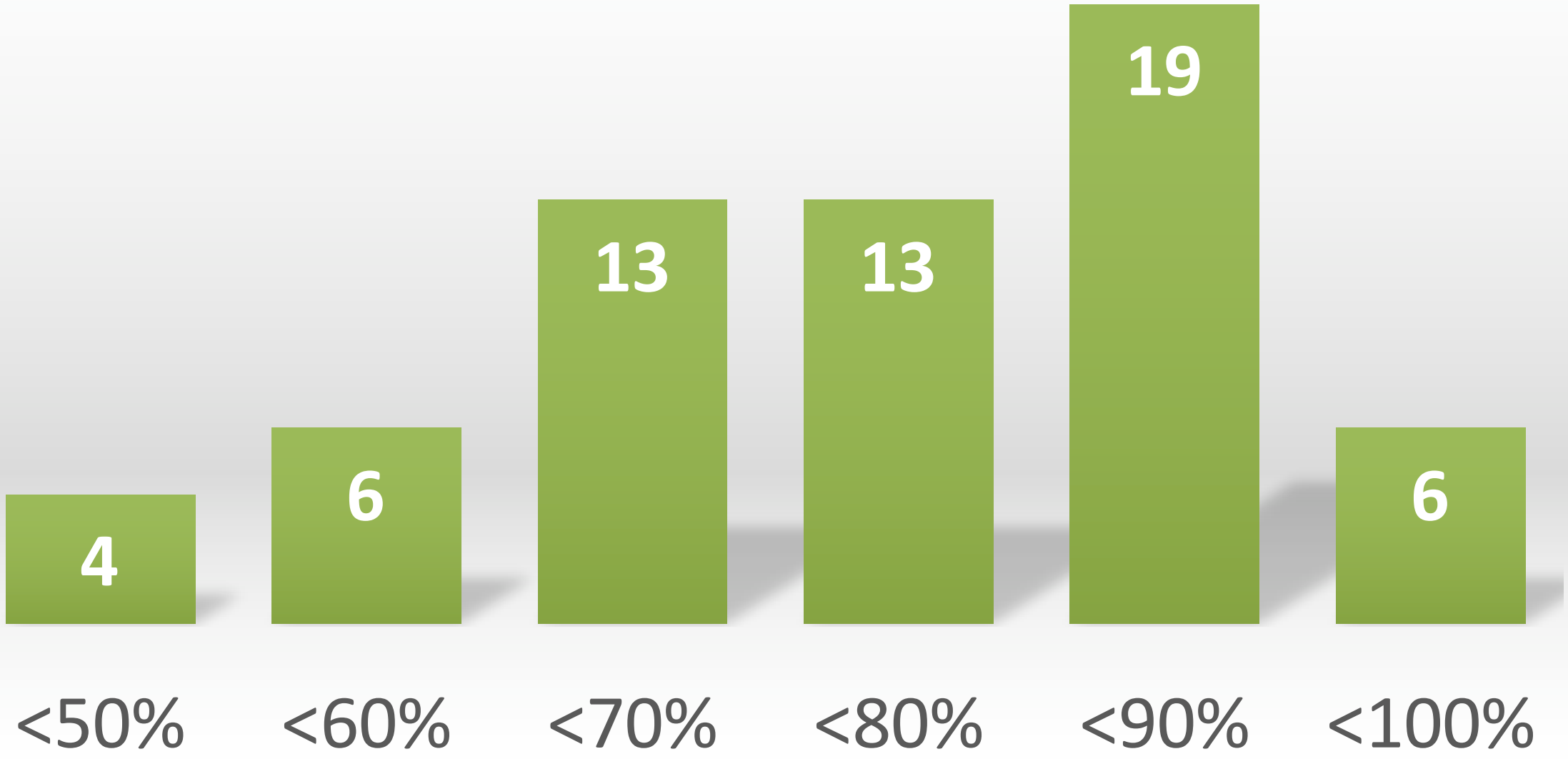
Midterm 2



MIDTERM 2 ANALYSIS

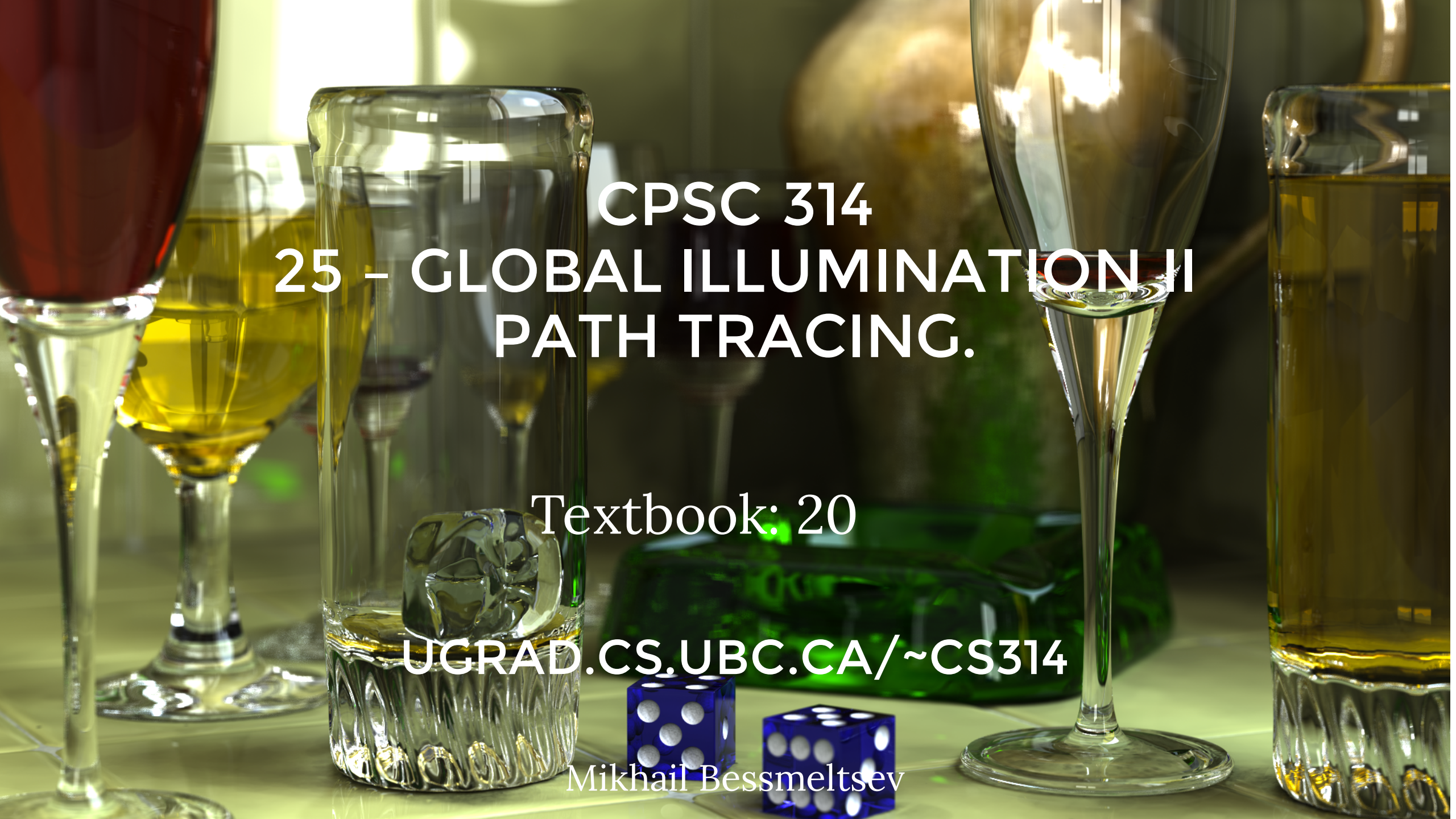
- (Whiteboard)

PROGRAMMING A4 OUT TODAY

- Ray Tracing
  - **C++**
    - In Javascript it would be VERY slow and hard to debug
  - Don't get stuck, ask for help
  - If you are unfamiliar with C++, post it on Piazza, we & others will help

  - Due in two weeks

- OR Path Tracing
  - For those who are brave to explore
  - To boldly go where no man has gone before ©
  - Harder to get the core working, but easier to get creative part + bonus



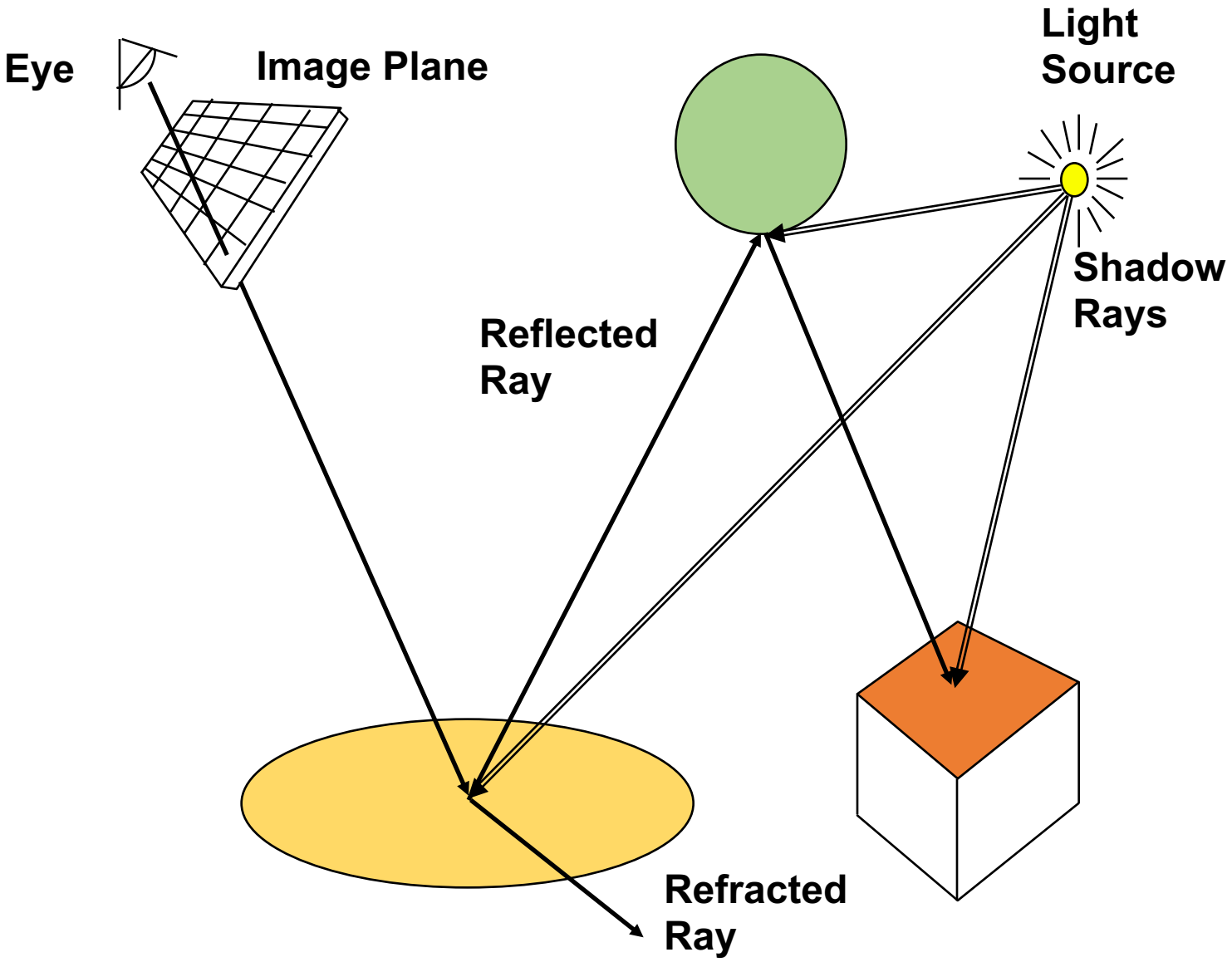
CPSC 314
25 – GLOBAL ILLUMINATION II
PATH TRACING.

Textbook: 20

UGRAD.CS.UBC.CA/~CS314

Mikhail Bessmeltsev

RAY TRACING: PROBLEM?



RAY TRACING LIMITATION

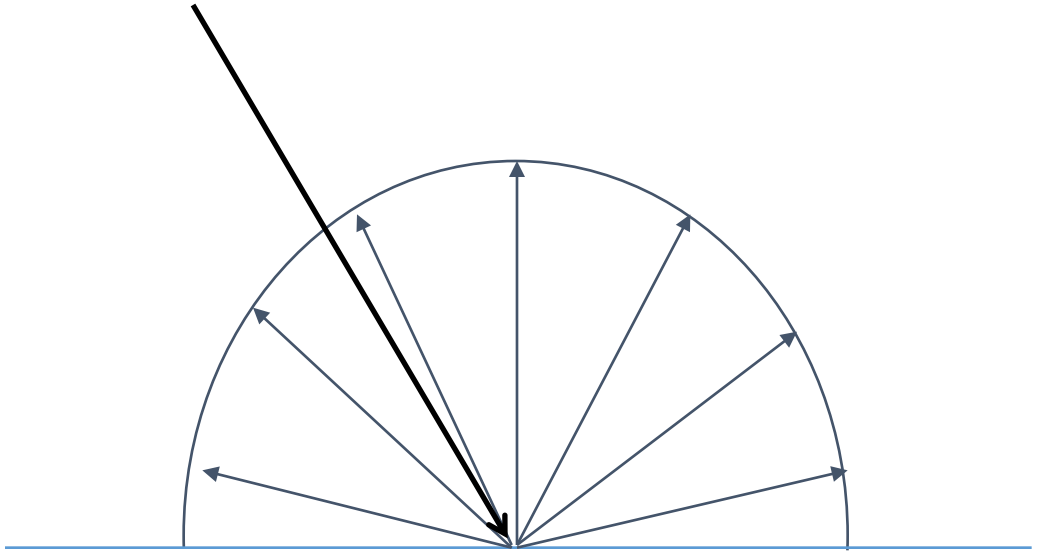
- Only specular reflections consider other objects
  - Well okay, refractions too
- Diffuse and glossy surfaces will only reflect light source!
- We're using Lambert and Phong models of **direct illumination**
- How can we model diffuse/glossy models in a similar way?

IDEA

- Every object is a light source!

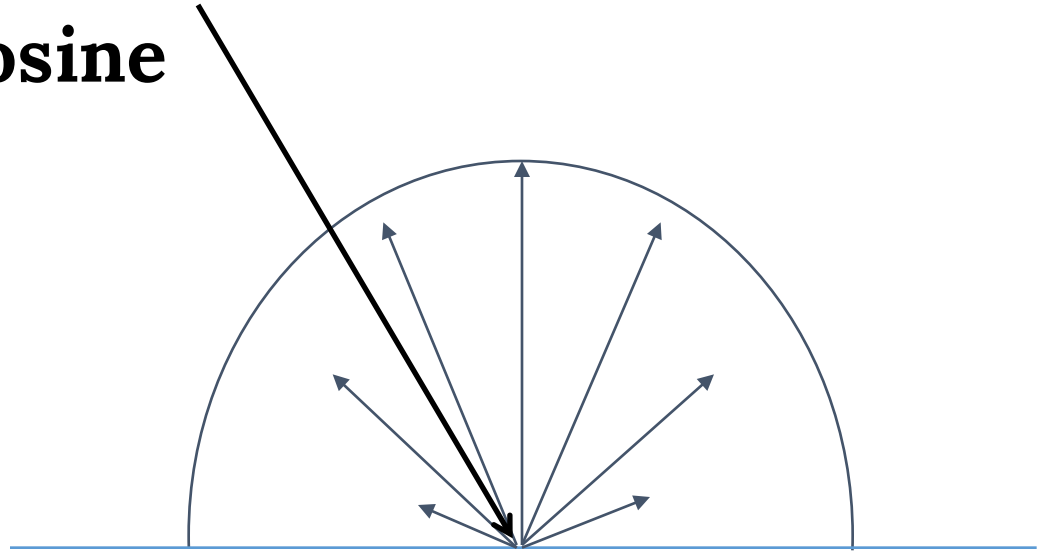
WHAT REALLY HAPPENS AT DIFFUSE SURFACE?

- Imagine a single photon hitting a diffuse surface
- It can't "scatter", it has to go somewhere
- Goes into a random direction
- Uniform distribution



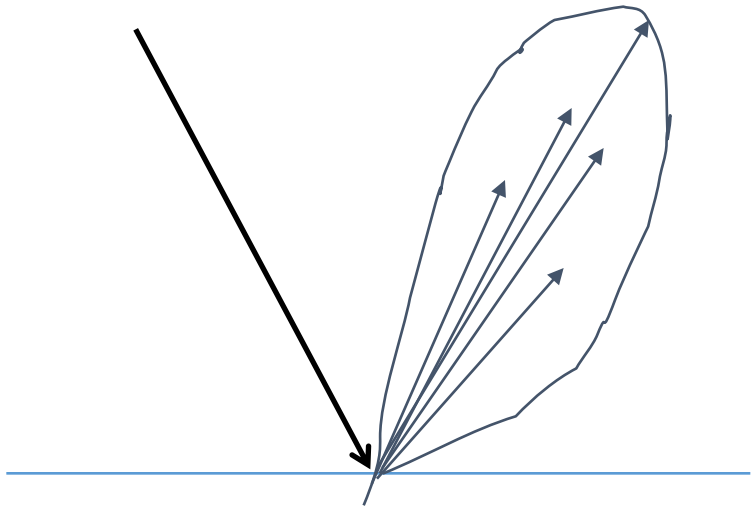
WHAT REALLY HAPPENS AT DIFFUSE SURFACE?

- Imagine a single photon hitting a diffuse surface
- It can't "scatter", it has to go somewhere
- Goes into a random direction
- Uniform distribution
- **Energy ~ cosine**

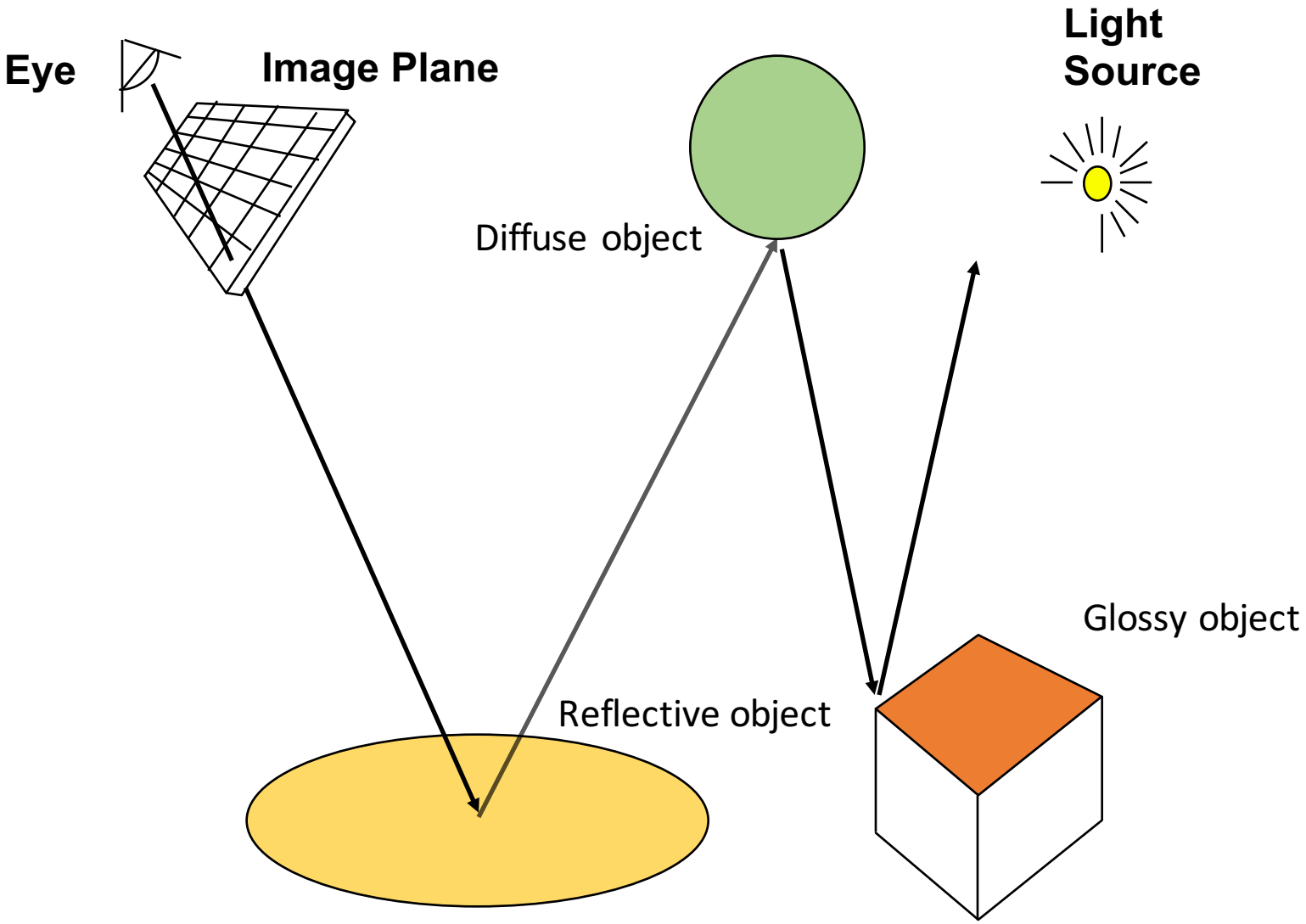


WHAT HAPPENS AT GLOSSY SURFACE?

- Goes most probably along the perfect reflection
- With a smaller probability deviates
- Gaussian distribution



PATH TRACING FRAMEWORK



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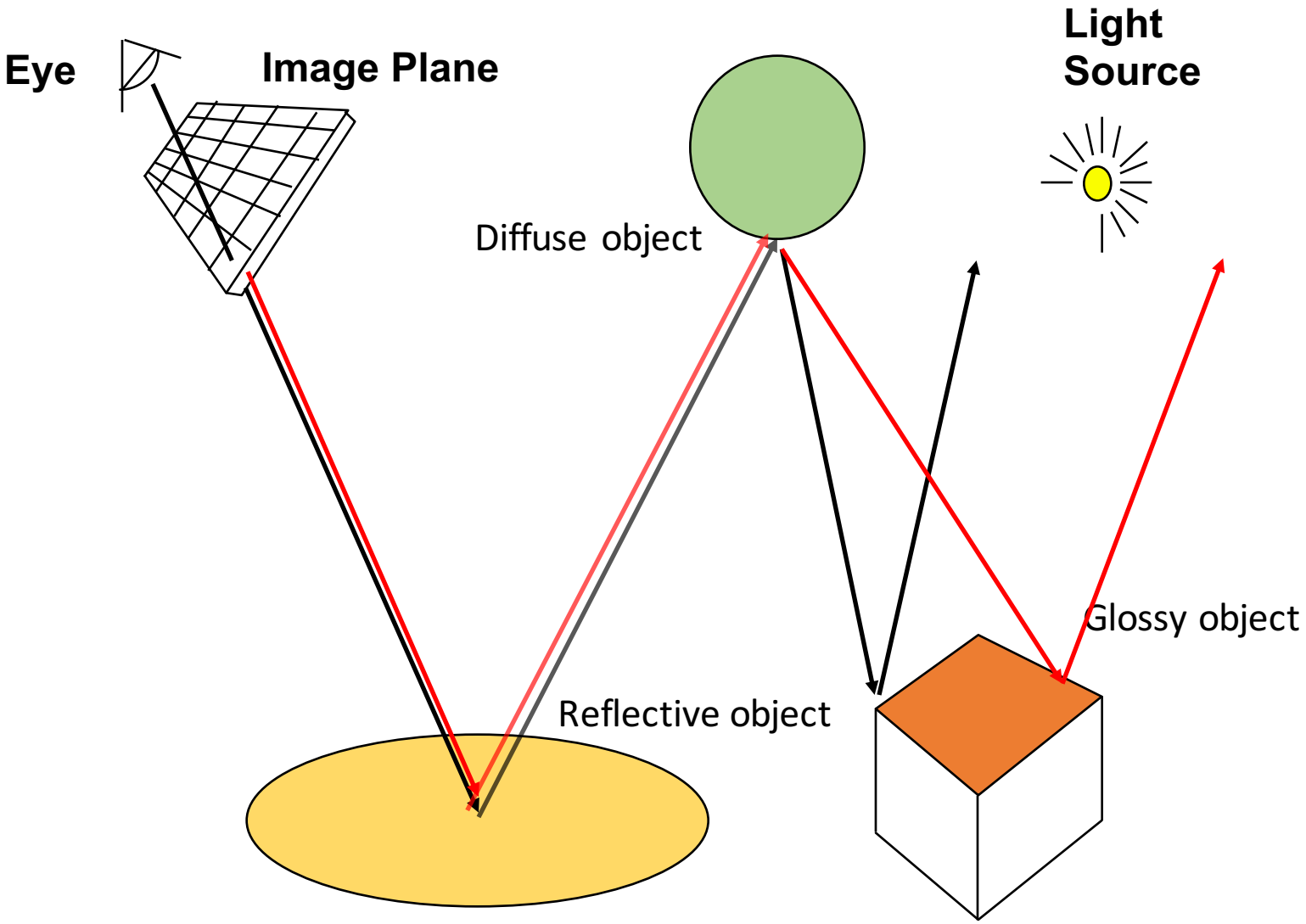

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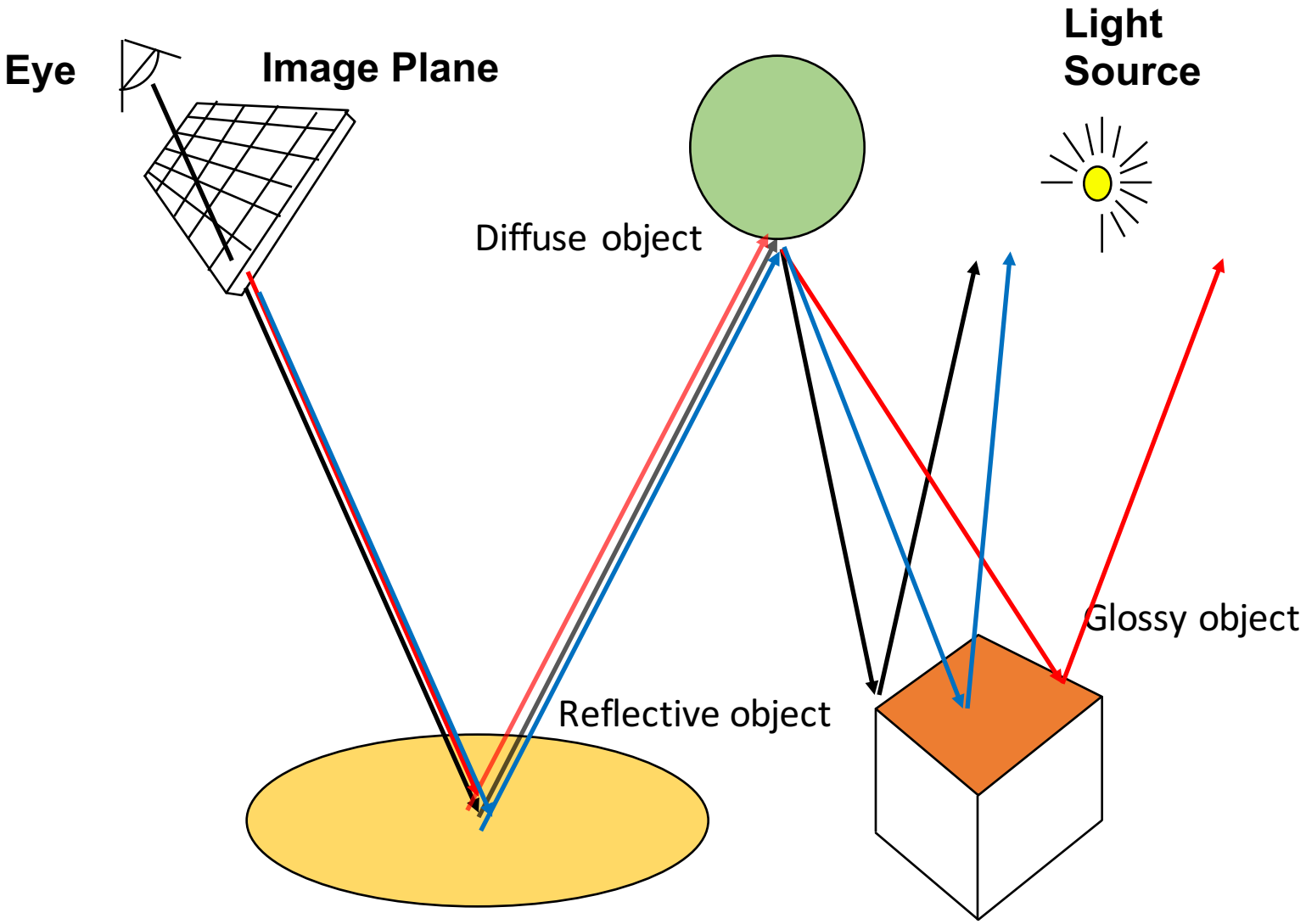

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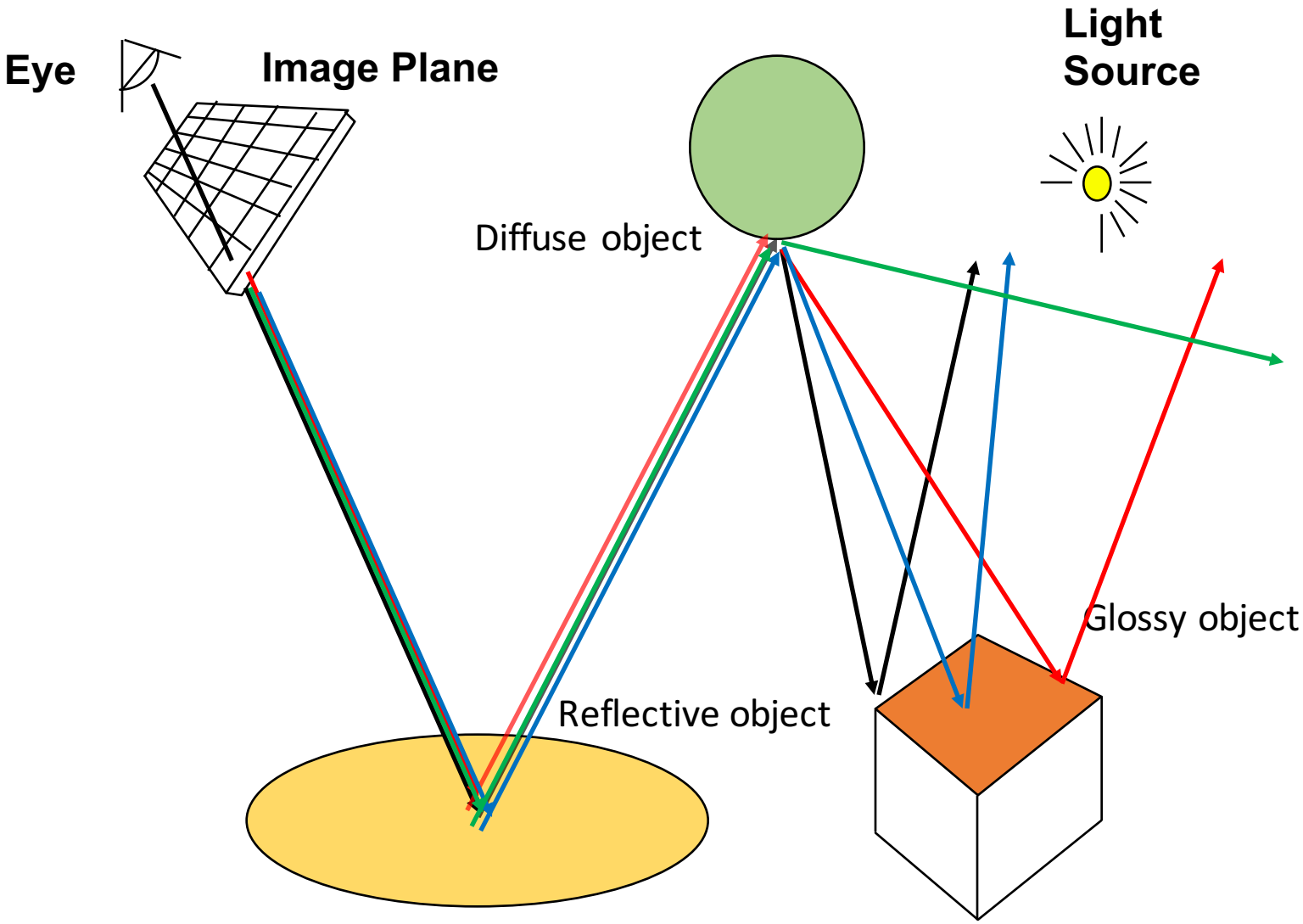


PATH TRACING ALGORITHM

1. Shoot a ray though pixel (i,j). Set *attenuation* to 1.0.
2. Find the closest intersection of the ray with an object
3. Randomly choose between "*emission*" and "*reflection*"
   a. If "emission", return **emissionColor;**
   b. If "reflection",

      Reflect a ray in a random direction
      rayWeight *= reflectance;
      Go to 2.

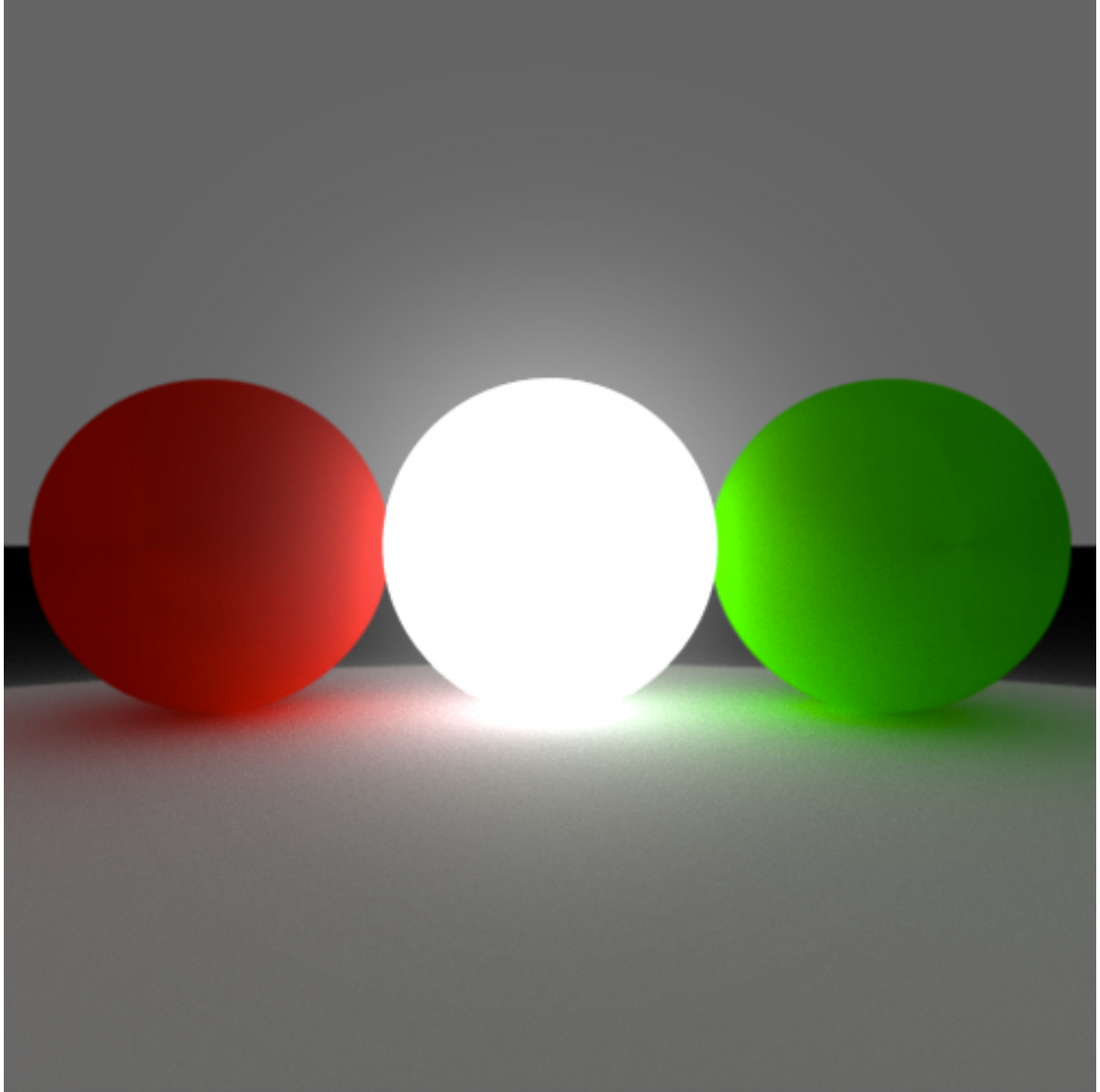
SIMPLEST PATH TRACER

- For all pixels (i,j):
  - Ray r = generateRay (i,j);
  - For k=1,…,N:
    - PixelColor(i,j) += pathTrace(r)/N;

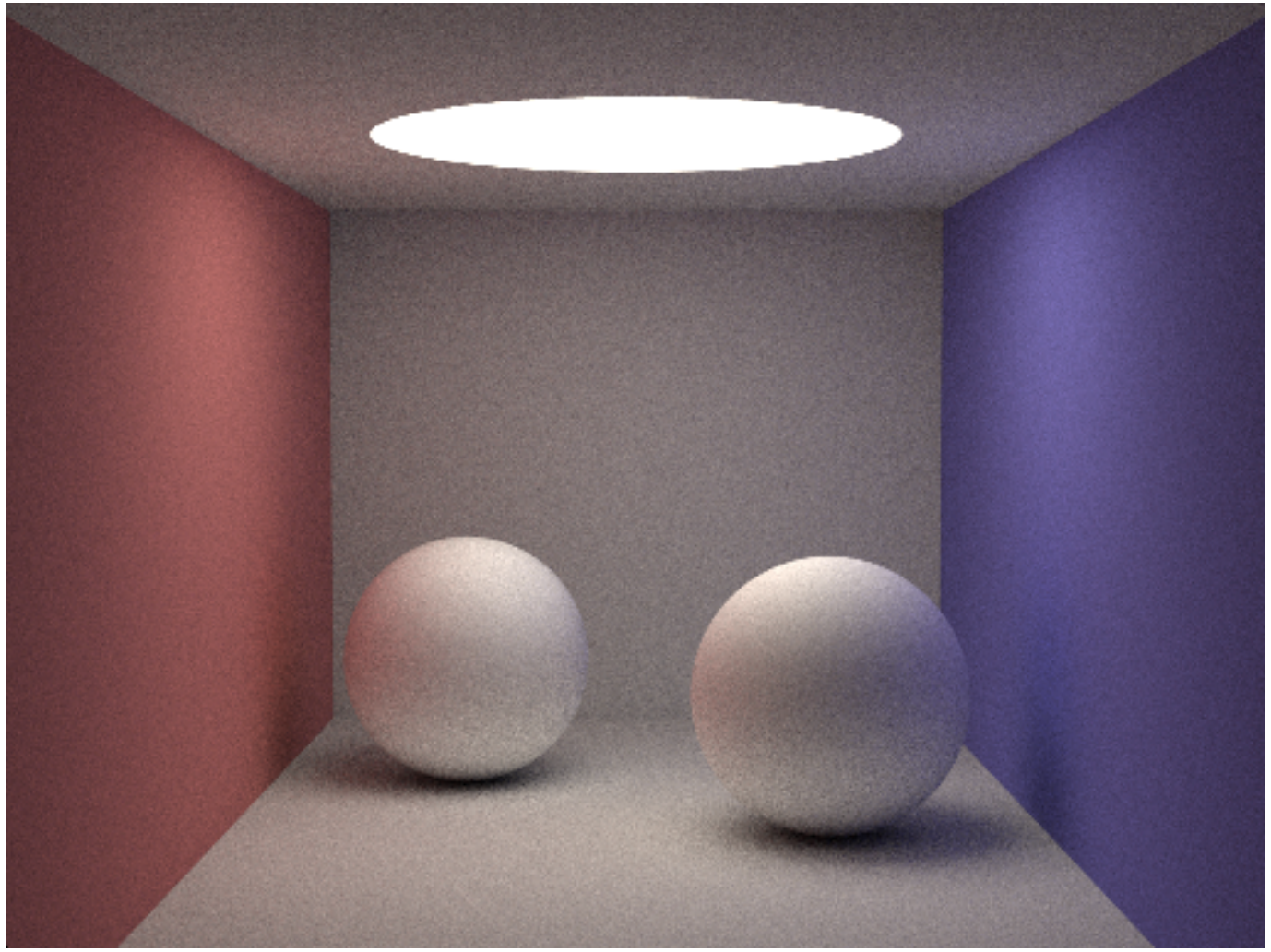
SIMPLEST PATH TRACER

```
PathTrace(Ray r) {
P = closestIntersection(r);
if (random(emit, reflect) == emit)
return EmissionColor;
else {
Ray v = {intersectionPt,
randomDirectionInHemisphere(r.normalWhereObjWasHit)};
double cos_theta = dot(v.direction, r.normalWhereObjWasHit);
return PathTrace(v)*cos_theta*reflectance;
}
}
```

EXAMPLE



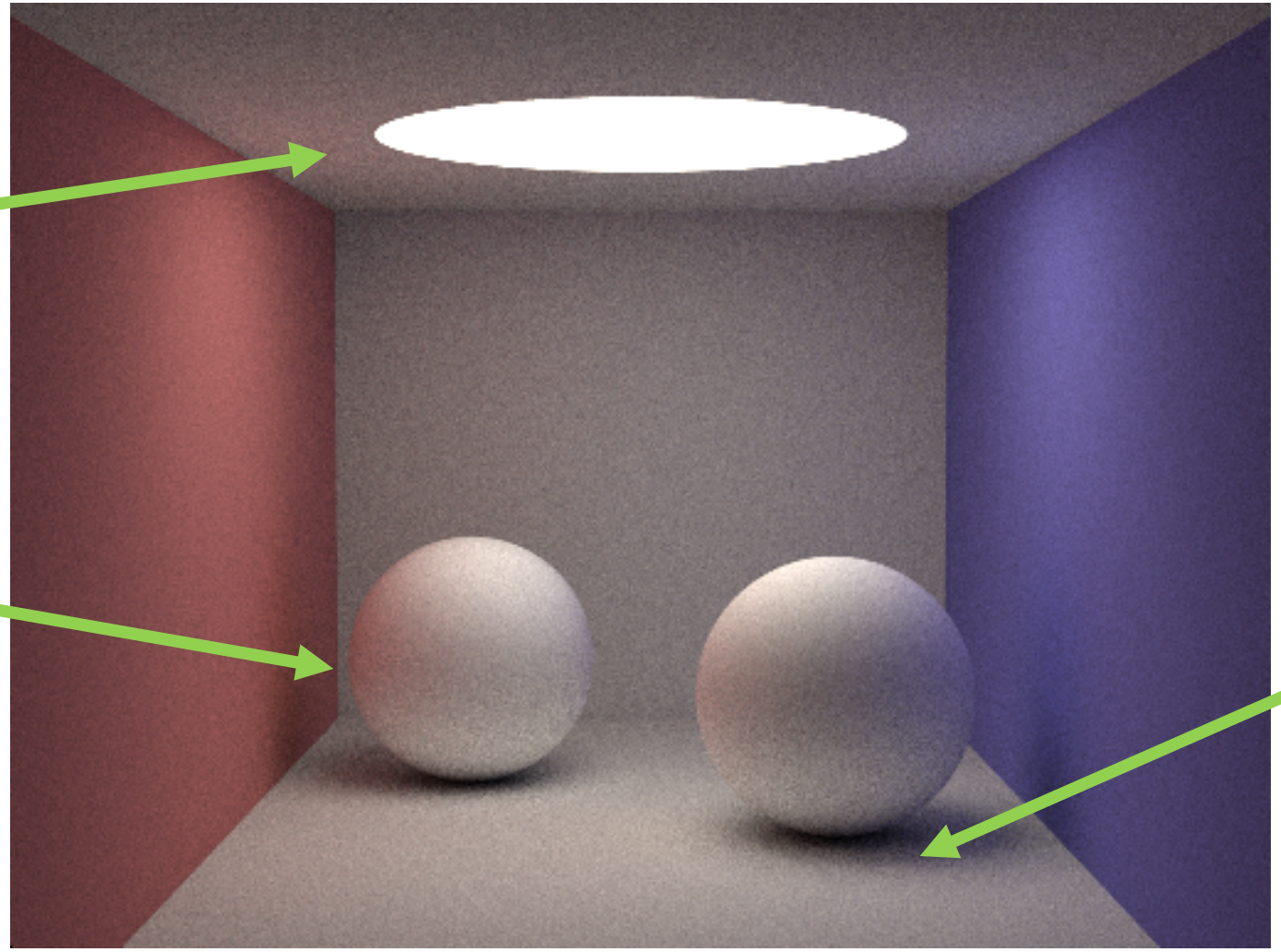
WHAT YOU GET



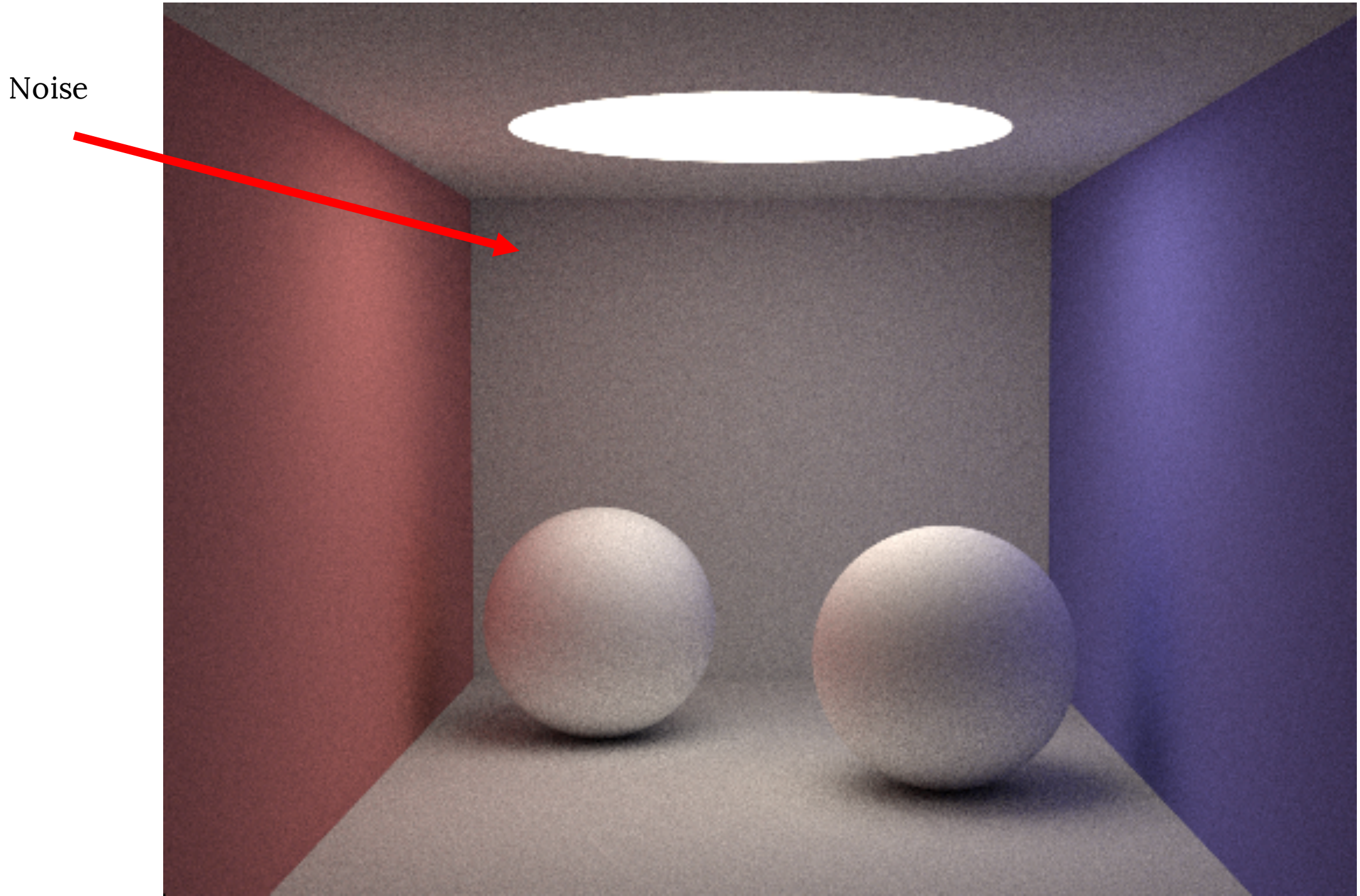
WHAT YOU GET

Area light

Reflections from diffuse objects 'color bleeding'



Soft shadows


Noise

MONTE CARLO METHODS

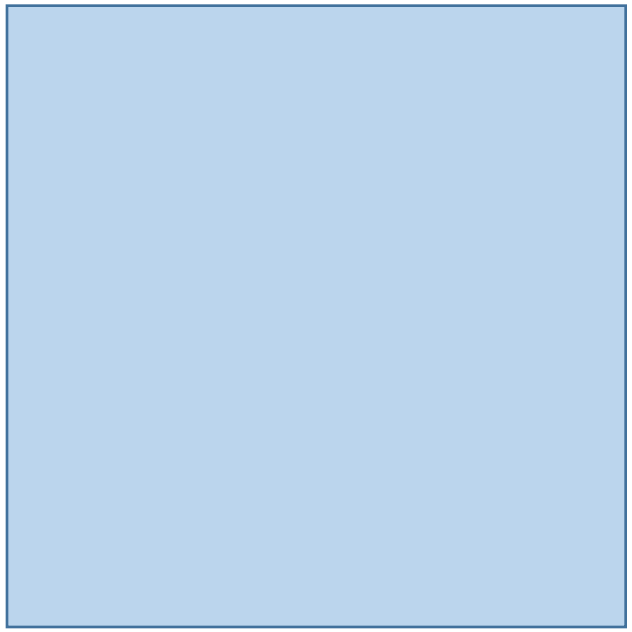
- General idea: compute something using random sampling
- Used for computing integrals of complex functions
- E.g. areas or volumes
  - If it's hard to compute analytically
  - But easy to test if a point is inside
- If we throw enough random samples, by the law of large numbers, mean ~ empirical mean

GENERATING RANDOM POINTS

- We usually have a single function random();
- That generates a random number from 0 to 1
- Uniform distribution

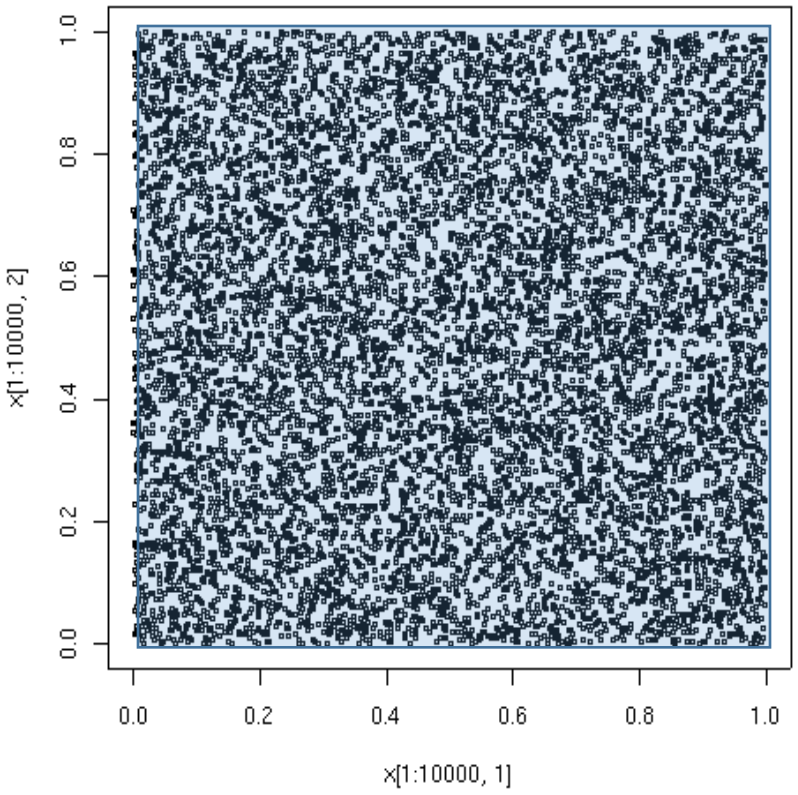
GENERATING RANDOM POINTS

- How to generate random points in a unit square?



GENERATING RANDOM POINTS

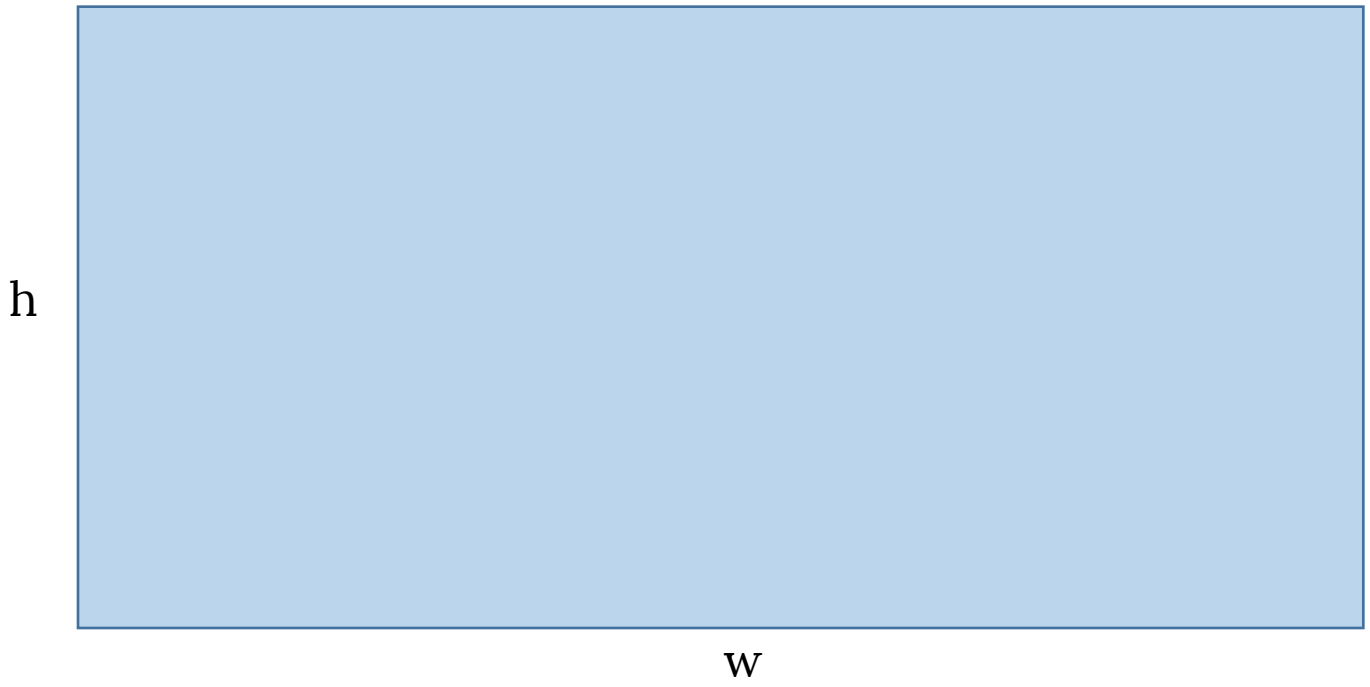
- How to generate random points in a unit square?




```
for (i=0…N)
{
    x = rand();
    y = rand();
}
```

GENERATING RANDOM POINTS

- How to generate random points in a rectangle?



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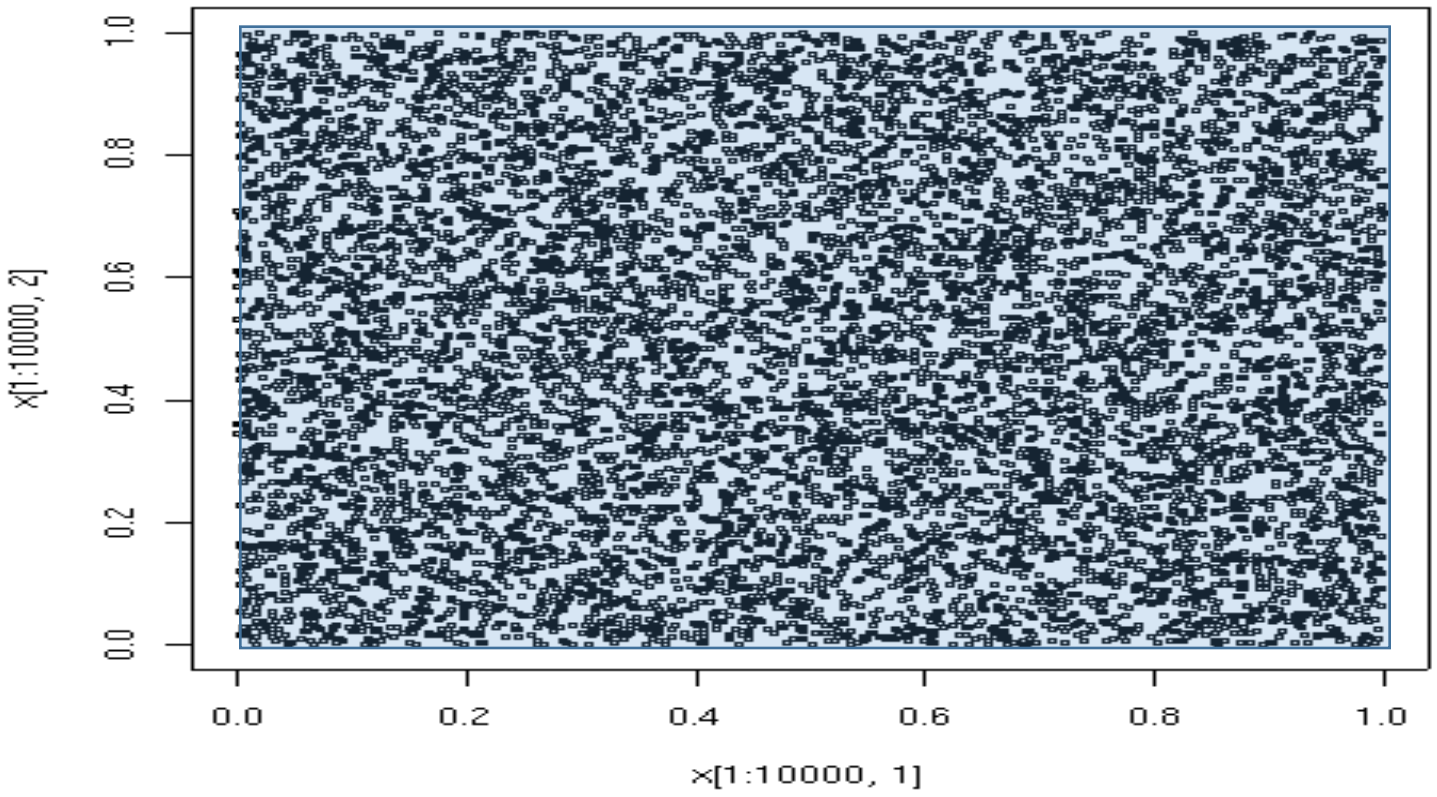
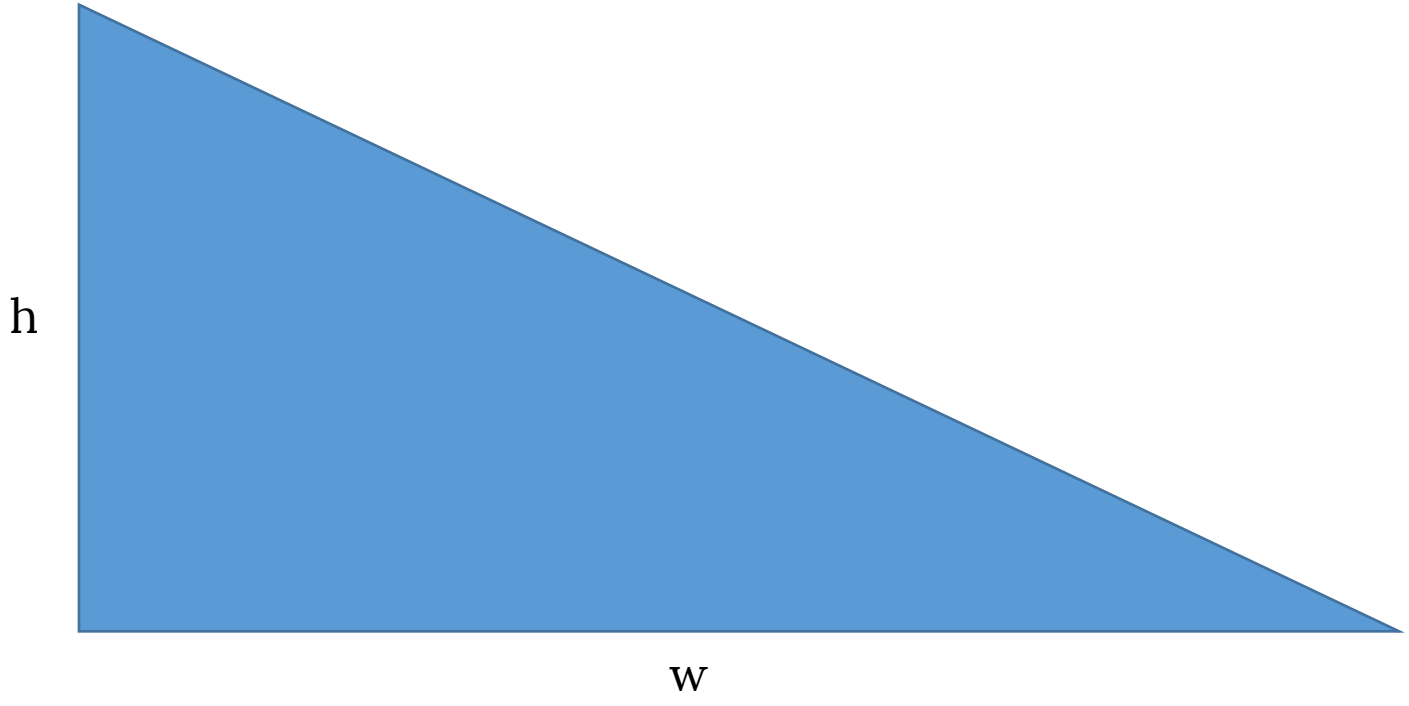



```
for (i=0…N)
{
    x = w*rand();
    y = h*rand();
}
```

GENERATING RANDOM POINTS

- In a right triangle?



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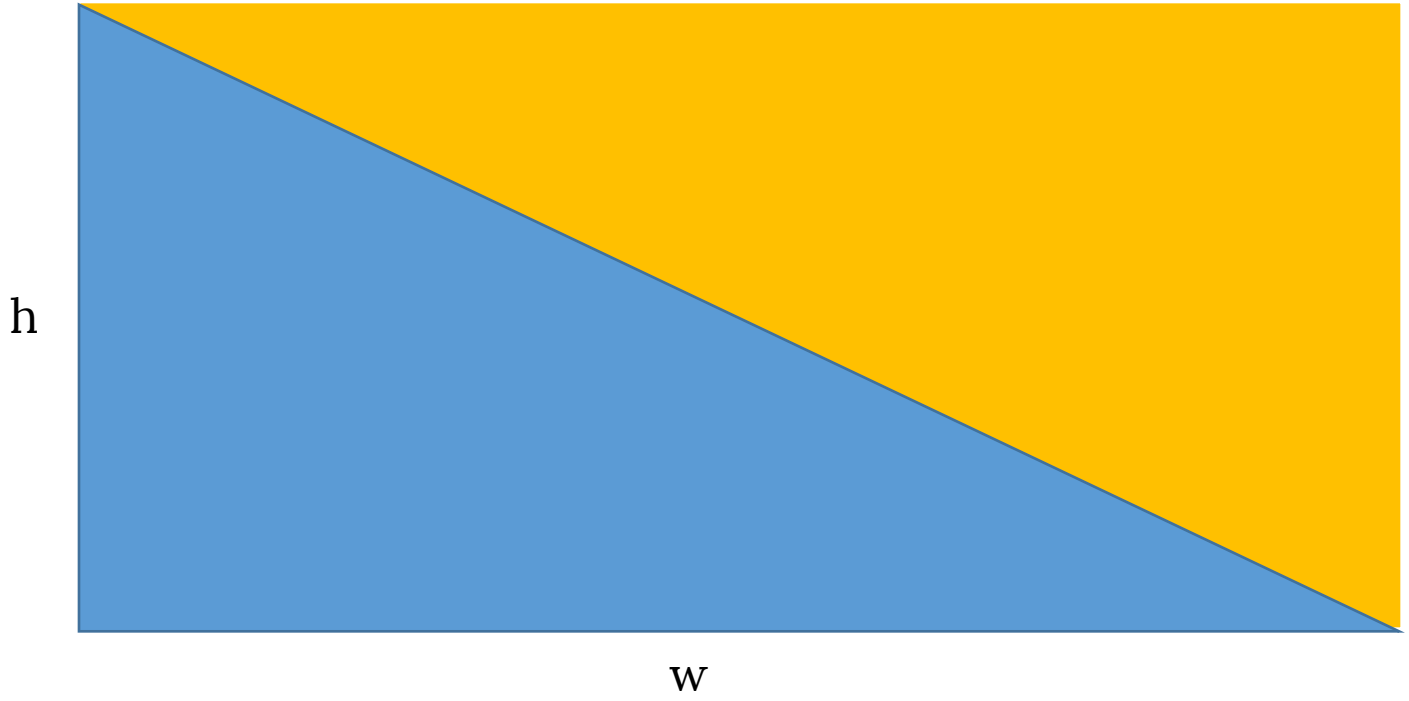

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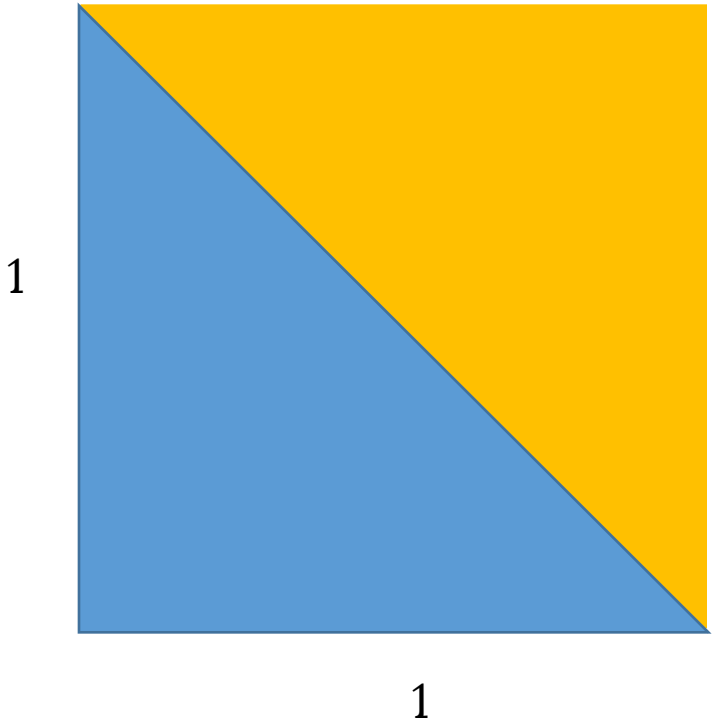

GENERATING RANDOM POINTS

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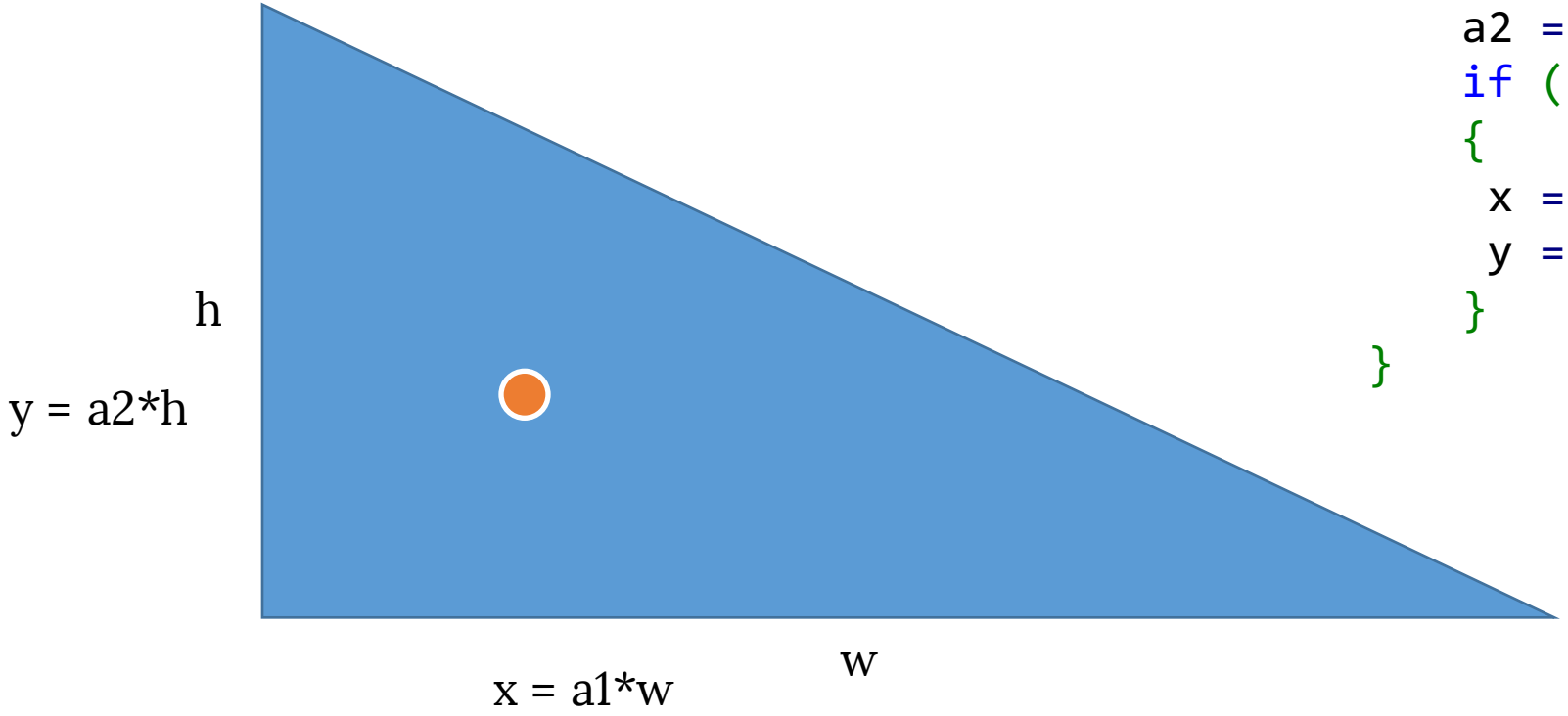
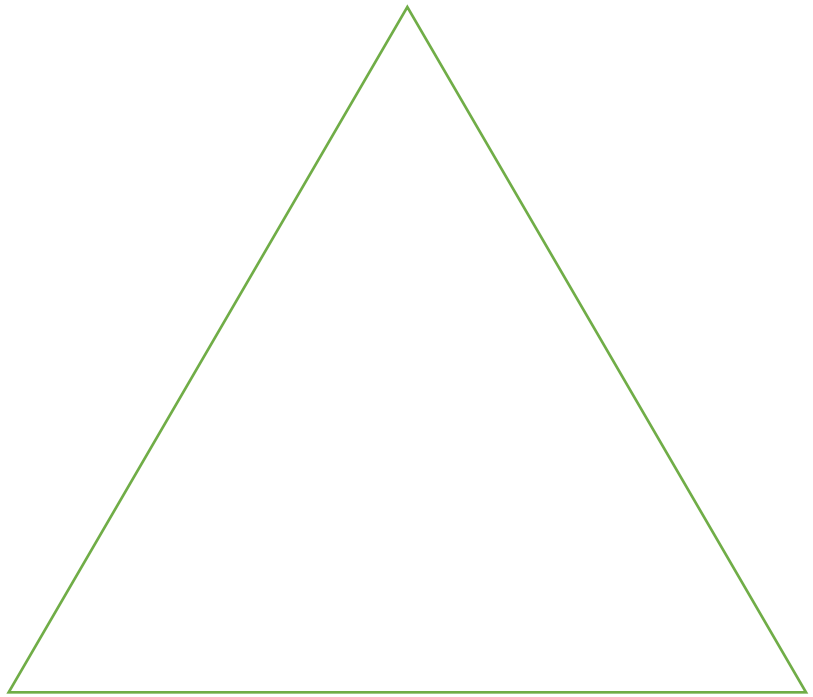



```
for (i=0…N)
{
    a1 = rand();
    a2 = rand();
    if (a1+a2<1)
    {
     x = a1*w;
     y = a2*h;
    }
}
```

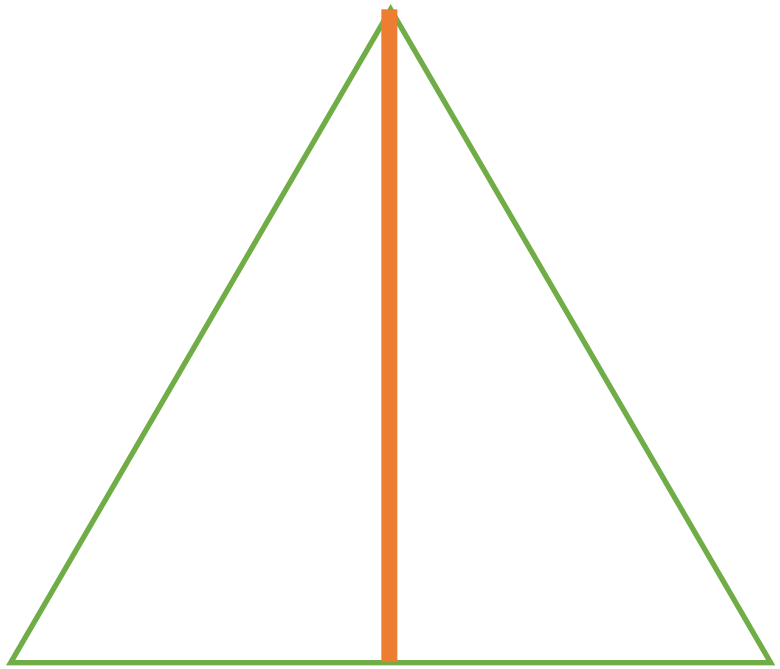
GENERATING RANDOM POINTS

- In an arbitrary triangle?



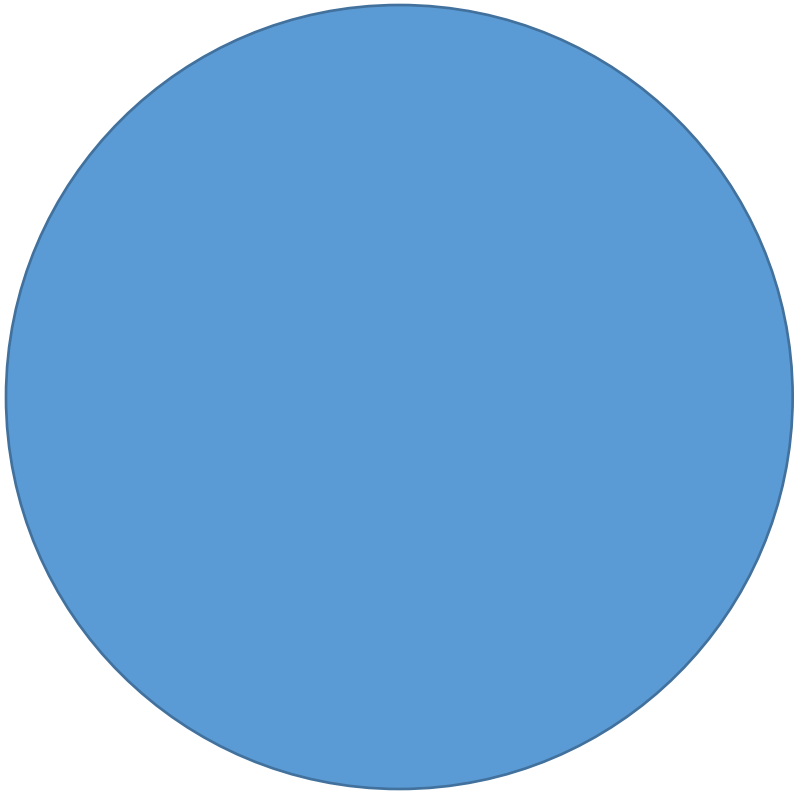
GENERATING RANDOM POINTS

- In an arbitrary triangle?



GENERATING RANDOM POINTS

- In a circle?



REJECTION SAMPLING

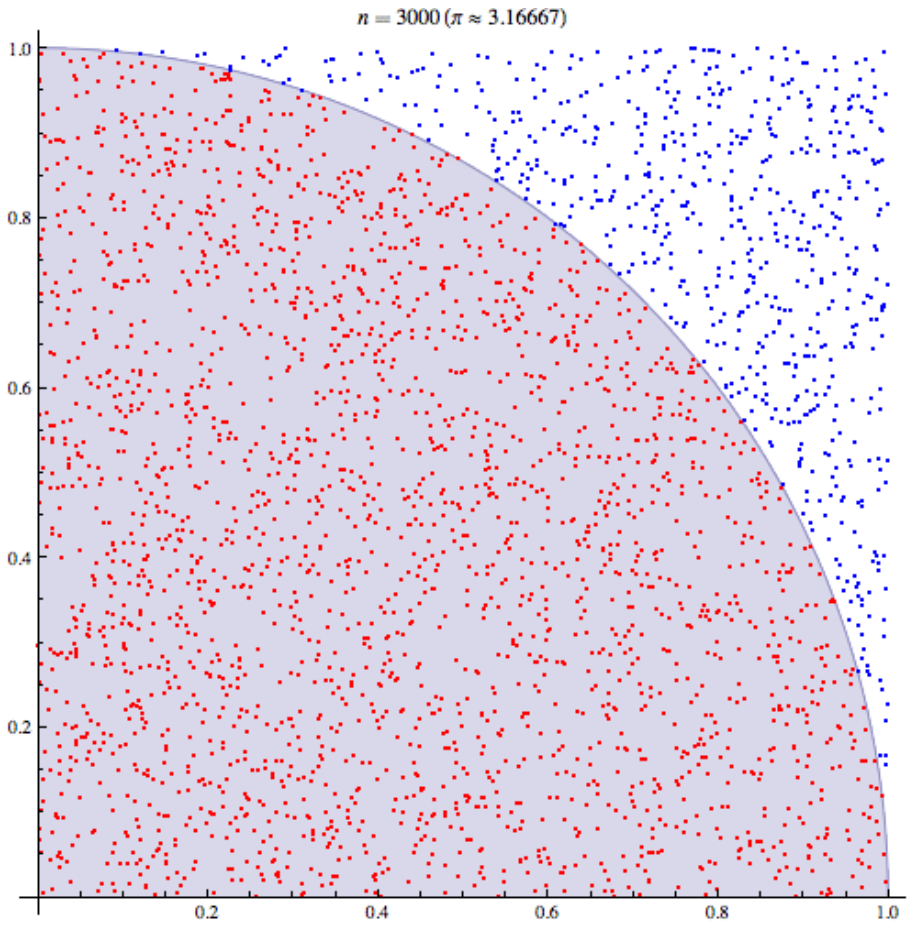
- Say you have a complicated shape, and you want to generate points uniformly in it

- One elegant way is rejection sampling:
  - Generate a point evenly in the bounding box
  - If it's not inside our shape, discard

- How many points will be rejected (ratio)?

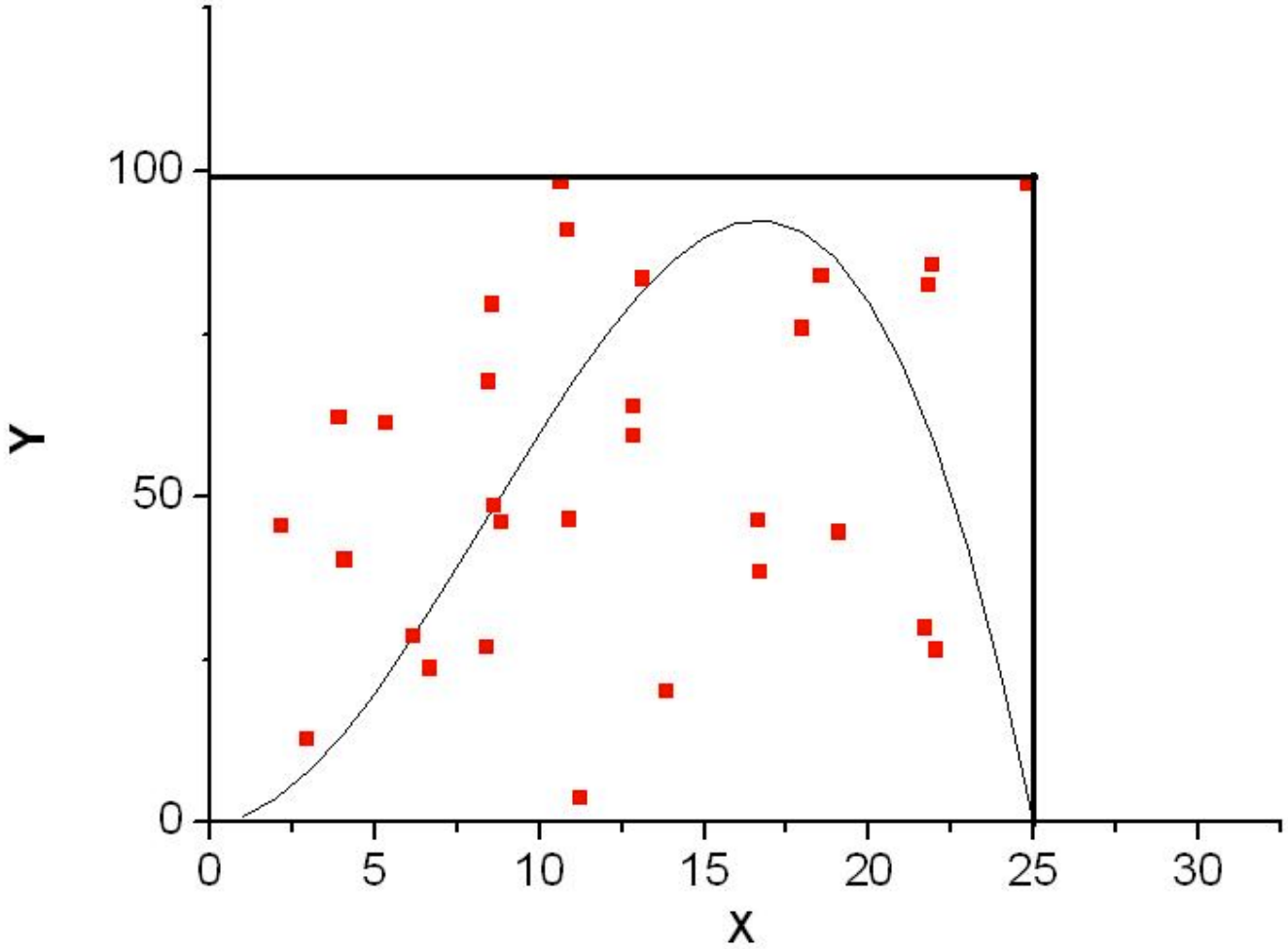
MONTE CARLO METHODS

- Example: approximating π:



MONTE CARLO METHODS

- Example: computing a weird integral



"Pi 30K" by CaitlinJo - Ow via Commons - https://commons.wikimedia.org/wiki/File:Pi_30K.gif#/media/File:Pi_30K.gif

MONTE-CARLO: RAY TRACING

- Now in RAY tracing, we can generate rays randomly from an area light source
- Instead of shooting a single shadow ray,
  - Generate many randomly towards a light source
    - Generate a point on the light source
    - Shoot a ray towards that point
  - Average their contribution

- Soft shadows in RAY tracing!

SIMPLEST PATH TRACER

```
PathTrace(Ray r) {
P = closestIntersection(r);
if (random(emit, reflect) == emit)
return EmissionColor;
else {
Ray v = {intersectionPt,
randomDirectionInHemisphere(r.normalWhereObjWasHit)};
double cos_theta = dot(v.direction, r.normalWhereObjWasHit);
return PathTrace(v)*cos_theta*reflectance;
}
}
```

HOW TO CHOOSE BETWEEN 3 ACTIONS?

1. “Go to 314 lecture”, P = 0.4
2. “Go have lunch instead”, P = 0.5
3. “Sleep in”, P = 0.1

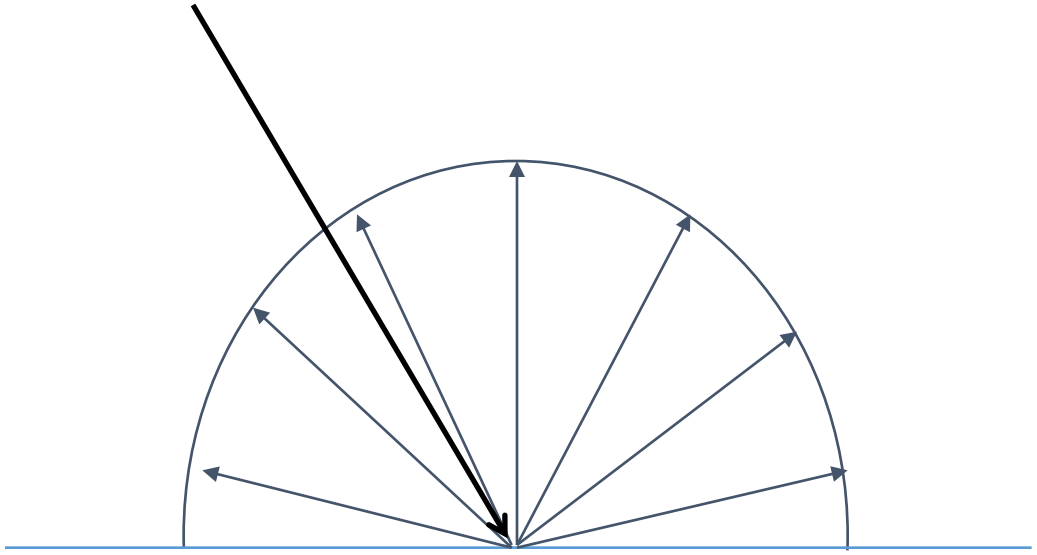
HOW TO CHOOSE BETWEEN 3 ACTIONS?

1. "Go to 314 lecture", P = 0.4
2. "Go have lunch instead", P = 0.5
3. "Sleep in", P = 0.1

```
x = random();
if (x < 0.4)
 return 1;
else if (x < 0.9)
 return 2;
else
 return 3;
```

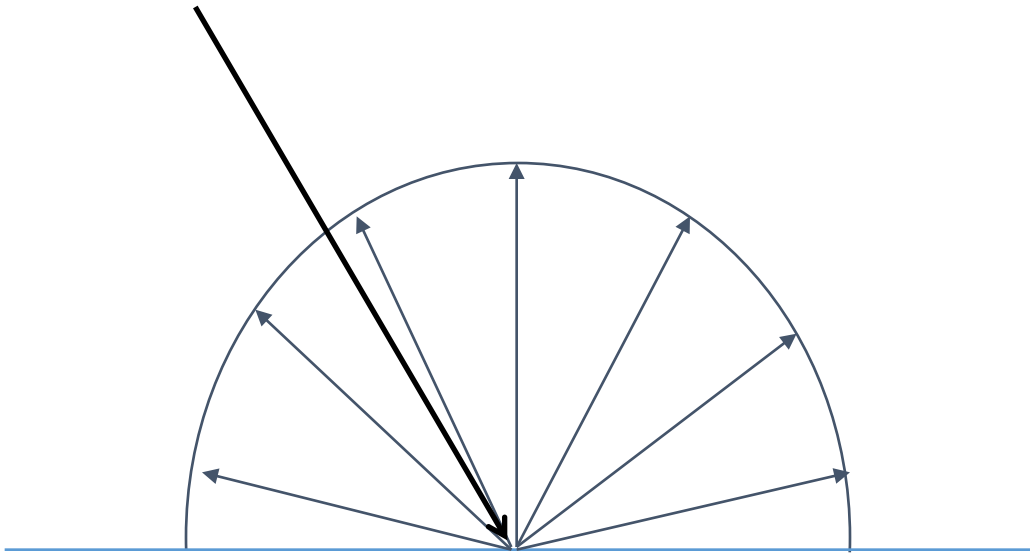
HOW TO GENERATE A DIRECTION IN HEMISPHERE?

- Evenly?



HOW TO GENERATE A DIRECTION IN HEMISPHERE?

- Evenly?
- Option 1:
  - $\phi = random(1.0);$
  - $\theta = random(1.0);$
  - $dir = \begin{pmatrix} \cos(\theta)\sin(\phi) \\ \sin(\theta)\sin(\phi) \\ \cos(\theta) \end{pmatrix}$



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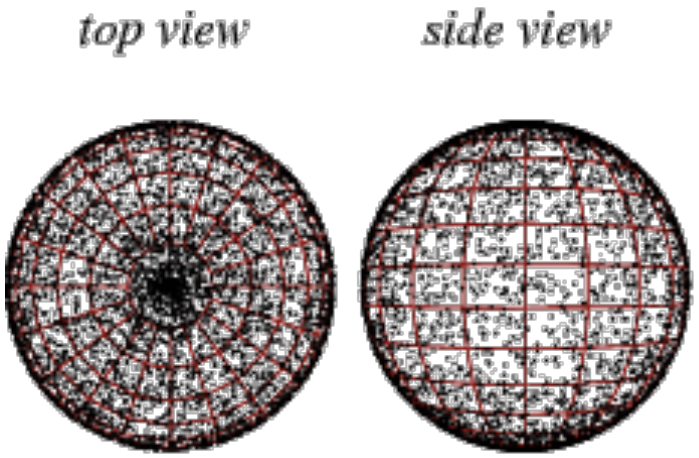
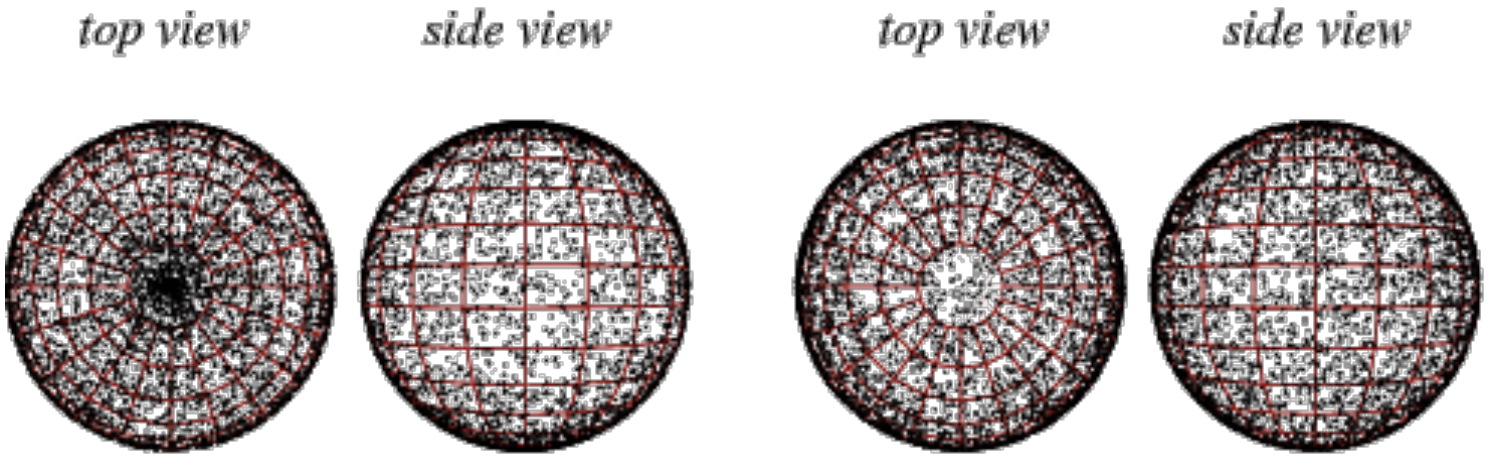


incorrectly distributed points

- It's not an even distribution!

HOW TO GENERATE A DIRECTION IN HEMISPHERE?

- Evenly?
- ~~Option 1:~~
  - ~~$\phi = random(1.0);$~~
  - ~~$\theta = random(1.0);$~~
  - ~~$dir = \begin{pmatrix} \cos(\theta)\sin(\phi) \\ \sin(\theta)\sin(\phi) \\ \cos(\phi) \end{pmatrix}$~~

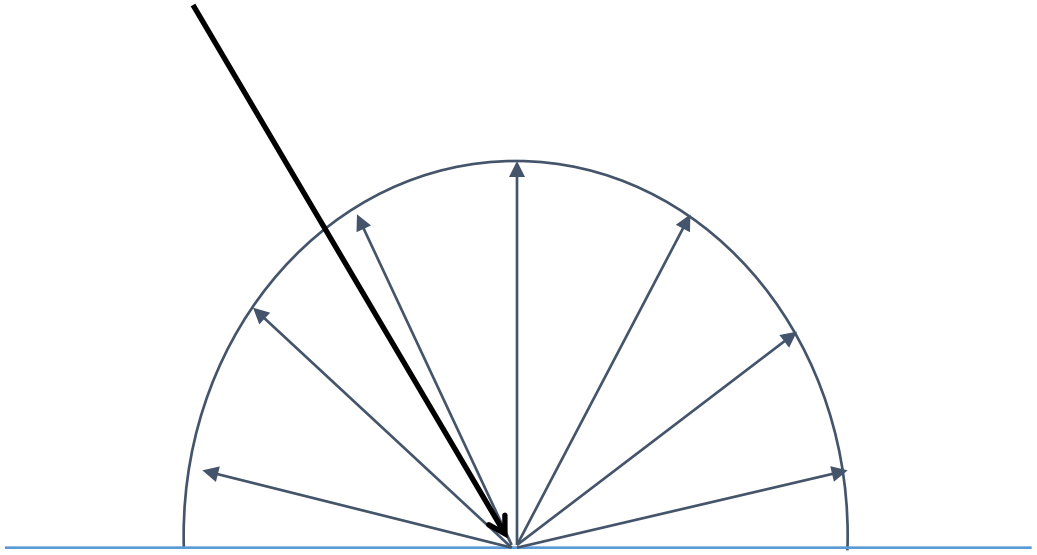


incorrectly distributed points *correctly distributed points*

- Option 2:
  - Generate z evenly
  - Generate θ evenly
  - $dir = \begin{pmatrix} \sqrt{1-z^2} \cdot \cos(\theta) \\ \sqrt{1-z^2} \cdot \sin(\theta) \\ z \end{pmatrix}$

BACK TO PATH TRACING

- Now we know how to reflect a ray randomly when surface is diffuse

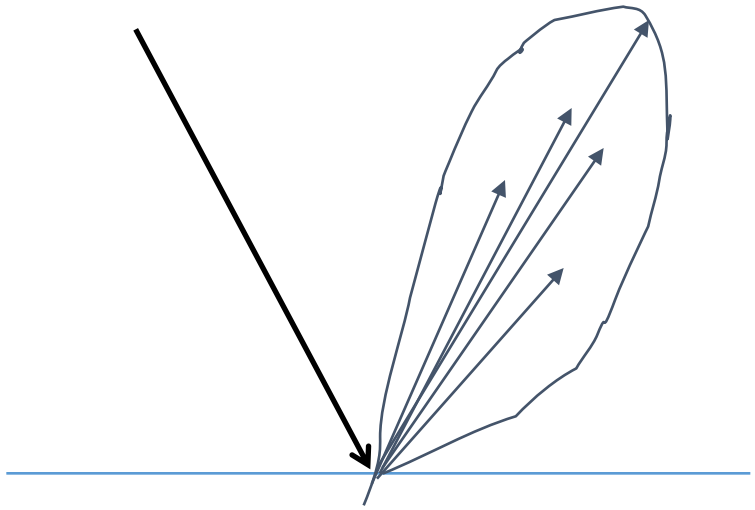


BACK TO PATH TRACING

- And we know how to choose between “emit” and “scatter” events
- We can similarly add “absorb”, “reflect”, “refract”

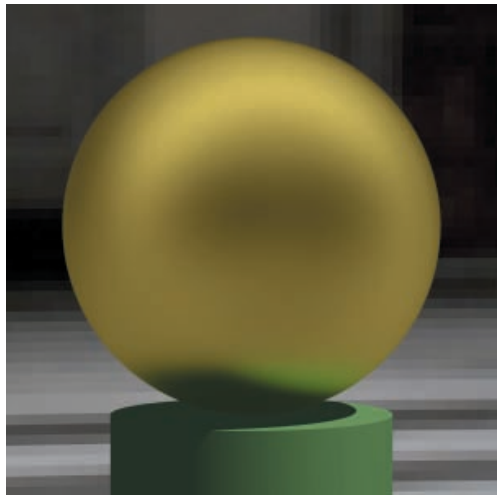
HOW TO GENERATE REFLECTION FOR A GLOSSY SURFACE

- Random direction in hemisphere
- Multiply energy by phong term!
- Details: http://www.raytracegroundup.com/downloads/Chapter25.pdf



HOW TO GENERATE REFLECTION FOR A GLOSSY SURFACE

(a)



(b)

(c)

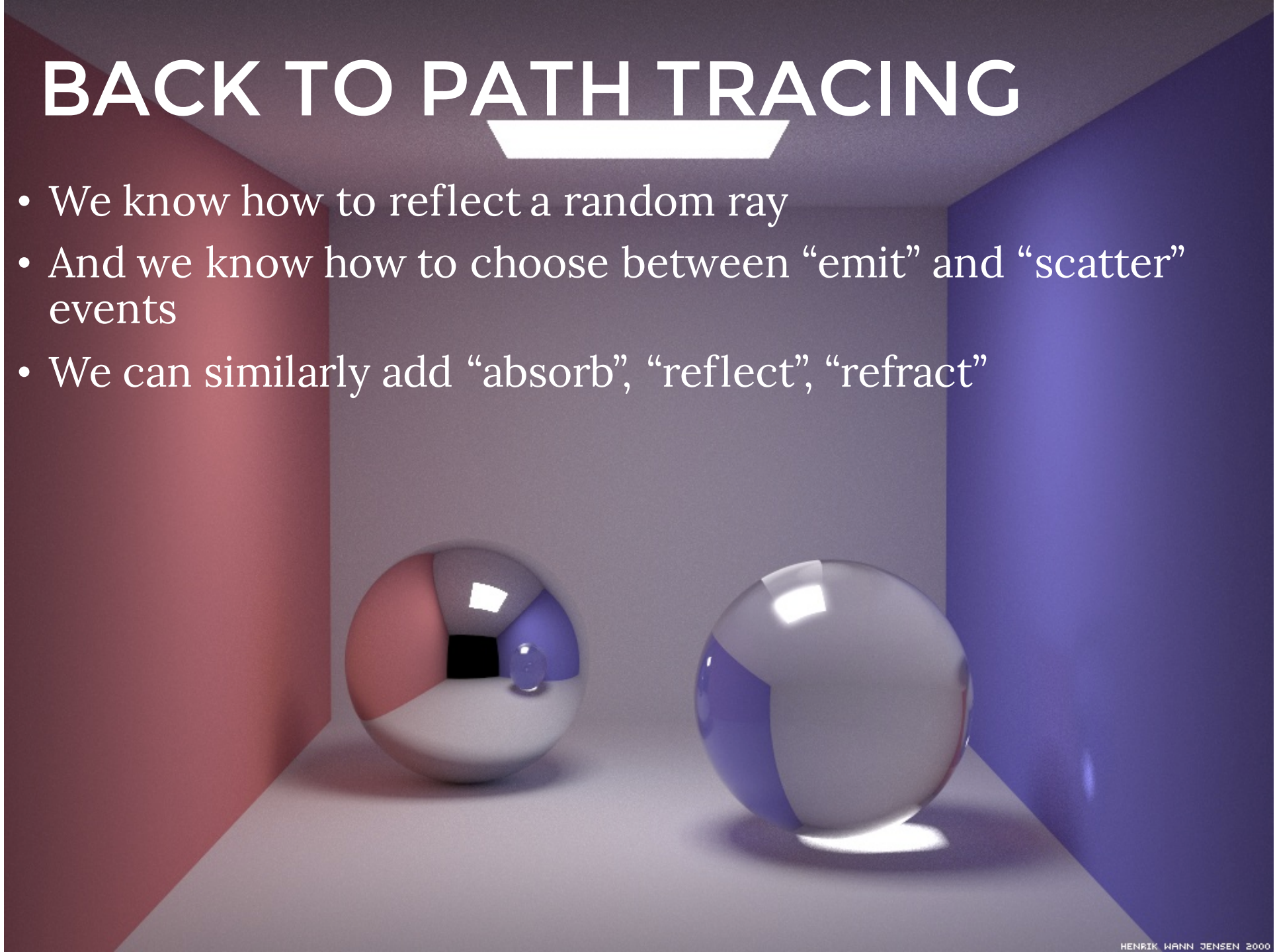
(d)

(e)

(f)

BACK TO PATH TRACING

- We know how to reflect a random ray
- And we know how to choose between “emit” and “scatter” events
- We can similarly add “absorb”, “reflect”, “refract”



RAY TRACING VS PATH TRACING

- Global illumination algorithms
- Rays emitted FROM camera

- Ray Tracing
  - Single ray per pixel
  - Supports indirect lighting only from specular surfaces
    - No color bleeding
  - Shoots shadow rays to compute direct illumination
    - Soft shadows are harder to get

- Path Tracing (*may produce renders indistinguishable from photos*)
  - Many rays per pixel, their color averaged
  - At each interaction, ray direction changes randomly with some distribution
  - No difference between light sources and objects
    - Soft shadows, complex materials, etc.
    - Supports all sorts of indirect lighting

BONUS 3

Half of a sphere of radius R ('object') is lit by a long light source (depicted as a blue line). The light source and the object are centered horizontally. At the edge of the light source there is a small mirror (depicted as a green line). What is the total illumination of the very tip of the sphere (red dot)?

Assume the object and the light have color (intensity) of (1,1,1) and the object is perfectly diffuse.