Investigation of Uniform Colour Scales in Different Colour Order Systems

Ferenc Szabó*
Ildikó Rozsovits**

* University of Pannonia
** Coloroid Ltd.

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- Visual Experiments
- Data analysis
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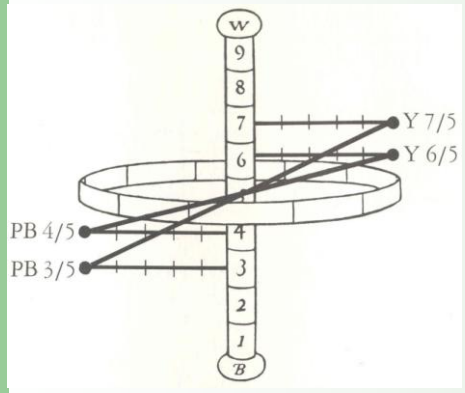
Motivation



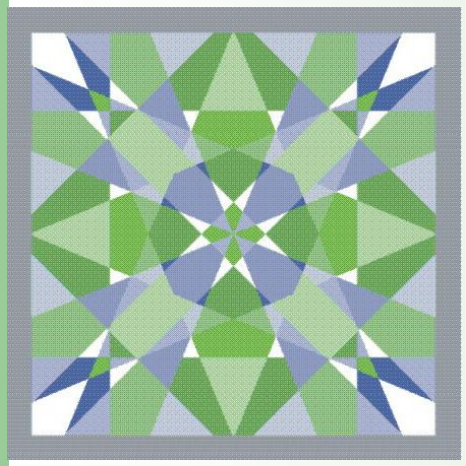
Colour Harmony models

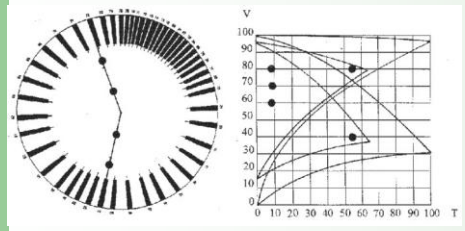
- One of the most important phenomenon in colour design is colour harmony.
- One of the characteristics of colour harmony is the *scale-like relationship* of colours in a collection.

Some example:

1. Factors of colour harmony according to the theory of Munsell *(„harmony = order")*
   - Balance
     - proportion of colour values and area
     - connection among hues
   - Regular steps of hue, value and chroma
     - uniform equal hue scales
     - scales passing through the neutral pole
     - elliptical path

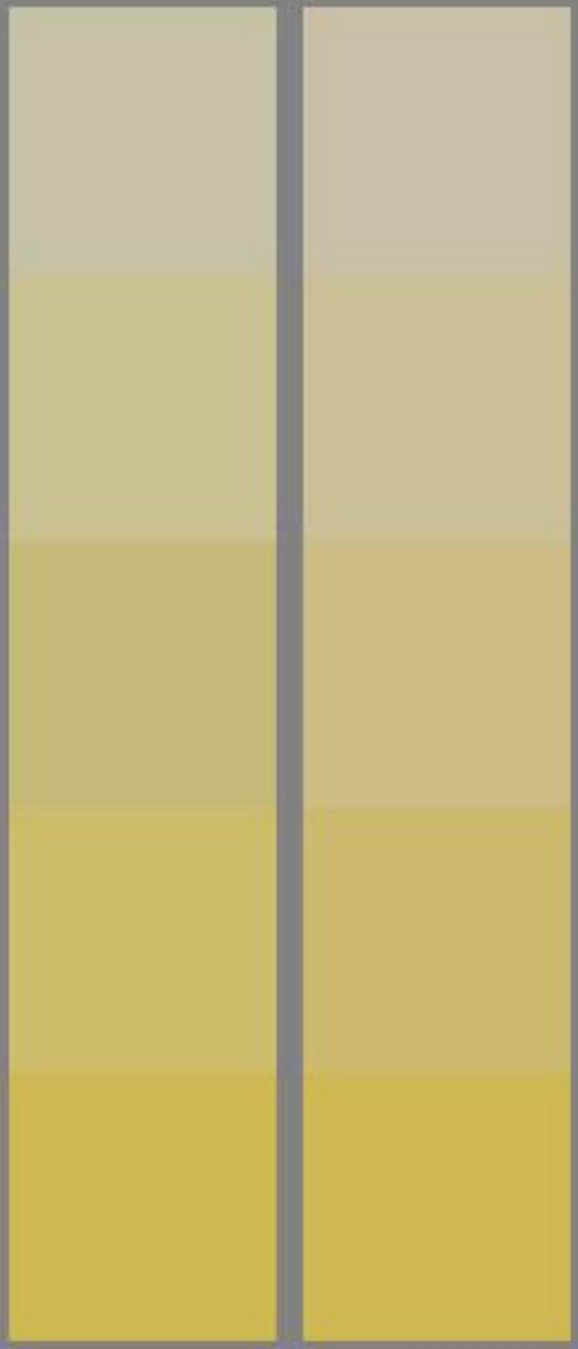
Motivation

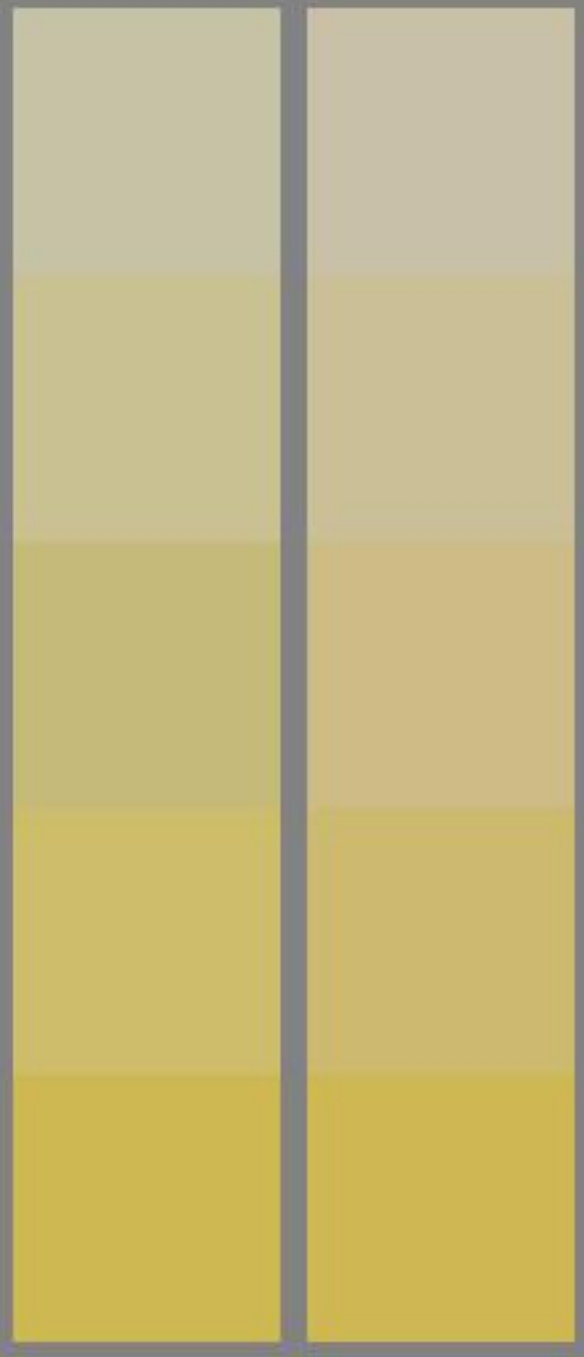




2. Factors of colour harmony according to the theory of colour dynamics (Nemcsics)
   - Scale-like relationship of colours
     - in saturation
     - in lightness
   - Connection among hues
   - Colour preference, contrast, association, aesthetic or functional content of colours…etc.

Let’s investigate scales!





S = 10
C = 10

S = 10
C = 20

S = 10
C = 30

S = 10
C = 40

S = 10
C = 50

NCS

V= 83.38
T= 20.57

V= 83.24
T= 27.52

V= 82.98
T= 34.48

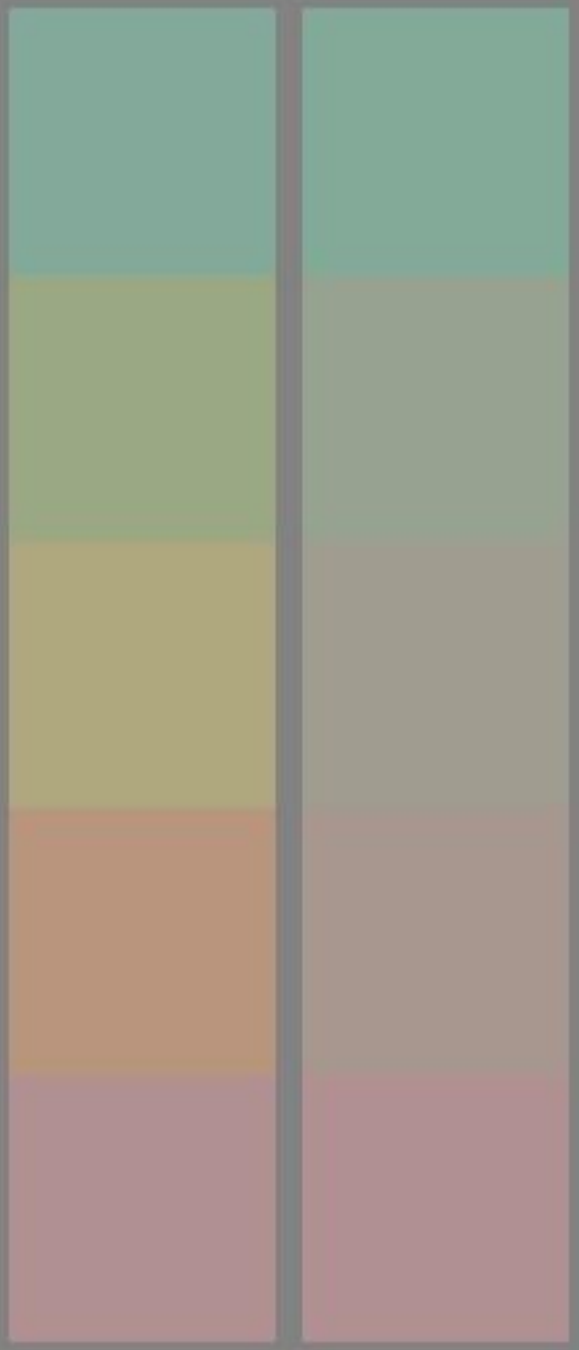
V= 82.96
T= 41.43

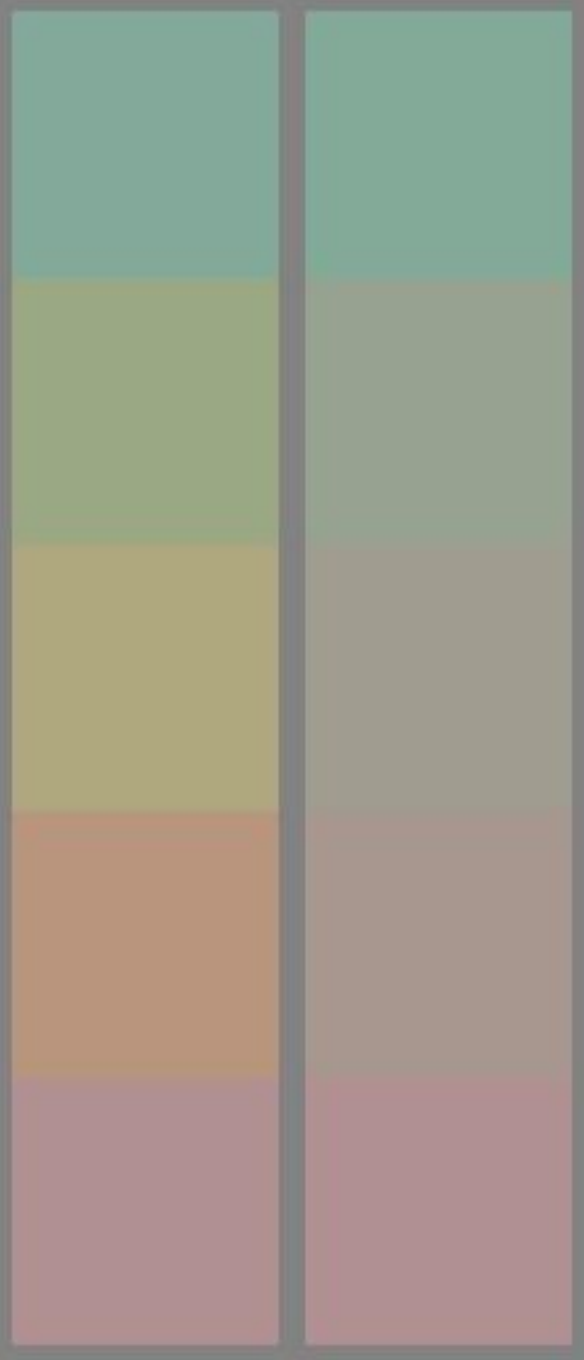
V= 82.82
T= 48.38

Coloroid

NCS hue:
Φ = Y

Coloroid hue:
A = 12.84





NCS	Coloroid
Φ= G S= 20 C= 20	A= 66 V= 9 T= 70
Φ= G50Y S= 20 C= 20	A= 75 V= 9 T= 69
Φ= Y S= 20 C= 20	A= 83 V= 9 T= 68
Φ= Y50R S= 20 C= 20	A= 92 V= 9 T= 67
Φ= R S= 20 C= 20	A= 31 V= 9 T= 66

Aims

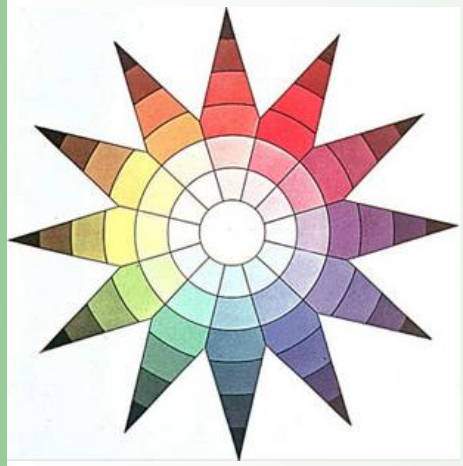
Expected results

- Discovering which colour order system or uniformity definition gives perceptually more uniform appearance.
- The qualification of the different colour order systems can be done *by uniformity*.
- Results on the uniformity of scales can show new fields for research and development of the colour order systems.

Authors have decided to investigate the perceptual uniformity of scales, which were selected to be equal step scales according to the notation of one or another colour order system.

These expected results have not been satisfied, but more interesting lessons can be drawn… ☺

Scales in different theories



Uniform colour scales

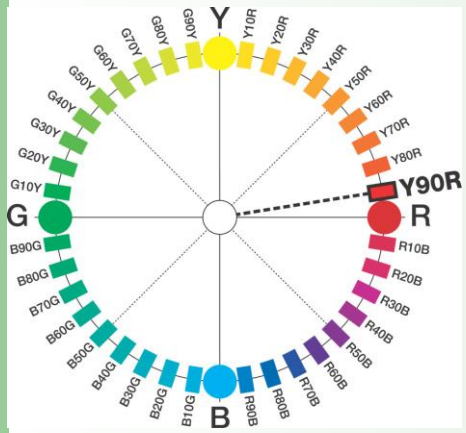
- Uniform colour scales can be created according to many aspects
  - Based on the uniformity of the physical properties of colours
  - According to colour perception
  - According to aesthetic feeling
  - According to colour appearance
  - According to the notation of a colour order system

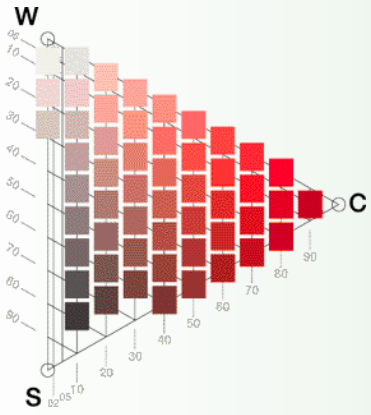
Each colour order system has its own notation and its own definition for uniformity.

- Most common colour order systems used in Hungary:
  - Swedish Natural Colour System (NCS)
  - Hungarian Coloroid Colour Order System

Both systems are said to be suitable for creating harmonious colour collections.

NCS Colour Order System





Idea behind NCS

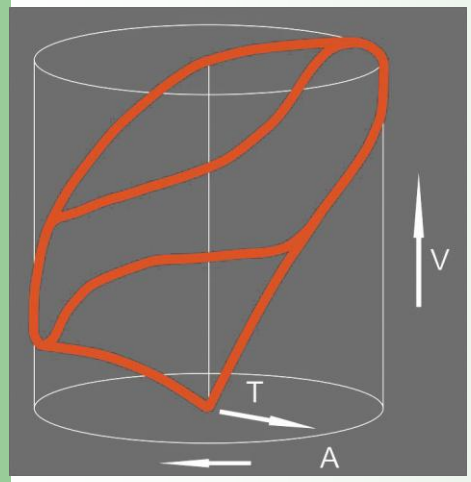
- The colour circle has four main hue (yellow, red, blue, green) according to Hering's opponent colour theory. There are equal number of steps between each main hue.

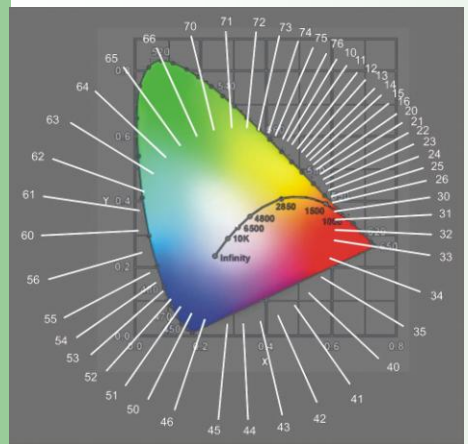
- In a hue section (hue triangle) there are equal number of steps between the most saturated colour and white and the most saturated colour and black.

System notations:

- The characteristics of NCS:
  - S: blackness – W: whiteness
  - C: chromaticness
  - Φ: hue

Coloroid Colour Order System





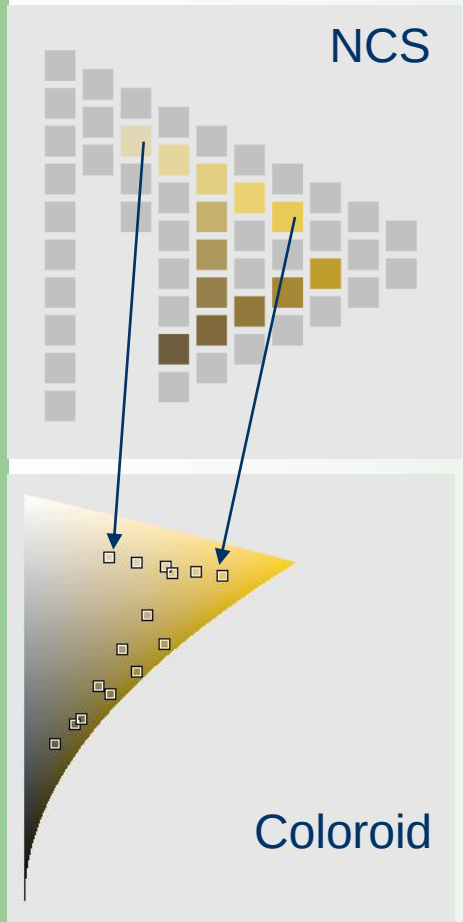
Idea behind Coloroid

- In daylight conditions we can differentiate more yellows and oranges than cool greens and violets.
- The minimum perceptible difference between colours under the new conditions was called harmony threshold.

System notations

- The characteristics of Coloroid: hue (A), saturation (T) and lightness (V).
- In the colour circle the angles distance vary unevenly according to the CIE Lab system. Hues are marked by two-digit numbers:
  - 10-16: yellows
  - 20-26: oranges
  - 30-35: reds
  - 40-46: purples, violets
  - 50-56: blues
  - 60-66: cold greens
  - 70-76: warm greens

Composition of experimental scales



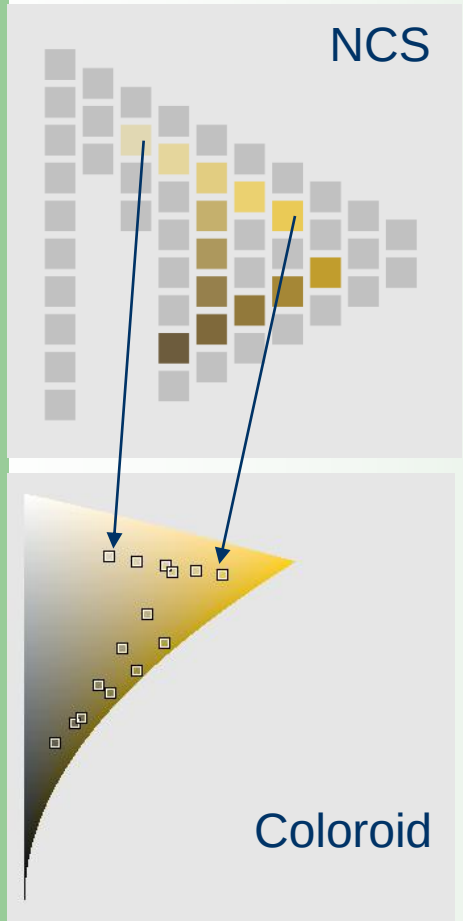
Method of selecting the uniform scales in the investigated colour order systems

1. NCS atlas and the standard samples' colorimetric data have been used for creating uniform five-step monochromatic and polychromatic scales in the NCS according to NCS notations.

2. The two end points of the scale have been looked up in the Coloroid colour space.

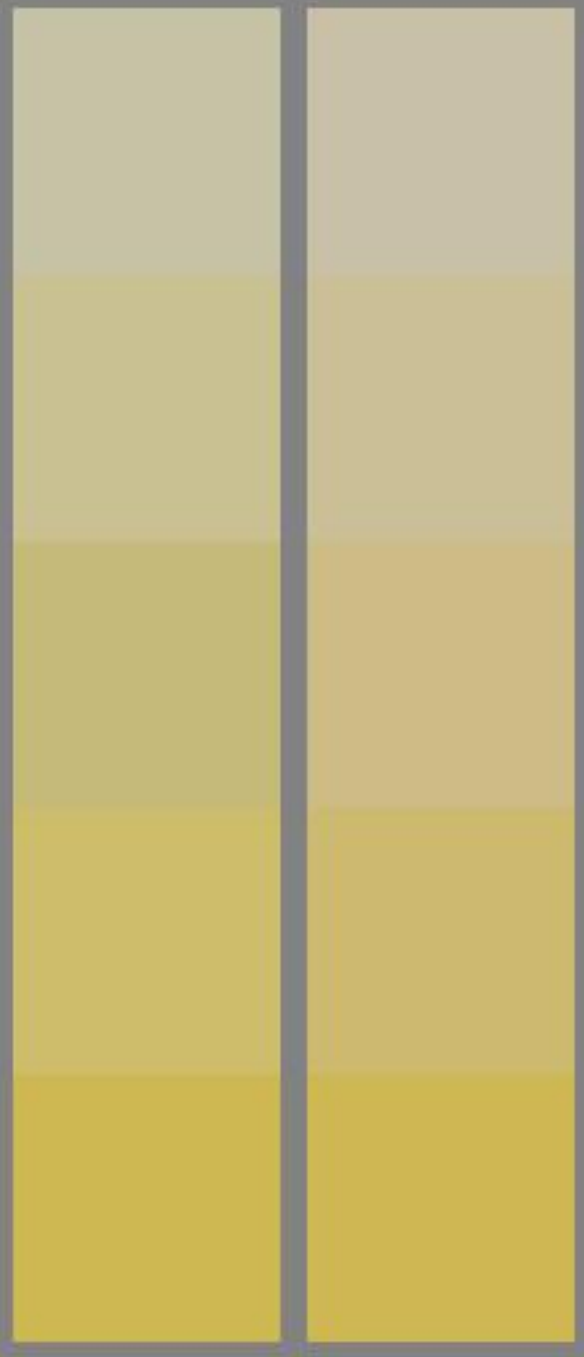
3. Equal step scales have been created in the Coloroid colour system according to the Coloroid notations using the two NCS endpoints as endpoints of the Coloroid colour scales.

Scales containing colours of equal hue



In the followings: monochromatic scales

- The mean hue of the NCS scale in Coloroid has been determined (A)
- The same Coloroid saturation (T) and lightness (*V*) for the end values have been chosen
- An equal step scale in the same Coloroid hue section has been generated according to Coloroid saturation (*T*) and lightness (*V*) values



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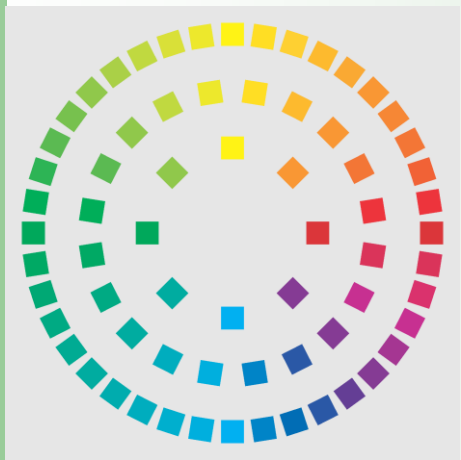
Coloroid

NCS hue:
Φ = Y

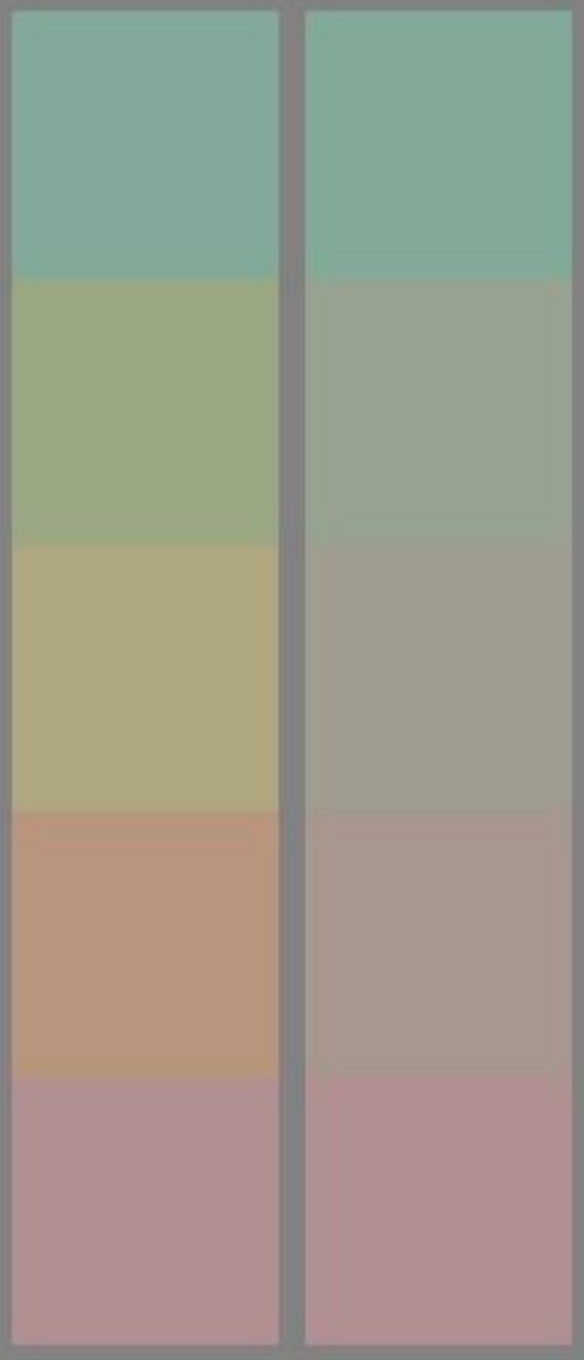
Coloroid hue:
A = 12.84

Scales containing colours of different hues



In the followings: Polychromatic scales

- the same NCS colours have been used as end points, transforming their NCS notation to the Coloroid colour system
- Equal step scales in the Coloroid system have been generated according to Coloroid hue (*A*), saturation (*T*) and lightness (*V*) values
- 25 monochrome or non-chromatic and 50 polychrome scale pairs were generated



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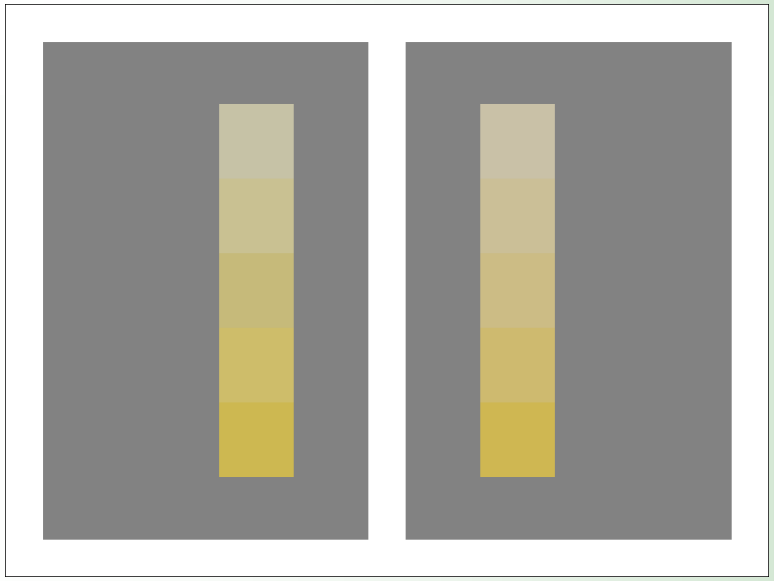
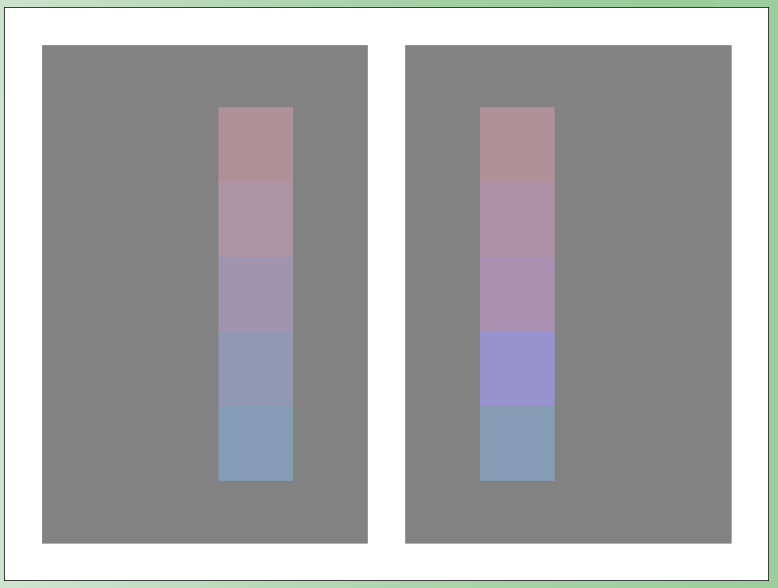
Experimental setup

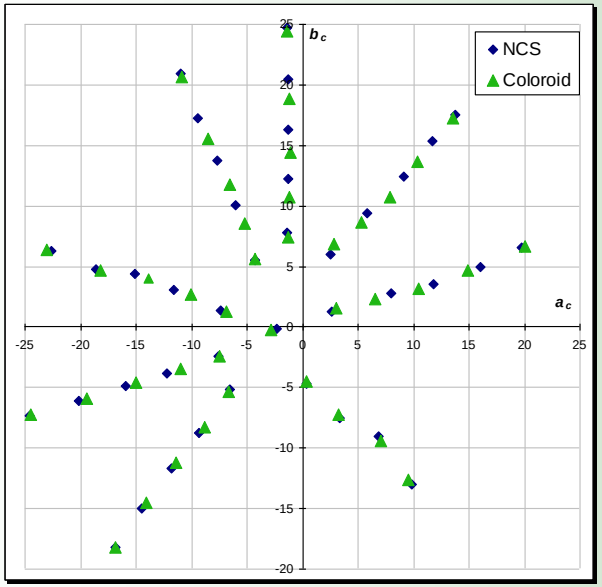


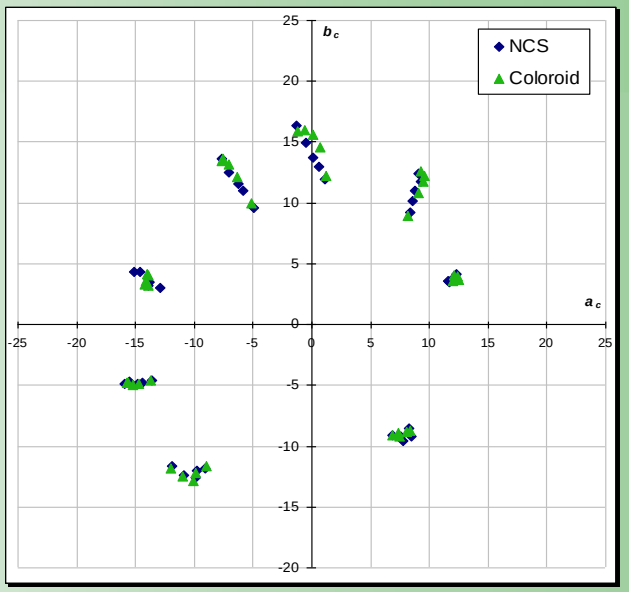


Experimental background

- In visual experiments, scales were visualized on a calibrated CRT display, on middle grey background (CIELAB *L**=50).
- Experiments were carried out in a dark room.
- Observers had to choose the more uniform colour scale.
- 30 observers (8 male, 22 female) with normal colour vision were participated in the experiments.

Analysis of appearance data

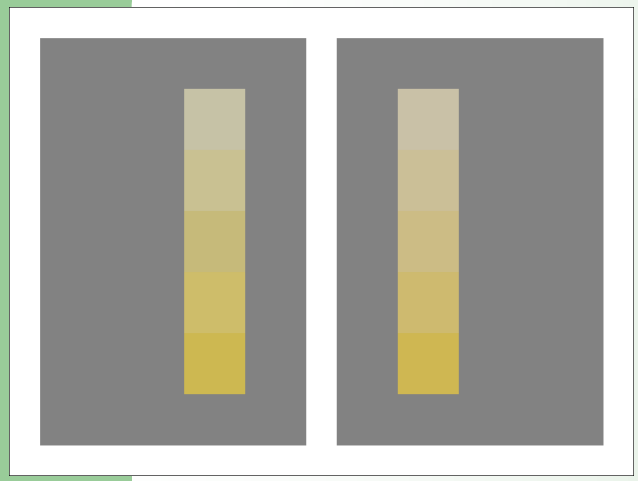




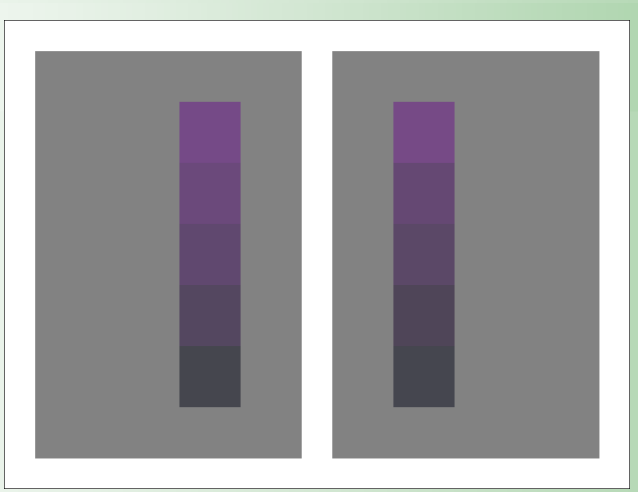
Monochrome scales

- In the Figures, co-ordinates of monochromatic scales can be seen on the CIECAM02 colour appearance model co-ordinate plane, parameterized according to the experiment viewing condition.
- As can be seen, there are no significant differences between the a_c-b_c co-ordinates of scale elements chosen from the NCS and the Coloroid colour order systems.

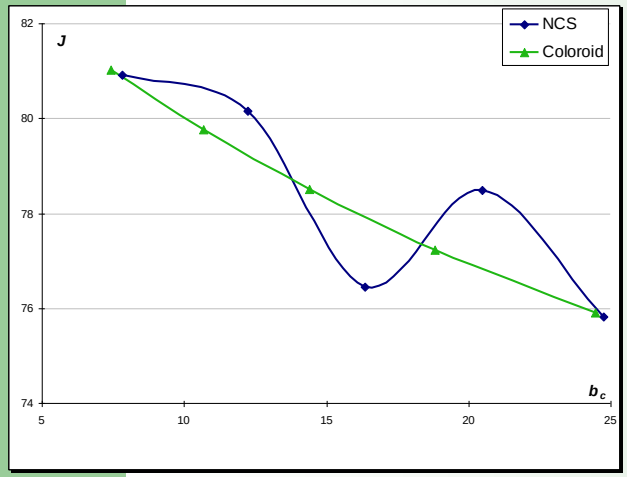
Visual estimation

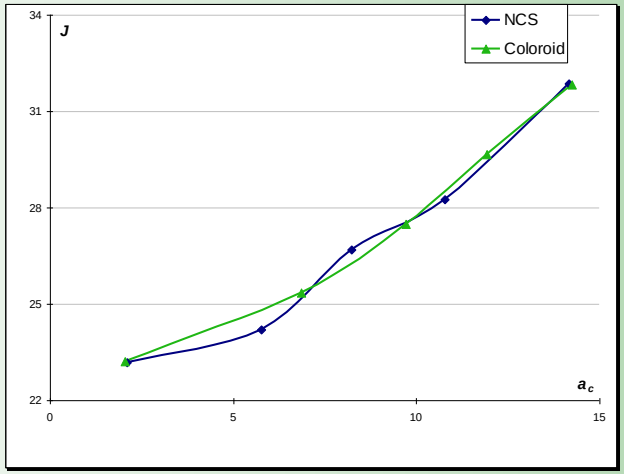


5. NCS – **Coloroid**



16. **Coloroid** – NCS

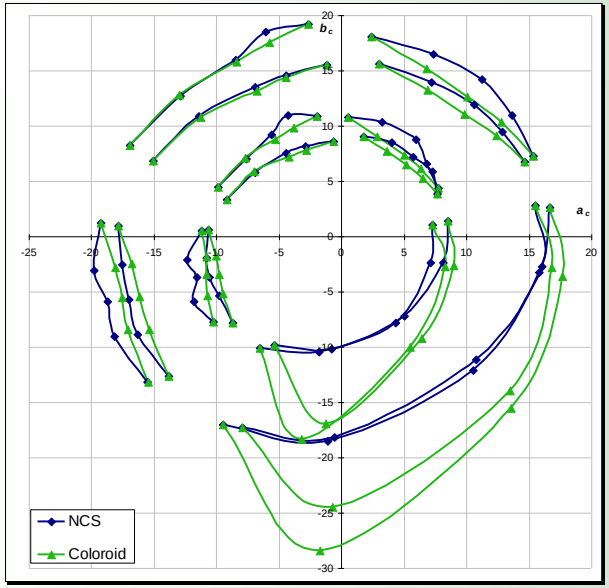


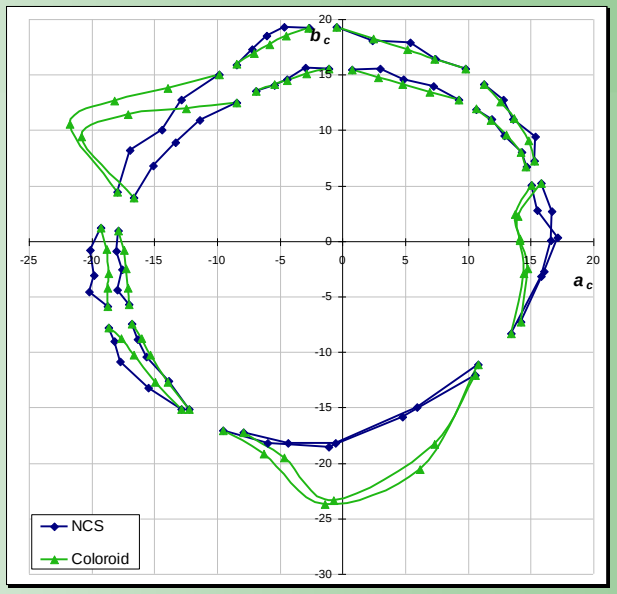


Monochrome scales

- Pairs difference between the visual results has not been significant because the uniformity differences among scale elements have been too small
- In case of some scales Coloroid system has been found to be visually more uniform. One reason can be that there is a big aberration of lightness within a hue in NCS.

Analysis of appearance data

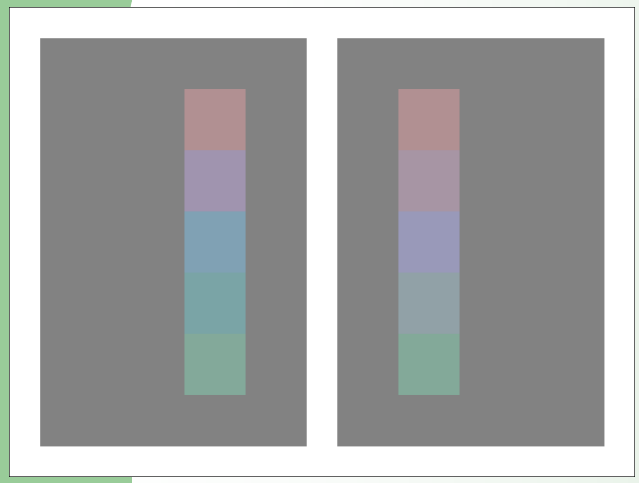




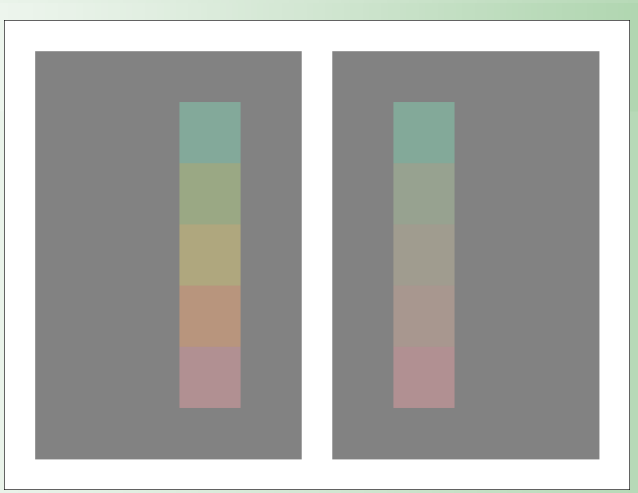
Polychrome scales

- In the Figures the scale elements of polychrome NCS and Coloroid scales are represented
- The same scale in the two systems is situated on quite different places in the CIECAM02 a_c–b_c plane

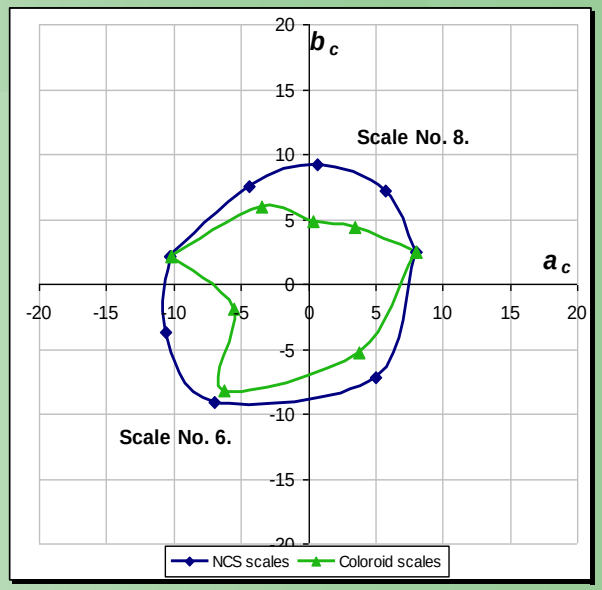
Visual estimation



6. NCS – **Coloroid**



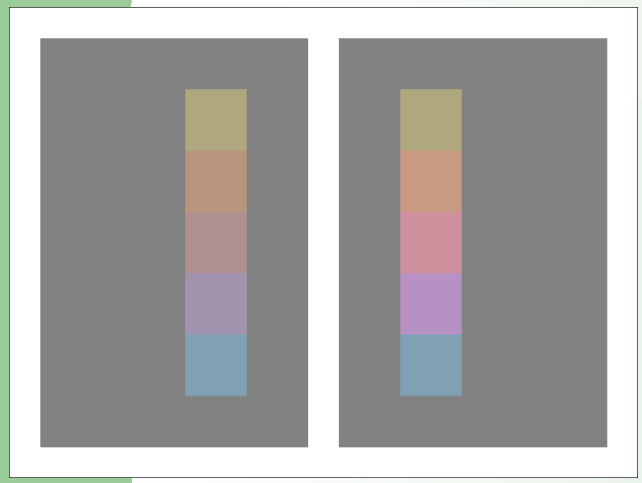
8. NCS – **Coloroid**



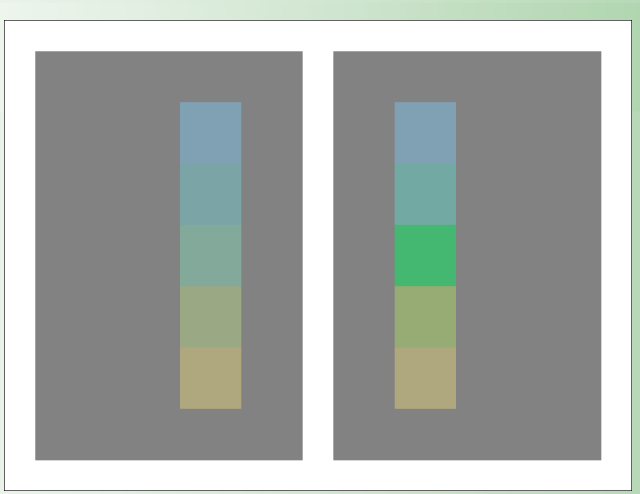
Polychrome scales

- Although the NCS polychrome scales seem to be more regular in the CIECAM02 a_c–b_c plane than the Coloroid ones, aberrations can be seen again in NCS regarding the CIECAM02 lightness correlate (J).
- In the different hue sections of NCS the same nuances have different lightness correlates (J) which cause larger colour differences between the scale elements.

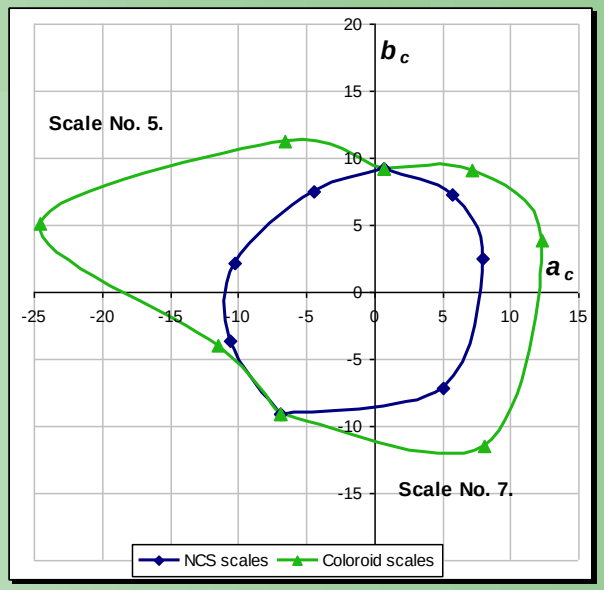
Visual estimation



5. **NCS** – Coloroid



7. **NCS** – Coloroid



Polychrome scales

- In the Coloroid colour system there is a large visual difference between the equal saturated colours at different hue angles.
- In CIECAM02 chroma is used for describing the intensity of colours, as well as in NCS, but it is described as saturation in Coloroid. It gives good uniformity in a hue section in every direction while lightness and saturation varies in equal steps.

Conclusions

- Aberrations according to the perception of lightness have been found in case of such NCS scales that are situated in the same hue sections. NCS globally does not represent either the spectral colours' lightness difference which causes aberrations according to the lightness in polychrome scales.
- In Coloroid we have found that colours with the same saturation in certain hue sections seem to be much more intense than in other hue sections. One possible reason is that Coloroid uses saturation for describing the intensity of colours, not chroma as NCS or CIECAM02.
- The big visual aberrations show that further development is needed in this field in Coloroid to achieve a real aesthetical uniformity. A possible solution can be the mathematical description of the so called "harmony threshold" of Coloroid, and define a suitable colour difference metric in this colour space which is still underway.

- These investigations provide visual results to the upgrade and further development of an aesthetically uniform colour space.

Thank you for your kind attention!

University of Pannonia, Veszprém, Hungary

Parliament with the river Danube, Budapest, Hungary

MEC Albert Apponyi programme

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NKTH
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