Pinhole cameras

- light detectors sum light over all incoming
  - directions
  - wavelengths
  - time

  } and area

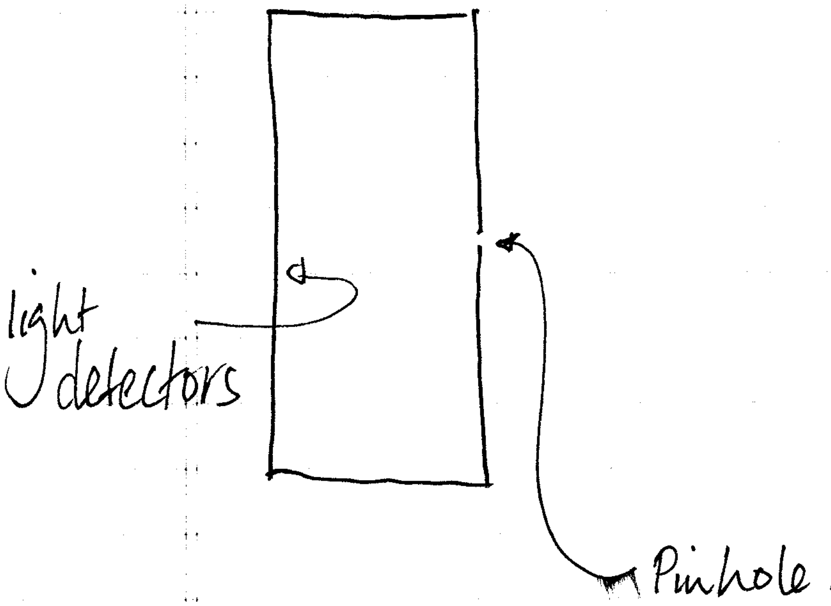
$$\text{response} = \int_{\Omega}\int_{\Lambda}\int_{T}\int_{D} S(\omega,\lambda,t,x)\cdot L(x,\omega,\lambda)\, dx\, dt\, d\lambda\, d\omega$$

sensitivity

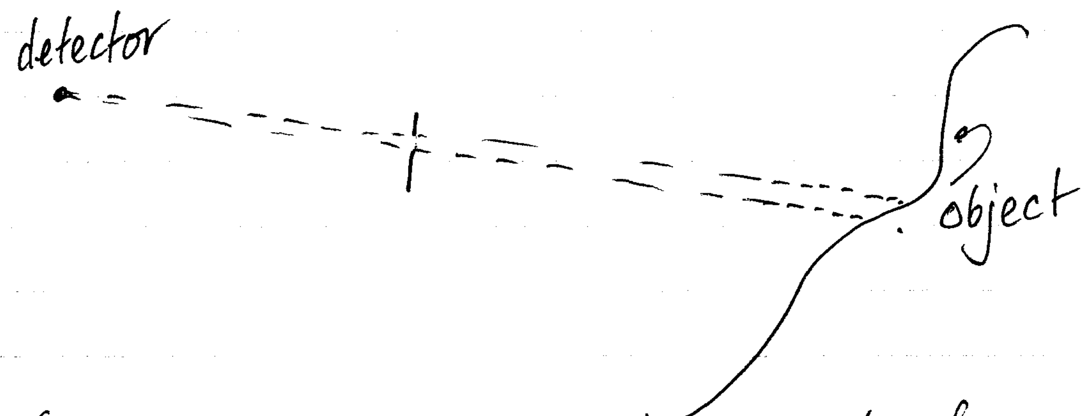
incoming radiance

- To avoid blurry images we must:
  - limit the time (T)
  - limit the range of directions (Ω)

~~Strategy~~ Method: Pinhole Camera



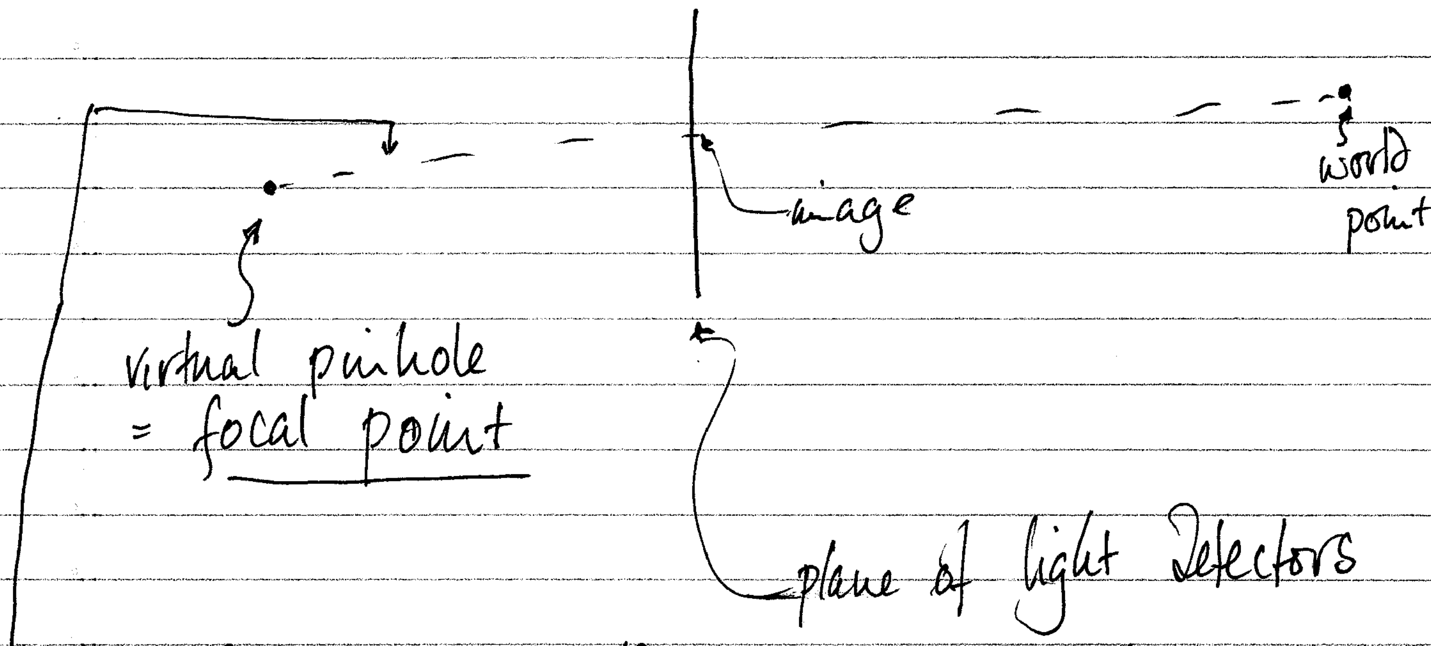
- We control time with a <u>shutter</u>
- dir'n with the pinhole



- Now each detector collects light from only one patch on the object.
- and we have an image.

- Image is upside down

- I like to use a "non-physical" pinhole



straight line from world point to focal point.

Notice:

- if $\underline{f} = (0,0,0)$
- Image plane is $(u, v, -f)$ — focal length.
- World point is (X, Y, Z)

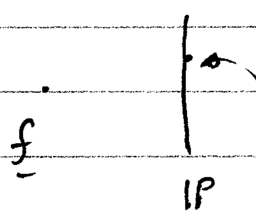
then image point is $\left(-f\dfrac{X}{Z}, -f\dfrac{Y}{Z}, +f\right)$

- We will render with a pinhole camera for the moment

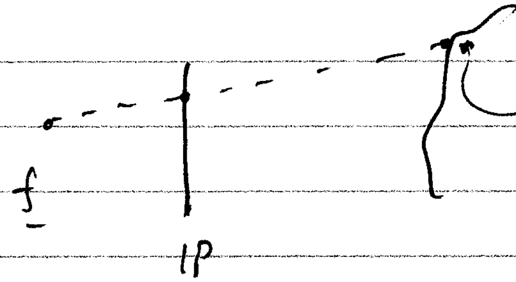
<u>Idea</u>:
- How bright is a pixel?

$\equiv$

- How bright is the point hit by ray through pixel?



how bright is this?



depends on this?

- <u>Strategy</u>:
  - Fire many rays out through pixel
  - Average of ray brightnesses = pixel brightness

- How bright is this point?
  - We use a local shading model, at first
  - Surface is Diffuse + Specular

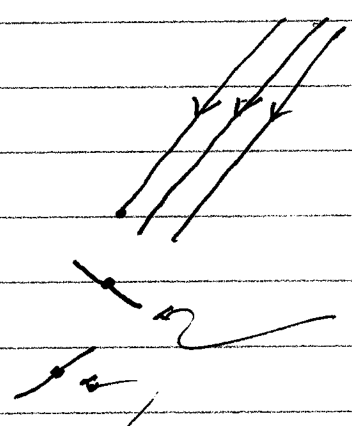
Diffuse surfaces.

- light arriving at a diffuse (Lambertian surface is scattered uniformly over outgoing directions
- Diffuse surfs do not change brightness when viewed from different dirs

- Much cloth, paint, rough surfs, etc.

· the ~~per~~ fraction of light scattered by a diffuse surface is its <u>albedo</u>

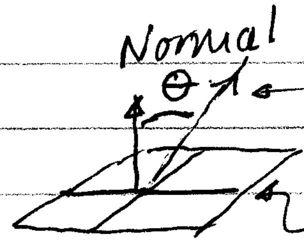
· the amount of light <u>received</u> by a diffuse surf depends on <u>geometry</u>



this patch "cuts" many rays

this patch cuts few rays.

# of rays cut $\propto \cos\theta$



Brightness of diffuse patch =

$$e \cdot \sum_{\left[\substack{\text{sources} \\ \text{it can see}}\right]} \cdot I_{source} \cdot \cos\theta_{source}$$

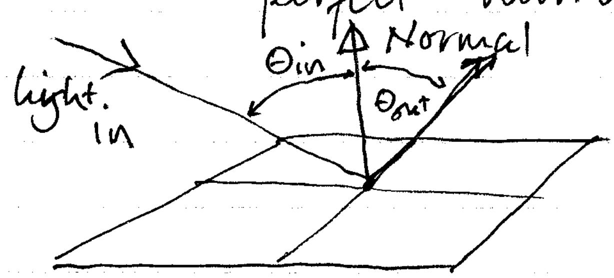
albedo of patch.

intensity of source

Q: can the patch see the source?

- <u>Specular surfaces:</u>

  - perfect mirrors



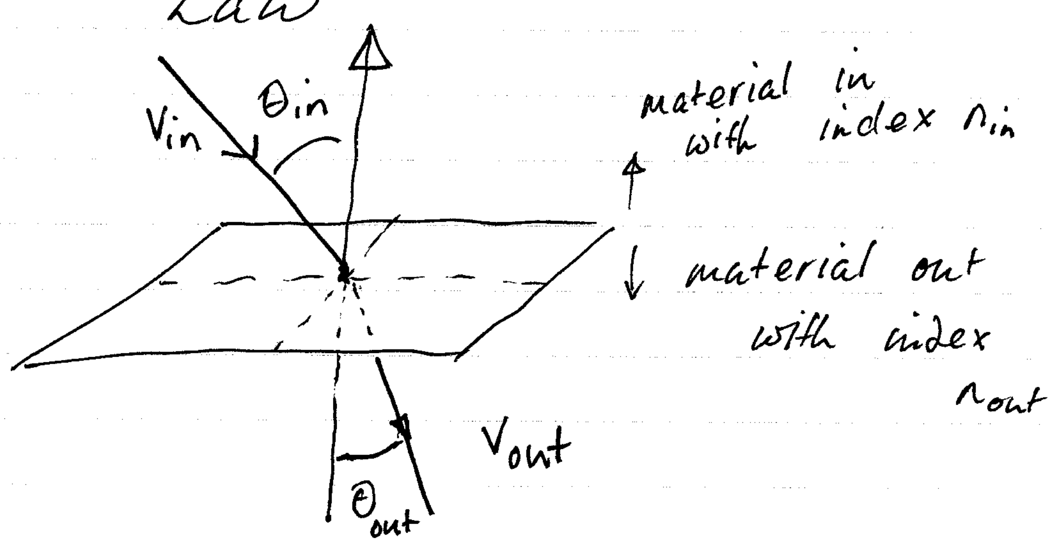
- $\theta_{out} = \theta_{in}$
- V_{in}, N, V_{out} are coplanar

- Brightness of specular surface in direction V_{out}

$$= \rho_s \{ \text{Brightness in } V_{in} \}$$

Translucent Surfaces:

- Light arriving at an interface is refracted according to SNELLS Law



$$n_{out} \sin\theta_{out} = n_{in} \sin\theta_{in}$$

(Originally discovered by Ibn Sahl,
640 years before Snell!)

Notice that

$\frac{n_{in}}{n_{out}} \sin\theta_{in}$ could be greater than 1

- Critical angle

  - if ~~..~~ $\frac{n_{in}}{n_{out}} \sin\theta_{in} = 1$,
    then θ_{in} is critical angle
  - light now travels along the interface
  - if $\theta_{in} > \theta_{crit}$, specular reflection occurs

Shading a refraction

$$\rho_t \cdot \{ \text{Brightness in } \cancel{\text{the}}\ V_{in} \}$$

transmitted

· <u>General Surface</u>

· diffuse component

(i.e. is there a blocker between here and Source?)

\+ specular component

(i.e. what is closest ~~of~~ patch in V_{in}?)

\+ transmitted component

(i.e. what is closest patch in V_{in})

Example intersection calculations:

sphere:

$$(\underline{x}-\underline{c})^T(\underline{x}-\underline{c}) = r^2$$

center — radius

Q: intersections on ray from $\underline{p}$ in direction $\underline{v}$

i.e. +ve t_0 such that

$\underline{p} + t_0 \underline{v}$ lies on sphere

i.e.: solve

quadratic equation $\rightarrow$ $$\boxed{(\underline{p}-\underline{c}+t\underline{v})^T(\underline{p}-\underline{c}+t\underline{v}) = r^2}$$

Cases: discriminant < 0

no real solution, stop

disc $= 0$

tangential ray

disc > 0

2 roots; find one with

Smallest $t > 0$

Q: is this sphere a blocker between $\underline{p}$ and $\underline{q}$?

i.e. is there a $0 < t_0 < 1$ s.t.

$\underline{p} + t_0(\underline{q} - \underline{p})$ lies on sphere.

Analysis as above.

Planes:

- a plane is $\underline{a} \cdot \underline{x} + c = 0$

- now use root finding

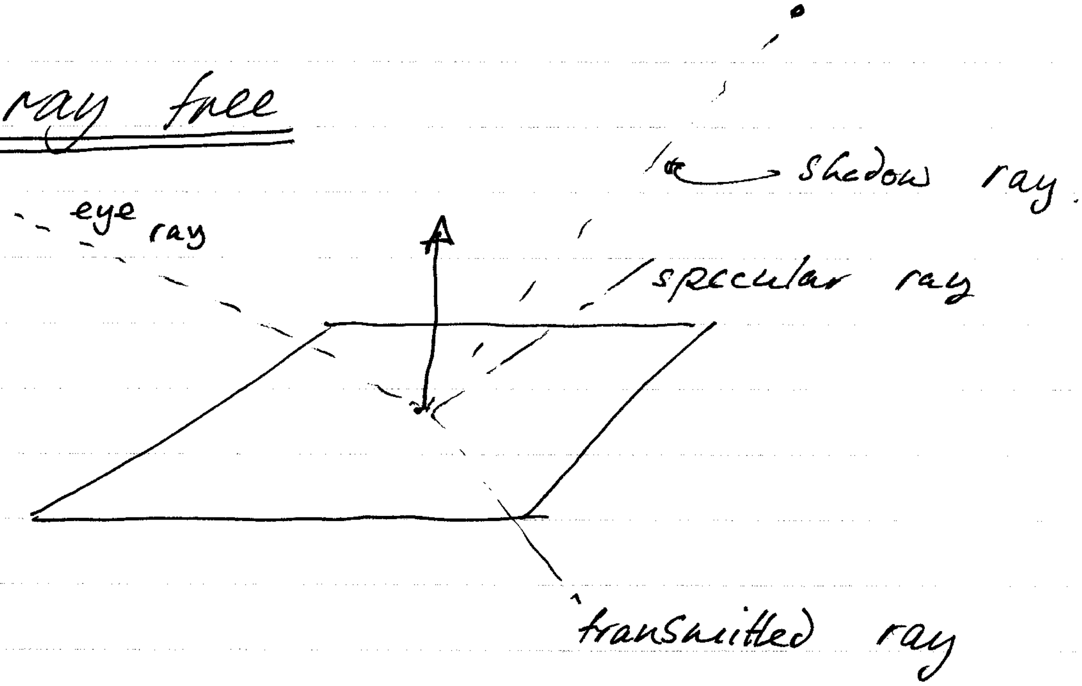
  i.e. $\underline{a} \cdot (\underline{p} + t\underline{v}) + c = 0$

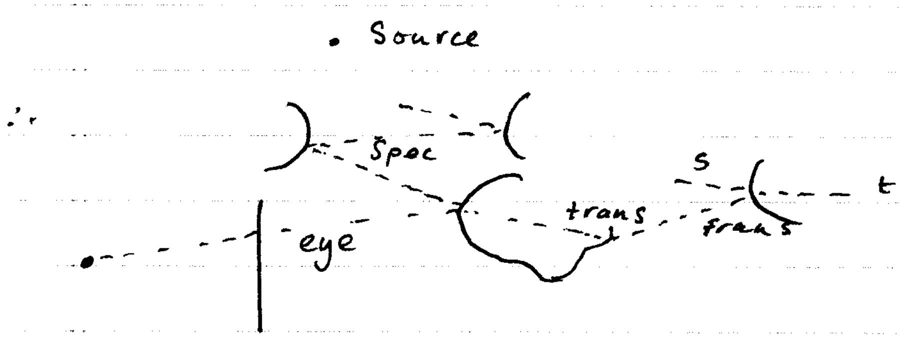
Triangles :

- we could intersect with the plane
  → but does the point lie inside the triangle?

- Test:
  - attach 3 planes to each triangle
  - each contains 1 edge
  - sign test

The ray tree





etc

Shading:

$$\rho_D \sum_{\left[\substack{\text{sources}\\ \text{patch}\\ \text{can}\\ \text{see}}\right]} \left\{ I_s \cos\theta_s \right\} + \rho_s \left[\begin{matrix}\text{Intensity in}\\ \text{specular}\\ \text{dirn}\end{matrix} \right]$$

$$+ \rho_t \left[\begin{matrix}\text{Intensity in}\\ \text{transmitted dir}\end{matrix} \right]$$

Shading in color

- All intensities in R, G, B
- All albedoes "

Pruning the ray tree

- depth
    - easy, efficient
    - usually OK
    - Bad with multiple spec, transmitted
- Accumulated Albedo
    - can go very deep
    -

Normals

- Sphere:

$$(\underline{x}-\underline{c})^T(\underline{x}-\underline{c}) = r^2$$

$\underline{p}$ is point on sphere

$\dfrac{\underline{p}-\underline{c}}{\|\underline{p}-\underline{c}\|}$ is unit normal

- Plane:

$$\underline{a}^T\underline{x} + c = 0$$

Normal: $\dfrac{\underline{a}}{\|\underline{a}\|}$