Colour computer vision: fundamentals, applications and challenges

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Outline

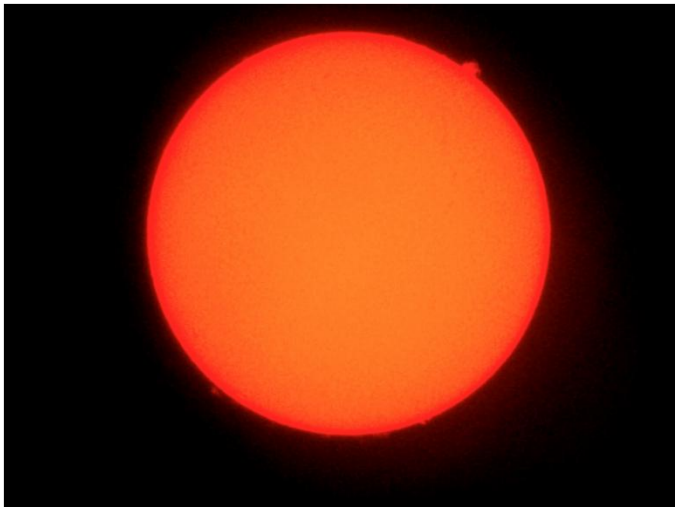
- Part 1: colorimetry and colour perception:
  - What is colour?
  - Colour spaces and differences
  - Environmental effects
  - Colour spaces and neurophisiology
- Part 2: colour computer vision:
  - Restoration
  - Segmentation
  - Pattern recognition
  - CBIR
  - Challenges

Part 1

Colorimetry and colour perception

Colour?

- Colour attached to the object or to the brain?
- How could we describe the colour of the star?
- Problems:
  - Colour naming and quantification.
  - Colour differences.
- Colour perception affected by:
  - Fatigue.
  - Psichology.
- Consider colour-based devices.
- Response: colour models or systems (colour spaces).



Colorimetry

- Science and technology to quantify and describe the human colour perception.

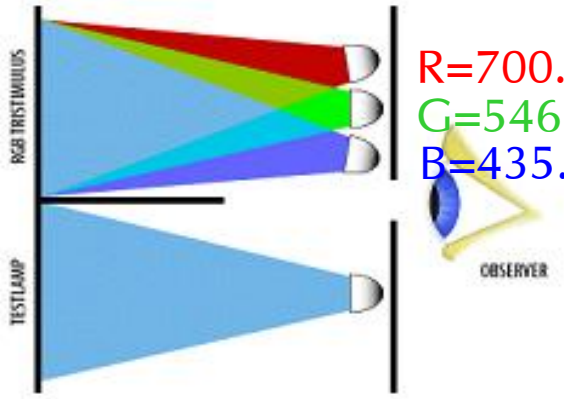
- **Trichromacy**: three independent channels for conveying color information. Most people make the same matching.
- **Metamers**: pairs of power spectrums that match perceptually.

- Thus… if the observer says a mixture is a match then receptor excitations of both stimuli must be equal.

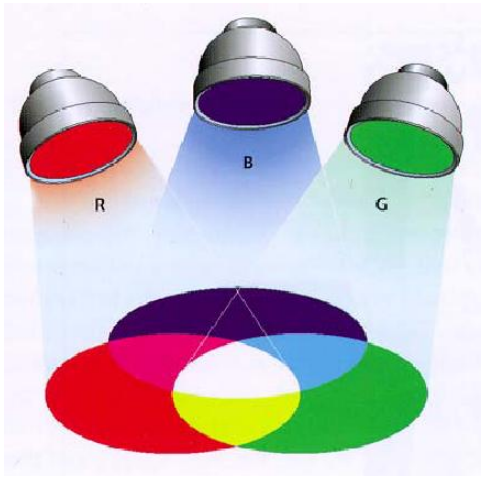
Colour matching experiment

- CIE: (*Comission Internationale de l'Eclairage*).
- Color matching experiment: human perception based standard (1931).
- Standard observer: a composite of a group of 15 to 20 people.

CIE Experiment

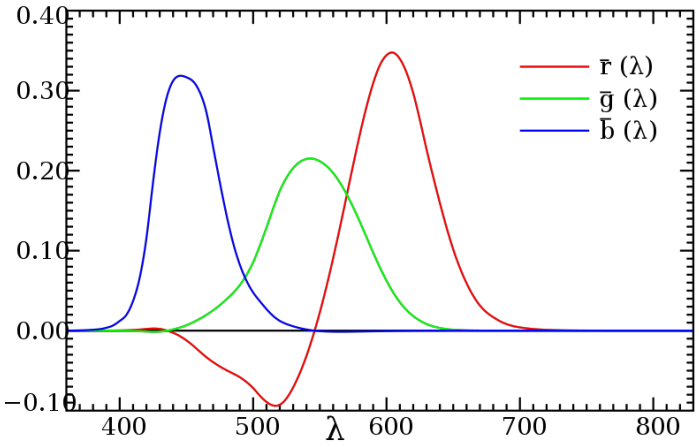


R=700.0 nm
G=546.1 nm
B=435.8 nm



Triestimulus values

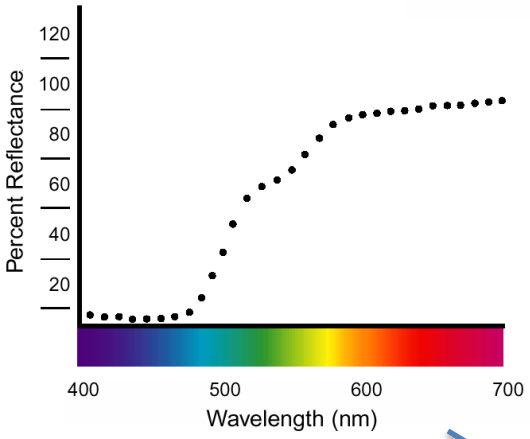
Colour adjustment functions

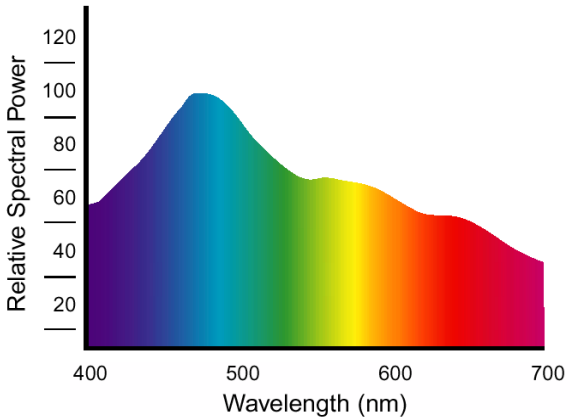


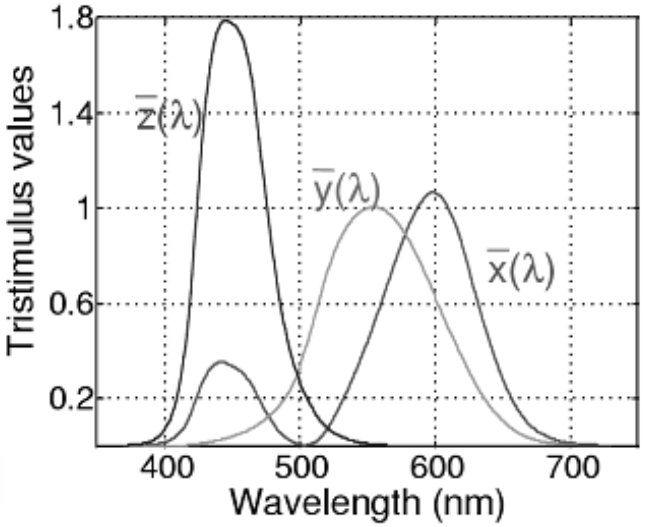
Wavelength (nm)

XYZ colour space

- Triestimulus values: negative values, highly correlated and not very intuitive.





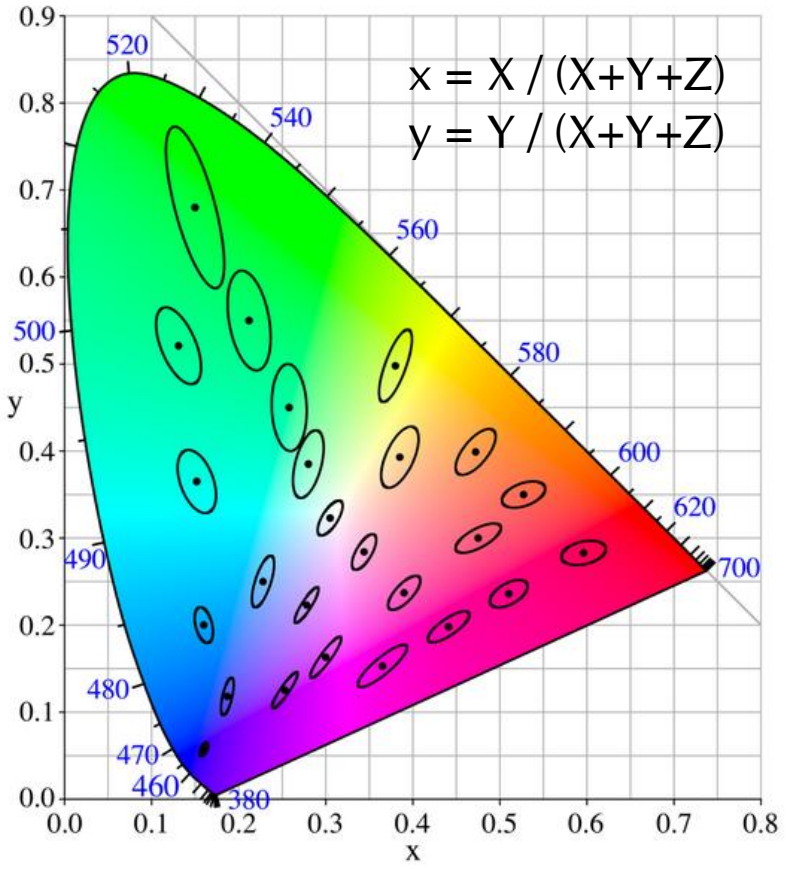


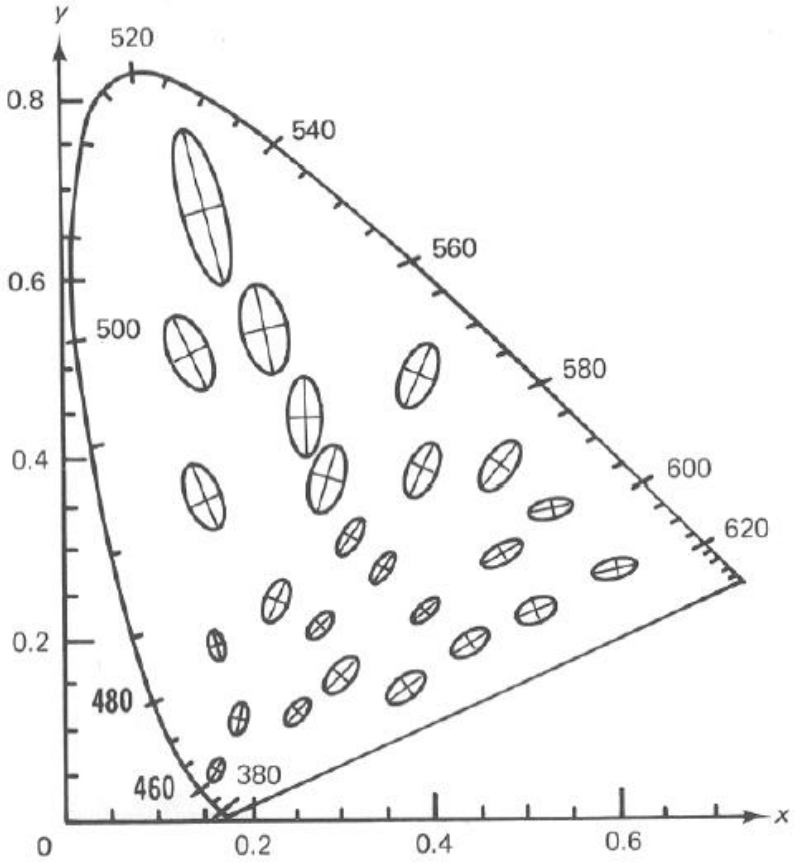
$$X = \int L(\lambda) \cdot \bar{x}(\lambda) \cdot d\lambda$$
$$Y = \int L(\lambda) \cdot \bar{y}(\lambda) \cdot d\lambda$$
$$Z = \int L(\lambda) \cdot \bar{z}(\lambda) \cdot d\lambda$$

X = 62.04
Y = 69.72
Z = 7.34

MacAdams Ellipses

- MacAdam diagram in the CIE 1931 colour space (Just Noticeable Differences)
- New concept: perceptual uniformity





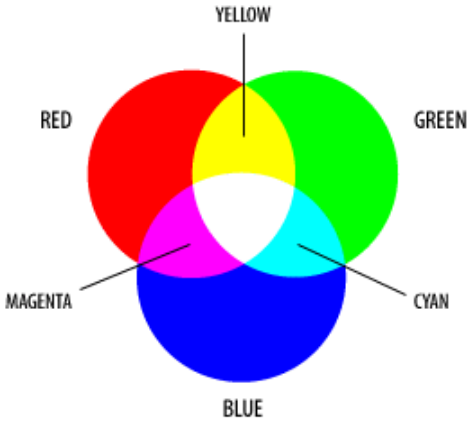
Color space used for TV

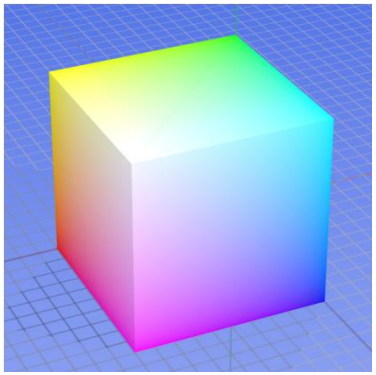
- Original RGB space cannot be directly applied:
  - Such exact primaries cannot be achieved.
  - XYZ colors are not physical.

- Linear transform from XYZ to RGB PAL EBU:
  - Standarized primaries are used (PAL EBU):

    Red: x=0,64, y=0,33, z=0,03
    Green: x=0,29, y=0,60, z=0,11
    Blue: x=0,15, y=0,06, z=0,79

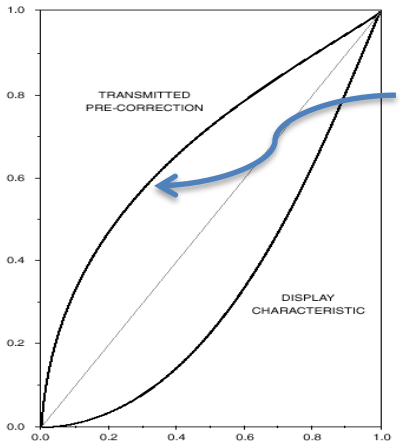
RGB used for TV





Colors are R, G, B triplets (vectors)

- Perceptually non-linear (non-uniform)
- A subset of the colours humans can perceive

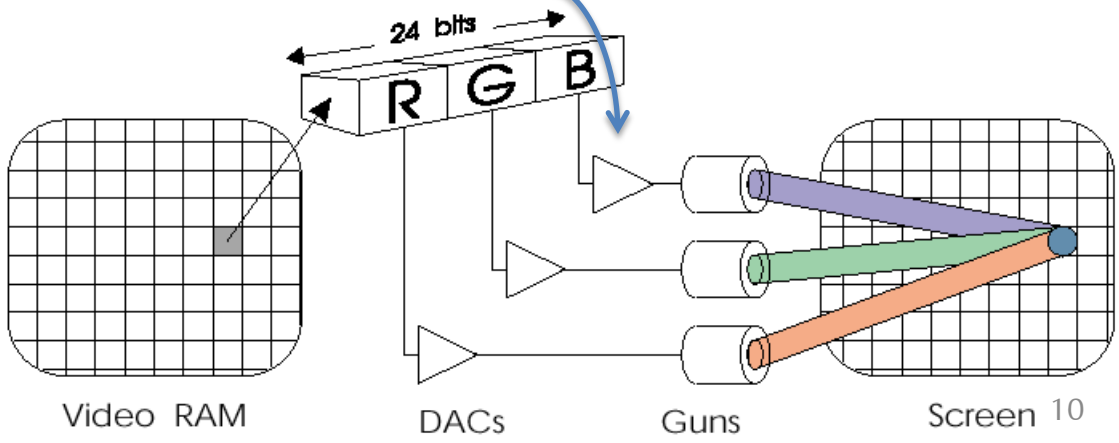


Gamma = 2.2 (1 / gamma = 0.45):

$R' \approx R^{0,45}$

$G' \approx G^{0,45}$

$B' \approx B^{0,45}$

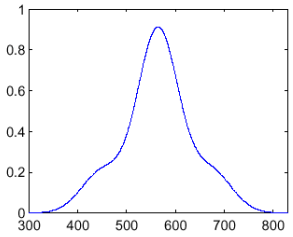


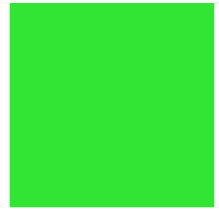
Basic colour attributes

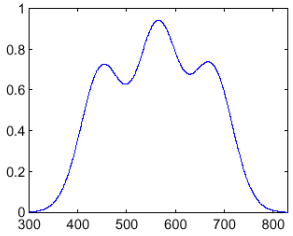
- Purity or Hue (red, yellow, blue, etc)

- Saturation or Chroma (rose, brilliant red, etc)

- Luminance (black, white, dark gray, etc)

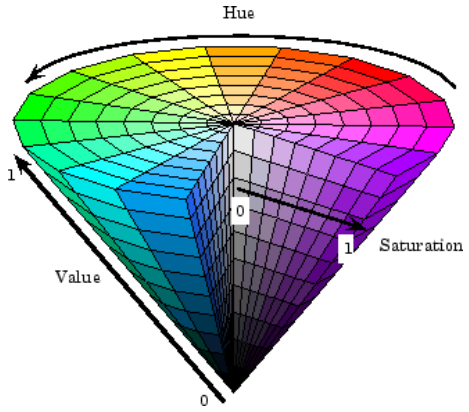


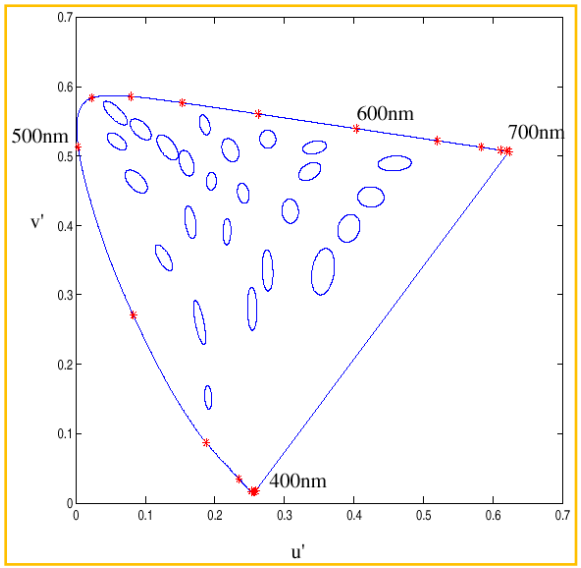


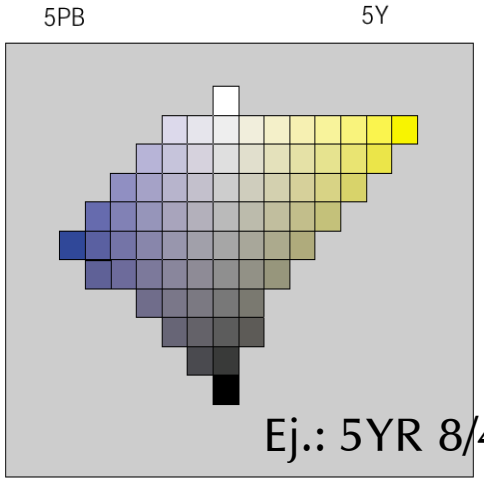


Other colour spaces

- Digital imaging: Y'U'V', YCrCb
  - Linear transform from RGB.
  - Two chrominance components plus Luminance.
- Polar coordinates: HSI, HSV, HLS.
- Perceptually uniform?:
  - Munsell (1905) notation system: Hue, value, Chroma.
  - L*a*b*, L*u*v* (CIE, 1976), CIECAM02, iCAM, ATTD.







Munsell

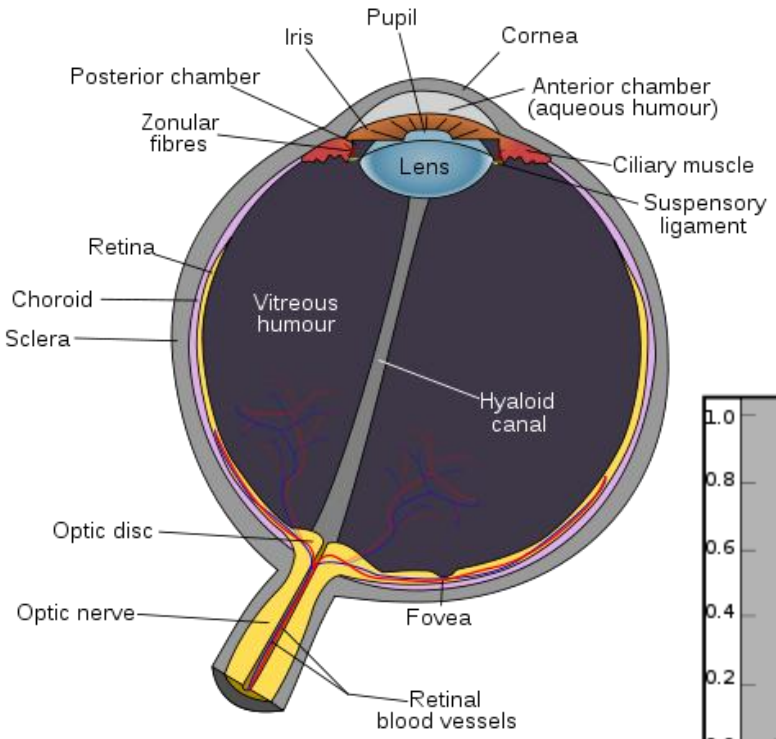
Chroma

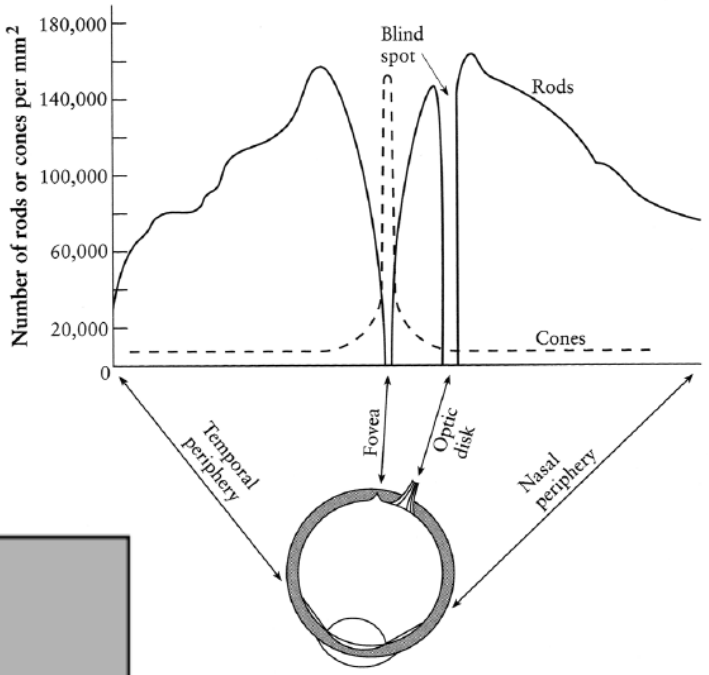
Colour perceived

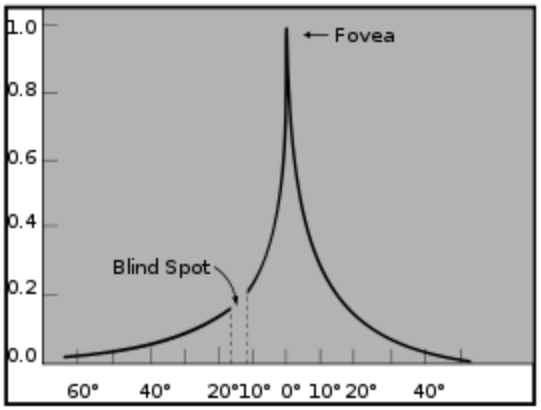
- Colour of light captured by a camera depends on:
  - Spectral reflectance of the surface light is leaving.
  - Spectral radiance of light falling on that patch.
  - Transfer functions of the camera.
- Color perceived depends on:
  - Physics of light.
  - Visual system receptors.
  - Brain processing, environment.

Schematic diagram of the human eye

- Human eye is our camera: iris, pupil, lens, and…
- Photoreceptors: rods and cones.







Relative acuity of the left human eye (horizontal section) in degrees from the fovea.

Colour appearing Phenomena

- Environmental effects and adaption.
- Adaption (to light / darkness, and chromatic -Stevens and Hunt effects-).

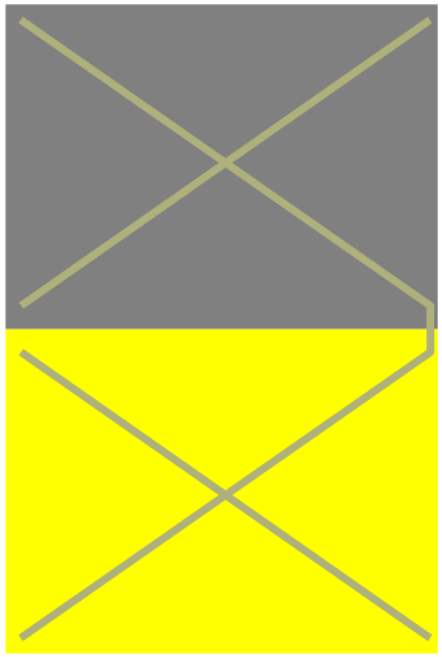
Lineal mapping

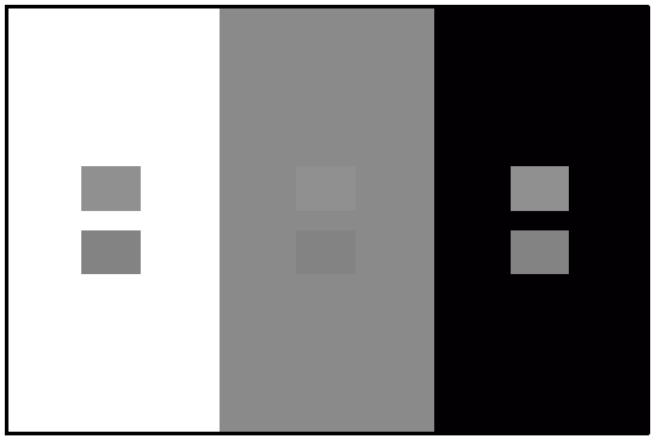
Perceptual mapping

- Simultaneous contrast and induction.
- Other effects: Abney, Helmholtz-Kohlrausch, Helson-Judd, Bartleson-Breneman.

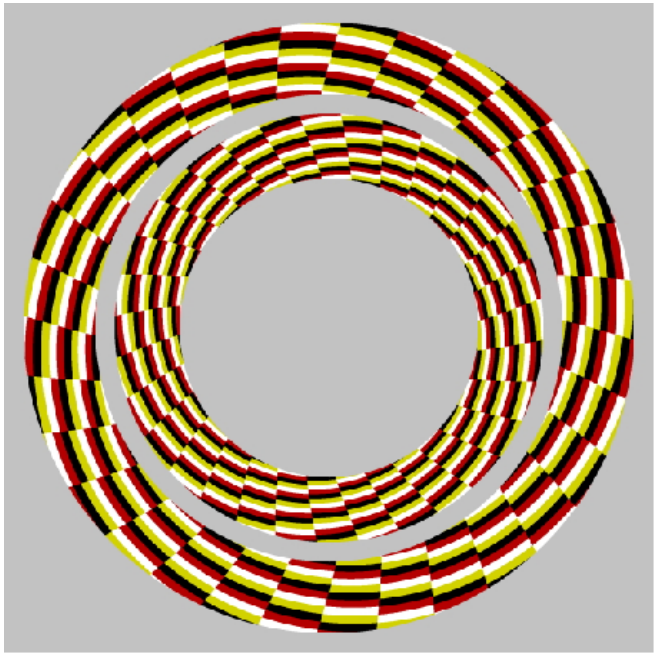
Some effects

Simultaneous contrast

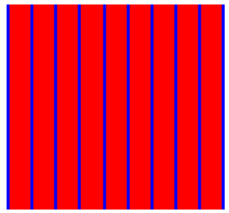


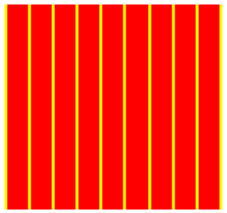


Crispening



De Color Appearance Models, fig 8-1





Spreading

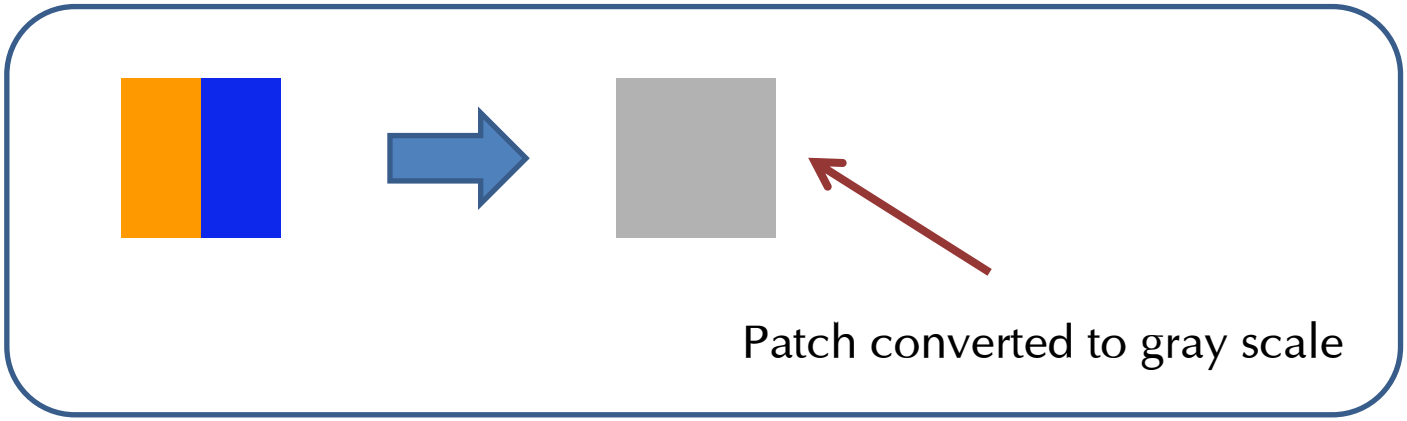
CIECAM02, iCAM, ATTD try to address these effects…

Chromatic adaption

Part 2

Colour computer vision

Role of colour in image processing



- Key to easily locate objects:

- Markets: textile, paintings, quality assessment, etc

Computing colour differences

- Euclidean for uniform spaces:

$$d_e(i,j) = \sqrt{(C_{i,R} - C_{j,R})^2 + (C_{i,G} - C_{j,G})^2 + (C_{i,B} - C_{j,B})^2}$$

- Others:
  - Weighted Euclidean: $d_{ep}(i,j) = \sqrt{p_R(C_{i,R} - C_{j,R})^2 + p_G(C_{i,G} - C_{j,G})^2 + p_B(C_{i,B} - C_{j,B})^2}$
  - Angular: $d_a(i,j) = a\cos \frac{C_i C_j^t}{\|C_i\| \, \|C_j\|}$

$$p_R = 2 + \frac{C_{i,R} + C_{j,R}}{512}$$

$$p_G = 4$$

$$p_B = 2 + \frac{512 - C_{i,R} - C_{j,R}}{512}$$

Image filtering and restoration

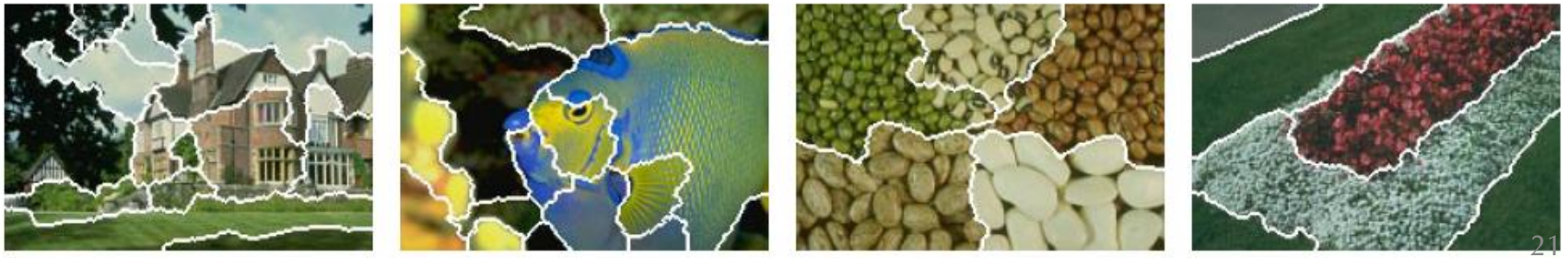
- Colour pixels are treated as vectors.
- Vectors cannot be sorted as scalars: statistic operators.
- Impulsive noise filtering (vector median filter, VMF).

Colour image segmentation

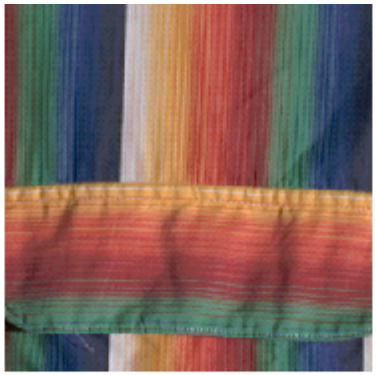
- **Target**: group adjacent pixels with a "similar" colour into a region.
- Colour pixels are three-component vectors.
- Many gray scale algorithms can be re-adapted but not all of them.
- Some have become very popular: mean shift (D. Comaniciu and P. Meer, 2002).

- Challenges: textured images, different illuminants, dissimilarity measurement.

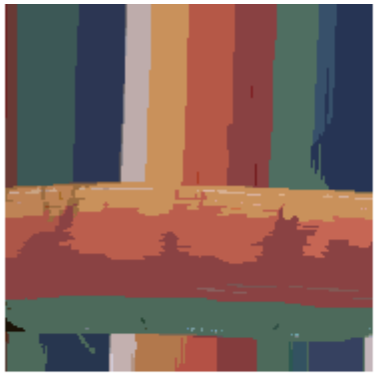
From Yining Deng, B. S. Manjunath and Hyundoo Shin, *color image segmentation*



Colour spaces and dissimilarity measurements

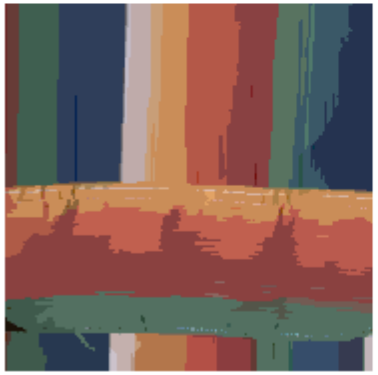


Original

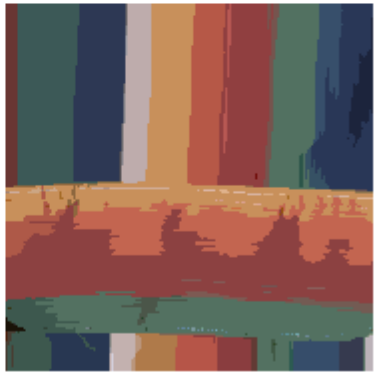


Euclidean (Y'U'V')

Angular (R'G'B')



Euclidean (R'G'B')



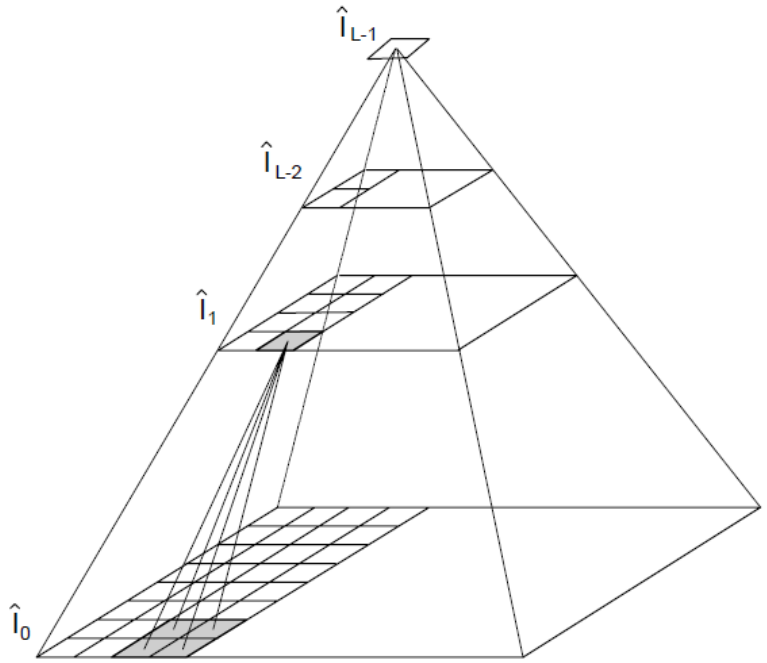
Weighted Euclid. (R'G'B')

Euclidean (CIELAB)

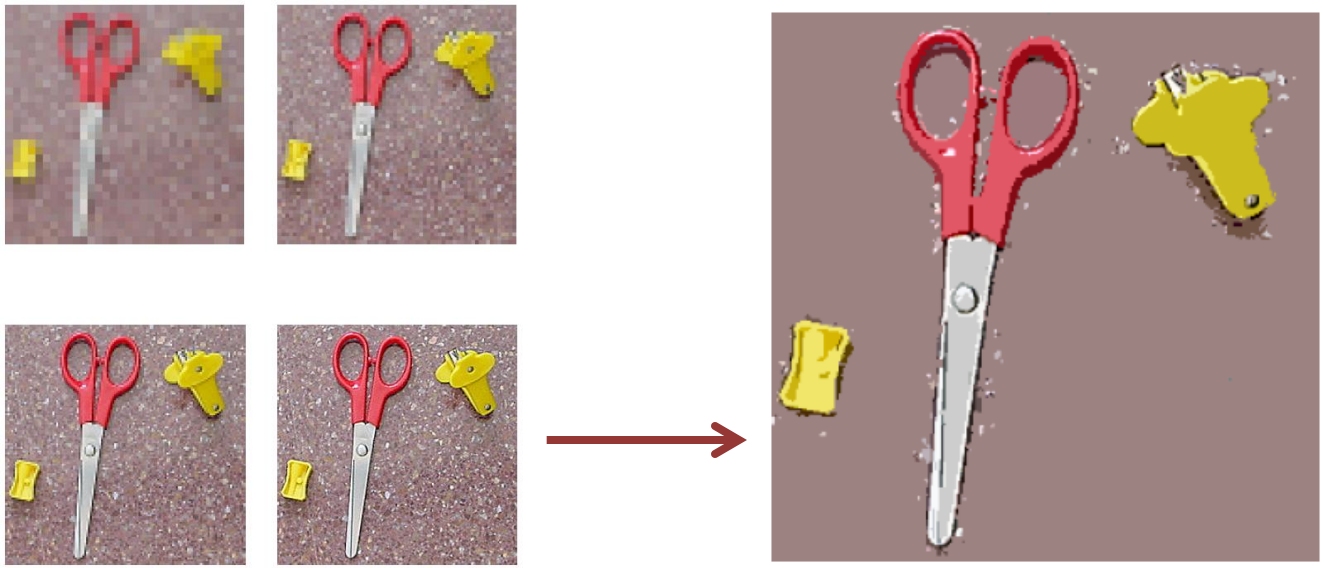
Euclidean (CIELUV)

Multirresolution imaging

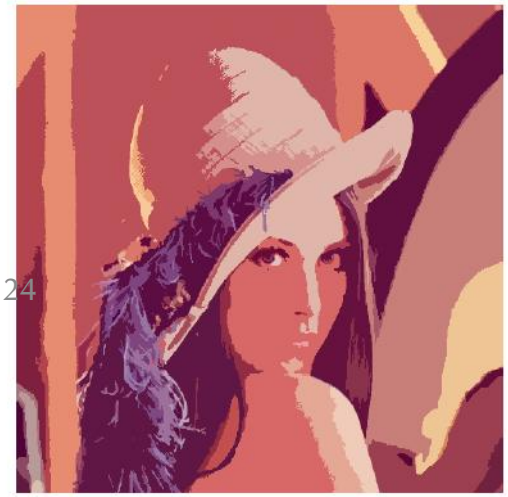
- Regular and irregular pyramids:



Multirresolution segmentation: results



Original →

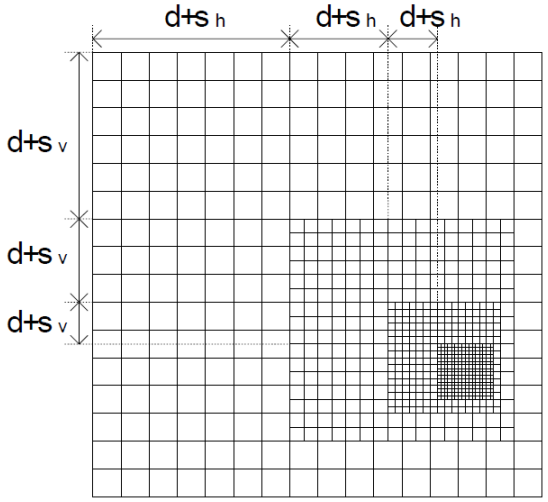


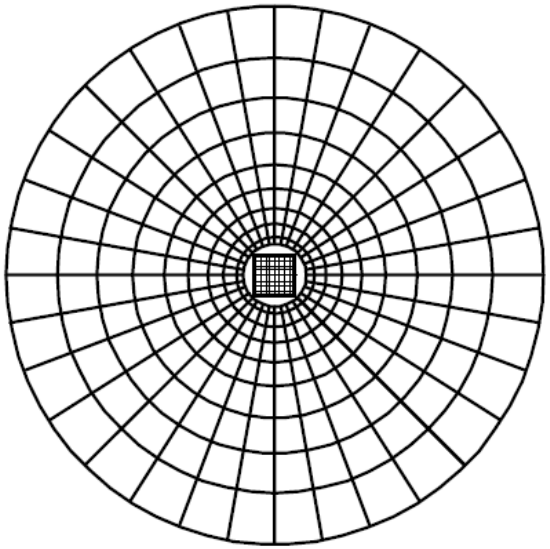
← Segmented

24

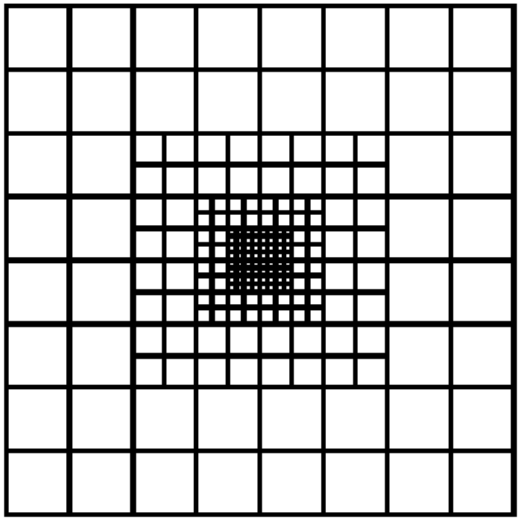
Foveal imaging

- Model peripheral vision against central.
- Attempts to mimic the retinal acuity profile.
- Non-uniform resolution of sensors.
- Lower the amount of data to be processed.

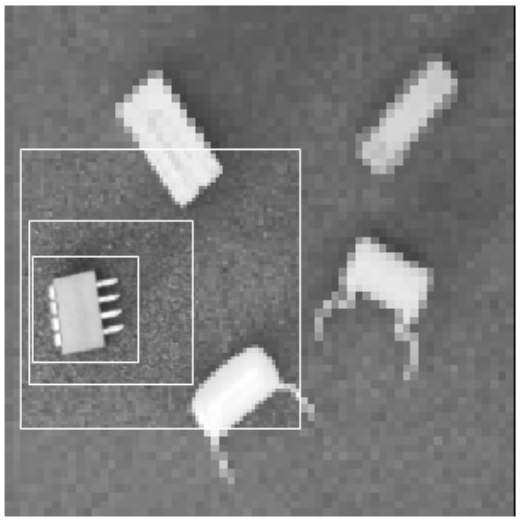




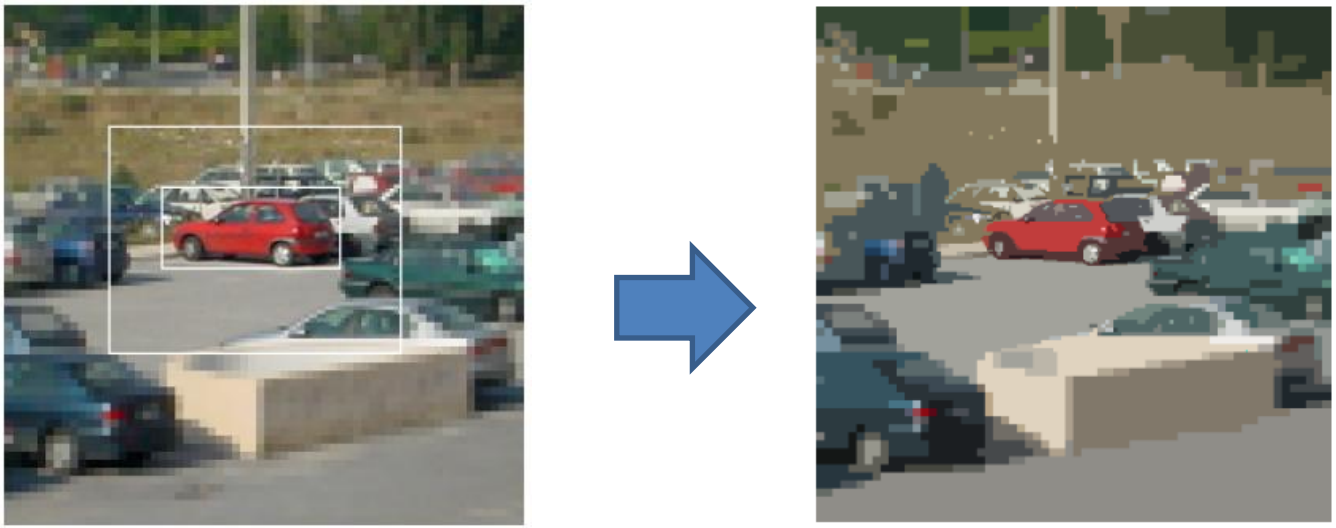
Log-polar

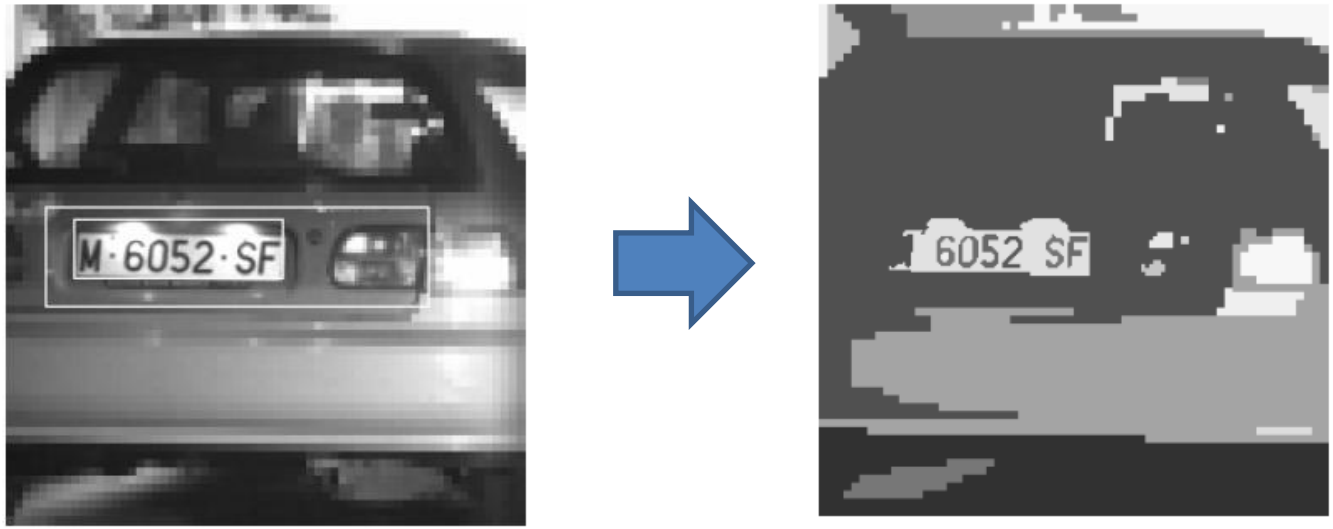


Cartesian-exponential



Foveal segmentation results





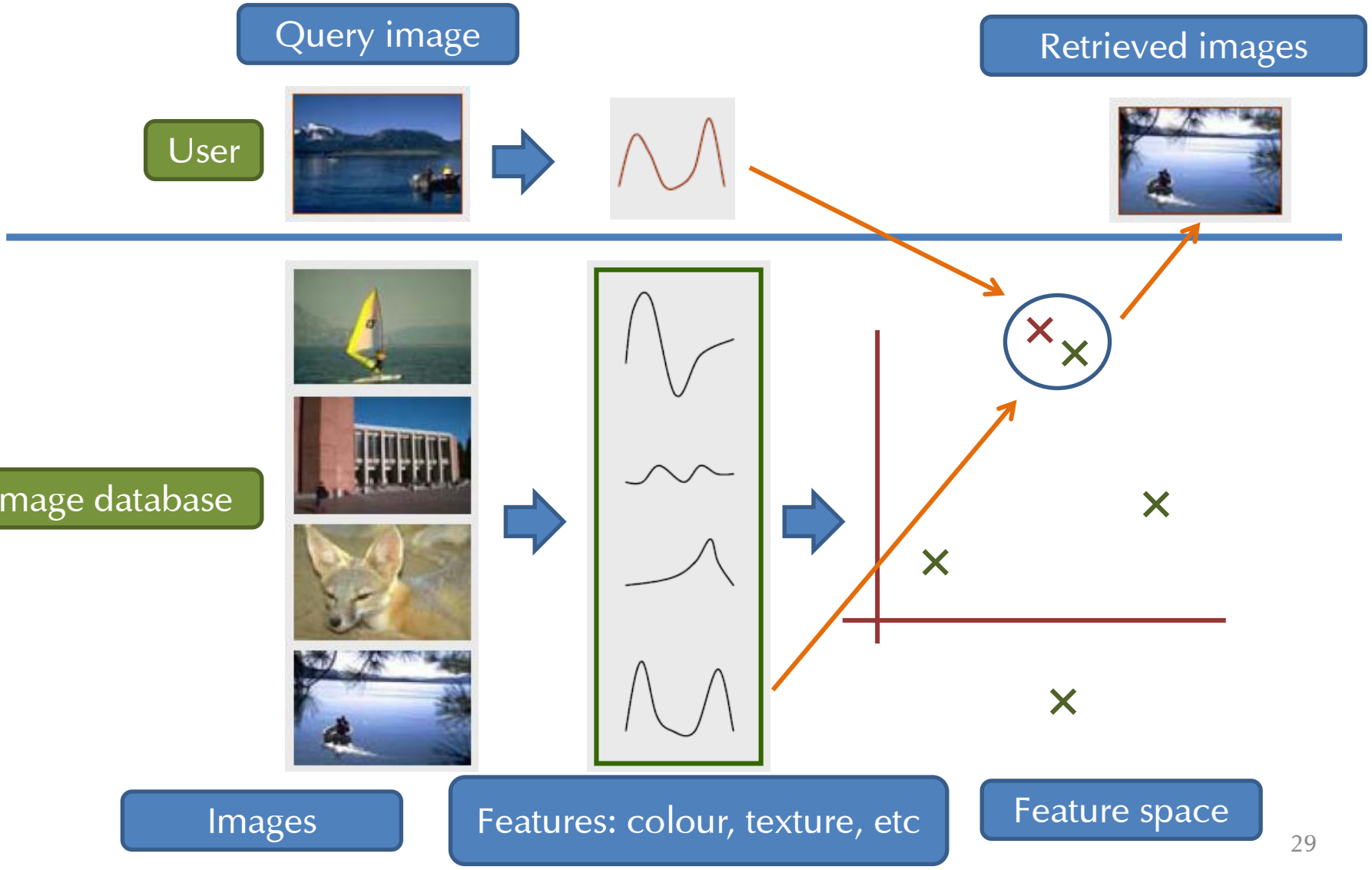
Content-Based Image Retrieval: CBIR

- Searching on a large database for images that match a query.
- Many questions to be addressed:
  - What kind of queries?
  - What constitutes a match?
  - How do we make such searches efficient?
- Applications:
  - Art collections, museums, TV databases.
  - Medical and Scientific.
  - Security (biometrics, pornography).
  - The World Wide Web.

Queries in CBIR

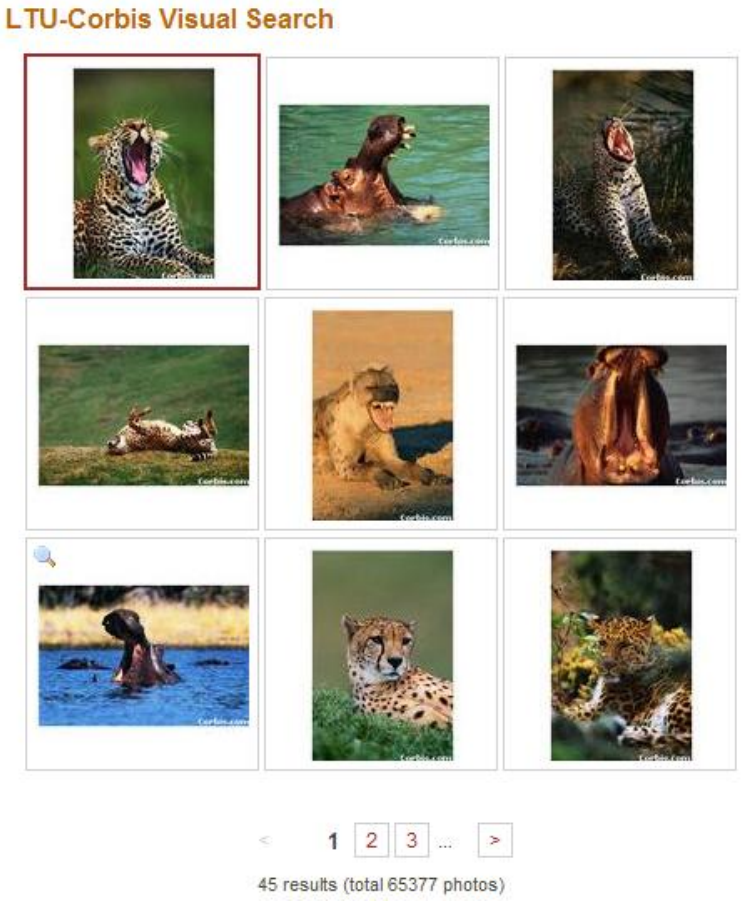
- A query could be:
  - An image provided by the user.
  - A simple and rough sketch.
  - A colour or texture pattern or layout.
  - A symbolic description: “pictures containing faces”

CBIR basic scheme



CBIR example results

- Example: http://corbis.demo.ltutech.com/en/demos/corbis/



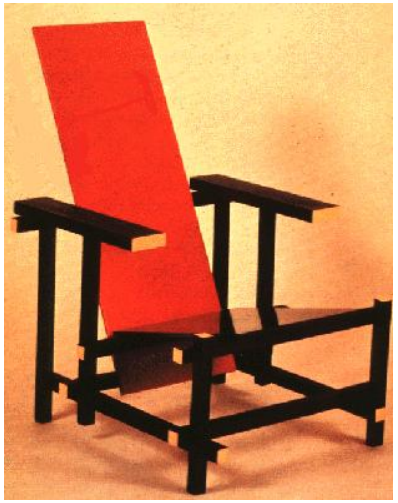
Some 21st century challenges (i)

- CBIR is really hard: it faces the challenge of matching the human visual system, evolved over a period of more than 100 million years !!

- Difficult matches for machines:

Some 21st century challenges (ii)

- Application examples:
  - Pedestrian recognition: variation of appearance, difficult environment.
  - Surveillance of crowded public places: many objects, occlusions, moving regions.
- Problems:
  - Scene and context categorization.
  - View point variation.
  - Occlusions.
  - object intra-class variation:



Thank you but…

Please, before leaving try to name the colours as quick as you can,

Hint for the first one: YELLOW

Further questions?... My e-mail: imolinac@eso.org