WIRTSCHAFTS UNIVERSITÄT WIEN

Escaping RGBland: Selecting Colors for Statistical Graphics

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Overview

- Motivation
  - Statistical graphics and color
  - Color vision and color spaces
- Palettes (in HCL space)
  - Qualitative
  - Sequential
  - Diverging
- Color blindness
- Software

Motivation: Statistical graphics

Information in statistical graphics is typically coded by:

- length
  - easy to decode for humans
  - best for aligned common scales
- area, volume
  - more difficult to decode
  - dependence on shape: long/thin is seen larger than compact/convex
  - dependence on color: lighter areas seen larger
- angle, slope
  - problematic for humans
  - dependence on orientation
- color
  - omni-present in statistical graphics

Motivation: Statistical graphics

- particularly important for shading areas (e.g., bar plots, pie charts, mosaic displays, heatmaps, . . .)
- avoid large areas of saturated colors
- powerful for encoding categorical information
- care needed for coding quantitative information

More often than not: Only little guidance about how to choose a suitable palette for a certain visualization task.

Question: What are useful color palettes for coding qualitative and quantitative information?

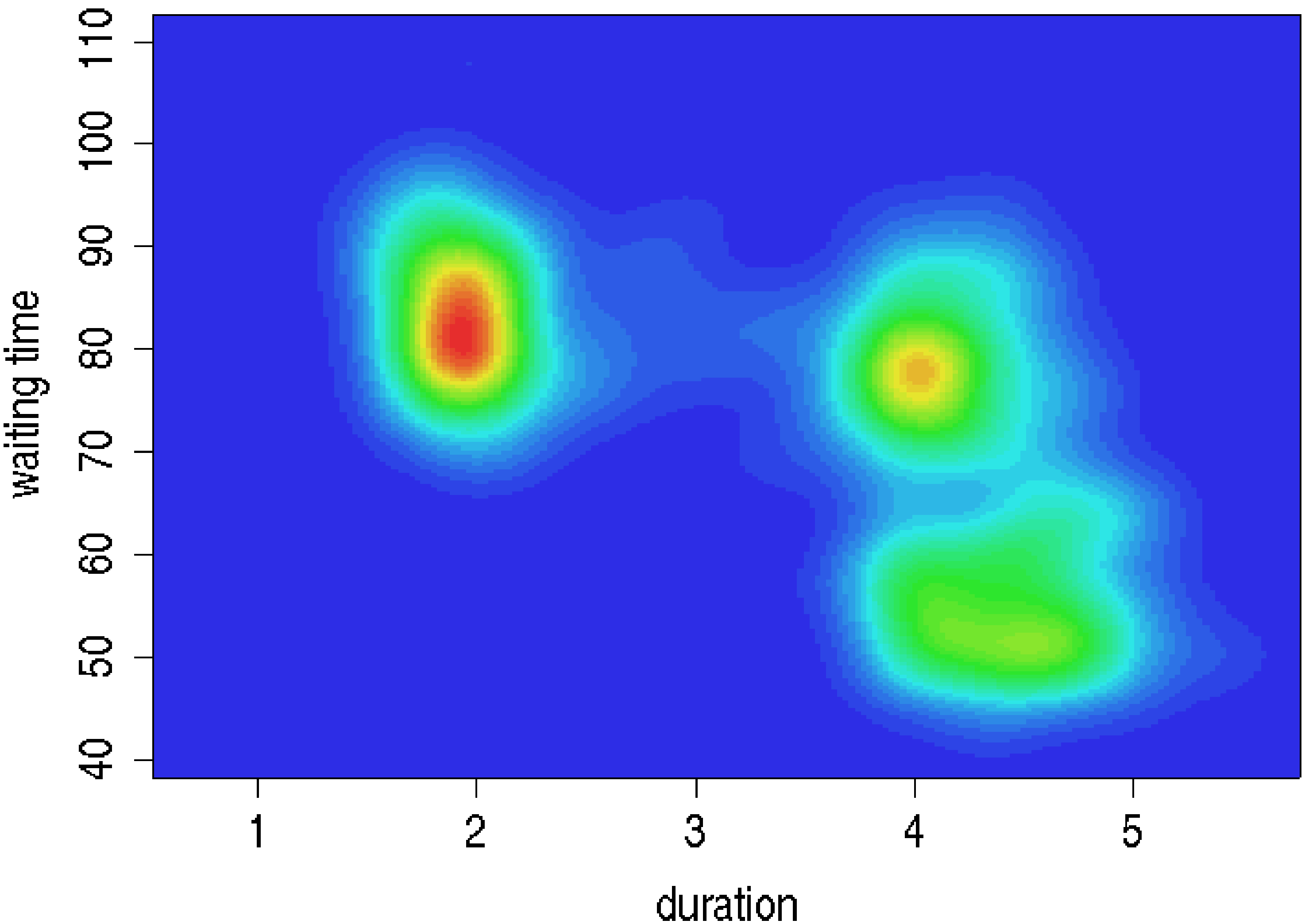
Currently: Many palettes are constructed based on HSV space, especially by varying hue.

Motivation: Statistical graphics

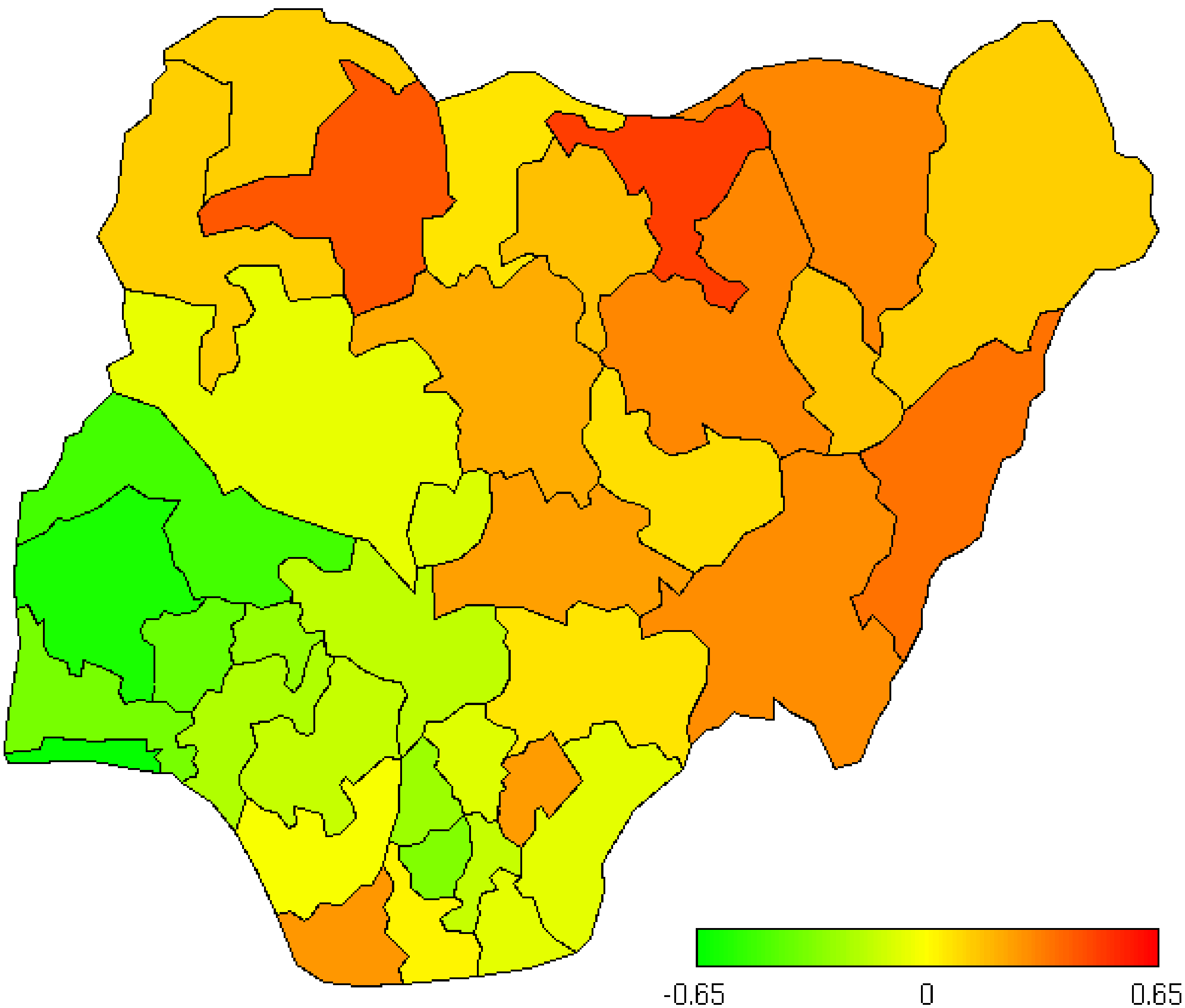
Examples:

- heatmap of bivariate kernel density estimate for Old Faithful geyser eruptions data,
- map of Nigeria shaded by posterior mode estimates for childhood mortality,
- pie chart of seats in the German parliament *Bundestag*,
- mosaic display of votes for the German Bundestag,
- model-based mosaic display for treatment of arthritis,
- scatter plot with three clusters (and many points).

Motivation: Statistical graphics



Motivation: Statistical graphics



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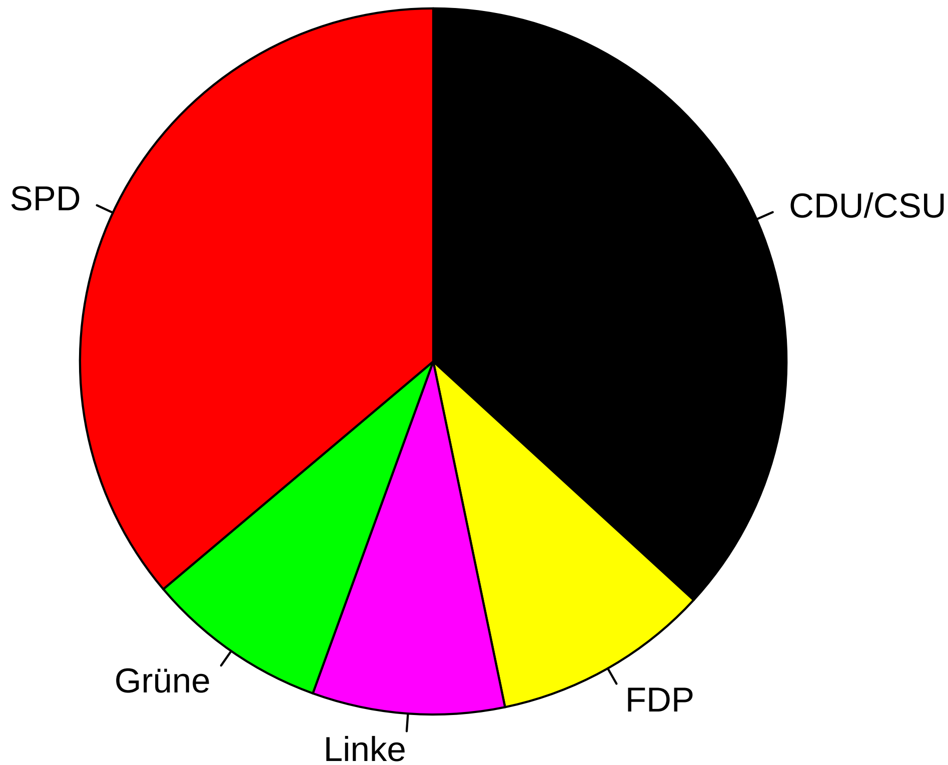

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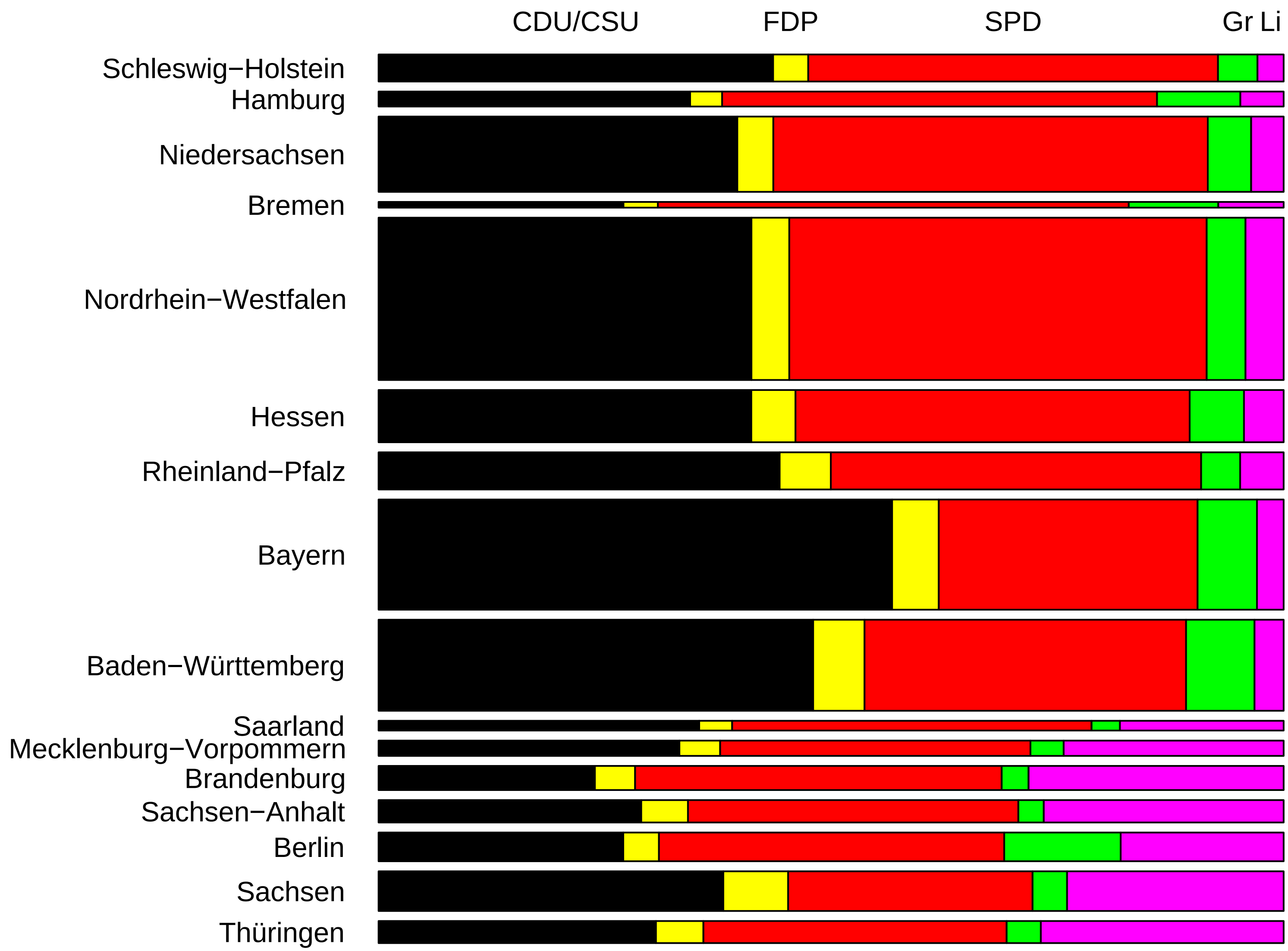

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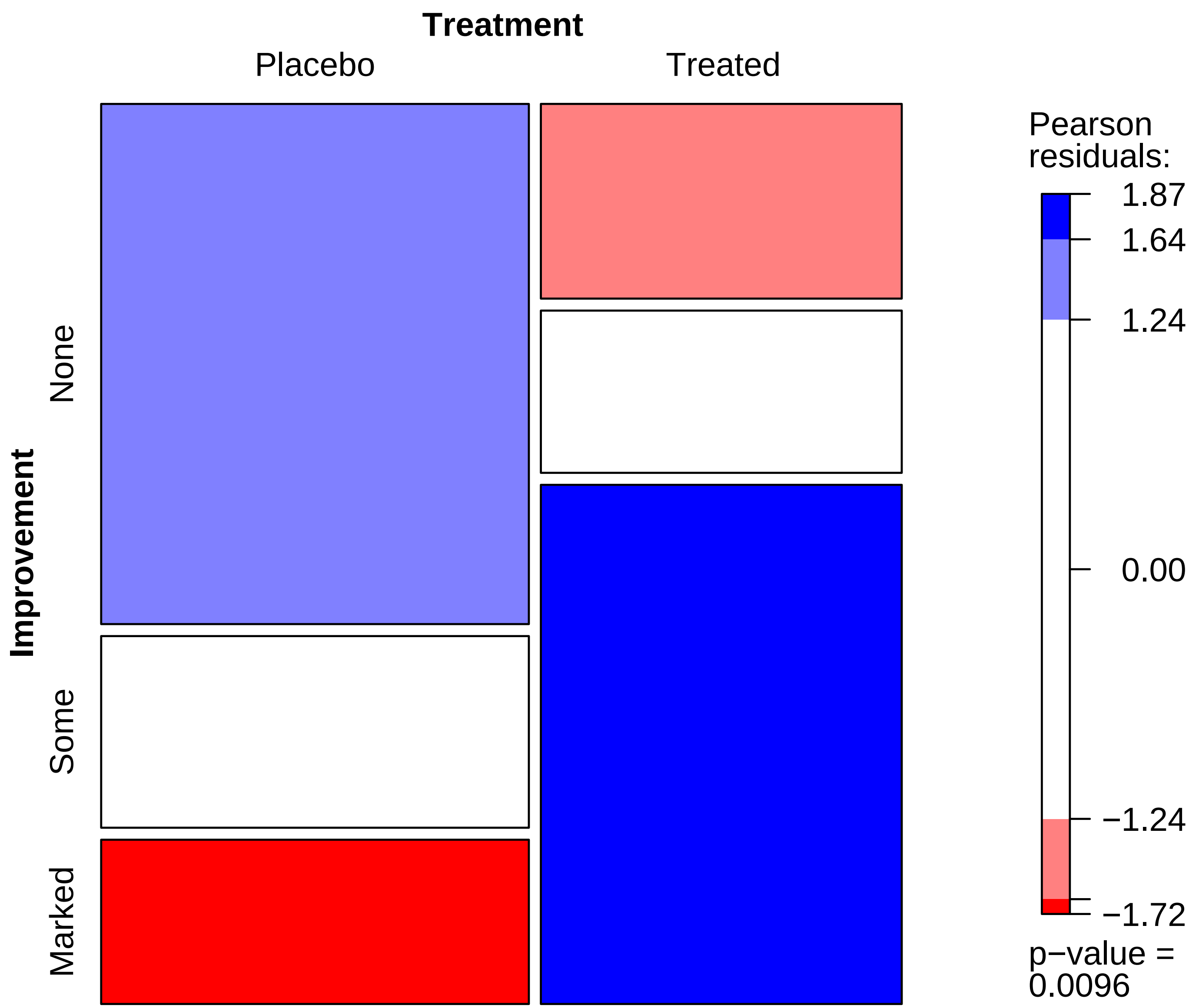

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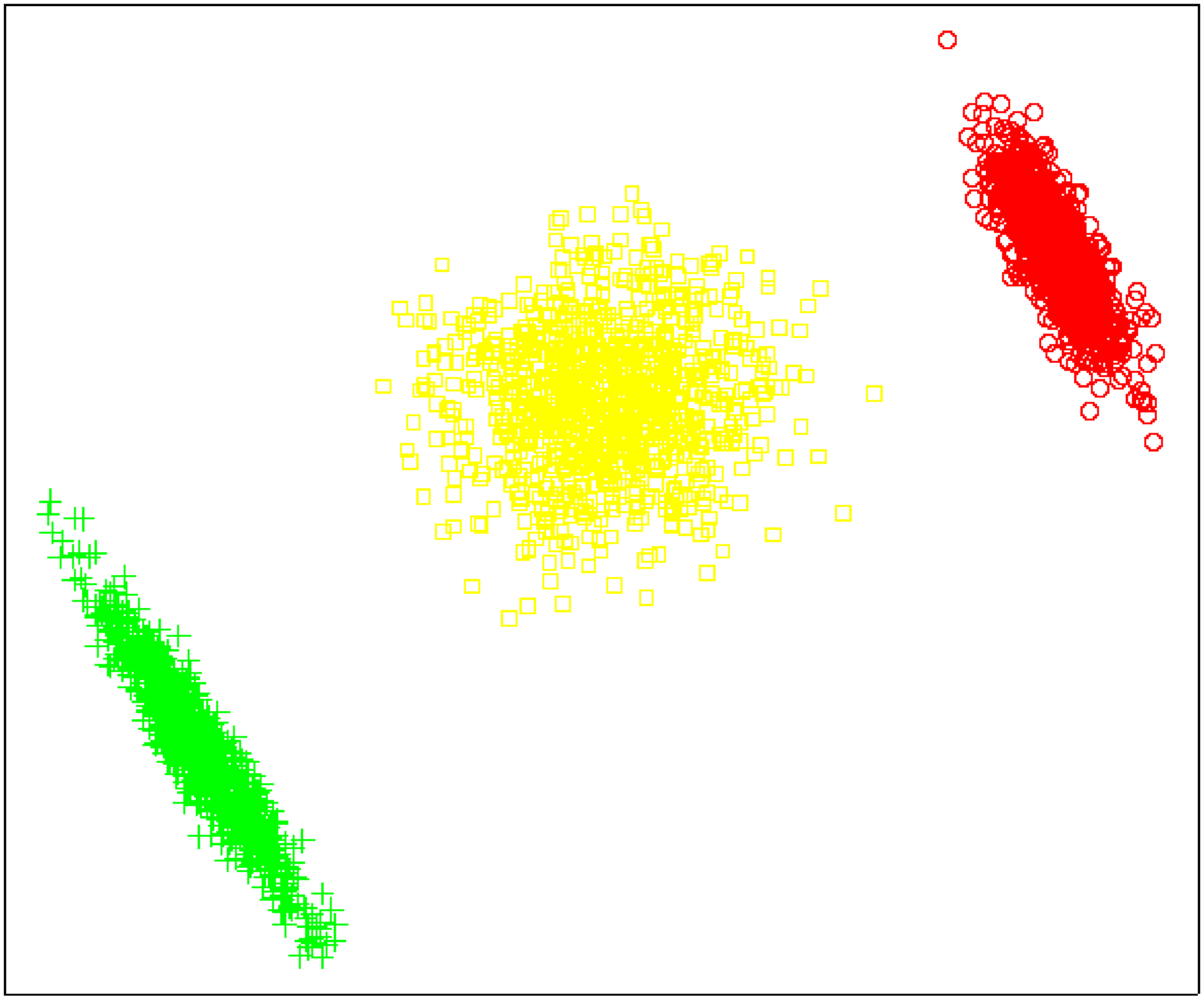


Motivation: Statistical graphics

Problems:

- Flashy colors: good for drawing attention to a plot but hard to look at for a longer time.
- Large areas of saturated colors: can produce distracting after-image effects.
- Unbalanced colors: light and dark colors are mixed; or “positive” and “negative” colors are difficult to compare.
- Quantitative variables are often difficult to decode.

Motivation: Statistical graphics

Solutions:

- Use pre-fabricated color palettes (with fixed number of colors) designed for specific visualization tasks: **ColorBrewer.org** (see Brewer, 1999).

  Problem: little flexiblity.

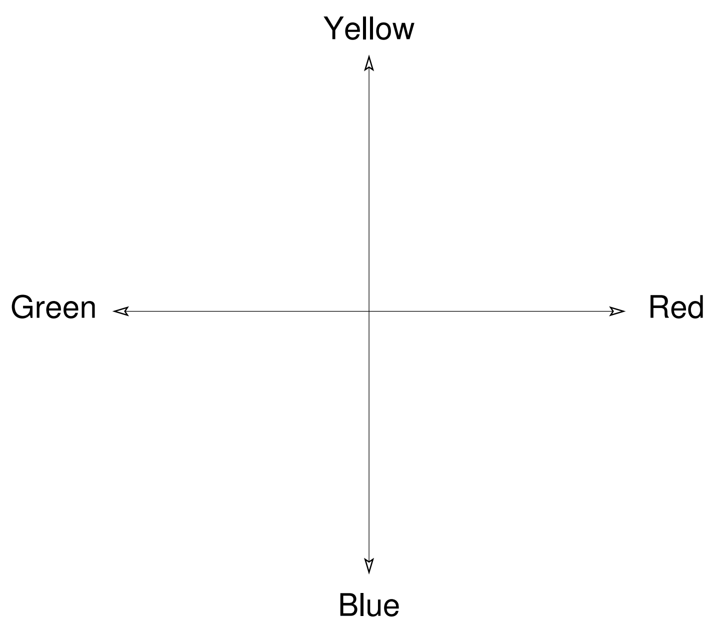
- Selecting colors along axes in a color space whose axes can be matched with perceptual axes of the human visual system.

  Leads to similar palettes compared to **ColorBrewer.org** but offers more flexibility via a general principle for choosing palettes.

Color vision and color spaces

Human color vision is hypothesized to have evolved in three distinct stages:

1. **light/dark** (monochrome only)
2. **yellow/blue** (associated with warm/cold colors)
3. **green/red** (associated with ripeness of fruit)



Color vision and color spaces

Due to these three color axes, colors are typically described as locations in a 3-dimensional space, often by mixing three primary colors, e.g., RGB or CIEXYZ.

Physiological axes do not correspond to natural perception of color but rather to polar coordinates in the color plane:

- **hue** (dominant wavelength)
- **chroma** (colorfulness, intensity of color as compared to gray)
- **luminance** (brightness, amount of gray)

Perceptually based color spaces try to capture these three axes of the human perceptual system, e.g., HSV or HCL.

Color vision and color spaces

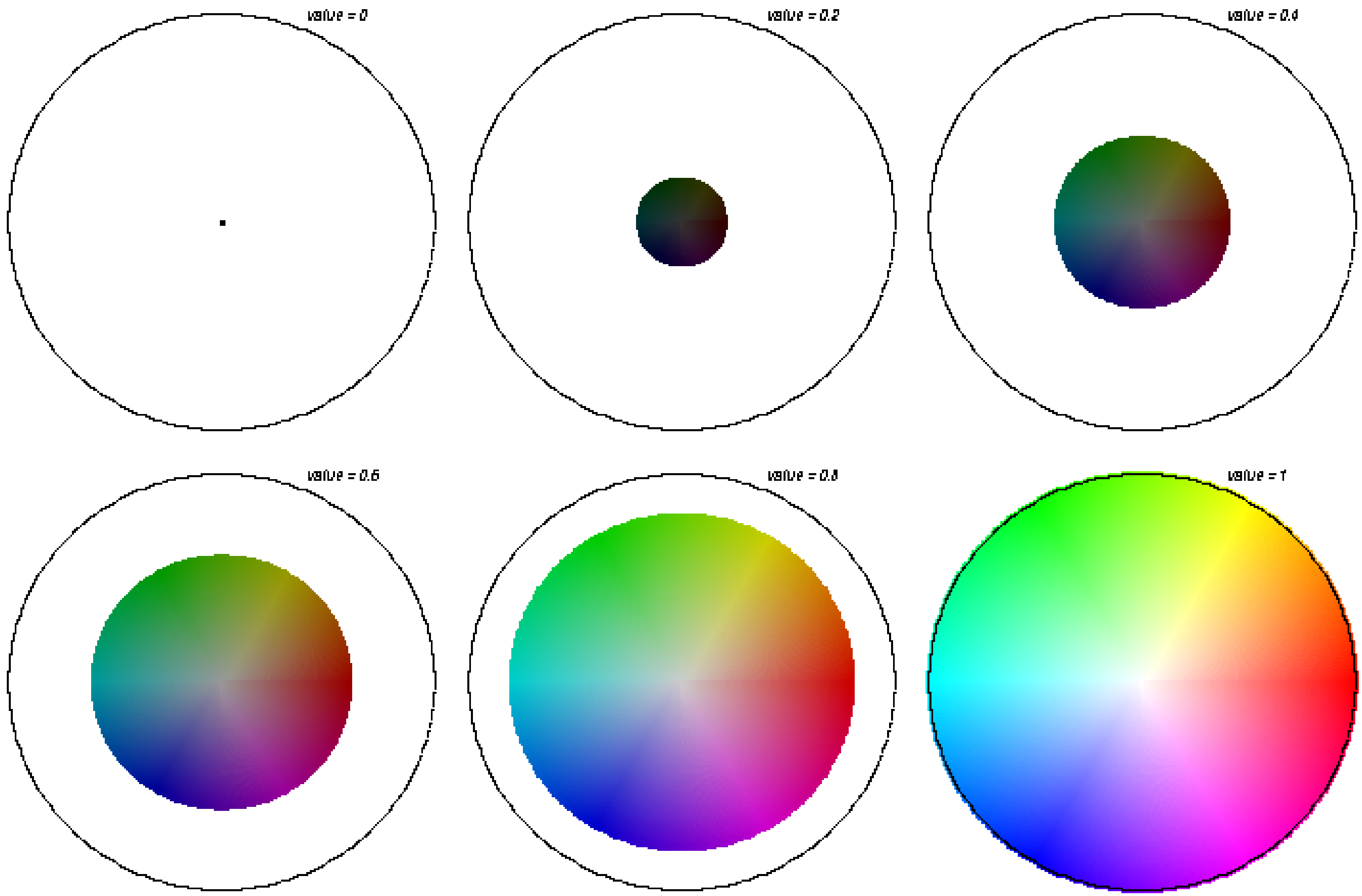
HSV space is a standard transformation of RGB space implemented in most computer packages.

Specification: triplet (H, S, V) with $H = 0, \ldots, 360$ and $S, V = 0, \ldots, 100$, often all transformed to unit interval (e.g., in R).

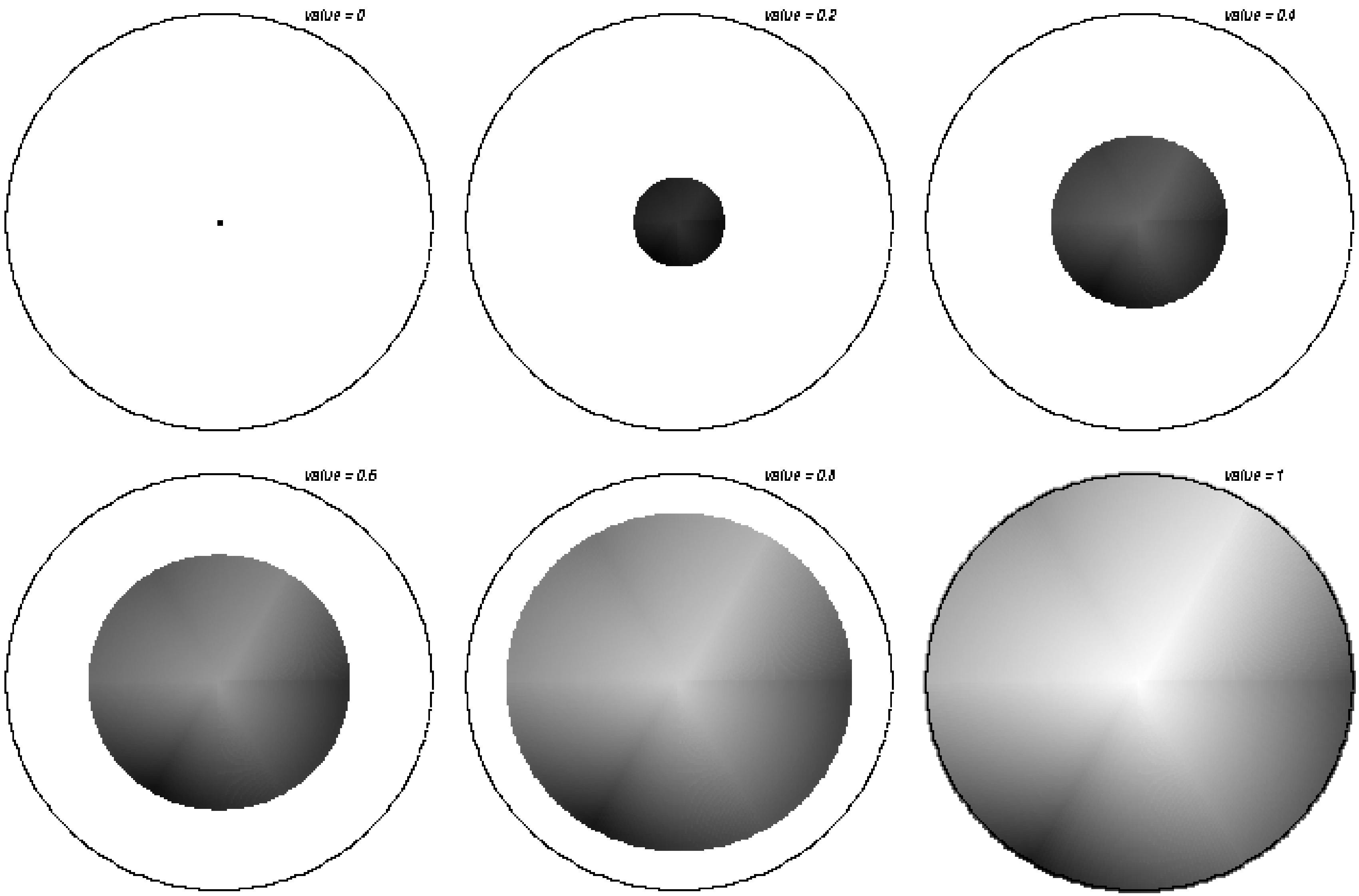
Shape: cone (or transformed to cylinder).

Problem: dimensions are confounded, hence not really perceptually based.

Color vision and color spaces



Color vision and color spaces



Color vision and color spaces

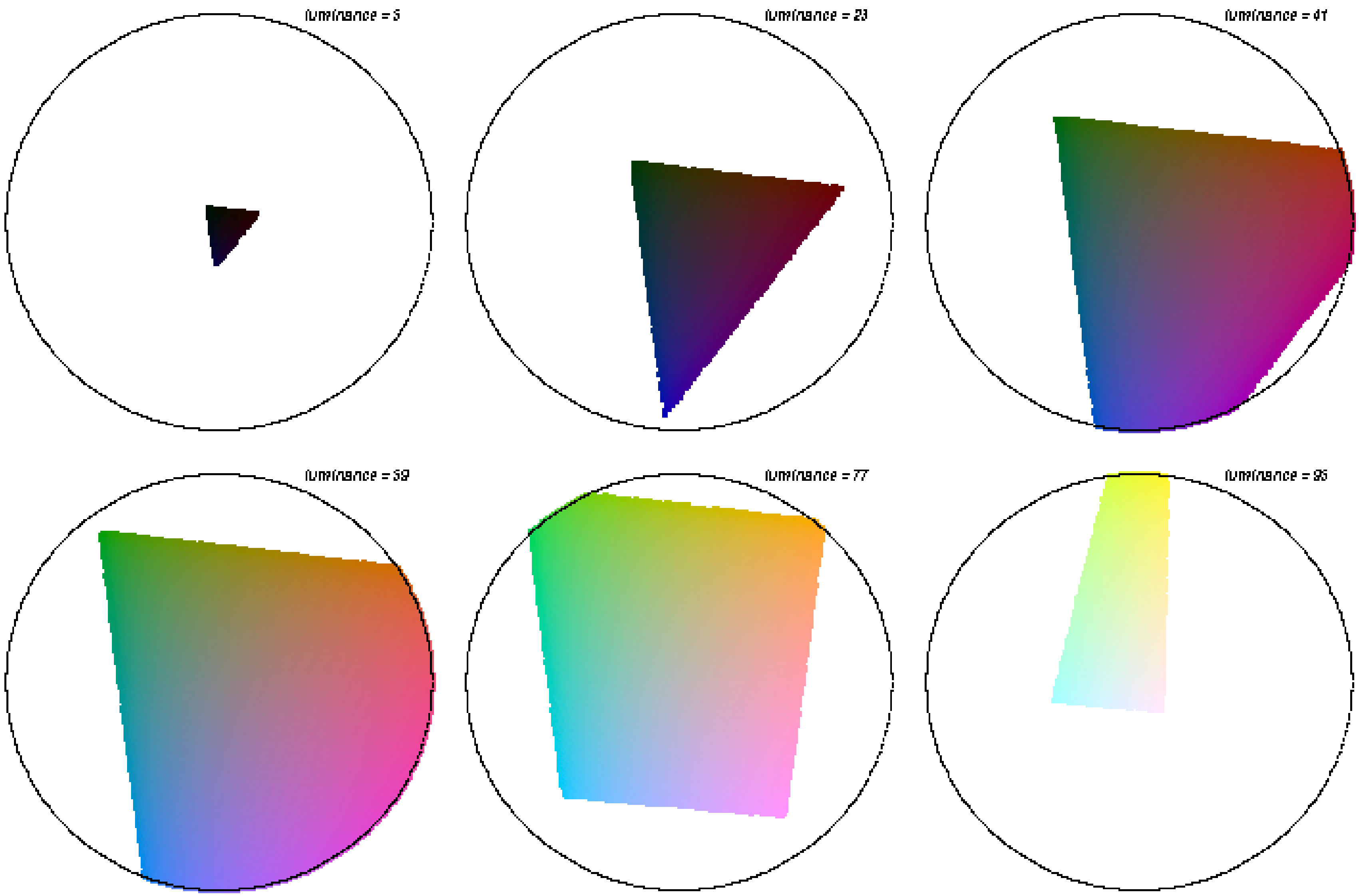
HCL space is a perceptually based color space, polar coordinates in CIELUV space.

Specification: triplet (H, C, L) with $H = 0, \ldots, 360$ and $C, L = 0, \ldots, 100$.

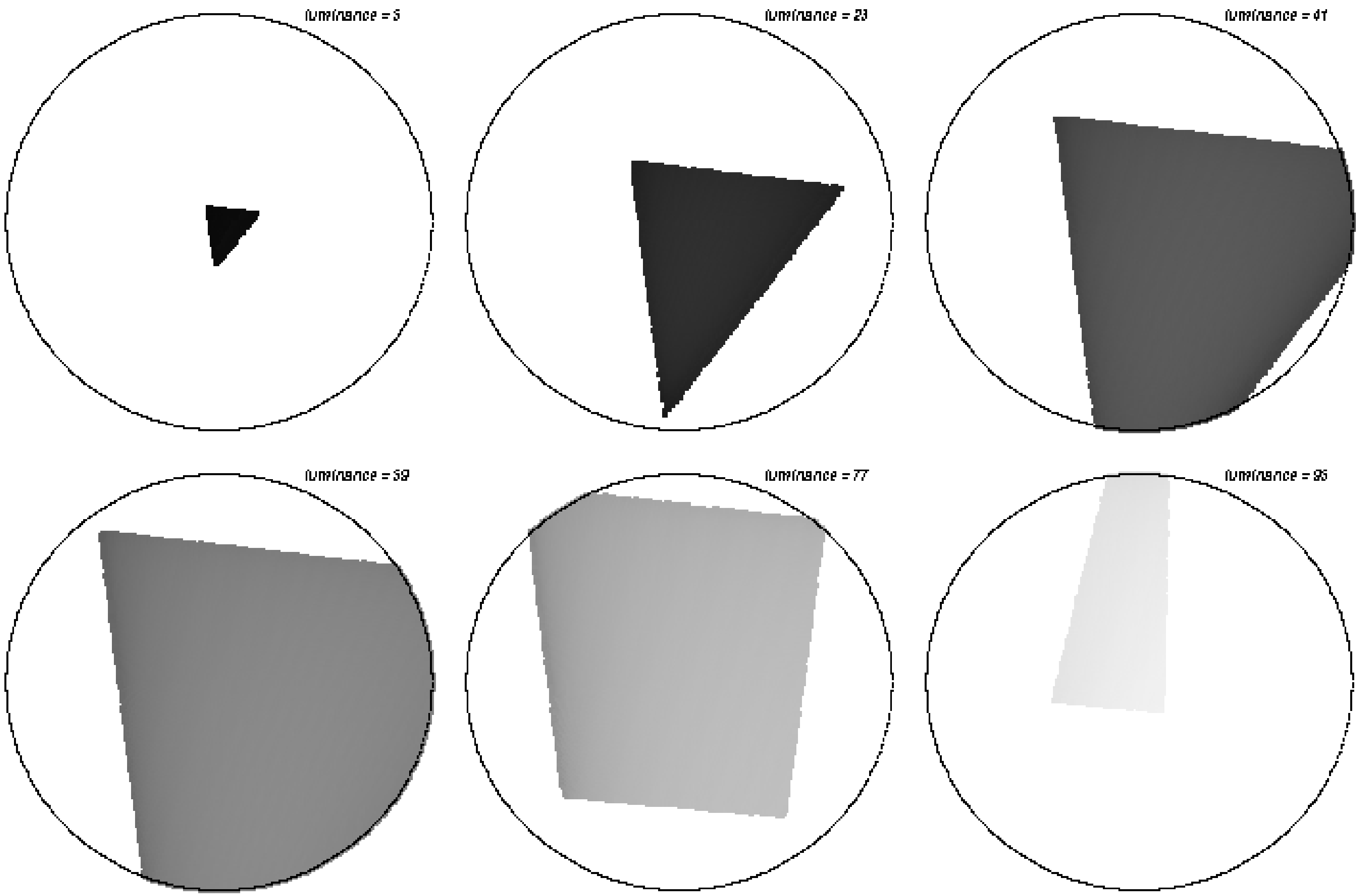
Shape: distorted double cone.

Problem: Care is needed when traversing along the axes due to distorted shape.

Color vision and color spaces



Color vision and color spaces



Palettes: Qualitative

Goal: Code qualitative information.

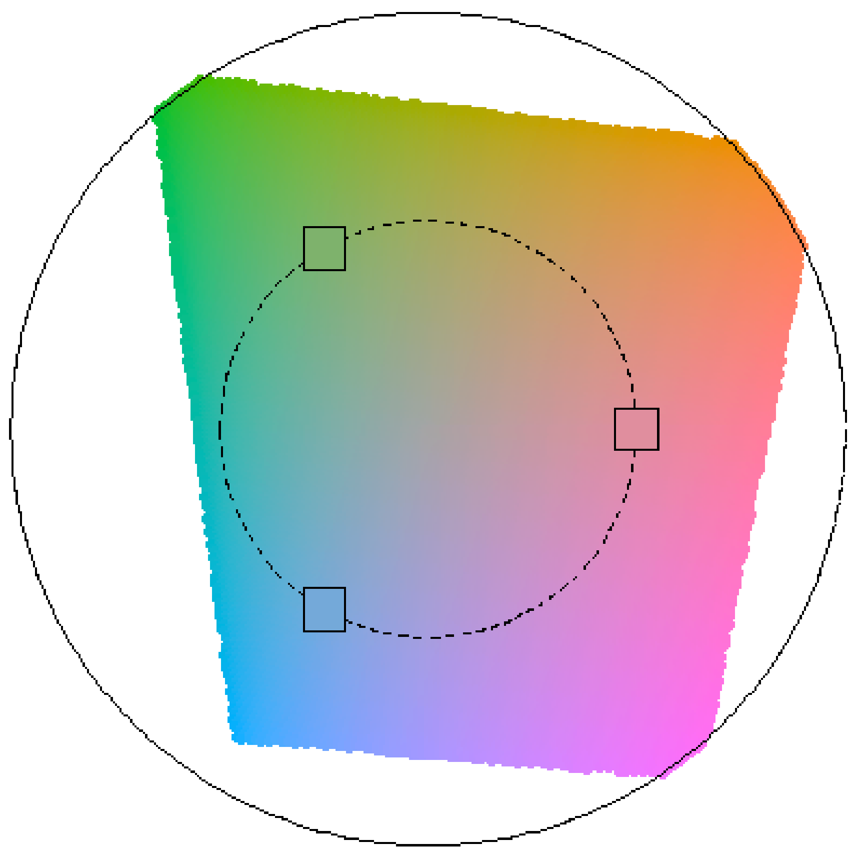
Solution: Use different hues for different categories.
Keep chroma and luminance fixed, e.g.,

$$(H, 50, 70)$$

Remark: The admissible hues (within HCL space) depend on the values of chroma and luminance chosen.

Hues can be chosen from different subsets of $[0, 360]$ to create different “moods” or as metaphors for the categories they code (see Ihaka, 2003).

Palettes: Qualitative



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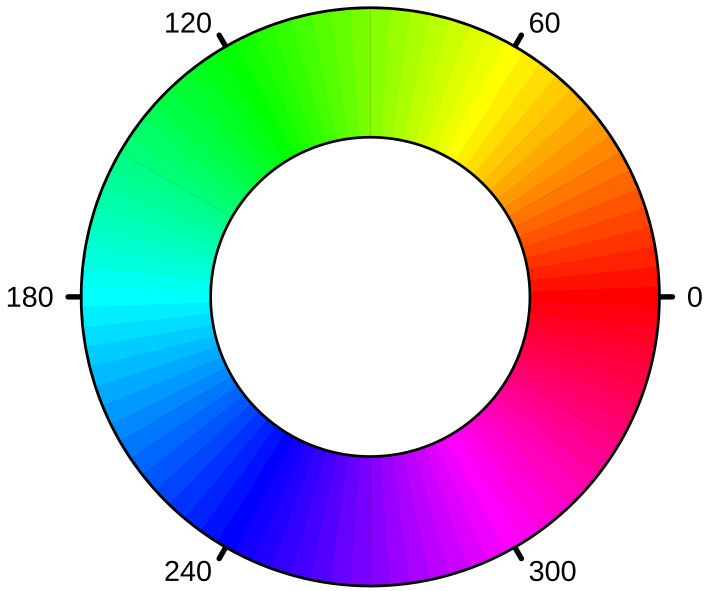

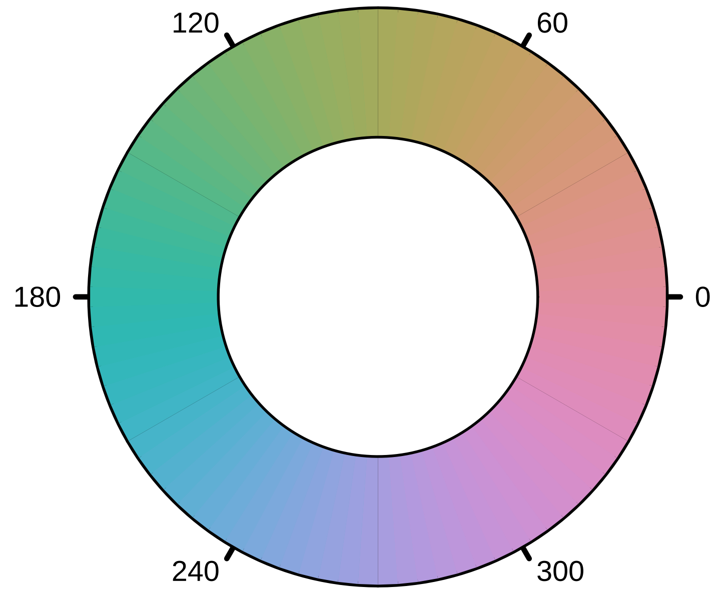

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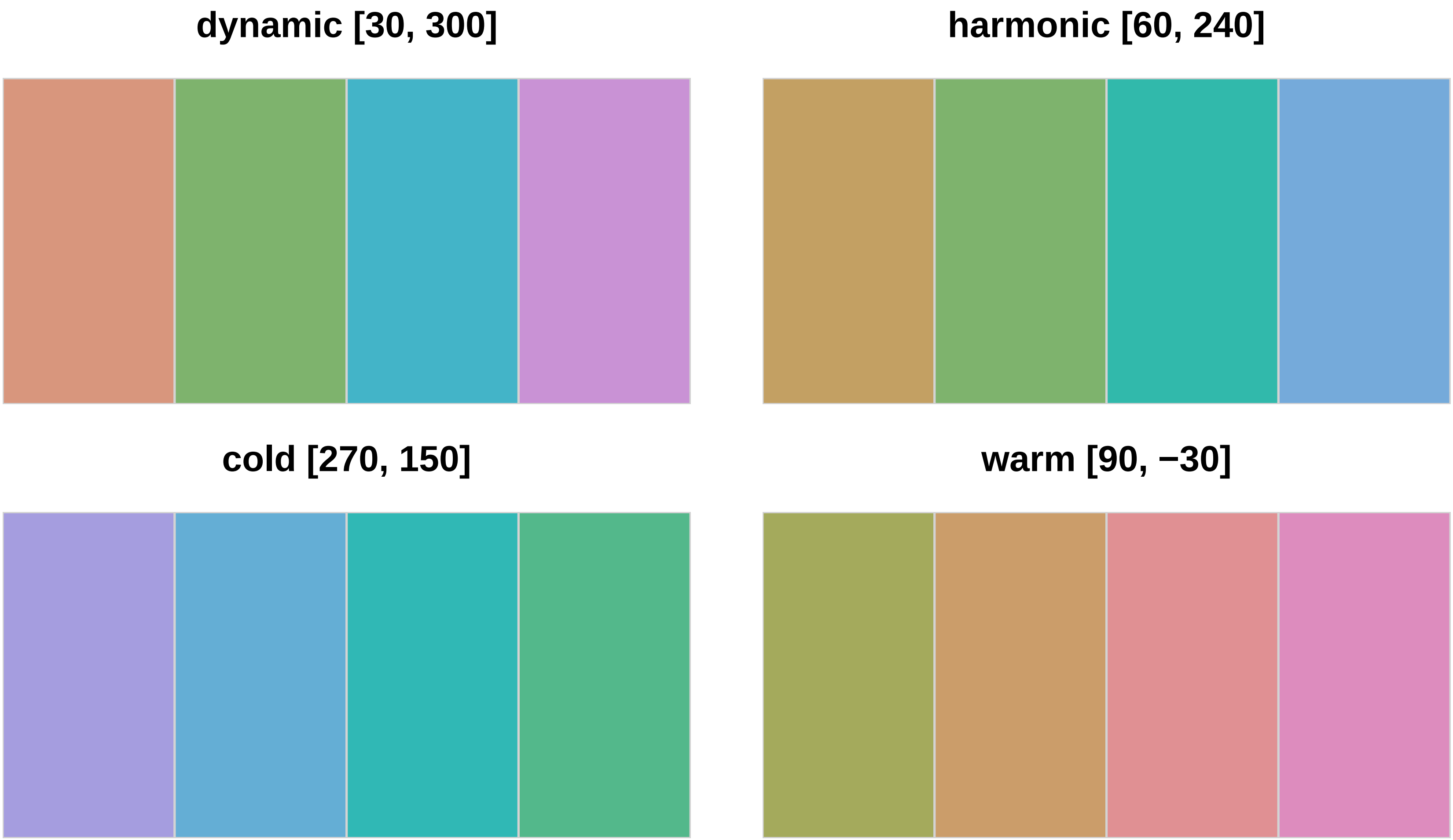

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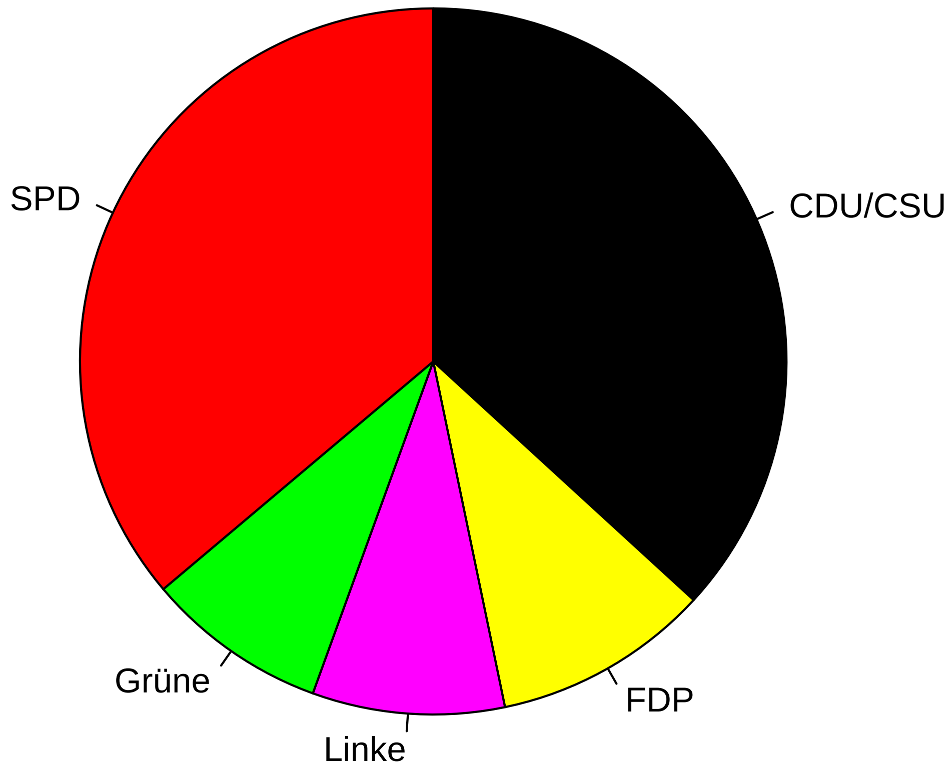

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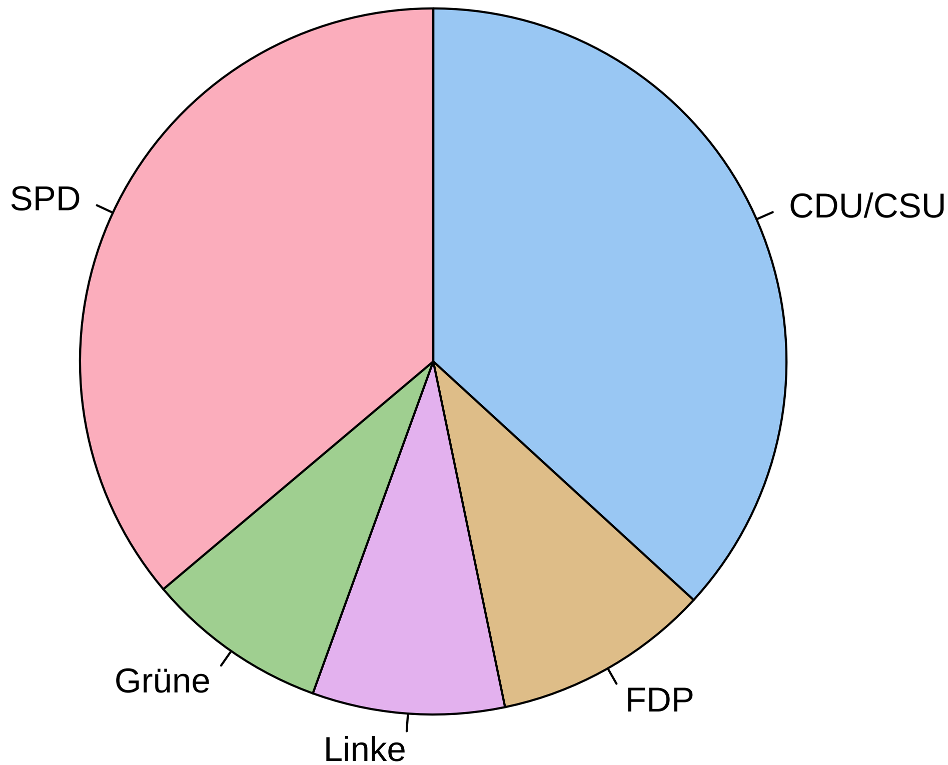

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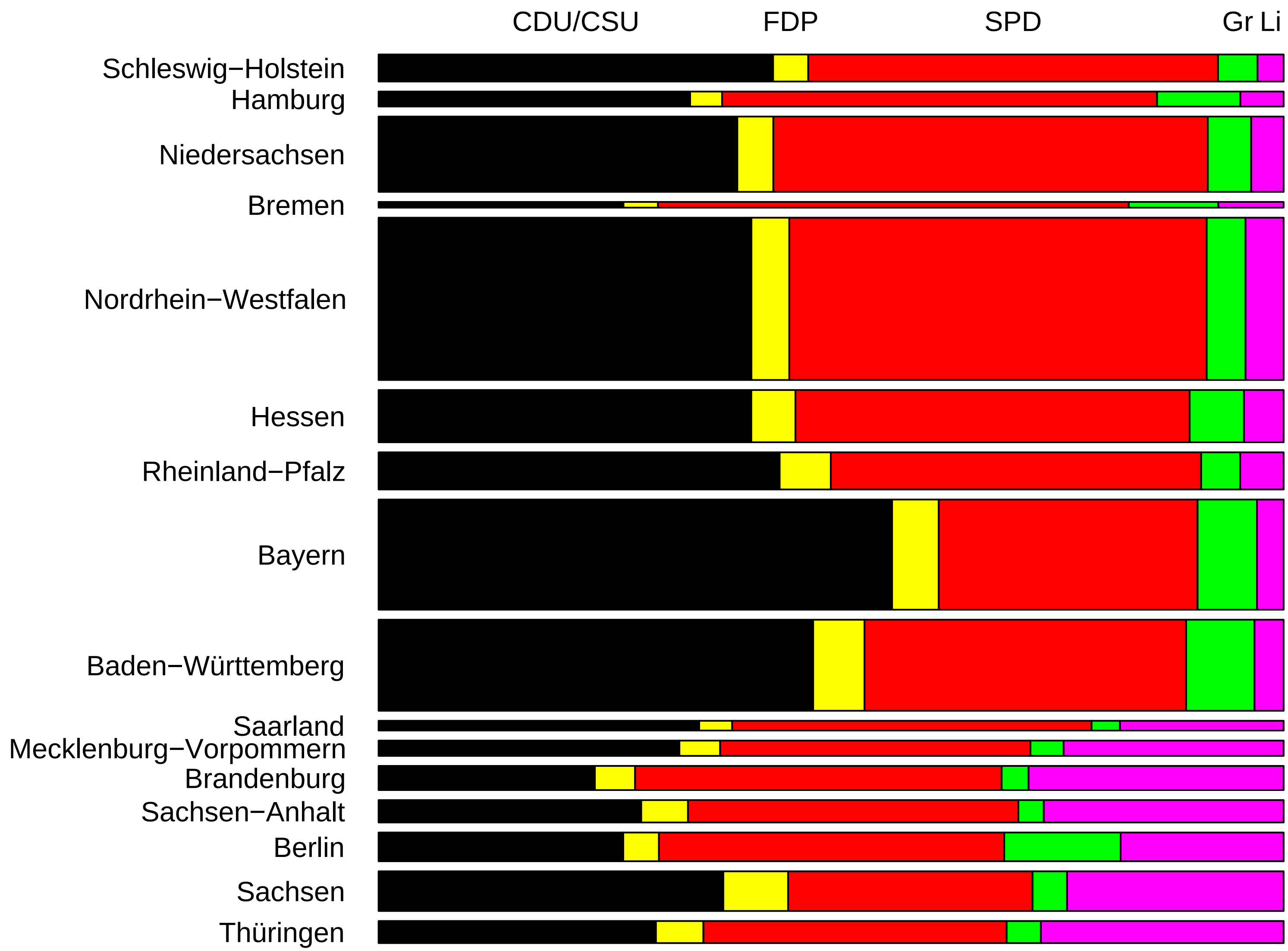

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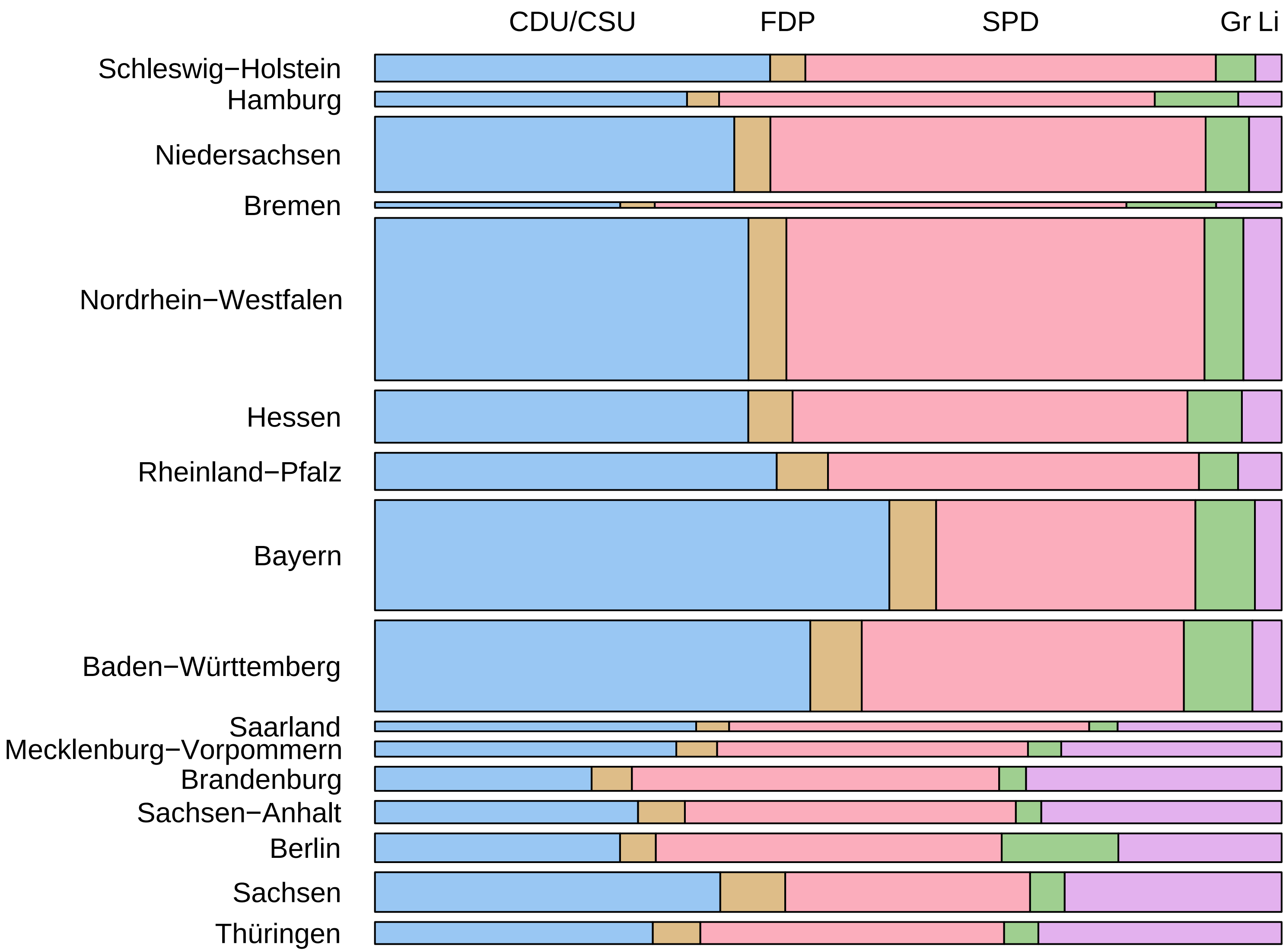

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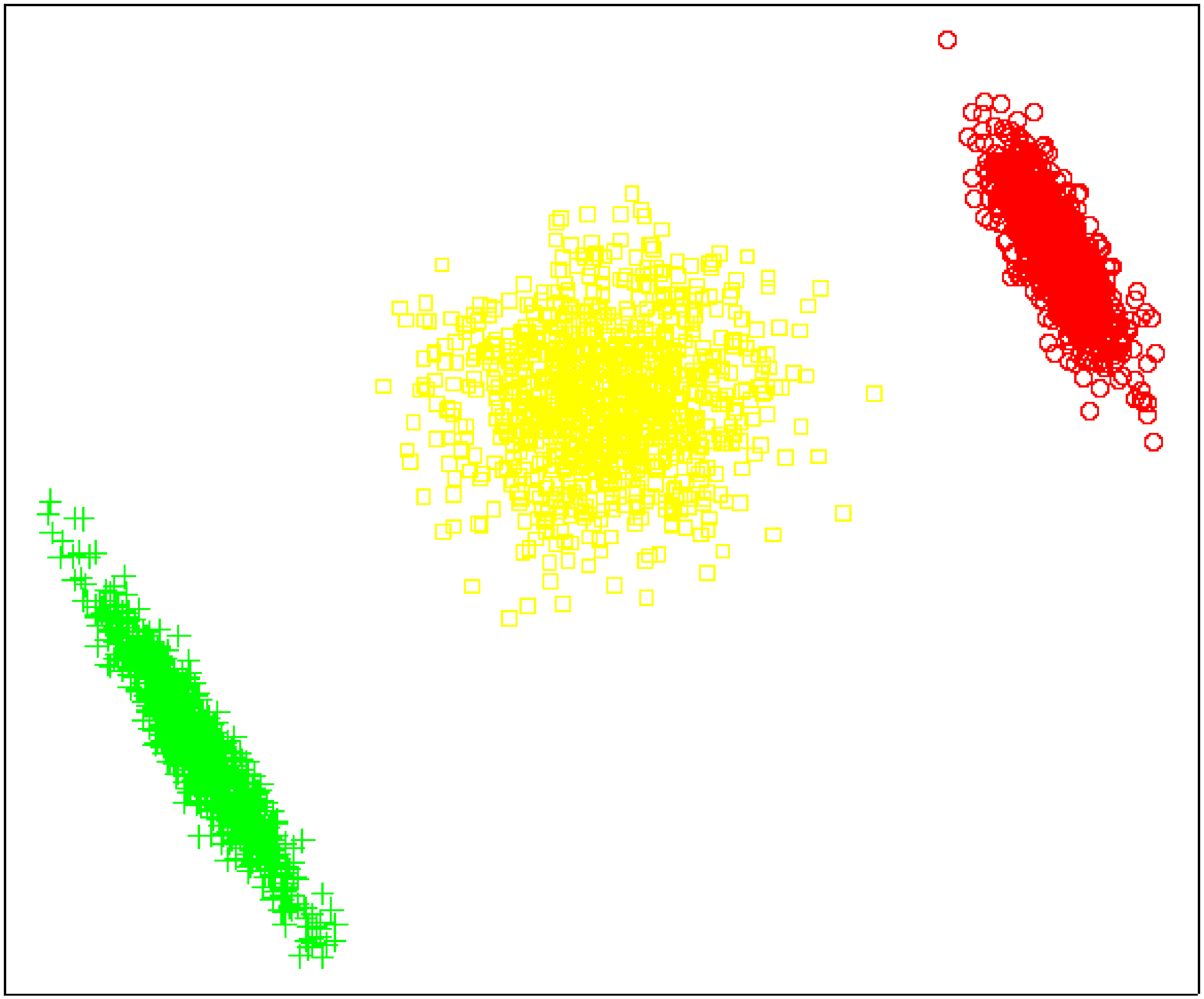

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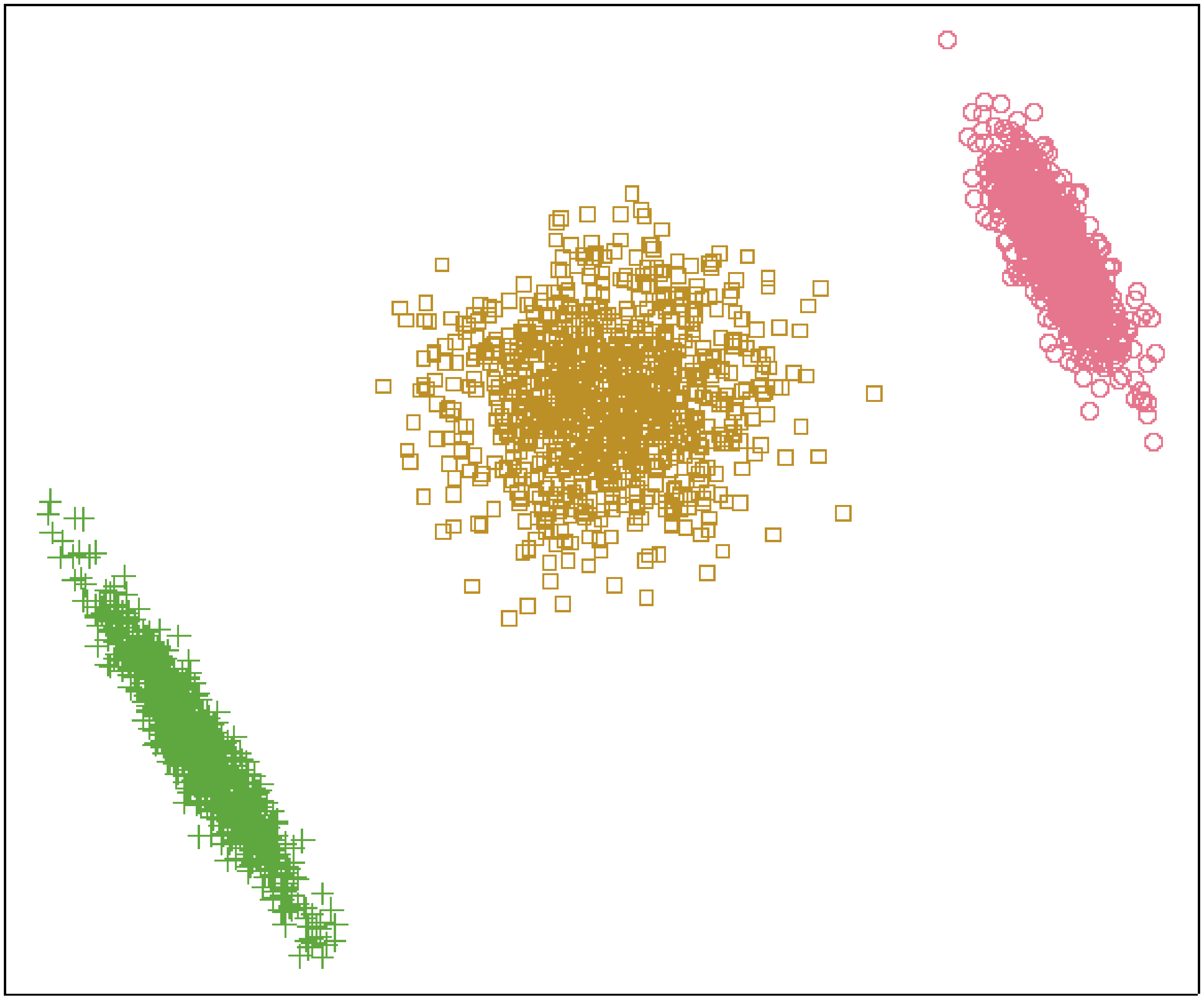


Palettes: Sequential

Goal: Code quantitative information. Intensity/interestingness i ranges in $[0, 1]$, where 0 is uninteresting, 1 is interesting.

Solution: Code i by increasing amount of gray (luminance), no color used, e.g.,

$$(H, 0, 90 - i \cdot 60)$$

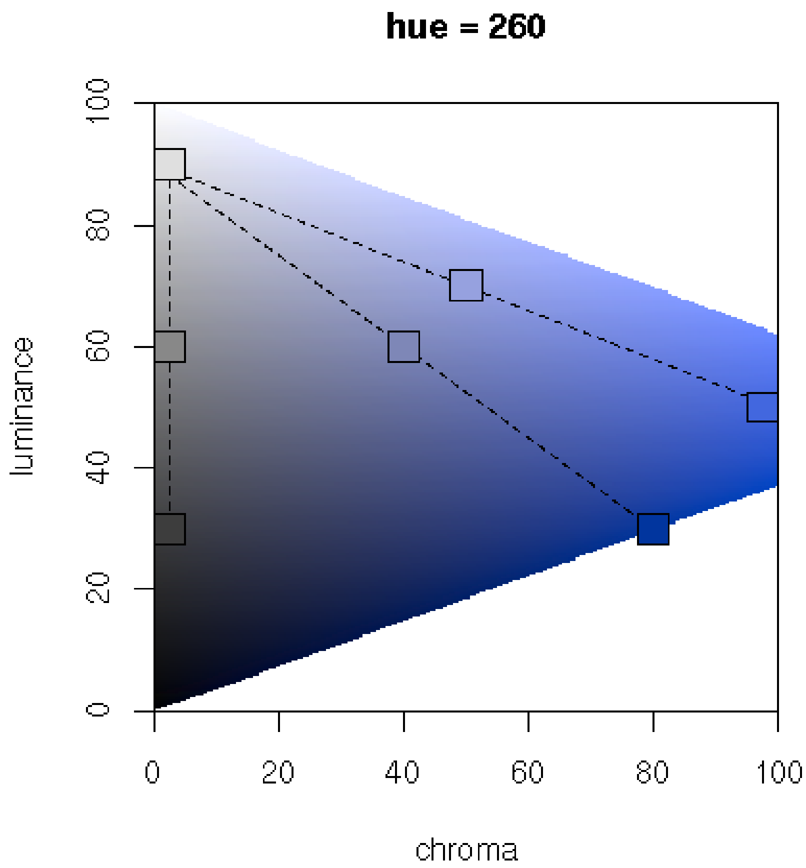
The hue H does not matter, chroma is set to 0 (no color), luminance ranges in $[30, 90]$, avoiding the extreme colors black and white.

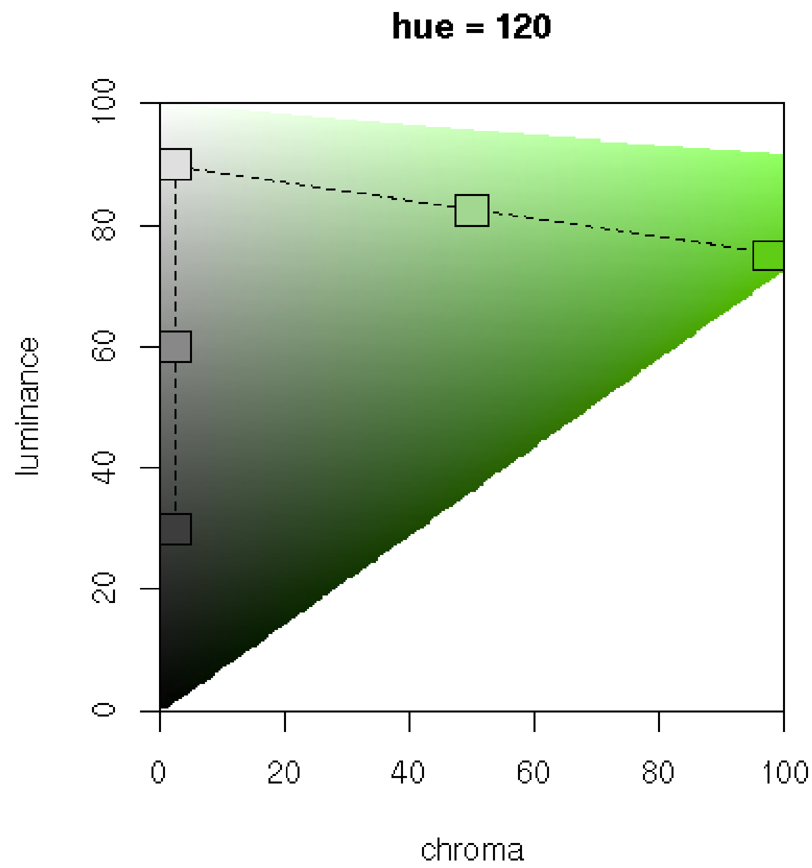
Modification: In addition, code i by colorfulness (chroma). Thus, more formally:

$$(H, 0 + i \cdot C_{\mathsf{max}}, L_{\mathsf{max}} - i \cdot (L_{\mathsf{max}} - L_{\mathsf{min}})$$

for a fixed hue H.

Palettes: Sequential





Palettes: Sequential

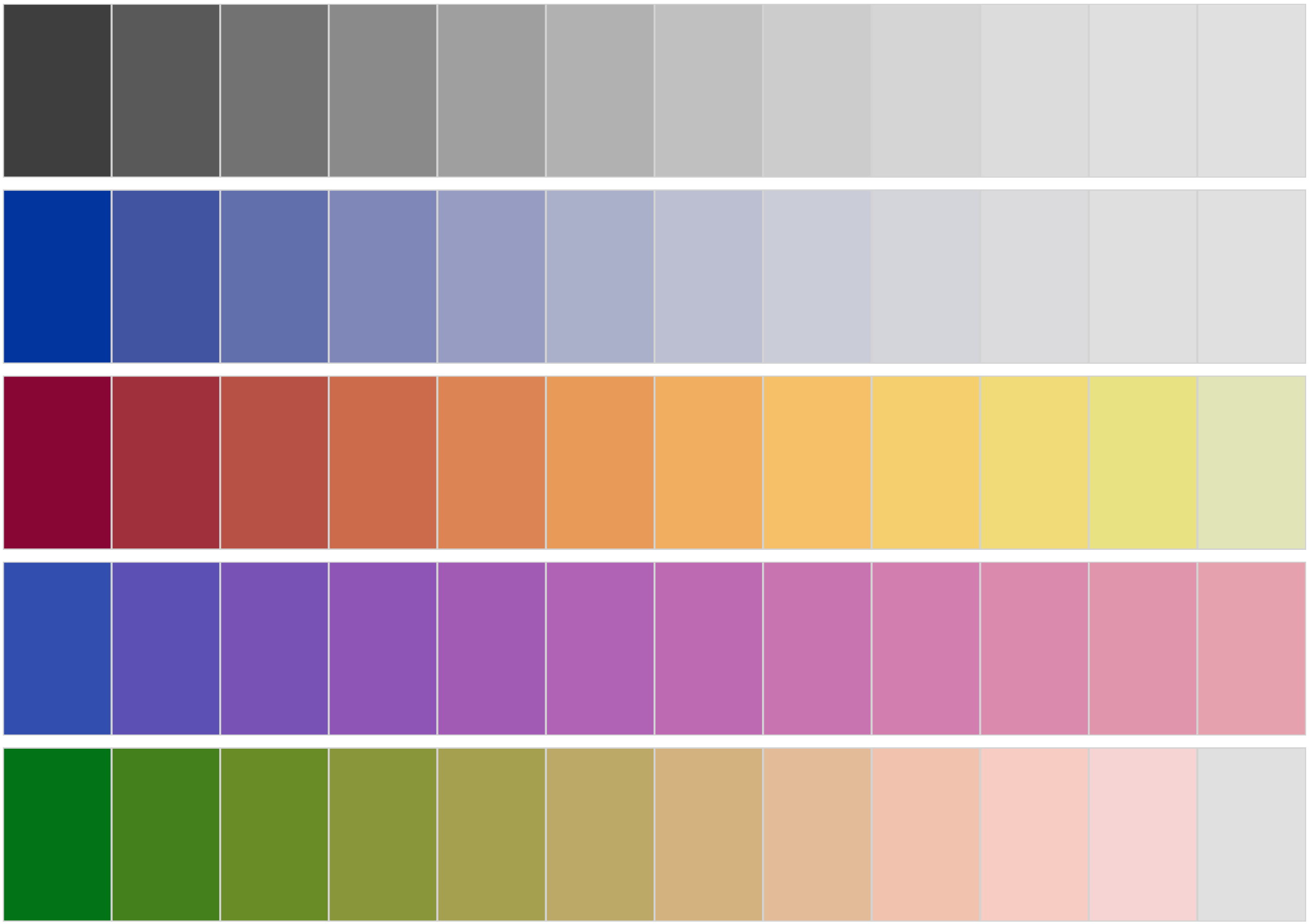
Modification: To increase the contrast within the palette even further, simultaneously vary the hue as well:

$$
\begin{aligned}
(H_2 - i \cdot (H_1 - H_2), \quad & C_{\mathsf{max}} - i^{p_1} \cdot (C_{\mathsf{max}} - C_{\mathsf{min}}), \\
& L_{\mathsf{max}} - i^{p_2} \cdot (L_{\mathsf{max}} - L_{\mathsf{min}})).
\end{aligned}
$$

To make the change in hue visible, the chroma needs to increase rather quickly for low values of i and then only slowly for higher values of i.

A convenient transformation for achieving this is to use i^p instead of i with different powers for chroma and luminance.

Palettes: Sequential



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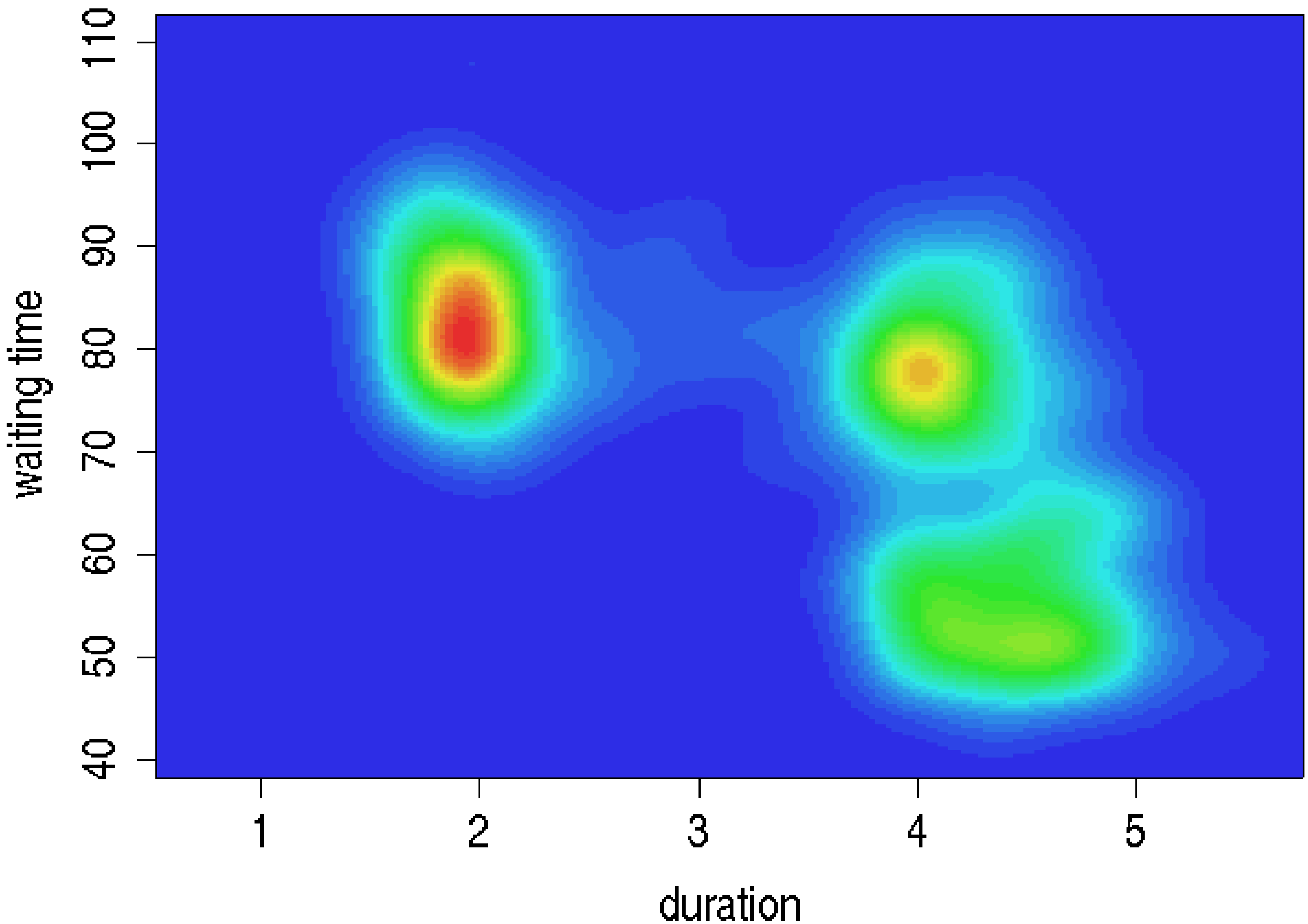

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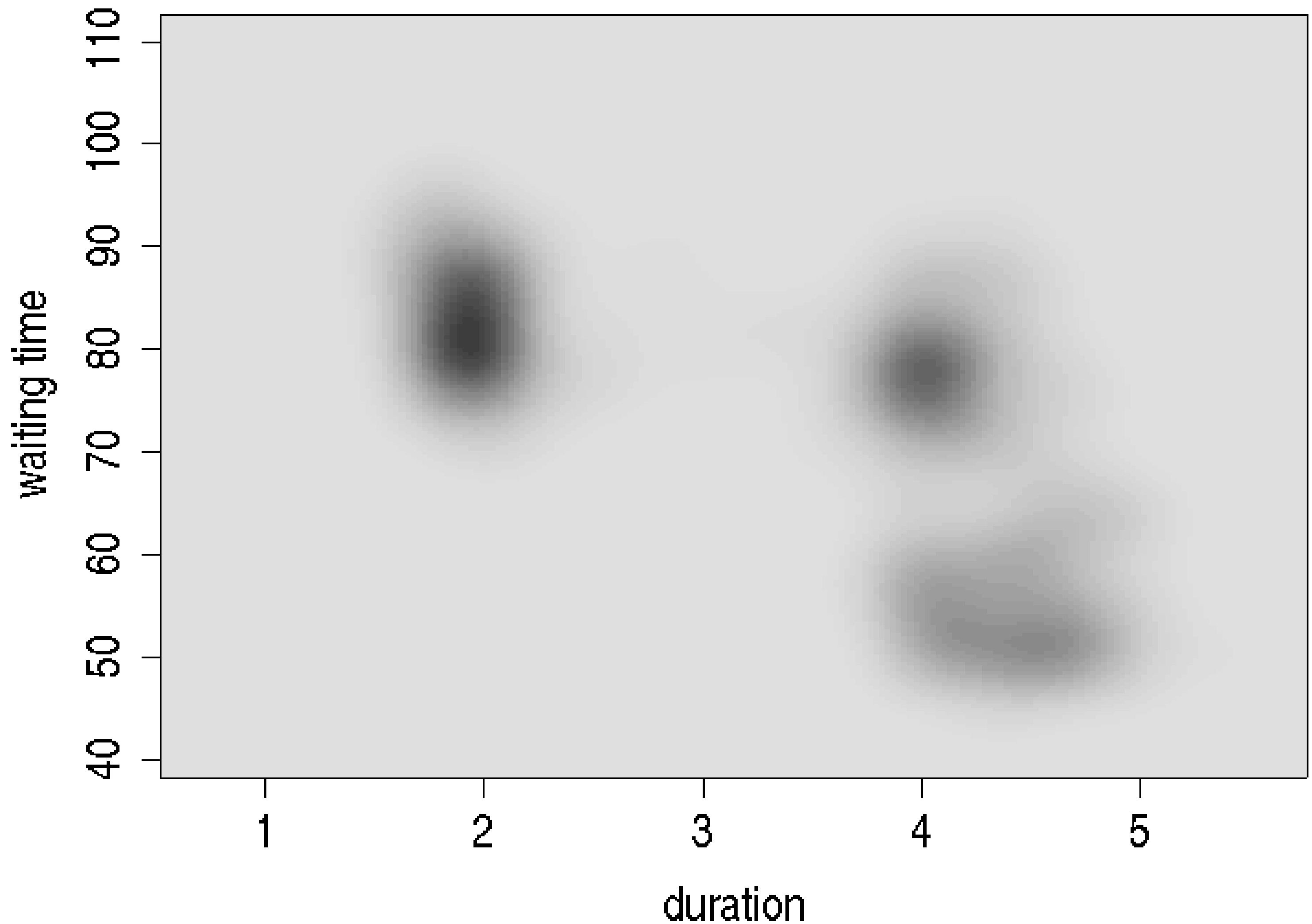

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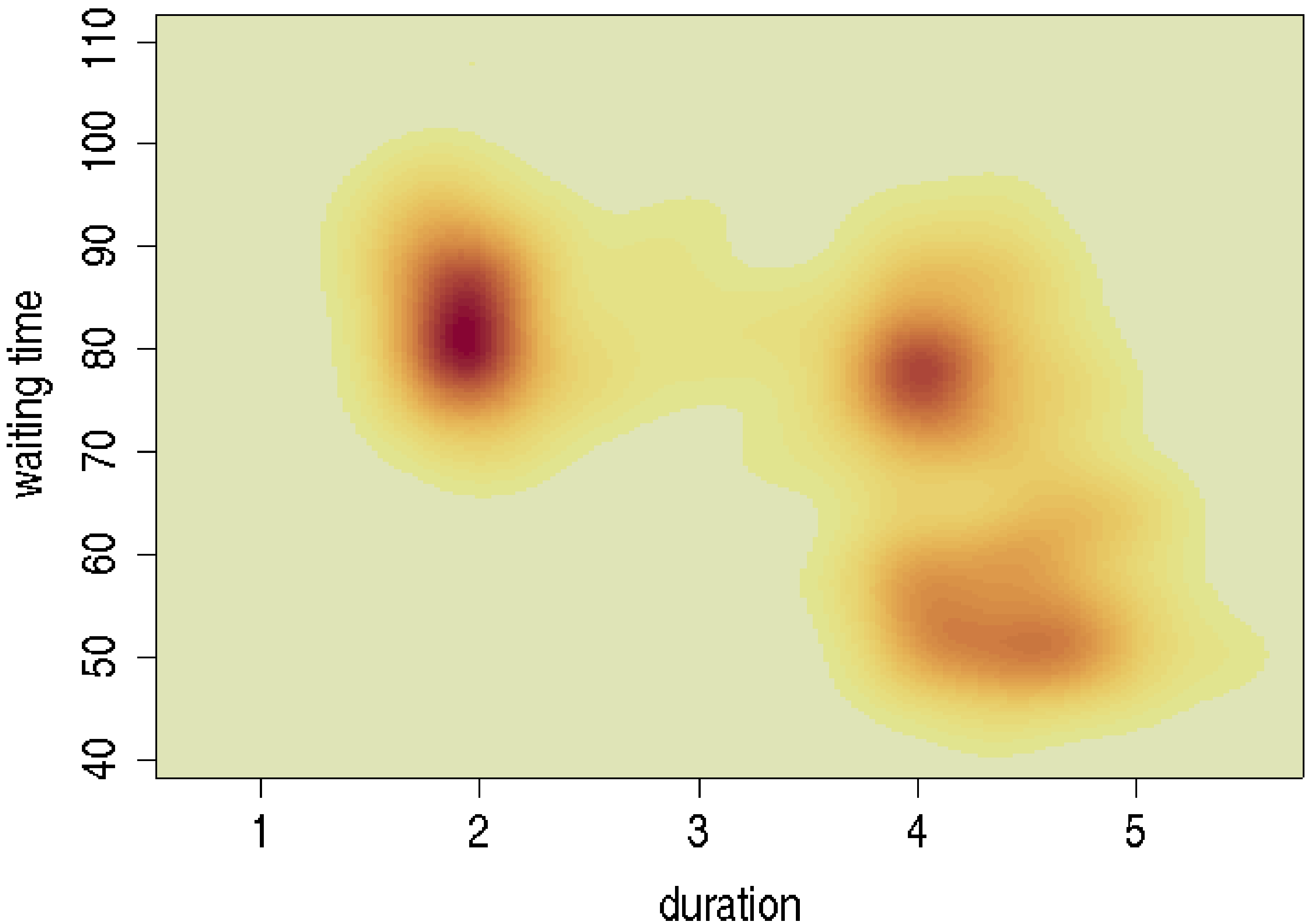


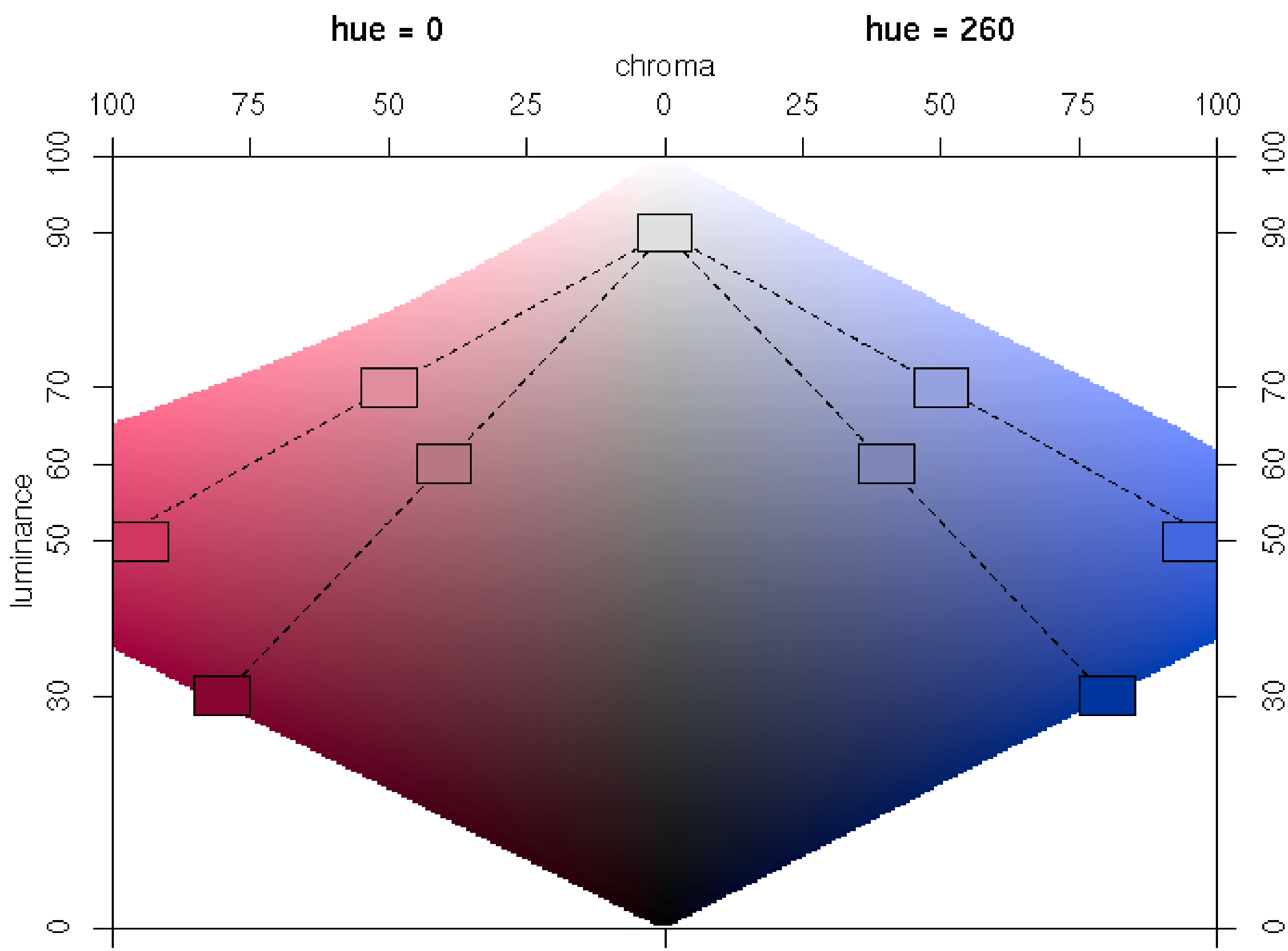
Palettes: Diverging

Goal: Code quantitative information. Intensity/interestingness i ranges in $[-1, 1]$, where 0 is uninteresting, ± 1 is interesting.

Solution: Combine sequential palettes with different hues.

Remark: To achieve both large chroma and/or large luminance contrasts, use hues with similar chroma/luminance plane, e.g., $H = 0$ (red) and $H = 260$ (blue).

Palettes: Diverging



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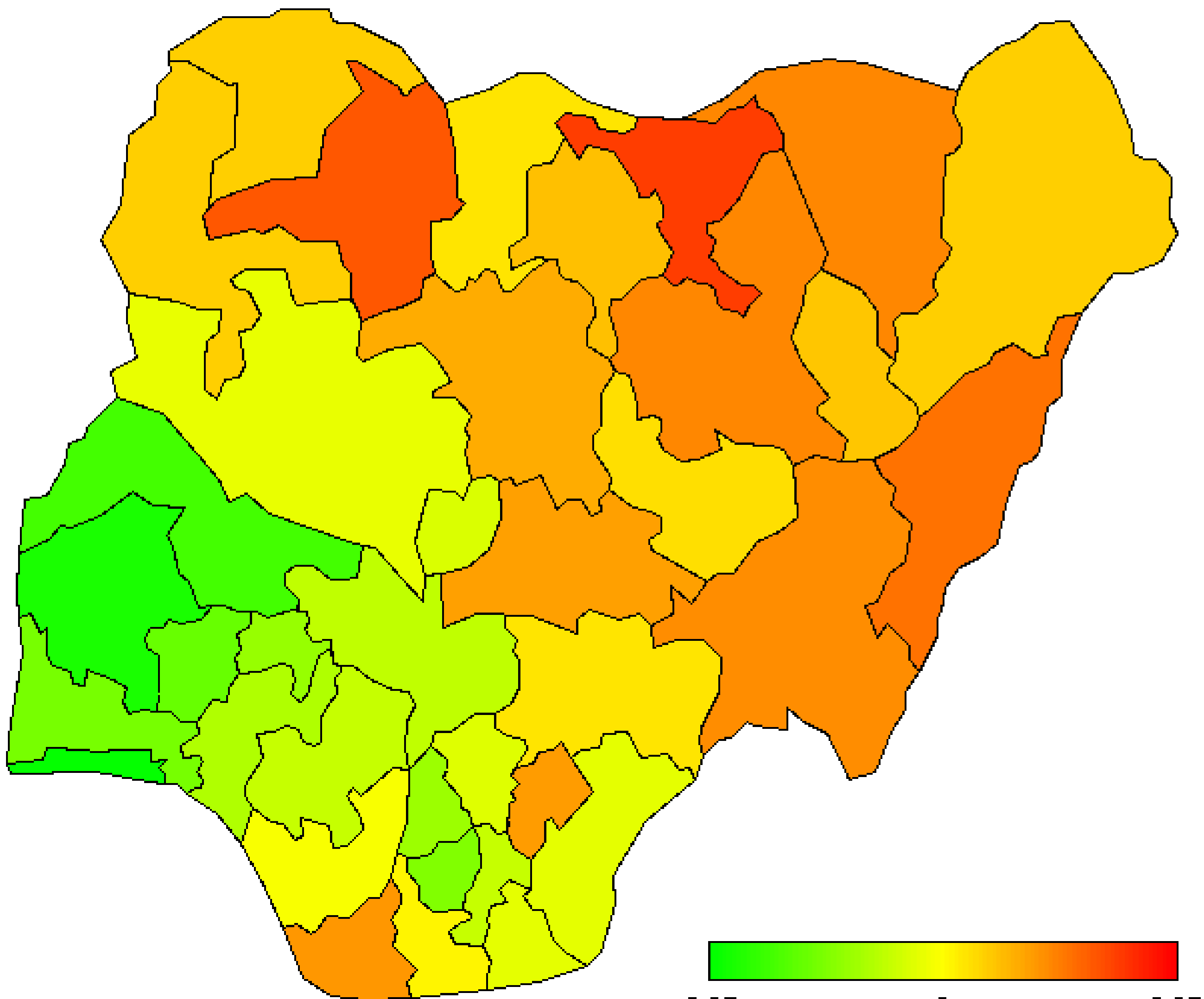

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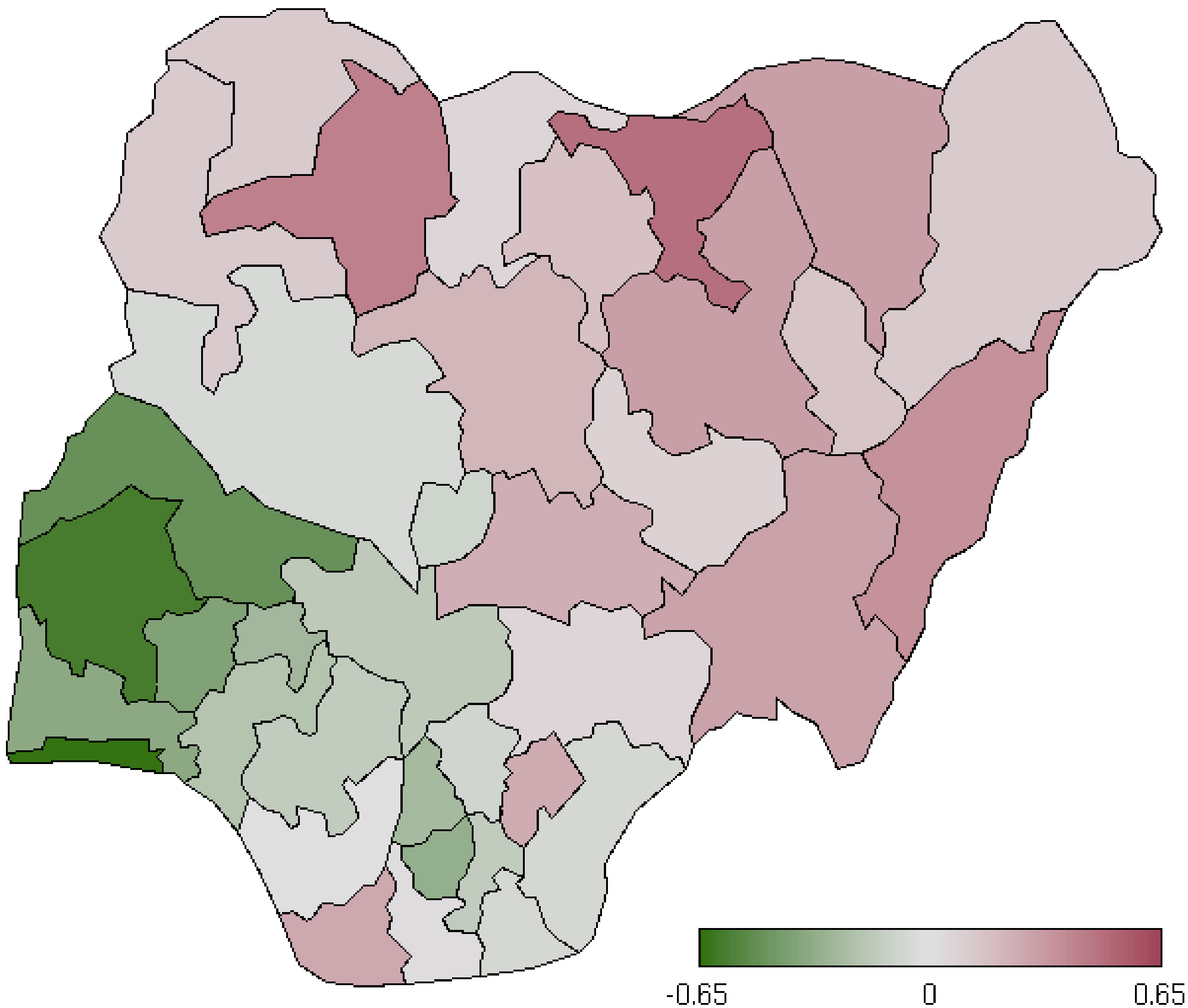
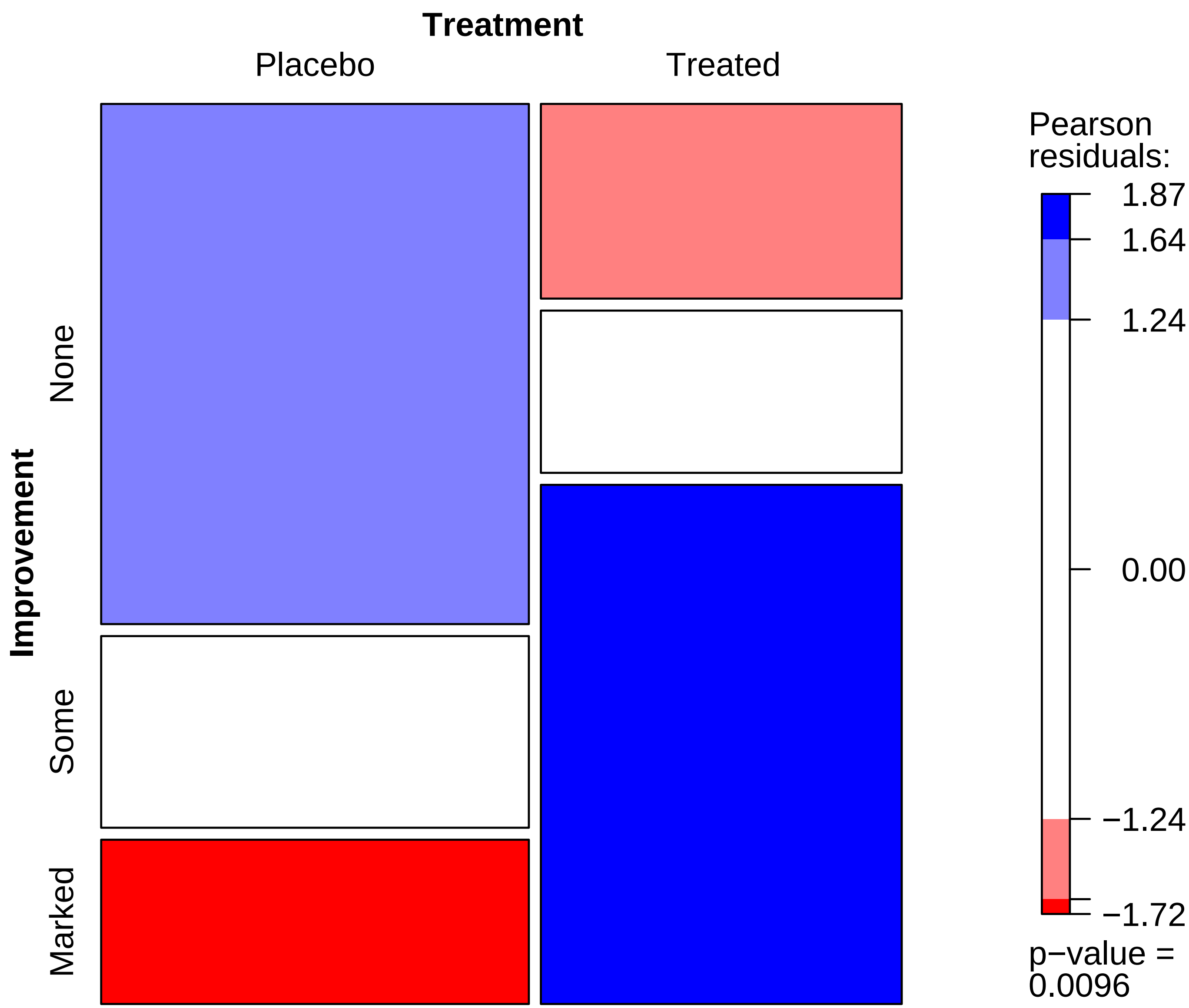


Palettes: Diverging



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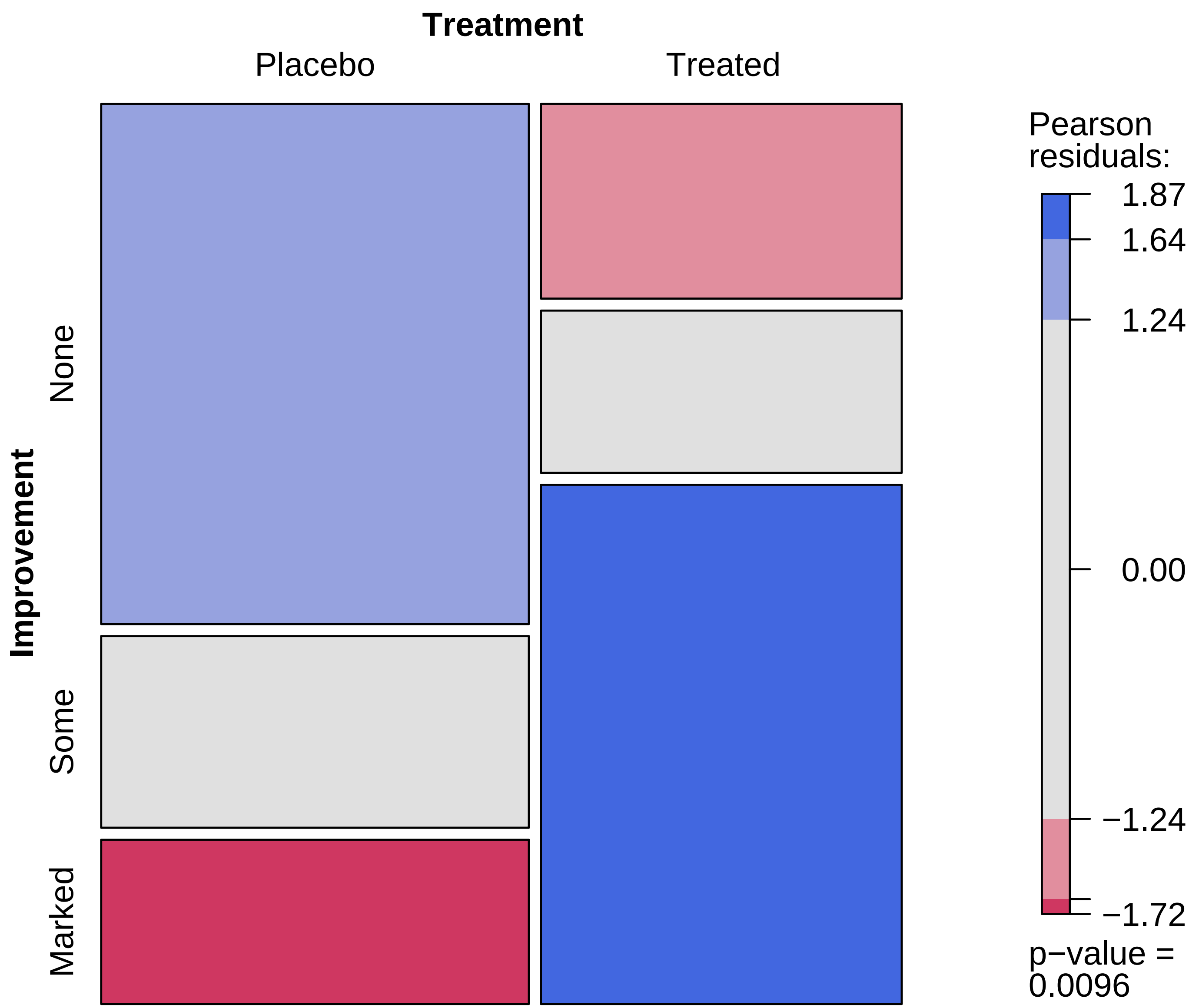


Color blindness

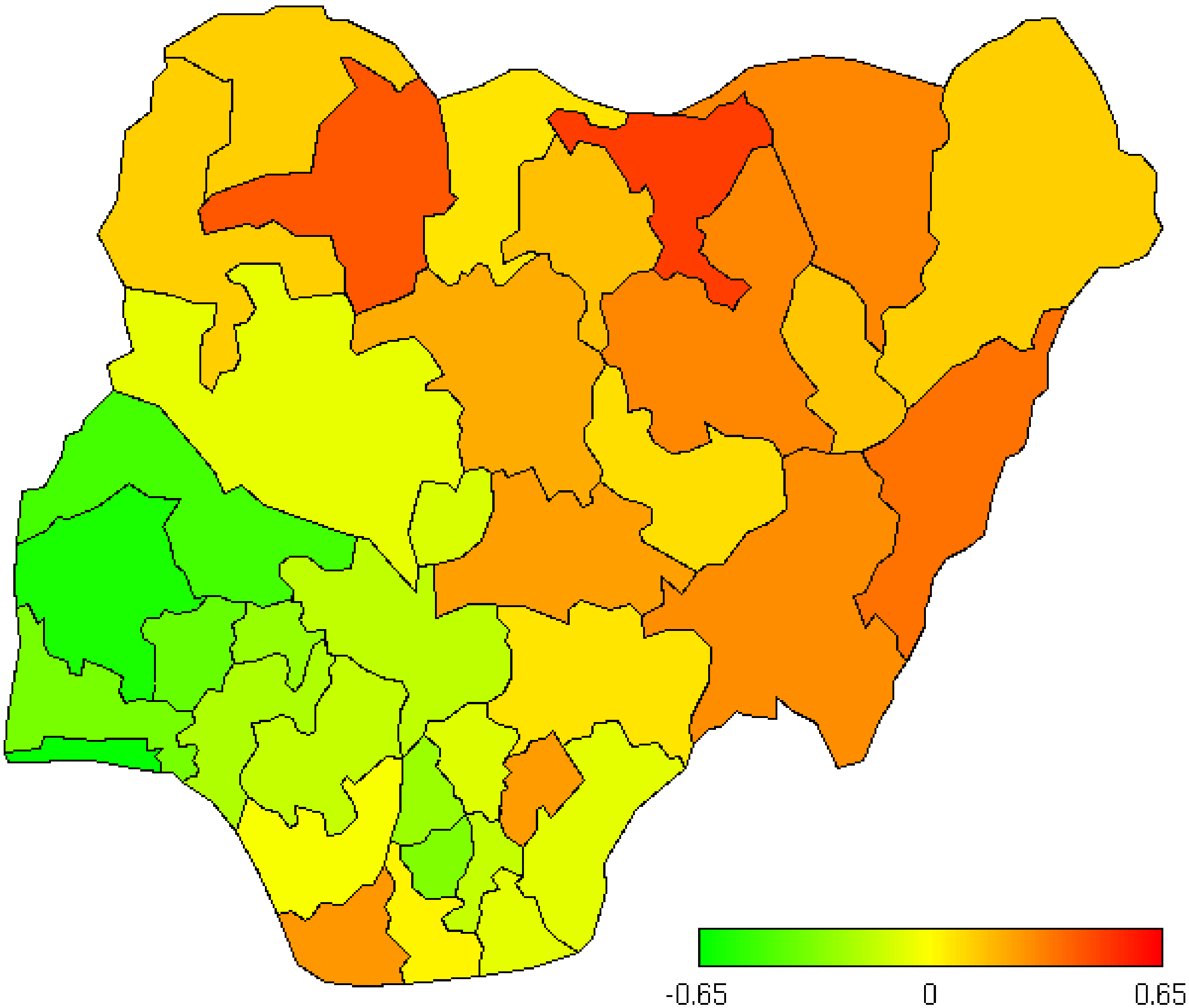
A few percent of humans (particularly males) have deficiencies in their color vision, typically referred to as *color blindness*.

The most common forms of color blindness are different types of red-green color blindness: *deuteranopia* (lack of green-sensitive pigment), *protanopia* (lack of red-sensitive pigment).

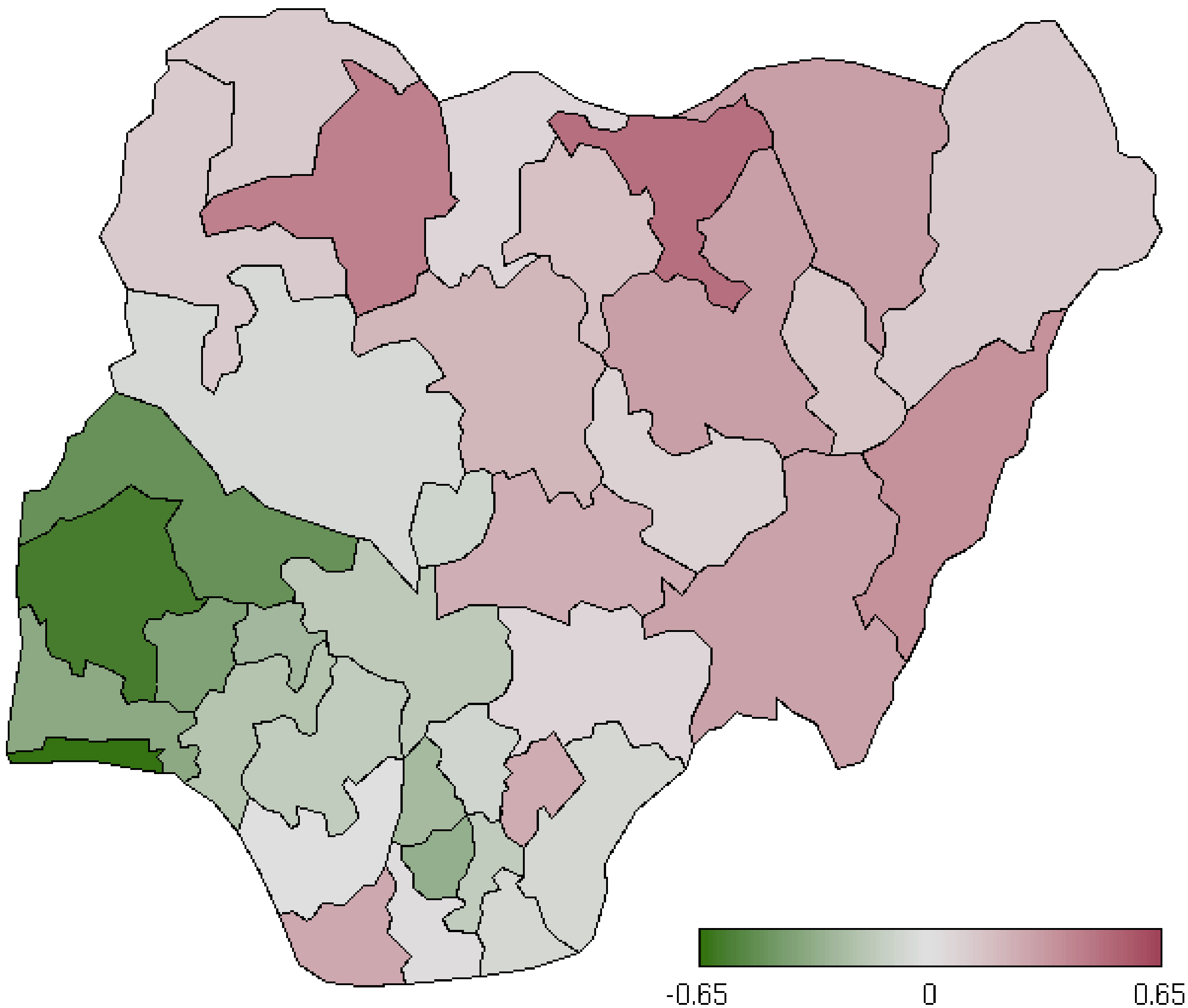
Construct suitable HCL colors:

- use large large luminance contrasts (visible even for monochromats),
- use chroma contrasts on the yellow-blue axis (visible for dichromats),
- check colors by emulating dichromatic vision, e.g., utilizing **dichromat** (Lumley 2006)

Color blindness



Color blindness



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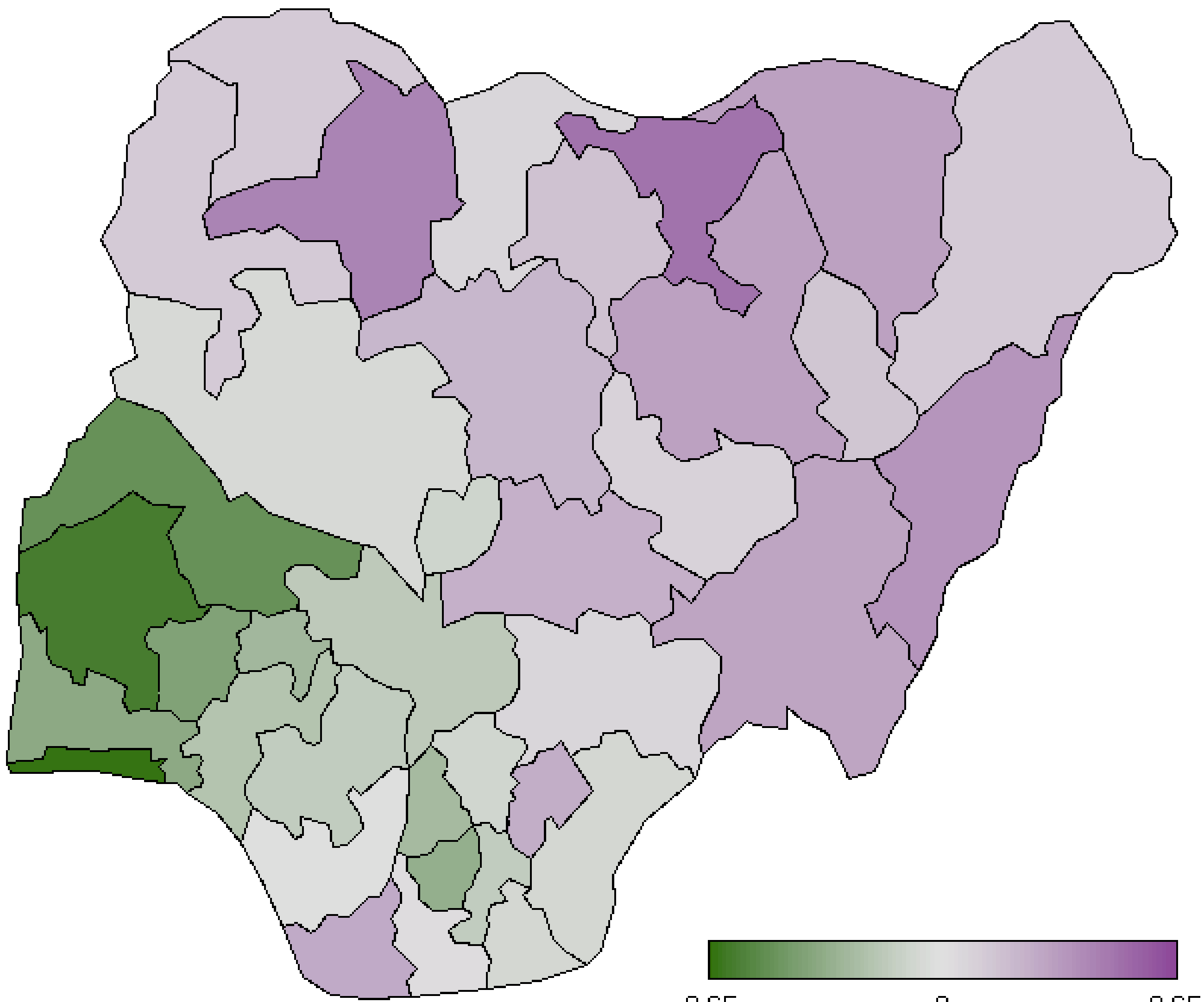

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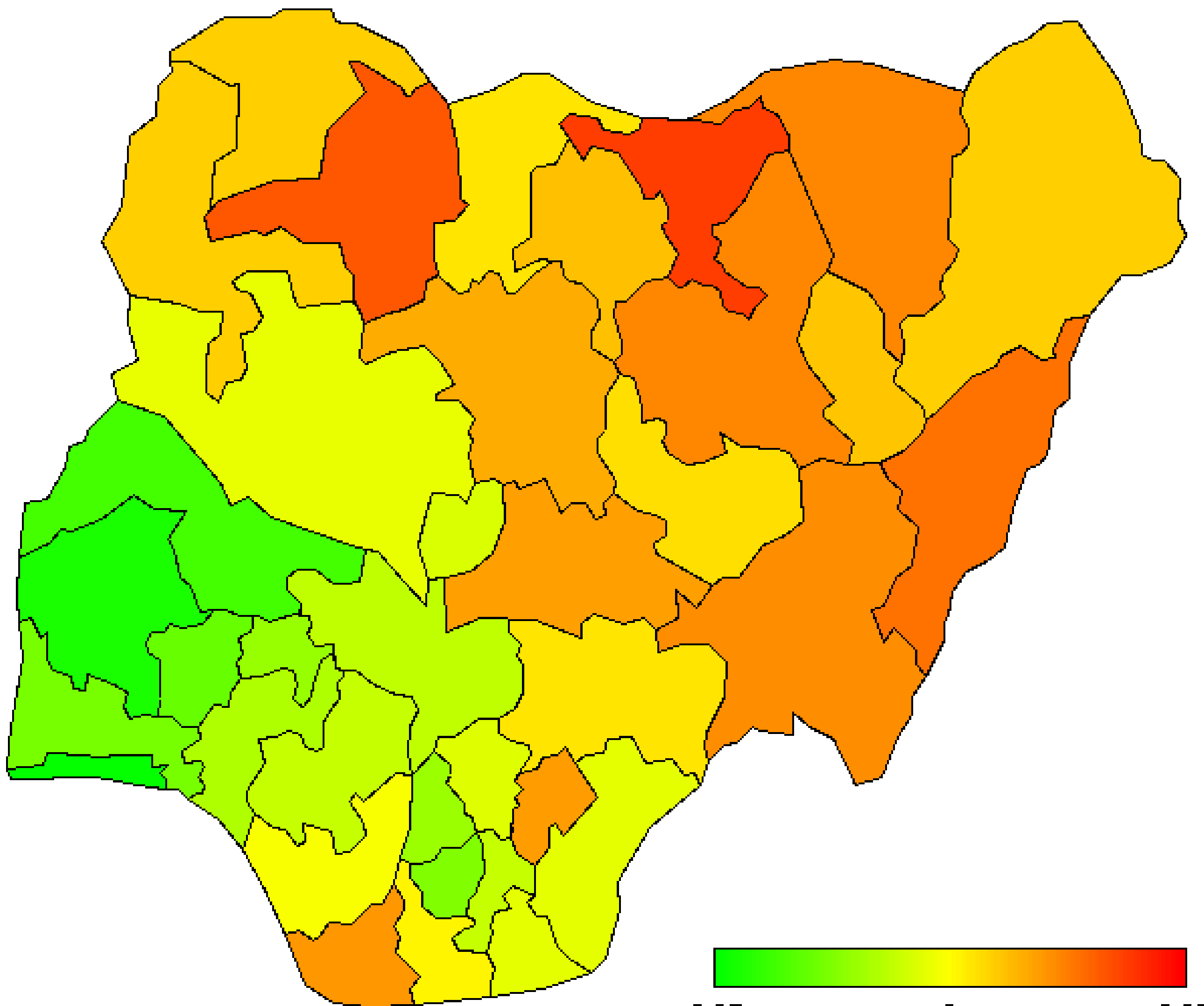

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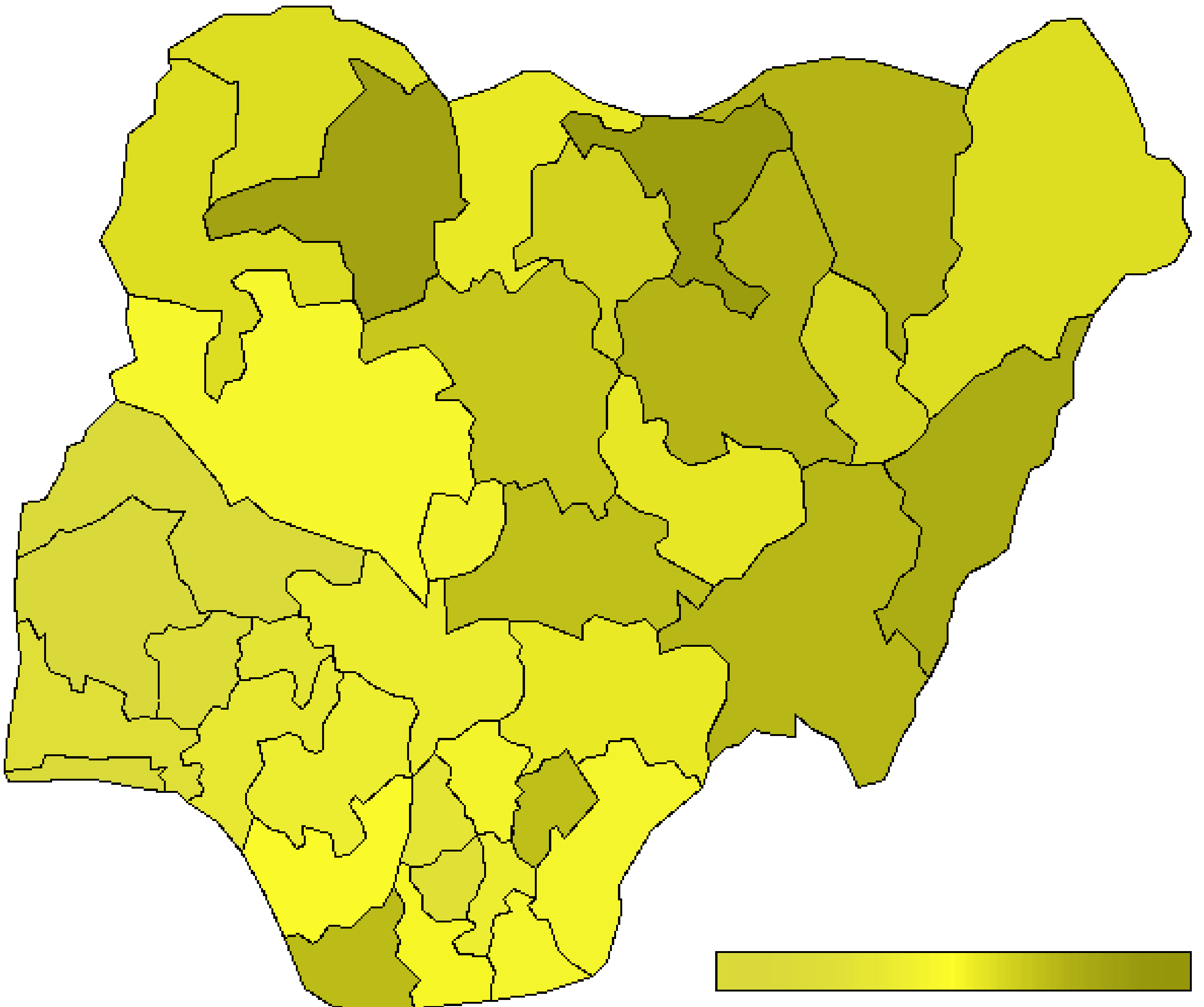

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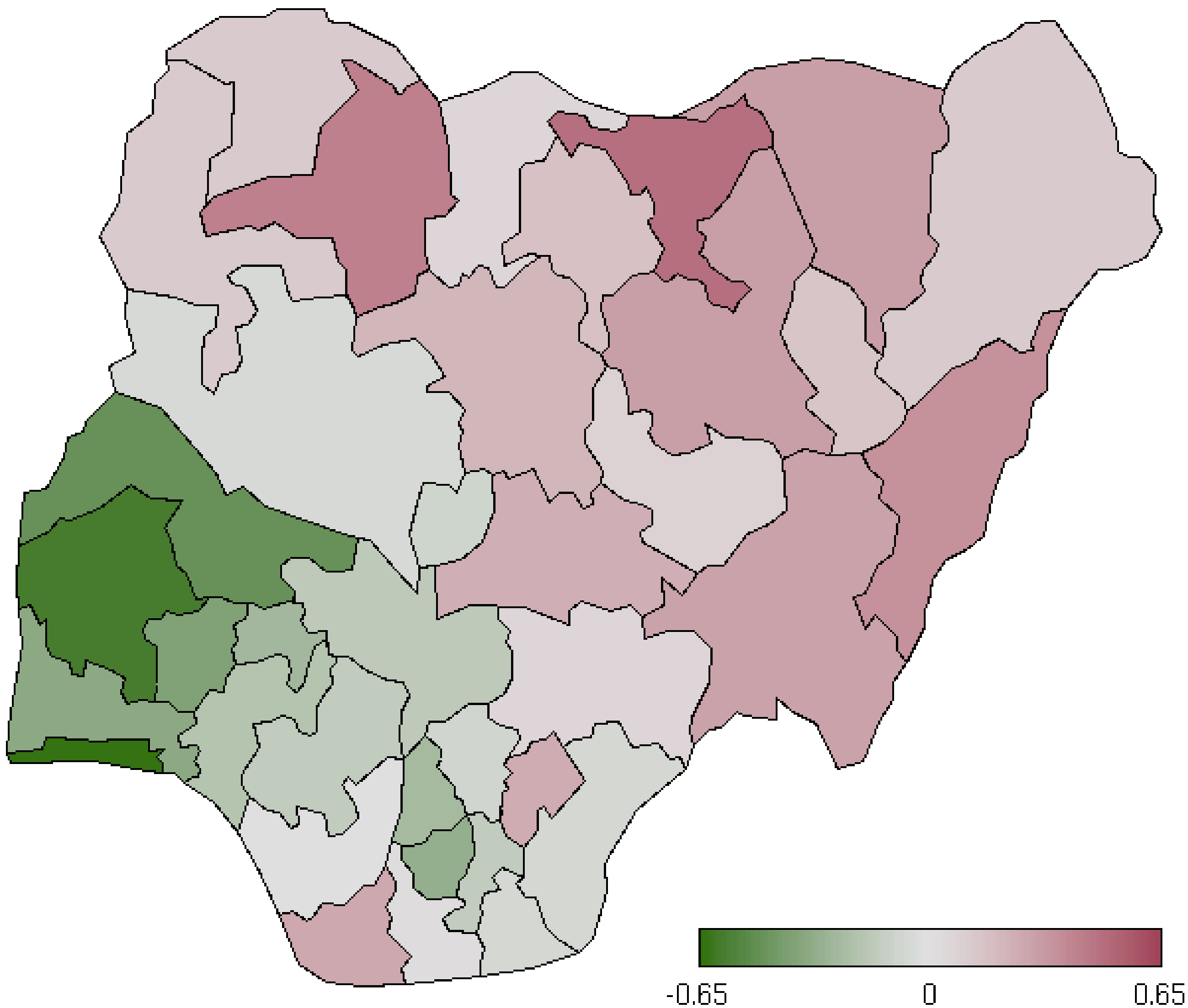

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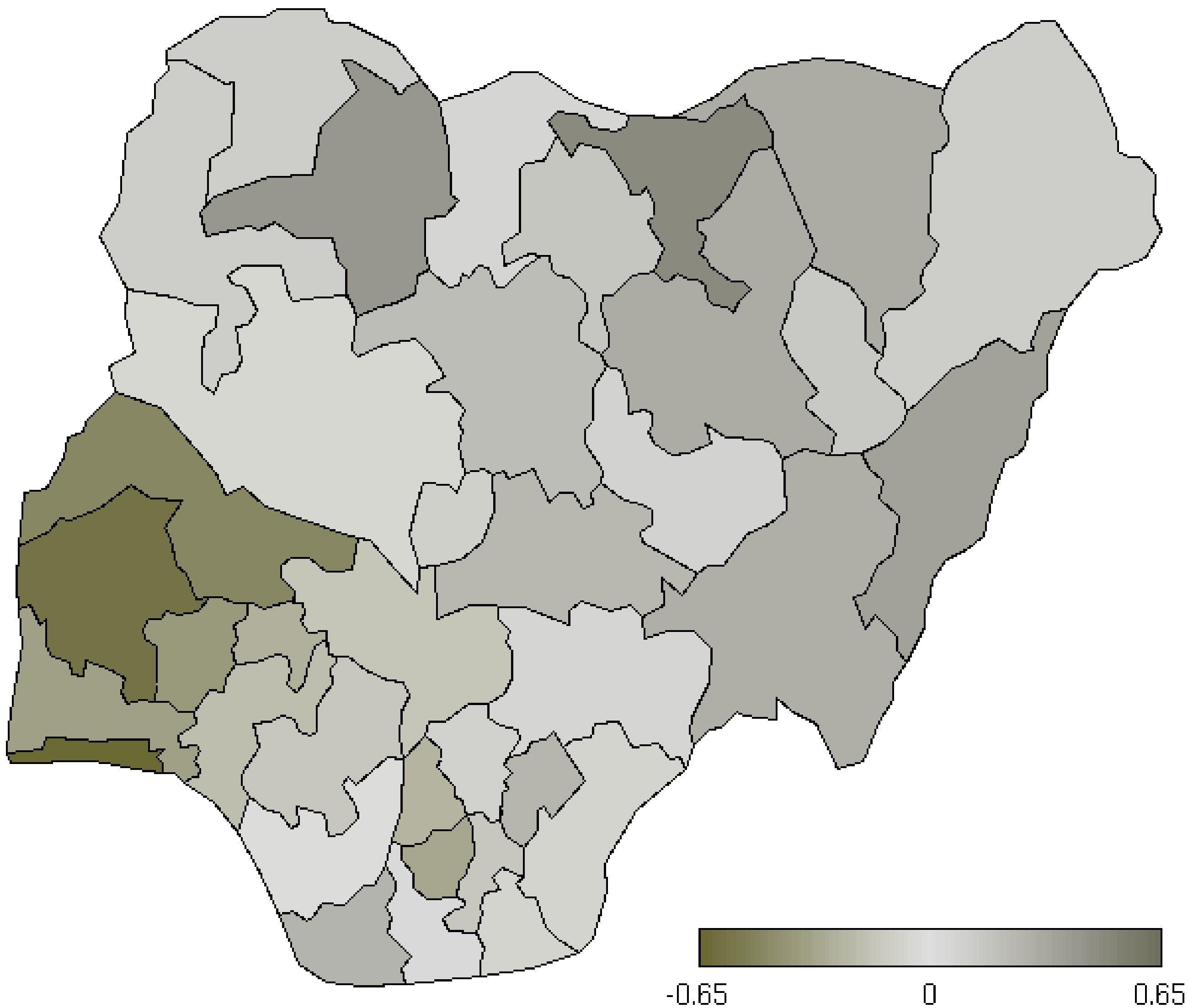

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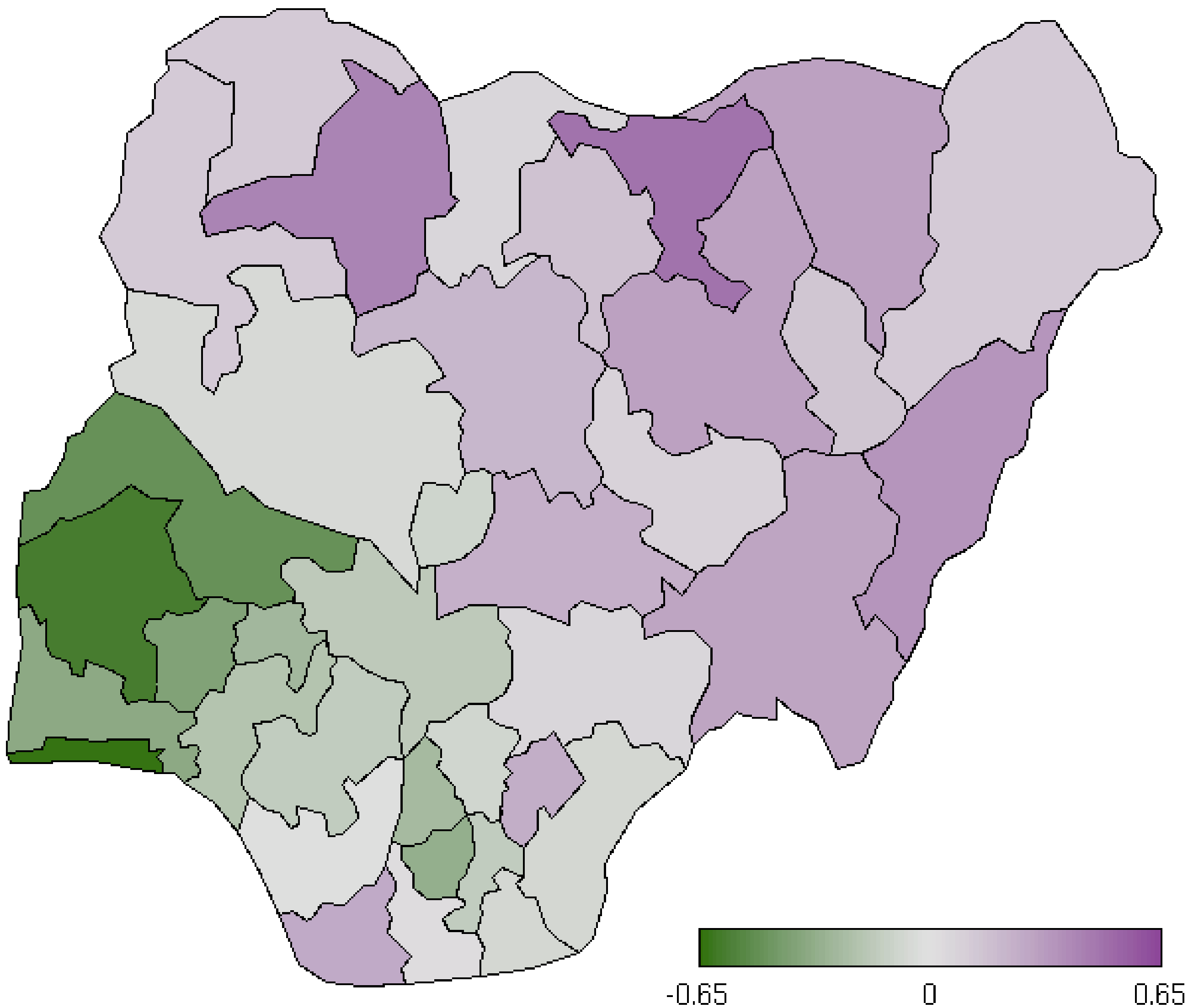

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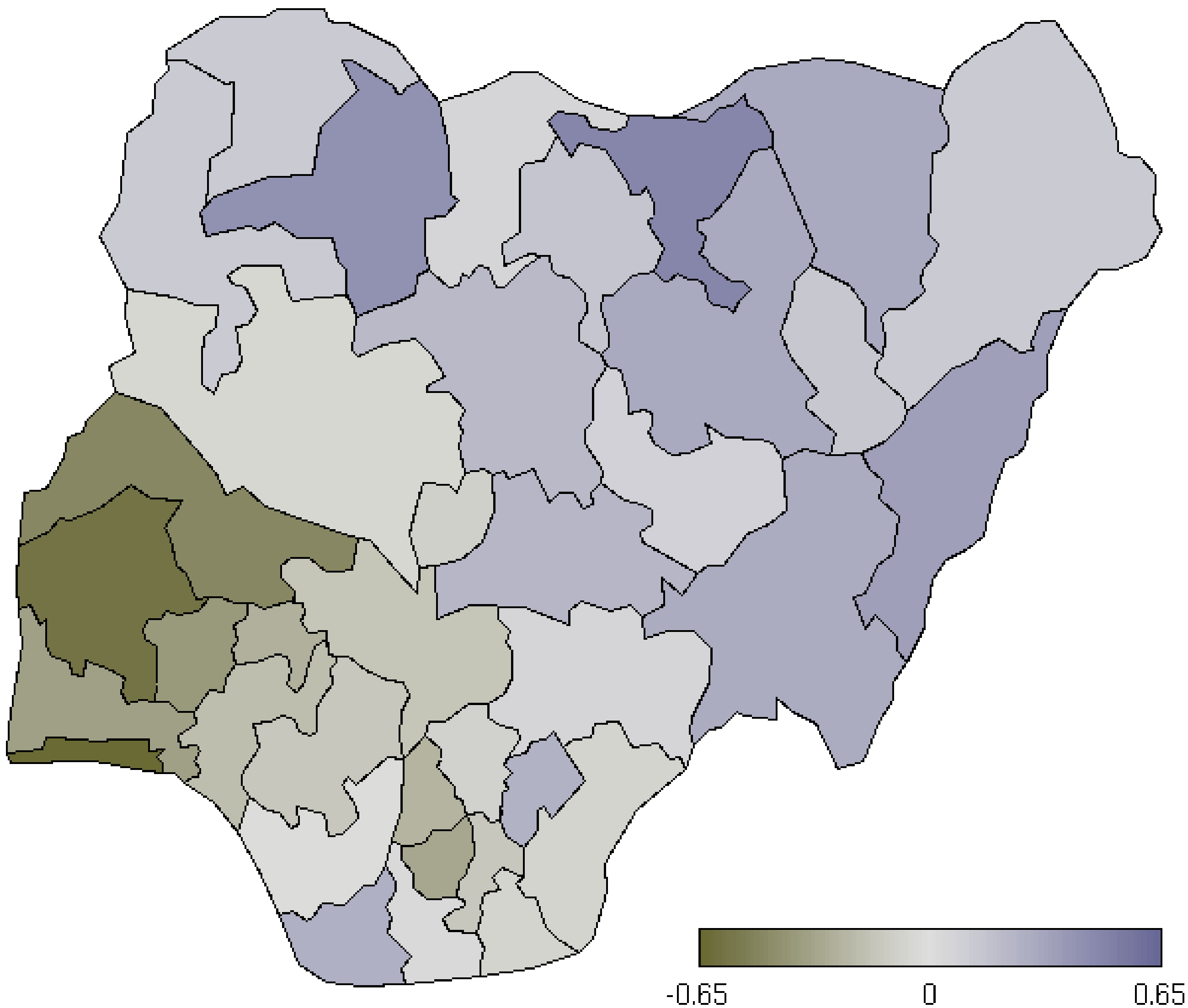

Software

Implementing HCL-based palettes is not difficult:

- If HCL colors are available, our formulas are straightforward to implement.
- If not, HCL coordinates typically need to be converted to RGB coordinates for display. Formulas are available, e.g., in Wikipedia (2007ab).

R has an implementation of various color spaces (including HCL) in Ross Ihaka's **colorspace** package. Based on this, our **vcd** package provides `rainbow_hcl()`, `sequential_hcl()`, `heat_hcl()`, and `diverge_hcl()`.

For documentation and further examples, see `?rainbow_hcl` and `vignette("hcl-colors", package = "vcd")`.

References

Brewer CA (1999). "Color Use Guidelines for Data Representation." In "Proceedings of the Section on Statistical Graphics, American Statistical Association," Alexandria, VA, 55–60.

Ihaka R (2003). "Colour for Presentation Graphics." In K Hornik, F Leisch, A Zeileis (eds.), "Proceedings of the 3rd International Workshop on Distributed Statistical Computing," Vienna, Austria, ISSN 1609-395X, URL http://www.ci.tuwien.ac.at/Conferences/DSC-2003/Proceedings/.

Lumley T (2006). "Color Coding and Color Blindness in Statistical Graphics." *ASA Statistical Computing & Graphics Newsletter*, **17**(2), 4-7. URL http://www.amstat-online.org/sections/graphics/newsletter/Volumes/v172.pdf.

Wikipedia (2007a). "CIELUV Color Space — Wikipedia, The Free Encyclopedia." URL http://en.wikipedia.org/wiki/CIELUV_color_space. accessed 2007-11-06.

Wikipedia (2007b). "HSV Color Space — Wikipedia, The Free Encyclopedia." URL http://en.wikipedia.org/wiki/HSV_color_space. accessed 2007-11-06.

Zeileis A, Hornik K, Murrell P (2007). "Escaping RGBland: Selecting Colors for Statistical Graphics." *Report 61*, Department of Statistics and Mathematics, Wirtschaftsuniversität Wien, Research Report Series. URL http://epub.wu-wien.ac.at/.

Zeileis A, Meyer D, Hornik K (2007). "Residual-based Shadings for Visualizing (Conditional) Independence." *Journal of Computational and Graphical Statistics*, **16**(3), 507–525. doi:10.1198/106186007X237856.