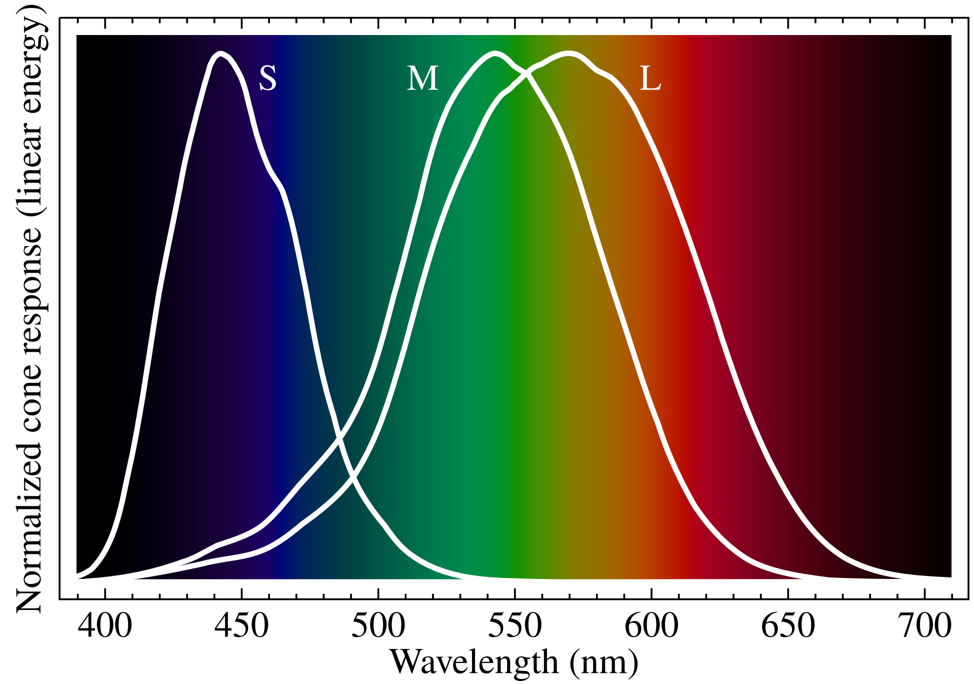
Color

The visual system

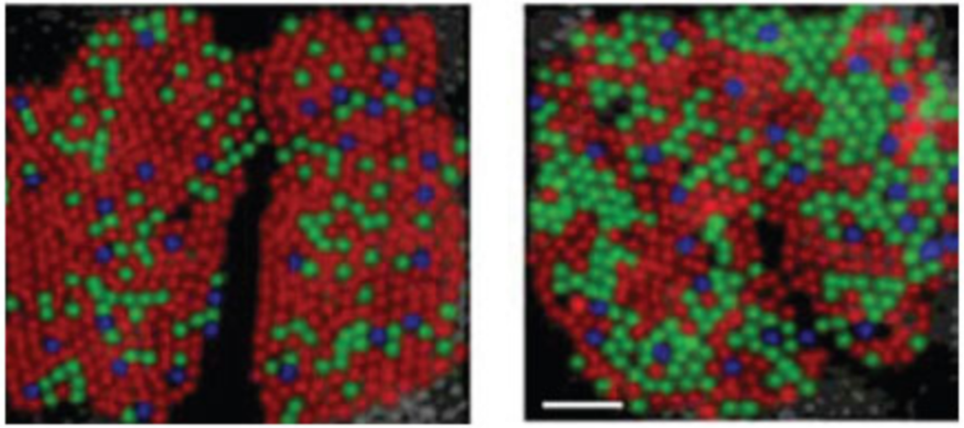
The retina of the eye has two kinds of receptors

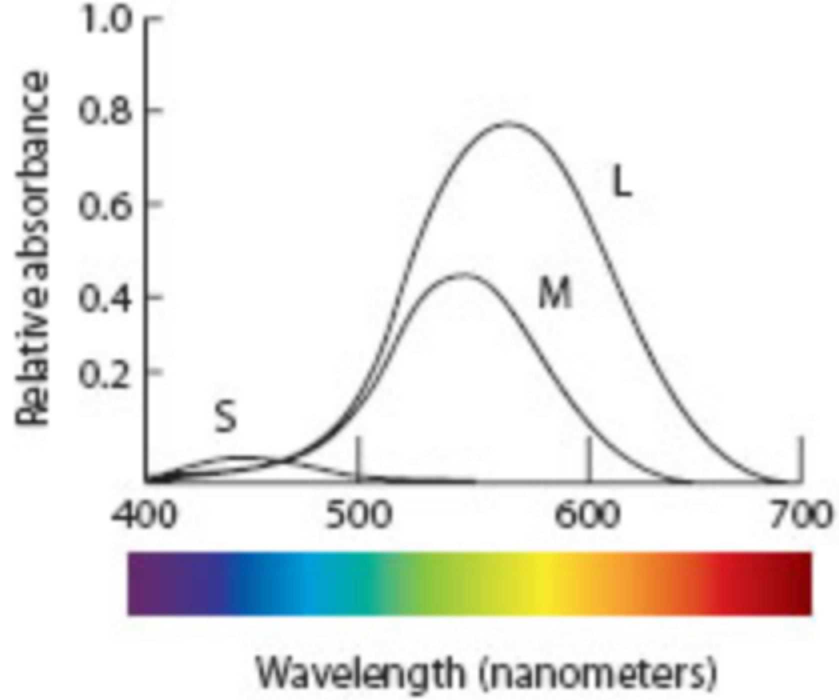
- rods: black and white vision in low light. Little role in the preception of colors.
- cones: color vision in normal light. Concentrated around the visual axis.



Responsivity of human cone cells

The visual system





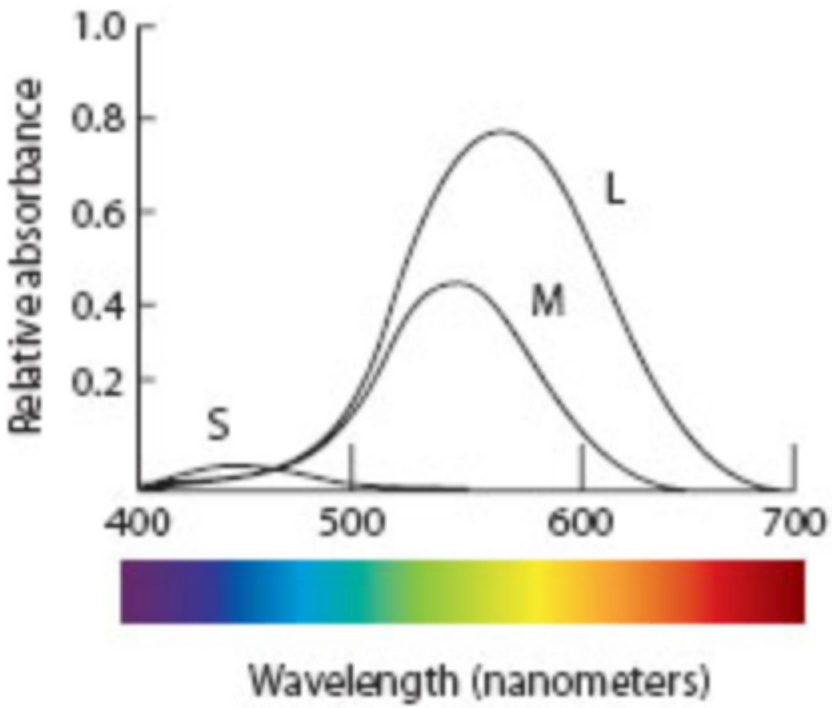
Images from Ware (2008)

How does this impact our work?

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

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

This effect is due to the low sensitivity of cones to blue wavelengths

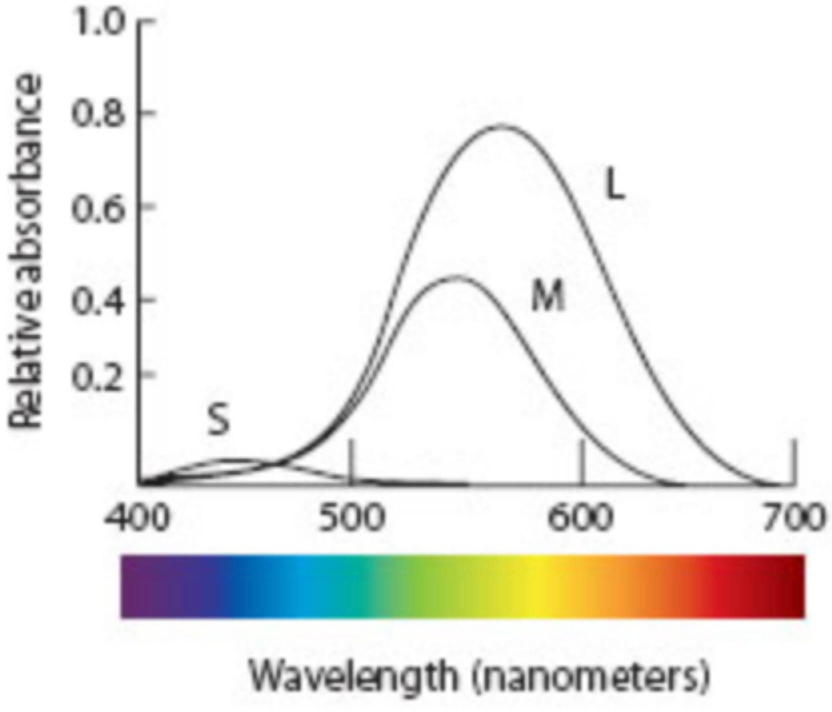


How does this impact our work?

Showing small yellow text on a white 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.

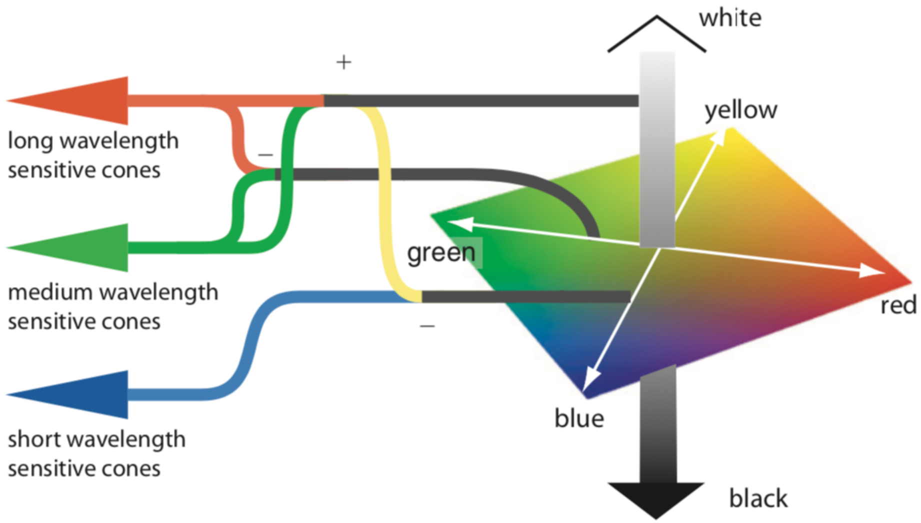
Yellow wavelengths excite two different types of cones, making it almost as light as pure white.

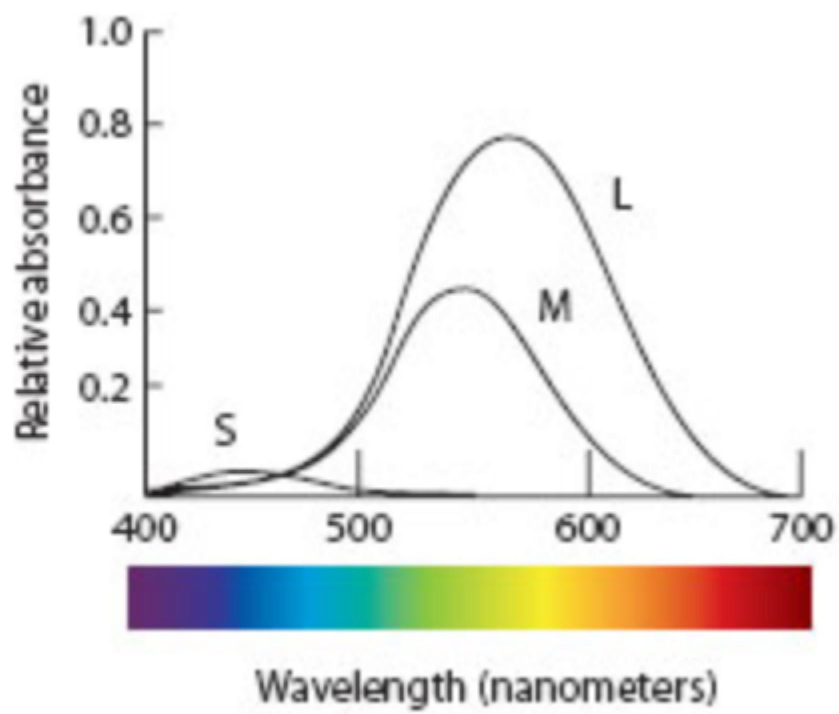


Opponent process theory

The brain *combines* signals from different cones to build three channels:

- Red-Green
- Yellow-Blue
- Black-White





Contrast

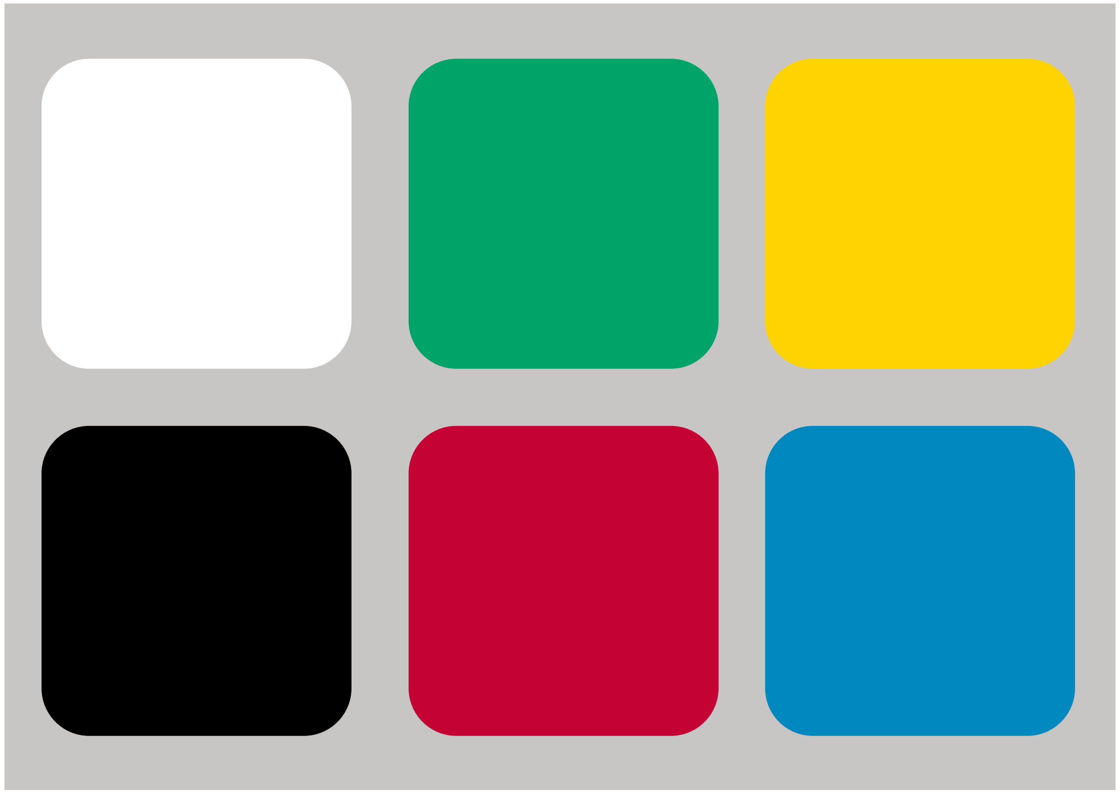
The effect of contrast is distortion of the appearance of a patch of color in a way that increases the difference between a color and its surroundings.

We talk about luminance contrast when it occurs on the black-white channel, and chromatic when it occurs on the other two channels

This phenomenon is called simultaneous contrast, where the background interpheres with our perception of a patch of color. It can create problems when reading values from a graphic.

Unique hues

When there is a strong positive or negative signal on one of the three channels, and a neutral one on the other two, we have “special” colors



In most languages, these six colors are identified as the basic ones [Brent Berlin and Paul Kay, 1969. *Basic Color Terms: Their Universality and Evolution*]

Color blindness

A considerable number of people is missing one or more color channels. Most commonly, the missing channel is the red-green one.

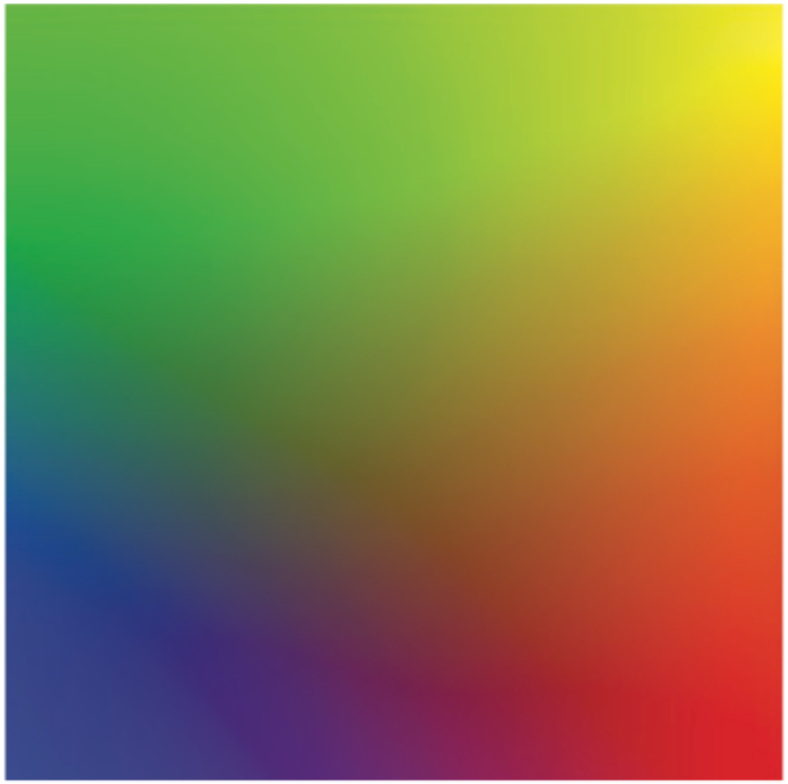
As we shall see, when designing a color scale we need to take this into account in order to be inclusive.

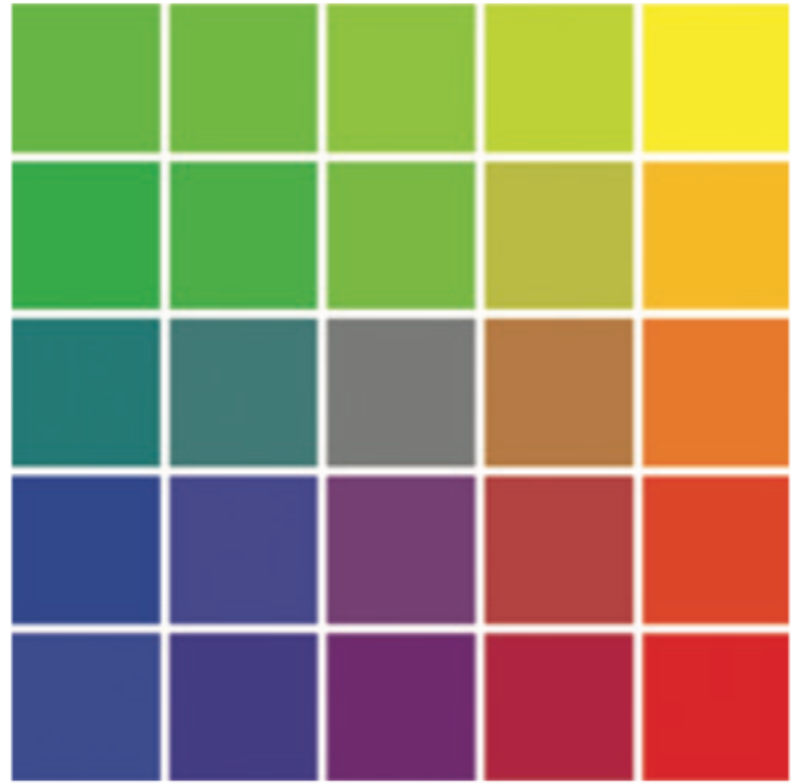
Saturation

Colors inducing a strong response on the chromatic channels are more “vivid”, and are said to be more saturated.

The maximum saturation for a given hue varies with luminance, because when colors are dark the difference between cone signals on chromatic channels is smaller.

Color segmentation

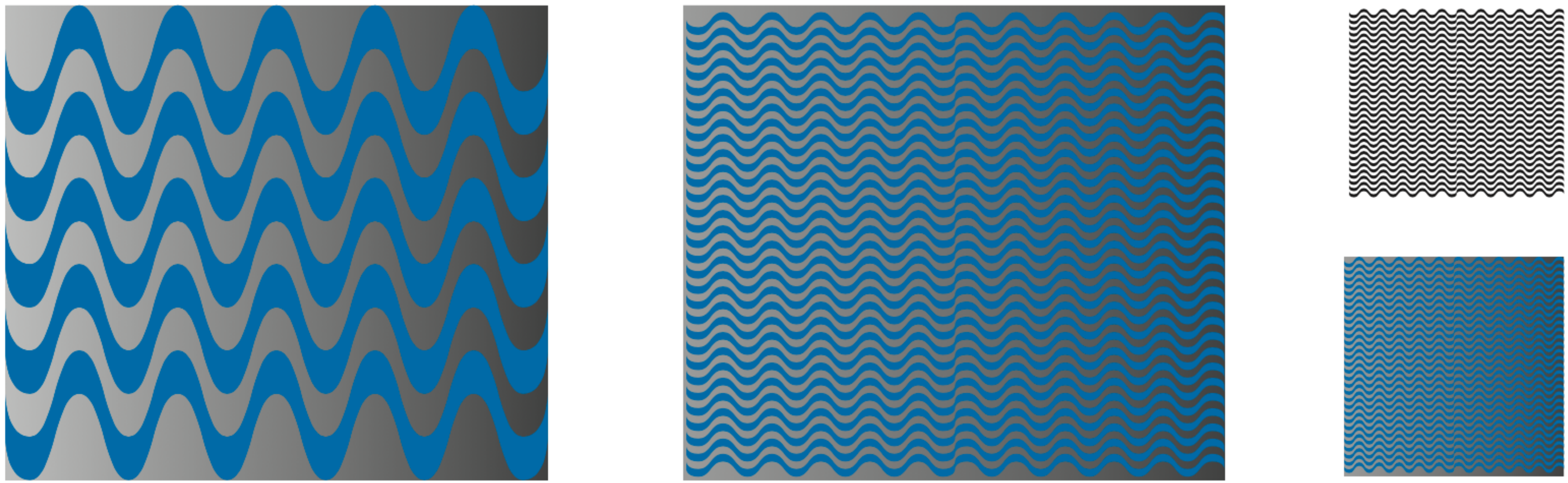




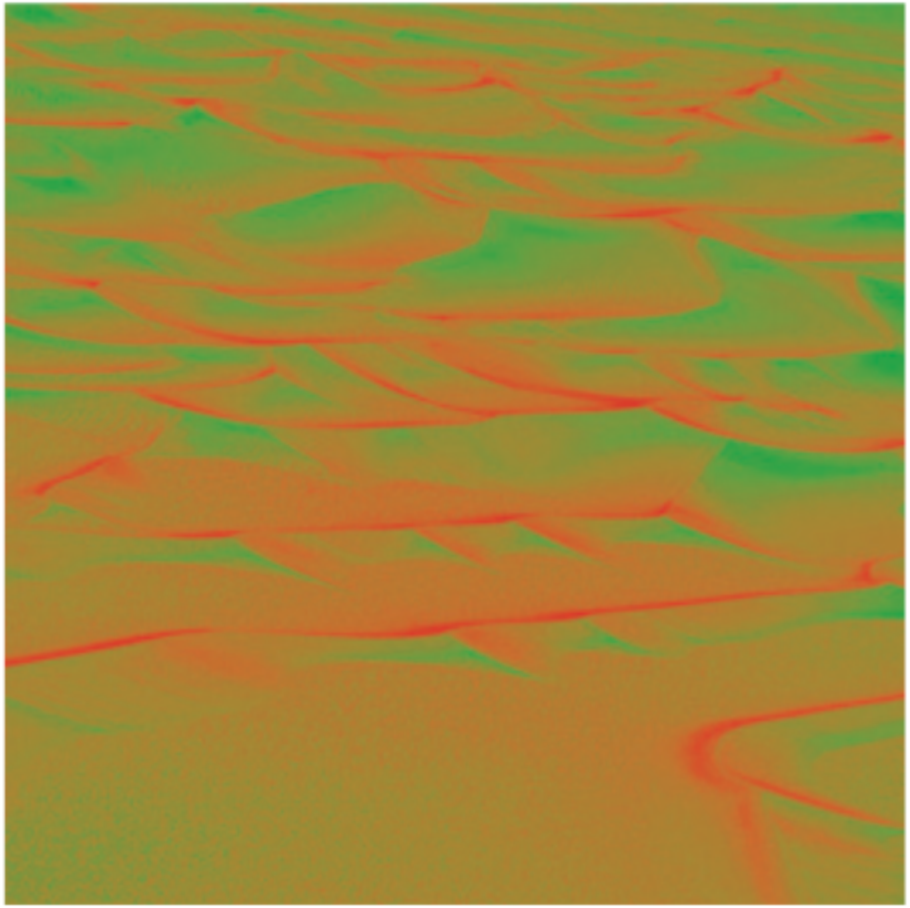
Remember the discriminability issue? Here is it at play!

Spatial detail

The luminance channel is more effective at conveying spatial details.



Recovering shapes from shades



We perceive three dimensional surfaces through changes of luminance, rather than through chromatic changes.

Color spaces

> To work with colors, we need to agree on a representation. Such representations of colors are called **color spaces**

The RGB color space

$(red, green, blue)$

In computer representations, each component goes from 0 to 255

Why red, green and blue? This is the set of colors with the widest *gamut*, that is the set of all colors that can be defined by means of combining the three primary colors.

(235, 91, 52) xxxx `#eb5b34`

Color spaces

RGB is computationally convenient, but is a poor fit for how our eyes work: it is not perceptually accurate.

In a perceptually uniform color space, colors with the same perceptual distance are at the same distance in the space.

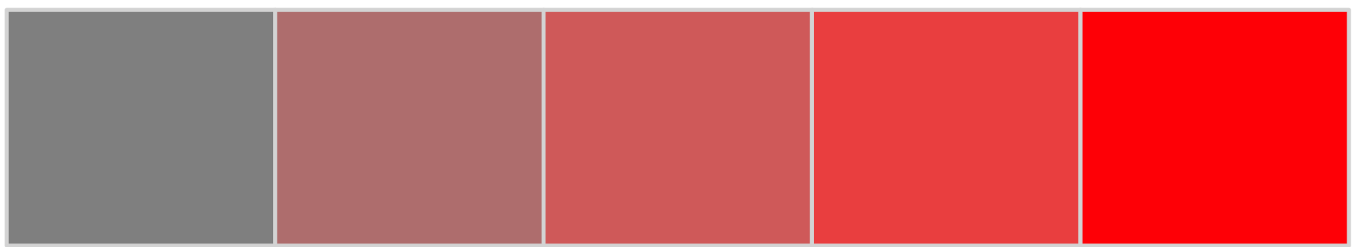
HCL color space

HCL - Hue

> What we intuitively think of as pure colors

HCL - Chroma

> The “colorfulness” or intensity of the color. From “vivid” to “muted”



HCL - Luminance

> Intuitively, the brightness of the color, or the amount of black mixed into the color.
> From “dark” to “light”

Interacting with the HSL color space

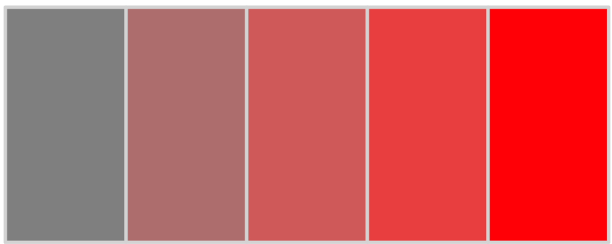
- https://bottosson.github.io/misc/colorpicker
- https://www.hsluv.org/
- https://tristen.ca/hcl-picker

HCL - mapping data types

Hue

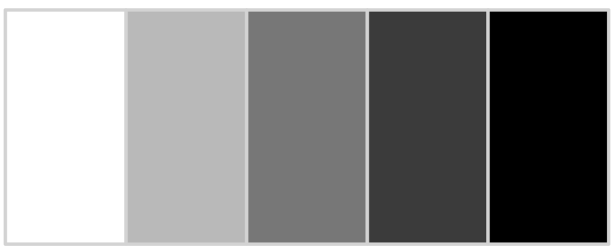
- Qualitative

Chroma



- Sequential

Luminance

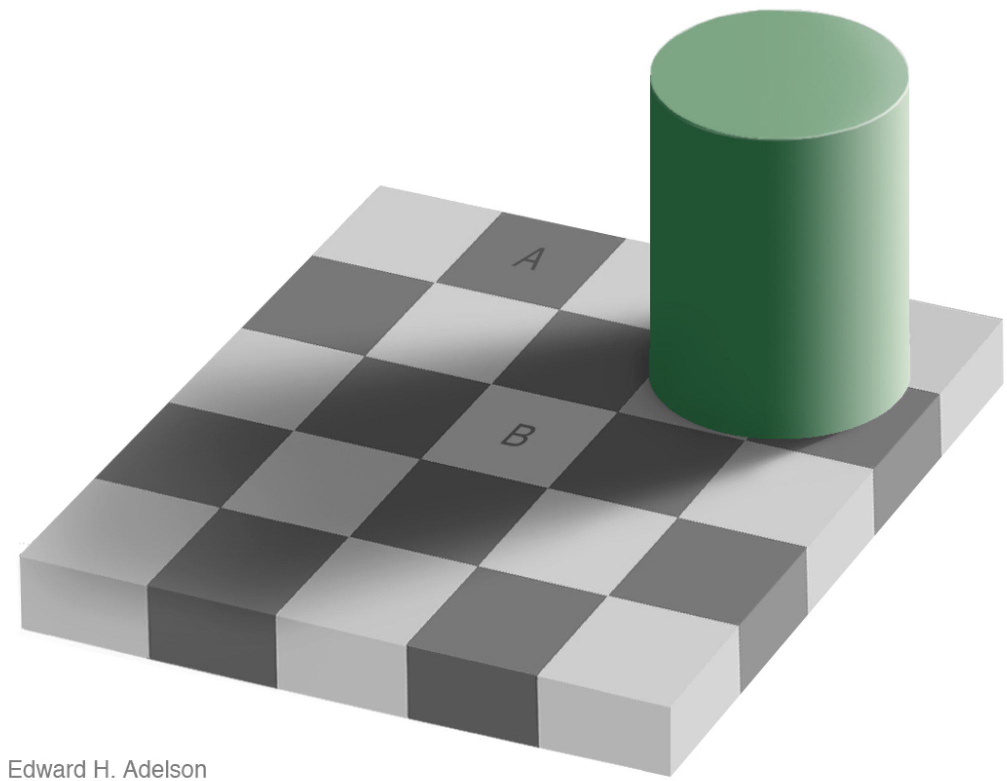


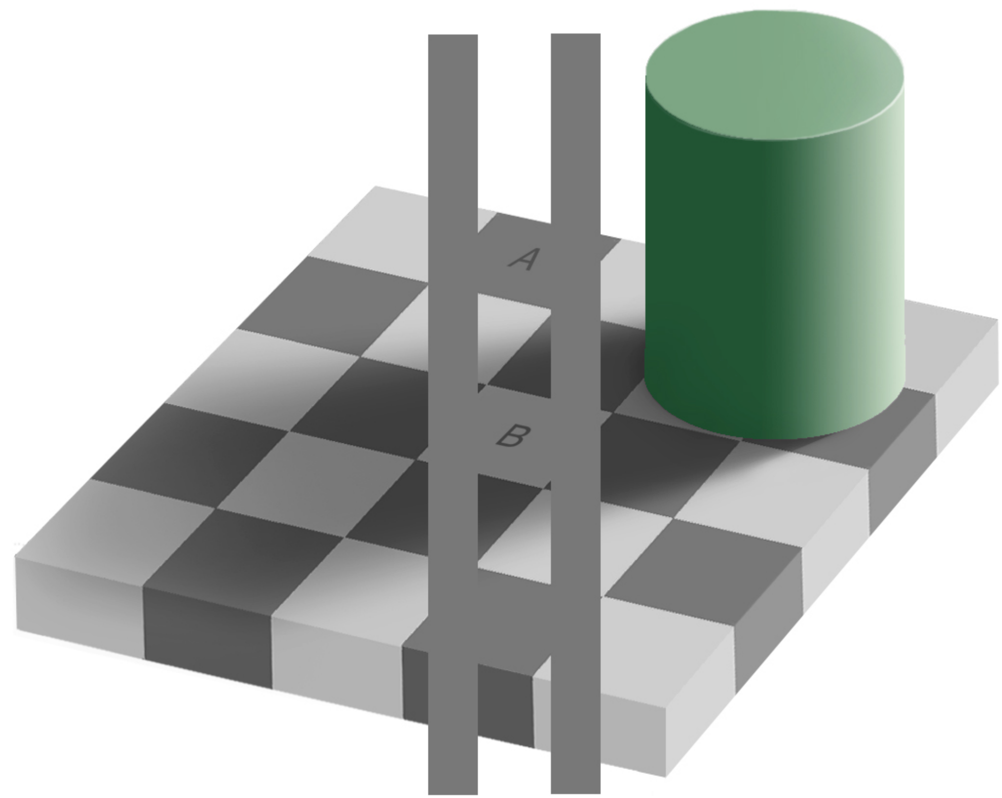
- Sequential

Sequential mapping pitfalls:

Source: https://socviz.co/lookatdata.html#perception-and-data-visualization

Sequential mapping pitfalls:





Source: https://socviz.co/lookatdata.html#perception-and-data-visualization

Sequential mapping with Chroma and Luminance

Because of the effects above, it is best not to encode more than 3 to 5 levels using the Chroma or Luminance channel, if we want our readers to be able to distinguish the levels (discriminability)

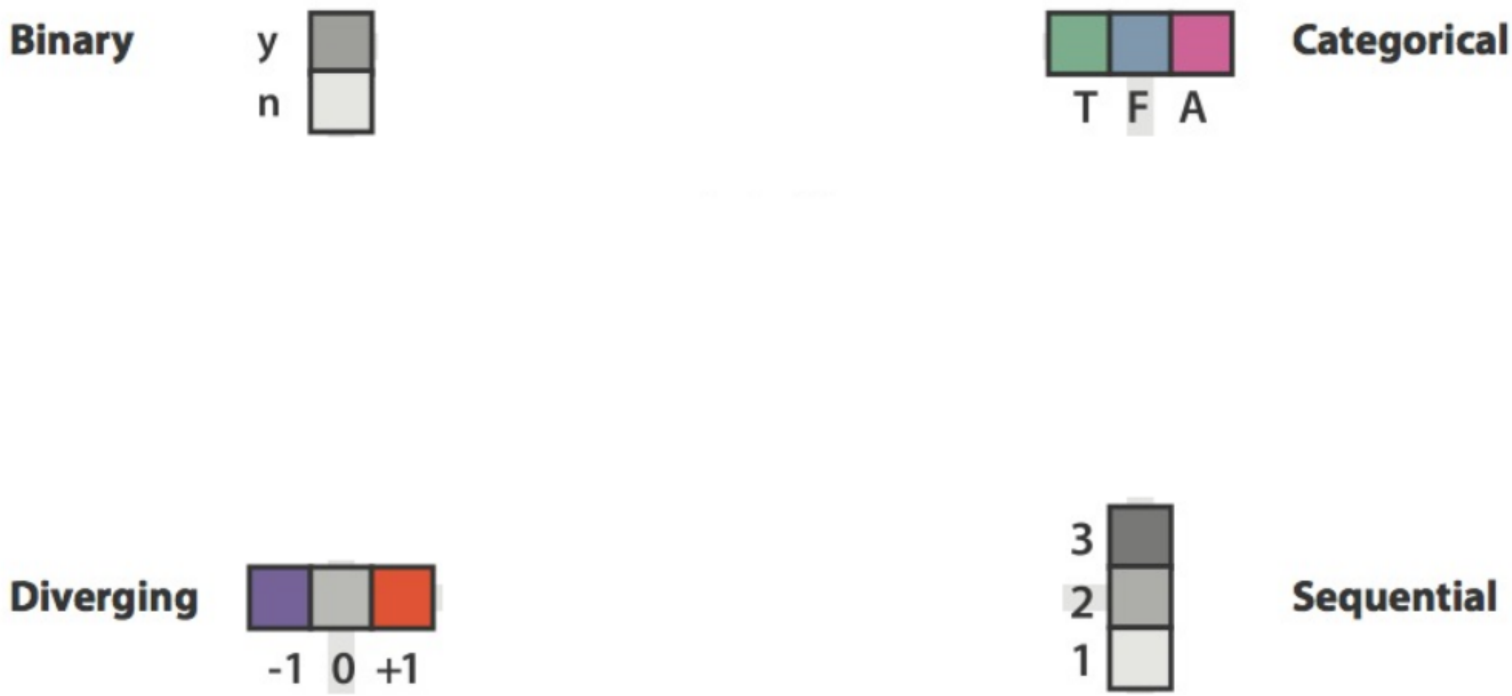
Colormaps

> A colormap specifies a mapping between colors and data values

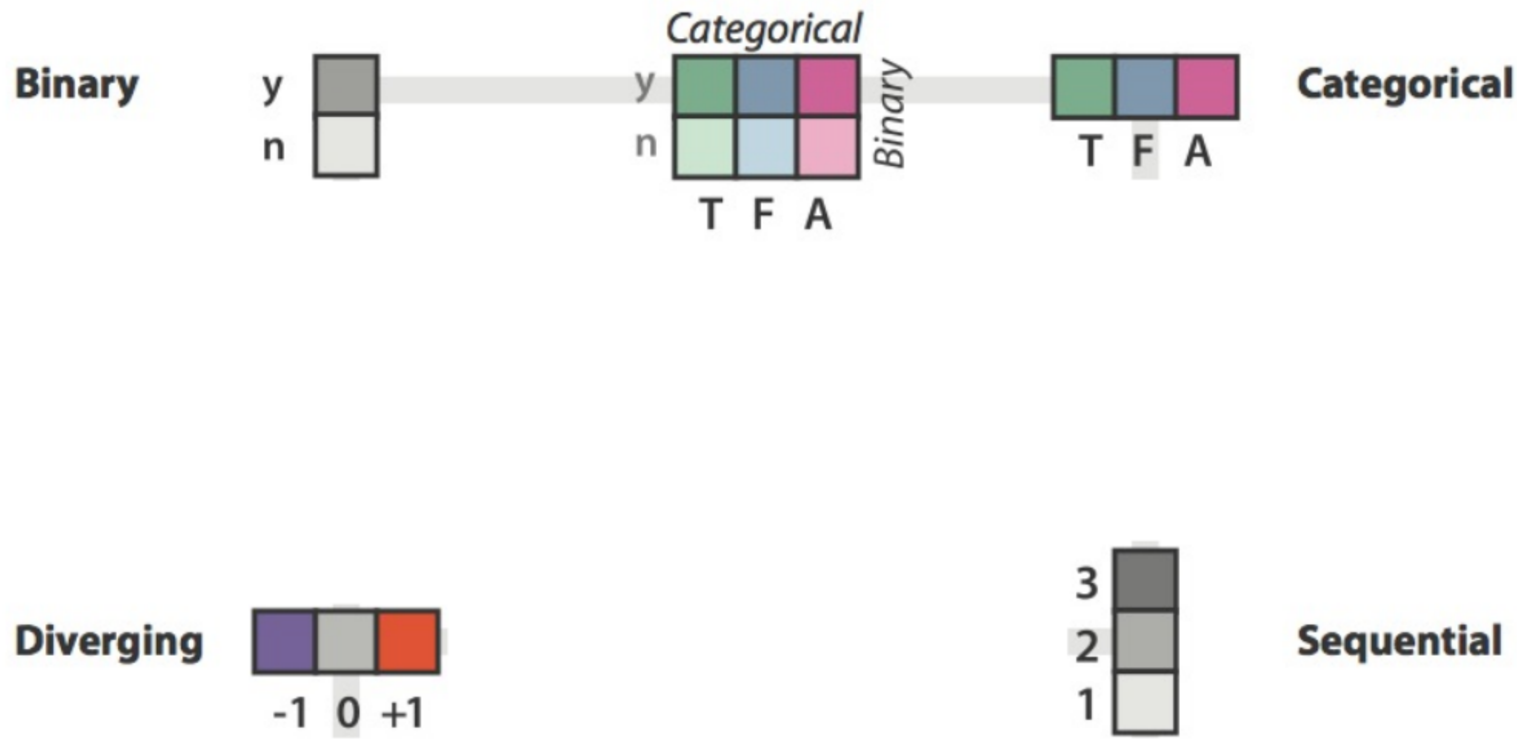
- Categorical
- Ordered
  - Sequential
  - Diverging

- Continuous vs. discrete

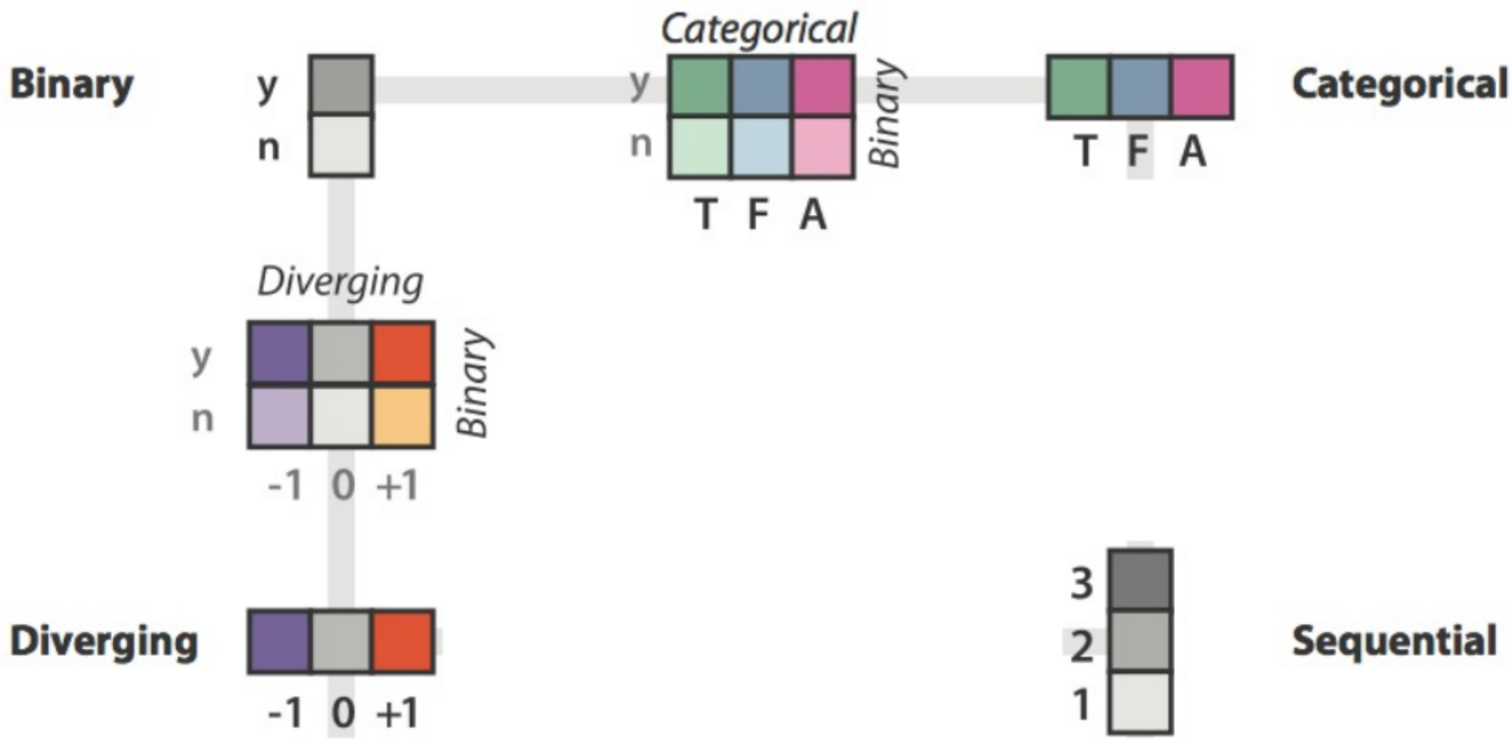
Encoding with color, a summary



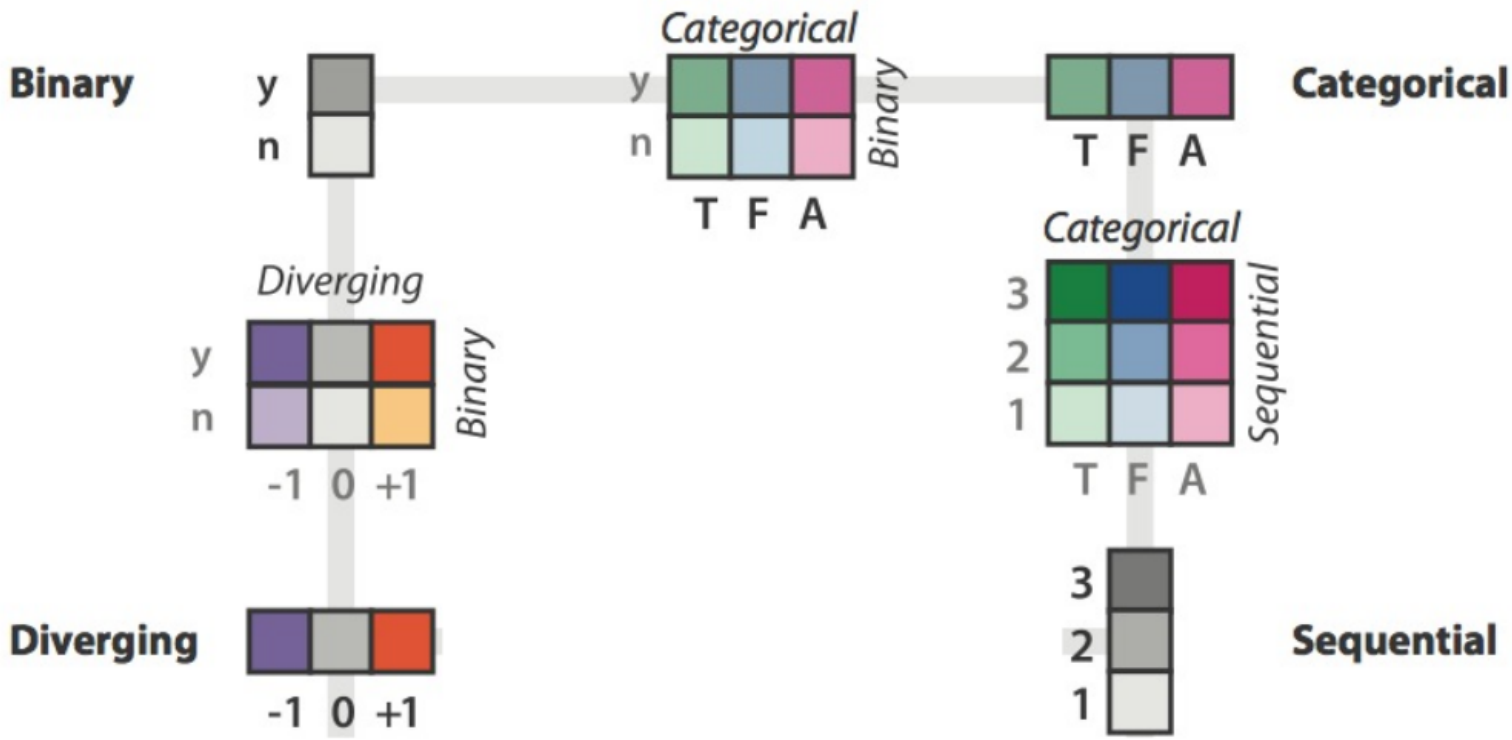
Encoding with color, a summary



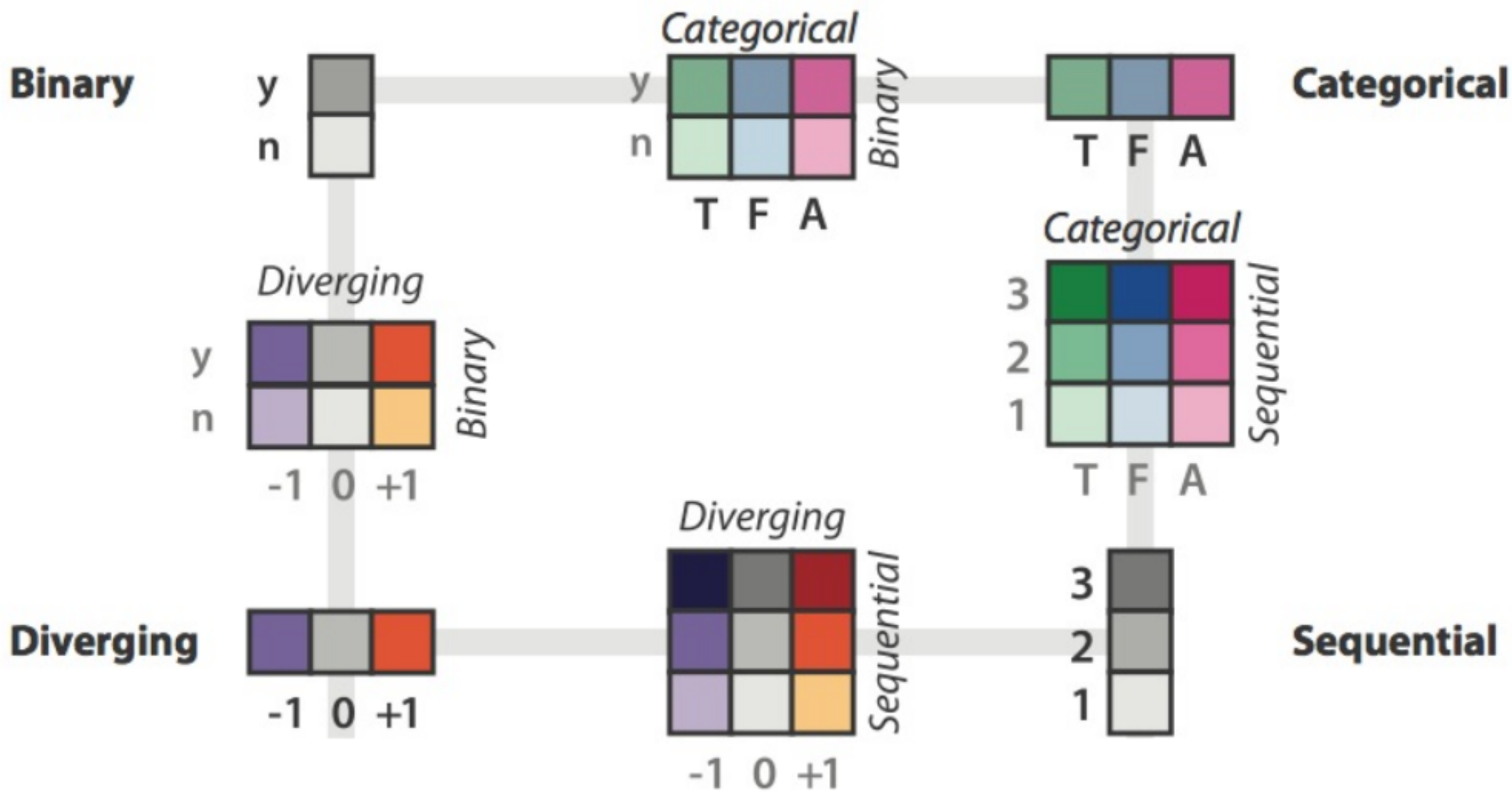
Encoding with color, a summary



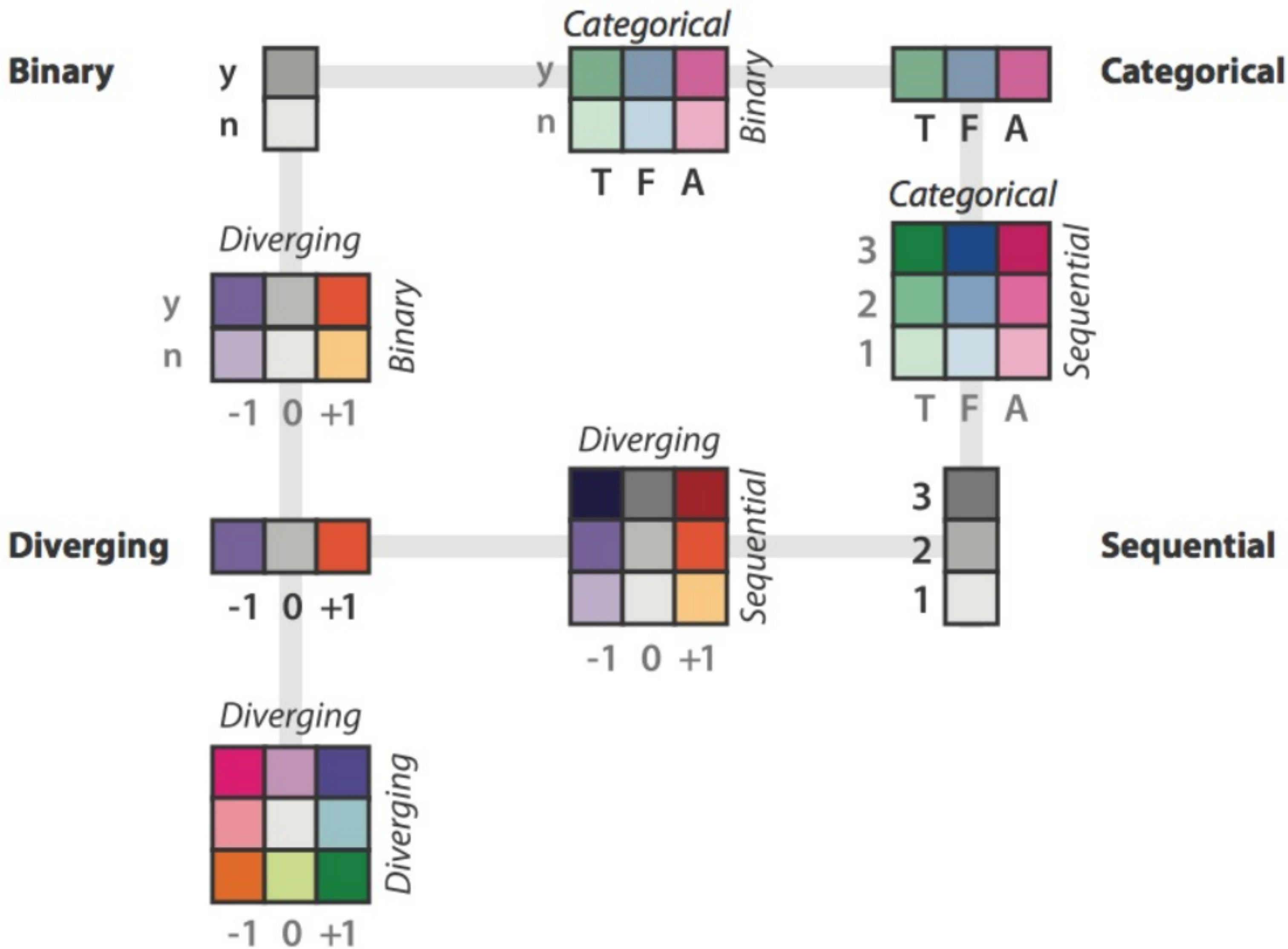
Encoding with color, a summary



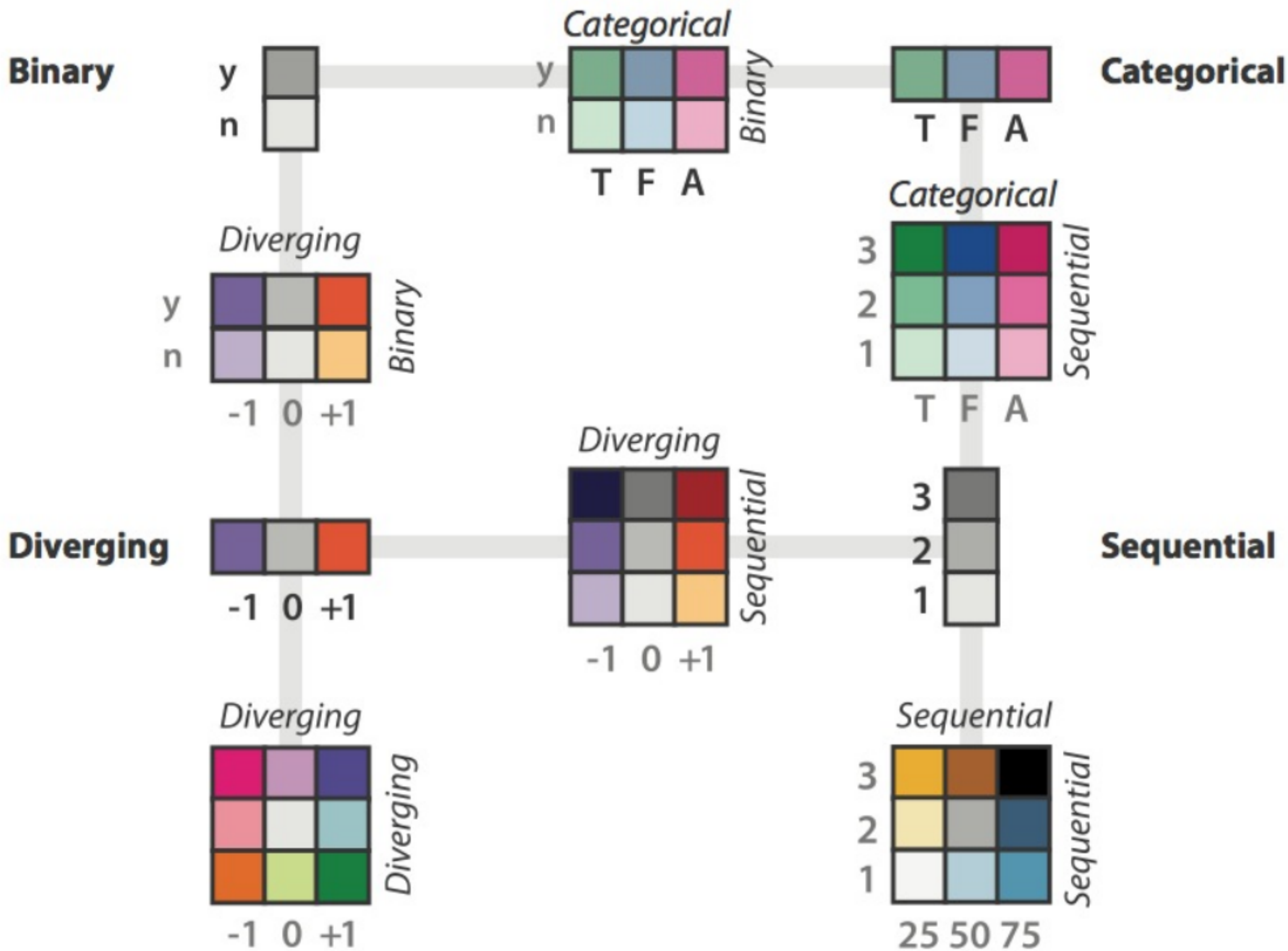
Encoding with color, a summary



Encoding with color, a summary



Encoding with color, a summary



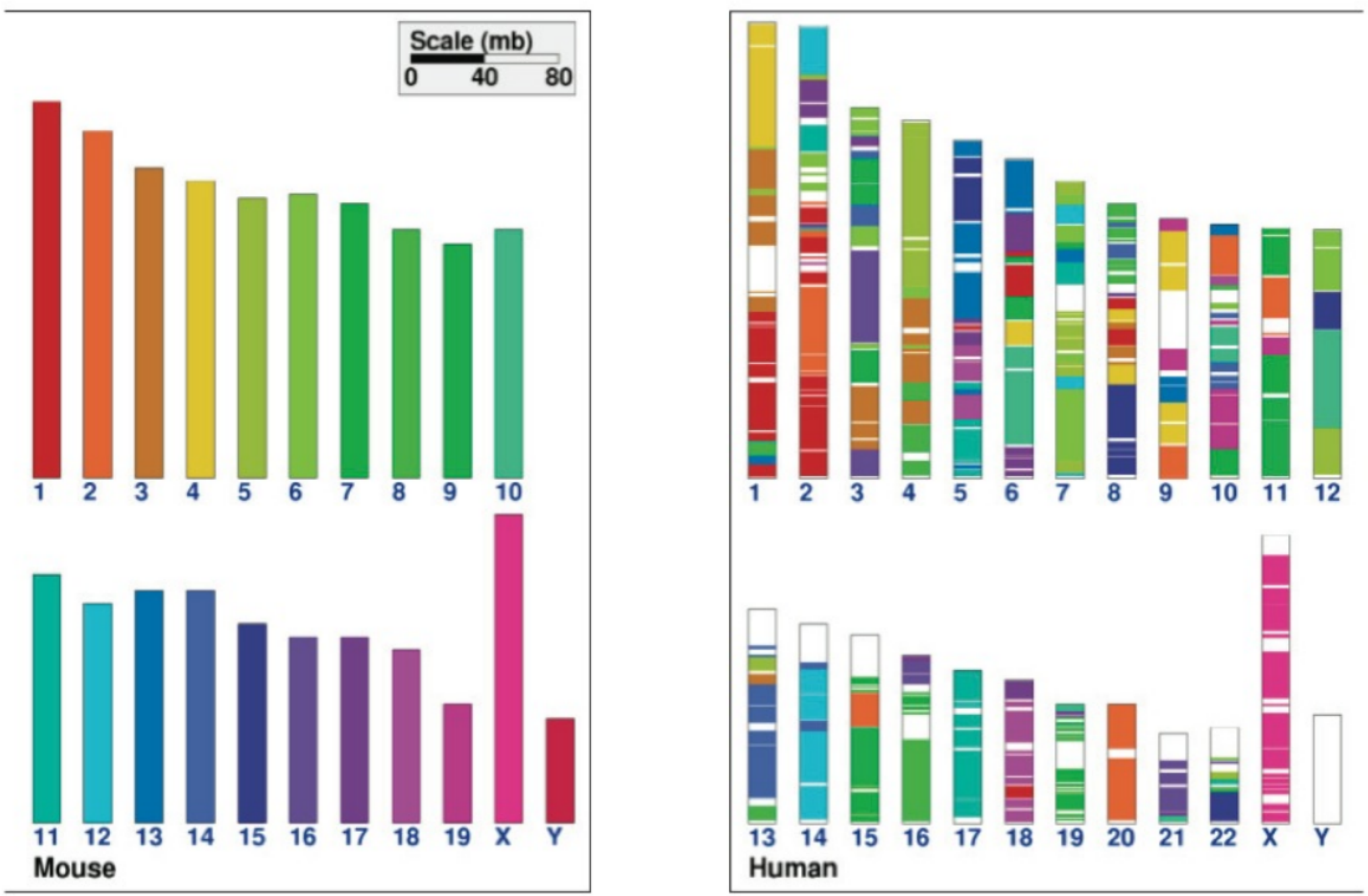
Categorical color maps

- Use mainly hue to encode different categories

There are mainly two things to pay attention to

- We can distinguish just about 12 bins of color, better to stick to at most 6
- Luminance contrast: we need our colored marks to “stand out” from the background.

Categorical color maps - a bad example



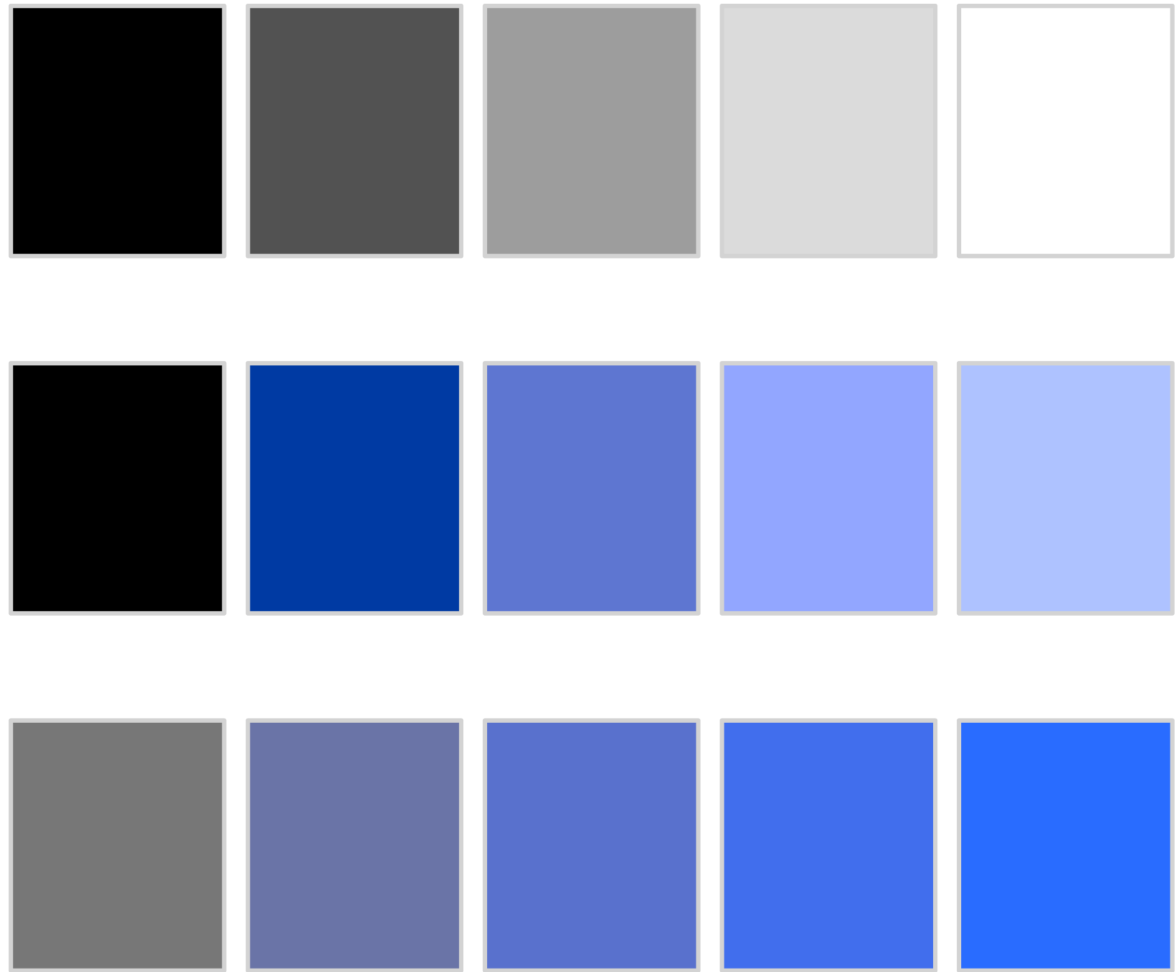
(a) (b)

Ordered colormaps: sequential

Just luminance

Luminance with hue

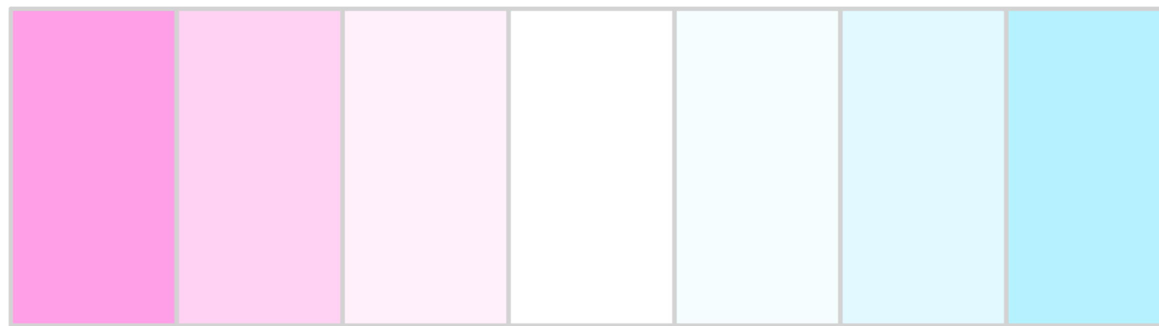
Just chroma



Ordered colormaps: diverging

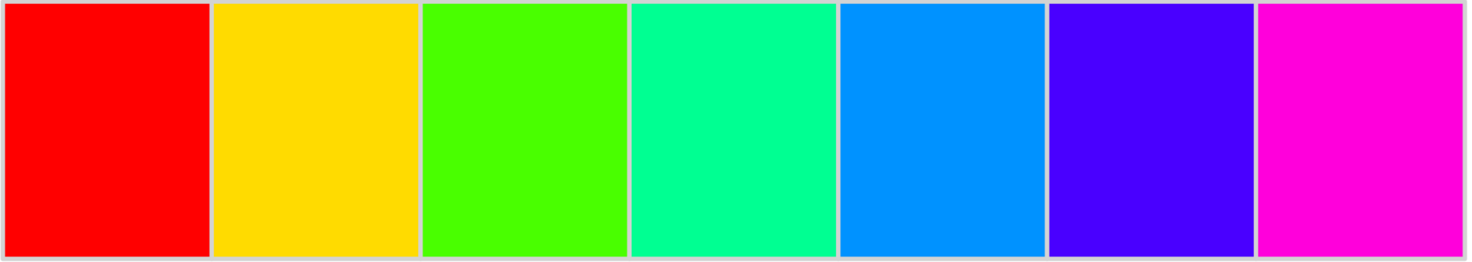
Variable luminance

Variable chroma

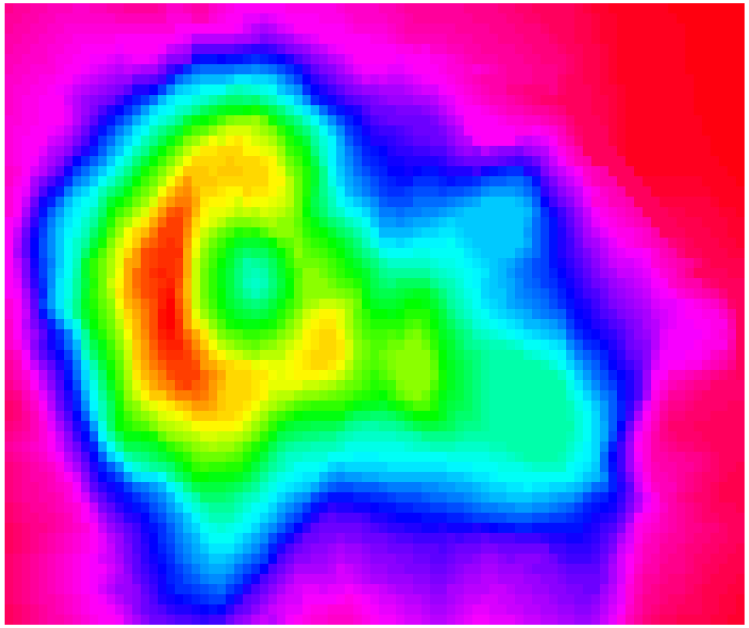


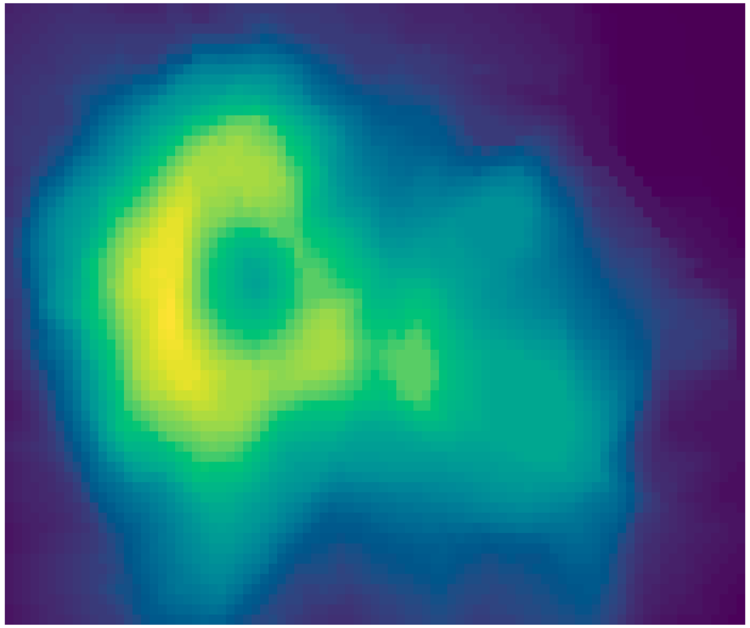
The rainbow color map

It’s often used to encode ordered data, why is it confusing?

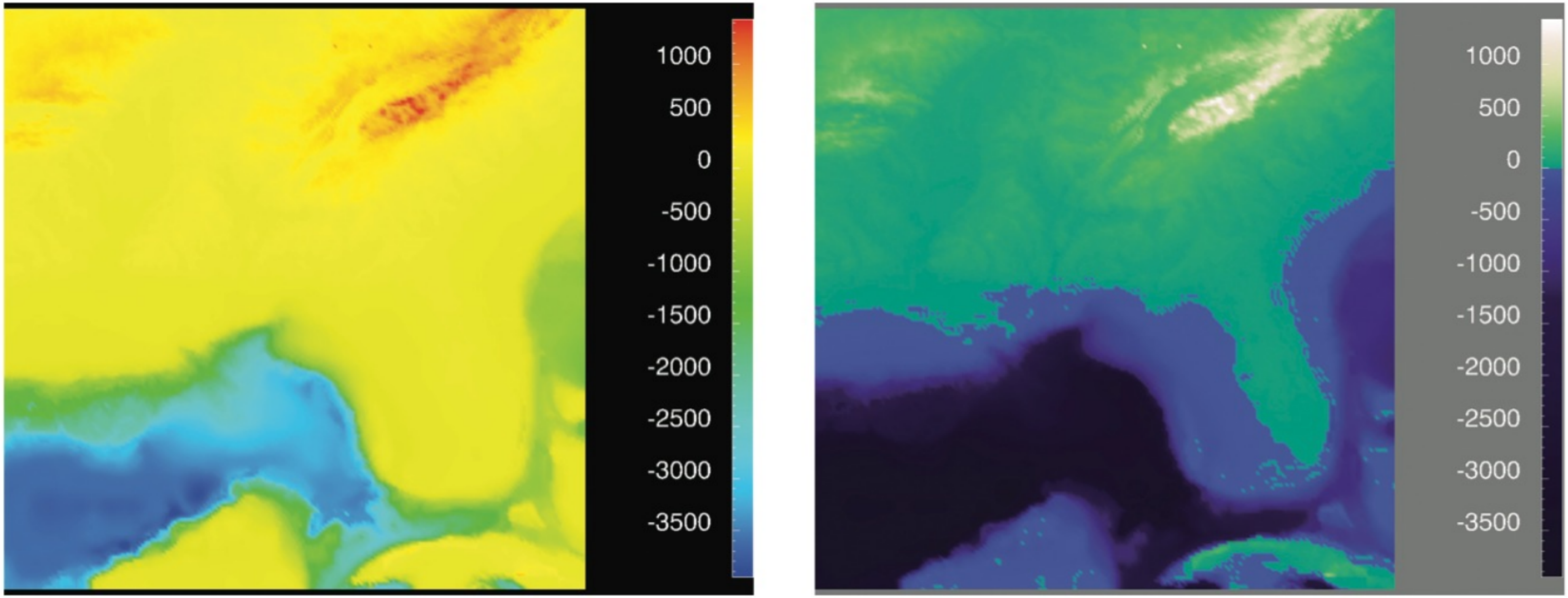


The rainbow color map



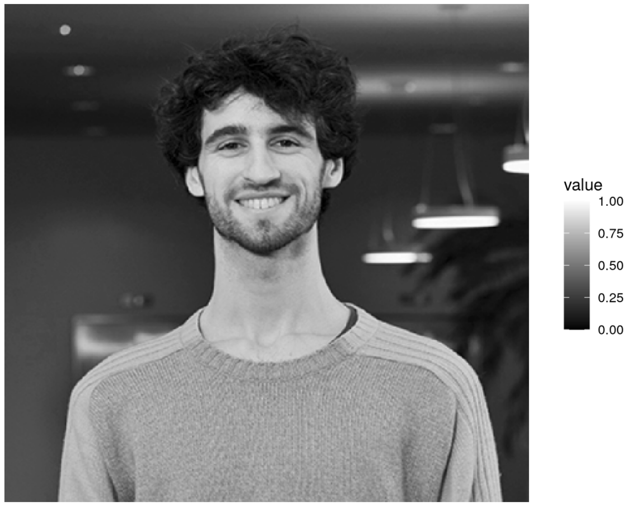


The rainbow color map



(a) (b)

The rainbow color map



An overview of R colormaps

You don’t need to create your colormaps from scratch. R sports a rich collection of colormaps ready for use

```
library(ggplot2)
library(RColorBrewer) # Qualitative. Visit https://colorbrewer2.org
library(viridis)      # Continuous
library(colorspace)   # General color-related utilities
```

Selecting a color palette

Install some additional libraries

```
# In the console
install.packages(c("colorspace", "shiny", "shinyjs"))
```

Call the wizard!

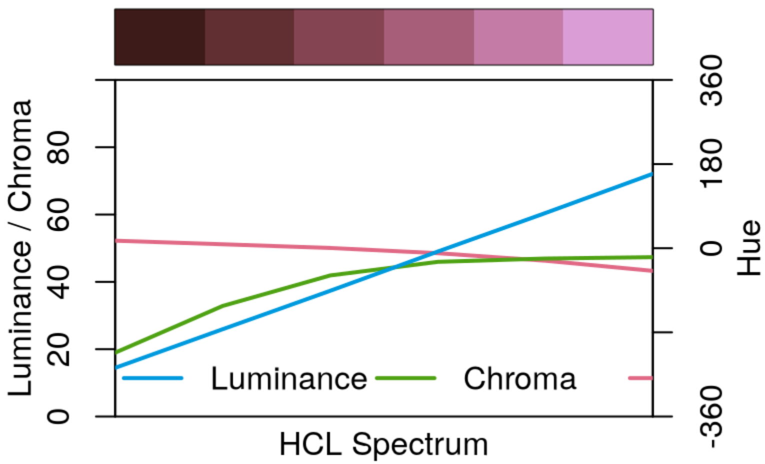
```
colorspace::hcl_wizard()
```

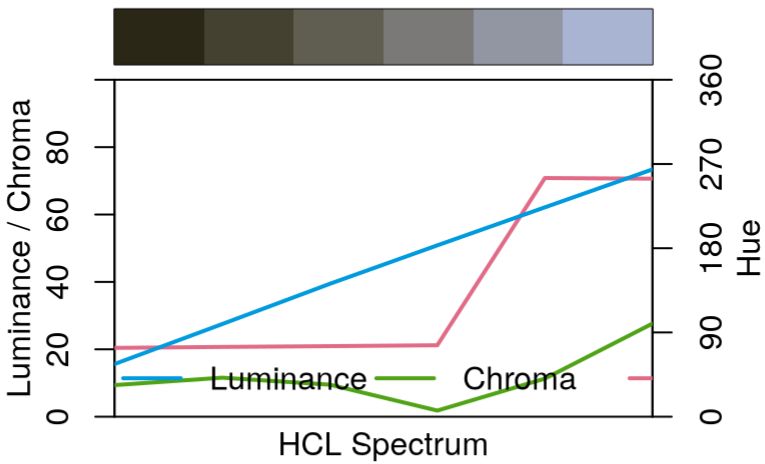
The specplot

The wizard shows, among other things, the `specplot` which reports how the HCL values change in the palette

```r
# You can pass any list of colors
colormap <- c("#3C1B18","#612E32","#854452","#A75E7
specplot(colormap)
```

```r
# Color blindness simulation: deutan, protan, trita
colormap <- c("#3C1B18","#612E32","#854452","#A75E7
specplot(deutan(colormap))
```



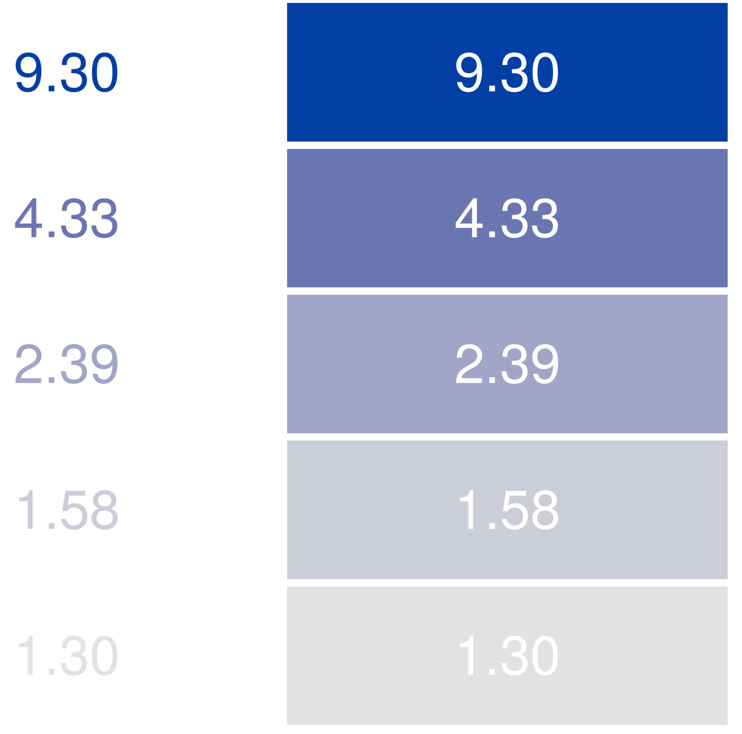


The contrast ratio

The contrast ratio, as defined by the World Wide Web Consortium, is a number quantifying the contrast with the background. It should be higher than 4 for text, as a general guideline

```r
colormap <- brewer.pal(5, "Pastel1")
contrast_ratio(colormap, "white", plot=T)
```

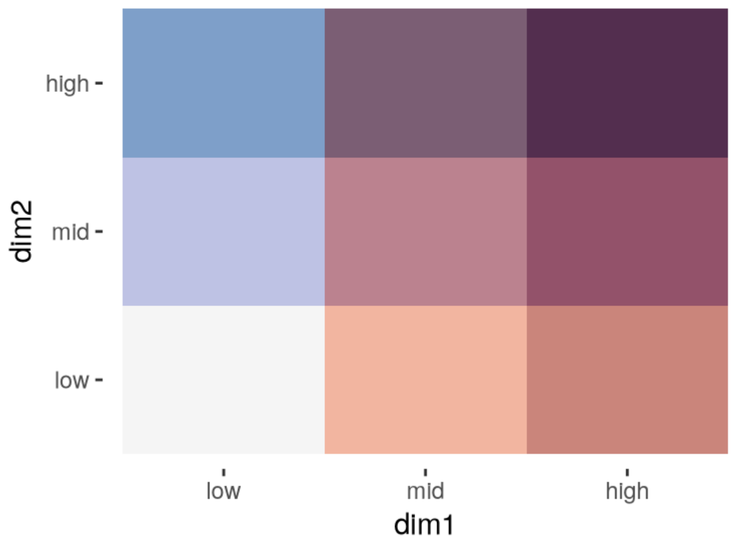
```r
colormap <- sequential_hcl(5)
contrast_ratio(colormap, "white", plot=T)
```

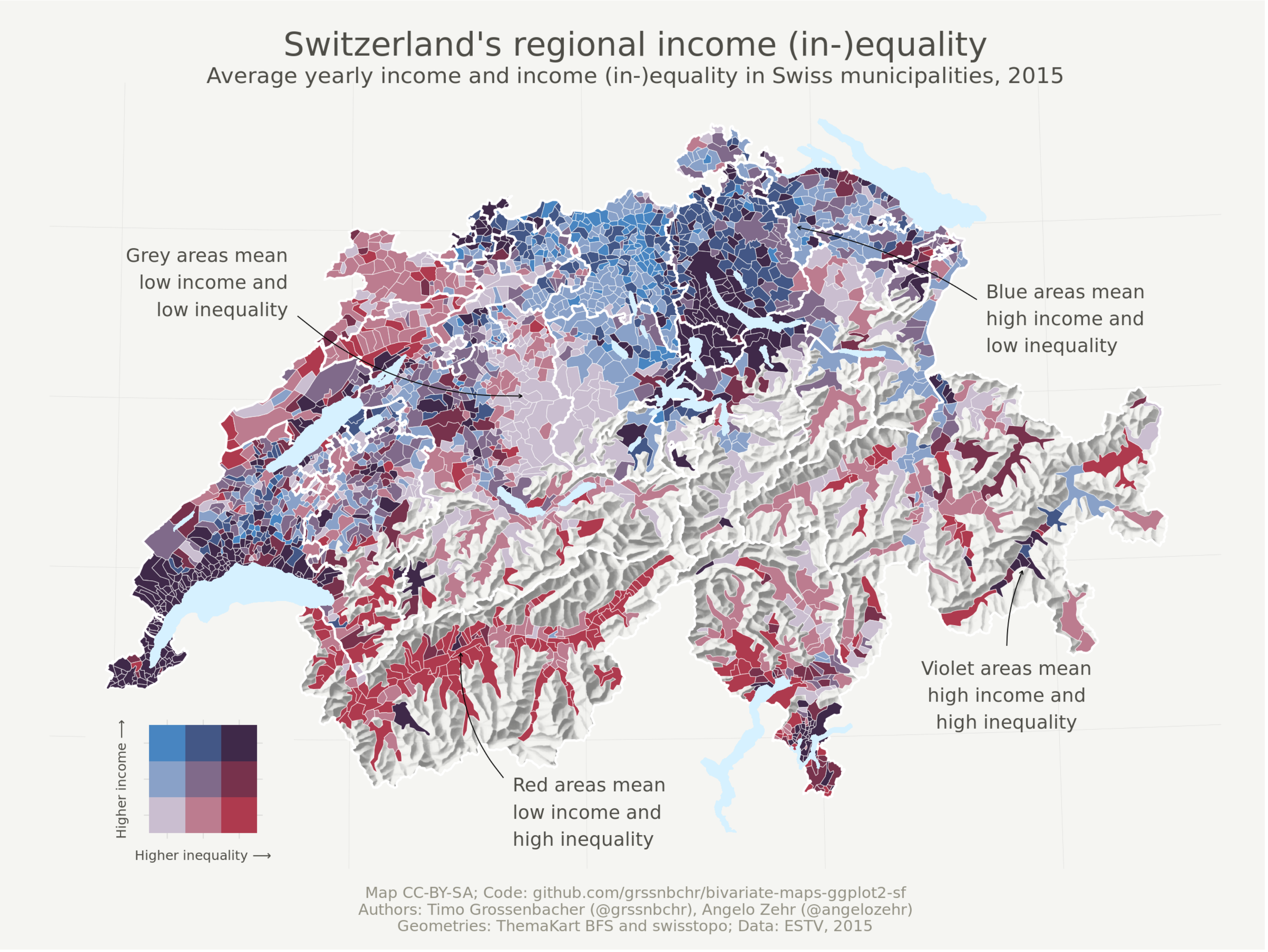



Bivariate color palettes

Can be used to encode two different variables with color: use with extreme care!

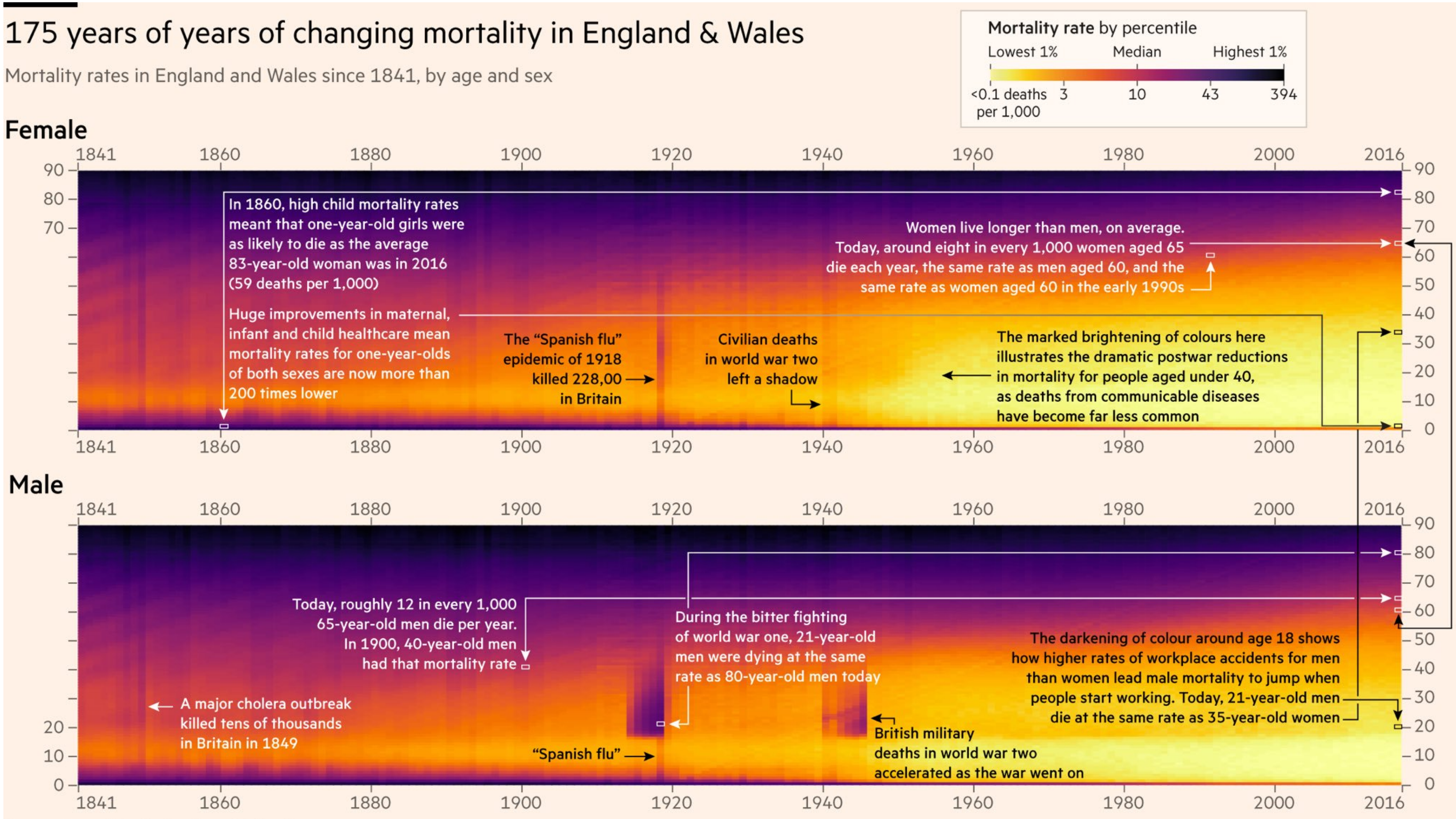
```
pal1 <- tibble(c1 = c("#f5f5f5","#EE744B","#9F1401"
               dim1 = c("low", "mid", "high"))
pal2 <- tibble(c2 = c("#f5f5f5","#878FD3","#07489C"
               dim2 = c("low", "mid", "high"))
crossing(pal1, pal2) %>%
  mutate(
    color = hex(mixcolor(0.5, hex2RGB(c1), hex2RGB(
    across(starts_with("dim"), ~ factor(.x,
                                   levels = c(
                                   ordered=T))
  ) %>%
  ggplot(aes(x=dim1, y=dim2, fill=color)) +
  geom_tile() +
  scale_fill_identity() +
  theme_classic() +
  theme(axis.line = element_blank())
```





Source: Timo Grossenbacher

Case study



Sources: Human Mortality Database, British Library
Graphic by John Burn-Murdoch, based on based on Schöley and Willekens (2017), and the work of Kieran Healy (2018)

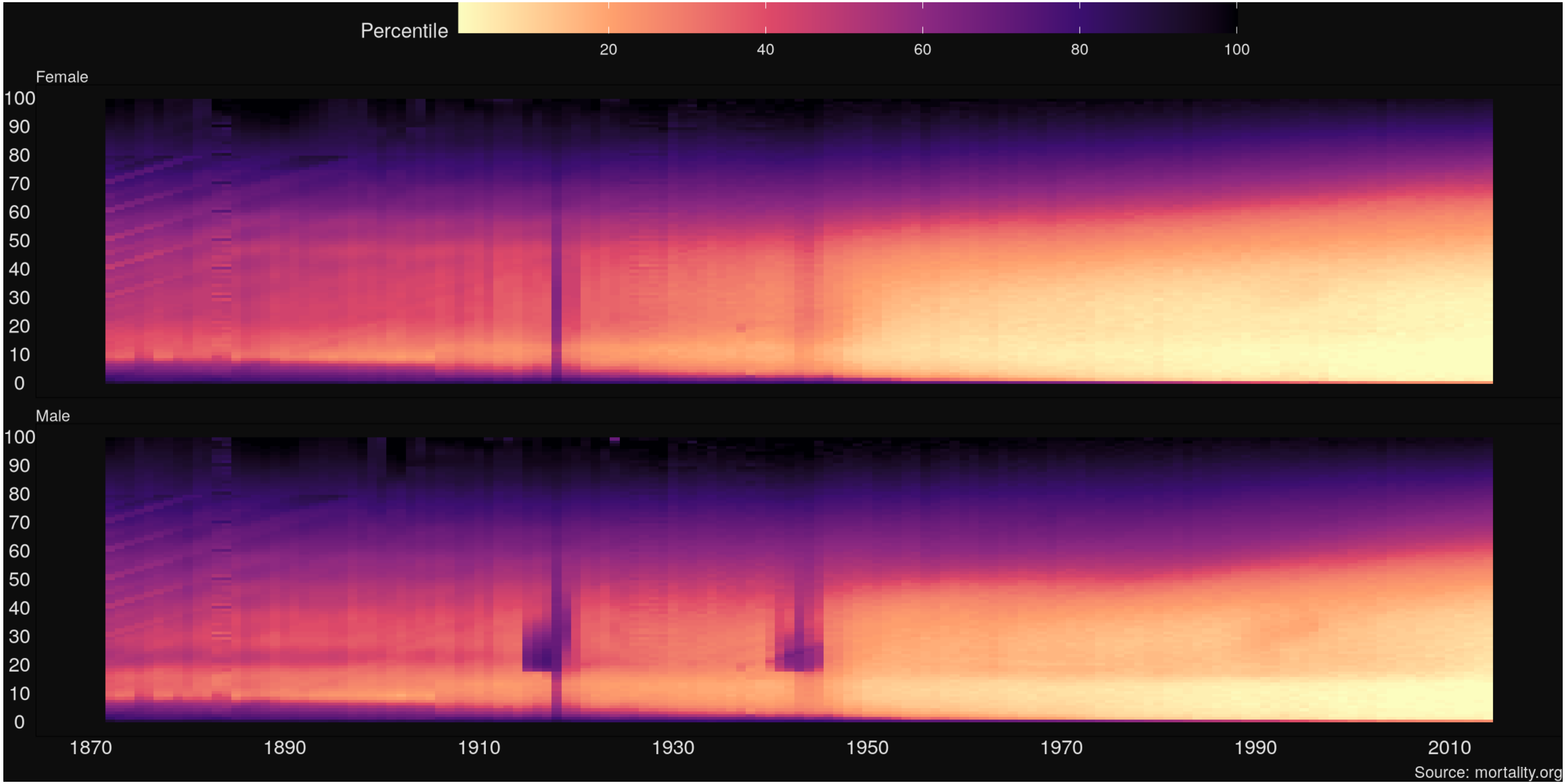
Solution

```r
bg_color <- "gray5"

mortality <-
  read_csv('death_rates_ITA.csv') |>
  #read_csv('Topics/Color/death_rates_ITA.csv') |>
  mutate(Percentile = ntile(Mortality, 100))

ggplot(mortality, aes(Year, Age, fill=Percentile)) +
  geom_tile() +
  scale_fill_viridis_c(
      option='magma',
      direction=-1,
      breaks = seq(20, 100, by=20)
  ) +
  scale_x_continuous( breaks=seq(1850, 2010, by=20) ) +
  scale_y_continuous( breaks=seq(0, 100, by=10) ) +
  facet_wrap(vars(Sex), ncol=1) +
  labs(
    caption = "Source: mortality.org"
  ) +
  theme_void() +
  theme(
    text = element_text(color = "gray90"),
    strip.text = element_text(hjust=0),
    axis.text.x = element_text(),
```

Solution


Percentile
20
40
60
80
100
Female
Male
100
90
80
70
60
50
40
30
20
10
0
1870
1890
1910
1930
1950
1970
1990
2010
Source: mortality.org