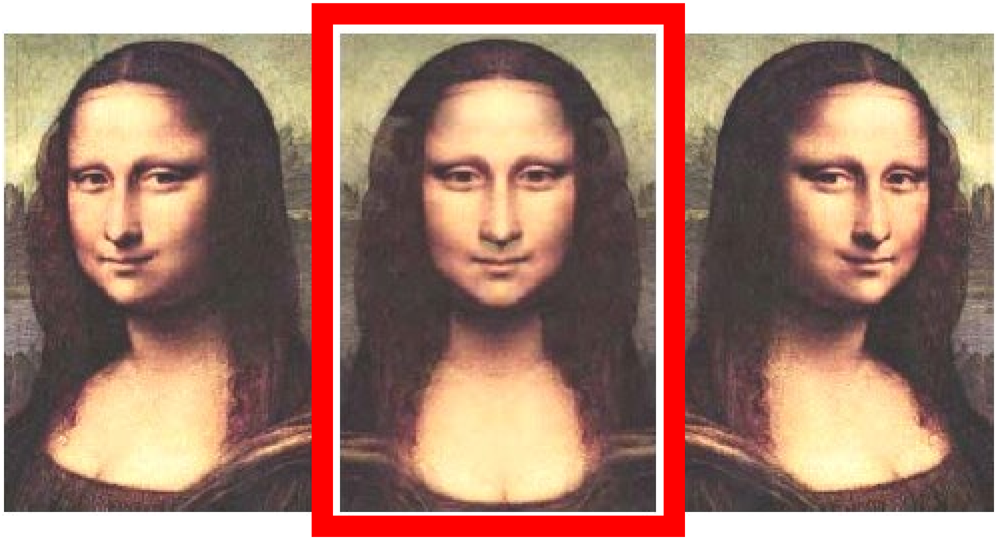
Image/View Morphing and Warping

CS334

Daniel G. Aliaga
Department of Computer Science
Purdue University

Motivation – Rendering from Images



- Given
  - left image
  - right image
- Create intermediate images
  - simulates camera movement

Related Work

- Panoramas (e.g., QuicktimeVR, etc)
  - user can look in any direction at few given locations but camera translations are ***not*** allowed…

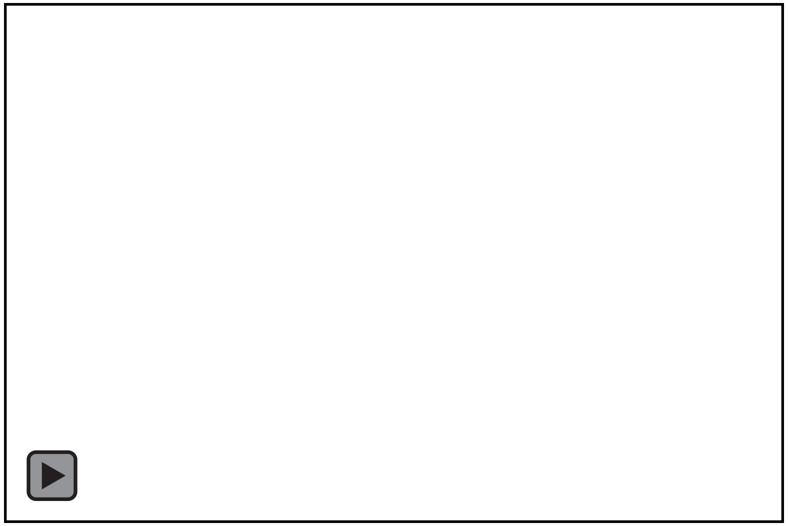
Topics

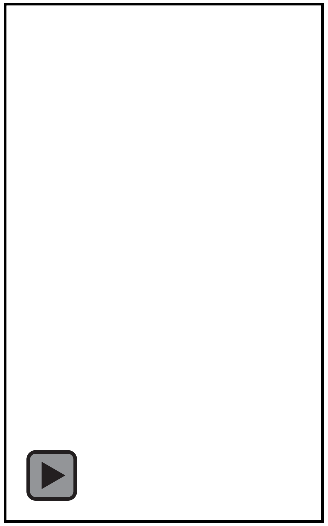
- Image morphing (2D)
- View morphing (2D+)
- Image warping (3D)

Topics

- Image morphing (2D)
- View morphing (2D+)
- Image warping (3D)

Image Morphing





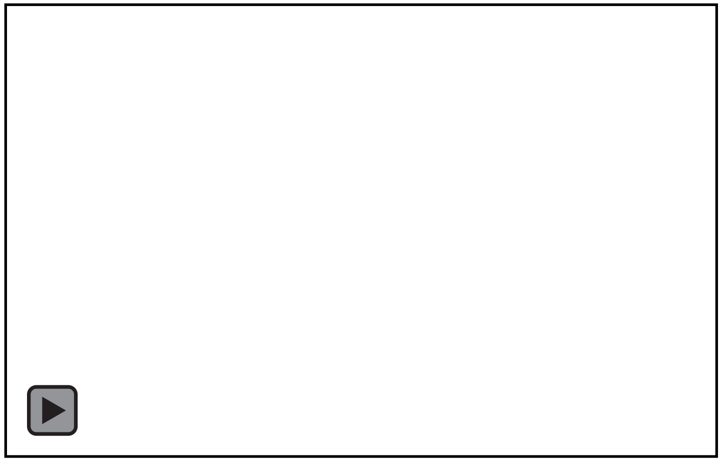


Image Morphing

- Identify correspondences between input/output image
- Produce a sequence of images that allow a smooth transition from the input image to the output image

Image Morphing

1. Correspondences

Image Morphing

1. Correspondences

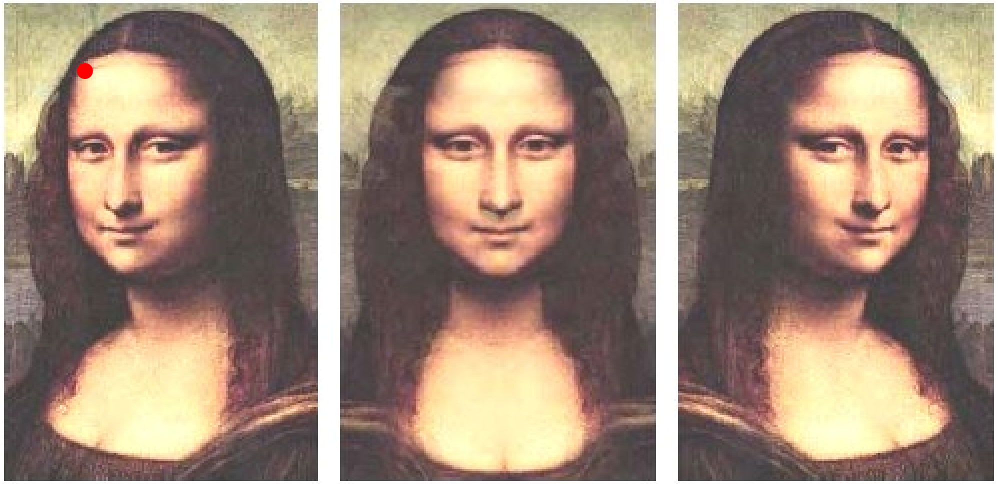


Image Morphing

1. Correspondences

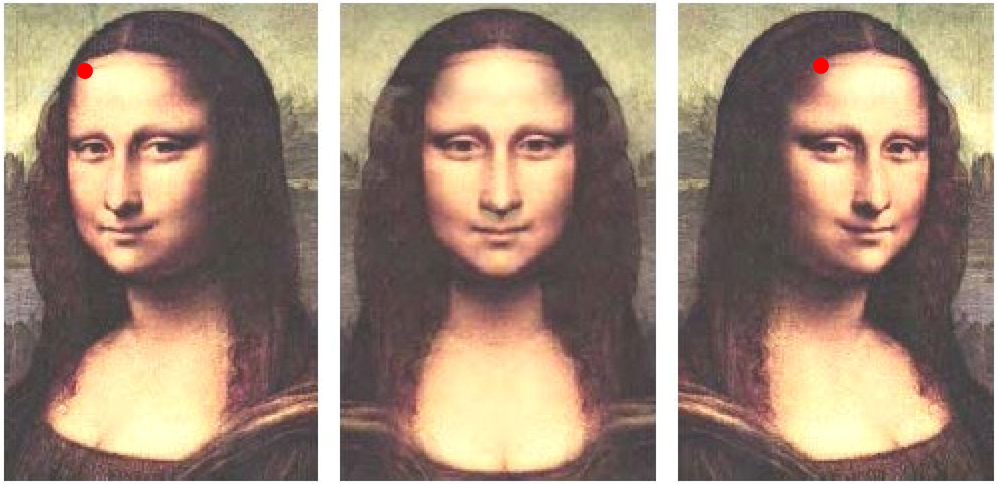


Image Morphing

1. Correspondences

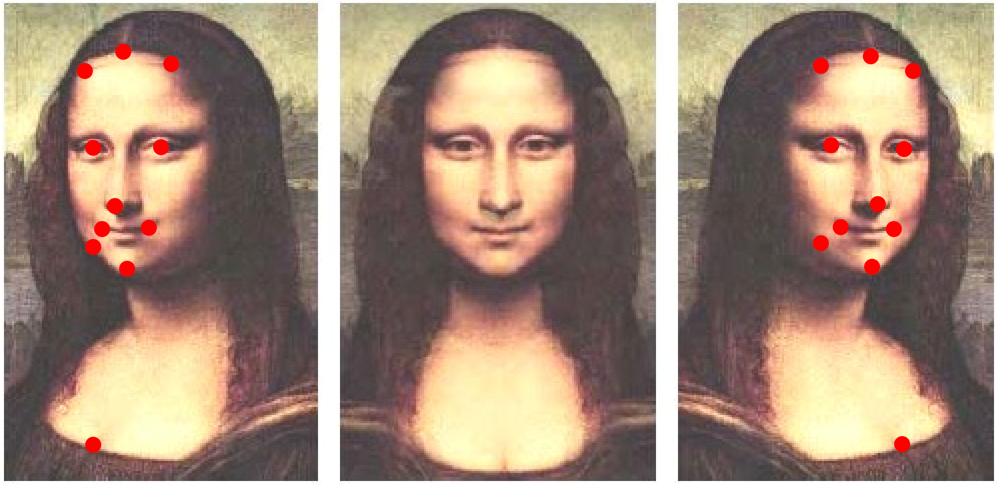
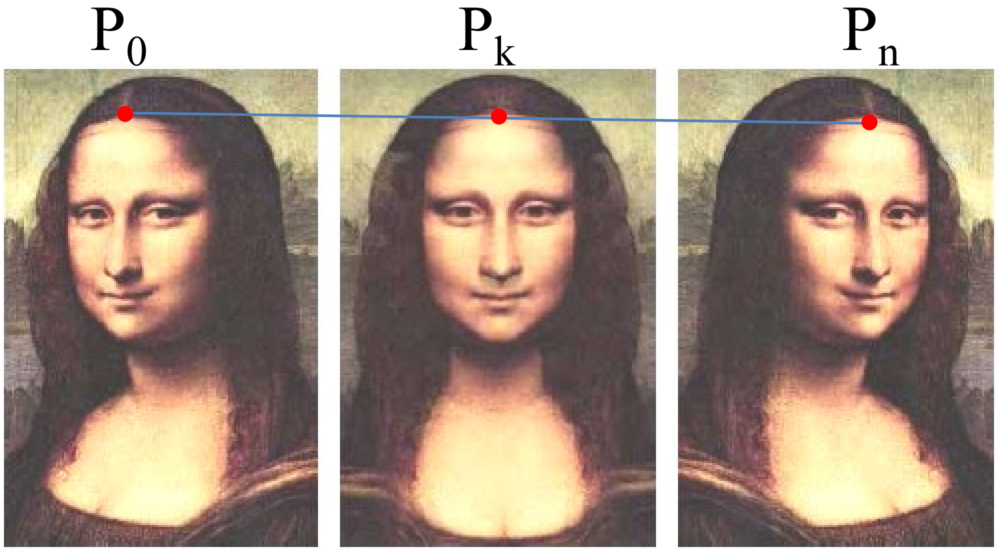


Image Morphing



1. Correspondences
2. Linear interpolation

$$P_k = (1 - \frac{k}{n})P_0 + \frac{k}{n}P_n$$

Image Morphing

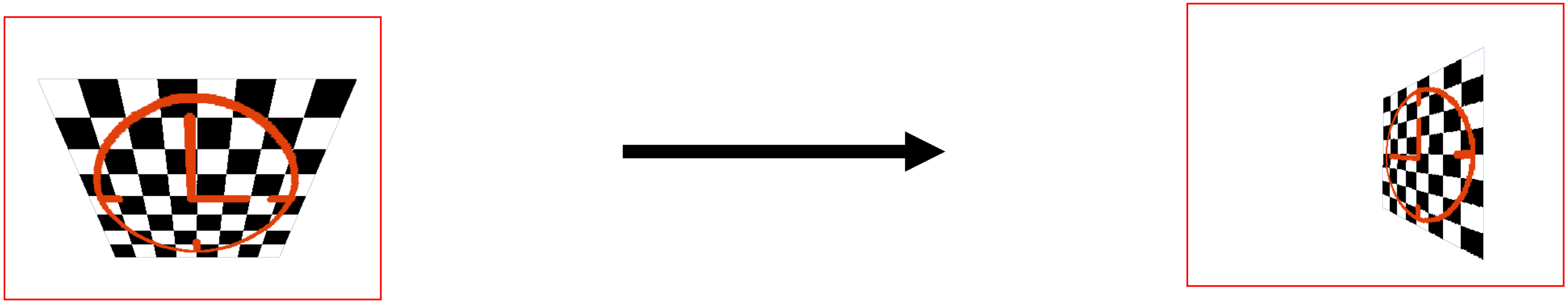


Image Morphing

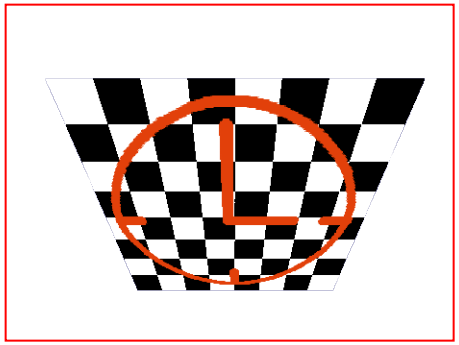
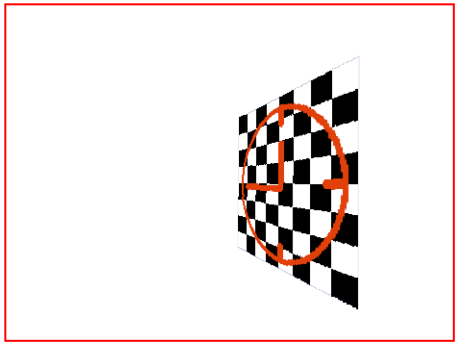
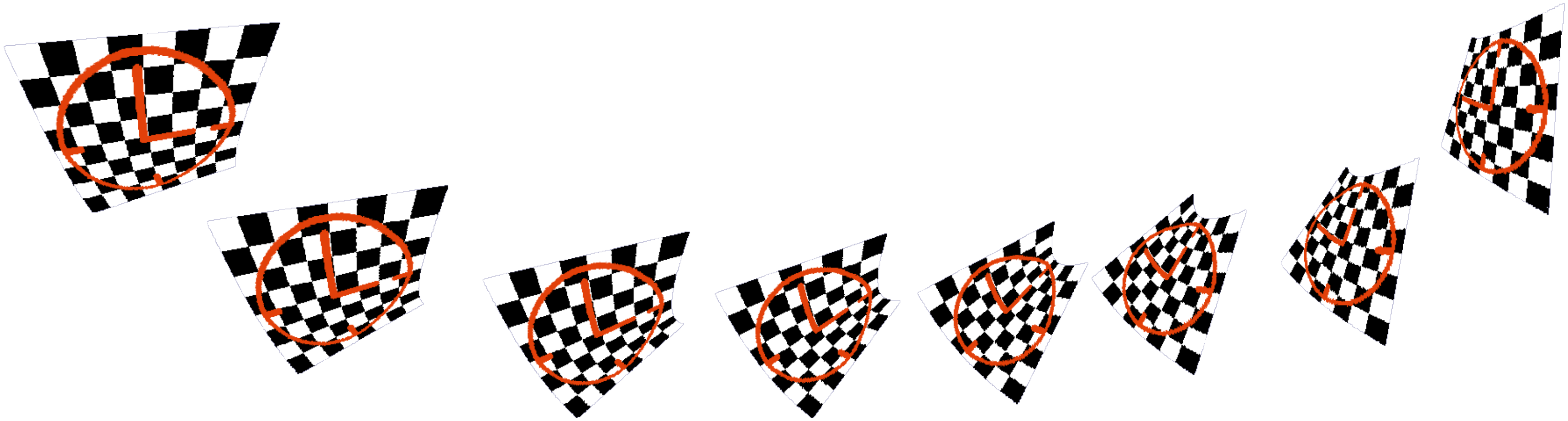


Image morphing is not shape preserving

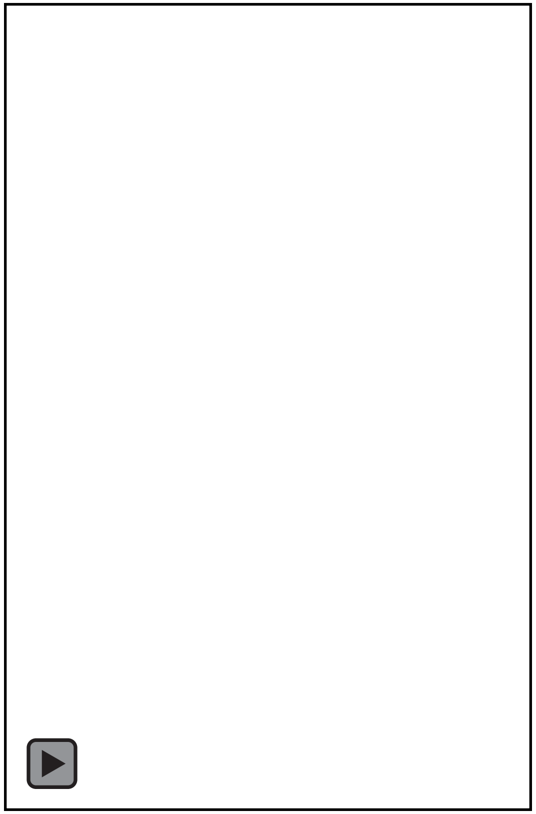


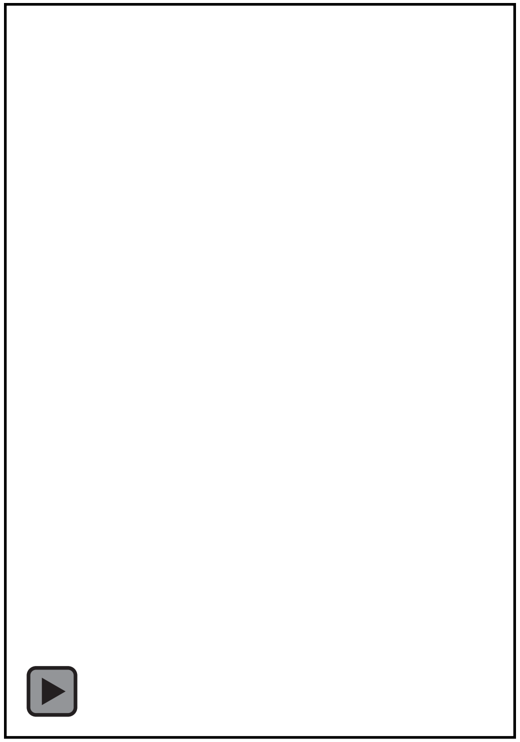


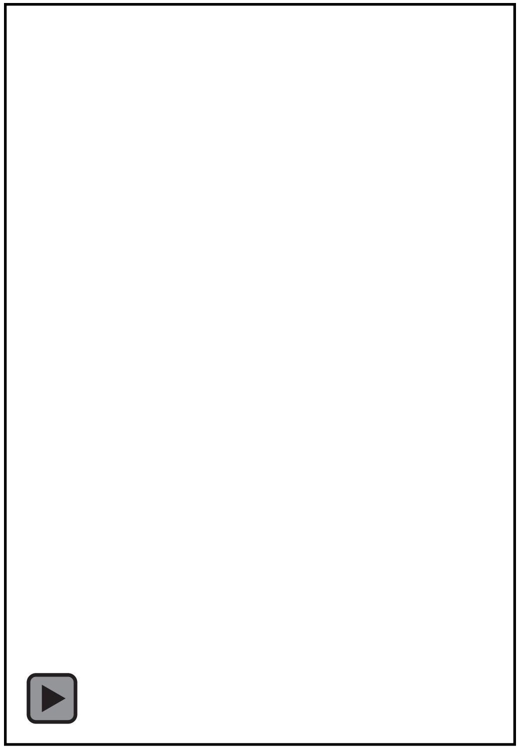
Topics

- Image morphing (2D)
- View morphing (2D+)
- Image warping (3D)

View Morphing



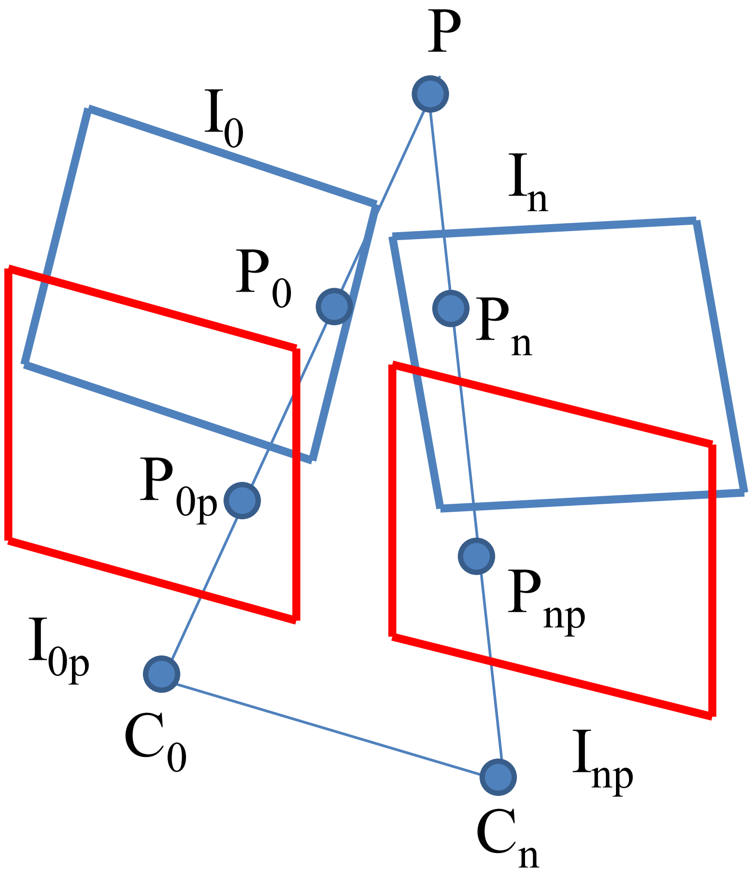




View Morphing

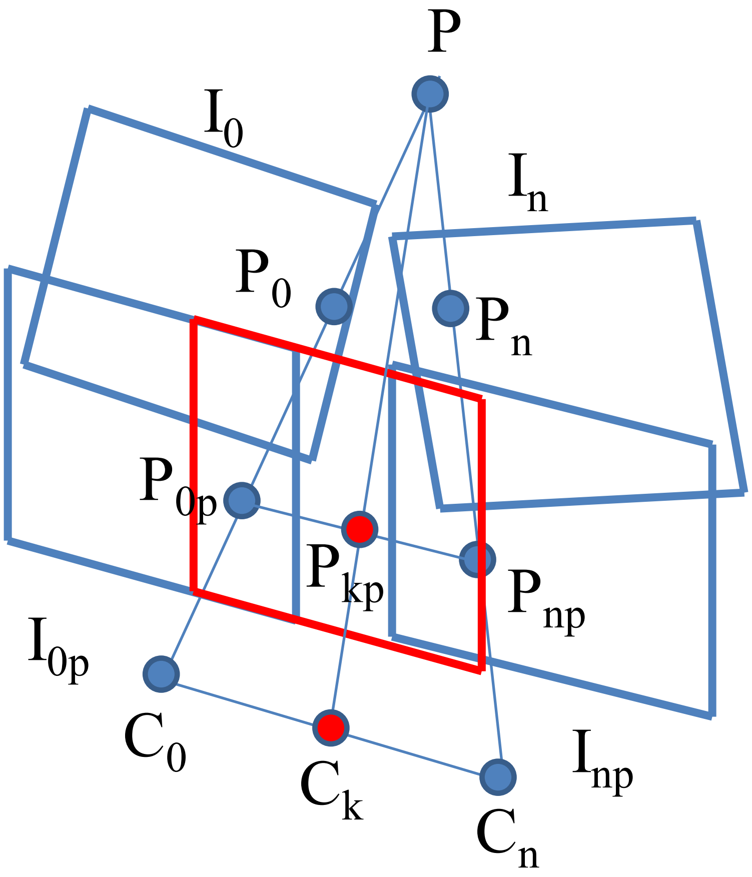
- Shape preserving morph
- Three step algorithm
  - Prewarp first and last images to parallel views
  - Image morph between prewarped images
  - Postwarp to interpolated view

Step 1: prewarp to parallel views



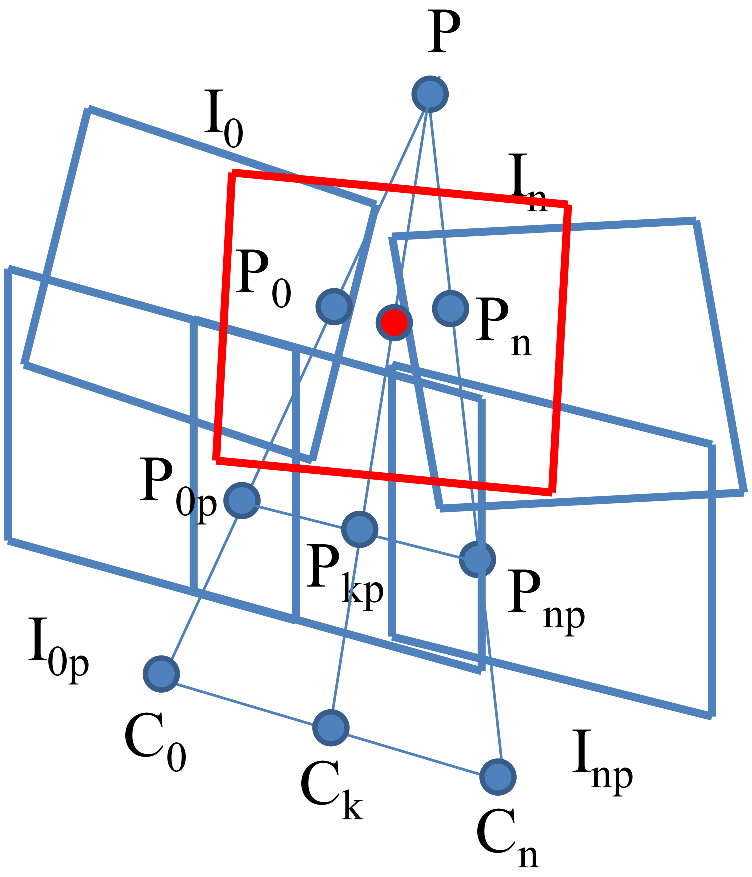
- Parallel views
  - same image plane
  - image plane parallel to segment connecting the two centers of projection
- Prewarp
  - compute parallel views I_{0p}, I_{np}
  - rotate I_0 and I_n to parallel views
  - prewarp correspondence is (P_0, P_n) -> (P_{op}, P_{np})

Step 2: morph parallel images



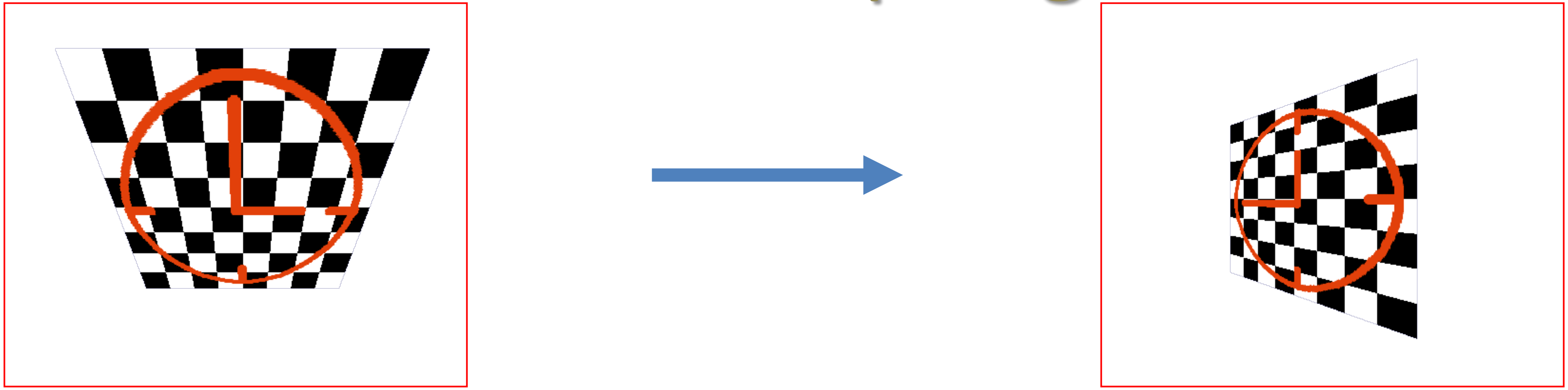
- Shape preserving
- Use prewarped correspondences
- Interpolate C_k from C_0 C_n

Step 3: postwarp image



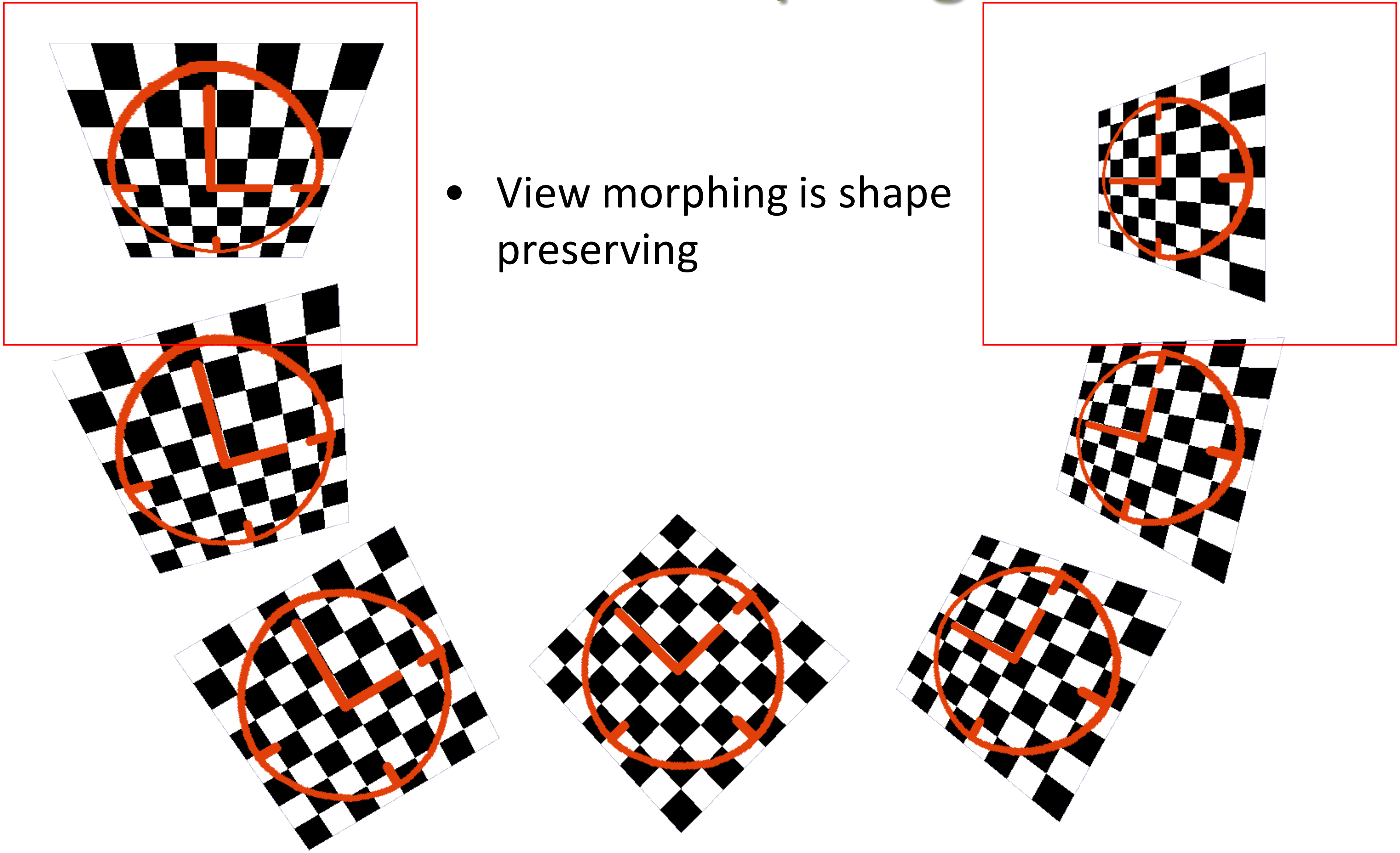
- Postwarp morphed image
  - create intermediate view
    - C_k is known
    - interpolate view direction and tilt
  - rotate morphed image to intermediate view

View morphing



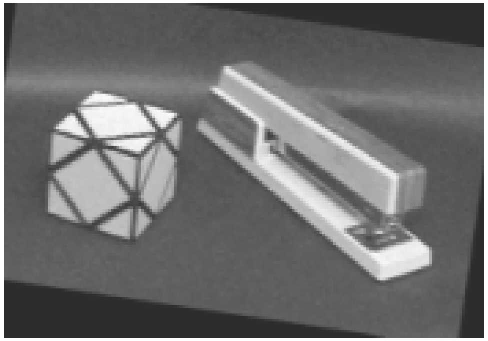
View morphing

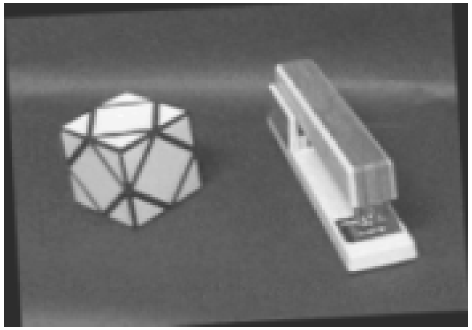
- View morphing is shape preserving

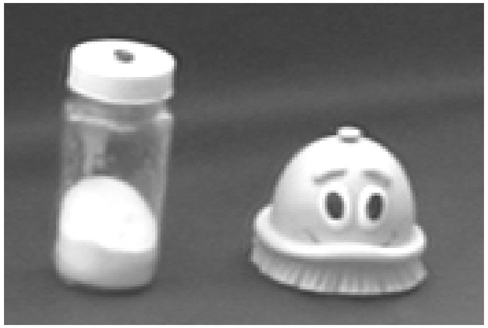


View Morphing Examples

- Using computer vision/stereo reconstruction techniques







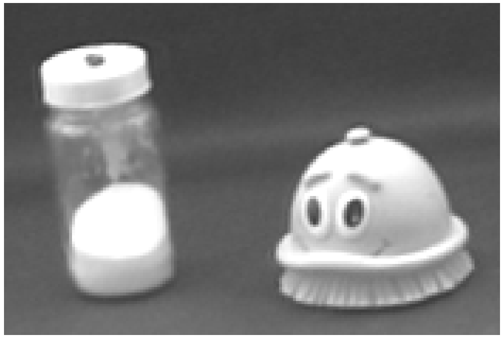
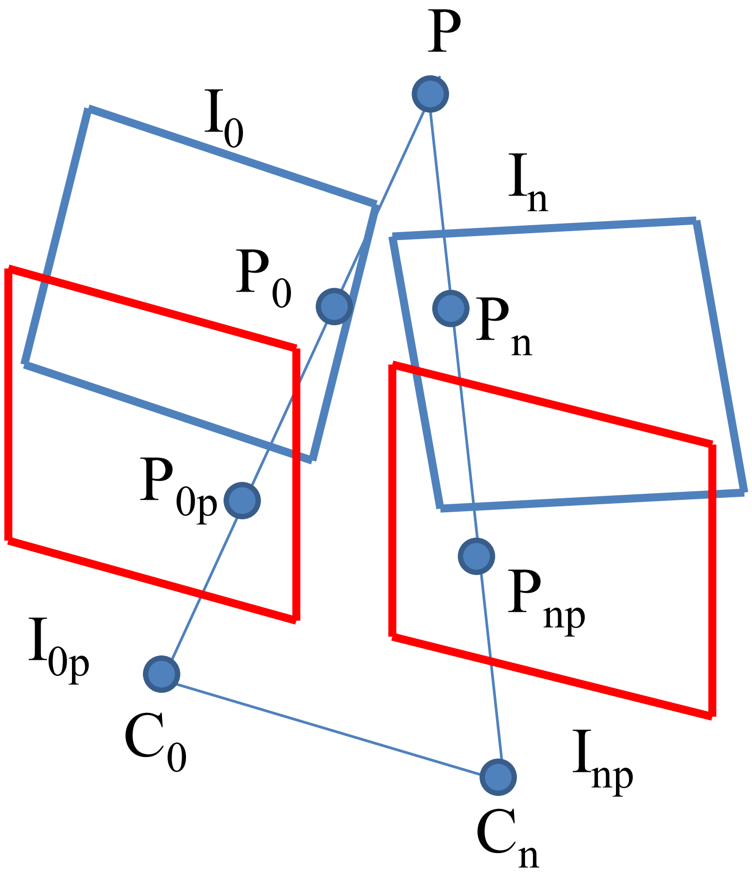


Image Transformations



- Intuitively, how do you compute the matrix M by which to transform P_0 to P_{0p} ?

Image Transformations

- A geometric relationship between input (u,v) and output pixels (x,y)
  - Forward mapping:

    (x,y) = (X(u,v), Y(u,v))

  - Inverse mapping:

    (u,v) = (U(x,y), V(x,y))

Image Transformations

- General matrix form is

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

and operates in the “homogeneous coordinate system”.

Affine Transformations

- Matrix form is

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

and accommodates translations, rotations, scale, and shear.

- How many unknowns? How to create matrix?

Affine Transformations

- Transformation can be inferred from correspondences; e.g.,

$$\begin{bmatrix} u_i \\ v_i \\ w_i \end{bmatrix} \Leftrightarrow \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix}$$

- Given ≥3 correspondences can solve for T

Perspective/Projective Transformations

- Matrix form is

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & 1 \end{bmatrix}\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

and it accommodates foreshortening of distant line and convergence of lines to a vanishing point;

also, straight lines are maintained but not their mutual angular relationships, and

only parallel lines parallel to the projection plane remain parallel

Perspective/Projective Transformations

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

- How many unknowns?
- How many correspondences are needed?

Direct Linear Transform

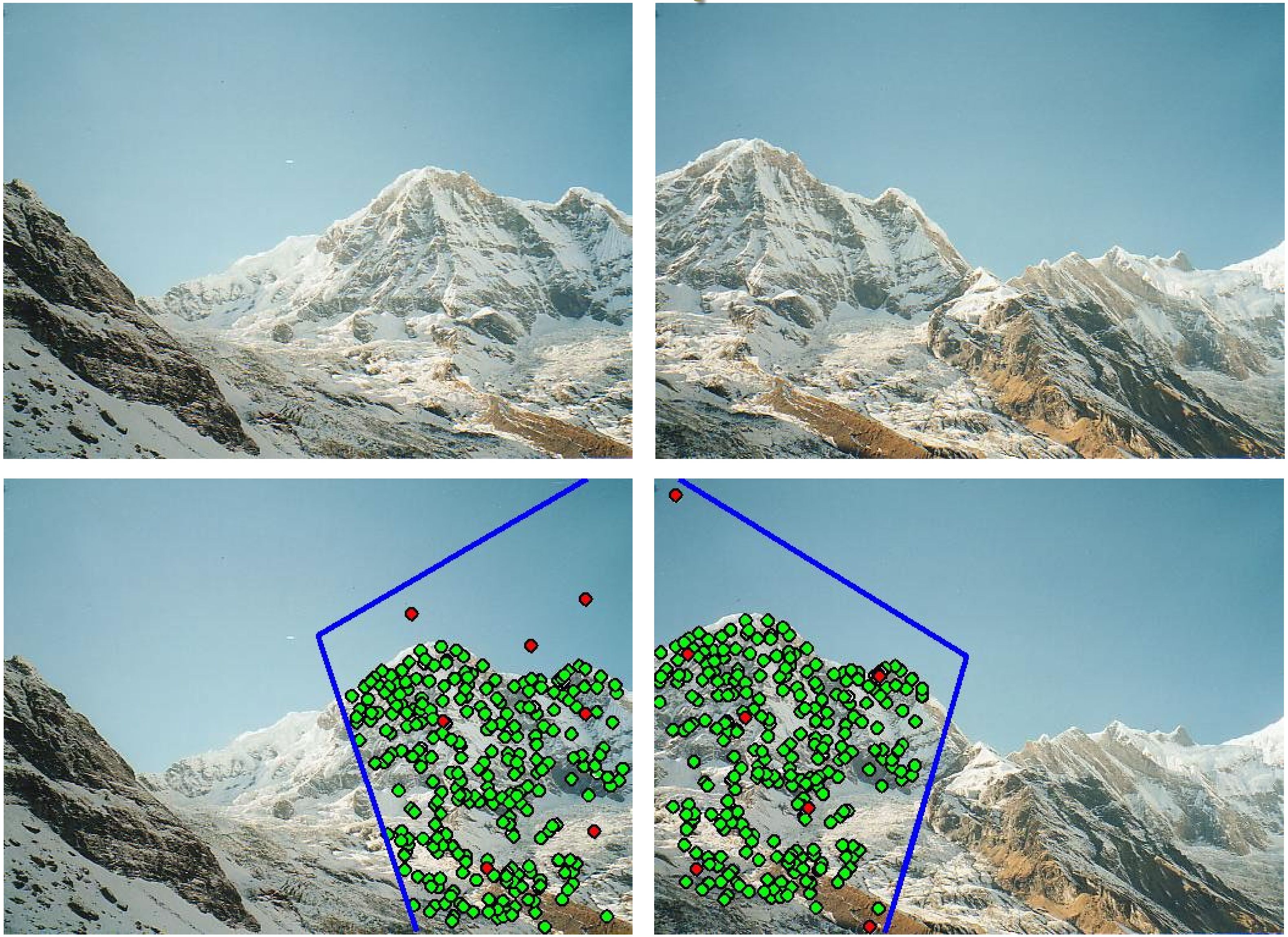
$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} x \\ y \\ z \end{bmatrix}$$

- Set $w = 1$ and $z = 1$, then have

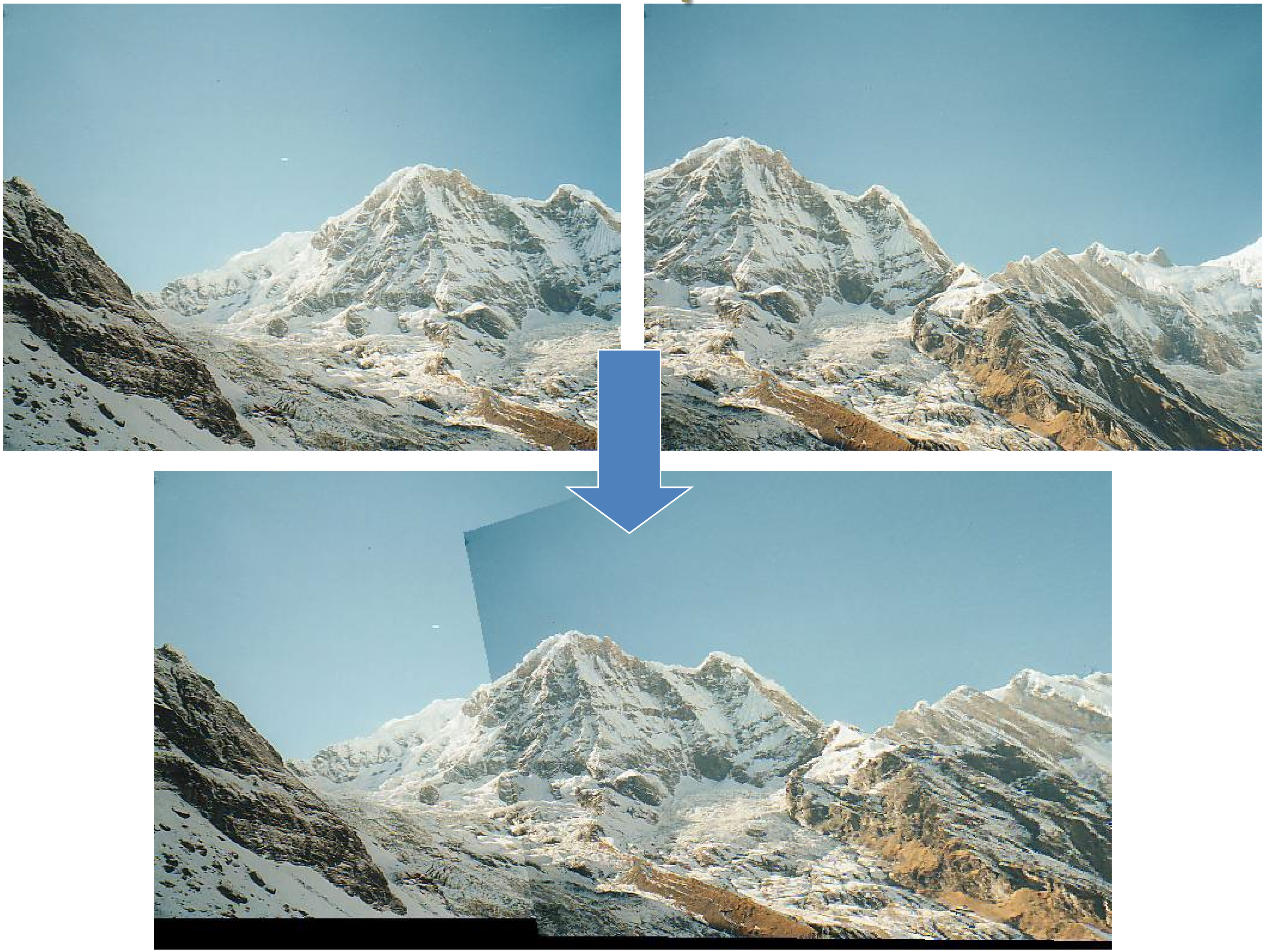
$$\alpha \begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & 1 \end{bmatrix} \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

- Divide line 1 and 2 by 3
- Rearrange terms to form…

Example

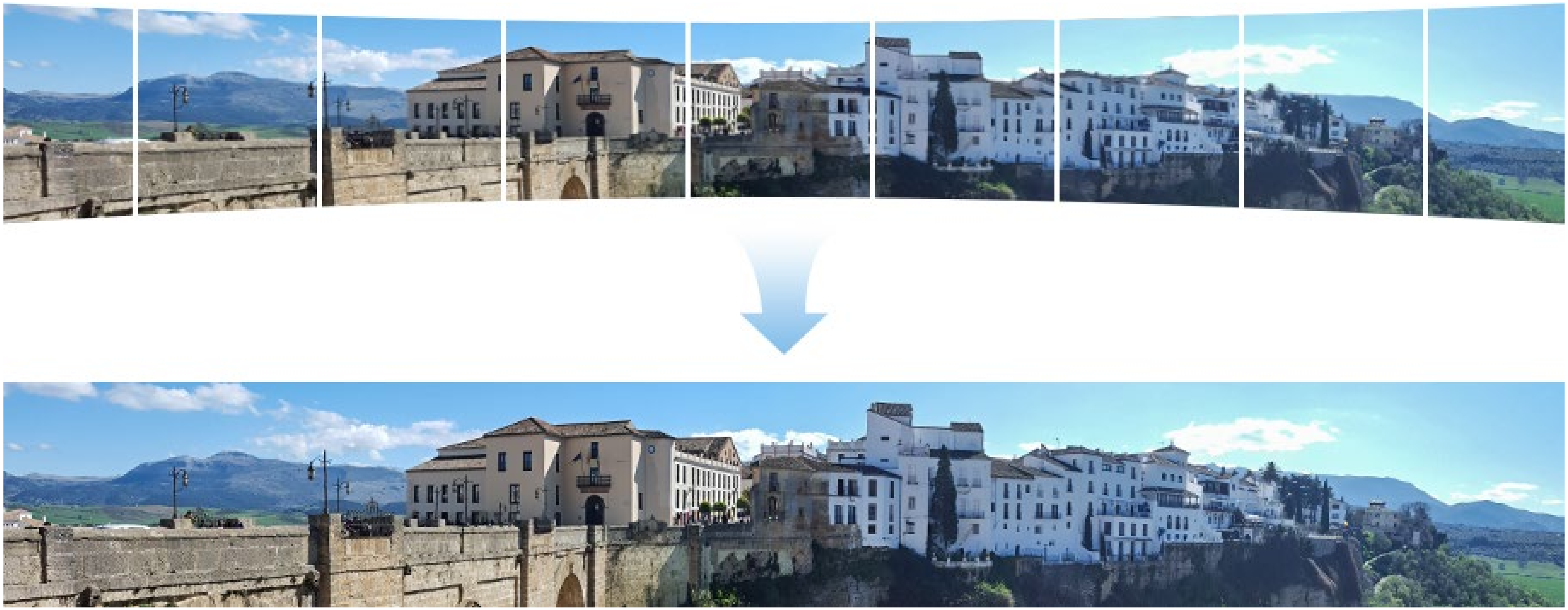


Example



“Image Stitching”

- A colloquial term for the same thing…



See blackboard…

$$\alpha(a_{11}u + a_{12}v + a_{13}) = x$$
$$\alpha(a_{21}u + a_{22}v + a_{23}) = y$$
$$\alpha(a_{31}u + a_{32}v + a_{33}) = 1$$

Divide 1st and 2nd line by 3rd line:

$$(a_{11}u + a_{12}v + a_{13}) = x(a_{31}u + a_{32}v + a_{33})$$
$$(a_{21}u + a_{22}v + a_{23}) = y(a_{31}u + a_{32}v + a_{33})$$

Rearrange terms:

$$a_{11}u + a_{12}v + a_{13} - a_{31}xu - a_{32}yv - a_{33}x = 0$$
$$a_{21}u + a_{22}v + a_{23} - a_{31}xu - a_{32}yv - a_{33}y = 0$$

See blackboard…

$$a_{11}u + a_{12}v + a_{13} - a_{31}xu - a_{32}yv - a_{33}x = 0$$
$$a_{21}u + a_{22}v + a_{23} - a_{31}xu - a_{32}yv - a_{33}y = 0$$

Assume $a_{33} = 1$,

$$a_{11}u + a_{12}v + a_{13} - a_{31}xu - a_{32}yv = x$$
$$a_{21}u + a_{22}v + a_{23} - a_{31}xu - a_{32}yv = y$$

Setup for 4+ points, yields 8 equations for 8 unknowns…

Perspective/Projective Transformations

- Solve Direct Linear Transform (DLT):

$$\begin{pmatrix}
u_0 & v_0 & 1 & 0 & 0 & 0 & -u_0x_0 & -v_0x_0 \\
u_1 & v_1 & 1 & 0 & 0 & 0 & -u_1x_1 & -v_1x_1 \\
u_2 & v_2 & 1 & 0 & 0 & 0 & -u_2x_2 & -v_2x_2 \\
u_3 & v_3 & 1 & 0 & 0 & 0 & -u_3x_3 & -v_3x_3 \\
0 & 0 & 0 & u_0 & v_0 & 1 & -u_0y_0 & -v_0y_0 \\
0 & 0 & 0 & u_1 & v_1 & 1 & -u_1y_1 & -v_1y_1 \\
0 & 0 & 0 & u_2 & v_2 & 1 & -u_2y_2 & -v_2y_2 \\
0 & 0 & 0 & u_3 & v_3 & 1 & -u_3y_3 & -v_3y_3
\end{pmatrix} A = b$$

where A is the vector of unknown coefficients a_{ij}

Topics

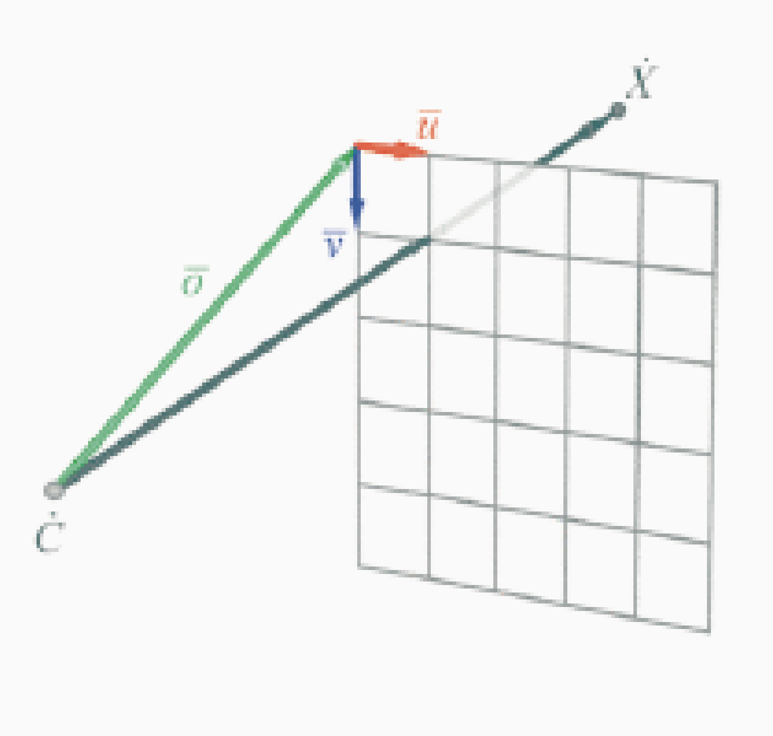
- Image morphing (2D)
- View morphing (2D+)
- Image warping (3D)

3D Image Warping

- Goal: “warp” the pixels of the image so that they appear in the correct place for a new viewpoint
- Advantage:
  - Don’t need a geometric model of the object/environment
  - Can be done in time proportional to screen size and (mostly) independent of object/environment complexity
- Disadvantage:
  - Limited resolution
  - Excessive warping reveals several visual artifacts

    (see examples)

3D Image Warping Equations

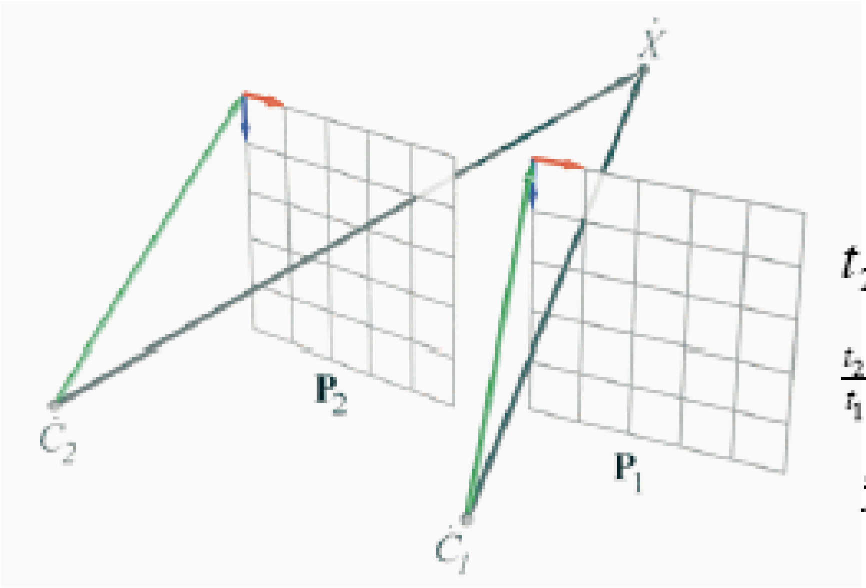


$$P = \begin{bmatrix} u_x & v_x & o_x \\ u_y & v_y & o_y \\ u_z & v_z & o_z \end{bmatrix}$$

$$\dot{X} = \dot{C} + t\, P\, \vec{x}$$

Some pictures courtesy of SIGGRAPH '99 course notes
(Leonard McMillan)

3D Image Warping Equations



$$\dot{C}_2 + t_2 P_2 \vec{x}_2 = \dot{C}_1 + t_1 P_1 \vec{x}_1$$

$$t_2 P_2 \vec{x}_2 = \dot{C}_1 - \dot{C}_2 + t_1 P_1 \vec{x}_1$$

$$t_2 \vec{x}_2 = P_2^{-1}\left(\dot{C}_1 - \dot{C}_2\right) + t_1 P_2^{-1} P_1 \vec{x}_1$$

$$\tfrac{t_2}{t_1} \vec{x}_2 = \tfrac{1}{t_1} P_2^{-1}\left(\dot{C}_1 - \dot{C}_2\right) + P_2^{-1} P_1 \vec{x}_1$$

$$\vec{x}_2 \doteq \underbrace{\tfrac{1}{t_1}}_{\delta} \underbrace{P_2^{-1}\left(\dot{C}_1 - \dot{C}_2\right)}_{e_{21}} + \underbrace{P_2^{-1} P_1}_{H_{21}} \vec{x}_1$$

3D Image Warping Equations

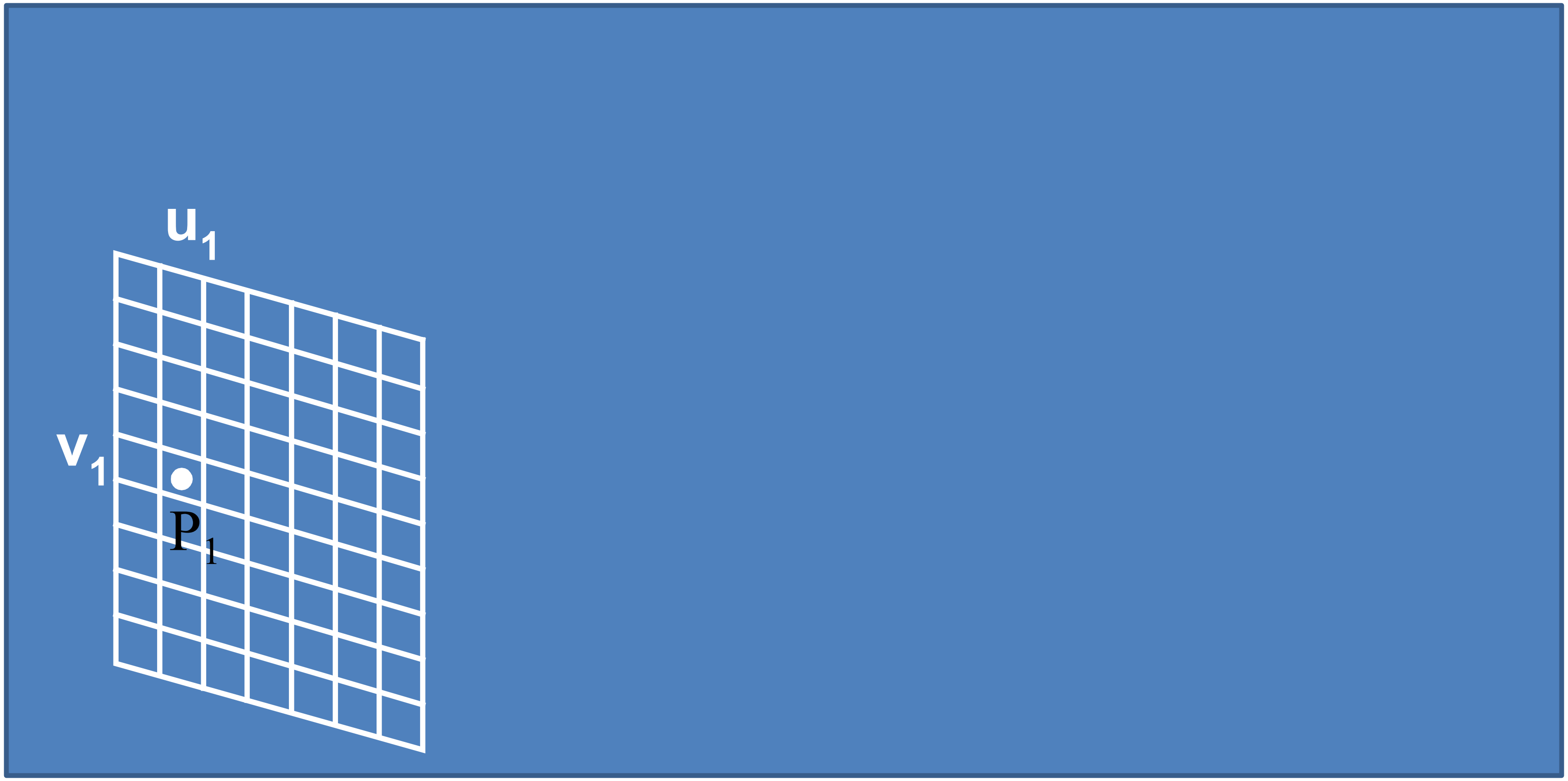
McMillan & Bishop Warping Equation:

$$x_2 = \underbrace{\delta(x_1)\, P_2^{-1}\, (c_1 - c_2)}_{\textit{Move pixels based on distance to eye}} + \underbrace{P_2^{-1}\, P_1\, x_1}_{\textit{\textasciitilde Texture mapping}}$$

- Per-pixel distance values are used to warp pixels to their correct location for the current eye position

3D Image Warping Equations

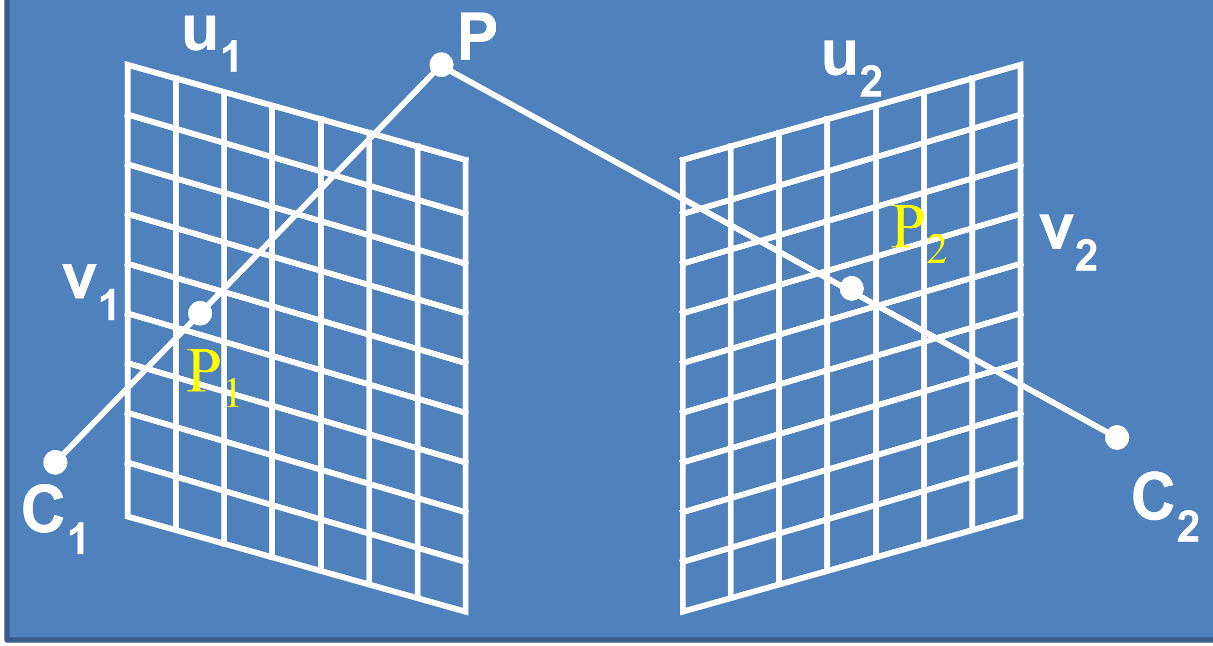
- Images enhanced with per-pixel depth [McMillan95]



3D Image Warping Equations

$$\dot{P} = \dot{C}_1 + (\bar{c}_1 + u_1\bar{a}_1 + v_1\bar{b}_1)w_1$$

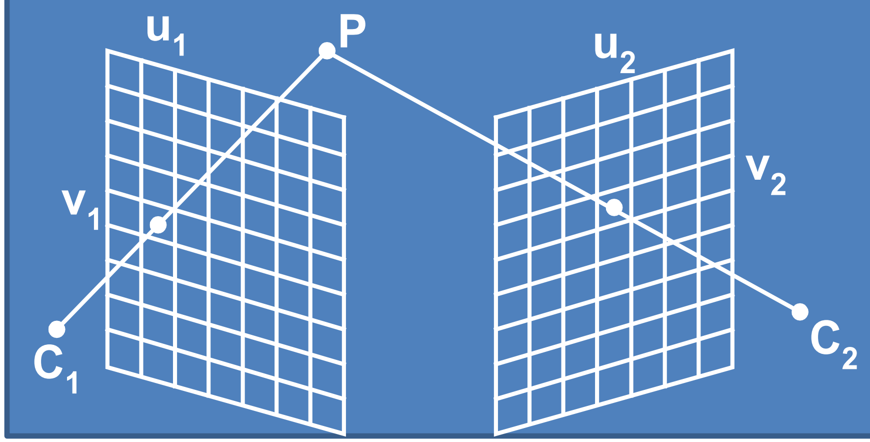
$$\dot{P} = \dot{C}_2 + (\bar{c}_2 + u_2\bar{a}_2 + v_2\bar{b}_2)w_2$$



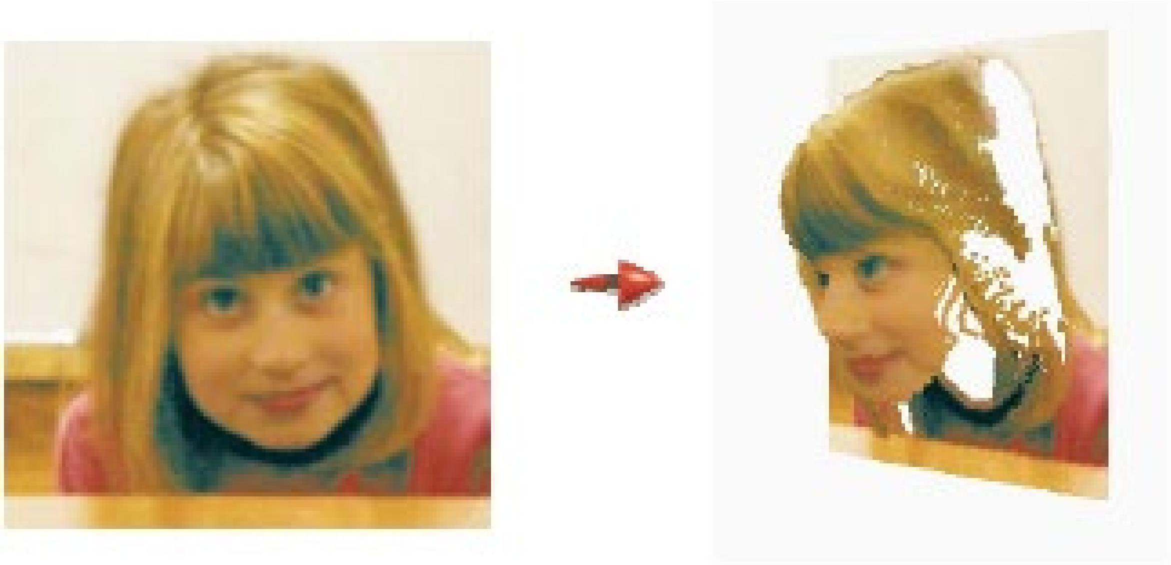
3D Image Warping Equations

$$u_2 = \frac{w_{11} + w_{12} \cdot u_1 + w_{13} \cdot v_1 + w_{14} \cdot \delta(u_1, v_1)}{w_{31} + w_{32} \cdot u_1 + w_{33} \cdot v_1 + w_{34} \cdot \delta(u_1, v_1)}$$

$$v_2 = \frac{w_{21} + w_{22} \cdot u_1 + w_{23} \cdot v_1 + w_{24} \cdot \delta(u_1, v_1)}{w_{31} + w_{32} \cdot u_1 + w_{33} \cdot v_1 + w_{34} \cdot \delta(u_1, v_1)}$$



3D Image Warping Example



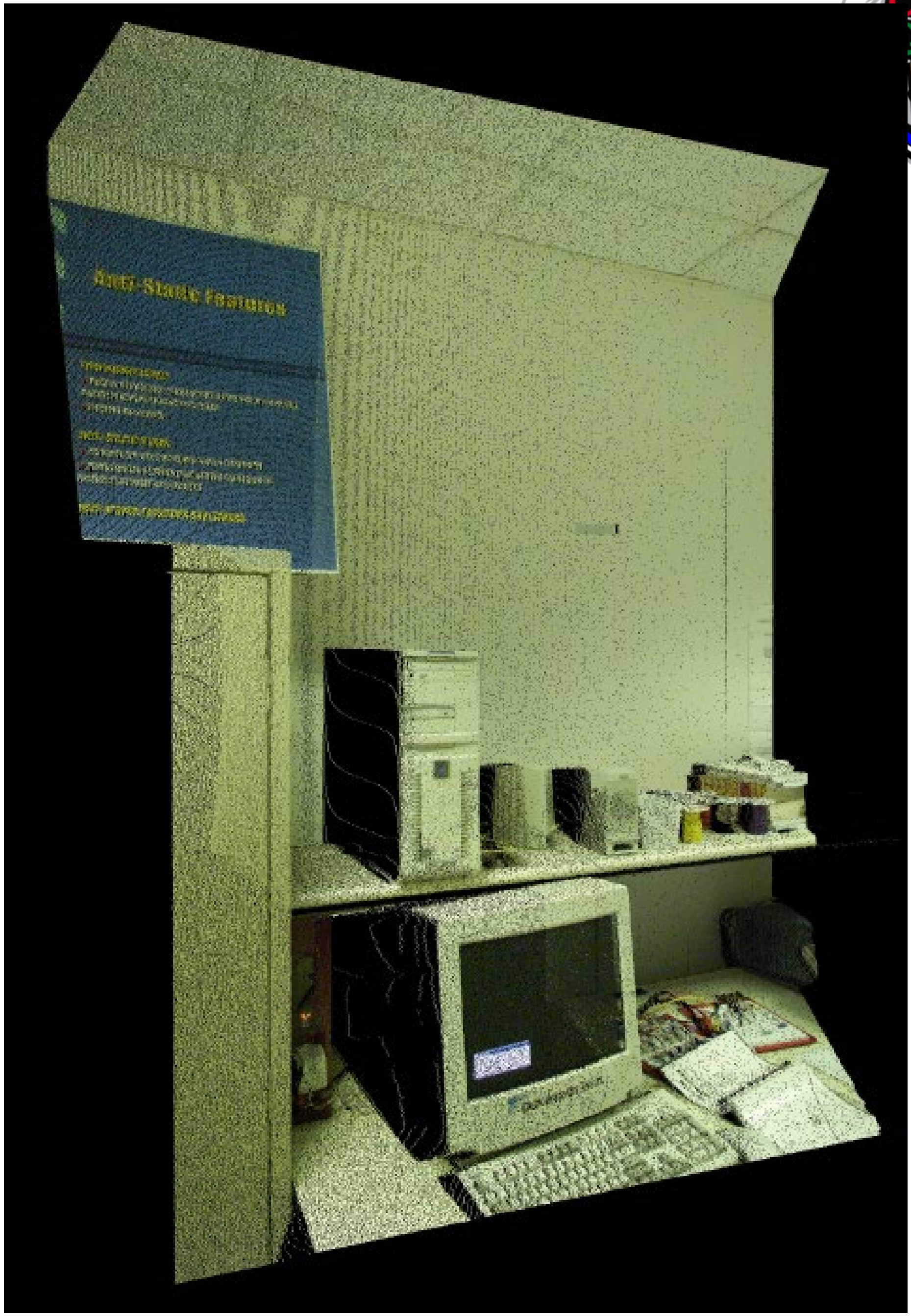
3D Image Warping Example

- DeltaSphere
  - Lars Nyland *et al.*

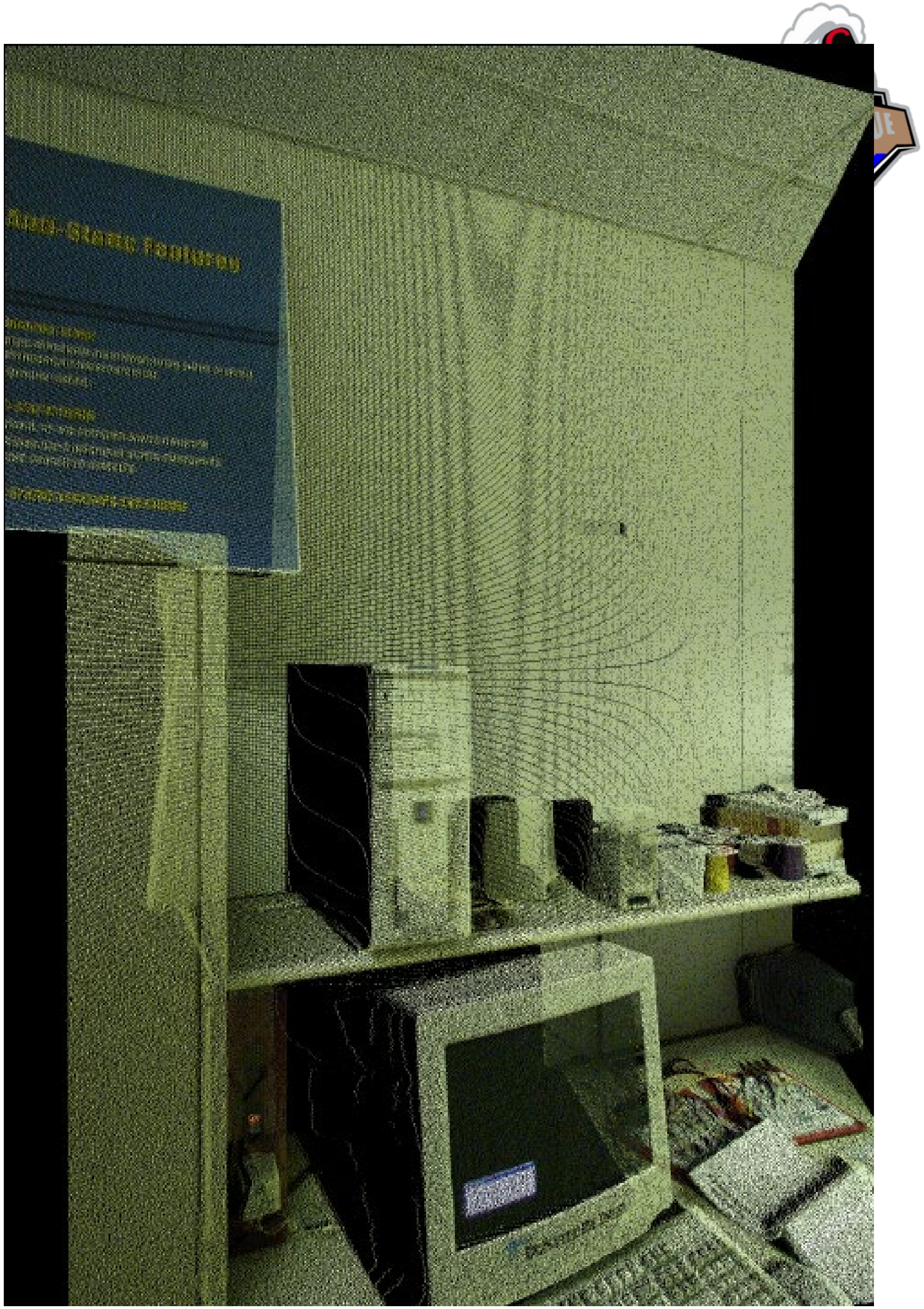
3D Image Warping Example

Anti-Static Features
GROUNDING STRAP
helps eliminate electrical noise when making experimental measurements
improves safety
ANTI-STATIC FLOOR
raised, so we can turn wires beneath
inhibits the buildup of static charges to protect sensitive circuits
ANTI-STATIC DESKTOPS AND CHAIRS
DONATED BY INTEL

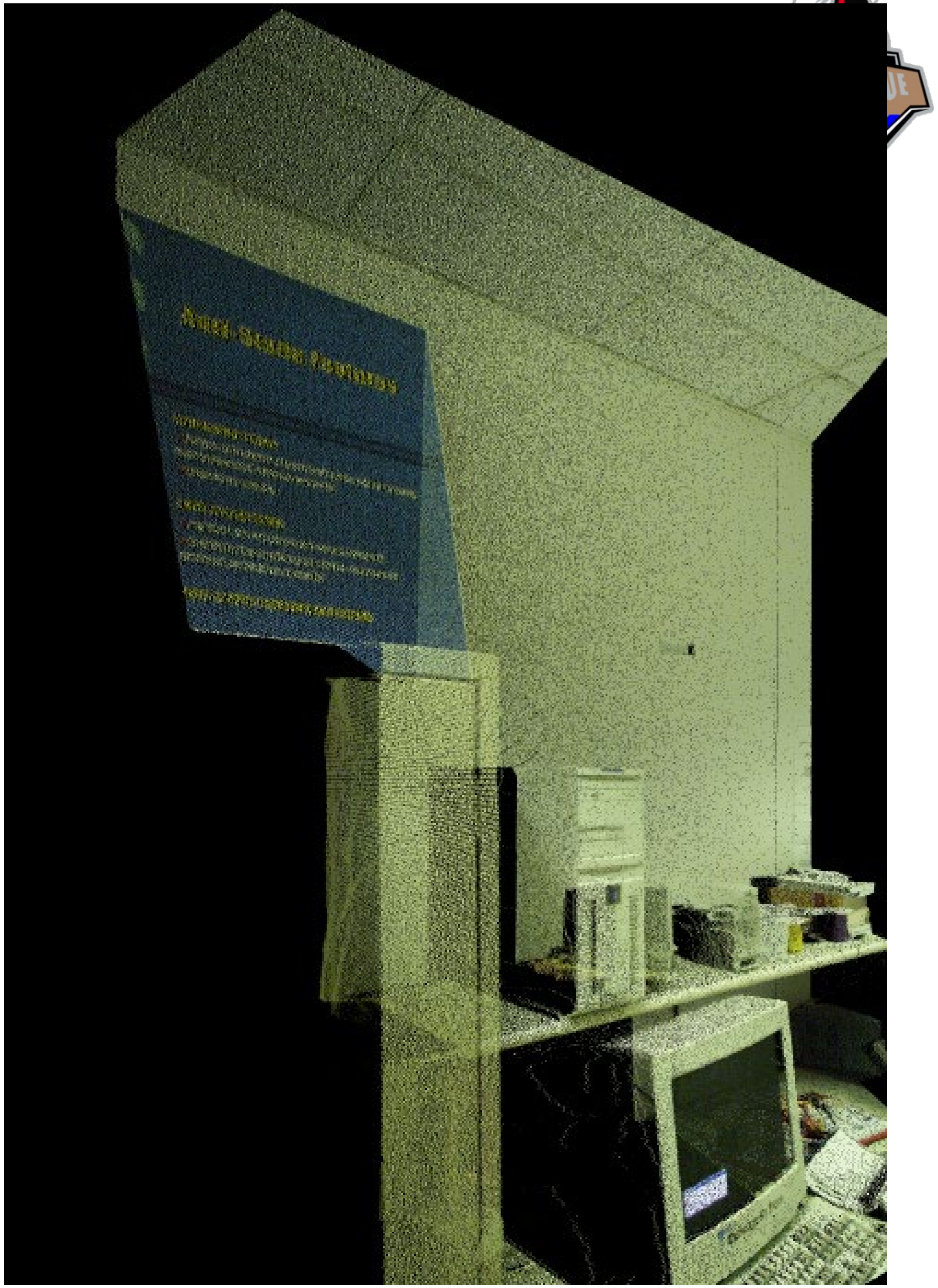
3D Image Warping Example



3D Image Warping Example

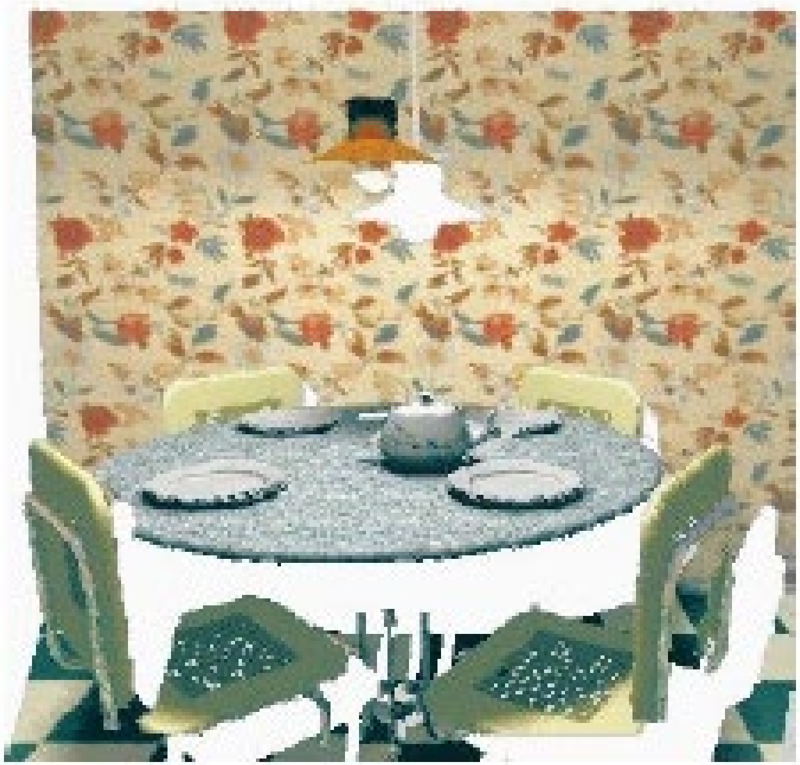


3D Image Warping Example



Disocclusions

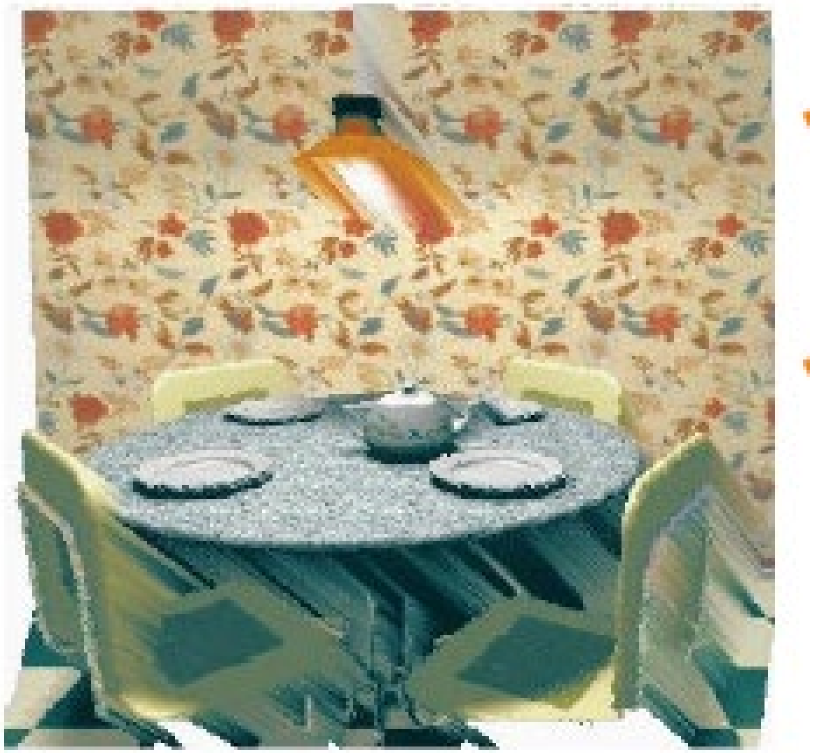
- Disocclusions (or exposure events) occur when unsampled surfaces become visible…



What can we do?

Disocclusions

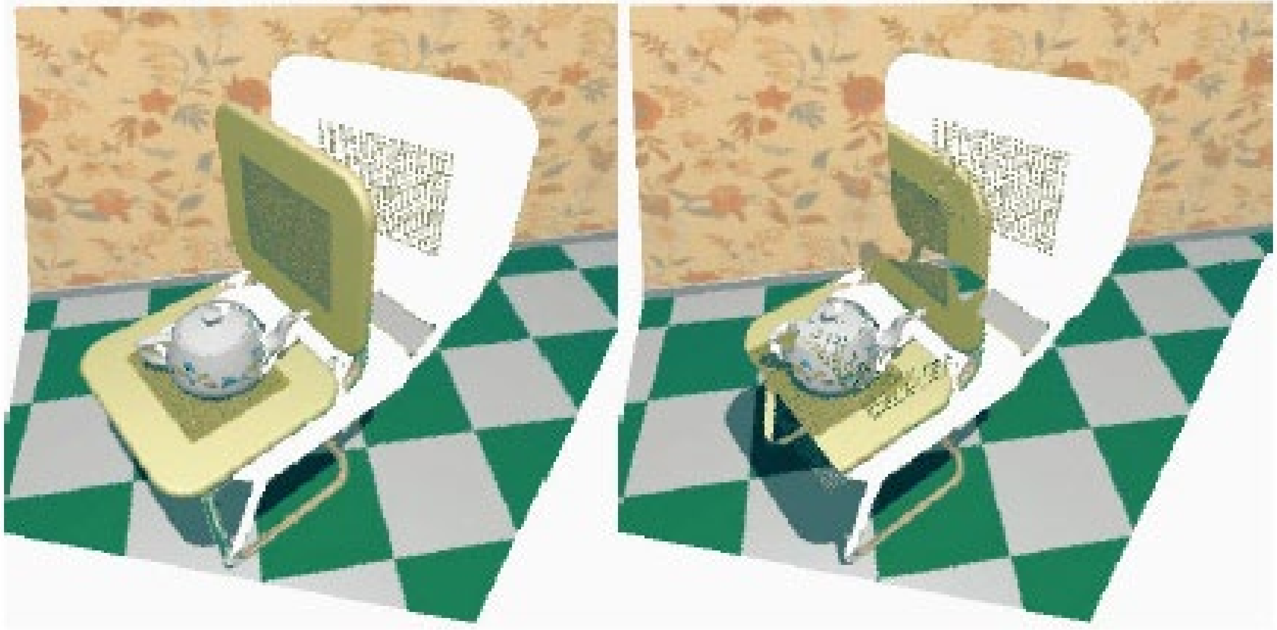
- Bilinear patches: fill in the areas



What else?

Rendering Order

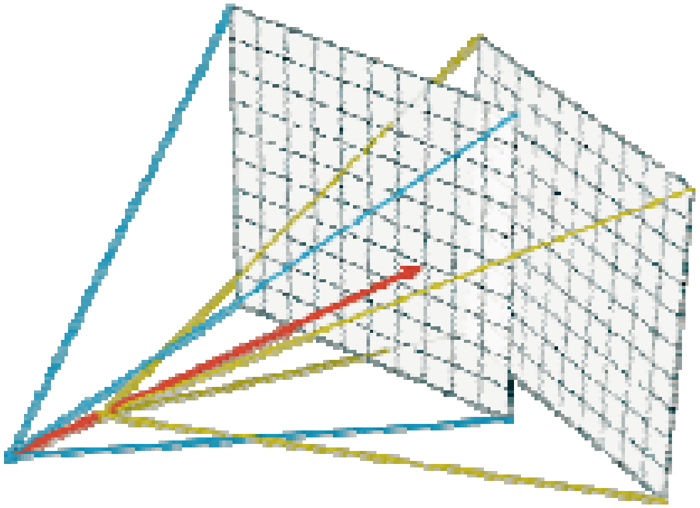
✓ The warping equation determines where points go…

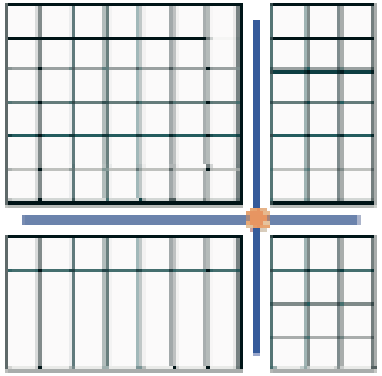


… but that is not sufficient

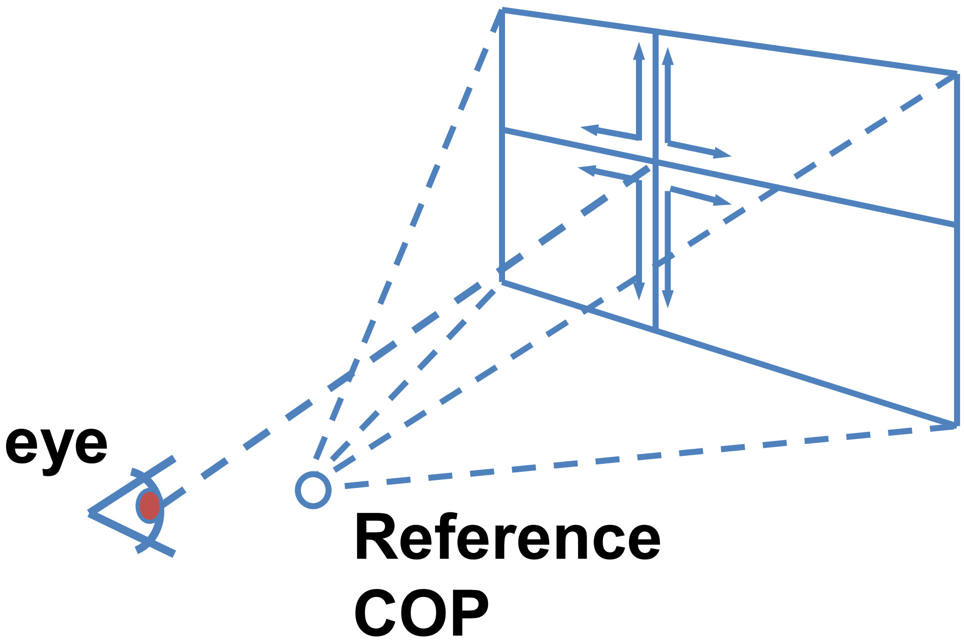
Occlusion Compatible Rendering Order

- Epipolar geometry
- Project the new viewpoint onto the original image and divide the image into 1, 2 or 4 "sheets"





Occlusion Compatible Rendering Order



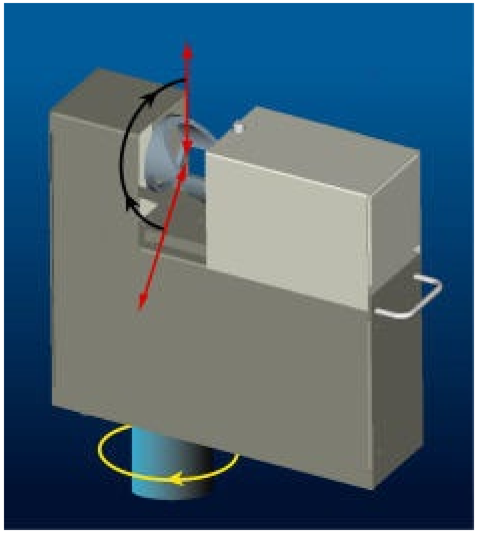
- A raster scan of each sheet produces a back-to-front ordering of warped pixels

Splatting

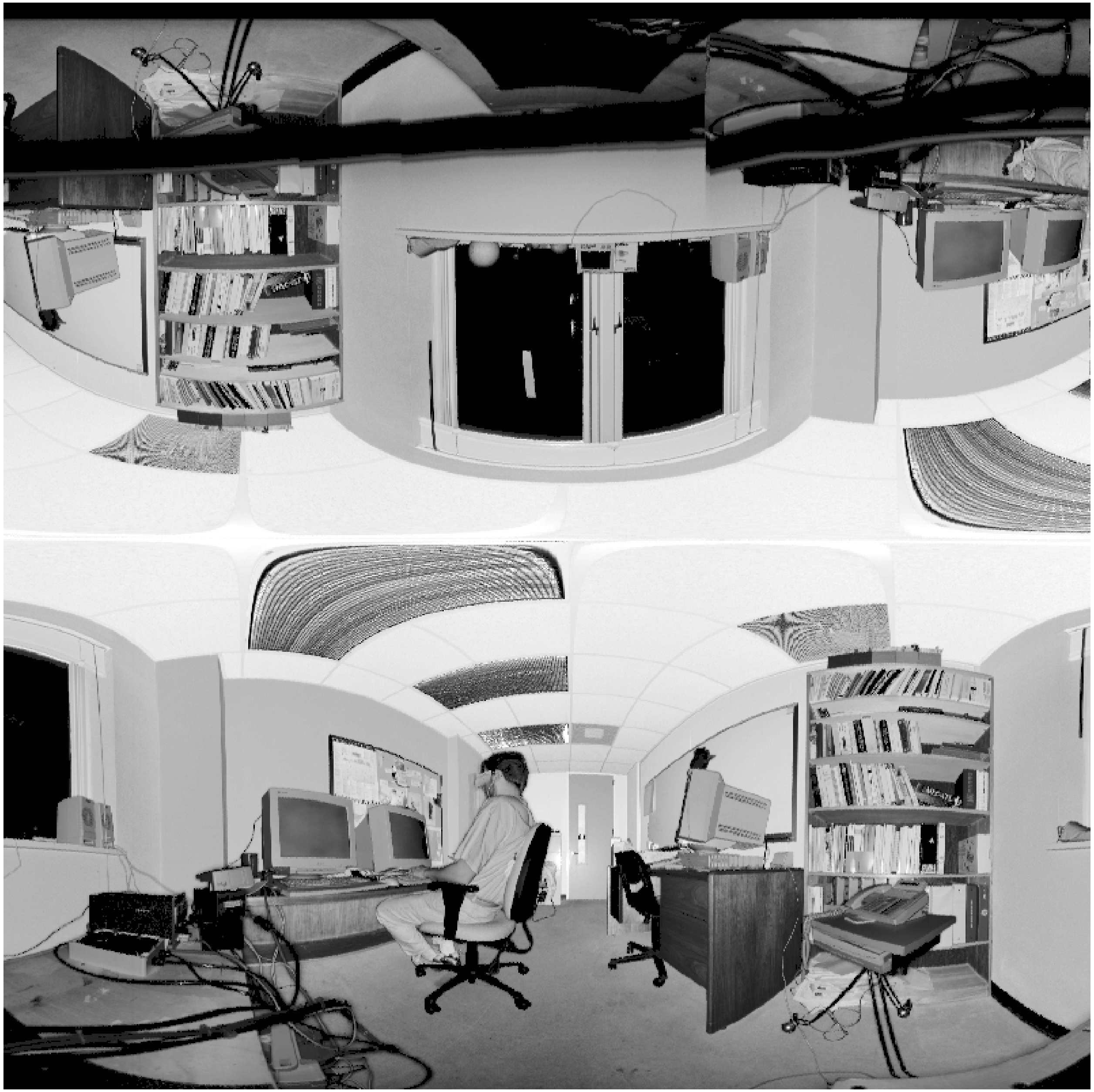
- One pixel in the source image does not necessarily project to one pixel in the destination image
  - e.g., if you are walking towards something, the sample might get larger…
- A solution: estimate shape and size of footprint of warped samples
  - expensive to do accurately
  - square/rectangular approximations can be done quickly (3x3 or 5x5 splats)
  - occlusion-compatible rendering will take care of oversized splats
  - *BUT large splats can make the image seem blocky/low-res*

More Examples Using the DeltaSphere

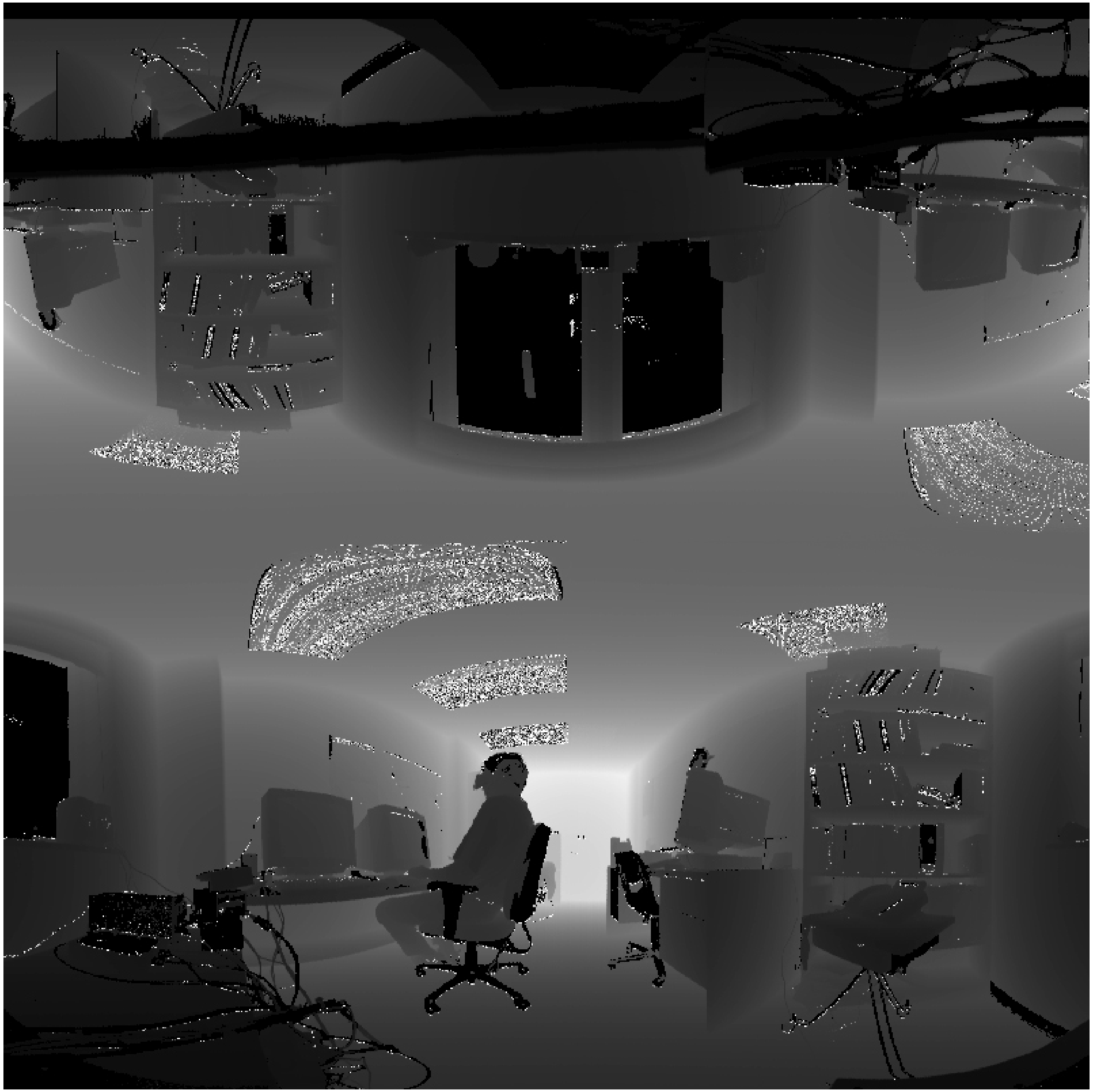
- Lars Nyland *et al.*



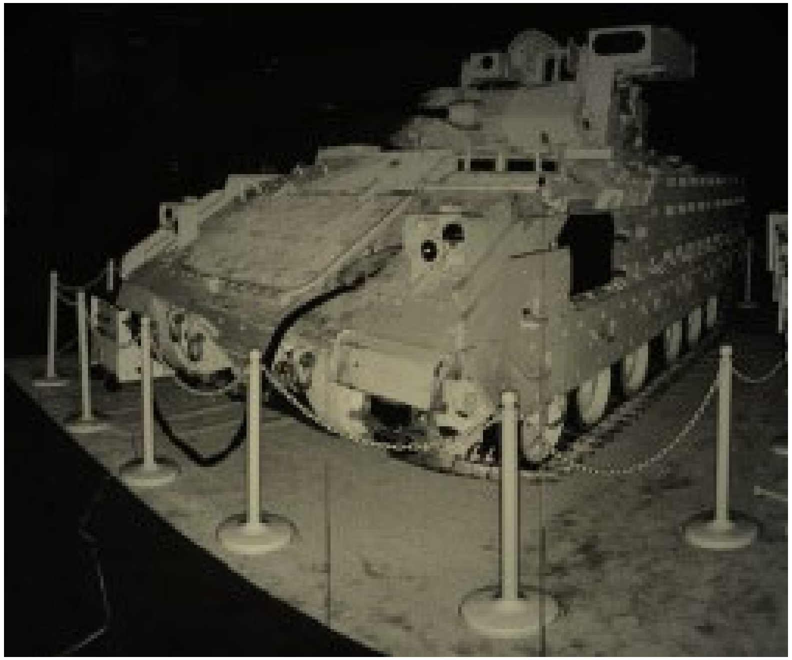
courtesy 3rd Tech Inc.



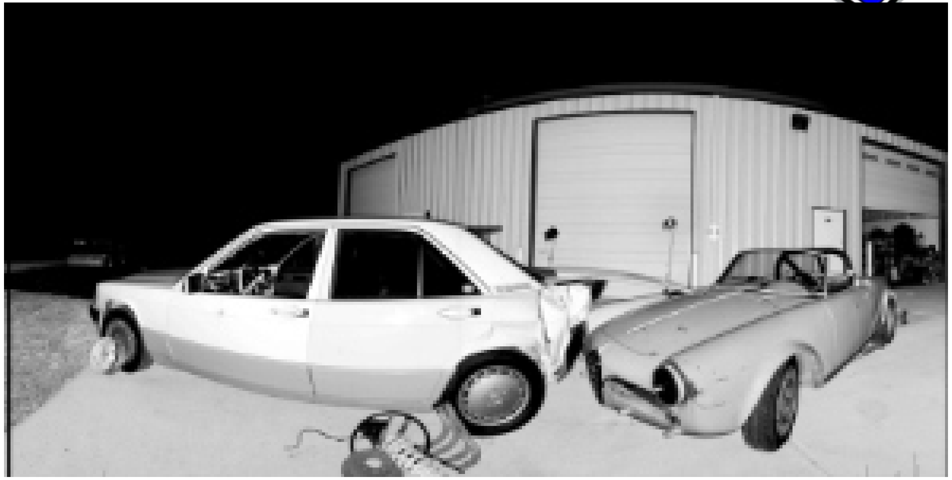
- 300° x 300° panorama
- this is the reflected light

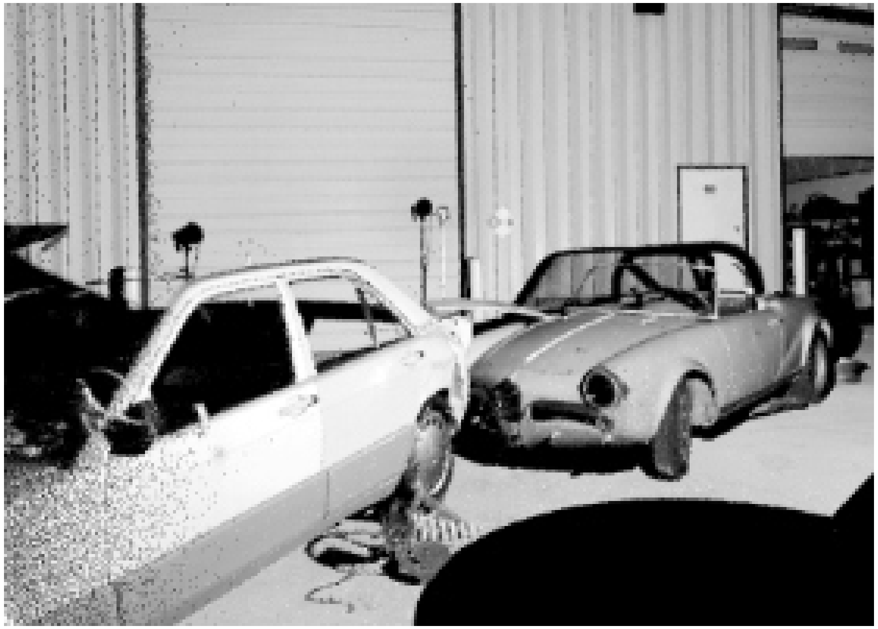


- 300° x 300° panorama
- this is the range light



spherical range panoramas

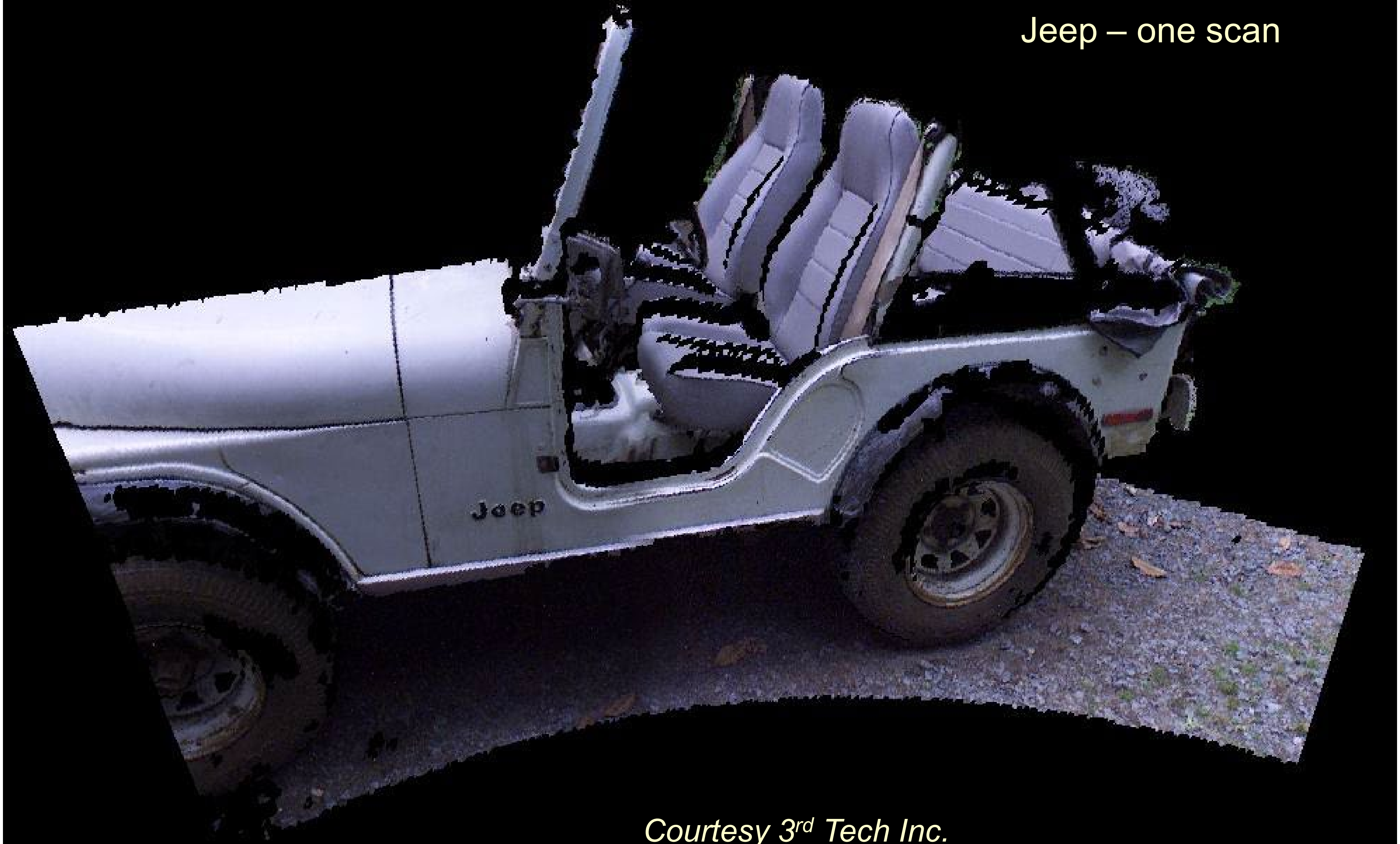




planar re-projection

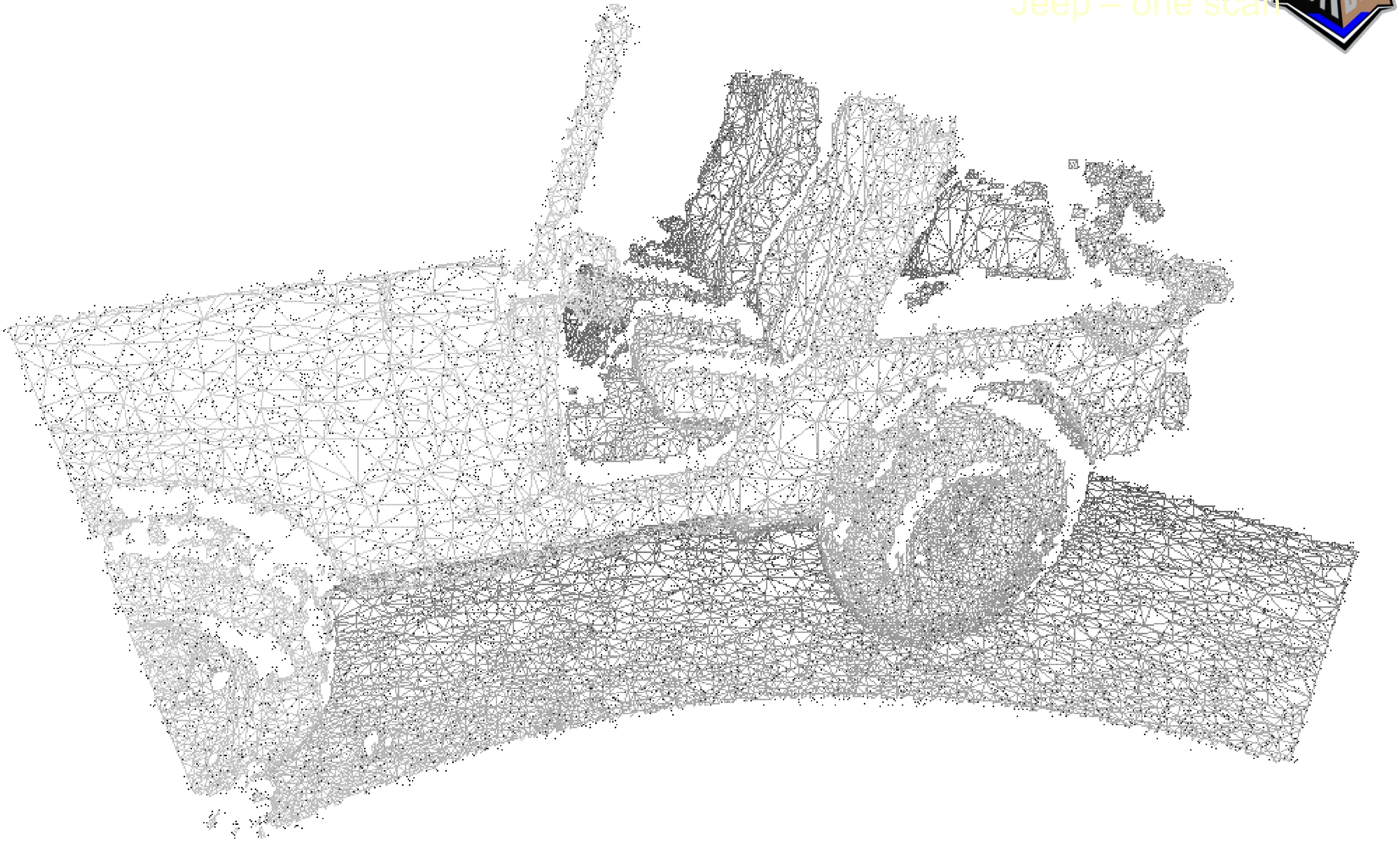
Courtesy 3rd Tech Inc.

Jeep – one scan



Courtesy 3rd Tech Inc.

Jeep – one scan



Courtesy 3rd Tech Inc.

Complete Jeep model

Courtesy 3rd Tech Inc.

3D Modeling
Can be Murder
3rdTech