

Data Visualization- Color Spaces

Dr. Claudius Zelenka

Kiel University

cze@informatik.uni-kiel.de

Afterimage

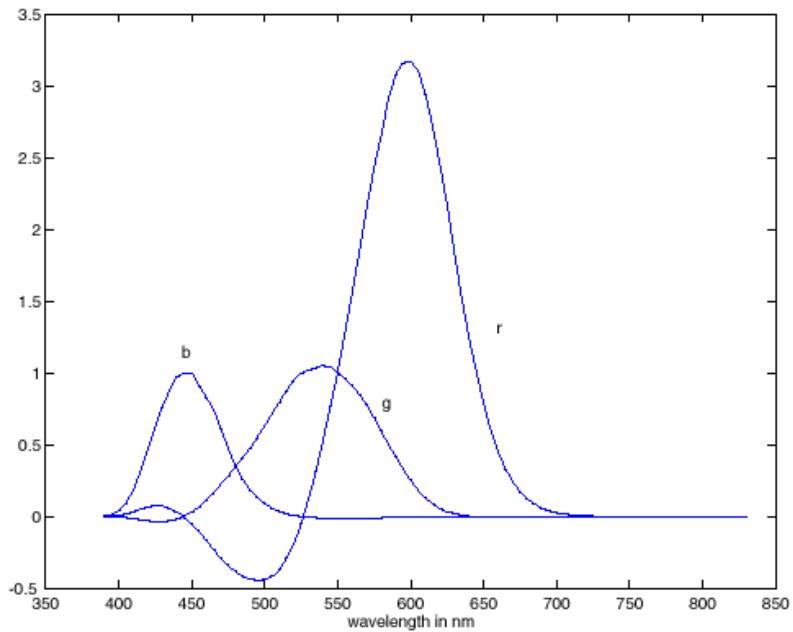
Stare at this for 20sec then look away and look at something white.

The after image will be a magenta rectangle with the text in cyan.

Due to oversaturation and adjustment of the M₁T₁P₁C₁E₁S₁.
<https://graphicdesign.stackexchange.com/questions/76824/what-are-the-pros-and-cons-of-using-lab-color>

Tristimulus model

- Any perceived color can be generated by some combination of three primary colors
- RGB Curve
- Negative Intensity
(color added to target light)



Cones (SML)
(short, medium, long)

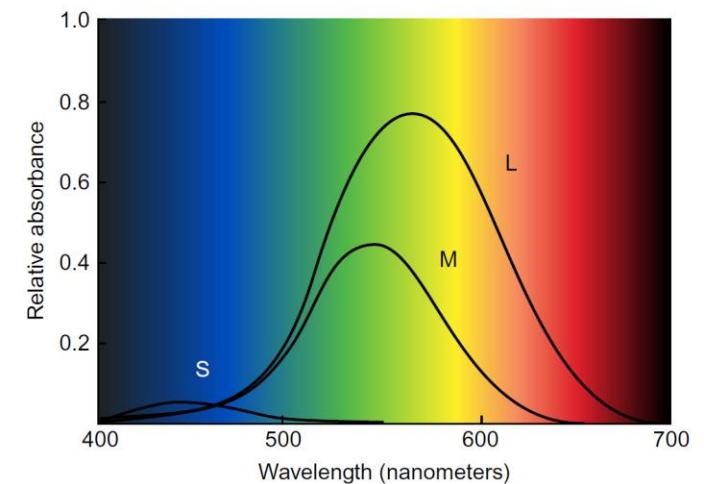
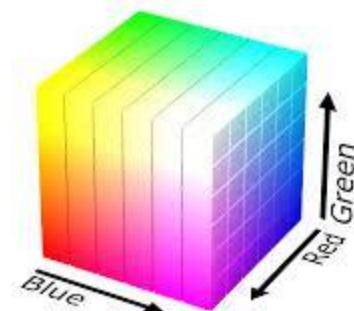


Figure courtesy of D. Forsyth

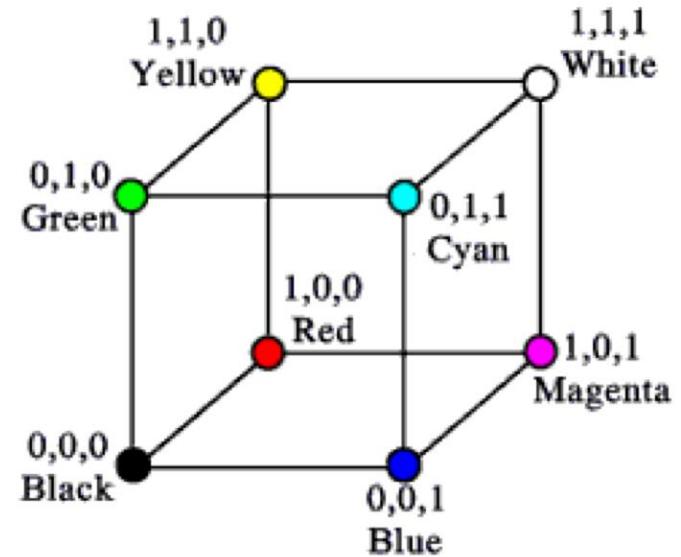
RGB

- RGB: good for display hardware

Corners of the RGB color cube



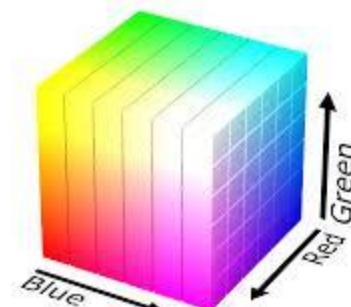
https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png



RGB

- RGB: good for display hardware

Corners of the RGB color cube

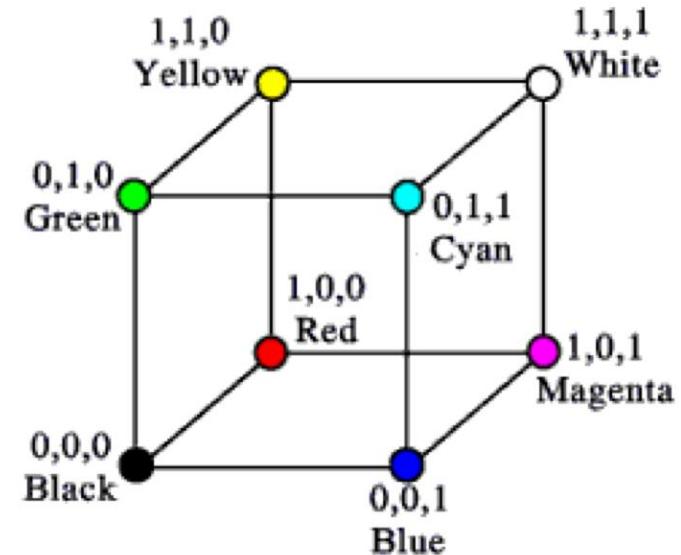


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

Red
+ Green

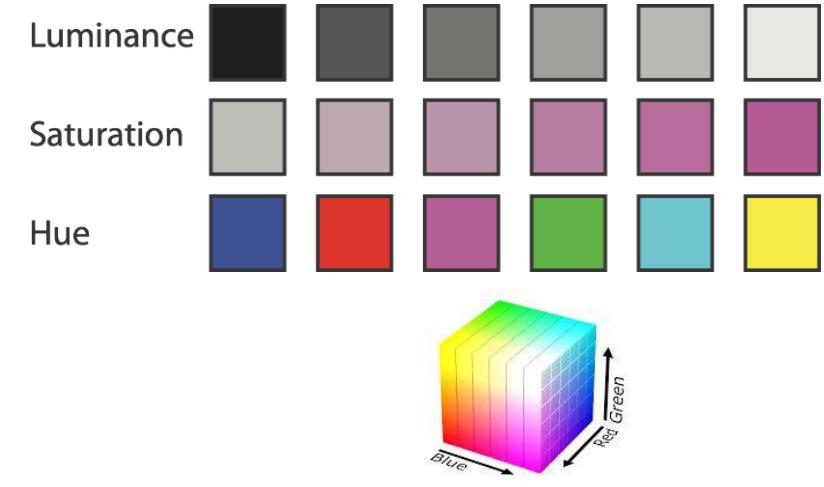


Major interference



Many color spaces

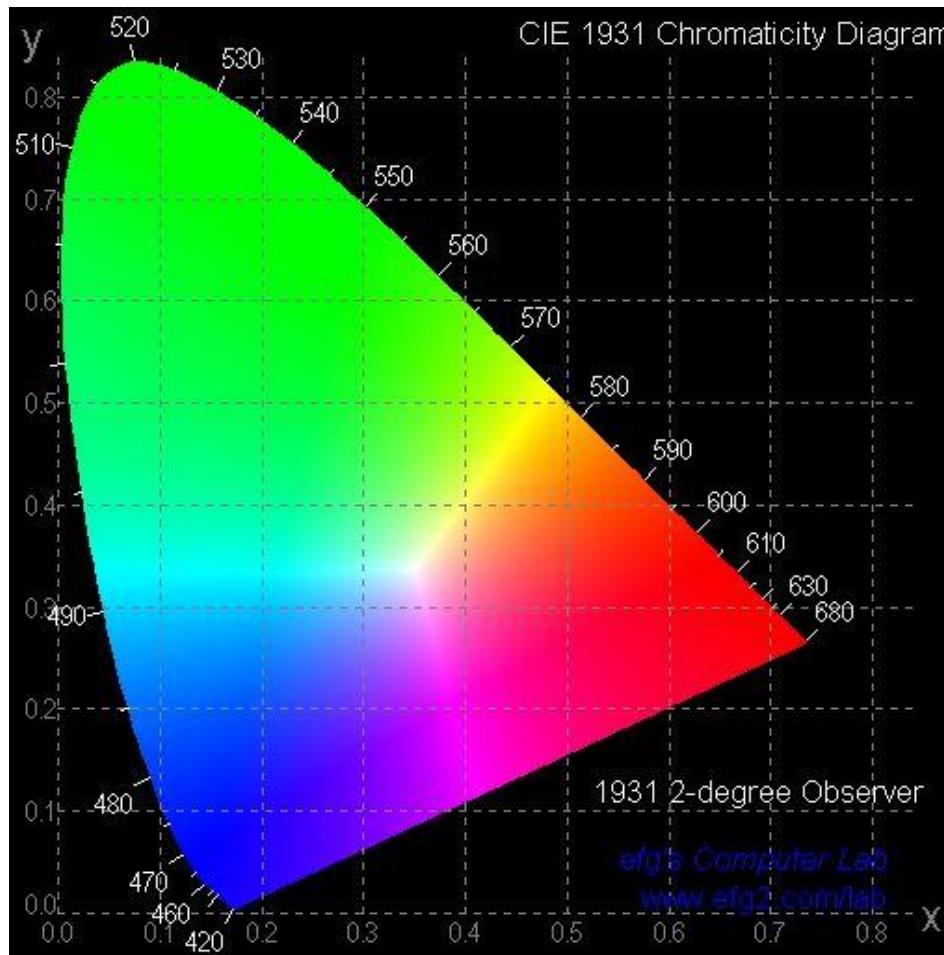
- Luminance (L^*), hue (H), saturation (S)
 - good for encoding
 - but not standard graphics/tools colorspace
- RGB: good for display hardware
 - poor for encoding & interpolation



https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

CIE 1931 Color space

- (Commission Internationale d'Éclairage)



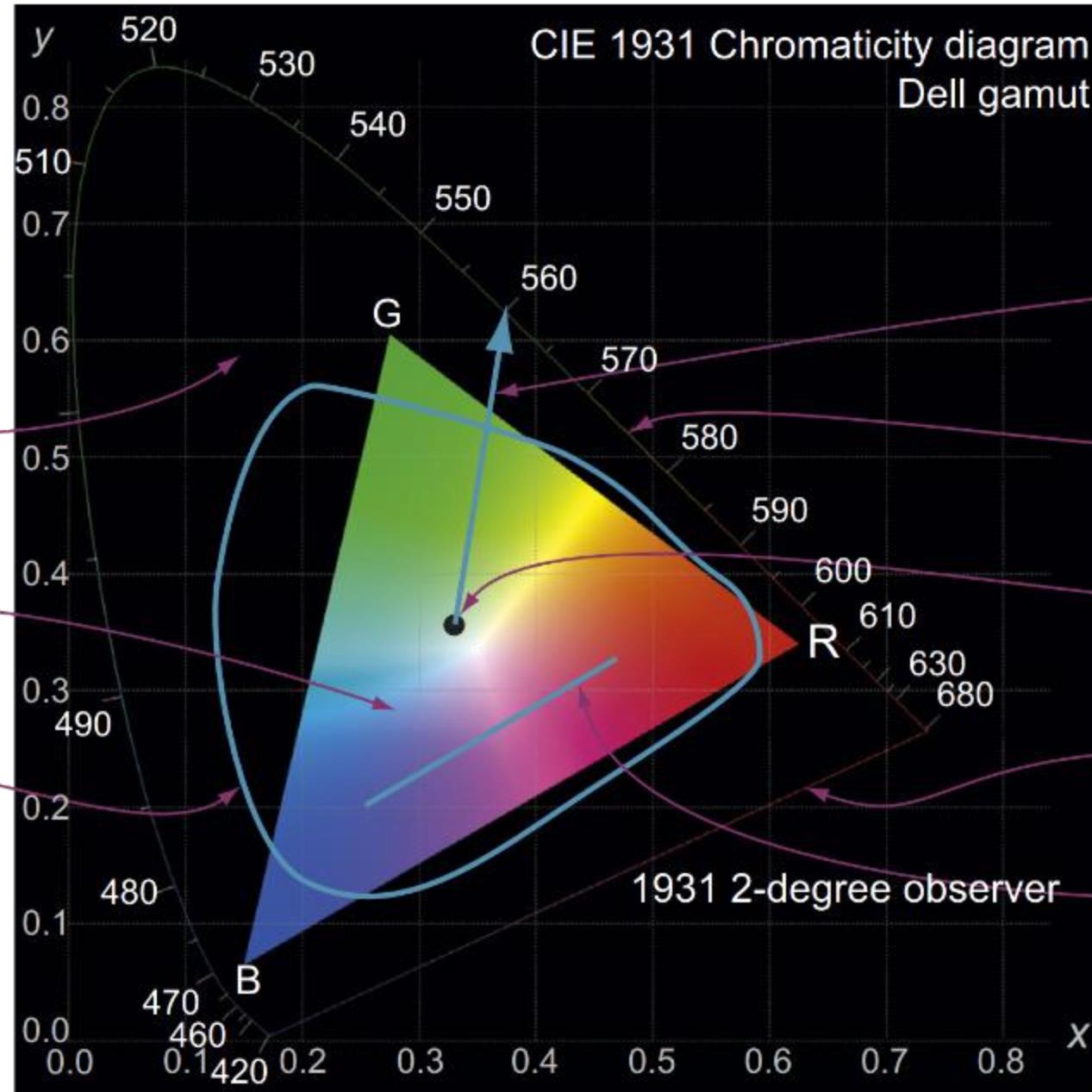
All visible colors

Gamut of all colors

Gamut of a monitor

Gamut of surface colors

CIE 1931 Chromaticity diagram
Dell gamut



Line of increasing saturation

Spectrum locus

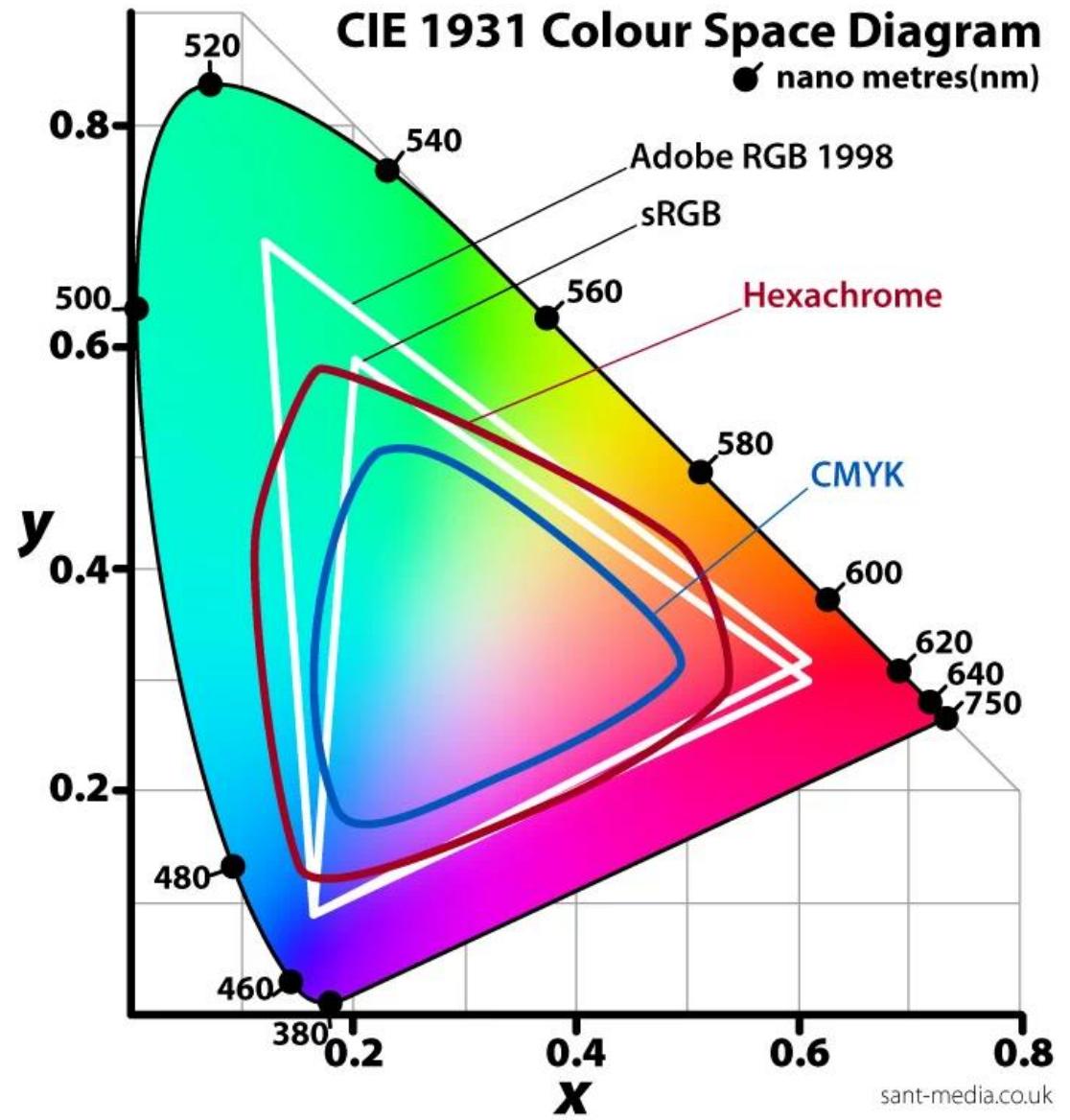
Equal-energy white

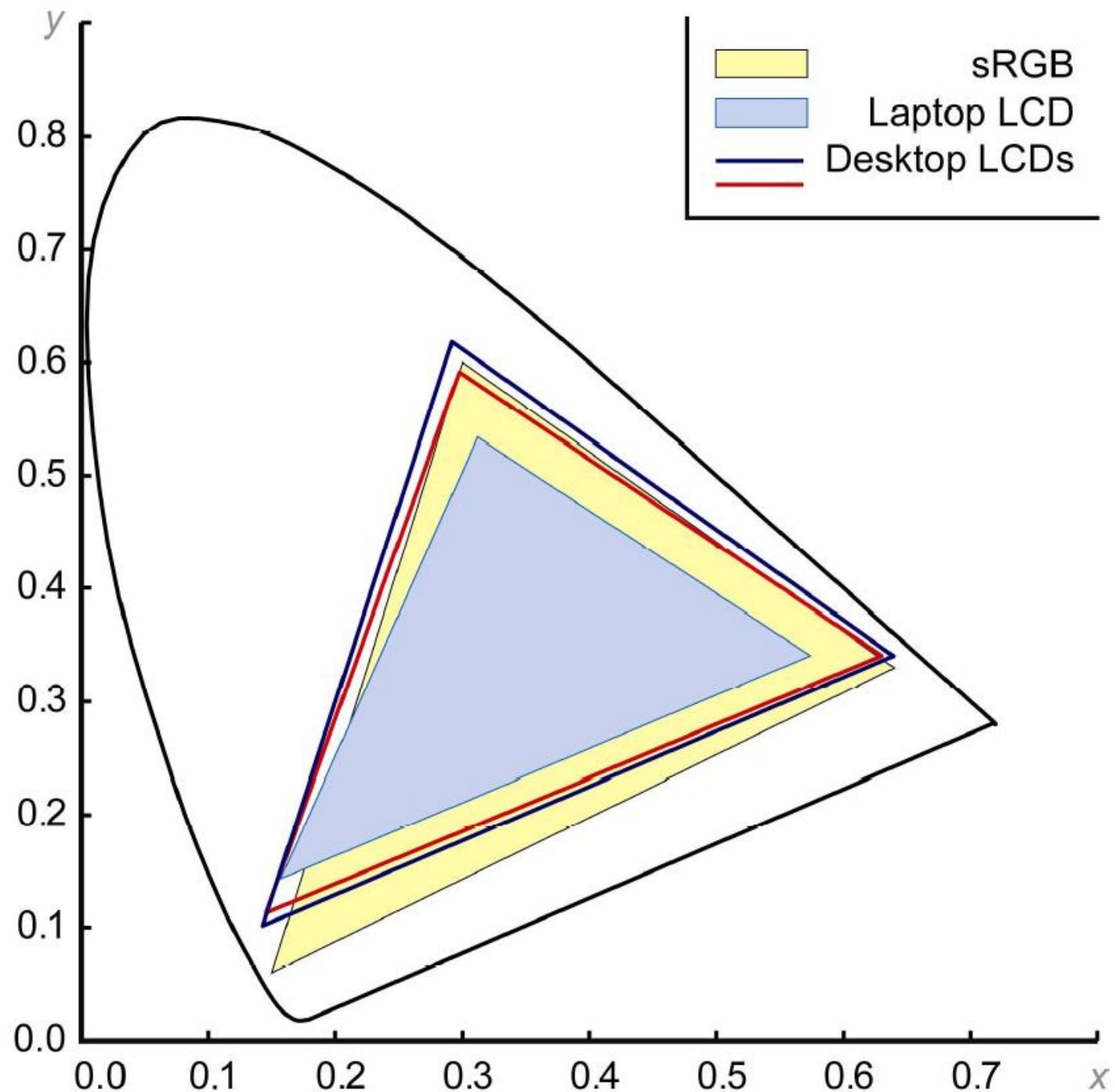
Purple boundary

Color mixture line

CIE 1931 comparison with RGB

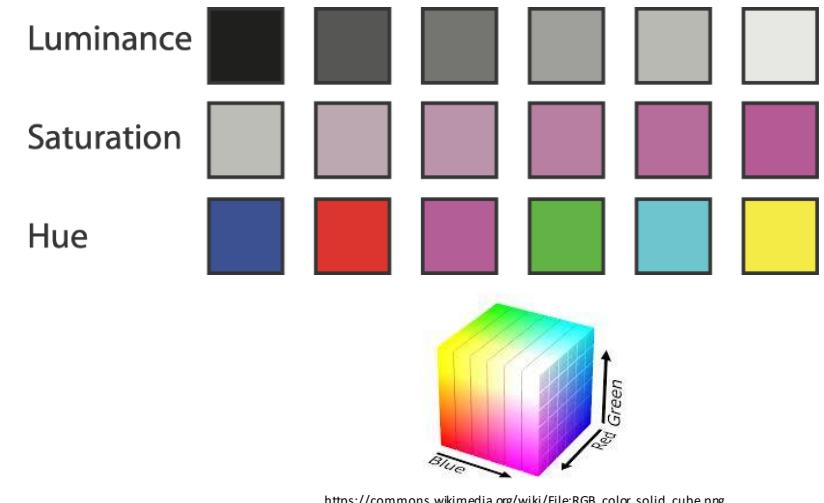
- sRGB color space
 - Developed for CRT monitors in 1996
- Adobe RGB 1998
 - Alternative to sRGB
- CMYK – Cyan Magenta Yellow Key
 - Standard for printing
- How to print black in CMYK?
- Hexachrome
 - 6 color additive model for model accurate colors in printing +orange +green



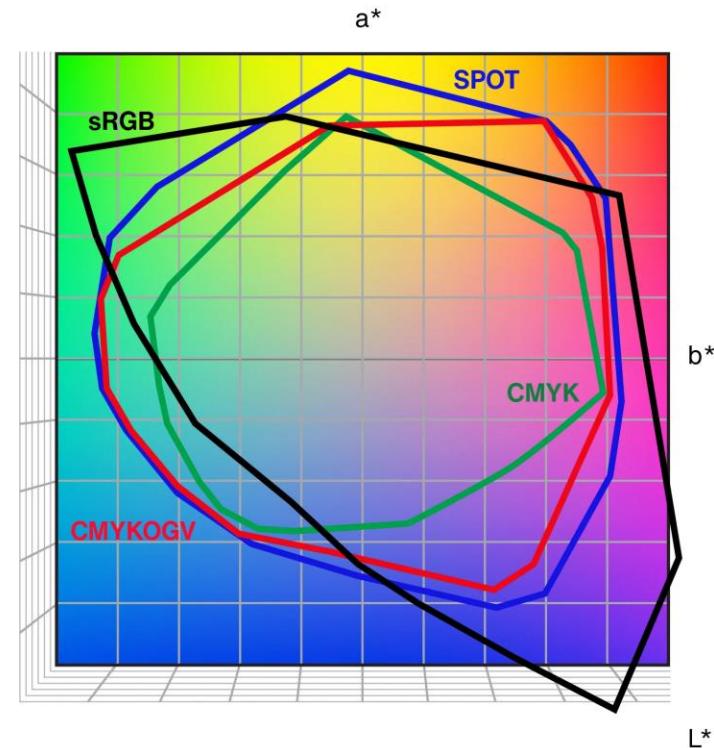


Many color spaces

- Luminance (L^*), hue (H), saturation (S)
 - good for encoding
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- RGB: good for display hardware
 - poor for encoding & interpolation
- CIE 1931 XY
- CIE LAB ($L^*a^*b^*$) 2011: good for interpolation



https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

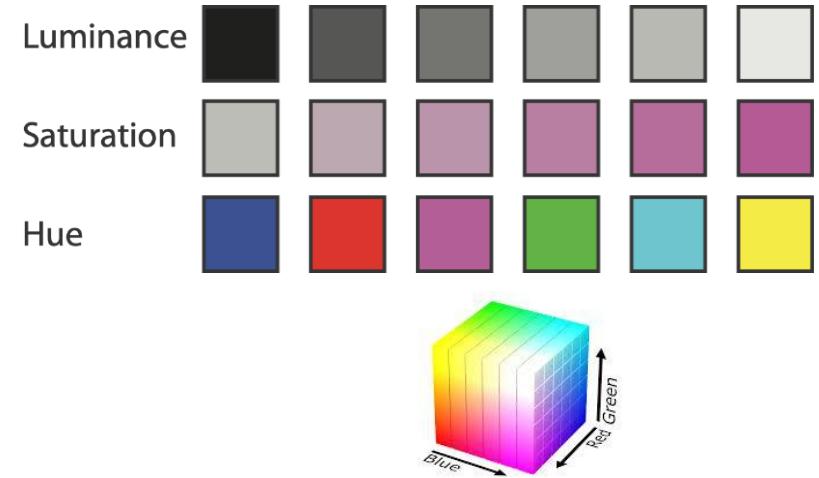


- CMYK vs RGB vs Lab



Many color spaces

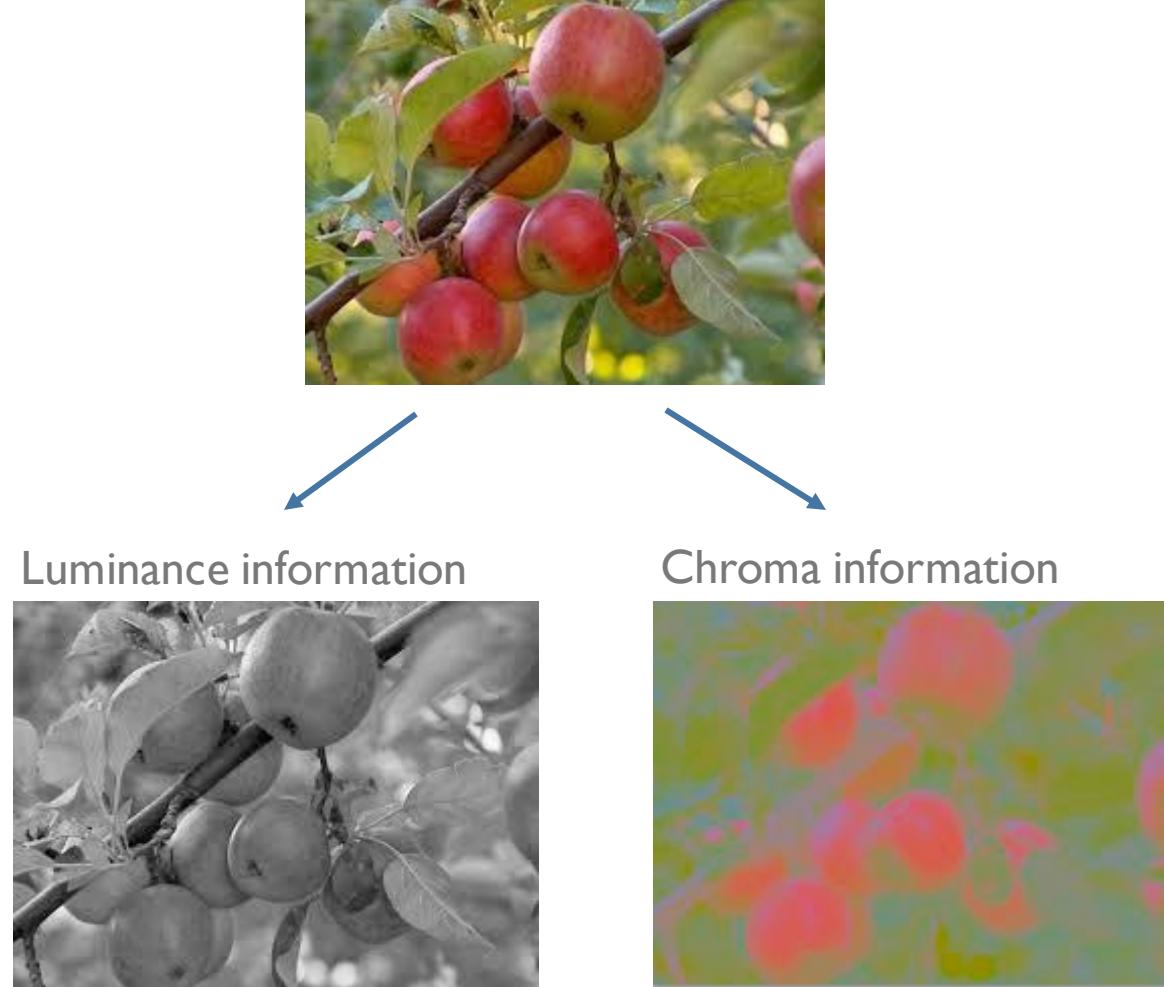
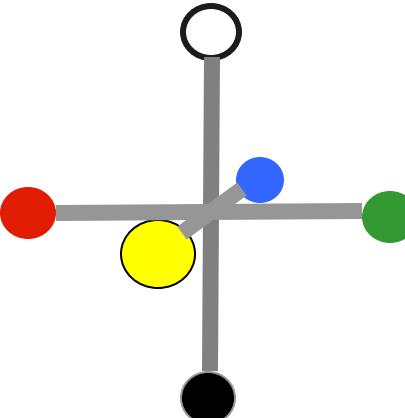
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 - hard to interpret, poor for encoding



https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

Perceptual colorspace: L*a*b*

- perceptual processing before optic nerve
 - one achromatic luminance channel (L*)
 - edge detection through luminance contrast
 - 2 chroma channels
 - red-green (a*) & yellow-blue axis (b*)
- CIE LAB
 - perceptually uniform
 - great for interpolating
 - complex shape
 - poor for encoding



[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

$L^*a^*b^*$ is closer to perception

- Opponent process

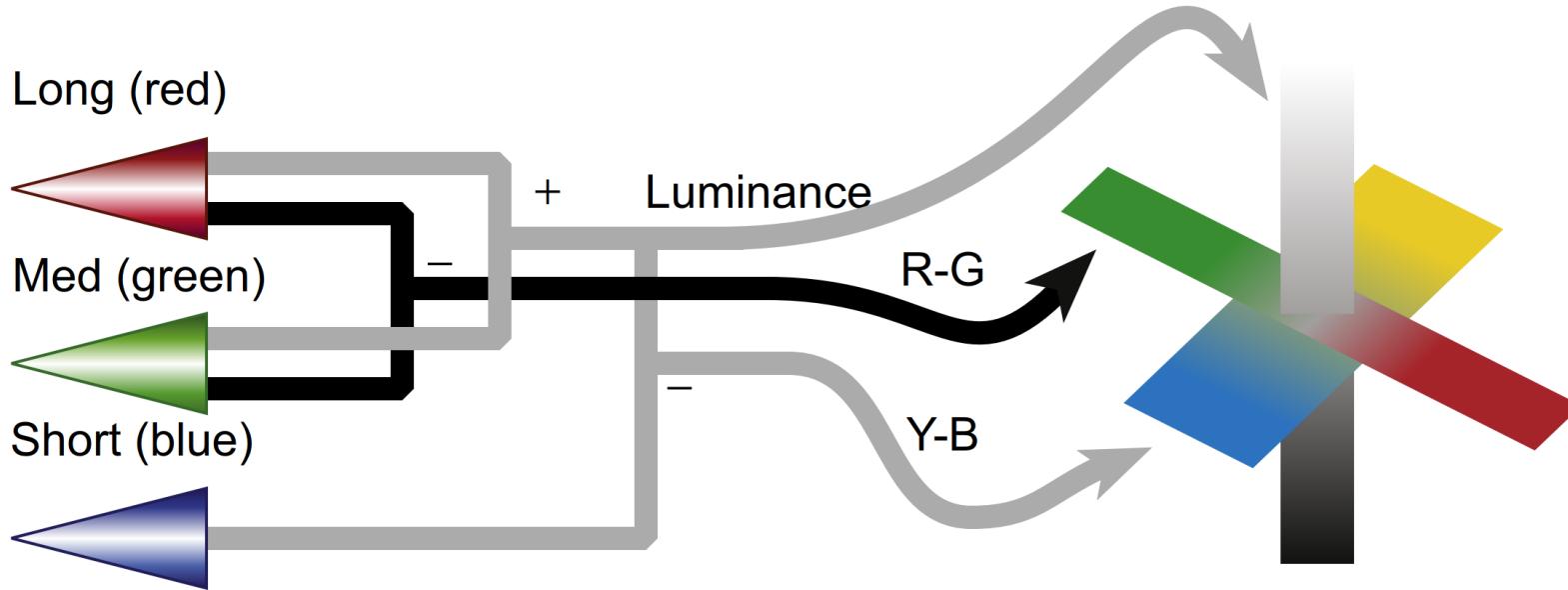
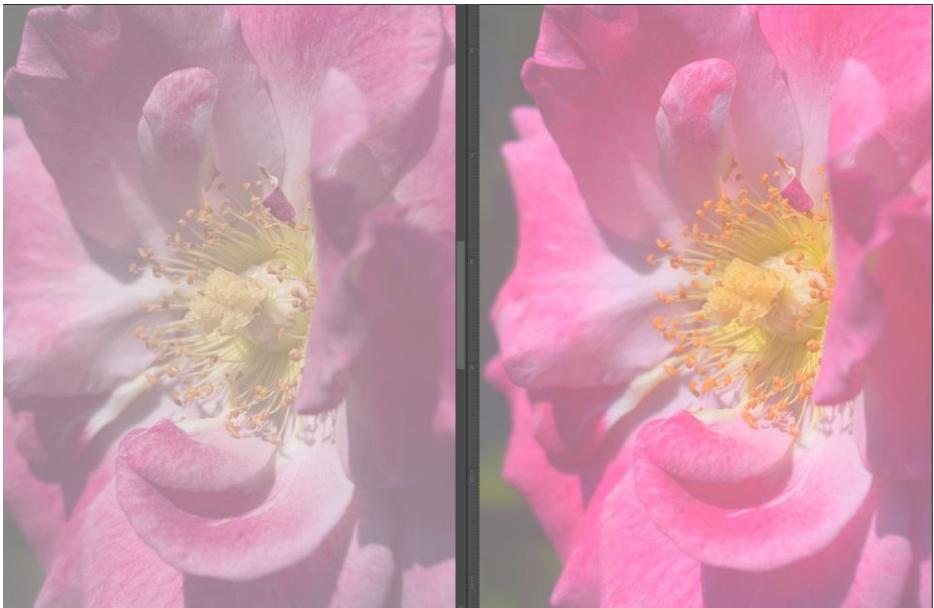


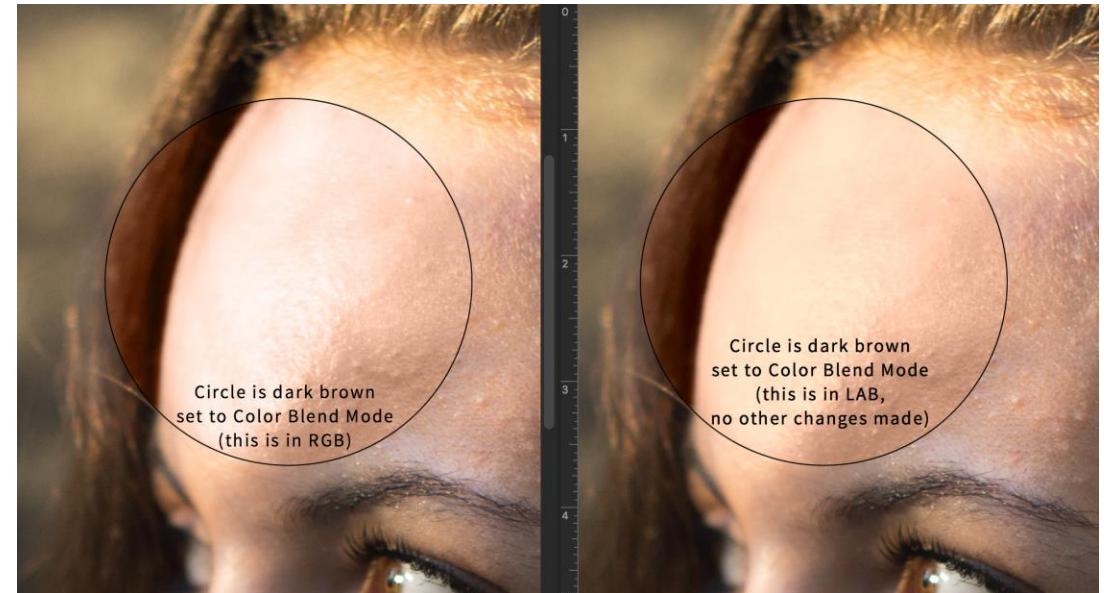
Figure 4.10 In the color opponent process model, cone signals are transformed into black-white (luminance), red-green, and yellow-blue channels.

RGB vs. L*a*b*



50% black point (128 RGB, 50L in L*a*b*)

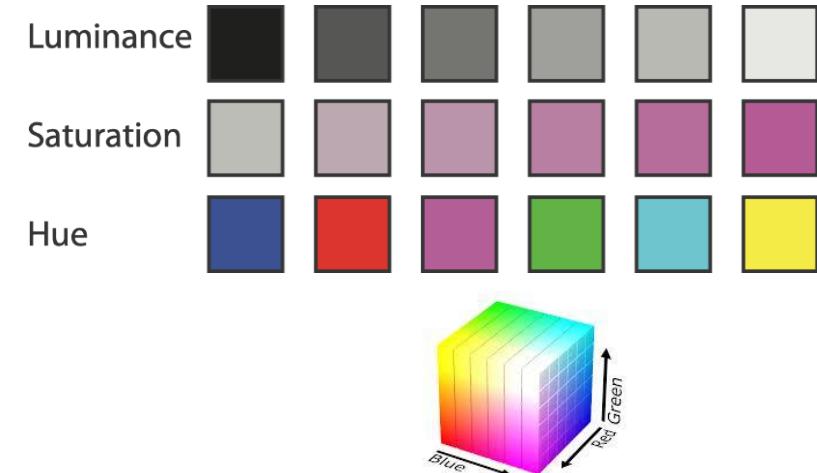
In RGB, because the black point is actually a composite of RGB, adjusting it flattens all of our colors quite a bit.



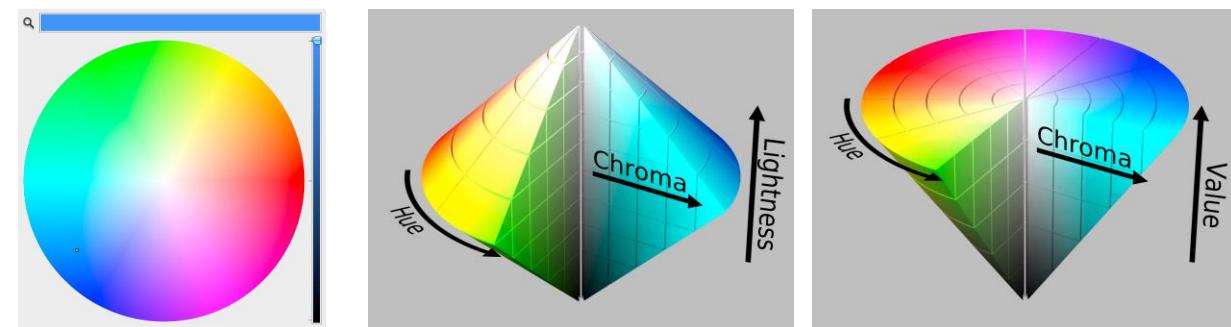
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- RGB: good for display hardware
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- CIE LAB ($L^*a^*b^*$): good for interpolation
 - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding

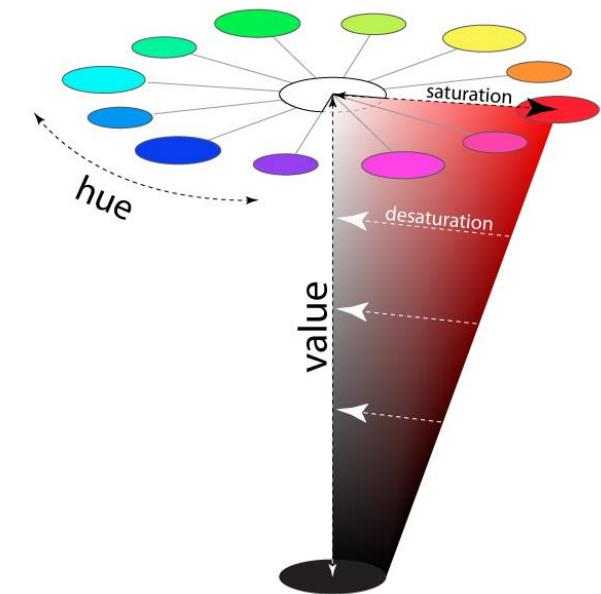
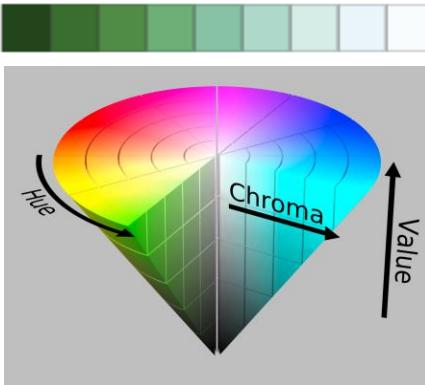
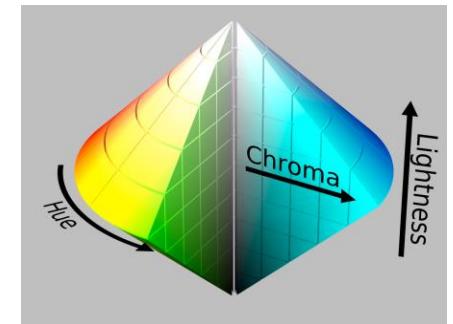
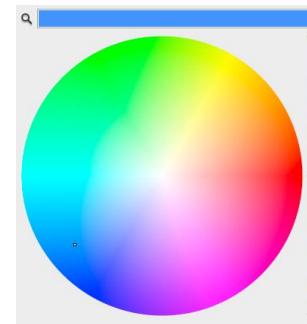


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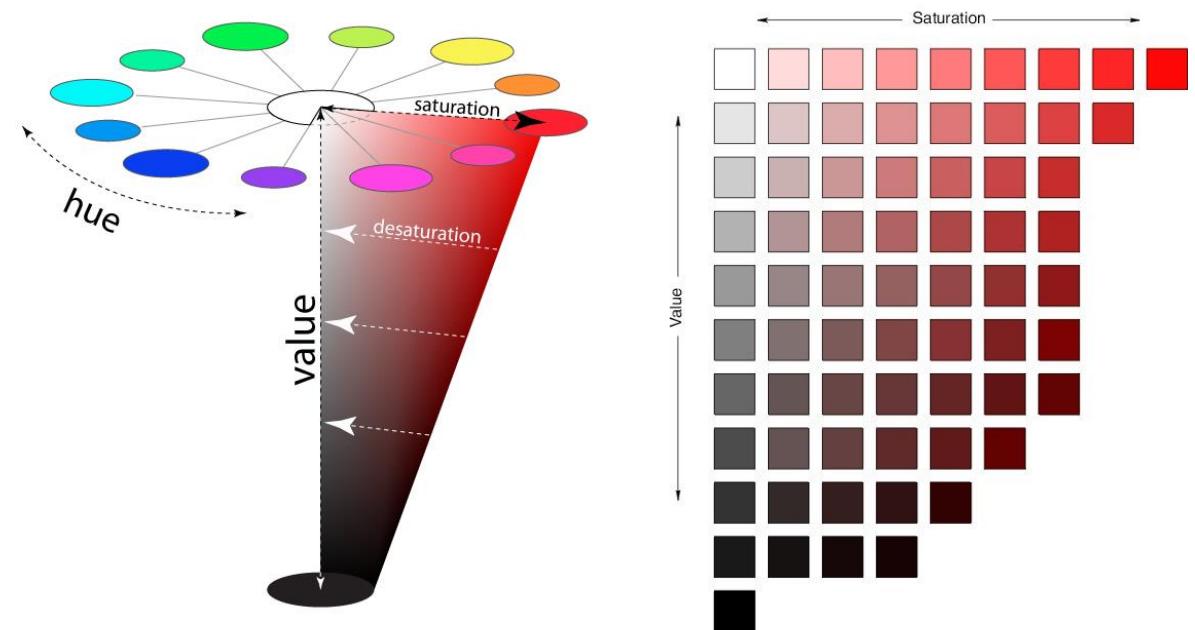
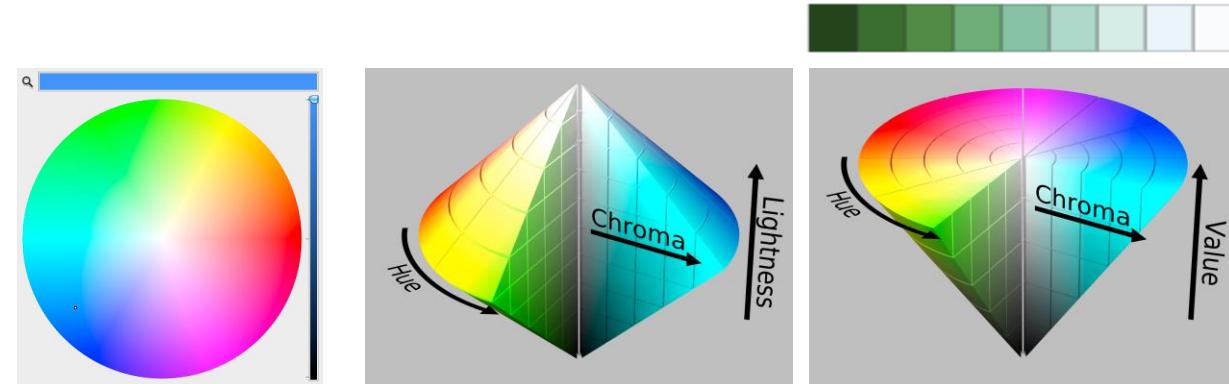
HSL/HSV

- HSL/HSV: somewhat better for encoding
 - hue/saturation wheel intuitive
- saturation
 - in HSV (single-cone) desaturated = white
 - in HSL (double-cone) desaturated = grey



HSL/HSV

- HSL/HSV: somewhat better for encoding
 - hue/saturation wheel intuitive
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 - in HSV (single-cone) desaturated = white
 - in HSL (double-cone) desaturated = grey
- luminance vs saturation
 - channels **not** very separable
 - typically not crucial to distinguish between these with encoding/decoding
 - key point is hue vs luminance/saturation

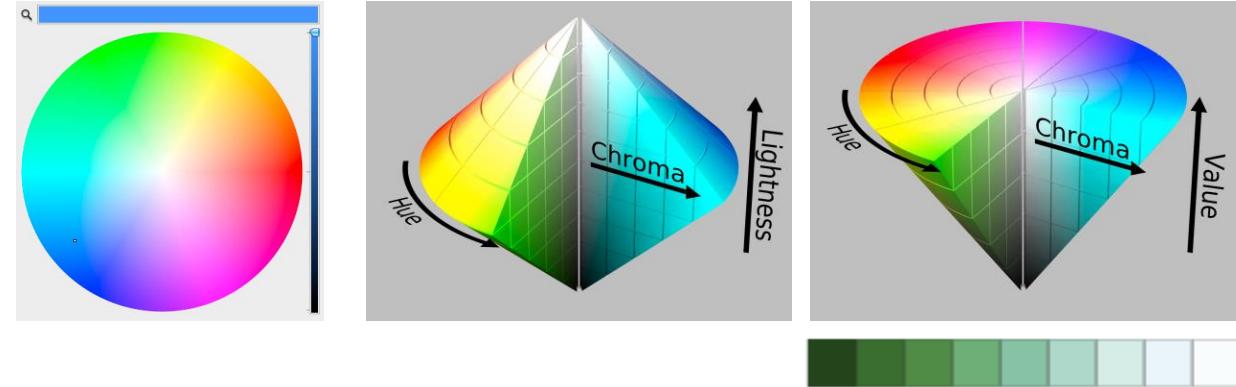


<http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/>

<http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/>

HSL/HSV: Pseudo-perceptual colorspace

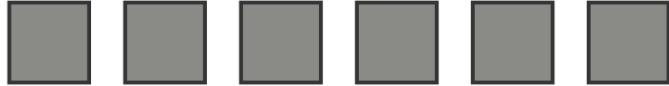
- HSL better than RGB for encoding **but beware**
 - L lightness \neq L* luminance



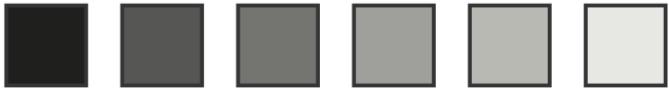
Corners of the RGB color cube



L from HLS
All the same

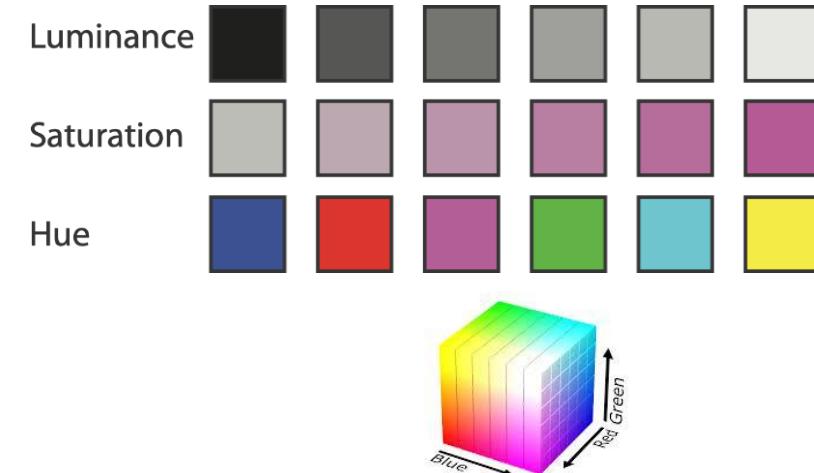


Luminance values

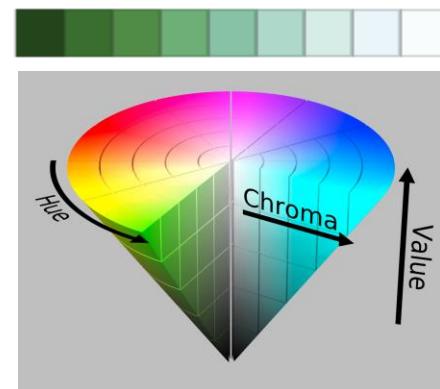
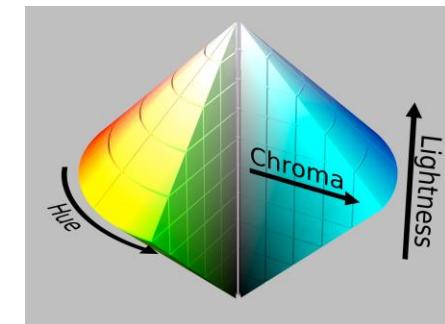
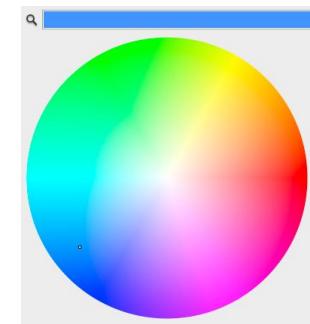


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- RGB: good for display hardware
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- CIE LAB ($L^*a^*b^*$): good for interpolation
 - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding
 - hue/saturation wheel intuitive
 - beware: only pseudo-perceptual!
 - lightness (L) or value (V) \neq luminance (L^*)

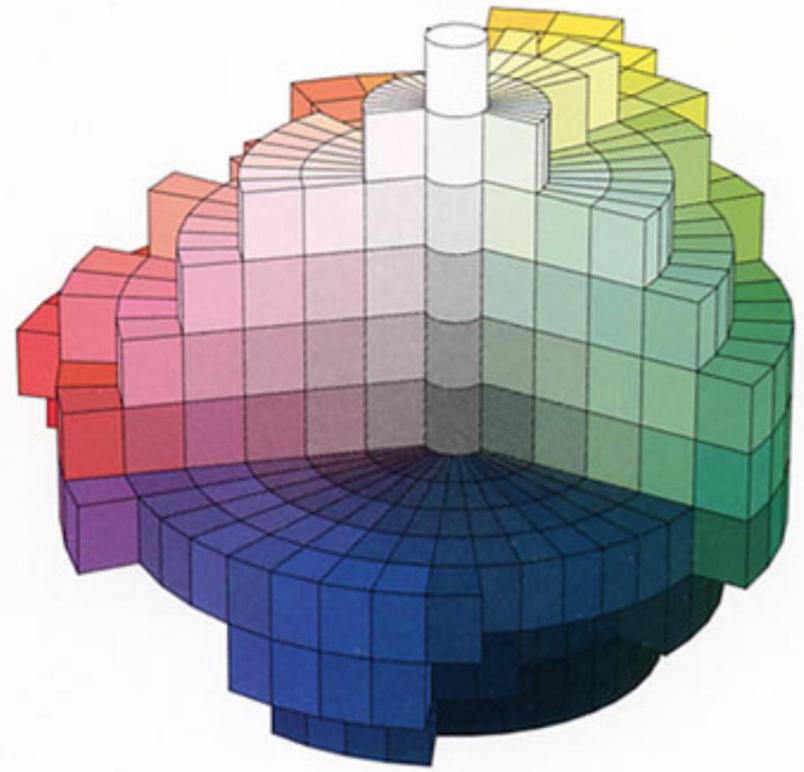


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png



Color Appearance

- given L , a^* , b^* , can we tell what color it is?
 - no, it depends
- chromatic adaptation
- luminance adaptation
- simultaneous contrast
- spatial effects
- viewing angle
- ...



Color/Lightness constancy: Illumination conditions

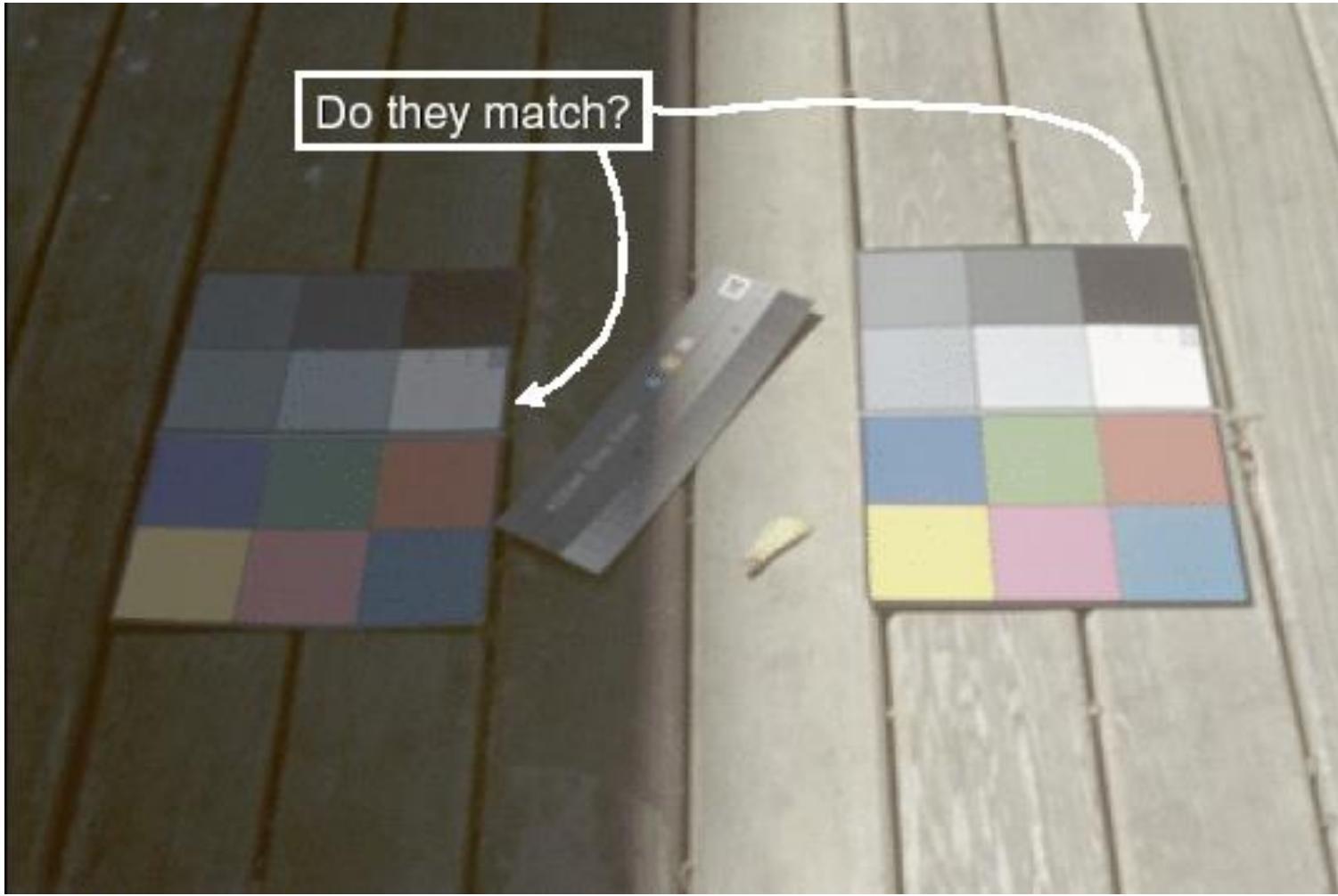


Image courtesy of John McCann via Maureen Stone

Color/Lightness constancy: Illumination conditions

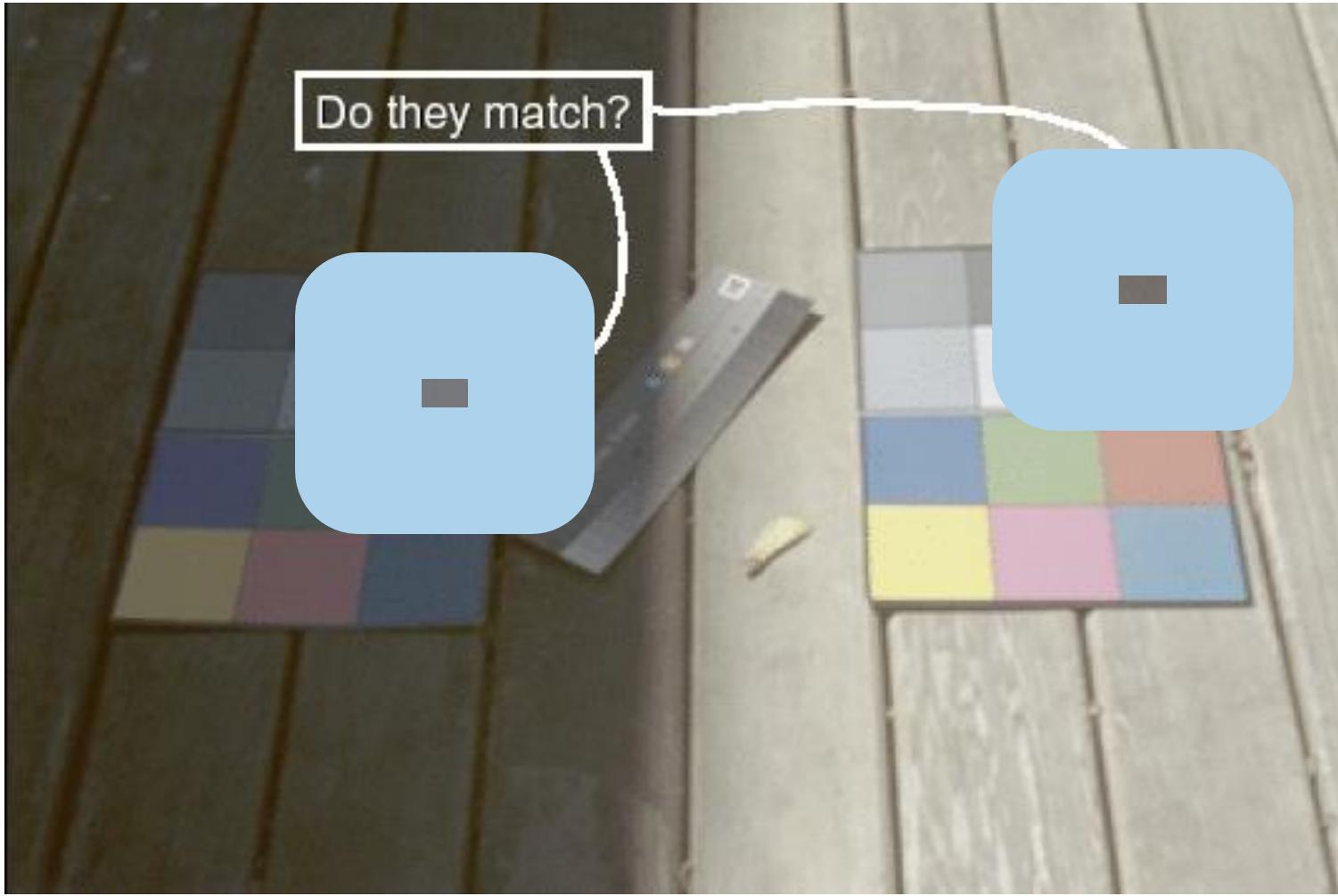
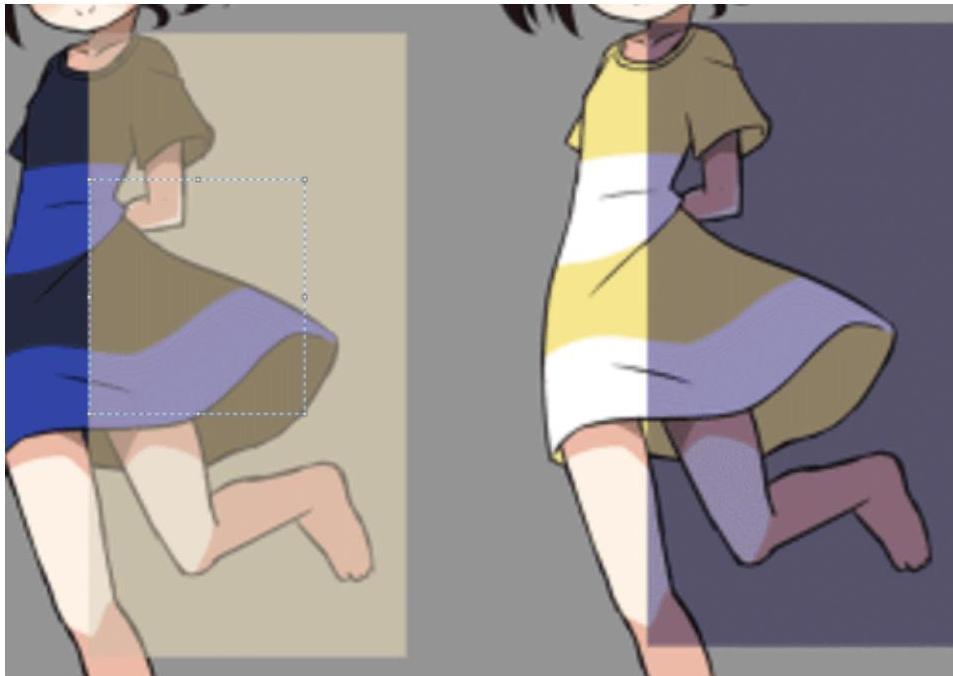


Image courtesy of John McCann via Maureen Stone

Contrast with background



Black and blue? White and gold?

<https://imqur.com/hxJjUQB>

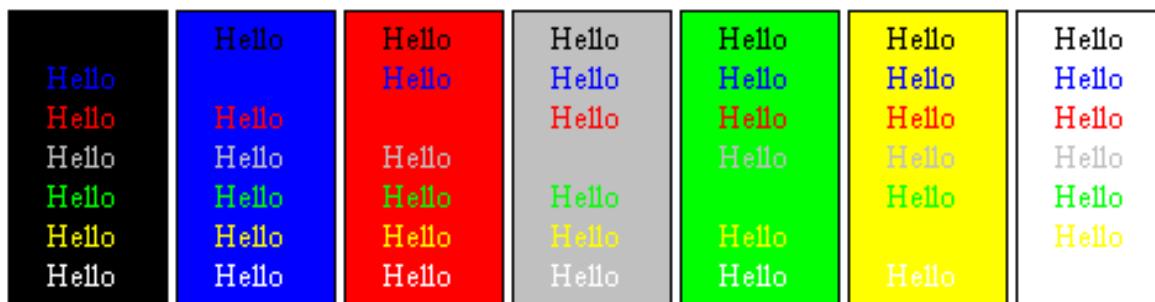
https://en.wikipedia.org/wiki/The_dress

Interaction with the background

Contrast
The difference
between foreground
and background colors
determines text
legibility.

Showing small blue text on a black background is a bad idea.
There is insufficient luminance contrast.

Showing small yellow text on a white background is a bad idea.
There is insufficient luminance contrast.



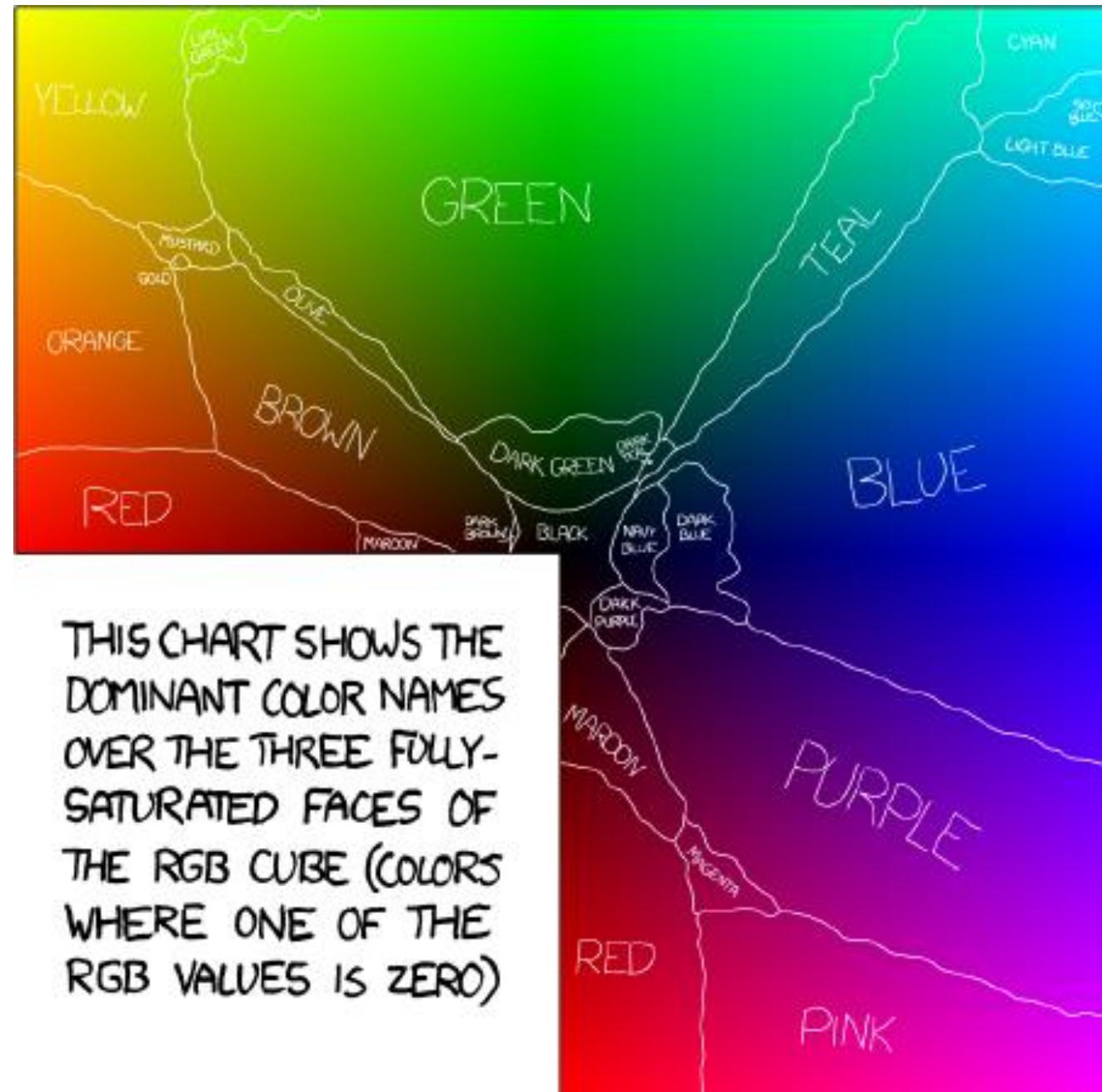
Bezold Effect: Outlines matter



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Which color is it?

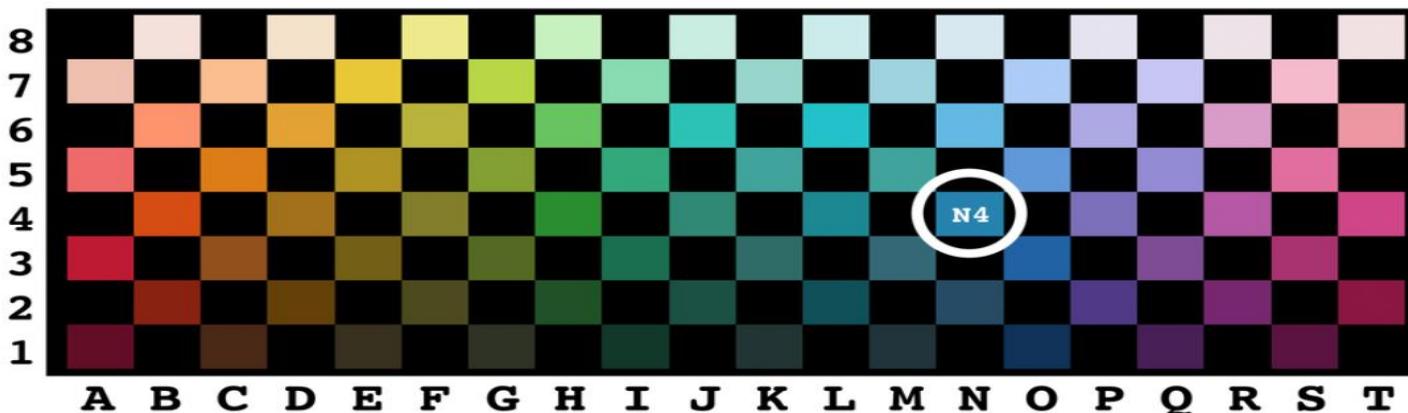
- Survey of 1.5 million people



Color depends on language

English has 11 words that everyone knows, the Papua-New Guinean language Berinmo has only five, and the Bolivian Amazonian language Tsimane' has only three words that everyone knows, corresponding to black, white and red.

<https://www.smithsonianmag.com/science-nature/why-different-languages-name-different-colors-180964945/>



Participants had to communicate one of the 80 color chip choices from across the color grid. Richard Futrell and Edward Gibson, CC BY

English



Spanish

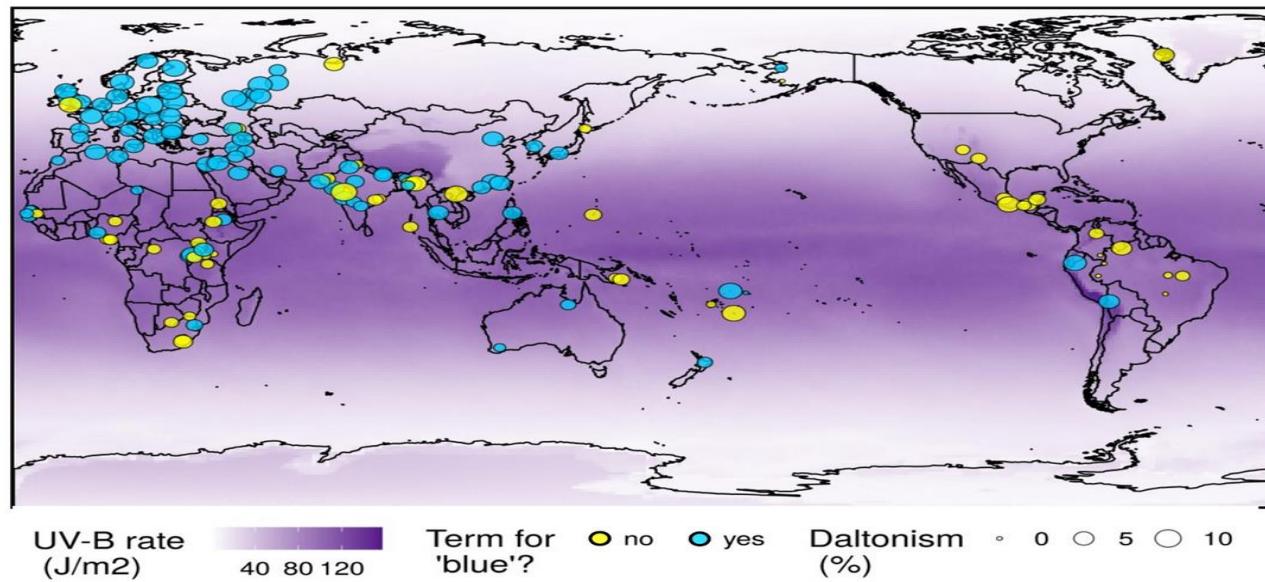


Tsimane'

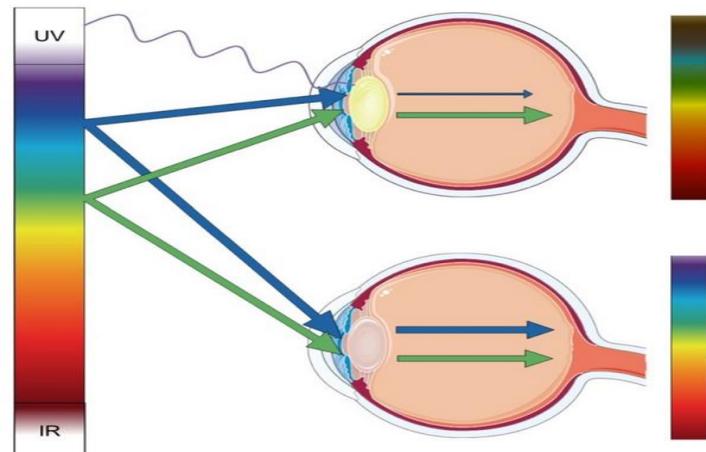


<https://news.mit.edu/2017/analyzing-language-color-0918>

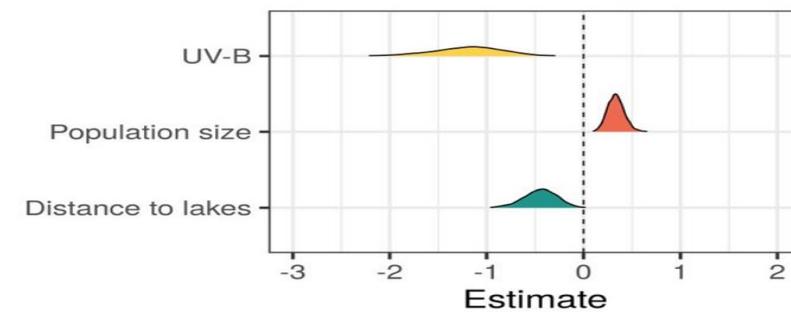
A Map of the populations



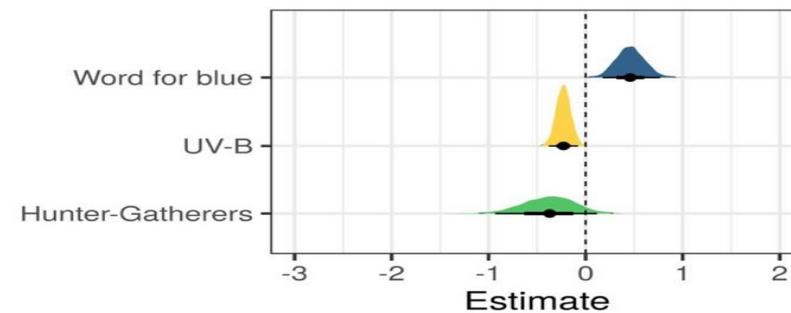
D Lens brunescence



B Predictors for blue



C Predictors for daltonism



Josserand, M., Meeussen, E., Majid, A. et al. Environment and culture shape both the colour lexicon and the genetics of colour perception. *Sci Rep* **11**, 19095 (2021). <https://www.nature.com/articles/s41598-021-98550-3>

Meaning of colors across cultures



	Western/ American	Japanese	Hindu	Native American	Chinese	Asian	Eastern European	Muslim	African	South American
Anger	Red	Red	Black				Red		Red	
Art / Creativity			Blue							
Authority	Black									
Bad Luck		Black								
Balance		Orange		Black		Green				
Beauty	Purple									
Calm										
Celebration		Purple			Black					
Children	Pink	Pink				White				
Cold	Blue	Blue	Blue							
Compassion			Green							
Courage	Red	Yellow	Orange				Red			
Cowardice	Yellow	Yellow								
Cruelty	Purple									
Danger	Red	Red		Yellow					Red	
Death	Black	Black	White	Black	White		Blue		Green	
Decadence	Purple	Purple								
Deceit		Yellow								
Desire	Red	Red	Orange							
Earthy	Brown					Brown				
Energy	Yellow	Orange	Red							

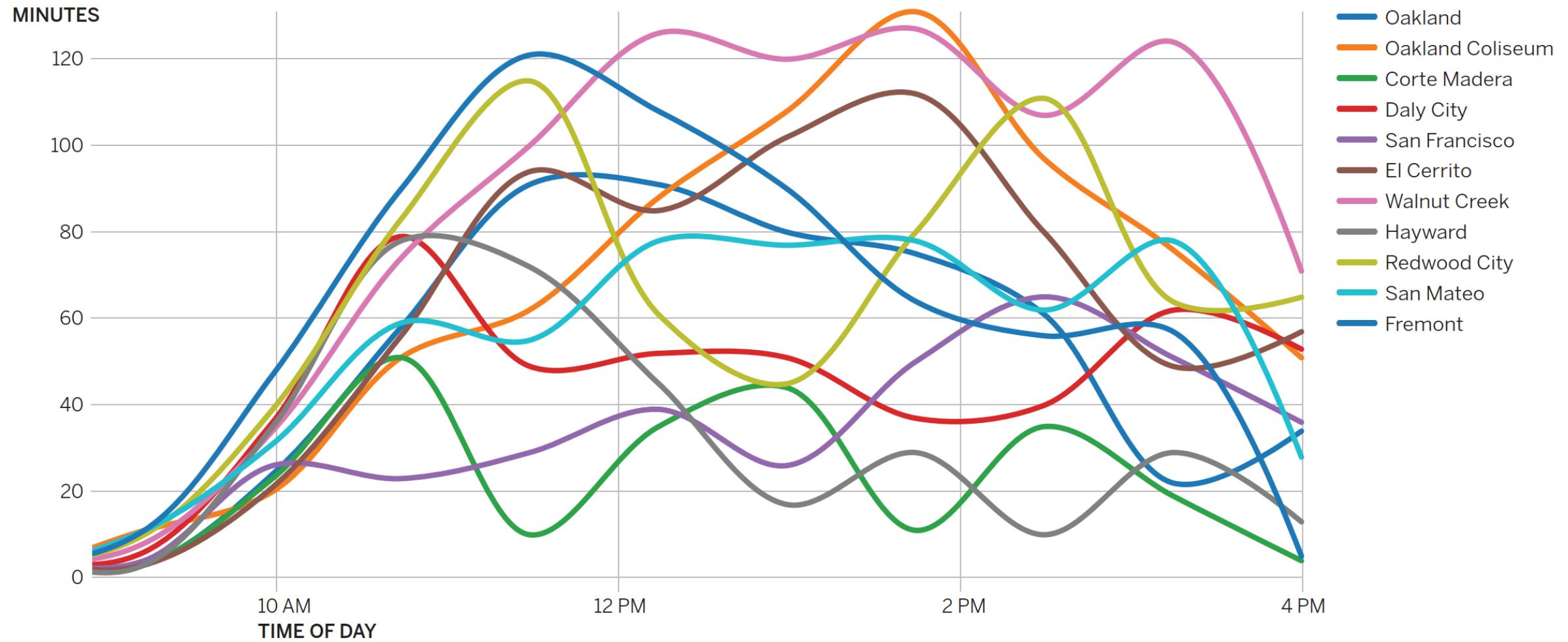
Colors in logo **COLOR** EMOTION GUIDE



6 Guidelines for using Color

1. Use less.
2. Use gray.
3. Complement or contrast.
4. Stick to the variables.
5. Think how, not which.
6. Bonus: Consider the color blind.

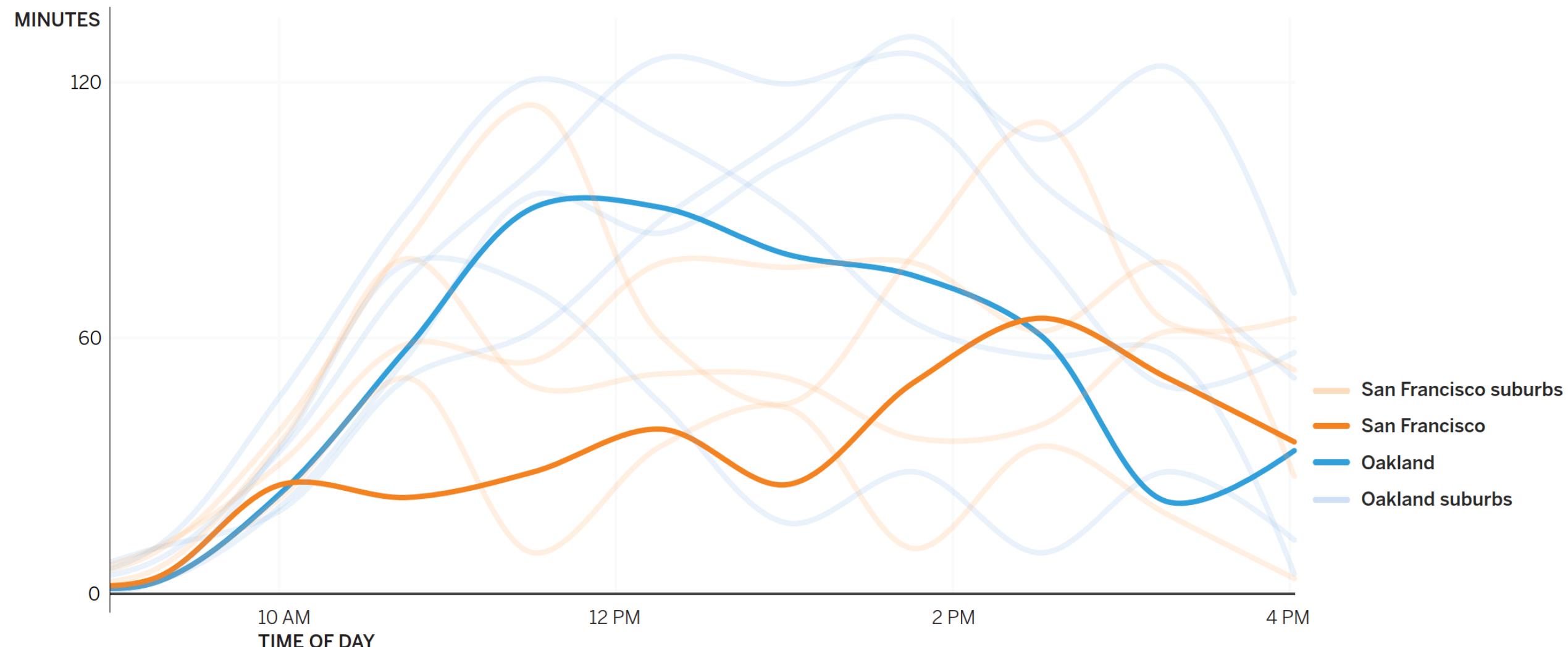
DMV NON-APPOINTMENT WAIT TIMES: SAN FRANCISCO VERSUS OAKLAND AREA



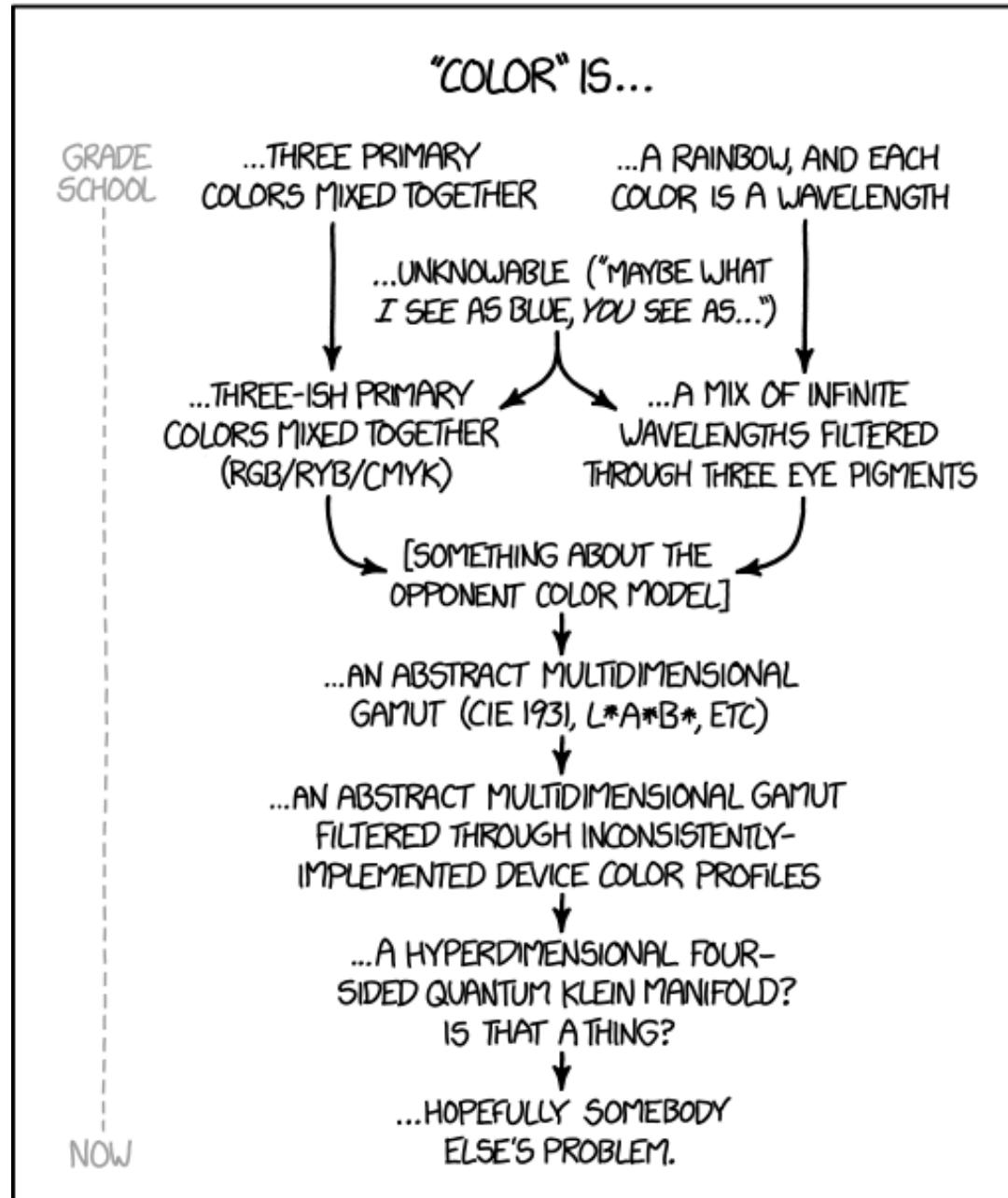
DMV = “Department of Motor Vehicles.”

Good Charts Workbook, Tips and Tools and Exercises – Scott Berinato

DMV NON-APPOINTMENT WAIT TIMES: TRY SAN FRANCISCO AT LUNCH, OAKLAND LATER



EVOLUTION OF MY UNDERSTANDING OF COLOR OVER TIME:



RGB is how displays perceive the world.

CMYK is how printers perceive the world.

Lab is how humans perceive the world.

“It’s no use going back to yesterday, because I was a different person then.”
(Alice in Wonderland)

Data Visualization Design

Dr. Claudius Zelenka

Kiel University

cze@informatik.uni-kiel.de

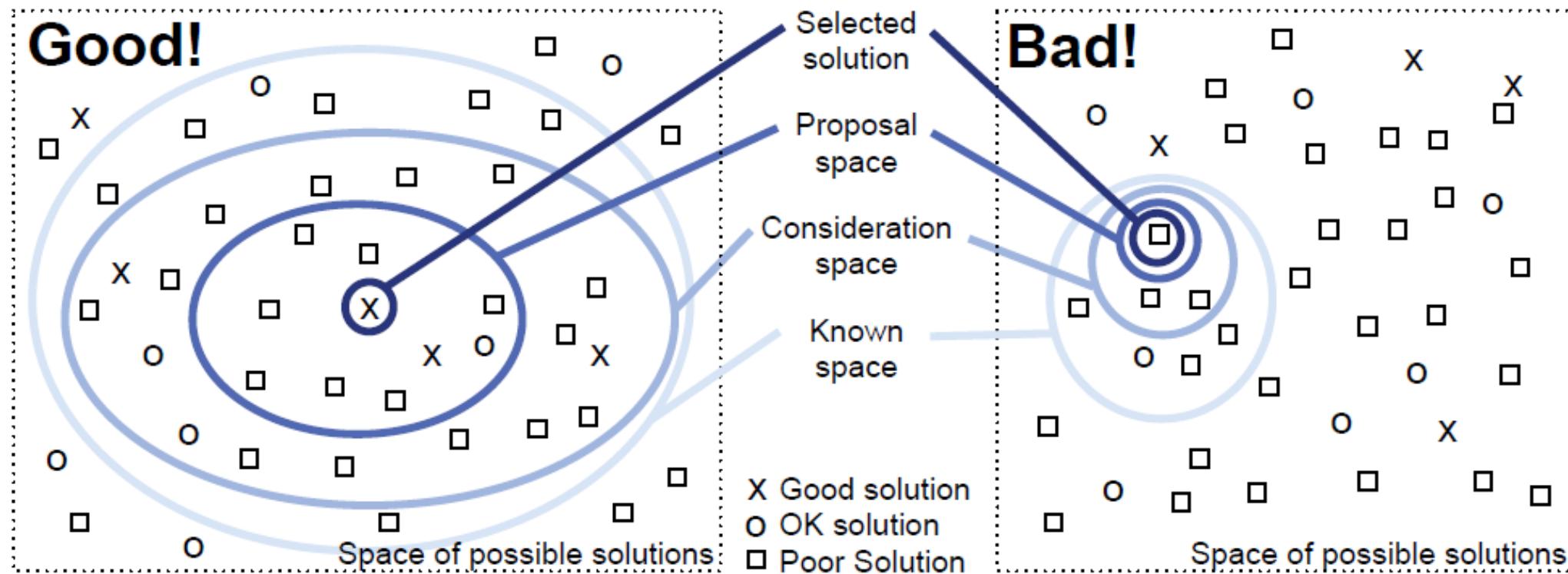
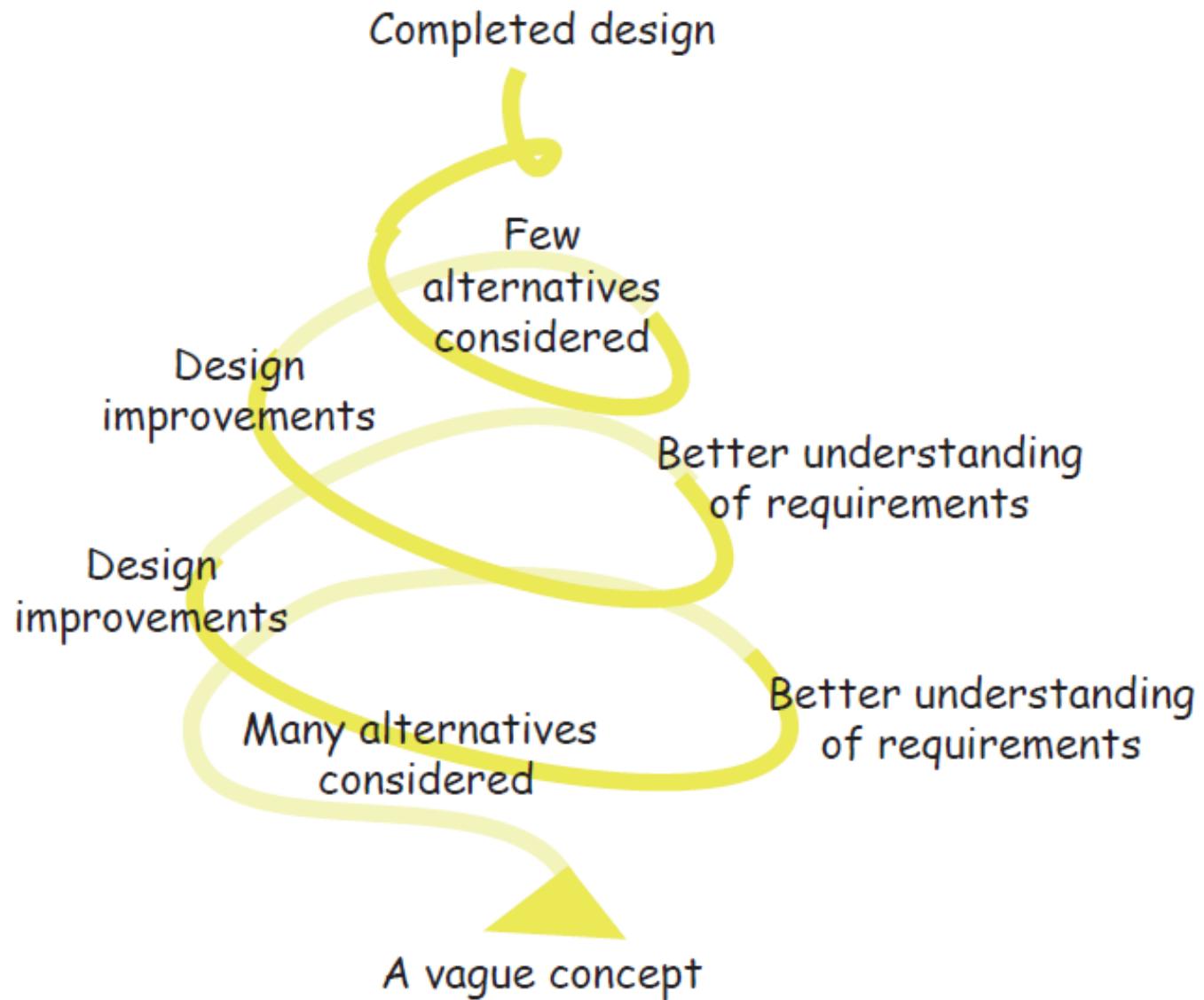


Figure 1.5. A search space metaphor for vis design.



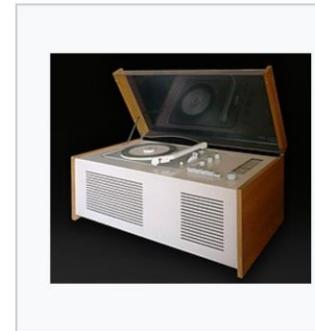
Disclaimer

- ‘I say begin by learning about data visualisation’s “black and whites”, the rules, then start looking for the greys. It really then becomes quite a personal journey of developing your conviction.’ - Jorge Camoes, Data Visualization Consultant
- ‘My key guiding principle? Know the rules, before you break them.’ - Gregor Aisch, Graphics Editor, The New York Times

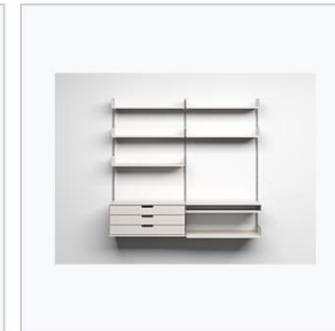
Dieter Rams (Mr. Braun)

Principles of good design:

1. Good design is innovative.
2. Good design makes a product useful.
3. Good design is aesthetic.
4. Good design makes a product understandable.
5. Good design is unobtrusive.
6. Good design is honest.
7. Good design is long lasting.
8. Good design is thorough down to the last detail.
9. Good design is environmentally friendly.
10. Good design is as little design as possible.



SK 61^[4]



Regalsystem 606, 1960

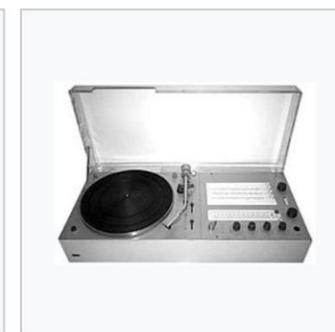


Tonarmwaage, 1962



T 1000, 1963

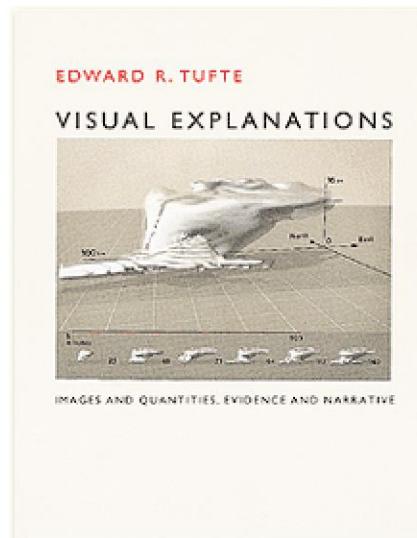
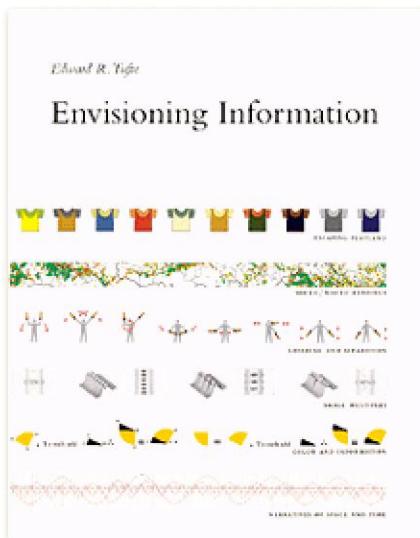
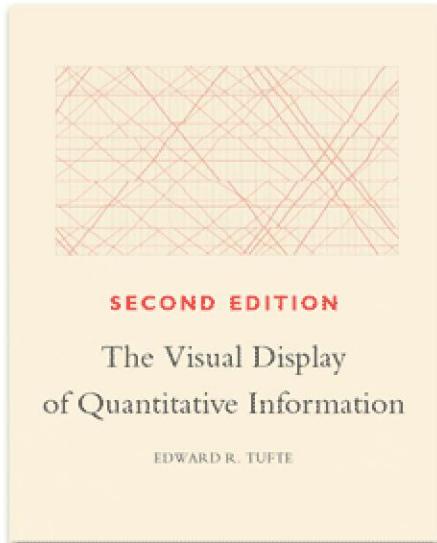
T 1000 CD, 1968



audio 310, 1971

Tufte's design principles for graphical excellence

- Edward Tuft



Edward Tuft

1. Practice: Graphical Integrity

2. Theory: Graphical Excellence

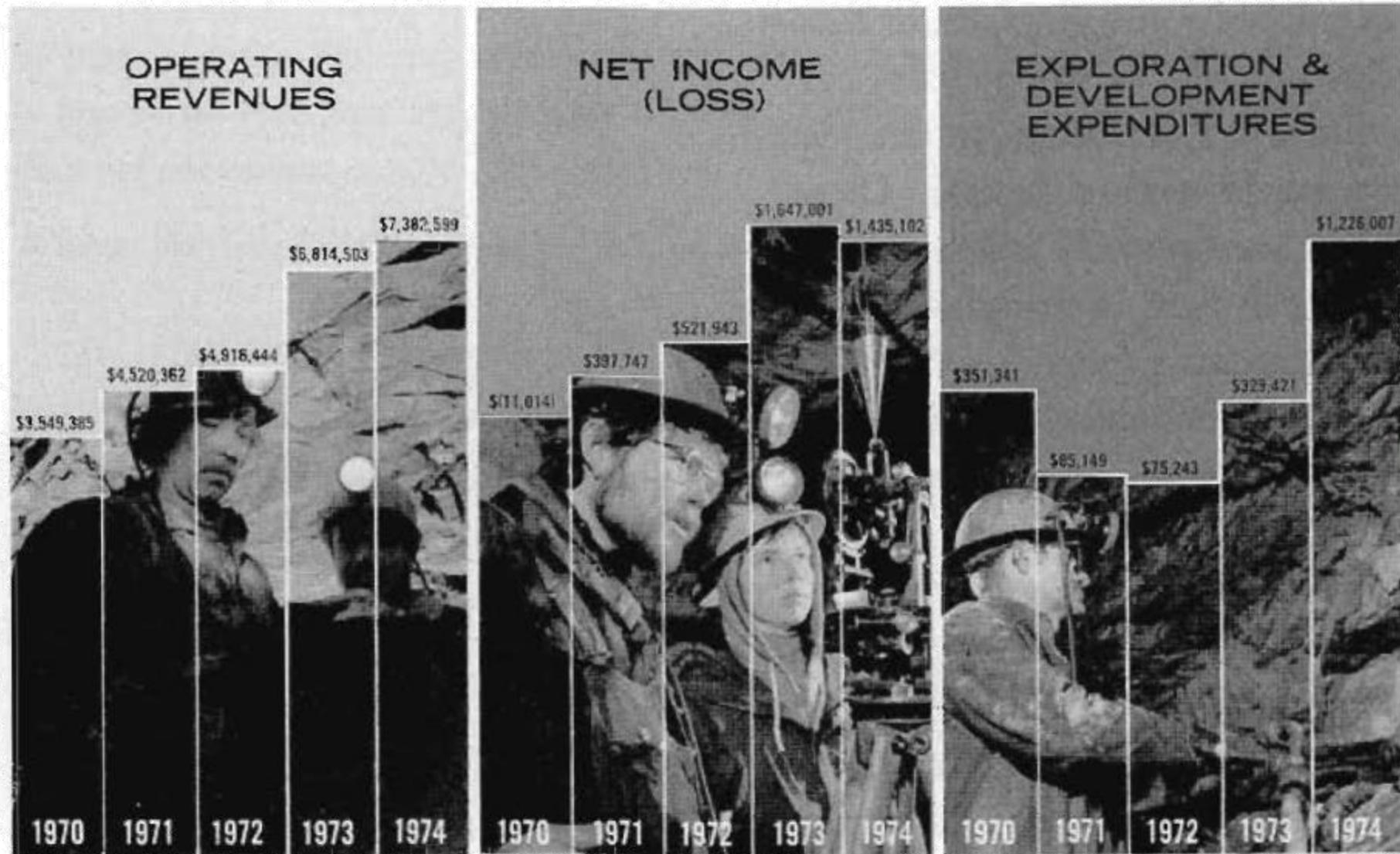
And how to achieve them with:

3. Design Principles for Data Graphics

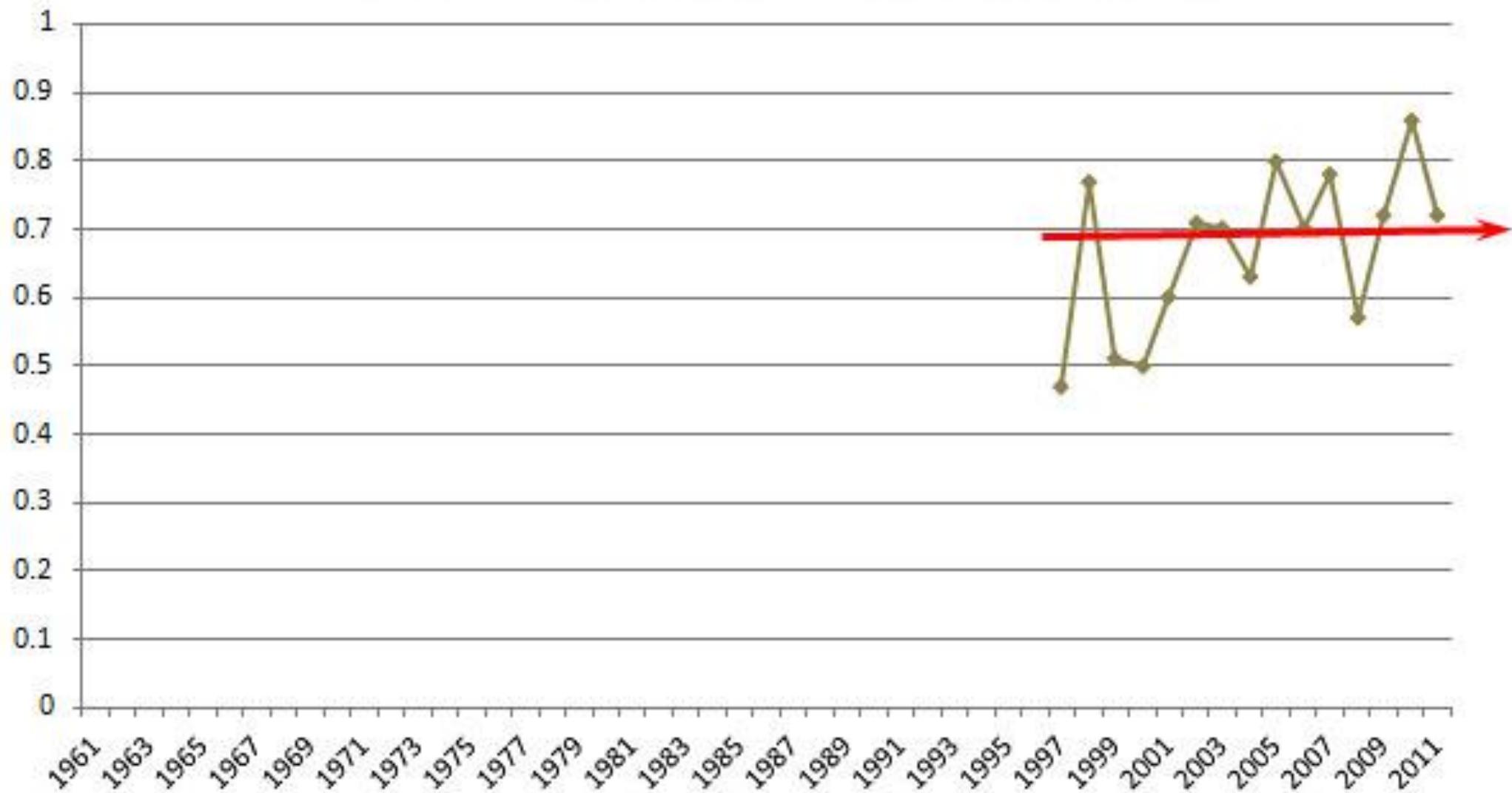
1. Graphical Integrity

Visual representations of data must tell the truth.

Missing scales

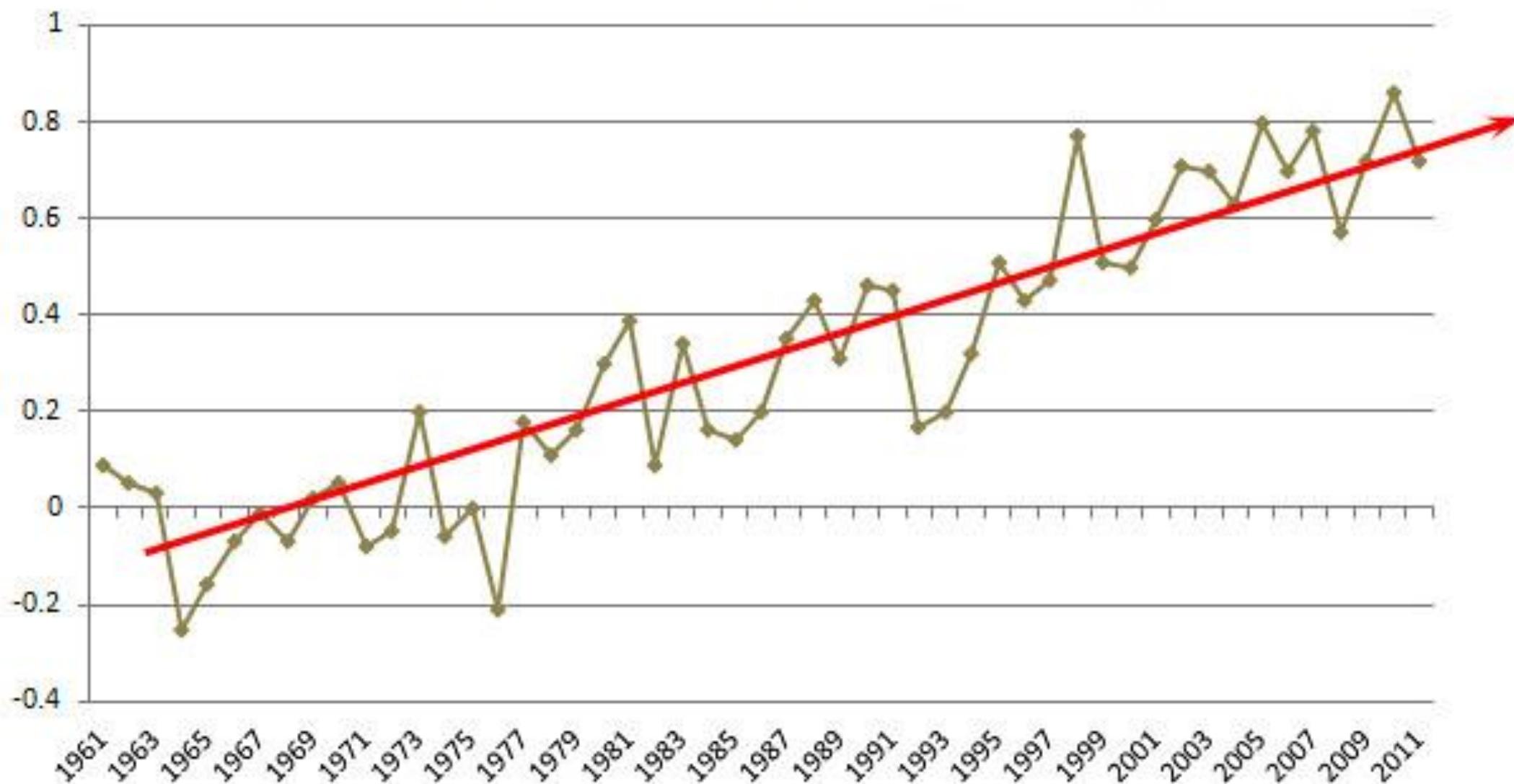


Temperature Anomaly -- Annual Mean (°C)

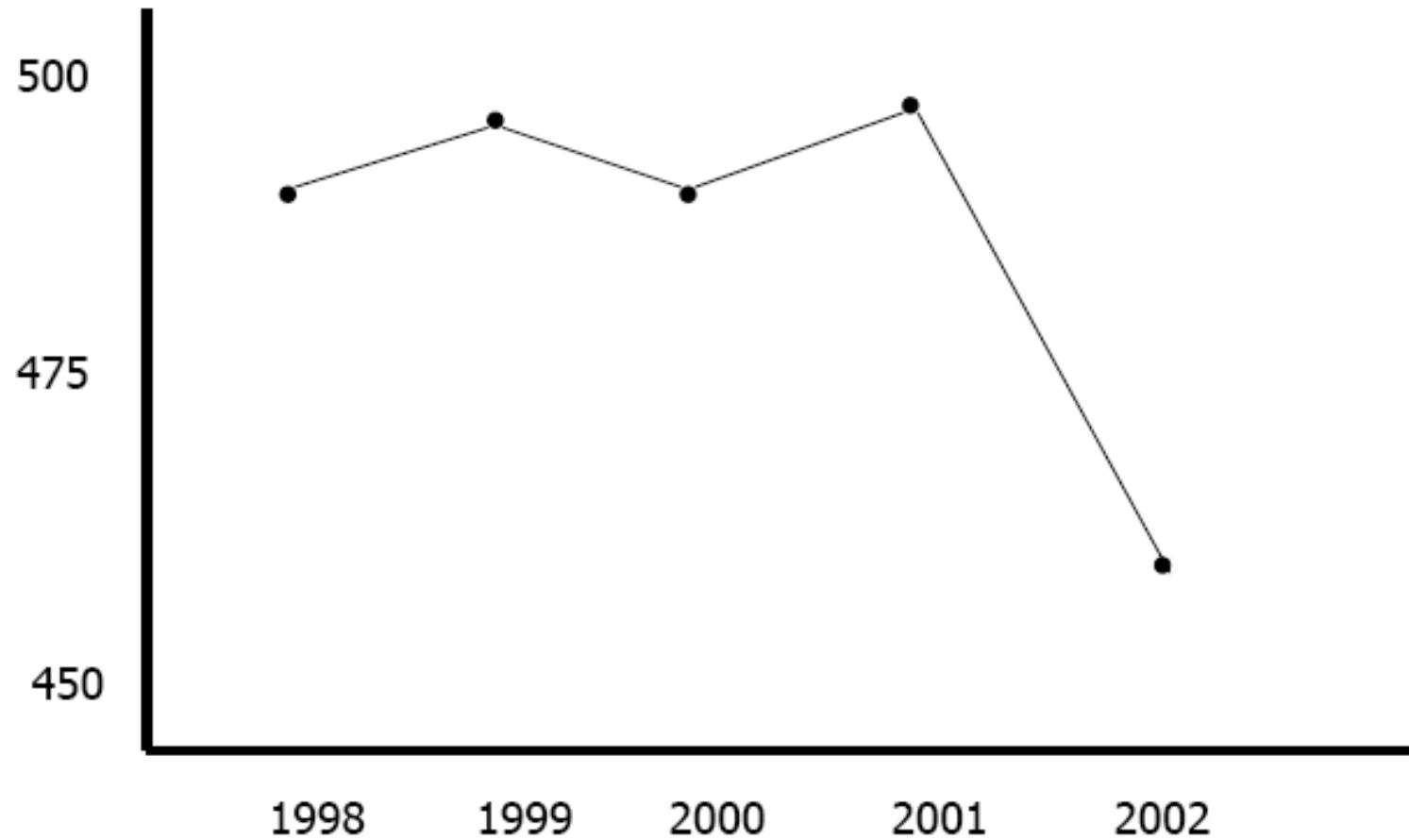


<https://www.motherjones.com/kevin-drum/2012/01/lying-charts-global-warming-edition/>

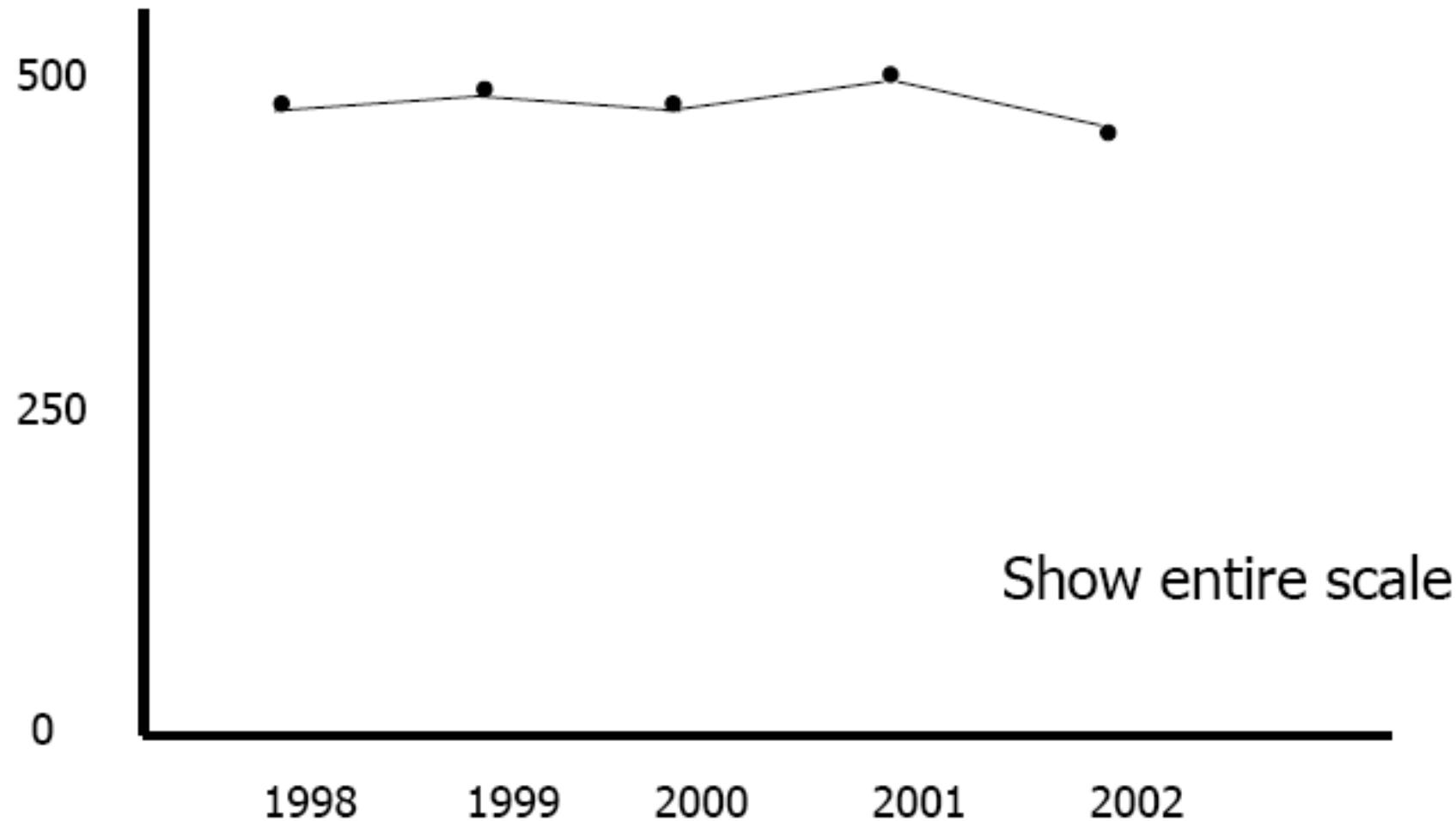
Temperature Anomaly -- Annual Mean ($^{\circ}\text{C}$)



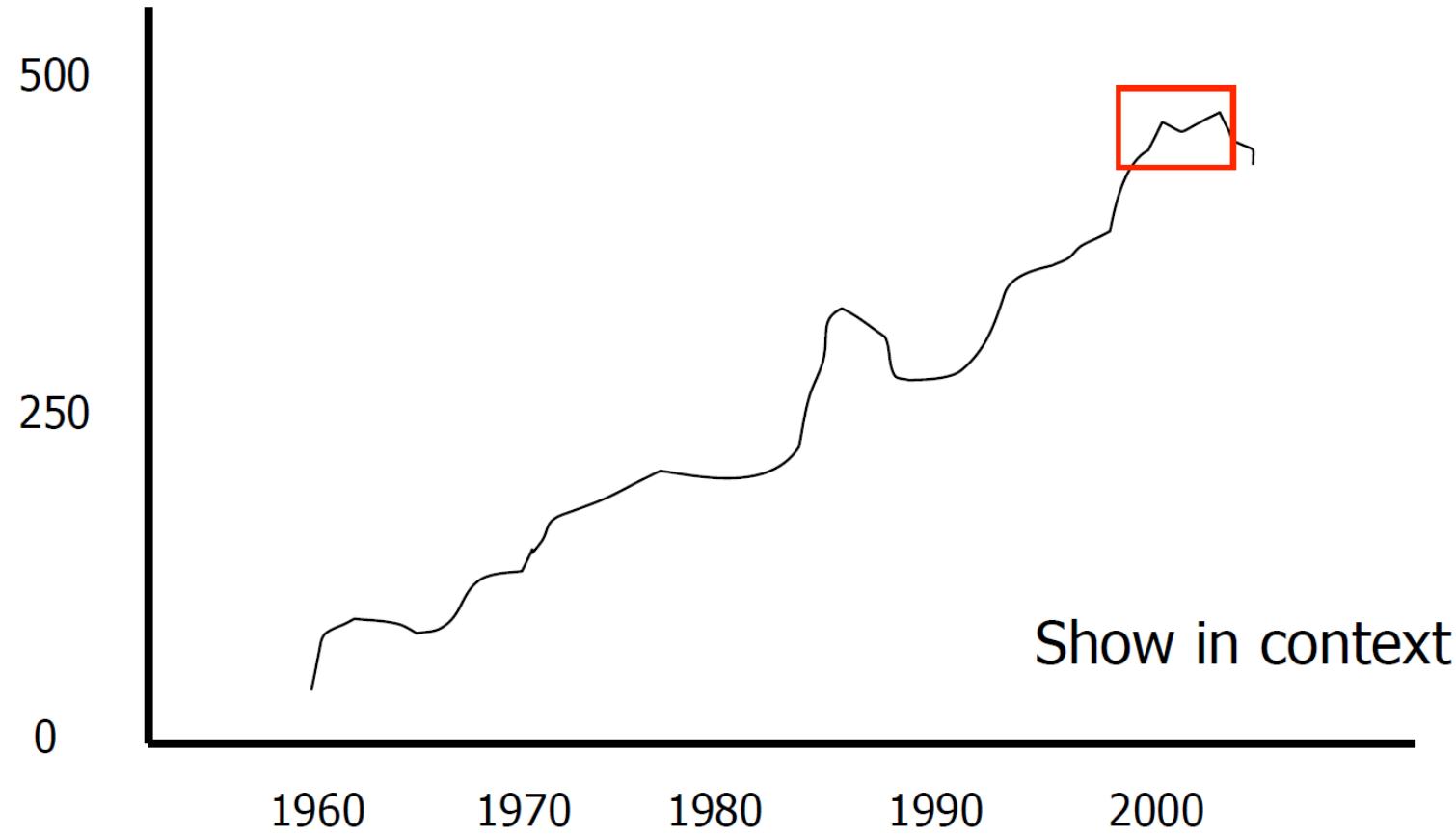
Distortion – Stock market crash?



Distortion

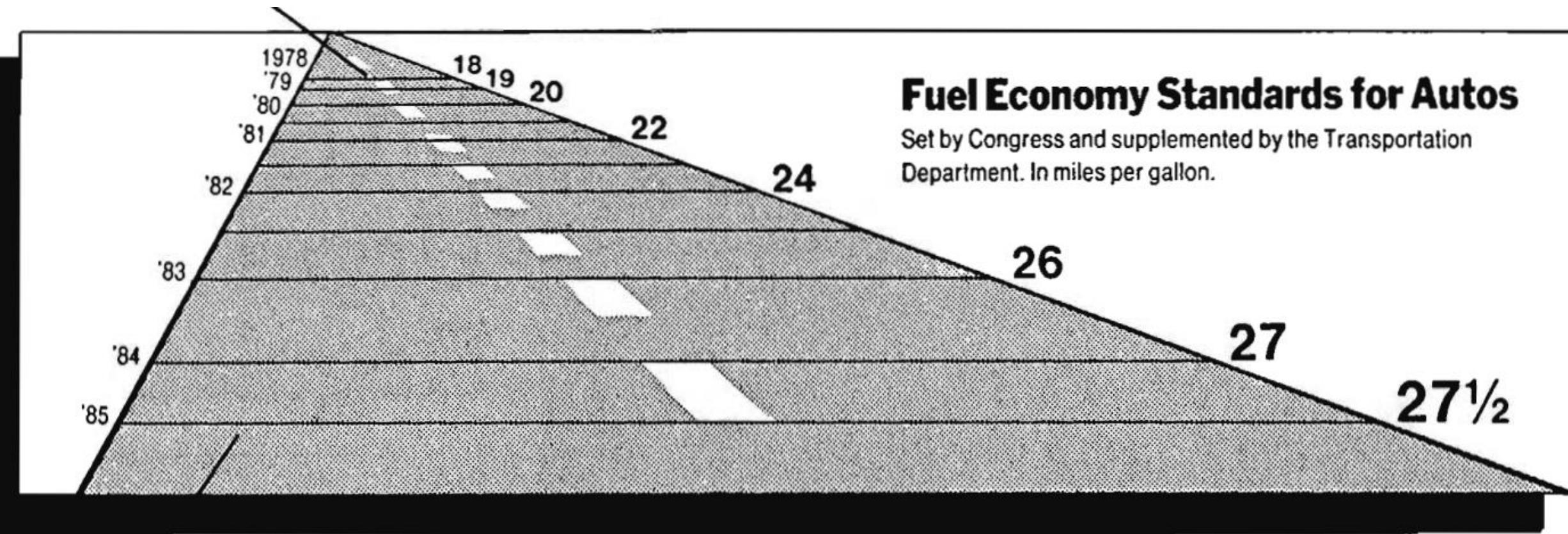


Distortion

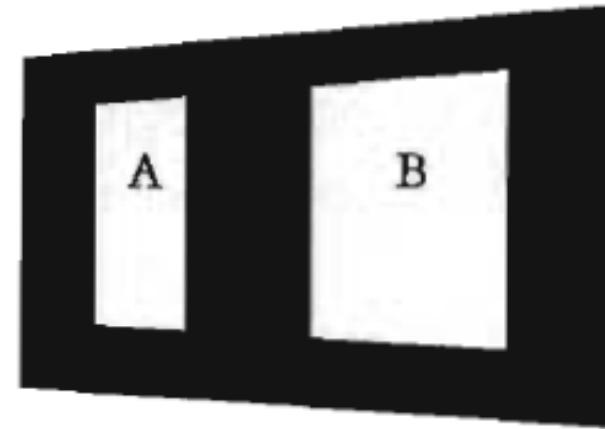


Context is essential for graphical integrity

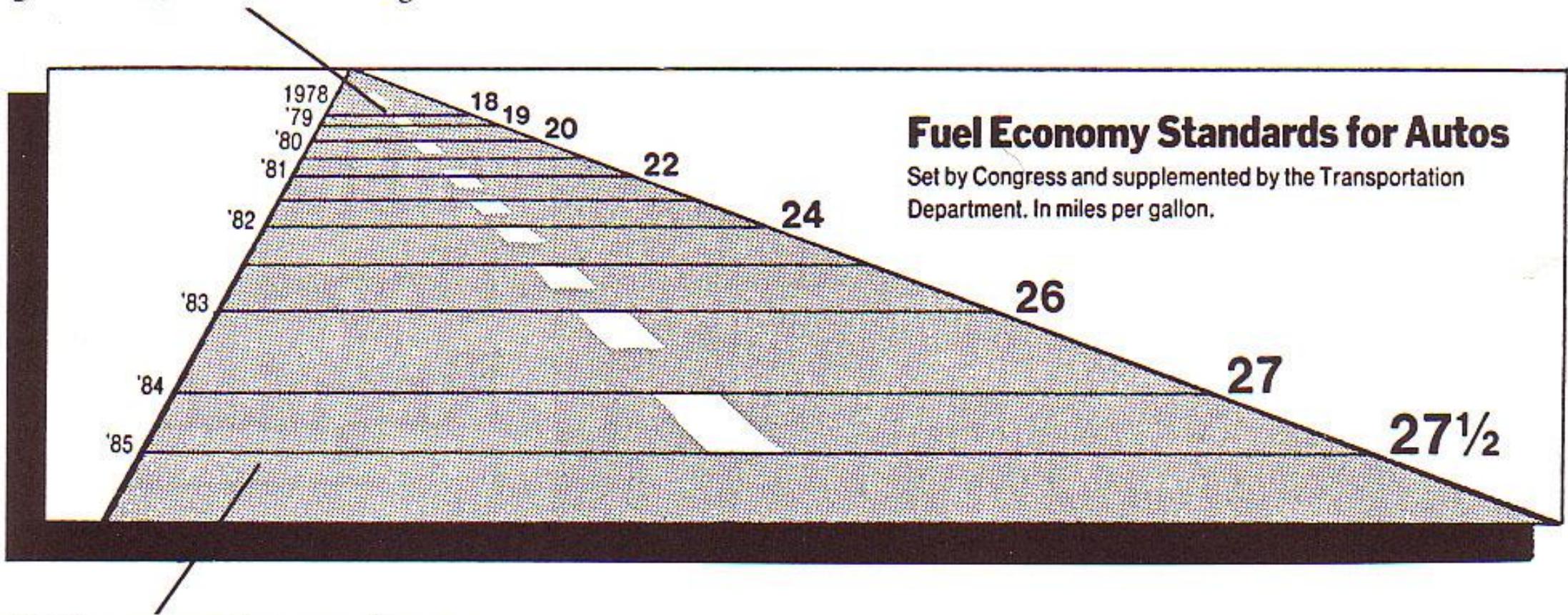
Lie Factor



I think I see that area B
is 3.14 times bigger than
area A. Is that correct?



This line, representing 18 miles per gallon in 1978, is 0.6 inches long.



This line, representing 27.5 miles per gallon in 1985, is 5.3 inches long.

Fuel Economy Standards for Autos

Set by Congress and supplemented by the Transportation Department. In miles per gallon.

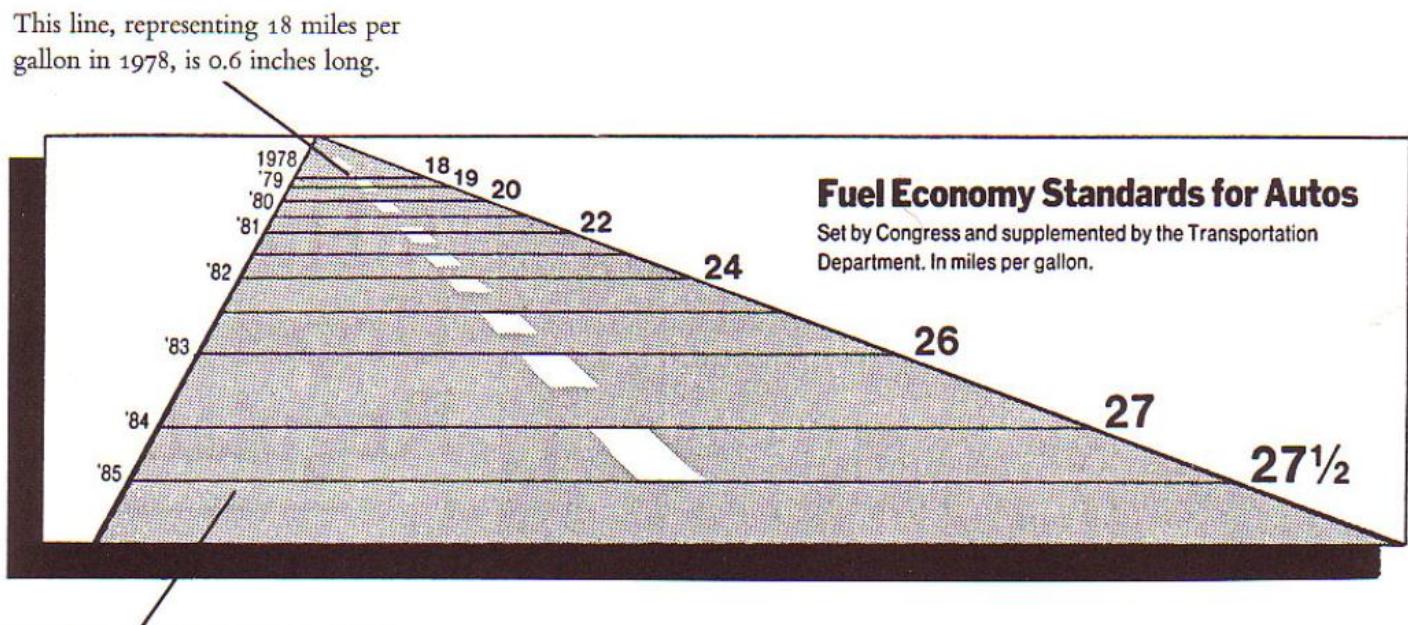
Lie Factor

$$\text{Lie Factor} = \frac{\text{Size of effect shown in graphic}}{\text{Size of effect in data}}$$

$$|\text{graph}| = (5.3 - 0.6) / 0.6 \\ = 783\%$$

$$|\text{data}| = (27.5 - 18) / 18 \\ = 53\%$$

$$\text{Lie Factor} = 783 / 53 \\ = 14.8$$



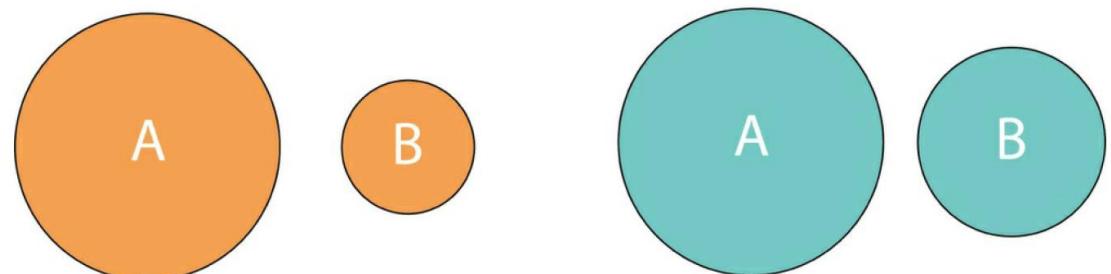
1. Graphical Integrity

- I. Clear, detailed, and thorough labeling should be used to defeat graphical distortion and ambiguity.
- II. The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented.

Figure 6.60 Illustrating the correct and incorrect circle size encoding

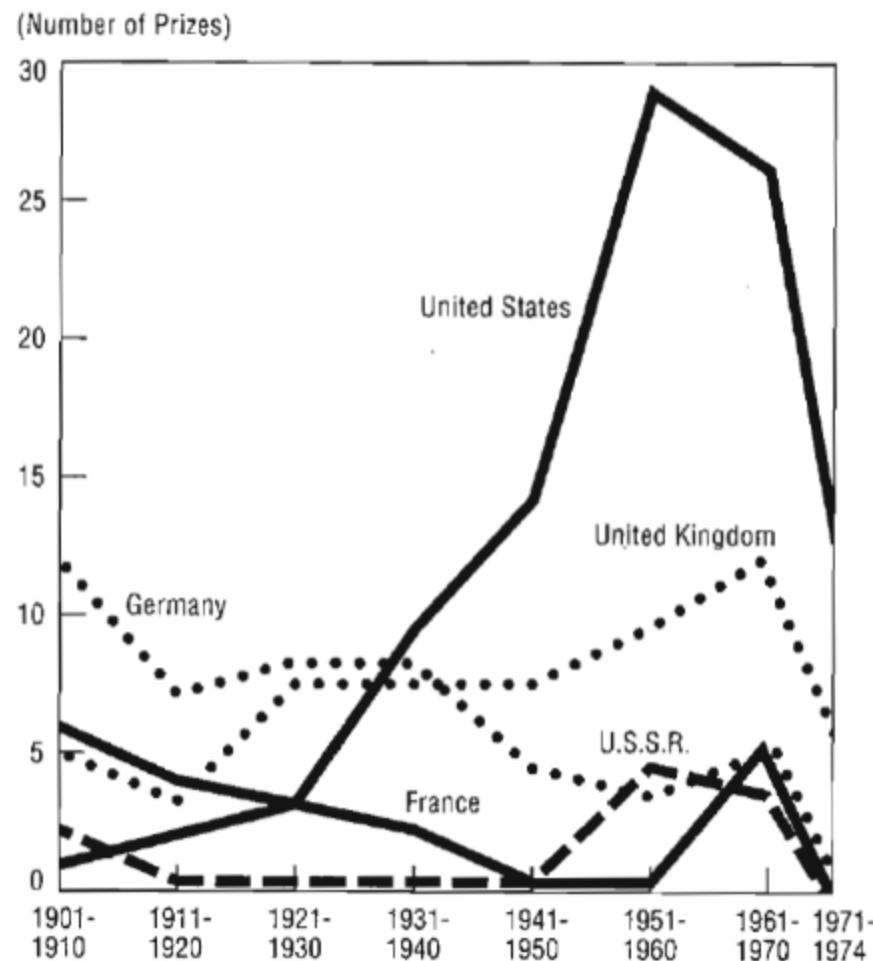
Variation in diameter

Variation in area

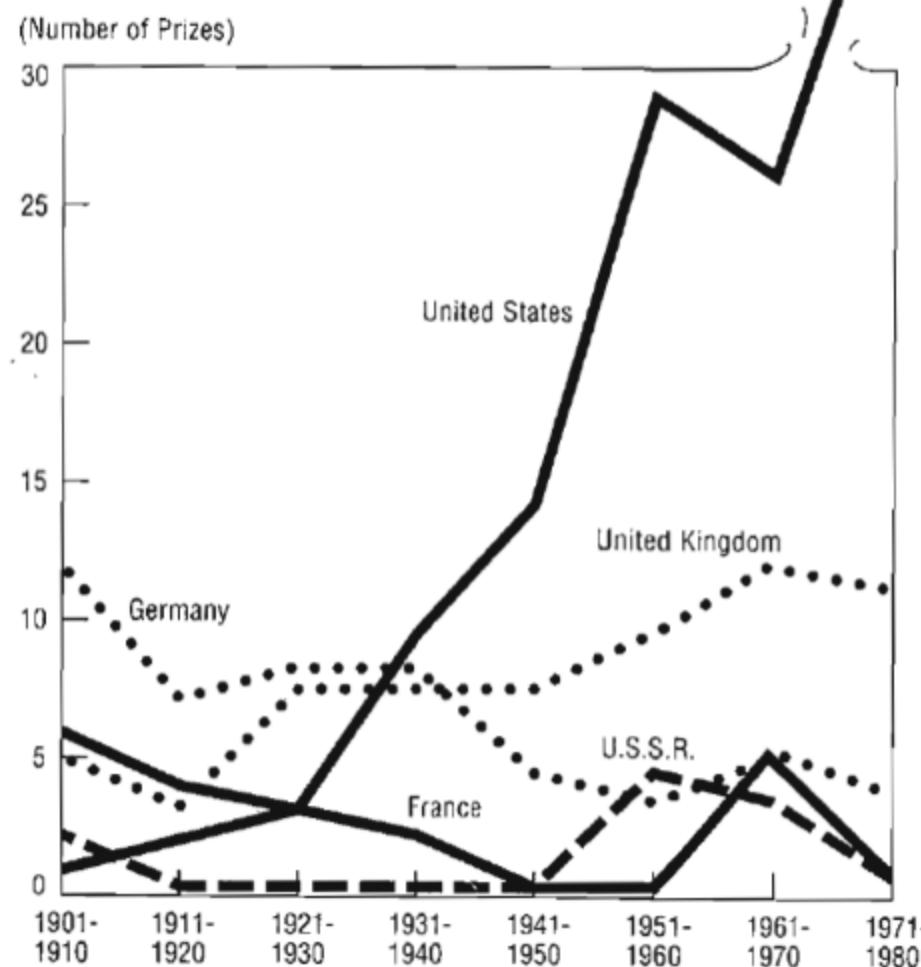


Design Variation

Nobel Prizes Awarded in Science,
for Selected Countries, 1901-1974

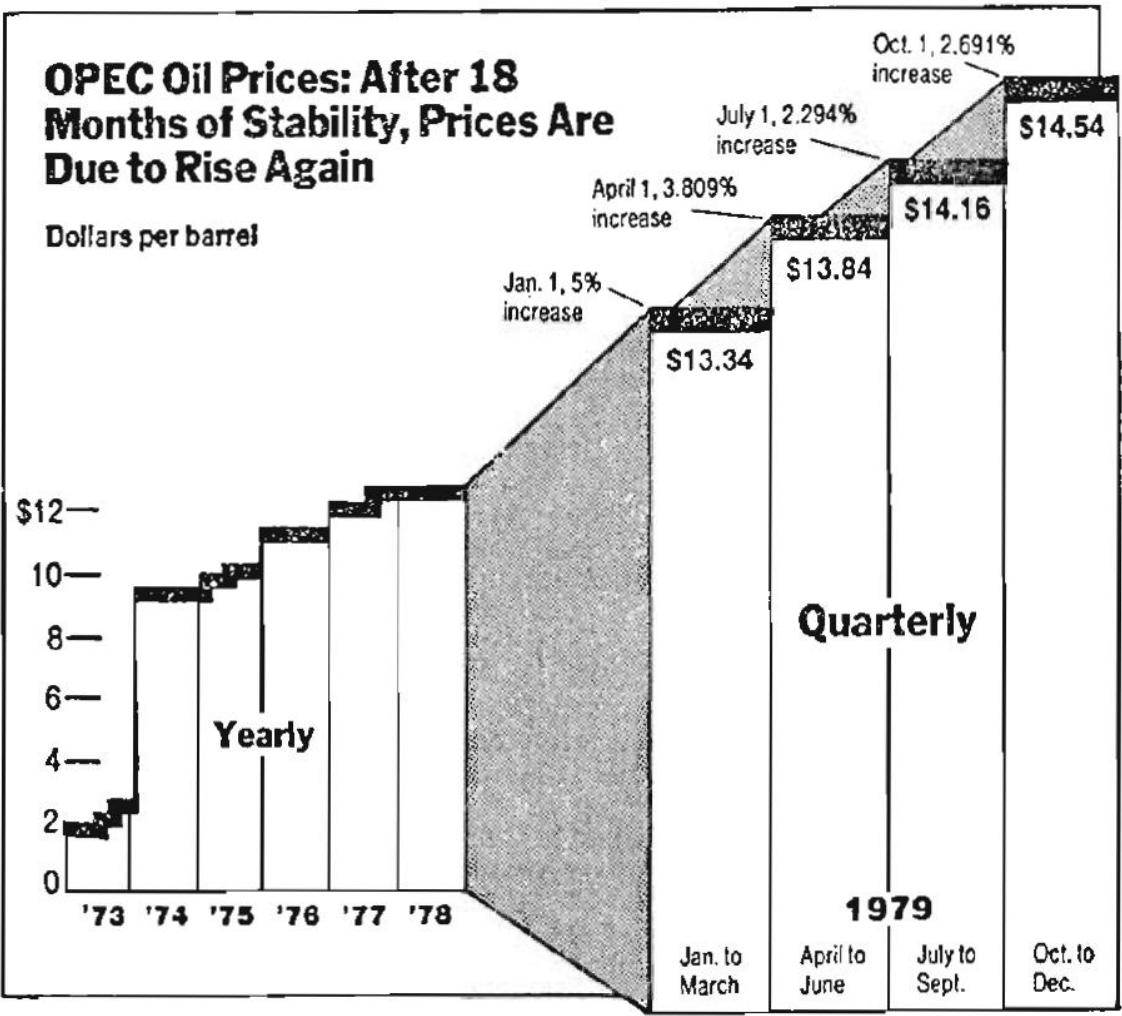


Nobel Prizes Awarded in Science,
for Selected Countries, 1901-1980



OPEC Oil Prices: After 18 Months of Stability, Prices Are Due to Rise Again

Dollars per barrel



The New York Times / Dec. 19, 1978

Five different vertical scales show the price:

<u>During this time</u>	<u>one vertical inch equals</u>
1973-1978	\$8.00
January-March 1979	\$4.73
April-June 1979	\$4.37
July-September 1979	\$4.16
October-December 1979	\$3.92

And two different horizontal scales show the passage of time:

<u>During this time</u>	<u>one horizontal inch equals</u>
1973-1978	3.8 years
1979	0.57 years

As the two scales shift simultaneously, the distortion takes on multiplicative force. On the left of the graph, a price of \$10 for one year is represented by 0.31 square inches; on the right side, by 4.69 square inches. Thus exactly the same quantity is $4.69/0.31 = 15.1$ times larger depending upon where it happens to fall on the surface of the graphic. That is design variation.

1. Graphical Integrity

- I. Clear, detailed, and thorough labeling should be used to defeat graphical distortion and ambiguity.
- II. The representation of numbers, as physically measured on the surface of the graphic itself, should be directly proportional to the numerical quantities represented.
- III. Show data variation, not design variation.

Edward Tuft

1. Graphical Integrity

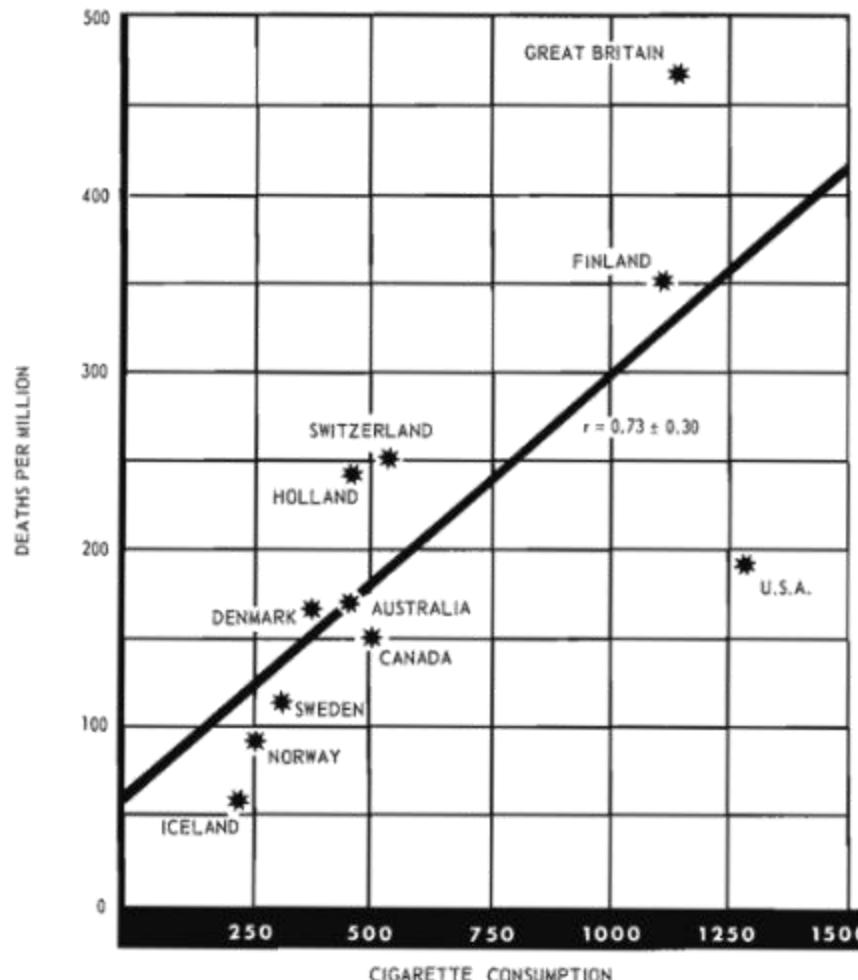
2. Graphical Excellence

And how to achieve them with:

3. Design Principles for Data Graphics

2. Graphical Excellence

CRUDE MALE DEATH RATE FOR LUNG CANCER
IN 1950 AND PER CAPITA CONSUMPTION OF
CIGARETTES IN 1930 IN VARIOUS COUNTRIES.

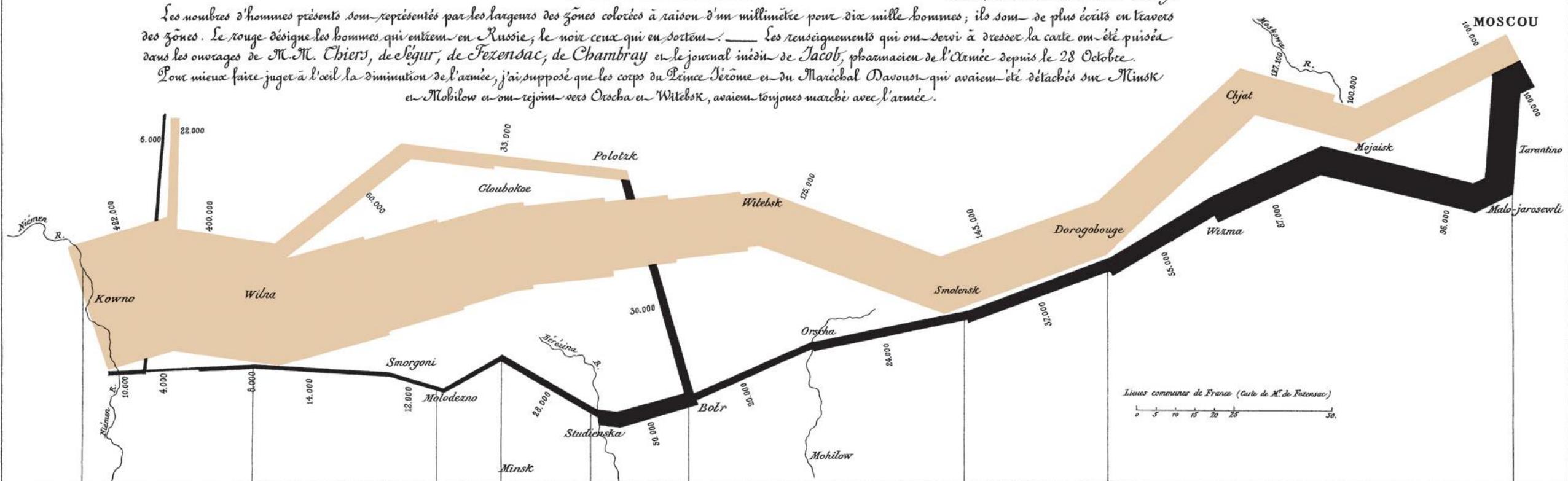


Report of the Advisory Committee to
the Surgeon General, *Smoking and Health*
(Washington, D.C., 1964), p. 176; based
on R. Doll, "Etiology of Lung Cancer,"
Advances in Cancer Research, 3 (1955),
1-50.

Carte Figurative des pertes successives en hommes de l'Armée Française dans la Campagne de Russie 1812-1813.
 Dressée par M. Minard, Inspecteur Général des Ponts et Chaussées en retraite
 Paris, le 20 Novembre 1869.

Les nombres d'hommes présents sont représentés par les largeurs des zones colorées à raison d'un millimètre pour dix mille hommes; ils sont de plus écrits en travers des zones. Le rouge désigne les hommes qui entrent en Russie, le noir ceux qui en sortent. — Les renseignements qui ont servi à dresser la carte ont été puisés dans les ouvrages de M. M. Chiers, de Séguir, de Fezensac, de Chambray et le journal inédit de Jacob, pharmacien de l'Armée depuis le 28 Octobre.

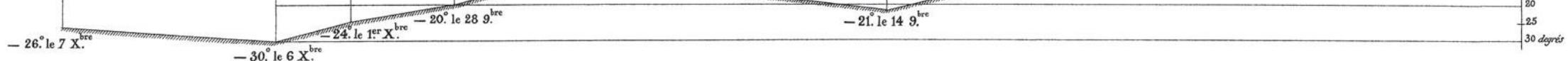
Pour mieux faire juger à l'œil la diminution de l'armée, j'ai supposé que les corps du Prince Jérôme et du Maréchal Davout qui avaient été détachés sur Minsk en Mohilow et se rejoignaient vers Orscha en Wilebsk, avaient toujours marché avec l'armée.



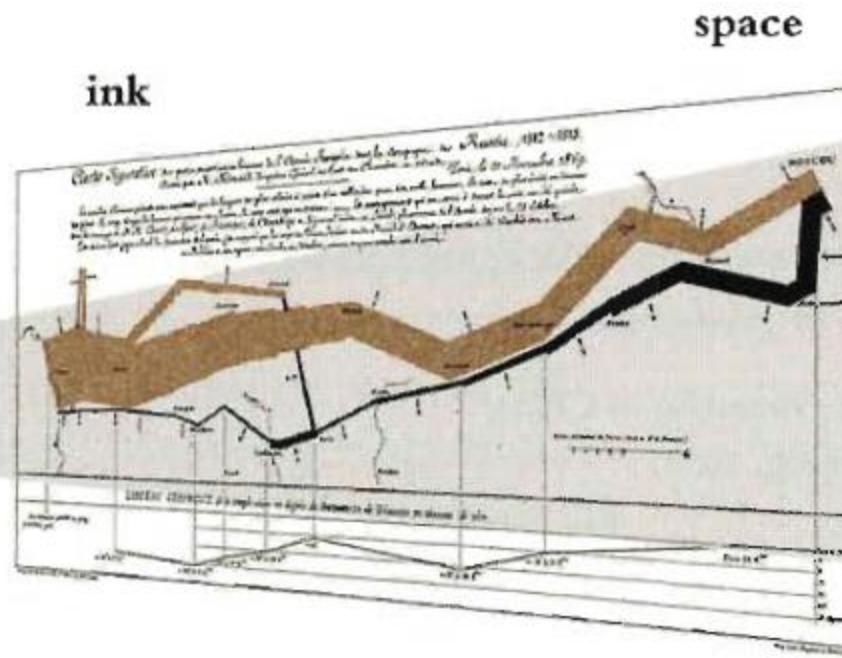
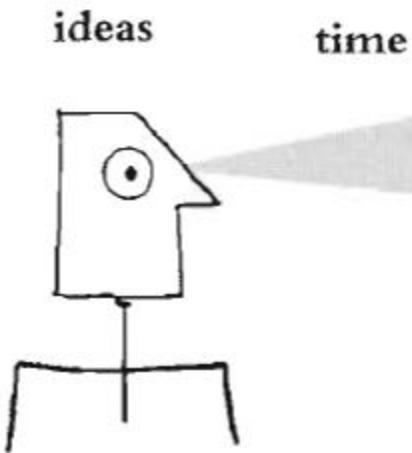
Lieux communs de France (Carte de M. de Fezensac)

TABLEAU CRAPHIQUE de la température en degrés du thermomètre de Réaumur au dessous de zéro.

Les Cosaques passent au galop
le Niemen gelé.



Ideas



2. Tufte Principles of Graphical Excellence

- I. *Graphical excellence* is the well-designed presentation of interesting data -- a matter of substance, of statistics, and of design.
- II. *Graphical excellence* consists of complex ideas communicated with clarity, precision, and efficiency.
- III. *Graphical excellence* is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space.
- IV. *Graphical excellence* is nearly always multivariate.
- V. *Graphical excellence* requires telling the truth about the data.

Edward Tuft

1. Graphical Integrity

2. Graphical Excellence

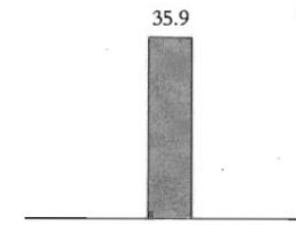
And how to achieve them with:

3. Design Principles for Data Graphics

3. Tuftes design principles

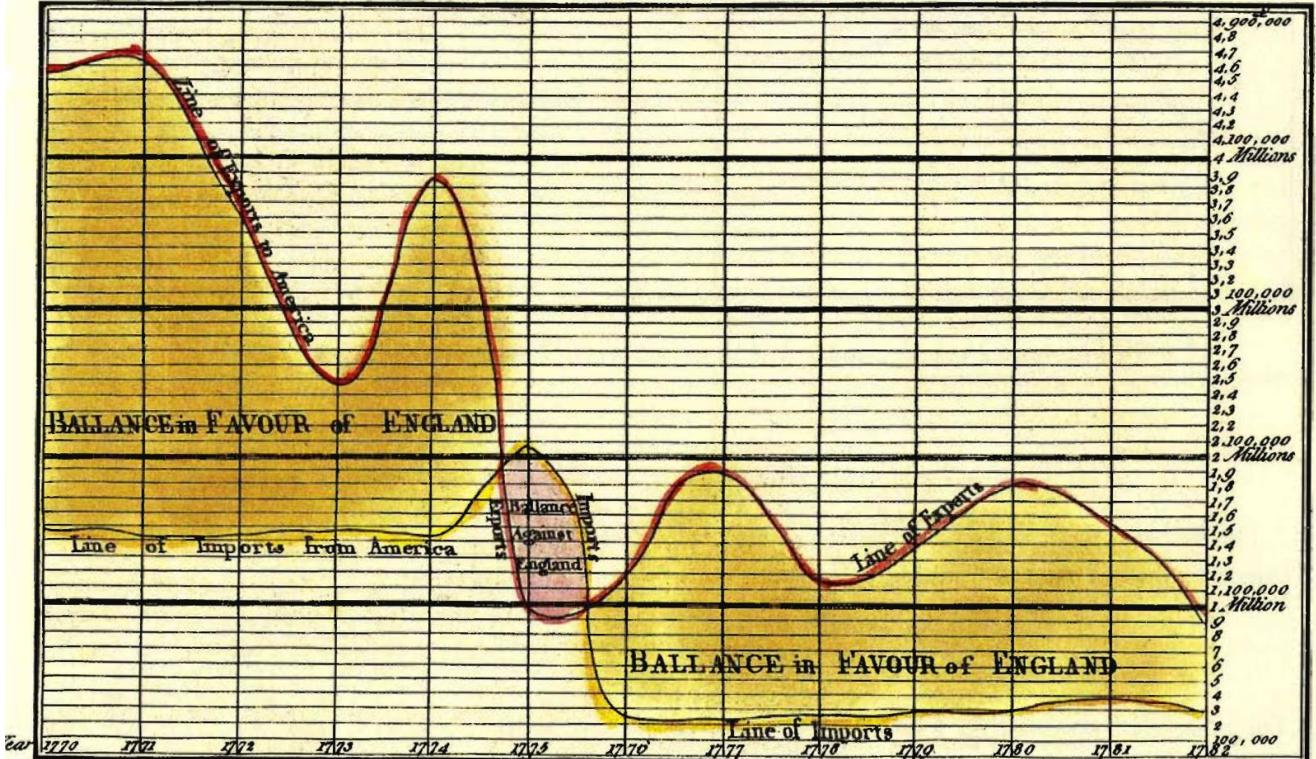
Fundamental principle of statistical graphics, patterns of good design.

- Above all else show the data
- Maximize the share of data ink, within reason
- Erase non data ink (chart junk), within reason
- Erase redundant data ink, within reason
- Revise and edit



Redundant encoding

*CHART of IMPORTS and EXPORTS of ENGLAND to and from all NORTH AMERICA
From the Year 1770 to 1782 by W. Playfair*



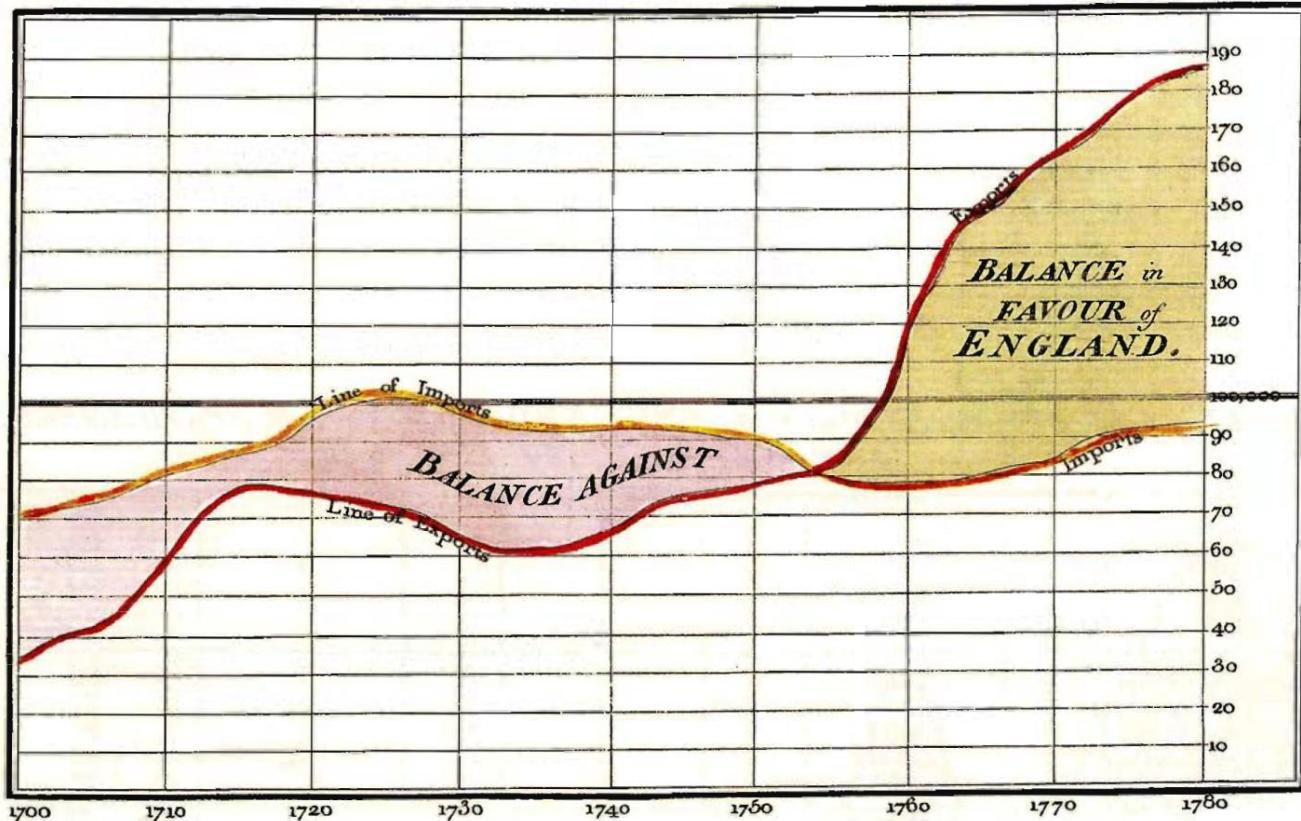
The Bottom Line is divided into Years the right-hand Line into HUNDRED THOUSAND POUNDS

J. Andie Sculp.

Published as the Act directs 20th Aug^o. 1785.

Playfair 1785

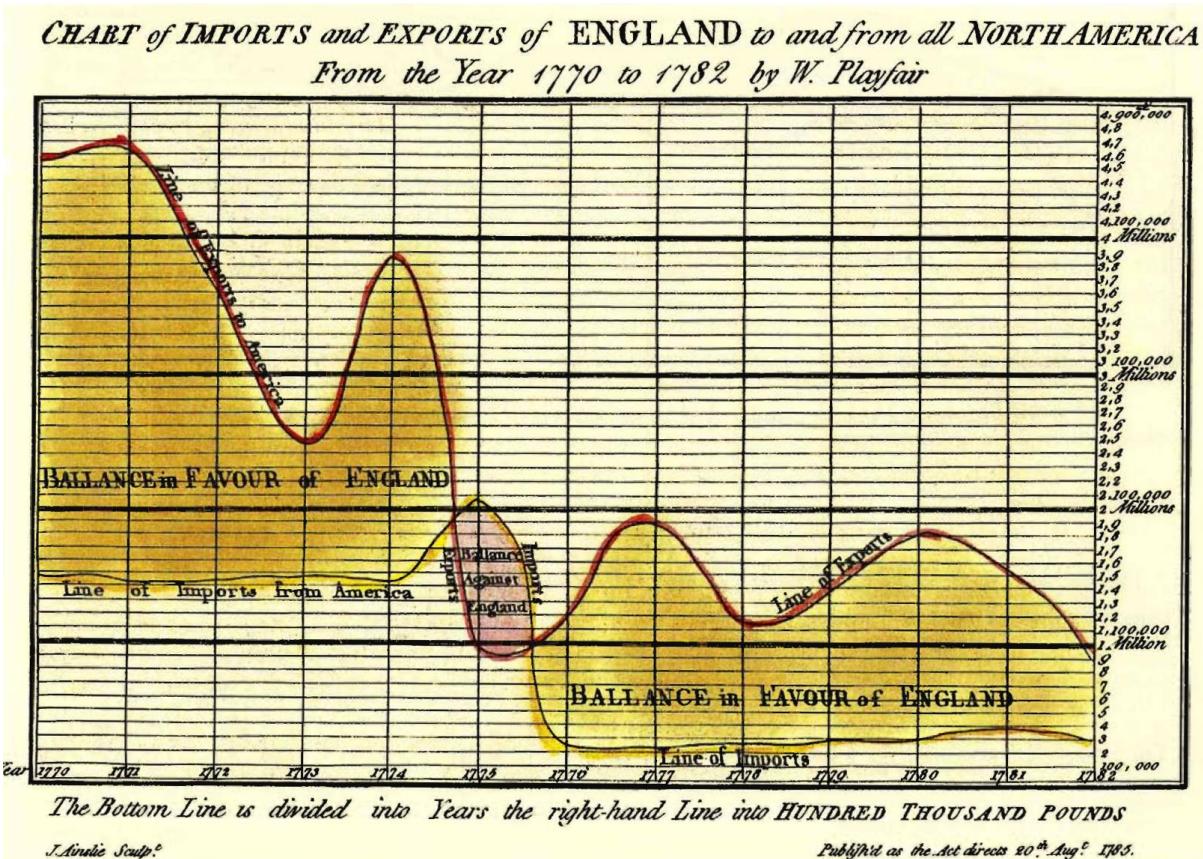
Exports and Imports to and from DENMARK & NORWAY from 1700 to 1780.



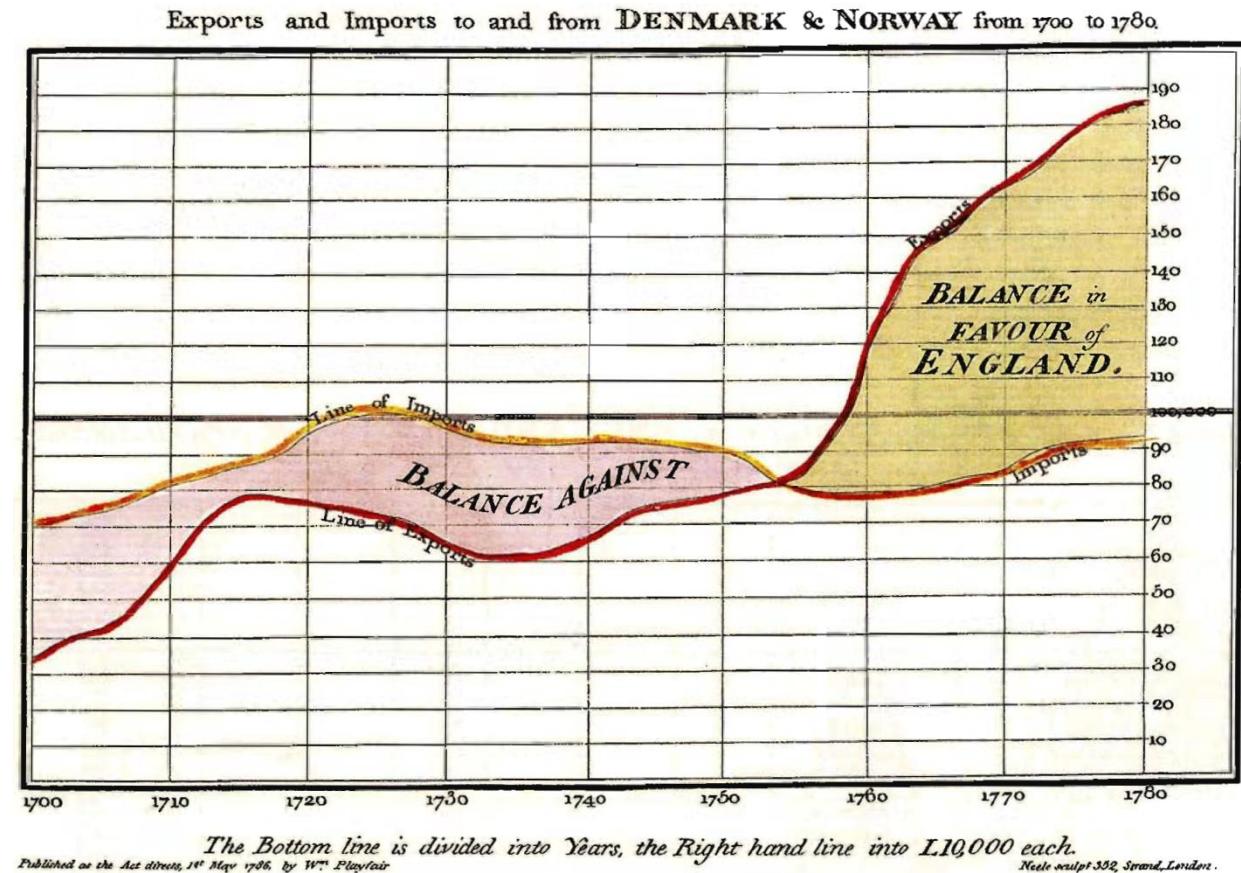
The Bottom line is divided into Years, the Right hand line into £10,000 each.
Published as the Act directs, 1st May 1786, by W^m Playfair
No. 66, Sculpt. 352, Strand, London.

Playfair 1786

Which one is better?



William Playfair 1785



William Playfair 1786

Playfair 1785 - 1786

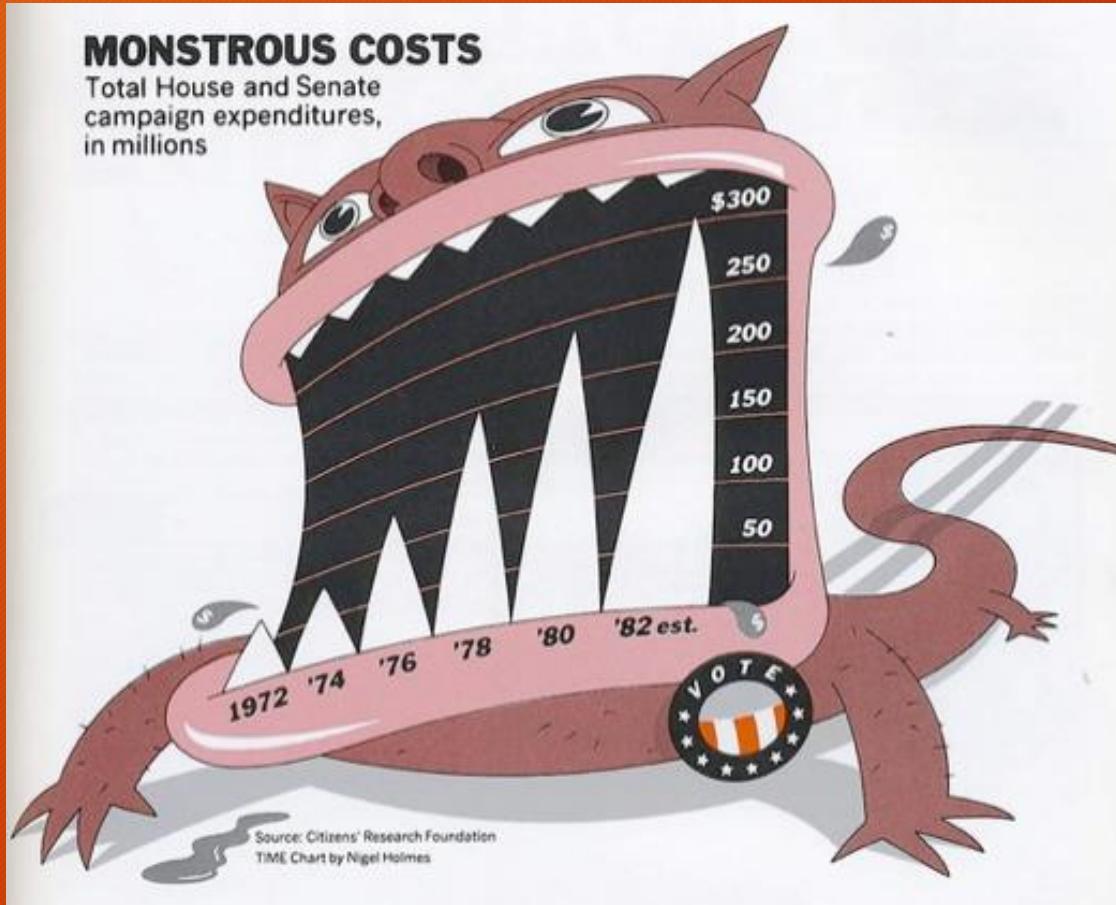
- Major improvement in one year:

Above all else, show the data

Fundamental principle of statistical graphics.

Data ink principle

- Maximize the share of data ink, within reason



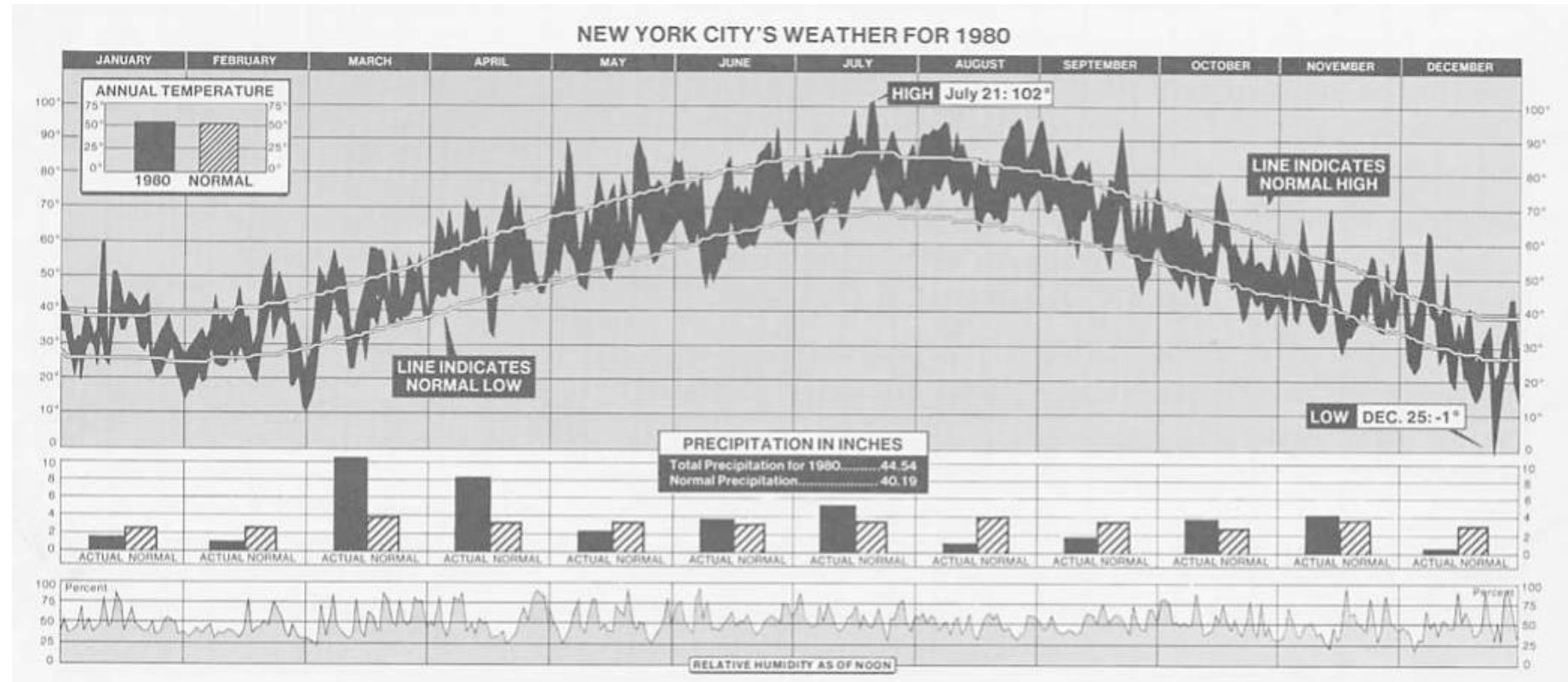
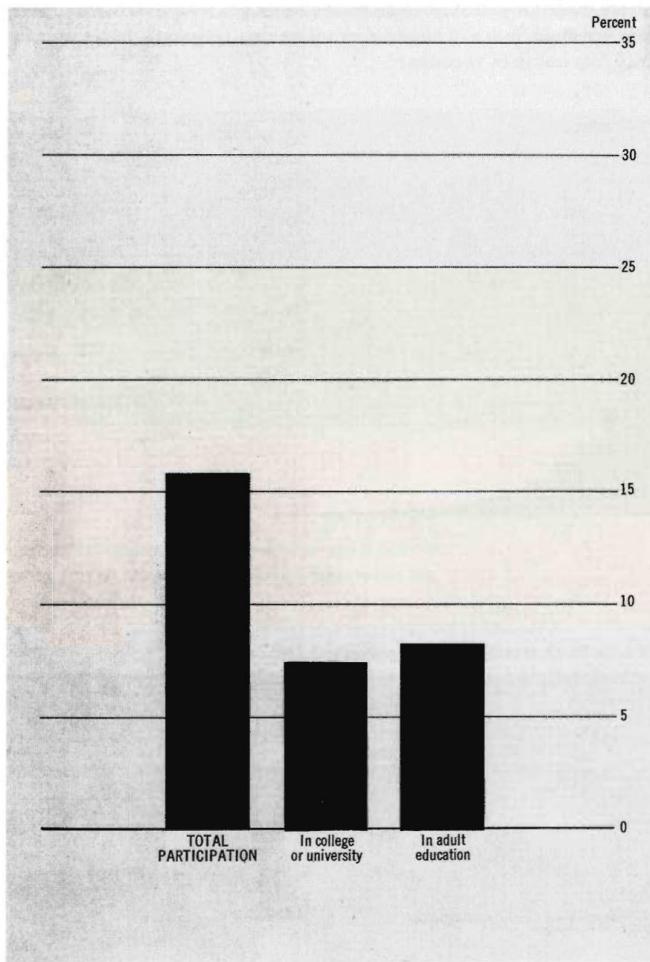
Data-ink ratio =
$$\frac{\text{data-ink}}{\text{total ink used to print the graphic}}$$

= proportion of a graphic's ink devoted to the non-redundant display of data-information

= 1.0 – proportion of a graphic that can be erased without loss of data-information.

Data density

data density of a graphic =
$$\frac{\text{number of entries in data matrix}}{\text{area of data graphic}}$$



Shrinking graphics

- Graphics can be shrunk way down
- Sparklines

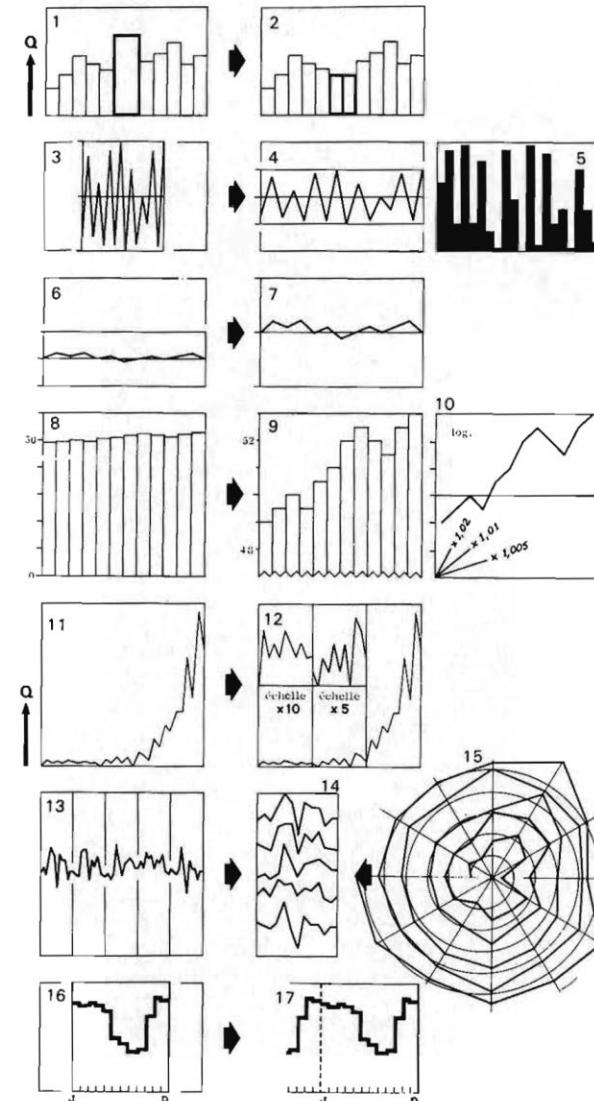


1999.1.1 65 months 2004.4.28 low high

Euro foreign exchange \$	1.1608	1.1907	.8252	1.2858
Euro foreign exchange ¥	121.32	130.17	89.30	140.31
Euro foreign exchange £	0.7111	0.6665	.5711	0.7235

2003.4.28 12 months 2004.4.28 low high

\$	1.1025	1.1907	1.0783	1.2858
¥	132.54	130.17	124.80	140.31
£	0.6914	0.6665	0.6556	0.7235



PROBLEMES GRAPHIQUES POSES PAR LES CHRONIQUES

Un total sur deux cases (sur deux ans) doit être divisé par deux (1).
Un total pour six mois sera multiplié par deux dans des cases annuelles.

Courbes trop pointues, réduire l'échelle des Q; la sensibilité angulaire s'inscrit dans une zone moyenne autour de 70°.
Si la courbe n'est pas réductible (grandes et petites variations) employer les colonnes remplies (5).
Courbes trop plates : augmenter l'échelle des Q.

Variations très faibles par rapport au total.
Celui-ci perd de l'importance et le zéro peut être supprimé, à condition que le lecteur voit sa suppression (9). Le graphique peut être interprété comme une accélération si l'étude fine des variations est nécessaire (échelle logarithmique (10) (v. p. 240).

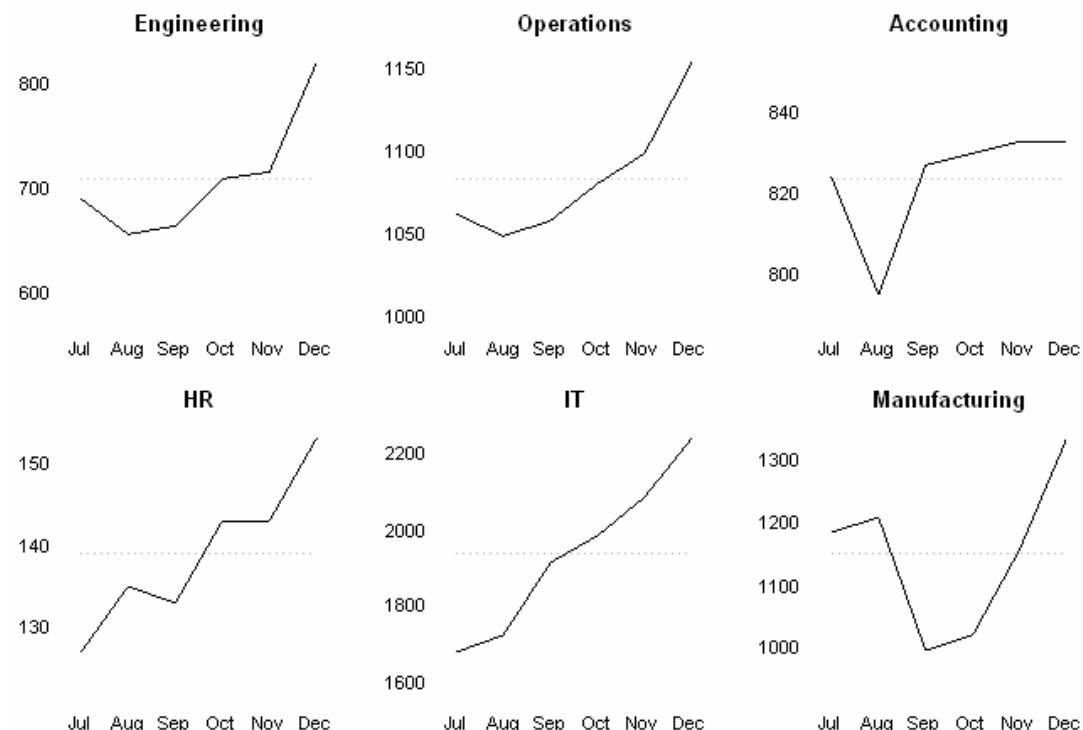
Très grande amplitude entre les valeurs extrêmes. Il faut admettre :
1º) Soit de ne pas percevoir les plus petites variations.
2º) Soit de ne s'intéresser qu'aux différences relatives (échelle logarithmique) sans connaître la quantité absolue.
3º) Soit admettre des périodes différentes dans la composante ordonnée et les traiter à des échelles différentes au-dessus de l'échelle commune (12).

Cycles très marqués.
Si l'étude porte sur la comparaison des phases de chaque cycle, il est préférable de décomposer (13) de manière à superposer les cycles (14). La construction polaire peut être employée, de préférence dans une forme spirale (15) (ne pas commencer par un trop petit cercle); pour spectaculaire qu'elle soit, elle est moins efficace que la construction orthogonale.

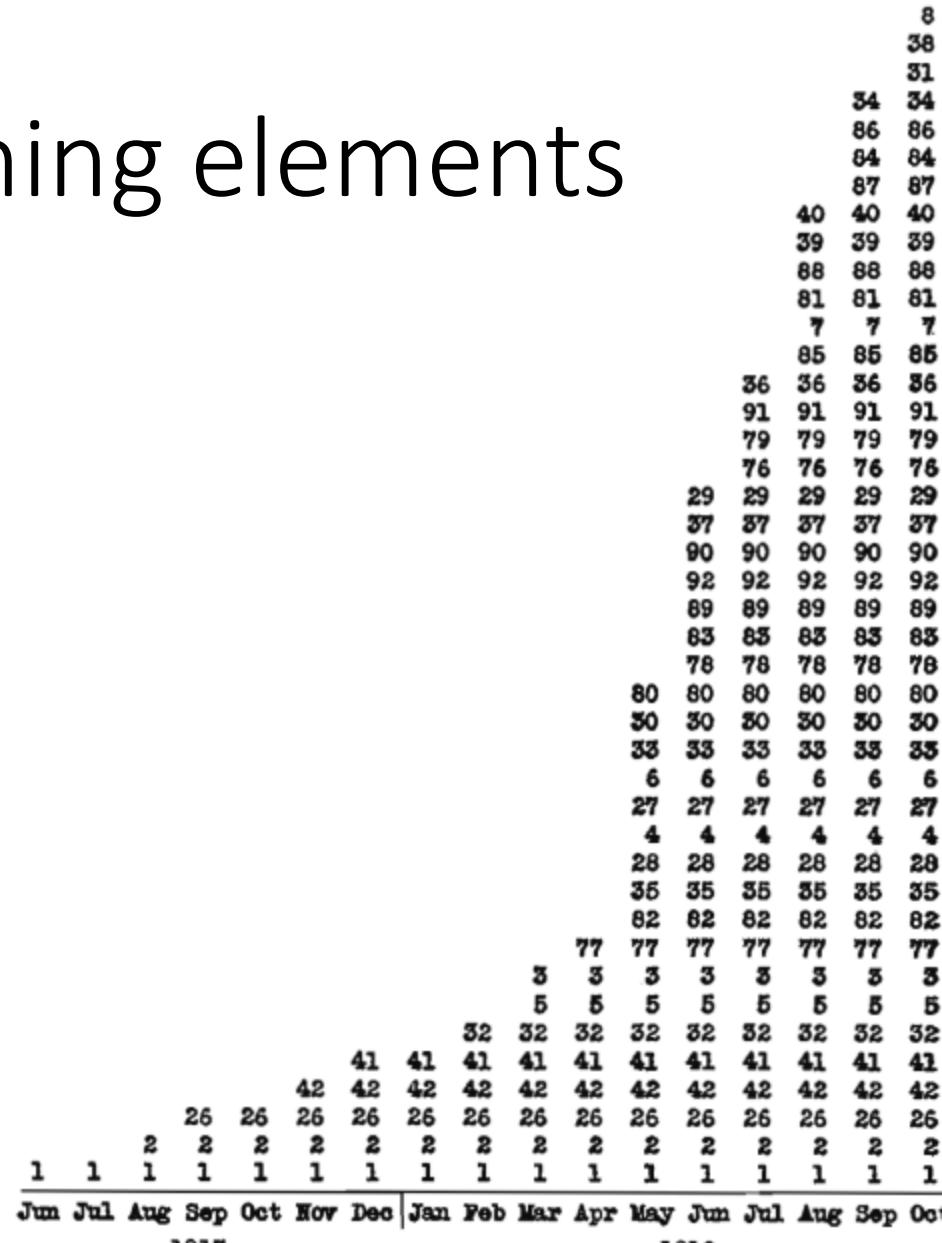
Courbes annuelles de pluie ou de température.
Un cycle possède deux phases (17), pourquoi n'en offrir qu'une à la perception du spectateur ? (16).

Small multiples

- Repeat visually similar elements nearby (within the eyespan) rather than spreading them apart



Multifunctioning elements



Leonard P. Ayres, *The War with Germany* (Washington, D.C., 1919), p. 102.

Proportion and Scale

- Graphics should tend towards the horizontal, greater in length than in height
 - Easier to label - It's easier to write and read
 - Our eye is naturally practiced in detecting deviations from the horizon
- High contrast display might occasionally be better than the "floating snake"
- Golden ratio is a good idea

lesser height



greater length

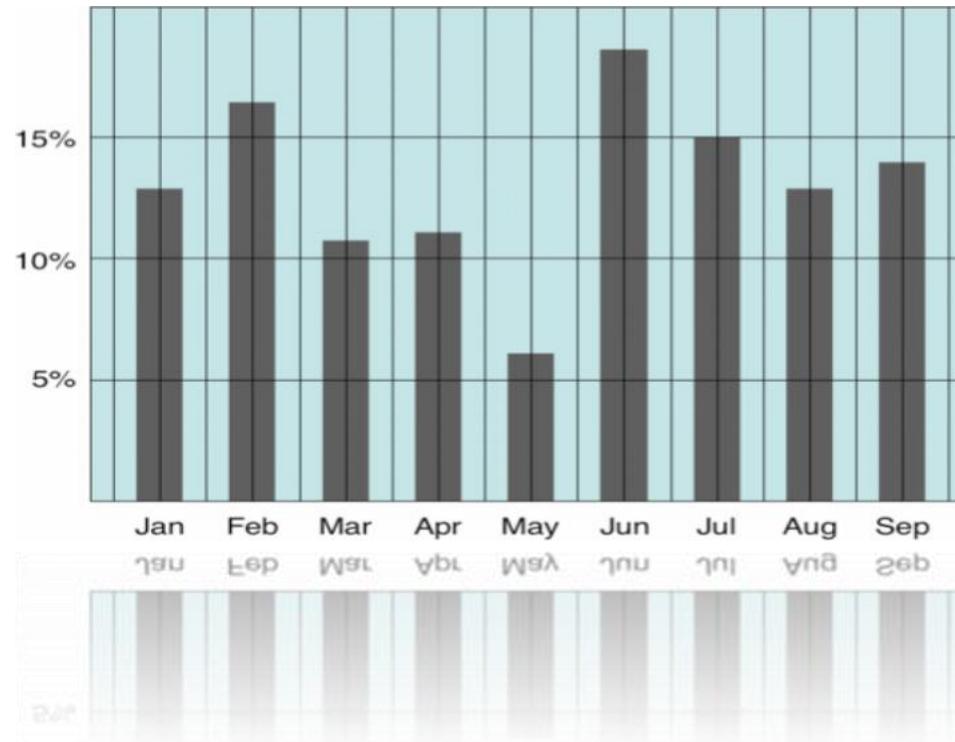


Revise and Edit.

'Answering the question of “what is the graphic trying to do?” is always helpful. At minimum the work I create needs to speak to this. Innovation doesn't have to be a wholesale out-of-the box approach. Iterating on a previous idea, moving it forward, is innovation.'

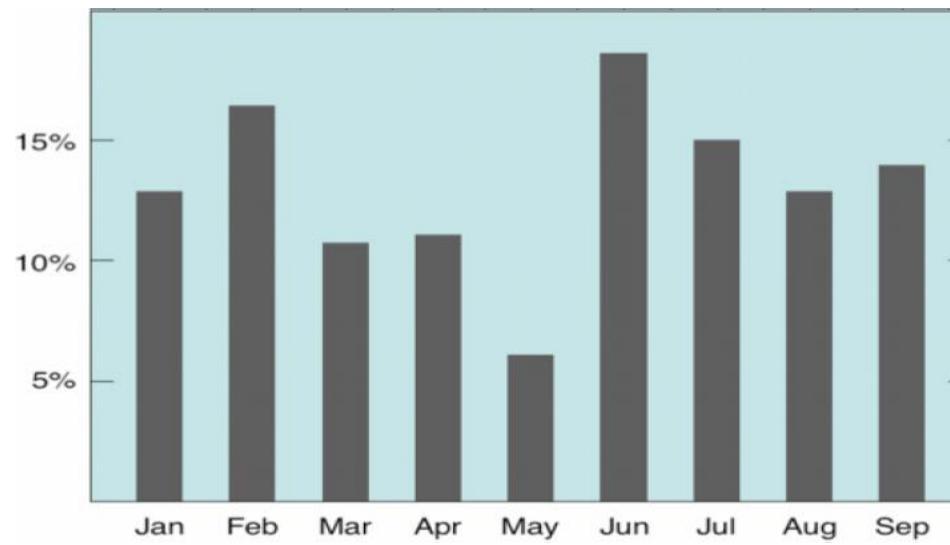
Sarah Slobin, Visual Journalist

Simplify

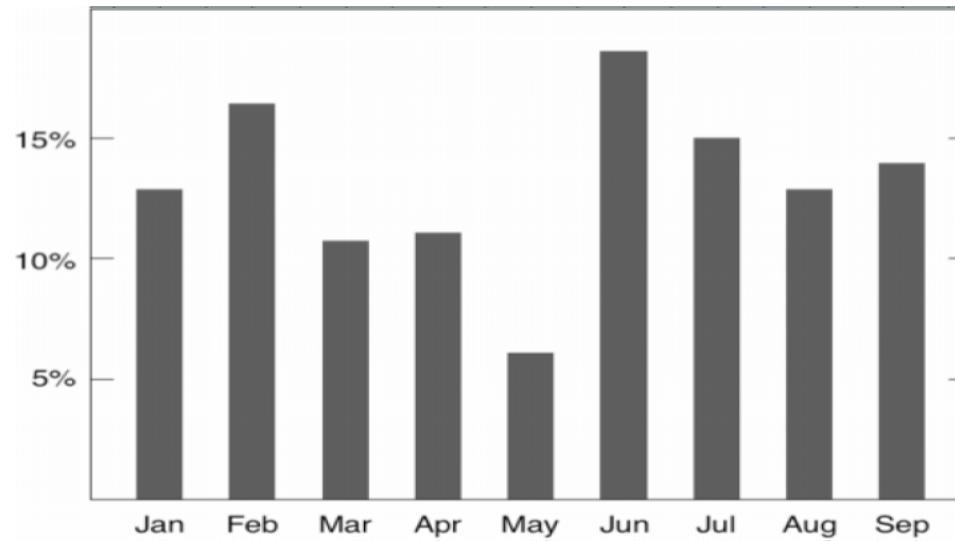


<http://www.tbray.org/ongoing/data-ink/di6>

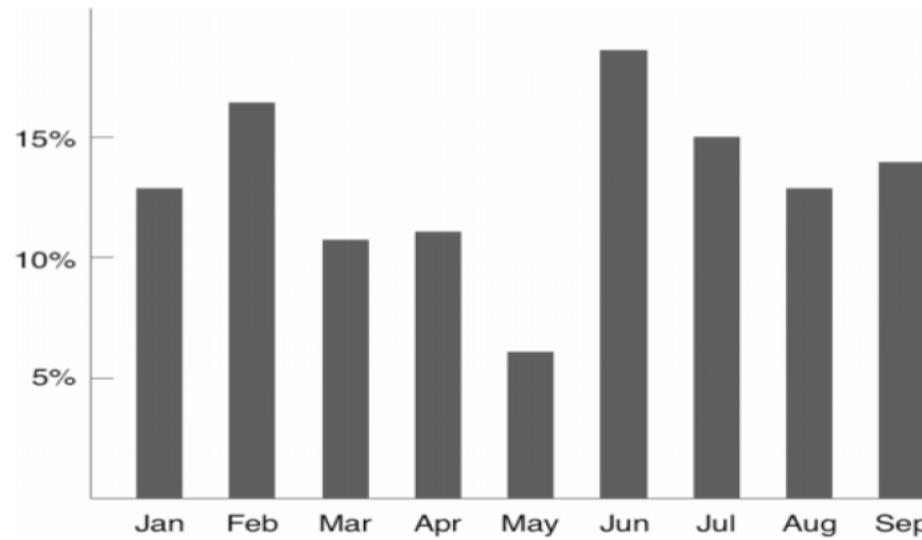
Simplify



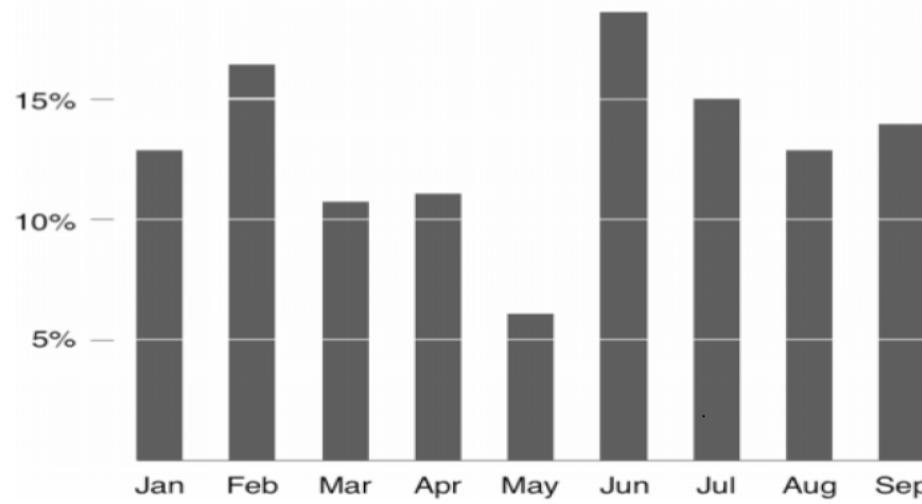
Simplify



Simplify

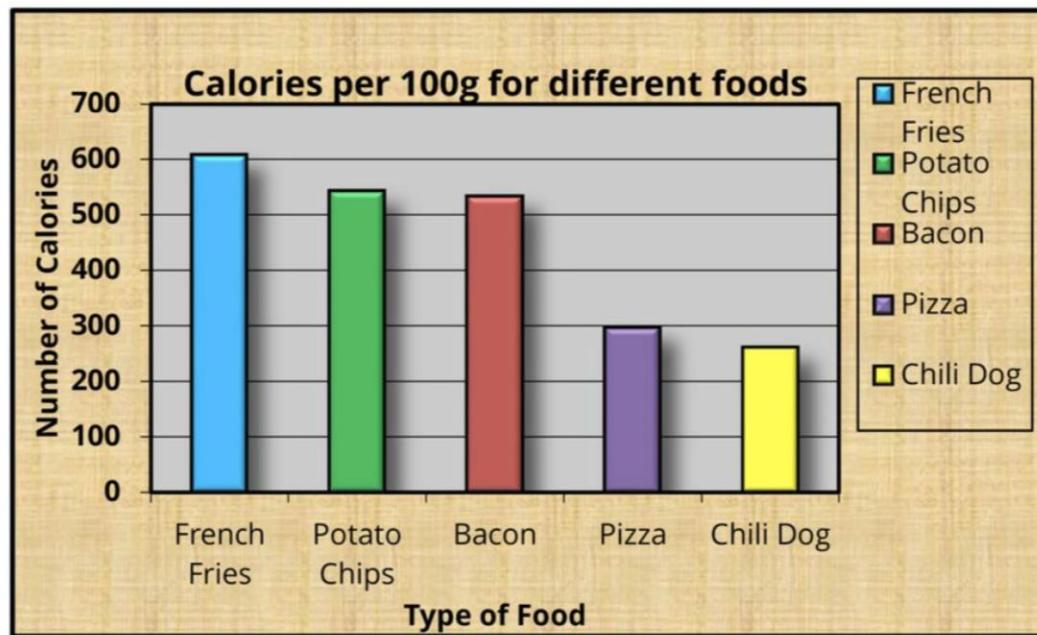


Simplify



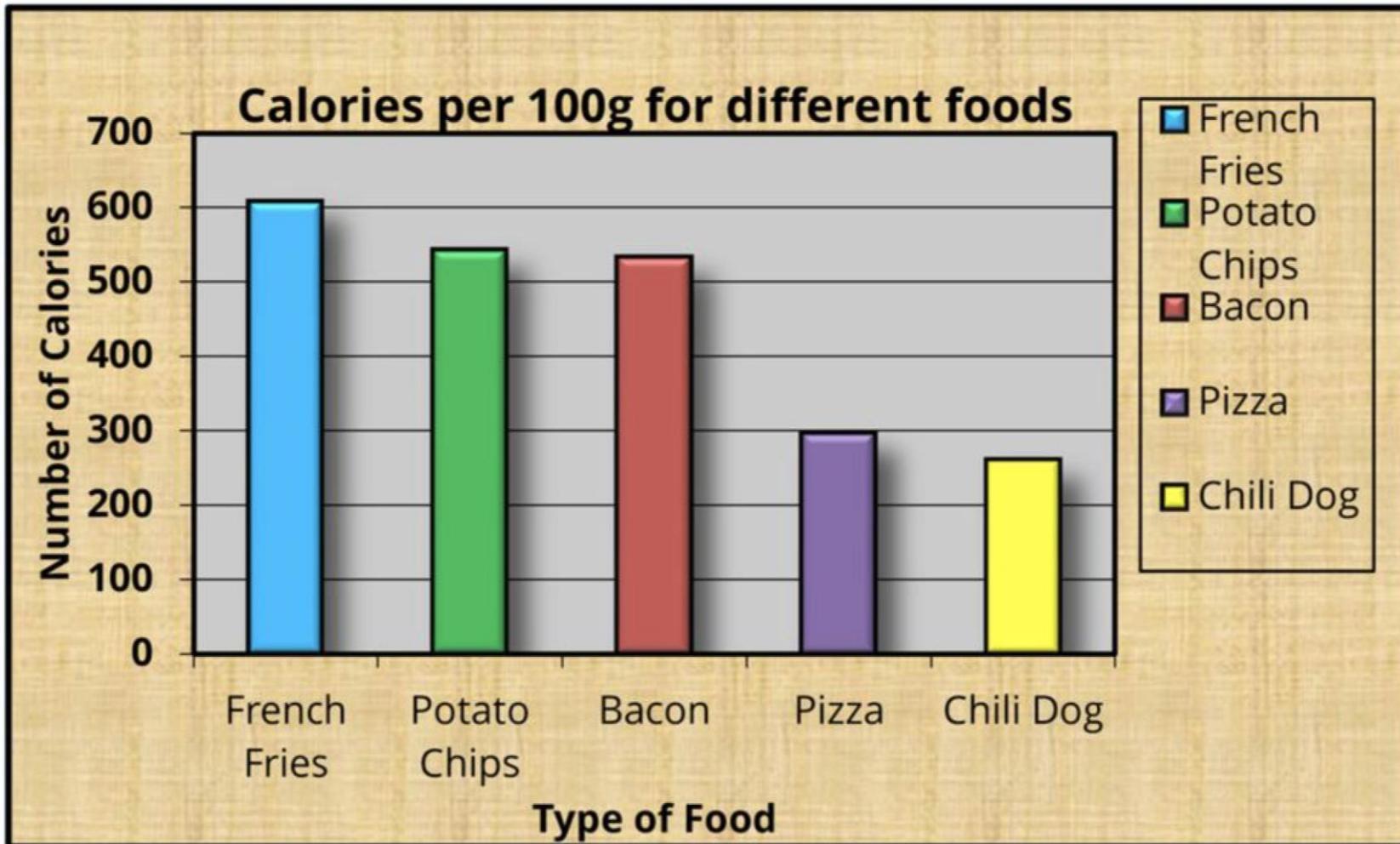
How to rework 2

Remove backgrounds

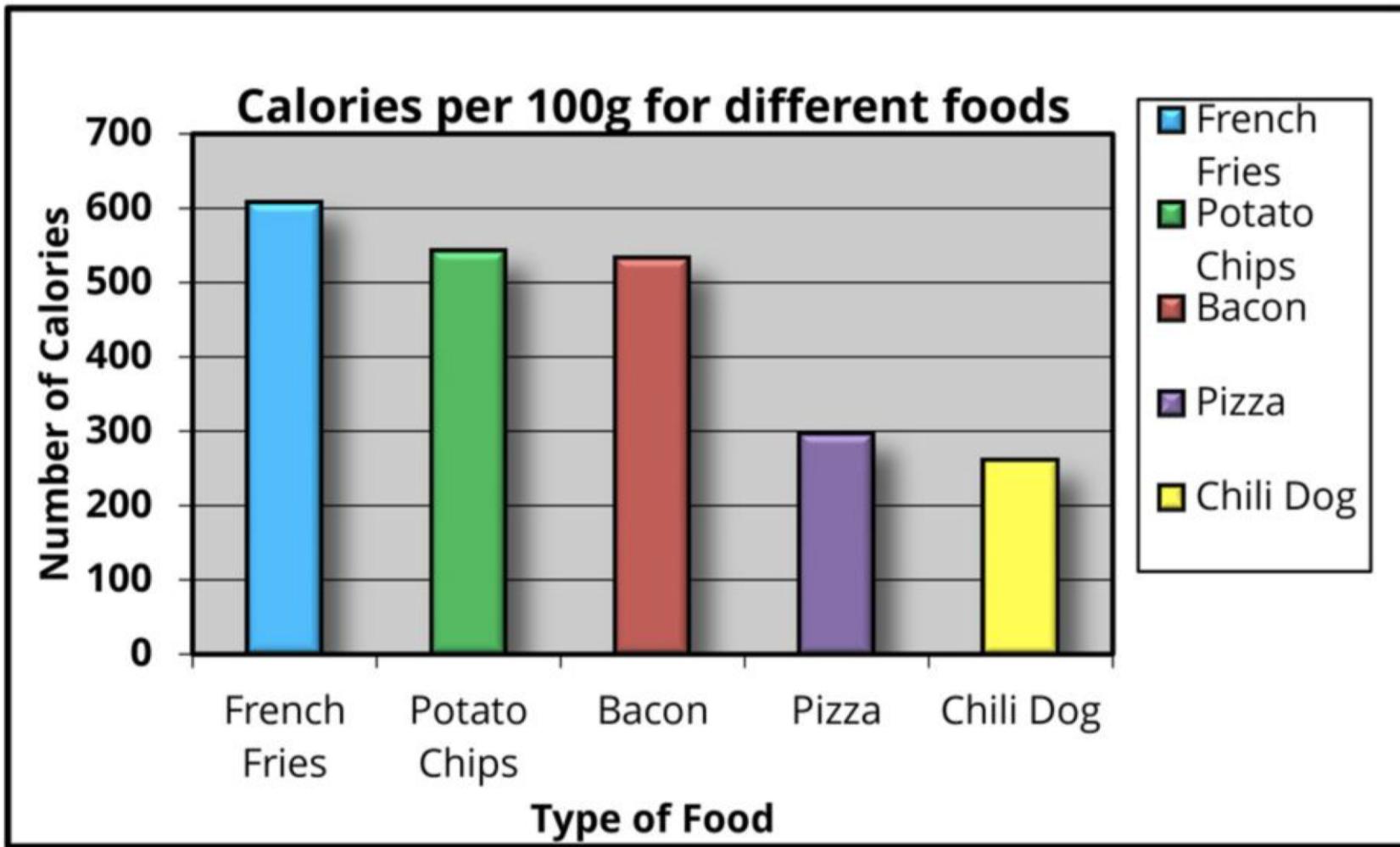


Example by Dr. Benjamin Bach, University of Edinburgh

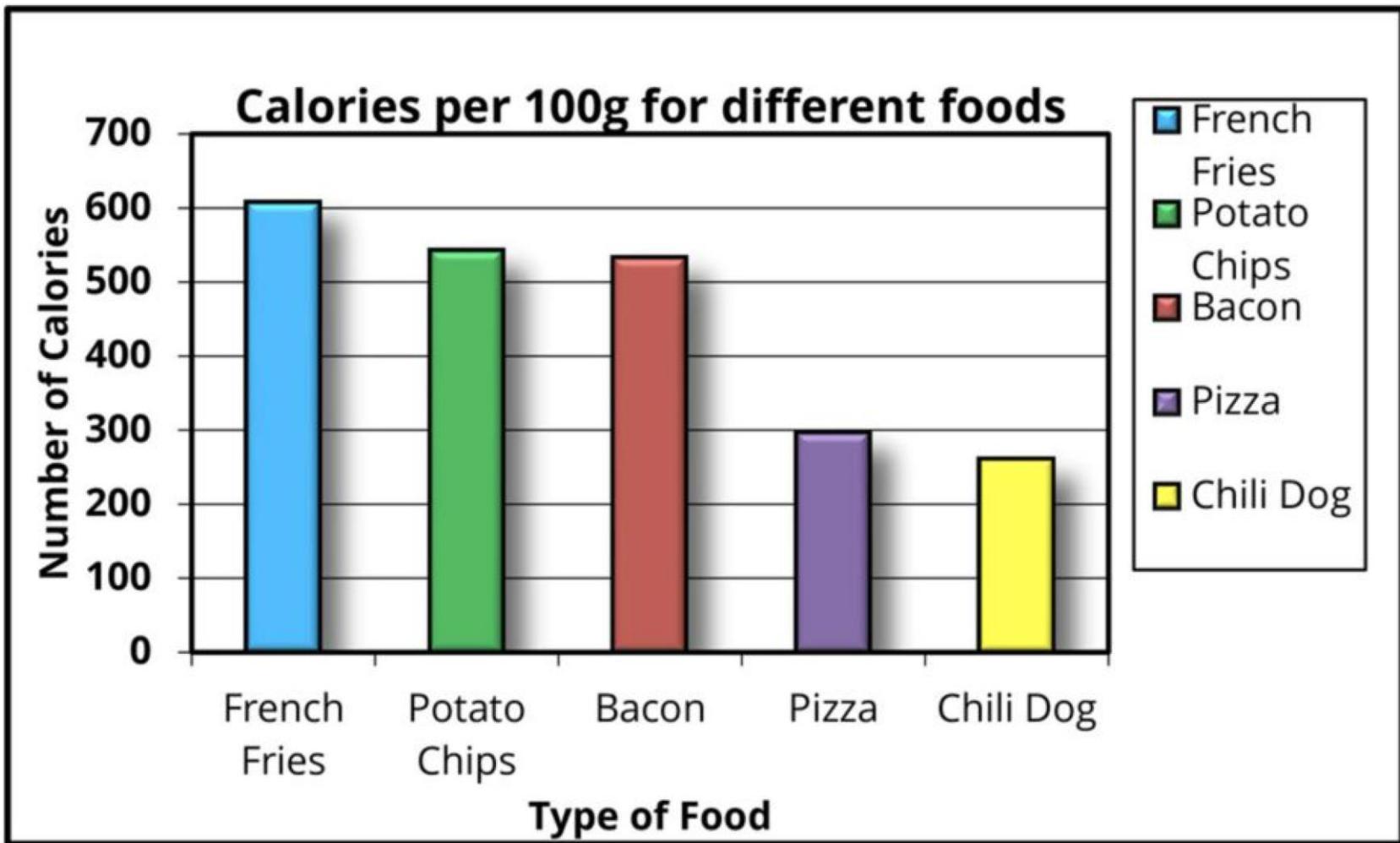
Remove backgrounds



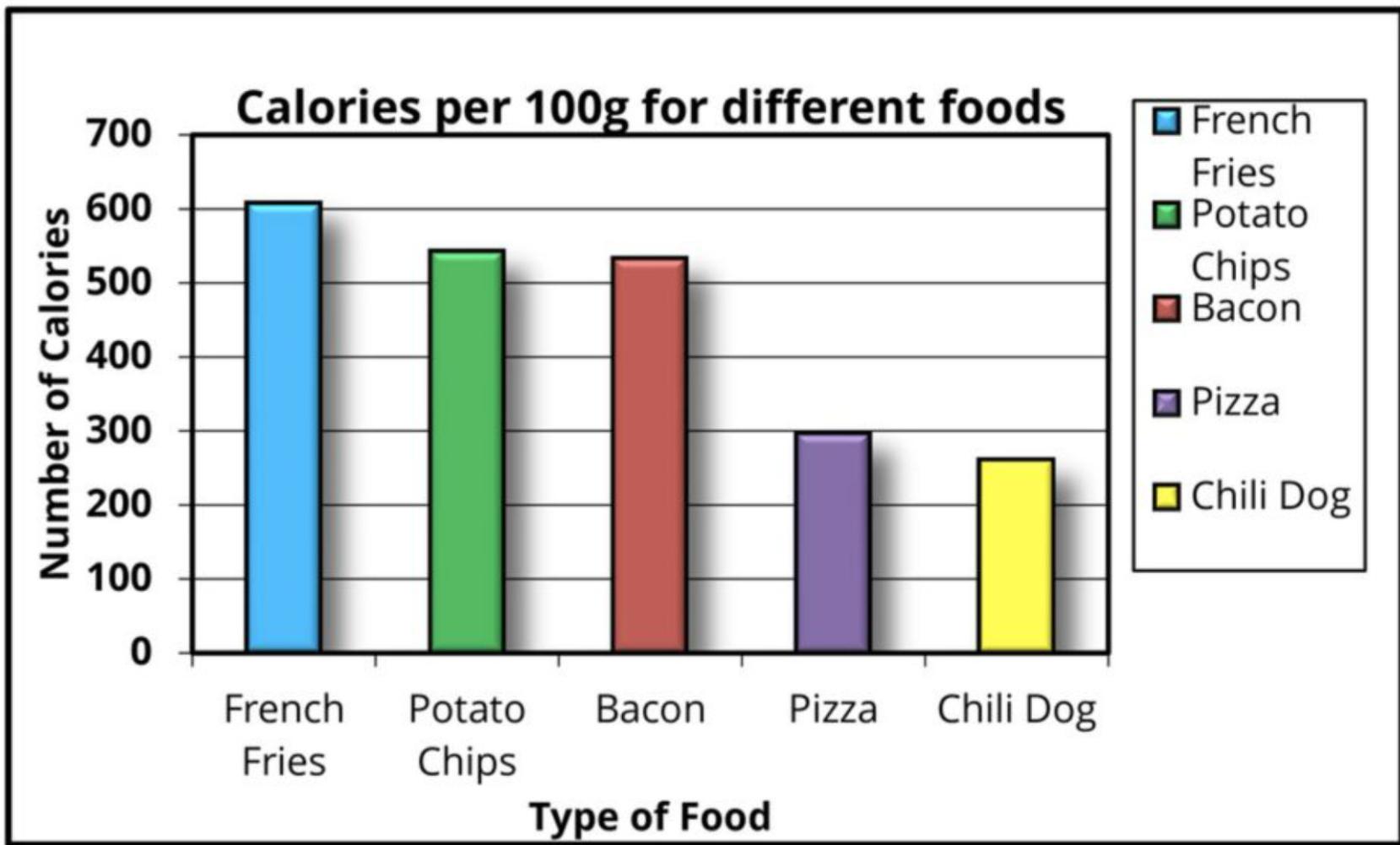
Remove backgrounds



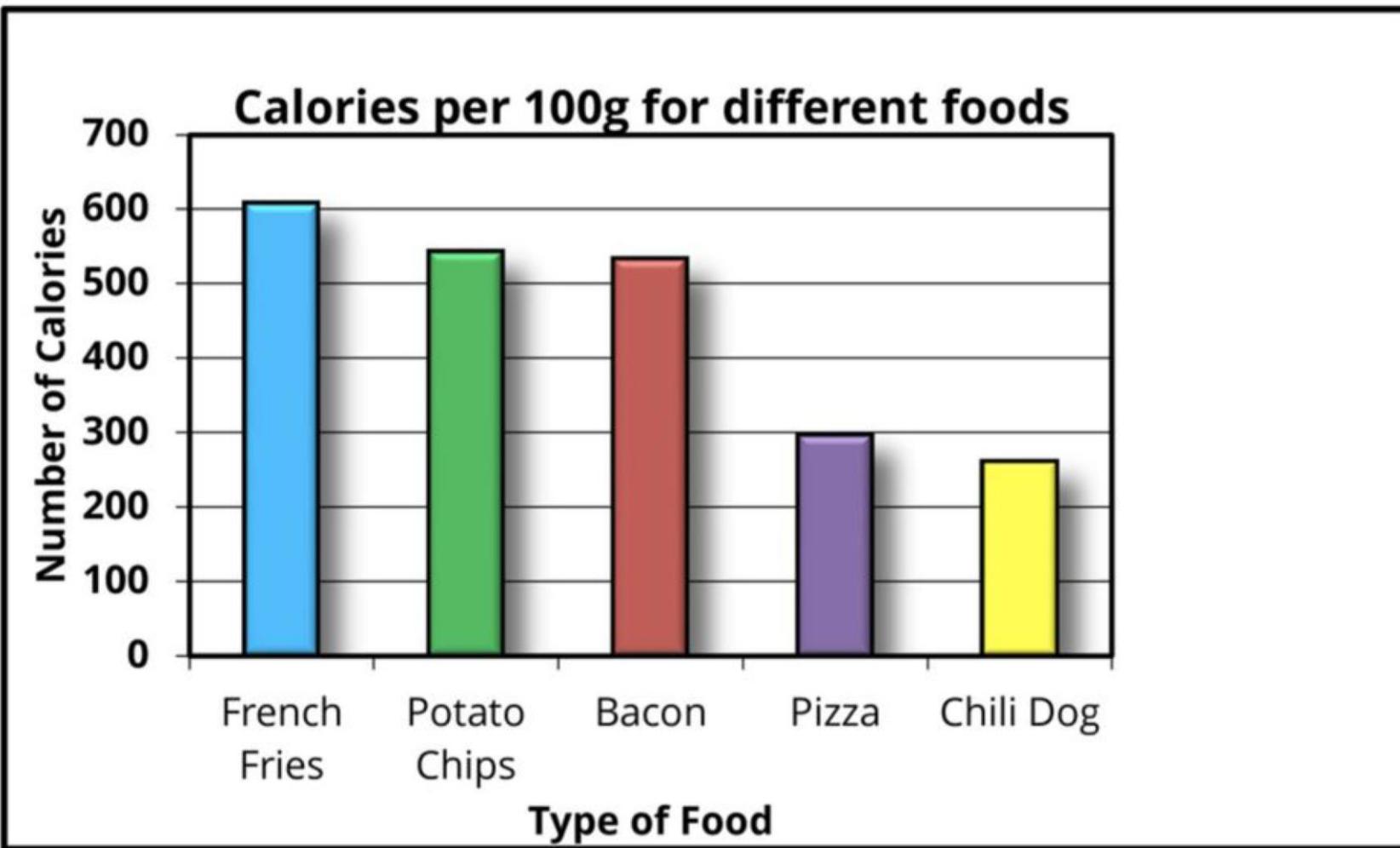
Remove backgrounds



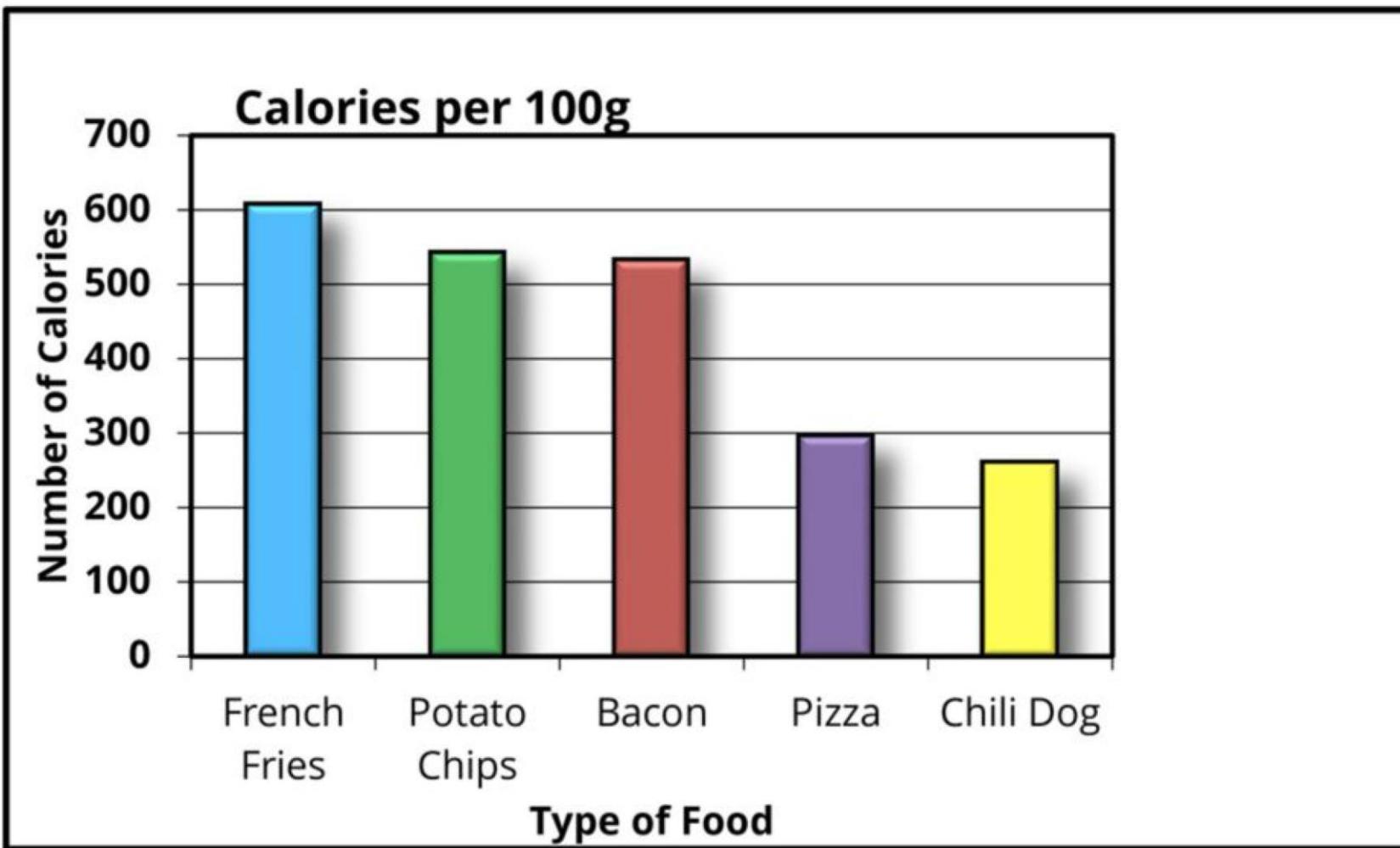
Remove redundant labels



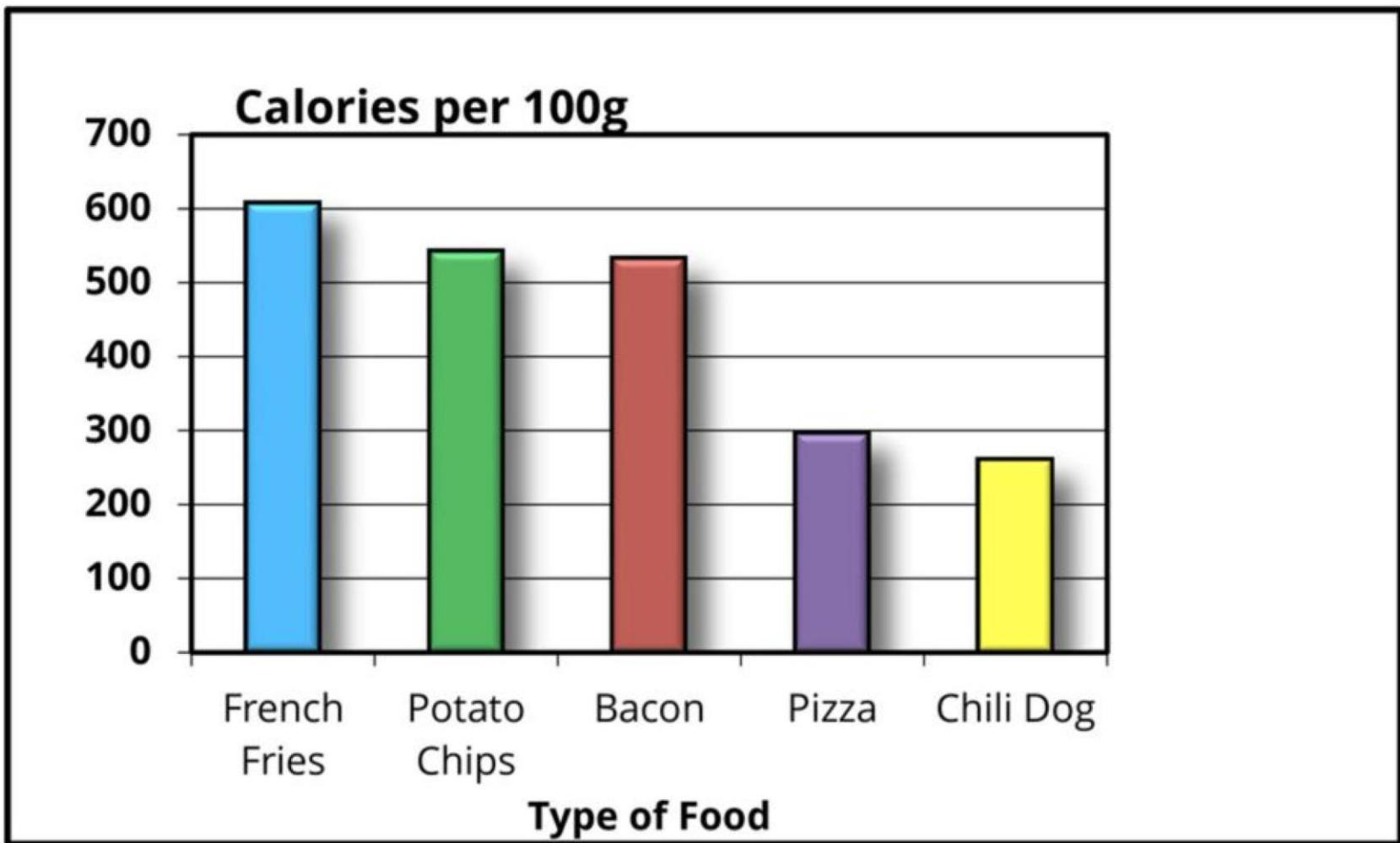
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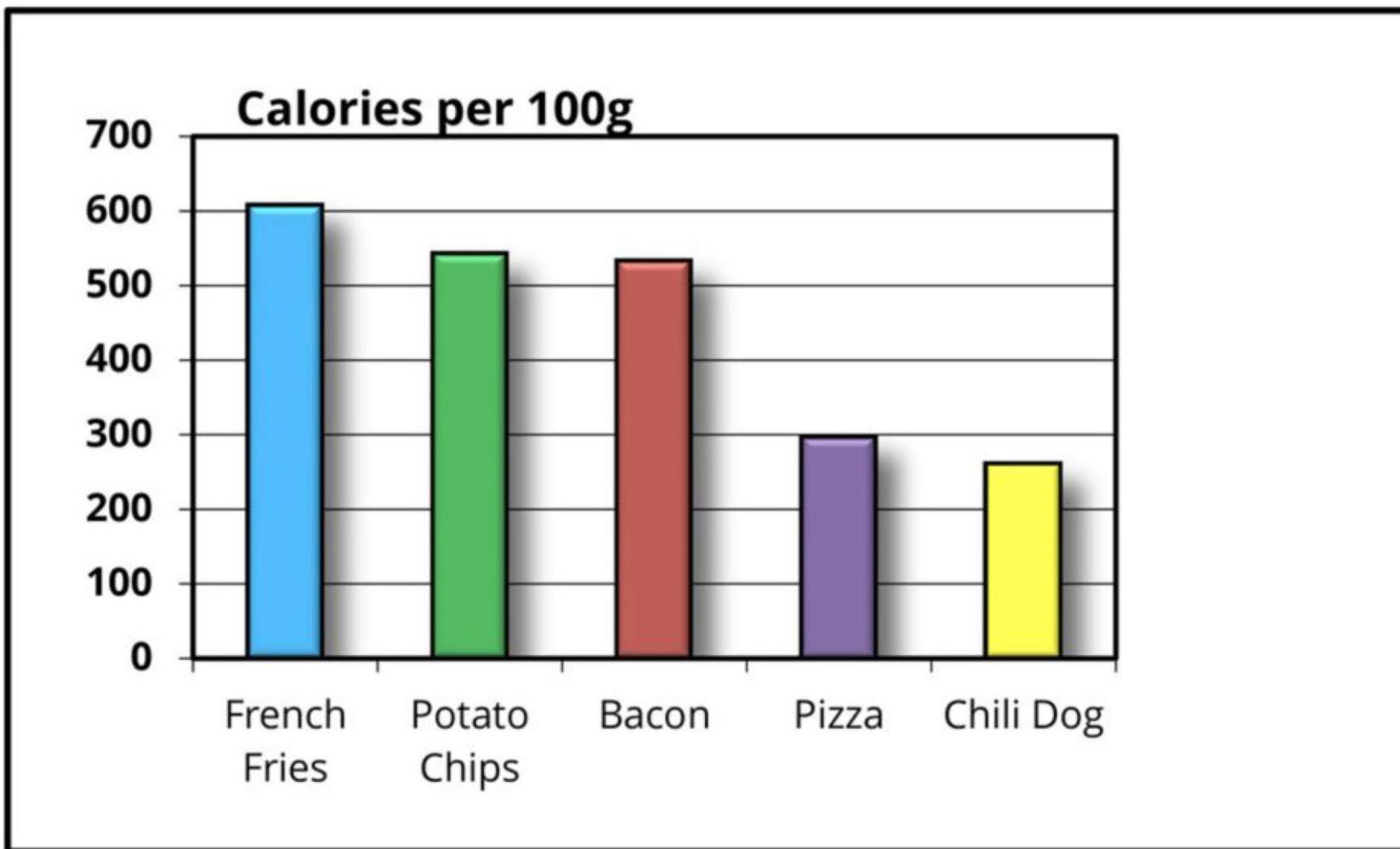
Remove redundant labels



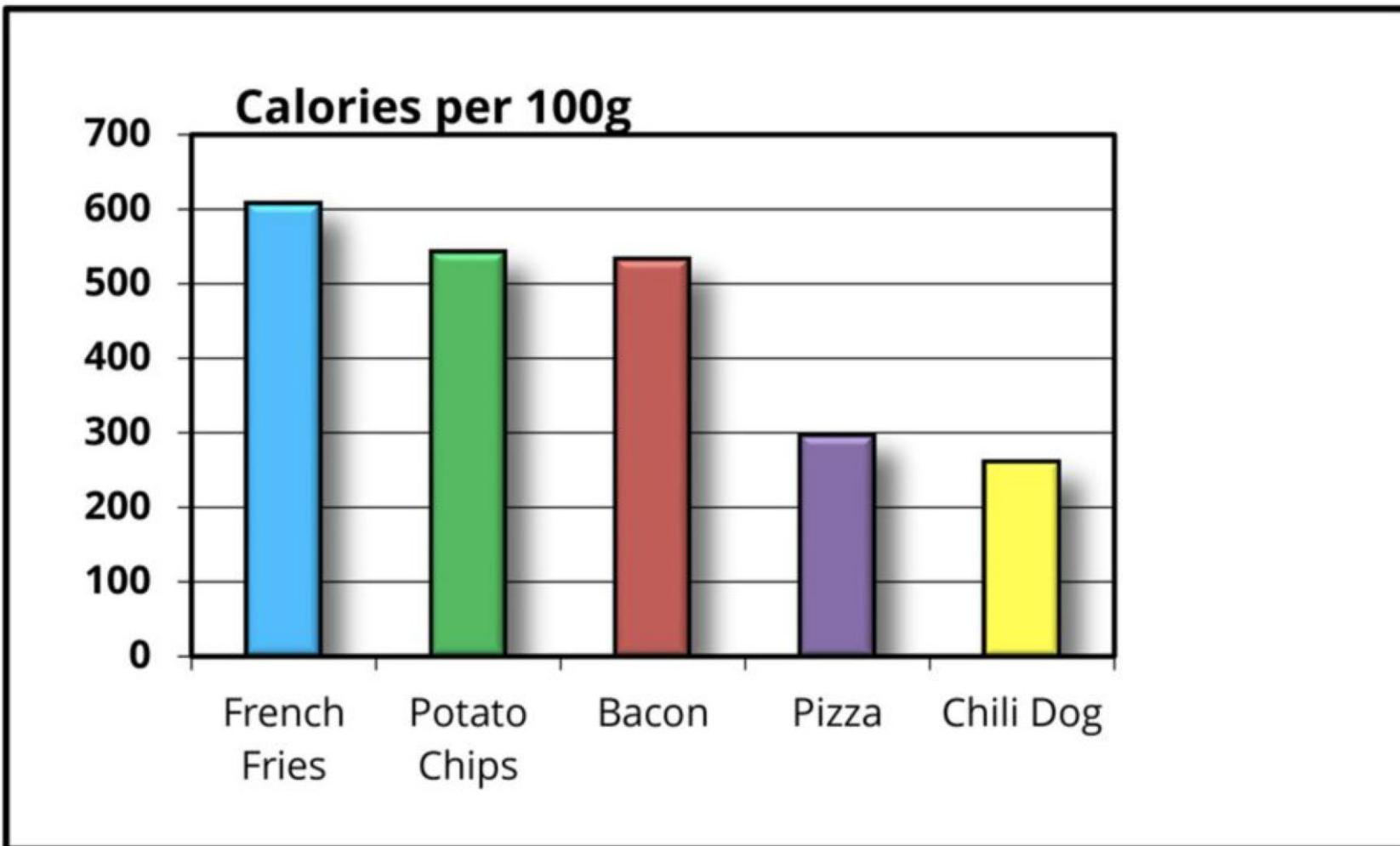
Remove redundant labels



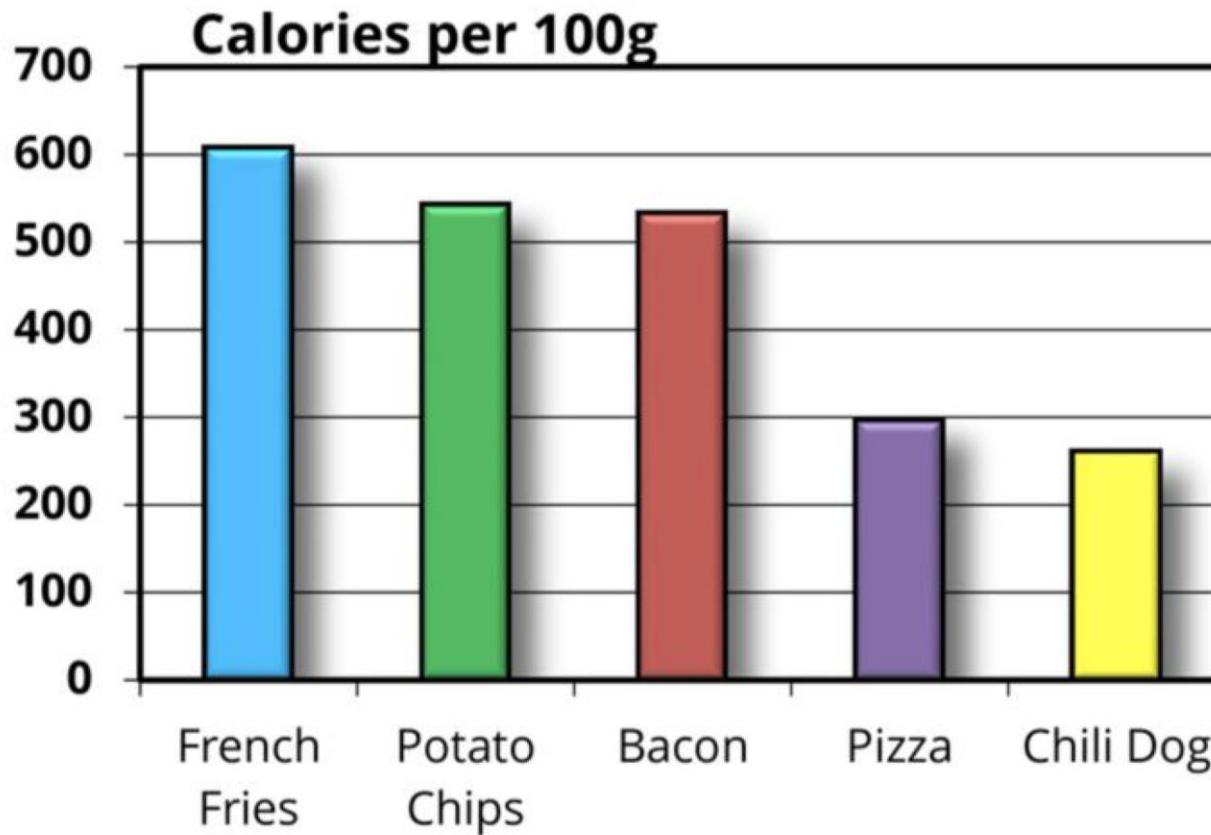
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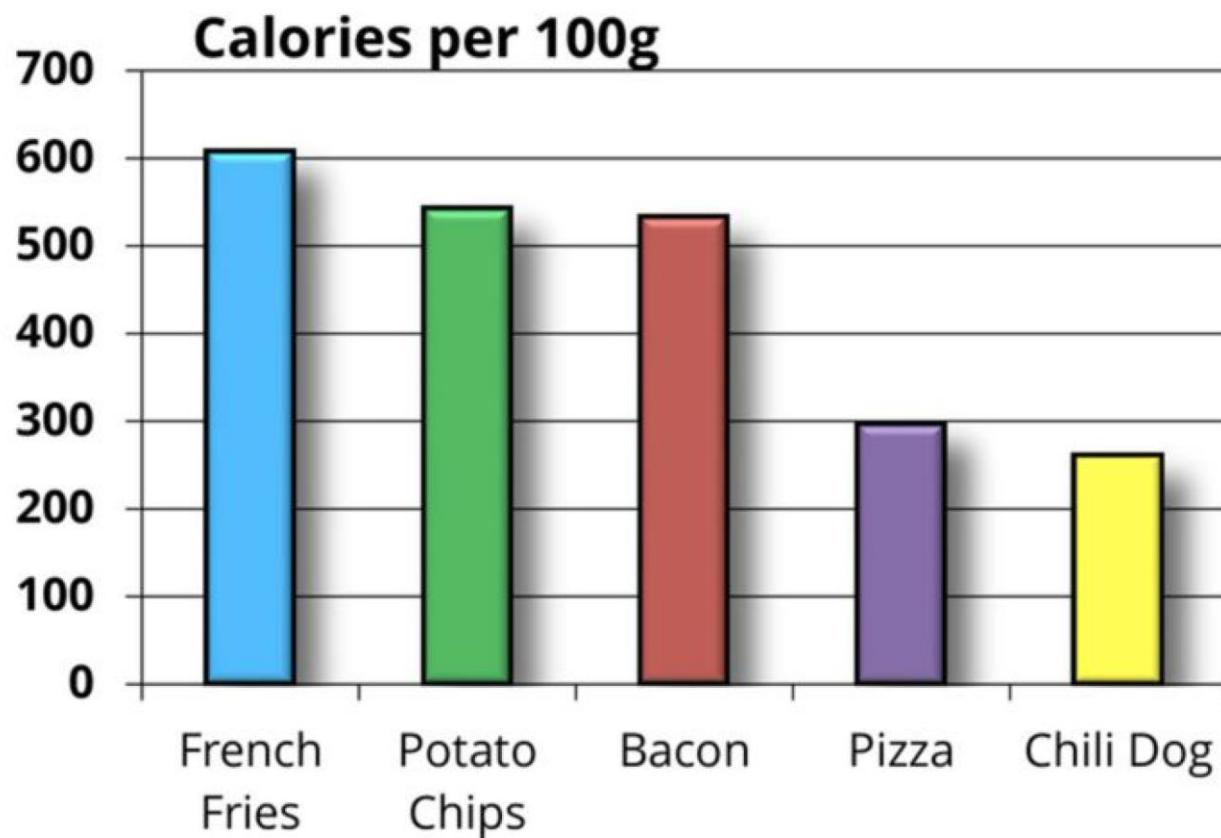
Remove borders



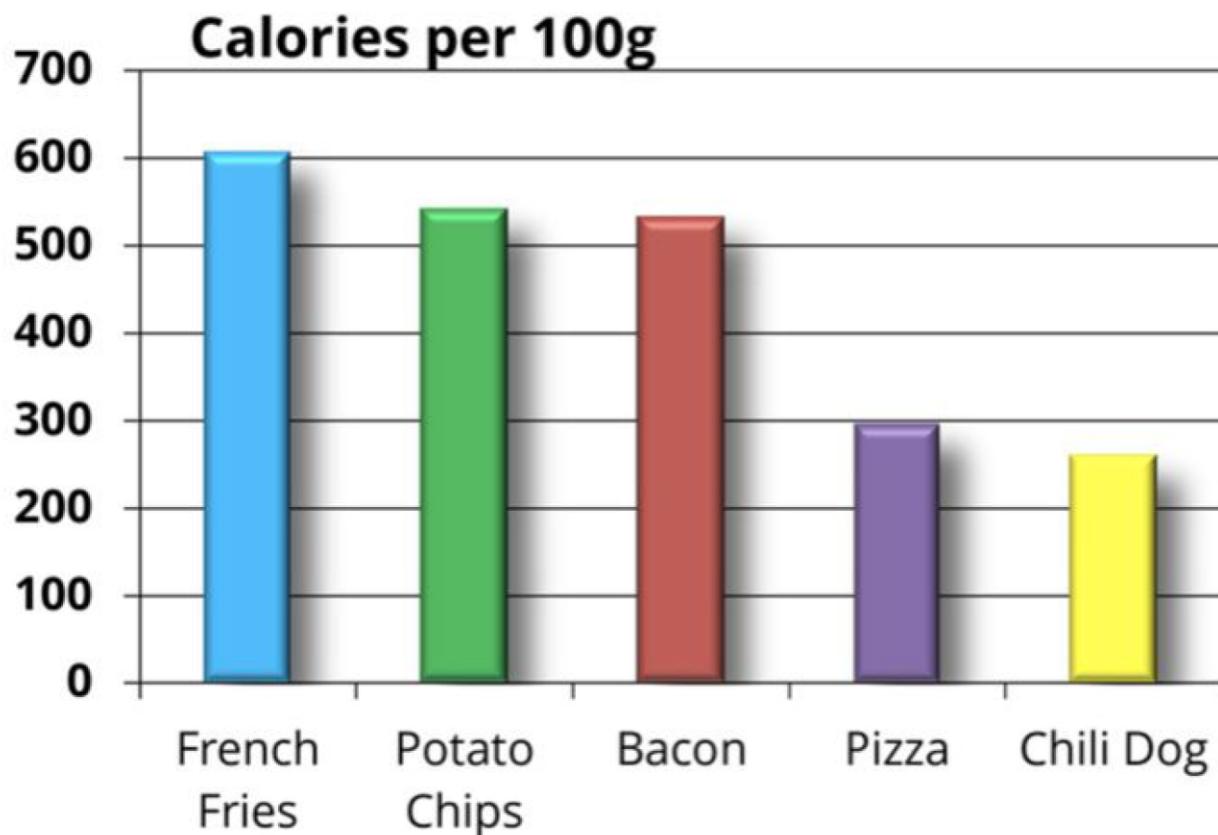
Remove borders



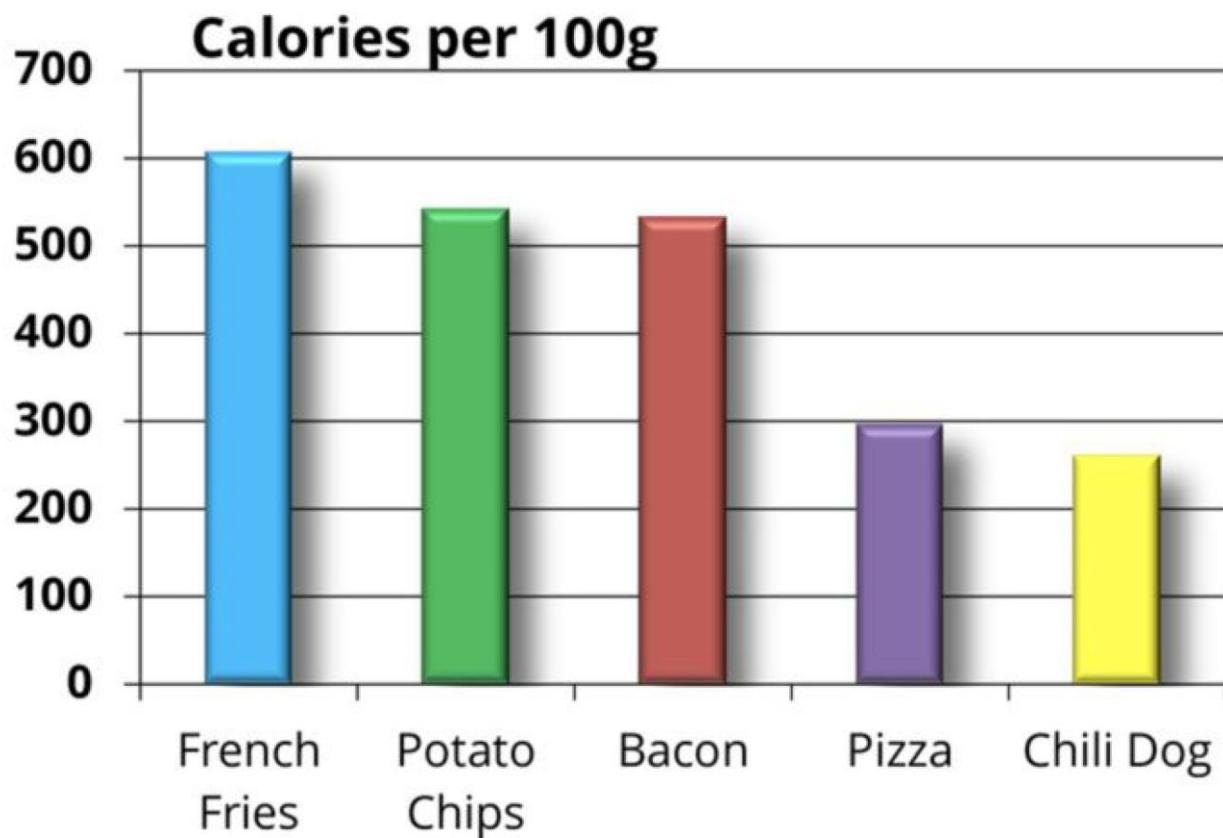
Remove borders



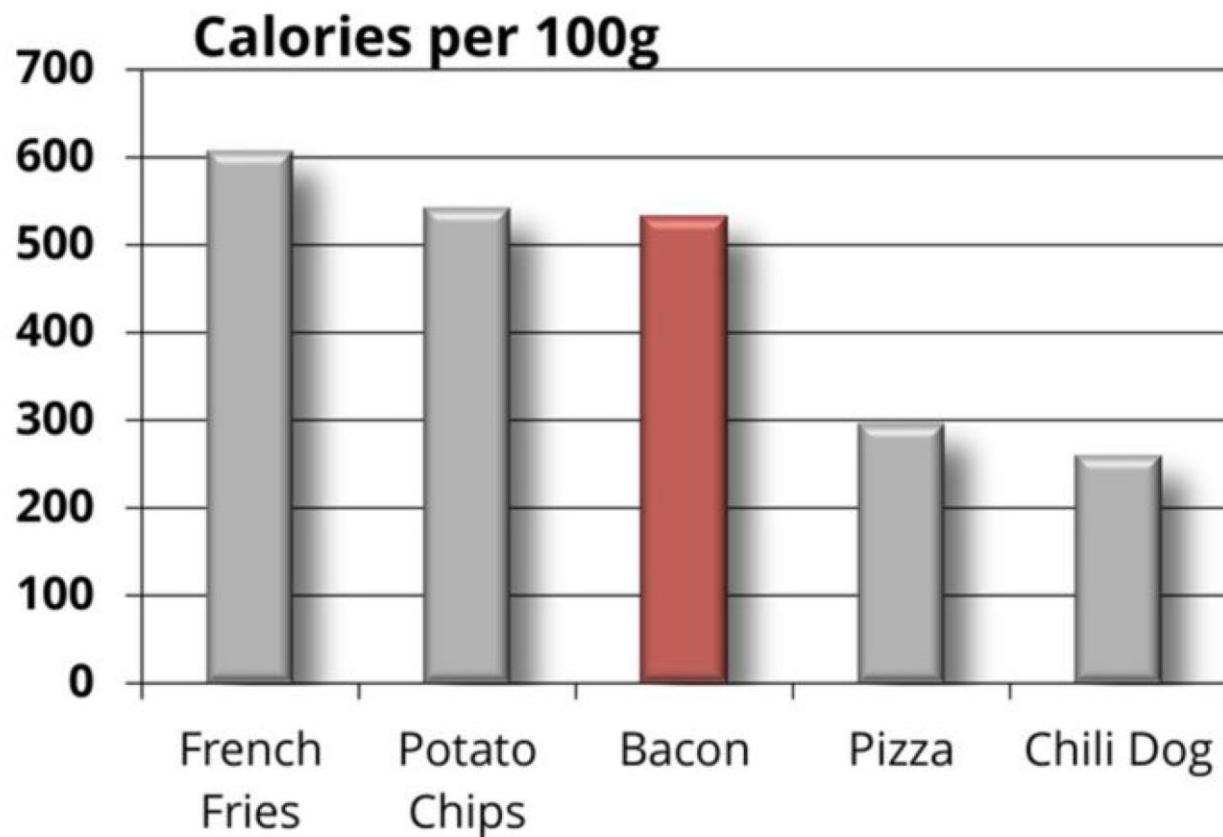
Remove borders



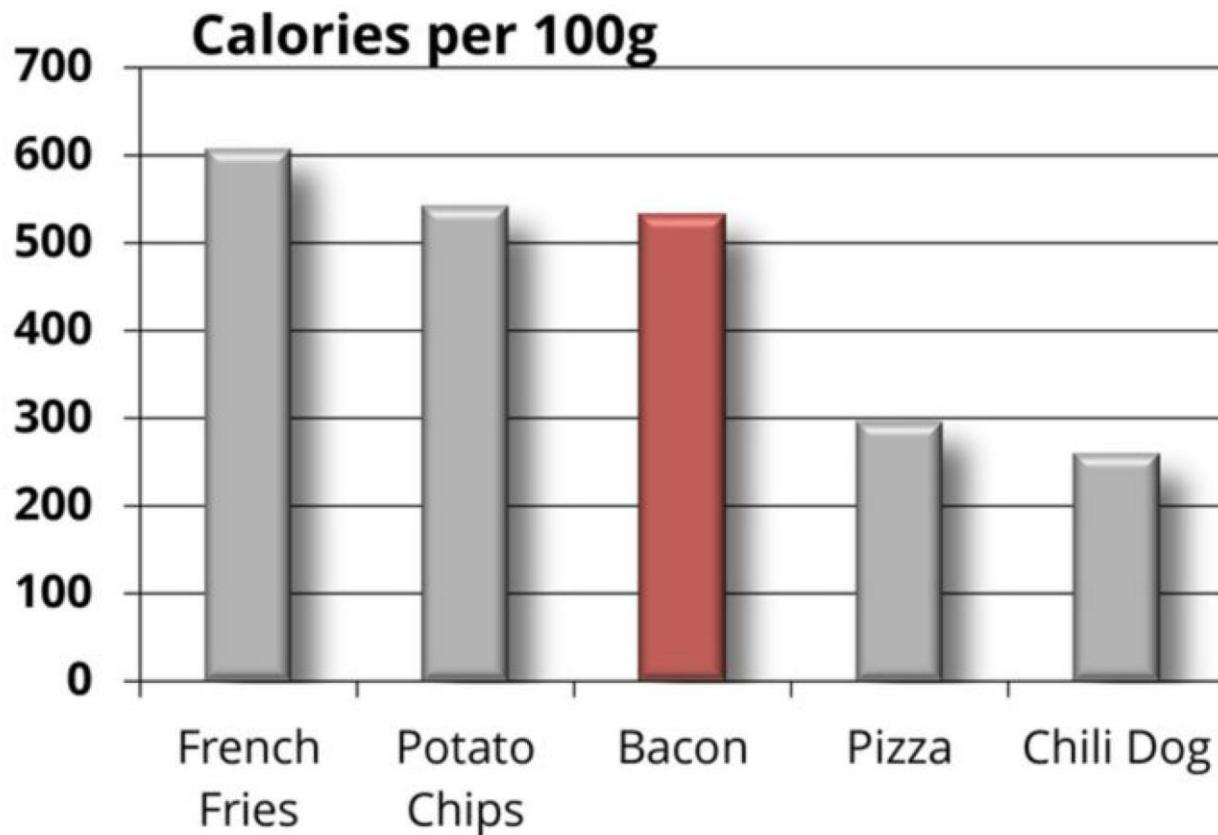
Reduce colors



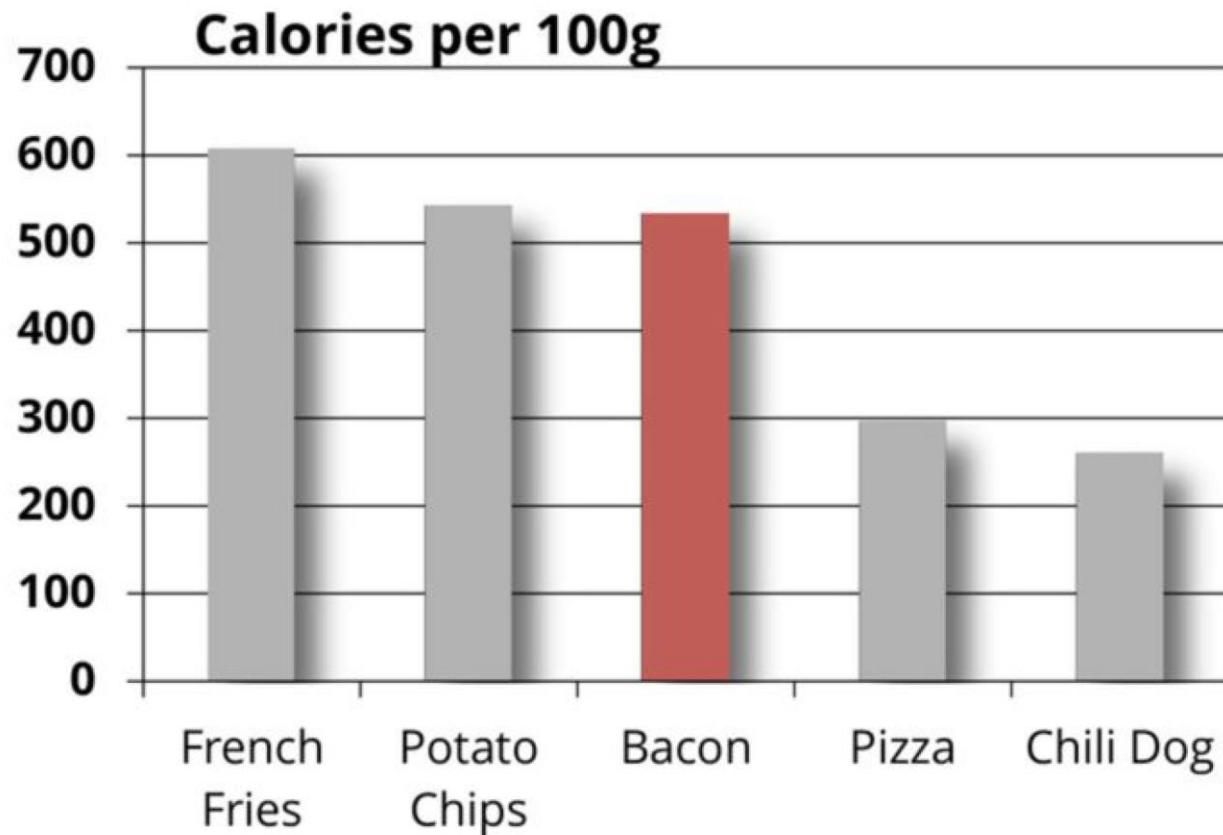
Reduce colors



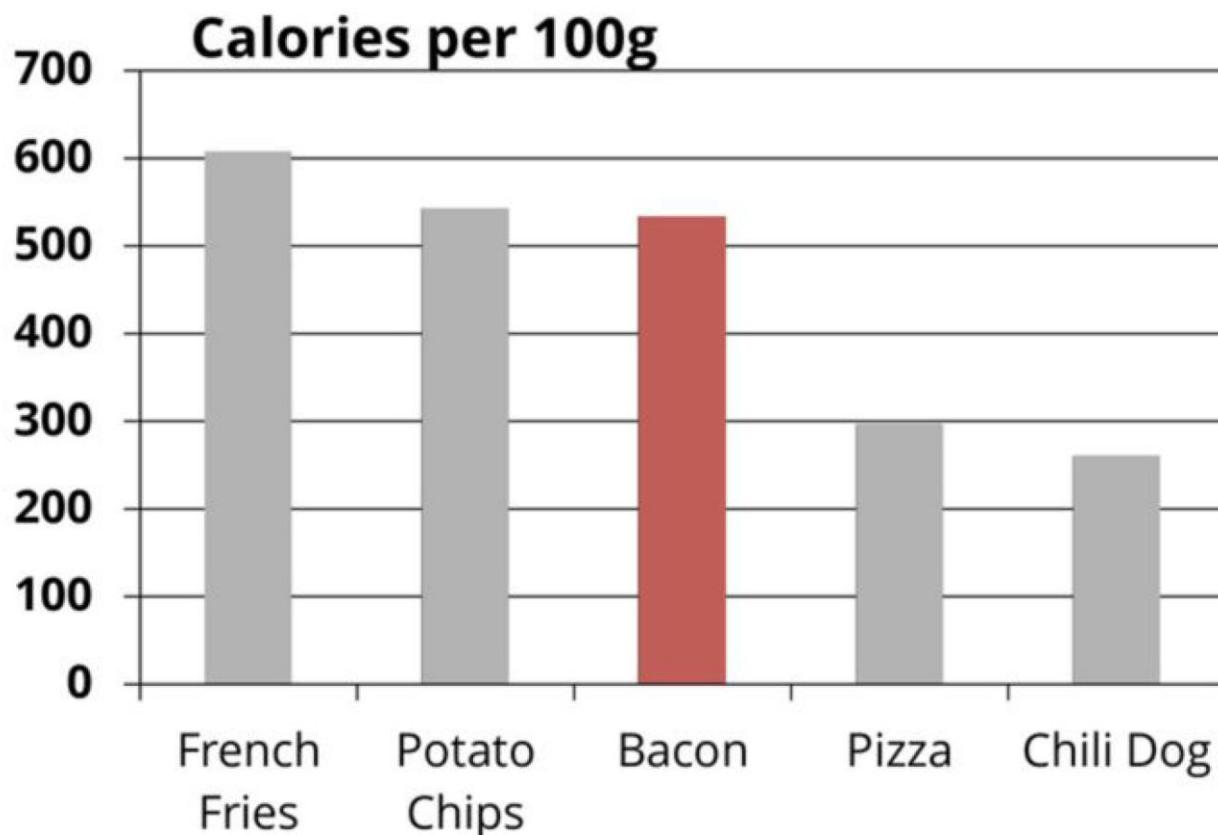
Remove special effects



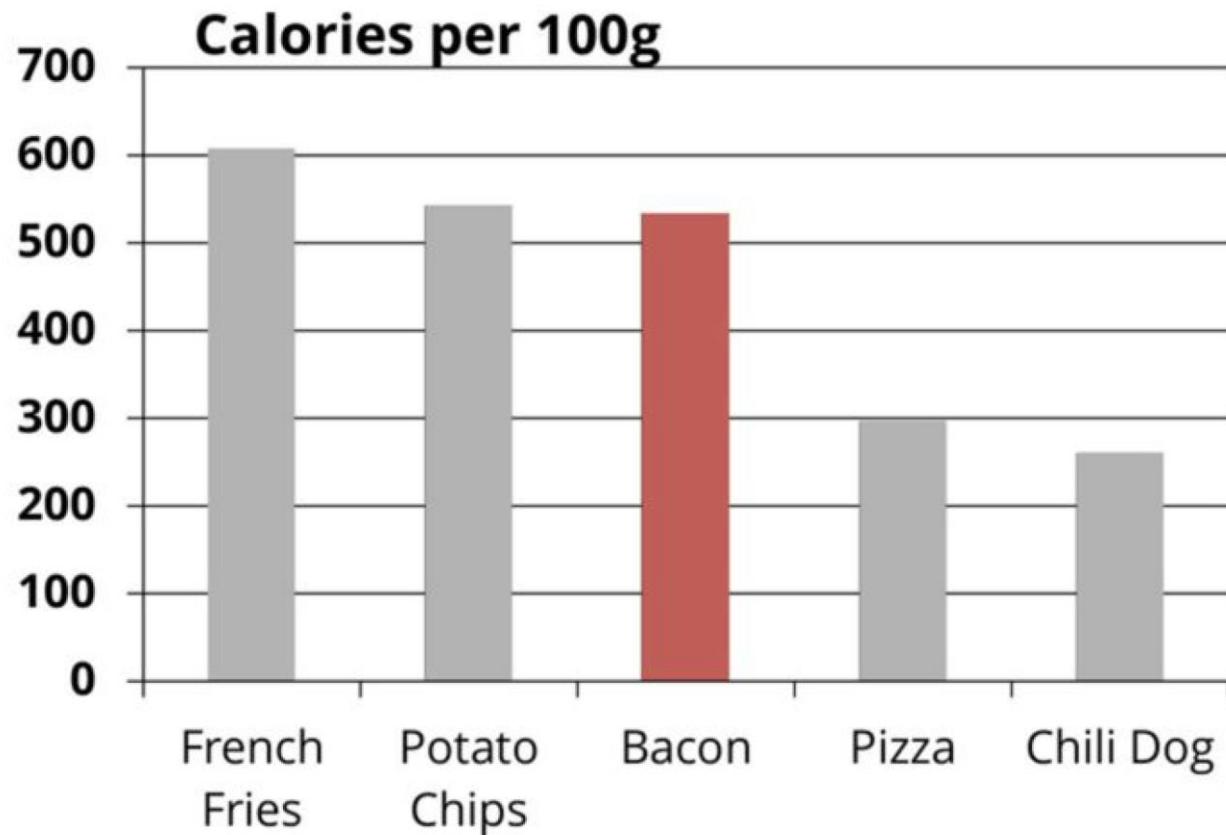
Remove special effects



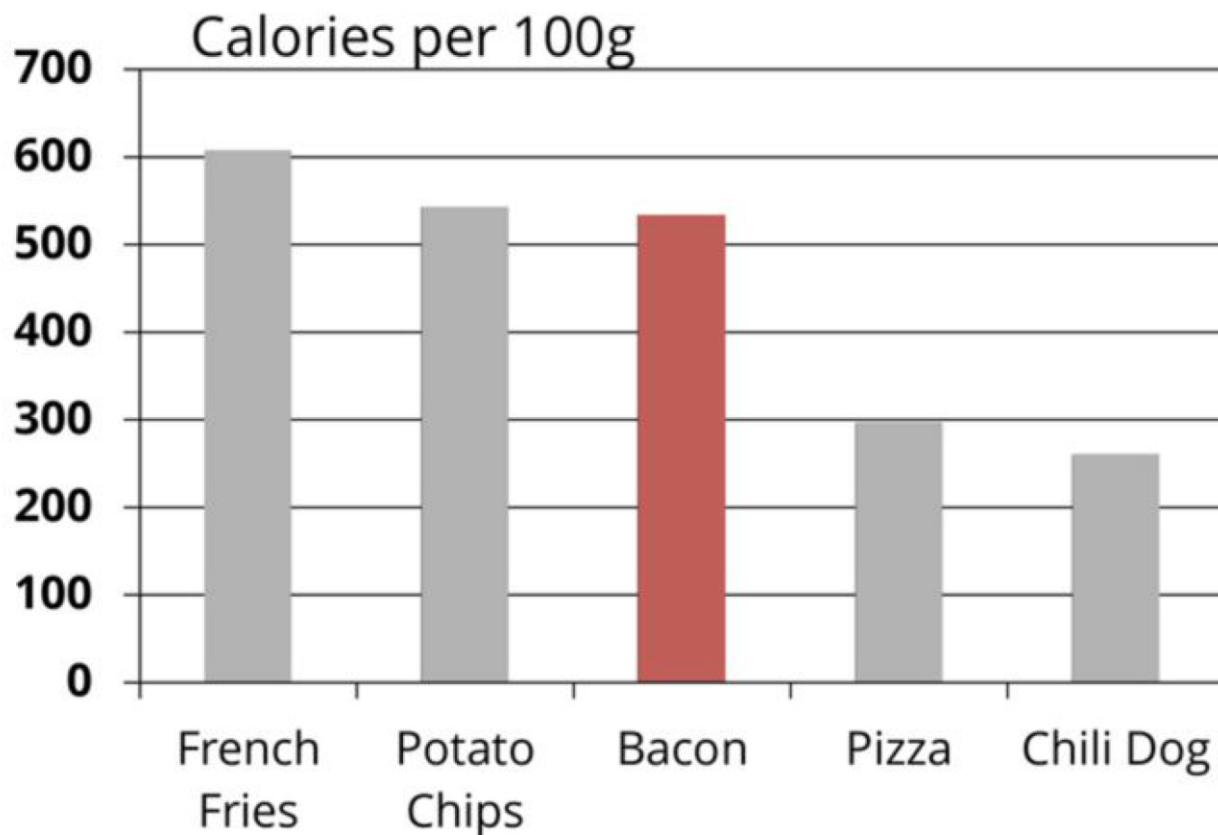
Remove special effects



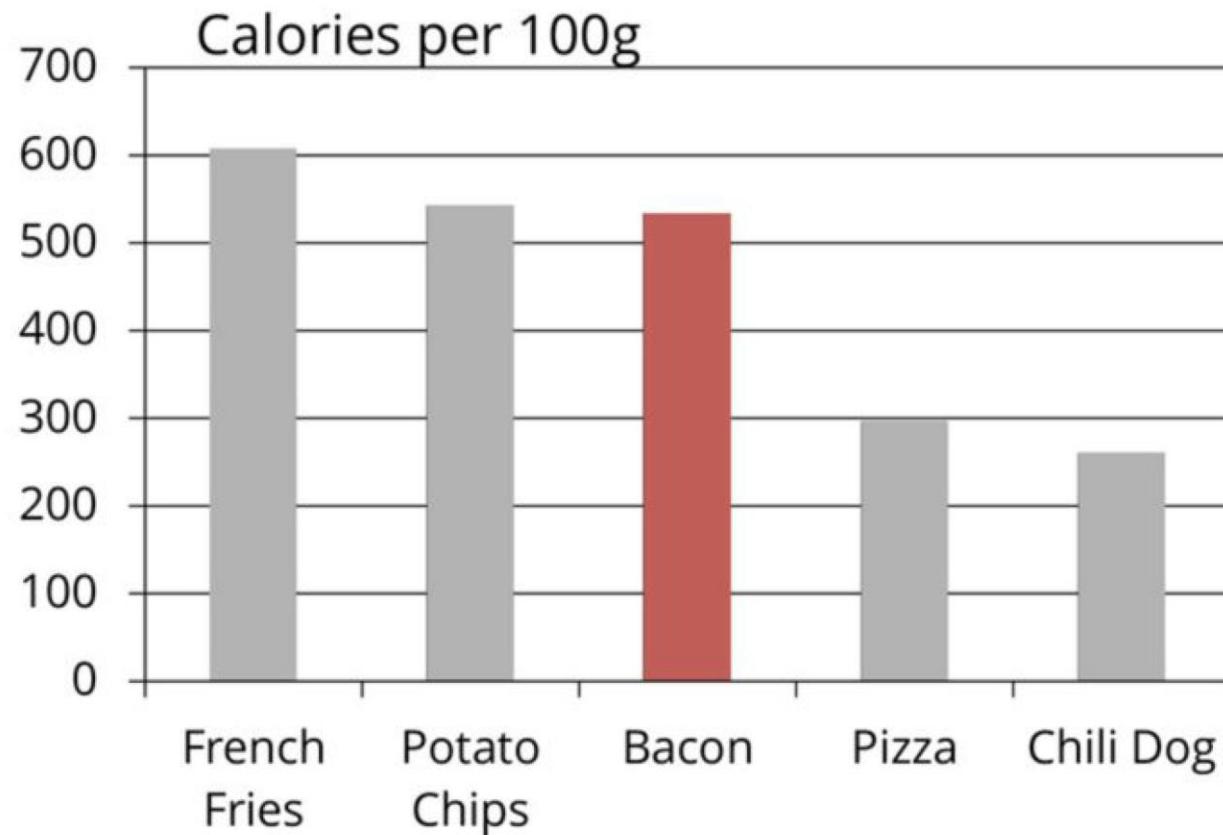
Remove bolding



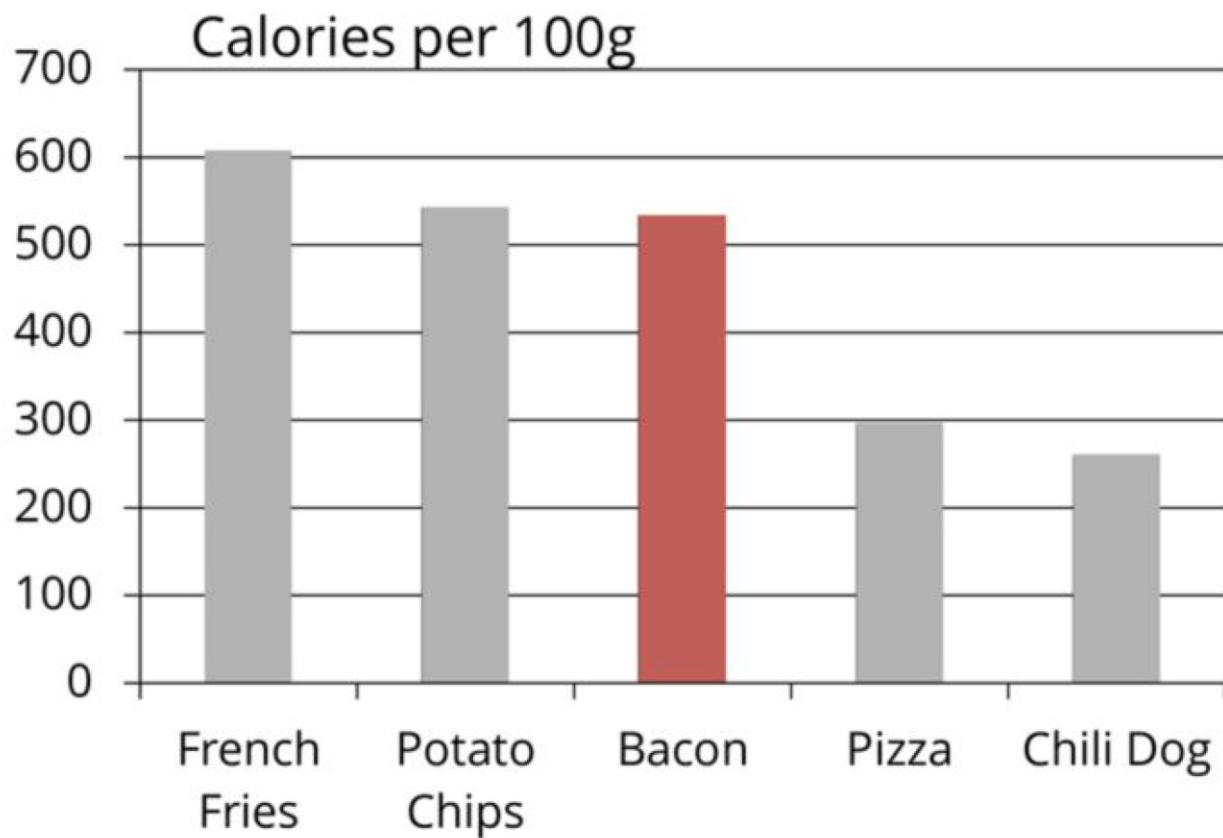
Remove bolding



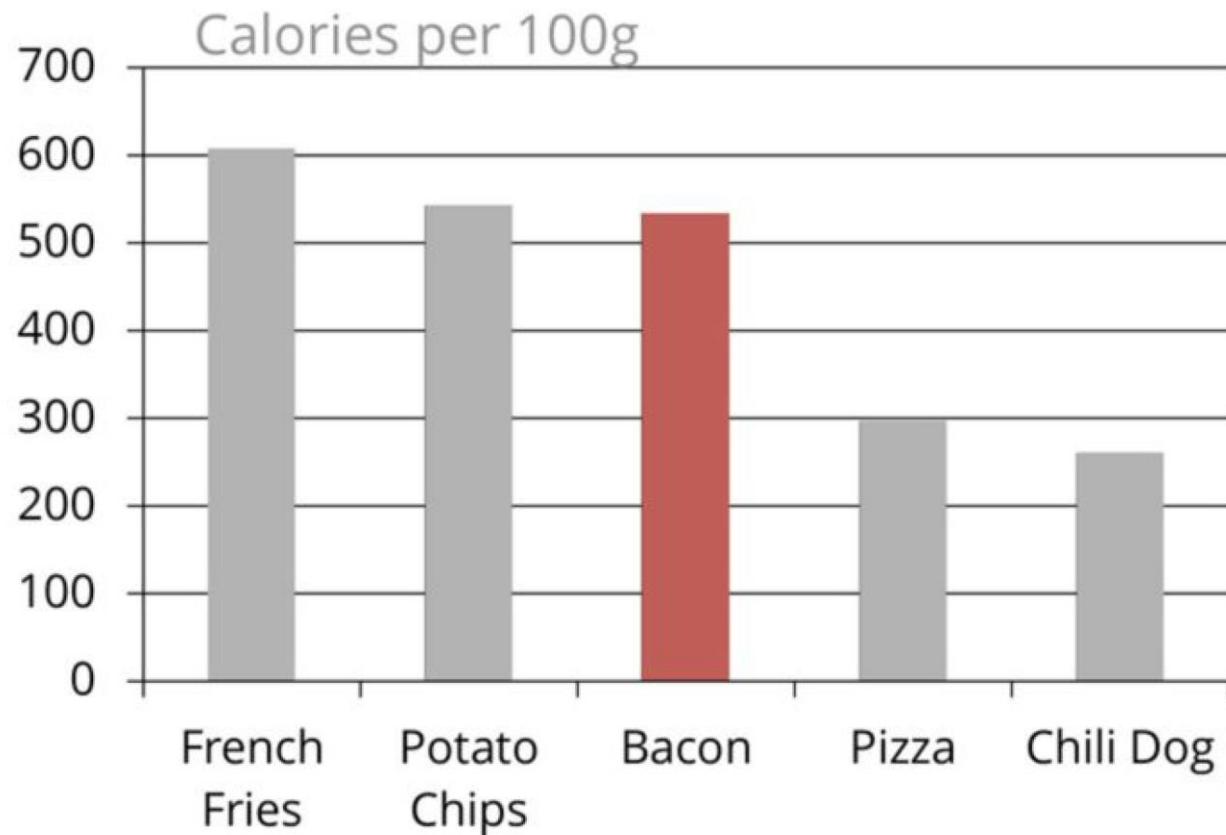
Remove bolding



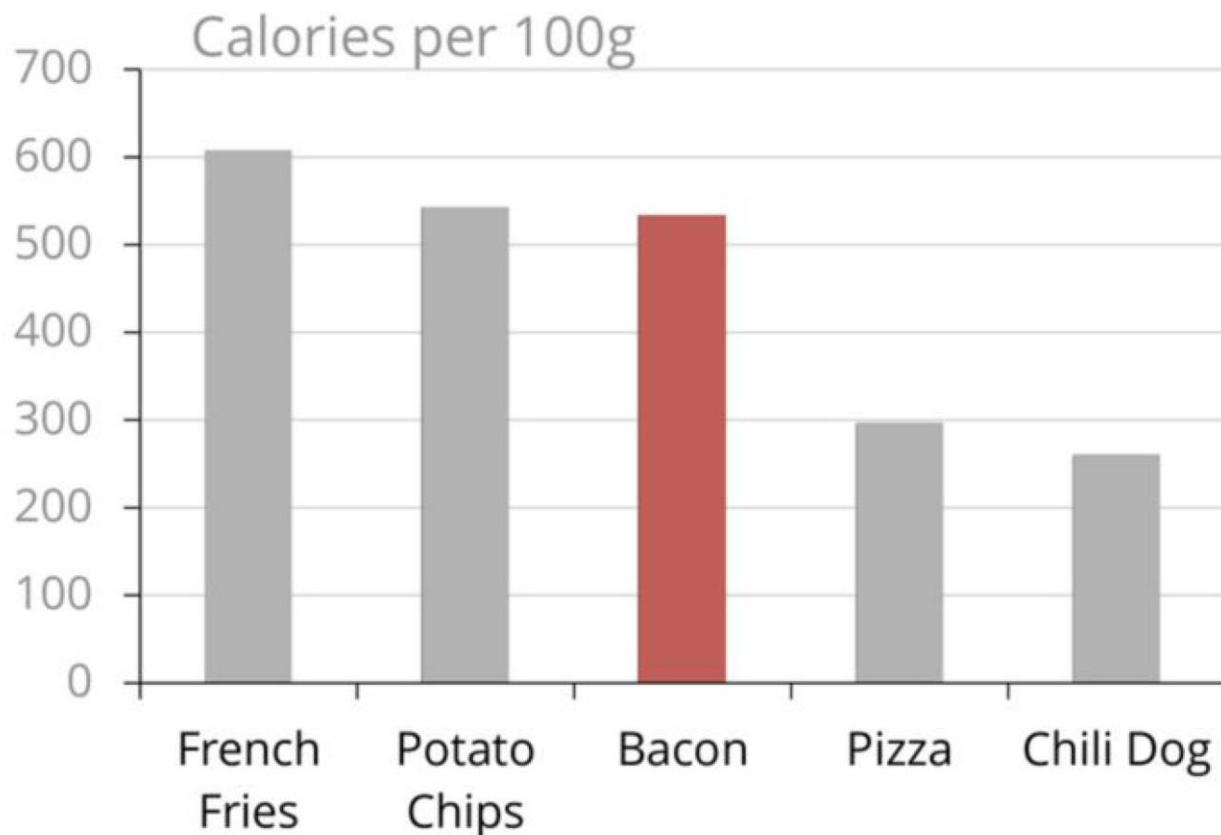
Lighten labels



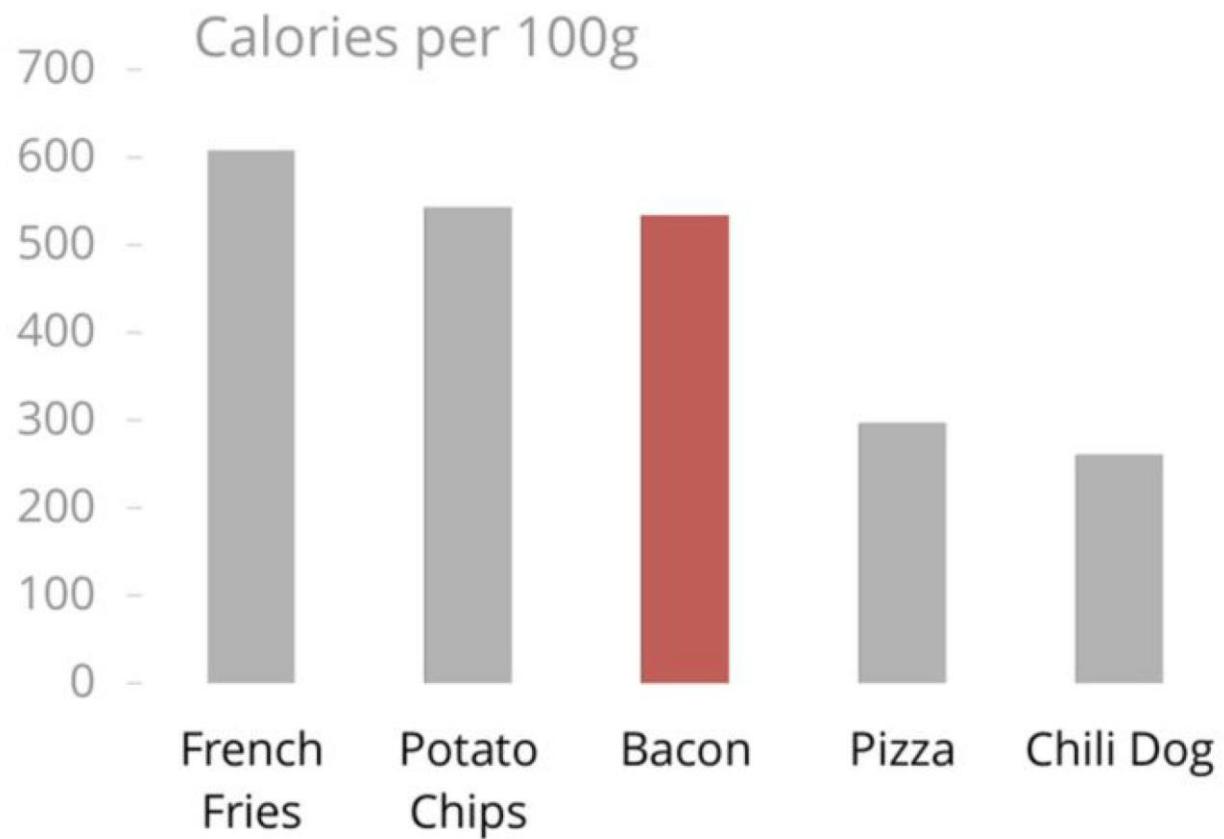
Lighten labels



Lighten lines



Direct label

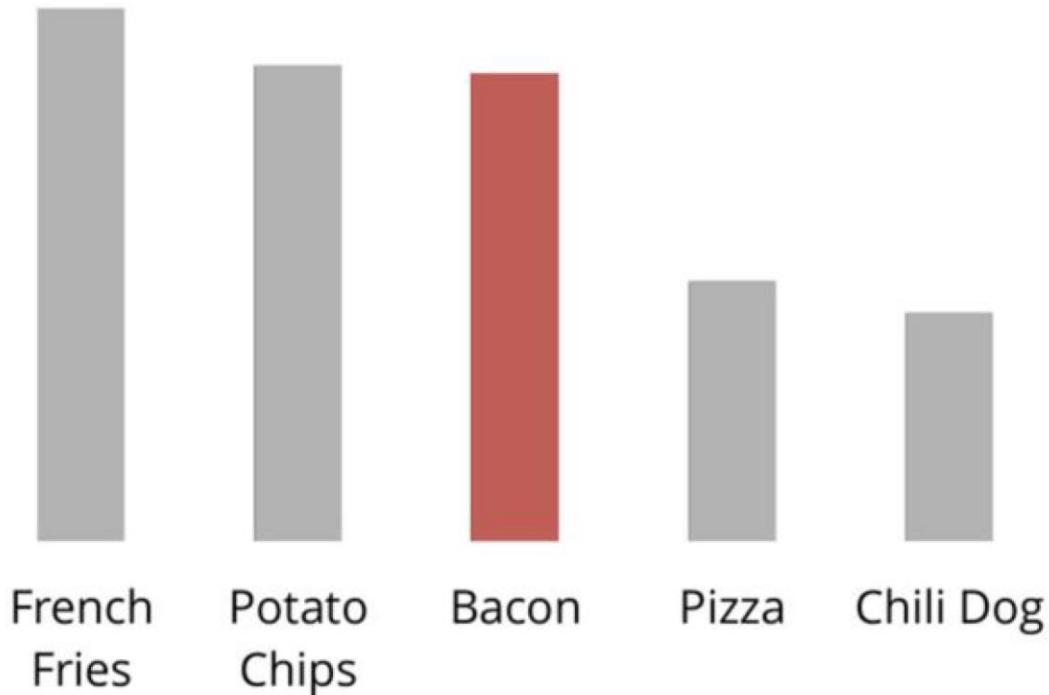


Direct label

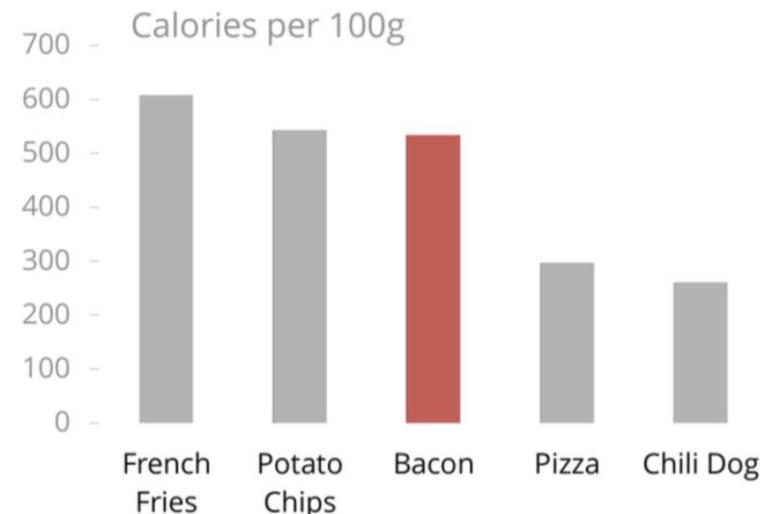
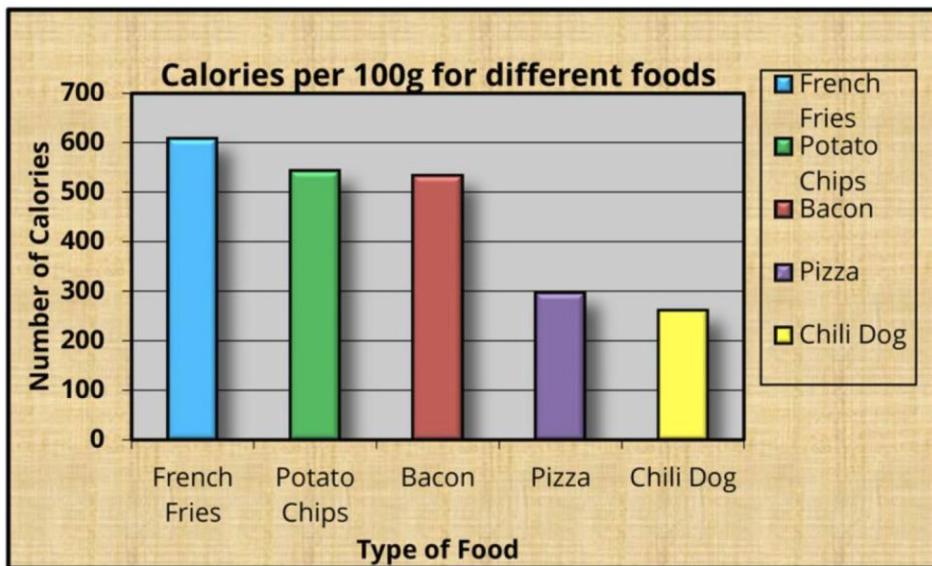
One step too far?

Calories per 100g

*Tufte: Erase non data ink, **within reason***



Data-ink ratio



Tuftes design principles

- Above all else show the data
 - Maximize the data-ink ratio
 - Erase non-data-ink
 - Erase redundant data-ink
 - Revise and edit
-
- Maximize data density
 - Shrink graphics
 - Use small multiples
 - multifunctioning elements



Data Visualization

Tabular data

Dr. Claudius Zelenka

Kiel University

cze@informatik.uni-kiel.de

Based on *Visualization Analysis & Design*, Tamara Munzner

