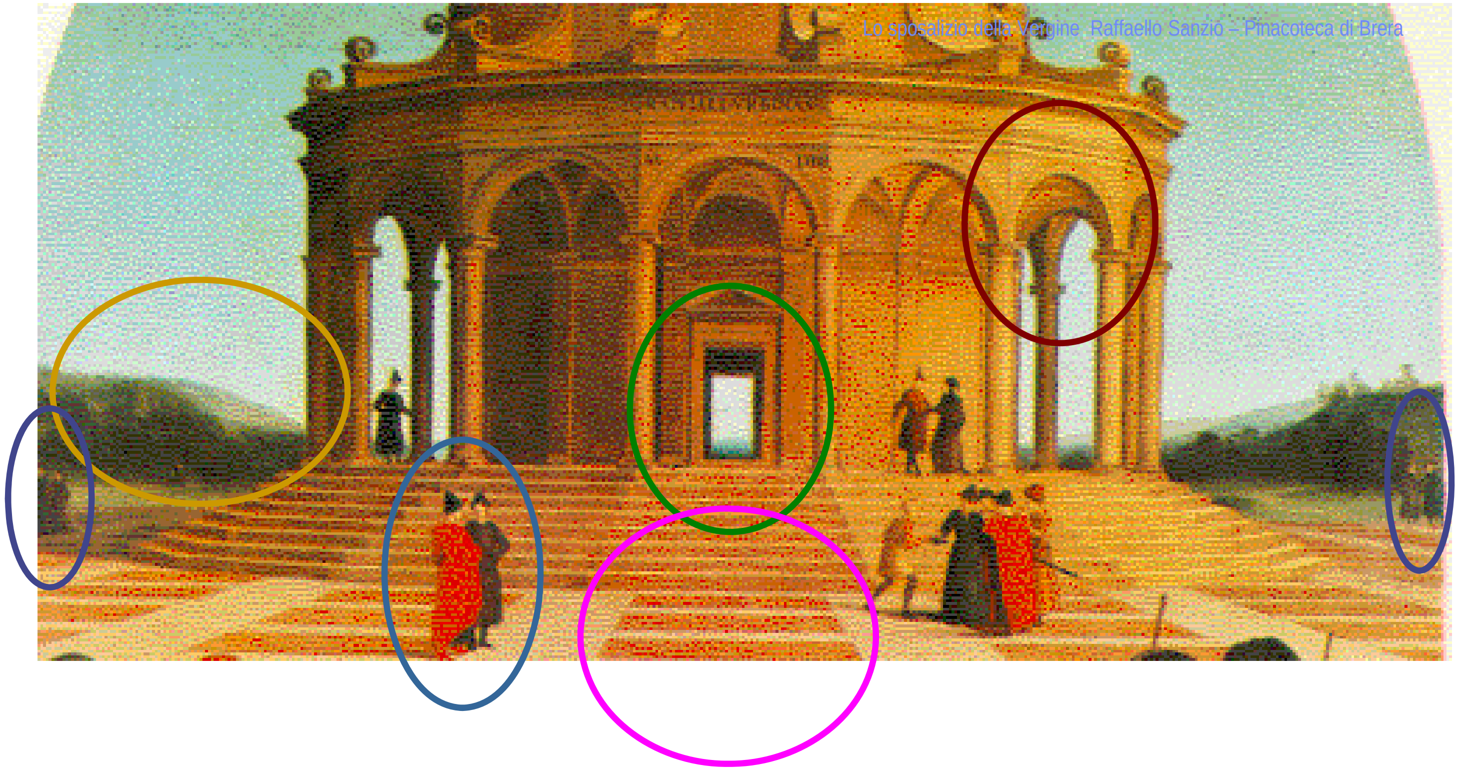
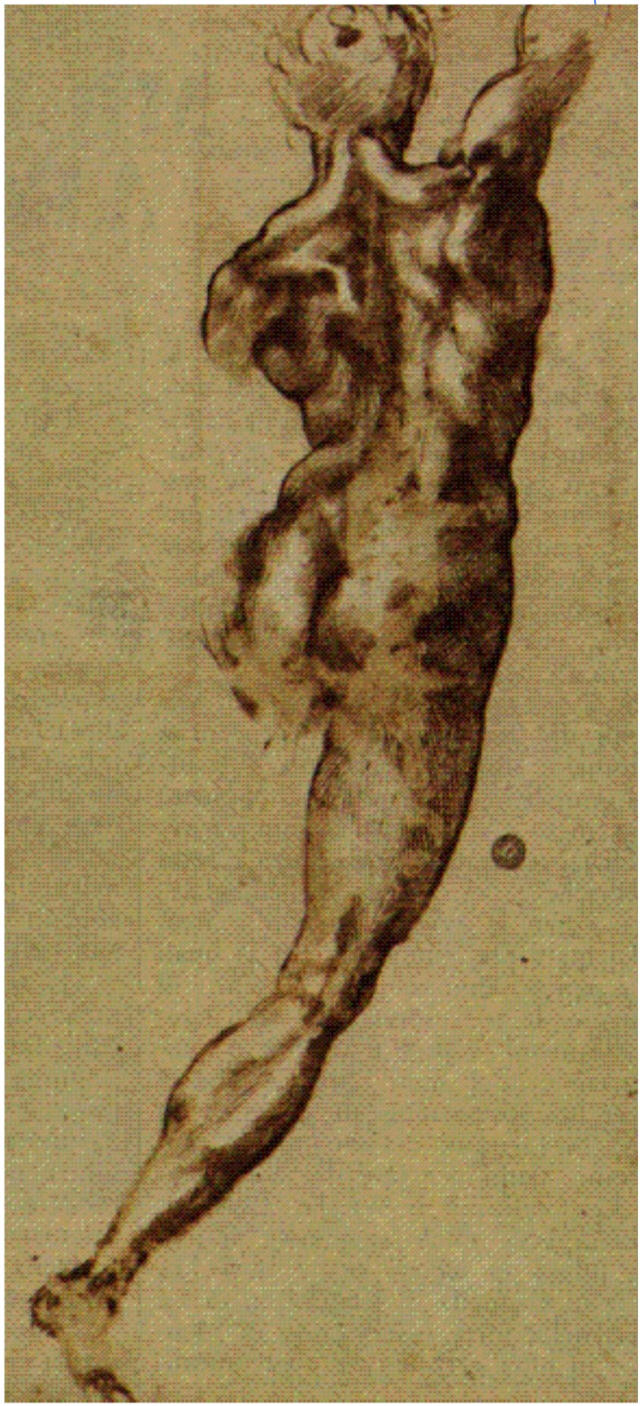
The photometric track

Raffaello Sanzio, Lo sposalizio della Vergine,
1504, Milano, Pinacoteca di Brera





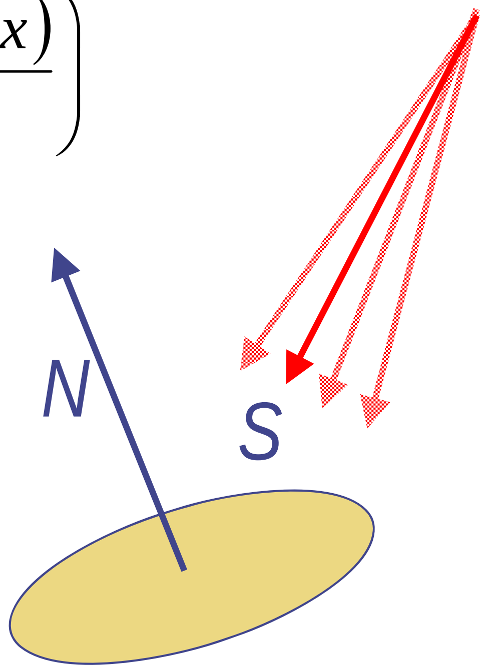
Michelangelo, 1528

Standard nearby point source model

- N is the surface normal, ρ is diffuse albedo, S is source vector - a vector from x to the source, whose length is the intensity term
- Assume that all points in the model are close to each other with respect to the distance to the source. Then the source vector doesn't vary much, and the distance doesn't vary much either, the computation are simplified.

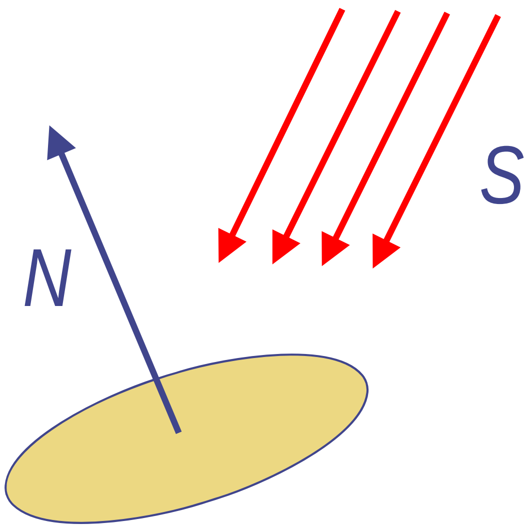
nearby point source model

$$\rho_d(x)\left(\frac{N(x)\cdot S(x)}{r(x)^2}\right)$$



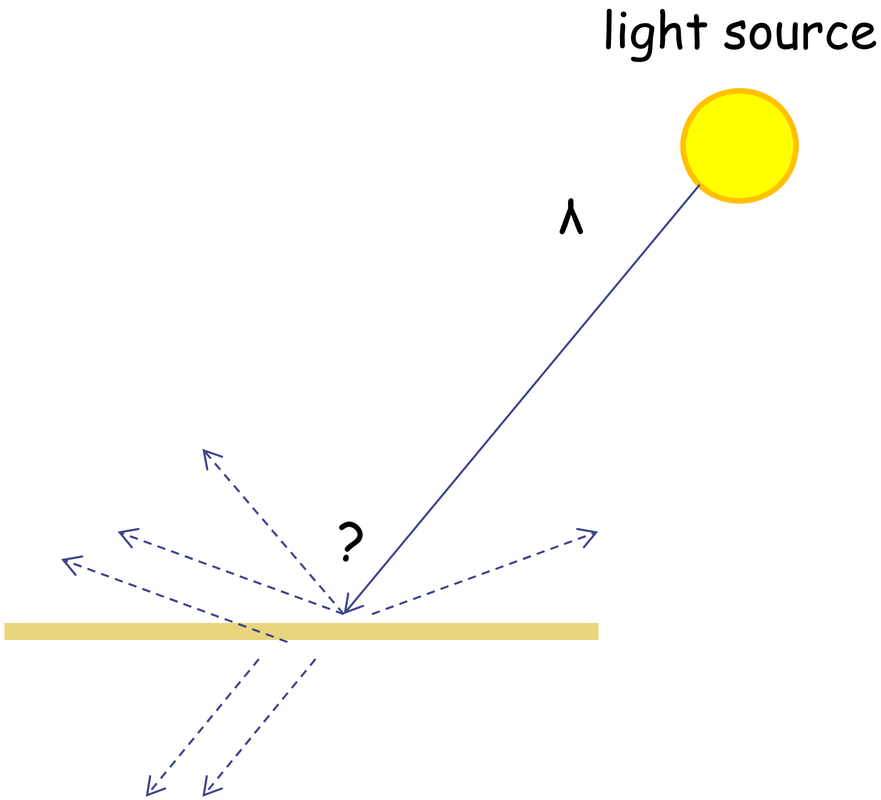
distant point source model

$$\rho_d(x)\left(N(x)\cdot S_d(x)\right)$$



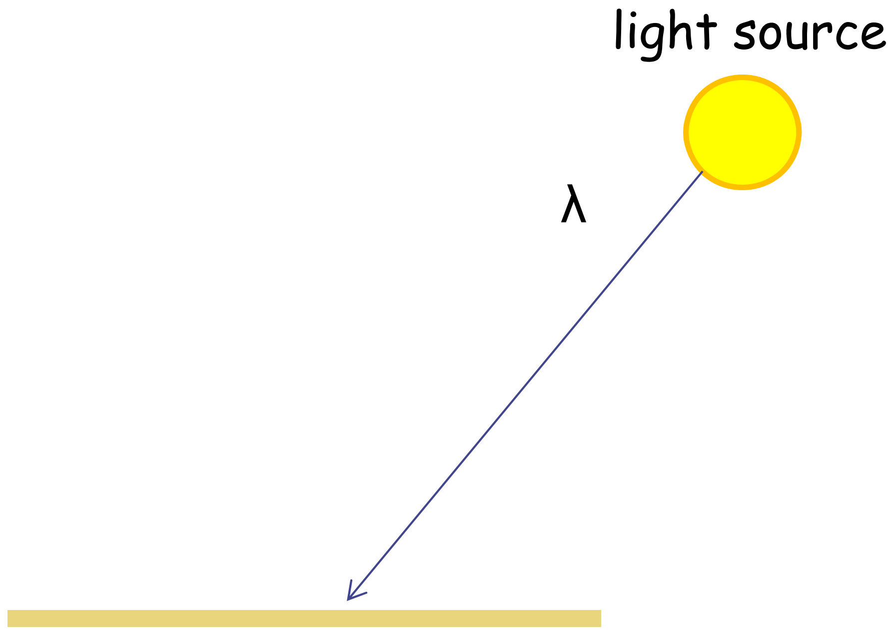
A photon's life choices

- Absorption
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Inter-reflection



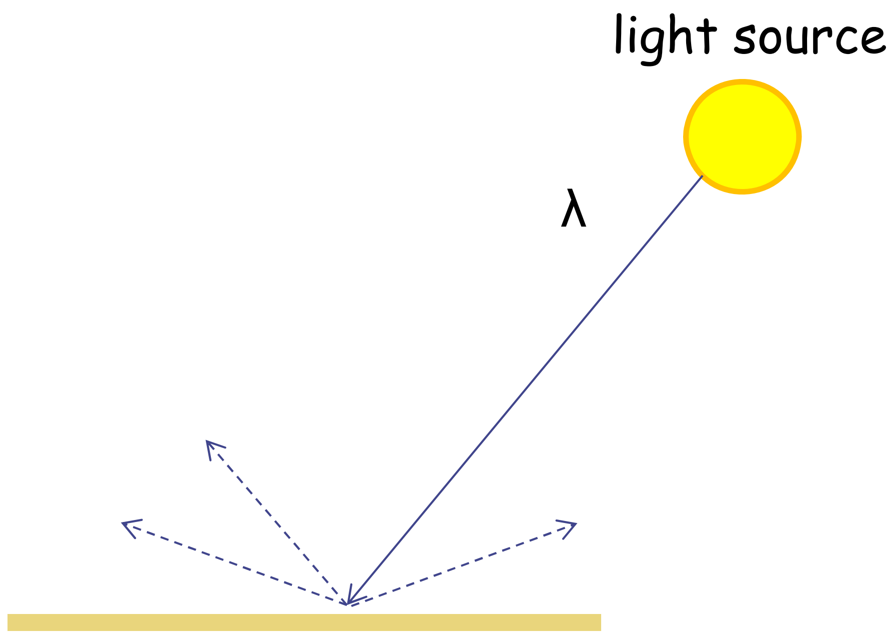
A photon's life choices

- **Absorption**
- Diffusion
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Inter-reflection



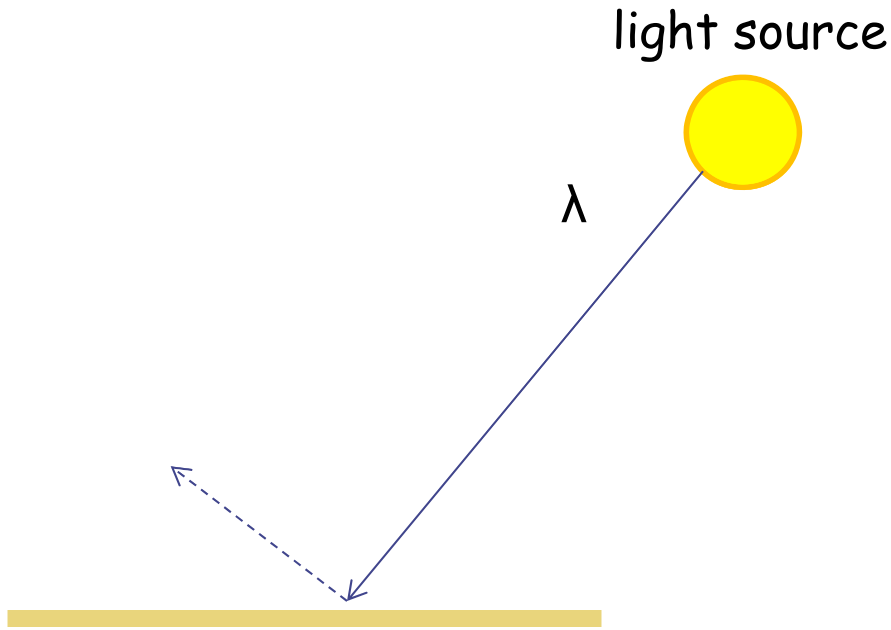
A photon's life choices

- Absorption
- **Diffuse Reflection**
- Reflection
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



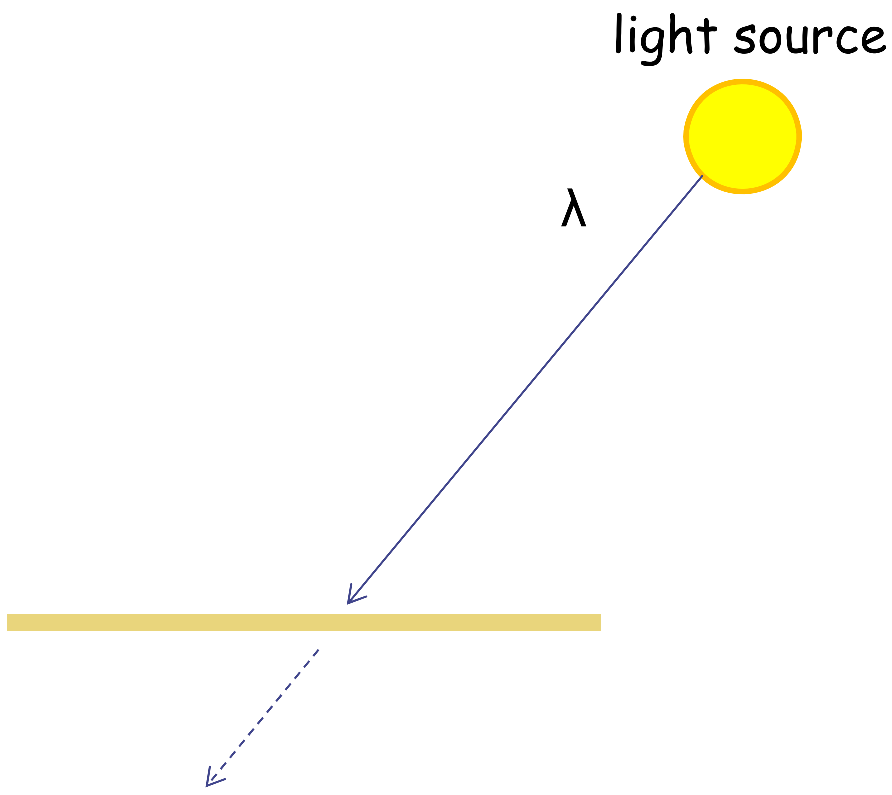
A photon's life choices

- Absorption
- Diffusion
- **Specular Reflection**
- Transparency
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



A photon's life choices

- Absorption
- Diffusion
- Reflection
- **Transparency**
- Refraction
- Fluorescence
- Subsurface scattering
- Phosphorescence
- Interreflection



A photon's life choices

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- **Refraction**
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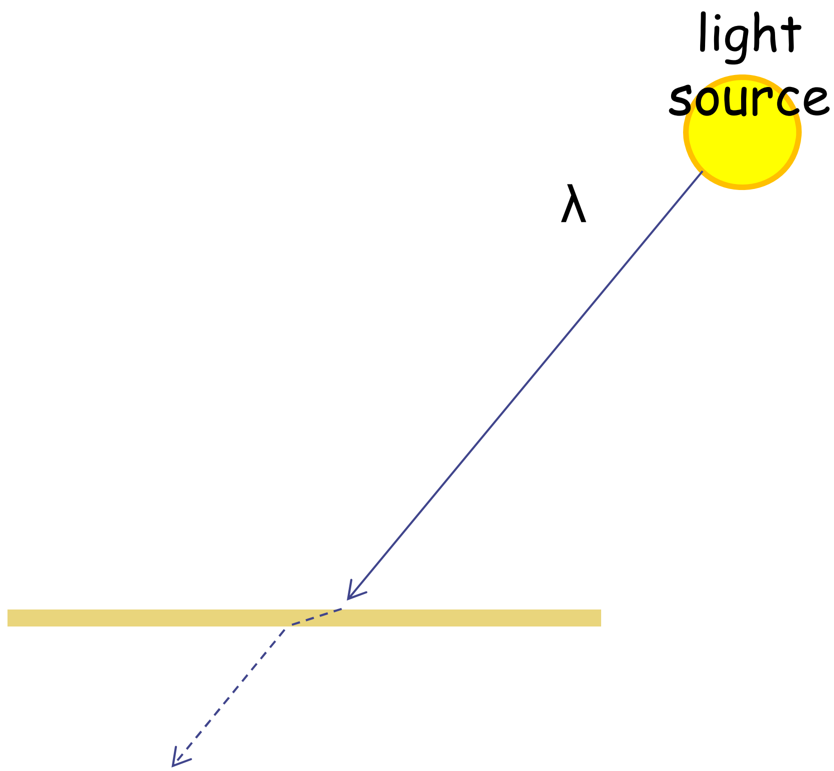

A photon's life choices

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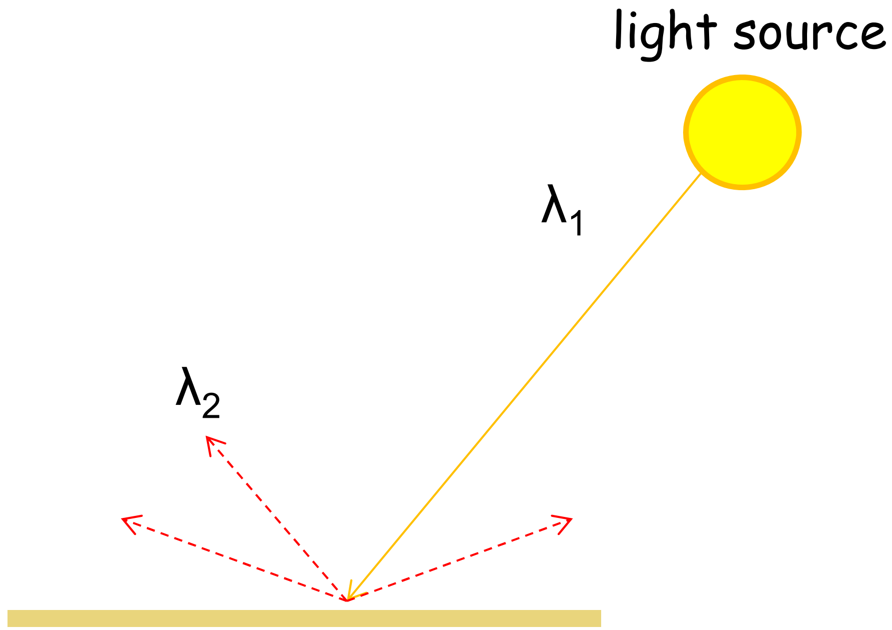

A photon's life choices

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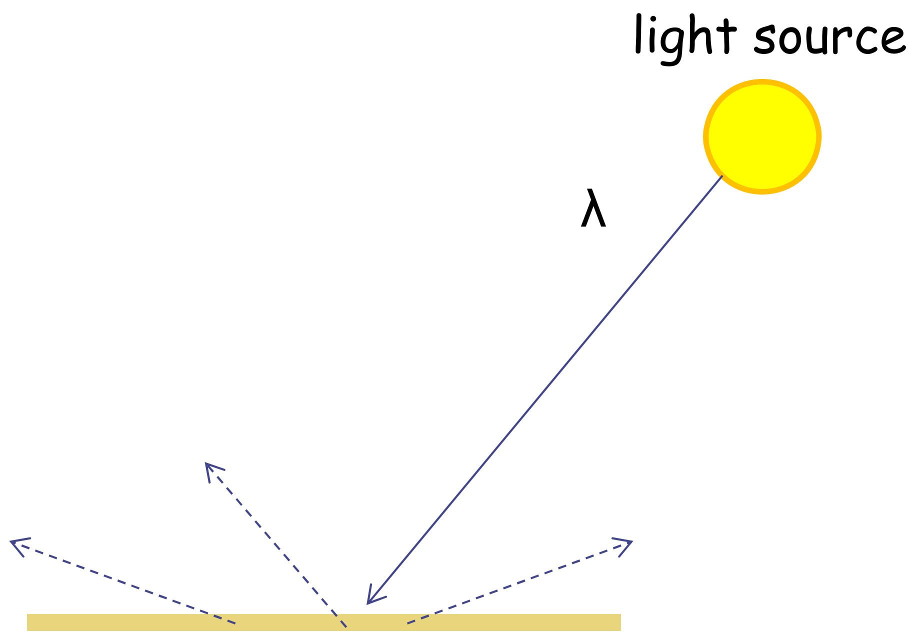

A photon's life choices

- Absorption
- Diffusion
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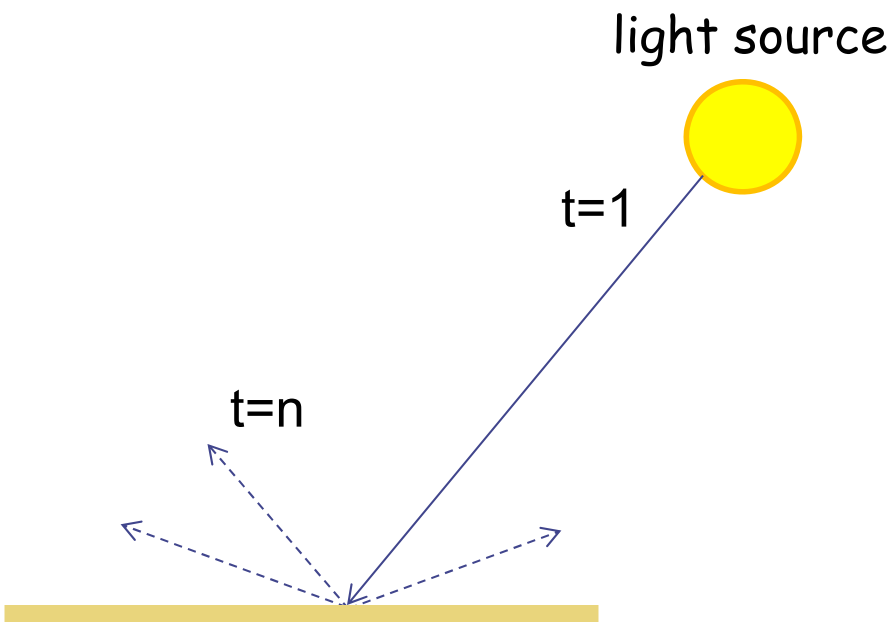
- Fluorescence
- Subsurface scattering
- **Phosphorescence**
- Interreflection



A photon's life choices

- Absorption
- Diffusion
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- Transparency
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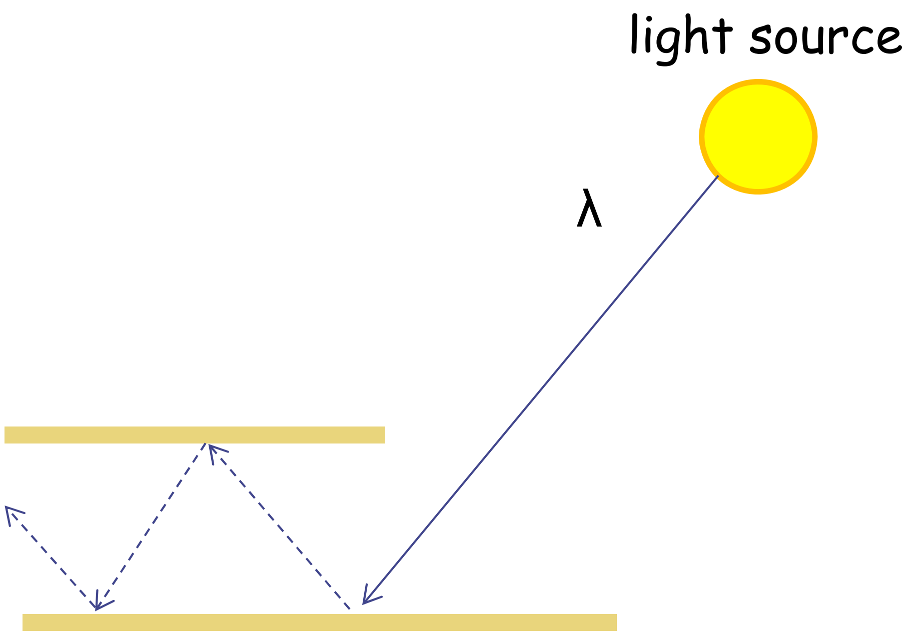
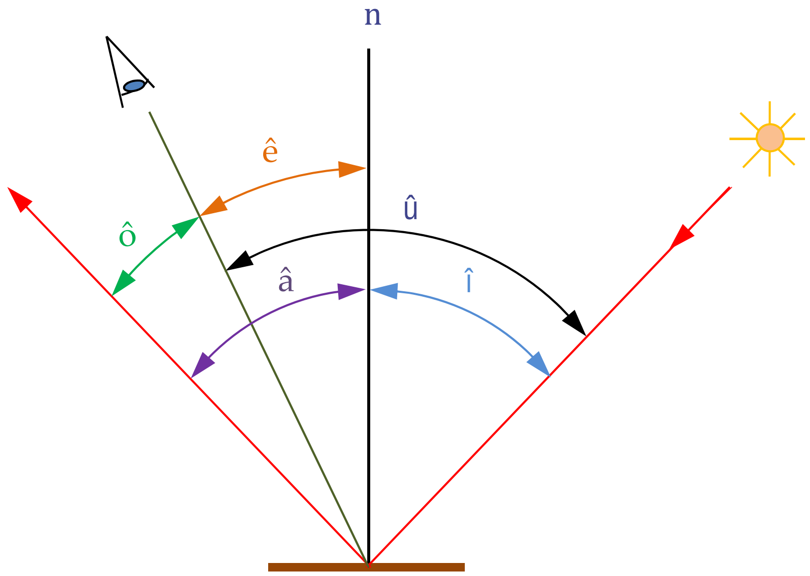
- Fluorescence
- Subsurface scattering
- Phosphorescence
- **Inter-reflection**



(Specular Interreflection)

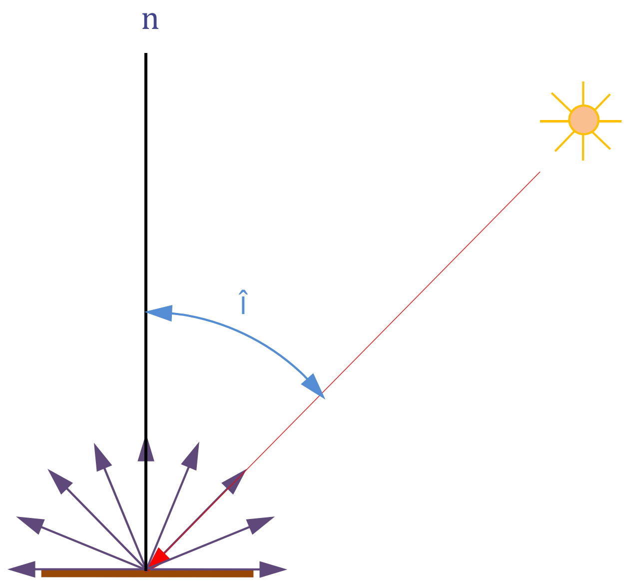
Local rendering

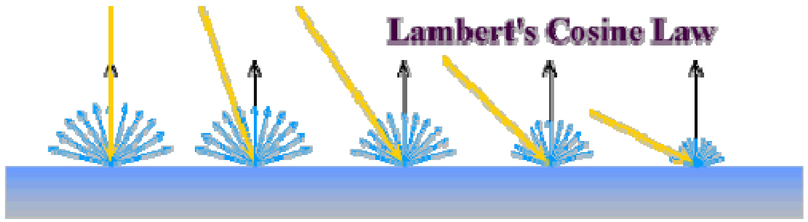
- Optical geometry of the light-source/eye-receiver system
- Notation:
  - n is the normal to the surface at the incidence point
  - î corresponds to the incidence angle
  - â = î is the reflectance angle
  - ô is the mirrored emergence angle
  - û is the phase angle
  - ê is the emergence angle.



The Lambertian model

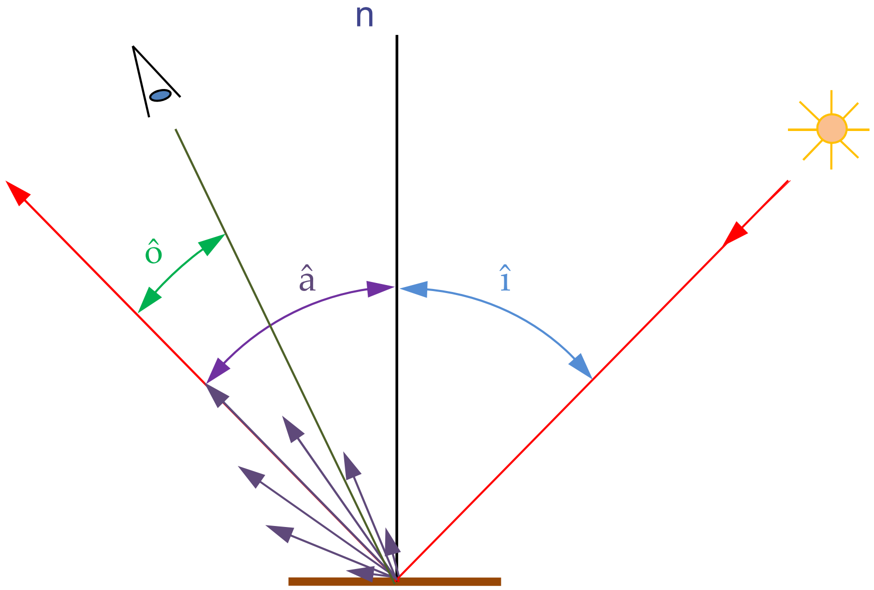
$$\Phi = \begin{cases} \cos \hat{\imath} & -\frac{\pi}{2} \leq \hat{\imath} \leq \frac{\pi}{2} \\ 0 & elsewhere \end{cases}$$

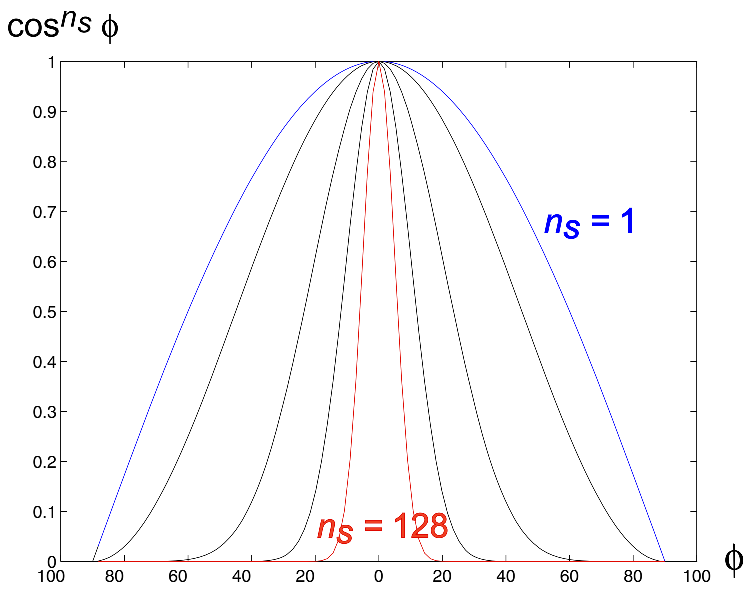




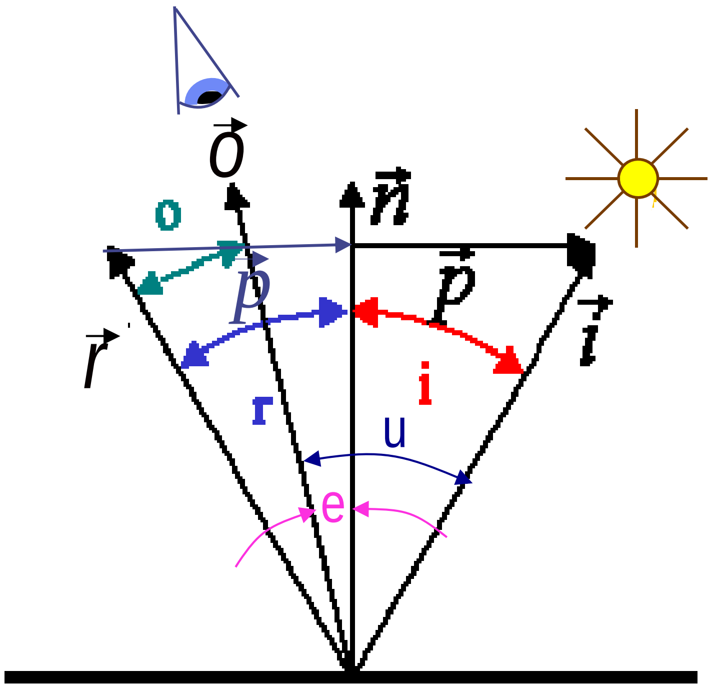
The specular model

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





The mirrored emergence angle



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

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

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

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

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

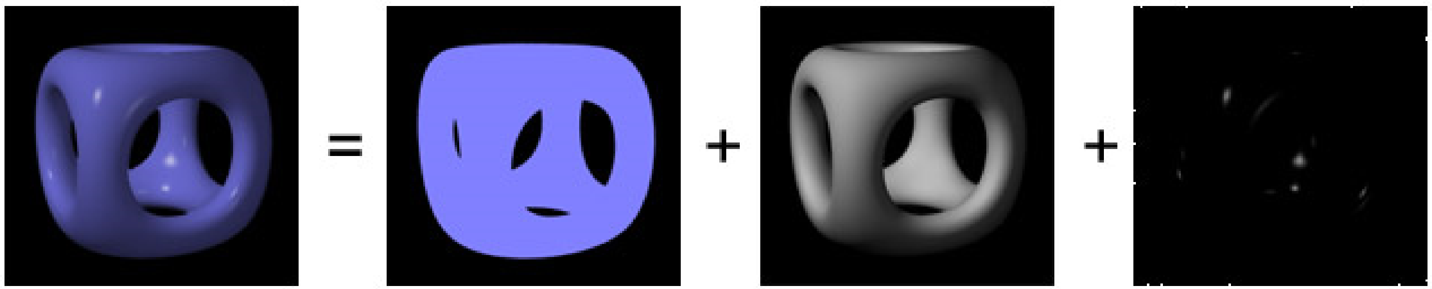
$\cos(o) = \vec{o}\vec{r}$ $\cos(i) = \vec{i}\vec{n}$

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

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

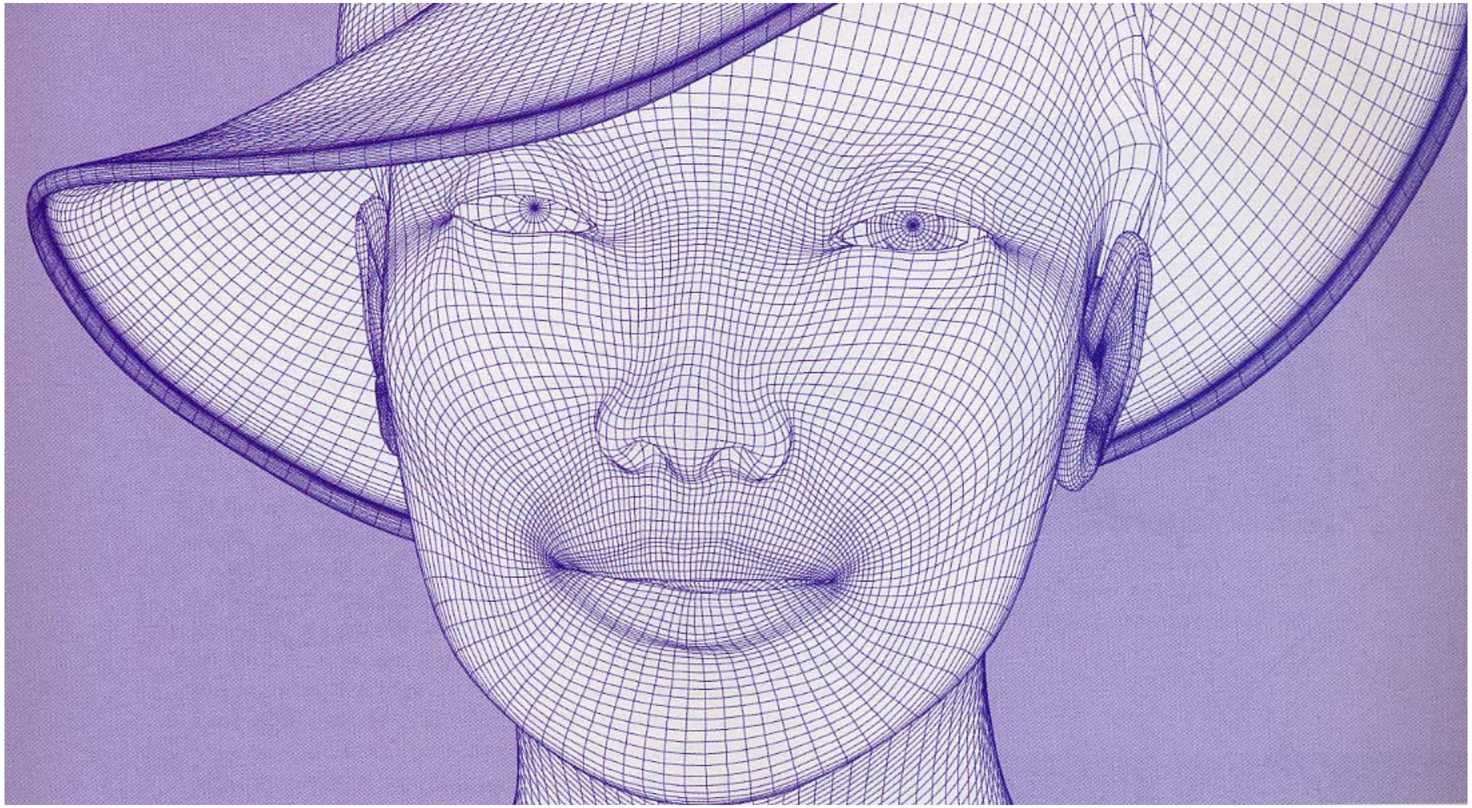
$$\Phi = a\cos\hat{\imath} + b\cos^{m}\hat{o} + c$$



color and ambient diffuse specularity

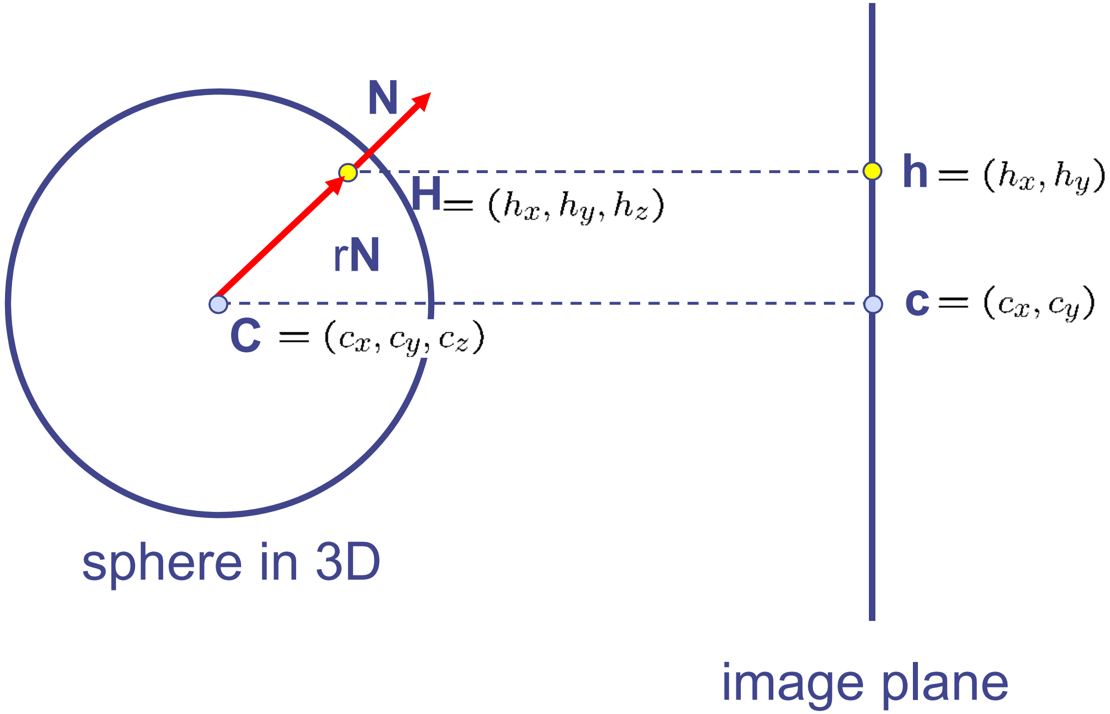
Bùi Tường Phong, Illumination for computer generated images, Commun. ACM 18 (6) (1975) 311317.

Wire frame



Computing the light source direction

Chrome sphere that has a highlight at position **h** in the image



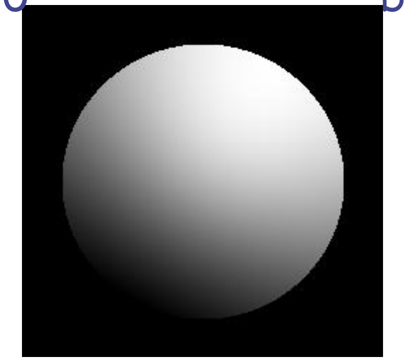
- Can compute **N** by studying this figure
  - Hints:
    - use this equation: $||H - C|| = r$
    - can measure **c**, **h**, and r in the image

Local rendering

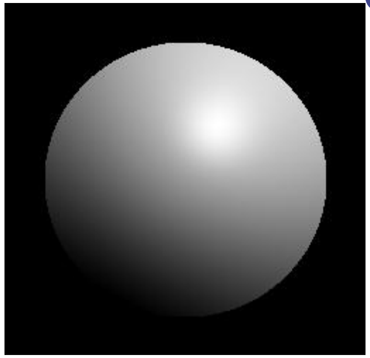
http://www.danielrobichaud.com/animation/#/marlene/

Sphere (m=10, c=0)

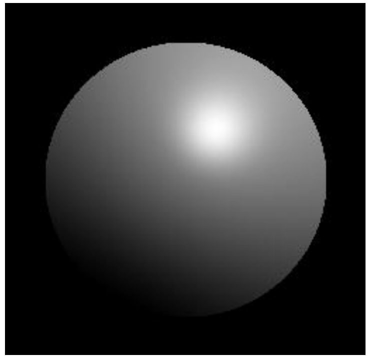
a=1.0 b=0.0



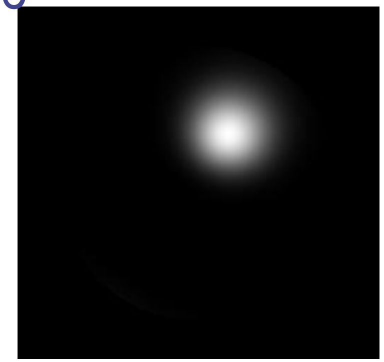
0.8 0.2



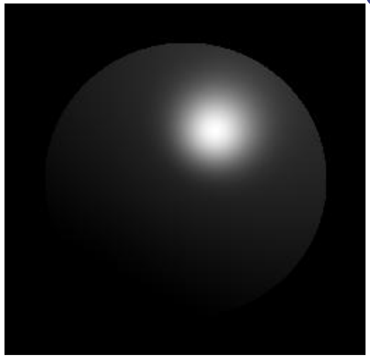
0.6 0.4



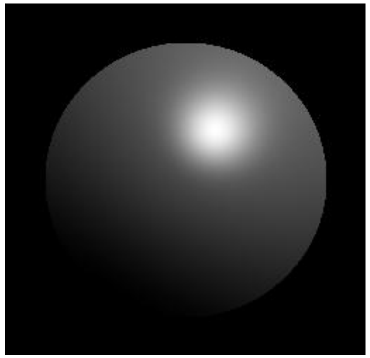
0.0 1.0



0.2 0.8

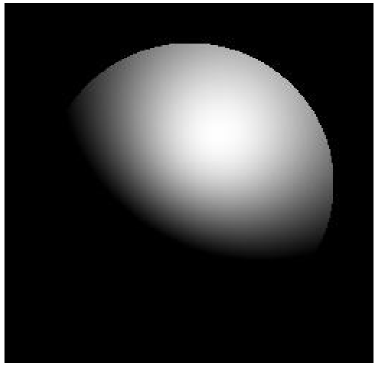


0.4 0.6

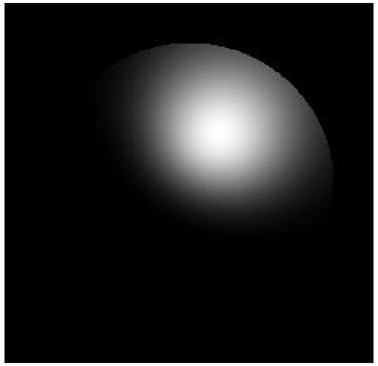


Specular sphere (b=0.9, c=0.1)

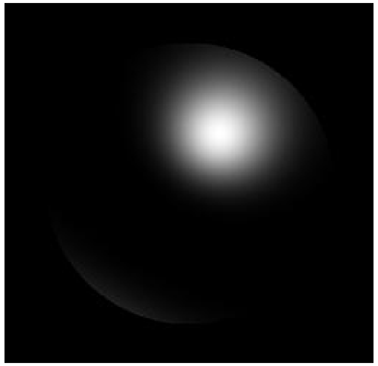
m=1



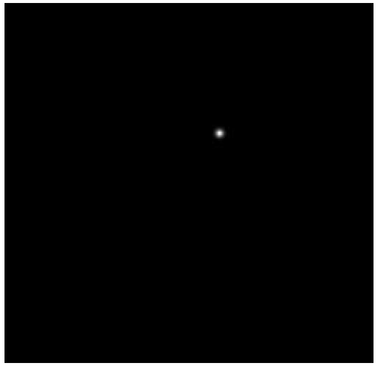
m=3



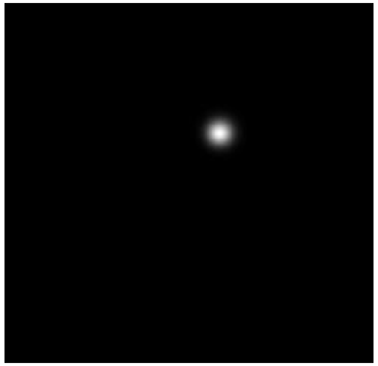
m=6



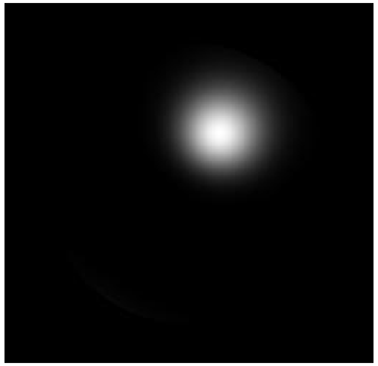
m=1000



m=100

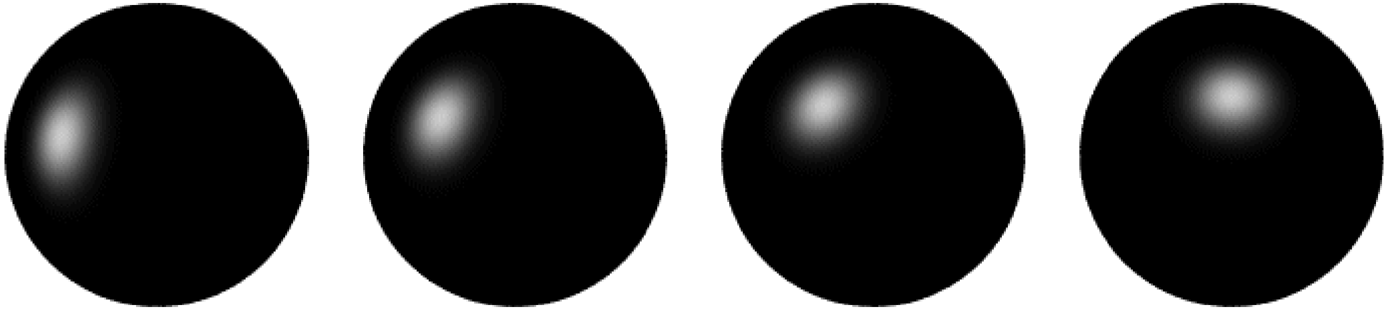


m=10



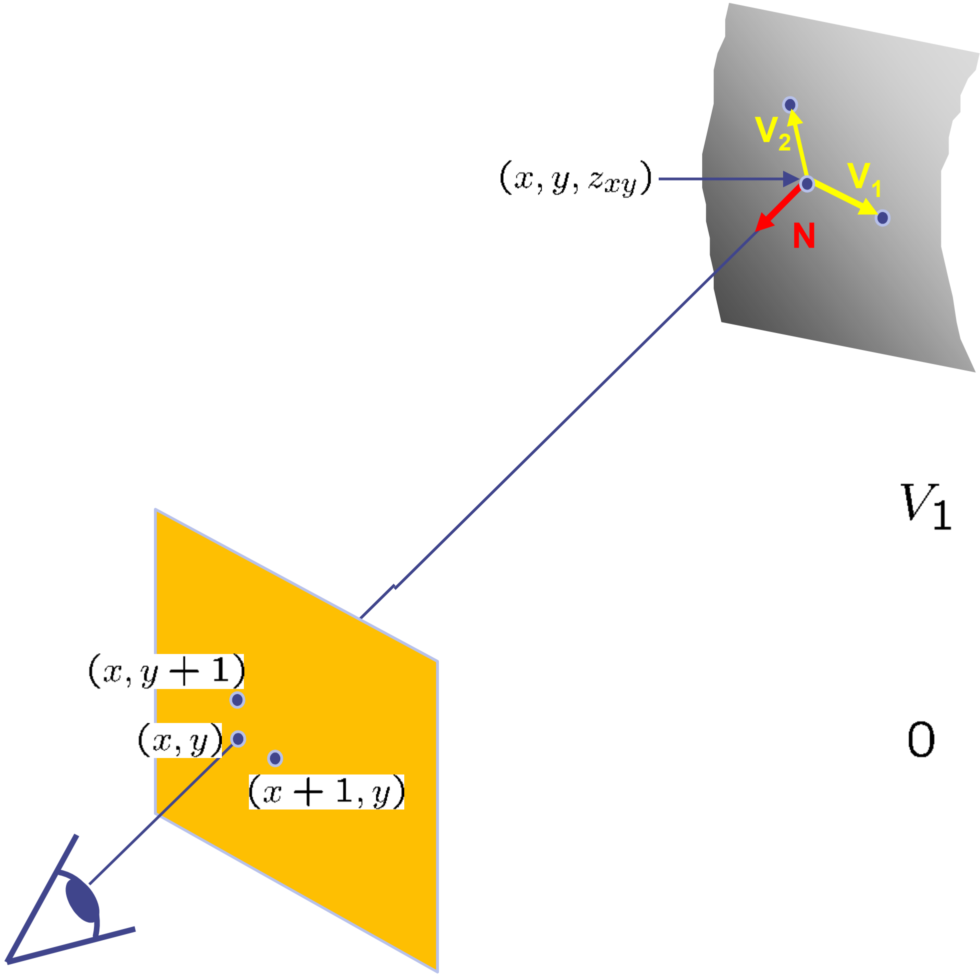
Computing light source directions

- Trick: place a chrome sphere in the scene



  - the location of the highlight tells you where the light source is

Depth from normals

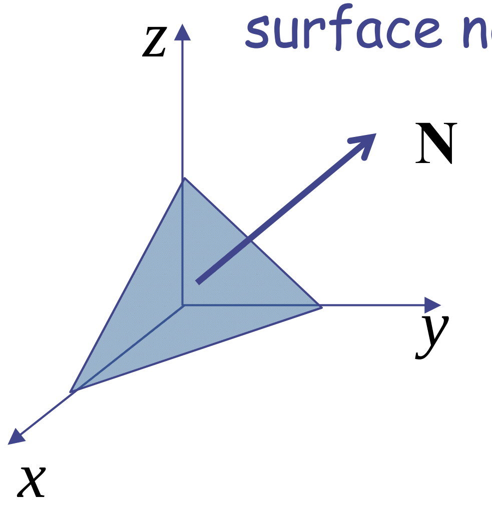


$$\begin{aligned} V_1 &= (x+1, y, z_{x+1,y}) - (x, y, z_{xy}) \\ &= (1, 0, z_{x+1,y} - z_{xy}) \end{aligned}$$

$$\begin{aligned} 0 &= N \cdot V_1 \\ &= (n_x, n_y, n_z) \cdot (1, 0, z_{x+1,y} - z_{xy}) \\ &= n_x + n_z(z_{x+1,y} - z_{xy}) \end{aligned}$$

- Get a similar equation for **V_2**
  - Each normal gives us two linear constraints on z
  - compute z values by solving a matrix equation

Surface Normal



Equation of plane

$$Ax + By + Cz + D = 0$$

or

$$\frac{A}{C}x + \frac{B}{C}y + z + \frac{D}{C} = 0$$

Let

$$-\frac{\partial z}{\partial x} = \frac{A}{C} = p \qquad -\frac{\partial z}{\partial y} = \frac{B}{C} = q$$

Surface normal

$$\mathbf{N} = \left(\frac{A}{C}, \frac{B}{C}, 1\right) = (p, q, 1)$$

$$\hat{\mathbf{n}} = \frac{1}{\sqrt{p^2 + q^2 + 1}}(p, q, 1)$$

Gradient space

$$s(x,y) = (x, y, f(x,y))$$

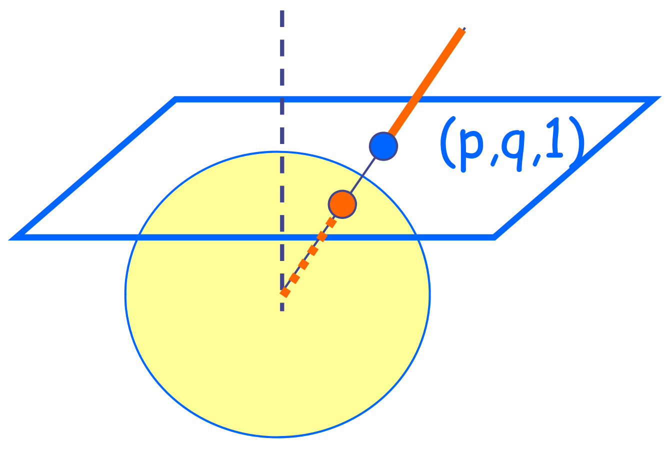
$$\frac{\partial s}{\partial x} = \left(1,0,\frac{\partial f}{\partial x}\right)^T \qquad \frac{\partial s}{\partial y} = \left(0,1,\frac{\partial f}{\partial y}\right)^T$$

$$\mathbf{n} = \frac{\partial s}{\partial x} \times \frac{\partial s}{\partial y} = \left(\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}, -1\right)^T$$

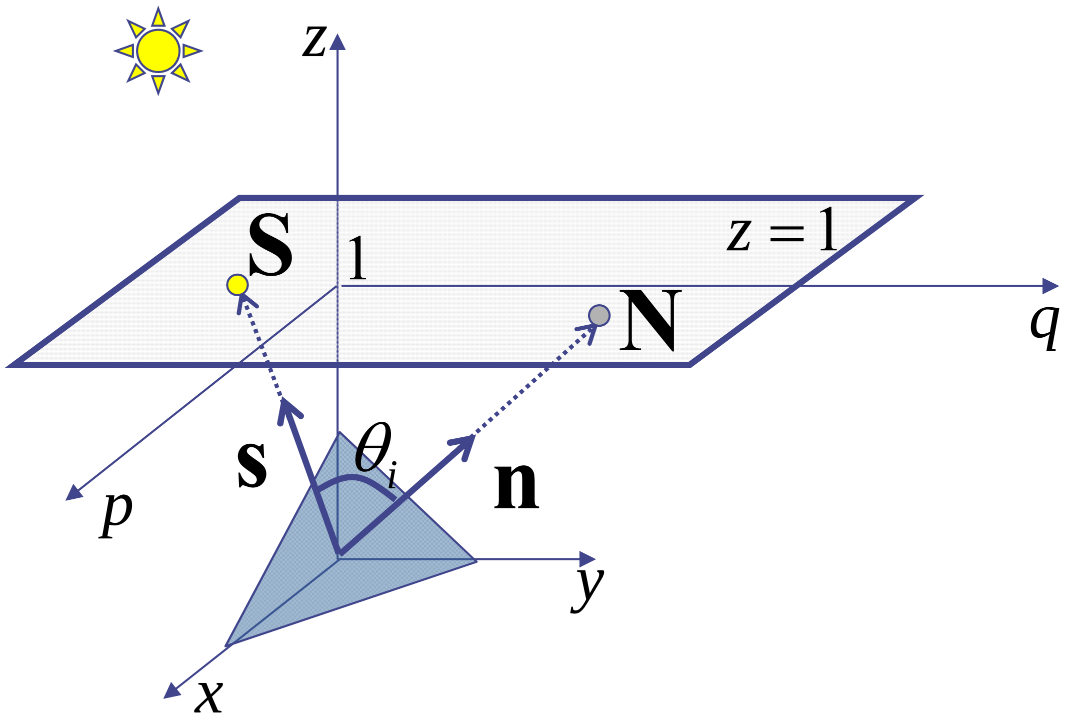
$$p = -\frac{\partial f}{\partial x} \qquad q = -\frac{\partial f}{\partial y}$$

$$\mathbf{n} = (p, q, 1)$$

$$\hat{\mathbf{n}} = \frac{1}{\sqrt{p^2 + q^2 + 1}}(p, q, 1)$$



Gradient Space



Normal vector

$$\mathbf{n} = \frac{\mathbf{N}}{|\mathbf{N}|} = \frac{(p, q, 1)}{\sqrt{p^2 + q^2 + 1}}$$

Source vector

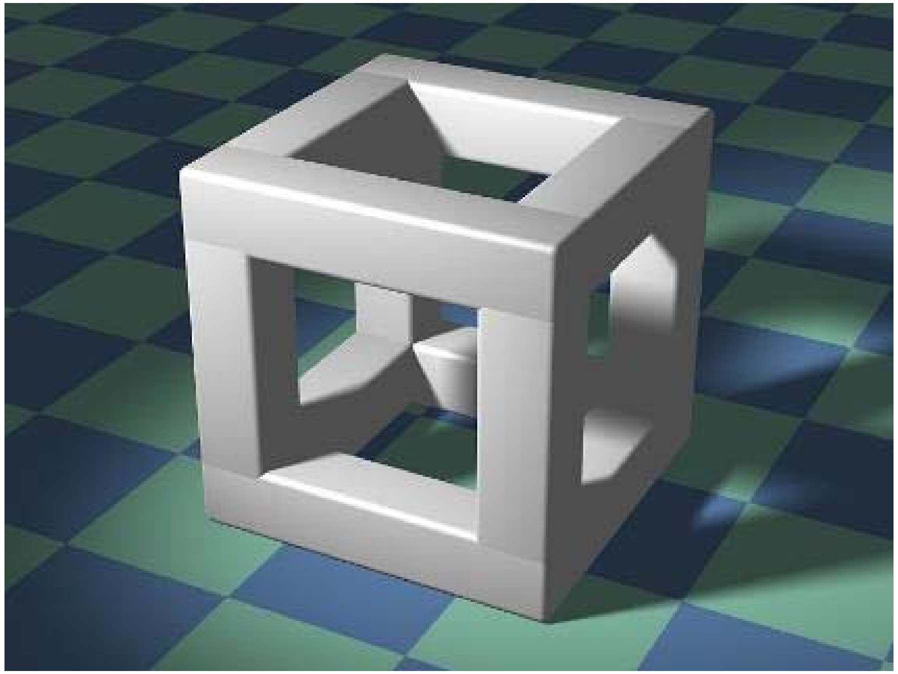
$$\mathbf{s} = \frac{\mathbf{S}}{|\mathbf{S}|} = \frac{(p_S, q_S, 1)}{\sqrt{p_S^2 + q_S^2 + 1}}$$

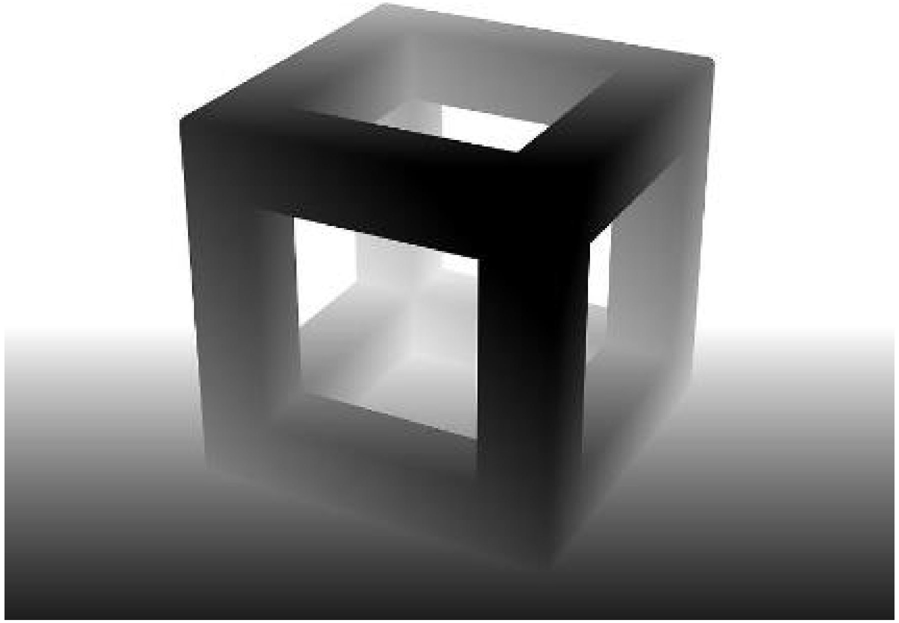
$$\cos\theta_i = \mathbf{n} \cdot \mathbf{s} = \frac{(pp_S + qq_S + 1)}{\sqrt{p^2 + q^2 + 1}\sqrt{p_S^2 + q_S^2 + 1}}$$

$z = 1$ plane is called the Gradient Space (p q plane)

Every point on it corresponds to a particular surface orientation

Range finder





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:

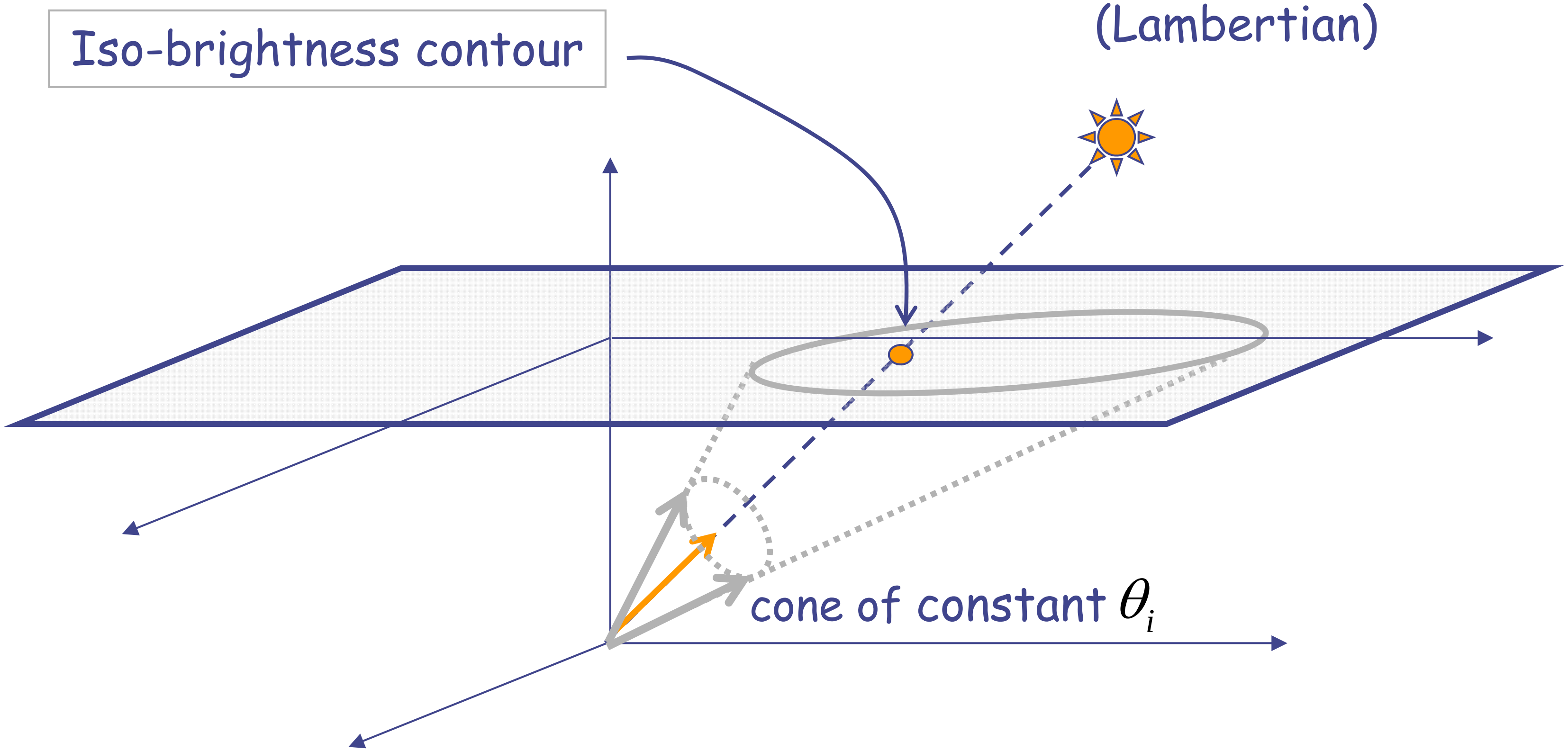
$$\cos\hat{\imath} = \frac{1+pp_s+qq_s}{\sqrt{1+p^2+q^2}\sqrt{1+p_s^2+q_s^2}} \qquad \cos\hat{e} = \frac{1}{\sqrt{1+p^2+q^2}} \qquad \cos\hat{u} = \frac{1}{\sqrt{1+p_s^2+q_s^2}}$$

Reflectance Map

- Lambertian case

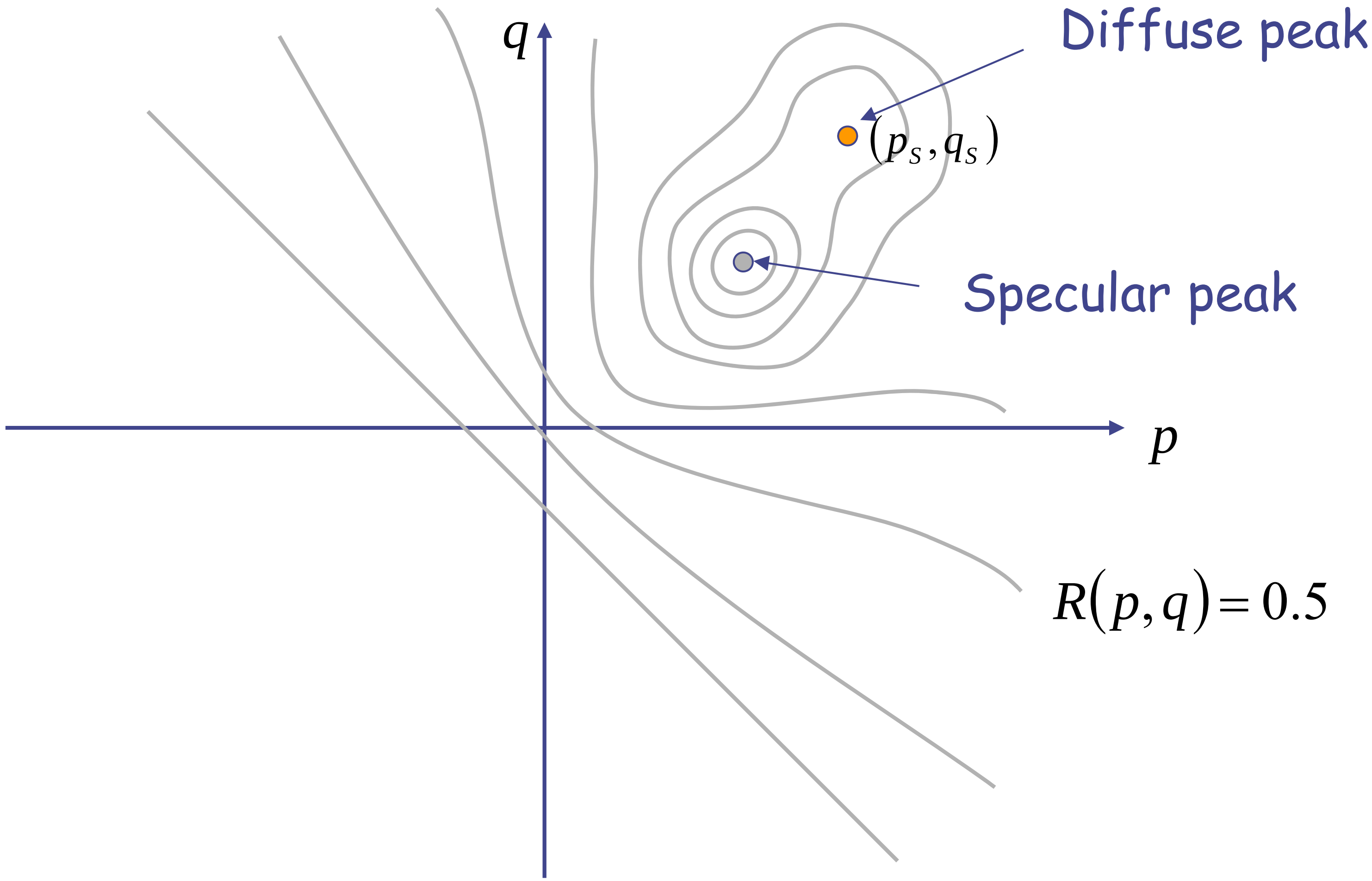
$$I = \cos\theta_i = \mathbf{n}\cdot\mathbf{s} = \frac{(pp_s + qq_s + 1)}{\sqrt{p^2+q^2+1}\sqrt{p_S^2+q_S^2+1}} = R(p,q)$$

Reflectance Map (Lambertian)



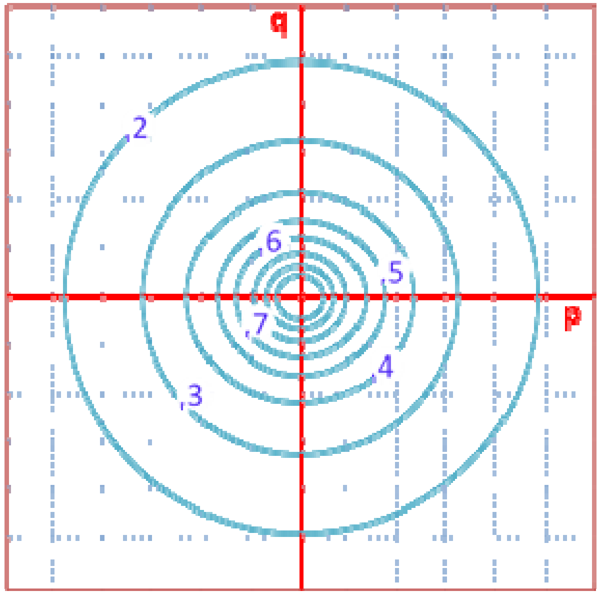
Reflectance Map

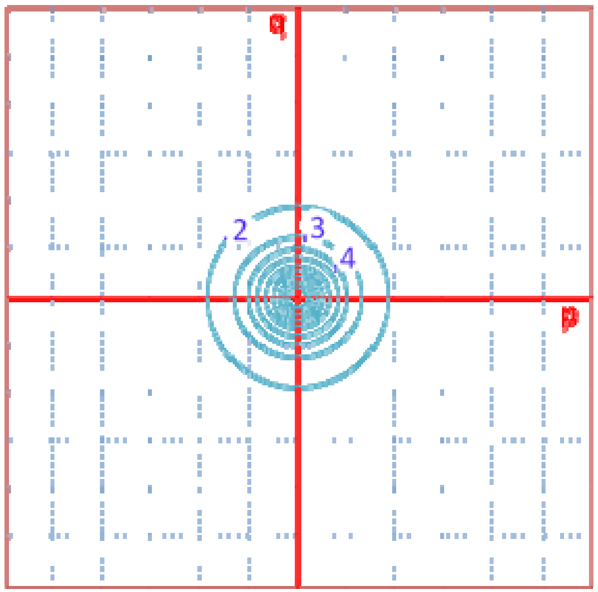
- Glossy surfaces

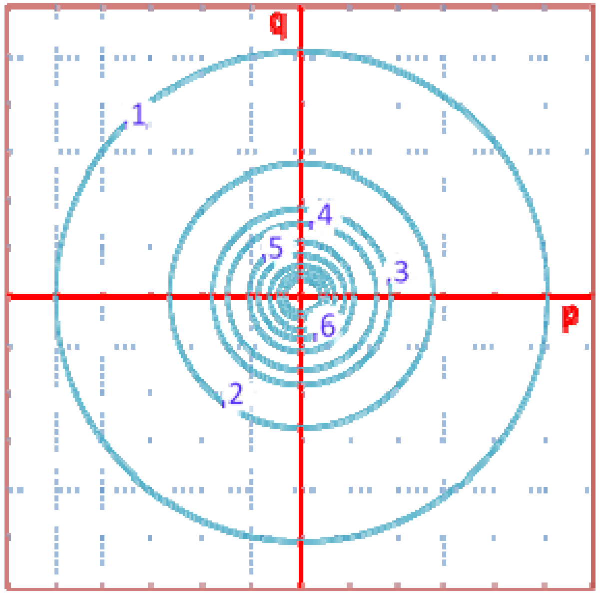


Reflectance maps

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

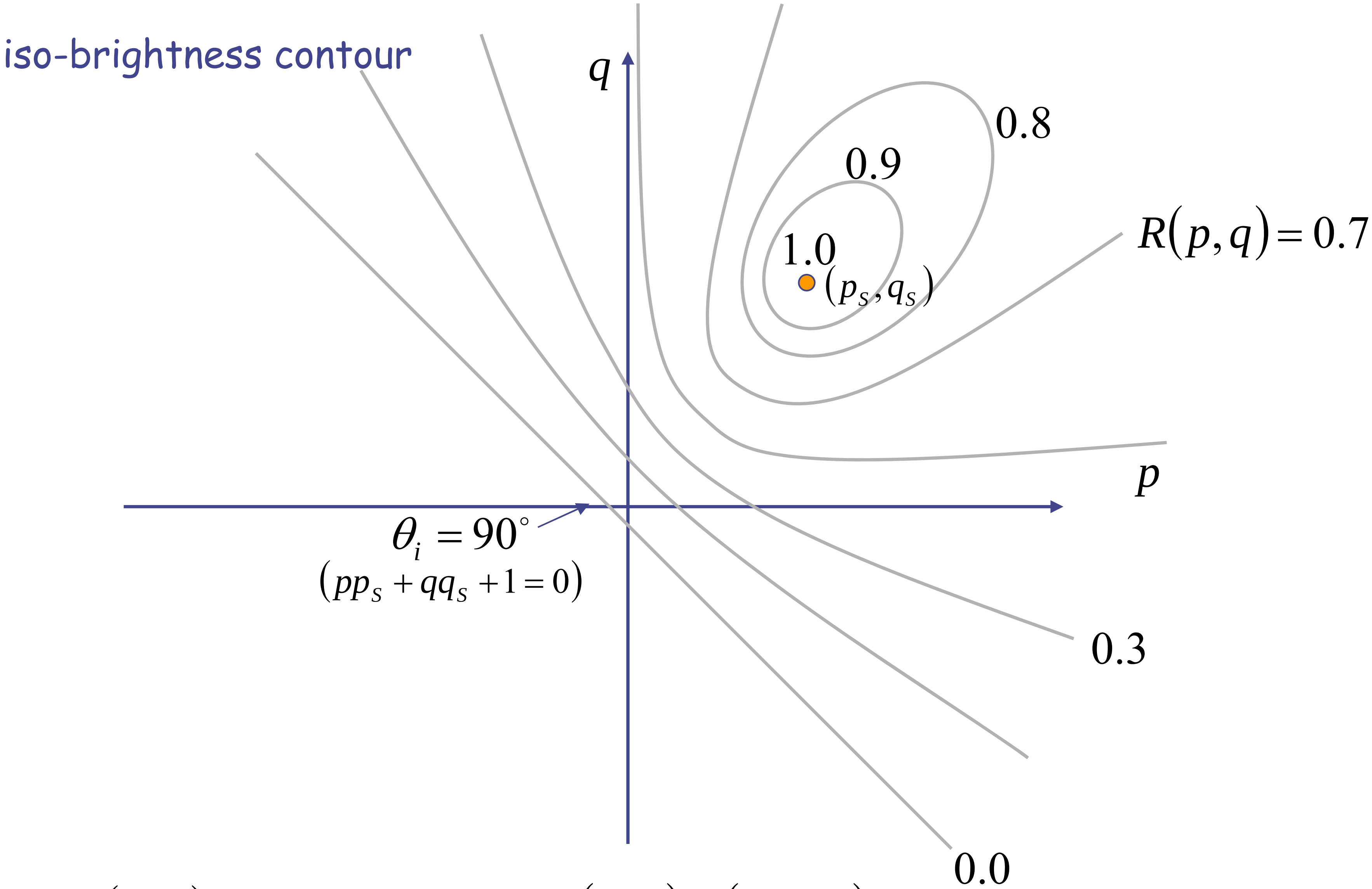






Reflectance Map

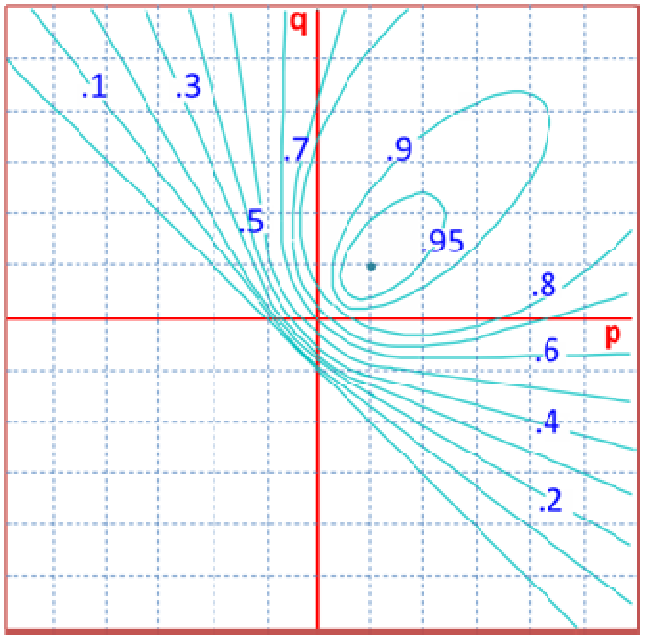
- Lambertian case

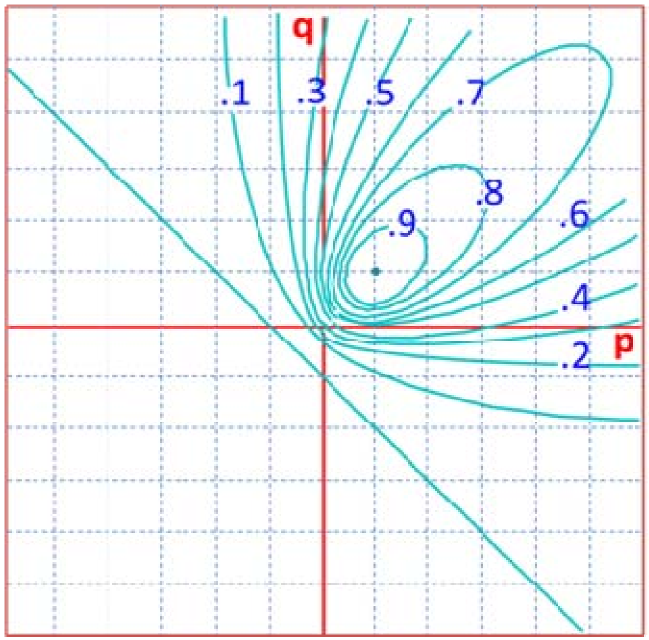


Note: $R(p,q)$ is maximum when $(p,q) = (p_S, q_S)$

Reflectance maps

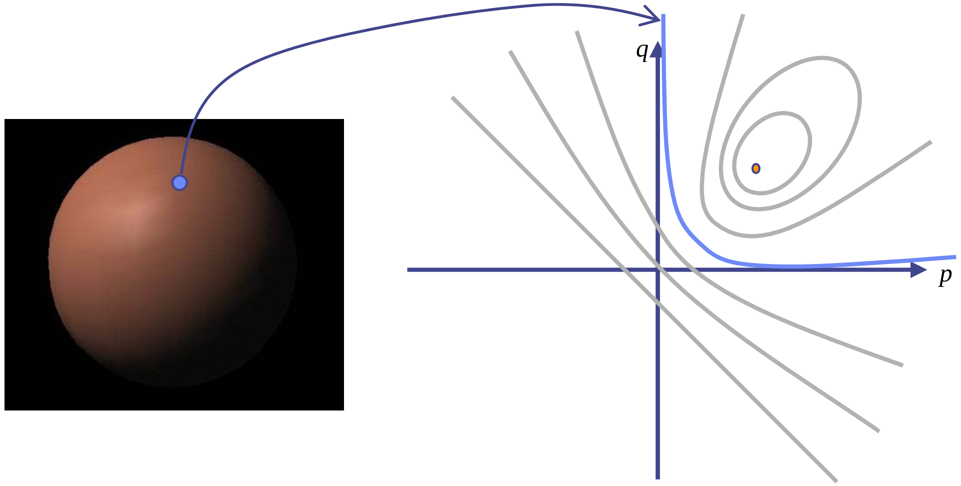
- Reflectivity map for a Lambertian model; having the camera on the z-axis (0,0,-1) and the light source positioned at (1, 1, -1). The isoluminance patterns are quadrics labelled with their corresponding ratios, the incident light source corresponds to the bisector of the first octant in 3D space.
-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





Shape from a Single Image?

- Given a single image of an object with known surface reflectance taken under a known light source, can we recover the shape of the object?

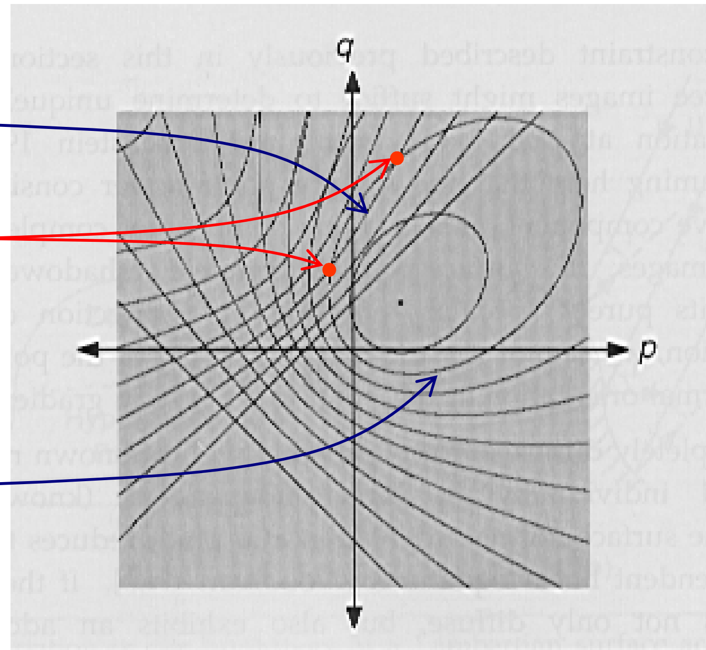


- Two reflectance maps?

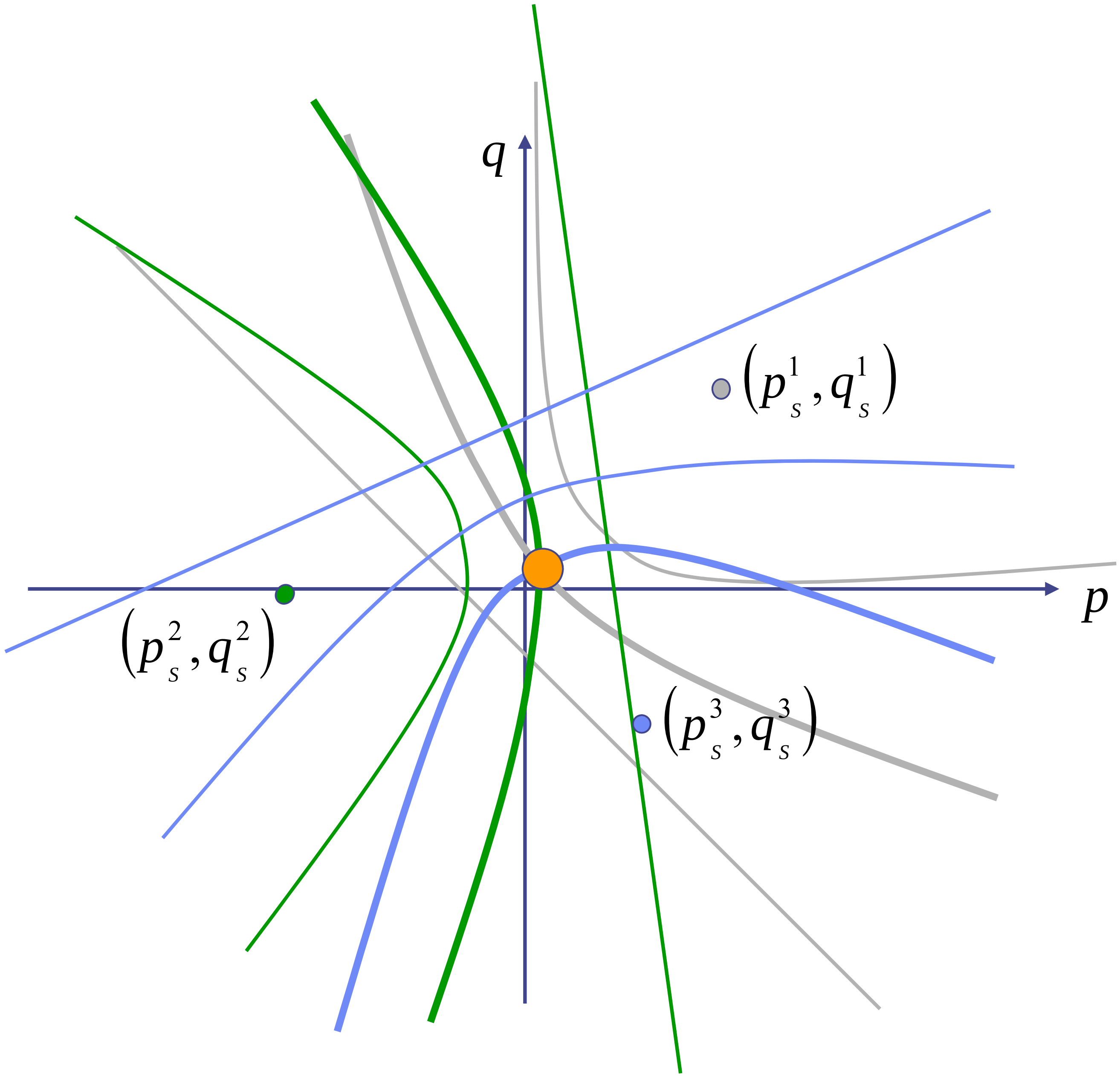
$R_2(p,q) = a$

Intersections: 2 solutions for p and q.

$R_1(p,q) = b$

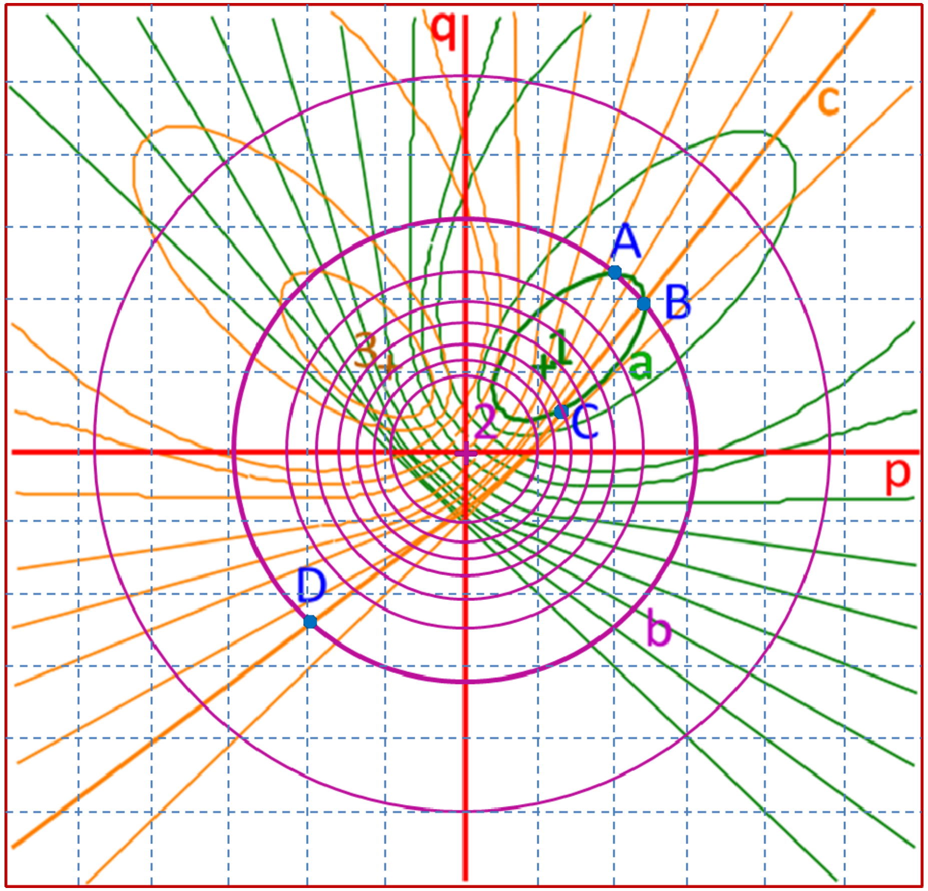


Photometric Stereo



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

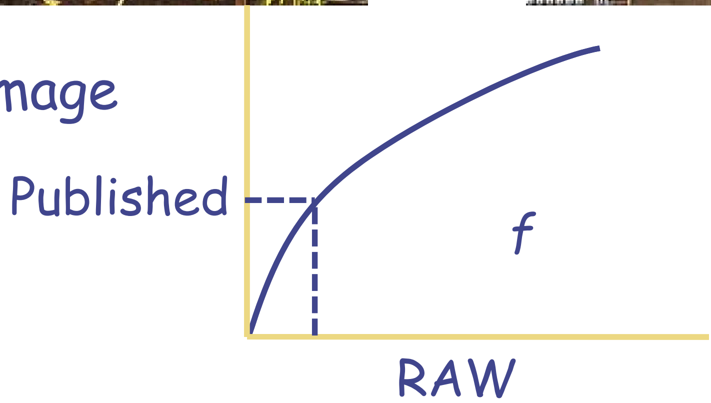
Φ_2=0,1

Radiometric Camera Calibration

- Pixel intensities are usually *not* proportional to the energy that hit the CCD

RAW image

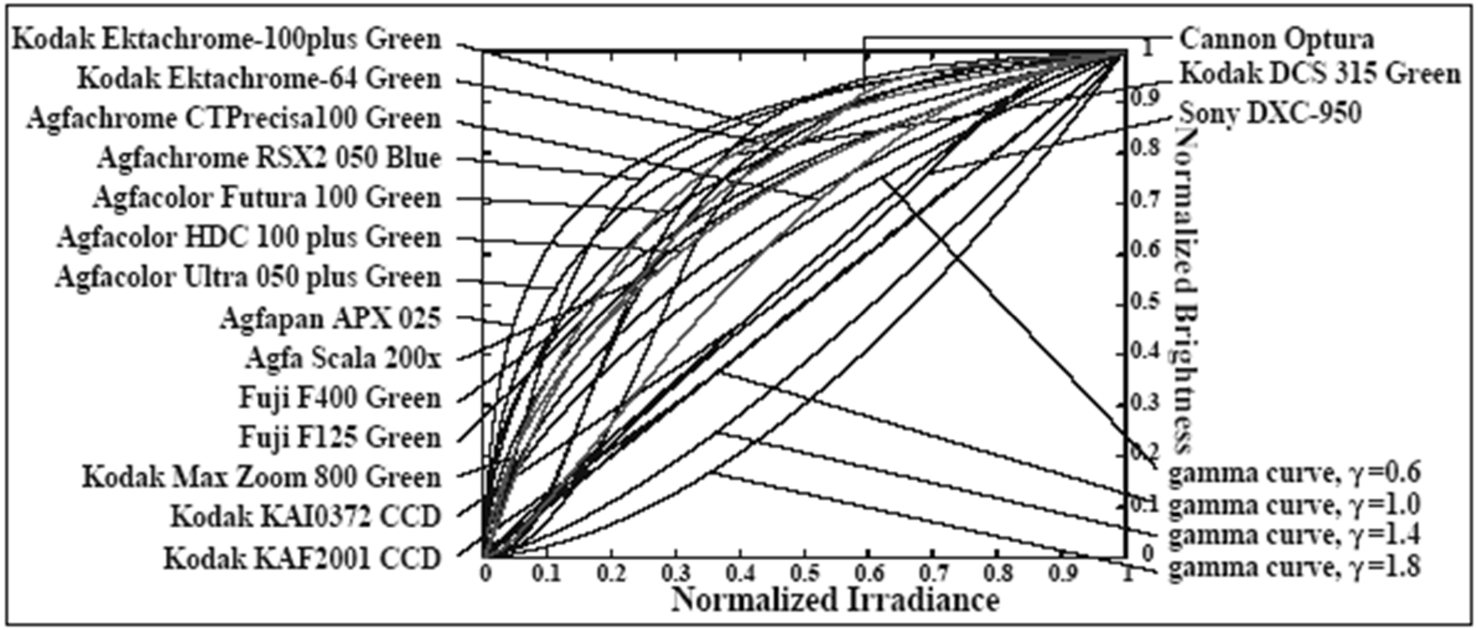
Published image



Austin Abrams

Radiometric Camera Calibration

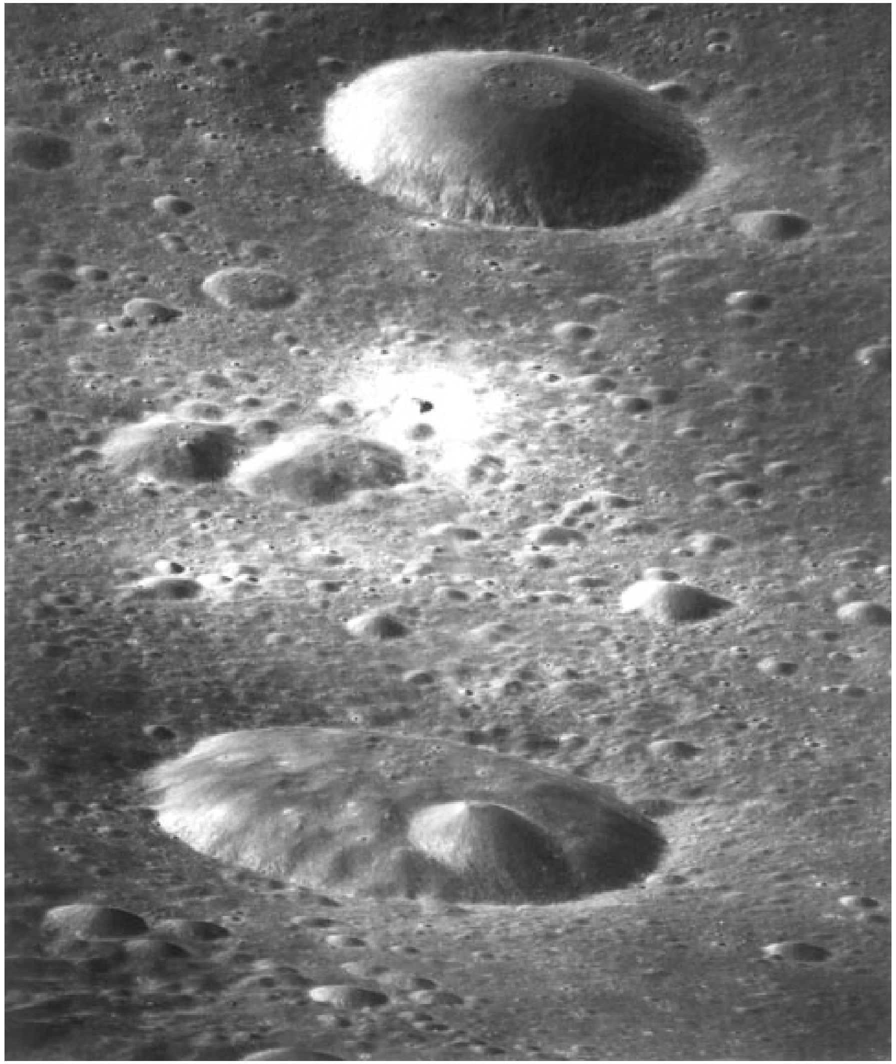
Observed = f(RAW)



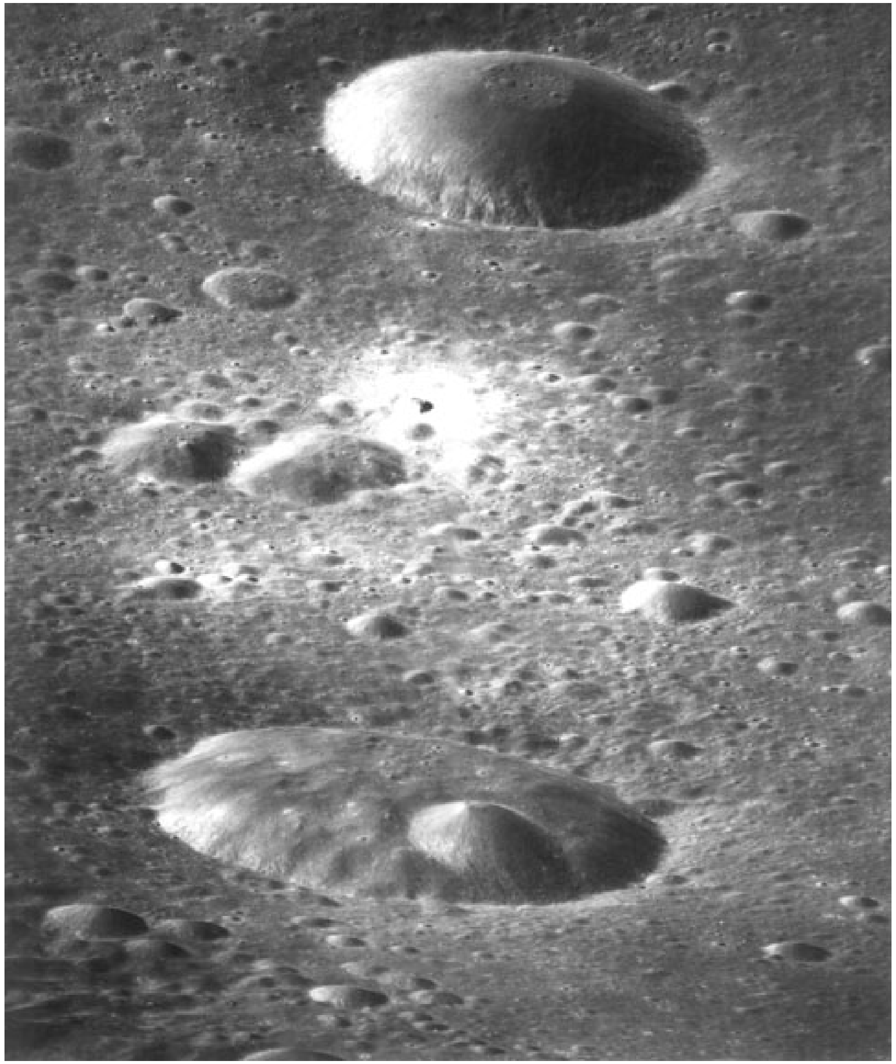
(Grossberg and Nayar)

f^{-1} (Observed) = RAW

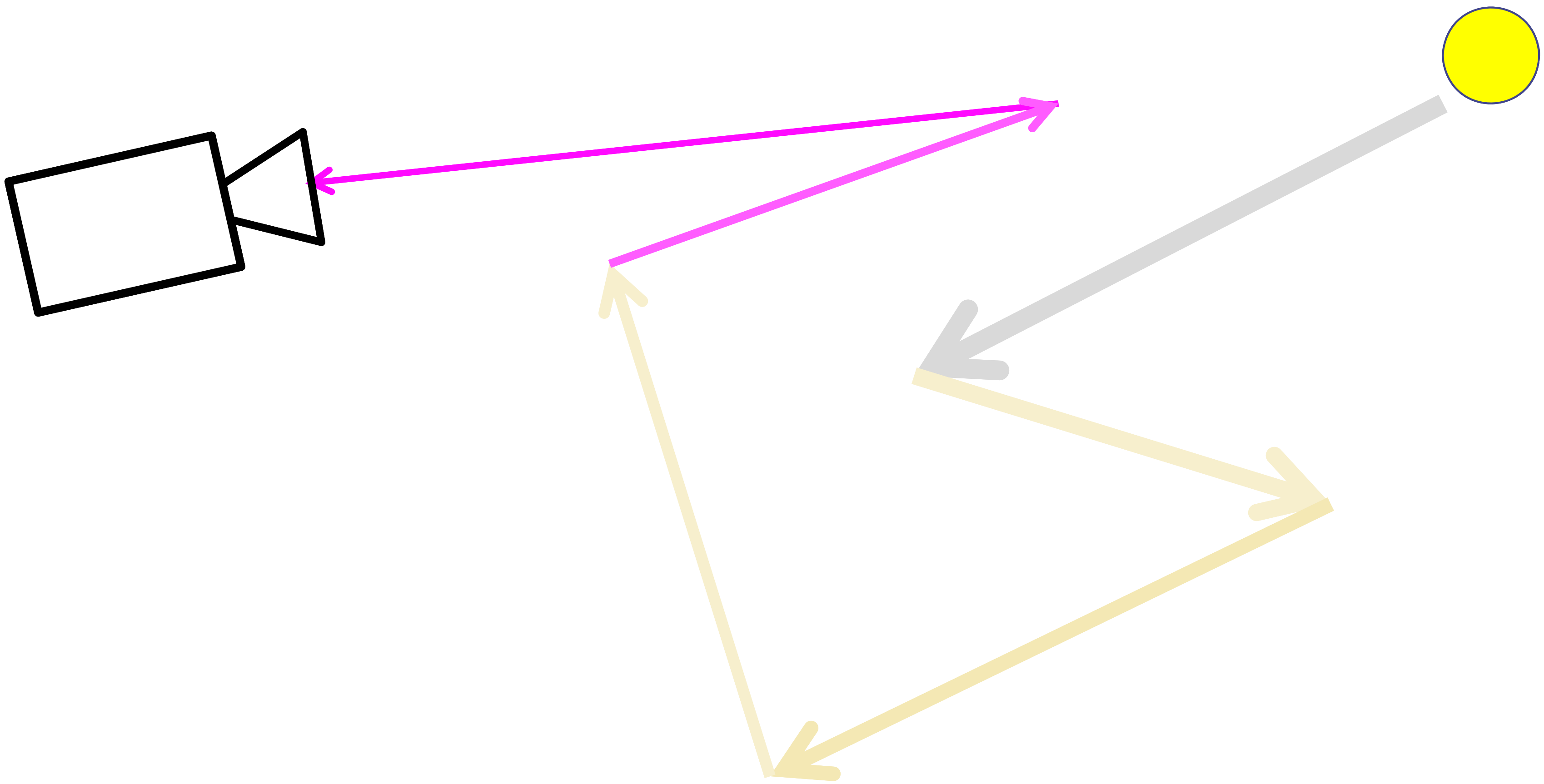
Vision is Inferential: Prior Knowledge



Vision is Inferential: Prior Knowledge

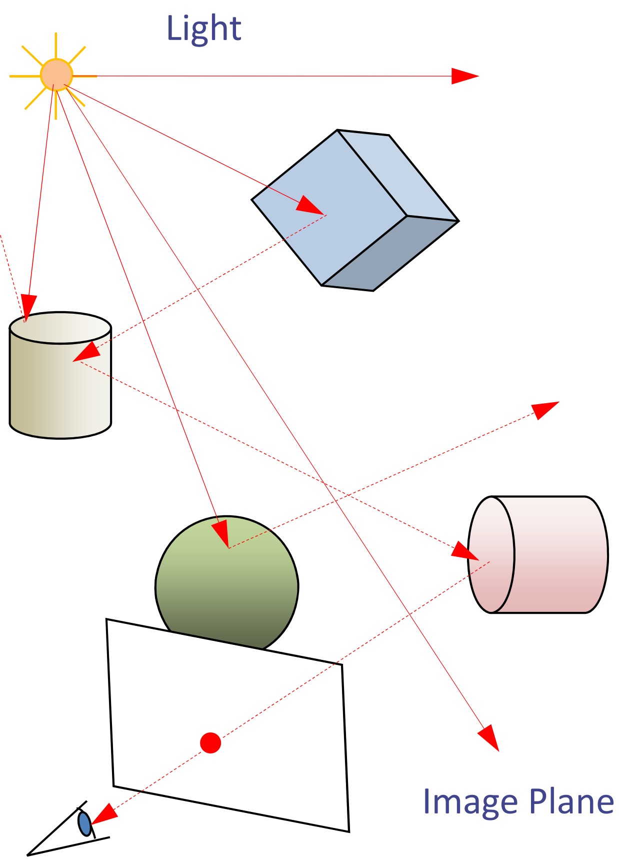


The life of a photon



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.

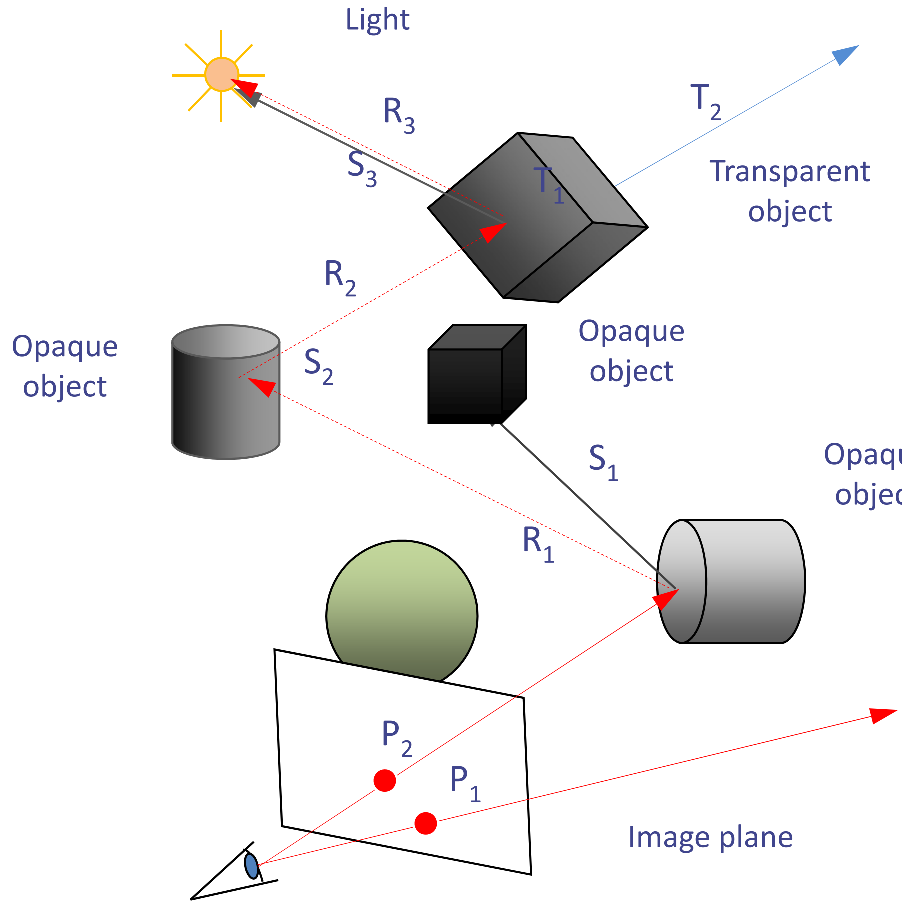
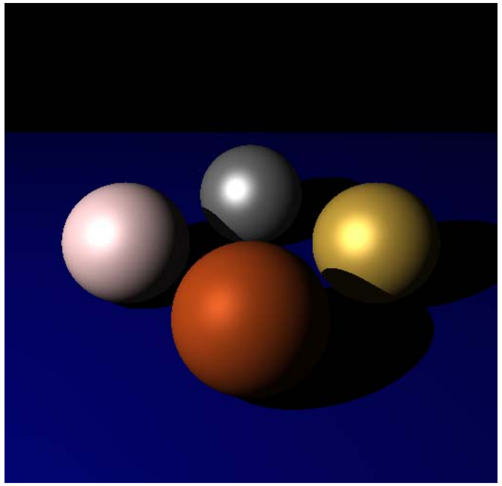
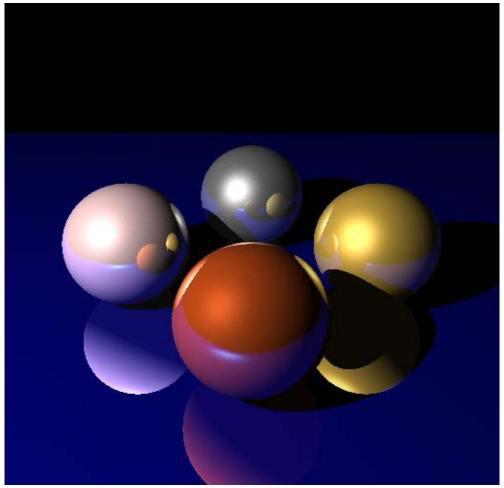


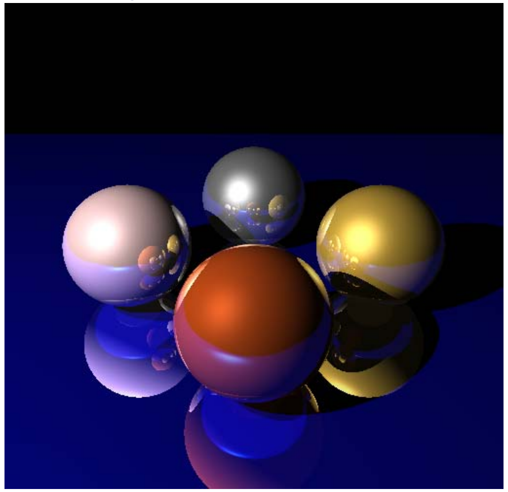
Figure. A background pixel corresponding to the ray P_1 and a pixel representing an object (ray P_2). The secondary rays triggered by the primary ray P_2 according to the three models: transmission (T_1 and T_2), reflection (R_1, R_2 and R_3), and tentative shadowing (S_1, S_2: true shadows, and S_3).

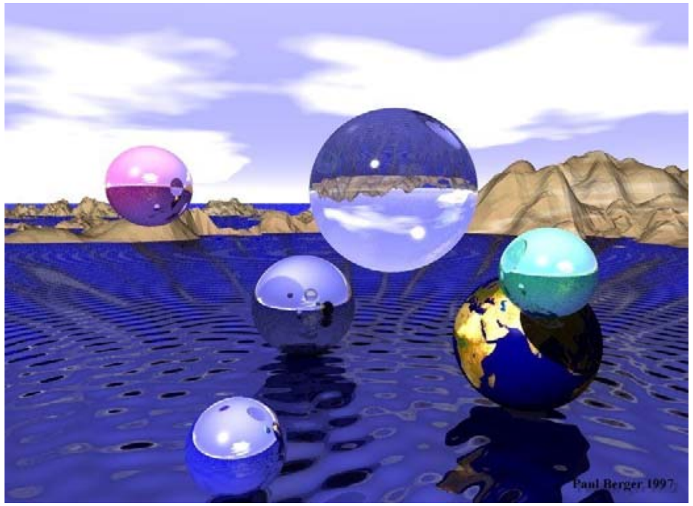
Reflections and transparencies

Created by David Derman – CISC 440

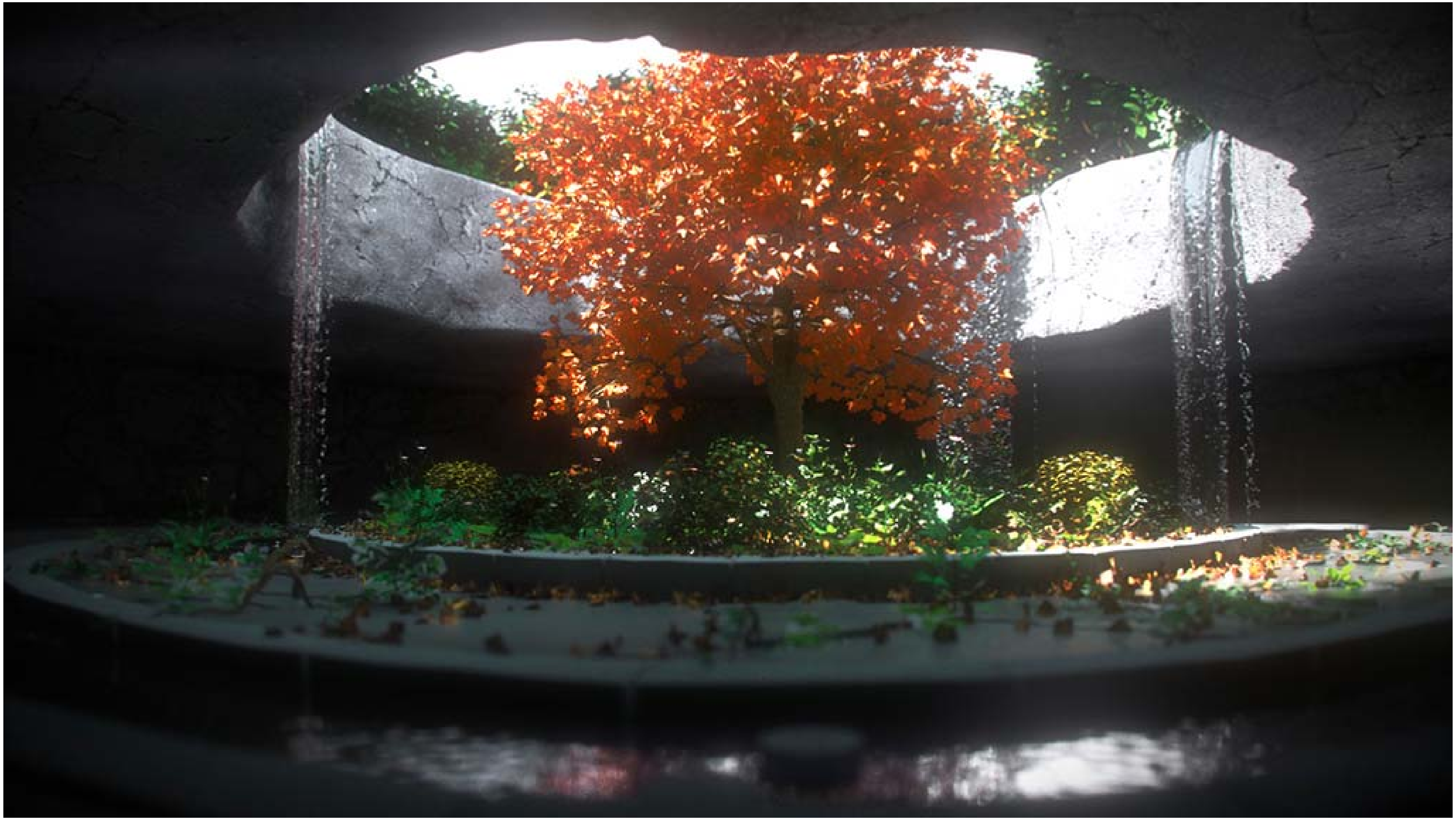








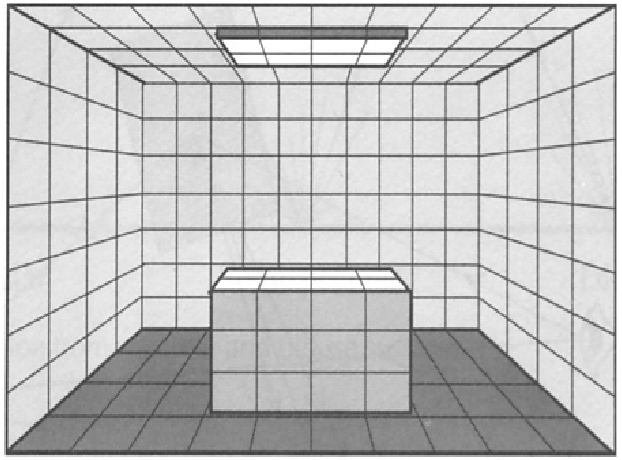
Example



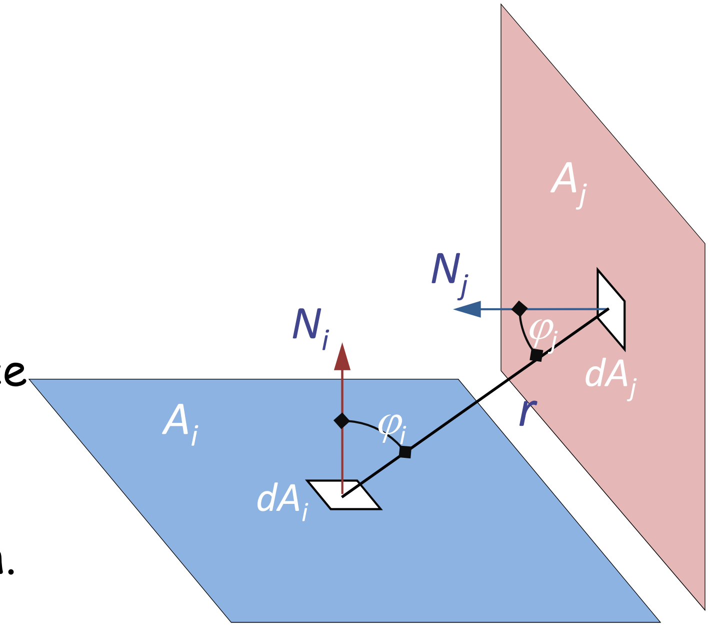
Global rendering: radiosity

- 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.

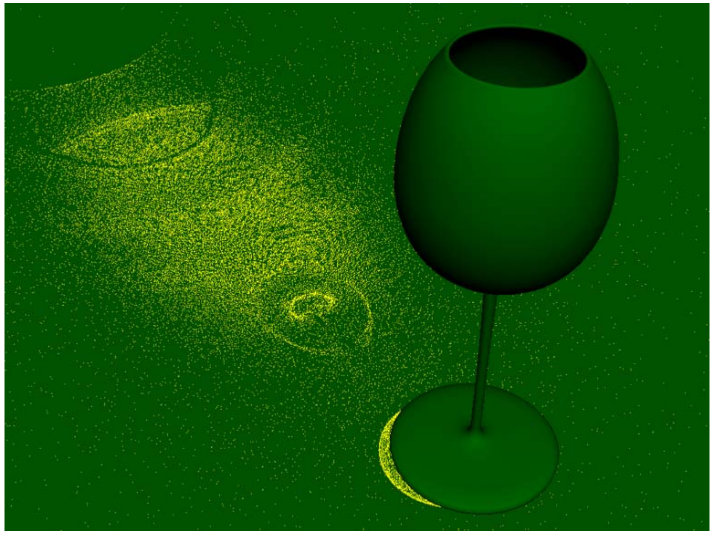


Example

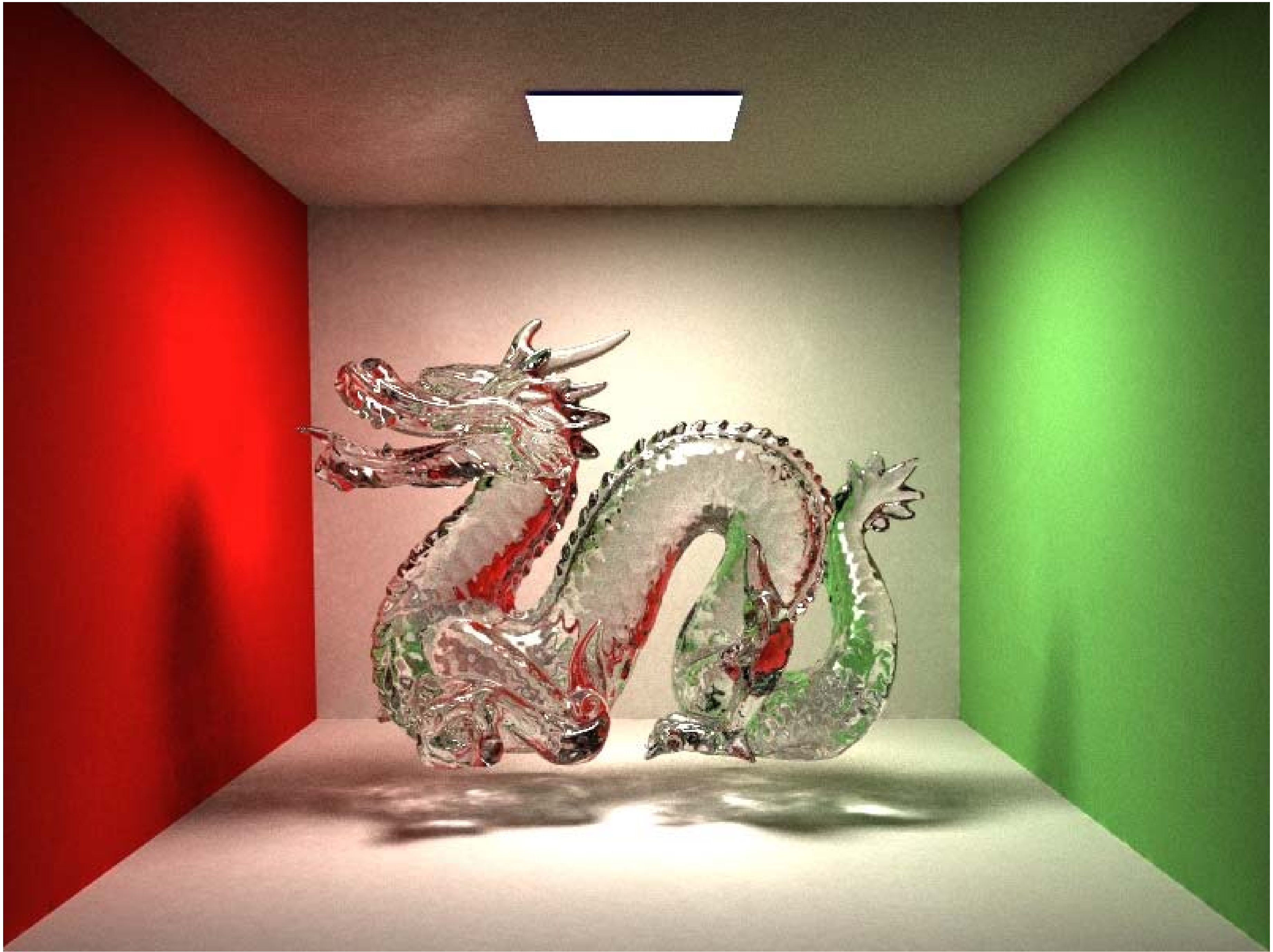
Global illumination photon mapping

- **Photon mapping** is a two-pass algorithm developed by Henrik Wann Jensen that approximately solves the rendering equation.
- Rays from the light source and rays from the camera are traced independently until some termination criterion is met, then they are connected in a second step to produce a radiance value.
- It is used to realistically simulate the interaction of light with different objects. Specifically, it is capable of simulating the refraction of light through a transparent substance such as glass or water, diffuse interreflection between illuminated objects, the subsurface scattering of light in translucent materials, and some of the effects caused by particulate matter such as smoke or water vapor.



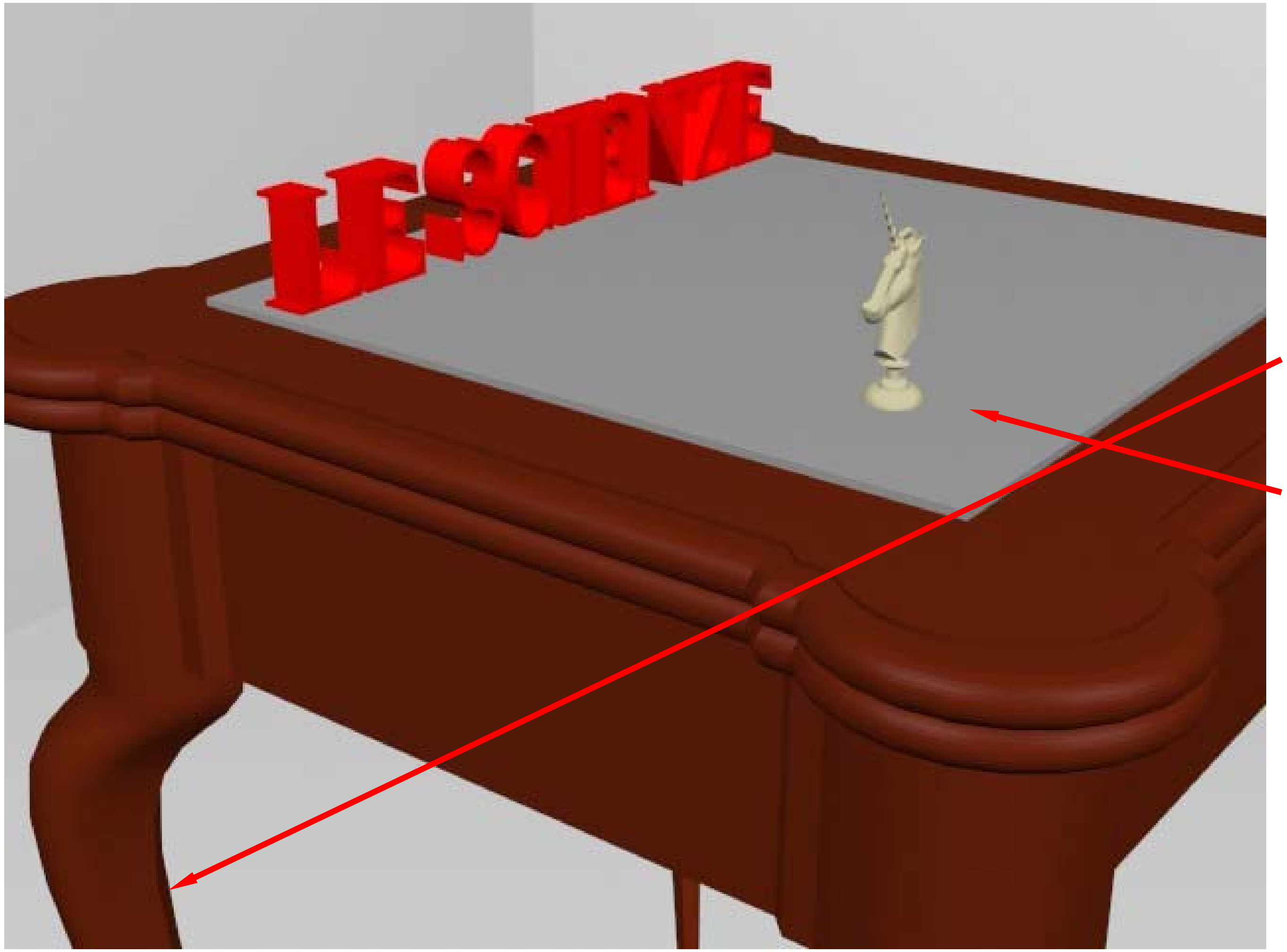




Example



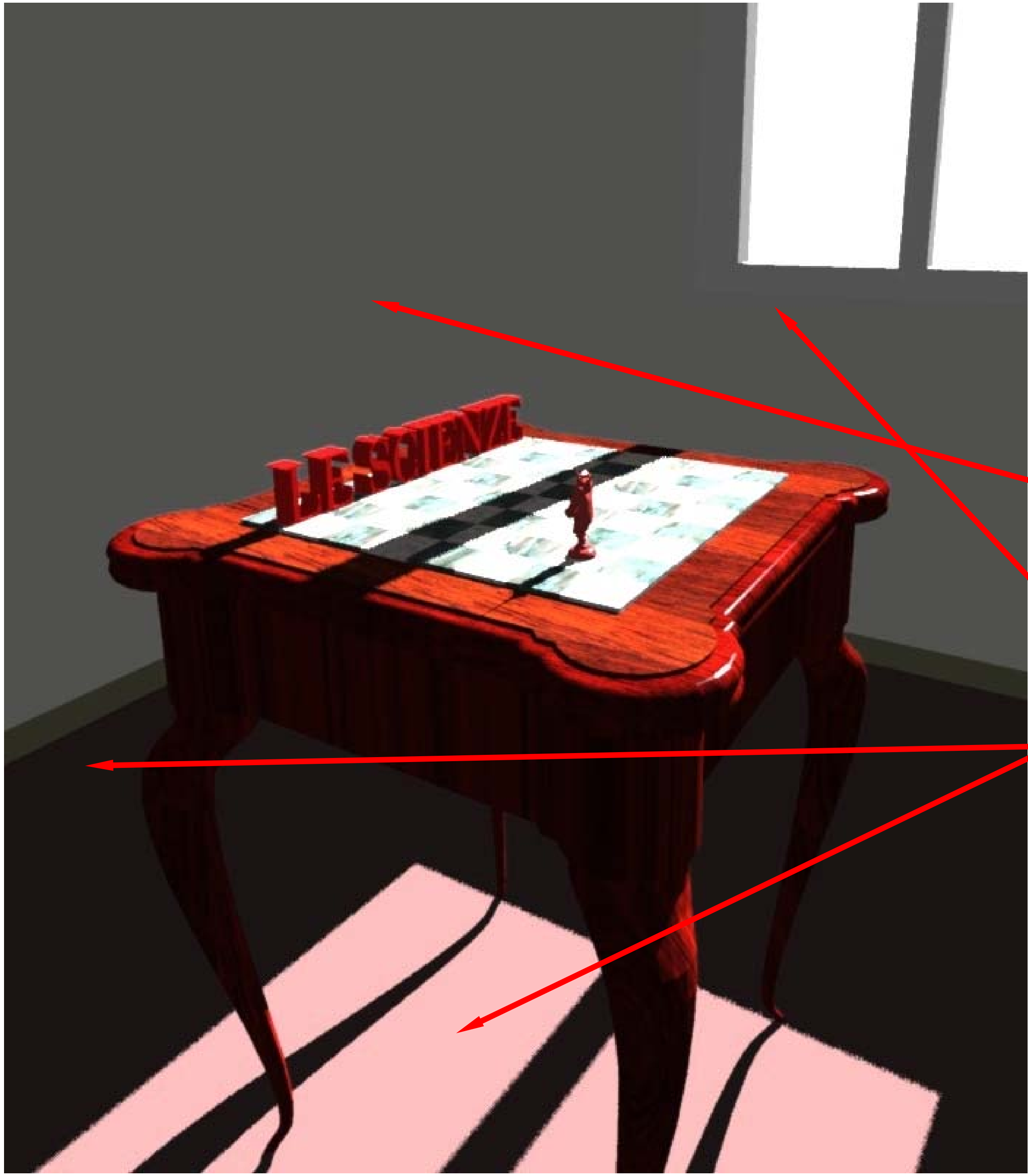
A comparison by Ledah Casburn

…. Phong model



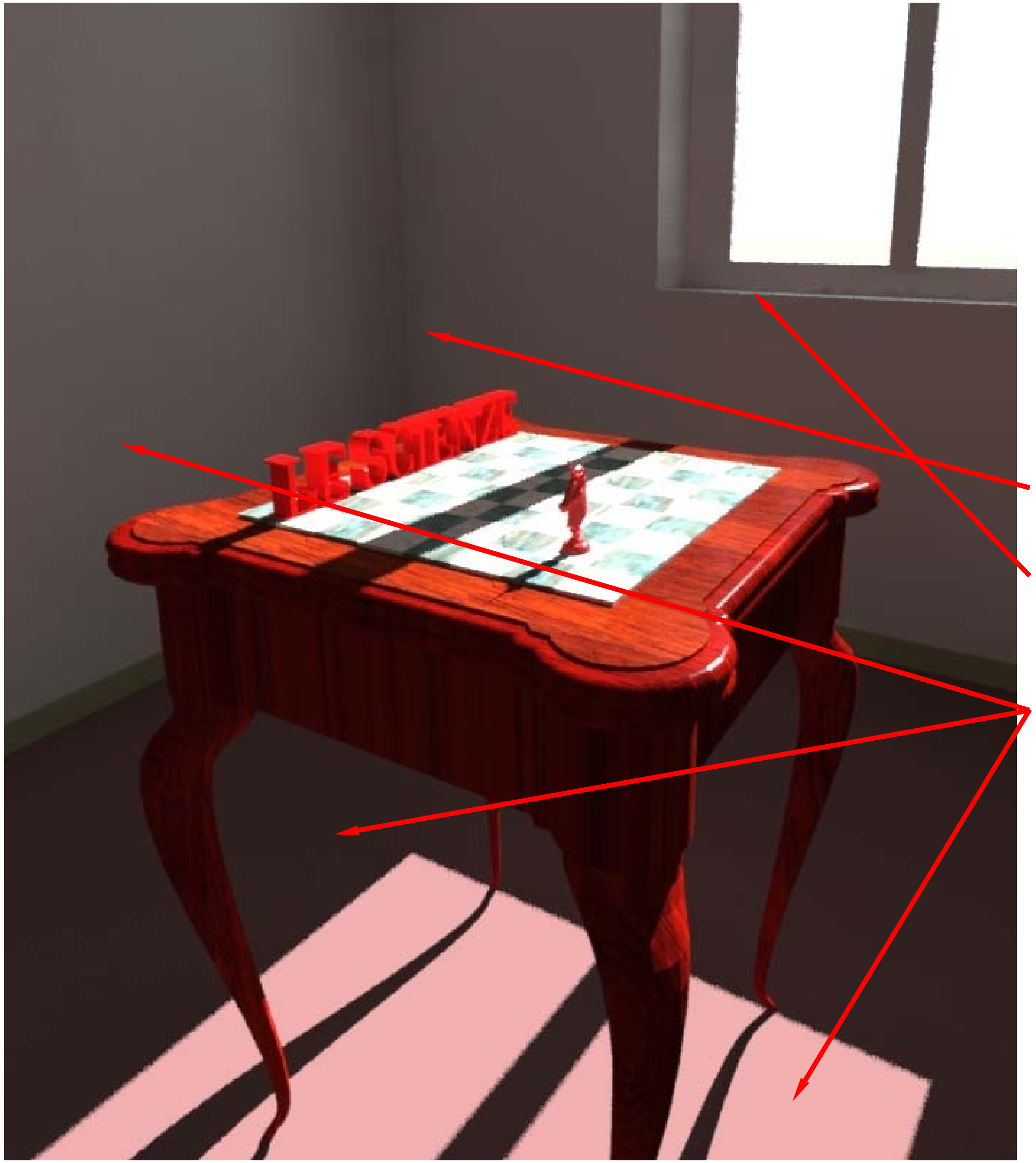
- No objects interactions
- No shadows

… ray tracing



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

.. radiosity



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

Award winning examples…
July-August 2000

Example: Render of the year 2014

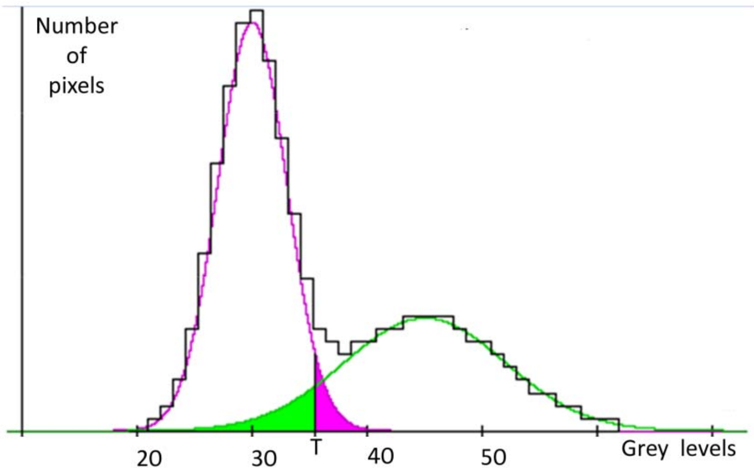
The betrothal of the Arnolfini

Jan Van Eyck 1434, National Gallery, London

Examples

Intensity re-distribution and rendering

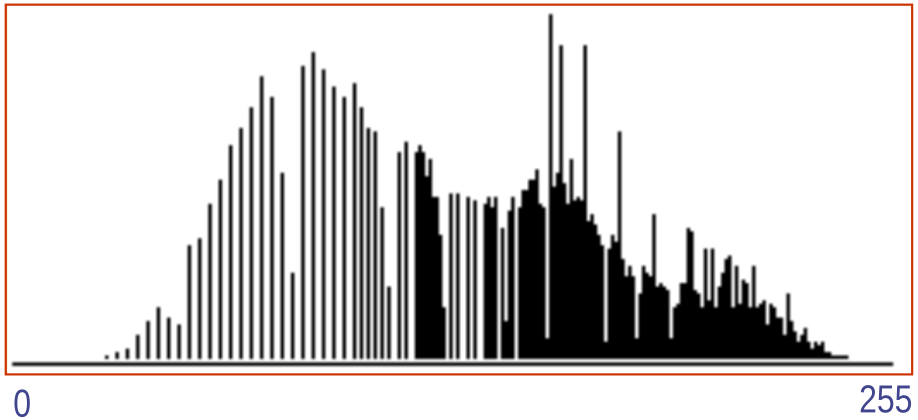
- An image histogram has in the abscissa the pixel grey (or color) value while the ordinate plots the number of occurrences of such value.
- Such histogram may be manipulated so as: to obtain a sharper image, to highlight some chromatic distributions, to correct over or under exposed images, to optimize 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

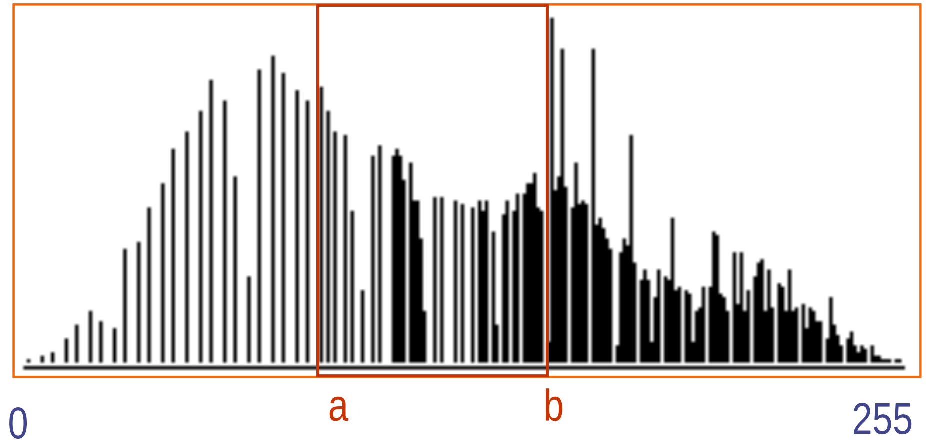


Extended dynamics

- 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:

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

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.

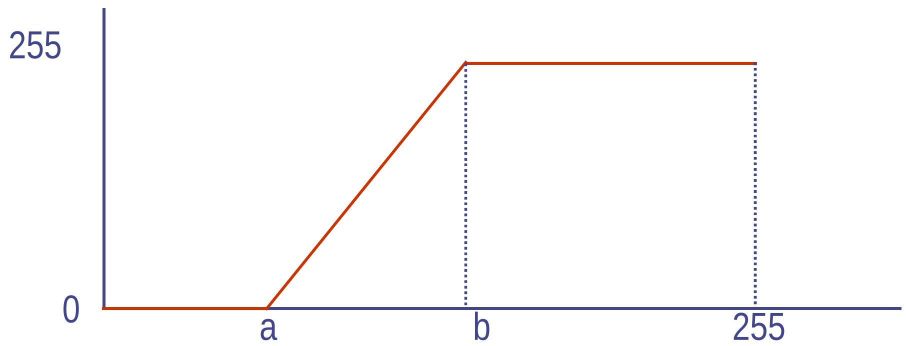


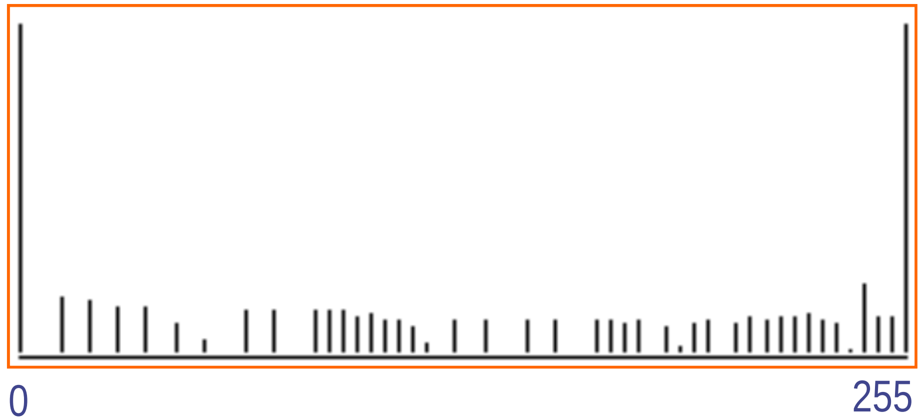
Stretching of a range in grey scale

- 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.

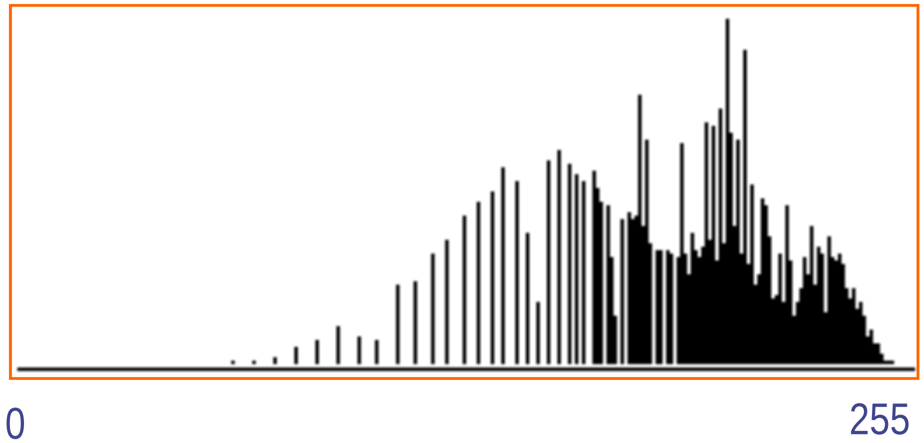




Under-exposure

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

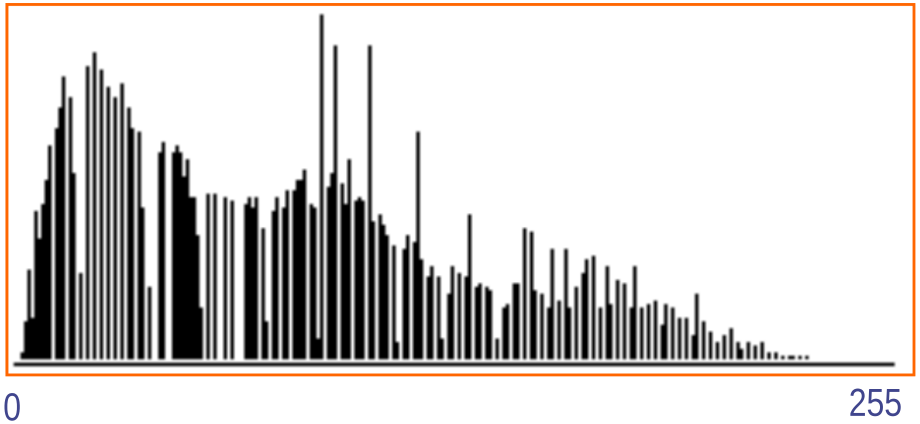
$$g(i,j) = \sqrt{255 g(i,j)}$$



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*.

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

Color-based image retrieval

- Given collection (database) of images:
  - Extract and store one color histogram per image

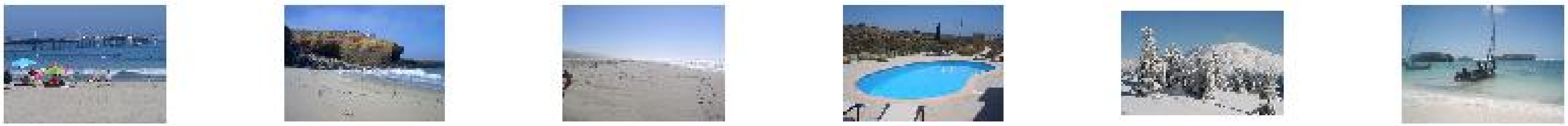
- Given new query image:
  - Extract its color histogram
  - For each database image:
    - Compute intersection between query histogram and database histogram
  - Sort intersection values (highest score = most similar)
  - Rank database items relative to query based on this sorted order

Example retrievals: Color-based image retrieval

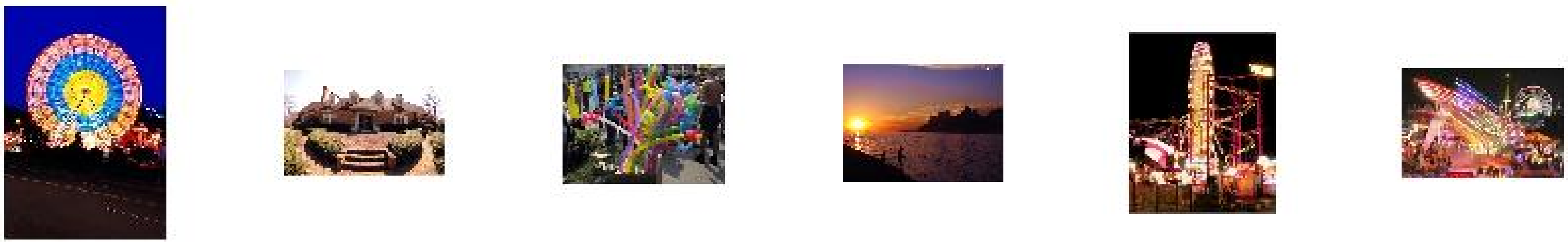
query

query

query



query



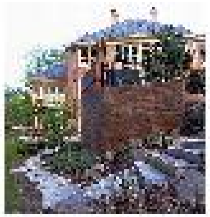
Example retrievals: Color-based image retrieval

query

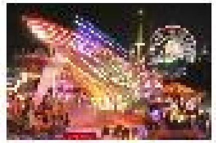





query





query