Lecture 18
Pinhole Camera Model
360 (Spherical) Panoramas, Part 1
Announcements

• HW3 due Wednesday

• P2 due in a week - how's it going?
Goals

• Understand where images come from (under the pinhole camera model)
  • Be able to derive the 3x4 pinhole projection matrix
  • Understand the interpretation of planar panorama stitching in terms of using homographies to map images onto a common plane.

• Get intuition for how to create 360 degree panoramas by mapping images onto a spherical surface instead.
Can we make 360 panoramas?

To answer this, we need to know how these images came to be. Why can we even make any panoramas with homographies?
Where do images come from?

497Cam, Mk I: Not Really A Camera At All.
497Cam, Mk II: A Pinhole Camera
Camera Obscura (pinhole camera)
The Effect of Pinhole Size

[Diagram of pinhole effect with images showing different pinhole sizes (2 mm, 1 mm, 0.6 mm)].
Aside: What about Lenses?

497Cam, Mk III
The Pinhole Camera Model

- 497Cam, Mk II:
The Pinhole Camera Model

- 497Cam, Mk IIM:

- Center of Projection (COP)
- Optical Axis
- Focal length (f)
- Image focal projection plane
- Camera (world) coordinates
- Image coordinates

M for Math

(now with terminology!)
How does that work?
Focal Length
The effect of Focal Length

$ \leftarrow \text{Cheap} \rightarrow \$

24mm  70mm  105mm  300mm
Projection in a Pinhole Camera

For a given 3D pt, where does it land in the image?

- Ms. Collins' geometric (10th grade) way:
\[
\frac{y'}{y} = \frac{c}{z}
\]

Camera coords

\[
\begin{align*}
y' &= -\frac{fy}{z} \\
x' &= -\frac{fx}{z} \\
z &= f
\end{align*}
\]

Image coords

\[
\begin{align*}
x' &= -\frac{fx}{z} \\
y' &= -\frac{fy}{z} \\
w &= 1
\end{align*}
\]
Projection in a Pinhole Camera

- Dr. Swenton's (15th grade) way:

\[
\begin{pmatrix}
\frac{-fx}{z} \\
\frac{-fy}{z} \\
1
\end{pmatrix} \Rightarrow \begin{pmatrix}
-fx \\
-fy \\
0
\end{pmatrix} \Rightarrow \begin{pmatrix}
x \\
y \\
\frac{-z}{f}
\end{pmatrix} = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & -1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix} \begin{pmatrix}
X \\
Y \\
Z \\
1
\end{pmatrix}
\]

Pinhole Projection Matrix
Reinterpreting Homographies

A 3x3 linear transformation, applied to a projection plane.
Reinterpreting Homography-aligned Panoramas

- Several image planes are warped (projected) onto a common image plane.
I'll ask it again:
Can we make 360 panoramas?
Planar Panoramas

We can't make 360 panoramas with homographies.
Spherical Panoramas

Idea: project images onto a sphere instead of a plane.

Example: Google Street View
Unwrapping a Sphere
Spherical Panoramas

What motion model should we use?
Spherical Panoramas

1. Warp planar images onto the surface of a sphere

2. Align with translational (!) motion model.

3. Stitch and blend as usual.