An Efficient Perception-Based Adaptive Color to Gray Transformation

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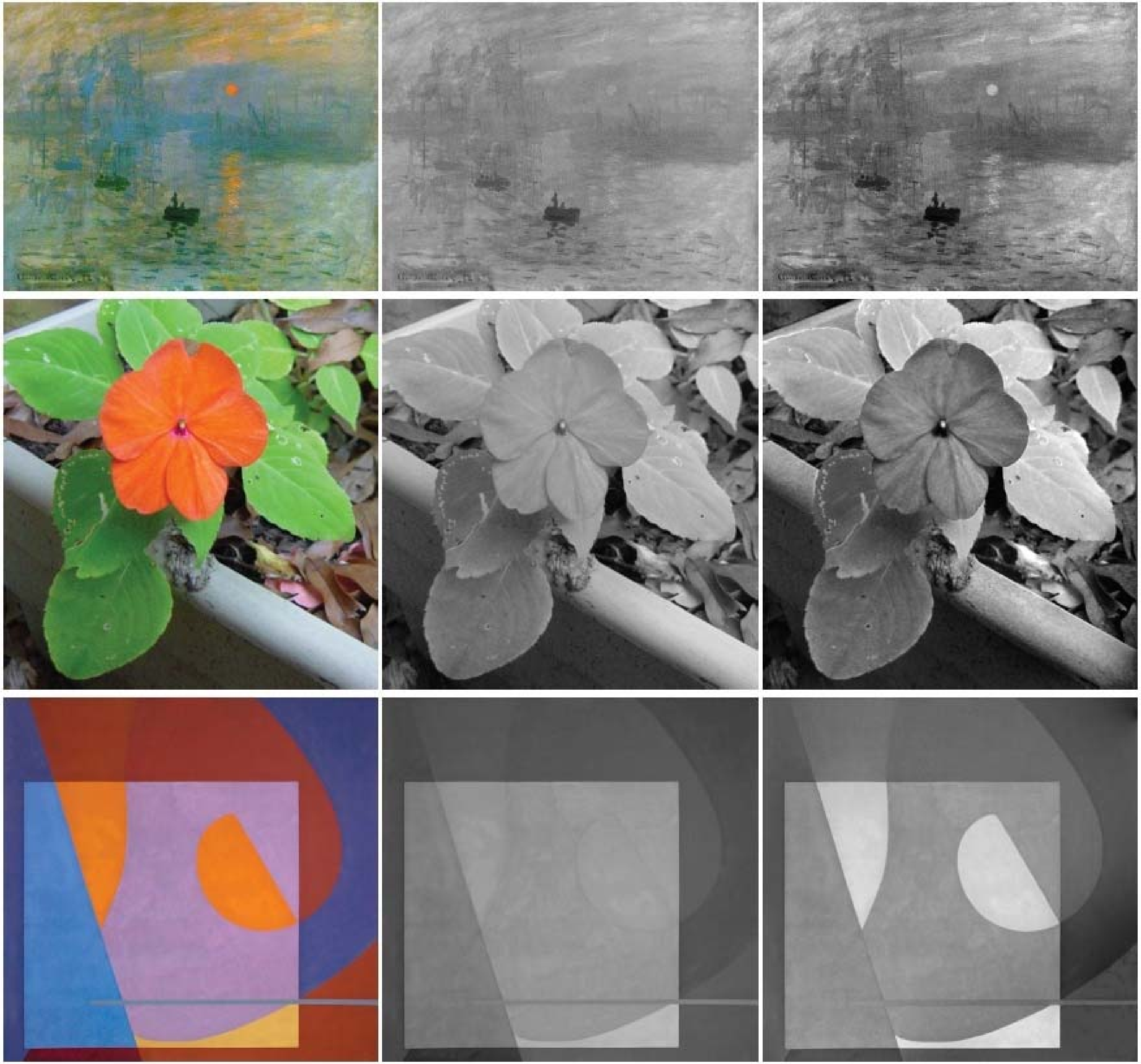
Outline

- **Aspects of Color to Gray transformation**
- **Previous work**
- **A new CIE Lab based local approach**
- **The COLOROID system**
- **Gradient inconsistency correction**
- **Conclusion, future work**



Some Aspects of Color to Gray

- 1. **Dimension reduction 3D to 1D**
  - Information loss is unavoidable
  - The appearance of loss depends on the method
- 2. **Color to Gray**
  - Artificial, **missing in the human visual system**
  - Which gradient attributes can be perceptually based?
  - Luminance vs. chrominance
- 3. **Display has less than [0,100] Y-range**
  - A color image has **over 200** color differences
  - Black and white has to be conserved as min-max?
  - Some e.g. dark blue colors 'look darker than black'
    - Simultaneous contrasts, color appearance

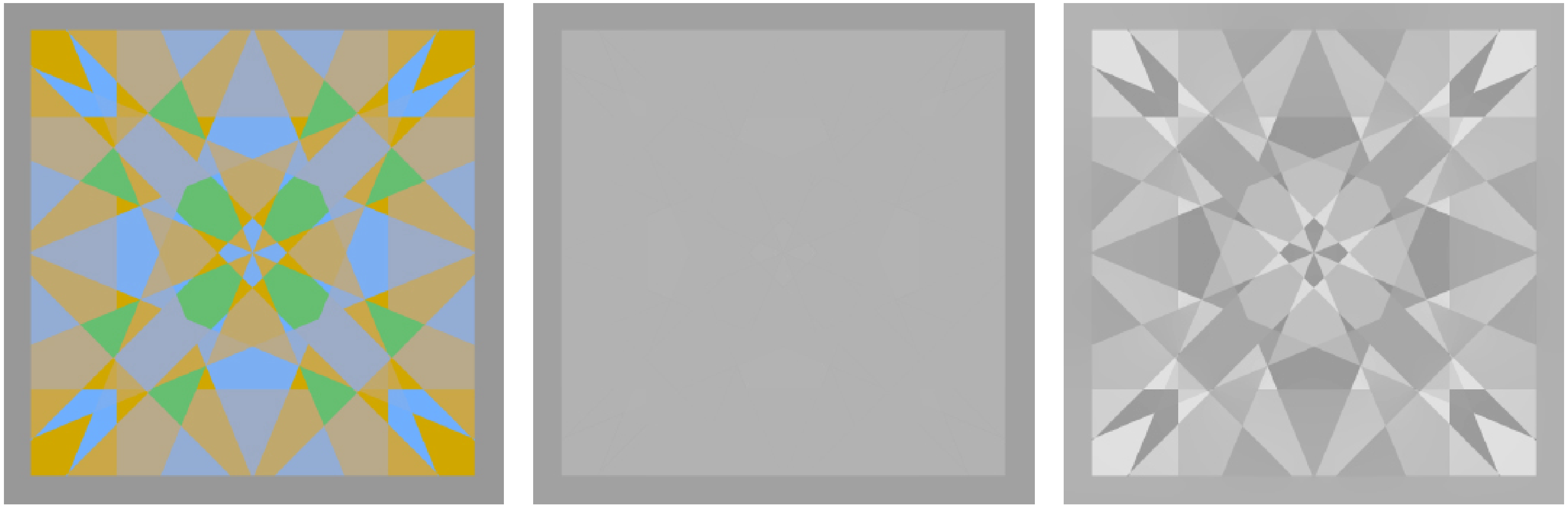
The original color image
Mapping to 3D display-gamut

Dimension reduction to 2D
Mapping to Hue-Plane of 580nm

Dimension reduction to 1D
Mapping to the neutral axis

When the „Convert to Grayscale” (to CIE-Y) kills all the details

- **A test image with const. luminance**
  - Widely used CIE-Y luminance conversion
  - Adaptive method based on reproduction of local chages



Previous work

- **Global vs. local approach**
- **Global**
  - speed, naturalness, luminance range
  - the same luminance for the same rgb triplets
- **Local**
  - local changes, contradictions, computational costs
  - different luminance for the originally same rgb triplets
- Some local changes **disappear** both due to global and adaptive methods

Previous work

- [Bala, Eschbach 04]
  - local enhancement via high-frequency chrominance information in the luminance
  - Image enhancement, possible artifacts

- [Grundland, Dogson 05]
  - *global* decolorize algorithm for contrast enhancing
  - expressing grayscale as continuous, image dependent, piecewise linear mapping

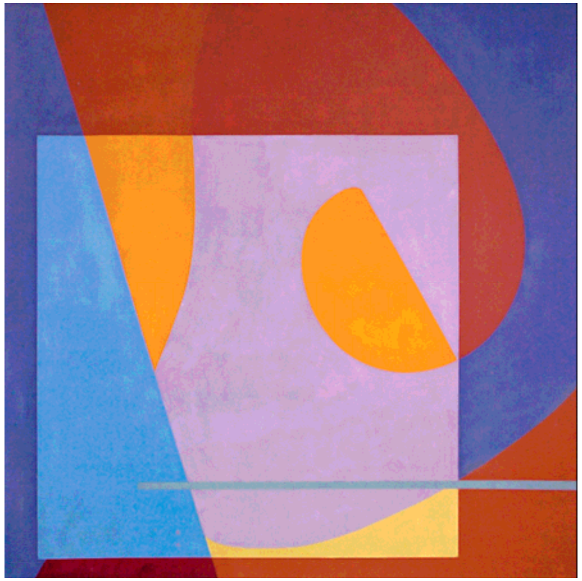
Previous work

- [Gooch et al. 05]
  - Color2Gray algorithm based on *local* contrasts
  - iterative minimization of an objective function
  - $O(N^4)$

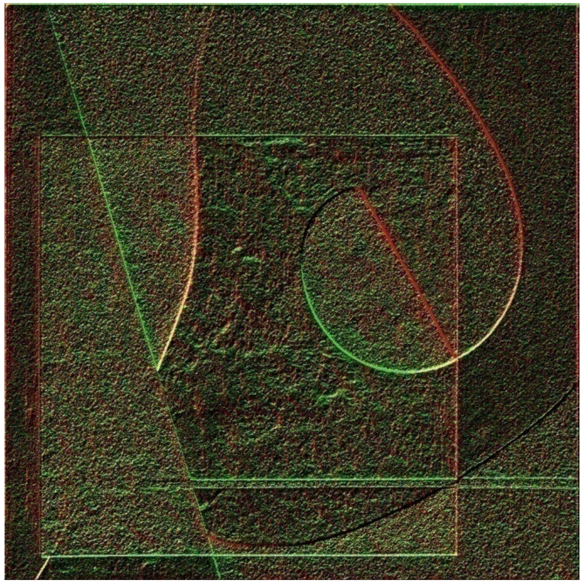
- [Rasche et al. 05]
  - *global* technique maintaining luminance consistency
  - constrained multidimensional scaling with color quantization → prone to quantization artifacts
  - enormous computational demands (depends on the number of colors)

Our Approach

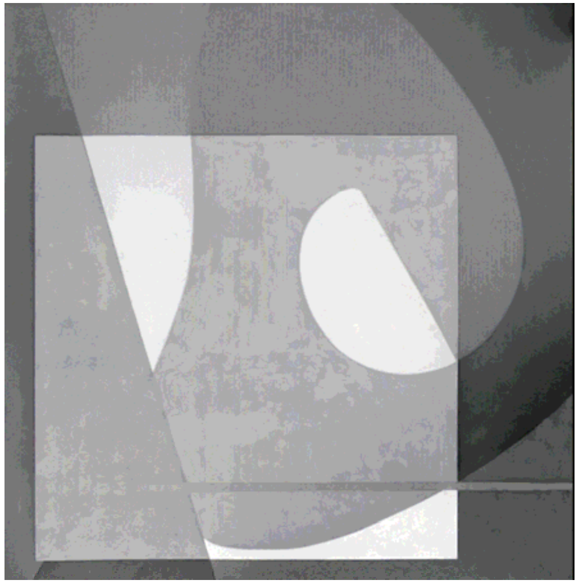
Input image



Gradient field



Grayscale image



→ **CIE Lab formula/ COLOROID formula**

→ **Inconsistency correction and direct 2D integration**

A new CIE Lab based gradient formula

- CIE Lab space is ***approximately*** uniform
  - L,a,b unit vectors build orthonormal basis
  - Opponent color channels

- The chrominance changes have smaller importance than luminance gradients
  - **GRAY GRADIENT** (Δ) $\neq$ **signed COLOR DIFFERENCE**

- $$\Delta = ([\Delta L]^p + [\Delta A]^p + [\Delta B]^p)^{1/p}$$
  - $\Delta A = \mathbf{w_a} \cdot \Delta a$, $\Delta B = \mathbf{w_b} \cdot \Delta b$, **weights are in [0.3...0.6]**
  - $p = 2 \ldots 4$, and $[\Delta x]^q = \text{sign}(\Delta x) \cdot (\text{abs}(\Delta x))^q$, $q = p$ or $1/p$
  - **luminance OR chrominance** (max norm, $p = \infty$) approach results in big gradients, and a strongly non-consistent gradient field

A classical test image Gooch et al. – 2005

Sunrise: color

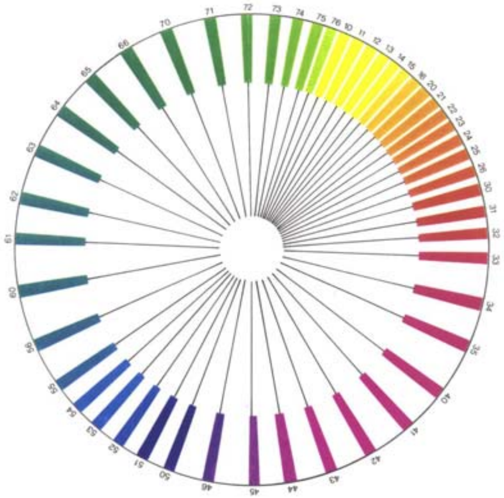
CIE-Y gray (real time)

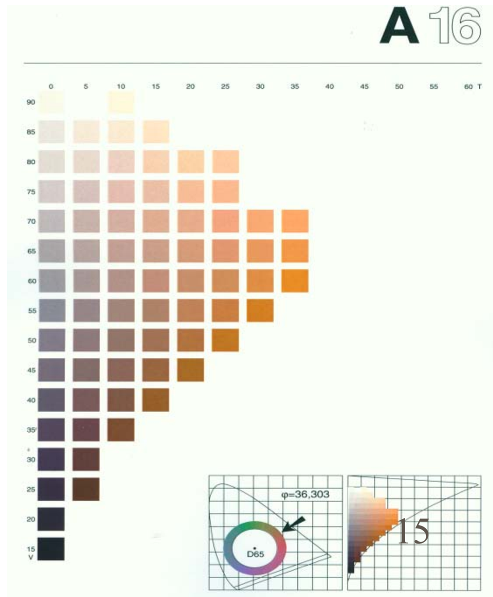
Gooch et al. 2005 (150 sec)

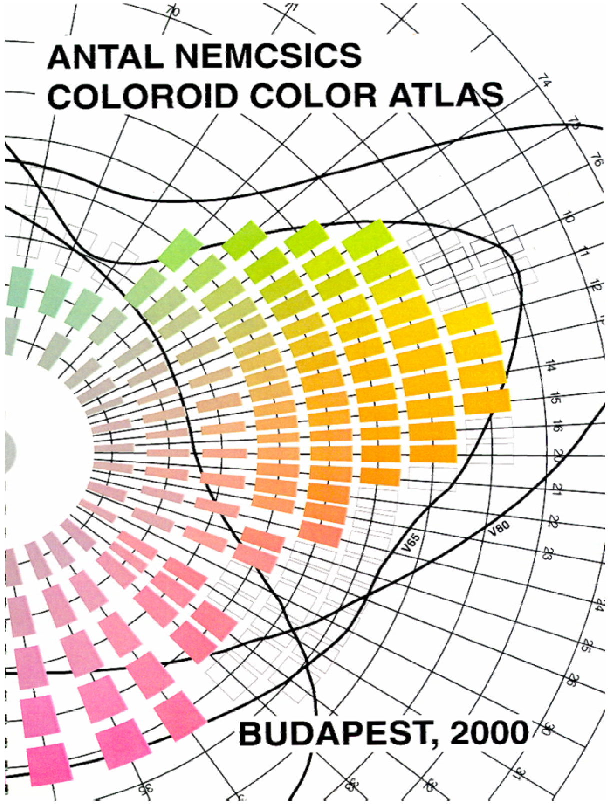
Our new method (0.3 sec, fine details)

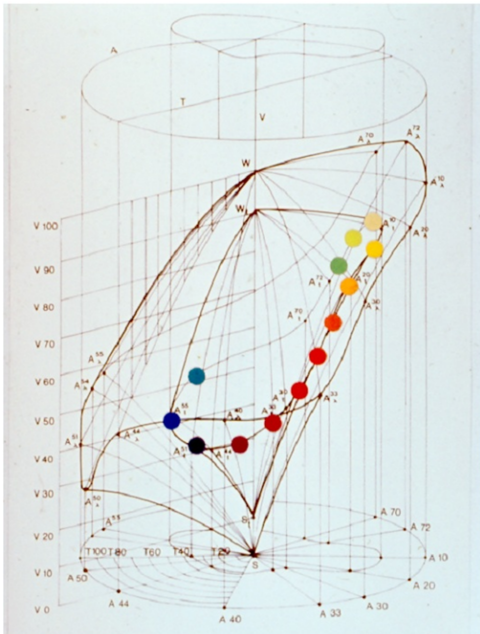
The COLOROID System (since 1962)

- **COLOROID** ***color-order system*** and ***color space***
- Based approx. **80.000** observers and **26 millions** elementary observations/decisions – unique number in colororistics
  - **Semi-adapted eye** (adaptation field: 1800 lux)
  - **Wide view-field observation**
  - **Simultaneous observation of a set of colors according to ’real-life‘ view-conditions**
- Simple and practical tool to describe aesthetical relationships
- Basis for computational color harmony

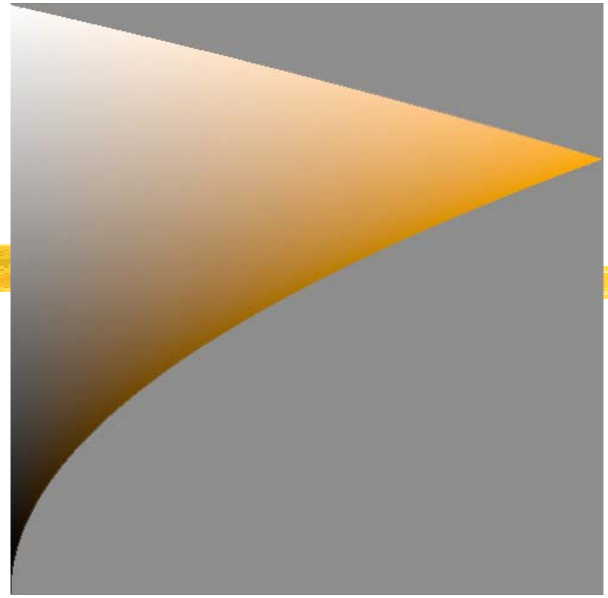




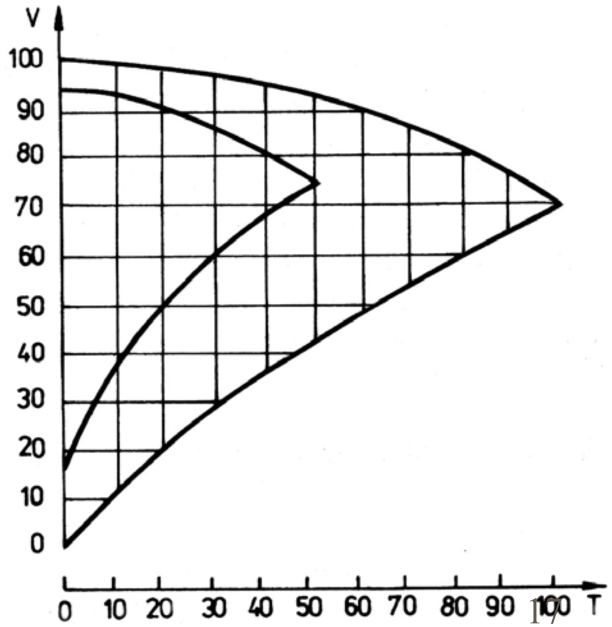

ANTAL NEMCSICS
COLOROID COLOR ATLAS
BUDAPEST, 2000



3 'axioms' of COLOROID



- Constant hues (**A**) form **planes** (!)
  - containing the neutral axis and a hue dependent limit-color (λ)
  - differently from most of other systems with curved surfaces, like e.g. Munsell
- Saturation (**T**) = const$_A$ · **ratio of the limit-color**
  - const$_A$ depends on hue
  - additive mixture of black, white and limit-color
- Lightness (**V**) = **10 · Y**^{½}
  - not 3rd root or log, like in ds line-element based spaces



COLOROID based gradient formula

- Some attributes of the gray-equivalent gradient can be observed using the COLOROID experimental tools
  - Saturation (for constant hue and lightness)
  - Hue difference term of $H(A_1,A_2)$ for medium saturated samples with medium lightness
- The gamut contains non-expected warpings
  - E.g. for bright turquoise uniform saturation series the

    Δ-gray values are **1, 2, 4, 0, -5** NON MONOTONOUS !
- The chrominance term has around 0.3 - 0.5-times less importance than in the color difference formulas

COLOROID based gradient formula

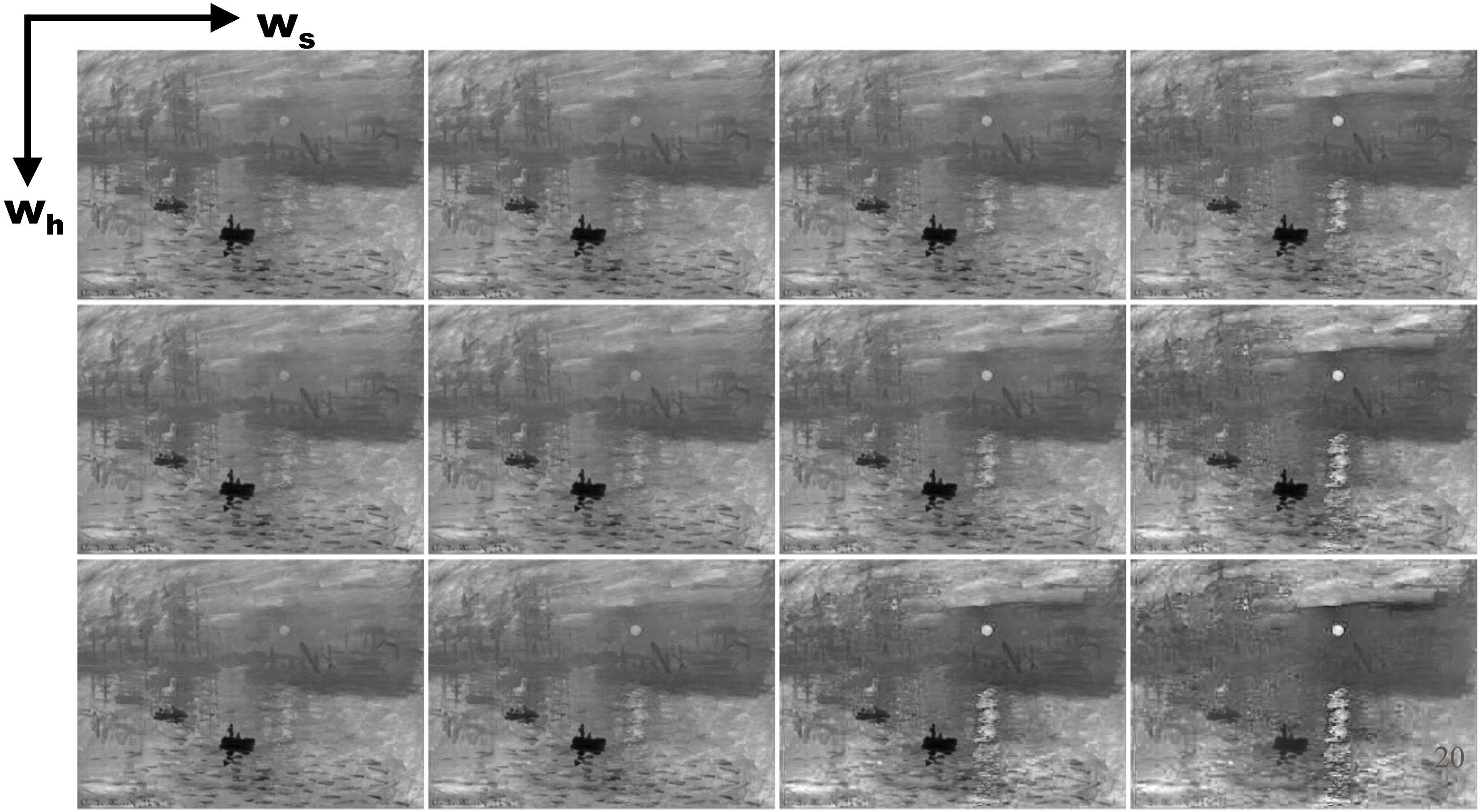
- $\Delta_{1,2} = dL\,(L_1, L_2) +$ (luminance)
  $dS\,(A_1,T_1,V_1, A_2,T_2,V_2) +$ (saturation)
  $dh\,(A_1,T_1, A_2,T_2)$ (hue term)

  - $dL = L_2 - L_1$
  - $dS = w_s \cdot [S(A_2,T_2,V_2) - S(A_1,T_1,V_1)]$
  - $dh = w_h \cdot H(A_1,A_2) \cdot [u(T_{1rel}) \cdot u(T_{2rel})]^{½}$

  - If one of the two saturations = 0, than the hue term = 0.
  - But also for opponent hues $dS \neq 0$
  - S and H functions are given by *tables and interpolation rules*

Non-Perceptual Approach Emphasized Effects

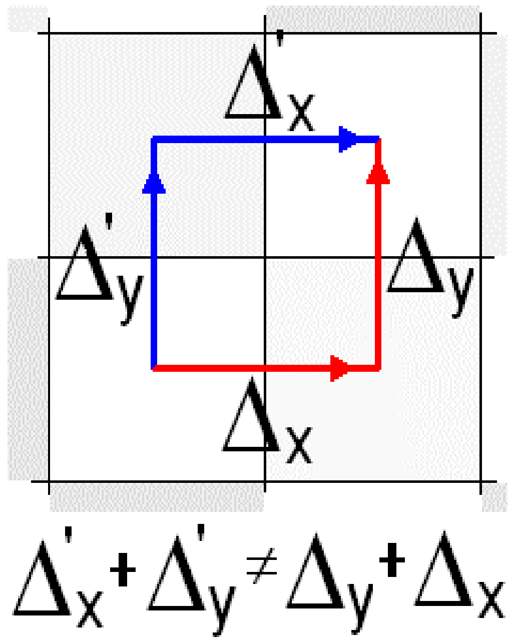
- 4 saturation * 3 hue parameter pairs
  - Percetually pleasant - second row, third column



Inconsistent Gradient Field (GF)

- **Inconsistency for 4 - pixel quadrats**

$$g_x(i,j) + g_y(i+1,j) \neq g_y(i,j) + g_x(i,j+1)$$



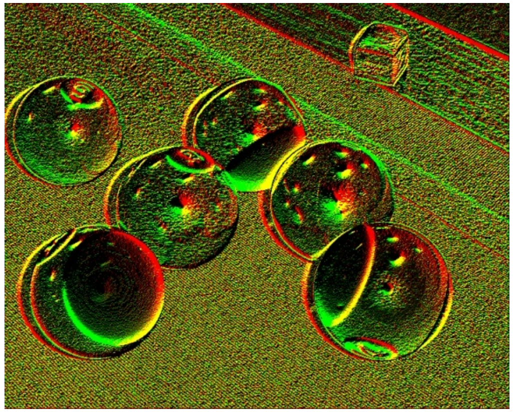
- **An inconsistent GF does not define an image unambiguously**

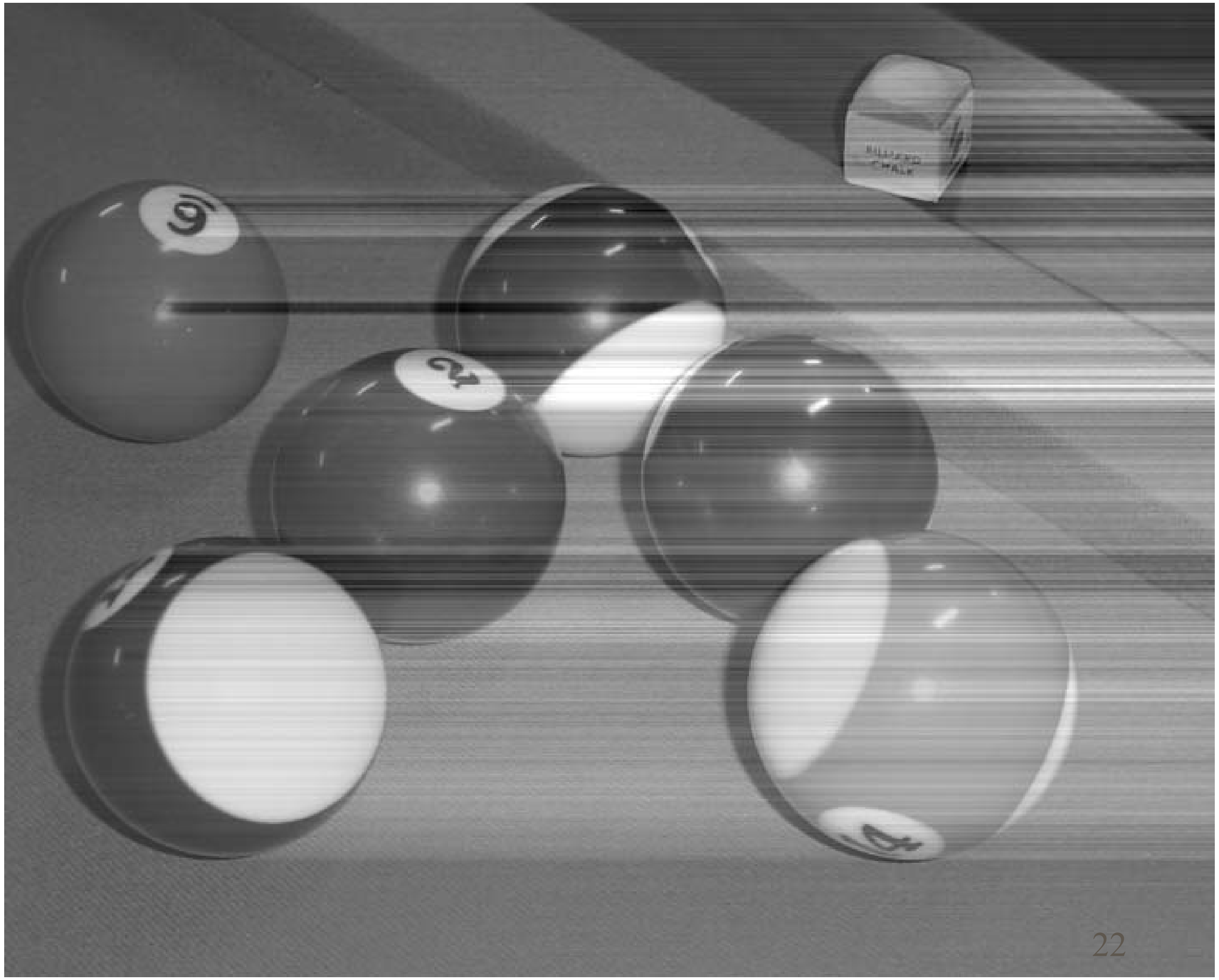
- There are only different approximations to found an image with a similar gradient field

- **GF-inconsistency correction method**
  Neumann&Neumann, CAe2005, Girona

Inconsistent Gradient Field

- **Direct 2D integration**





New solution technique: Correction of GF inconsistency

- All of earlier methods work with the pixel- unknowns of the image (**u**)
- It is possible to modify the GF and find the **nearest consistent gradient field** (a really GF approach, the solution is also in the GF)
- Knowing a consistent GF: direct integration with

  ’1 addition pro pixel‘ cost
- Number of unknowns: x and y **gradient components**

$$Y*(X-1) + X*(Y-1) \approx 2 * X * Y$$

- Number of equations is: $(X-1)*(Y-1) \approx X * Y$
  - Dimension of the consistent GF subspace is appr. two-times smaller than the dimension of the inconsistent GFs.

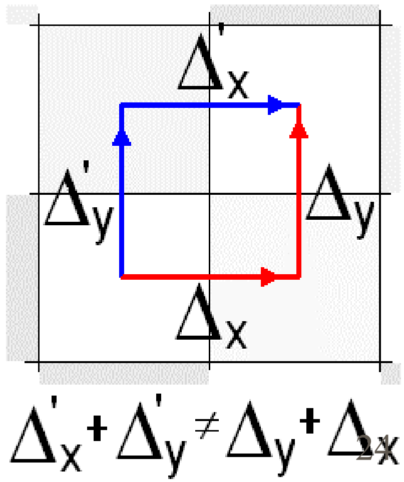
New solution technique: Correction of GF inconsistency

- Orthogonal Projection from the starting inconsistent GF **to the NEAREST POINT of linear subspace of the consistent GFs**
- $g_x(i,j) + g_y(i+1,j) - g_y(i,j) - g_x(i,j+1) = E_{ij} \neq 0$

  $\mathbf{N}_{ij} = (0,\ldots,0, +1, +1, -1, -1, 0,\ldots,0)$

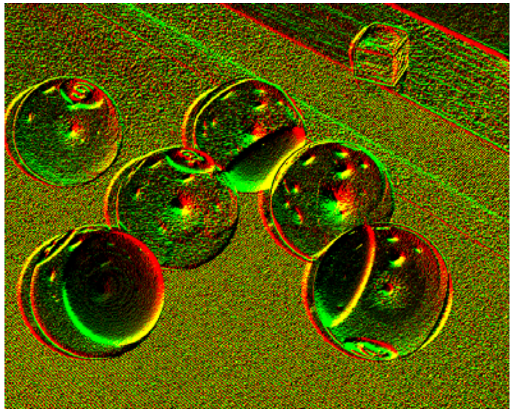
  One row of the eq. is formally: $\mathbf{N}_{ij}\,\mathbf{g} = E_{ij}$, for consistent GF: $\mathbf{N}_{ij}\,\mathbf{g} = 0$

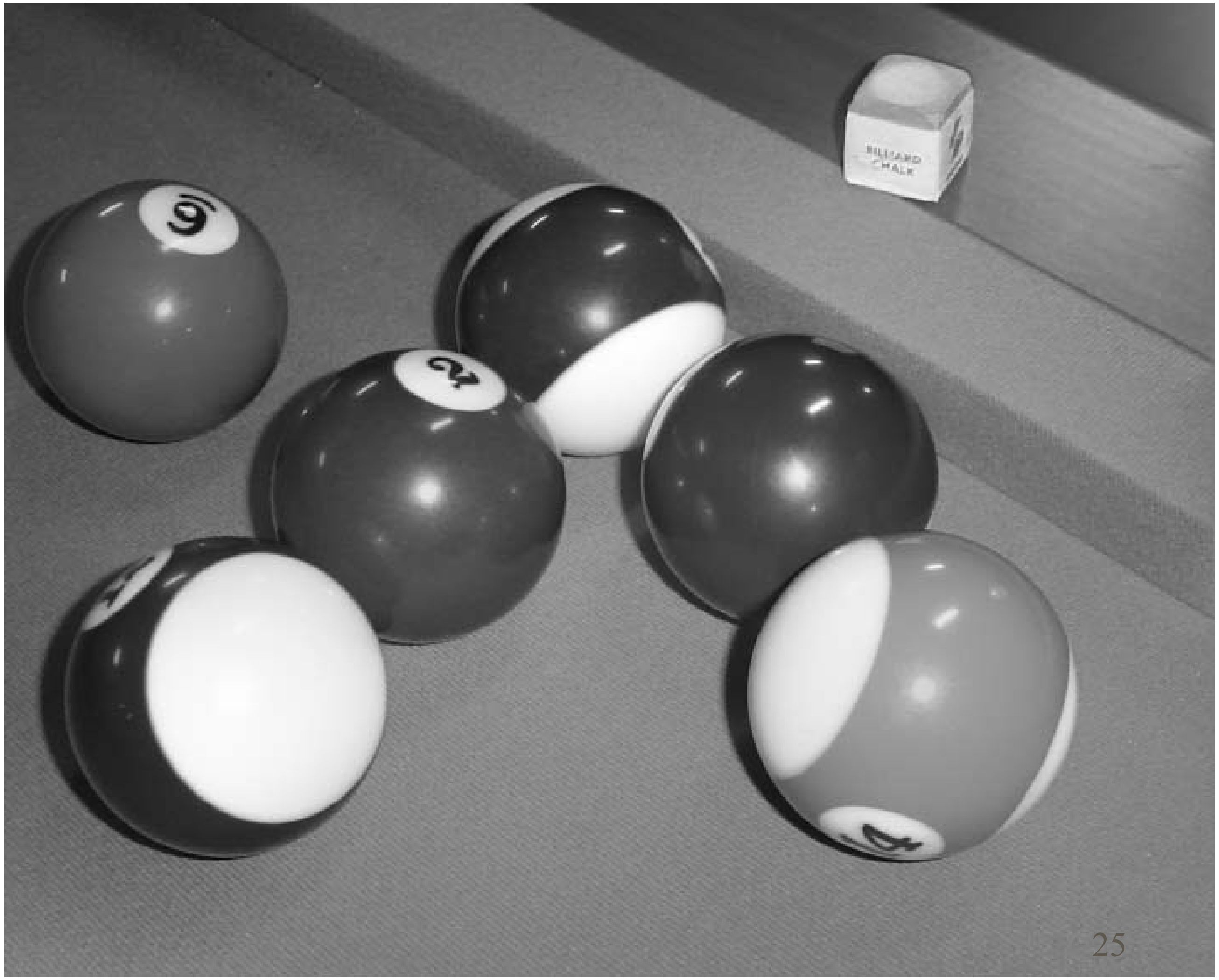
- The (over)projection step, cyclically or with max-E_{ij} selection until the max E_{ij} < eps
  - $\mathbf{g}_{new} = \mathbf{g} - \frac{1}{4} * s * E_{ij} \cdot \mathbf{N}_{ij}$
  - $g_x(i,j) := g_x(i,j) - \frac{1}{4} * s * E_{ij}$
  - $g_y(i,j) := g_y(i,j) + \frac{1}{4} * s * E_{ij}$
  - $0 < s < 2$, recommended $s = 1.5\ldots1.8$



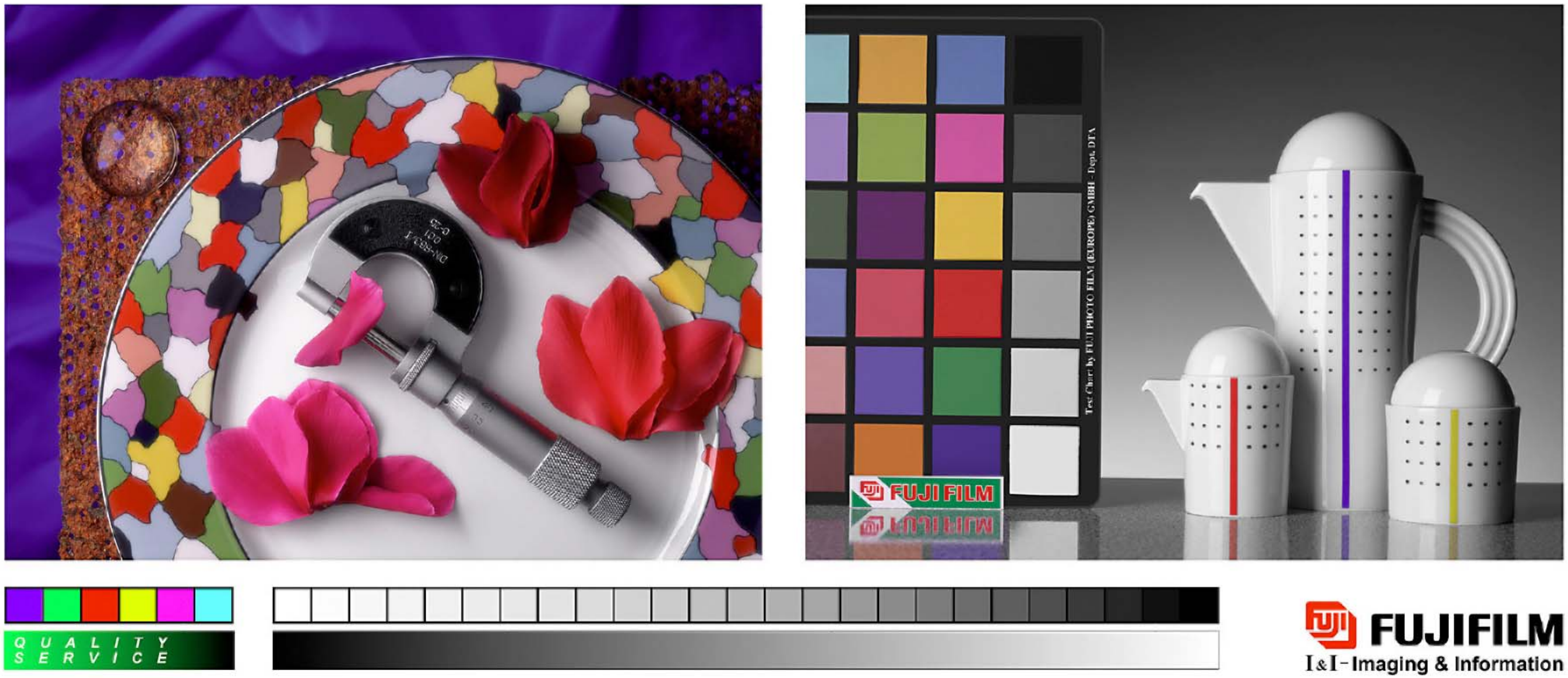
New solution technique: Correction of GF inconsistency

- **Direct 2D integration**

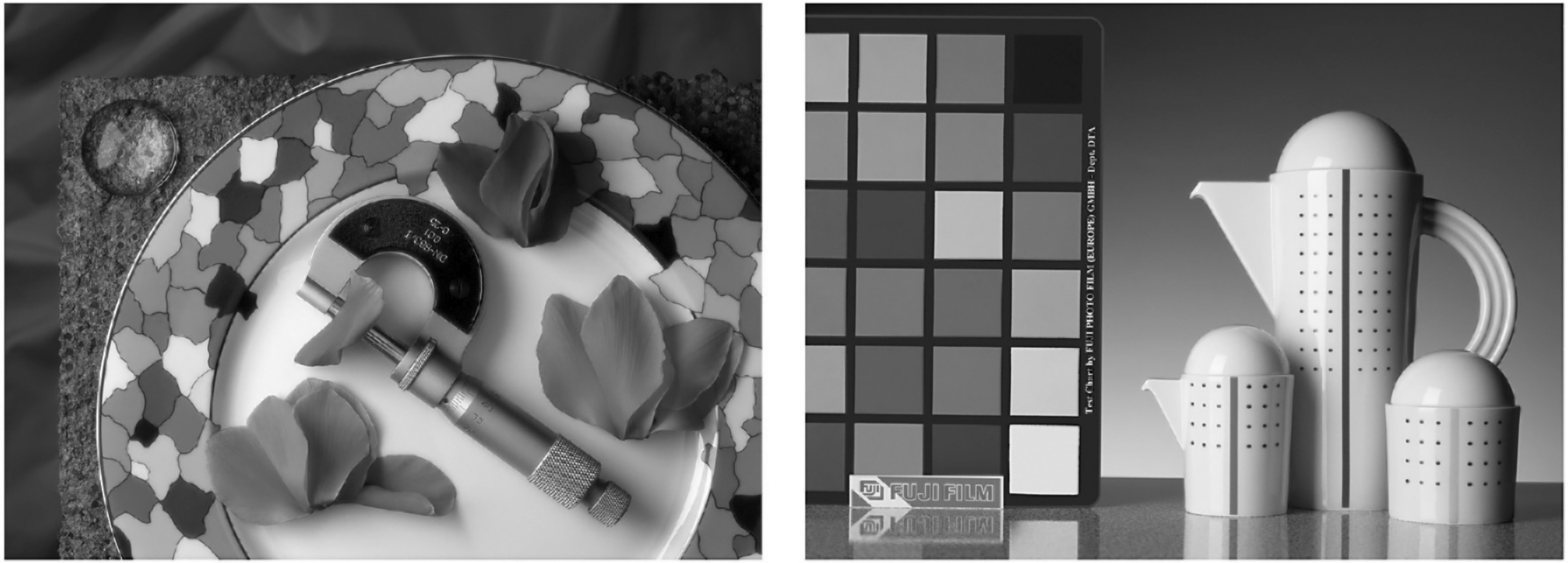




Color Test Image



CIE-Y luminance



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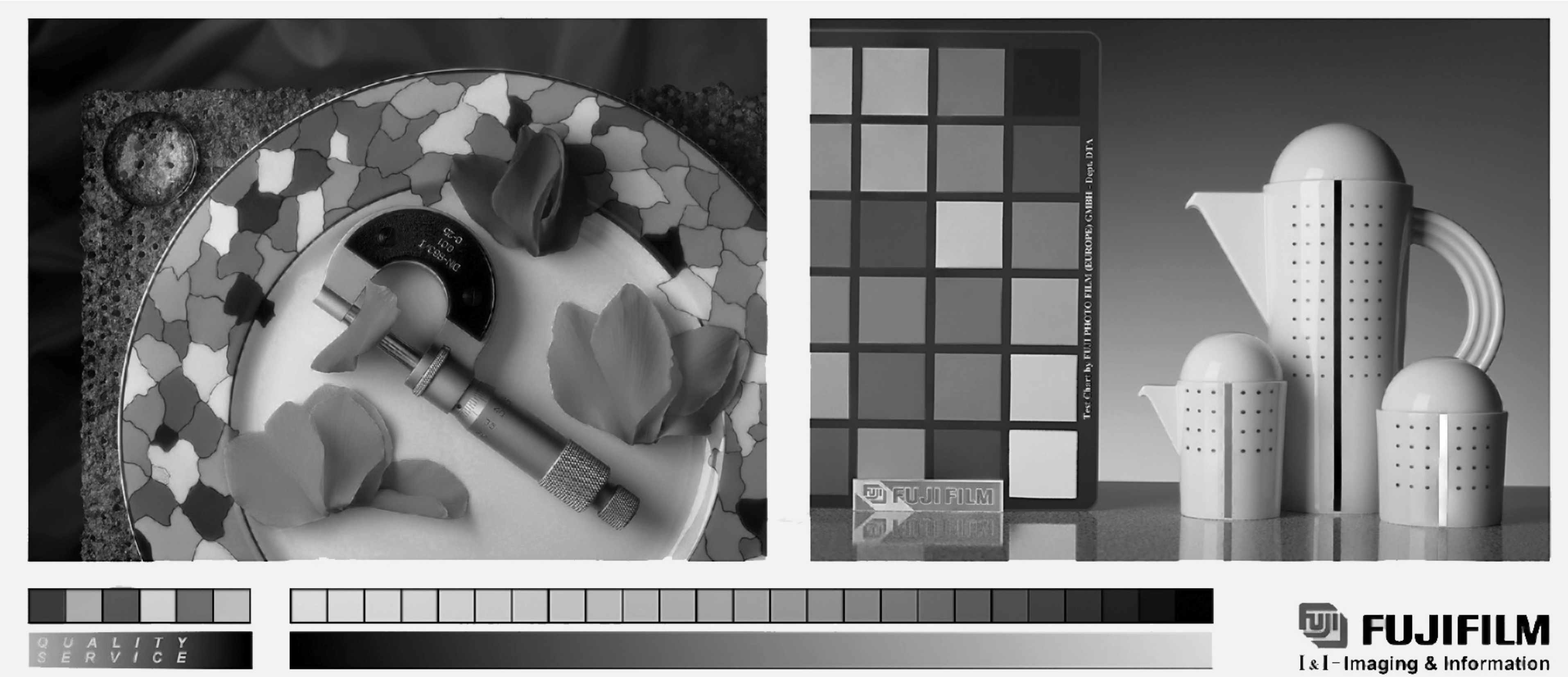
Adaptive COLOROID based method



Conclusion, Future Work

- + perceptually based color to grayscale transformation
- ++ new formulas for grad computation
  - CIE Lab based
  - COLOROID based perceptual approach

- + Gradient-inconsistency correction method very efficient
- ++Simple iteration and the 2D integration leads to the image

- - Further reserch of fine structure of COLOROID gradient formula
  - dark, white, and near to gray-axis regions
- - Implementation of the real-time multiresolution projection method
  for the Color2Gray

Original Color Image

CIE-Y luminance

Adaptive COLOROID based method

Questions ?

An Efficient Perception-Based Adaptive Color to Gray Transformation

http://www.cgg.cvut.cz/~cadikm/color_to_gray/

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