Introduction to computer vision

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Introduction to computer vision

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Introduction to computer vision

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T1: 1.2 A brief history

T2: 1.1 Light in space

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T2: 1.3 Important special cases

$$\nabla \cdot \mathbf{E} = \rho/\varepsilon_0$$

$$\nabla \cdot \mathbf{B} = 0$$

$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

$$\nabla \times \mathbf{B} = \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mu_0 \boldsymbol{j}_c$$

where

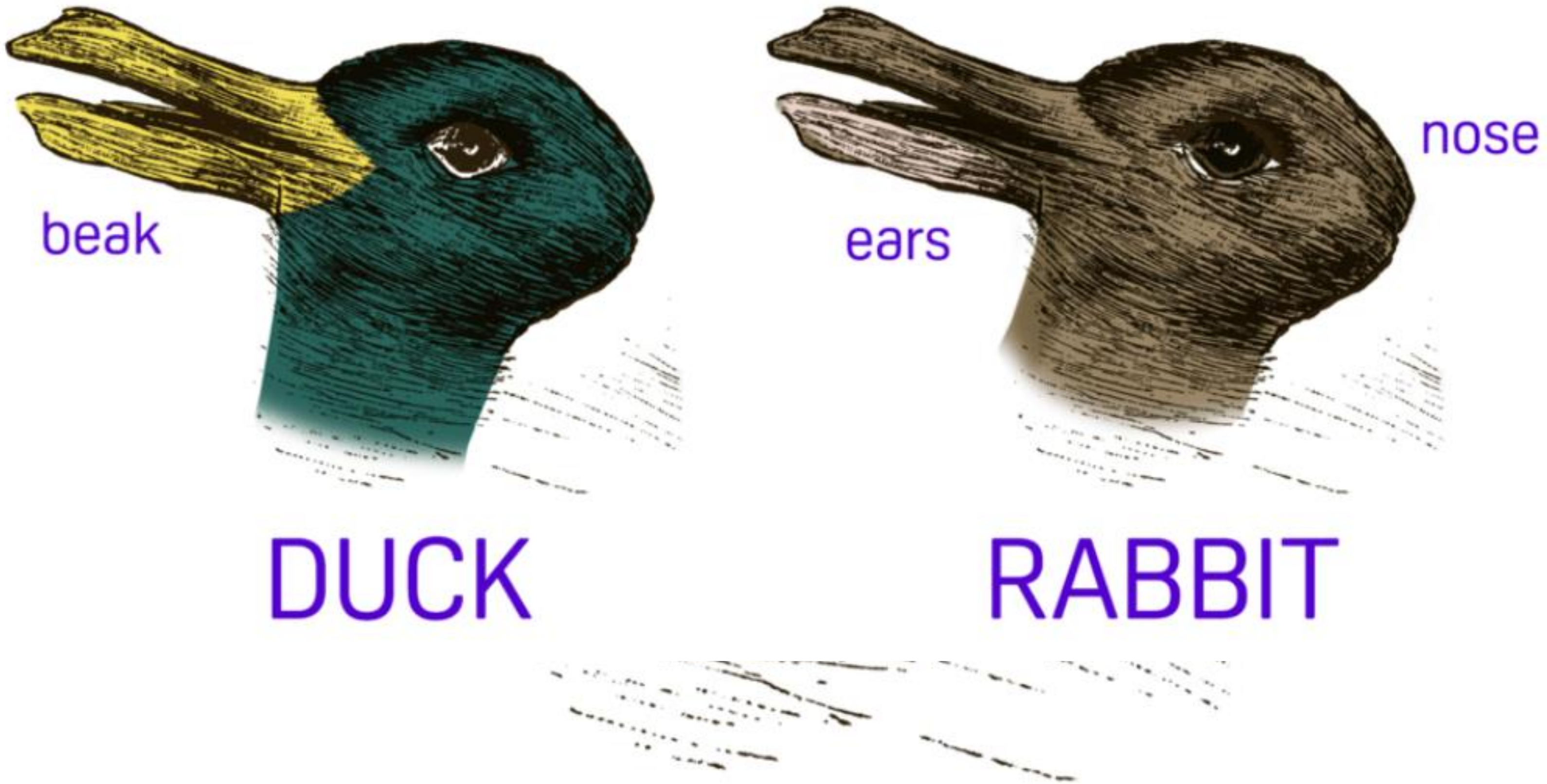
$$\nabla = \hat{\mathbf{i}}\frac{\partial}{\partial x} + \hat{\mathbf{j}}\frac{\partial}{\partial y} + \hat{\mathbf{k}}\frac{\partial}{\partial z}$$

What is computer vision?

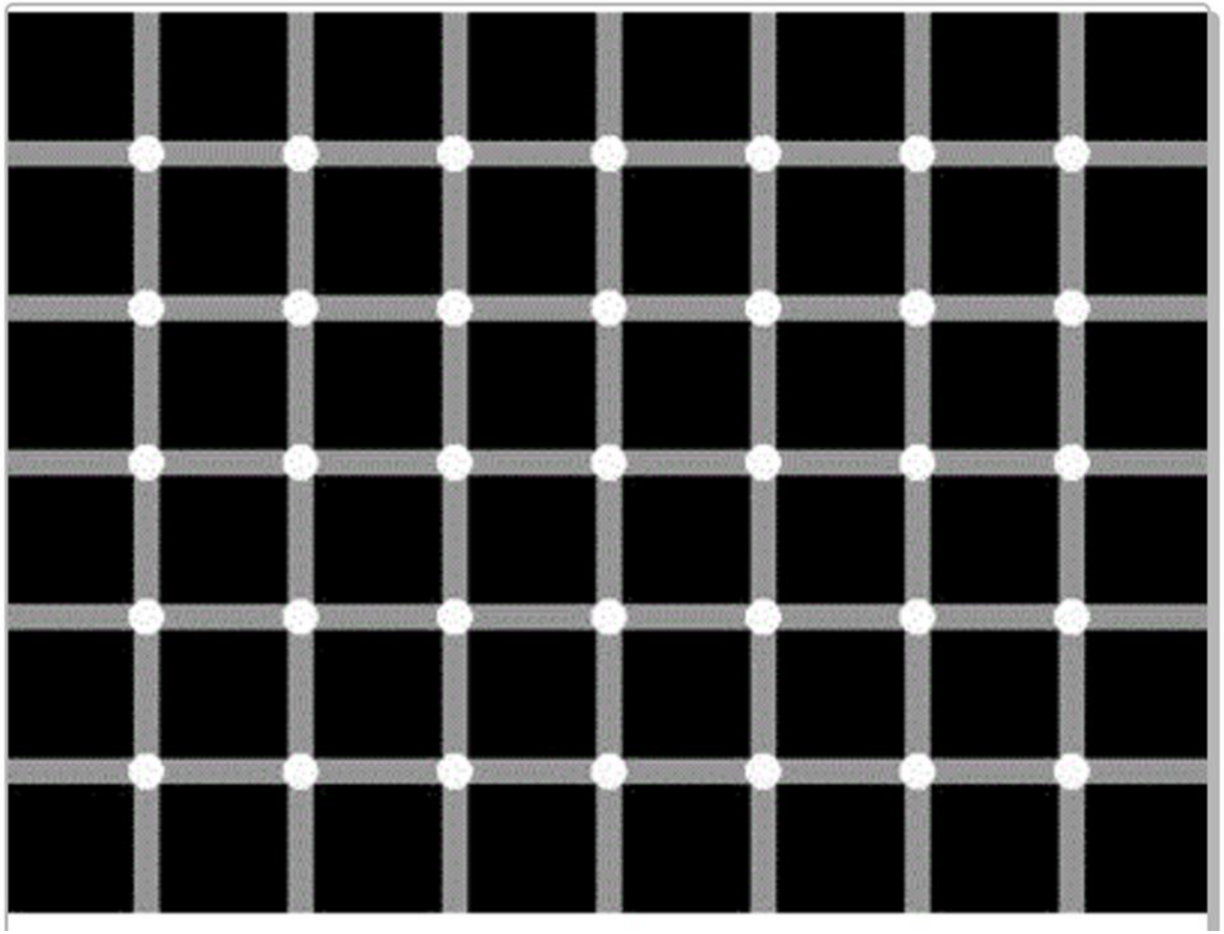
What is computer vision?

- Humans perceive the three-dimensional structure of the world around
- Looking at the flower, have you mentioned the following?
- Shape, colour, petal, light, shades, …

Psychologists – Optical illusion



Psychologists – Optical illusion

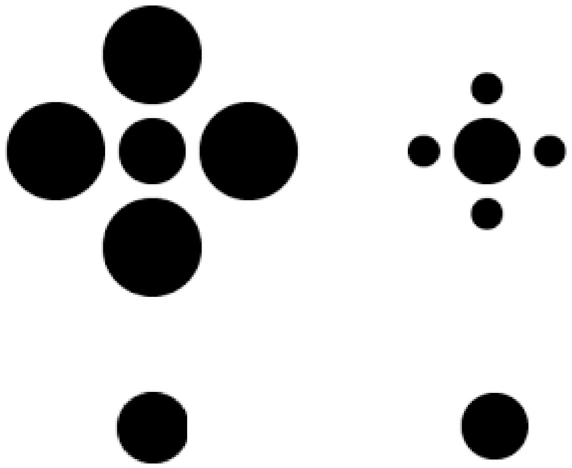


Psychologists – Optical illusion

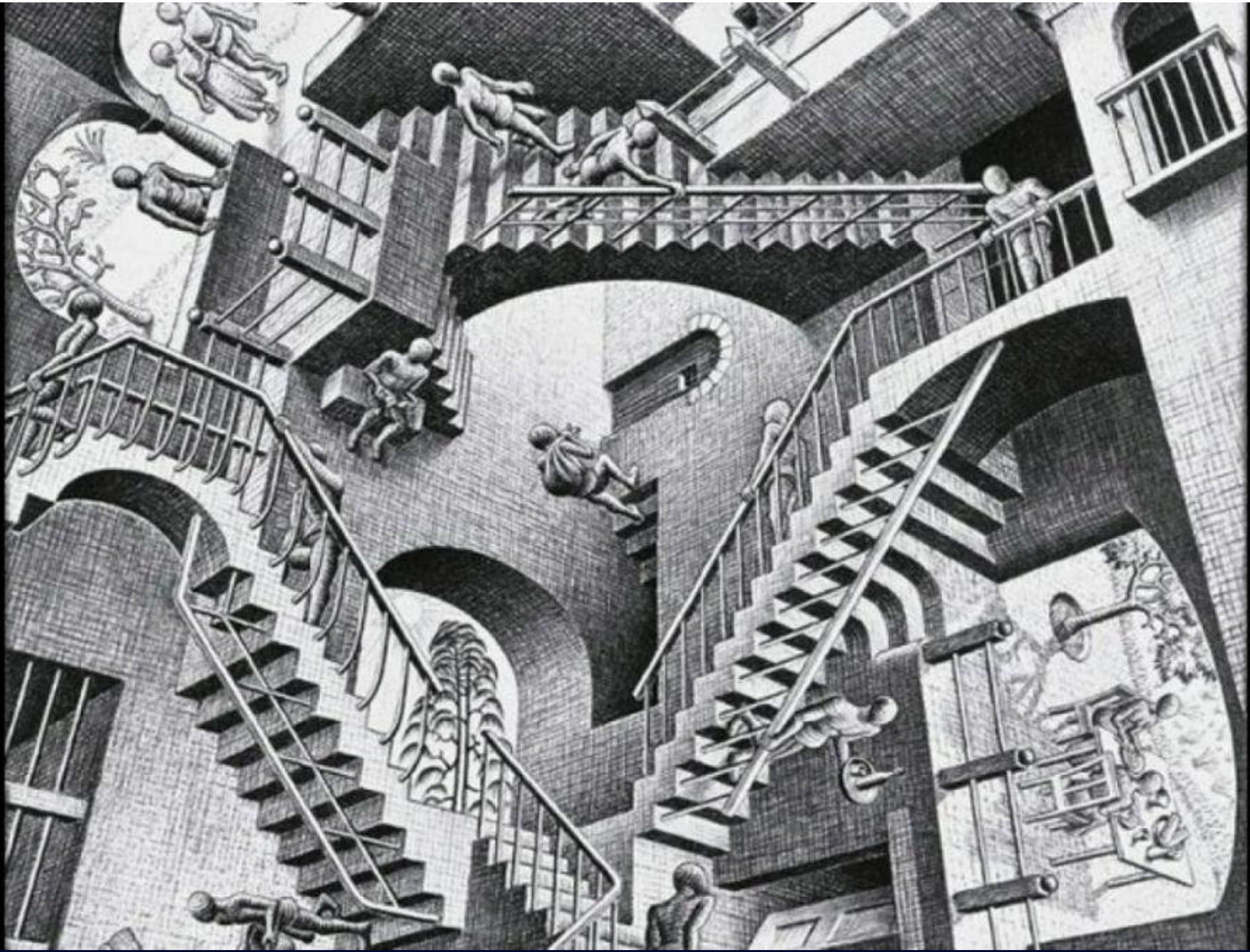
https://www.optics4kids.org/optical-illusions

https://www.google.com/imgres?imgurl=https%3A%2F%2Fth-thumbnailer.cdn-si-edu.com%2FlOP6pAo3Zcm4udhvY32OrdcyMQg%3D%2F800x800%2Fhttps%3A%2F%2Ftf-cmsv2-smithsonianmag-media.s3.amazonaws.com%2Ffiler%2Fa4%2F6c%2Fa46c4a80-bd88-43e0-bf28-c965096905e3%2Fjan5_3dstaircase.gif&tbnid=cqEeEFrEOgwNeM&vet=12ahUKEwiVtf-Kw7OBAxVb5jgGHQ2wC2UQMygSegUIARCaAQ..i&imgrefurl=https%3A%2F%2Fwww.smithsonianmag.com%2Fsmart-news%2Fsee-most-mind-bending-optical-illusions-2020-180976684%2F&docid=8G6DyHisDycFLM&w=800&h=800&q=best%20optical%20illusions&ved=2ahUKEwiVtf-Kw7OBAxVb5jgGHQ2wC2UQMygSegUIARCaAQ

Psychologists – Optical illusion



Psychologists – Optical illusion



CV is an inverse problem

- Seeking to recover some unknowns
- given insufficient information
- to fully specify the solution
- Resort to physics-based and probabilistic models

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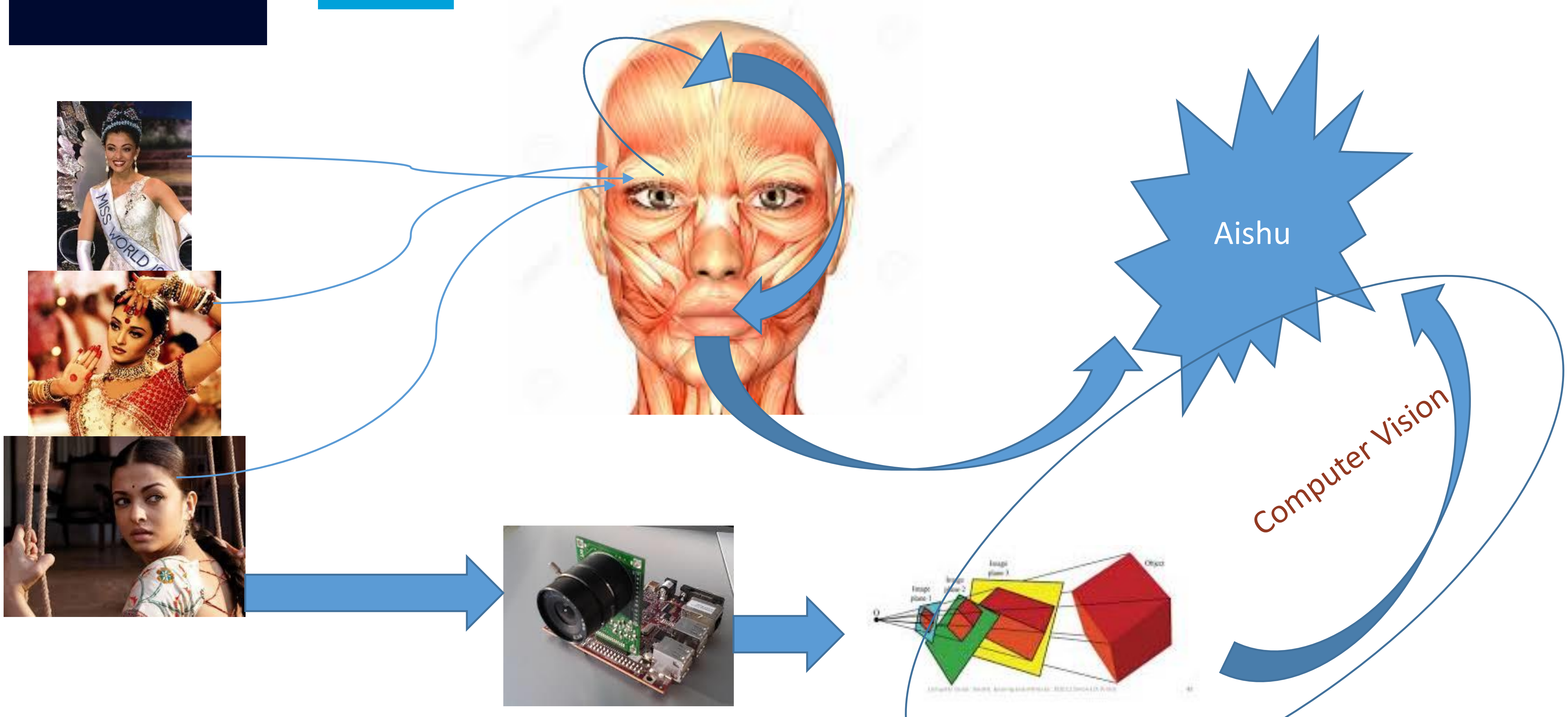
Forward models in CV -

- Developed in physics and CG
- Radiometry/process of measuring radiation by means of physical devices
- Optics/science concerned with the genesis and propagation of light
- Sensor design/tranduction

What is computer vision? – inverse problem



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Applications of CV - OCR

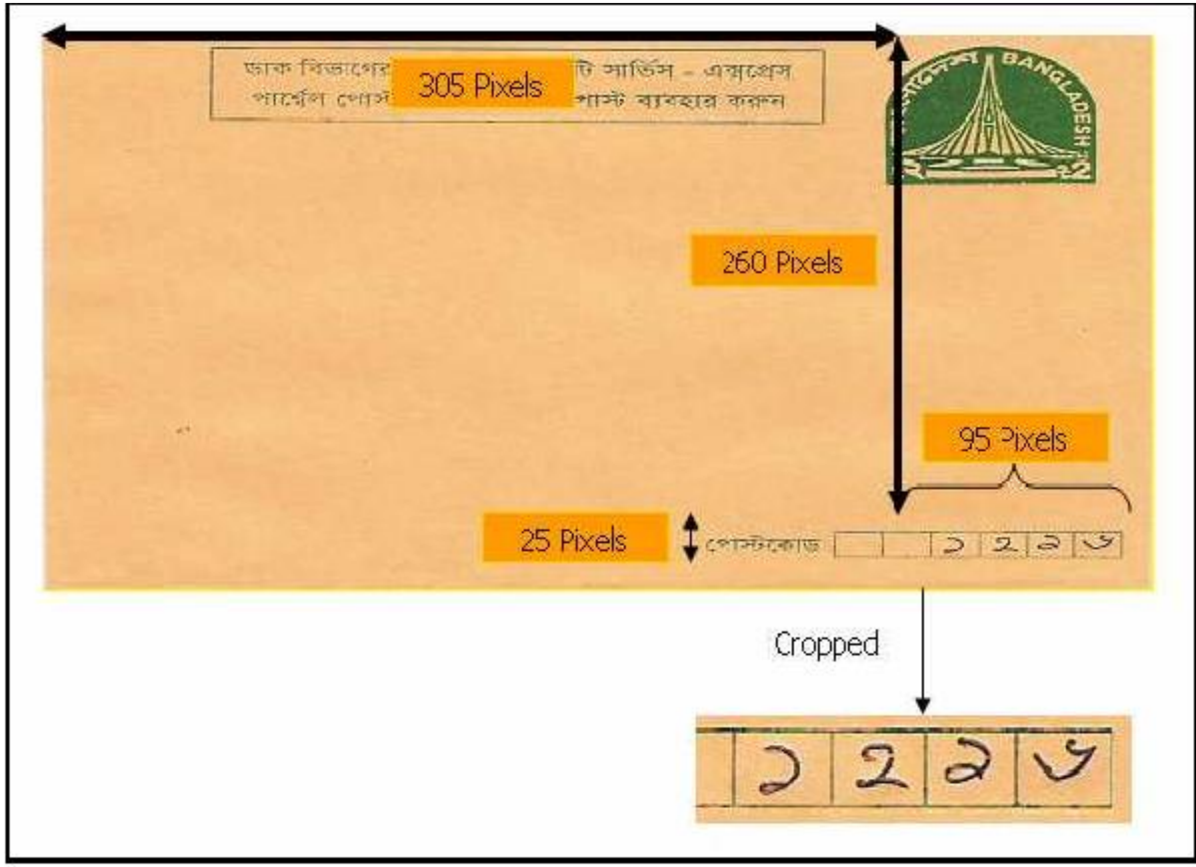
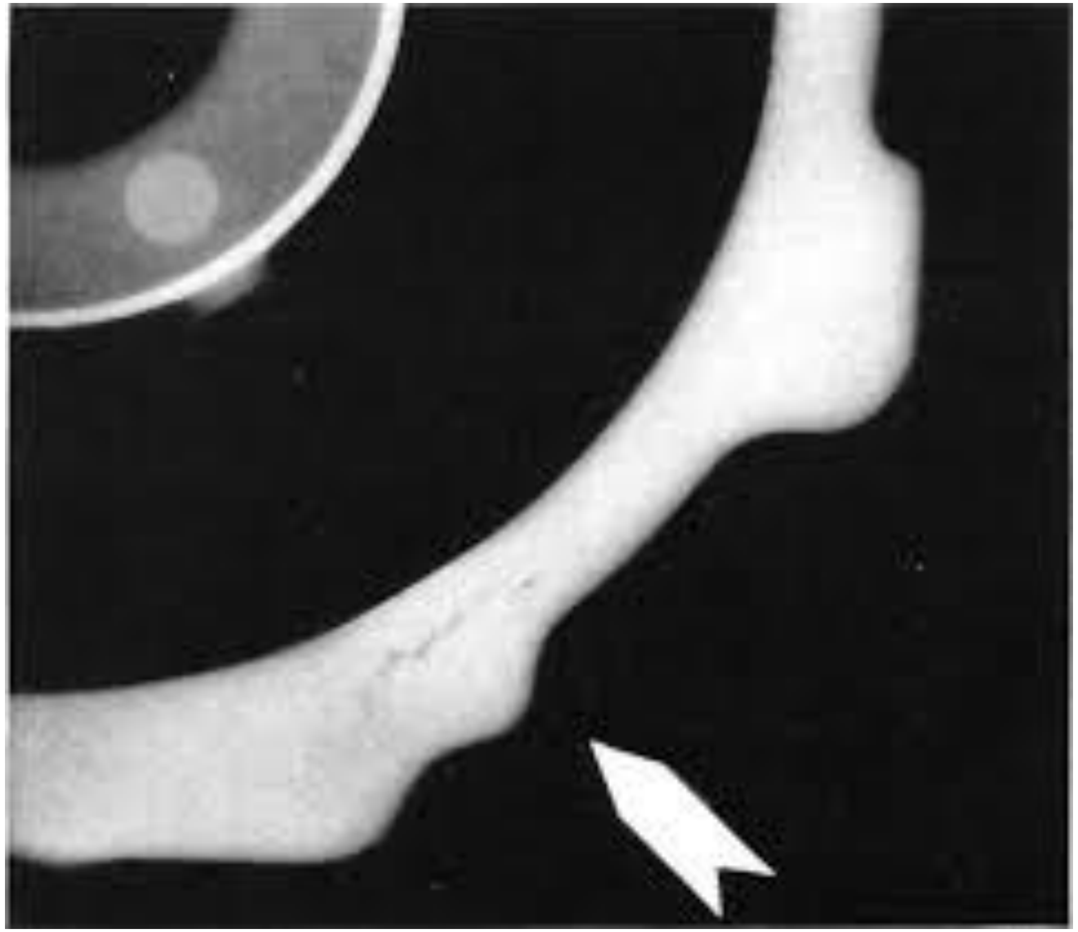
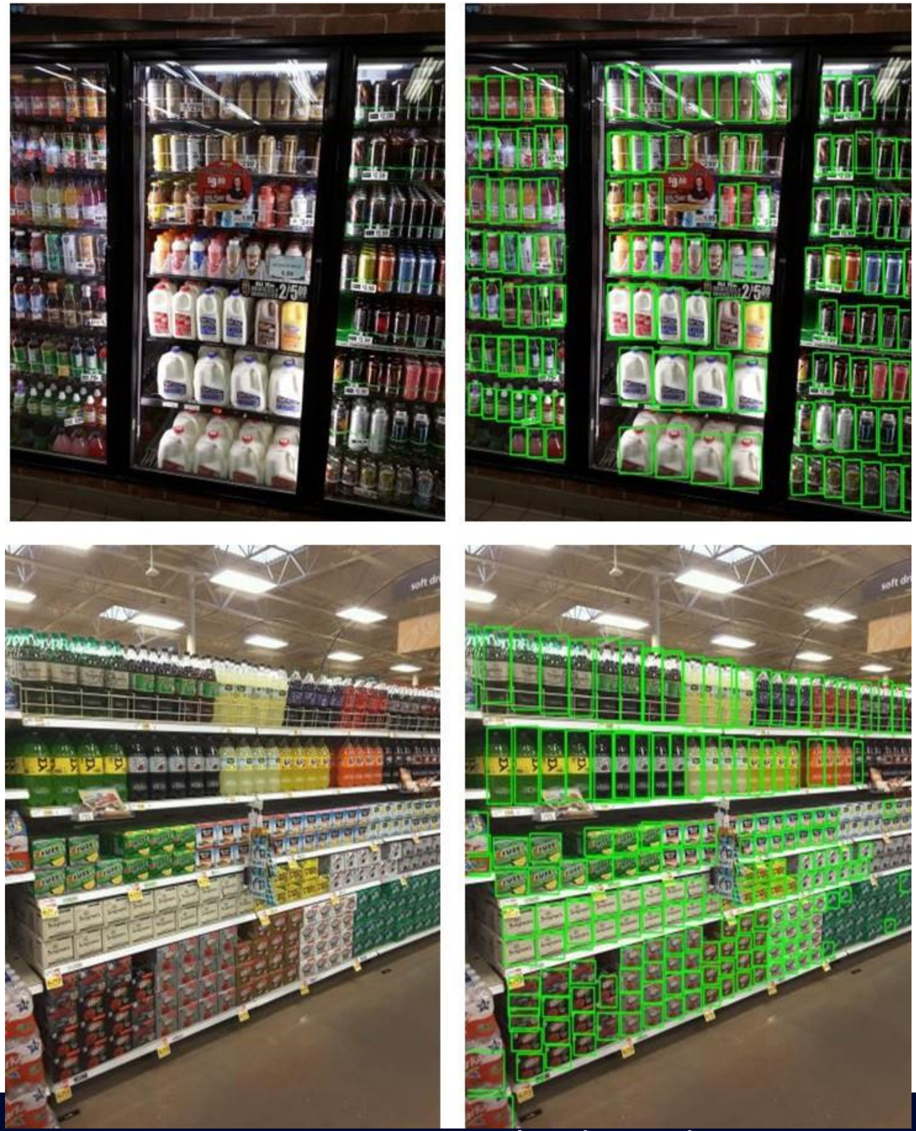


FIGURE 1:

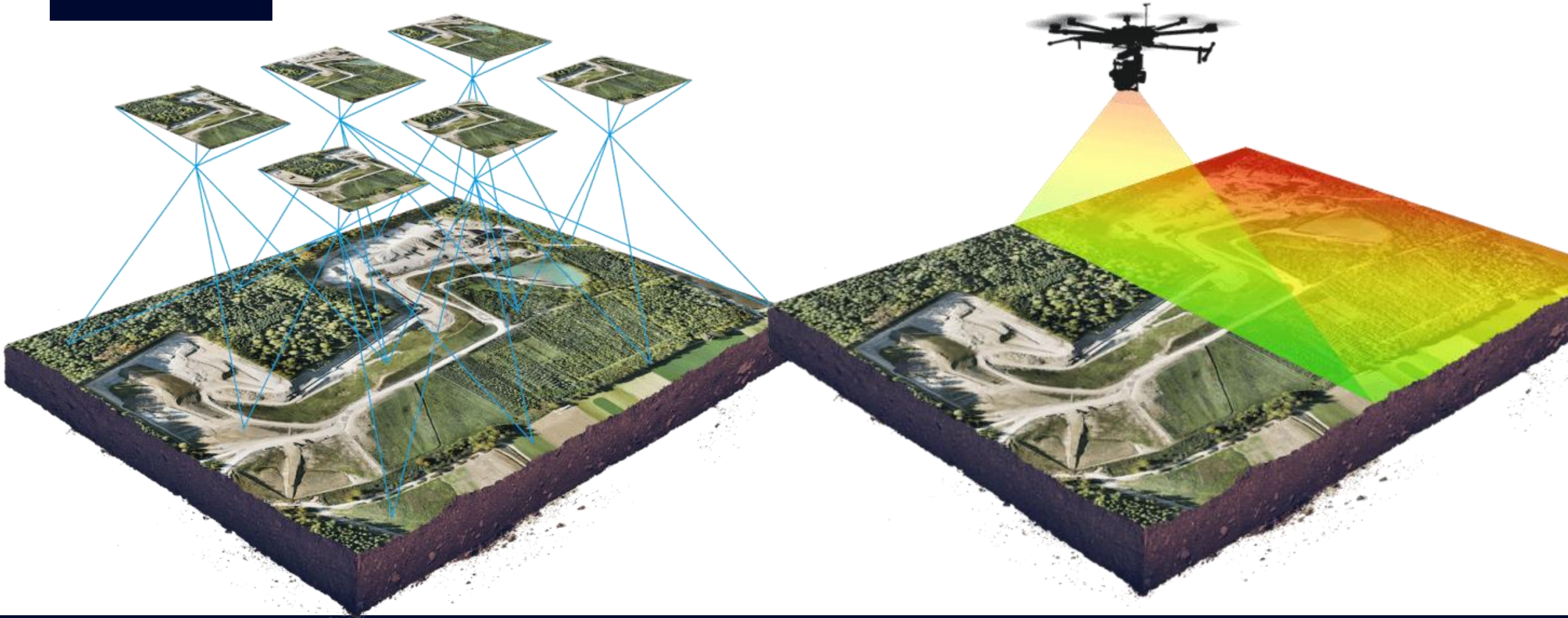
Applications of CV – Machine inspection



Applications of CV - Retail



Applications of CV – 3D model building (photogrammetry)



Applications of CV - Medical imaging

Applications of CV -

Applications of CV -

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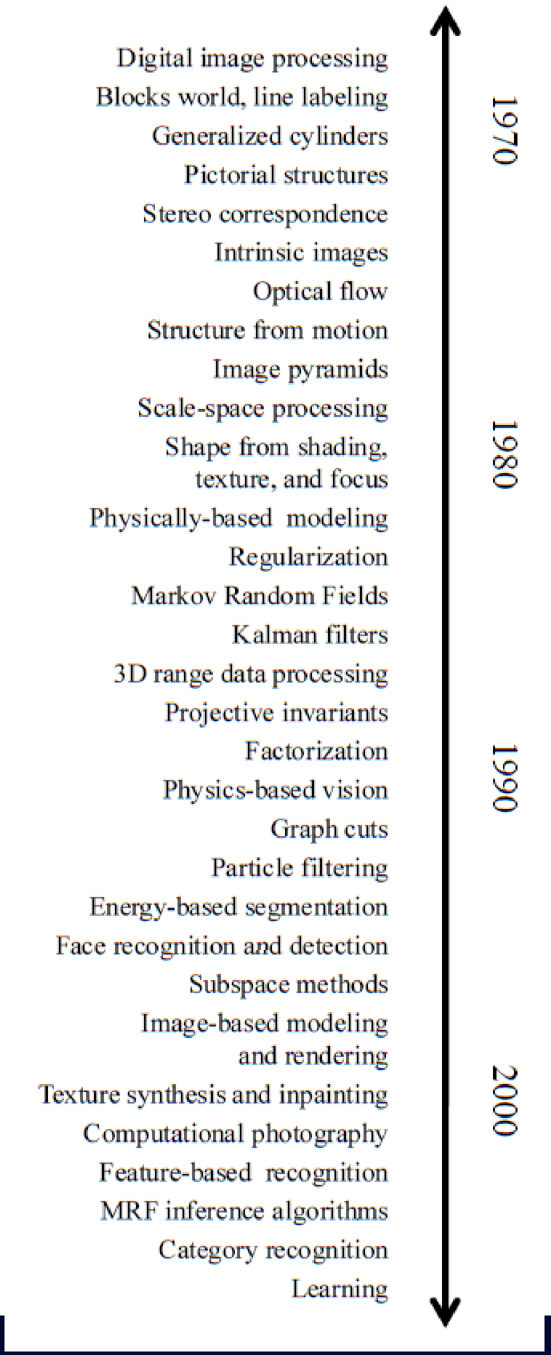
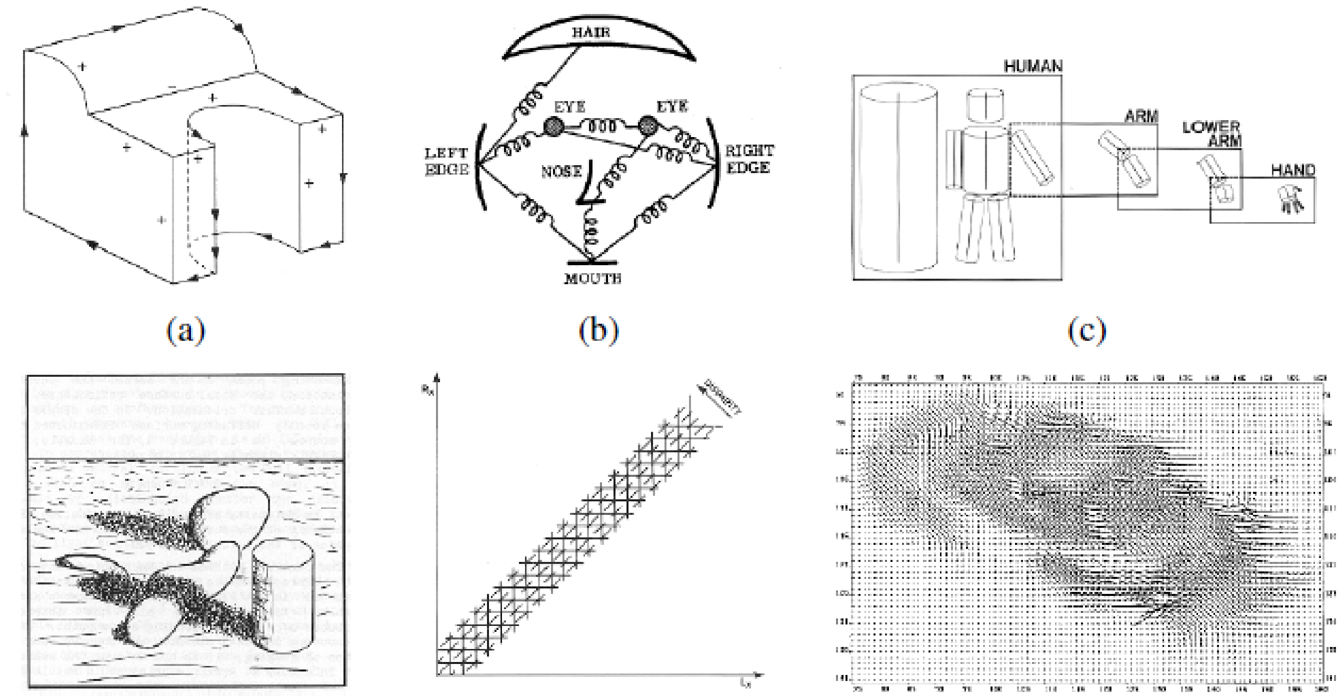
History of CV



History of CV – 1970s



(a) (b) (c)

(d) (e) (f)

Figure 1.7 Some early (1970s) examples of computer vision algorithms: (a) line labeling (Nalwa 1993) © 1993 Addison-Wesley, (b) pictorial structures (Fischler and Elschlager 1973) © 1973 IEEE, (c) articulated body model (Marr 1982) © 1982 David Marr, (d) intrinsic images (Barrow and Tenenbaum 1981) © 1973 IEEE, (e) stereo correspondence (Marr 1982) © 1982 David Marr, (f) optical flow (Nagel and Enkelmann 1986) © 1986 IEEE.

Description of a (visual) information processing system

- Computational theory: What is the goal of the computation (task)
- Representations and algorithms: How are the input, output
- Hardware implementation: How are al/rep mapped onto actual hardware,
- analysis of the problem specification and known constraints

History of CV – 1980s

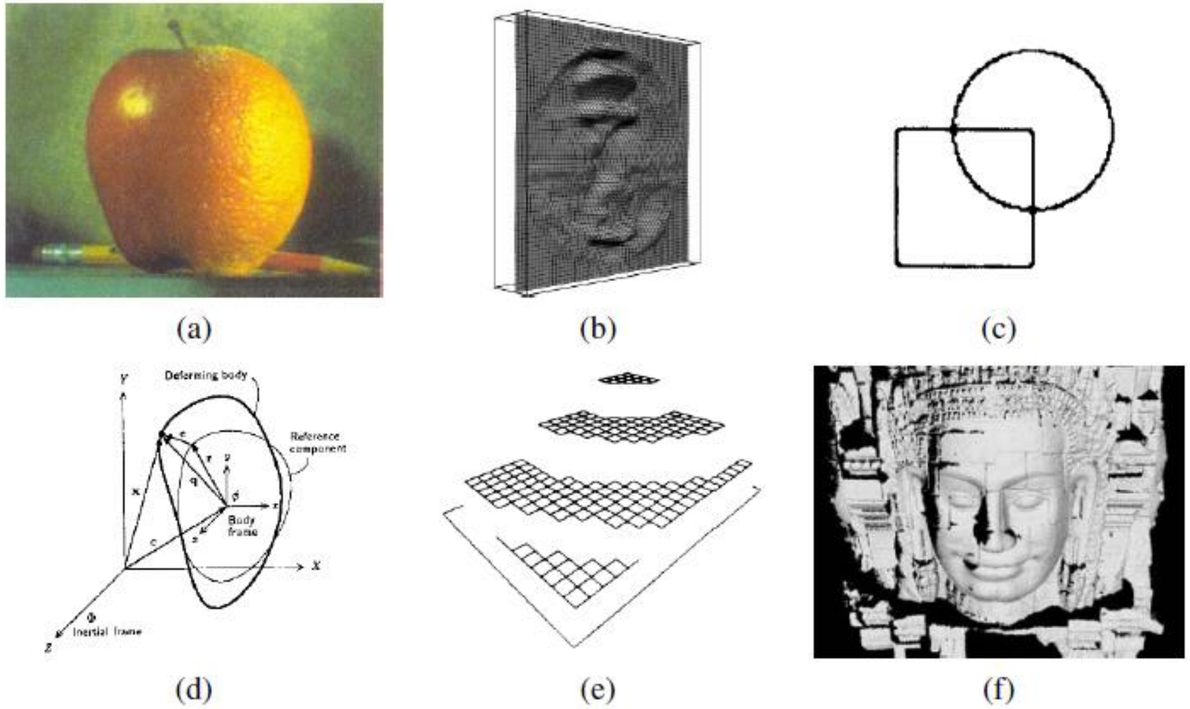


Figure 1.8 Examples of computer vision algorithms from the 1980s: (a) pyramid blending (Burt and Adelson 1983b) © 1983 ACM, (b) shape from shading (Freeman and Adelson 1991) © 1991 IEEE, (c) edge detection (Freeman and Adelson 1991) © 1991 IEEE, (d) physically based models (Terzopoulos and Witkin 1988) © 1988 IEEE, (e) regularization-based surface reconstruction (Terzopoulos 1988) © 1988 IEEE, (f) range data acquisition and merging (Banno, Masuda, Oishi *et al.* 2008) © 2008 Springer.

History of CV – 1980s

- Pyramids using the concept of scale-space processing
- Shape from X techniques
- Dynamically evolving contour trackers
- Discrete Markov Random Field (MRF) models

History of CV – 1990s

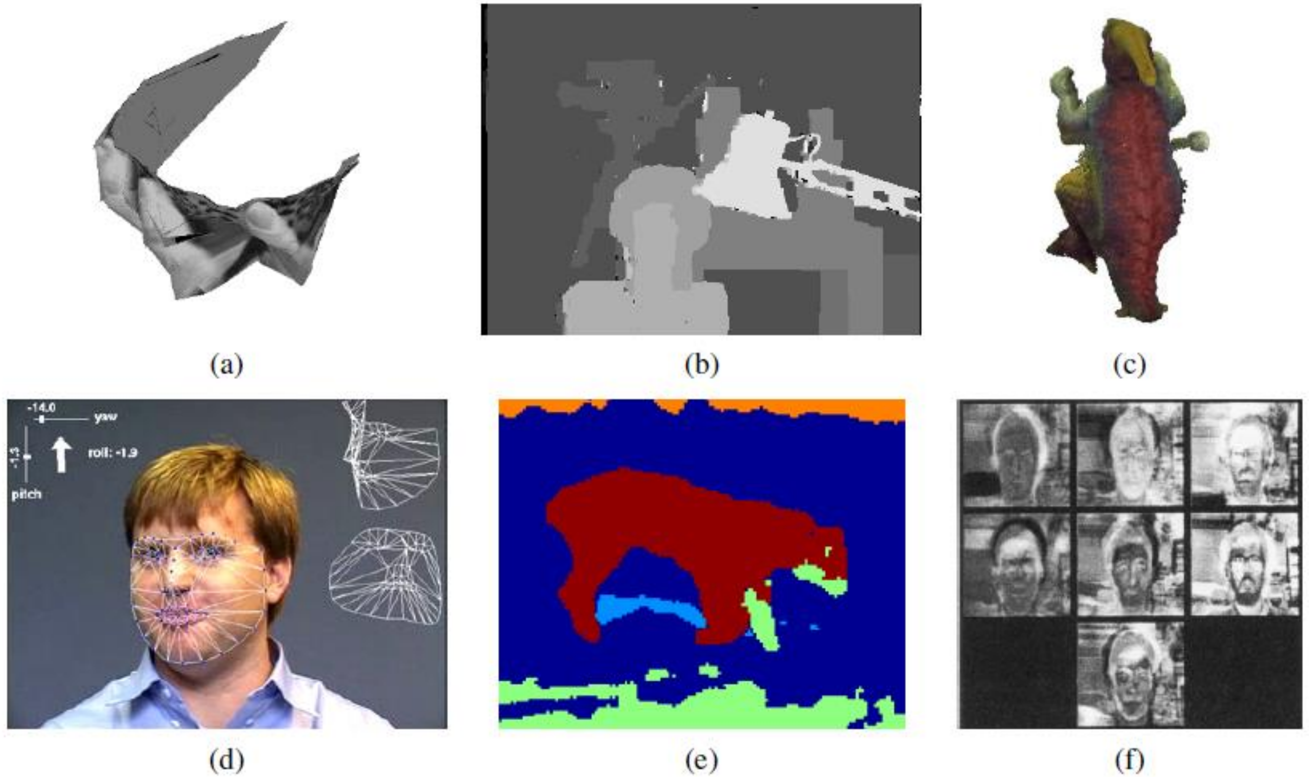


Figure 1.9 Examples of computer vision algorithms from the 1990s: (a) factorization-based structure from motion (Tomasi and Kanade 1992) © 1992 Springer, (b) dense stereo matching (Boykov, Veksler, and Zabih 2001), (c) multi-view reconstruction (Seitz and Dyer 1999) © 1999 Springer, (d) face tracking (Matthews, Xiao, and Baker 2007), (e) image segmentation (Belongie, Fowlkes, Chung *et al.* 2002) © 2002 Springer, (f) face recognition (Turk and Pentland 1991a).

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History of CV – 1990s

- Projective reconstructions
- Physics-based vision
- Optical flow methods
- Statistical learning techniques

History of CV – 2000s

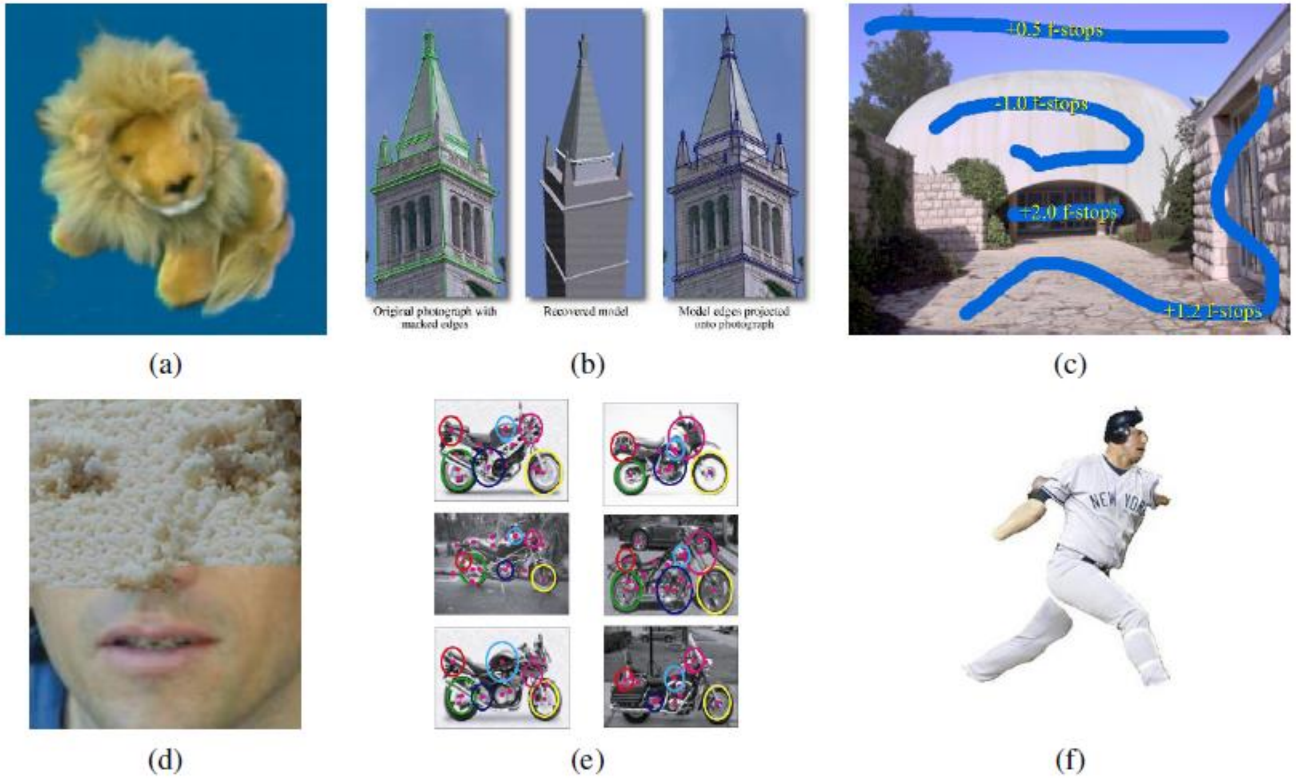

Figure 1.10 Recent examples of computer vision algorithms: (a) image-based rendering (Gortler, Grzeszczuk, Szeliski *et al.* 1996), (b) image-based modeling (Debevec, Taylor, and Malik 1996) © 1996 ACM, (c) interactive tone mapping (Lischinski, Farbman, Uyttendaele *et al.* 2006a) (d) texture synthesis (Efros and Freeman 2001), (e) feature-based recognition (Fergus, Perona, and Zisserman 2007), (f) region-based recognition (Mori, Ren, Efros *et al.* 2004) © 2004 IEEE.

History of CV – 2000s

- Image-based rendering, such as image stitching
- Feature-based techniques
- Algorithms for complex global optimization problems
- machine learning techniques to computer vision problems

Definition of CV

Computer vision is the science of endowing computers or other machines with vision, or the ability to see. Vision is the interpretation of images that leads to actions or decisions, as in the navigation of an autonomous robot - Erik G. Learned-Miller

Computer vision (or image understanding) is generally defined as the construction of explicit, meaningful descriptions of the structure and the properties of the 3-dimensional world from 2-dimensional images - Andreas Schierwagen

visual functionalities that give rise to semantically meaningful interpretations of the visual world. - Stanford University vision lab

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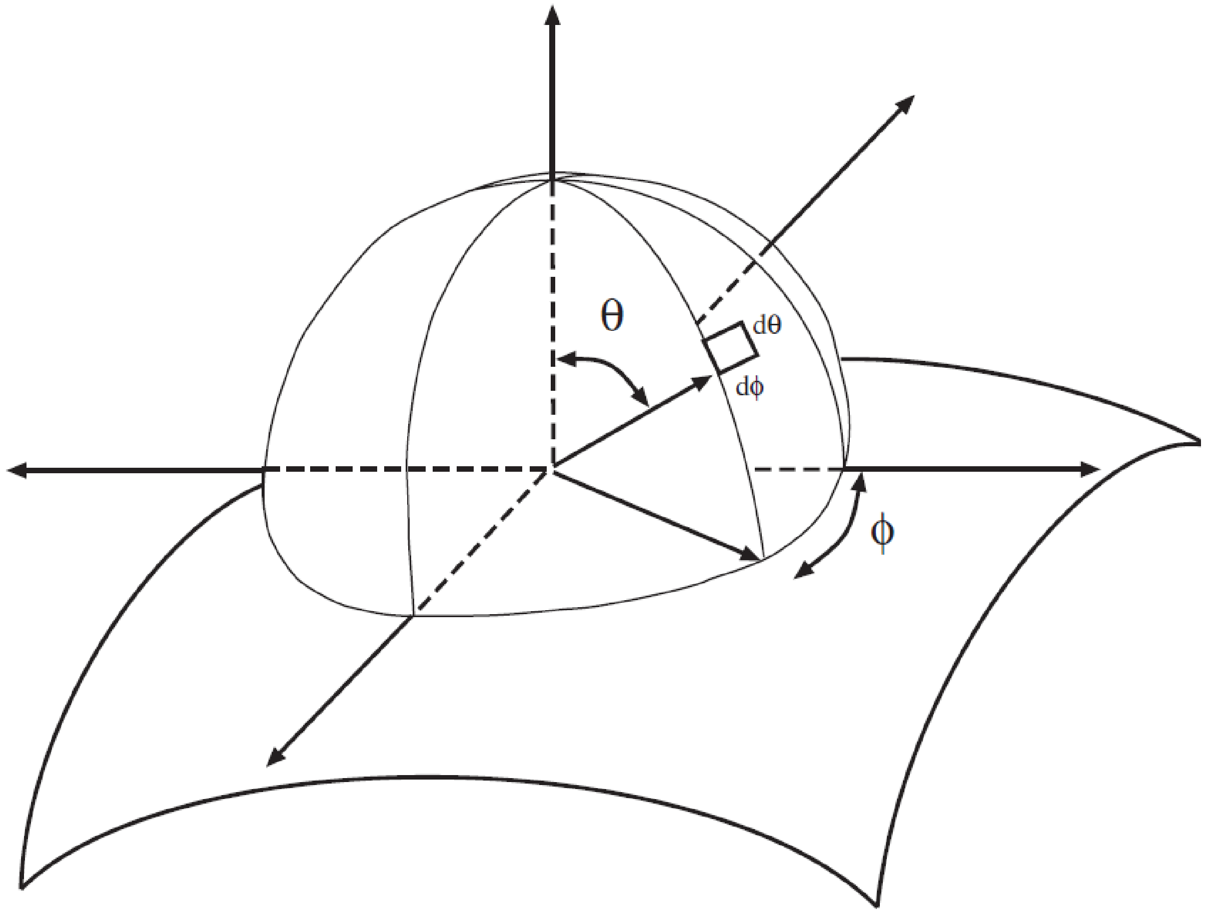
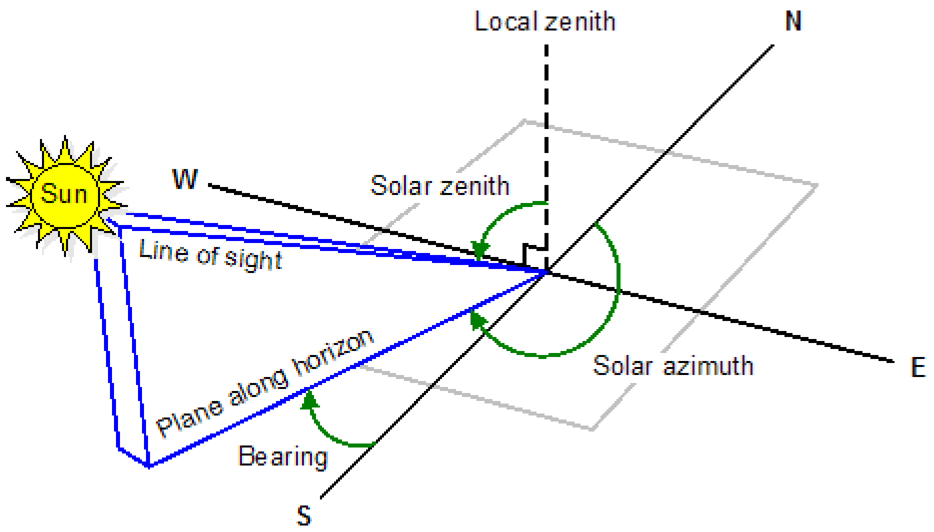
Light in space

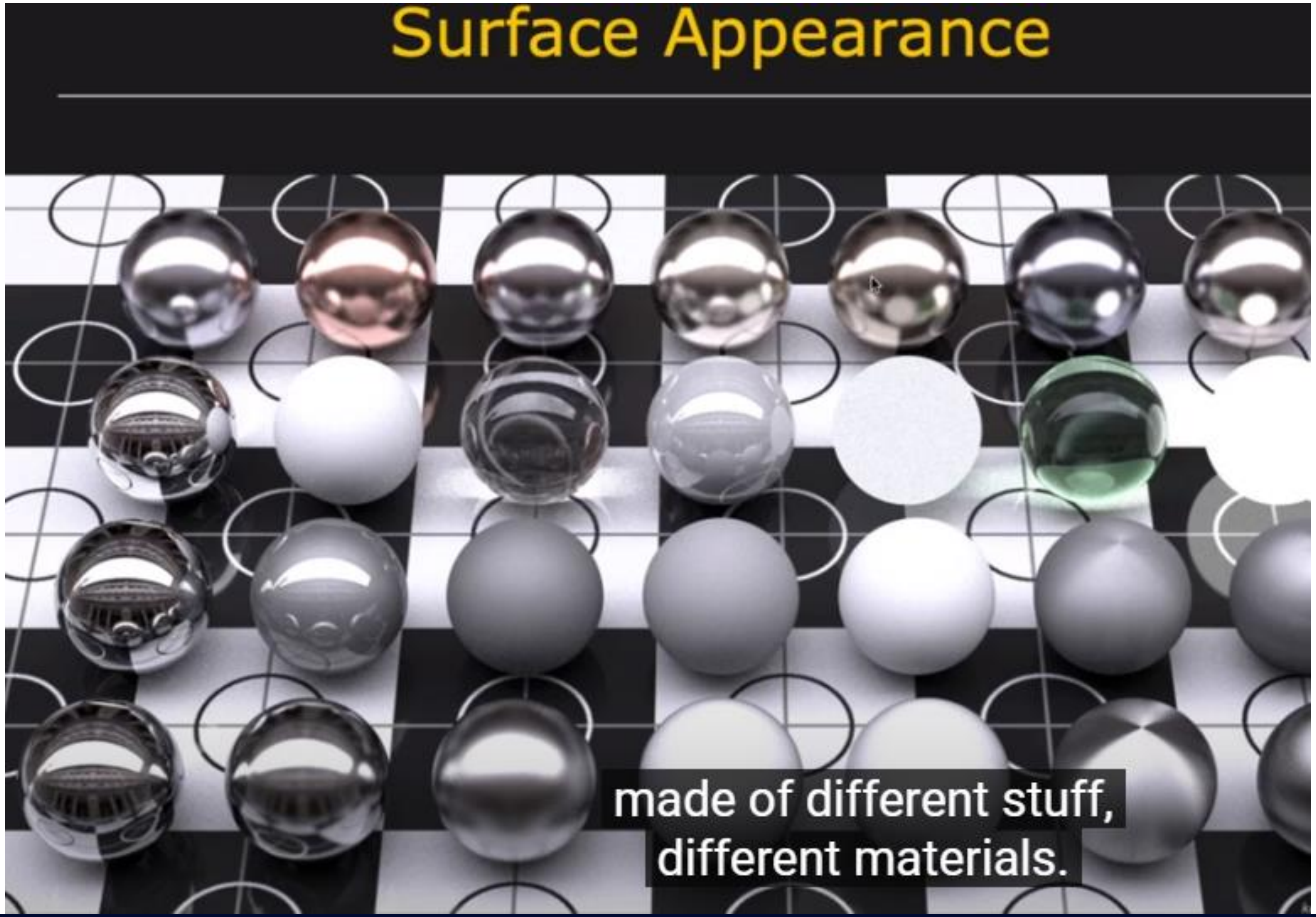
- The measurement of light is a field in itself, known as radiometry
- Two sources that generate the same pattern on this input hemisphere
- must have the same effect on the surface at this point
- Two surfaces that generate the same pattern on a source’s output hemisphere
- Must receive the same amount of energy from the source

Light in space





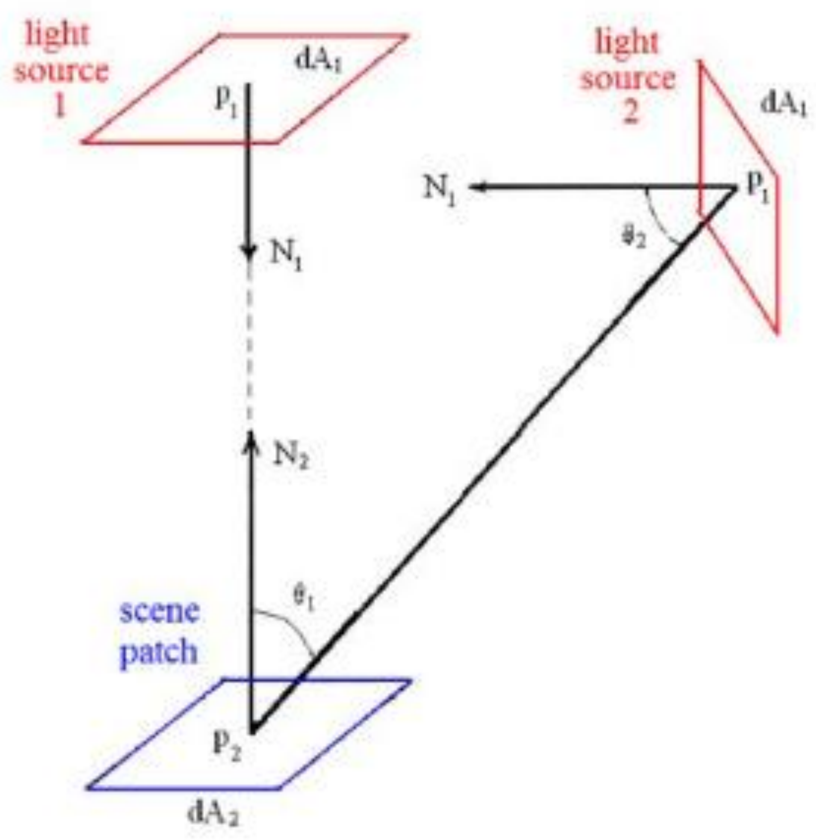
Light in space



Light in space

- The orientation of the surface patch with respect to
- The direction in which the illumination is travelling is important
- As a source is tilted wrt the direction in which the illumination is travelling
- it “looks smaller” to a patch of surface
- As a patch is tilted wrt the direction in which the illumination is travelling
- it “looks smaller” to the source

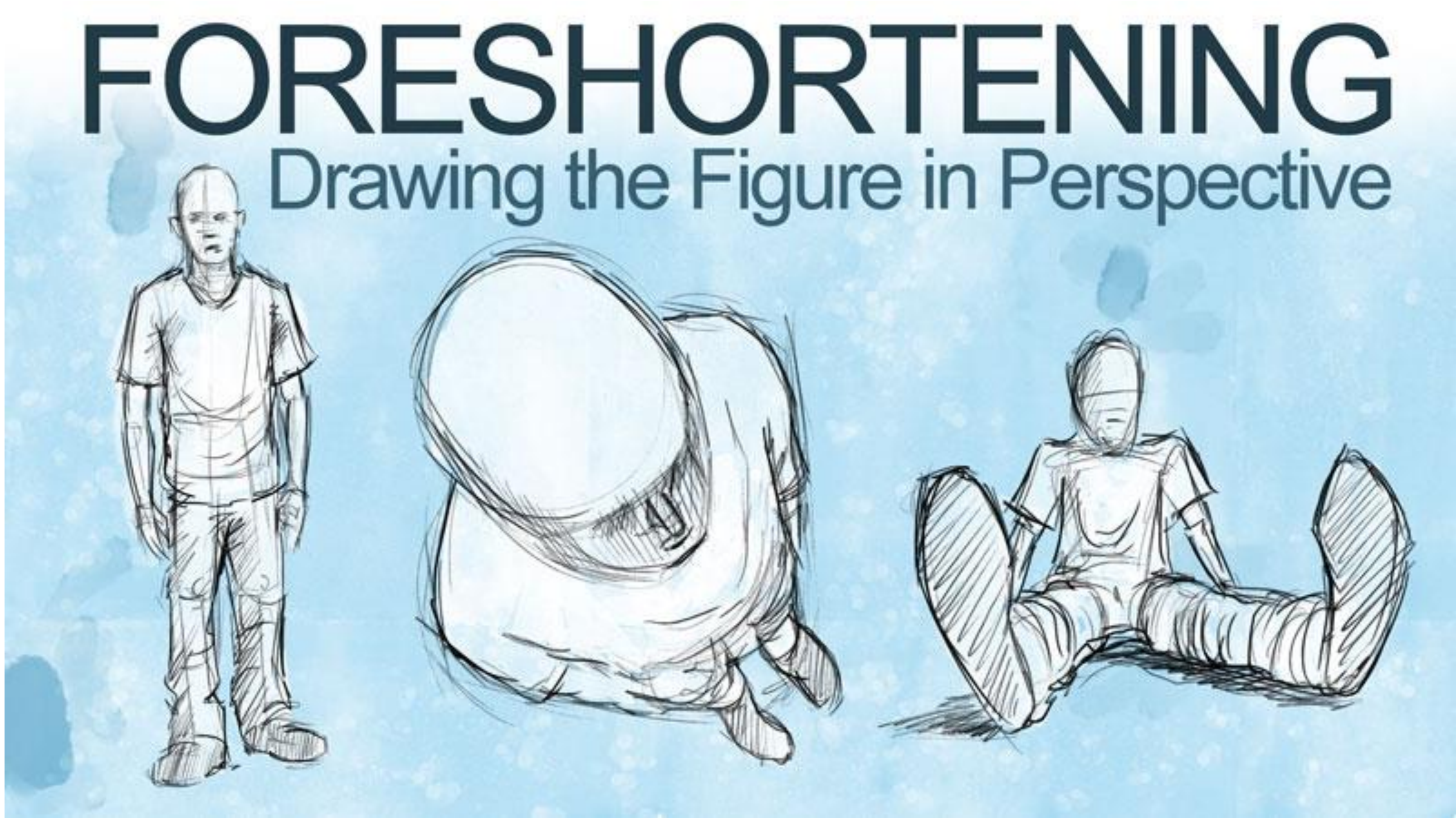
Light in space



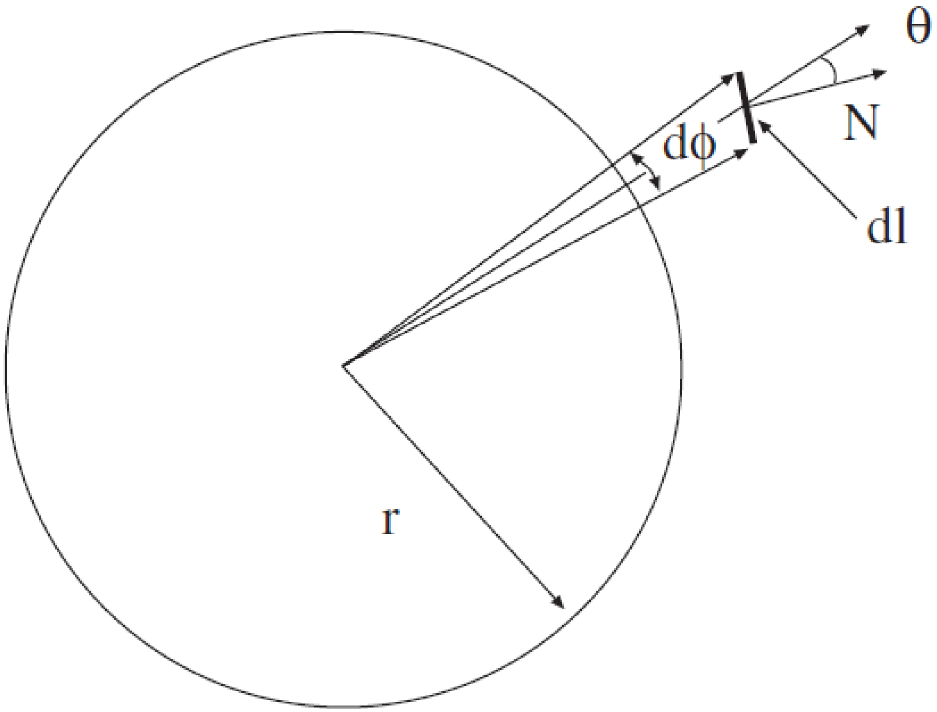
Light in space - foreshortening

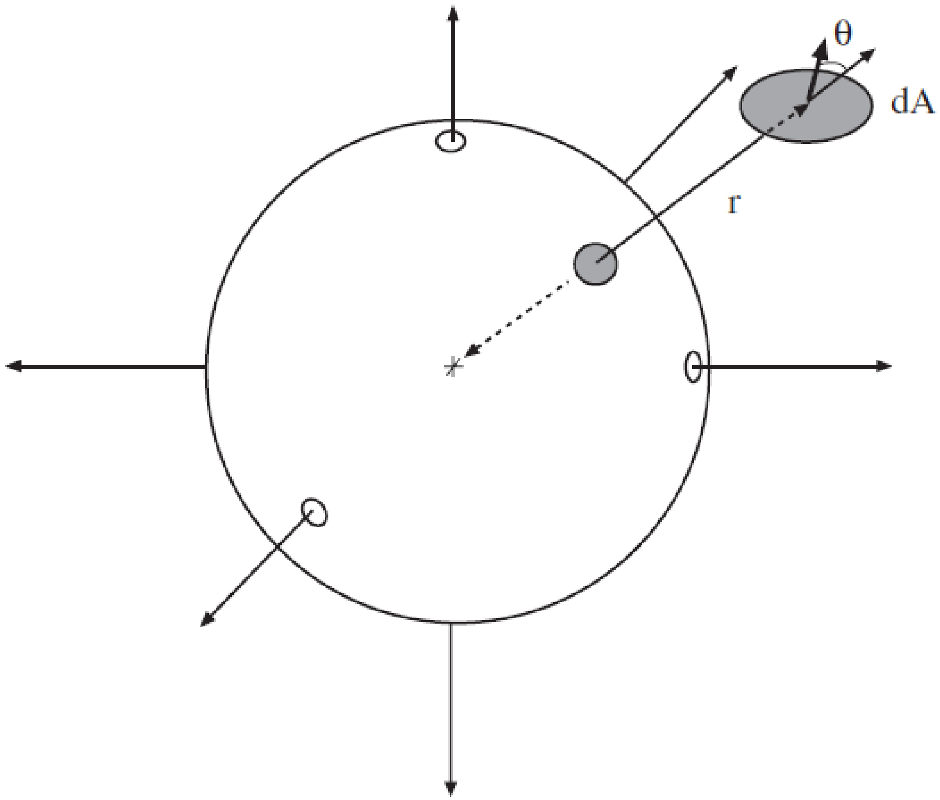
- From the point of view of the source a small patch appears the same as
- a large patch that is heavily foreshortened
- must receive the same energy
- The effect is known as foreshortening

Light in space - foreshortening



Light in space – Solid angle





Light in space – Solid angle

- The angle subtended on the plane by a line length dl at a point p
- projecting the line segment onto the unit circle whose center is at p;
- the length of the result is the required angle in radians
- $$d\phi = \frac{dl \cos\theta}{r}$$

Light in space – Solid angle

- The solid angle subtended by a patch of surface at a point x
- projecting the patch onto the unit sphere whose center is at x;
- the area of the result is the required solid angle (steradian)
- solid angle captures the intuition in foreshortening
- $d\omega = \frac{dA\cos\theta}{r^2}$ $\quad$ $d\omega = \sin\theta d\theta d\phi$

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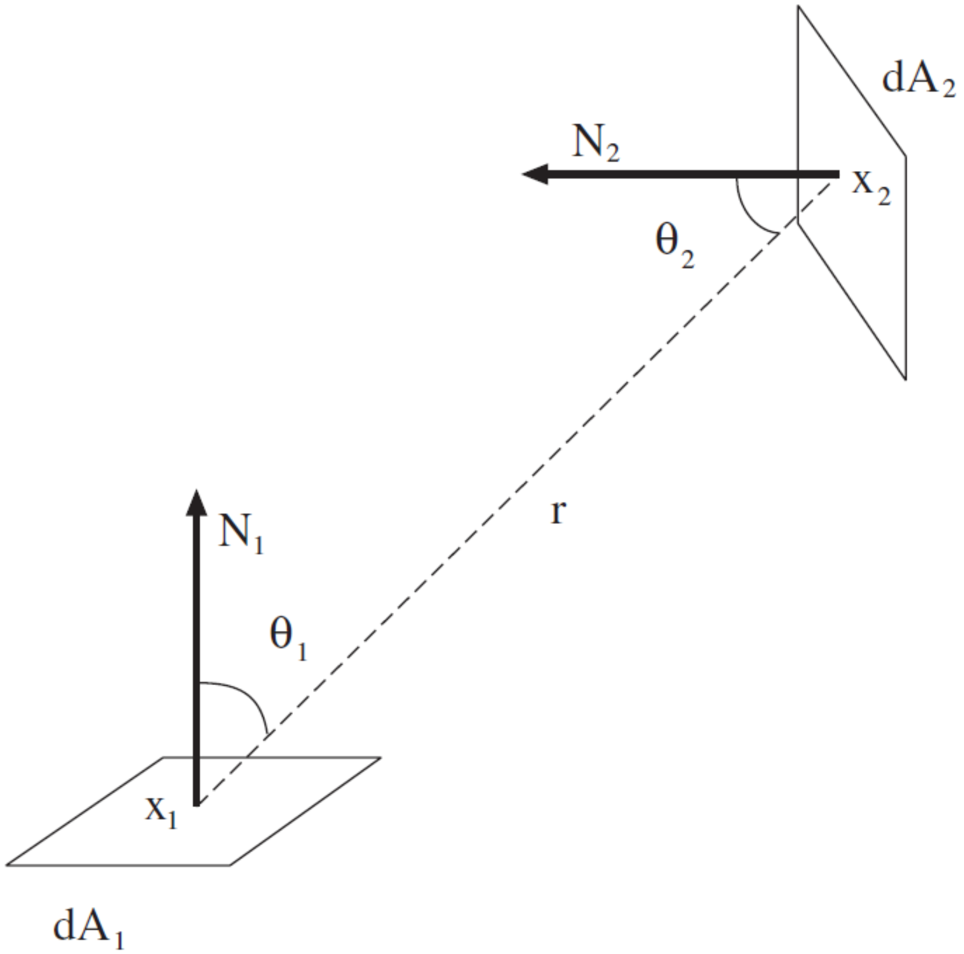
Light in space – Radiance

- The distribution of light in space is a function of position and direction
- Appropriate unit for measuring the distribution of light in space is radiance
- The amount of energy travelling at some point in a specified direction
- per unit time, per unit area perpendicular to the direction of travel,
- Per unit solid angle

Light in space – Radiance

- unit of radiance - watts per square meter per steradian $(W m^{-2} sr^{-1})$.
- a small patch viewing a source frontally collects more energy than
- the same patch viewing a source radiance along a nearly tangent direction
- radiance at a point in space is usually denoted L(x, direction),
- where x is a coordinate for position, direction as x1->x2

Light in space – Radiance



Light in space – Radiance

- radiance at the patch is L(x1, θ, ϕ), the energy transmitted by the patch into
- an infinitesimal region of solid angle dω around the direction θ, ϕ in time dt
- $$L(\boldsymbol{x}_1, \theta, \phi)(\cos\theta_1 dA_1)(d\omega)(dt),$$
- The radiance leaving x1 in the direction of x2 is L(x1, x1 → x2)
- This means that, in time dt, the energy leaving x1 towards x2 is
- $$d^3E_{1\to 2} = L(\boldsymbol{x}_1, \boldsymbol{x}_1 \to \boldsymbol{x}_2)\cos\theta_1 d\omega_{2(1)} dA_1 dt$$

Radiance is constant along (unoccluded) straight lines.

From the expression for solid angle above,

$$d\omega_{2(1)} = \frac{\cos\theta_2 dA_2}{r^2}$$

Now the energy leaving 1 for 2 is:

$$\begin{aligned} d^3E_{1\to 2} &= L(\boldsymbol{x}_1, \boldsymbol{x}_1 \to \boldsymbol{x}_2)\cos\theta_1 d\omega_{2(1)} dA_1 dt \\ &= L(\boldsymbol{x}_1, \boldsymbol{x}_1 \to \boldsymbol{x}_2)\frac{\cos\theta_1 \cos\theta_2 dA_2 dA_1 dt}{r^2} \end{aligned}$$

Because the medium is a vacuum, it does not absorb energy, so that the energy arriving at 2 from 1 is the same as the energy leaving 1 in the direction of 2. The energy arriving at 2 from 1 is:

$$\begin{aligned} d^3E_{1\to 2} &= L(\boldsymbol{x}_2, \boldsymbol{x}_1 \to \boldsymbol{x}_2)\cos\theta_2 d\omega_{1(2)} dA_2 dt \\ &= L(\boldsymbol{x}_2, \boldsymbol{x}_1 \to \boldsymbol{x}_2)\frac{\cos\theta_2 \cos\theta_1 dA_1 dA_2 dt}{r^2} \end{aligned}$$

which means that $L(\boldsymbol{x}_2, \boldsymbol{x}_1 \to \boldsymbol{x}_2) = L(\boldsymbol{x}_1, \theta, \phi)$, so that *radiance is constant along (unoccluded) straight lines.*

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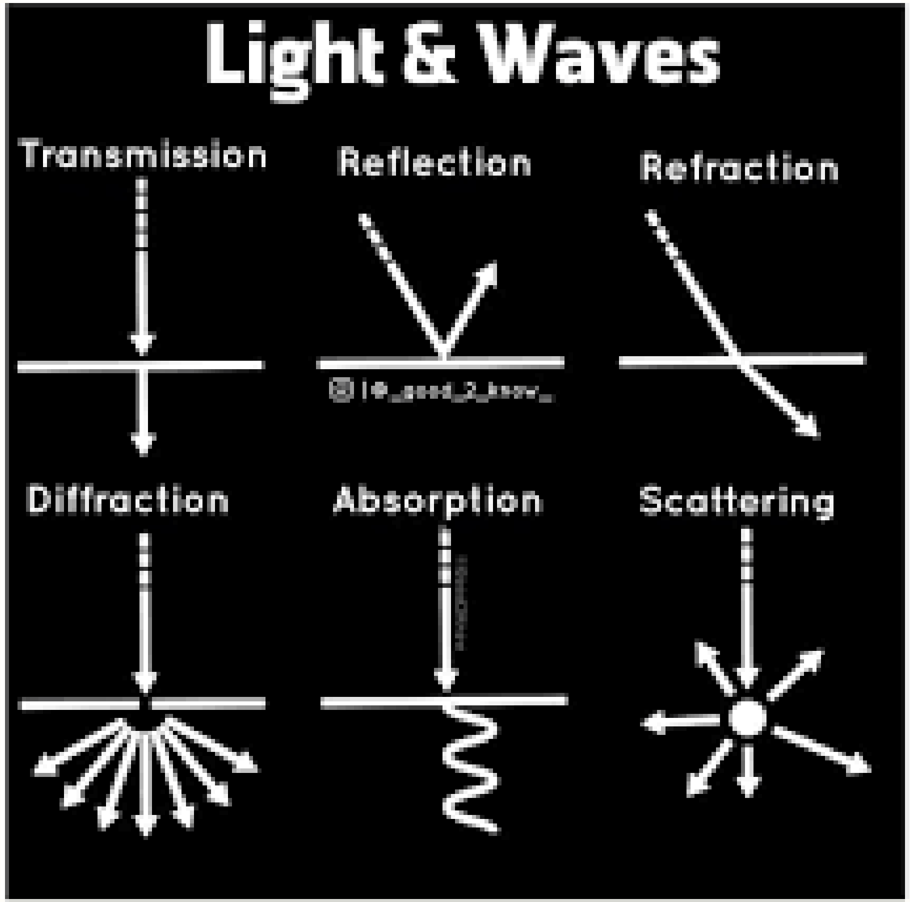
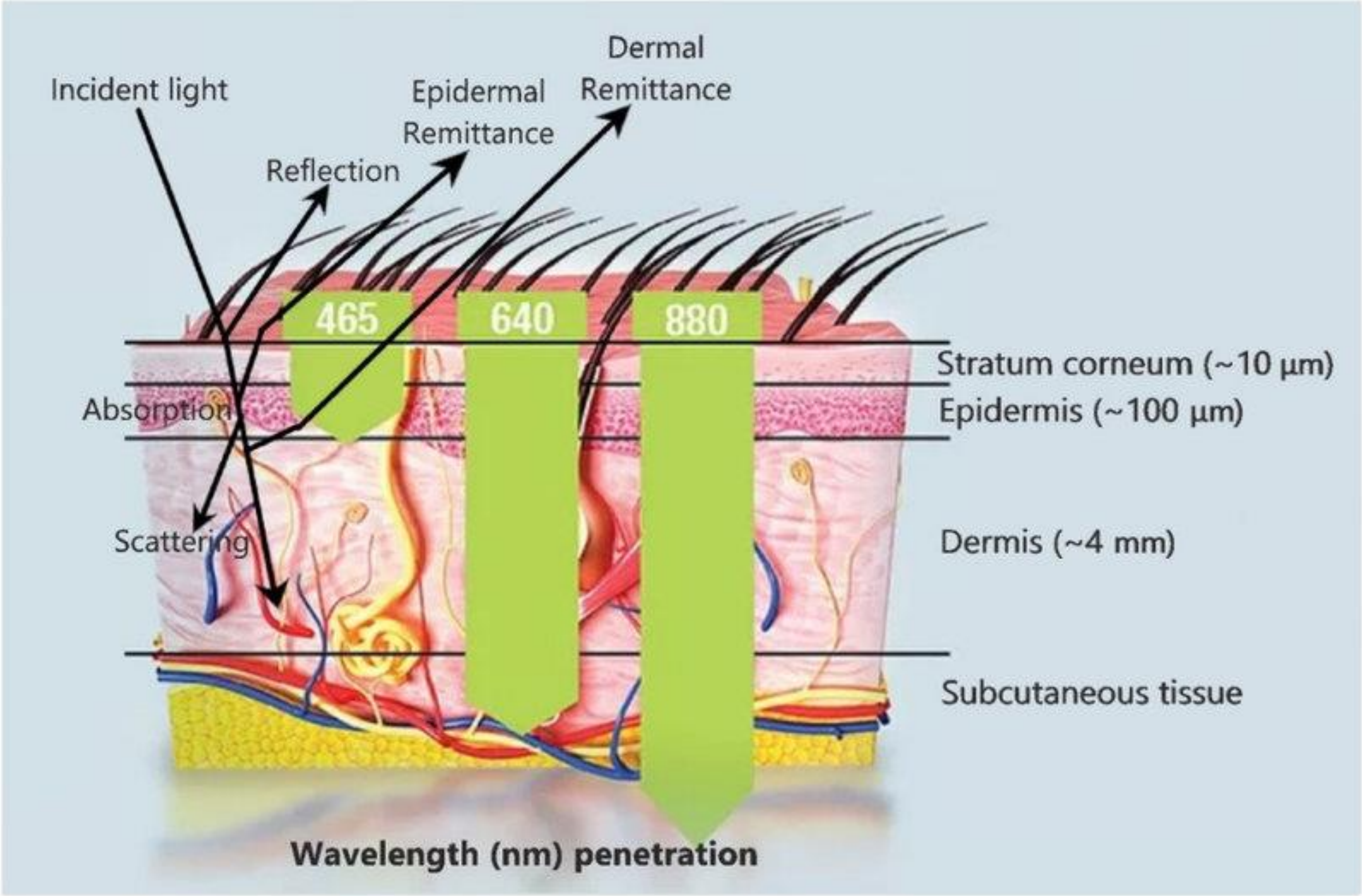
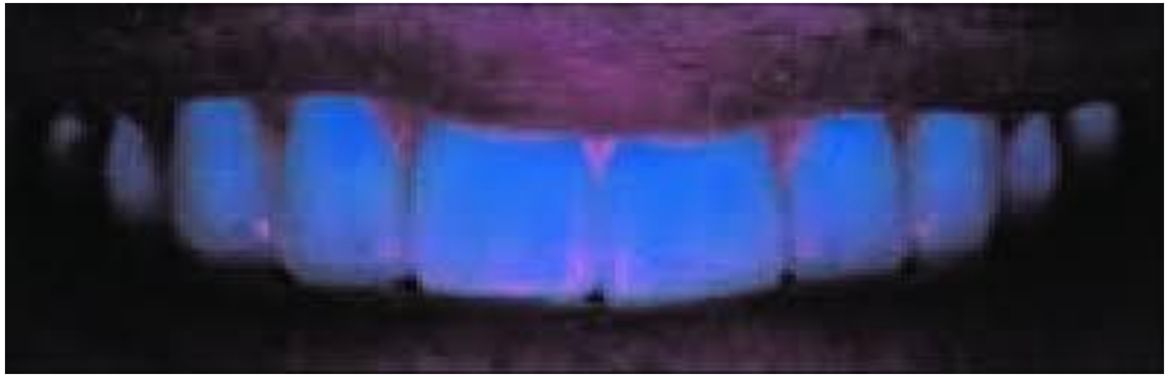
Light at surfaces





Light at surfaces – Identification of fake teeth



Light at surfaces – Identification of fake currency

Light at surfaces – scorpion glow

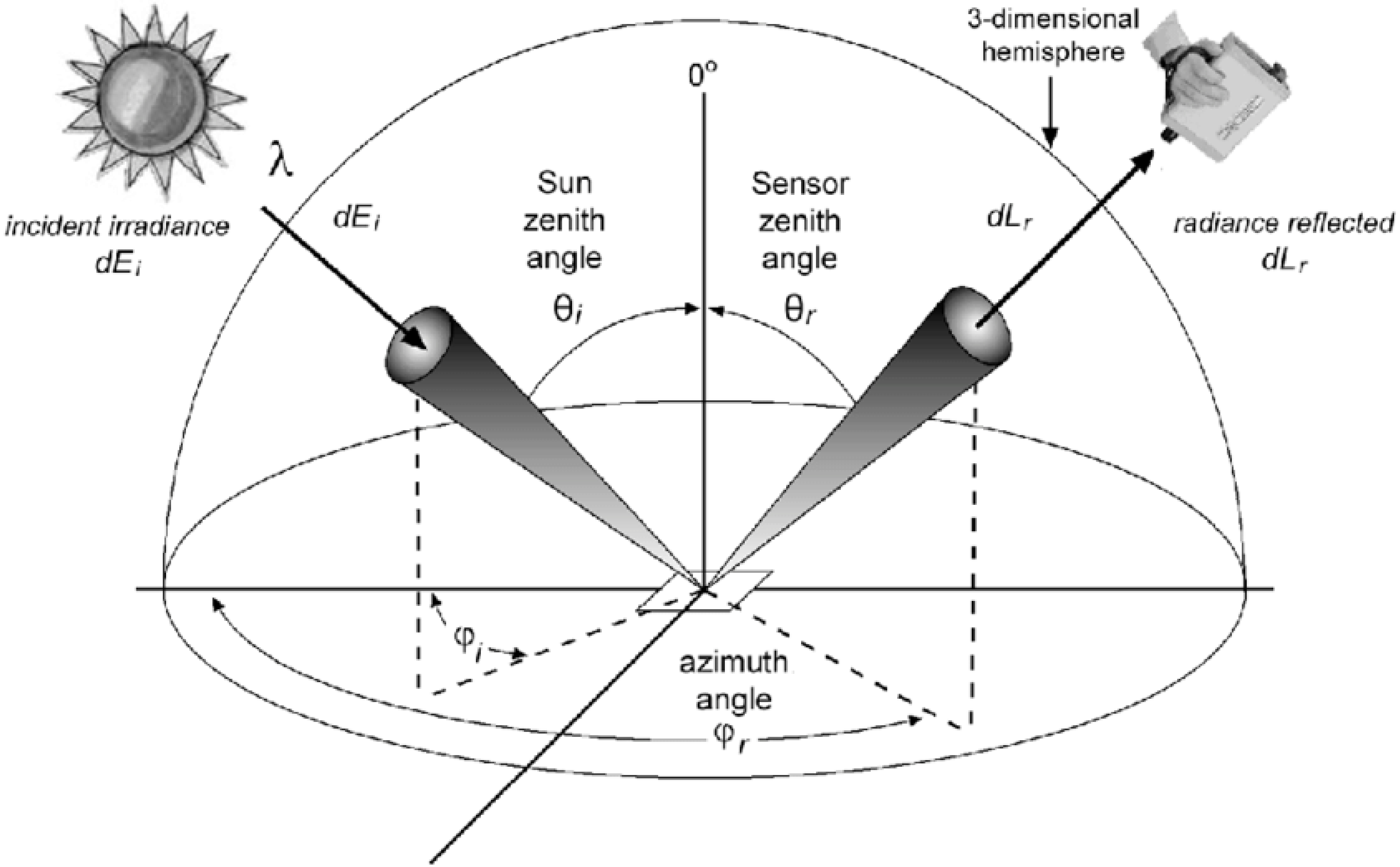
Light at surfaces - Fluorescence

- Some surfaces to absorb light at one wavelength,
- then radiate light at a different wavelength as a result
- This phenomenon is called as fluorescence
- Human teeth, false teeth under UV light

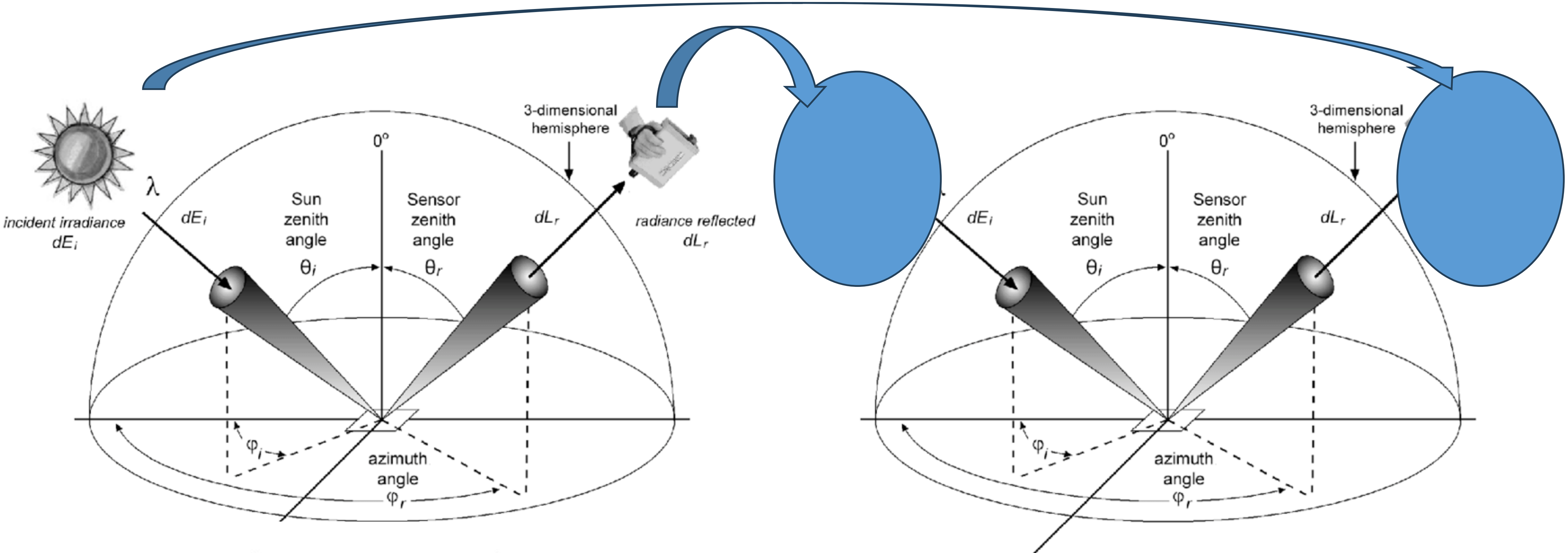
Light at surfaces - assumptions

- Radiance leaving a point on a surface is due only to radiance arriving at this point
- all light leaving a surface at a given wavelength is due to light
- arriving at that wavelength
- surfaces do not generate light internally, and
- treat sources separately.

The Bidirectional Reflectance Distribution Function (BRDF)



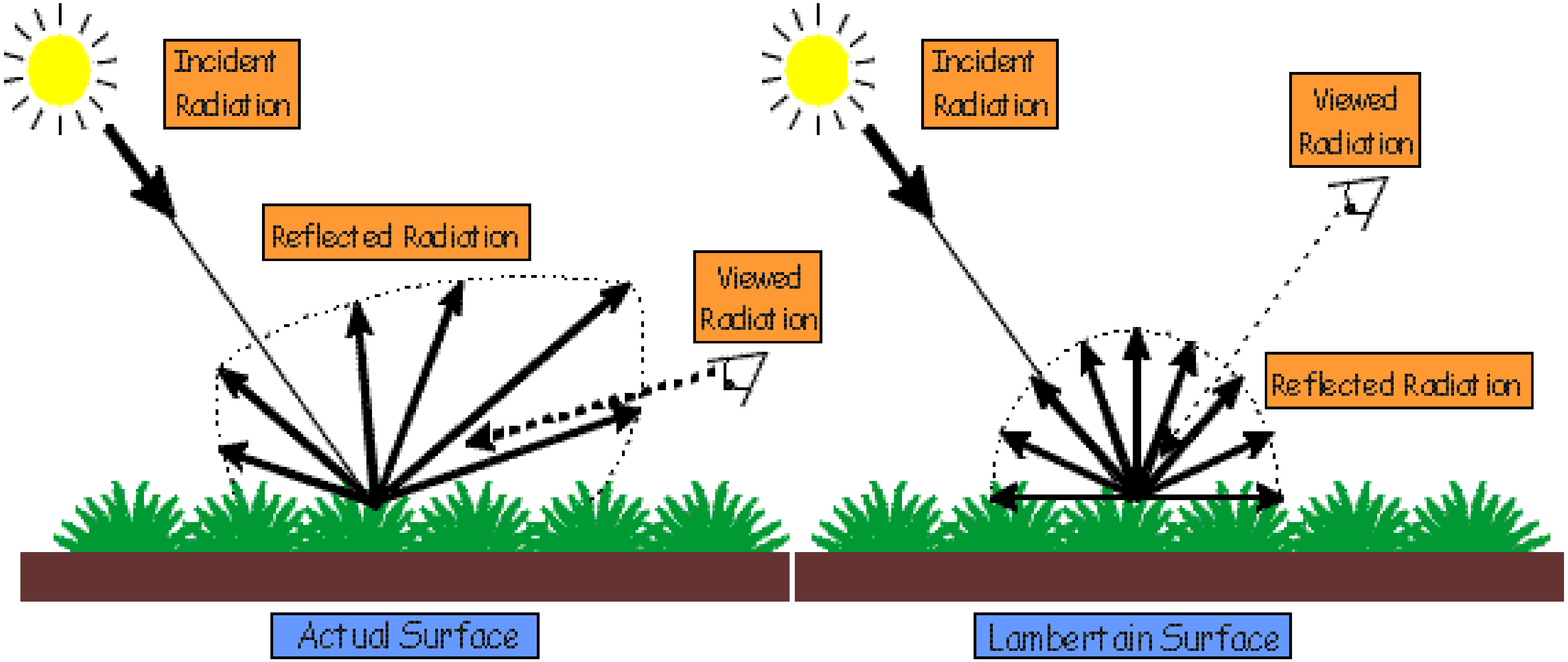
The Bidirectional Reflectance Distribution Function (BRDF) – Helmholtz reciprocity



$$\rho_{bd}(\theta_o, \phi_o, \theta_i, \phi_i)$$

$$\rho_{bd}(\theta_i, \phi_i, \theta_o, \phi_o)$$

The Bidirectional Reflectance Distribution Function (BRDF)



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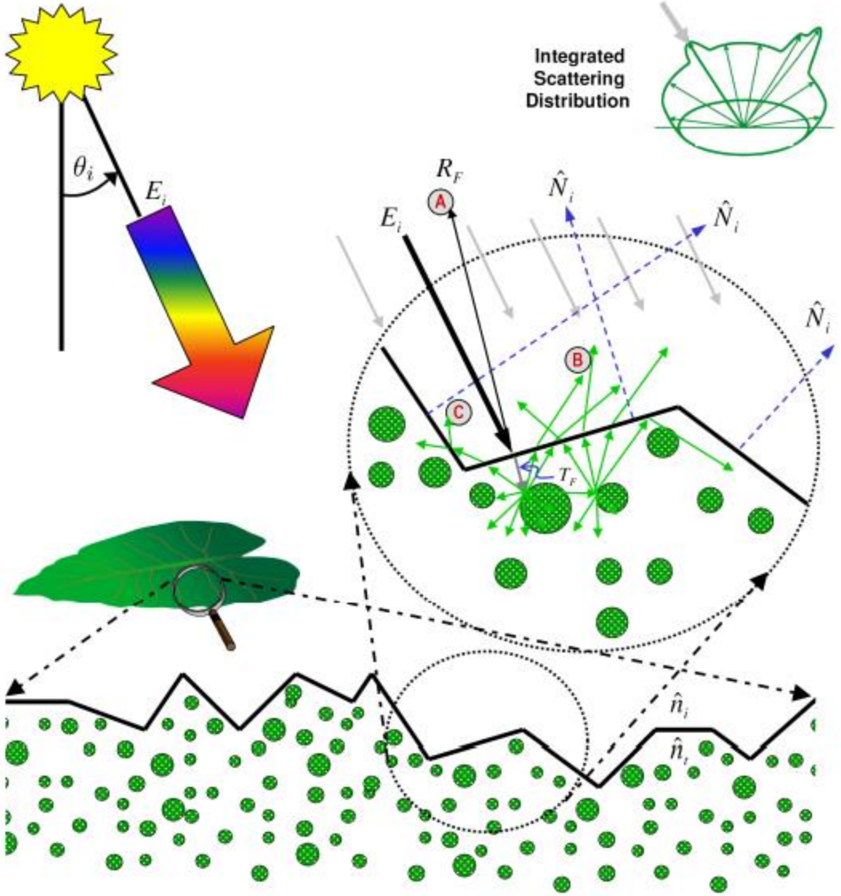
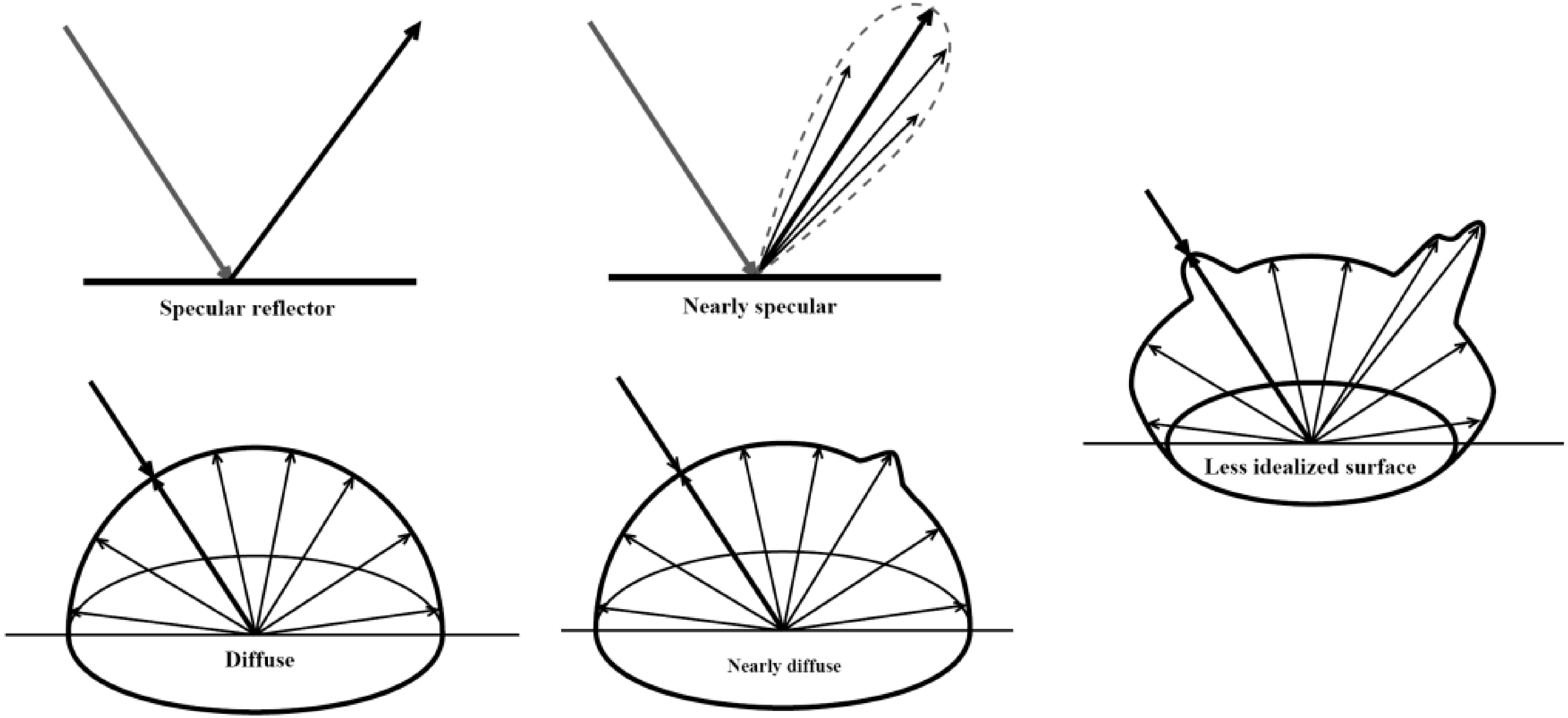
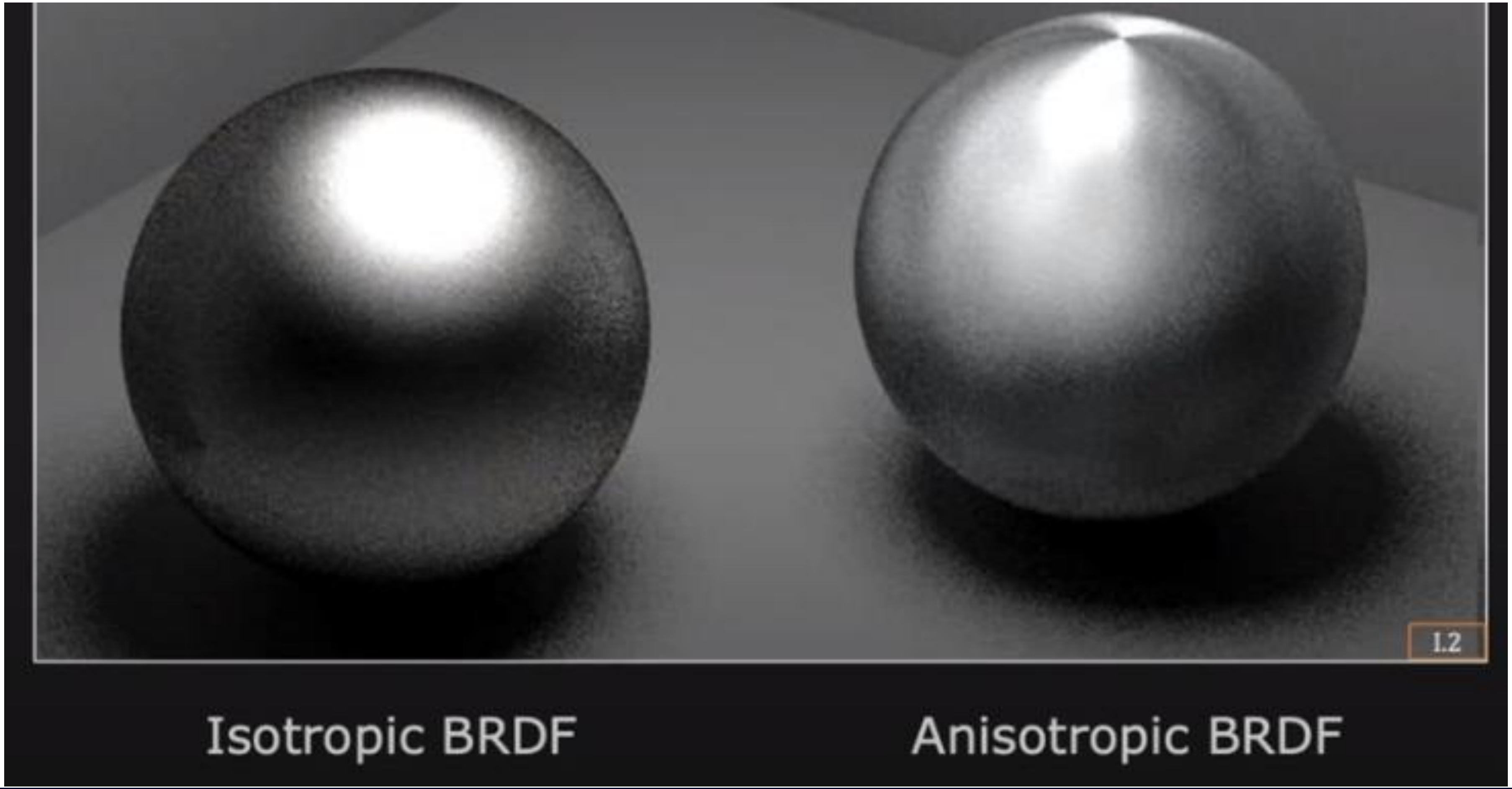


Figure 4: Detailed view of light scatter from material.

The Bidirectional Reflectance Distribution Function (BRDF)



The Bidirectional Reflectance Distribution Function (BRDF) – Isotropic and anisotropic



The Bidirectional Reflectance Distribution Function (BRDF)

- A surface illuminated by radiance Lo(x, θi, ϕi)
- receives irradiance Li(x, θi, ϕi) cos θidω
- BRDF is defined as ratio of radiance in outgoing direction to the incident irradiance
- $$\rho_{bd}(\theta_o, \phi_o, \theta_i, \phi_i) = \frac{L_o(\boldsymbol{x}, \theta_o, \phi_o)}{L_i(\boldsymbol{x}, \theta_i, \phi_i) \cos \theta_i d\omega}$$

  units of inverse steradians (sr)^(−1)

Properties of BRDF

$$L_o(\boldsymbol{x}, \theta_o, \phi_o) = \rho_{bd}(\theta_o, \phi_o, \theta_i, \phi_i) L_i(\boldsymbol{x}, \theta_i, \phi_i) \cos\theta_i d\omega$$

$$L_o(\boldsymbol{x}, \theta_o, \phi_o) = \int_\Omega \rho_{bd}(\theta_o, \phi_o, \theta_i, \phi_i) L_i(\boldsymbol{x}, \theta_i, \phi_i) \cos\theta_i d\omega$$

$$\begin{aligned} \int_\Omega \frac{1}{\cos\theta} \cos\theta d\omega &= \int_0^{2\pi} \int_0^{\frac{\pi}{2}} \sin\theta d\theta d\phi \\ &= 2\pi \end{aligned}$$

Properties of BRDF

$$
\begin{aligned}
2\pi &\geq \int_{\Omega_o} L_o(\boldsymbol{x}, \theta_o, \phi_o) \cos\theta_o d\omega_o \\
&= \int_{\Omega_o} \int_{\Omega_i} \rho_{bd}(\theta_o, \phi_o, \theta_i, \phi_i) L_i(\boldsymbol{x}, \theta_i, \phi_i) \cos\theta_i d\omega_i d\omega_o \\
&= \int_{\Omega_o} \int_{\Omega_i} \rho_{bd}(\theta_o, \phi_o, \theta_i, \phi_i) d\omega_i d\omega_o \\
&= \int_0^{2\pi} \int_0^{\frac{\pi}{2}} \int_0^{2\pi} \int_0^{\frac{\pi}{2}} \rho_{bd}(\theta_o, \phi_o, \theta_i, \phi_i) \sin\theta_i d\theta_i d\phi_i \sin\theta_o d\theta_o d\phi_o
\end{aligned}
$$

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$$\nabla \times \mathbf{B} = \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t} + \mu_0 \boldsymbol{j}_c$$

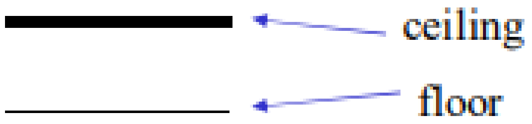
where

$$\nabla = \hat{\mathbf{i}} \frac{\partial}{\partial x} + \hat{\mathbf{j}} \frac{\partial}{\partial y} + \hat{\mathbf{k}} \frac{\partial}{\partial z}$$

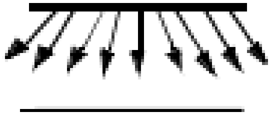
Important special cases - radiosity

The radiometric term radiosity means the rate at which energy leaves a surface, which is the sum of the rates at which the surface emits energy and reflects (or transmits) energy received from all other surfaces.

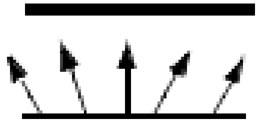
- Consider a room with only floor and ceiling:



- Suppose the ceiling is actually a fluorescent drop-panel ceiling which emits light…



- The floor gets some of this light and reflects it back



- The ceiling gets some of this reflected light and sends it back… you get the idea.

Important special cases - radiosity

- Let the ceiling emit 12 units of light per second
- Let the floor reflect 50% of what it gets; let it get 1/3 of the light from the ceiling (based on geometry)
- And let the ceiling get 1/3 of the floor's light (based on geometry), and reflect 75% of what it gets
- Writing B_1 for the ceiling's total light, and B_2 for the floor's, and E_1 and E_2 for the light generated internally by each, we have:

ceiling:

$$E_1 = 12, B_1 = E_1 + \rho_1(F_{2-1}B_2) = 12 + \frac{3}{4}\cdot\frac{1}{3}B_2$$

floor:

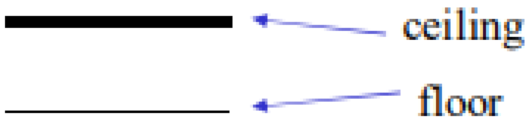
$$E_2 = 0, B_2 = E_2 + \rho_2(F_{1-2}B_1) = 0 + \frac{1}{2}\cdot\frac{1}{3}B_1$$

- First, we'll solve this simple case, then write equations for the more general case

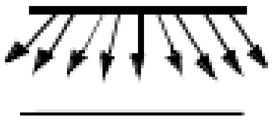
Important special cases - radiosity

The radiometric term radiosity means the rate at which energy leaves a surface, which is the sum of the rates at which the surface emits energy and reflects (or transmits) energy received from all other surfaces.

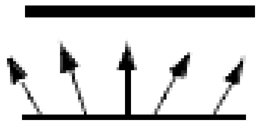
- Consider a room with only floor and ceiling:



- Suppose the ceiling is actually a fluorescent drop-panel ceiling which emits light…

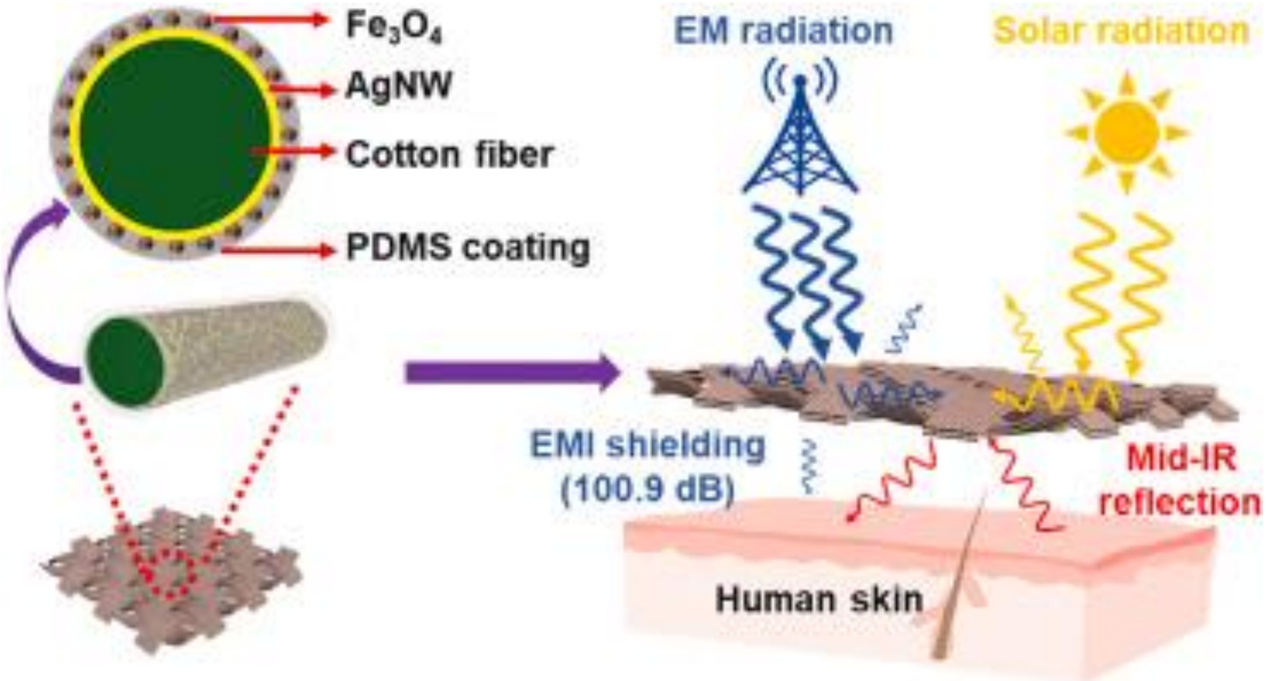


- The floor gets some of this light and reflects it back



- The ceiling gets some of this reflected light and sends it back… you get the idea.

Important special cases



Important special cases - Radiosity

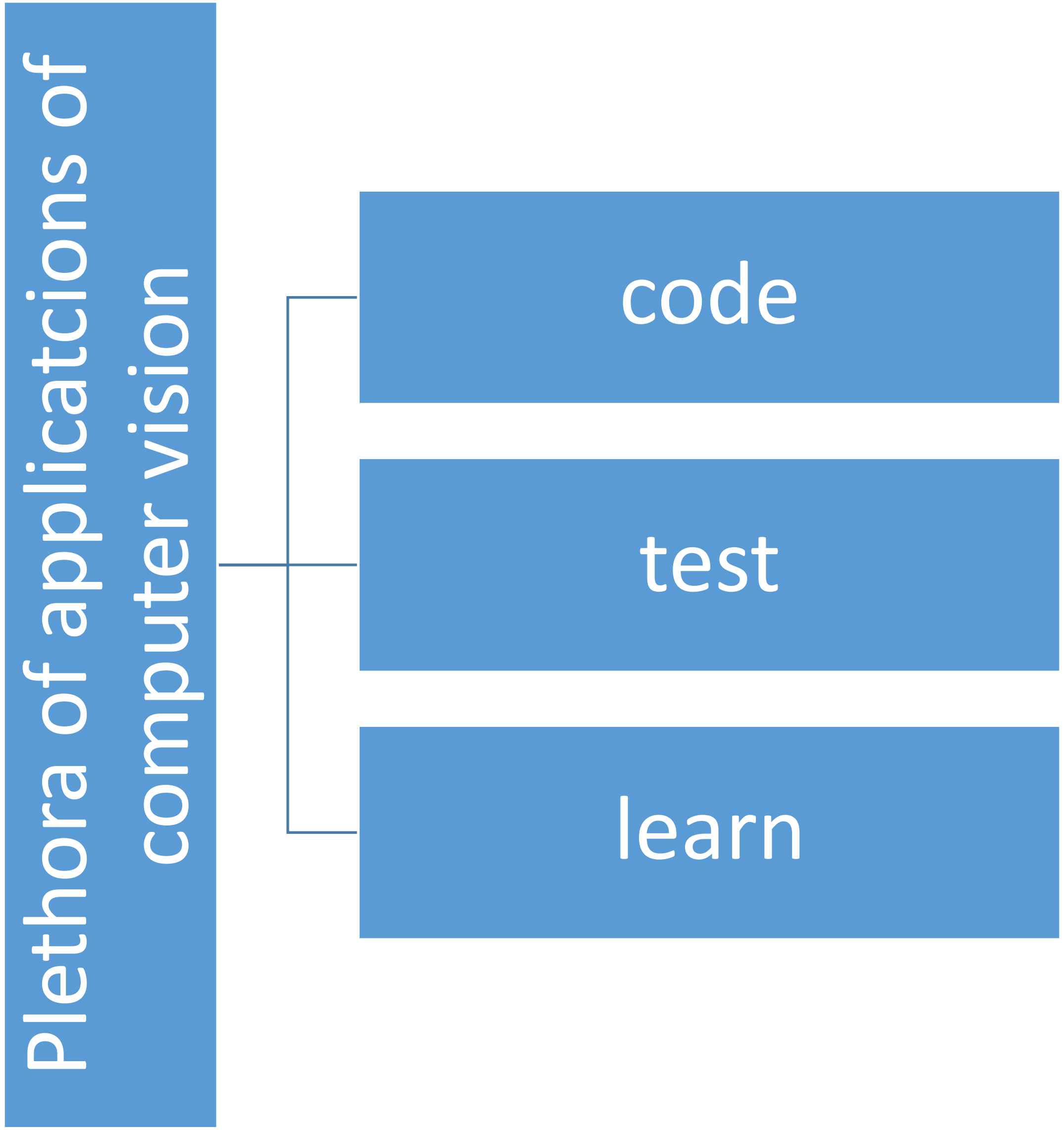
- Radiosity, defined as total power leaving a point on a surface per unit area on surface
- To obtain the radiosity of a surface at a point,
- sum the radiance leaving the surface at that point over the whole exit hemisphere.
- $$B(\boldsymbol{x}) = \int_{\Omega} L(\boldsymbol{x}, \theta, \phi) \cos\theta d\omega$$

Important special cases - radiosity

$$B(\boldsymbol{x}) = \int_{\Omega} L(\boldsymbol{x}, \theta, \phi) \cos\theta d\omega$$

$$\begin{aligned} &= L_o(\boldsymbol{x}) \int_0^{\frac{\pi}{2}} \int_0^{2\pi} \cos\theta \sin\theta d\phi d\theta \\ &= \pi L_o(\boldsymbol{x}) \end{aligned}$$

Conclusion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