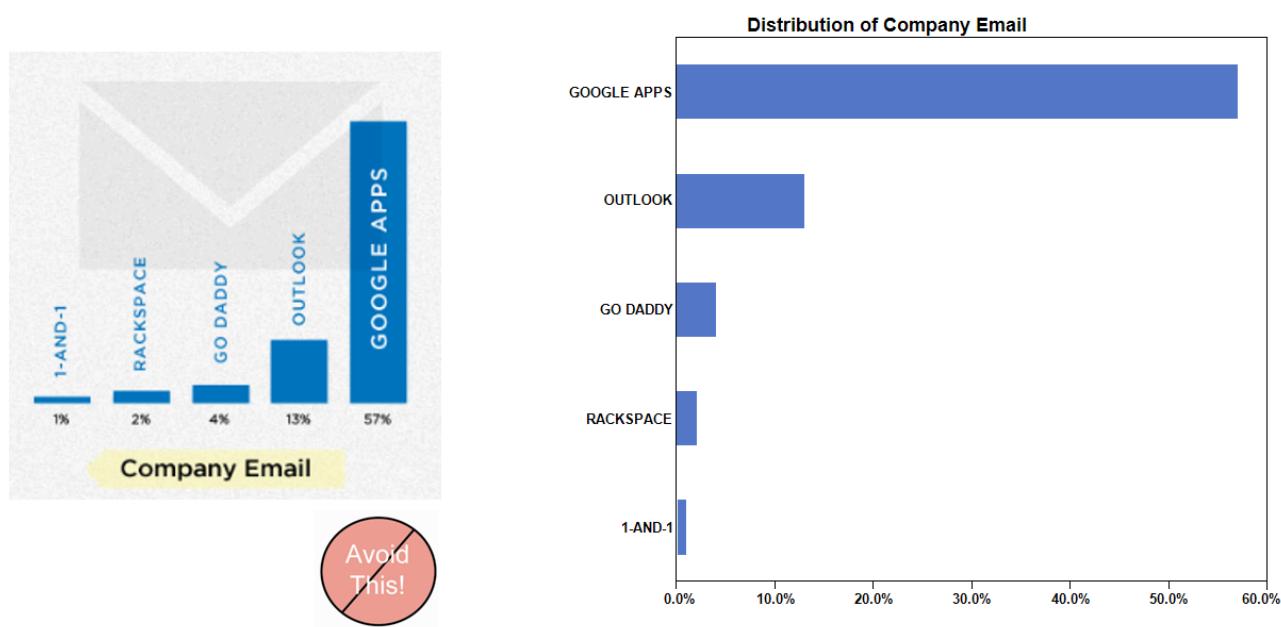
Graph typography

Avoid using artistic fonts



Graph Labeling

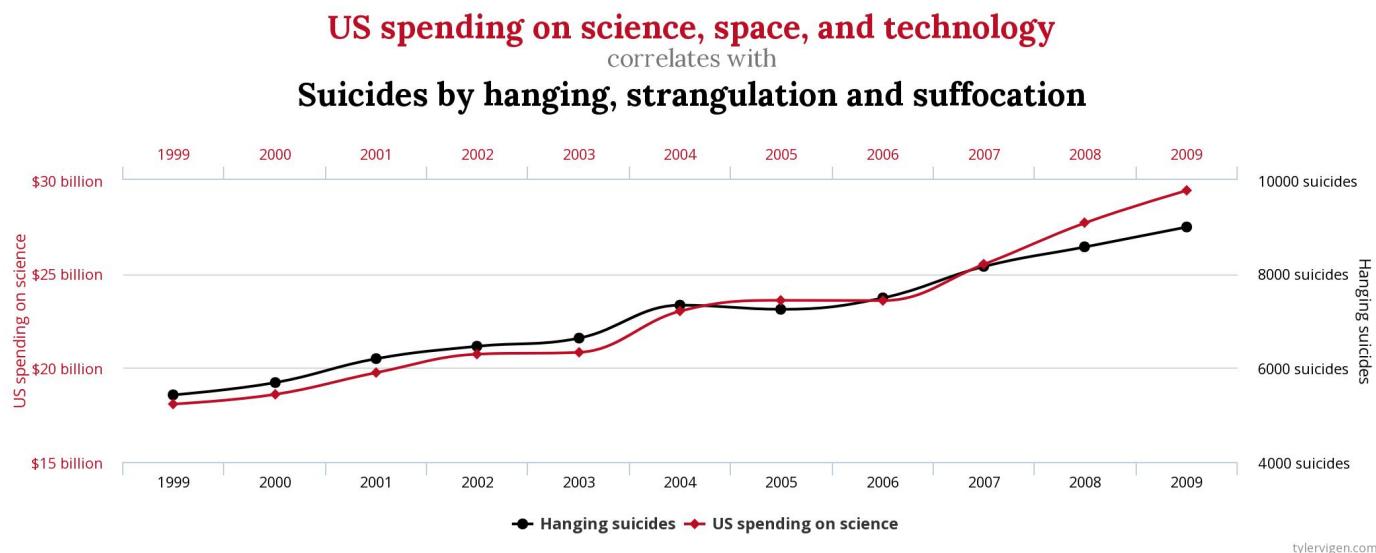
Orientation of label should be reader friendly



Three Bugs of Charts Interpretation

- The **Patternicity** bug: We detect interacting patterns, regardless of whether or not they are real.
 - The **Storytelling** bug: We immediately come up with a coherent explanation for those patterns.
 - The **Confirmation** bug: We start seeing all further information we receive, even the one that conflicts with our explanation, in a way that confirmed it. We refuse to give our explanation up, no matter what.
-

Three Bugs example



Source: [Spurious Correlation](#)

Stop the Fallacy of Visual Storytelling

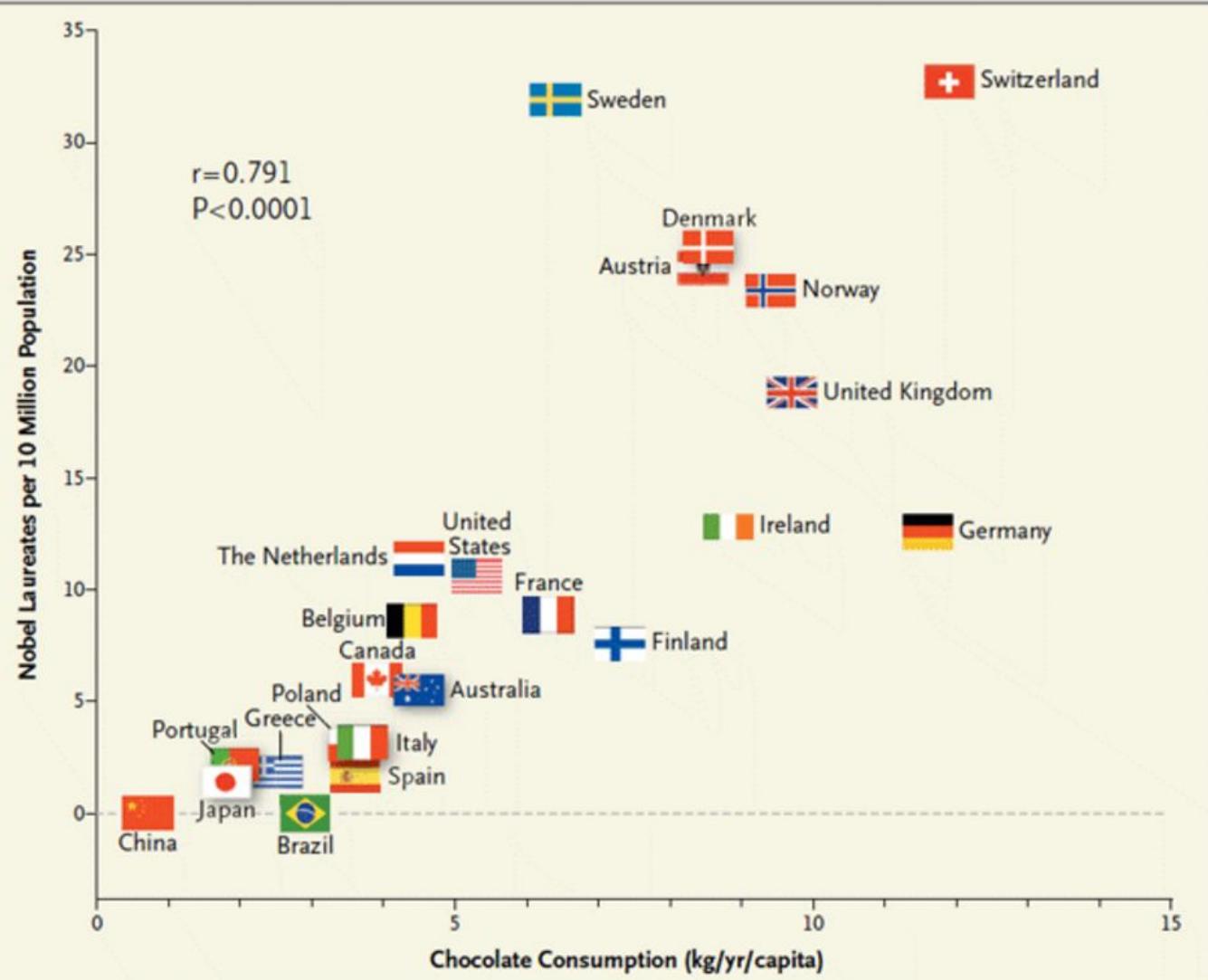


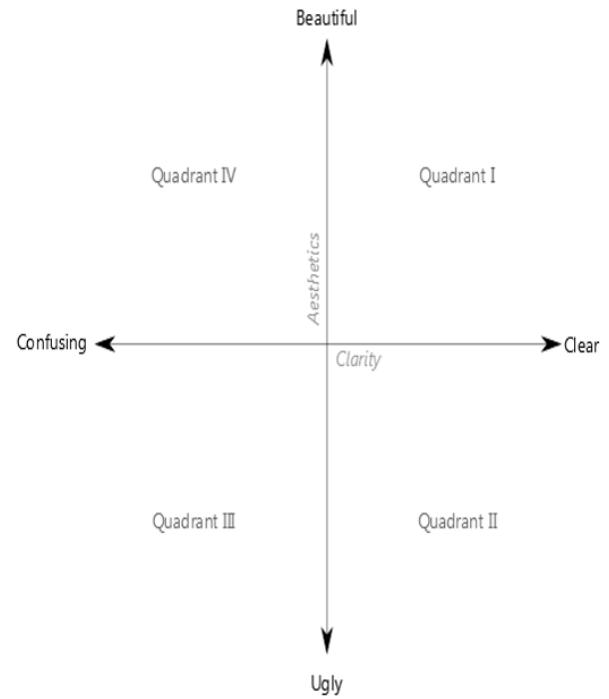
Figure 1. Correlation between Countries' Annual Per Capita Chocolate Consumption and the Number of Nobel Laureates per 10 Million Population.

NEW ENGLAND JOURNAL OF MEDICINE

Source: Franz H. Messerli (2012) [Chocolate Consumption, Cognitive Function, and Nobel Laureates](#), *The New England Journal of Medicine*.

Data Visualization: Clarity or Aesthetics?

Mapping data visualizations on a Cartesian coordinate system where "clarity" is placed along the horizontal (x) axis and "aesthetics" is placed along the vertical (y) axis provides a framework to gage the objective and subjective merits of a graphic:



Source: [Data Visualisation: Clarity or Aesthetics](#)

A Tale of Four Quadrants

Beautiful

Apple Employment History

Employment at the Cupertino tech giant has skyrocketed over the past 17 years. While a lot of time and attention was paid to design choices like fonts on this chart, it doesn't really help you figure out what's going on. And the column heights are downright misleading.

70K total employees



Apple, Inc. Employment History, 1994 - 2011

Between the return of Steve Jobs in 1997 and his death in 2011, Apple grew from 10,000 employees to over 63,000. A look at the timeline shows how key product launches fueled this growth:

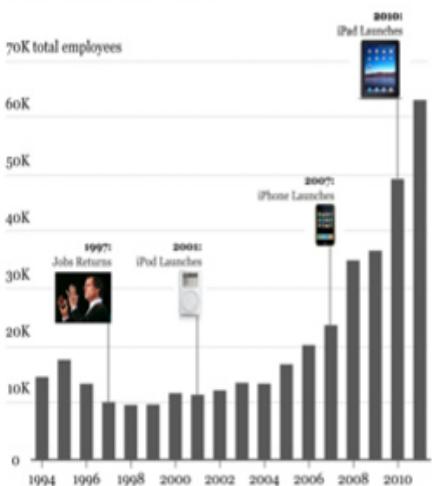


Photo: Eric Risberg/AP

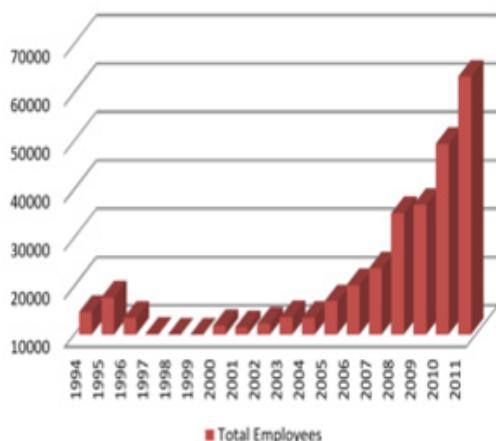
Source: www.sec.gov | Ben Jones

Confusing

Clear

Clarity

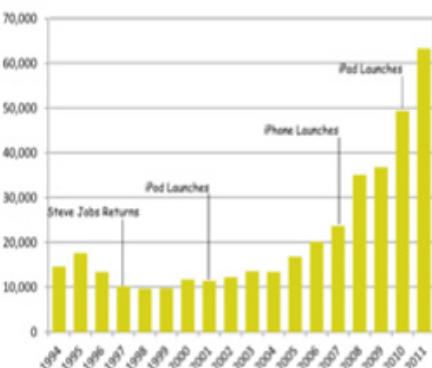
Total Apple Employees



■ Total Employees

Total Apple Employees

See how Steve Jobs's return to Apple was followed by innovative product launches and growth in employment

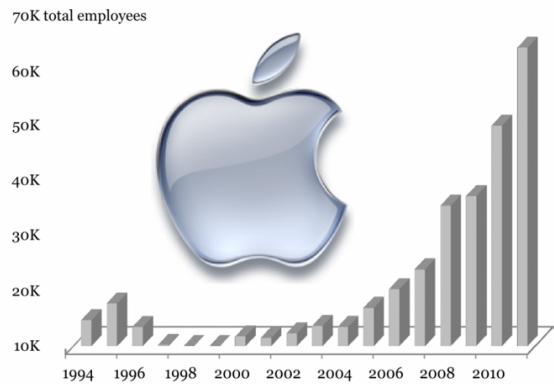


Quadrant IV – Confusing yet Beautiful

- Why is it “beautiful”?
 - Well placed & aligned title & lead-in.
 - Attention to detail with font selection.
 - Inclusion of image.
- Why is it “confusing”?
 - Y-axis starts at 10K (column height misleading).
 - 3D effect makes it difficult to gage heights.
 - Title & lead-in aren’t helpful.

Apple Employment History

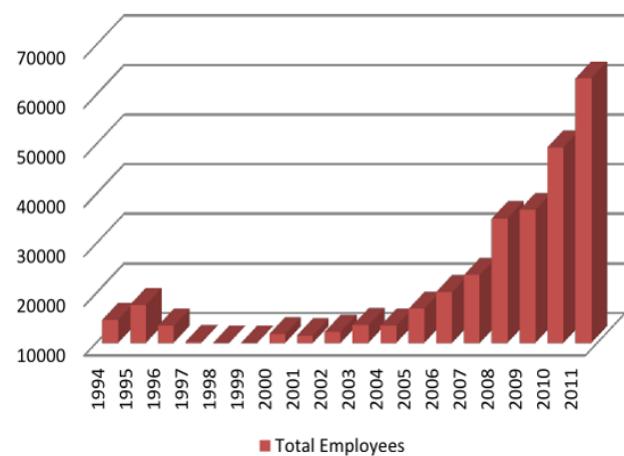
Employment at the Cupertino tech giant has skyrocketed over the past 17 years. While a lot of time and attention was paid to design choices like fonts on this chart, it doesn’t really help you figure out what’s going on. And the column heights are downright misleading.



Quadrant III – Confusing and Ugly

- Why is it “ugly”?
 - Horrible font & color choice.
 - Grid lines are too dark & distracting.
 - Format of axes (vertical x-axis labels, number format of y-axis).
- Why is it “confusing”?
 - Y-axis starts at 10K (column height misleading).
 - 3D effect makes it difficult to gage heights.
 - No lead-in or call-outs to provide context.

Total Apple Employees

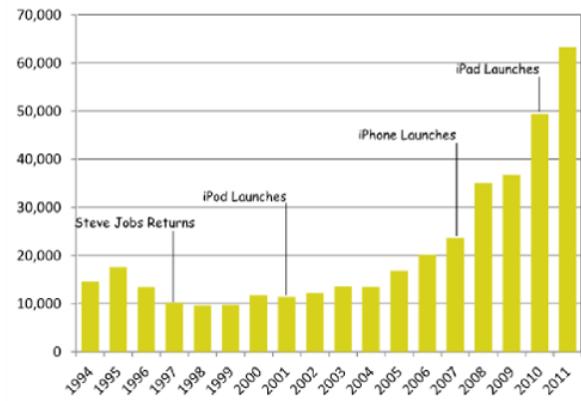


Quadrant II – Clear but Ugly

- Why is it “ugly”?
 - Poor color (puke yellow?) and font (Comic Sans?) choices.
 - Slightly pixelated – poor attention to image quality detail.
 - Chart details – axis orientation, grid lines, outline.
- Why is it “clear”?
 - The y-axis starts at 0 and the 2D columns are easy to gauge.
 - For the first time, we see call-outs of relevant events on the timeline.
 - This time the lead-in paragraph is actually informative.

Total Apple Employees

See how Steve Jobs's return to Apple was followed by innovative product launches and growth in employment



Quadrant I – Clear and Beautiful

- Why is it “beautiful”?
 - Good font & color choices throughout.
 - Soft gridlines don’t distract.
 - All elements well aligned and spaced.
 - High res images are “useful” chartjunk.
- Why is it “clear”?
 - The y-axis starts at 0 and the 2D columns are easy to gauge.
 - Call-outs with images aid cognition.
 - Improved title & lead-in verbiage provide further elucidation.
 - For the first time, a photo credit and data source are included.

Apple, Inc. Employment History, 1994 - 2011

Between the return of Steve Jobs in 1997 and his death in 2011, Apple grew from 10,000 employees to over 63,000. A look at the timeline shows how key product launches fueled this growth:

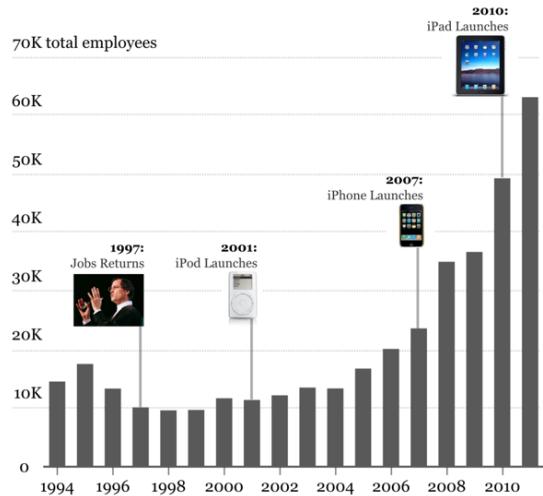


Photo: Eric Risberg/AP

Source: www.sec.gov | Ben Jones

References

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Few, Stephen (2012) (2nd edition) **Show Me the Numbers: Designing Tables and Graphs to Enlighten**, Analytics Press, Oakland, USA

Cairo, Alberto (2019) **How Charts Lie**, W.W. Norton & Company, USA.

Robbins, Naomi B. (2005) **Creating More Effective Graphs**, John Wiley & Sons, New Jersey, USA

Wong, Dona M. (2010) **The Wall Street Journal Guide to Information Graphics**, W. W. Norton & Company, Inc. New York.

Tufte, Edward (2nd Edition) **The Visual Display of Quantitative Information**, Graphics Press LLC, Connecticut, USA.

Highly recommended blog

- [The Functional Art](#)
- [Junk Charts](#)
- [Perceptual Edge](#)
- [EagerEyes](#)
- [Statistical Graphics and more](#)
- [Visualizing data](#)
- [Visualizing Economics](#)