Lecture: Color

Juan Carlos Niebles and Ranjay Krishna

Stanford AI Lab

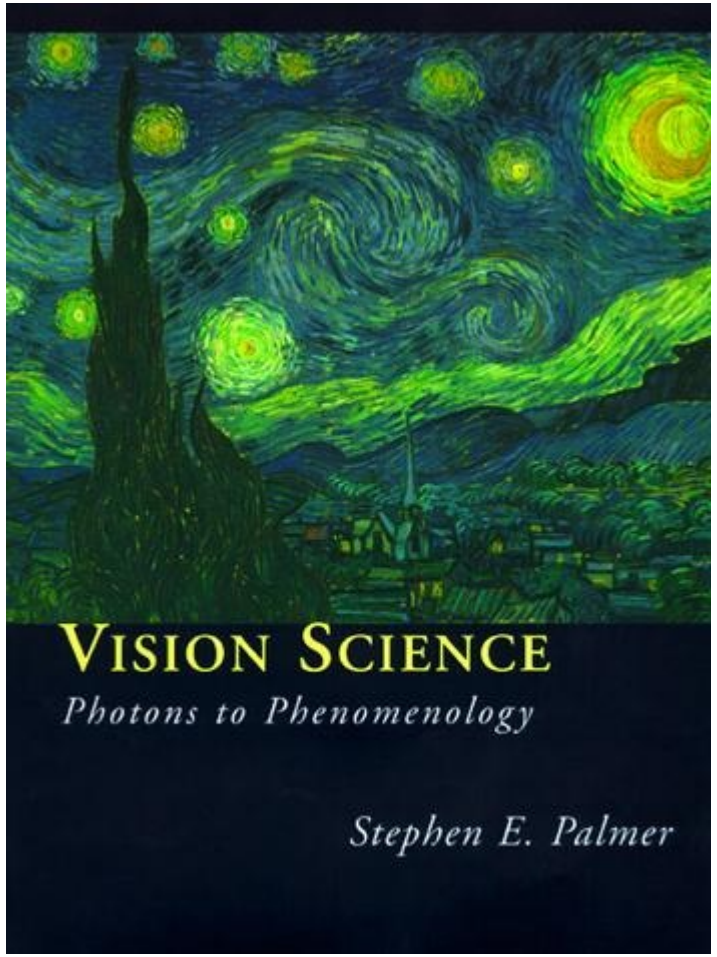
Overview of Color

- What is color?
- Color spaces
- White balancing

What is color?

- The result of interaction between physical light in the environment and our visual system.

- A *psychological property* of our visual experiences when we look at objects and lights, *not a physical property* of those objects or lights.



Slide credit: Lana Lazebnik

Interaction of light and surfaces

- What is the observed color of any surface under monochromatic light?

Olafur Eliasson, *Room for one color*

James Turrell, Breathing Light

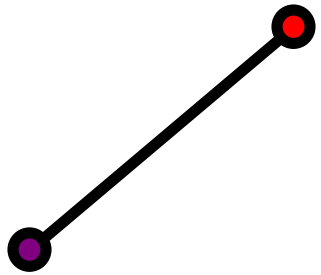
Inspired Drake in “Hotline Bling”

Overview of Color

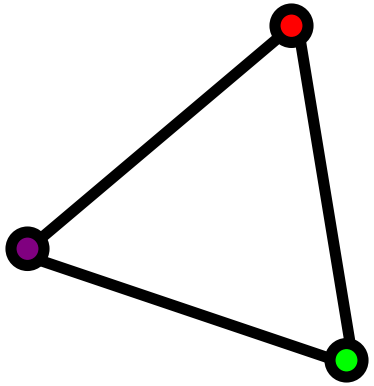
- What is color?
- Color spaces
- White balancing

Linear color spaces

- Defined by a choice of three *primaries*
- The coordinates of a color are given by the weights of the primaries used to match it



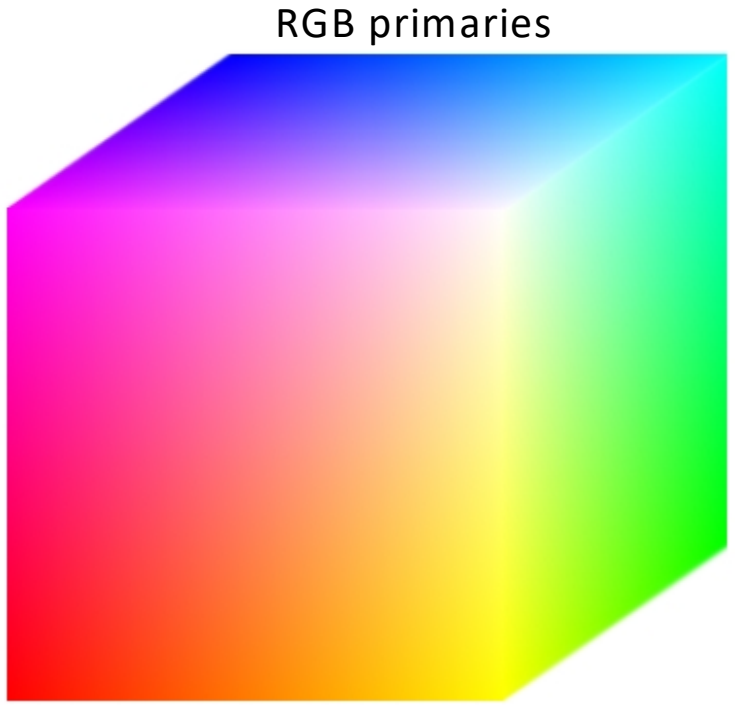
mixing two lights produces colors that lie along a straight line in color space



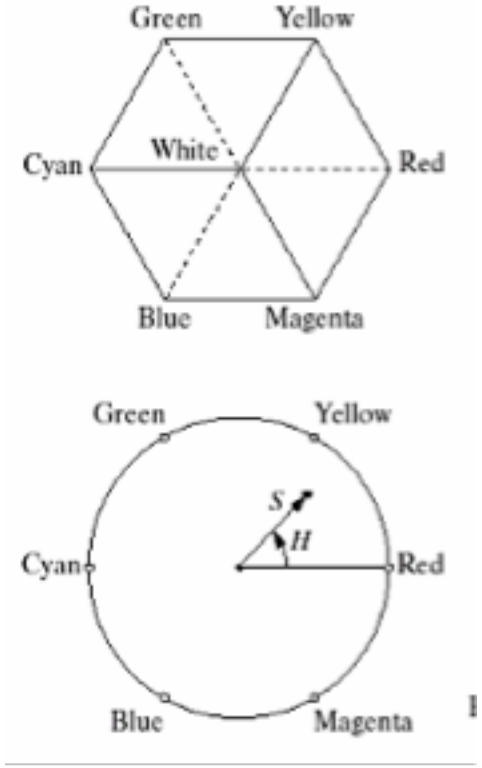
mixing three lights produces colors that lie within the triangle they define in color space

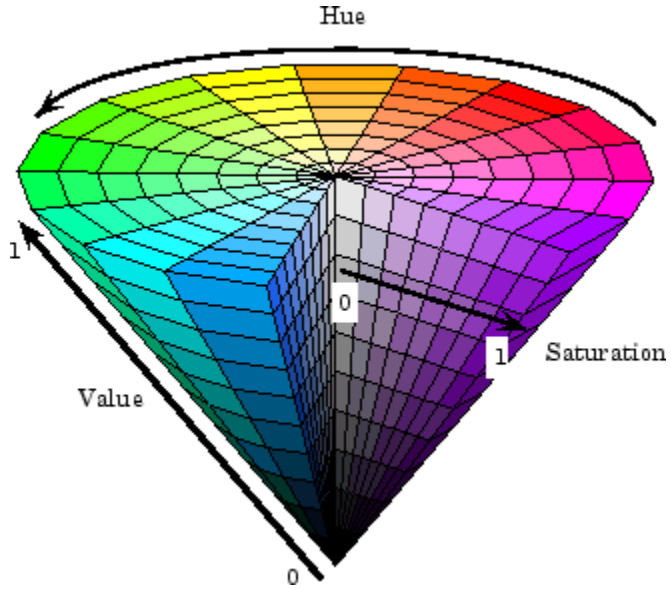
RGB space

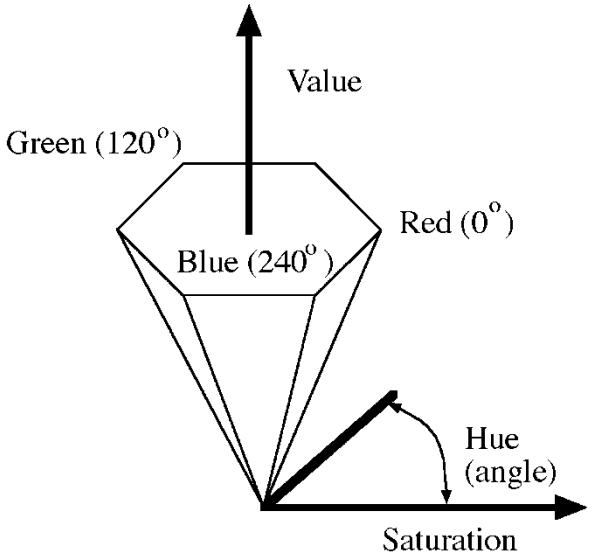
- Primaries are monochromatic lights (for monitors, they correspond to the three types of phosphors)



Nonlinear color spaces: HSV

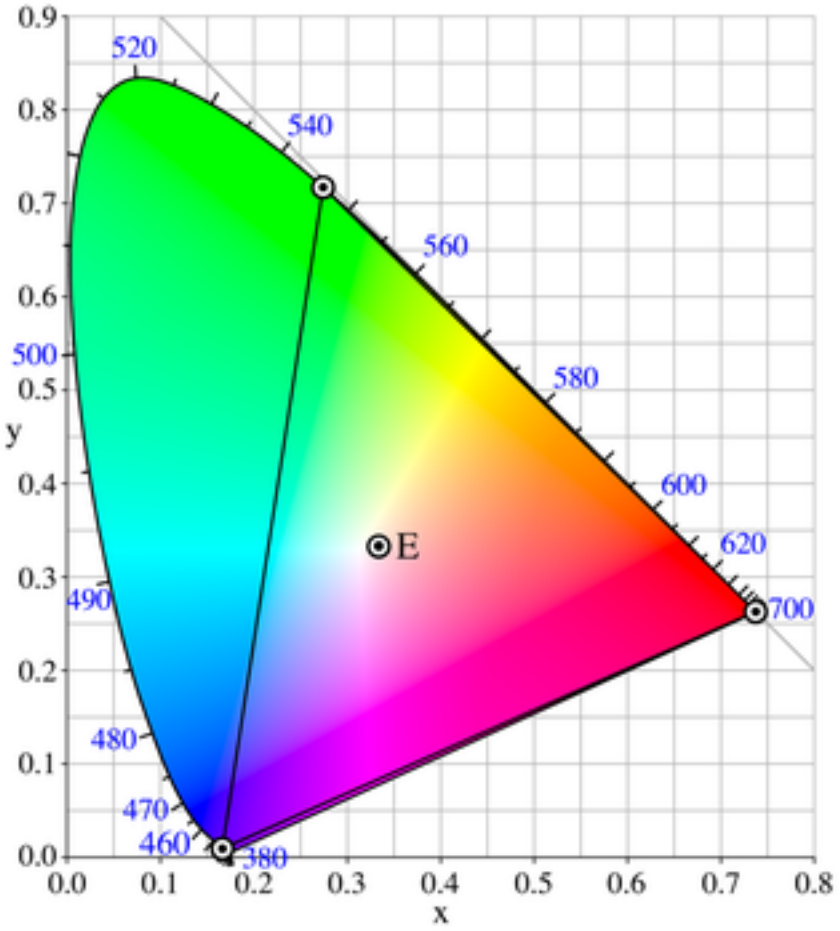






- Perceptually meaningful dimensions: Hue, Saturation, Value (Intensity)
- RGB cube on its vertex

Linear color spaces: CIE XYZ



- First attempt to produce a color space based on measurements of human color perception The Y parameter corresponds to brightness or *luminance* of a color.
- *Y* as luminance. *Z* is like blue stimulation, and *X* is a mix (a linear combination) of cone response curves chosen to be nonnegative.
- "Lab" is another color space you will use in HWs that is derived from this space.
- 2D visualization: draw (*x*,*y*), where $x = X/(X+Y+Z)$, $y = Y/(X+Y+Z)$

http://en.wikipedia.org/wiki/CIE_1931_color_space

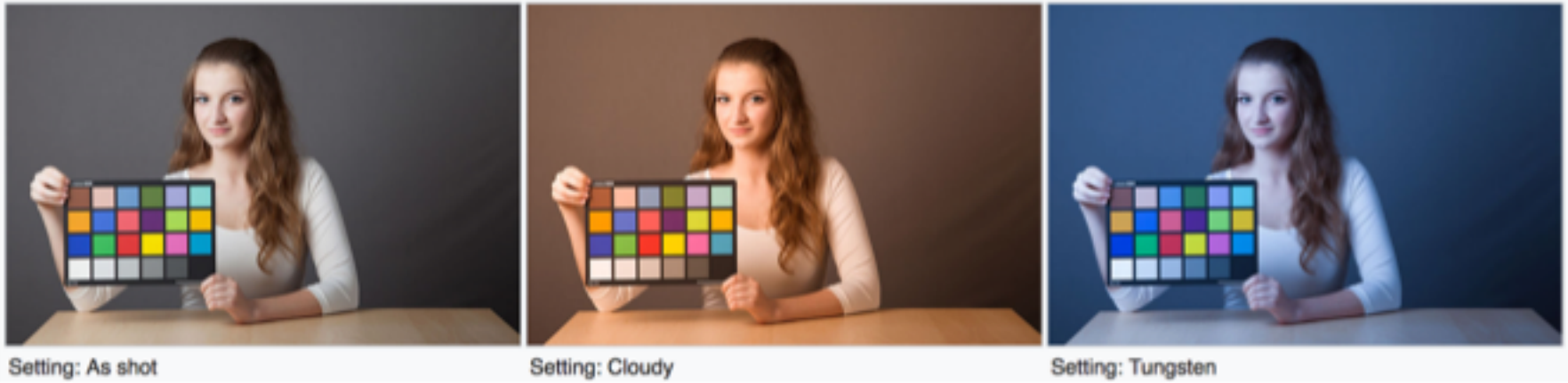
Overview of Color

- What is color
- Color spaces
- White balancing

White balancing

Neutral light | Warm light | Cold light

Comparison of resulted colors as shot by the digital camera for different light qualities (color temperature): Neutral, Warm and Cold.[15]



Setting: As shot | Setting: Cloudy | Setting: Tungsten

White balance

- When looking at a picture on screen or print, we adapt to the illuminant of the room, not to that of the scene in the picture
- When the white balance is not correct, the picture will have an unnatural color “cast”

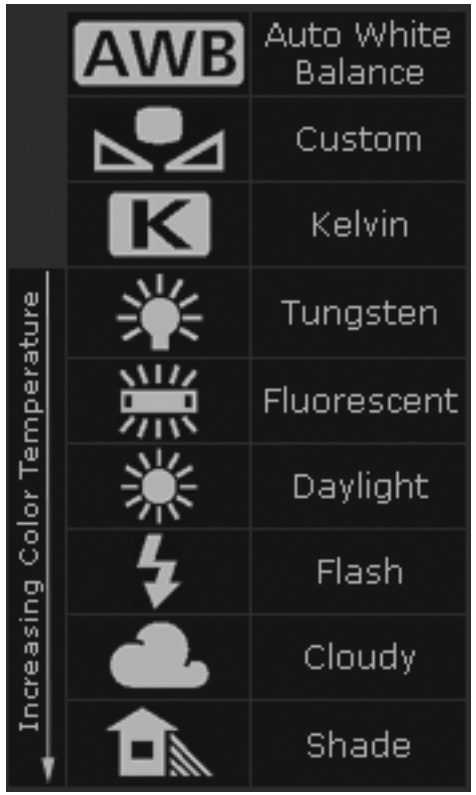
incorrect white balance

correct white balance

http://www.cambridgeincolour.com/tutorials/white-balance.htm

White balance

- Film cameras:
  - Different types of film or different filters for different illumination conditions
- Digital cameras:
  - Automatic white balance
  - White balance settings corresponding to several common illuminants
  - Custom white balance using a reference object



http://www.cambridgeincolour.com/tutorials/white-balance.htm

Slide: F. Durand

White balance

- Von Kries adaptation
  - Multiply each channel by a gain factor
  - A more general transformation would correspond to an arbitrary 3x3 matrix

Slide: F. Durand

White balance

- Von Kries adaptation
  - Multiply each channel by a gain factor
  - A more general transformation would correspond to an arbitrary 3x3 matrix
- Best way: gray card
  - Take a picture of a neutral object (white or gray)
  - Deduce the weight of each channel
    - If the object is recoded as r_w, g_w, b_w use weights $1/r_w$, $1/g_w$, $1/b_w$

Slide: F. Durand

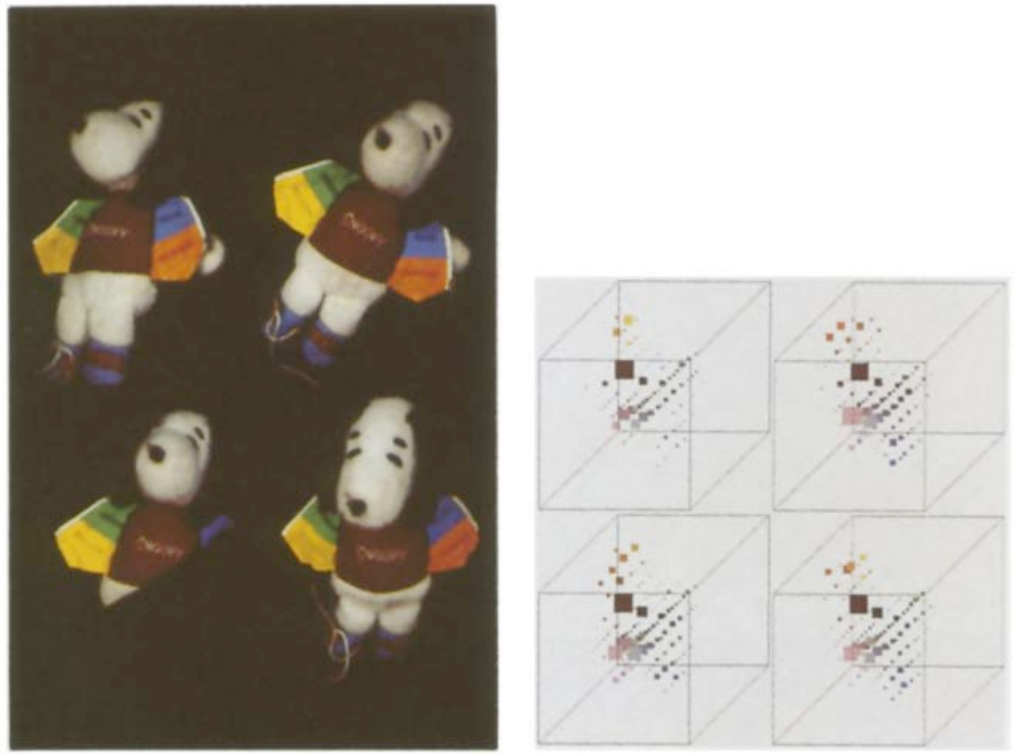
White balance

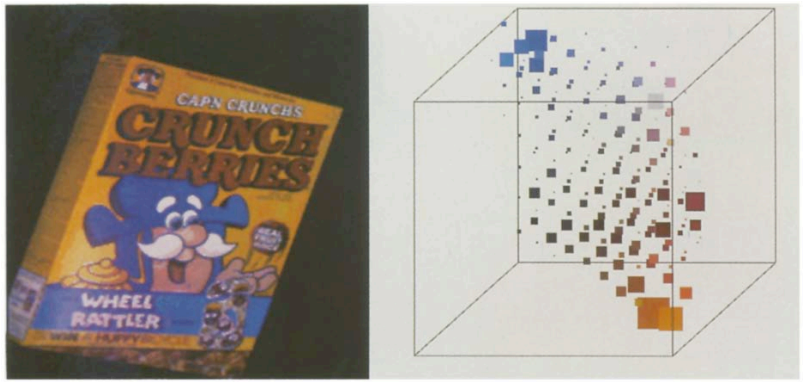
- Without gray cards: we need to “guess” which pixels correspond to white objects
- Gray world assumption
  - The image average r_{ave}, g_{ave}, b_{ave} is gray
  - Use weights $1/r_{ave}$, $1/g_{ave}$, $1/b_{ave}$
- Brightest pixel assumption (non-staurated)
  - Highlights usually have the color of the light source
  - Use weights inversely proportional to the values of the brightest pixels
- Gamut mapping
  - Gamut: convex hull of all pixel colors in an image
  - Find the transformation that matches the gamut of the image to the gamut of a “typical” image under white light
- Use image statistics, learning techniques

Slide: F. Durand

Uses of color in computer vision

Color histograms for indexing and retrieval

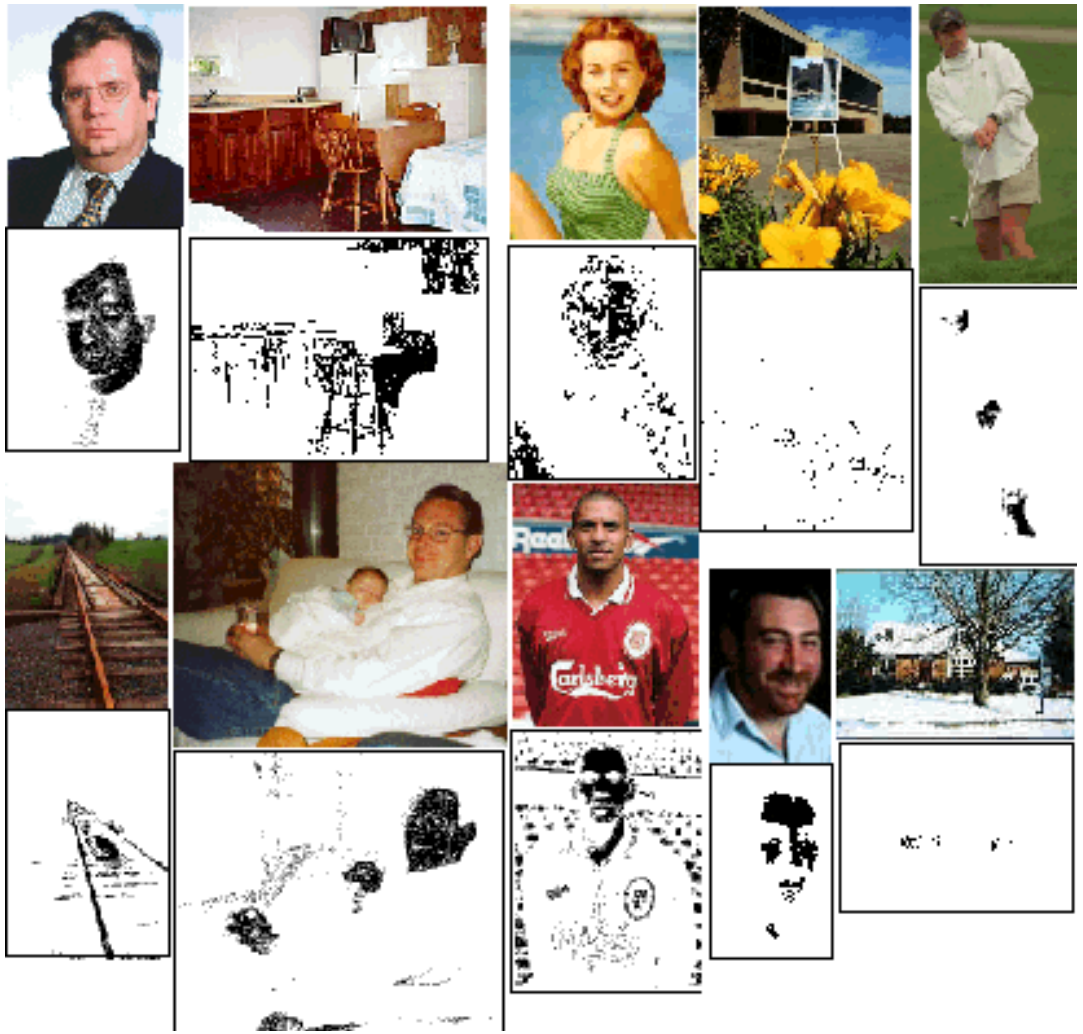




Swain and Ballard, Color Indexing, IJCV 1991.

Uses of color in computer vision

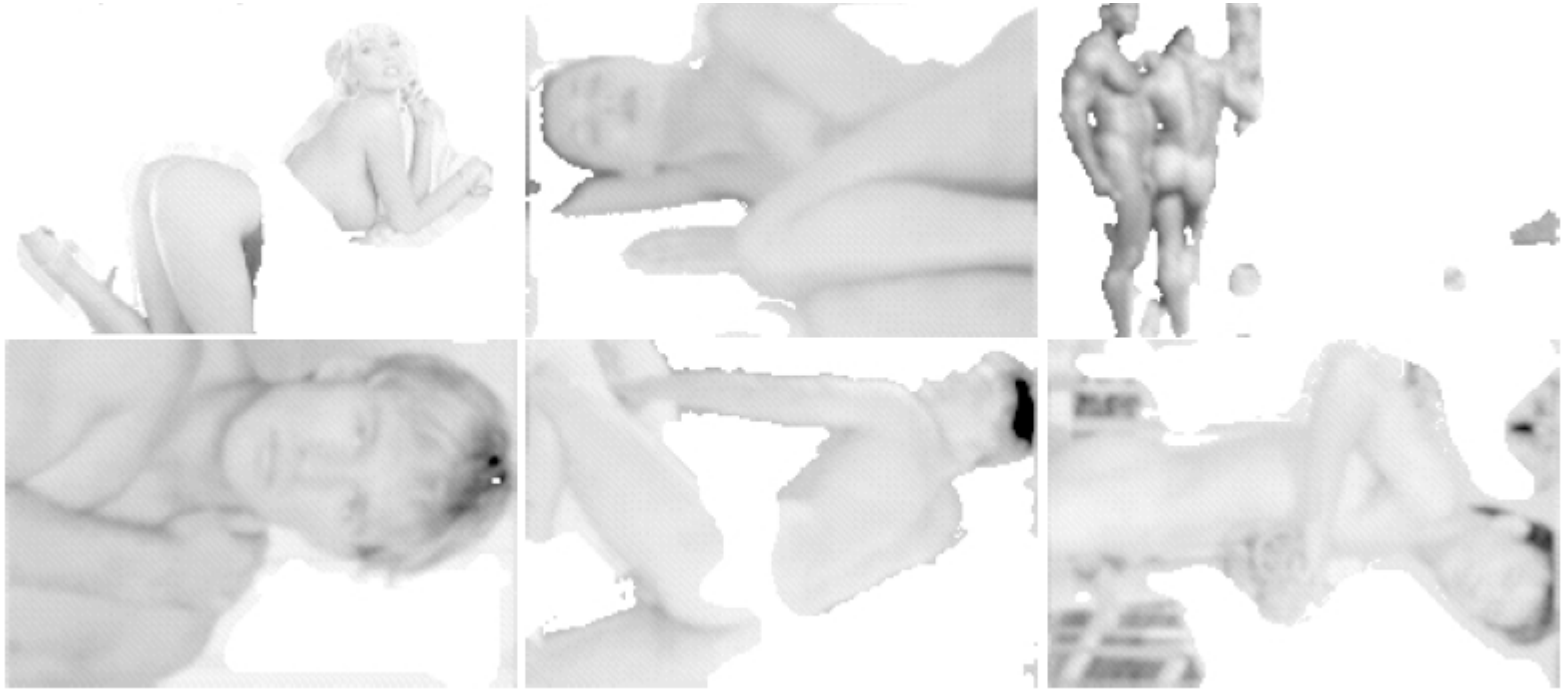
Skin detection



M. Jones and J. Rehg, Statistical Color Models with Application to Skin Detection, IJCV 2002.

Uses of color in computer vision

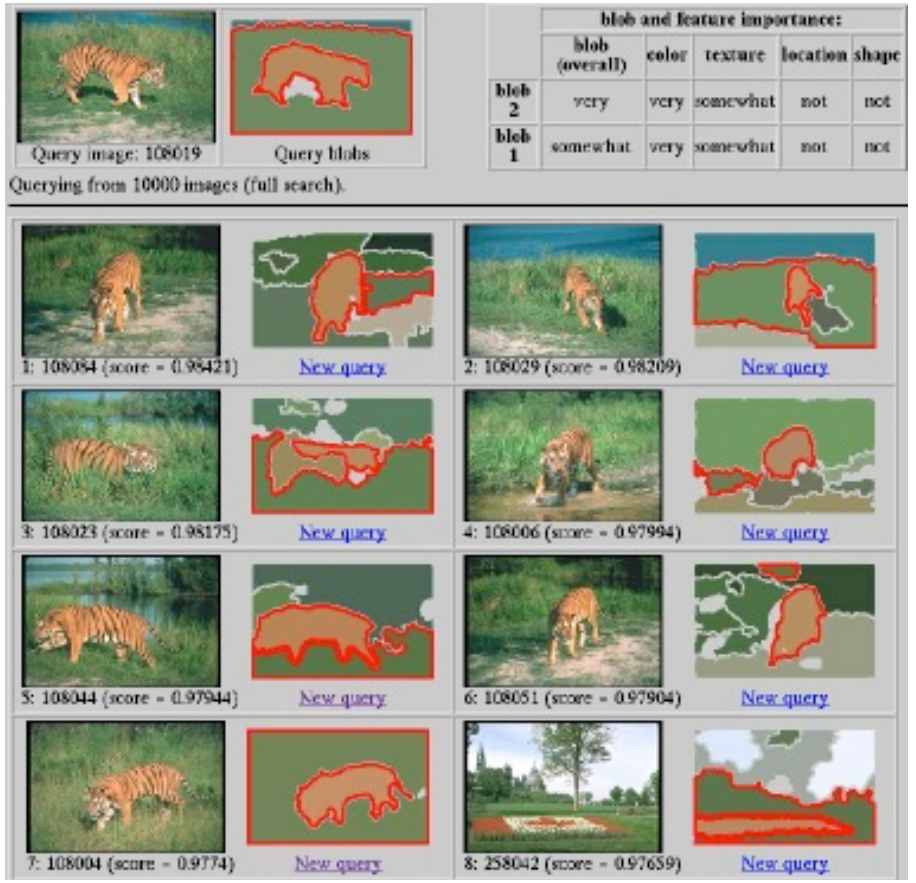
Nude people detection



Forsyth, D.A. and Fleck, M. M., ``Automatic Detection of Human Nudes.'' *International Journal of Computer Vision* , **32** , 1, 63-77, August, 1999

Uses of color in computer vision

Image segmentation and retrieval



C. Carson, S. Belongie, H. Greenspan, and Ji. Malik, Blobworld: Image segmentation using Expectation-Maximization and its application to image querying, ICVIS 1999.

Source: S. Lazebnik

Uses of color in computer vision

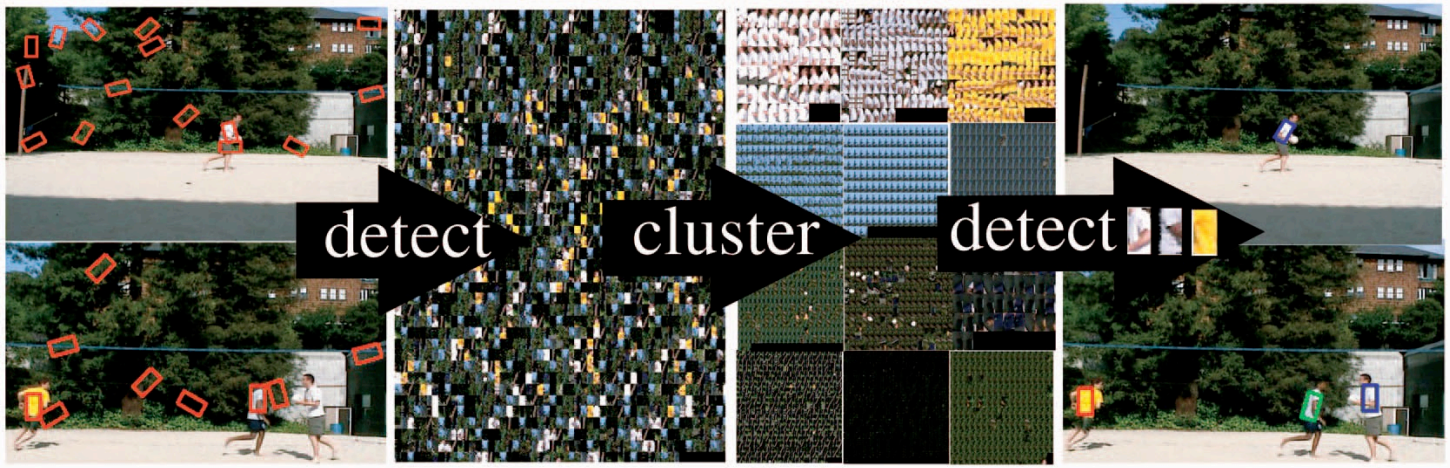
Robot soccer

M. Sridharan and P. Stone, Towards Eliminating Manual Color Calibration at RoboCup. RoboCup-2005: Robot Soccer World Cup IX, Springer Verlag, 2006

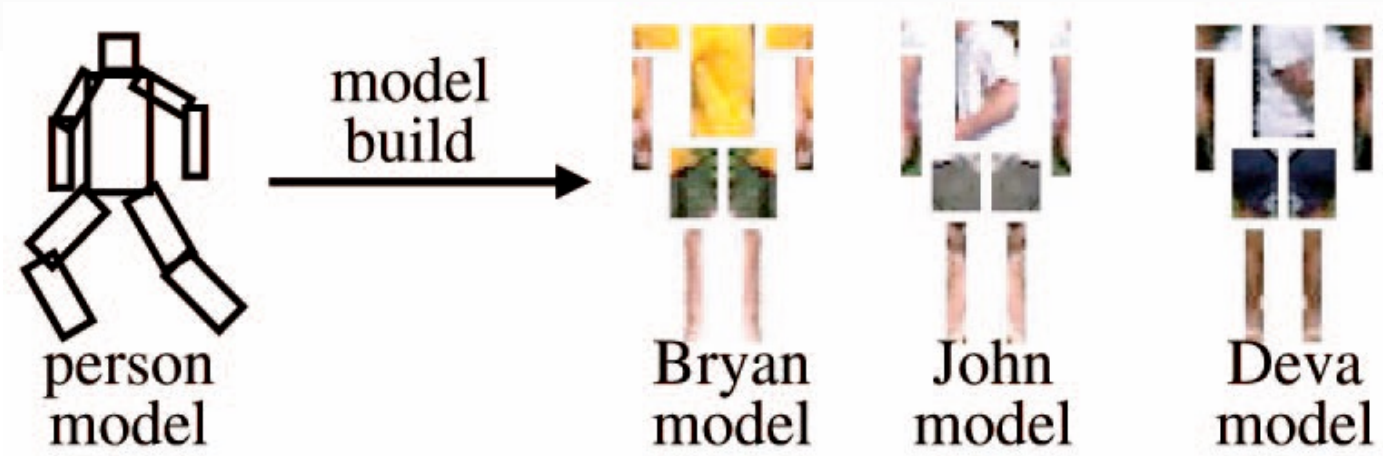
Source: K. Grauman

Uses of color in computer vision

Building appearance models for tracking



D. Ramanan, D. Forsyth, and A. Zisserman. Tracking People by Learning their Appearance. PAMI 2007.



Source: S. Lazebnik