Light and Color

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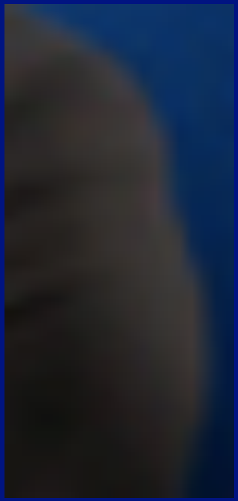
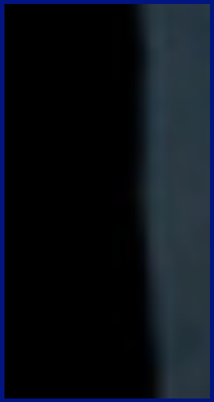
Key issues

- Physical
  - what makes a pixel take its brightness values?
- Inference
  - what can we recover from the world using those brightness values?
- Human
  - What can people do?
    - which suggests problems we might be able to solve

By nickwheeleroz, on Flickr



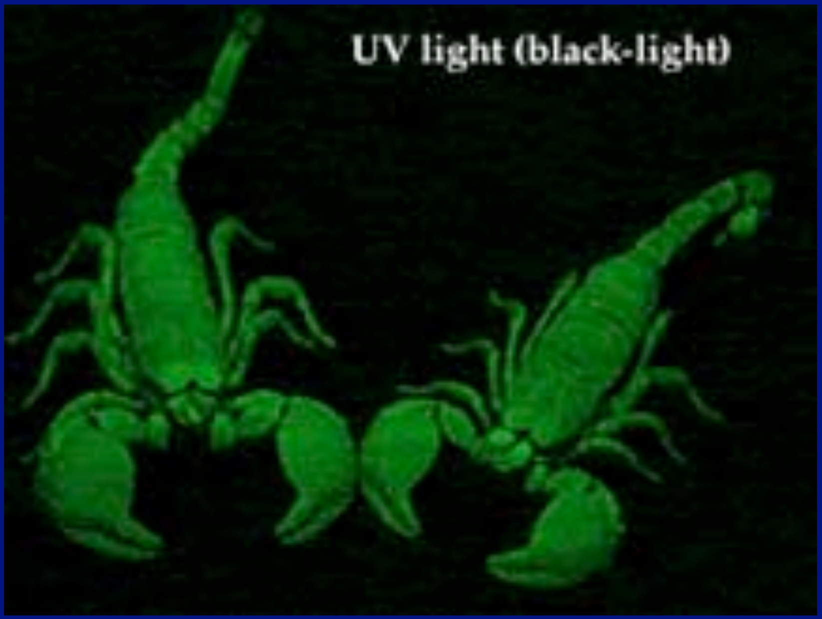


By nickwheeleroz, on Flickr

Processes

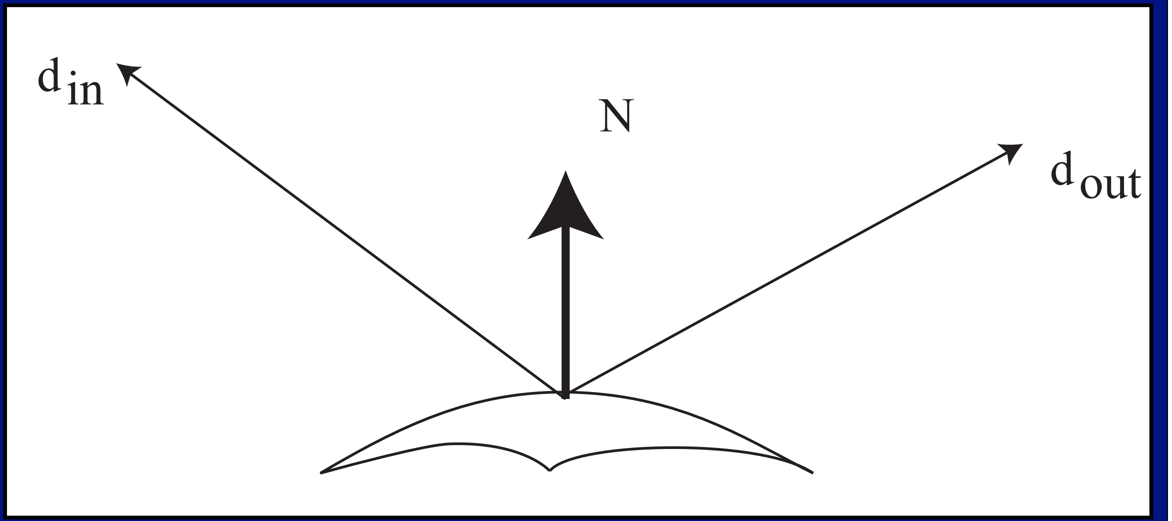
- Cameras
  - film: non-linear
  - CCD: linear, with non-linearities made by electronics
- Light
  - is reflected from a surface
  - got there from a source
- Many effects when light strikes a surface -- could be:
  - absorbed; transmitted; reflected; scattered
  - Simplify
    - Assume that
      - surfaces don’t fluoresce
      - surfaces don’t emit light (i.e. are cool)
      - all the light leaving a point is due to that arriving at that point


White light (indoor)


UV light (black-light)

Specularities

- For some surfaces, reflection depends strongly on angle
  - mirrors (special case)
    - incoming direction, normal and outgoing direction are coplanar
    - angle din, normal and angle dout, normal are the same
  - specular surfaces
    - light reflected in a "lobe" of directions
    - eg slightly battered metal surface
    - can see light sources specularly reflected
      - specularities



Flickr, by suzysputnik

Flickr, by piratejohnny

- Specularities are relatively easy to detect
  - small and bright (usually)

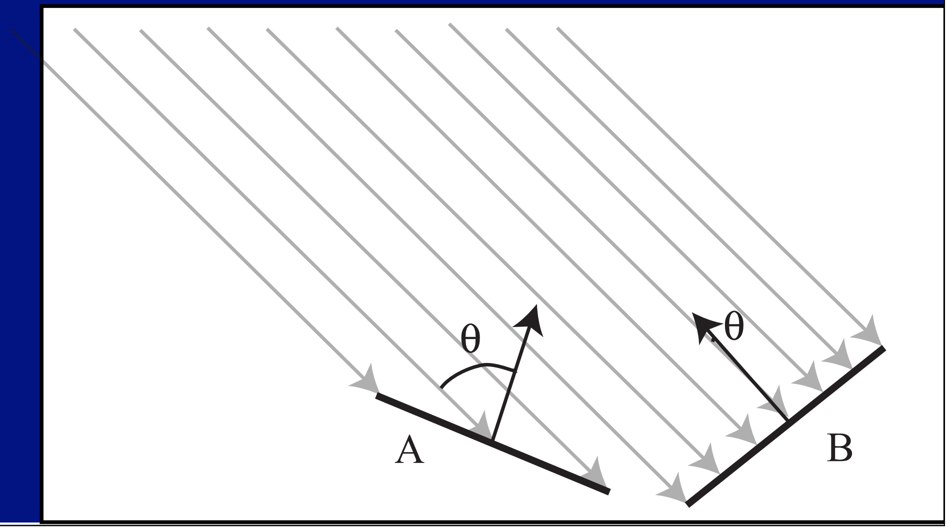
Diffuse reflection

- Light leaves the surface evenly in all directions
  - cotton cloth, carpets, matte paper, matte paints, etc.
  - most “rough” surfaces
  - Parameter: Albedo
    - percentage of light arriving that leaves
    - range 0-1
      - practical range is smaller

Point source at infinity

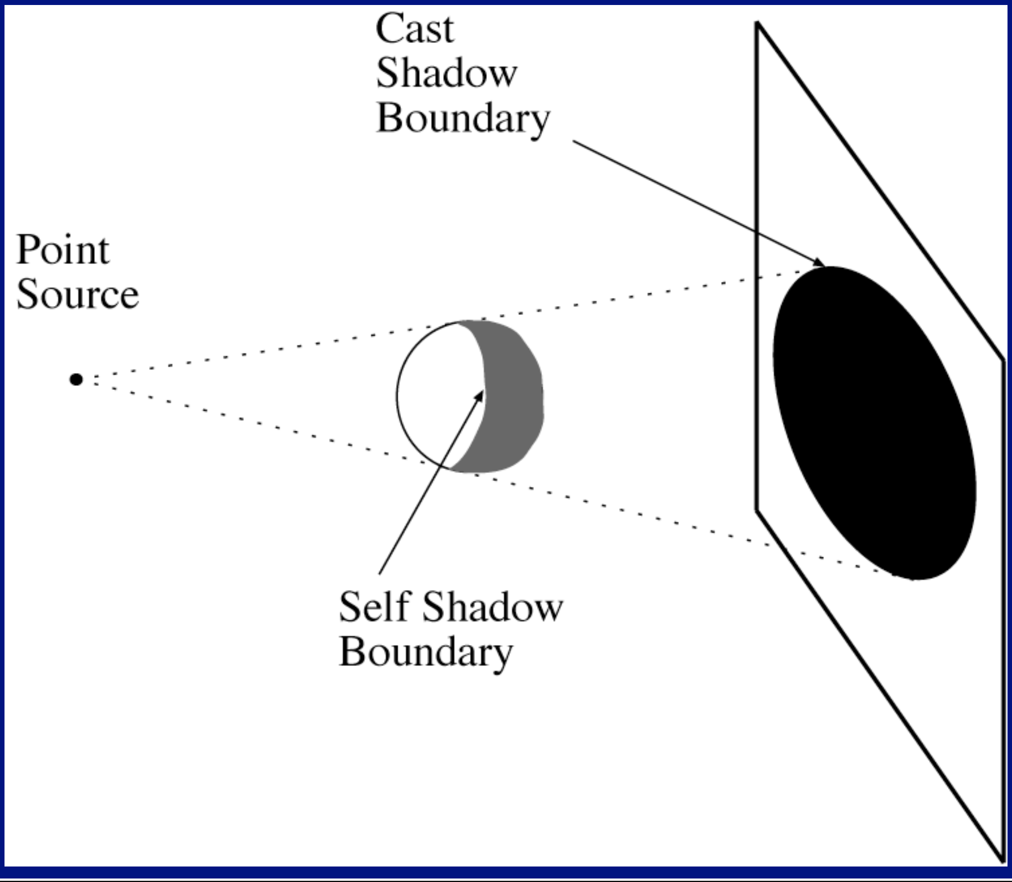
- E.g. the sun
  - energy travels in parallel rays
  - energy density received is proportional to cos theta
- Write:
  - p for albedo
  - S for source vector
  - N for normal
  - I for image intensity

$$I(\mathbf{x}) = \rho(\mathbf{x})\mathbf{S} \cdot \mathbf{N}(\mathbf{x})$$

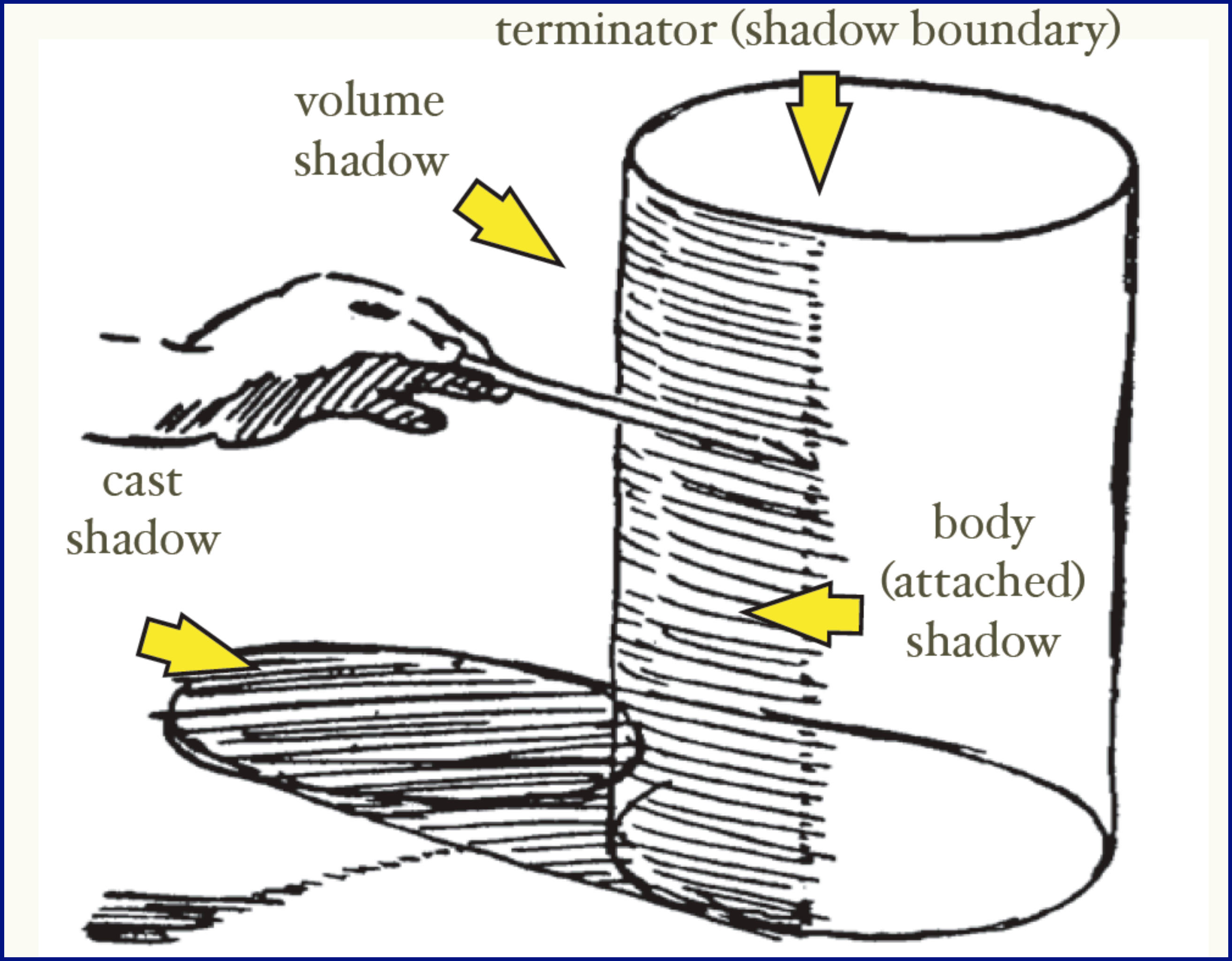


Shadows cast by a point source

- A point that can't see the source is in shadow
- For point sources, the geometry is simple



Cues to shape - shadows



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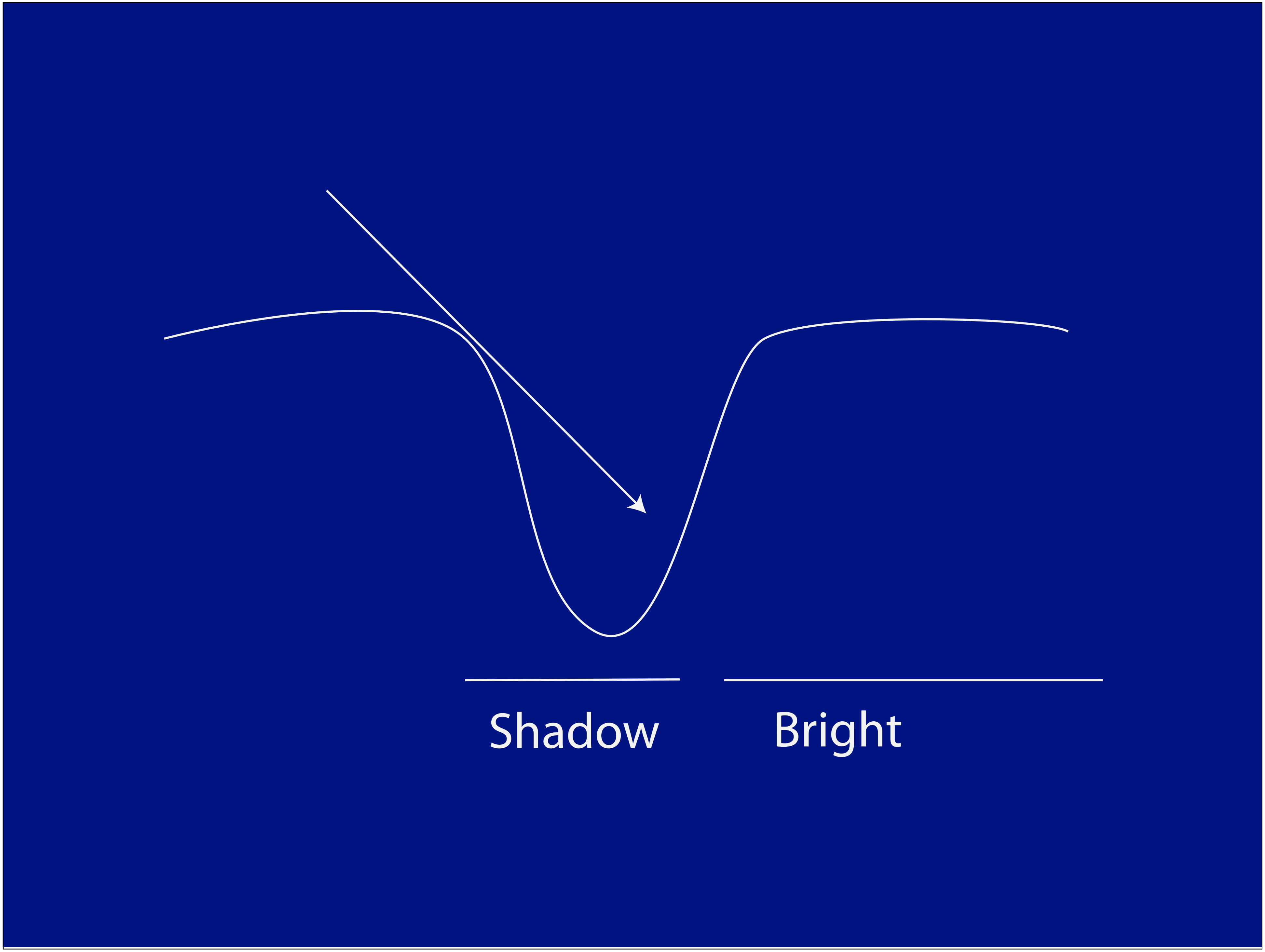
Shadow
Bright

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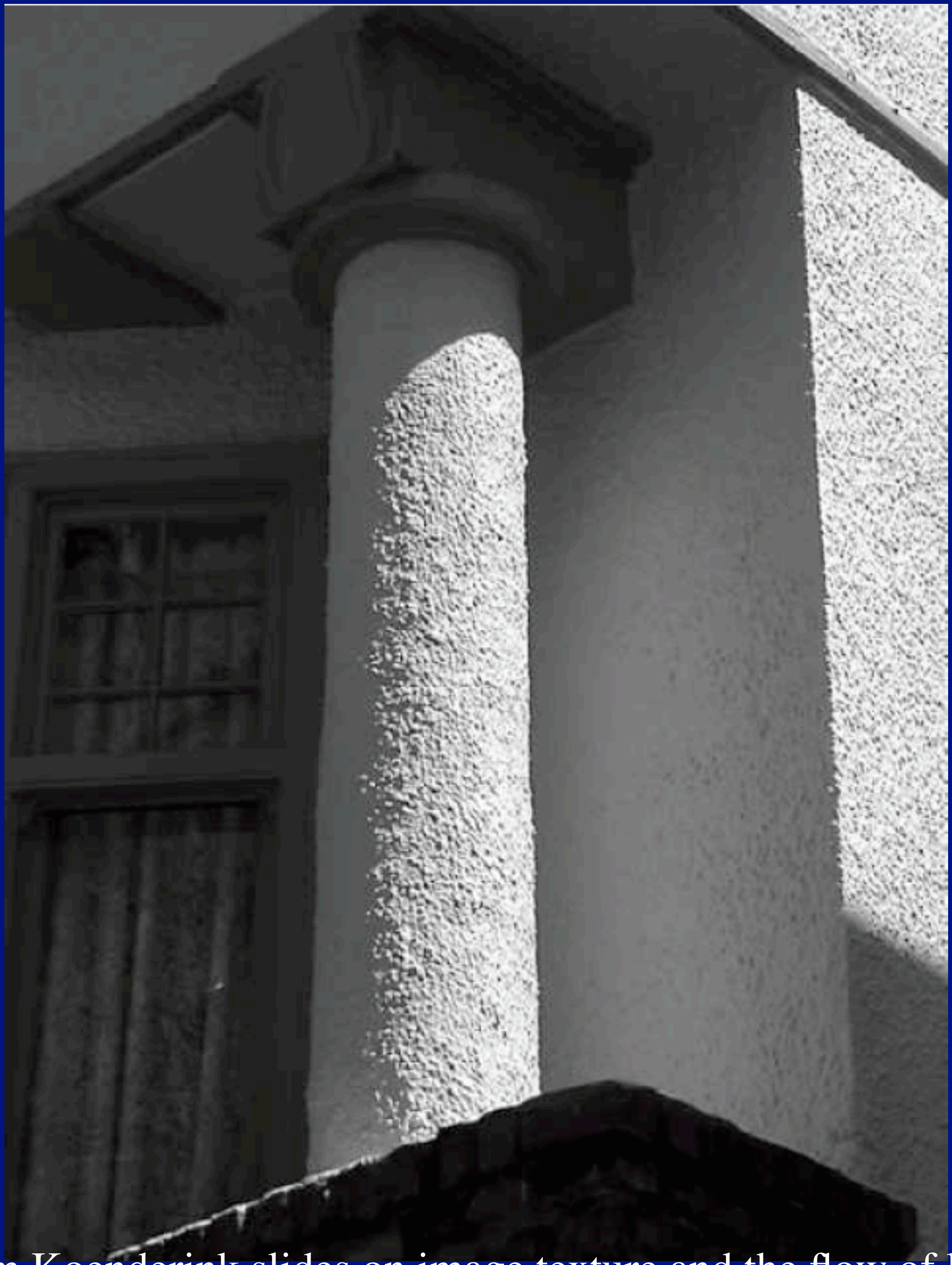

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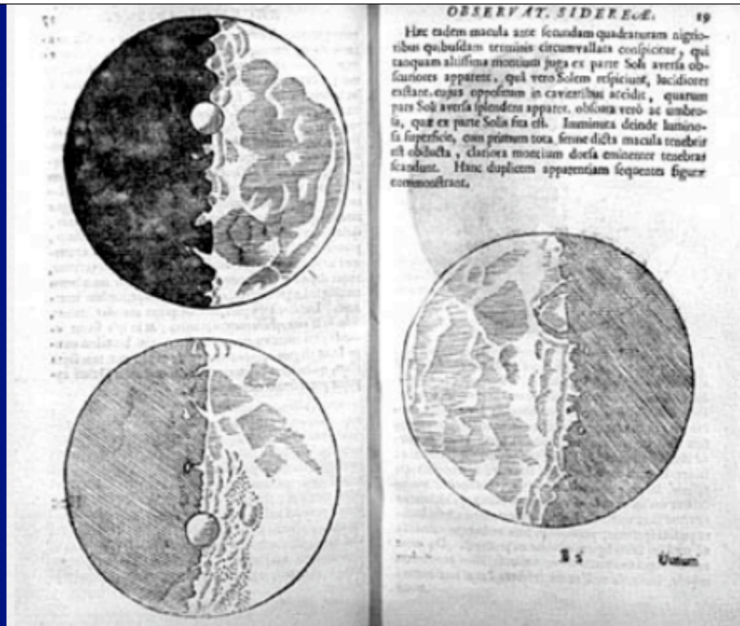
Shadow geometry can be very nasty

From Hel Des, on Flickr



OBSERVAT. SIDEREAE. 19

Hæc eadem macula ante secundam quadraturam nigrioribus quibusdam terminis circumvallata conspicitur, qui tanquam altissima montium iuga ex parte Soli aversa obscuriores apparent, quâ vero Solem respiciunt, lucidiores extant, cuius oppositum in cavitatibus accidit, quarum pars Soli aversa splendens apparet, obscura verò ac umbrosa, quæ ex parte Solis sita est. Imminuta deinde luminosa superficie, cum primum tota ferme dicta macula tenebris est obducta, clariora montium dorsa eminenter tenebras scandunt. Hanc duplicem apparentiam sequentes figuræ commonstrant.

B 5 Unum

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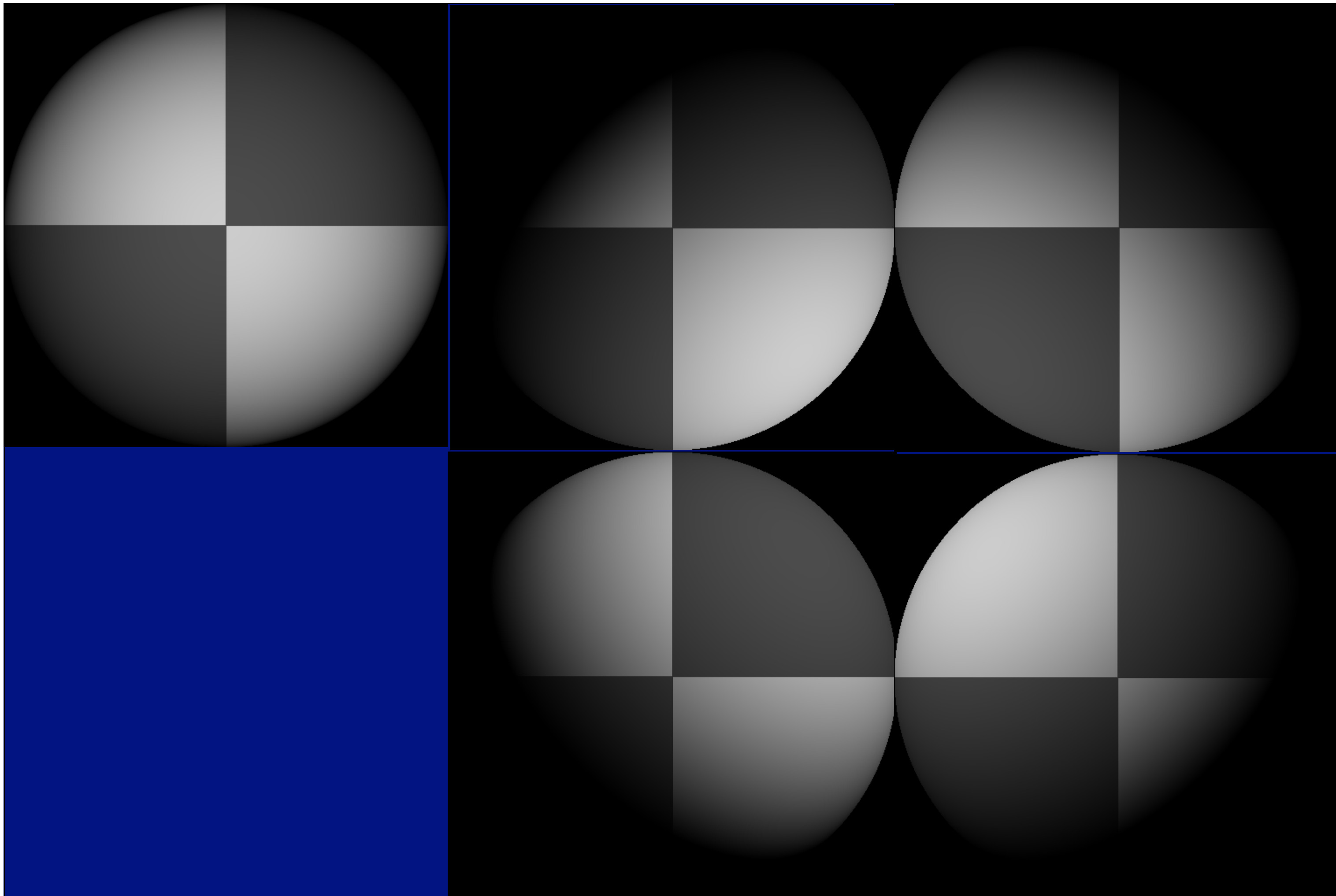
Photometric stereo

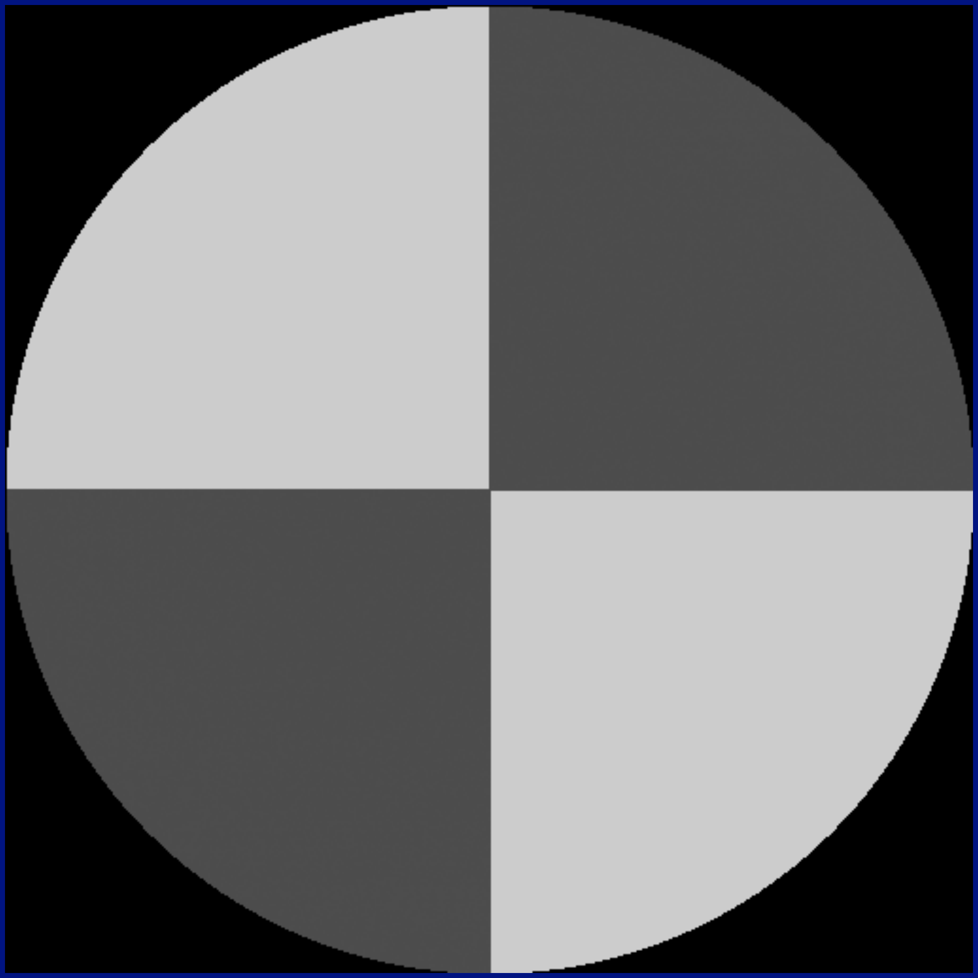
- Assume:
  - a set of point sources that are infinitely distant
  - a set of pictures of an object, obtained in exactly the same camera/object configuration but using different sources
  - A Lambertian object (or the specular component has been identified and removed)



Each image is: $$I_i(\mathbf{x}) = \mathbf{S}_i \cdot (\rho(\mathbf{x})\mathbf{N}(\mathbf{x}))$$

So if we have enough images with known sources, we can solve for

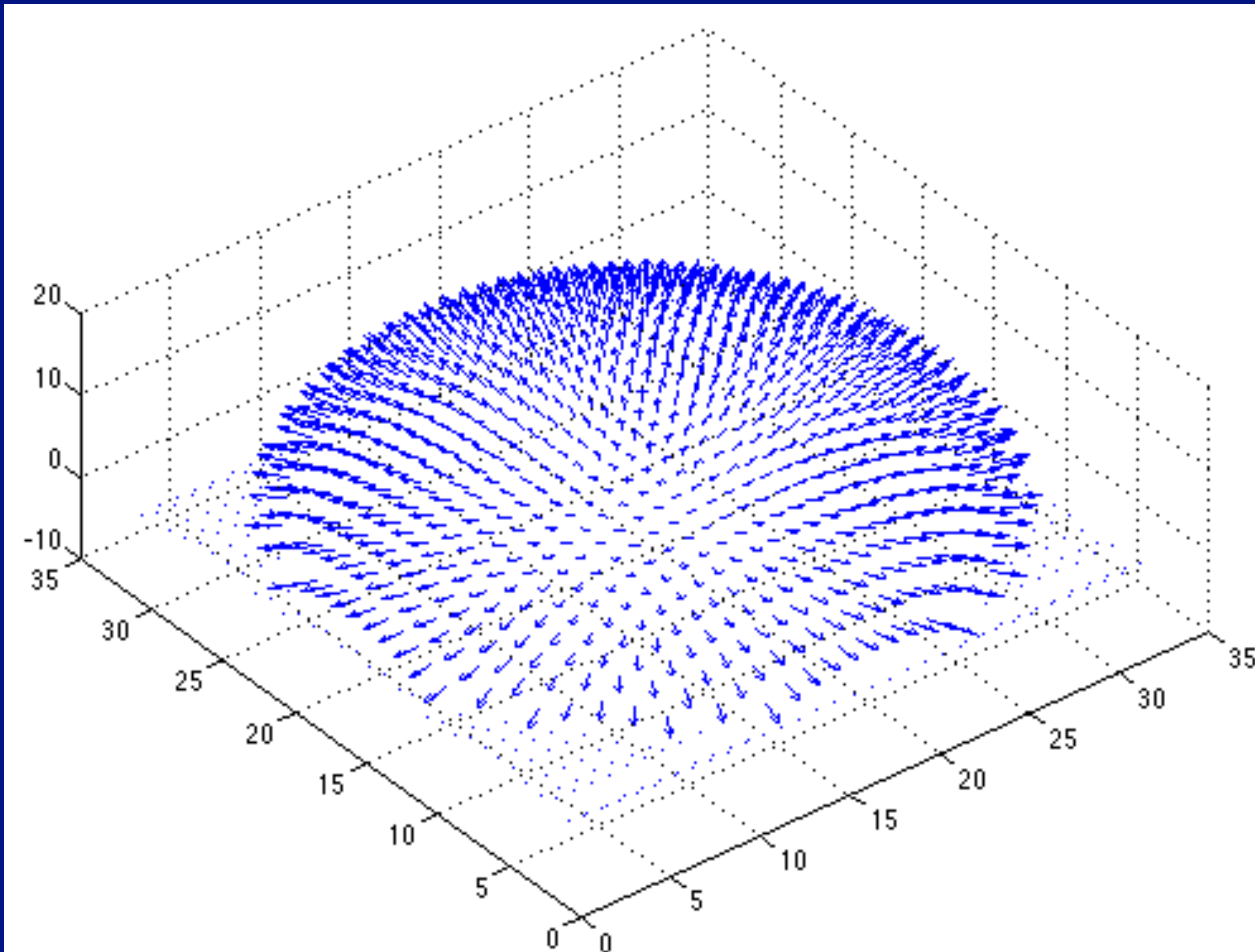
$$\mathbf{B}(\mathbf{x}) = (\rho(\mathbf{x})\mathbf{N}(\mathbf{x}))$$



$$\mathbf{B}(\mathbf{x}) = (\rho(\mathbf{x})\mathbf{N}(\mathbf{x}))$$

And the albedo (shown here) is given by:

$$\sqrt{\mathbf{B}(\mathbf{x}) \cdot \mathbf{B}(\mathbf{x})}$$



20
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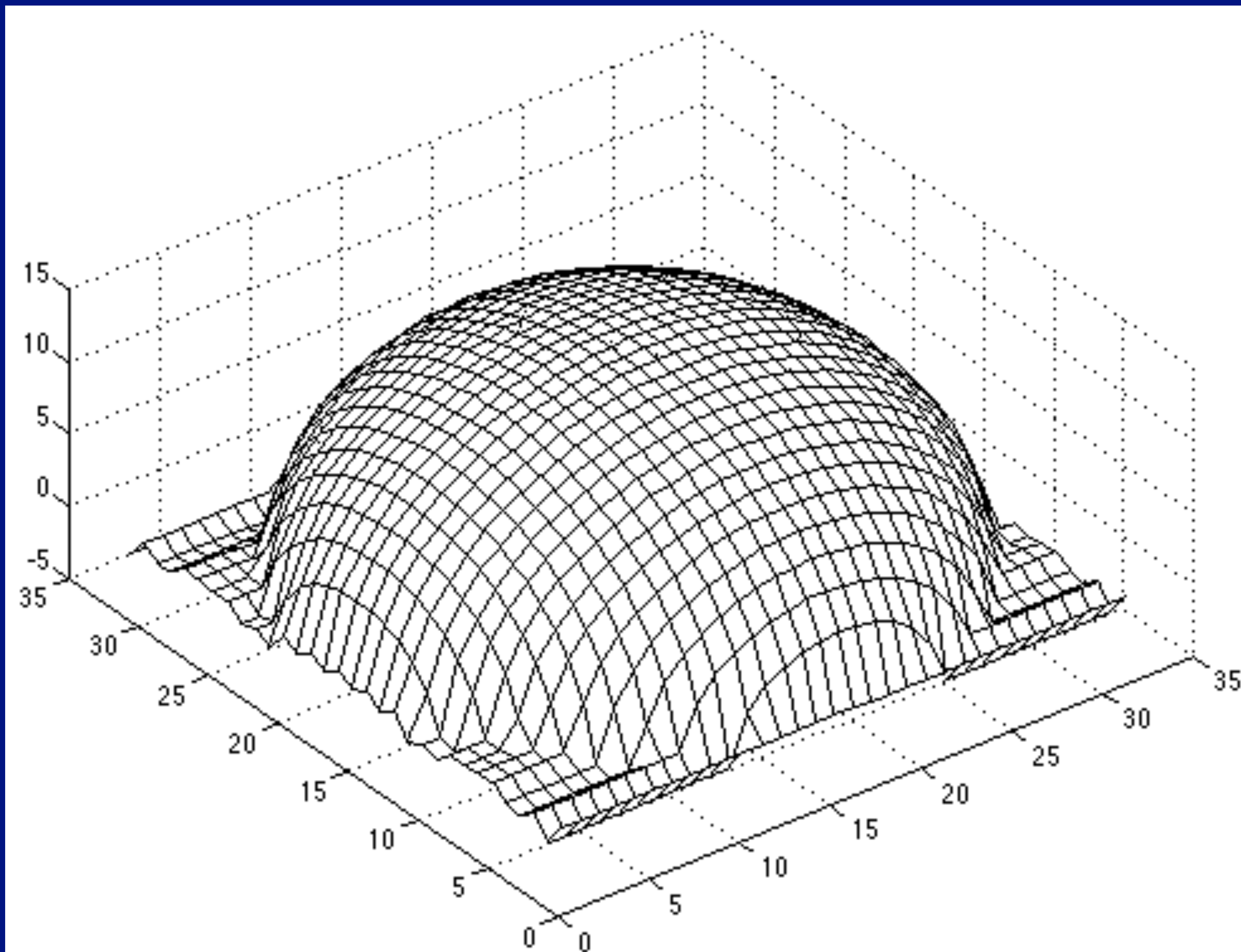
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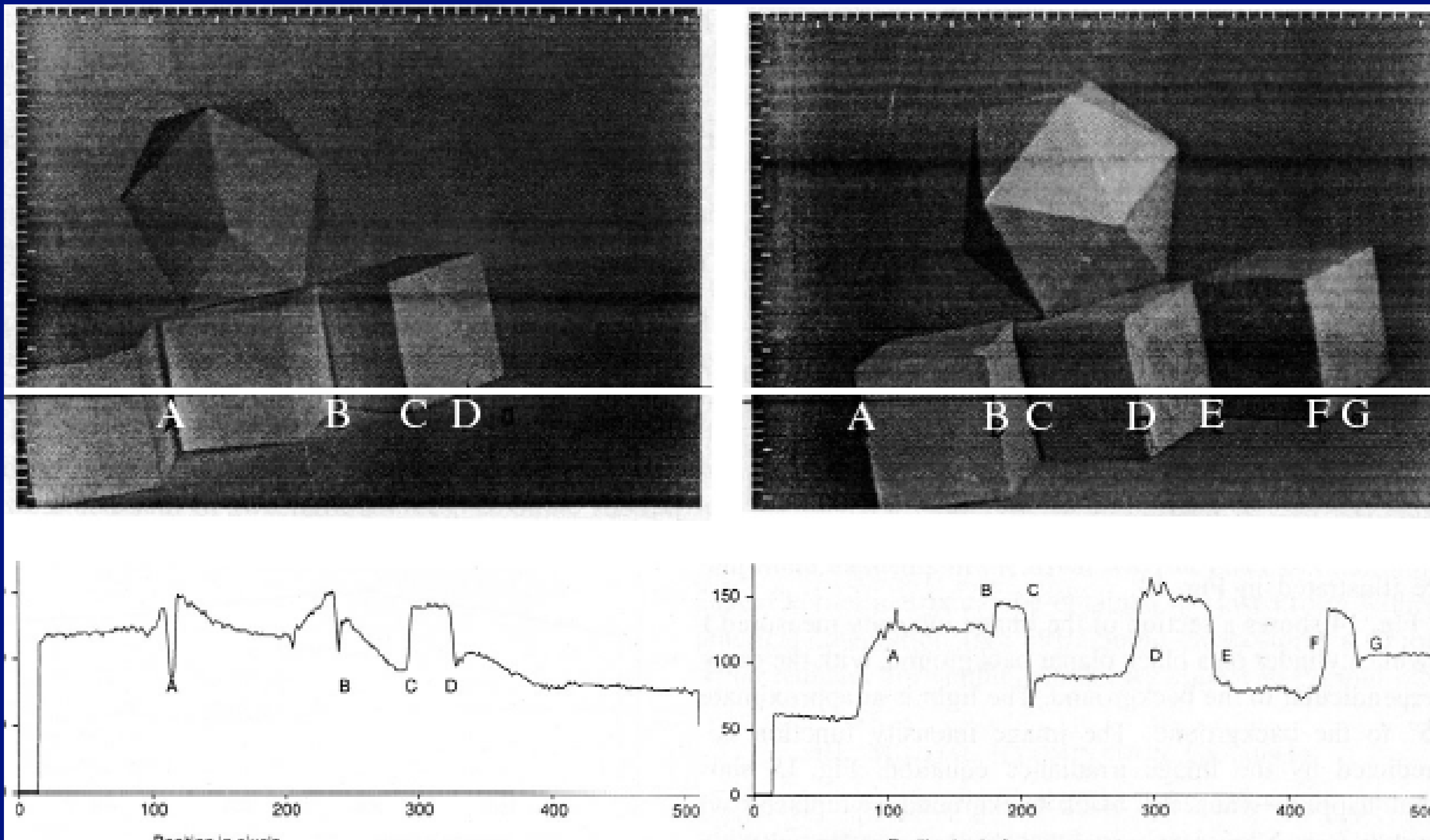
35

Curious Experimental Fact

- Prepare two rooms, one with white walls and white objects, one with black walls and black objects
- Illuminate the black room with bright light, the white room with dim light
- People can tell which is which (due to Gilchrist)

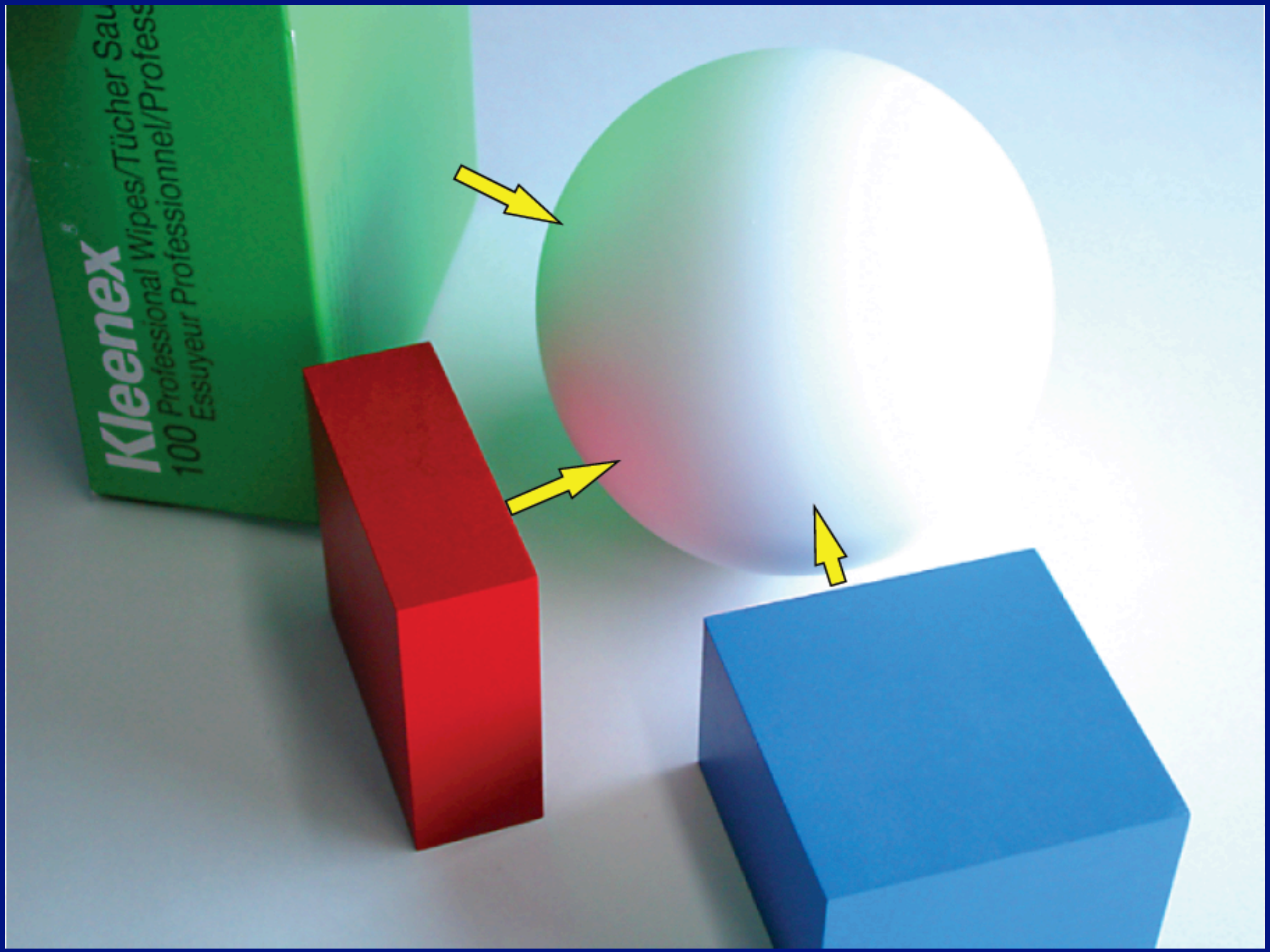
- Why? (a local shading model predicts they can’t).


A B C D
A B C D E F G
A B C D
0 100 200 300 400 500
Position in pixels
150 100 50 0
A B C D E F G
0 100 200 300 400 500
Position in pixels

Interreflections

- Issue:
  - local shading model is a poor description of physical processes that give rise to images
    - because surfaces reflect light onto one another
  - This is a major nuisance; the distribution of light (in principle) depends on the configuration of every radiator; big distant ones are as important as small nearby ones (solid angle)
  - The effects are easy to model
  - It appears to be hard to extract information from these models

Interreflections



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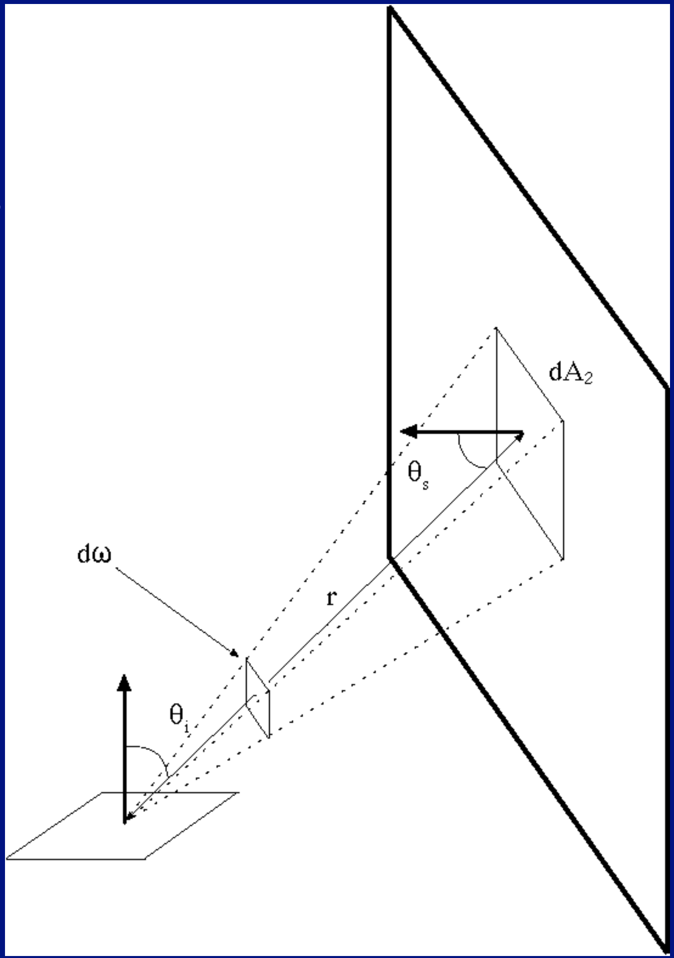
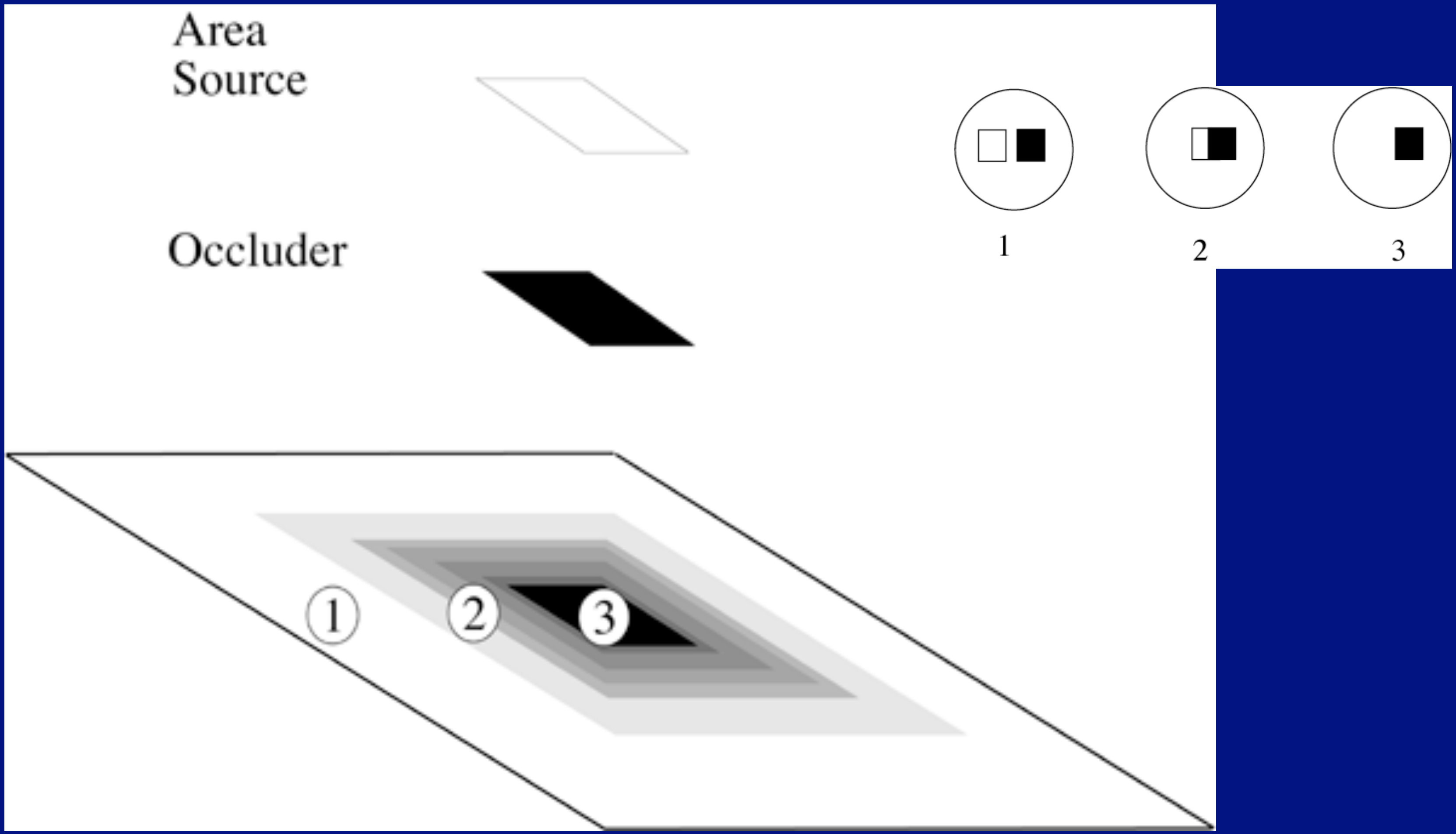
Area sources



- Examples: diffuser boxes, white walls.
- The energy received at a point due to an area source is obtained by adding up the contribution of small elements over the whole source

Area Source Shadows



Shape from shading

- Recover a shape representation from the shading field
  - people seem to be able to do it
  - Qn’s:
    - what shape representation?
    - how?
  - there is a story in computer vision, but we know it’s wrong

Original with Tracking
Retextured Video


By Technicolour Yawp, on Flickr

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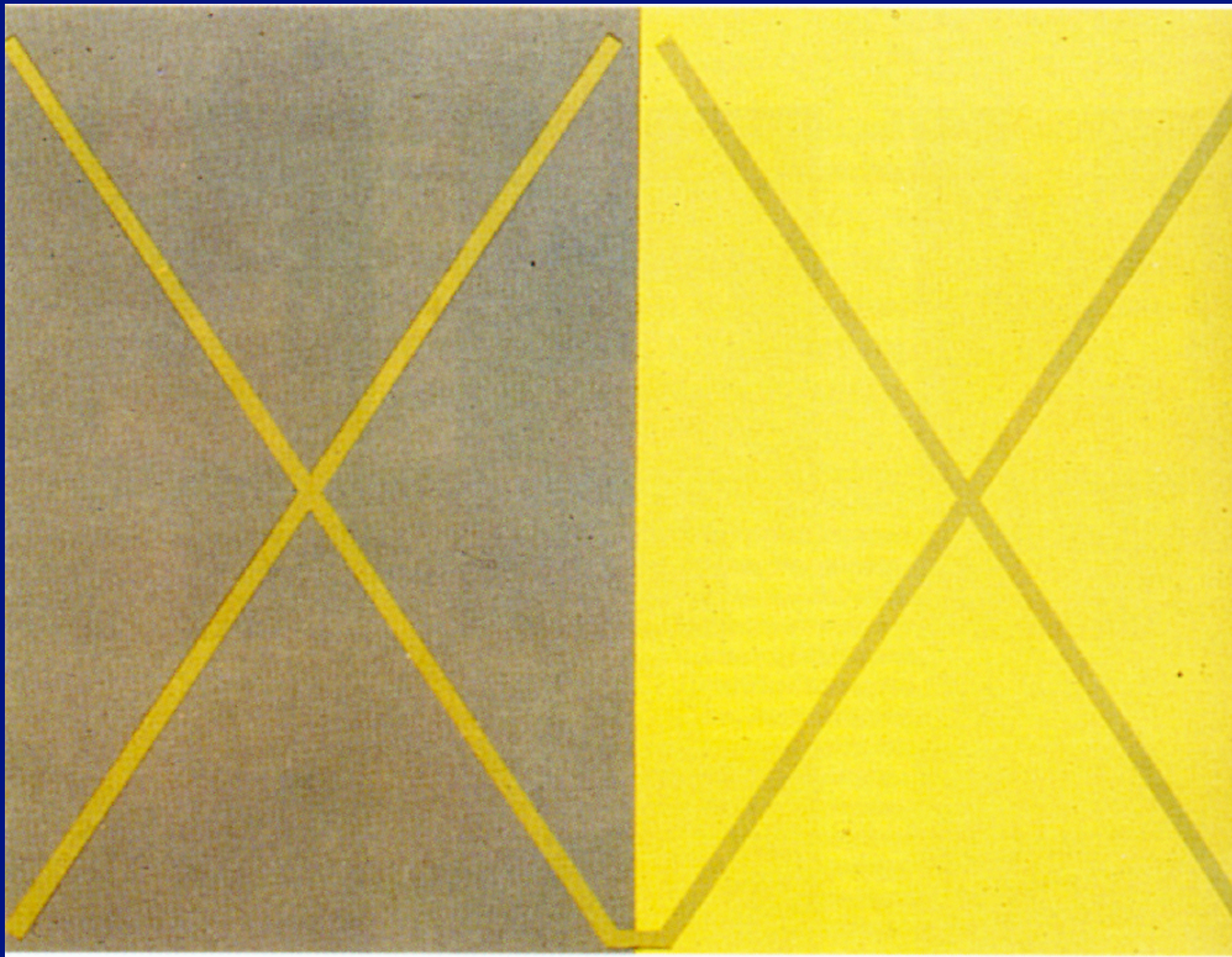
Causes of colour

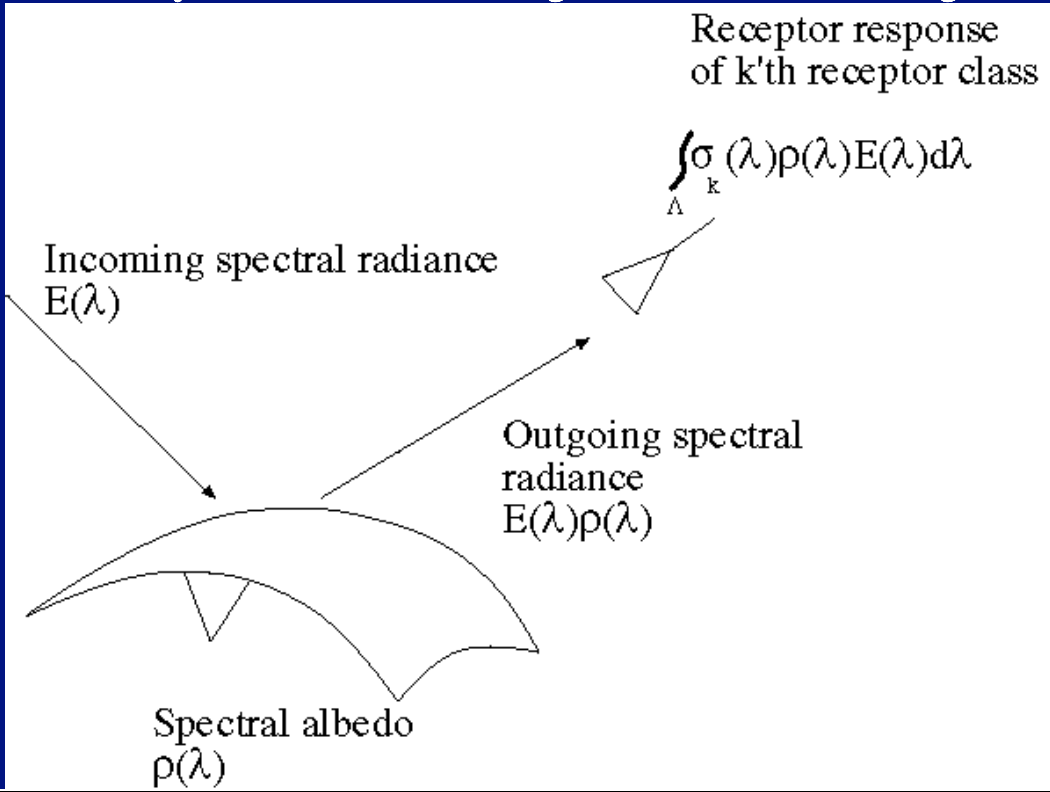
- The sensation of colour is caused by the brain.
- One way to get it is the response of the eye to the presence/absence of light at various wavelengths.
  - Dreaming, hallucination, etc.
  - Pressure on the eyelids
- Light could be
  - emitted with wavelengths absent (flourescent light vs. incandescent light)
  - differentially reflected - e.g. paint on a surface
  - differentially refracted - e.g. Newton's prism
  - subject to wavelength dependent specular reflection (most metals).
  - Flourescence -
    - invisible wavelengths absorbed and reemitted at visible wavelengths.
  - Phosphorescence (ditto, energy, longer timescale)

XXXXX	BLUE	YELLOW
XXXXX	GREEN	BLUE
XXXXX	RED	GREEN
XXXXX	YELLOW	RED
XXXXX	BLUE	YELLOW
XXXXX	RED	GREEN
XXXXX	GREEN	BLUE
XXXXX	BLUE	YELLOW
XXXXX	YELLOW	RED
XXXXX	RED	GREEN



The color of objects

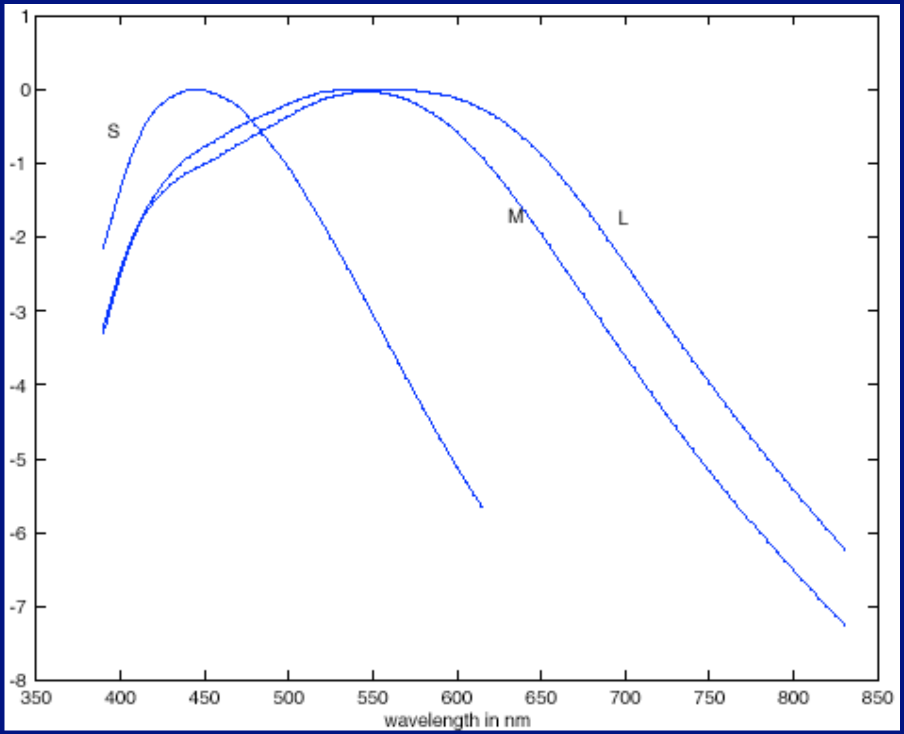
- Colored light arriving at the camera involves two effects
  - The color of the light source
  - The color of the surface
  - Changes caused by different colored light sources can be large



Color receptors and color deficiency

- Trichromacy is justified -
  - in color normal people, there are three types of color receptor (shown by molecular biologists).
- Some people have fewer;
  - most common deficiency is red-green color blindness in men. Red and green receptor genes are carried on the X chromosome. Most red-green color blind men have two red genes or two green genes. Yields an evolutionary story.
- Deficiency
  - can be caused by CNS, by optical problems in the eye, or by absent receptors
- Other color deficiencies:
  - Anomalous trichromacy
  - Achromatopsia
  - Macular degeneration

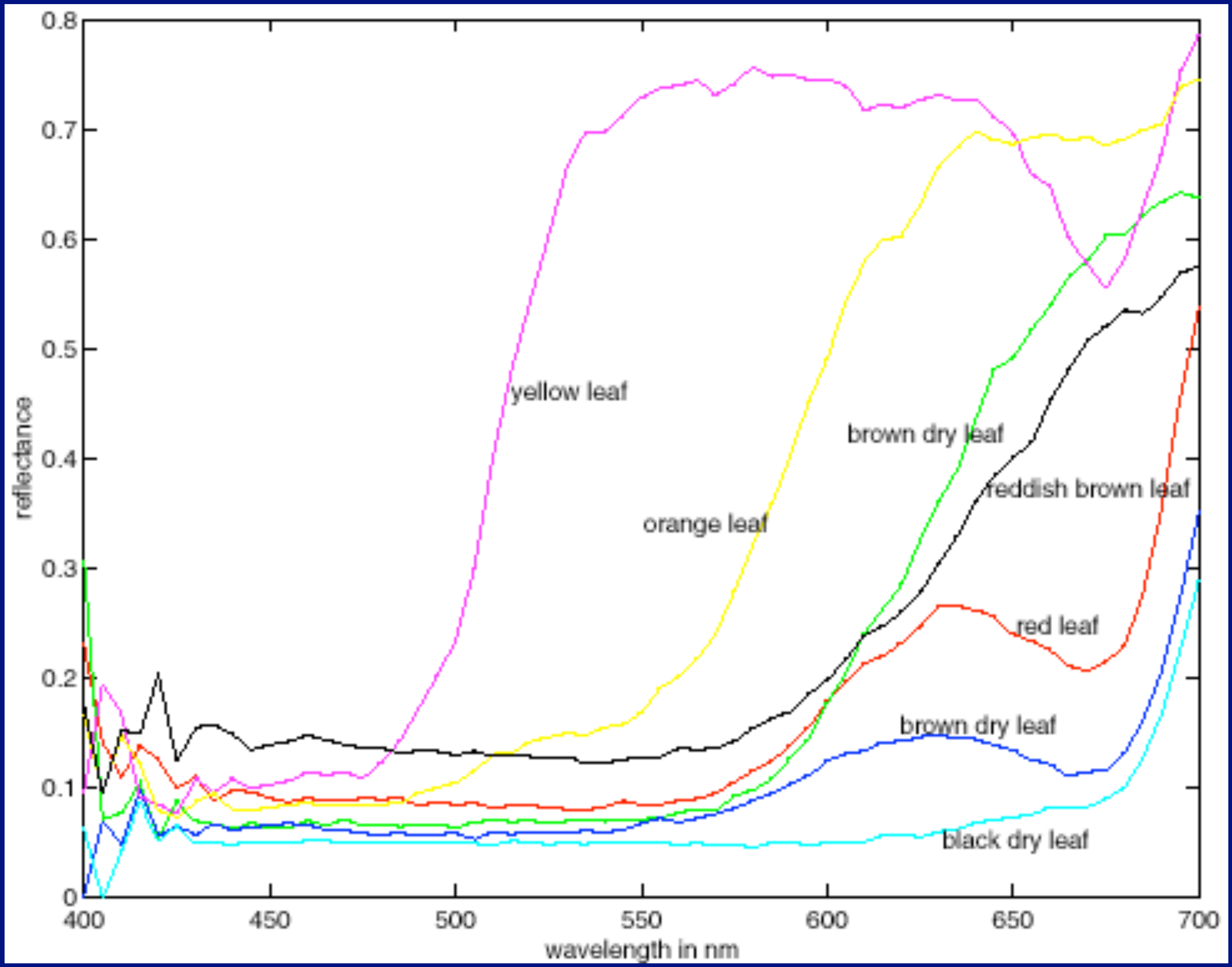
Color receptors



Principle of univariance: cones give the same kind of response, in different amounts, to different wavelengths. Output of cone is obtained by summing over wavelengths.

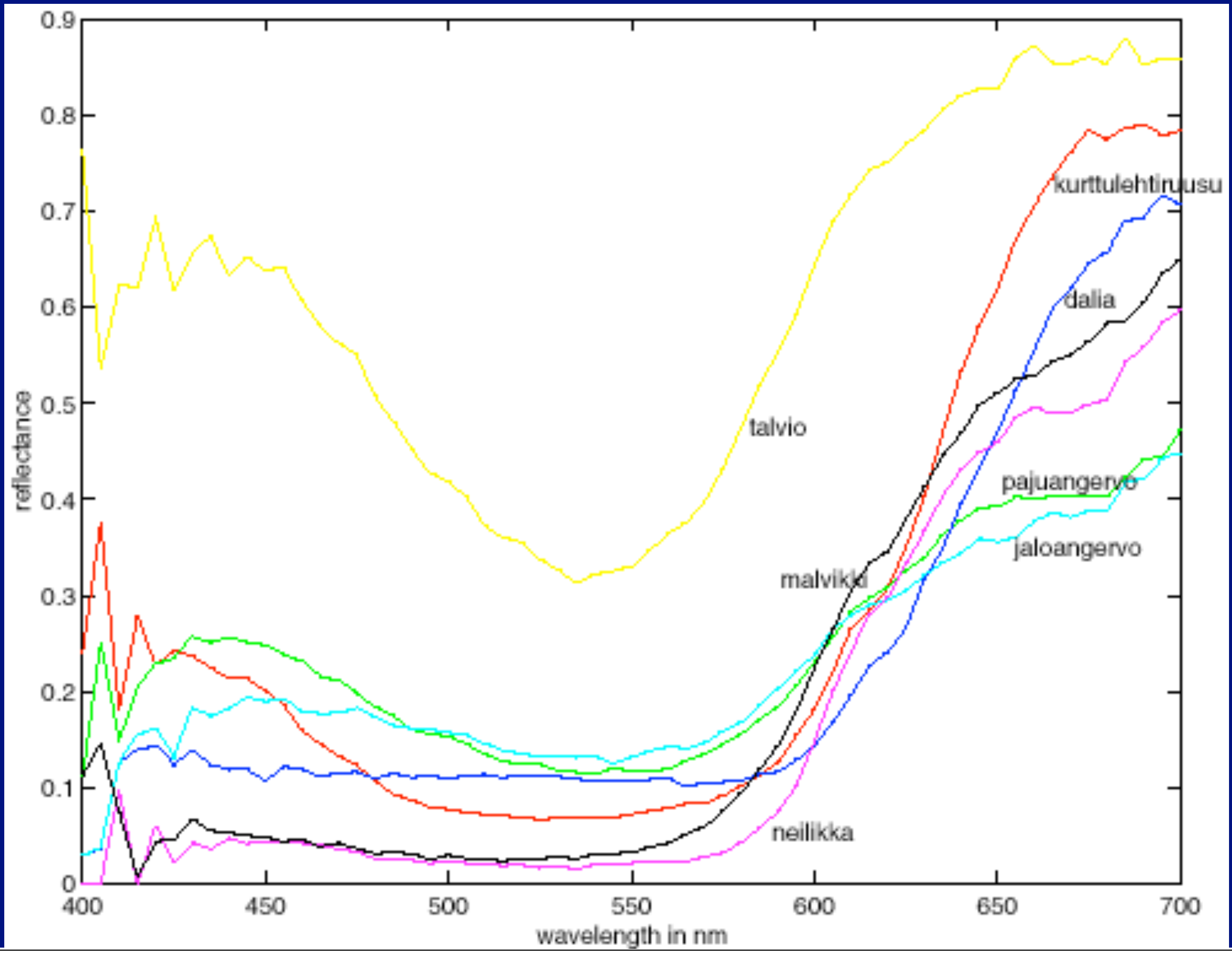
Responses measured in a variety of ways

Leaf reflectances

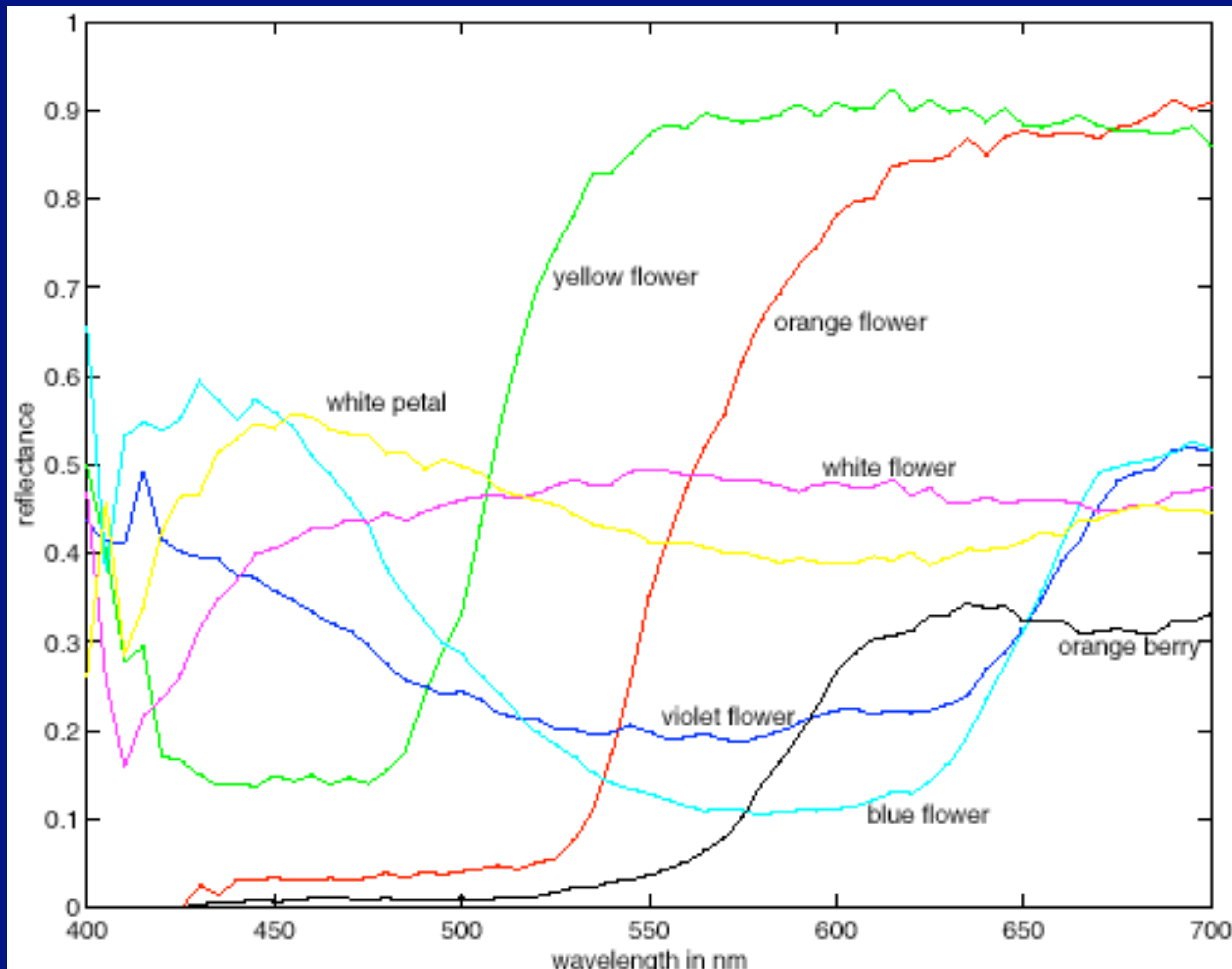


Petal reflectances

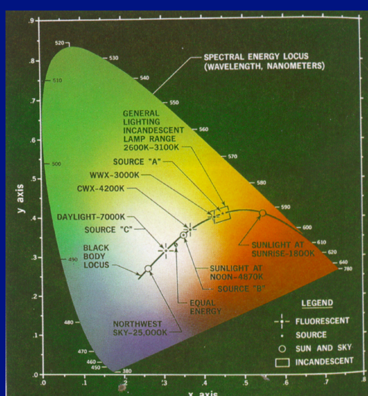
Different red flowers

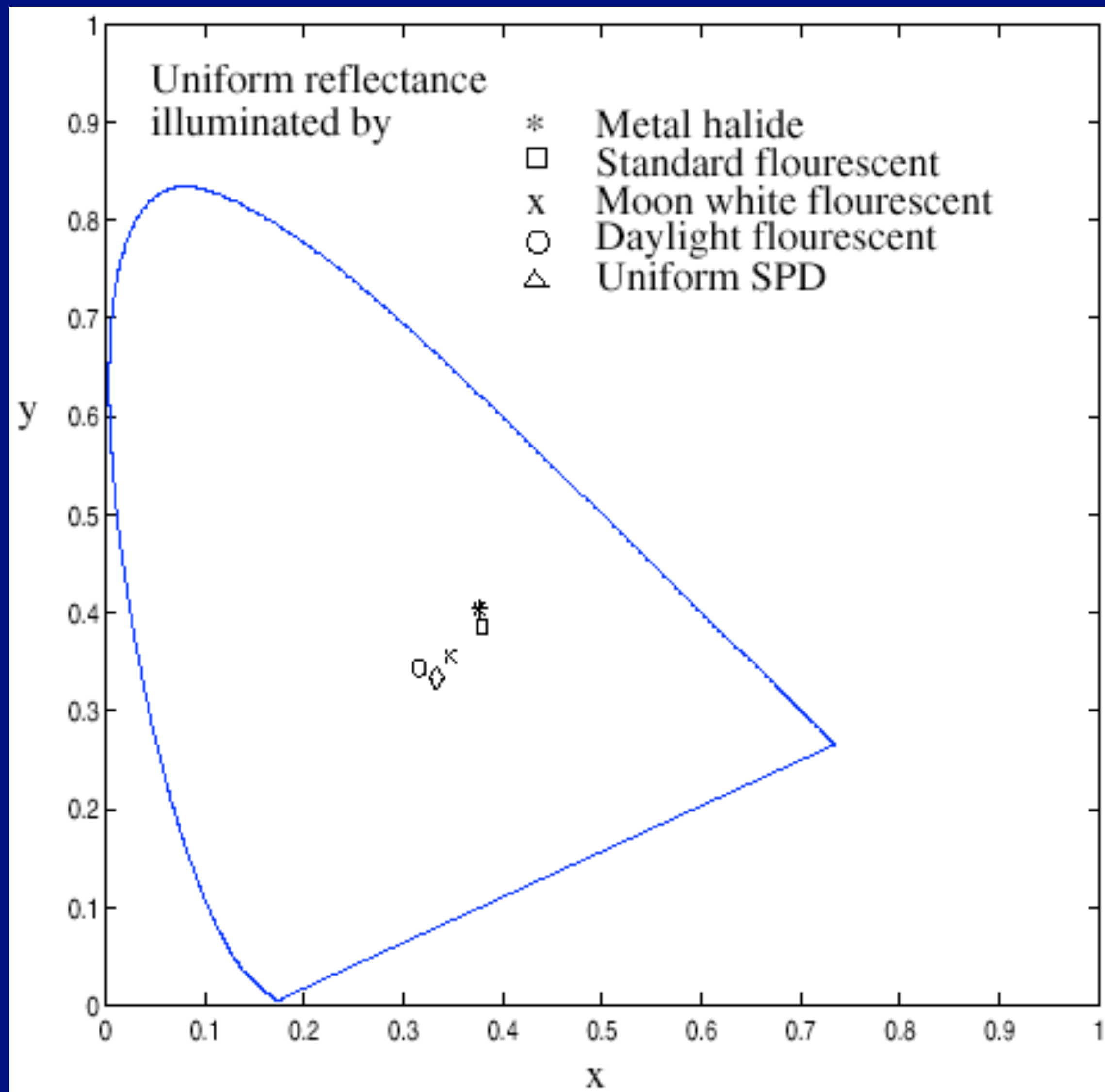


Petal reflectances

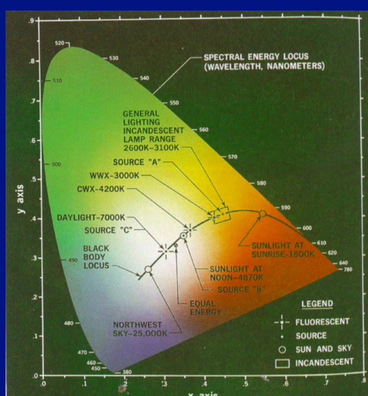


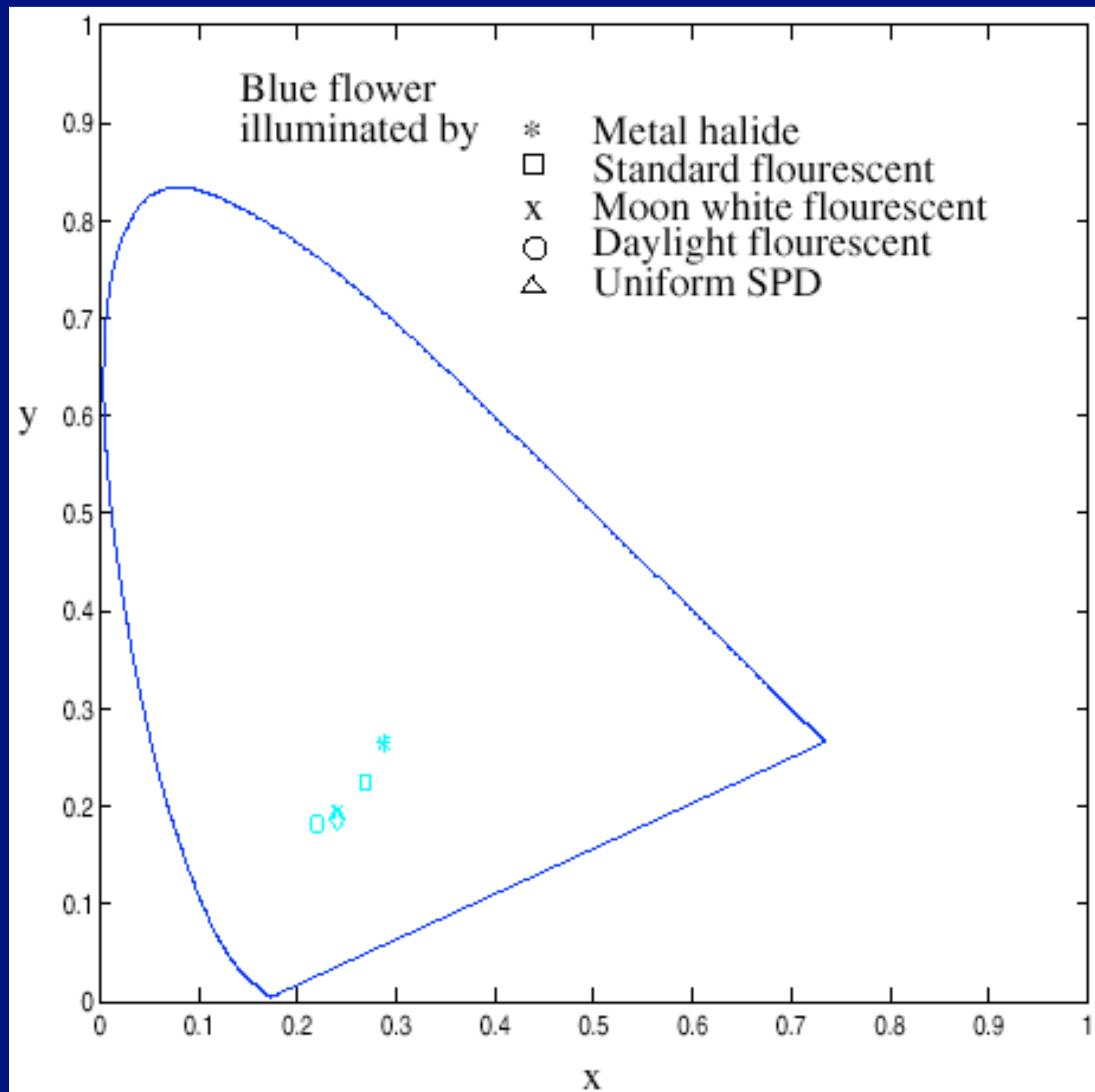
Different lights on uniform reflectances



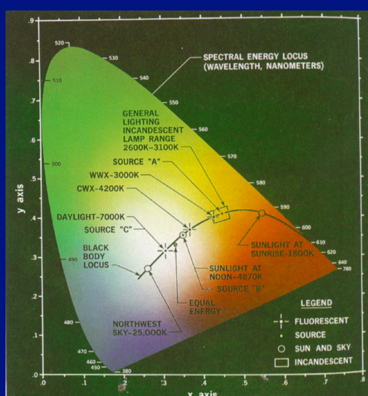


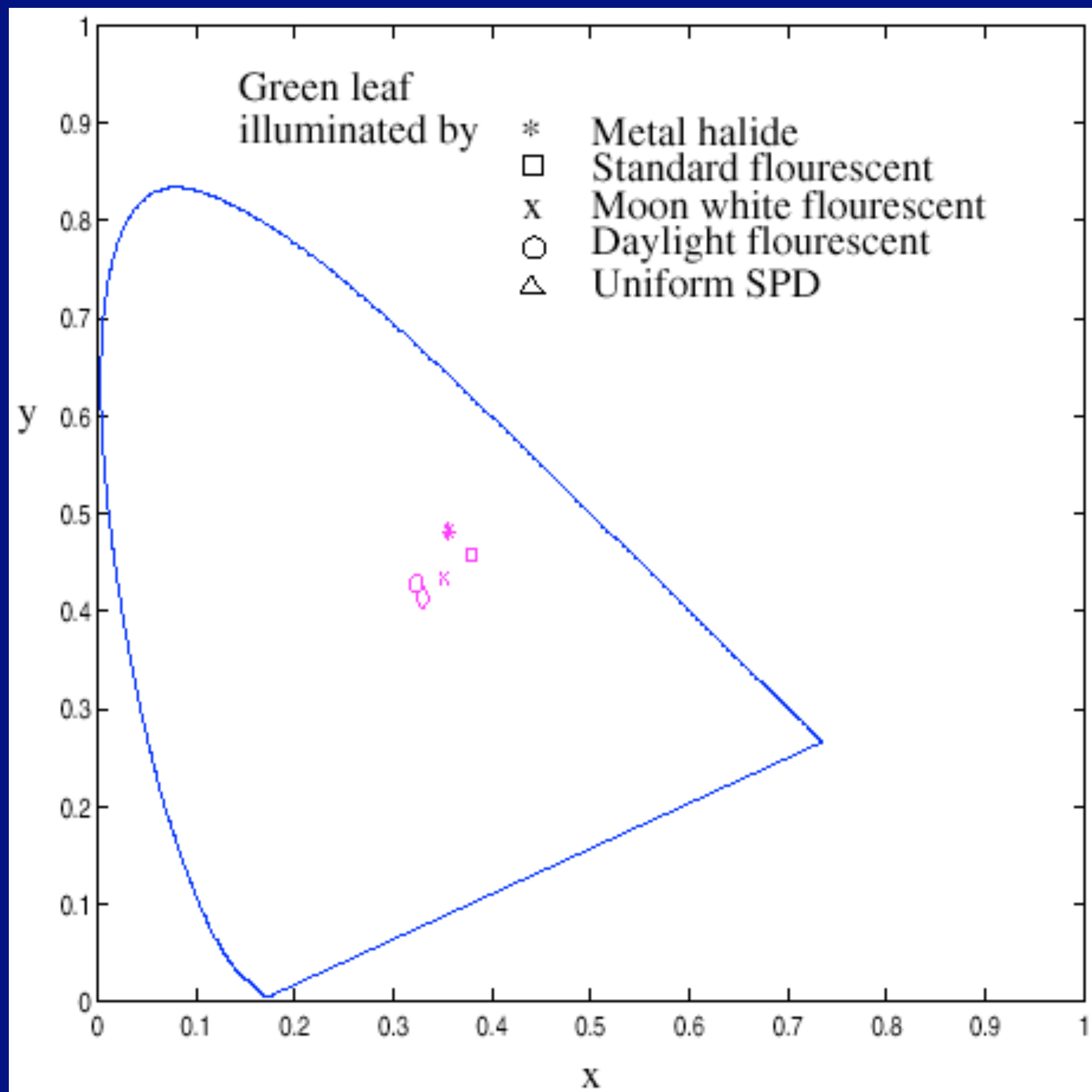
Different lights on blue flower



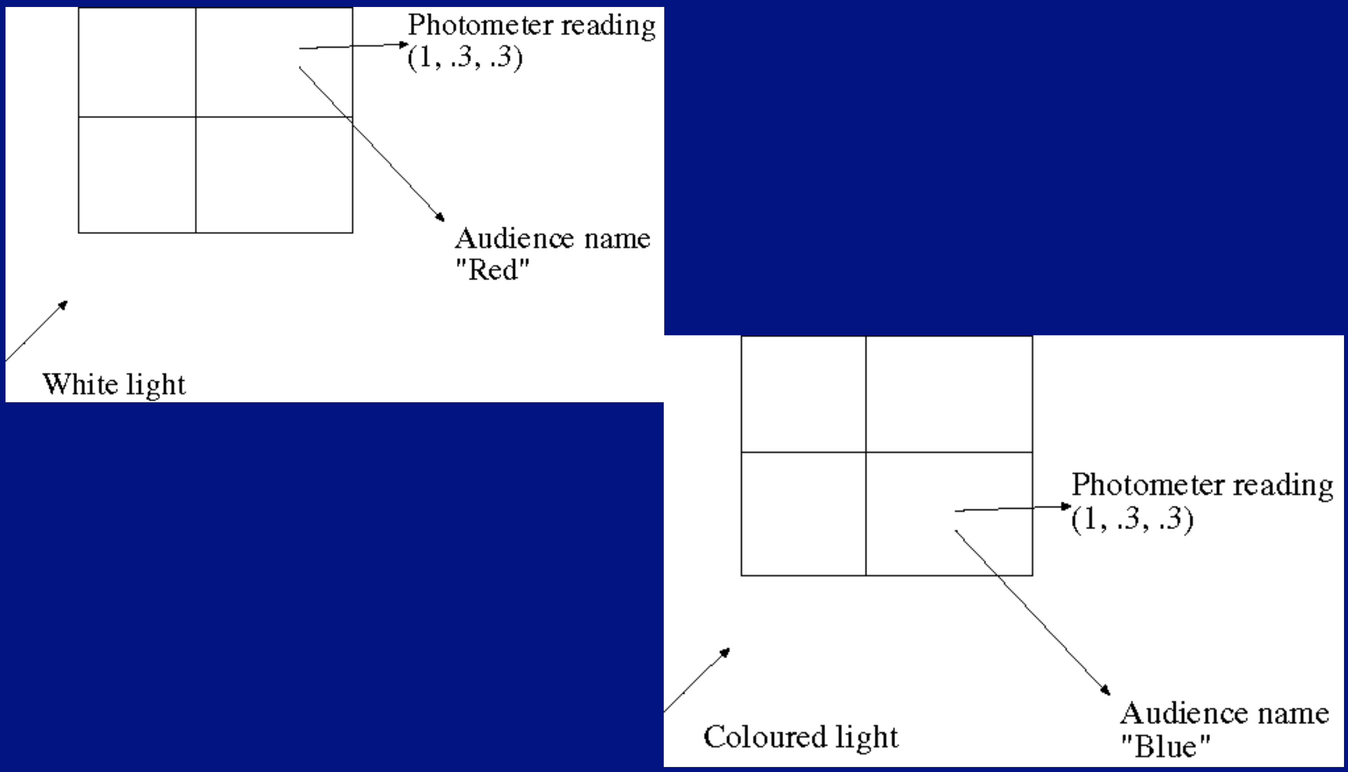


Different lights on green leaf





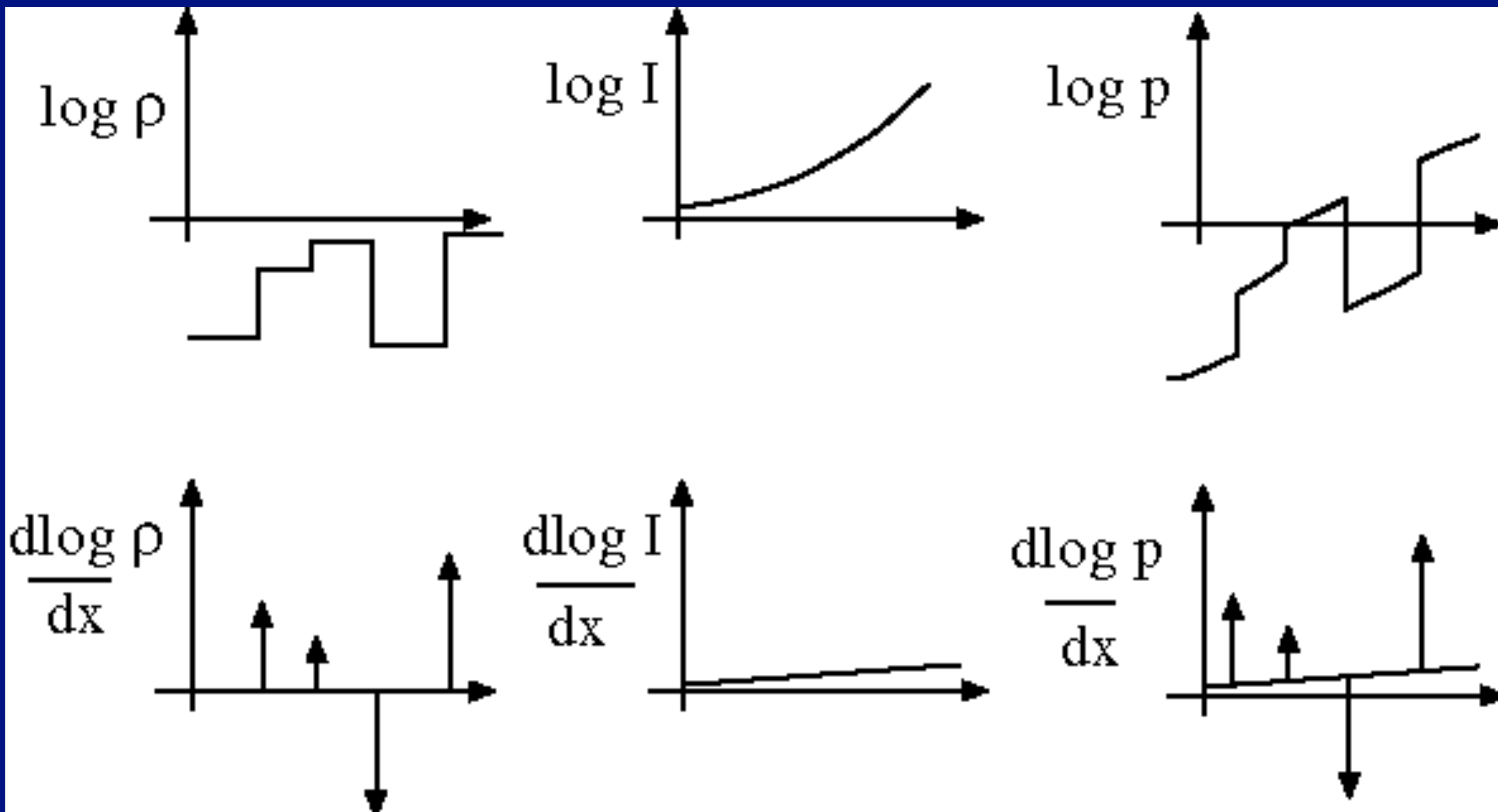
Land’s Demonstration



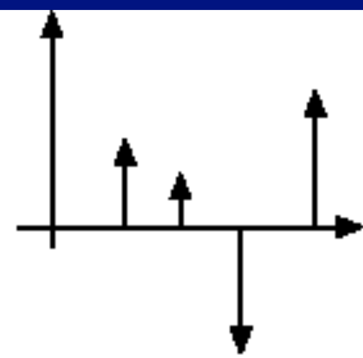
By nickwheeleroz, on Flickr

Lightness Constancy

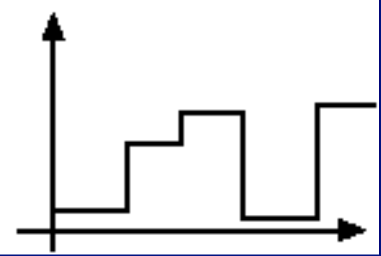
- Lightness constancy
  - how light is the surface, independent of the brightness of the illuminant
  - issues
    - spatial variation in illumination
    - absolute standard
  - Human lightness constancy is very good
- Assume
  - frontal 1D “Surface”
  - slowly varying illumination
  - quickly varying surface reflectance

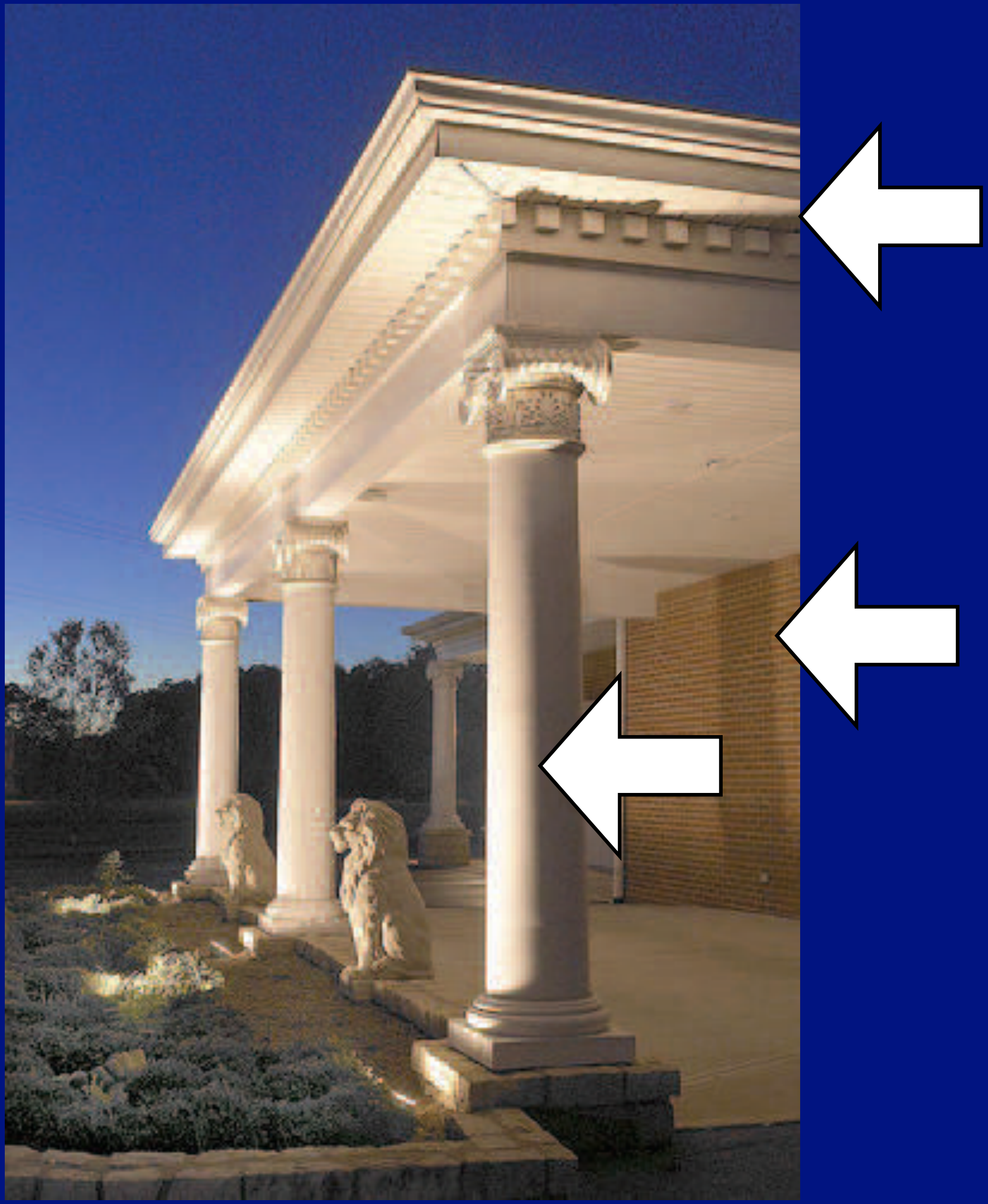

log ρ
log I
log p
dlog ρ / dx
dlog I / dx
dlog p / dx

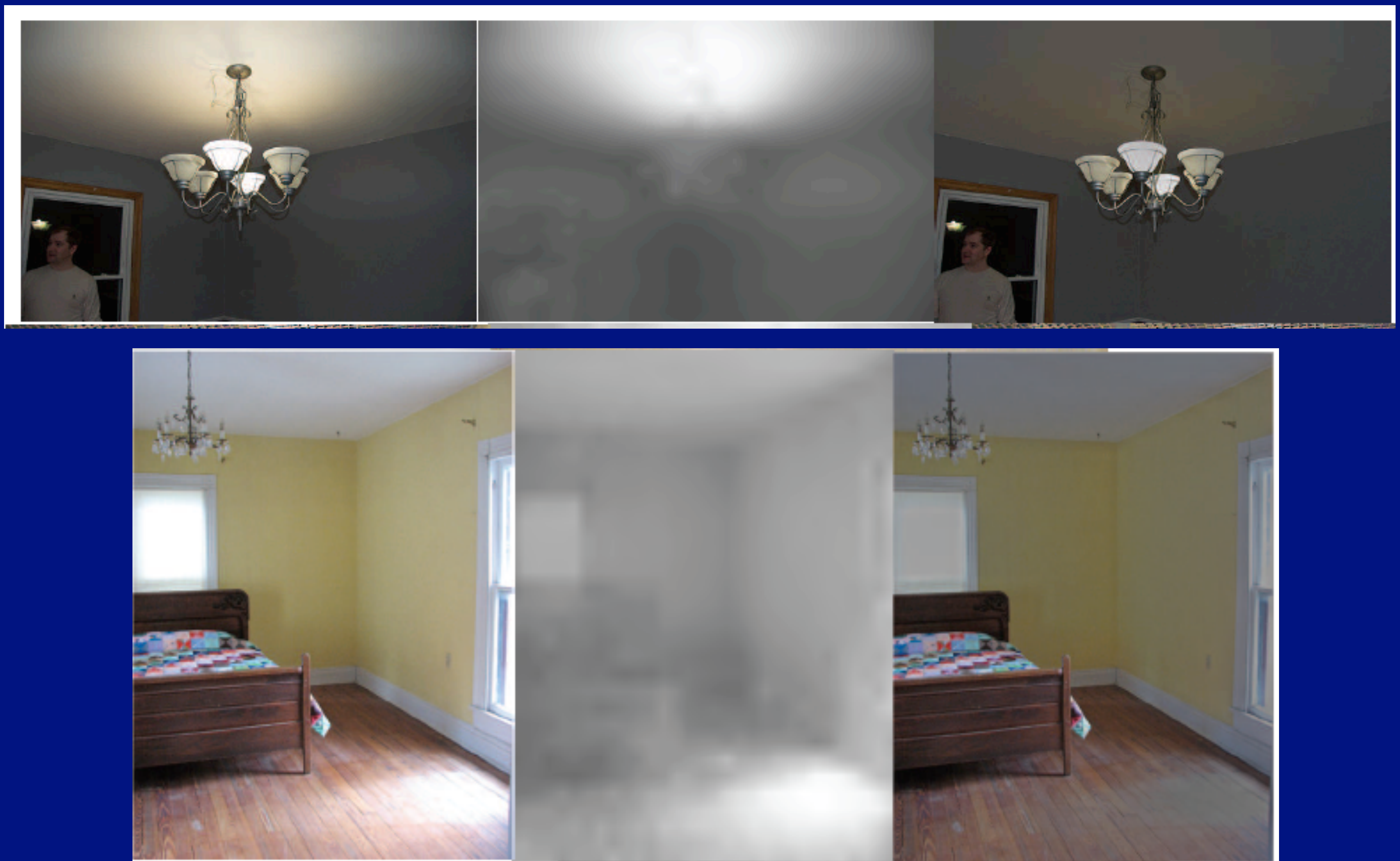
Thresholded $\frac{d\log p}{dx}$



Integrate
This to get







Karsch et al in review 10

Simplest colour constancy

- Adjust three receptor channels independently
  - Von Kries
  - Where does the constant come from?
    - White patch
    - Averages
    - Some other known reference (faces, nose)

Stage lighting

From Koenderink slides on image texture and the flow of light

Karsch et al in review 10