Image Analysis and Processing

Introduction

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Content of the whole course

1. Theory
   - Linear and non-linear filtering
   - Transforms and enhancements
   - Segmentation and texture analysis
2. Tutorials

Syllabus

1. **Introduction, image perception and representation**
2. Enhancements – Histogram & pixelwise transforms.
3. Transforms – FFT, Laplace, Z, Hough.
4. Filtering – Linear filters.
5. Compression – Image coding.
6. Texture analysis – Modelling, classification, segmentation.
7. Geometry – Transforms, matching.
8. Mathematical Morphology I – non-linear filtering.
9. Mathematical Morphology II – distances, residues, HMT.
10. Segmentation I – Thresholding, split & merge, snakes.
11. Segmentation II – Watershed, SRG, recent PDE methods.

Introduction to image processing/image analysis

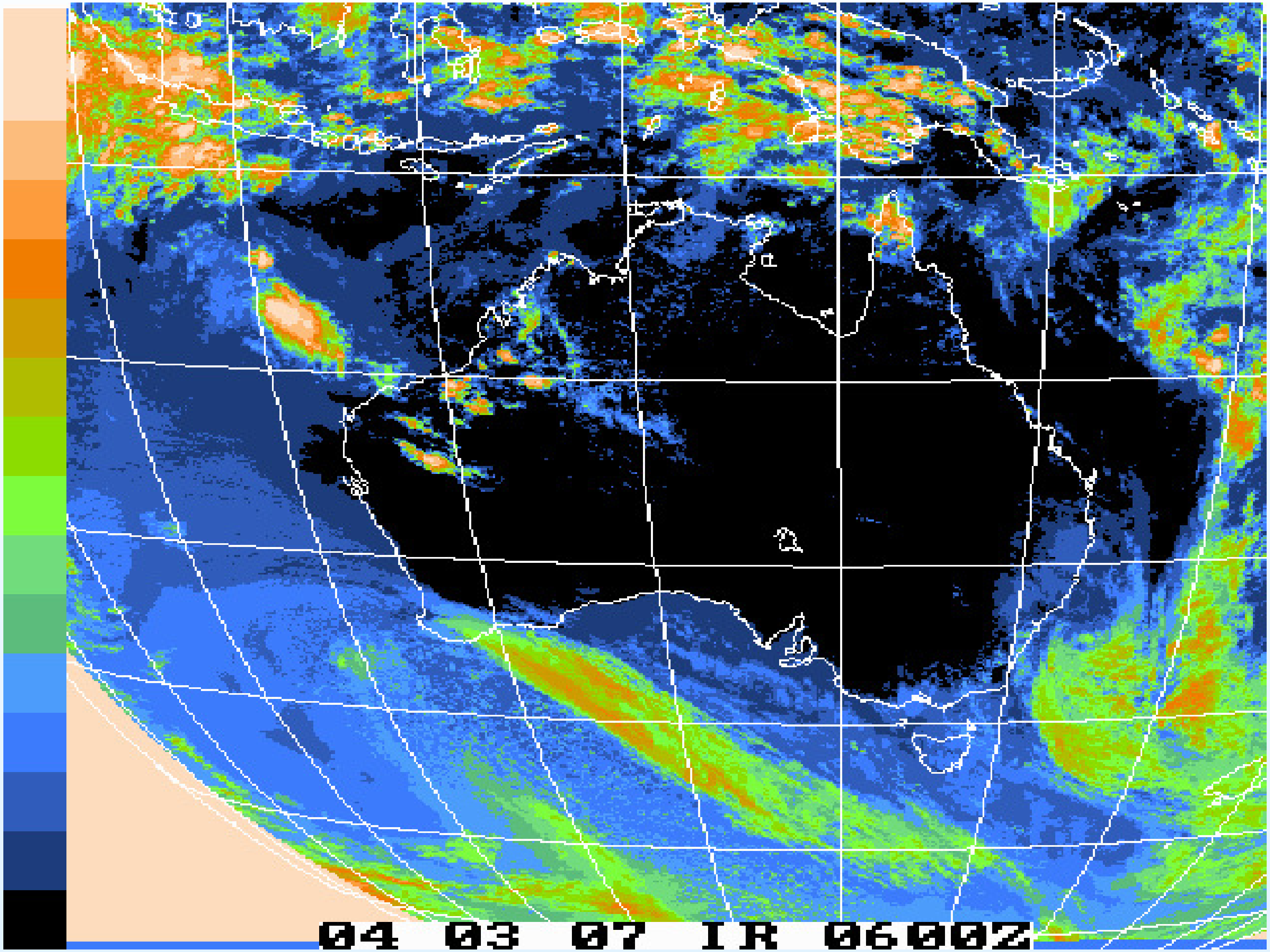
What is Image Analysis/Image Processing

- Two different things: Image Processing is the act of *modifying* an image.
- The goal of image processing is to make visible things that aren't.
- Image Analysis is the act of getting information out of images.
- The goal of image analysis is to interpret images.
- In the process of conducting image analysis, we will use many image processing techniques (e.g. denoising, feature extraction, etc).

Examples of image processings

- False colour rendering
- Deblurring
  - spatial
  - motion
  - optical sections
- Enhancements
  - Brightness/contrast (histogram equalization)
  - Denoising
  - Geometrical transforms (rotation, scaling, affine, etc)
- Coding (compression)
- Feature extraction (e.g. texture)

Example of false colour map



Source: Australian Bureau of Meteorology

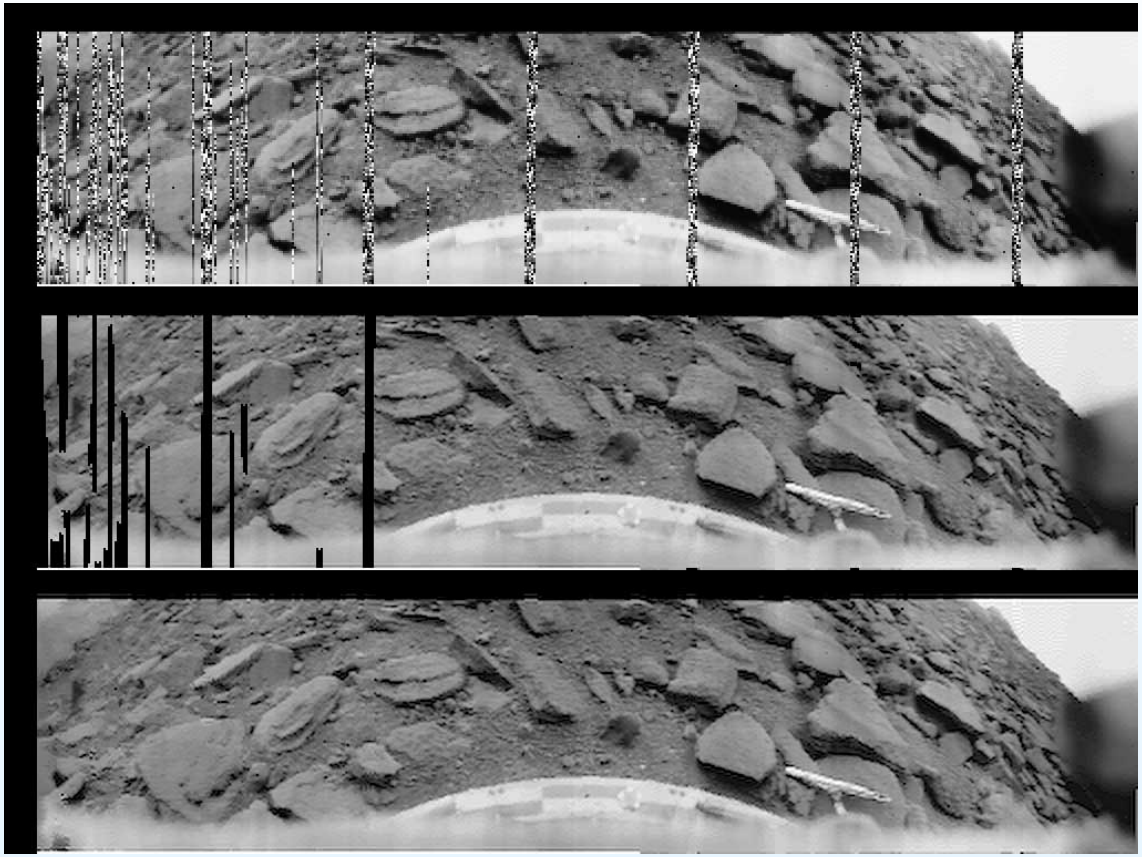
Example of deblurring

Source: *Unshake* `http://www.zen147963.zen.co.uk/`

Example of deblurring

Source: *Unshake* `http://www.zen147963.zen.co.uk/`

Example of advanced data interpolation



Venera 9, images of Venus: Combination of multiple views, inpainting by PDE flow.

Source: `http://www.mentallandscape.com/V_DigitalImages.htm`

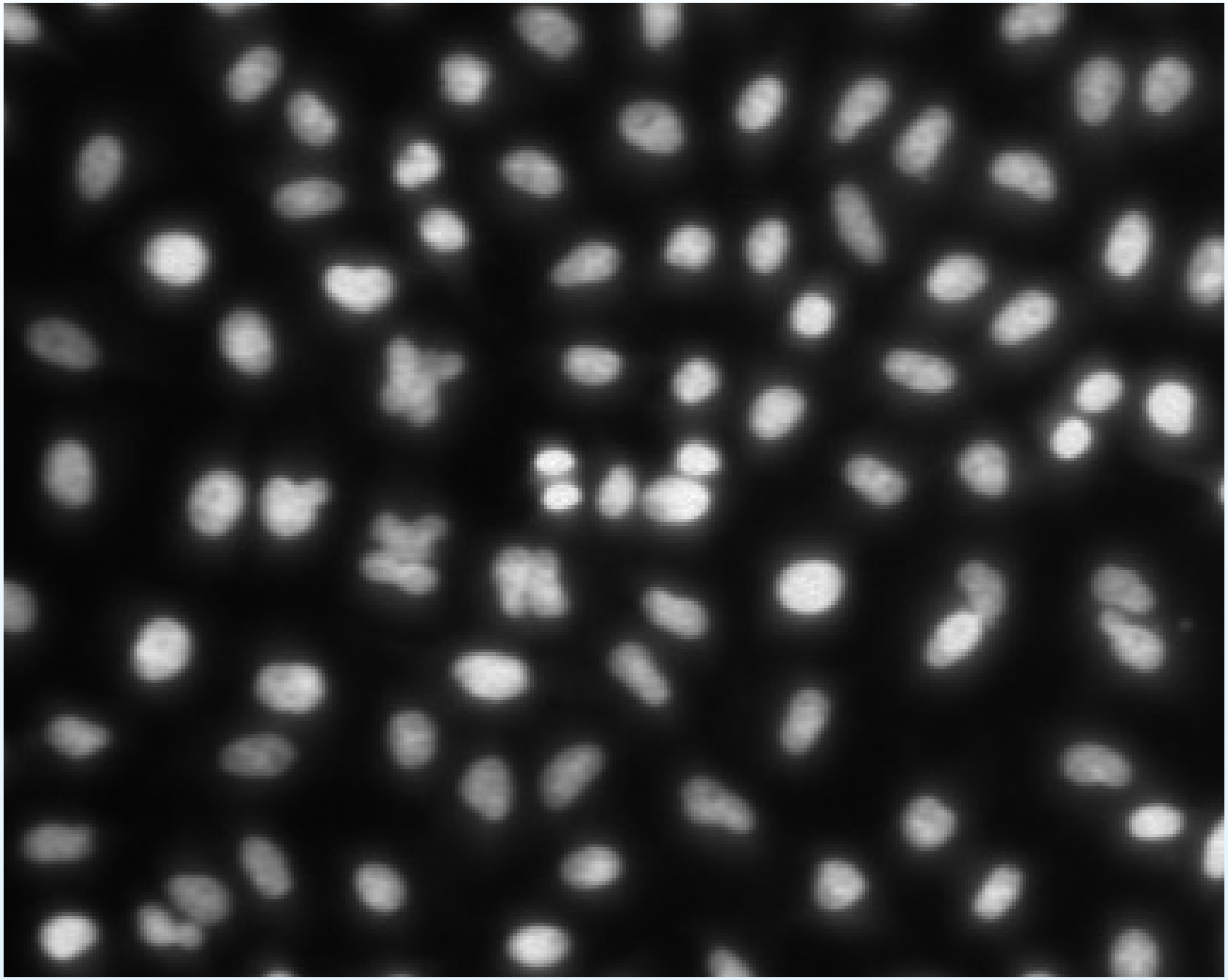
The Murphy principle works on Venus

Venera 13, camera 1, spring loaded soil sampler

The Murphy principle works on Venus

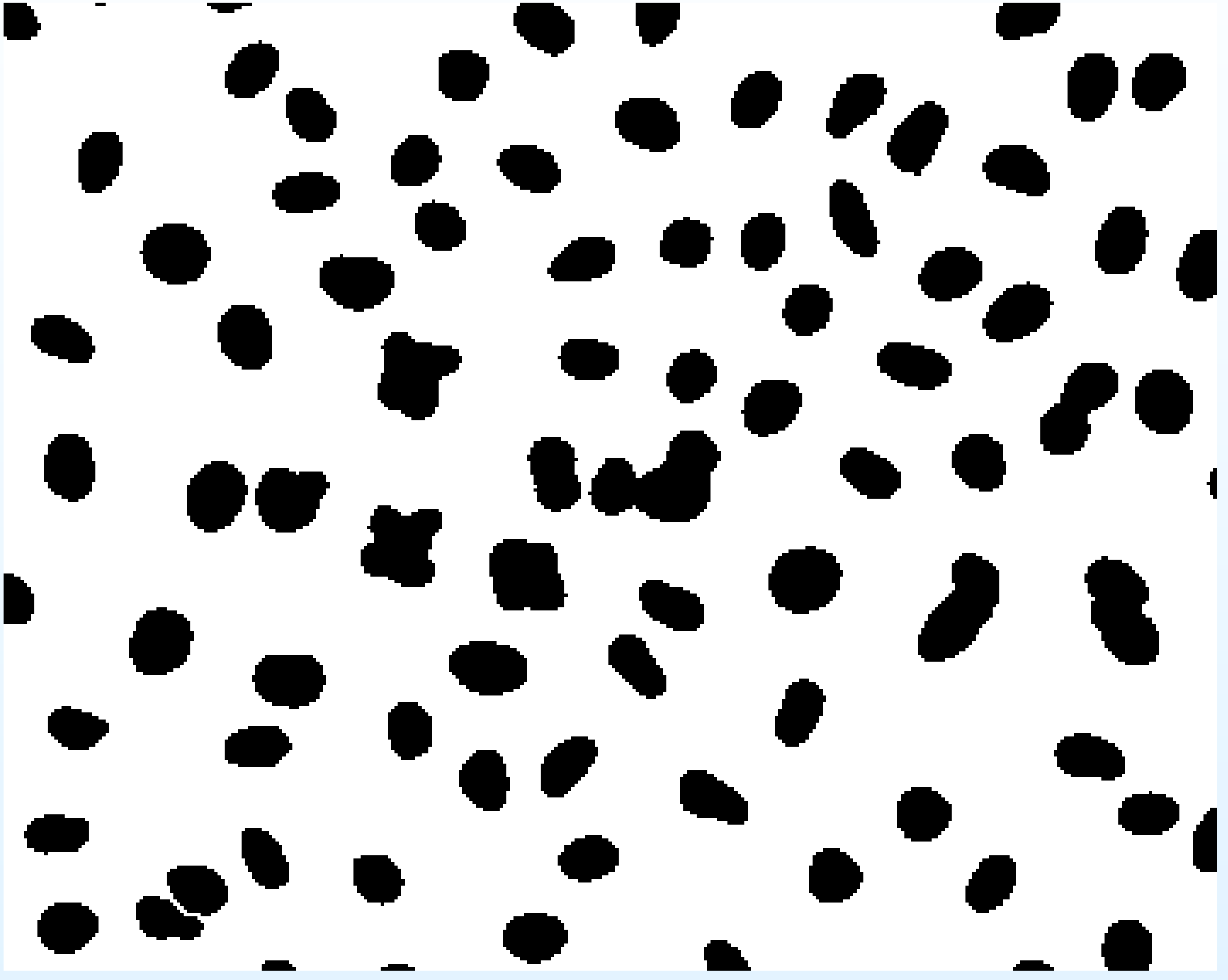
Venera 14, camera 1, spring loaded camera hood sampler

Examples of image analysis: cell counting



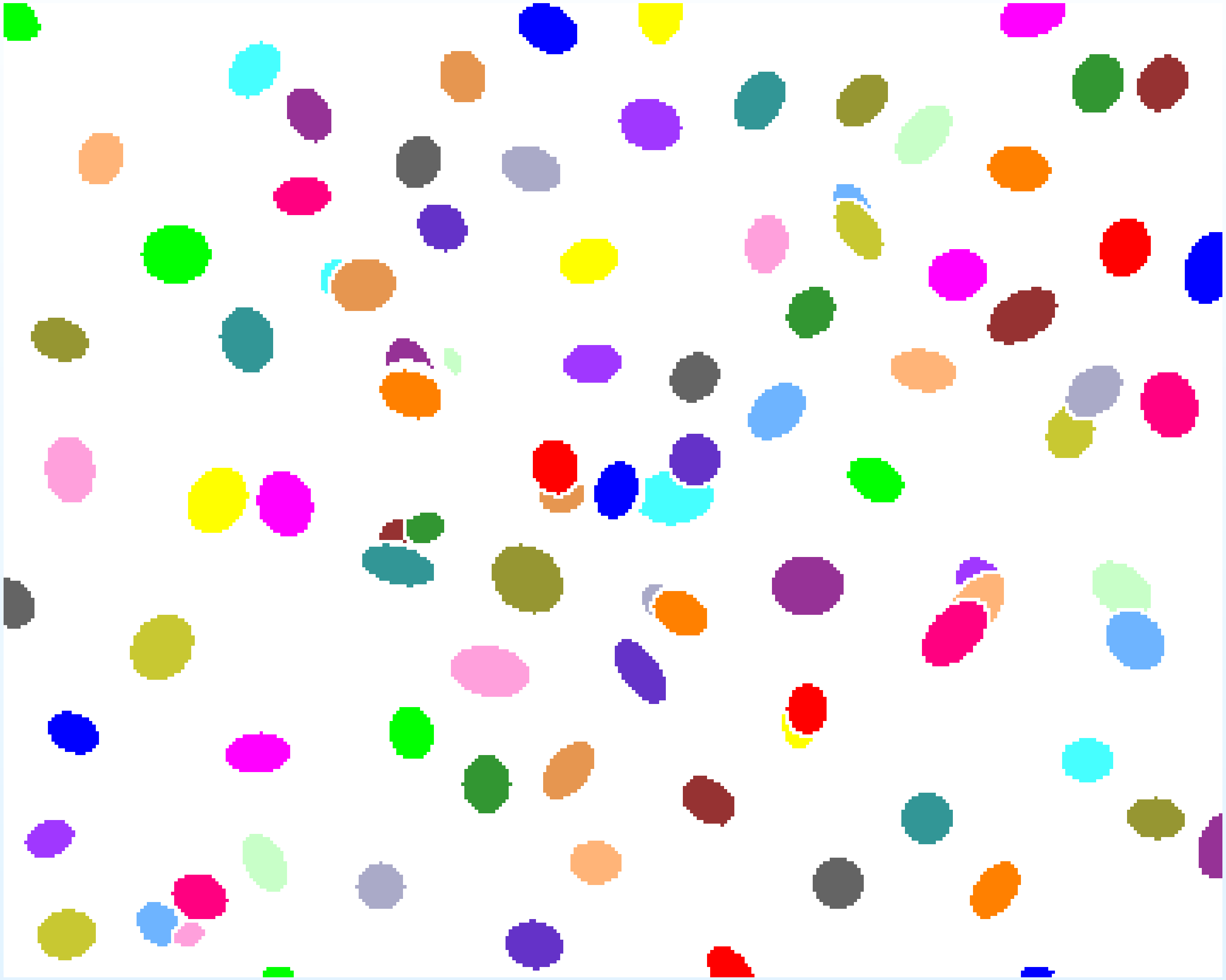
Cell nuclei

Examples of image analysis: cell counting



Segmentation

Examples of image analysis: cell counting



Object splitting

Why do we process images ?

- Image processing covers many different fields, among the most common:
  - Image data transmission (coding, compression, steganography);
  - Image filtering (enhancement, deblurring, special effects)
  - Image understanding (segmentation, pattern recognition, machine intelligence).
- Some application areas:
  - Science (medicine, materials science, biology, astronomy, remote sensing)
  - Law enforcement (face recognition, hyper-resolution)
  - Arts (special effects, film restoration, communication)

Why do we process images (cont.)?

- Is is economically sensible do use image processing:
  - Automation of visual tasks (surveillance, quality control, industrial vision)
  - Cheap and/or plentiful captors (cameras are everywhere)
  - Enhanced senses (IR, UV, X-rays)
- When there is no other choice
  - Hubble space telescope in its early years
  - Robots in remote or dangerous locations (on Mars at present)
  - Forensic data (in its widest sense)
- When we want to make full use of the data
  - High-depth, high resolution sensors,
  - Multi-spectral data,
  - Rendering of 3D data,
- And far more.

Imaging basics: formation and perception

What are images ?

- Usually an image is a 2-D array of single values (grey-level images) or a 2-D array of 3-component vectors (R-G-B images). A single element of these arrays is called a pixel (**pic**ture **el**ement).
- Images can be 3-D or more (n-D arrays).
- Images can have time series of images (movies).
- Images can have a vector with many components for each pixel (multi- and hyperspectral images).
- Images can be collections of spatially connected arrays of various meanings (components).
- Image collections can be related spatially (stereo pairs).

Image can be fairly complicated things. We will mostly deal with the 2-D, grey-level or colour, single component case.

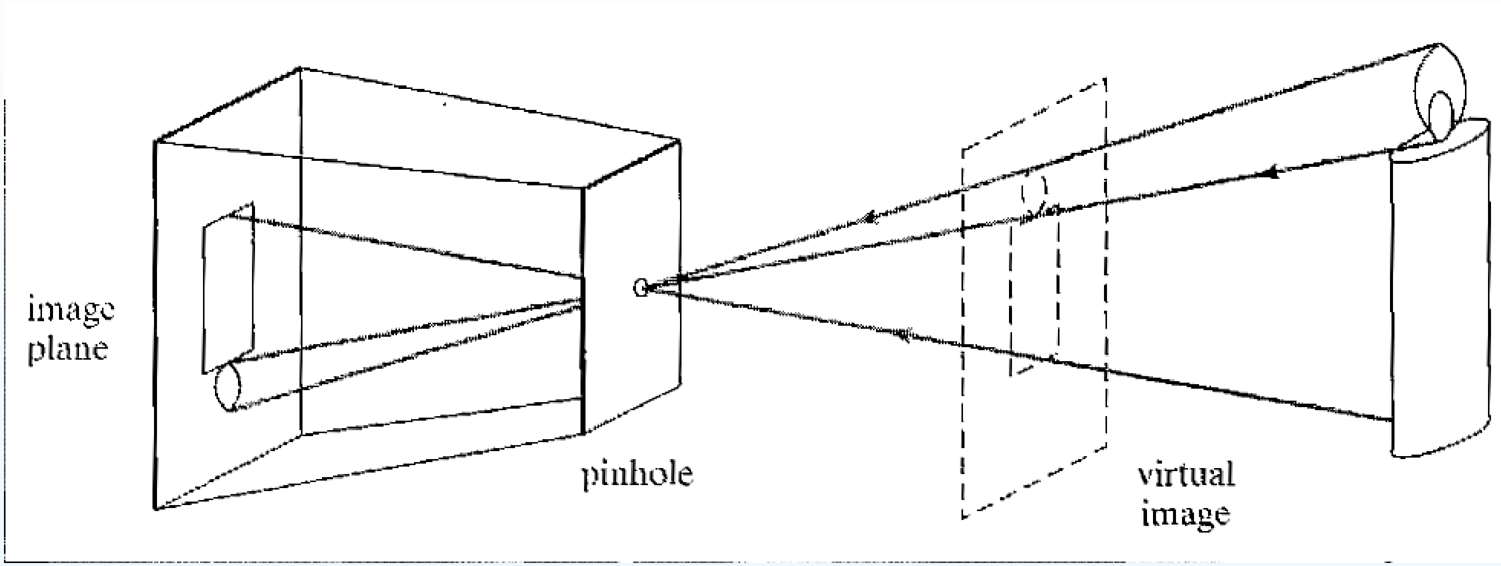
What does an image represent ?

- Projection of reality onto a surface/volume
- Mathematical image

$$I = f(R)$$

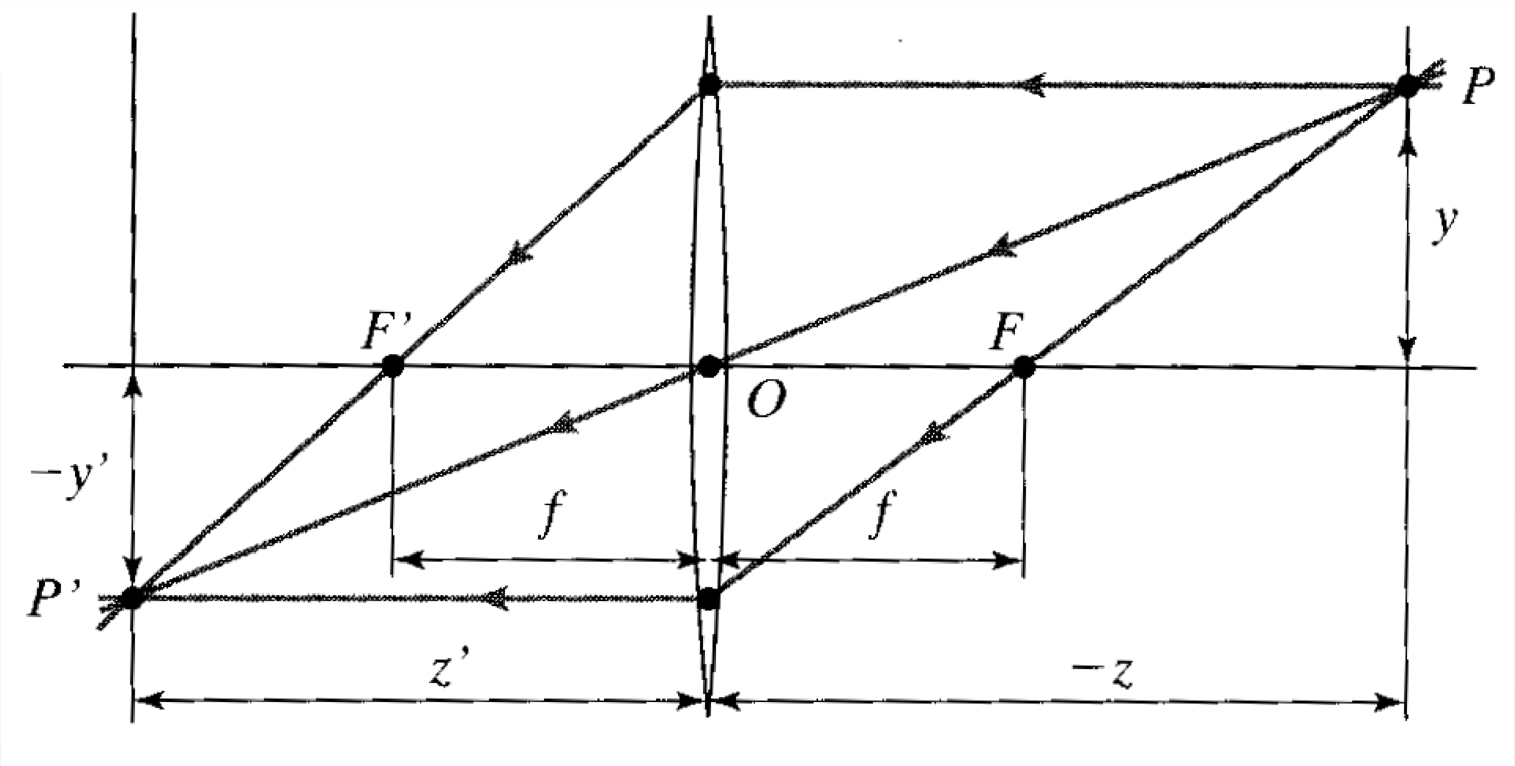
- Whole slew of problems associated with function f.
- It is worth spending some time on understanding the process of image formation and perception.

Image formation: pinhole camera



- Advantages: Simple geometry, always in focus, useful model.
- Drawbacks: Too simplistic: no diffraction, no abberations.

Thin lens camera



Actually a somewhat realistic model for some instruments, e.g. telescopes. Issues:

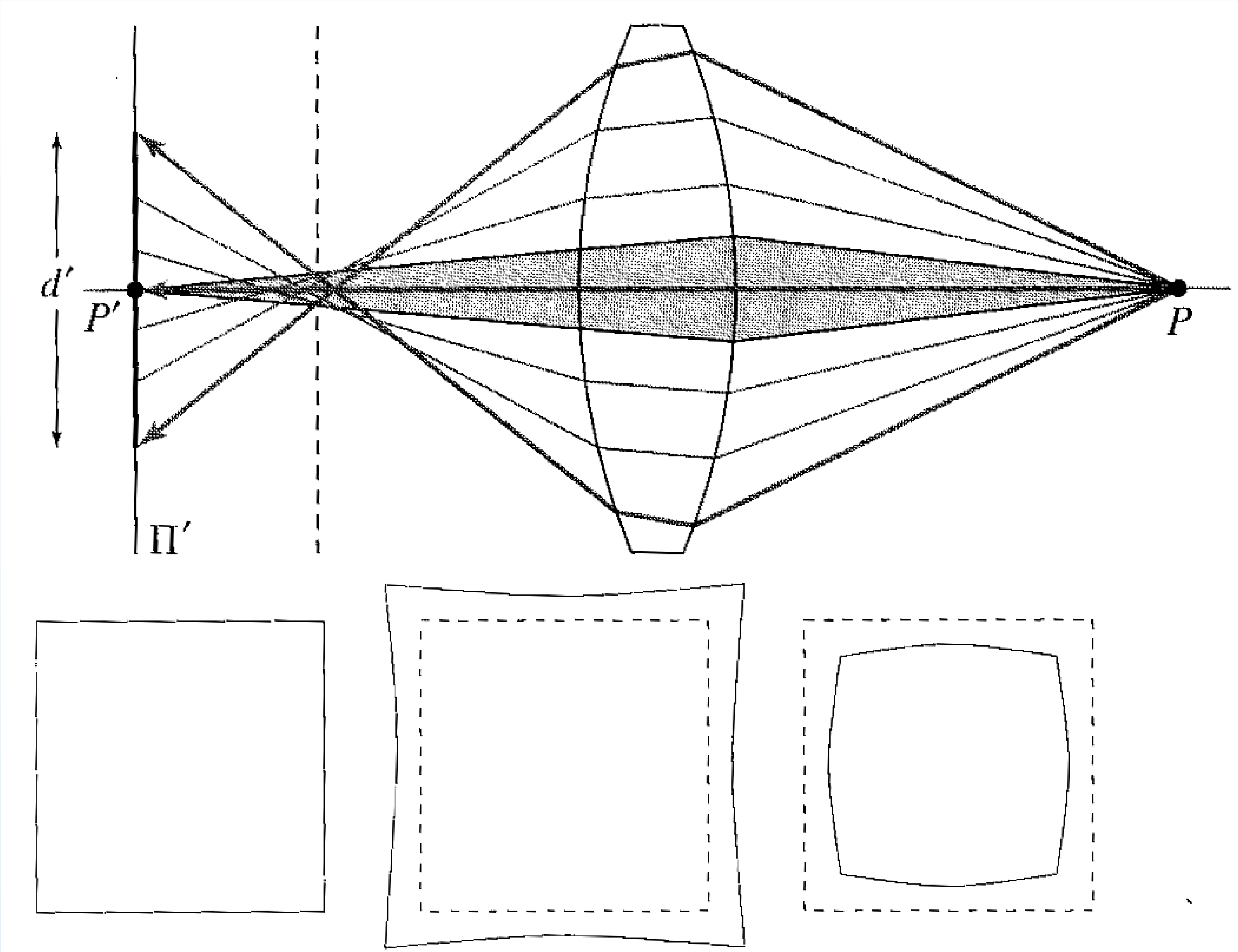
- Depth of field, F number,
- Field of view,
- Diffraction, etc.

Real cameras

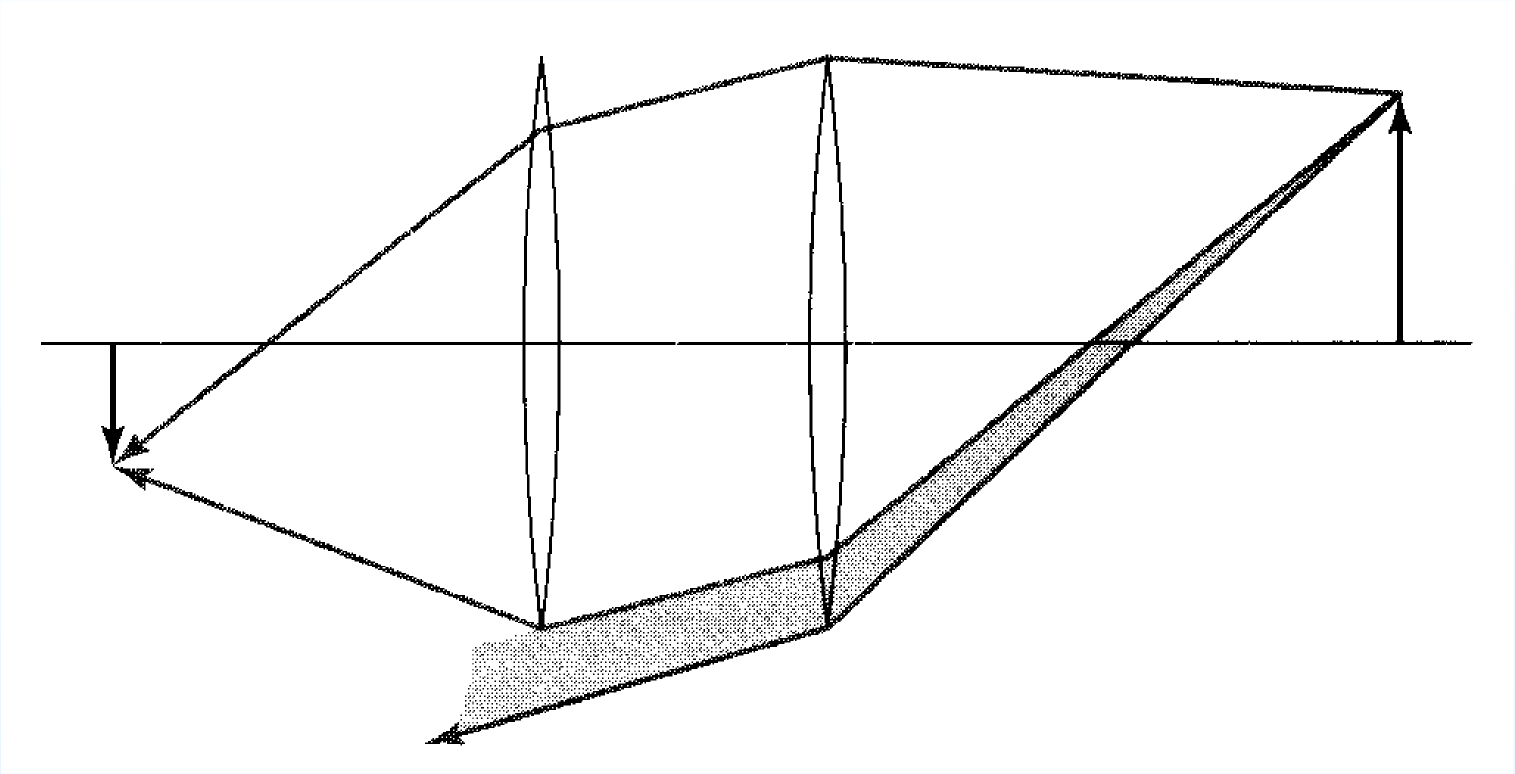
Real cameras have:

- Thick, multiple lens
- Geometric aberrations: spherical lens, barrel-pincushion, vignetting, etc.
- Chromatic aberrations: due to refraction index dependent of wavelength.

Real cameras: spherical aberration



Real cameras: vignetting



Sensors: photography

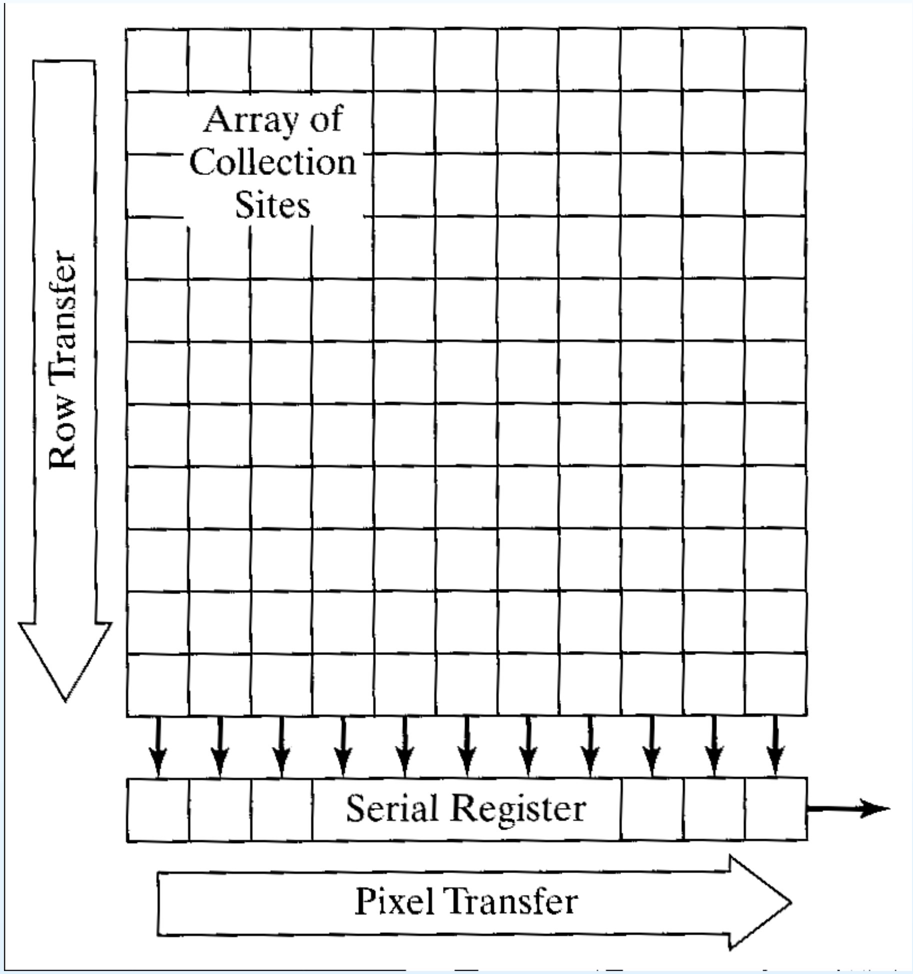
First photography: ca 1816, now lost. Among oldest photos on record is the following, original also lost in late 19th century.

Sensors: history

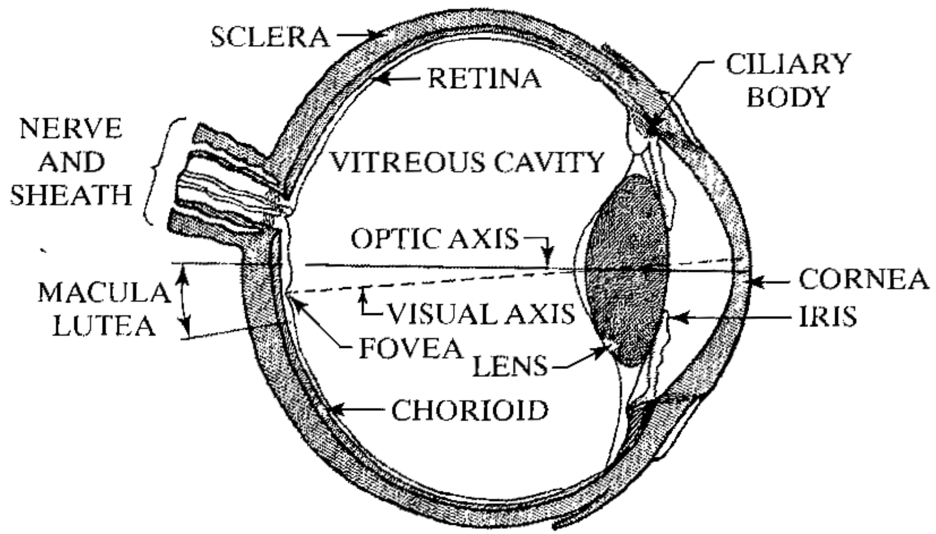
- First recorded photography: 1822
- Daguerréotypes: 1839 (popular photography)
- Wet plate: 1850 – Negative/positive process, immediate processing required.
- Gelatine process: 1870 – Latent image
- Photographic film: 1889 by Eastman
- Cinema : 1895 by Lumière brothers
- Colour photography: 1908
- Television: 1920s

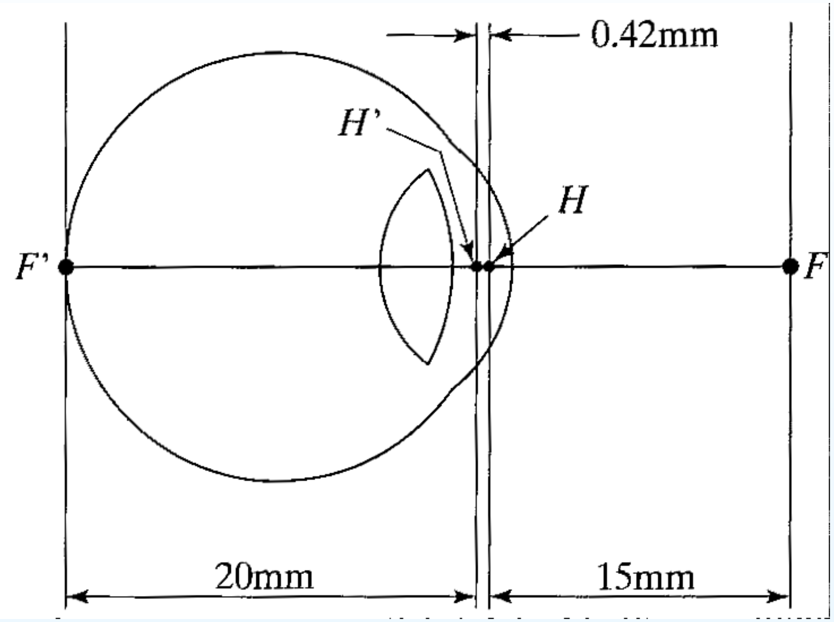
Sensors: CCDs

Invented 1970, used in astronomy and in TV. Ubiquitous nowadays, being displaced in consumer electronics by CMOS sensors.



The eye





Rods and cones, colour perception,
Neurons/optic nerve,
Brightness control, tracking, interpretation, etc.
Physiology still being researched.

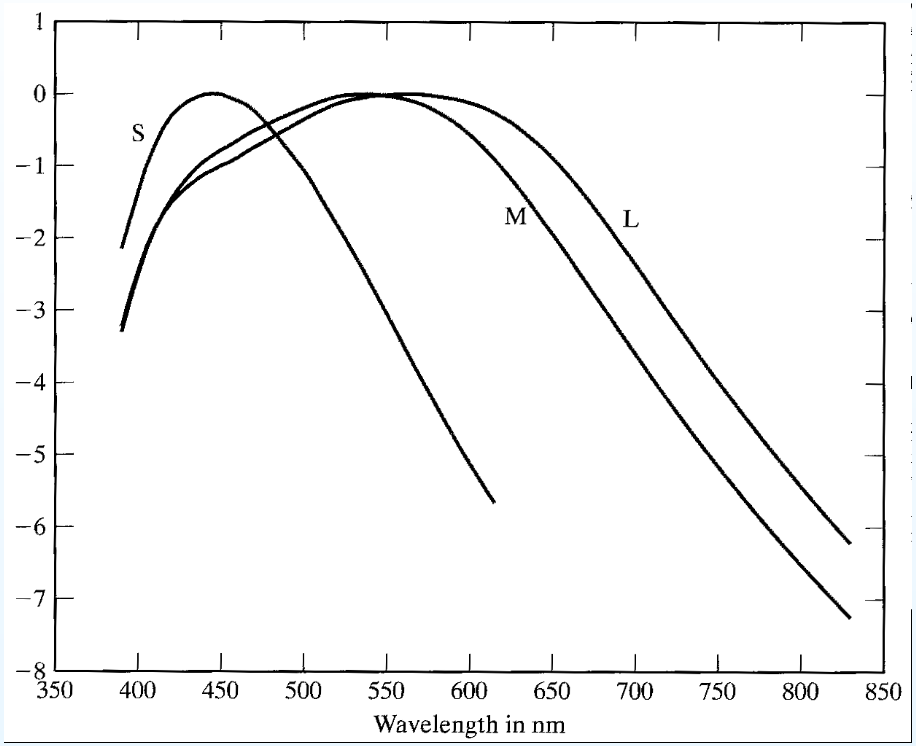
Light

- Visible light is a subset of the electro-magnetic spectrum, from 380 to 720nm wavelength.
- A light source is characterized by (i) its strength and (ii) its spectrum.
- A monochromatic source is characterized by a wavelength λ and its luminance L.
- The eye:
  - Cannot distinguish individual frequencies (unlike hearing).
  - Instead obeys the GRASSMAN Laws:

$$\sum_{i=1}^{N} L_i = L_w + L_r$$

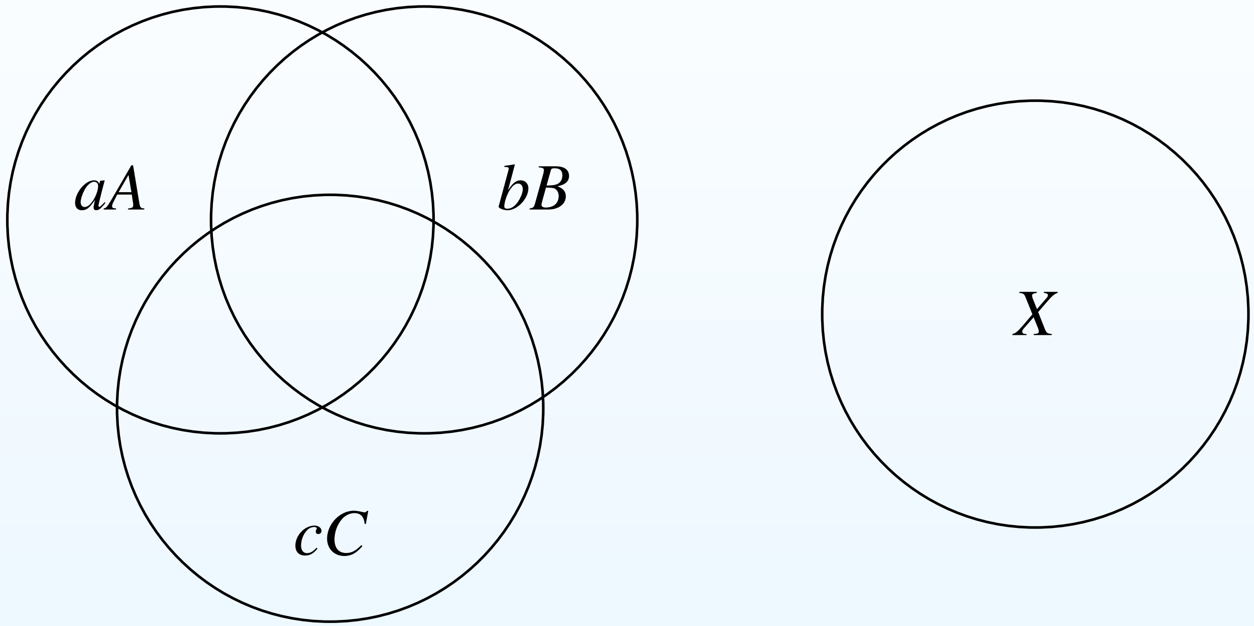
i.e: the addition of N colours is equivalent to the addition of a white flux L_w and the flux of a single resulting monochromatic colour L_r of wavelength λ_r (3 variables).

Colour perception



- There are 3 types of colour sensors in the eye (cones);
- Each type have a different spectral response.
- This suggests a 3-stimulus colour representation scheme : combining 3 stimuli of 3 different wavelengths can produce most colours seen in nature.

Colour matching experiment

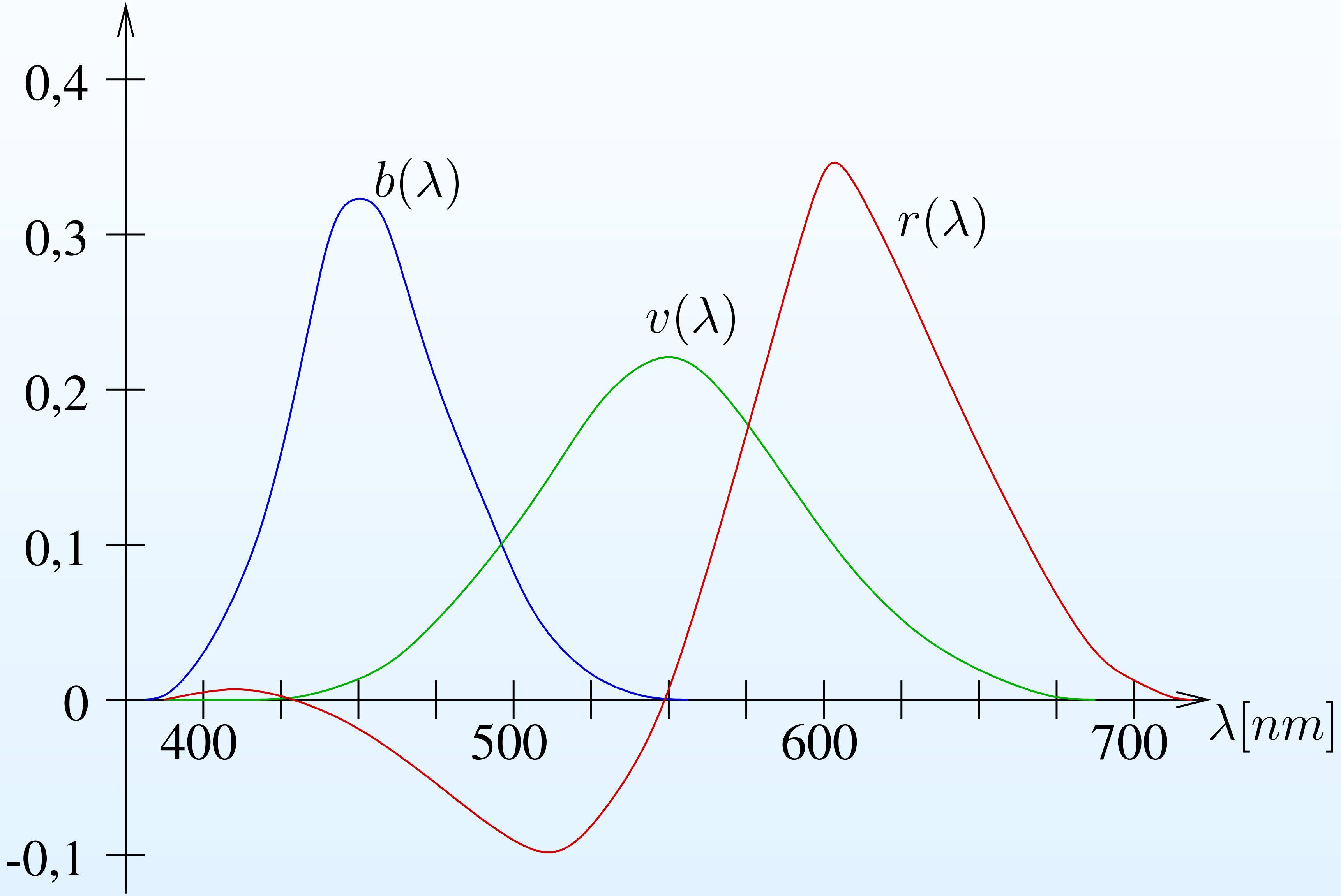


- A, B and C are 3 "primary" colours (light sources projected on a screen),
- a, b, c are 3 ponderation factors,
- Via experimentations, one tries to obtain colour X from $aA + bB + cC$.
- If a match is impossible, one or more of the primary colours is added to X instead, giving the equivalent to negative a, b or c.

CIE RGB standard

- In 1931, the Commission Internationale de l'Éclairage (CIE) did the colour matching experiment using 3 monochromatic sources: red (645.2 nm), green (526.3.1 nm) and blue (444.4 nm).
- This gave rise to the CIE RGB system.
- With this system, it is possible to represent most natural colours
- Some wavelengths require negative weights.

Colour matching functions



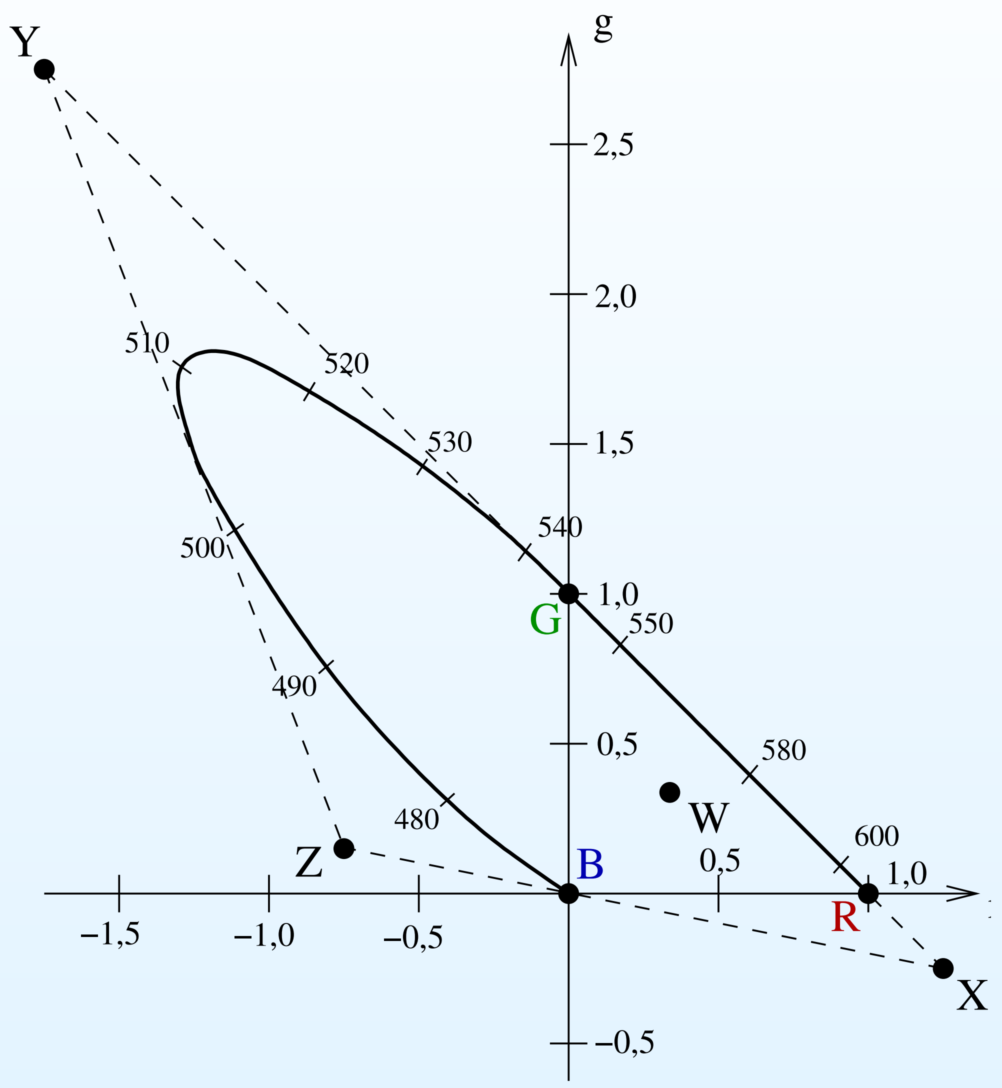
CIE XYZ standard

- To avoid negative weights, CIE designed a tri-stimulus system derived from RGB called XYZ, where all weights are positive.
- RGB / XYZ conversion by linear combination:

$$(1) \quad \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} 2,769 & 1,7518 & 1,13 \\ 1 & 4,5907 & 0,0601 \\ 0 & 0,0565 & 5,5943 \end{pmatrix} \begin{pmatrix} R \\ G \\ B \end{pmatrix}$$

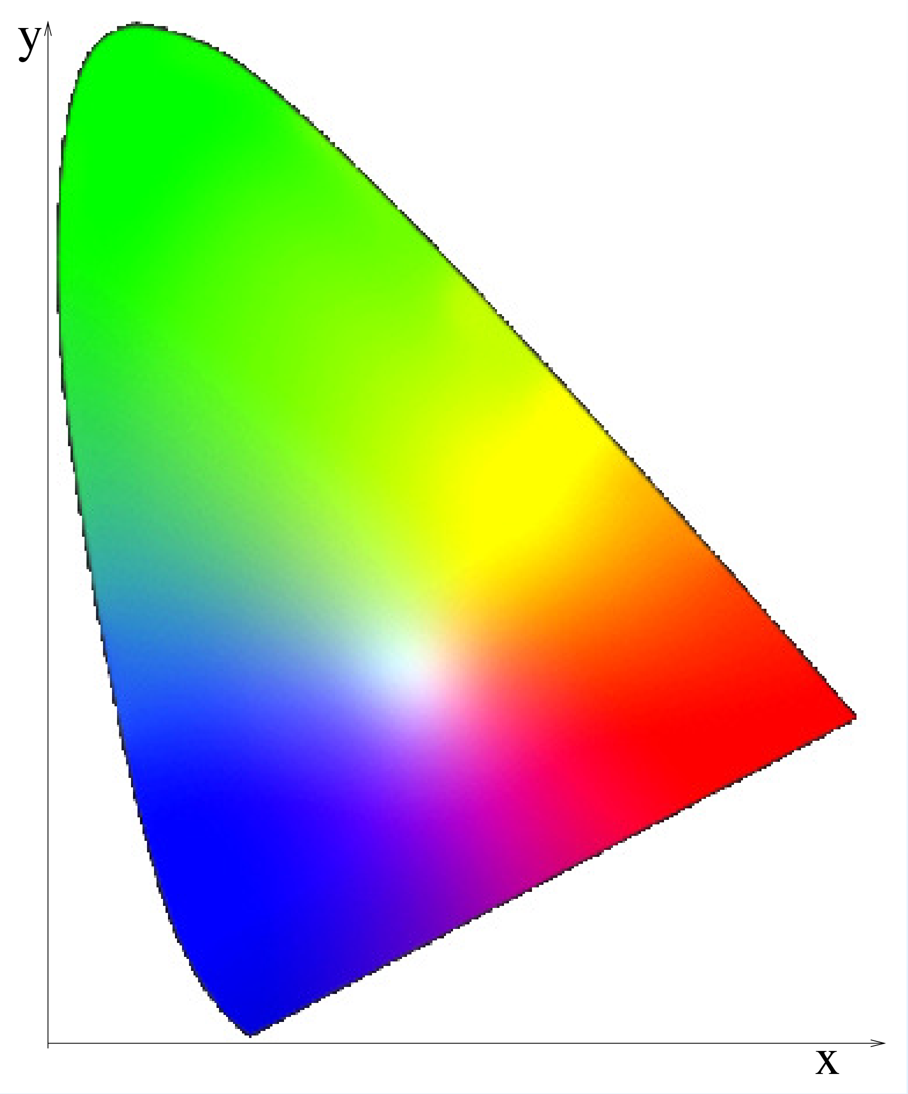
- Because a 3-stimulus (3-D) system is hard to represent, one most often uses the xyz system, which is normalized w.r.t $X+Y+Z$ (i.e. $x = \frac{X}{X+Y+Z}$).
- In this system only 2 variables are independent.

XYZ system



Y
g
2,5
2,0
1,5
1,0
0,5
−0,5
510
520
530
540
550
580
600
500
490
480
G
W
Z
B
R
X
0,5
1,0
−1,5
−1,0
−0,5

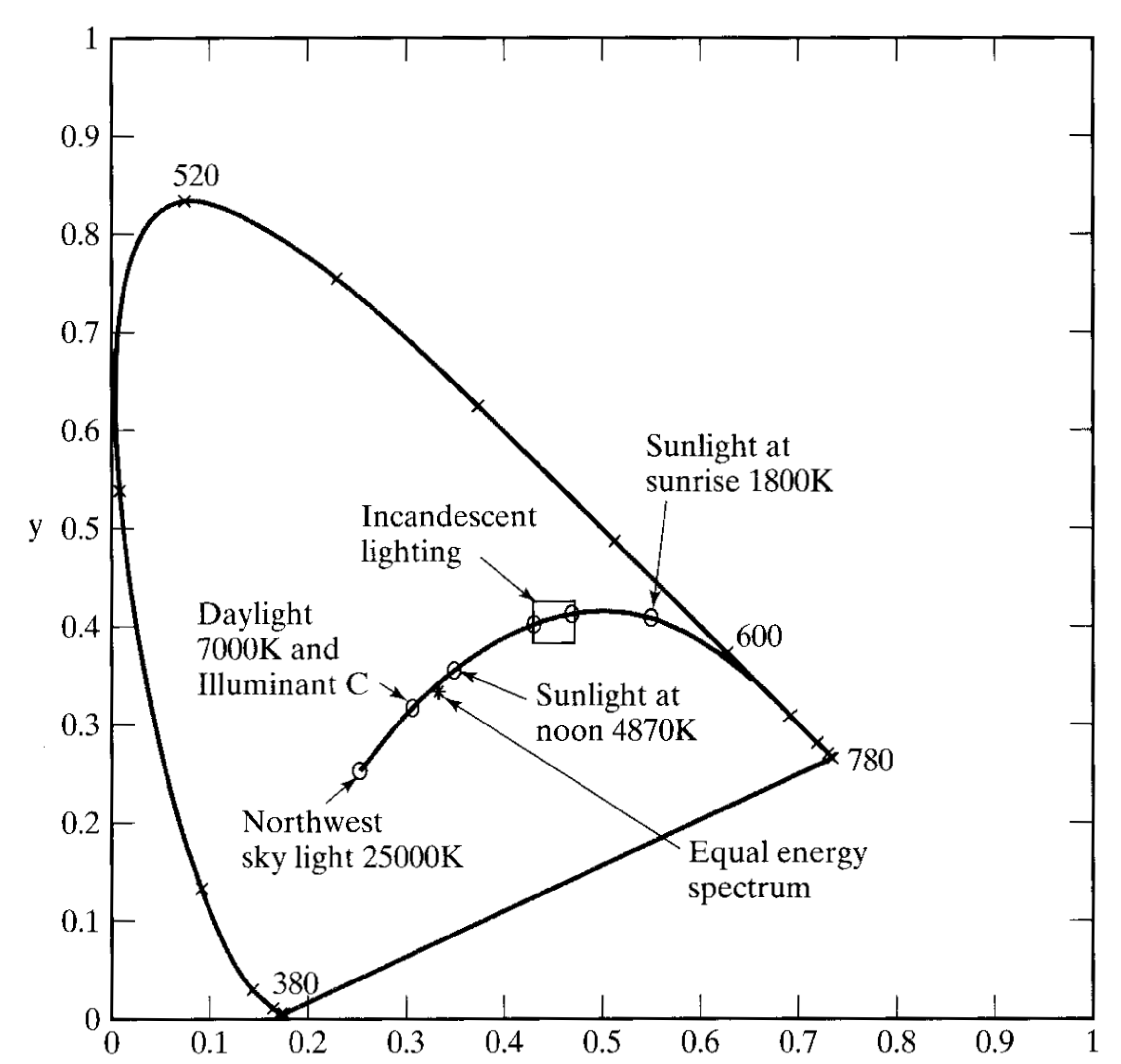
xy representation



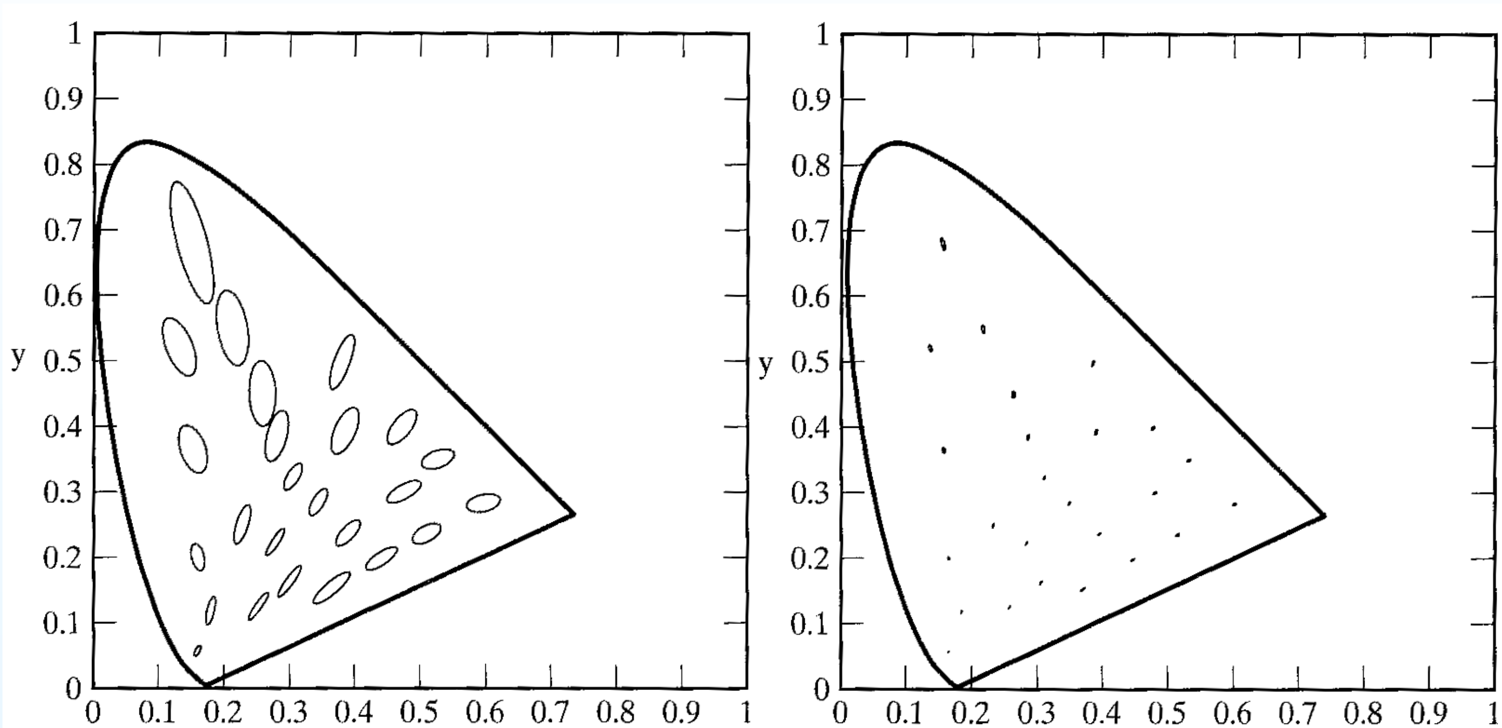
More on xy

- Monochromatic colours are on the inverted U.
- Equal energy point at $x = y = 1/3$.
- Again, xy is a reduced version of the full 3D colour space.
- The xy chromatic diagram is the locus of chrominance of maximal luminosity.
- For all its goodness, xy is not very intuitive. Other systems decompose colours in Hue, Saturation and Lightness.

Colour temperature

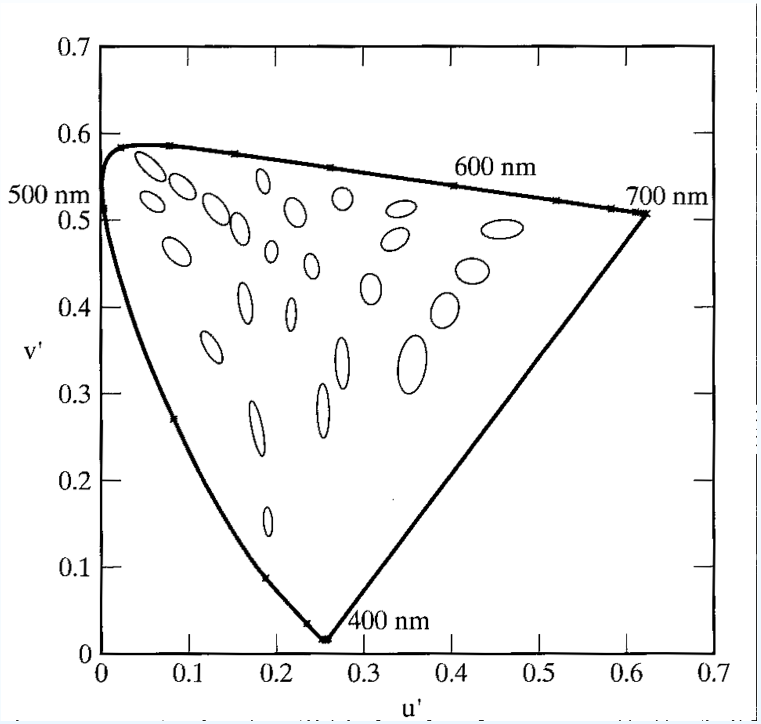


Colour difference perception



- Another human observer experiment: how far do you need to move away from a colour to notice a difference?
- Can we create a colour space where the differences are homogeneous, a *uniform* colour space?
- I.e: can we reduce the ellipses above (MacAddam ellipses) to circles?

CIE $u'v'$ system



- Simple linear transform:

$$(u', v') = \left(\frac{4X}{X + 15Y + 3Z}, \frac{9Y}{X + 15Y + 3Z} \right)$$

- This ignores differences in brightness
- A variety of non-linear transforms can be used

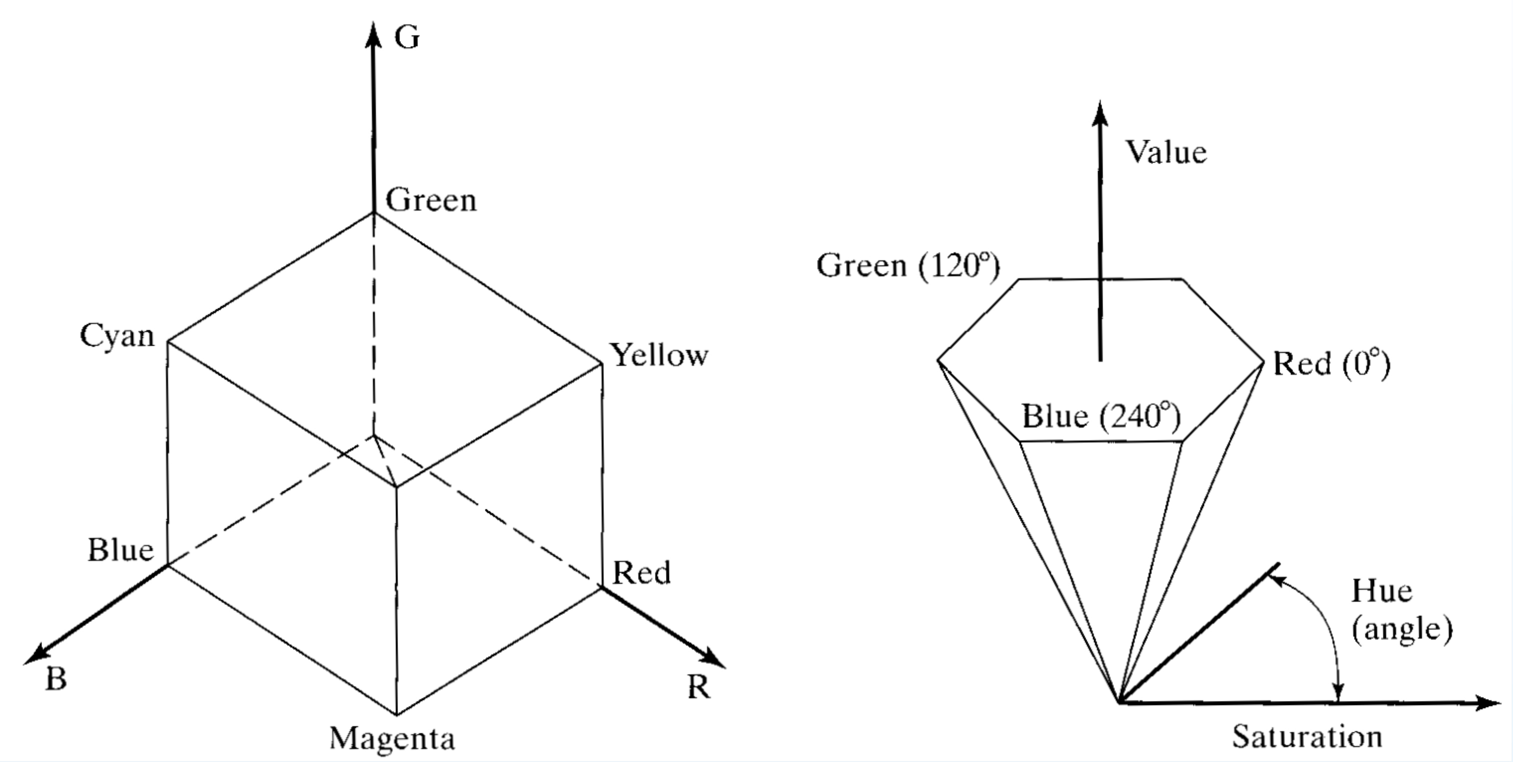
CIE Lab system

- Among those is the CIE Lab system.

$$
\begin{aligned}
L^* &= 116\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - 16 \\
a^* &= 500\left[\left(\frac{X}{X_n}\right)^{\frac{1}{3}} - \left(\frac{Y}{Y_n}\right)^{\frac{1}{3}}\right] \\
b^* &= 200\left[\left(\frac{Y}{Y_n}\right)^{\frac{1}{3}} - \left(\frac{Z}{Z_n}\right)^{\frac{1}{3}}\right]
\end{aligned}
$$

- Here X_n, Y_n, Z_n are the XYZ coordinates of a reference white patch.
- Lab is important because it is substantially uniform.

RGB vs HSV


G
Green
Cyan
Yellow
Blue
Red
B
R
Magenta
Value
Green (120°)
Red (0°)
Blue (240°)
Hue
(angle)
Saturation

CMY substractive system

- RGB and its derivatives are *additive* colour representation systems.
- For the printed media, colours added to a white page substract wavelengths.
- The system for printed media is called *CYM* (Cyan, Yellow, Magenta). When added together, this produces black.
- Often *K* is added (black) as a separate colour: *CYMK* because creating a perfect black out of a substracting system is hard.

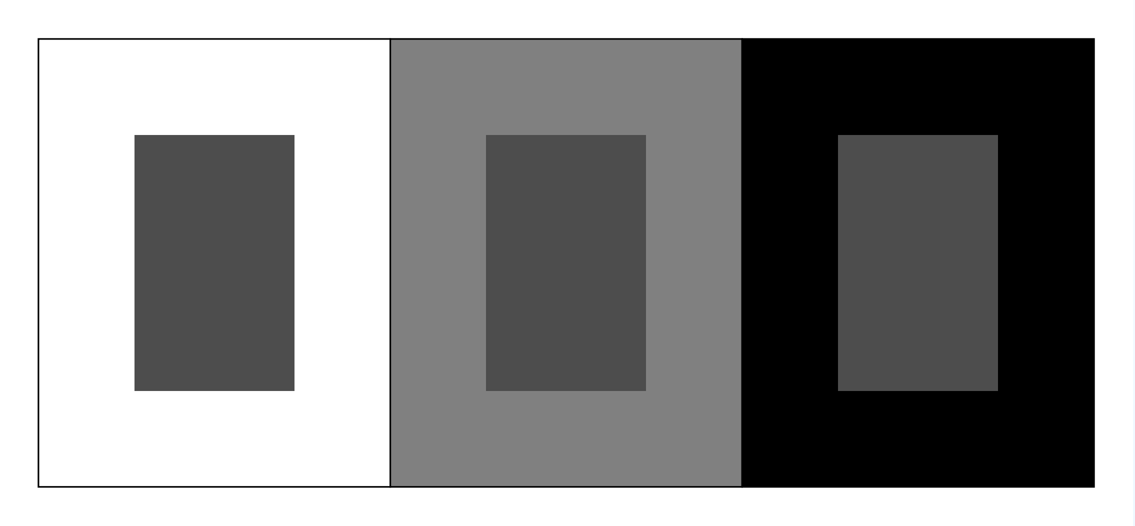
Everyday colour representation

- Computers, consumer electronics, etc use uncalibrated RGB (*not* CIE) with non-linear brightness curve (gamma).
- Most printers use uncalibrated *CYMK*
- As a result: limited gamut, colour matching problems. Exception: Apple hardware.
- TV uses a system called YC_bC_r (luminance/chrominance).

Other points on colour perception

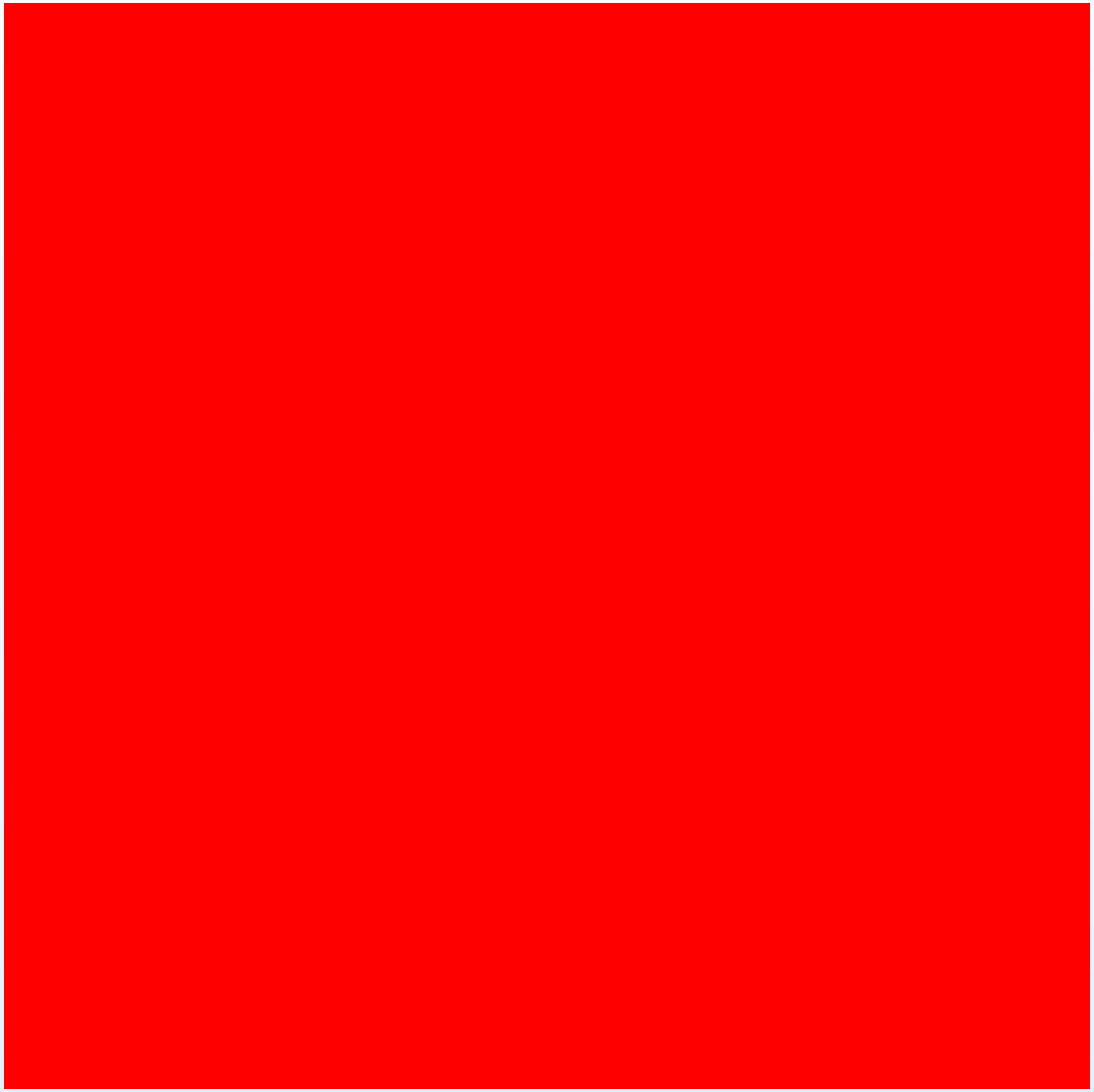
- Spatial and temporal effects are ignored
  - Chromatic adaptation: ability of the visual system to adapt to a dominant colour.
  - Assimilation: influence of surrounding colours towards these colours
  - Contrast: influence of surrounding colour to move away from these colours.
- Everyone is different. About 10% of males have some sort of "colour blindness", i.e. lack of one or more kind of receptors, usually the red cones. Some rare females can have 4 kinds of receptors.
- Illumination is a big factor. We are all colour blind at night (rod receptors are more sensitive than cones).
- We've only scratched the surface.

Example of contrast perception



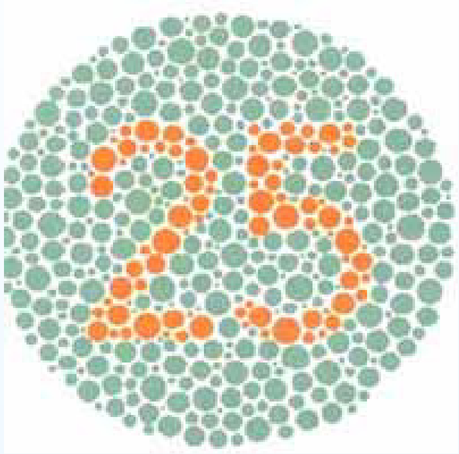
Which is the darkest inner rectangle?

Example of chromatic adaptation

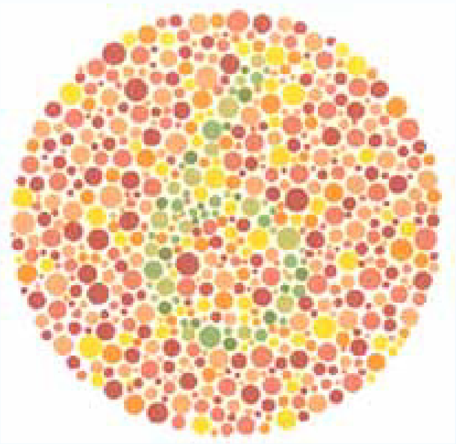


Example of chromatic adaptation

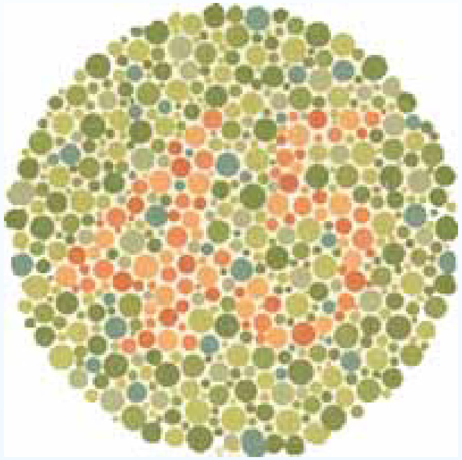
Colour perception test



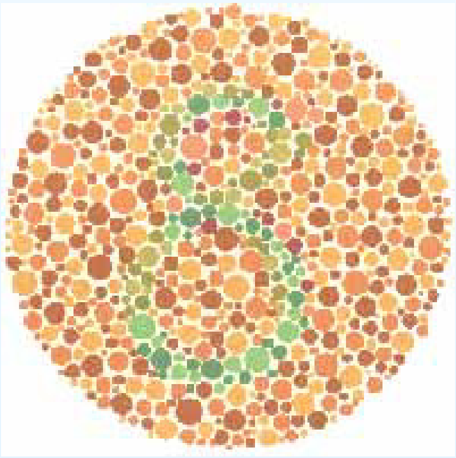
(a)



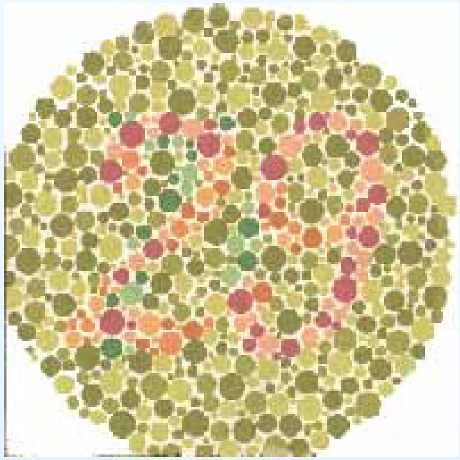
(b)



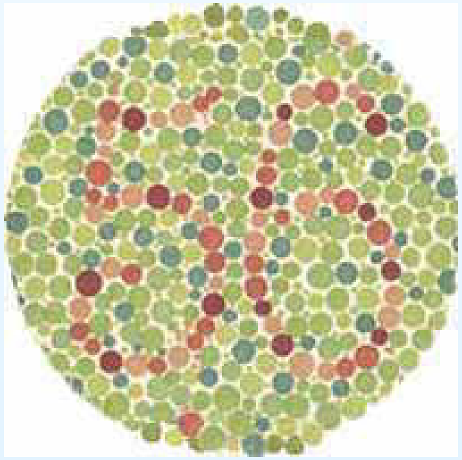
(c)



(d)



(e)



(f)

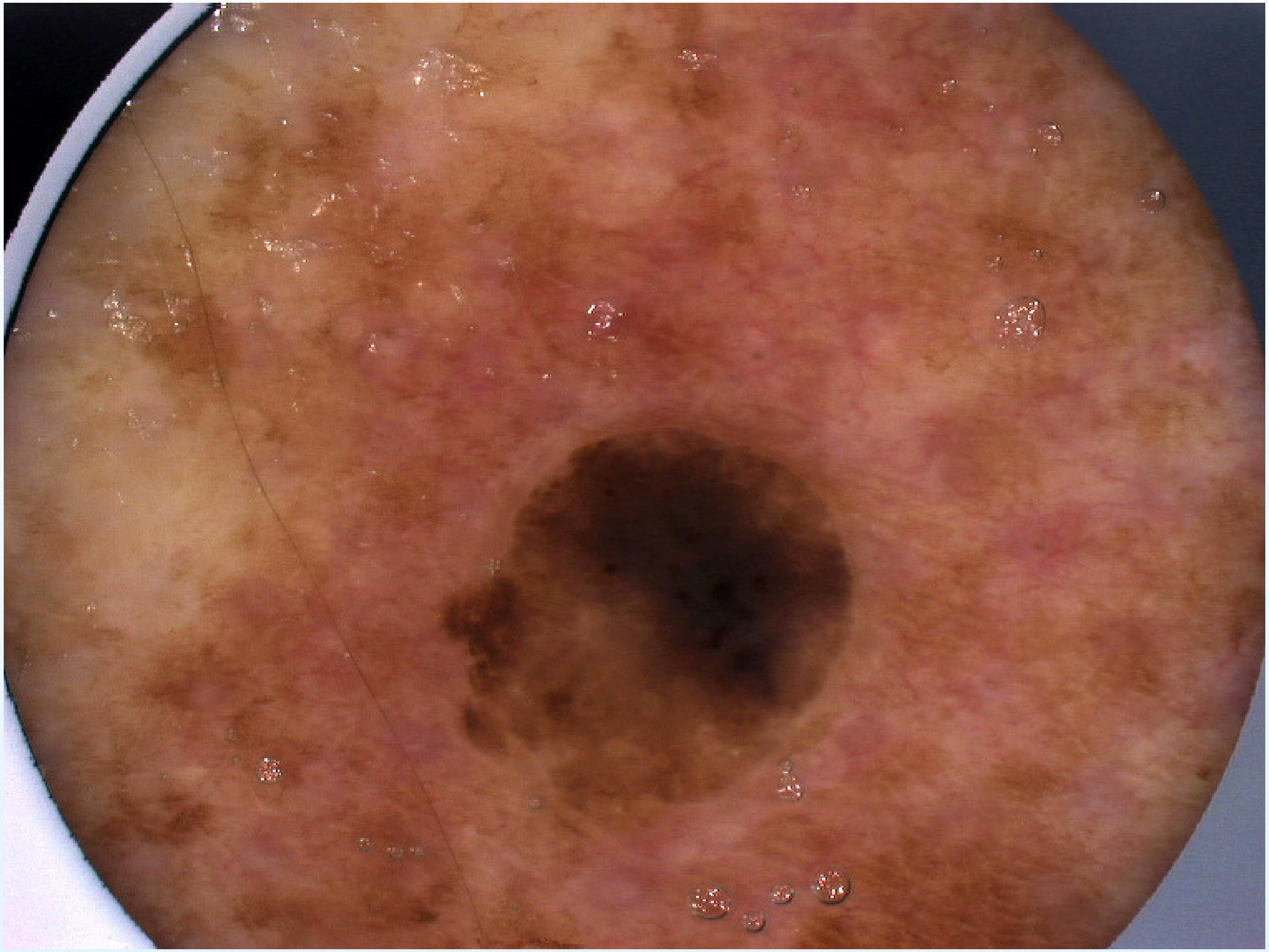
Application: melanoma diagnosis

Solarscan device

Hand piece

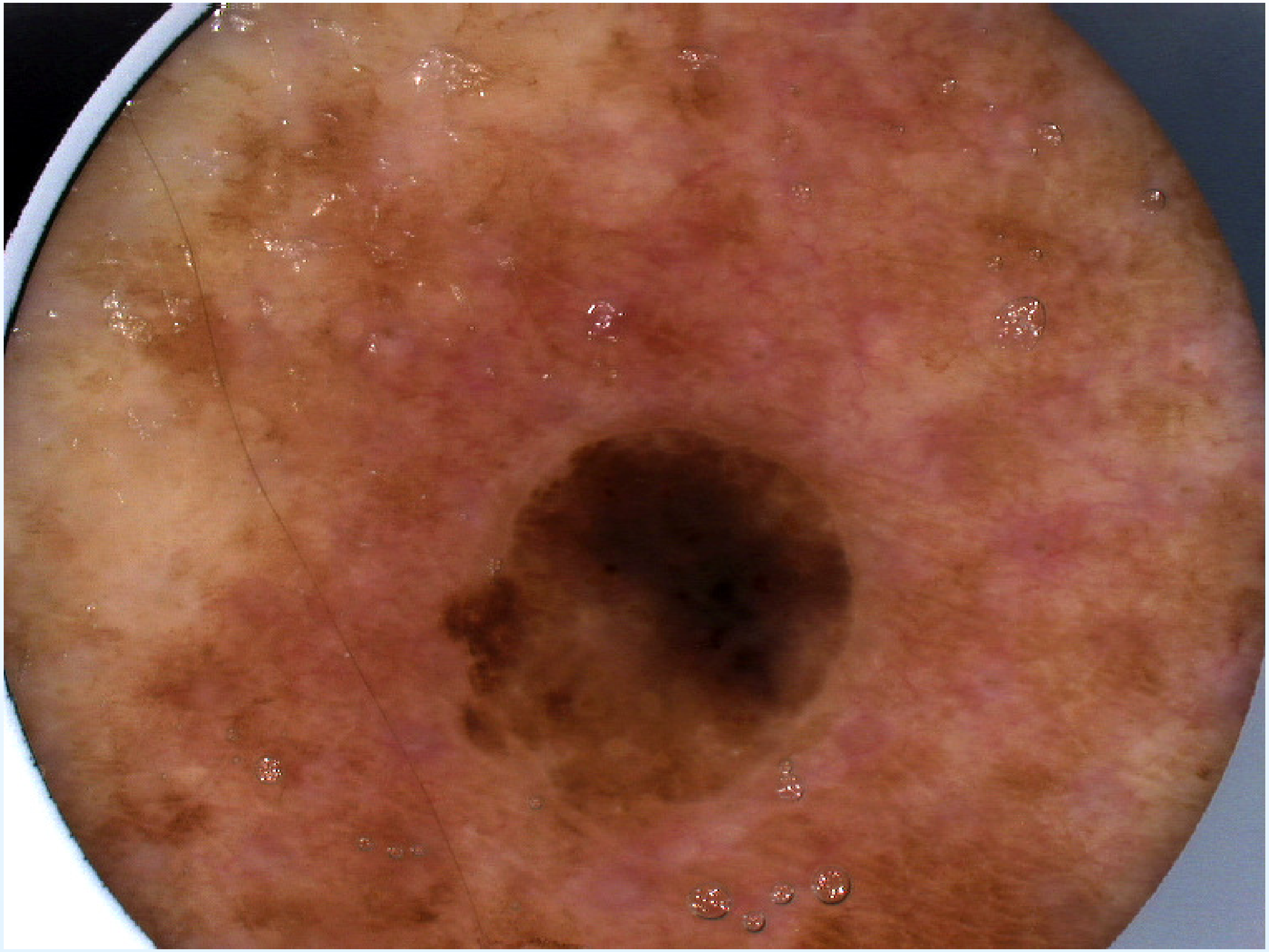
Polartechnics Solarscan^{tm} device, see http://www.polartechnics.com.au.

Absolute colour segmentation



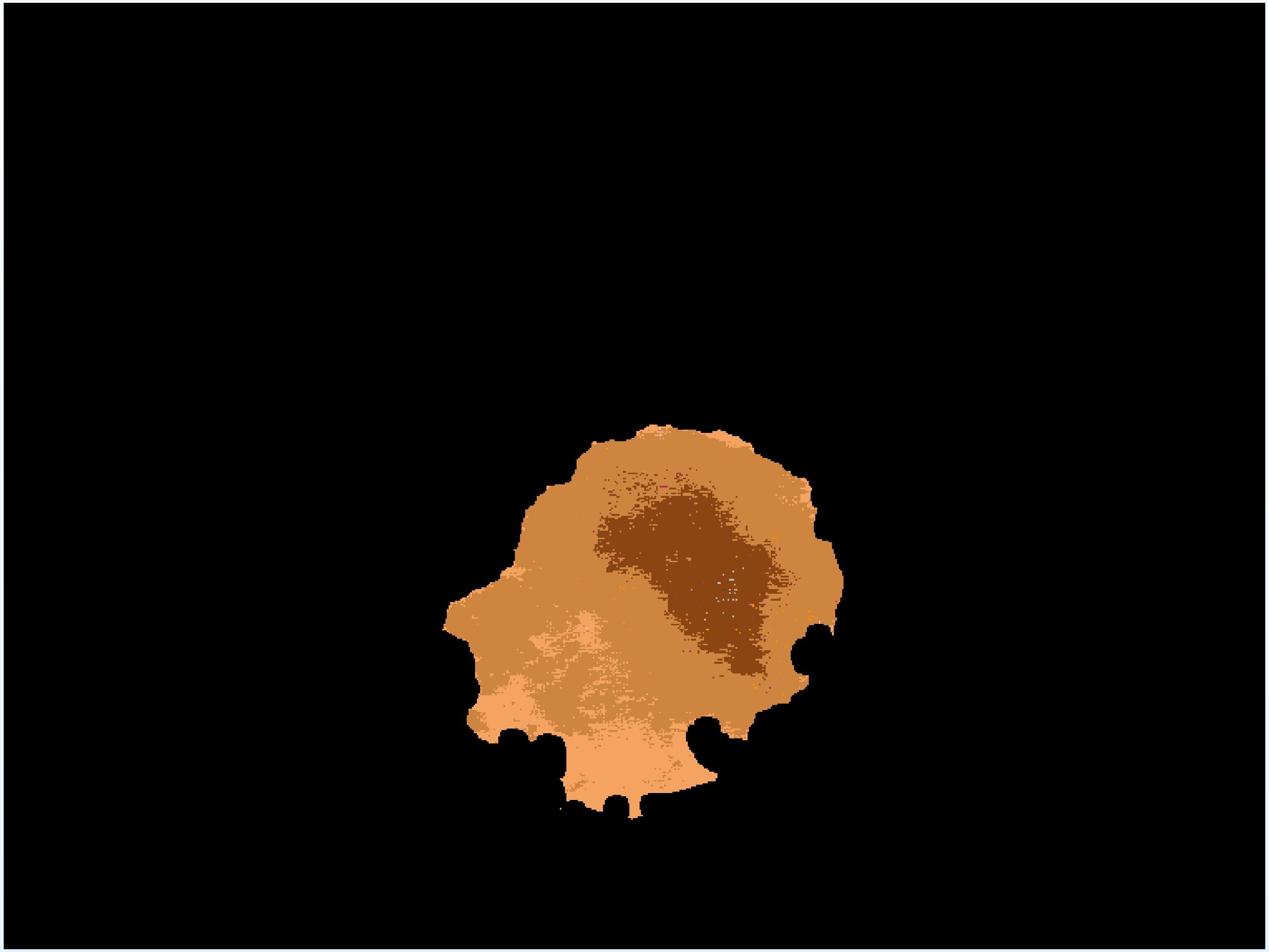
Uncalibrated lesion 1

Absolute colour segmentation



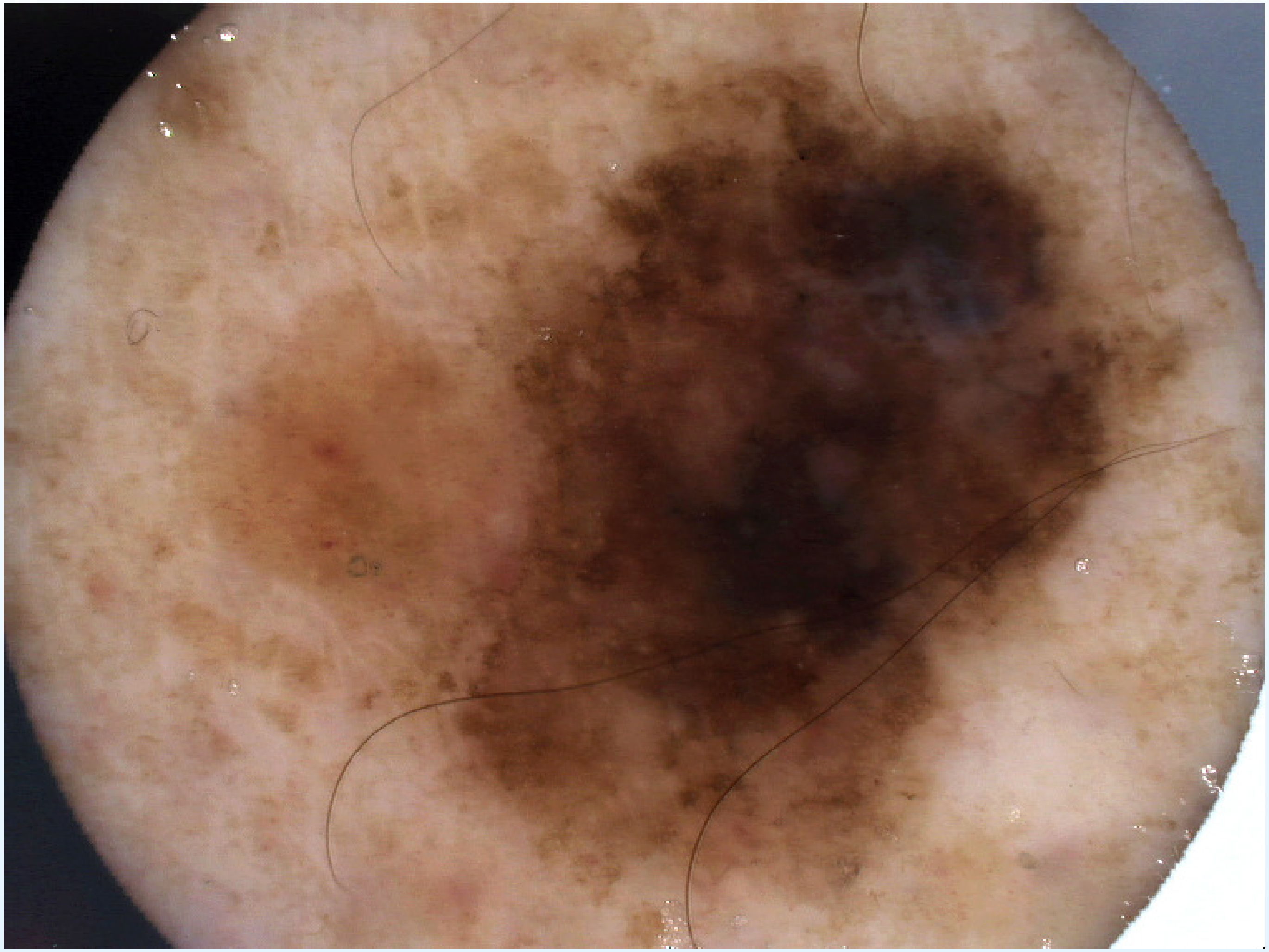
Calibrated lesion 1

Absolute colour segmentation



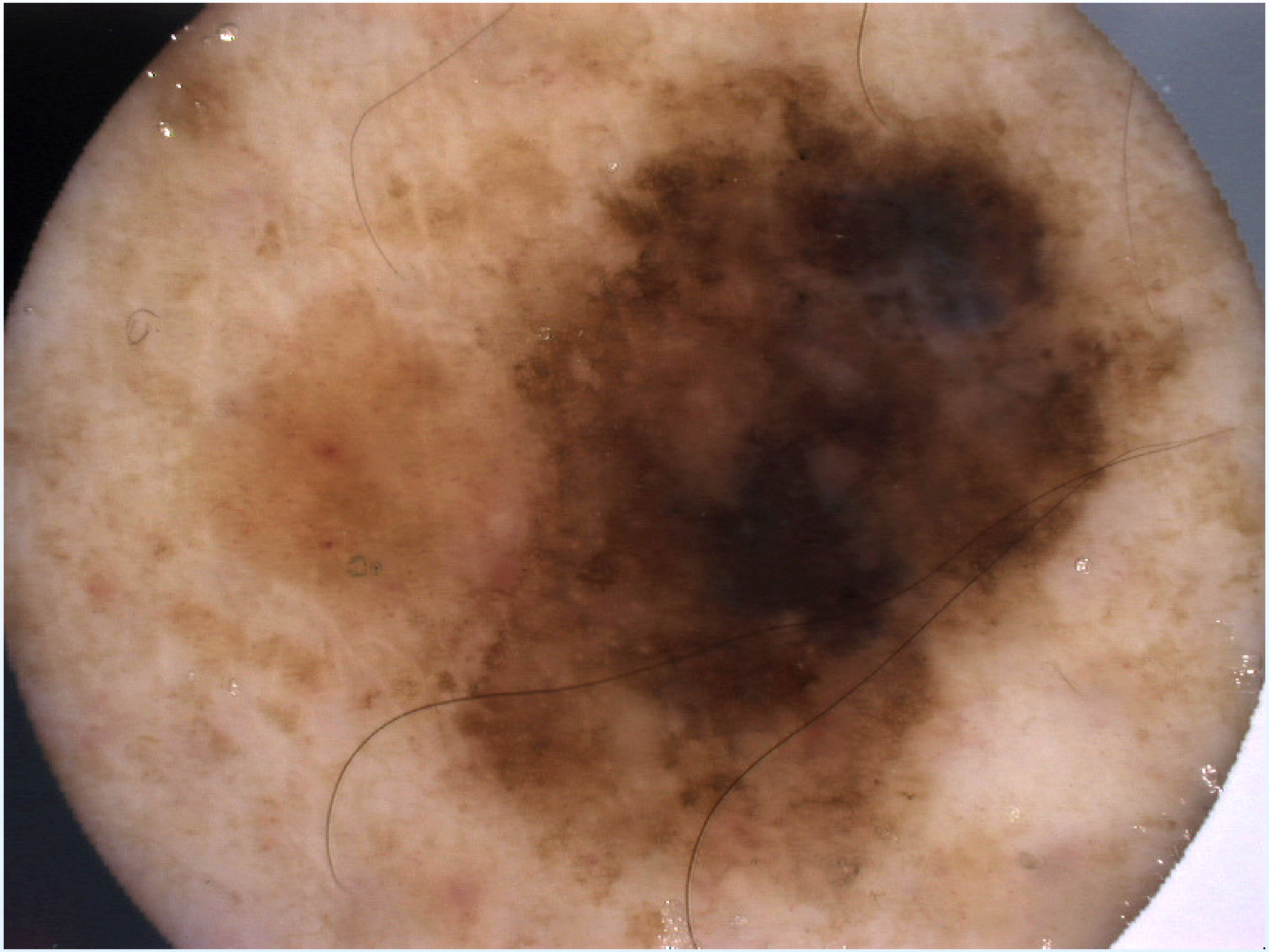
Colour identification for lesion 1 -> benign

Absolute colour segmentation



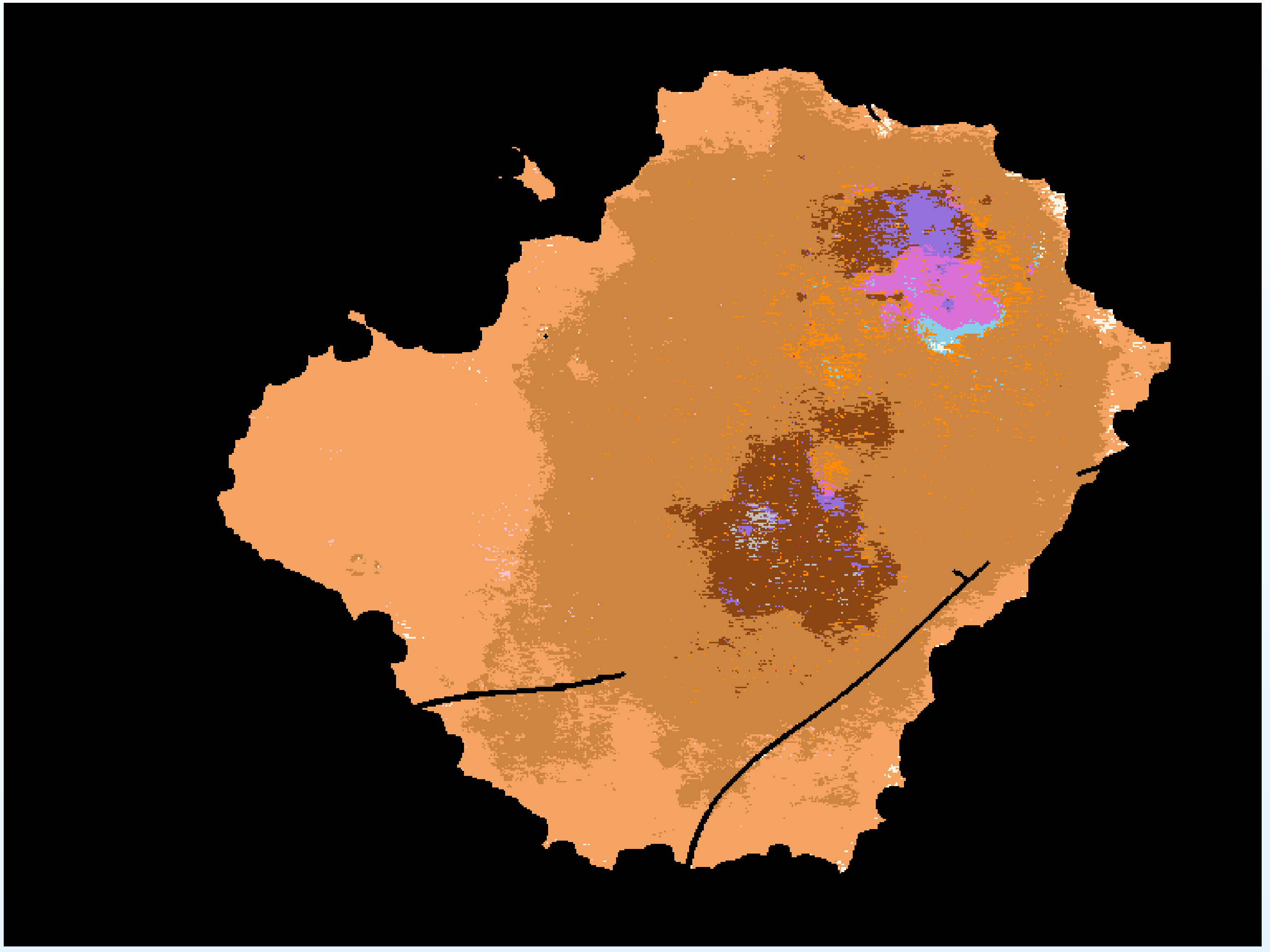
Uncalibrated lesion 2

Absolute colour segmentation



Calibrated lesion 2

Absolute colour segmentation



Colour identification for lesion 2 -> melanoma

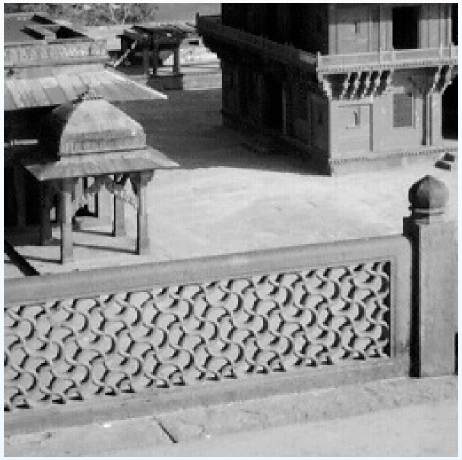
Image representation

2-D arrays of 8-bit data

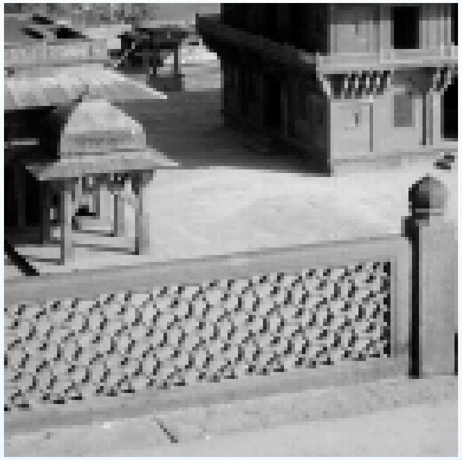
- Simplest image representation: collection of 1 (GL) or 3 (Colour) 2-D arrays of 8-bit data.
- Enough to represent most visible grey levels (256) , and most visible colours (255^3 = 16 millions).
- Most problems that occur with more dimensions, more channels, more bit depths, etc. can be illustrated within that framework.

Resolution

Resolution pyramid, influence of the spatial resolution



full



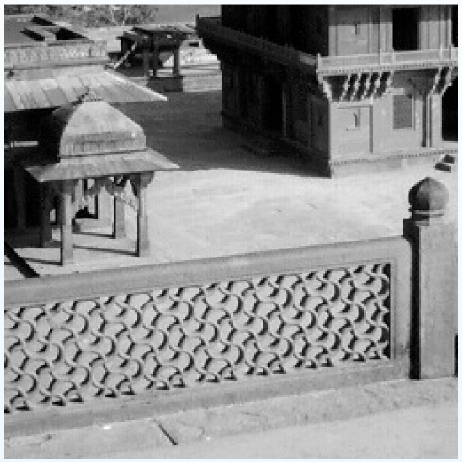
half

1/4

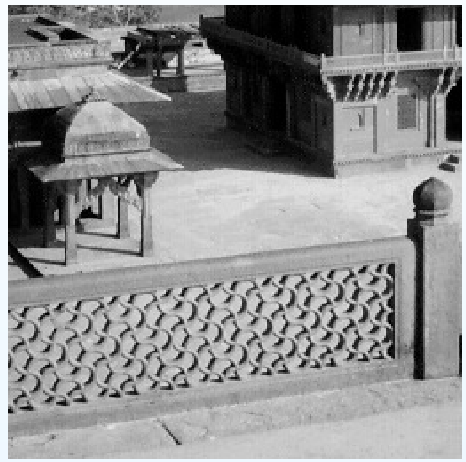
1/8

Bit depth

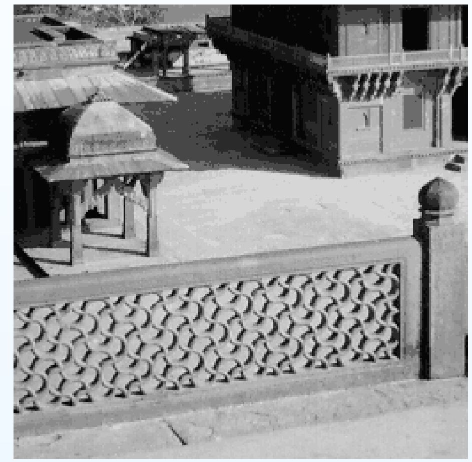
Influence of the number of grey levels.



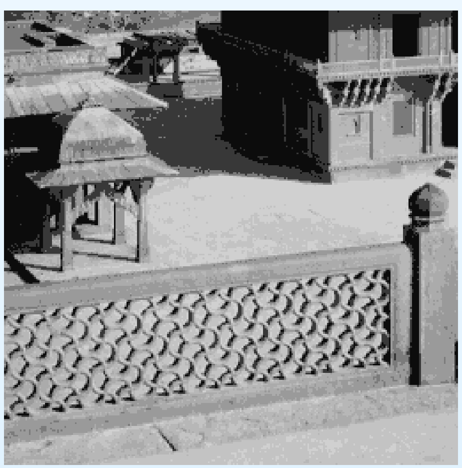
256 gl



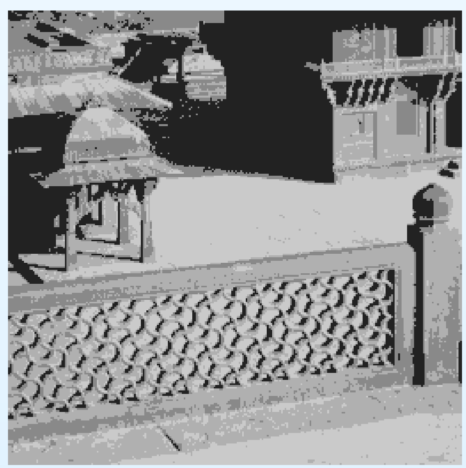
64 gl



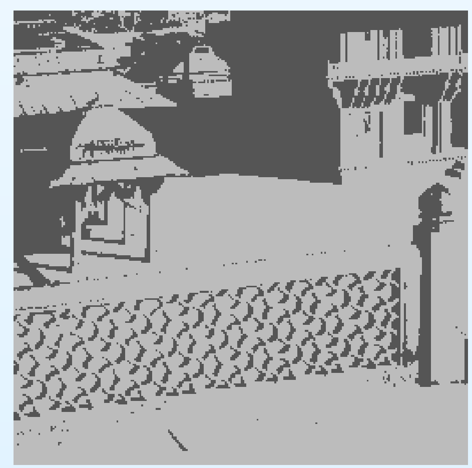
16 gl



8 gl

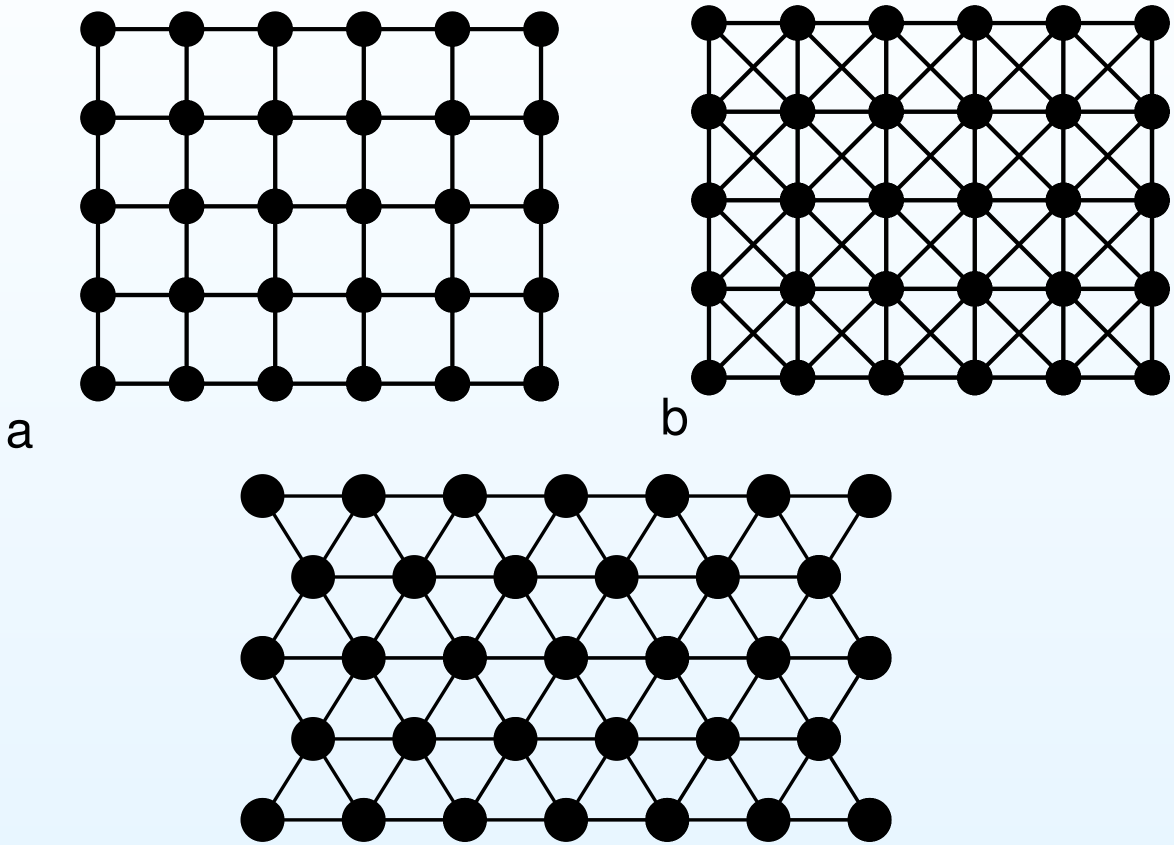


4 gl



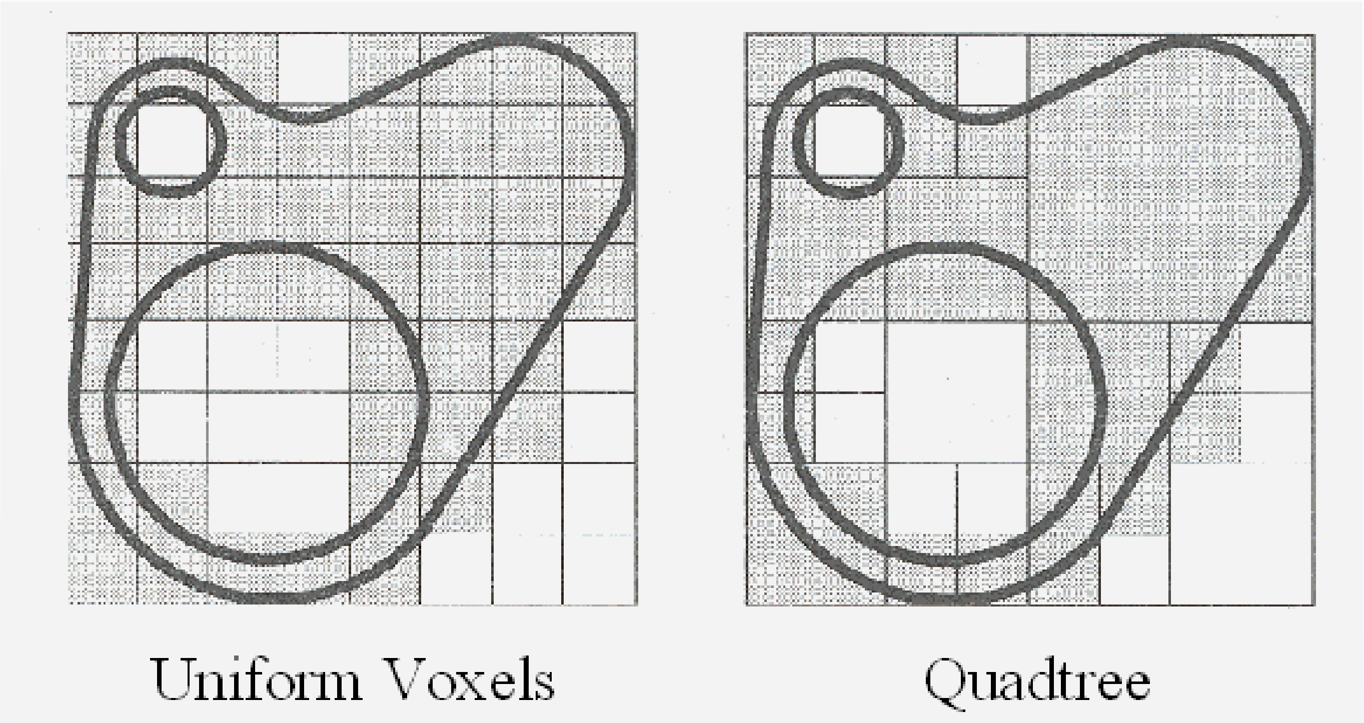
2 gl

Graph



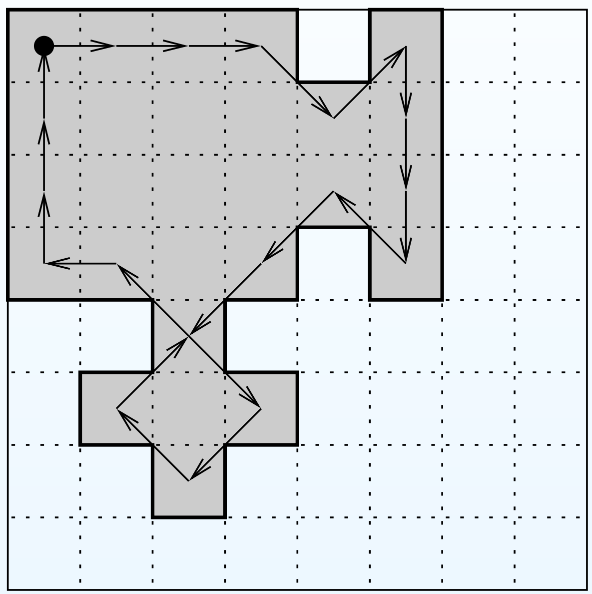
Synonym: connection graph, grid.

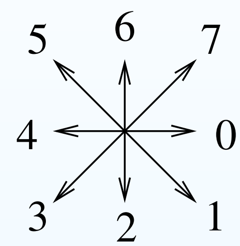
Other representations: Quadtrees



Quadtrees are a hierarchical space decomposition structure, which allow for more efficient representation than straight pixel in general. The fundamental idea behind the quadtree is that any image can be split into four quadrants. Each quadrant may again be split in four sub quadrants, etc. In the quadtree, the image is represented by a parent node, while the four quadrants are represented by four child nodes, in a predetermined order.

Other representations: Chain-coded contours





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Chain-coded contours can allow users to store shapes efficiently.

References and acknowlegements

- D.A. Forsyth and Jean Ponce, “Computer Vision, a Modern Approach”. Prentice-Hall, USA 2003.
- Marc Van Droogenbroeck. “Cours d’Analyse d’Images”. Université de Liège, 2001-2003.

- Hugues Talbot, my next-door colleague.