

Ray Tracing, Part I

Geoffrey Matthews

Department of Computer Science
Western Washington University

Fall 2015

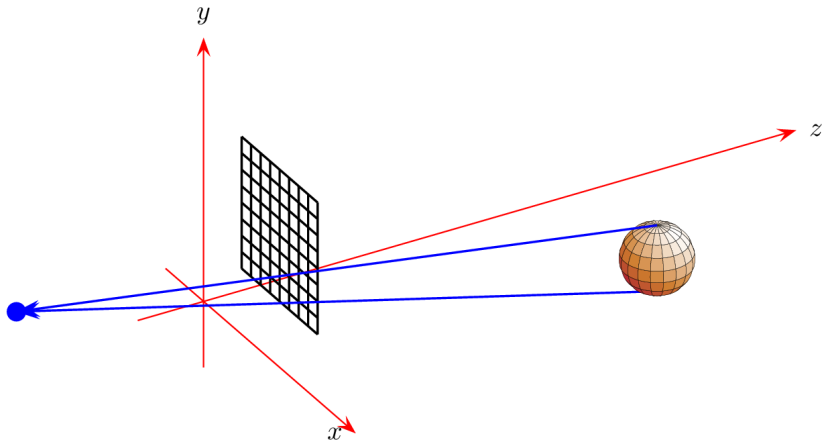
Readings

- ▶ <https://www.siggraph.org/education/materials/HyperGraph/raytrace/rtrace0.htm>
- ▶ <https://www.cs.unc.edu/~rademach/xroads-RT/RTarticle.html>
- ▶ <http://www.cs.utah.edu/~shirley/books/fcg2/rt.pdf>
- ▶ <http://www.povray.org/>
- ▶ <http://www.pbrt.org/>

Ray Traced Images Achieve Maximal Realism

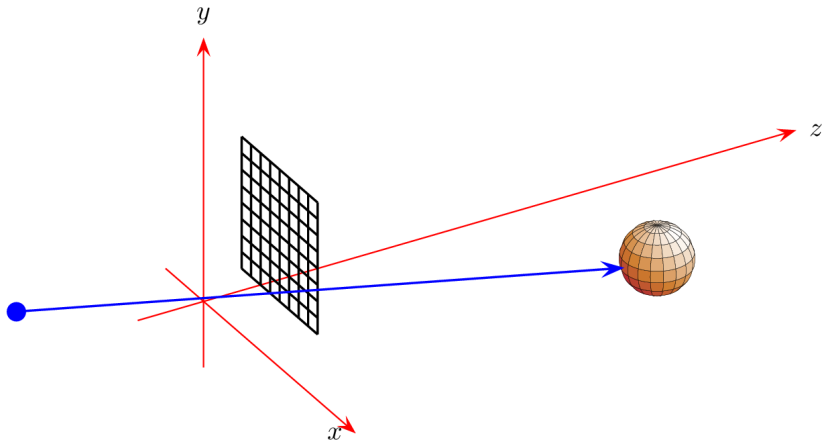


Two ways of rendering a picture: object order



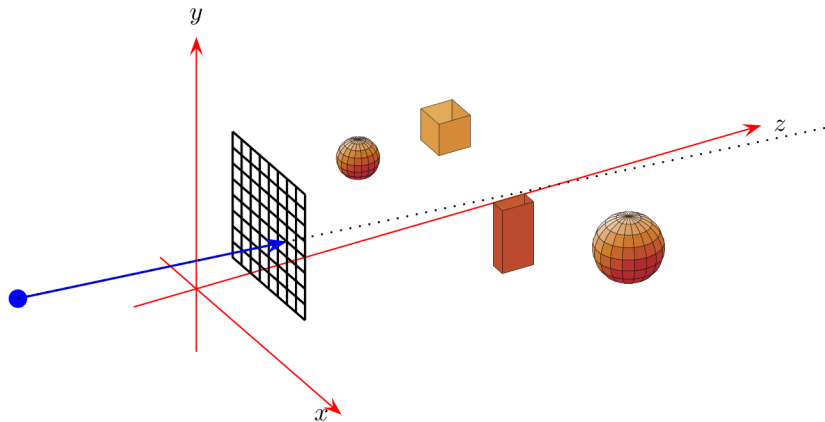
- For each object in the world, find the colors it would put on the screen.

Two ways of rendering a picture: image order



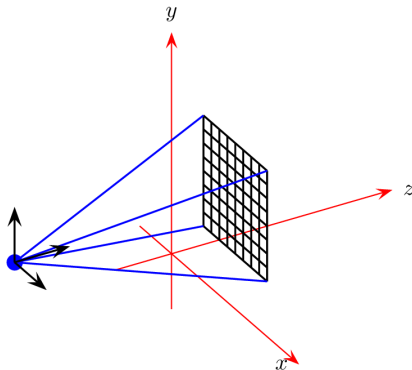
- For each pixel on the screen, find the objects that would color it.

Ray casting, a simplified ray tracing



- ▶ Given an eye position and a pixel position, construct a ray.
- ▶ Project the ray into the scene and find the closest intersection.
- ▶ Use object to compute color.

Camera

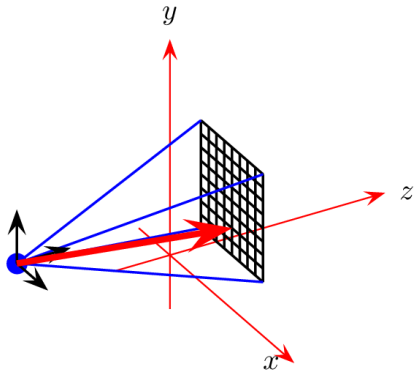


- ▶ A frame: **origin** point, and **right**, **up**, **forward** vectors.
- ▶ A distance, width and height for the image plane.

$$\langle p, r, u, f, d, w, h \rangle$$

- ▶ Would it matter if d, w, h were all doubled?

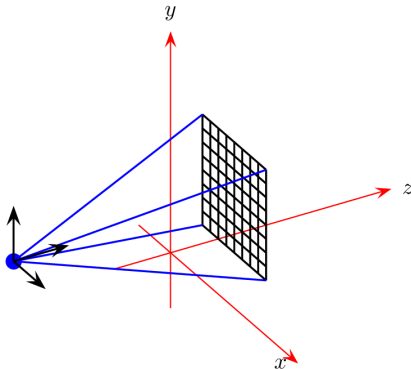
Finding vectors from the eye to the image plane



- ▶ Give an expression for the upper left corner.
- ▶ Give an expression for the upper right corner.
- ▶ Give an expression for a point 30% of the way across the image plane and 10% up from the bottom.

$$\langle p, r, u, f, w, h \rangle$$

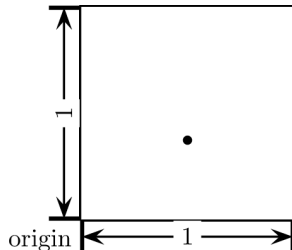
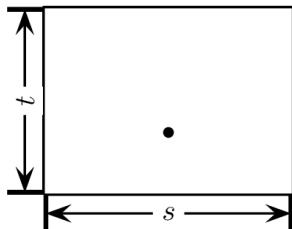
Other camera representations



- ▶ Lookat: eye point, lookat point, up vector, width, aspect ratio.
- ▶ Eye and four points
- ▶ Eye, lower left corner, two vectors
- ▶ Eye and four vectors

Normalized screen coordinates

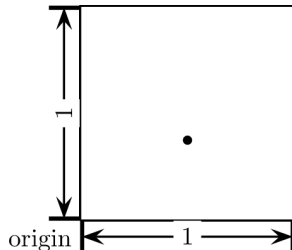
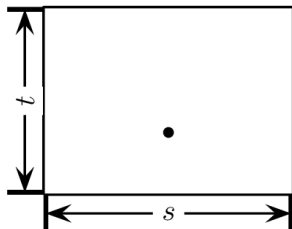
origin



- ▶ *Normalized* screen coordinates map the entire surface to the $(0, 1) \times (0, 1)$ square.
- ▶ Suppose the screen is 640×480 , with origin in the upper left, and we have a point at $(300, 400)$ on the screen.
- ▶ What are the point's normalized screen coordinates?

Normalized screen coordinates

origin

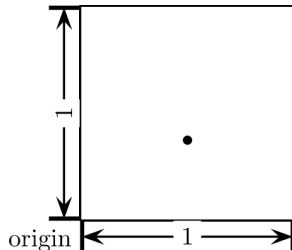
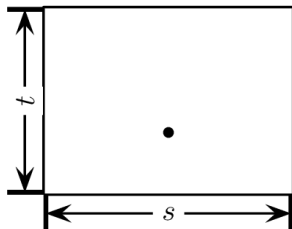


- ▶ *Normalized* screen coordinates map the entire surface to the $(0, 1) \times (0, 1)$ square.
- ▶ Suppose the screen is 640×480 , with origin in the upper left, and we have a point at $(300, 400)$ on the screen.
- ▶ What are the point's normalized screen coordinates?

$$\left(\frac{300}{640}, 1 - \frac{400}{480} \right)$$

Normalized screen coordinates

origin



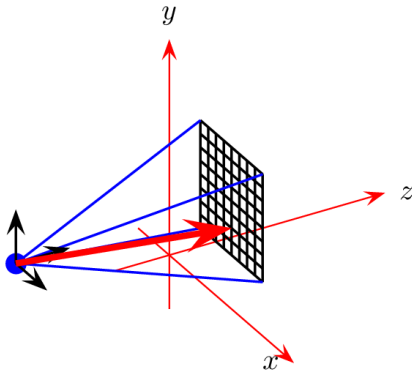
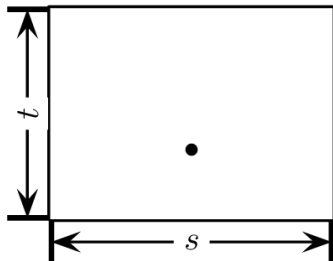
- ▶ *Normalized* screen coordinates map the entire surface to the $(0, 1) \times (0, 1)$ square.
- ▶ Suppose the screen is 640×480 , with origin in the upper left, and we have a point at $(300, 400)$ on the screen.
- ▶ What are the point's normalized screen coordinates?

$$\left(\frac{300}{640}, 1 - \frac{400}{480} \right)$$

- ▶ Why did I use s and t and not w and h ?

Mapping from Pixel to Camera Ray

origin

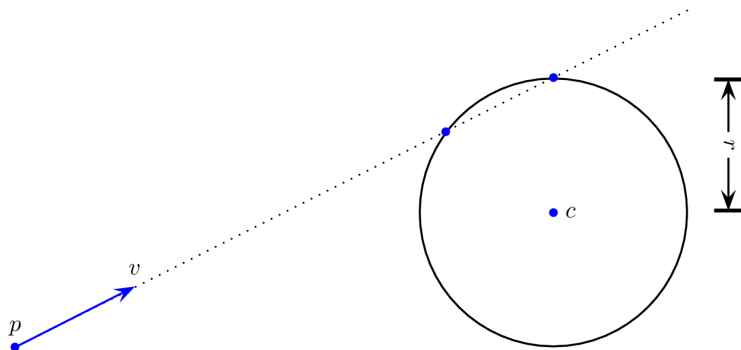


- ▶ Given a pixel position on the screen, find the ray in the camera.
- ▶ Map screen position to normalized position in $(0, 1) \times (0, 1)$
- ▶ Map normalized position in $(0, 1) \times (0, 1)$ to vector in world space.

Ray tracing process

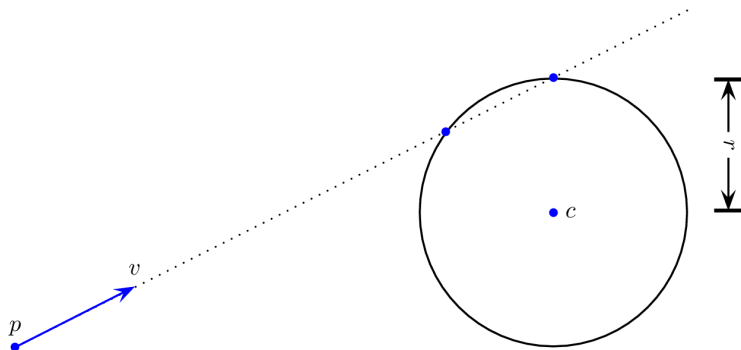
- ▶ Input: a camera and a set of objects
- ▶ Output: an image
- ▶ For each pixel in the image:
 - ▶ Find the ray in the camera for that pixel.
 - ▶ For all objects in the set:
 - ▶ find the closest in front of the camera that intersects the ray
 - ▶ Find the color of that object at the intersection point.
 - ▶ Color the pixel in the image with that color.

Intersecting a ray and a sphere



- ▶ Sphere defined by center and radius.
- ▶ Ray defined by point and vector.
- ▶ Assume sphere is centered at origin (replace p with $p - c$).
- ▶ Equation to solve?

Intersecting a ray and a sphere



- ▶ Sphere defined by center and radius.
- ▶ Ray defined by point and vector.
- ▶ Assume sphere is centered at origin (replace p with $p - c$).
- ▶ Equation to solve?
- ▶ Solve for t : $|p + tv|^2 = r^2$

Solving quadratic

$$\begin{aligned}|p + tv|^2 &= (p + tv) \cdot (p + tv) \\&= \sum_i (p_i + tv_i)(p_i + tv_i) \\&= \sum_i (p_i^2 + 2p_i v_i t + v_i^2 t^2) \\&= \sum_i p_i^2 + 2 \sum_i p_i v_i t + \sum_i v_i^2 t^2 \\&= (p \cdot p) + 2(p \cdot v)t + (v \cdot v)t^2\end{aligned}$$

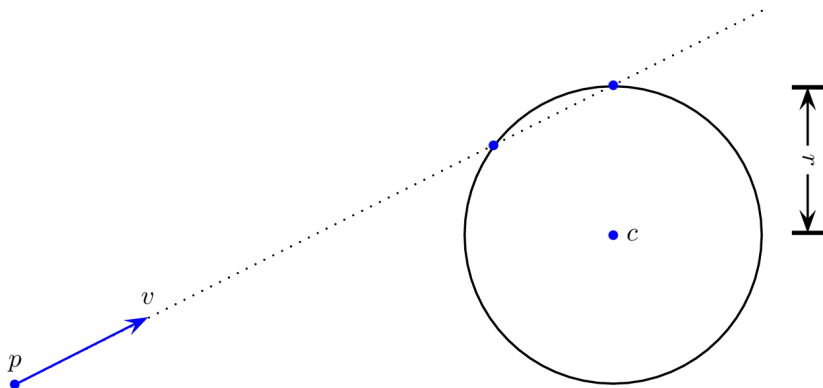
So, in the quadratic $at^2 + bt + c = 0$,

$$a = v \cdot v \quad (= 1 \text{ if you normalized your rays})$$

$$b = 2p \cdot v$$

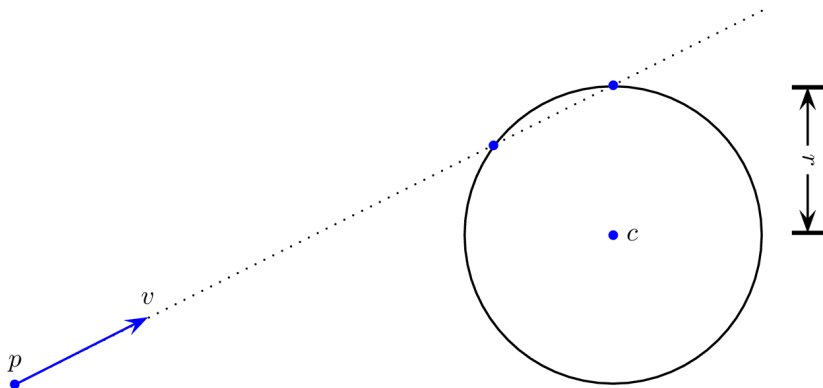
$$c = p \cdot p - r^2$$

Intersecting a ray and a sphere



- What equation would we have to solve if we did this in world coordinates?

Intersecting a ray and a sphere



- ▶ What equation would we have to solve if we did this in world coordinates?
- ▶ $|(p + tv) - c|^2 = r^2$
- ▶ Much simpler in object coordinates (replace p with $p - c$).

Still something missing ...

