Visual cues – The human headway

Overlapping objects

Quantized scenes

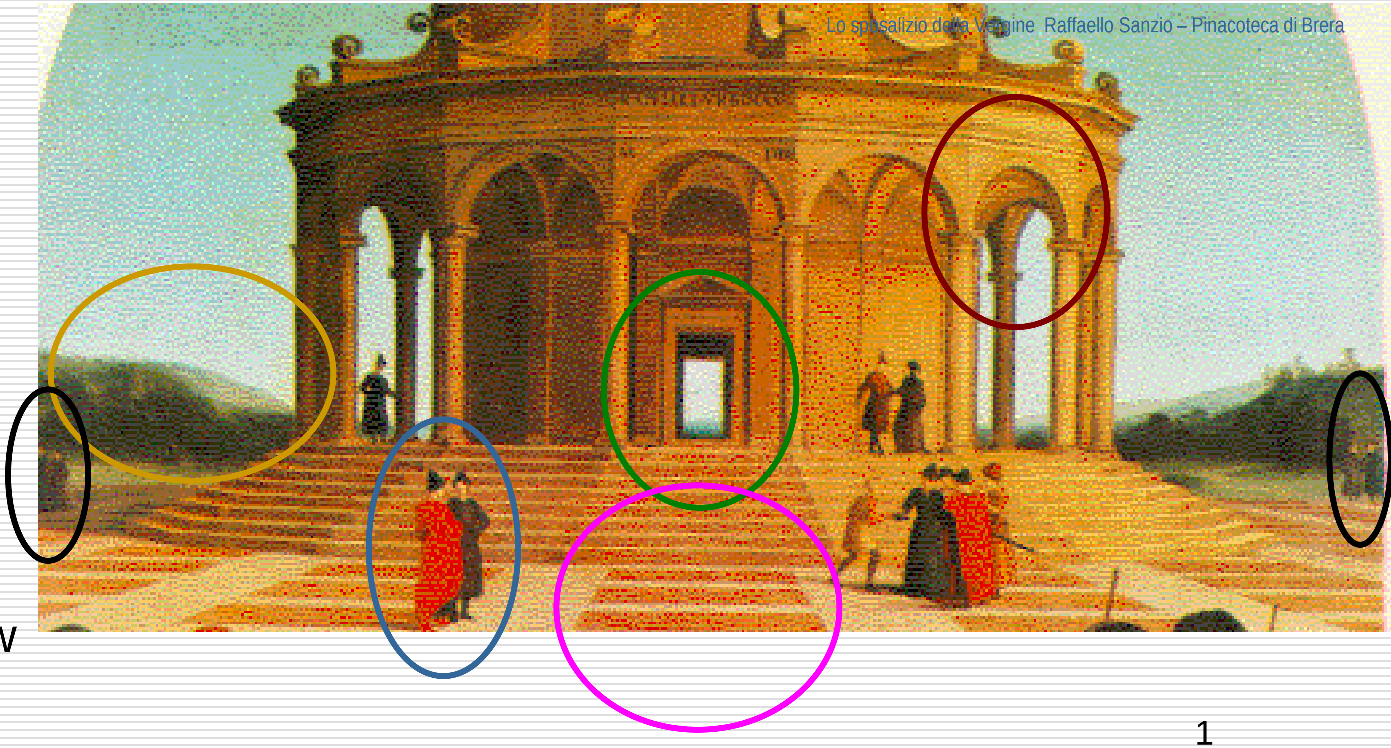
Perspective geometry

Depth from shading

Multi-presence

Depth from texture

Height in the field of view



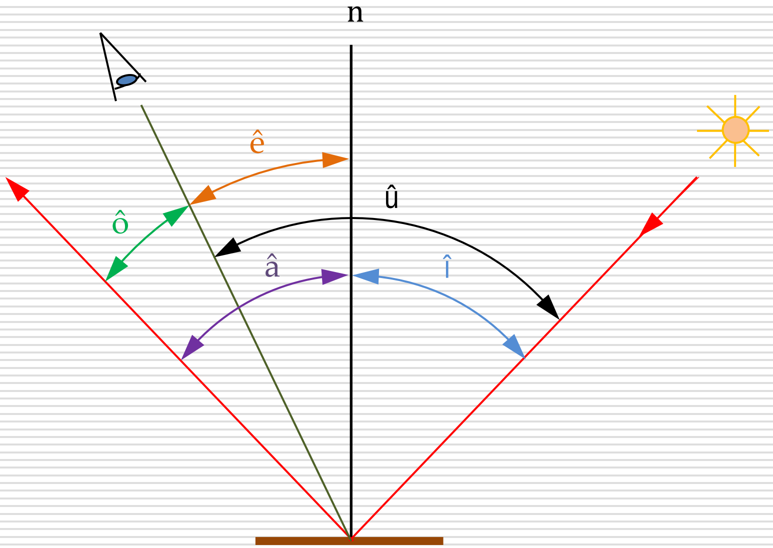
Lo sposalizio della Vergine Raffaello Sanzio – Pinacoteca di Brera

The photometric track

Michelangelo 1528

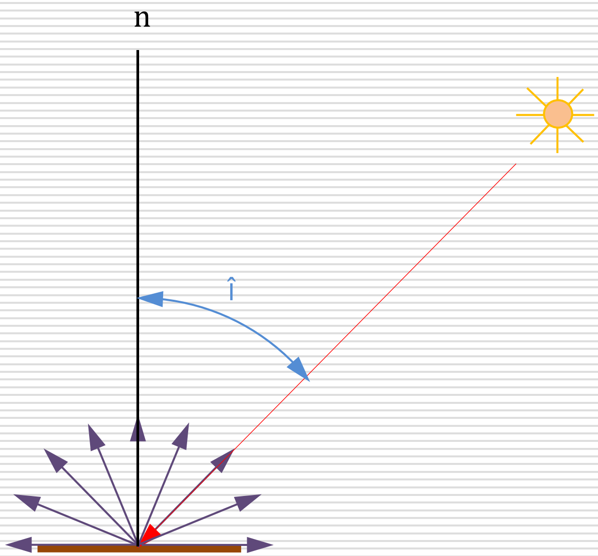
Local rendering

- Optical geometry of the light-source/eye-receiver system
- Notation:
  - n is the normal to the surface at the incidence point
  - î corresponds to the incidence angle
  - â = î is the reflectance angle
  - ô is the mirrored emergence angle
  - û is the phase angle
  - ê is the emergence angle.



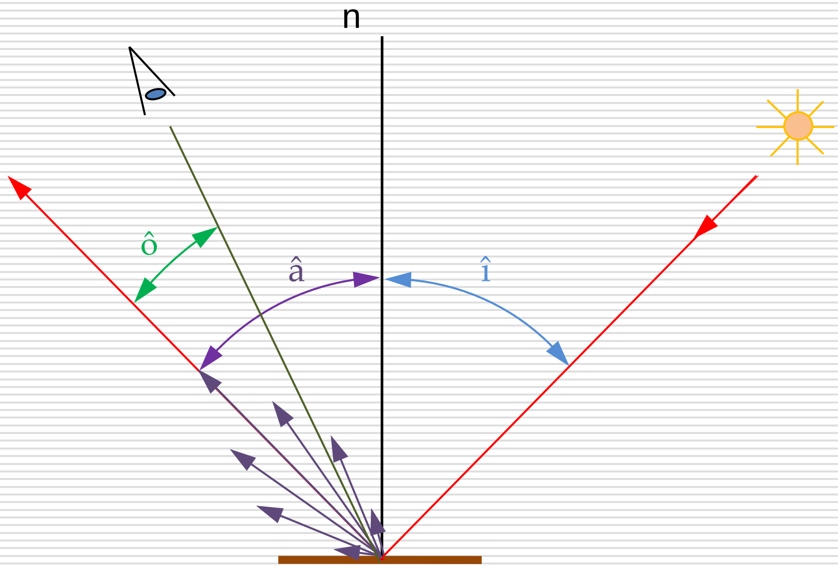
The Lambertian model

$$\Phi = \begin{cases} \cos \hat{\imath} & -\frac{\pi}{2} \leq \hat{\imath} \leq \frac{\pi}{2} \\ 0 & elsewhere \end{cases}$$



The specular model

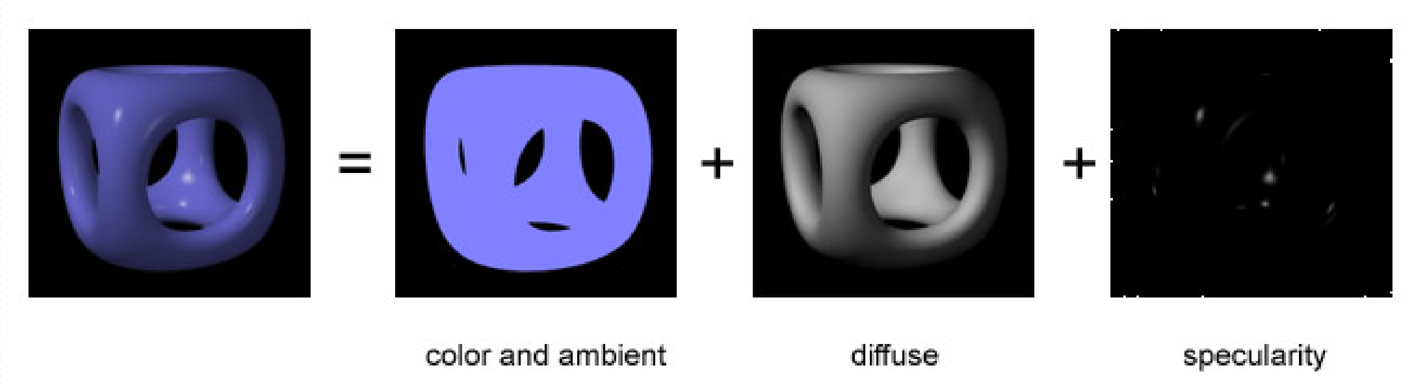
$$\Phi = \begin{cases} \cos^m \hat{o} & -\frac{\pi}{2} \le \hat{o} \le \frac{\pi}{2} \\ 0 & elsewhere \end{cases}$$



The Phong model

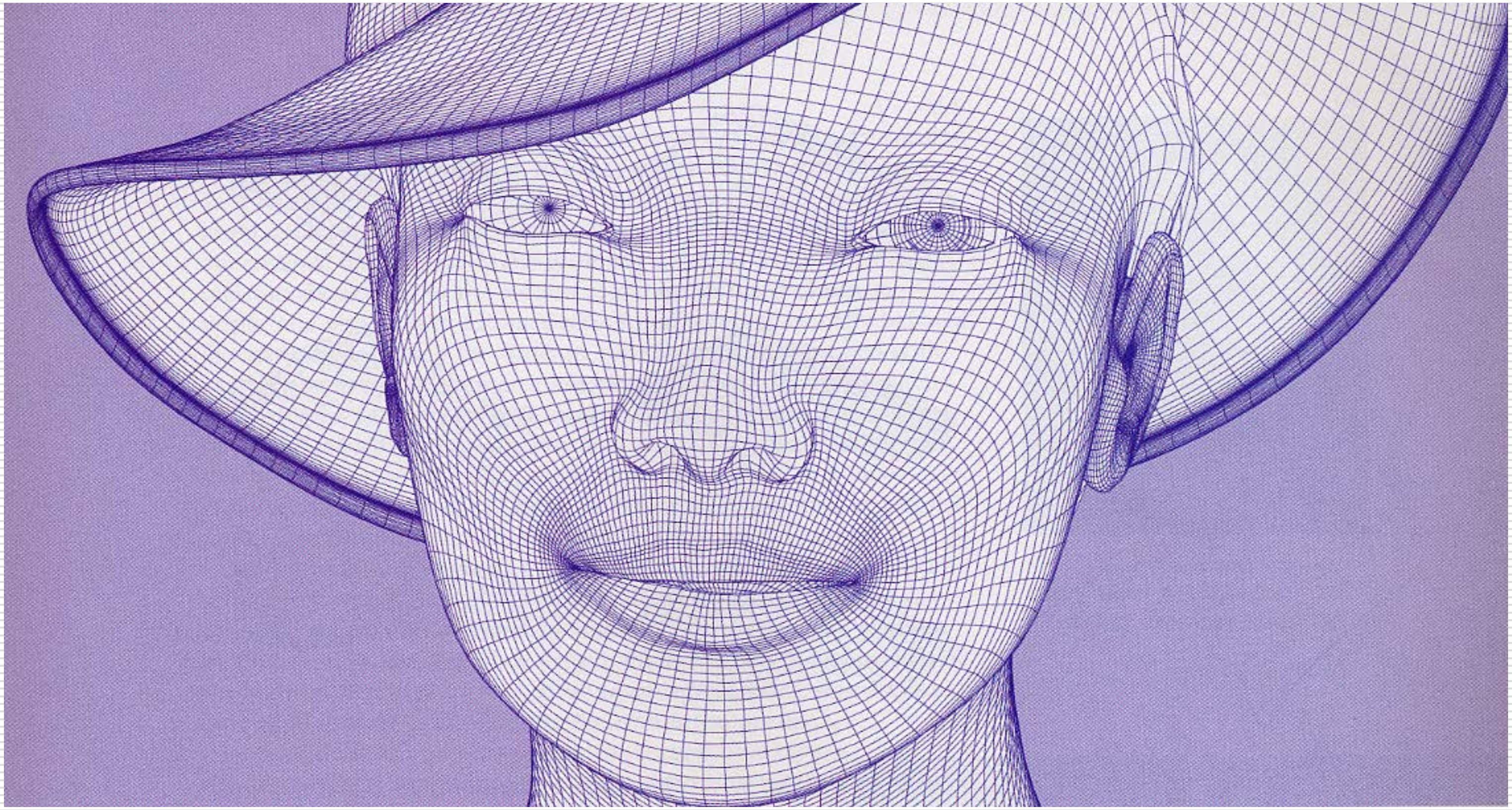
- *a* is the amount of incident light diffused according to a Lambertian model (isotropic) independent from the receiver's position
- *b* is the amount of incident light specularly reflected by the object, which depends on the phase angle, and m being the exponential specular reflection coefficient
- *c* accounts for the background illumination

$$\Phi = a\cos\hat{i} + b\cos^m\hat{o} + c$$



Bùi Tường Phong, Illumination for computer generated images, Commun. ACM 18 (6) (1975) 311317.

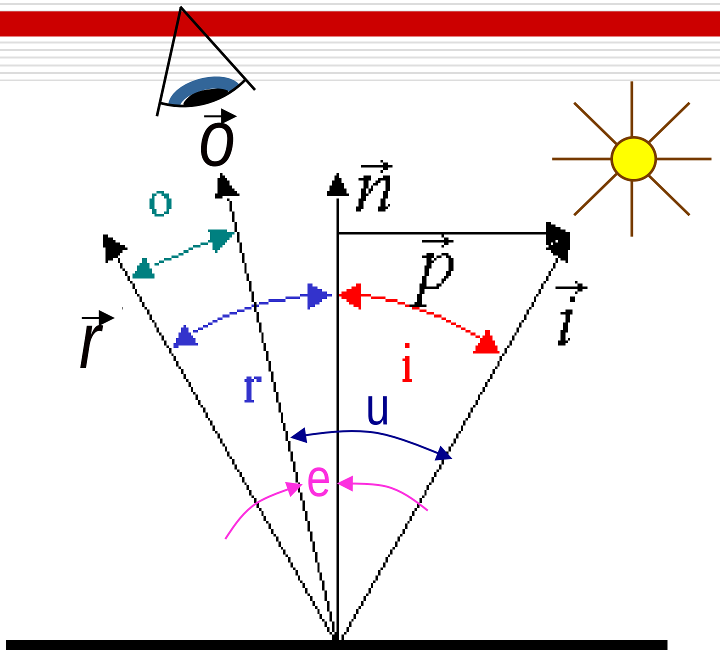
Wire frame



Local rendering

http://www.danielrobichaud.com/marlene.html?Submit=Play+Clip

The mirrored emergence angle



$$\|\vec{r}\| = \|\vec{o}\| = \|\vec{n}\| = \|\vec{i}\| = 1$$

$$(\vec{i}\,\vec{n})\vec{n} + \vec{p} = \vec{i} \rightarrow \vec{p} = \vec{i} - (\vec{i}\,\vec{n})\vec{n}$$

$$\vec{r} = \vec{i} - 2\vec{p} = 2(\vec{i}\,\vec{n})\vec{n} - \vec{i}$$

$$\vec{r}\vec{o} = 2(\vec{i}\,\vec{n})(\vec{n}\vec{o}) - (\vec{i}\,\vec{o})$$

$\cos(e) = \vec{n}\vec{o}$

$\cos(o) = \vec{o}\vec{r}$

$\cos(u) = \vec{o}\vec{i}$

$\cos(i) = \vec{i}\,\vec{n}$

cos (o) = 2 cos (i) cos (e) - cos (u)

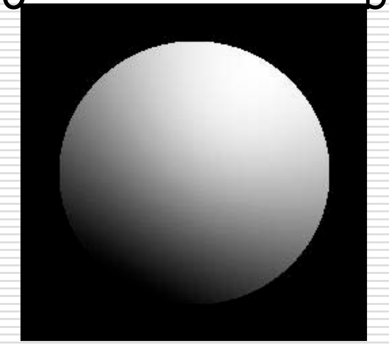
Reflectance maps

- Let us take a reference system where the optical axis of the acquisition system (the receiver) coincides with the z axis.
- The surface described by the function z = f(x, y) has the normal vector: $(\partial z/\partial x, \partial z/\partial y, -1)^t$.
- Calling $p=\partial z/\partial x$ and $q=\partial z/\partial y$ there is a one-to-one correspondence between the plane p, q (called *gradient plane)* and the normal directions to the surface.
- The three angles î, û and ê may be computed with the following formulas:

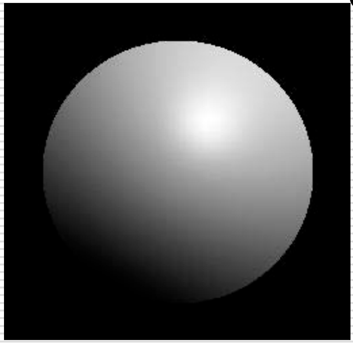
$$\cos \hat{\imath} = \frac{1 + pp_s + qq_s}{\sqrt{1+p^2+q^2}\sqrt{1+p_s^2+q_s^2}} \qquad \cos \hat{e} = \frac{1}{\sqrt{1+p^2+q^2}} \qquad \cos \hat{u} = \frac{1}{\sqrt{1+p_s^2+q_s^2}}$$

Sphere (m=10, c=0)

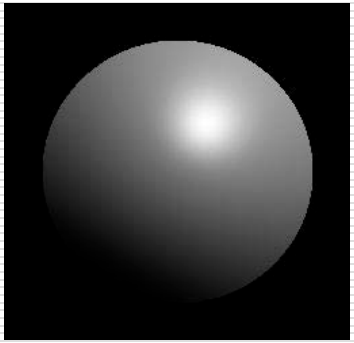
a=1.0 b=0.0



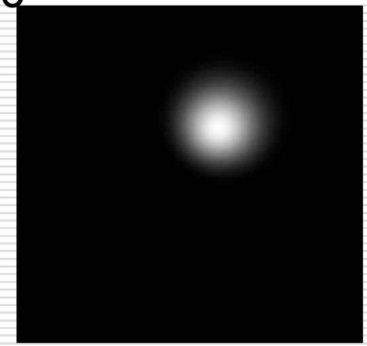
0.8 0.2



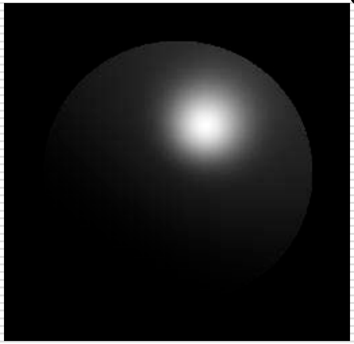
0.6 0.4



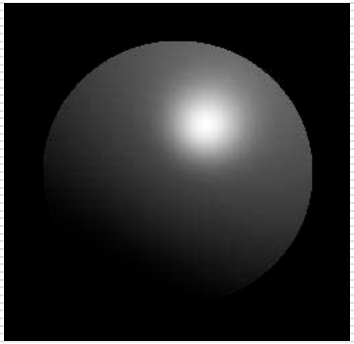
0.0 1.0



0.2 0.8

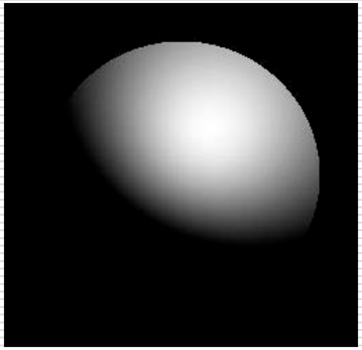


0.4 0.6

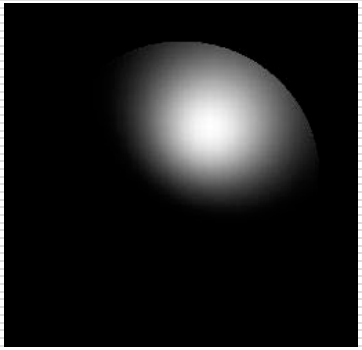


Specular sphere (b=0.9, c=0.1)

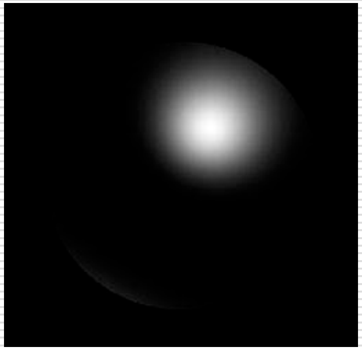
m=1



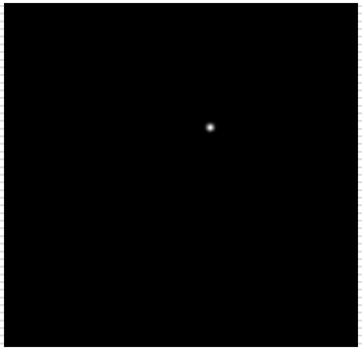
m=3



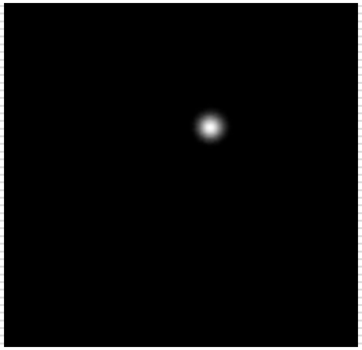
m=6



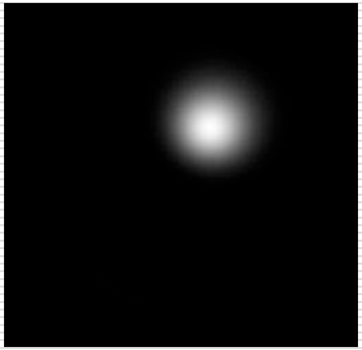
m=1000



m=100

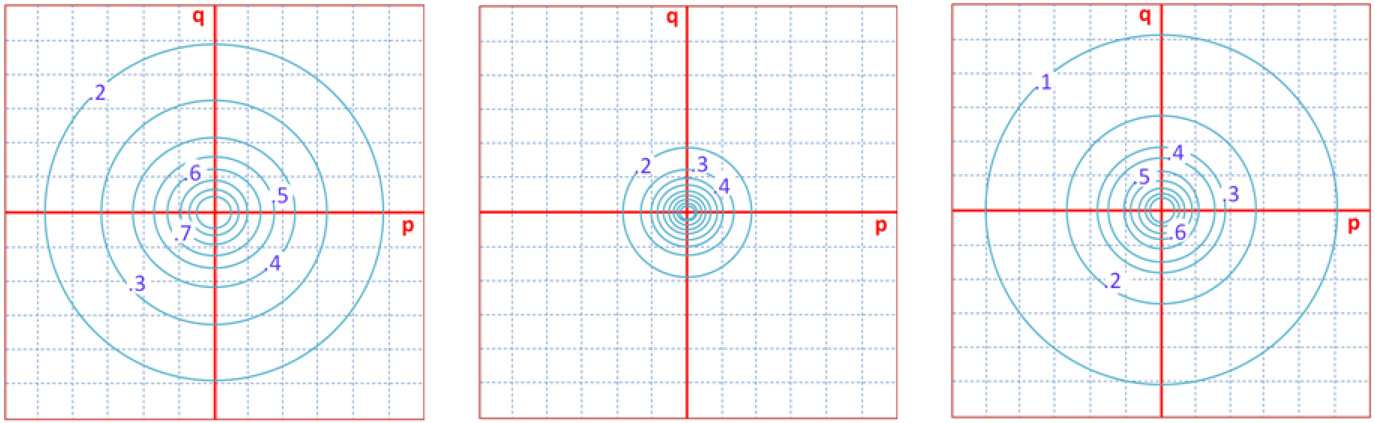


m=10



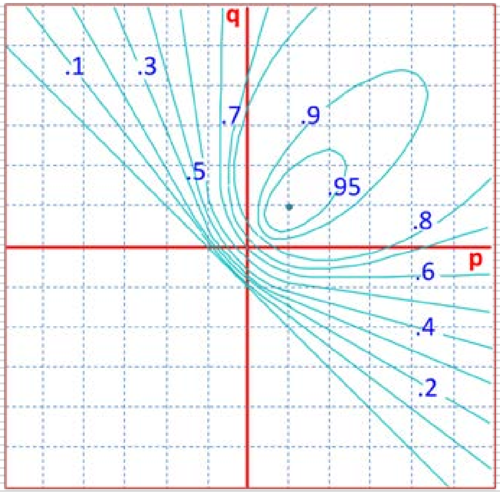
Reflectance maps

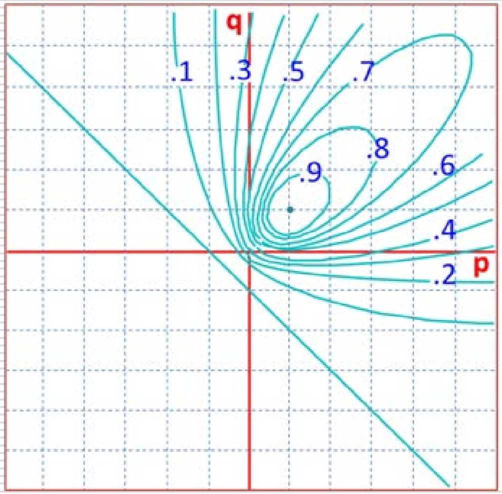
- a) reflectivity map for a Lambertian case having both camera and light source coincident with the z-axis (0, 0, -1);
- b) the specular case having the specularity index m=3;
- c) an intermediate case with a = b = 0.5, m=3 and c = 0



Reflectance maps

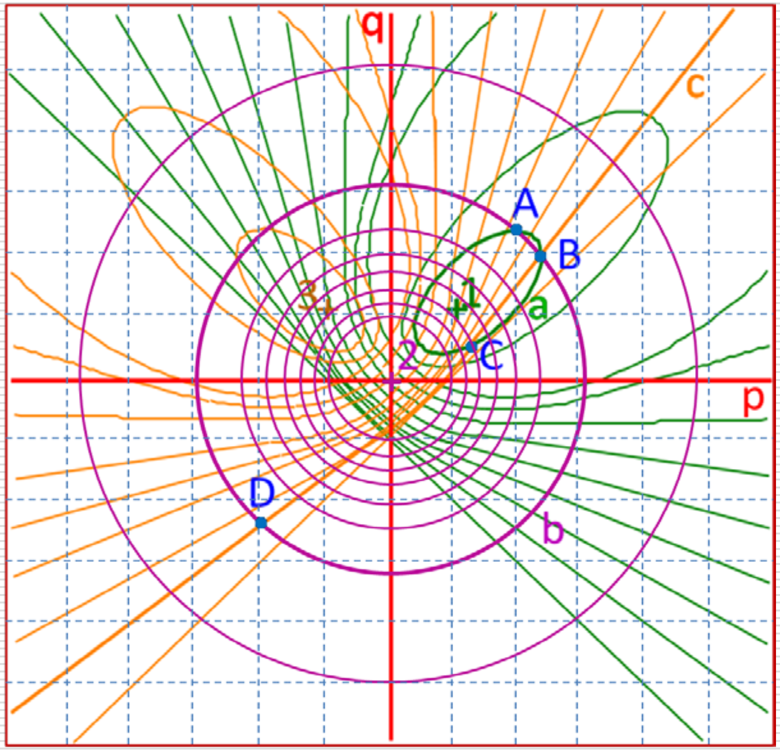
- a) Reflectivity map for a Lambertian model; having the camera on the z-axis (0, 0, -1) and the light source positioned at (1, 1, -1). The isoluminance patterns are quadrics labelled with their corresponding ratios, the incident light source corresponds to the bisector of the first octant in 3D space.
- b) Reflectivity map for a specular model having the specularity index is m = 3.





Photometric analysis

- Overlapped isoluminance patterns, for the Lambertian model, with three different positions of the light source used [(1,1,-1), (0,0,-1), (-1, 1,-1)] for determining the attitude of an object's facet.



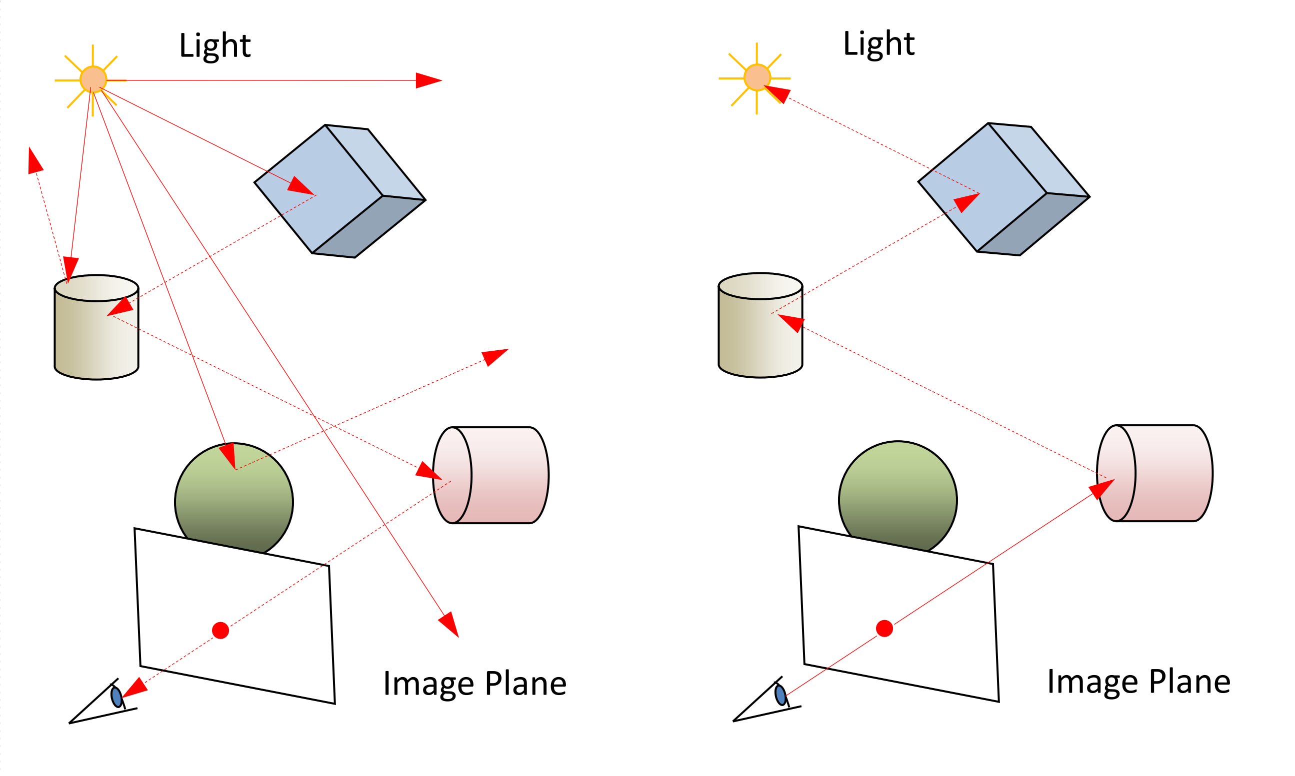
Φ_1=0,95

Φ_2=0,3

Φ_2=0,1

Global rendering: ray tracing

- The two basic schemes of forward and backward ray tracing, this is last is computationally efficient but and cannot properly model diffuse reflections and all other changes in light intensity due to non-specular reflections



Global rendering: ray tracing

- A ray sent from the eye to the scene through the image plane may intersect an object; in this case secondary rays are sent out and three different lighting models can be considered:
  - *transmission*. The secondary ray is sent in the direction of refraction, following the Descartes'law;
  - *reflection*. The secondary ray is sent in the direction of reflection, and the Phong model is applied;
  - *shadowing*. The secondary ray is sent toward a light source, if intercepted by an object the point is shadowed, if it reaches the source the ray is not considered anymore.

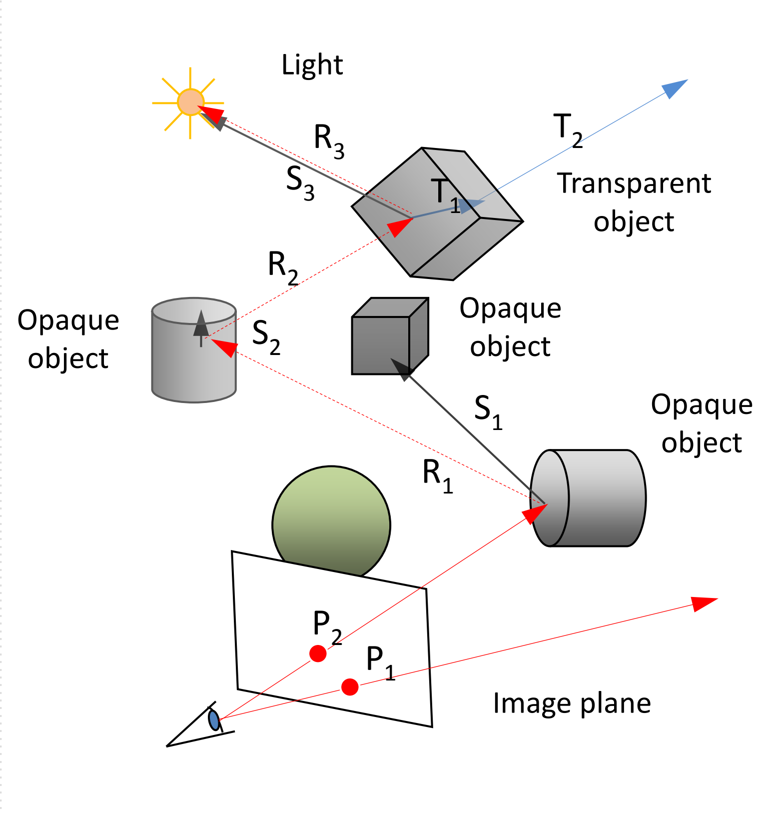
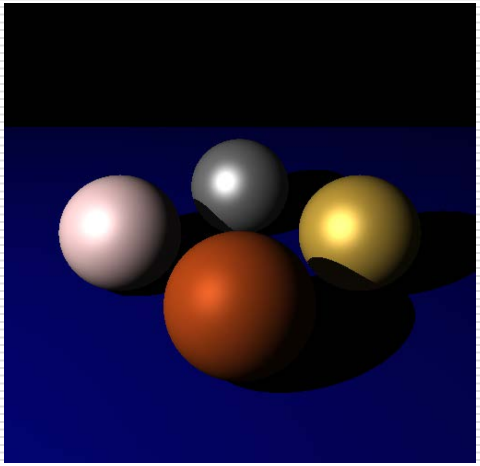
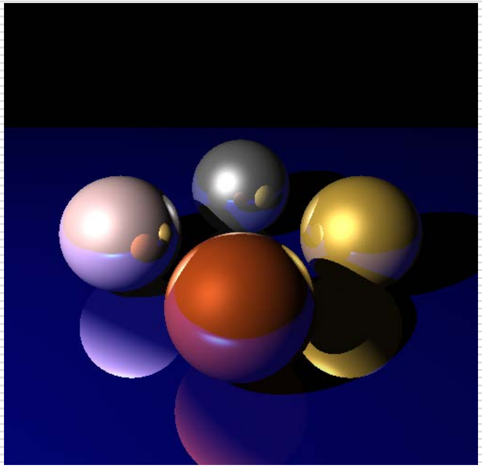


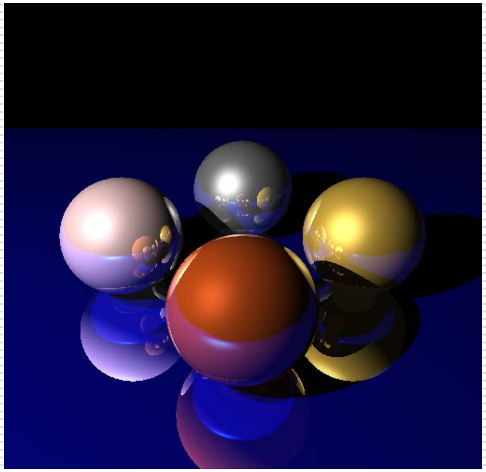
Figure. A background pixel corresponding to the ray P_1 and a pixel representing an object (ray P_2). The secondary rays triggered by the primary ray P_2 according to the three models: transmission (T_1 and T_2), reflection (R_1, R_2 and R_3), and tentative shadowing (S_1, S_2: true shadows, and S_3).

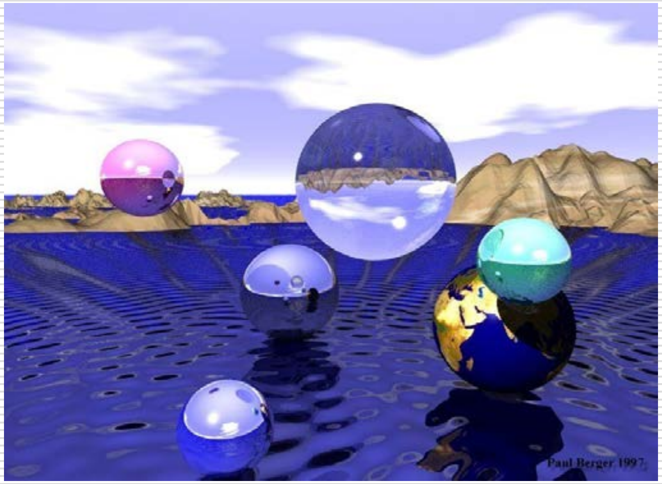
Reflections and transparencies

Created by David Derman – CISC 440

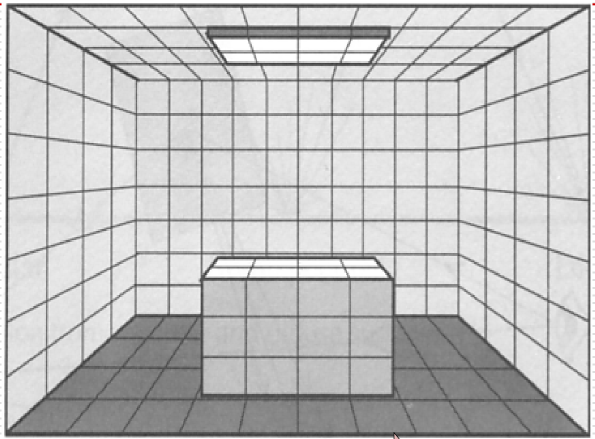








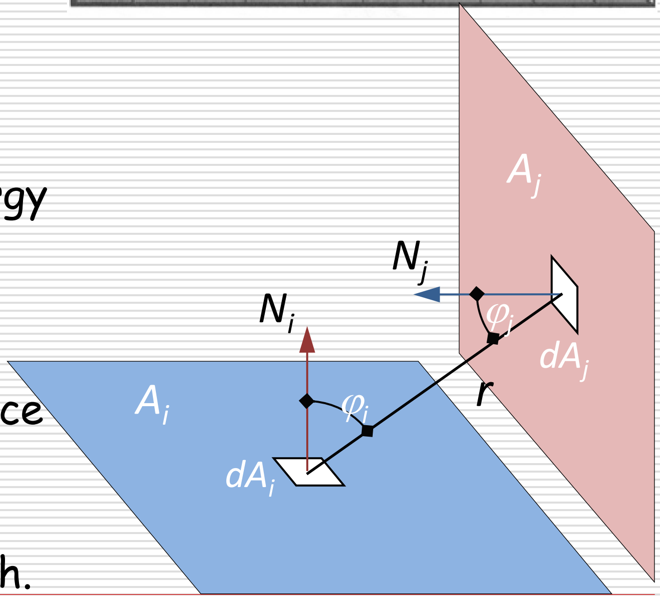
Global rendering: radiosity



- The **radiosity** method has been developed to model the diffuse-diffuse interactions so gaining a more realistic visualization of surfaces.
- The diffused surfaces scatter light in all directions (i.e. in Lambertian way). Thus a scene is divided into *patches* - small flat polygons. For each patch the goal is to measure energies emitted from and reflected to respectively. The radiosity of the patch *i* is given by:

$$B_i = E_i + \rho_i \sum_{j=1}^{n} B_j F_{ij}$$

- Where E_i represents the energy emitted by patch i, ρ_i the reflectivity parameter of patch i, and $\sum_{j=1}^{n} B_j F_{ij}$ the energy reflected to patch i from the n patches j around it, depending on the *form factors* F_{ij}.
- The form factor represents the fraction of light that reaches patch *i* from patch *j*. It depends on the distance and orientation of the two patches.
- A scene with *n* patches, follows a system of *n* equations for which the solution yields the radiosity of each patch.



Example

A comparison by Ledah Casburn

…. Phong model

- No objects interactions
- No shadows

… ray tracing

- is there a corner?
- is the window in depth?
- is the floor properly rendered?

.. radiosity

- there is a corner
- the window is in depth
- floor and walls are clearer and pink

Exemples

Award winning examples…
July-August 2000

Norbert Kern - trace 101 h 18 min (AA 0.1)   Machine - 1,4 GHz Athlon C / 1 GB RAM

Award winning examples…
January-February 2002

Stephen M. Farrell - trace 2d 4h 43m 30s Machine - 1.4 GHz Thunderbird; 512 MB RAM

The betrothal of the Arnolfini

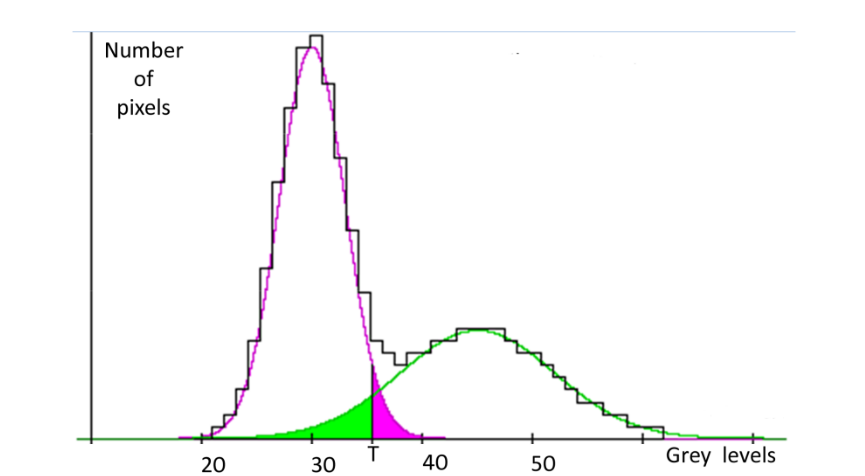
Jan Van Eyck 1434, National Gallery, London

Examples

Intensity re-distribution and rendering

- An image histogram has in the abscissa the pixel grey (or color) value while the ordinate plots the number of occurrences of such value.
- Such histogram may be manipulated so as: to obtain a sharper image, to highlight some chromatic distributions, to correct over or under exposed images, to optimize the contrast distribution, etc..
- The information conveyed by histogram is limited to the first order statistics, corresponding to the number of pixels having a given grey value, or color component. Working on the histogram, gross level repartitions can be extracted such as dark vs. bright parts dominant levels (e.g. local maxima) up to splitting the histogram into a conjunction of bounded repartitions.
- In order to distinguish automatically an object from its background a typical approach is:

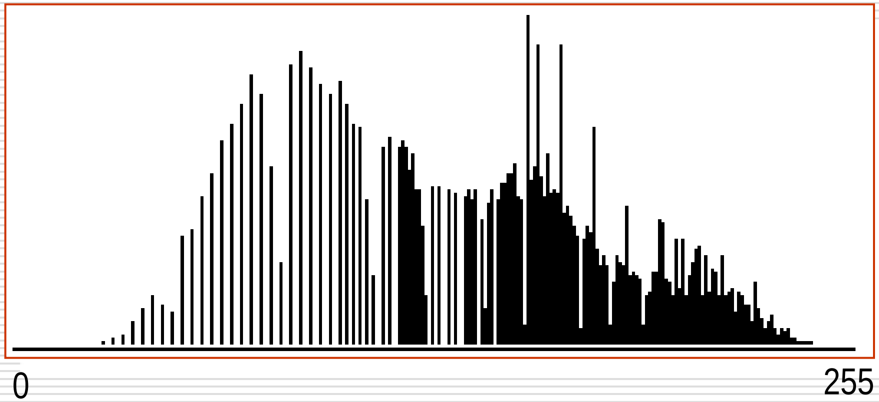
- i) firstly produce the grey level histogram (this process applies on the RGB components as well);
- ii) find the best bi-Gaussian fit to the histogram distribution;
- iii) compute the threshold T by minimizing the misplaced pixels (either background pixels in the foreground or vice-versa). The misplaced pixel are represented by the green (levels approximately between 25 and T) and magenta (levels between T and 40) values respectively



Original image

- Image: History of Saint Peter by Masaccio, around 1427, Church of the Holy Spirit, Florence

- Histogram

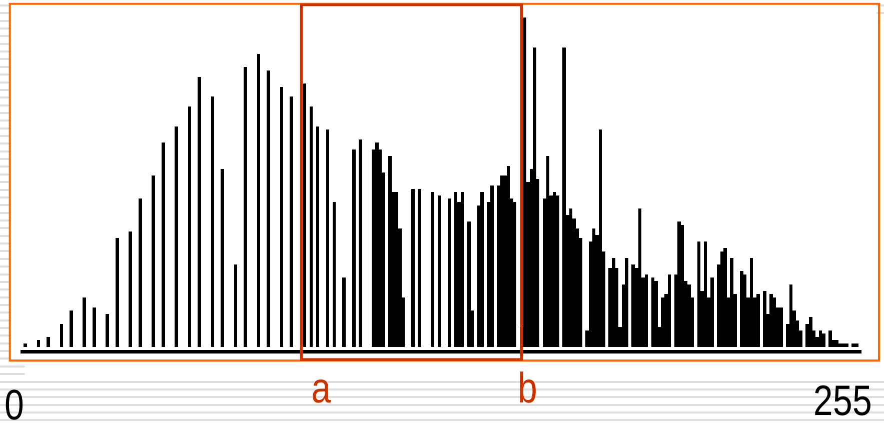


Extended dynamics

- To profit from the full grey level scale, note that very clear and dark pixels are absent, the pixel distribution may extended by stretching with the following formula:

$$g(i,j) = 255 - \frac{g(i,j) - g_{\mathbf{min}}}{g_{\mathbf{max}} - g_{\mathbf{min}}}$$

where g_{max}, and g_{min} correspond to the maximum and minimum grey levels respectively, and 255-0 is the whole available grey level scale.

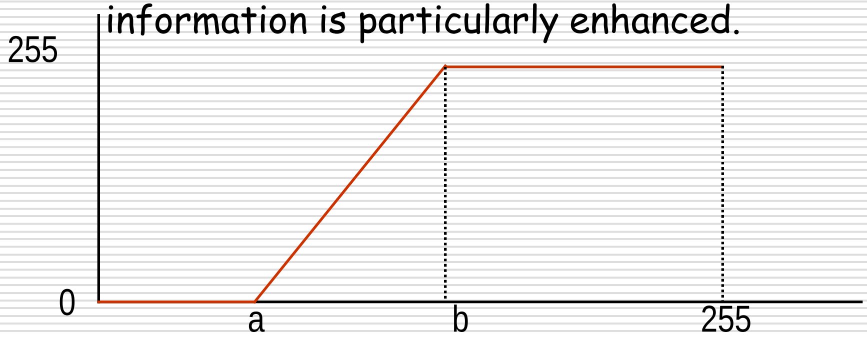


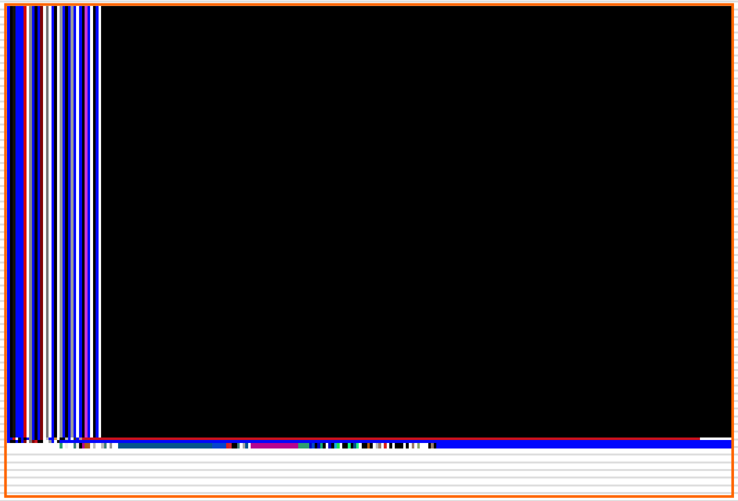
Stretching of a range in grey scale

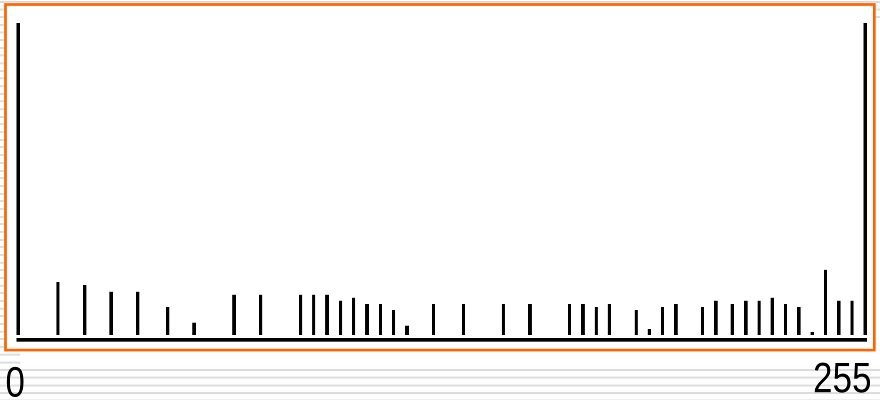
- To enhance significant details in the image the whole dynamics can be concentrated on a given interval [a, b] of the grey scale; then a linear transformation inside the interval can be computed by:

$$g(i,j)=\begin{cases} 0 & \text{if} \quad g(i,j)\le a \\ 255-\dfrac{g(i,j)-a}{b-a} & \text{if} \quad a\le g(i,j)\le b \\ 255 & \text{if} \quad g(i,j)\ge b \end{cases}$$

- This process produces the maximal contrast on the interval [a,b] of the grey scale. Considering this chosen interval no specific information is particularly enhanced.



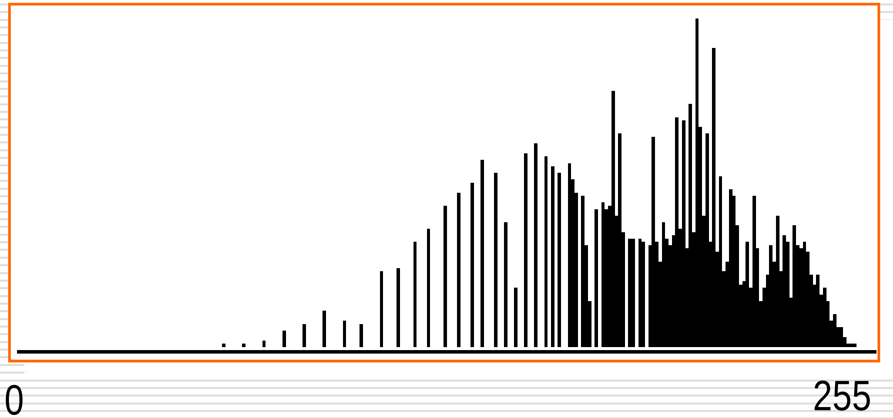




Under-exposure

- To compensate or even create lighting effects as, for instance, under-exposure, a non linear transformation of the grey levels can be performed by:

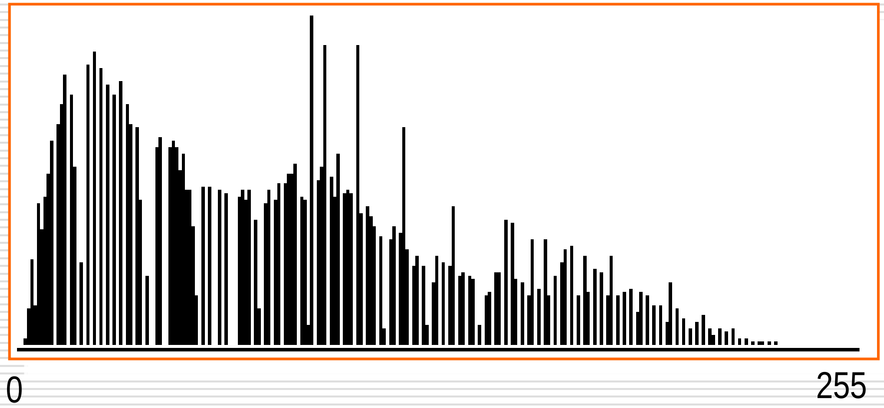
$$g(i,j) = \sqrt{255 g(i,j)}$$



Over-exposure

- To compensate or even create lighting effects as, for instance, over-exposure, a non linear transformation of the grey levels can be performed by:

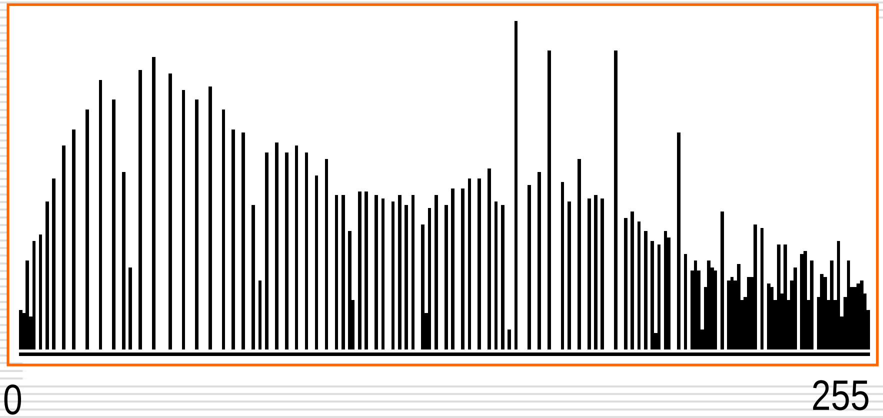
$$g(i,j) = \frac{g(i,j)^2}{255}$$



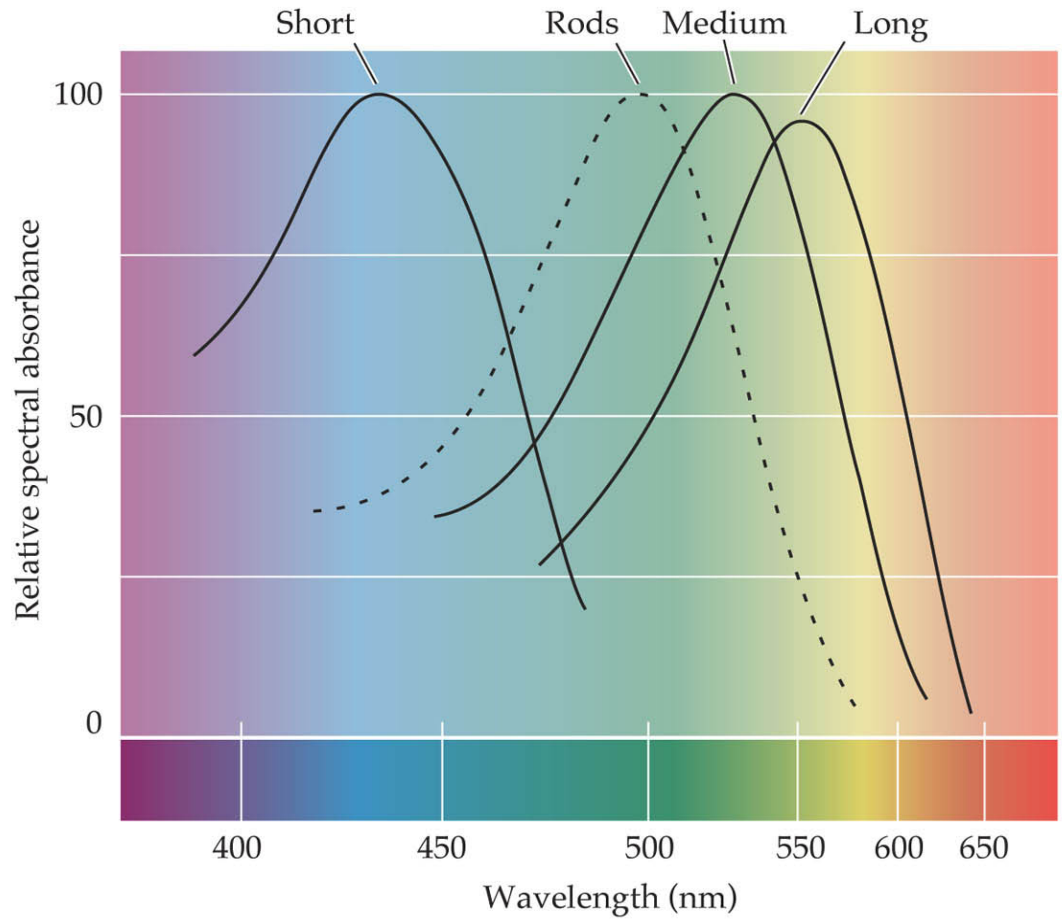
Uniform distribution

- To obtain a *uniform distribution* of image contrast a technique known as *equalization* is employed. This technique consists in making the empiric grey level distribution as close as possible to a uniform distribution, in an adaptive way. The more uniform is a grey level distribution, the better contrasted is the associated image – i.e. *maximal entropy*.

$$g'(i,j) = 255 \frac{\sum_{s=0}^{g(i,j)} h(s)}{\sum_{s=0}^{255} h(s)}$$



Human eye color sensors:
Types of Cones



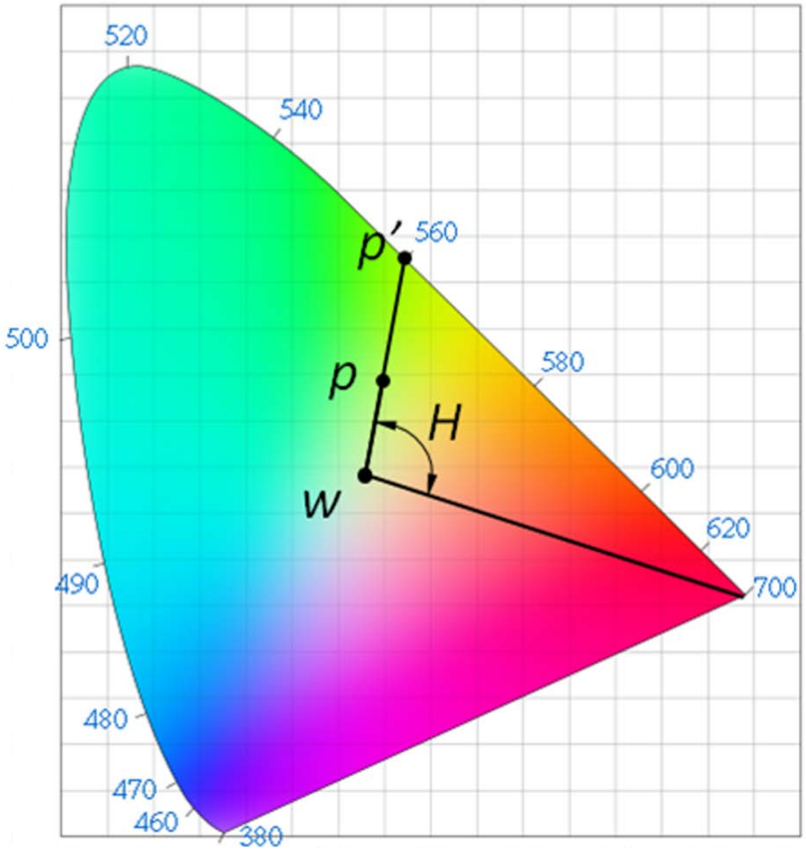
NEUROSCIENCE, Third Edition, **Figure 10.12**

Color representation

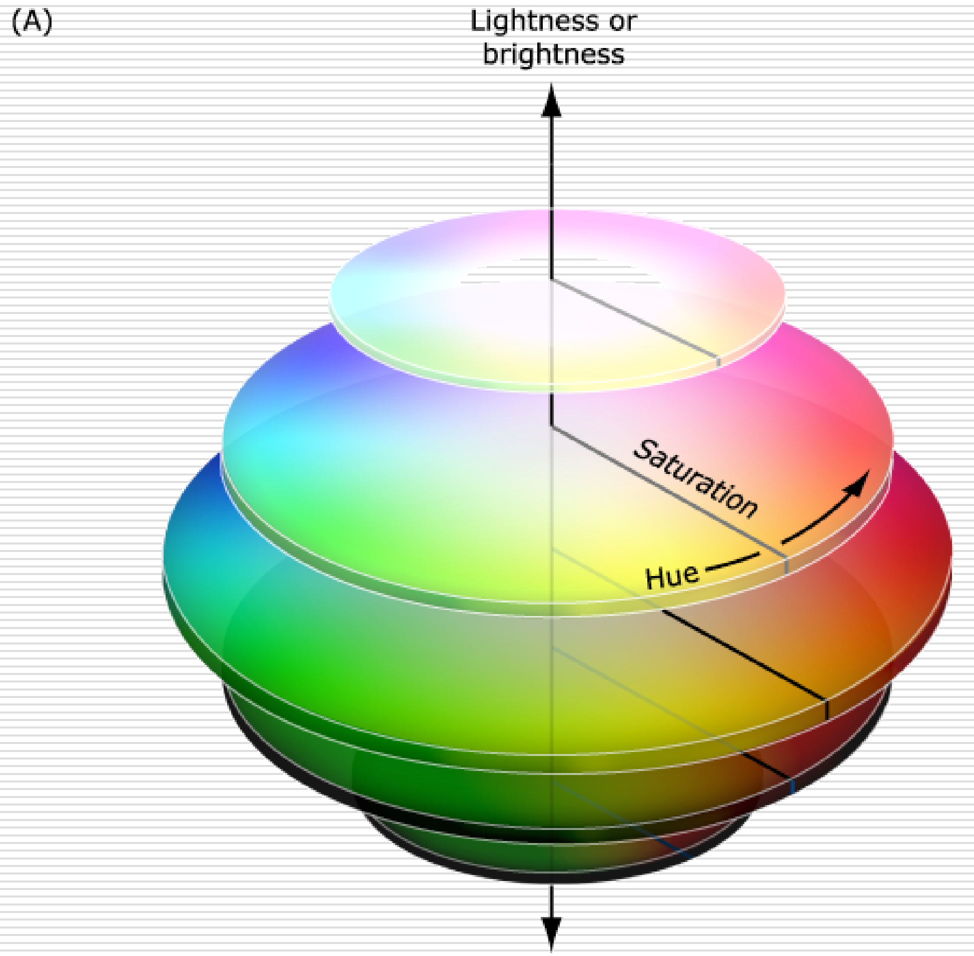
$$C = G + B \quad M = B + R \quad Y = R + G$$

$$C + R = M + G = Y + B = White$$

- The models of color perception are firstly based on *primary colors*, **R**ed, **G**reen, **B**lue (RGB).
- Color-mixing works differently, depending whether a camera (receiver) or a TV set (emitter) is considered: this leads to the triplet of secondary colors **C**yan, **M**agenta, **Y**ellow (CMY) which forms a basis for pigments.
- The color triangle (originated from **physiological experiments**) represents the white color in the centre, and the locus of monochromatic colors on the border.
- The **H**ue (first chromatic variable) is given by the angle between a color ***p*** and the ray connecting the corner 700 nm.
- The **S**aturation, i.e. the ratio ***wp/wp'***, where ***p'*** represents the pure color perceived for that given wavelength.
- The grey scale (**I**ntensity) cannot be else than perpendicular to the triangle plane.
- This representation gave rise to a simple linear model and formulas to convert the R,G,B into the H,S,I one.



Color Qualities:
Hue, Saturation and Brightness



NEUROSCIENCE, Third Edition, Figure 10.12

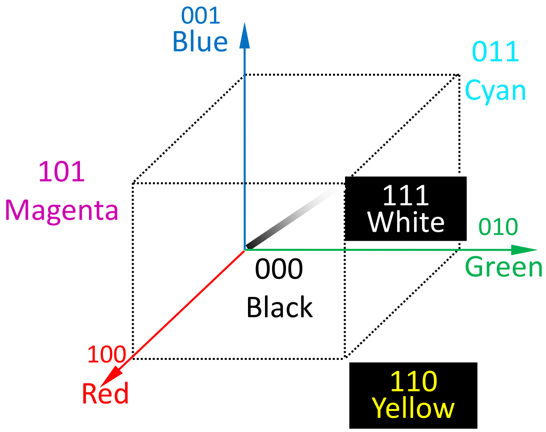
R,G,B convertion into H,S,I

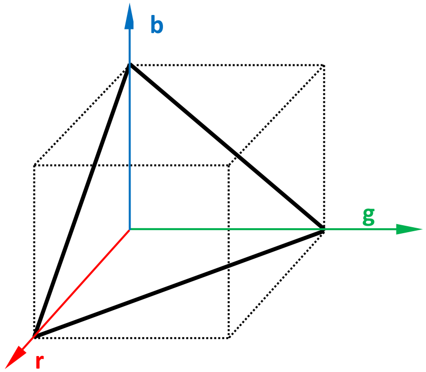
- to normalize the intensity, all variables are divided by the sum R+G+B, e.g. r = R/(R+G+B).
- The **I**ntensity is measured by the distance to the black. $I = \frac{R+G+B}{3}$ possibly normalized for a given Imax equal to 1.
- The **H**ue, which is an angle, is given by its cosine:

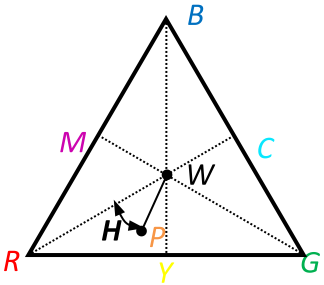
$$\cos H = \frac{\frac{1}{2}\left[(R-G)+(R-B)\right]}{\sqrt{(R-G)^2+(R-B)(G-B)}}$$

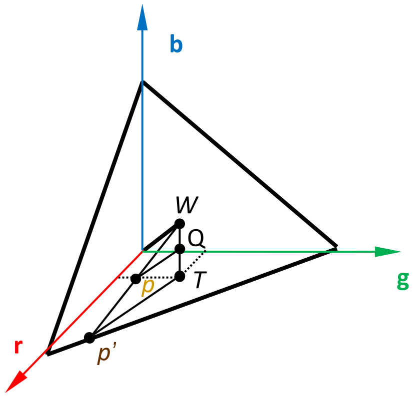
- The **S**aturation is obtained by the Thales' theorem:
  - T : projection of W in the plane (r,g), whence T = (1/3 , 1/3 , 0)
  - Q : projection of P on WT, whence Q = (1/3 , 1/3 , b)

$$S = \frac{WP}{WP'} = \frac{WQ}{WT} = \frac{WT-QT}{WT} = \frac{1/3 - b}{1/3}$$





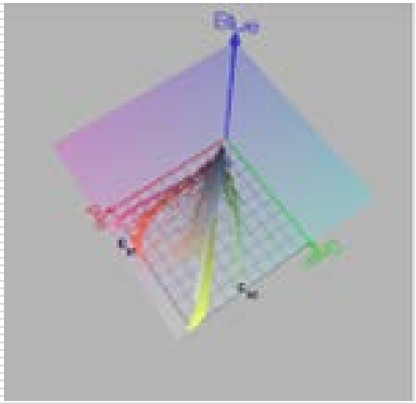
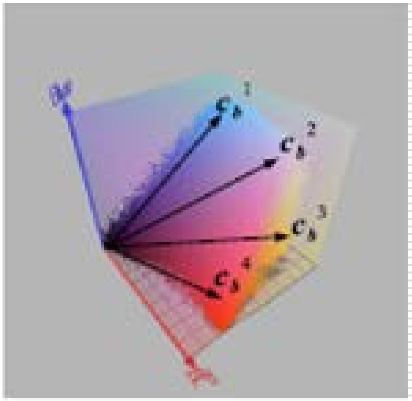




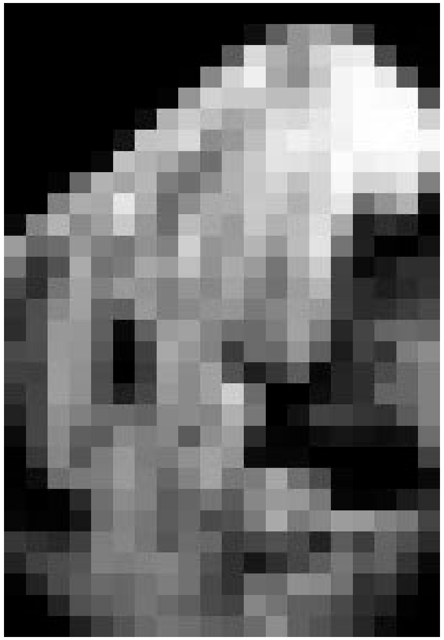
Color distribution

- Examples of natural color images and their color distribution in RGB space (colourSpace Software, available on: http://www.couleur.org).
- The color components are clearly visible in the pictures containing caps, case of monochromatic items; b) less apparent in a fine grained textured image of the baboon.



Spatial resolution

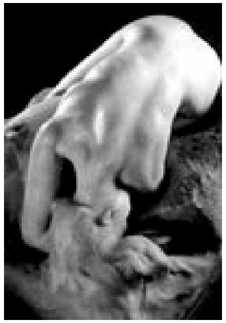



200 x 300

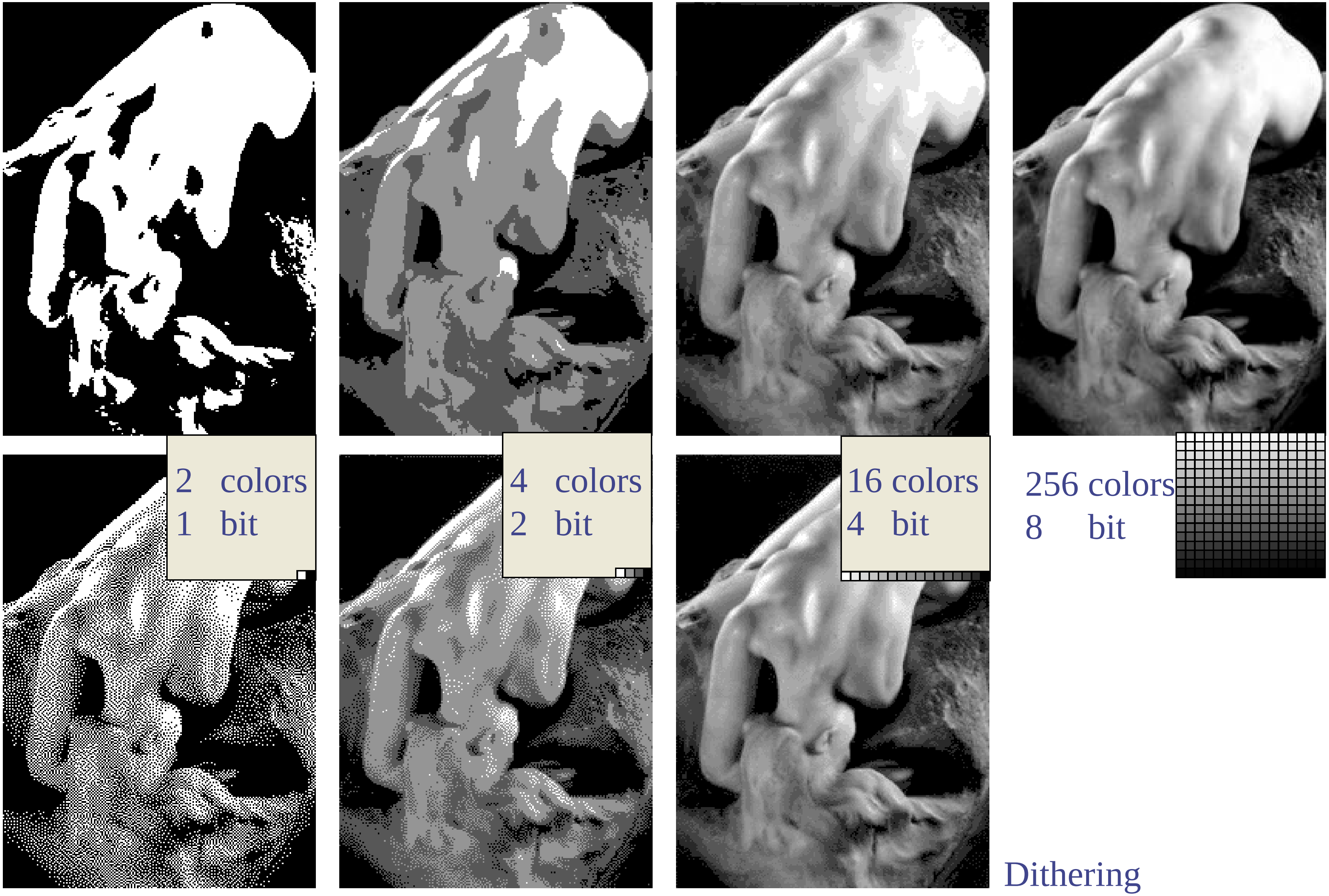
20 x 30

40 x 60

100 x 150



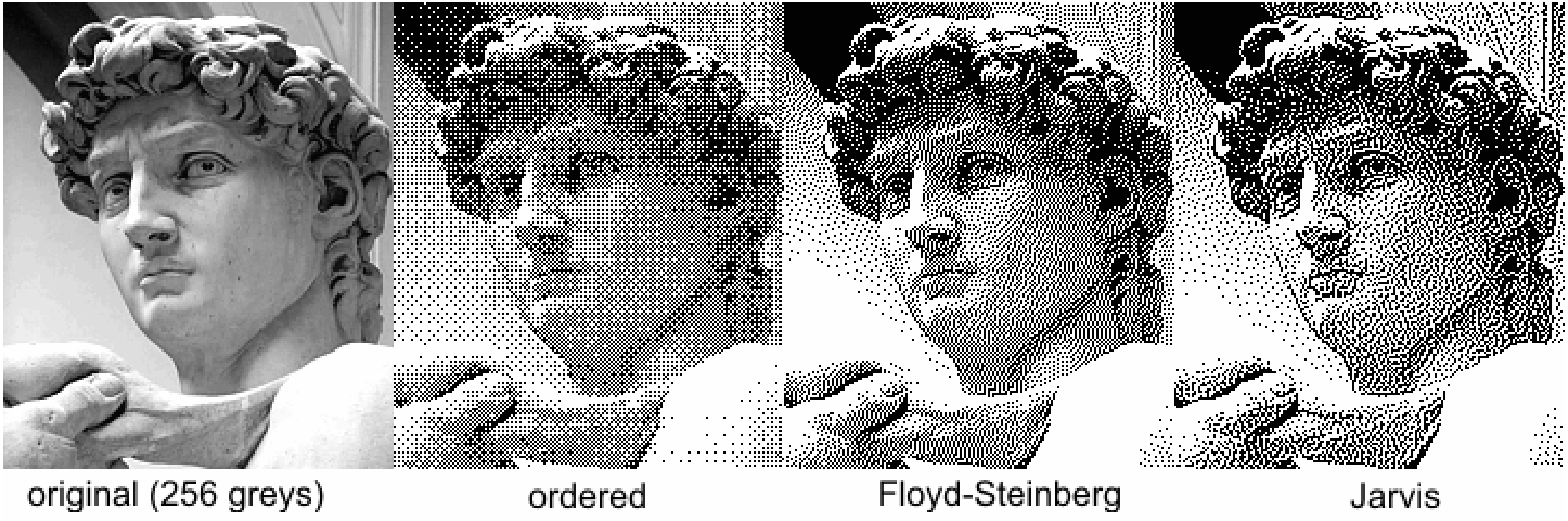
Gray level resolution



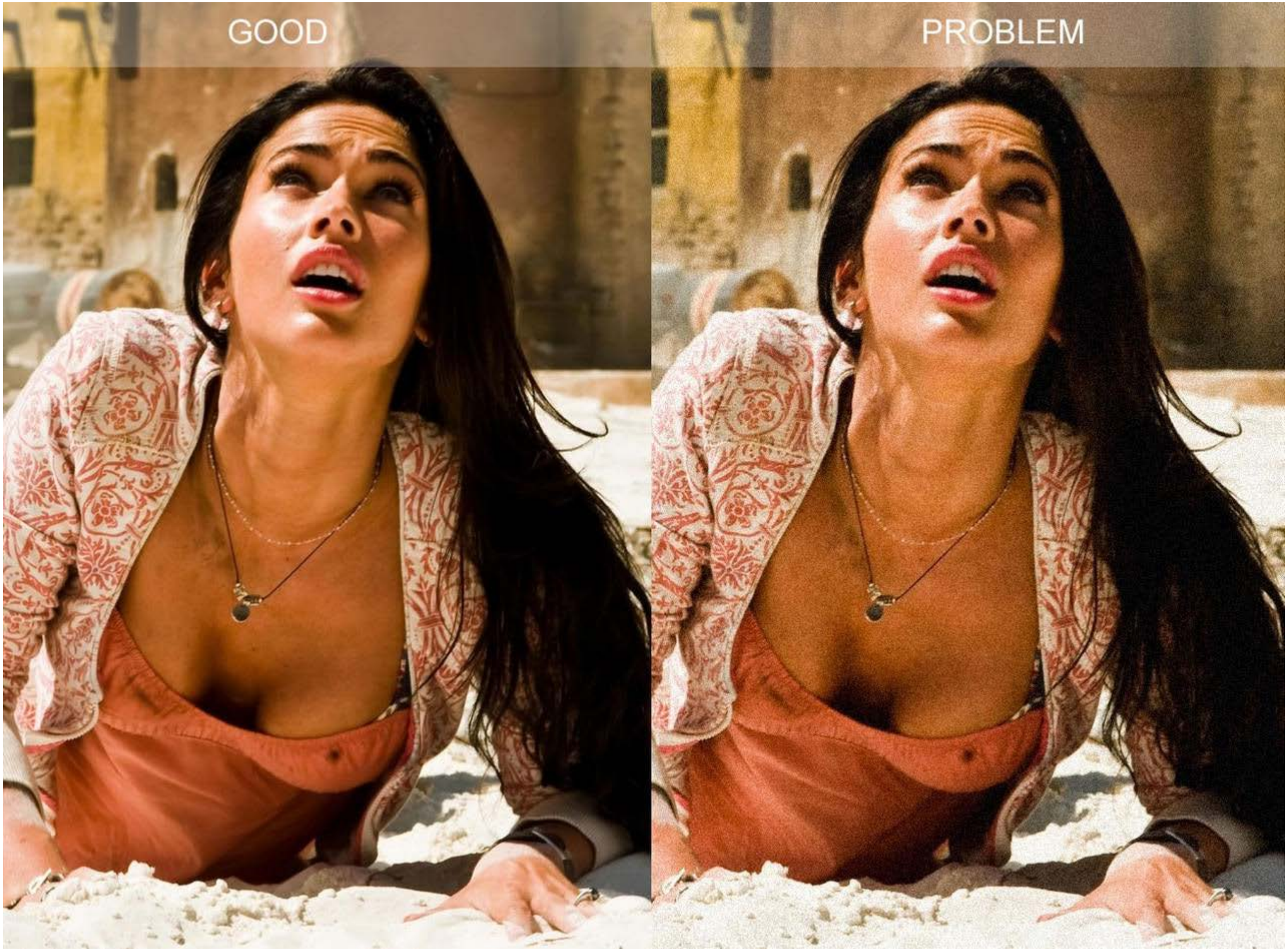
Dithering

Gray level dithering

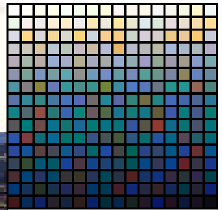
- Dither is an intentionally applied form of noise used to randomize quantization error, preventing large-scale patterns such as color banding in images.



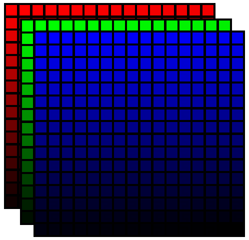
Color level dithering



Color level resolution



256 colors
8 bit



16M colors
24 bit

Dithering