# Ray Tracing, Part I

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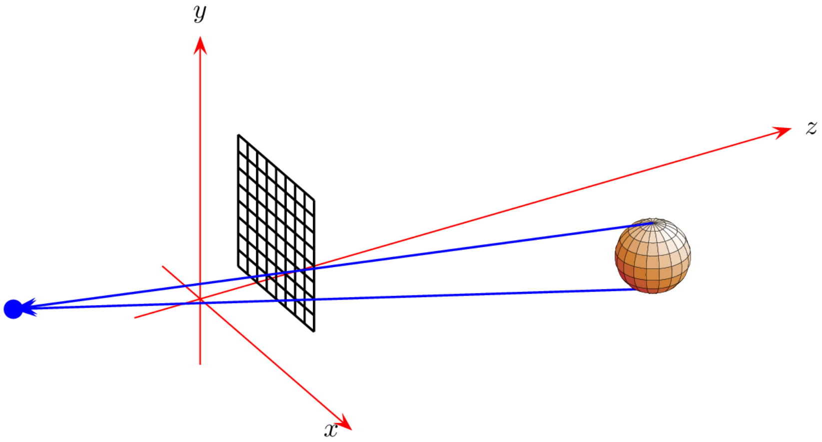
# Readings

- 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/

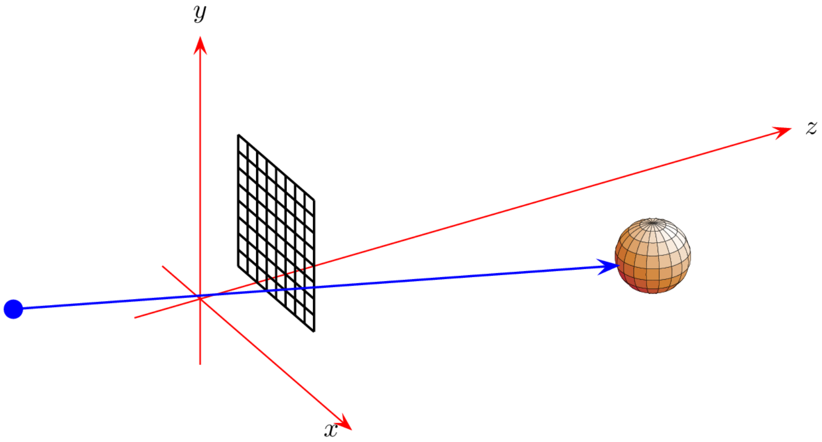
# Ray Traced Images Achieve Maximal Realism

# Two ways of rendering a picture: object order



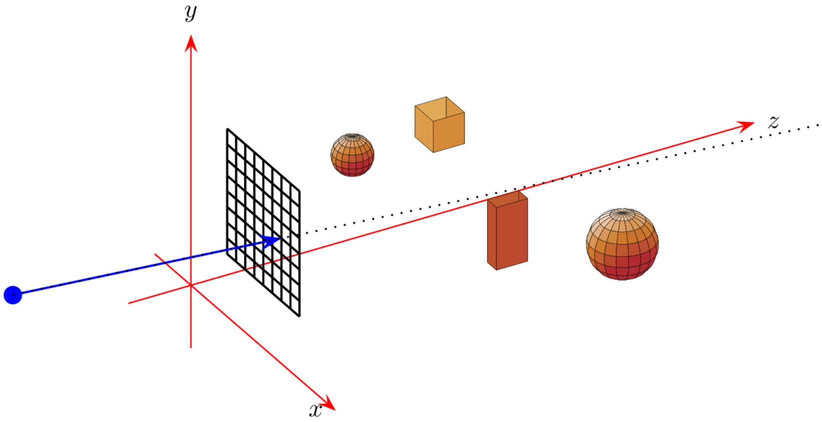

- For each object in the world, find the colors it would put on the screen.

# Two ways of rendering a picture: image order



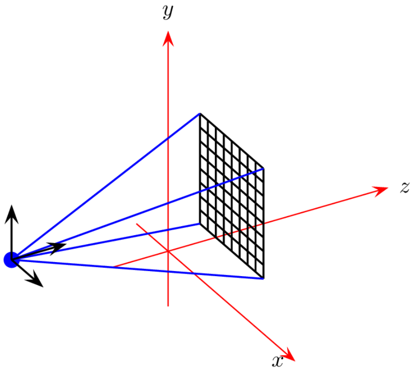

- For each pixel on the screen, find the objects that would color it.

# 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

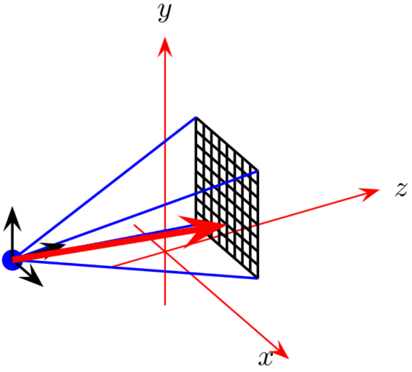



- A frame: **origin** point, and **right**, **up**, **forward** vectors.
- A distance, width and height for the image plane.

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

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

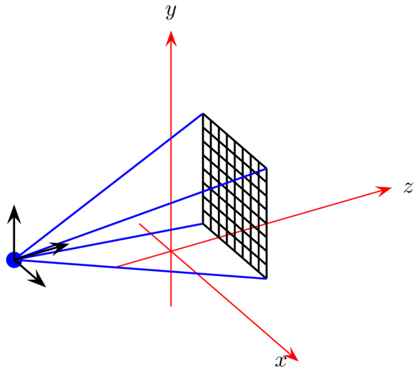
# Finding vectors from the eye to the image plane




- 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.

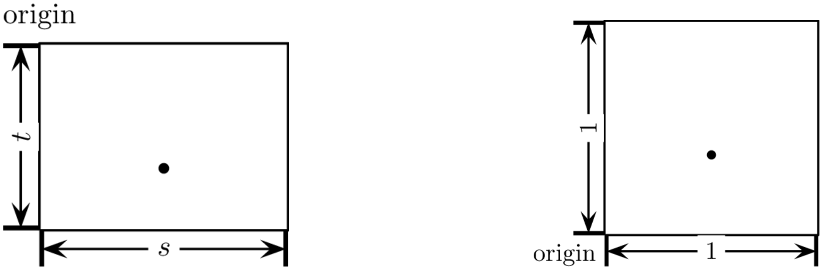
$$\langle p, r, u, f, d, w, h \rangle$$

# Other camera representations



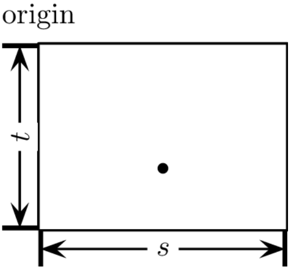

- Lookat: eye point, lookat point, up vector, width, aspect ratio.
- Eye and four points
- Eye, lower left corner, two vectors
- Eye and four vectors

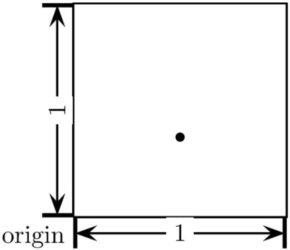
# Normalized screen coordinates




- *Normalized* screen coordinates map the entire surface to the $(0, 1) \times (0, 1)$ square.
- Suppose the screen is $640 \times 480$, 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

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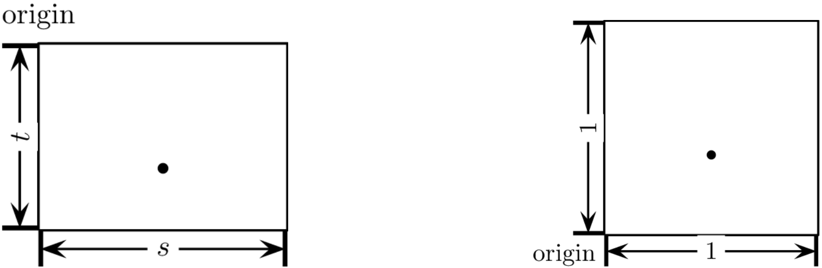
$$\left(\frac{300}{640}, 1 - \frac{400}{480}\right)$$

# Normalized screen coordinates

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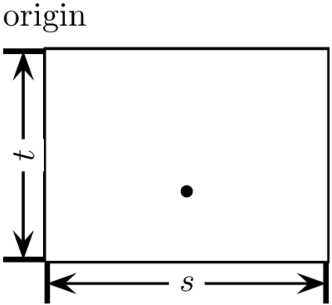
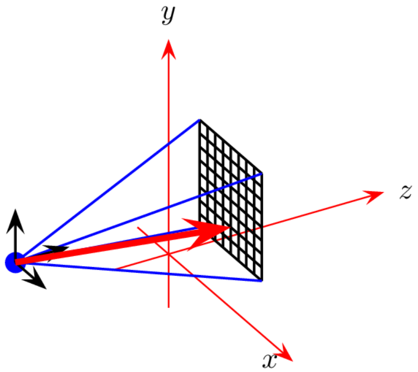
$$\left(\frac{300}{640}, 1 - \frac{400}{480}\right)$$

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

# Mapping from Pixel to Camera Ray



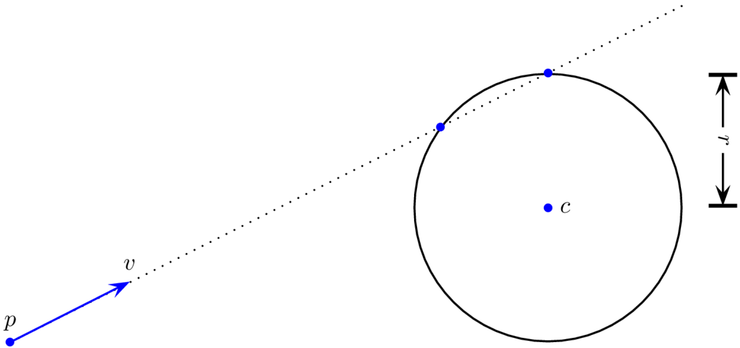




- Given a pixel position on the screen, find the ray in the camera.
- Map screen position to normalized position in $(0,1) \times (0,1)$
- Map normalized position in $(0,1) \times (0,1)$ to vector in world space.

# Ray casting process

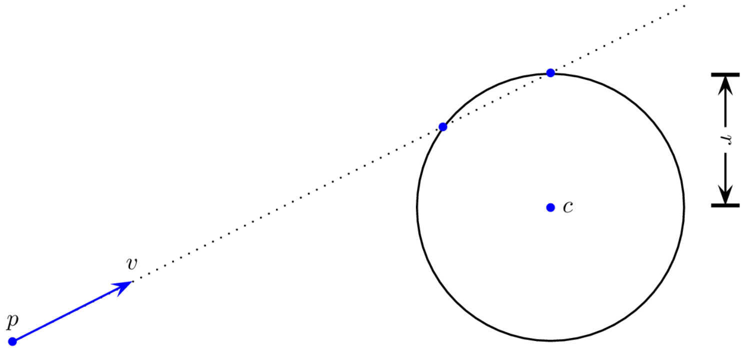
- Input: a camera and a set of objects
- Output: an image
- For each pixel in the image:
  - Find the ray in the camera for that pixel.
  - For all objects in the set:
    - find the closest in front of the camera that intersects the ray
  - Find the color of that object at the intersection point.
  - 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 $t$: $|p + tv|^2 = r^2$

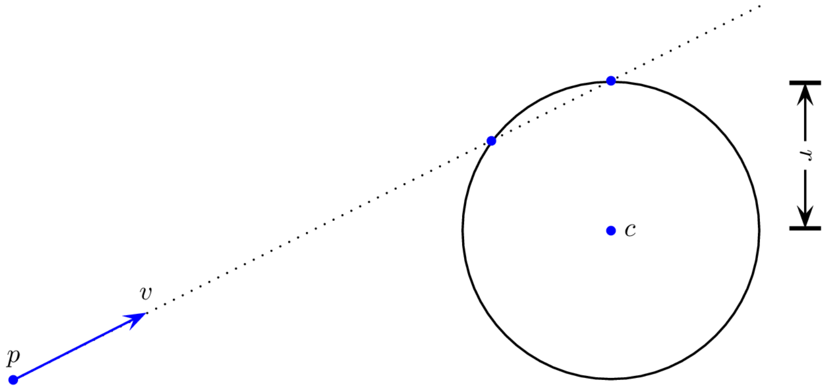
# Solving quadratic

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

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

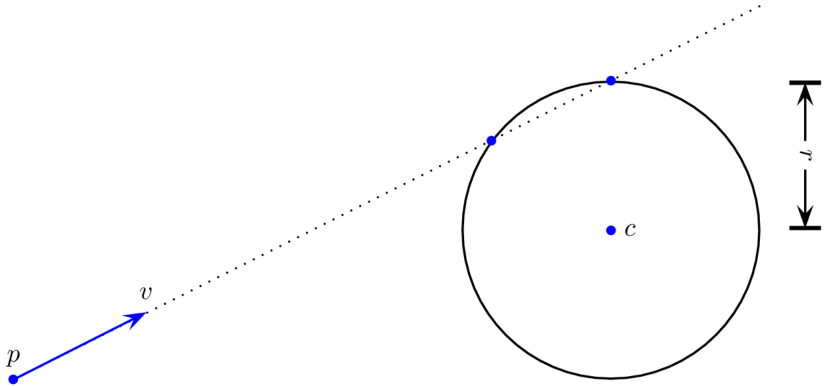
$$
\begin{aligned}
a &= v\cdot v \quad (= 1 \text{ if you normalized your rays}) \\
b &= 2p\cdot v \\
c &= p\cdot p - r^2
\end{aligned}
$$

# 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 ...