Designing Usable Sequential Color Schemes for Geovisualizations

Sequential Color Scheme Generator 1.0

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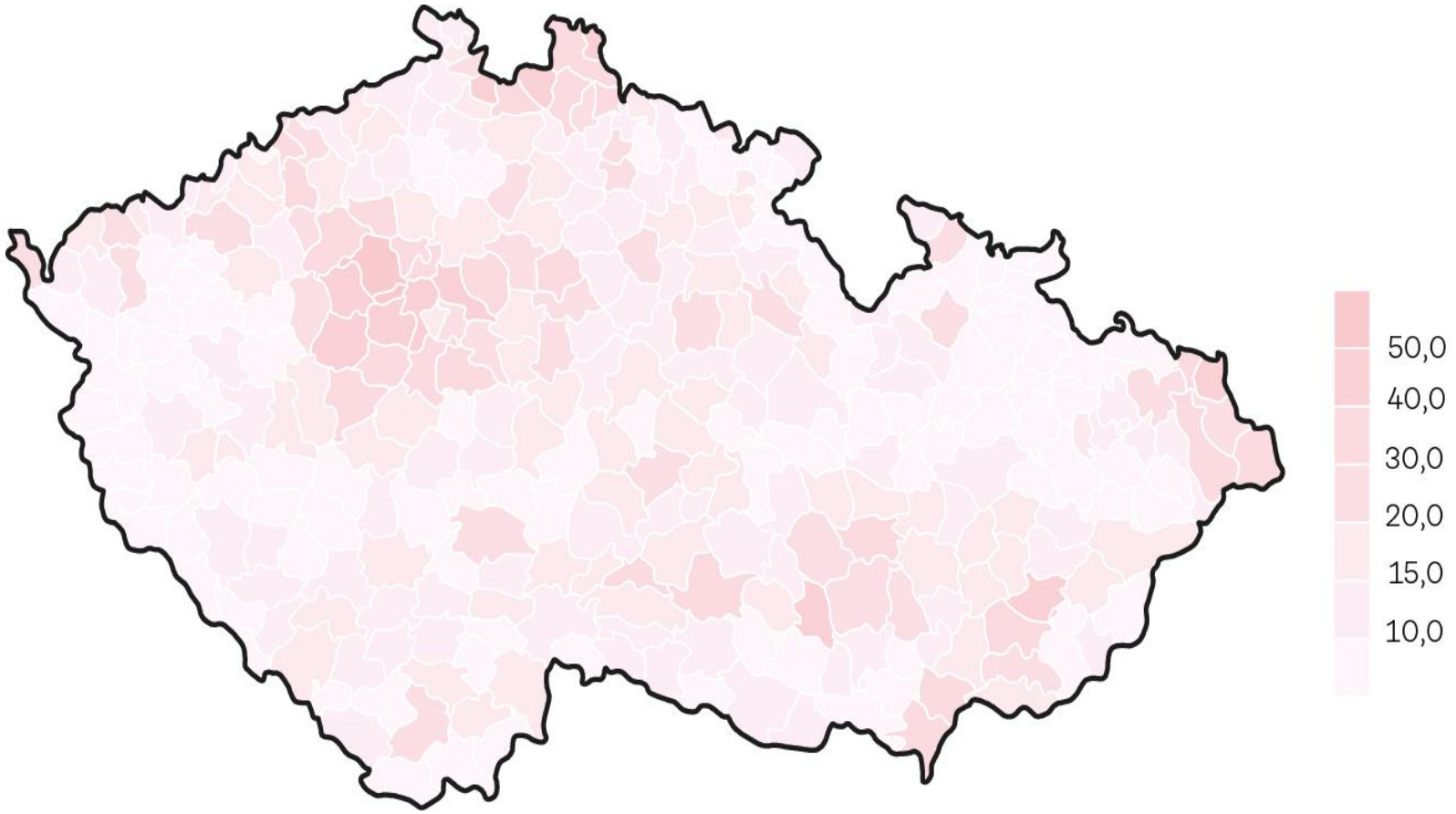
Basic cartographic rule

- shades of sequential schemes on the map must be differentiable

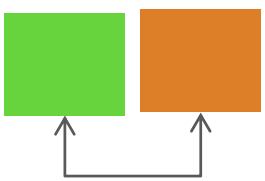


Color Distance

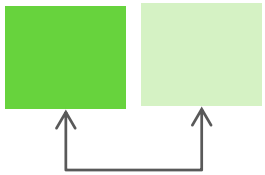
- CIE: metric, that allows to quantify perceived difference between two colors
- ΔE (Empfindung = sensation)
- CIEDE2000 method (ΔE_{00}) – the most precise, the most complex

$$\Delta E_{00}^{*} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}}$$

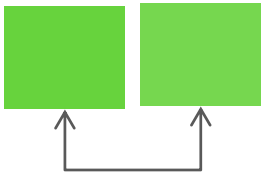
Here the parameter factors, k_L, k_C and k_H,are correction factors related with observation environment. Lightness, chroma, and hue weighting factors, S_L, S_C *and* S_H, respectively describe visual perception action on three attributes. Rotation factor R_T is used to correct deflection in the blue region.



$\Delta E_{00} = 50$



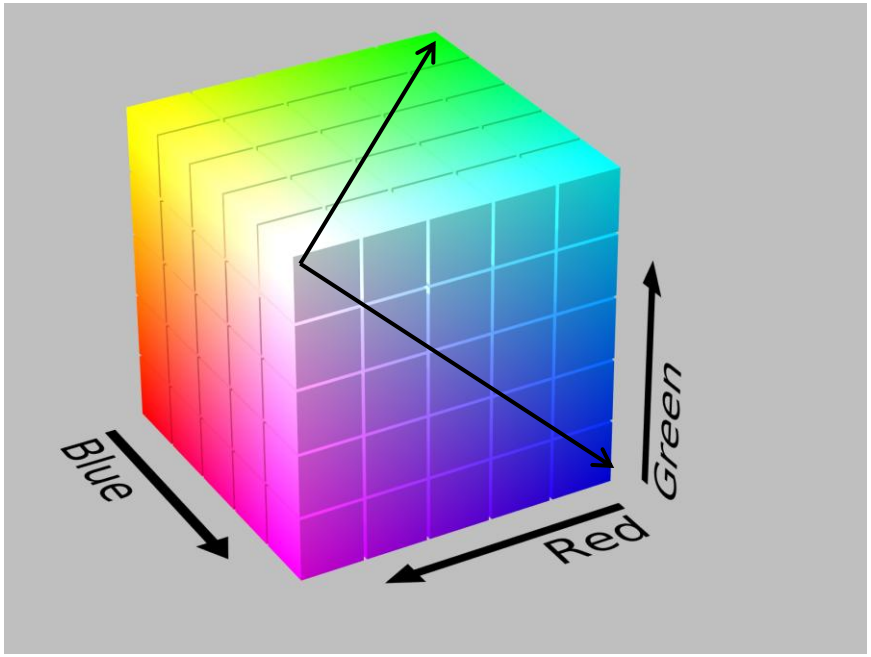
$\Delta E_{00} = 20$



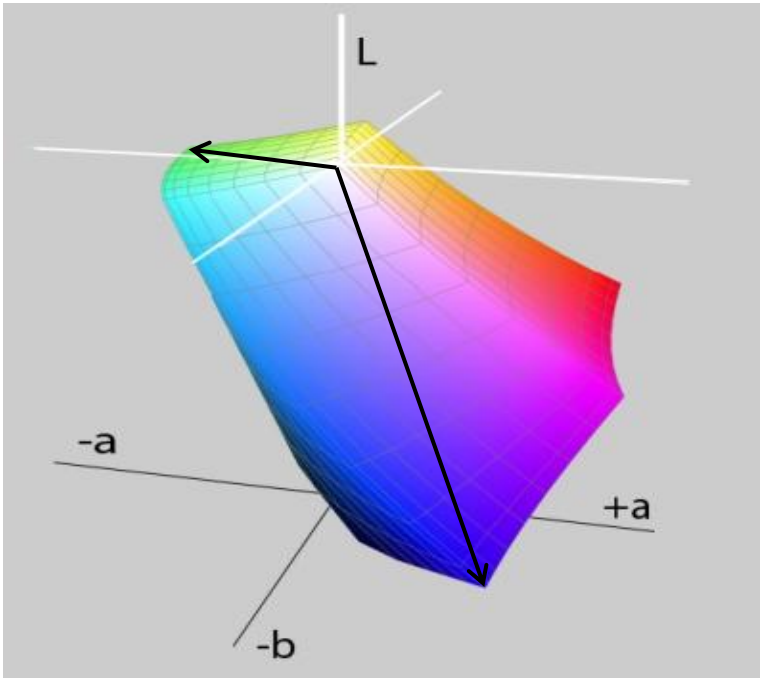
$\Delta E_{00} = 2$

Color Distance

sRGB in RGB

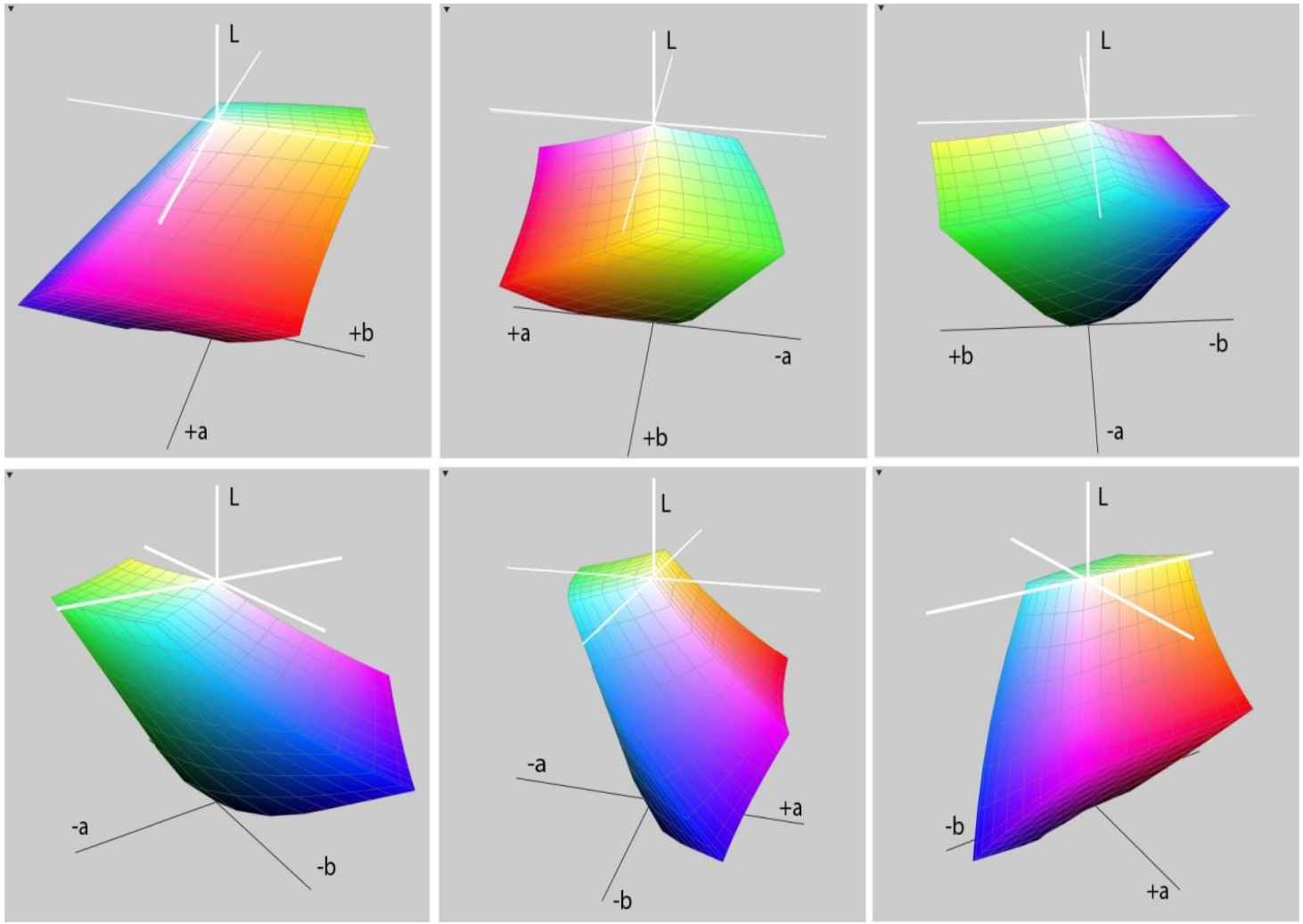


sRGB in LAB



Color Distance

- sRGB in LAB



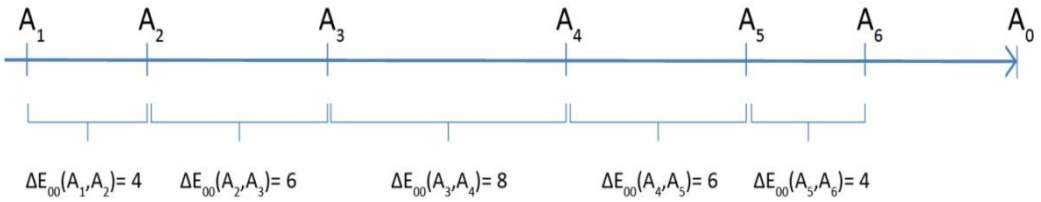
Color Distance

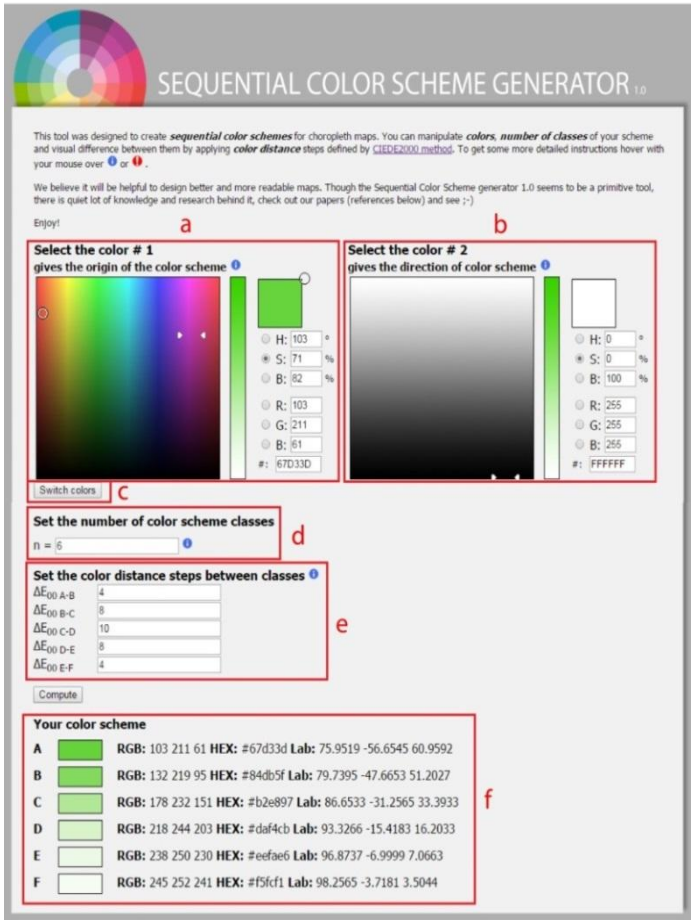
- has been empirically proven to be an important factor of maps readability

- Brychtova, A. and Coltekin, A. (2015), “Discriminating classes of sequential and qualitative colour schemes”, International Journal of Cartography, Vol. 1 No. 1, pp. 62–78, doi: 10.1080/23729333.2015.1055643
- Brychtova, A. (2015), Modern Trends in Cartography, (Brus, J., Vondráková, A. and Voženílek, V.,Eds.)Modern Trends in Cartography: Selected Papers of CARTOCON 2014, Lecture No., doi:10.1007/978-3-319-07926-4.
- Brychtova, A. and Coltekin, A. (2014), “An Empirical User Study for Measuring the Influence of Colour Distance and Font Size in Map Reading Using Eye Tracking”, The Cartographic Journal, doi: 10.1179/1743277414Y.0000000103
- Brychtová, A. a Vondráková, A. (2014), “Green versus Red: Eye-tracking evaluation of sequential colour schemes”, SGEM 2014 Informatics, Geoinformatics and Remote Sensing Proceedings Volume III, STEF92 Technology Ltd., Sofia, Bulgaria, p. 8., doi: 10.5593/SGEM2014/B23/S11.082

Sequential Color Scheme Generator 1.0

- On-line tool for designing sequential color schemes
- The user can define
  - Number of classes (shades)
  - The leading color of the scheme
  - Color distance steps between shades, CIEDE2000 formula





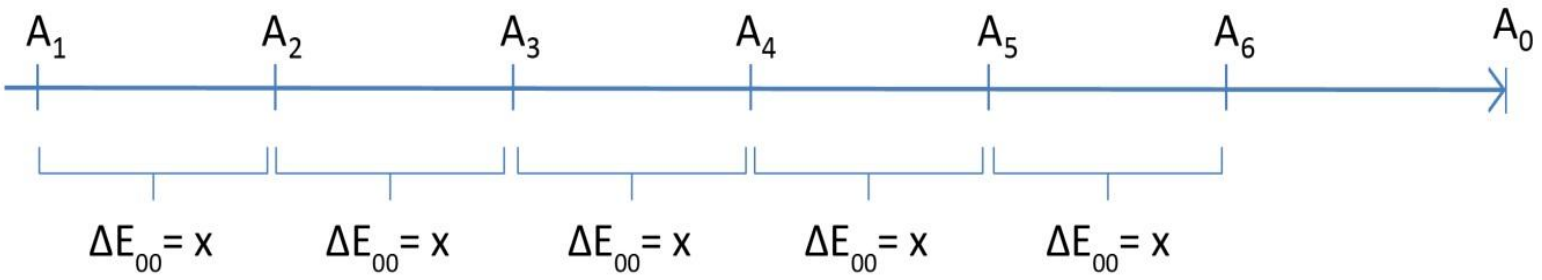
Sequential Color Scheme Generator 1.0

http://eyetracking.upol.cz/color

How it works…

Input variables:

1. *First color* of the sequantial scheme A_1
2. *Auxiliary color* A_0
3. *Number of classes (shades)* of the sequential scheme n,
4. $n-1$ values of *color distance* ΔE_{00} between adjacent shades of the sequential scheme A_i a A_{i+1} , $\forall i \in \{1, \ldots, n-1\}$



How it works…

$$R_{lin} = \begin{cases} \frac{R}{12{,}92}, & if\ R \leq 0{,}04045 \\ \sqrt[5]{\left(\frac{R+0{,}055}{1+0{,}055}\right)^{12}}, & otherwise\ R > 0{,}04045 \end{cases}$$

$$G_{lin} = \begin{cases} \frac{G}{12{,}92}, & if\ G \leq 0{,}04045 \\ \sqrt[5]{\left(\frac{G+0{,}055}{1+0{,}055}\right)^{12}}, & otherwise\ G > 0{,}04045 \end{cases}$$

$$\Delta E_{00} = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T \frac{\Delta C'}{k_C S_C} \frac{\Delta H'}{k_H S_H}}$$

where k_L, k_C a k_H are parametric coefficients adjusting the equation according to observer environment, S_L, S_C *a* S_H are weighting coefficinents for brightness, saturation and hue respectively, and R_T rotary factor adjusting the variation in the blue region

where R_{lin}, G_{lin}, B_{lin} are values after reverse gamma correction and they assumes values from the interval $\langle 0; 1 \rangle$, input coordinates sRGB $[R, G, B]$ assumes values from the interval $\langle 0; 1 \rangle$ as well.

How it works…

$$A_i = (a_i, b_i, L_i)$$
$$A_{i+1} = (a_{i+1}, b_{i+1}, L_{i+1})$$

$$A_{i+1} = A_i + \boldsymbol{u}t_i, \forall i \in 1, \dots, n-1$$

where

$$L_{i+1} = L_i + u_1 t_i,$$
$$a_{i+1} = a_i + u_2 t_i,$$
$$b_{i+1} = b_i + u_3 t_i,$$

$t \in \mathbb{R}^+, \forall i \in \{1, \dots, n-1\}$.

$$C_{i,ab} = \sqrt{(a_i)^2 + (b_i)^2} \qquad C_{i+1,ab} = \sqrt{(a_i + u_2 t_i)^2 + (b_i + u_3 t_i)^2}$$

$$\bar{C}_{ab} = \frac{C_{i,ab} + C_{i+1,ab}}{2}$$

$$G = 0{,}5\left(1 - \sqrt{\frac{\bar{C}_{ab}{}^7}{\bar{C}_{ab}{}^7 + 25^7}}\right)$$

$$a_i' = (1+G)a_i \qquad a_{i+1}' = (1+G)(a_i + u_2 t)$$

$$C_i' = \sqrt{(a_i')^2 + (b_i)^2} \qquad C_{i+1}' = \sqrt{(a_2')^2 + (b_2)^2}$$

$$h_i' = \operatorname{atan}2(b_i, a_i') \bmod 360° \quad h_{i+1}' = \operatorname{atan2}(b_{i+1}, a_{i+1}') \bmod \langle h_i' - 180° | h_i' + 180° \rangle$$

$$\text{where } x \bmod \langle a|b \rangle = a + (x-a) \bmod (b-a)$$

$$\Delta L' = -u_i t$$
$$\Delta C' = C_{i+1}' - C_i'$$
$$\Delta h' = h_{i+1}' - h_i'$$
$$\Delta H' = 2\sqrt{C_i' C_{i+1}'} \sin\left(\frac{\Delta h'}{2}\right)$$
$$\bar{L}' = L_i + \frac{u_i t}{2}$$
$$\bar{C}' = \frac{C_i' + C_{i+1}'}{2}$$

$$\bar{h}' = \frac{h_i' + h_{i+1}'}{2}$$

$$T = 1 - 0{,}17\cos\left(\bar{h}' - 30°\right) + 0{,}24\cos\left(2\bar{h}'\right) + 0{,}32\cos\left(3\bar{h}' + 6°\right) - 0{,}2\cos\left(4\bar{h}' - 63°\right)$$

$$\Delta\theta = 30e^{-\left(\frac{\bar{h}' - 275°}{25}\right)^2}$$

$$R_C = 2\sqrt{\frac{\bar{C}_{ab}^{*\,7}}{\bar{C}_{ab}^{*\,7} + 25^7}}$$

$$S_L = 1 + \frac{0{,}015\left(\bar{L}' - 50\right)^2}{\sqrt{20 + \left(\bar{L}' - 50\right)^2}}$$

$$S_C = 1 + 0{,}0045\bar{C}'$$

$$S_H = 1 + 0{,}015\bar{C}'T$$

$$R_T = -\sin(2\Delta\theta)R_C$$

$$\Delta E_{00}(A_i, A_{i+1}) = \sqrt{\left(\frac{\Delta L'}{k_L S_L}\right)^2 + \left(\frac{\Delta C'}{k_C S_C}\right)^2 + \left(\frac{\Delta H'}{k_H S_H}\right)^2 + R_T\left(\frac{\Delta C'}{k_C S_C}\right)\left(\frac{\Delta H'}{k_H S_H}\right)}$$

where

$$atan\,2(y, x) = \begin{cases} tan^{-1}\left(\frac{y}{x}\right), & y > 0, x \geq 0 \\ tan^{-1}\left(\frac{y}{x}\right) + 180°, & x < 0 \\ tan^{-1}\left(\frac{y}{x}\right) + 360°, & y > 0, x < 0 \\ 90°, & y = 0, x > 0 \\ 270°, & y = 0, x < 0 \\ 0°, & y = 0, x = 0 \end{cases}$$

and $x \bmod n = x - \left\lfloor \frac{x}{m} \right\rfloor \cdot m$, where $\left\lfloor \frac{x}{m} \right\rfloor$ denotes the entire lower part of the value $\frac{x}{m}$, $m \in \mathbb{Z}$.

Sequential Color Scheme Generator 1.0

- Transformed to CIELAB, the set of possible sRGB colors forms a non-convex shape
- There could exist inner points of the line segment $|A_1A_0|$, which lie outside the sRGB color space

$$If\ \left((R_i < 0\ or\ R_i > 255)\ or\ (G_i < 0\ or\ G_i > 255)\ or\ (B_i < 0\ or\ B_i > 255)\right)\ then$$

$$If\ \left(\Delta E_{00}(A_1, A_i) < \Delta E_{00}(A_1, A_0)\right)\ then$$

$$If\ (R_i < 0)\ then\ R_i = 0$$

$$If\ (R_i > 255)\ then\ R_i = 255$$

$$If\ (G_i < 0)\ then\ G_i = 0$$

$$If\ (G_i > 255)\ then\ G_i = 255$$

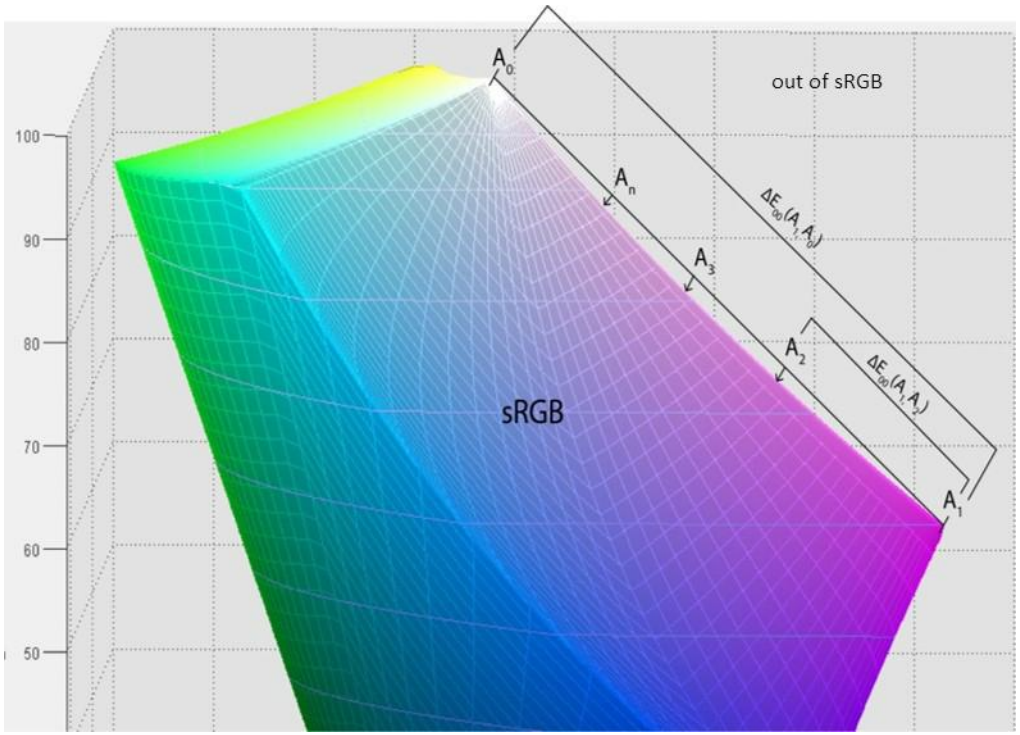
$$If\ (B_i < 0)\ then\ B_i = 0$$

$$If\ (B_i > 255)\ then\ B_i = 255$$

$$else$$

$$terminate\ computation$$

where $i \in \{2, \dots, n-1\}$



Sequential Color Scheme Generator 1.0

- Between sRGB and CIELAB color spaces doesn't exist any one-to-one correspondence
- The line defined by the user could run away of the space sRGB

$$If\ \left((R_i < 0\ or\ R_i > 255)\ or\ (G_i < 0\ or\ G_i > 255)\ or\ (B_i < 0\ or\ B_i > 255)\right)\ then$$

$$If\ \left(\Delta E_{00}(A_1, A_i) < \Delta E_{00}(A_1, A_0)\right)\ then$$

$$If\ (R_i < 0)\ then\ R_i = 0$$

$$If\ (R_i > 255)\ then\ R_i = 255$$

$$If\ (G_i < 0)\ then\ G_i = 0$$

$$If\ (G_i > 255)\ then\ G_i = 255$$

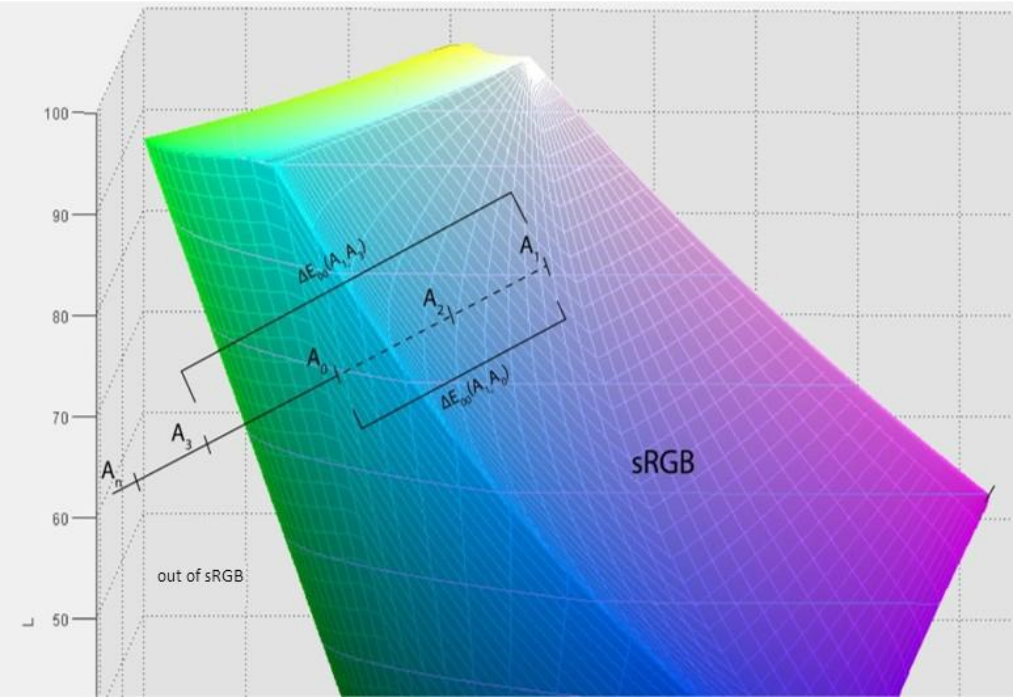
$$If\ (B_i < 0)\ then\ B_i = 0$$

$$If\ (B_i > 255)\ then\ B_i = 255$$

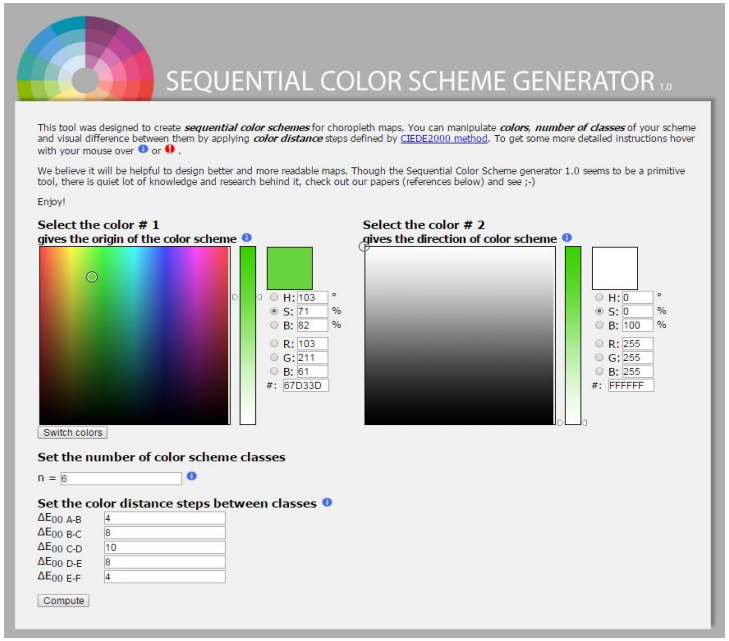
$$else$$

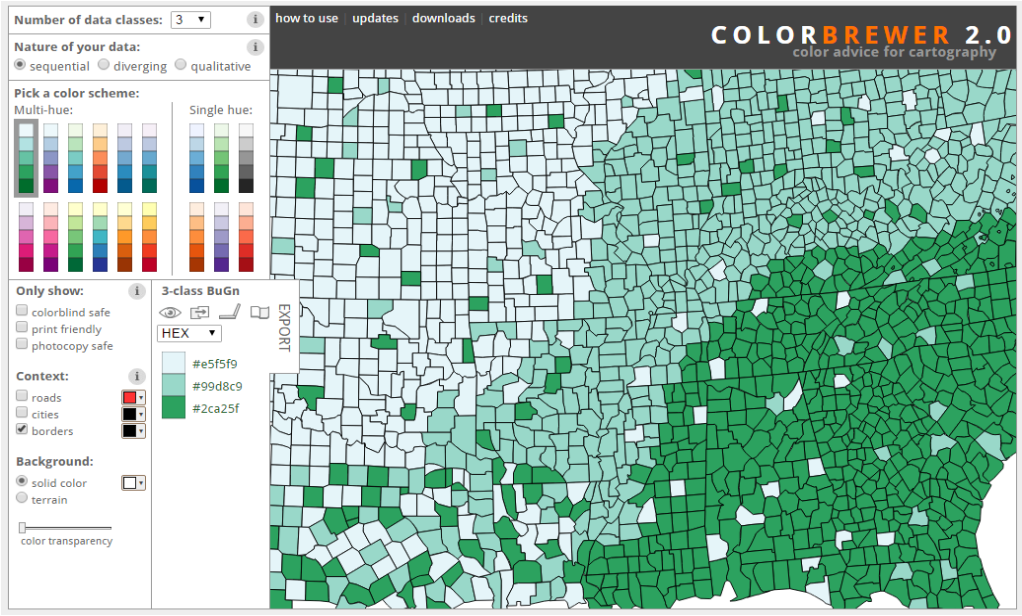
$$terminate\ computation$$

where $i \in \{2, \ldots, n-1\}$



Sequential Color Scheme Generator 1.0 vs ColorBrewer 2.0

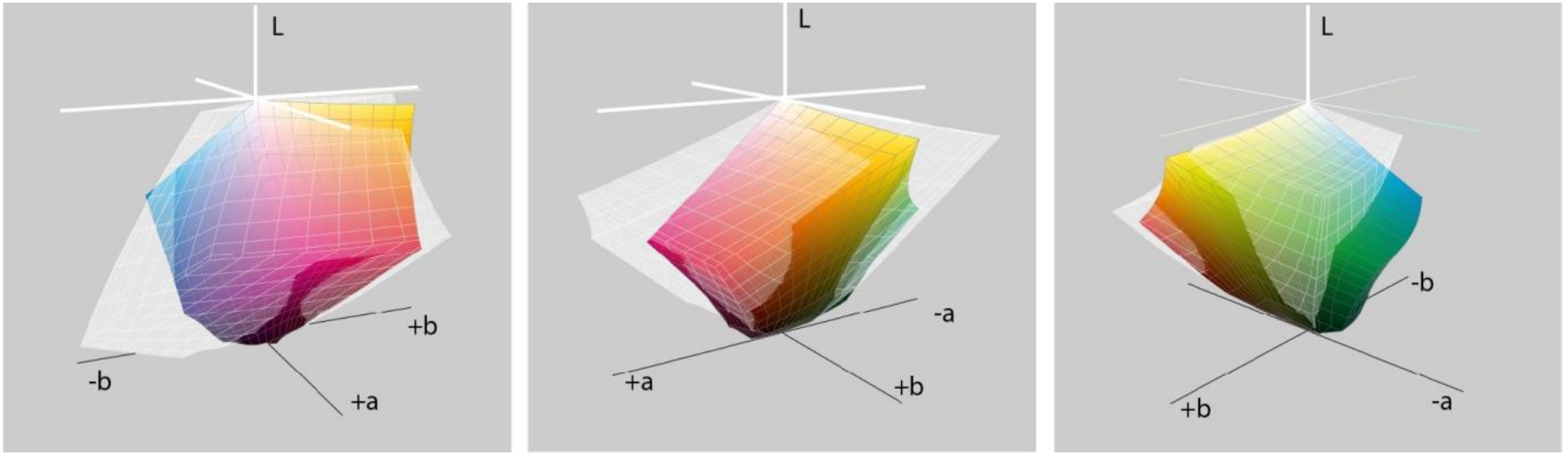




- ✚ Users can set all parameters of the color scheme without any limits
- − Users have to understand colors a bit ☺
- − The user interface is imperfect and complicated (look forward the v2!)
- ✚ Based on research of map users color distance perception

Future plans

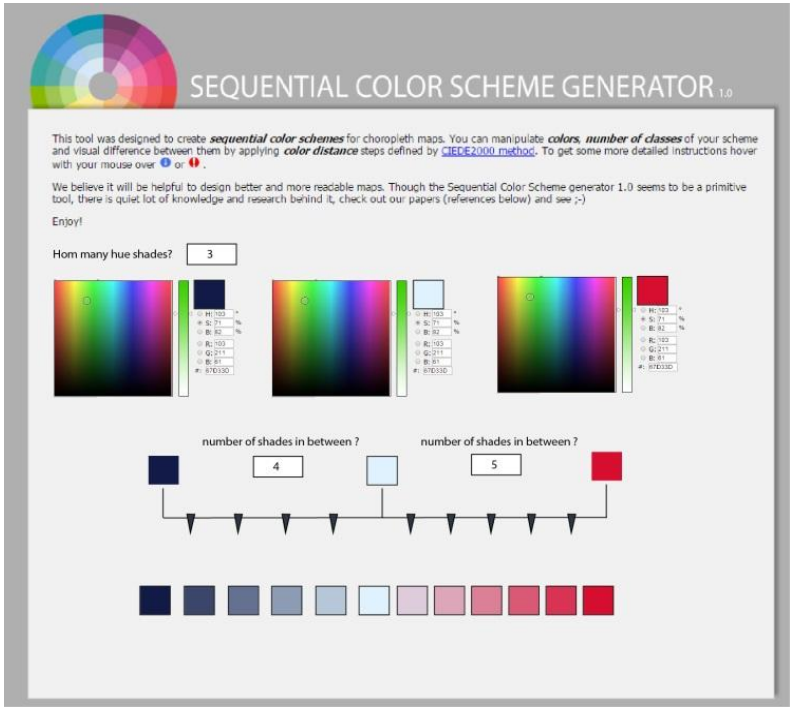
- Implement computations in various color spaces (especially for printing – FOGRA39)

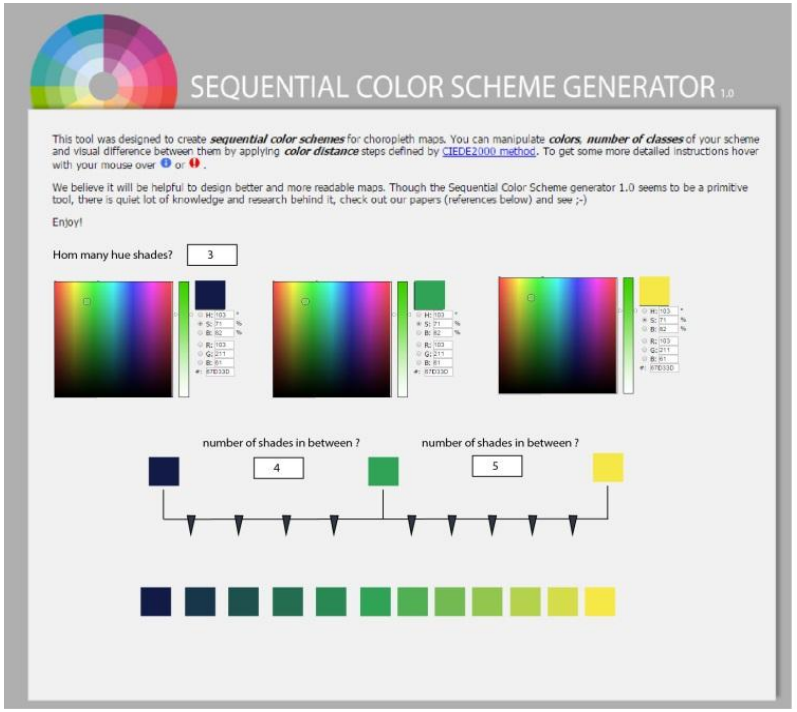


Coated FOGRA 39 vs. sRGB

Future plans

- easier creation of divergent and multi-hue sequential color schemes





Thank you for your attention

http://eyetracking.upol.cz/color/