RuSSIR
Russian Summer School in Information Retrieval 2008

Content Based Image Retrieval

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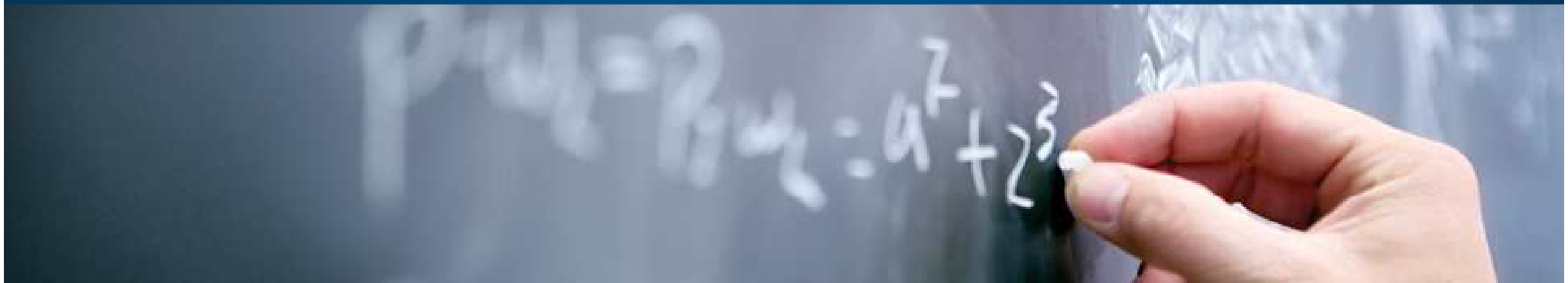
Tutorial outline

- Lecture 1
  - Introduction
  - Applications
- Lecture 2
  - Performance measurement
  - Visual perception
  - Color features
- Lecture 3
  - Texture features
  - Shape features
  - Fusion methods
- Lecture 4
  - Segmentation
  - Key points detection
- Lecture 5
  - Multidimensional indexing
  - Survey of existing systems

Lecture 2
Performance measurement
Visual perception
Color features



Lecture 2: Outline

- Performance measurement
  - Retrieval effectiveness
- Some facts about human visual perception
- Color features
  - Color fundamentals
  - Color spaces
  - Color features: histograms and moments
  - Comparison

Performance measurement

Performance concerns

- Efficiency
  - Important due to the large data size
- Retrieval effectiveness
  - No similarity metric which exactly conforms to human perception

Problems in effectiveness evaluation

- Define a common image collection
  - Corel Photo CDs
  - Brodatz texture collection: http://www.ux.uis.no/~tranden/brodatz.html
  - CoPhIR: http://cophir.isti.cnr.it/whatis.html
  - Participate in ImageCLEF, TRECVID, imageEVAL, ROMIP
- Obtain relevance judgement
  - Use of collections with predefined subsets (Corel collection)
  - Image grouping (medical)
  - Simulating users
  - User judgements
    - Pooling
    - Different types of judgement data (relevant – not relevant, ranking, …)

Effectiveness measurement

- “You can see, that our results are better”

Effectiveness measurement

- "You can see, that our results are better"
- User comparison
- Numerical-valued measures
  - Rank of the best image
  - Average rank of relevant images
  - Percentage of weighted hits
  - Percentage of similarity ranking

$$P = \frac{\sum_{i=1}^{n} w_i}{\sum_{i=1}^{N} w_i}$$

$$S(i) = \sum_{k=K_1}^{K_2} Q(i,k), \quad K_1 = P(i) - \sigma(i), \quad K_2 = P(i) + \sigma(i)$$

Effectiveness measurement (2)

- Numerical-valued measures
  - Recall and precision

$$precision = \frac{\text{No. relevant documents retrieved}}{\text{Total No. documents retrieved}},$$

$$recall = \frac{\text{No. relevant documents retrieved}}{\text{Total No. relevant documents in the collection}}$$

    - Average recall/precision
    - Recall at N, Precision at N
    - F-measure

Effectiveness measurement (3)

- Numerical-valued measures
  - Target testing
  - Error rate

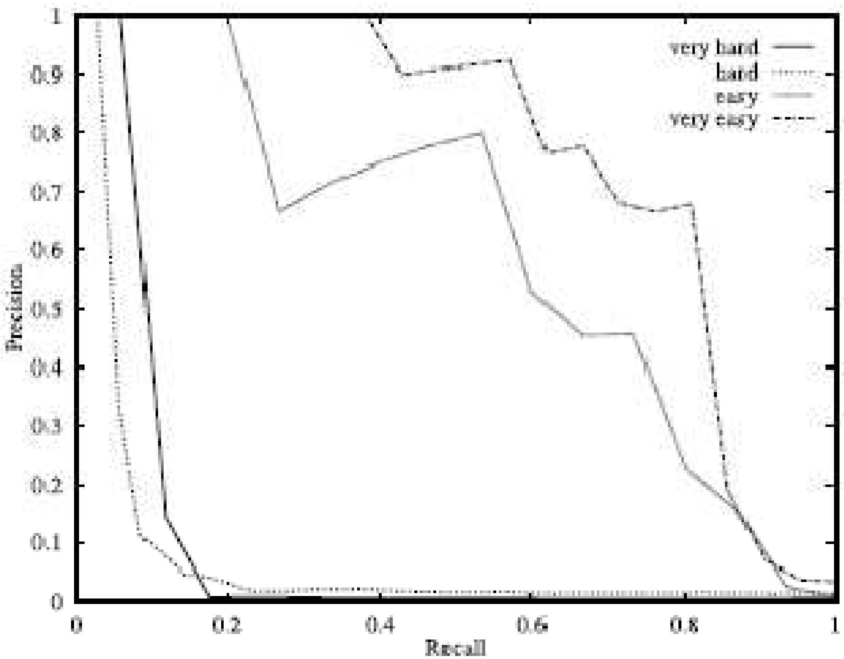
$$\text{Error rate} = \frac{\text{No. non-relevant images retrieved}}{\text{Total No. images retrieved}}$$

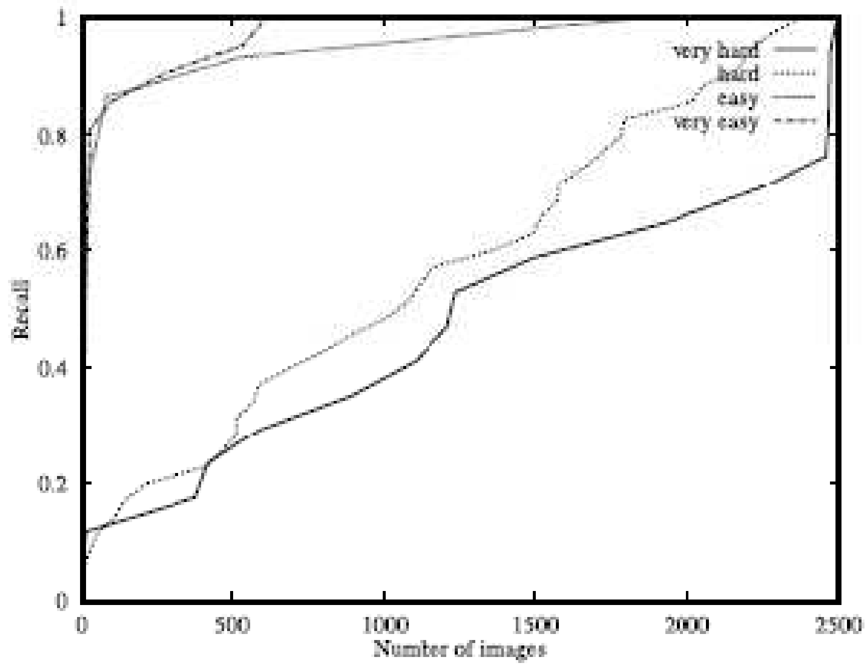
  - Retrieval efficiency

$$\text{Retrieval efficiency} = \begin{cases} \dfrac{\text{No. relevant images retrieved}}{\text{Total No. images retrieved}} \\ \quad \text{if No. retrieved} > \text{No. relevant,} \\ \dfrac{\text{No. relevant images retrieved}}{\text{Total No. relevant images}} \quad \text{otherwise.} \end{cases}$$

Effectiveness measurement (3)

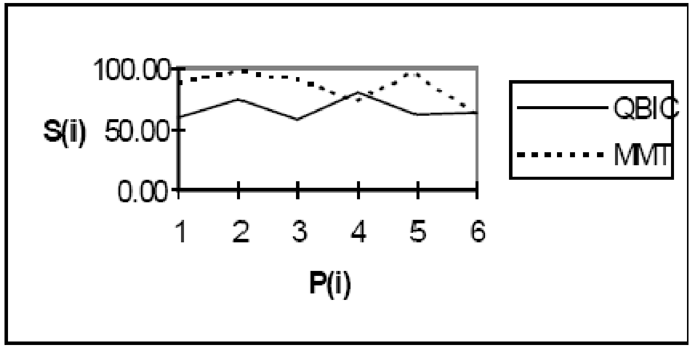
- Graphical representations
  - Precision versus Recall graphs
  - Precision at N versus N, Recall at N versus N
  - Retrieval accuracy versus noise graph



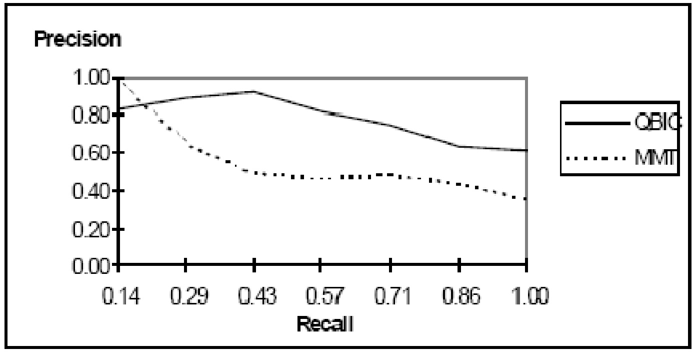


Effectiveness measurement (4)

- Different measurement (QBIC versus MMT)



(a)



(b)

Average performance measured using (a) the percentage of similarity ranking method (b) recall and precision pair

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Some facts about our visual perception

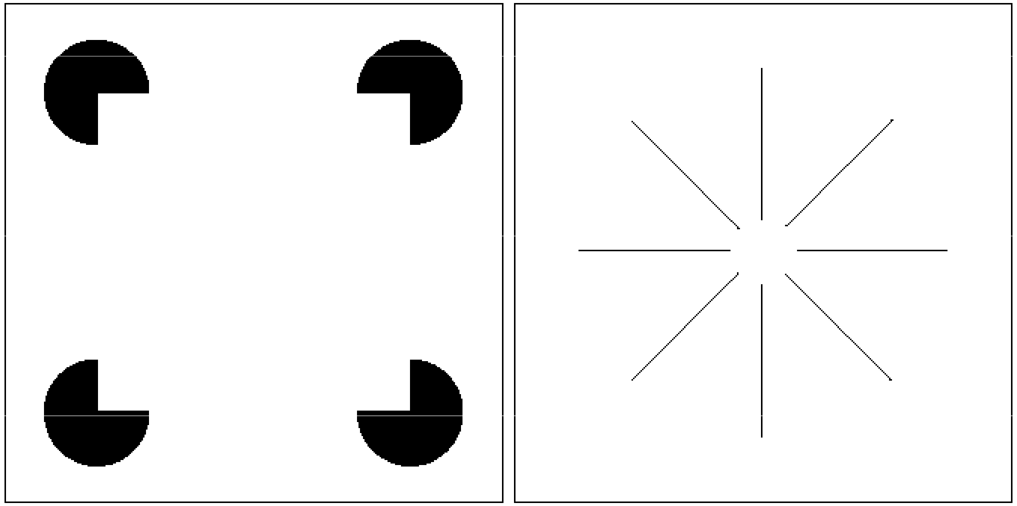
- We are driven by a desire to make meanings

  (We all seem to 'see things' in inkblots, flames, stains, clouds and so on.)

- Human visual perception is self-learning
  - If you are an European, it is hard to recognize Japanese and Chinese faces
  - We are looking for the known objects in the picture

Some facts about our visual perception

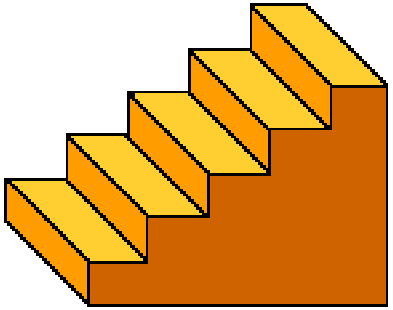
- We are looking for the known objects in the picture



Some well known optical illusions

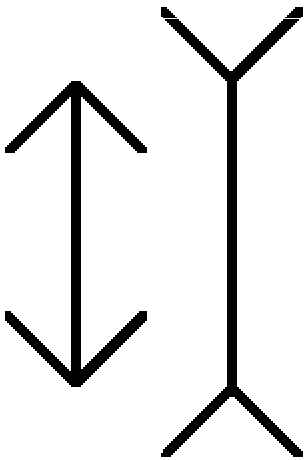
Some facts about our visual perception

- Cultural and environmental factors affects the way we see things



Are these stairs goes up or down?

- Arabs would read this (right to left) as a set of stairs going down



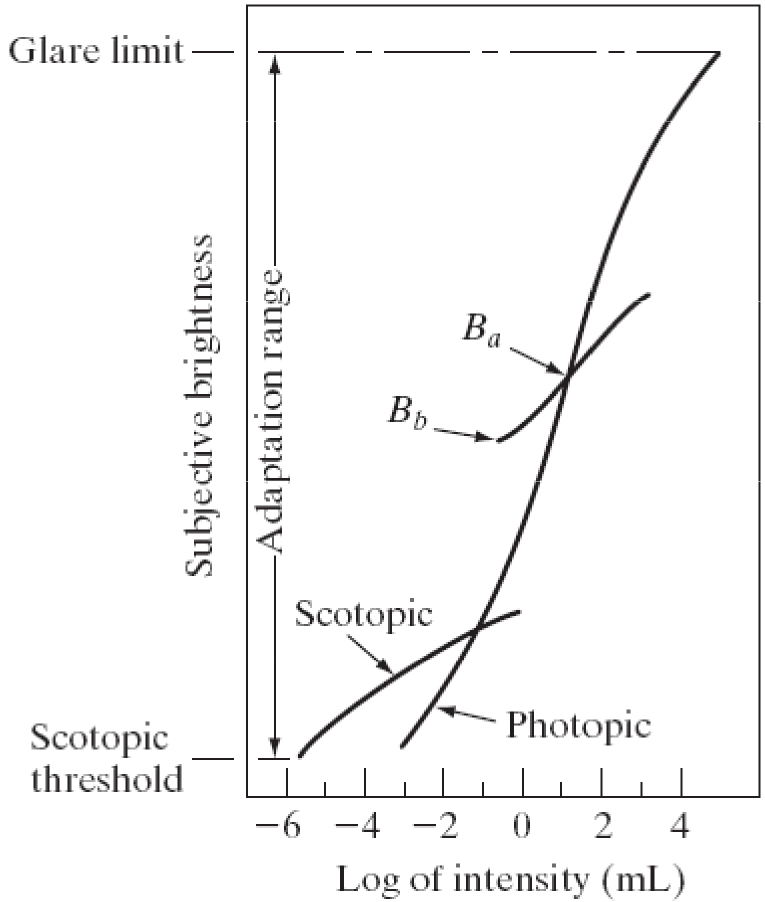
Is left line shorter than the right one?

- Left: *outside* corner of a building
- Right: *inside* corner of a room

Inside corner may appear to be nearer (and therefore larger)

Some facts about our visual perception

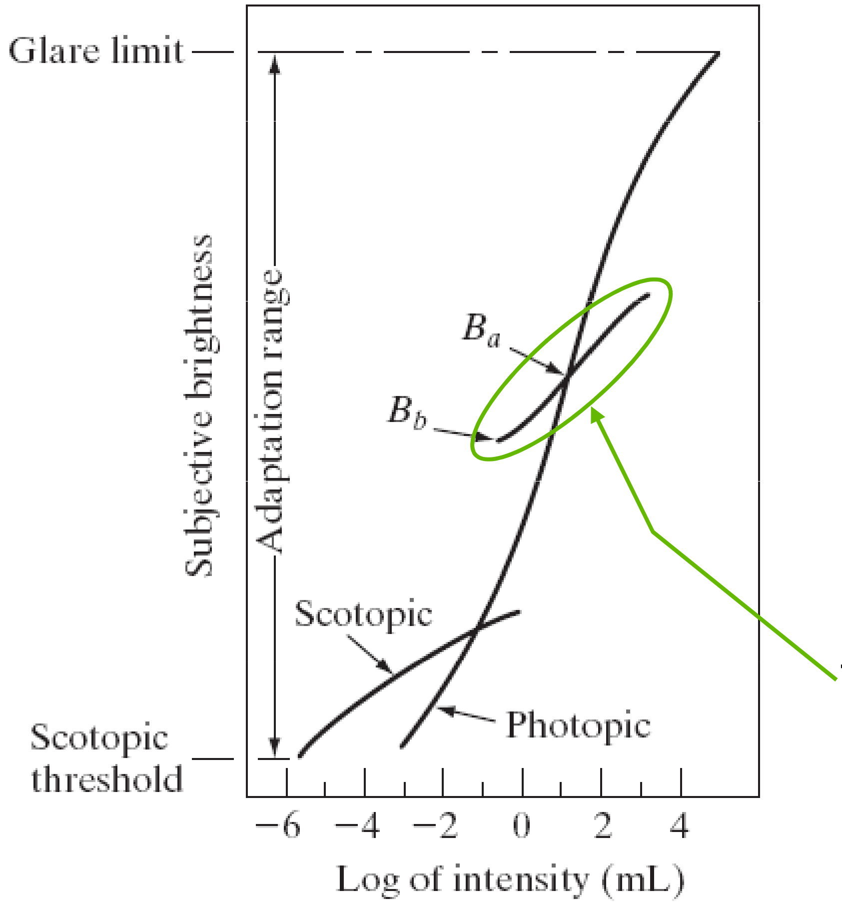
- Brightness adaptation and discrimination



- Range of light intensity levels to which human visual system can adapt: order of 10^{10}
- Subjective brightness (perceived intensity) is a logarithmic function of the actual light intensity

Some facts about our visual perception

- Brightness adaptation and discrimination



  - The human visual system cannot operate over such a range (10^{10}) simultaneously
  - It accomplishes this variation by changing its overall sensitivity – brightness adaptation phenomena

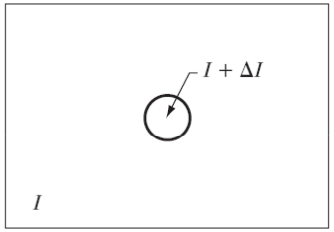
The range of subjective brightness that the eye can perceive when adapted to the level B_a

B_a – brightness adaptation level

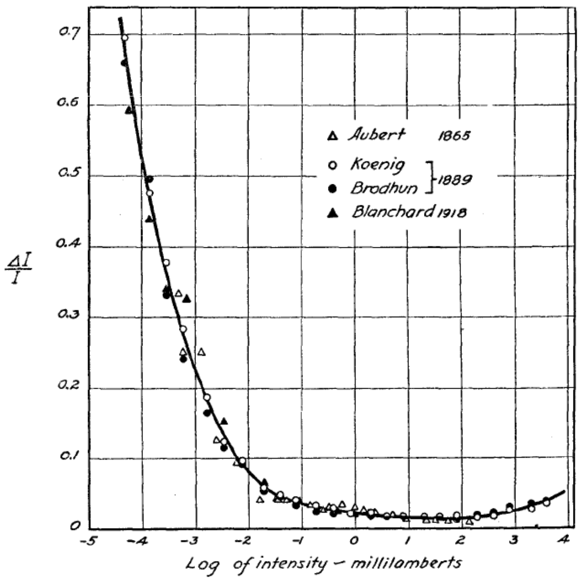
B_b – below it all stimuli are perceived as black

Some facts about our visual perception

- Brightness adaptation and discrimination



Basic experimental setup used to characterize brightness discrimination.



  - The eye discriminates between changes in brightness at any specific adaptation level.

    $\frac{\Delta I_c}{I}$ – Weber ratio,

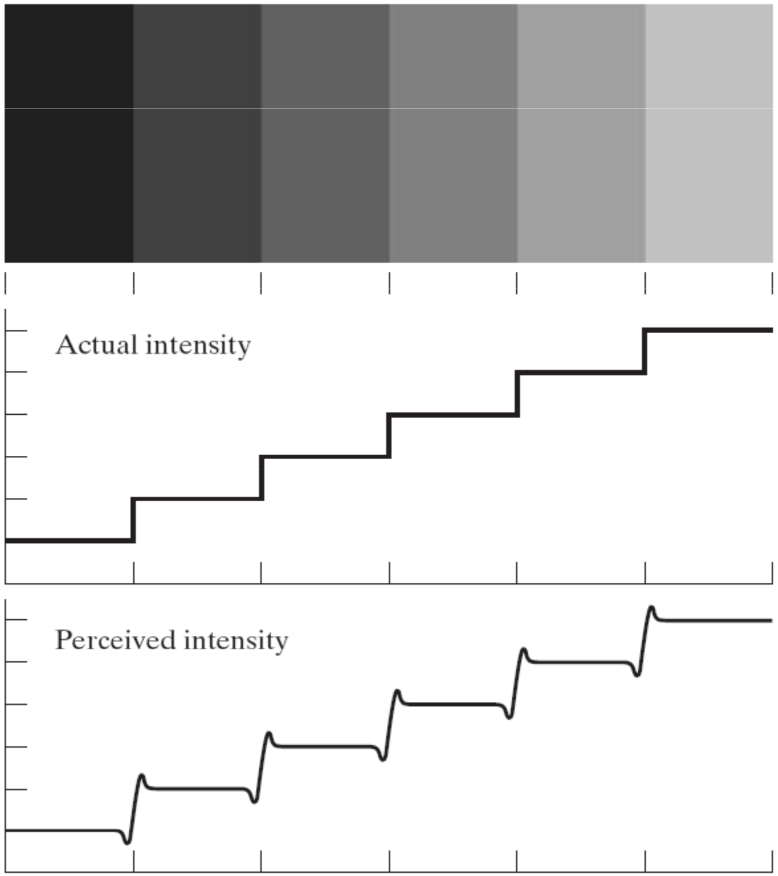
    ΔI_c – the increment of illumination discriminable 50% of the time;

    I – background illumination.

- Small values of Weber ratio mean good brightness discrimination (and vice versa).
- At low levels of illumination brightness discrimination is poor (rods) and it improves significantly as background illumination increases (cones).

Some facts about our visual perception

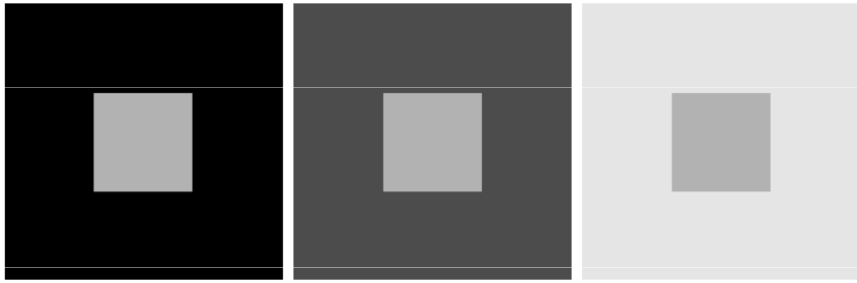
- Perceived brightness is not a simple function of intensity

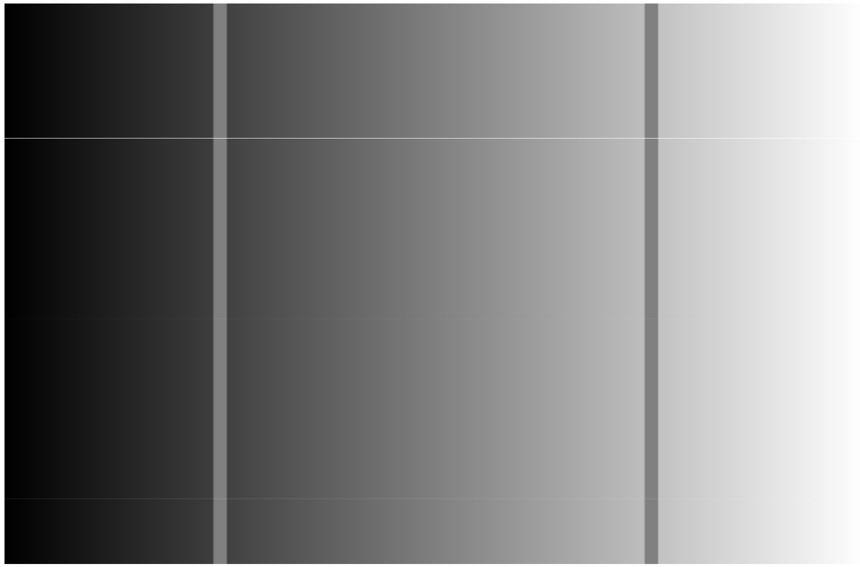


  - Mach band effect (Scalloped effect)

Some facts about our visual perception

- Perceived brightness is not a simple function of intensity





  - Simultaneous contrast

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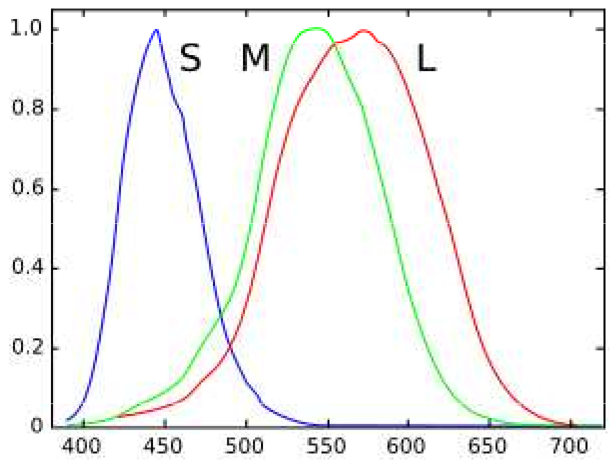
Color fundamentals

- Color in the eye



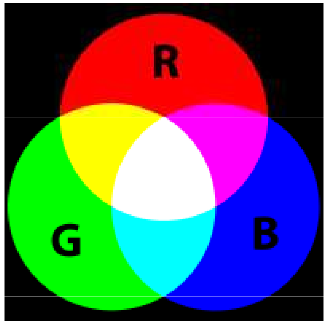
Normalized typical human cone cell responses (S, M, and L types) to monochromatic spectral stimuli

– Varying sensitivity of different cells in the retina (cones) to light of different wavelengths:
  - S-cones: short-wavelength (blue);
  - M-cones: middle-wavelength (green);
  - L-cones: long-wavelength (red).

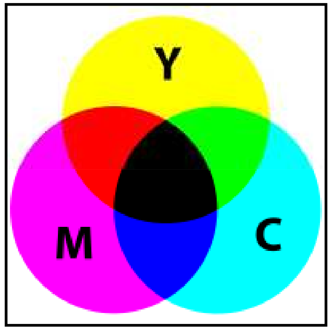
Cone type	Name	Range	Peak wavelength
S	β	400–500 nm	420–440 nm
M	γ	450–630 nm	534–545 nm
L	ρ	500–700 nm	564–580 nm

Color fundamentals

- Primary and secondary colors



Mixture of lights
(Additive primaries)



Mixture of pigments
(Subtractive primaries)

  - Due to different absorption curves of the cones, colors are seen as variable combinations of the so-called primary colors: red, green and blue.
  - The primary colors can be added to produce the secondary colors of light: magenta (R+B), cyan (G + B), and yellow (R + G).
  - For pigments and colorants, a primary color is the one that subtracts (absorbs) a primary color of light and reflects the other two.

Color fundamentals

- Brightness, hue, and saturation
  - Brightness is a synonym of intensity
  - Hue represents the impression related to the dominant wavelength of the color stimulus
  - Saturation expresses the relative color purity (amount of white light in the color)
  - Hue and Saturation taken together are called the chromaticity coordinates (polar system)

Color fundamentals

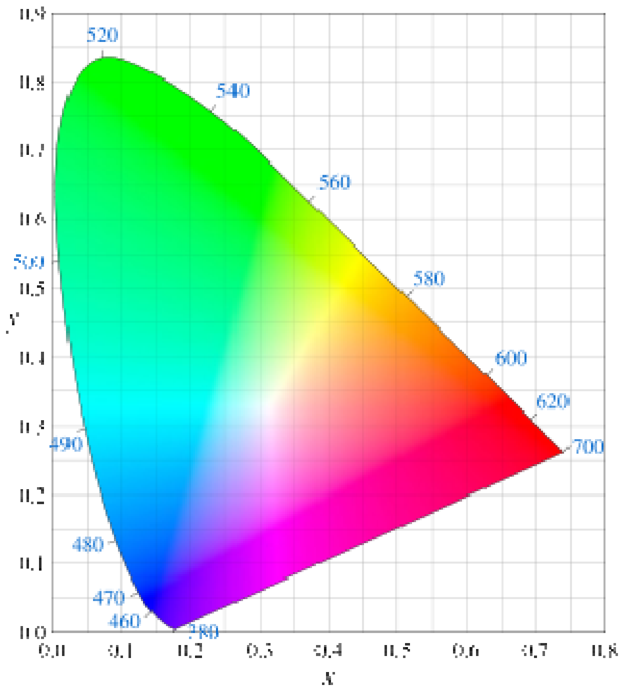
- From tristimulus values to chromaticity coordinates
  - The amounts of red, green, and blue needed to form any particular color are called the tristimulus values and denoted by X, Y, and Z
  - The chromaticity coordinates *x* and y (Cartesian system) are obtained as:

$$x = \frac{X}{X+Y+Z}, \quad y = \frac{Y}{X+Y+Z}, \quad z = \frac{Z}{X+Y+Z}$$

$$x + y + z = 1$$

Color fundamentals

• CIE xy Chromaticity Diagram

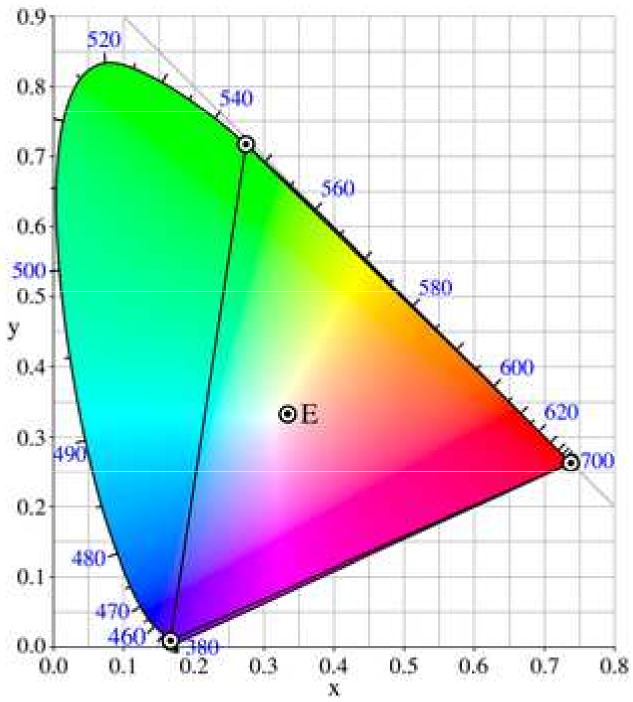


The CIE 1931 chromaticity diagram.

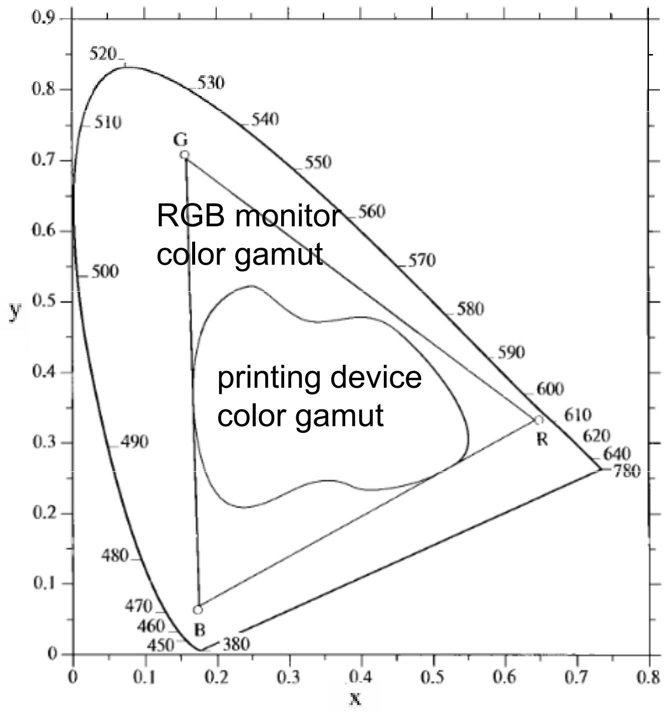
- Created by the International Commission on Illumination (CIE) in 1931.
- Function of x (red) and y (green) : z = 1 – (x + y).
- The outer boundary is the spectral (monochromatic) locus, wavelengths shown in nm.
- (x,y) = (1/3,1/3) is a flat energy spectrum point (point of equal energy).
- Any point on the boundary is completely saturated.
- Boundary → point of equal energy : saturation → 0

Color fundamentals

- Color Gamut



Gamut of the CIE RGB primaries and location of primaries on the CIE 1931 xy chromaticity diagram.



Typical gamuts of a monitor and of a printing device.

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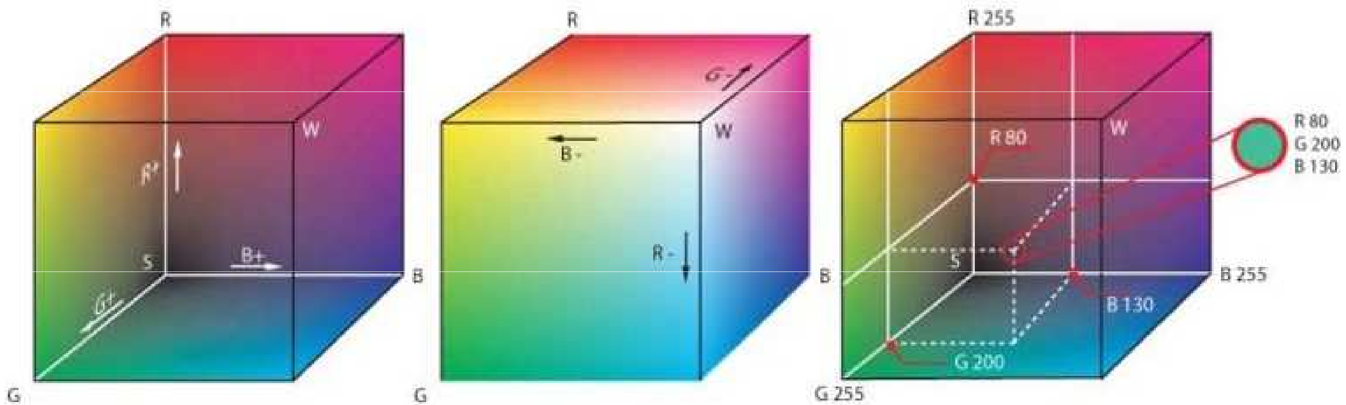
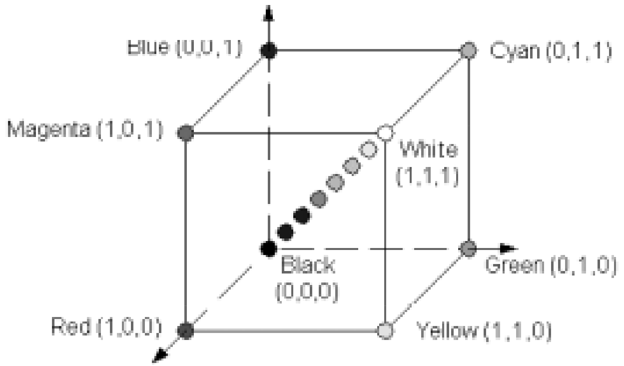
Color spaces

- The purpose of a *color space* (or *color model* or *color system*) is to facilitate the specification of colors in some standard way.
- A color model provides a *coordinate system* and a *subspace* in it where each color is represented by a single point.
- Common color spaces:
  - RGB (monitors, video cameras),
  - CMY/CMYK (printers),
  - HSI/HSV/HSL/HSB (image processing),
  - CIE Lab (image processing).

Color spaces

- RGB color space

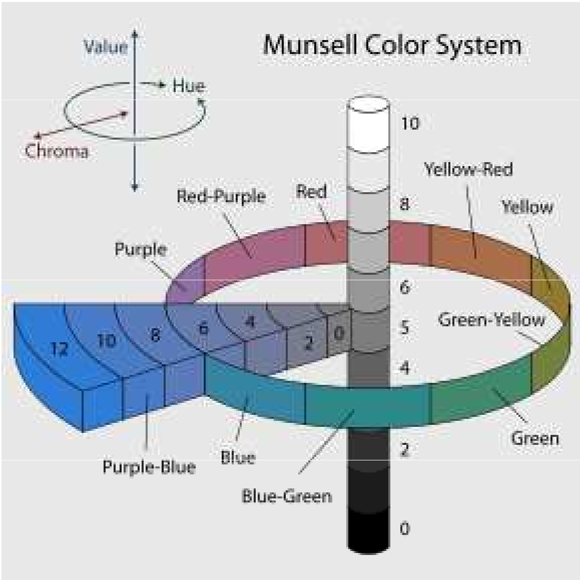




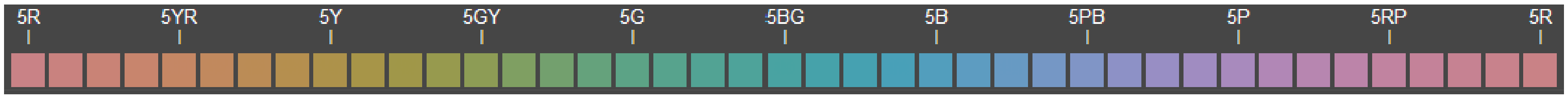
If R,G, and B are represented with 8 bits (24-bit RGB image), the total number of colors is $(2^8)^3$=16,777,216

Color spaces

- Munsell color system



  - By Professor Albert H. Munsell in the beginning of the 20th century.
  - Specifies colors based on 3 color dimensions, hue, value (lightness), and chroma (color purity or colorfulness).



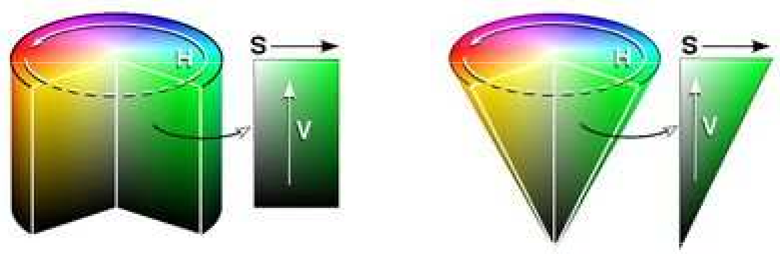
Munsell hues; value 6 / chroma 6

Color spaces

- HSI/HSL/HSV/HSB color spaces
  - RGB, CMY/CMYK are hardware oriented color spaces (suited for image acquisition and display).
  - The HSI/… (Hue, Saturation, Intensity/Lightness/ Value/Brightness) are perceptive color spaces (suited for image description and interpretation).
  - Allow the decoupling of chromatic signals (H+S) from the intensity signal (I).

Color spaces

- HSI/HSL/HSV/HSB color spaces

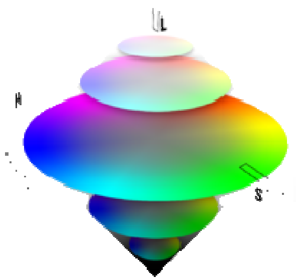


Graphical depiction of HSV (cylinder and cone)

$$I = \frac{R+G+B}{3}$$

$$L = \frac{\max(R,G,B)+\min(R,G,B)}{2}$$

$$V = \max(R,G,B)$$



Graphical depiction of HSL

http://www.easyrgb.com/index.php?X=MATH

Color spaces

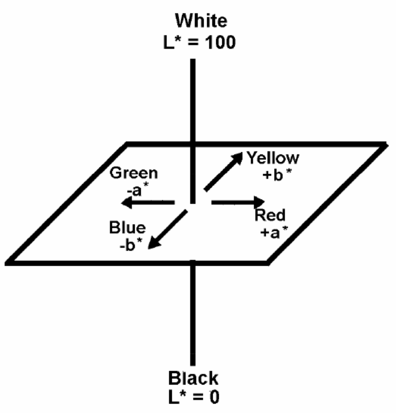
- CIE L*a*b color space
  - It's a *device independent* and *perceptually uniform* color model.
  - It allows the color gamuts of monitors and output devices to be related to one another.
  - The L*a*b* components are given by

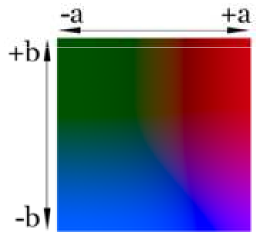
$$L^* = 116 * h\left(\frac{Y}{Y_W}\right) - 16$$

$$a^* = 500\left[h\left(\frac{X}{X_W}\right) - h\left(\frac{Y}{Y_W}\right)\right]$$

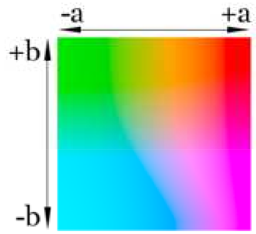
$$b^* = 200\left[h\left(\frac{Y}{Y_W}\right) - h\left(\frac{Z}{Z_W}\right)\right]$$

$$h(q) = \begin{cases} \sqrt[3]{q} & if \quad q > 0.008856 \\ 7.787q + 16/116 & otherwise \end{cases}$$





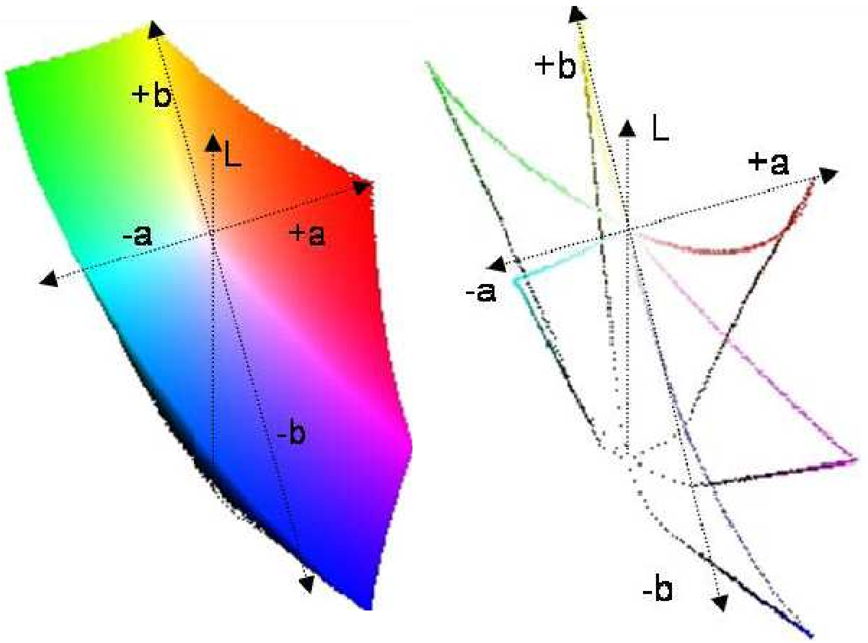
Lightness 75%



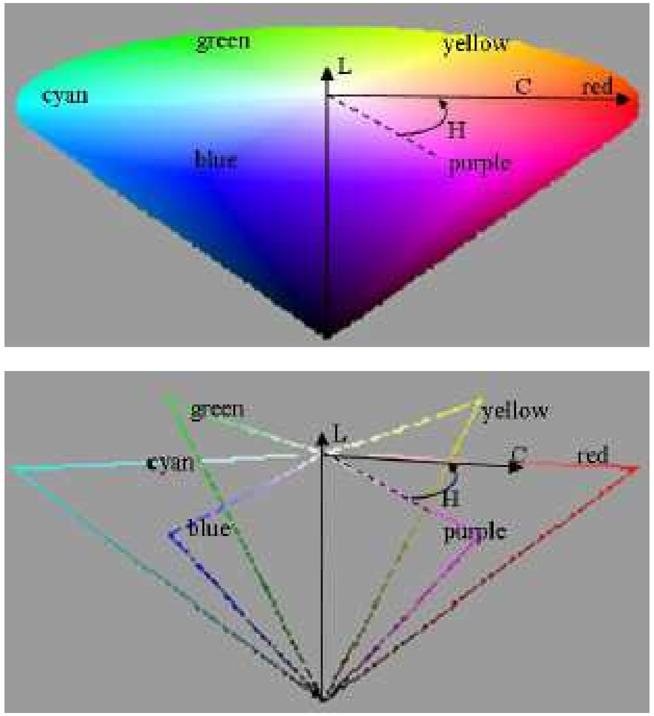
Lightness 25%

Color spaces

- HCL color space



CIE Lab color space



HCL color space

Color spaces

- HCL color space

$$L = \frac{Q.Max(R,G,B) + (1-Q).Min(R,G,B)}{2}$$

$$C = \frac{Q.\left(R - G| + |G - B| + |B - R|\right)}{3}$$, where $Q = e^{\alpha\gamma}$, $\alpha = \left(\frac{Min(R,G,B)}{Max(R,G,B)} \cdot \frac{1}{Y_0}\right)$, $Y_0 = 100$

$$H = \arctan\left(\frac{G-B}{R-G}\right)$$

And finally to allow hue to vary in an interval from -180° to +180°:

$$\text{if } ((R-G) \geq 0 \text{ and } (G-B) \geq 0), \text{ then } H = \tfrac{2}{3}H$$
$$\text{if } ((R-G) \geq 0 \text{ and } (G-B) < 0), \text{ then } H = \tfrac{4}{3}H$$
$$\text{if } ((R-G) < 0 \text{ and } (G-B) \geq 0), \text{ then } H = 180 + \tfrac{4}{3}H$$
$$\text{if } ((R-G) < 0 \text{ and } (G-B) < 0), \text{ then } H = \tfrac{3}{4}H - 180.$$

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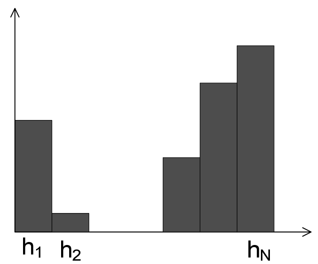
Color features

Color features

Color histograms | **Color moments**



$$F(I) = (h_1^I, h_2^I, \ldots, h_N^I)$$

Metrics: L_1, L_2, L_∞

Statistical moments for every color channel

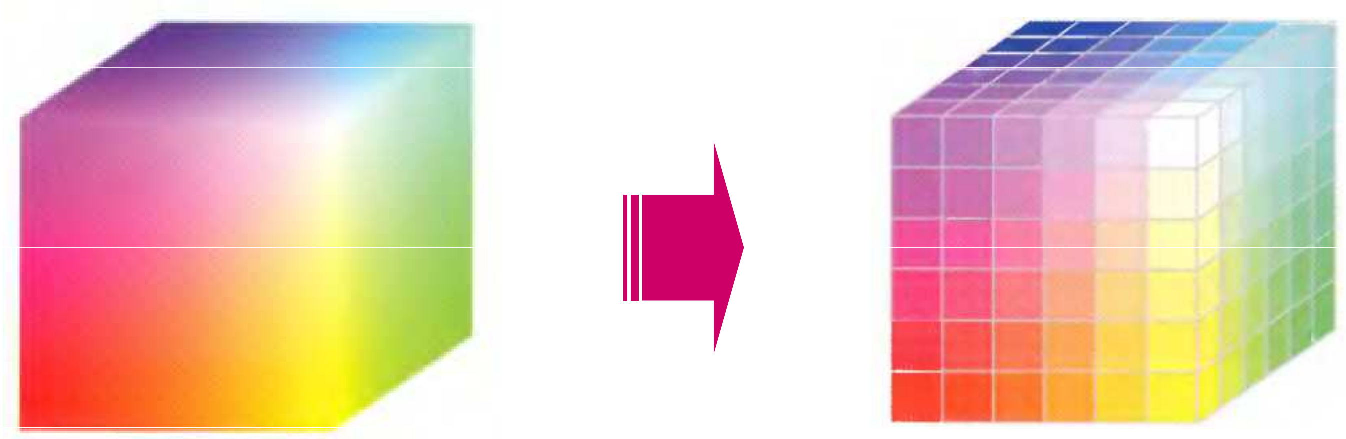
$$F(I) = (E_1^I, E_2^I, E_3^I, \sigma_1^I, \sigma_2^I, \sigma_3^I, s_1^I, s_2^I, s_3^I)$$

Metrics: $\sim L_1$

Stricker M., Orengo M. Similarity of Color Images. Proceedings of the SPIE Conference, vol. 2420, p. 381-392, 1995

Color histograms

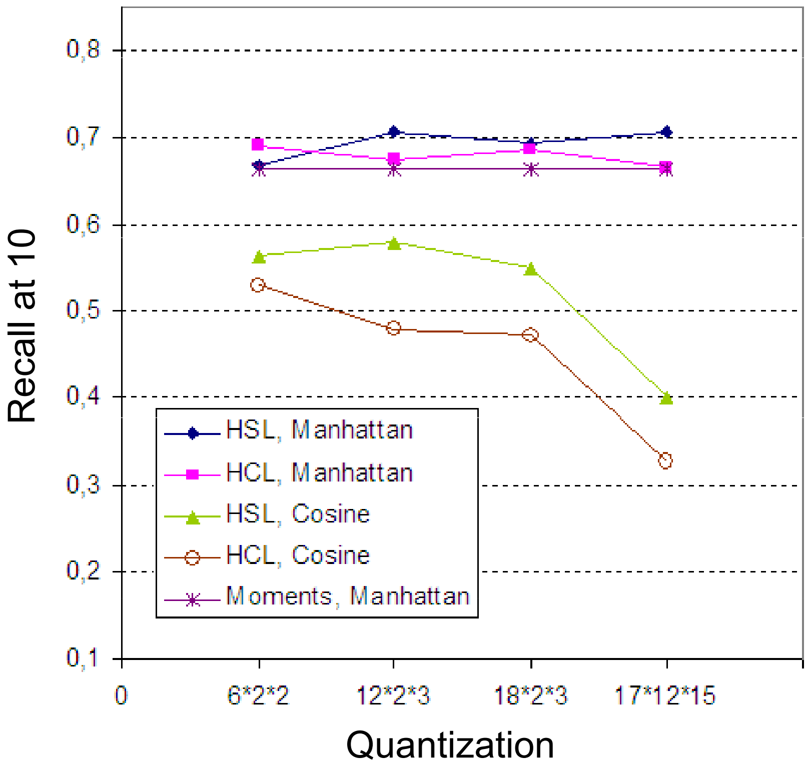
- Quantization of color space



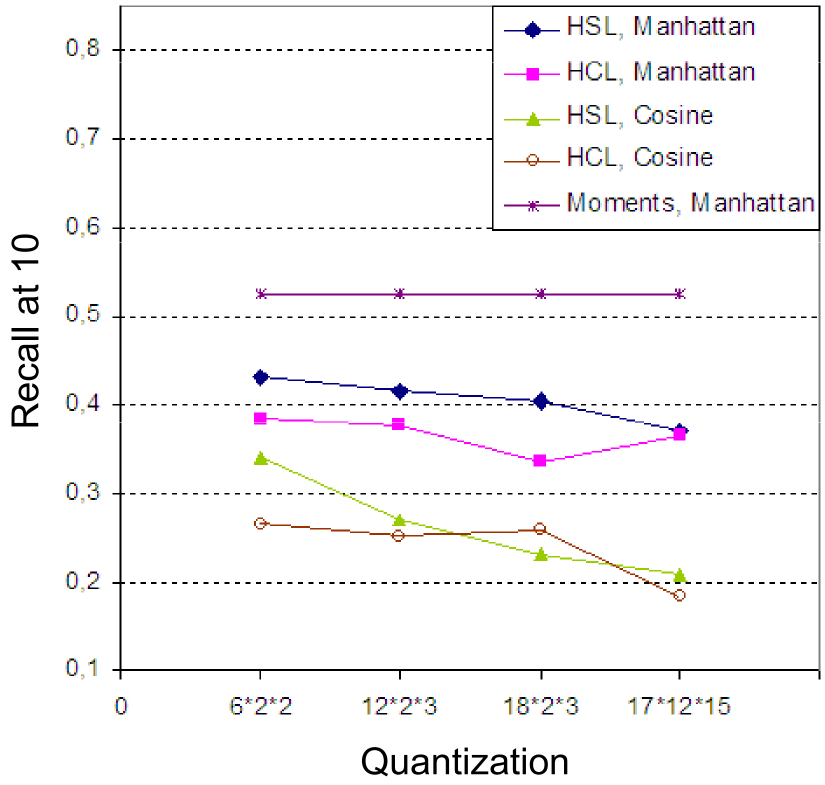
  - Quantization is important: size of the feature vector.
  - When no color similarity function used:
    - Too many bins – similar colors are treated as dissimilar.
    - Too little bins – dissimilar colors are treated as similar.

Color histograms

- Quantization of color space: recall



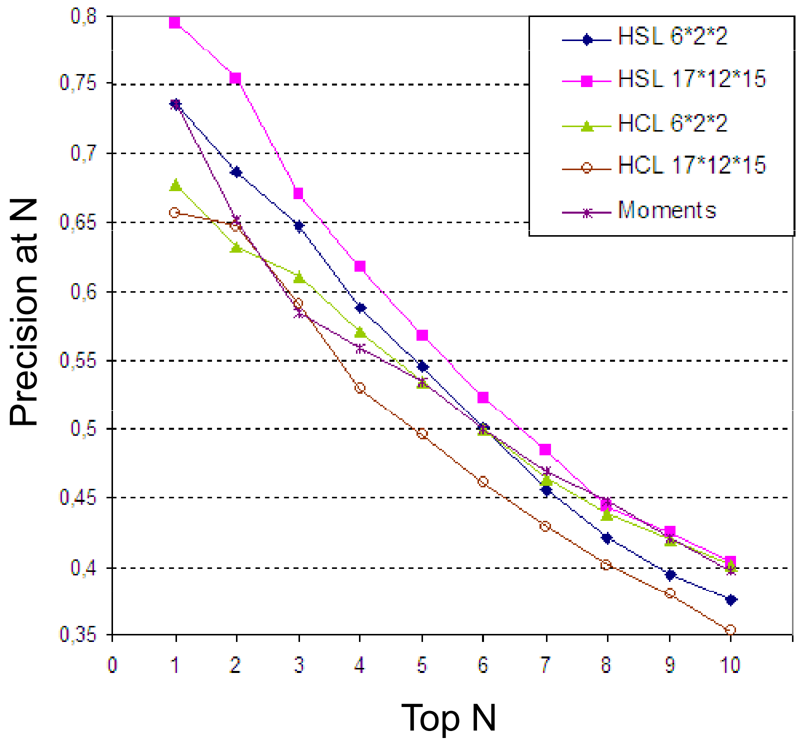
ImageDB-100



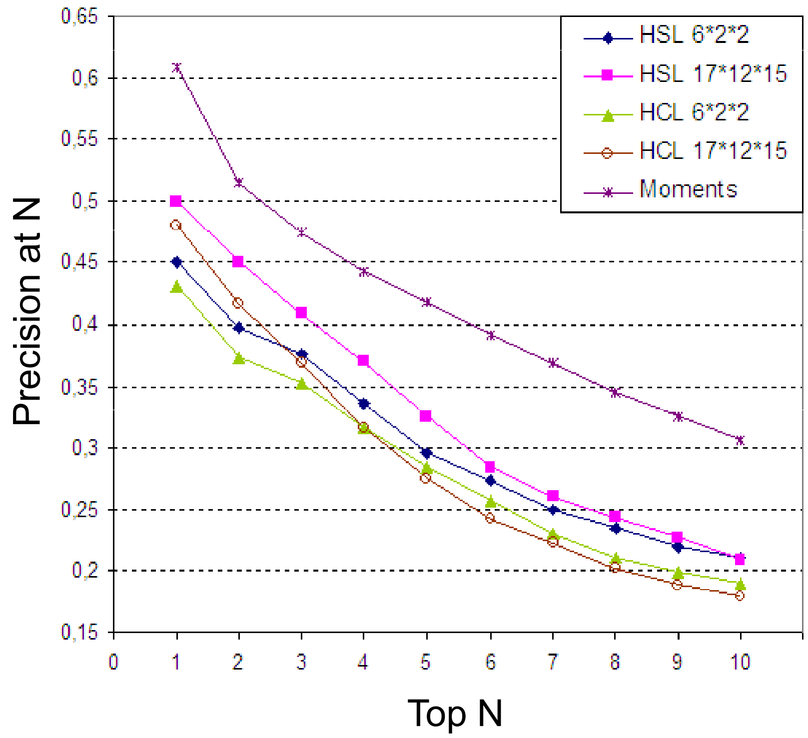
ImageDB-1000

Color histograms

- Quantization of color space: precision



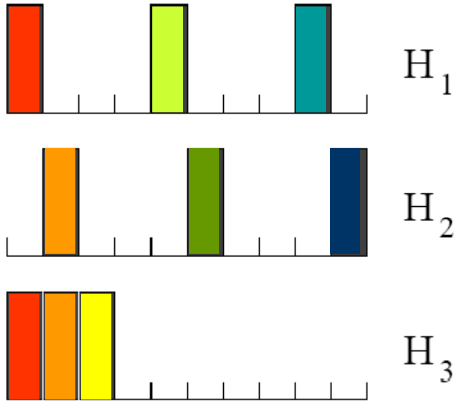
ImageDB-100



ImageDB-1000

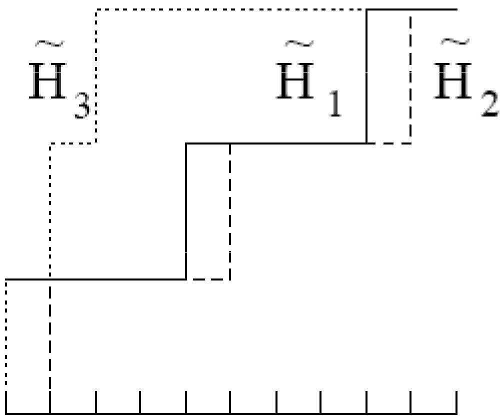
Color histograms: main disadvantages

1. Colors similarity across histo bins is not considered:



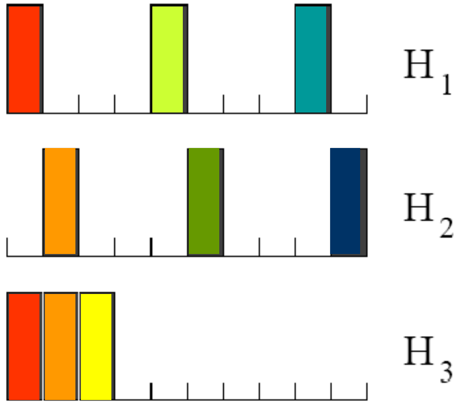
$d(H_1, H_2) > d(H_1, H_3)$

- Cumulative histograms



Color histograms: main disadvantages

1. Colors similarity across histo bins is not considered:



$d(H_1, H_2) > d(H_1, H_3)$

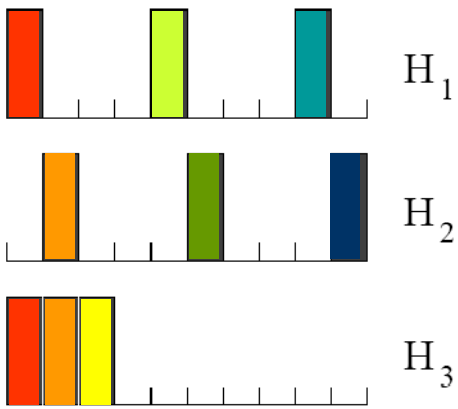
- Cumulative histograms
- $$d(H_1, H_2) = \sqrt{(H_1 - H_2) \cdot A \cdot (H_1 - H_2)^T}$$

  A – matrix with color similarity coefficients

Niblack W., Barber R., et al. The QBIC project: Querying images by content using color, texture and shape. In IS&T/SPIE International Symposium on Electronic Imaging: Science & Technology, Conference 1908, Storage and Retrieval for Image and Video Databases, Feb. 1993

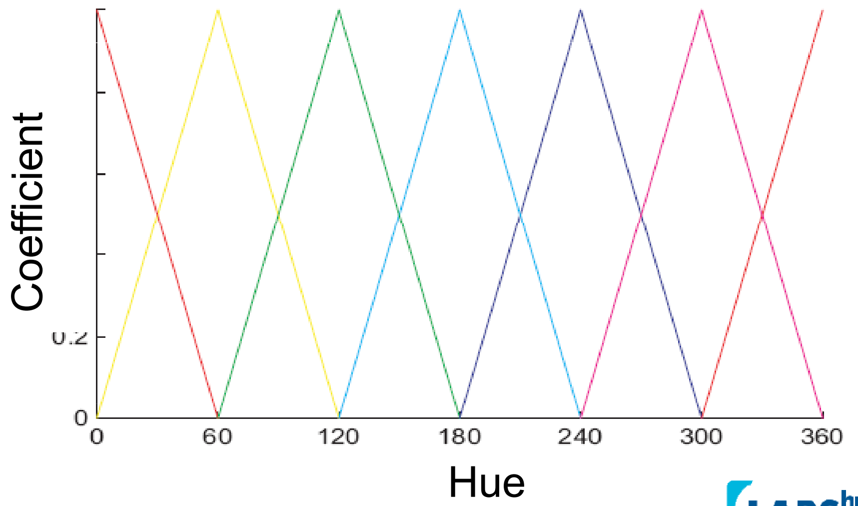
Color histograms: main disadvantages

1. Colors similarity across histo bins is not considered:



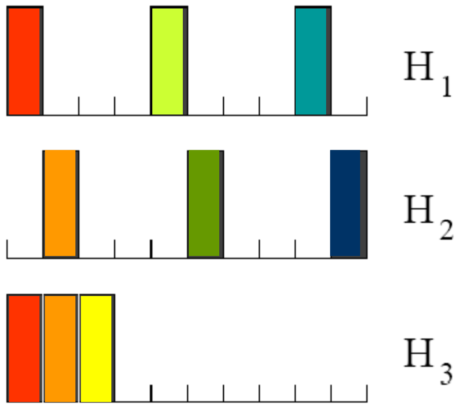
$d(H_1, H_2) > d(H_1, H_3)$

- Cumulative histograms
- $d(H_1, H_2) = \sqrt{(H_1 - H_2) \cdot A \cdot (H_1 - H_2)^T}$
- Fuzzy histo



Color histograms: main disadvantages

1. Colors similarity across histo bins is not considered:



$d(H_1, H_2) > d(H_1, H_3)$

- Cumulative histograms
- $d(H_1, H_2) = \sqrt{(H_1 - H_2) \cdot A \cdot (H_1 - H_2)^T}$
- Fuzzy histo
- Color similarity measure

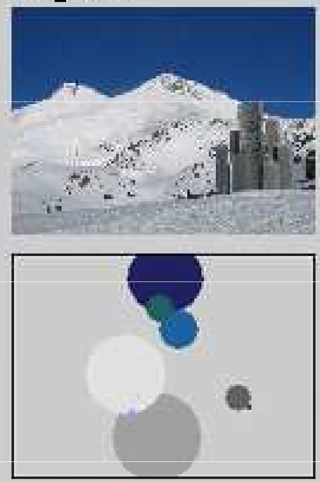
$$\triangle E_{RGB} = \sqrt{\triangle R^2 + \triangle G^2 + \triangle B^2}$$

$$D_{cyl} = \sqrt{\triangle L*^2 + C*_1^2 + C*_2^2 - 2C*_1 C*_2 \cos(\triangle H)}$$

Color histograms: main disadvantages

2. Spatial color layout is not considered:

img239



```
( 3, 0.242552,  77, 99)
( 1, 0.218489,  60, 65)
(21, 0.208021,  81, 13)
(19, 0.108854,  88, 41)
(13, 0.079948,  78, 30)
(27, 0.070677, 120, 78)
(31, 0.030260,  64, 87)
(19, 0.013958, 126, 83)
```

bin number (color num) — amount of color — position of color

$$dist(Q,I) = \sum_{i=1}^{N} \begin{cases} \alpha \,|\, h_i^Q - h_i^I \,|\, \sqrt{(x_i^Q - x_i^I)^2 + (y_i^Q - y_i^I)^2}, & h_i^Q \neq 0,\ h_i^I \neq 0; \\ \beta h_i^Q, & h_i^Q \neq 0,\ h_i^I = 0; \\ \beta h_i^I, & h_i^I \neq 0,\ h_i^Q = 0. \end{cases}$$

Color moments

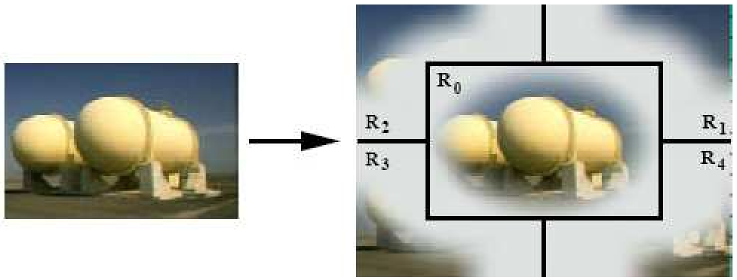
- Average, standard deviation, skewness

$$E_i = \frac{1}{N}\sum_{j=1}^{N} p_{ij} \quad , \quad \sigma_i = \left(\frac{1}{N}\sum_{j=1}^{N}(p_{ij} - E_i)^2\right)^{\frac{1}{2}} \quad \text{and} \quad s_i = \left(\frac{1}{N}\sum_{j=1}^{N}(p_{ij} - E_i)^3\right)^{\frac{1}{3}}$$

$$d_{\text{mom}}(H, I) = \sum_{i=1}^{r} w_{i1}|E_i - F_i| + w_{i2}|\sigma_i - \varsigma_i| + w_{i3}|s_i - t_i|$$

- Average, covariance matrix of the color channels

- Consider spatial layout: fuzzy regions



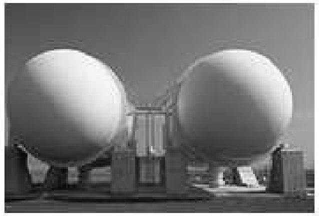
Stricker M., Dimai A. Spectral Covariance and Fuzzy Regions for Image Indexing. Machine Vision and Applications, vol. 10., p. 66-73, 1997

LABS hp

Lecture 2: Outline

- Performance measurement
  - Retrieval effectiveness
- Some facts about human visual perception
- Color features
  - Color fundamentals
  - Color spaces
  - Color features: histograms and moments
  - Comparison

Histograms or color moments? (1)

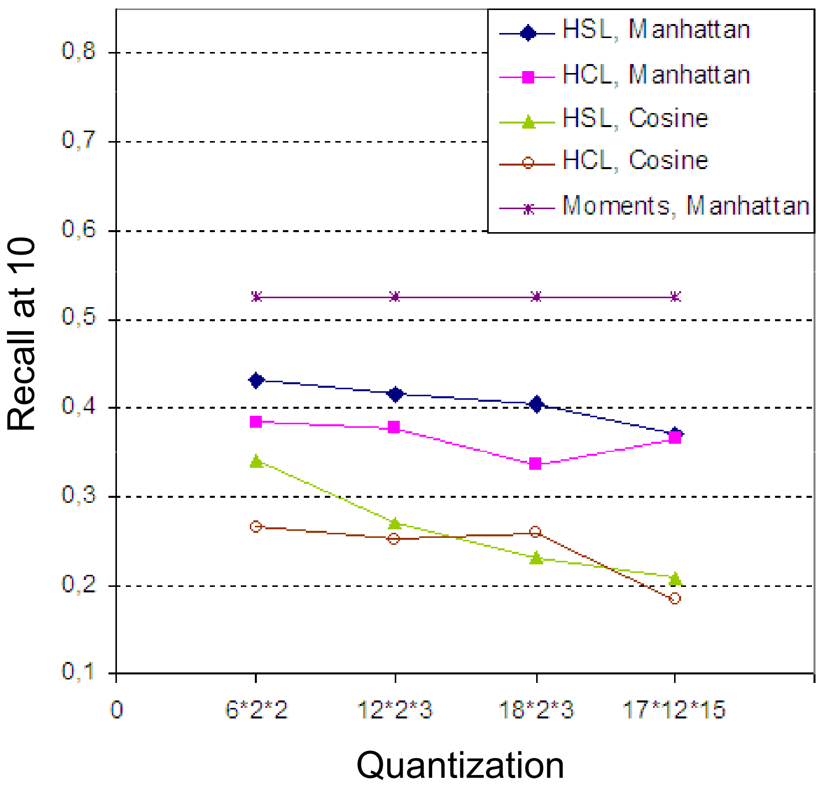


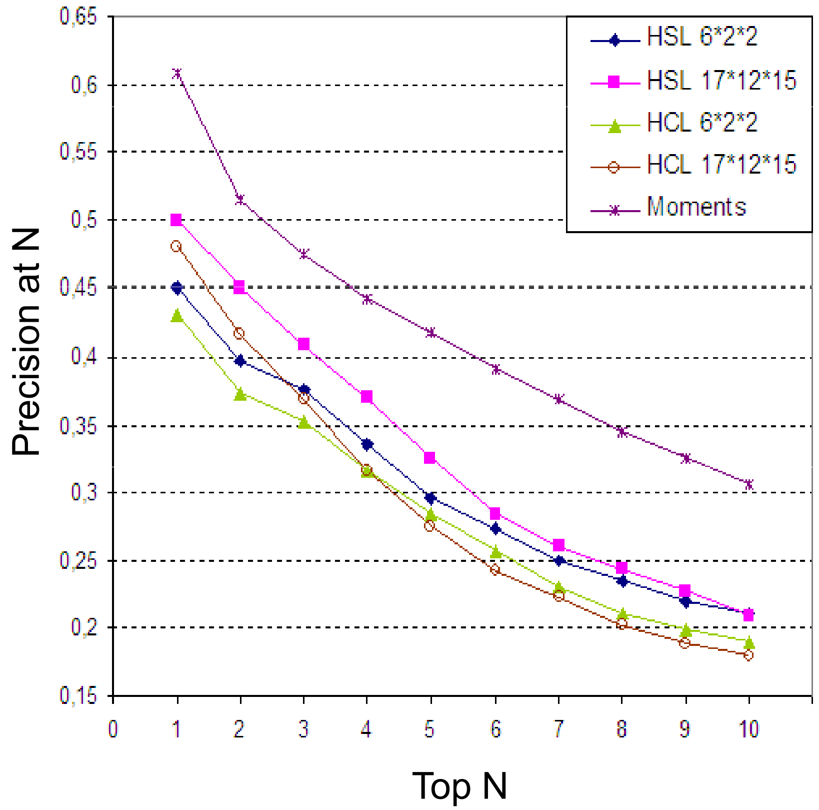
Stricker M., Orengo M. Similarity of Color Images. ... (3000 images)

index	sim. measure	rank of the image			max. rank
					
9 moments	W_1	4	5	8	8
	W_2	2	8	6	8
	W_3	4	6	9	9
8/2/2	L_∞	34	98	79	98
16/4/4	L_∞	3	57	42	57
cum. hist. 8/2/2	L_1	53	162	30	162
16/4/4	L_1	33	354	8	354
8/2/2	L_2	65	158	34	158
16/4/4	L_2	15	306	11	306
8/2/2	L_1	138	394	48	394
16/4/4	L_1	4	132	6	132
histogram 8/2/2	L_2	71	541	102	541
16/4/4	L_2	10	1358	75	1358

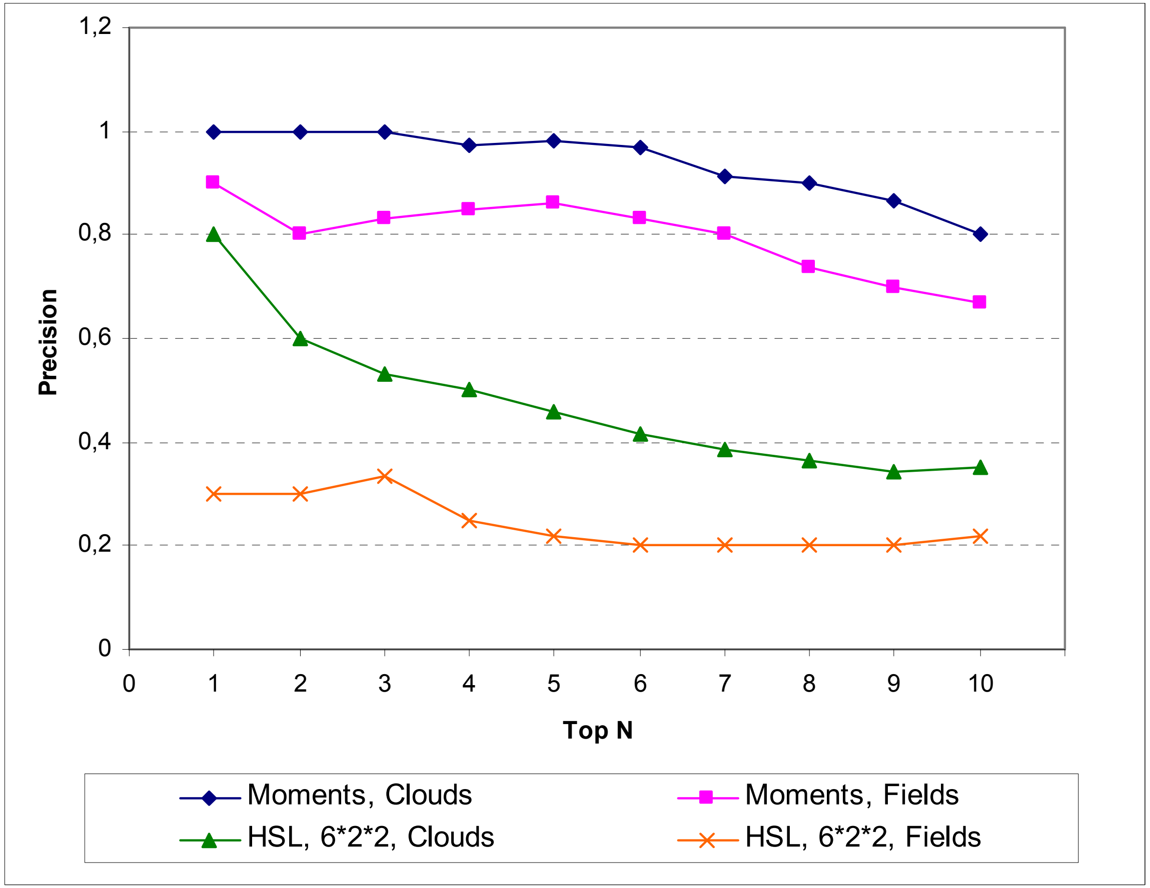
Histograms or color moments? (2)

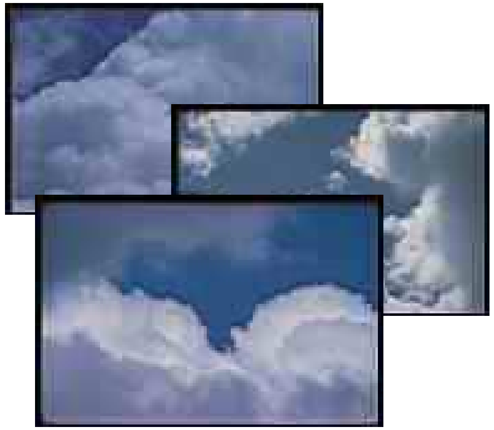
ImageDB-1000



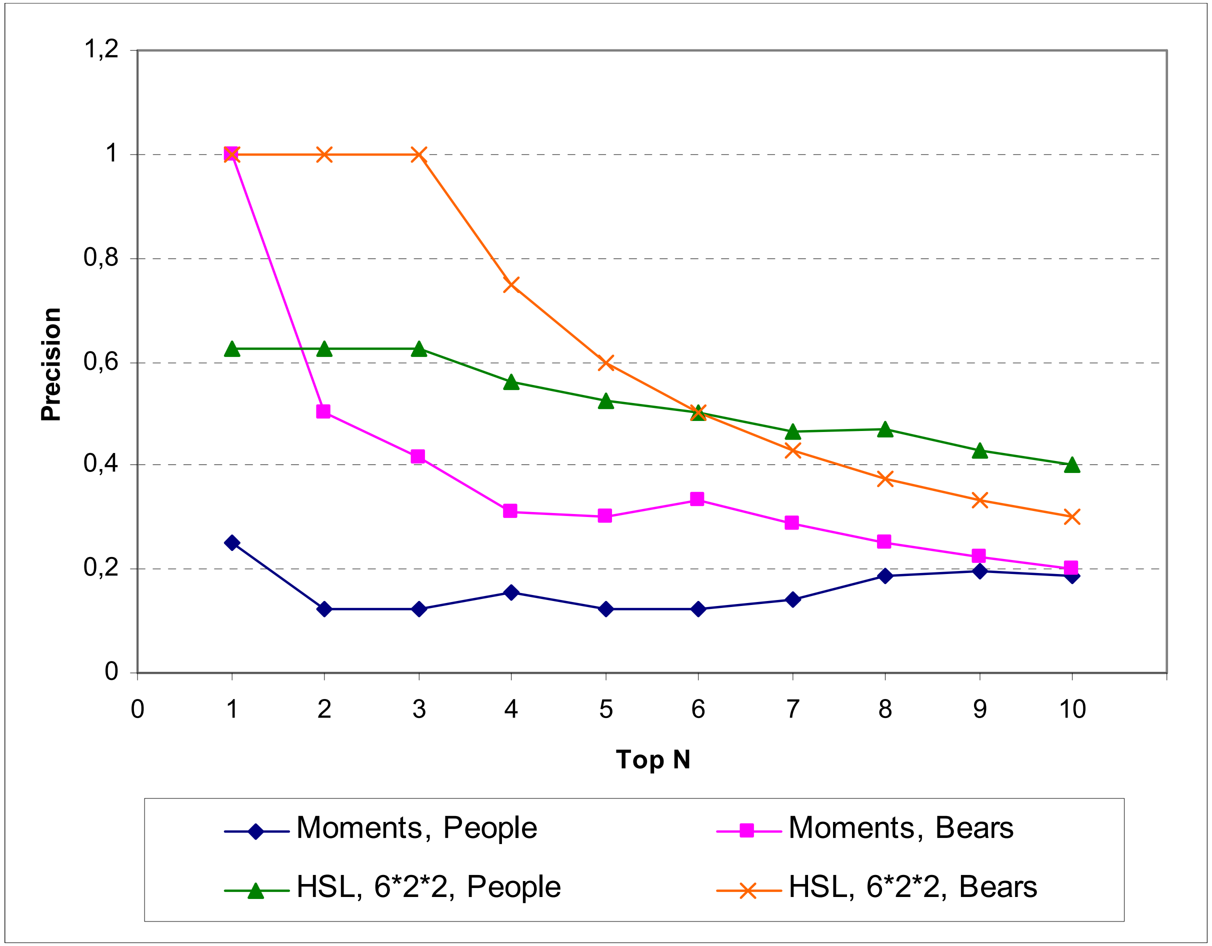


Histograms or color moments? (3)





Histograms or color moments? (4)



Lecture 2: Resume

- Performance: efficiency and effectiveness
  - Lack of the common benchmark collections and retrieval effectiveness measurement
- Human visual perception is very complex
  - Have to take into account known facts about our perception to reduce the semantic gap
- Color features: histograms and moments
  - On heterogeneous collections moments are slightly better
  - Fusion of histograms and moments can give better results

Lecture 2: Bibliography

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