Computational Photography and Video:

Warping, Morphing and Mosaics

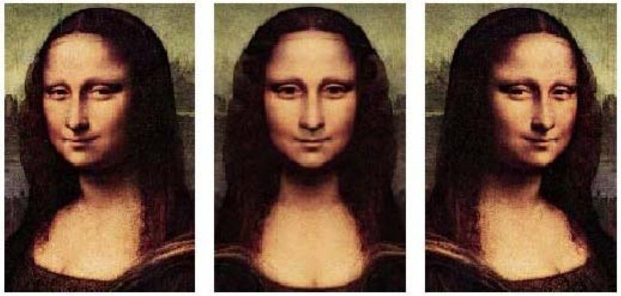
Prof. Marc Pollefeys

ETH

inf Informatik Computer Science

Today's schedule

- Last week's recap
- Warping
- Morphing
- Mosaics



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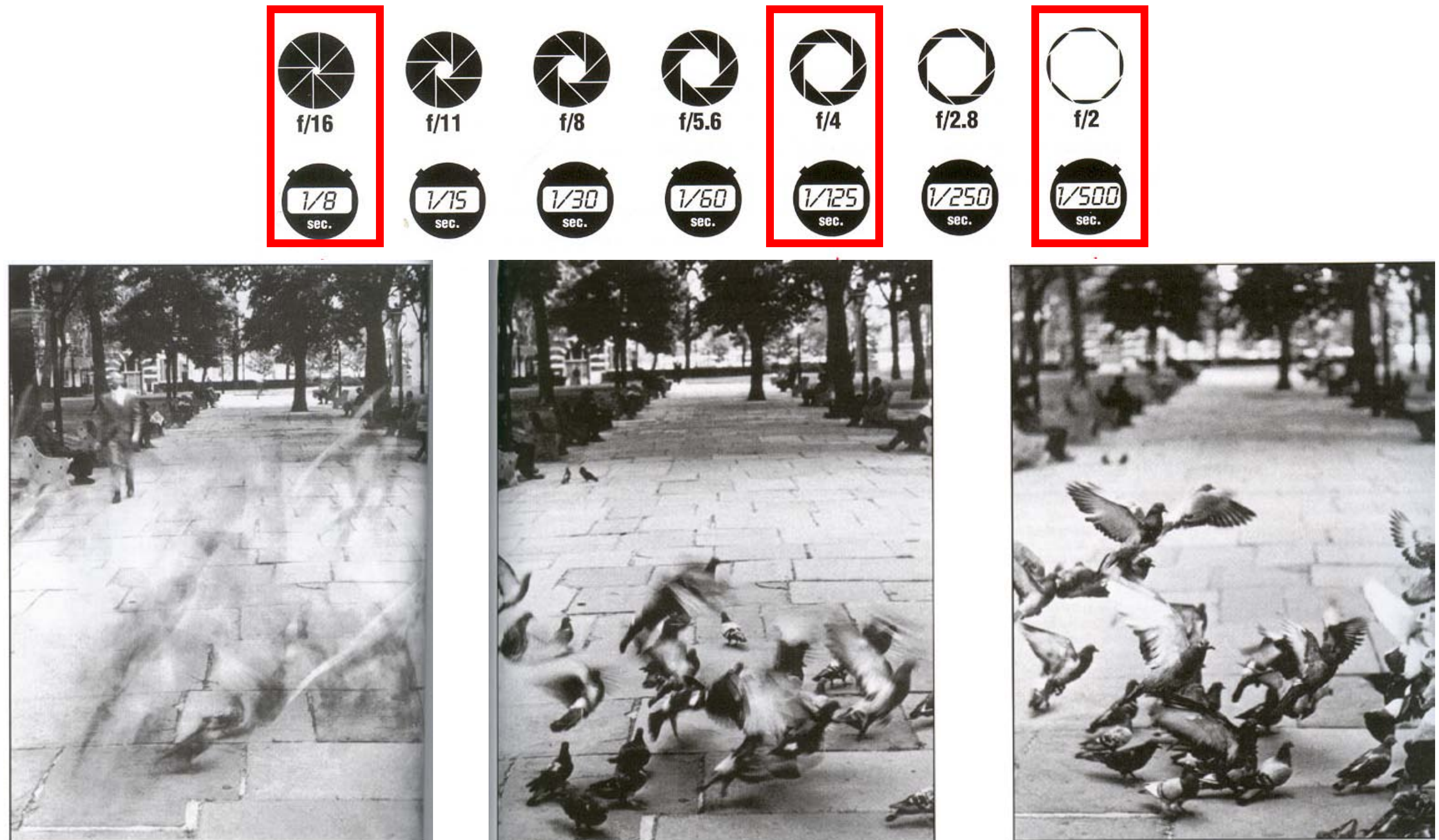
Exposure: shutter vs. aperture

- Trade-off motion blur vs. depth-of-field



Small aperture (deep depth of field), slow shutter speed (motion blurred). *In this scene, a small aperture (f/16) produced great depth of field; the nearest paving stones as well as the farthest trees are sharp. But to admit enough light, a slow shutter speed (1/8 sec) was needed; it was too slow to show moving pigeons sharply. It also meant that a tripod had to be used to hold the camera steady.*

Medium aperture (moderate depth of field), medium shutter speed (some motion sharp). *A medium aperture (f/4) and shutter speed (1/125 sec) sacrifice some background detail to produce recognizable images of the birds. But the exposure is still too long to show the motion of the birds' wings sharply.*

Large aperture (shallow depth of field), fast shutter speed (motion sharp). *A fast shutter speed (1/500 sec) stops the motion of the pigeons so completely that the flapping wings are frozen. But the wide aperture (f/2) needed gives so little depth of field that the background is now out of focus.*

(also gain/ISO sensitivity)

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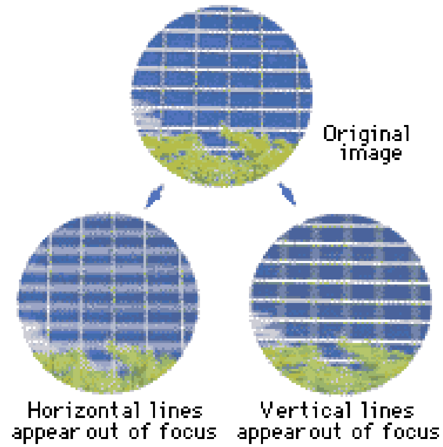
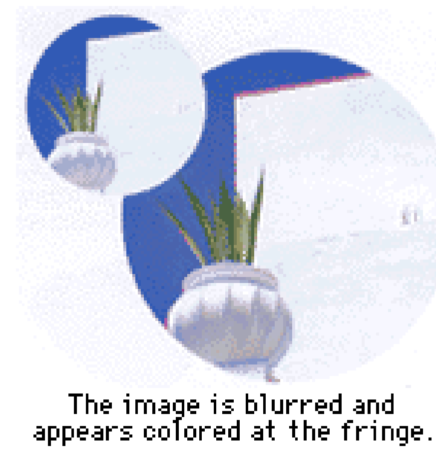
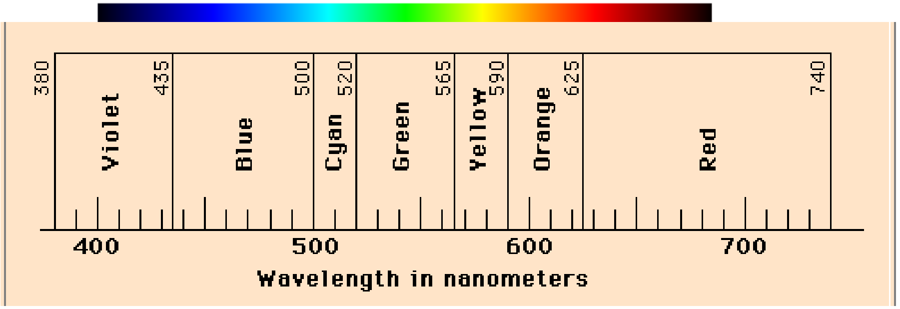
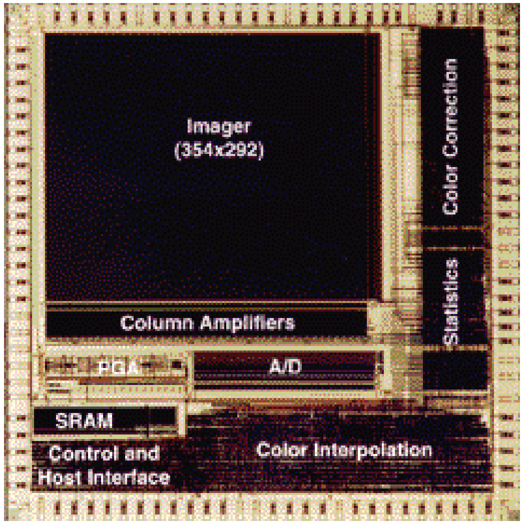
Imperfect lenses: aberrations, etc.

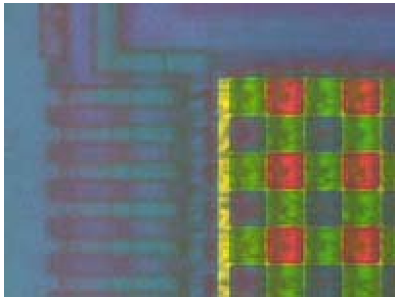


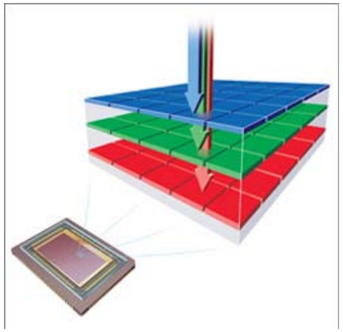


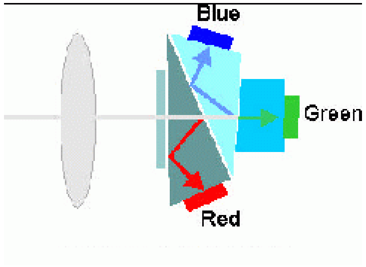
Sensors and color

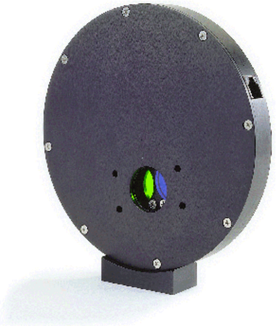












Schedule	Computational Photography and Video	
24 Feb	Introduction to Computational Photography	
3 Mar	More on Camera,Sensors and Color	Assignment 1
10 Mar	Warping, Mosaics and Morphing	Assignment 2
17 Mar	Blending and compositing	Assignment 3
24 Mar	High-dynamic range	Assignment 4
31 Mar	*TBD*	Project proposals
7 Apr	*Easter holiday – no classes*	
14 Apr	*TBD*	Papers
21 Apr	*TBD*	Papers
28 Apr	*TBD*	Papers
5 May	*TBD*	Project update
12 May	*TBD*	Papers
19 May	*TBD*	Papers
26 May	*TBD*	Papers
2 June	Final project presentation	Final project presentation

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Image Warping

image filtering: change ***range*** of image

$$g(x) = T(f(x))$$

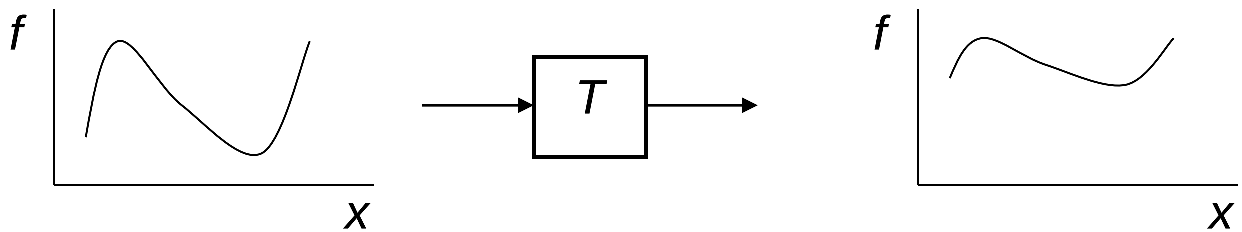
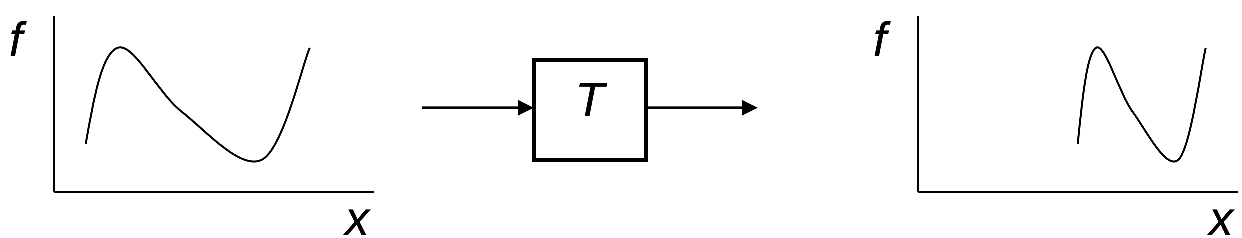


image warping: change ***domain*** of image

$$g(x) = f(T(x))$$



today lots of slides from Alexei Efros

Image Warping

image filtering: change ***range*** of image

$$g(x) = T(f(x))$$

f

$\longrightarrow \boxed{T} \longrightarrow$

g

image warping: change ***domain*** of image

$$g(x) = f(T(x))$$

f

$\longrightarrow \boxed{T} \longrightarrow$

g

Parametric (global) warping

- Examples of parametric warps:

translation

rotation

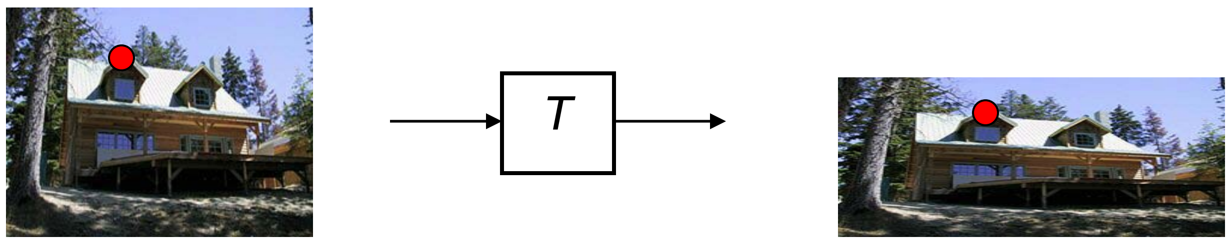
aspect

affine

perspective

cylindrical

Parametric (global) warping



p = (x,y) **p'** = (x',y')

- Transformation T is a coordinate-changing machine:

  p' = T(p)

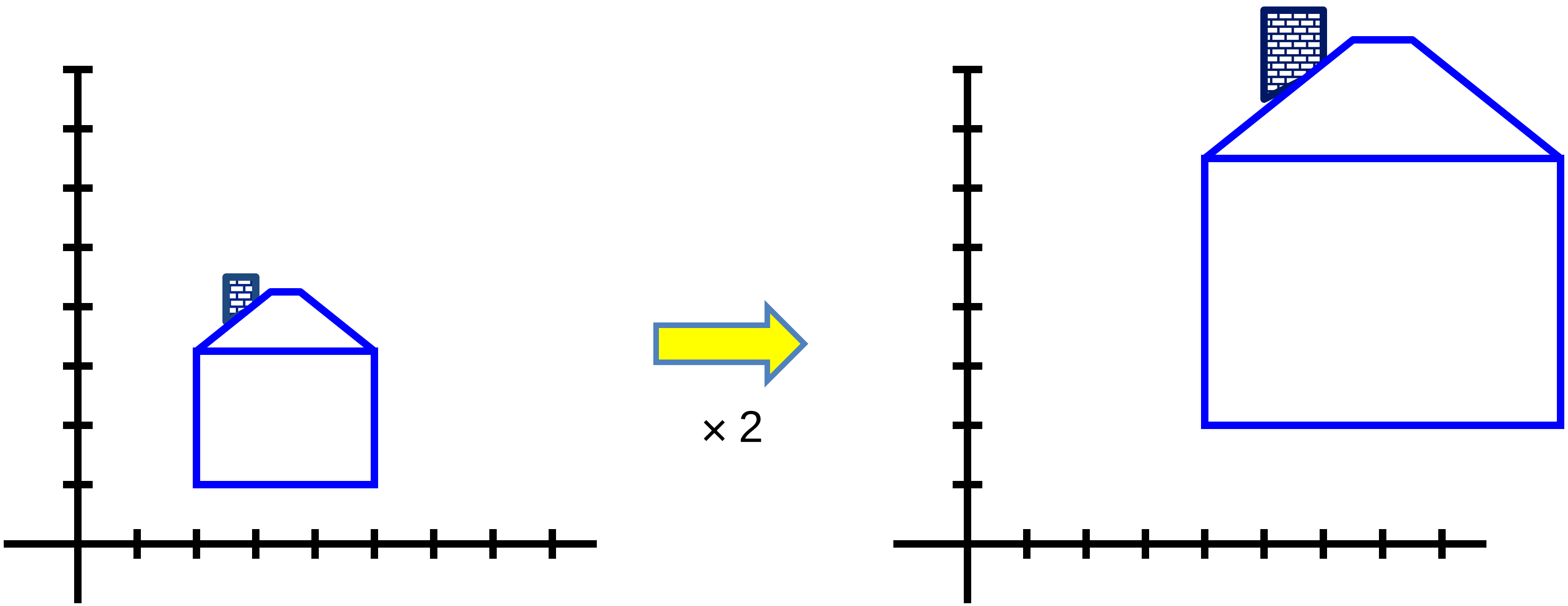
- What does it mean that T is global?
  - Is the same for any point p
  - can be described by just a few numbers (parameters)
- Let's represent T as a matrix:

  p' = **M**p

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \mathbf{M} \begin{bmatrix} x \\ y \end{bmatrix}$$

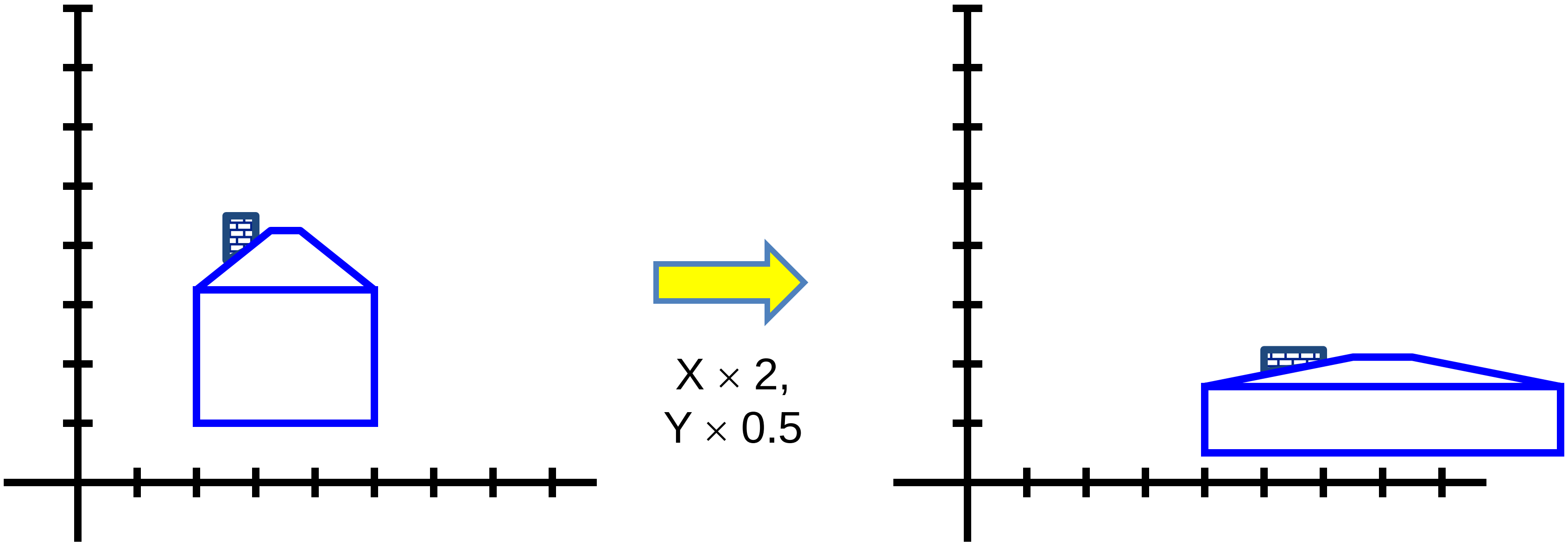
Scaling

- *Scaling* a coordinate means multiplying each of its components by a scalar
- *Uniform scaling* means this scalar is the same for all components:



Scaling

- *Non-uniform scaling*: different scalars per component:



Scaling

- Scaling operation:

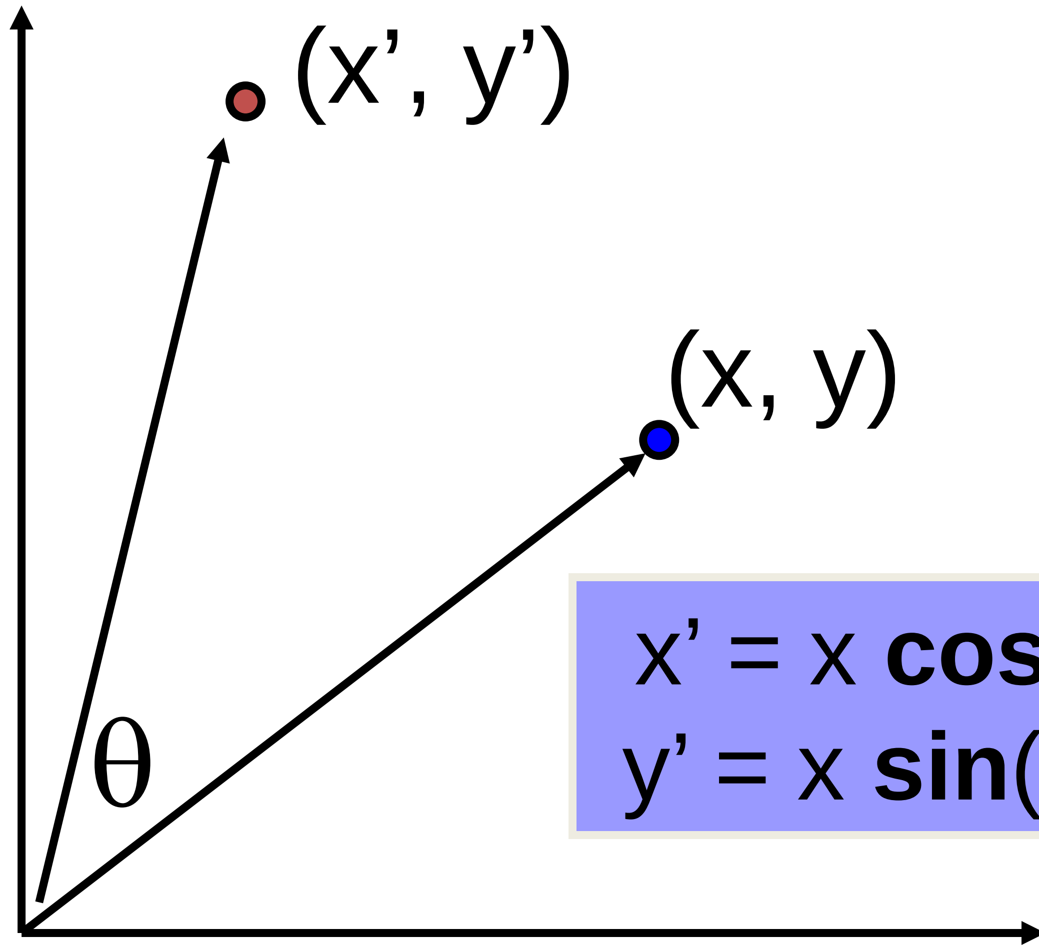
$$x' = ax$$
$$y' = by$$

- Or, in matrix form:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \underbrace{\begin{bmatrix} a & 0 \\ 0 & b \end{bmatrix}}_{\textit{scaling matrix S}} \begin{bmatrix} x \\ y \end{bmatrix}$$

What’s inverse of S?

2-D Rotation



$$x' = x\,\mathbf{cos}(\theta) - y\,\mathbf{sin}(\theta)$$
$$y' = x\,\mathbf{sin}(\theta) + y\,\mathbf{cos}(\theta)$$

2-D Rotation

- This is easy to capture in matrix form:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \underbrace{\begin{bmatrix} \cos(\theta) & -\sin(\theta) \\ \sin(\theta) & \cos(\theta) \end{bmatrix}}_{\mathbf{R}} \begin{bmatrix} x \\ y \end{bmatrix}$$

- Even though sin(θ) and cos(θ) are nonlinear functions of θ,
  - ***x' is a linear combination of x and y***
  - ***y' is a linear combination of x and y***

- What is the inverse transformation?
  - Rotation by –θ
  - For rotation matrices $\mathbf{R}^{-1} = \mathbf{R}^{T}$

2x2 Matrices

- What types of transformations can be represented with a 2x2 matrix?

2D Identity?

$$x' = x$$
$$y' = y$$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

2D Scale around (0,0)?

$$\boldsymbol{x}' = \boldsymbol{s}_x * \boldsymbol{x}$$
$$\boldsymbol{y}' = \boldsymbol{s}_y * \boldsymbol{y}$$

$$\begin{bmatrix} \boldsymbol{x}' \\ \boldsymbol{y}' \end{bmatrix} = \begin{bmatrix} \boldsymbol{s}_x & 0 \\ 0 & \boldsymbol{s}_y \end{bmatrix} \begin{bmatrix} \boldsymbol{x} \\ \boldsymbol{y} \end{bmatrix}$$

2x2 Matrices

- What types of transformations can be represented with a 2x2 matrix?

2D Rotate around (0,0)?

$$x' = \cos\Theta * x - \sin\Theta * y$$
$$y' = \sin\Theta * x + \cos\Theta * y$$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\Theta & -\sin\Theta \\ \sin\Theta & \cos\Theta \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

2D Shear?

$$x' = x + sh_x * y$$
$$y' = sh_y * x + y$$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} 1 & sh_x \\ sh_y & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

2x2 Matrices

- What types of transformations can be represented with a 2x2 matrix?

2D Mirror about Y axis?

$$x' = -x \qquad y' = y$$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

2D Mirror over (0,0)?

$$x' = -x \qquad y' = -y$$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

2x2 Matrices

- What types of transformations can be represented with a 2x2 matrix?

2D Translation?

$$x' = x + t_x$$
$$y' = y + t_y$$

NO!

Only linear 2D transformations can be represented with a 2x2 matrix

All 2D Linear Transformations

- Linear transformations are combinations of …
  - Scale,
  - Rotation,
  - Shear, and
  - Mirror
- Properties of linear transformations:
  - Origin maps to origin
  - Lines map to lines
  - Parallel lines remain parallel
  - Ratios are preserved
  - Closed under composition

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix} \begin{bmatrix} e & f \\ g & h \end{bmatrix} \begin{bmatrix} i & j \\ k & l \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

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Homogeneous Coordinates

- **Q: How can we represent translation as a 3x3 matrix?**

$$x' = x + t_x$$

$$y' = y + t_y$$

Homogeneous Coordinates

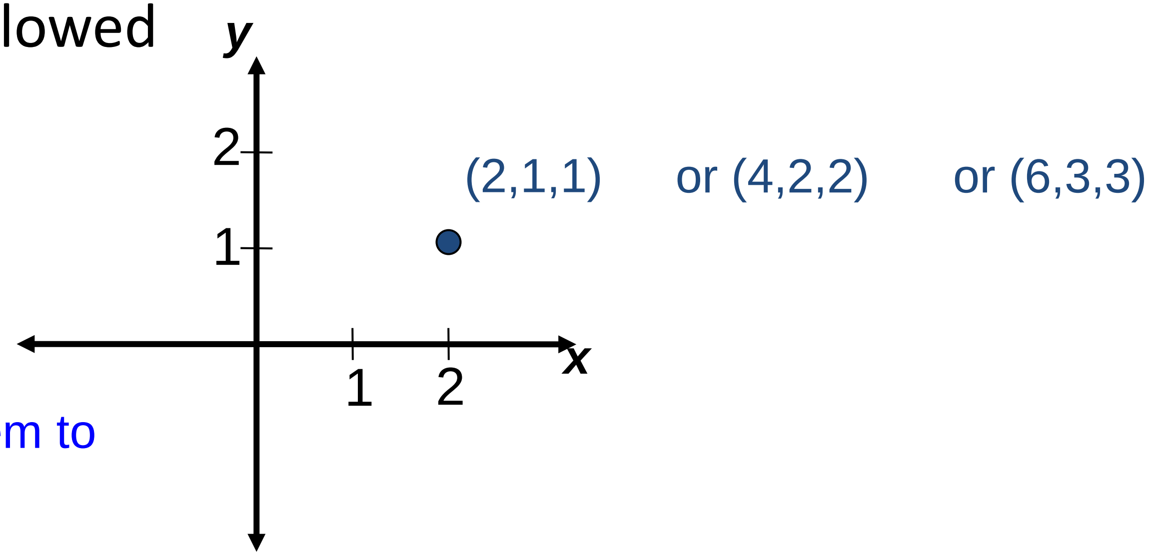
Homogeneous coordinates

– represent coordinates in 2 dimensions with a 3-vector

$$\begin{bmatrix} x \\ y \end{bmatrix} \xrightarrow{\text{homogeneous coords}} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

Homogeneous Coordinates

- Add a 3rd coordinate to every 2D point
  - (x, y, w) represents a point at location (x/w, y/w)
  - (x, y, 0) represents a point at infinity
  - (0, 0, 0) is not allowed



Convenient coordinate system to represent many useful transformations

Homogeneous Coordinates

Q: How can we represent translation as a 3x3 matrix?

$$x' = x + t_x$$

$$y' = y + t_y$$

A: Using the rightmost column:

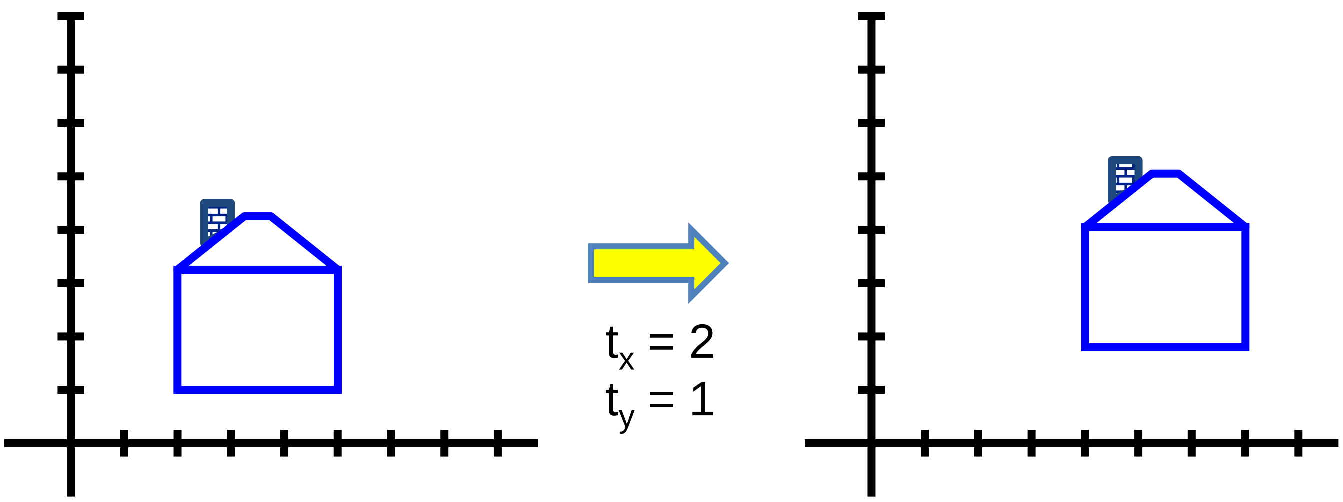
$$\mathbf{Translation} = \begin{bmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{bmatrix}$$

Translation

Example of translation

Homogeneous Coordinates

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix} = \begin{bmatrix} x + t_x \\ y + t_y \\ 1 \end{bmatrix}$$



Basic 2D Transformations

- Basic 2D transformations as 3x3 matrices

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & t_x \\ 0 & 1 & t_y \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

Translate

$$\begin{bmatrix} \boldsymbol{x}' \\ \boldsymbol{y}' \\ 1 \end{bmatrix} = \begin{bmatrix} \boldsymbol{s}_x & 0 & 0 \\ 0 & \boldsymbol{s}_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \boldsymbol{x} \\ \boldsymbol{y} \\ 1 \end{bmatrix}$$

Scale

$$\begin{bmatrix} x' \\ y' \\ 1 \end{bmatrix} = \begin{bmatrix} \cos\Theta & -\sin\Theta & 0 \\ \sin\Theta & \cos\Theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ 1 \end{bmatrix}$$

Rotate

$$\begin{bmatrix} \boldsymbol{x}' \\ \boldsymbol{y}' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & \boldsymbol{sh}_x & 0 \\ \boldsymbol{sh}_y & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \boldsymbol{x} \\ \boldsymbol{y} \\ 1 \end{bmatrix}$$

Shear

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Affine Transformations

- Affine transformations are combinations of …
  - Linear transformations, and
  - Translations
- Properties of affine transformations:
  - Origin does not necessarily map to origin
  - Lines map to lines
  - Parallel lines remain parallel
  - Ratios are preserved
  - Closed under composition
  - Models change of basis

$$\begin{bmatrix} x' \\ y' \\ w \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \\ w \end{bmatrix}$$

Projective Transformations

- Projective transformations …
  - Affine transformations, and
  - Projective warps
- Properties of projective transformations:
  - Origin does not necessarily map to origin
  - Lines map to lines
  - Parallel lines do not necessarily remain parallel
  - Ratios are not preserved
  - Closed under composition
  - Models change of basis

$$\begin{bmatrix} x' \\ y' \\ w' \end{bmatrix} = \begin{bmatrix} a & b & c \\ d & e & f \\ g & h & i \end{bmatrix} \begin{bmatrix} x \\ y \\ w \end{bmatrix}$$

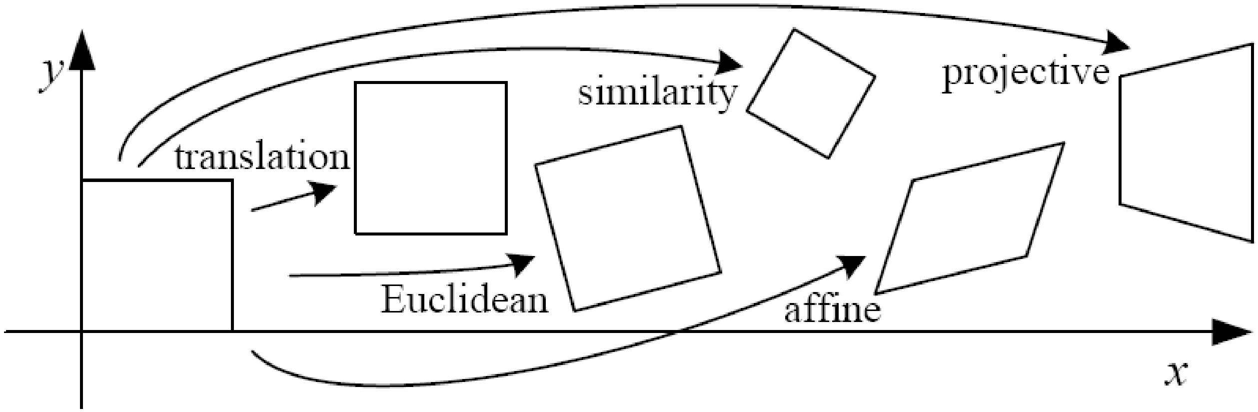
Matrix Composition

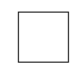
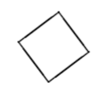
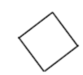
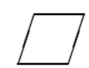
- Transformations can be combined by matrix multiplication

$$\begin{bmatrix} x' \\ y' \\ w' \end{bmatrix} = \left(\begin{bmatrix} 1 & 0 & tx \\ 0 & 1 & ty \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \cos\Theta & -\sin\Theta & 0 \\ \sin\Theta & \cos\Theta & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} sx & 0 & 0 \\ 0 & sy & 0 \\ 0 & 0 & 1 \end{bmatrix} \right) \begin{bmatrix} x \\ y \\ w \end{bmatrix}$$

p' = $T(t_x,t_y)$ $R(\Theta)$ $S(s_x,s_y)$ **p**

2D image transformations

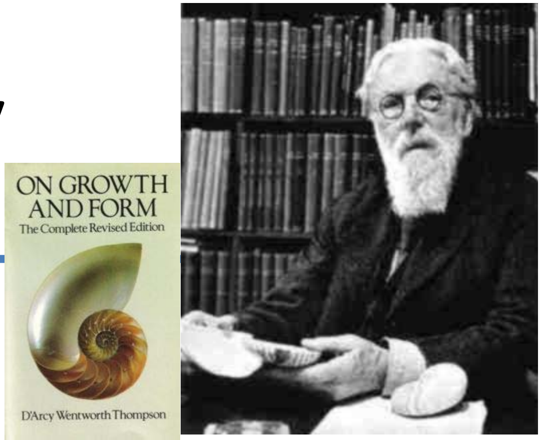


Name	Matrix	# D.O.F.	Preserves:	Icon
translation	$\left[\begin{array}{c\|c} \boldsymbol{I} & \boldsymbol{t} \end{array}\right]_{2\times 3}$			
rigid (Euclidean)	$\left[\begin{array}{c\|c} \boldsymbol{R} & \boldsymbol{t} \end{array}\right]_{2\times 3}$			
similarity	$\left[\begin{array}{c\|c} s\boldsymbol{R} & \boldsymbol{t} \end{array}\right]_{2\times 3}$			
affine	$\left[\begin{array}{c} \boldsymbol{A} \end{array}\right]_{2\times 3}$			
projective	$\left[\begin{array}{c} \tilde{\boldsymbol{H}} \end{array}\right]_{3\times 3}$			

These transformations are a nested set of groups

- Closed under composition and inverse is a member

Image Warping in Biology



- D'Arcy Thompson
  - http://www-groups.dcs.st-and.ac.uk/~history/Miscellaneous/darcy.html
  - http://en.wikipedia.org/wiki/D'Arcy_Thompson
- Importance of shape and structure in evolution

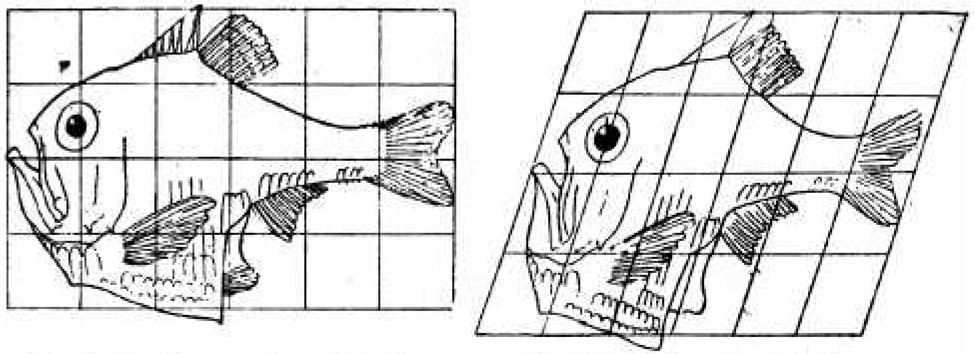
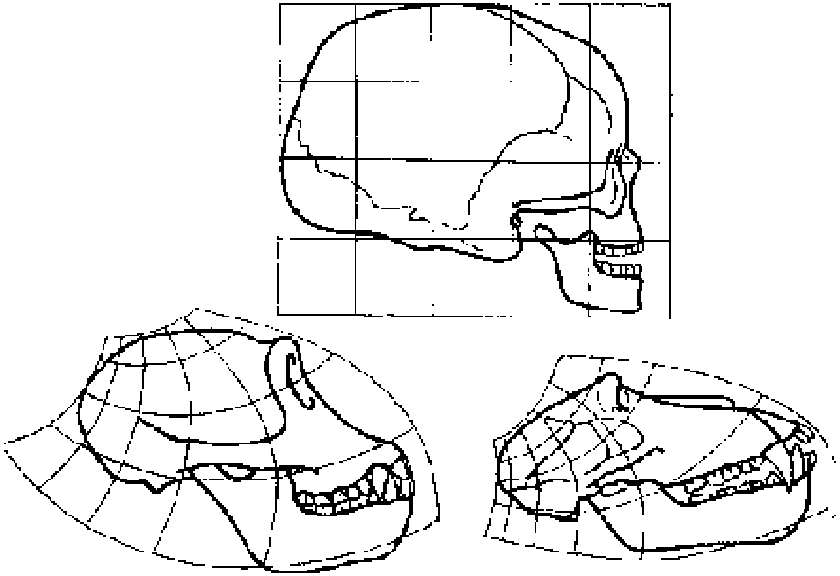


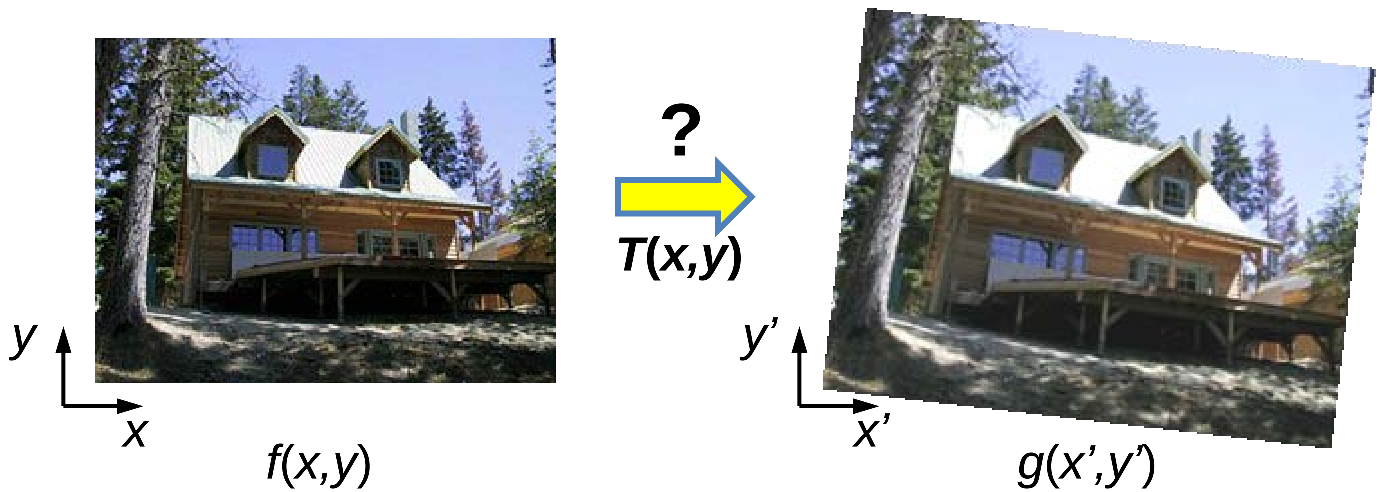
Fig. 517. *Argyropelecus Olfersi.* Fig. 518. *Sternoptyx diaphana.*



Skulls of a human, a chimpanzee and a baboon and transformations between them

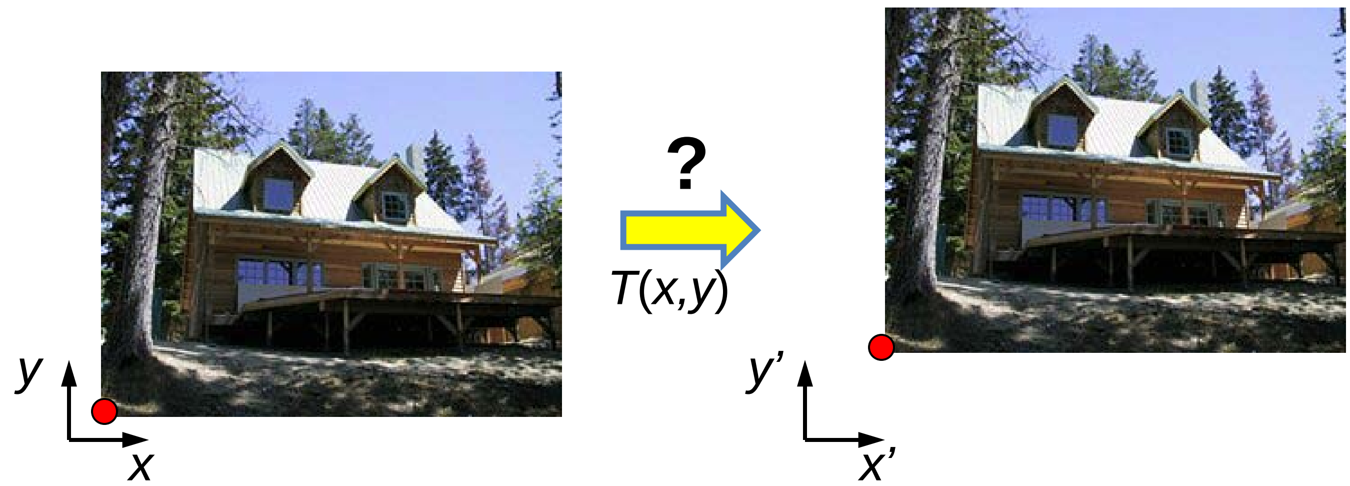
Slide by Durand and Freeman

Recovering Transformations



- What if we know *f* and *g* and want to recover the transform T?
  - – willing to let user provide correspondences
    - How many do we need?

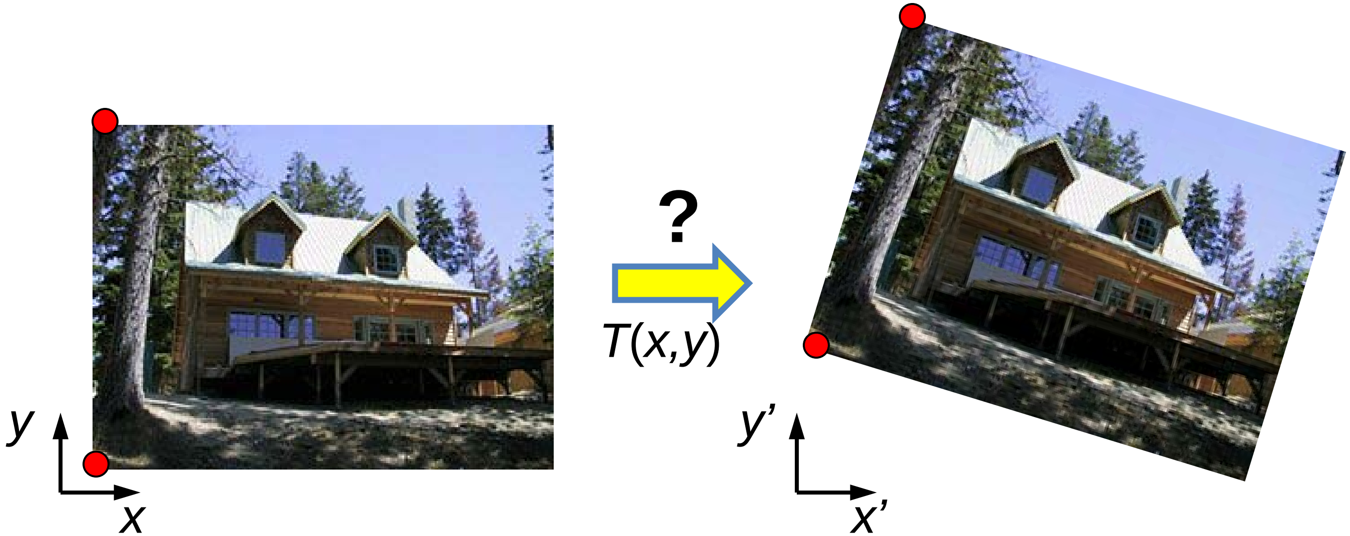
Translation: # correspondences?



- How many correspondences needed for translation?
- How many Degrees of Freedom?
- What is the transformation matrix?

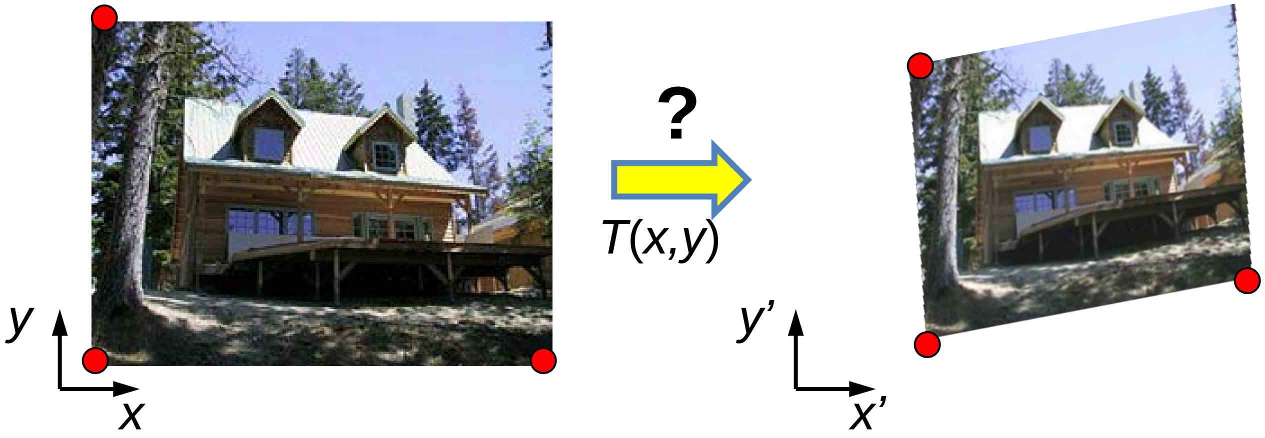
$$\mathbf{M} = \begin{bmatrix} 1 & 0 & p'_x - p_x \\ 0 & 1 & p'_y - p_y \\ 0 & 0 & 1 \end{bmatrix}$$

Euclidian: # correspondences?



- How many correspondences needed for translation+rotation?
- How many DOF?

Affine: # correspondences?



- How many correspondences needed for affine?
- How many DOF?

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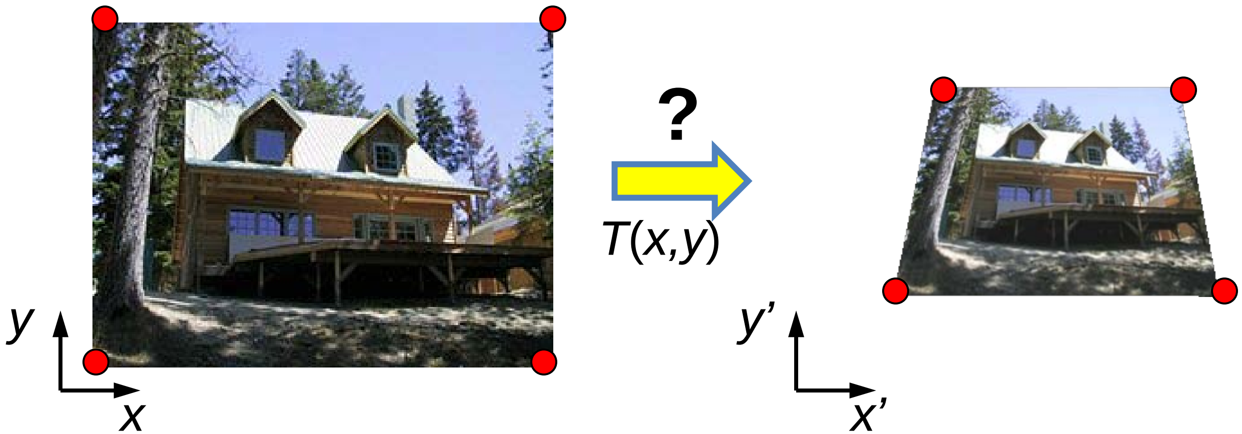
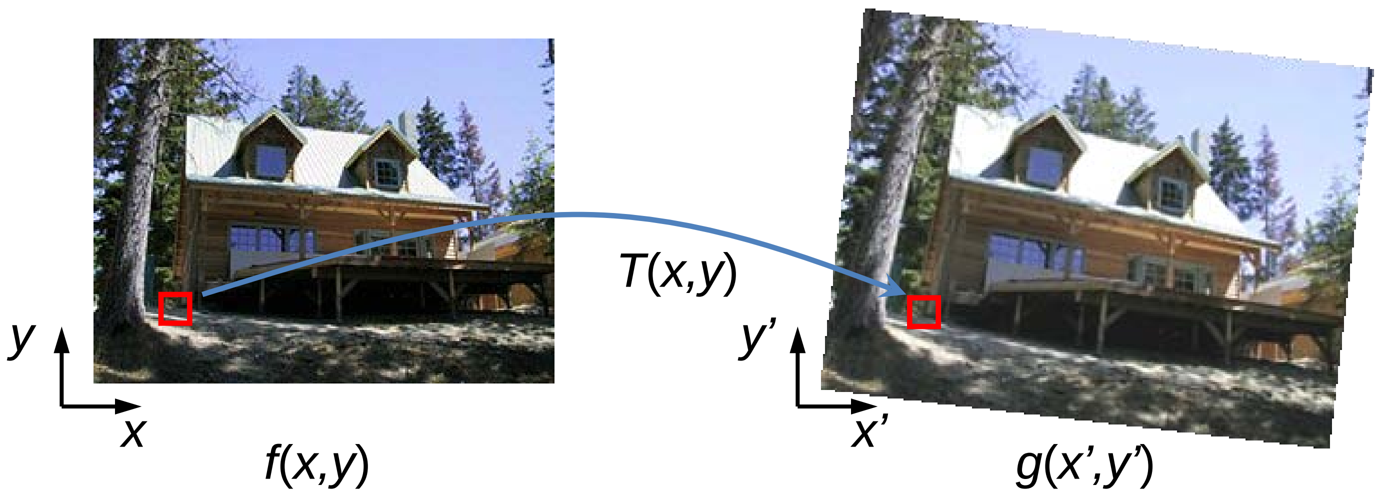
Projective: # correspondences?



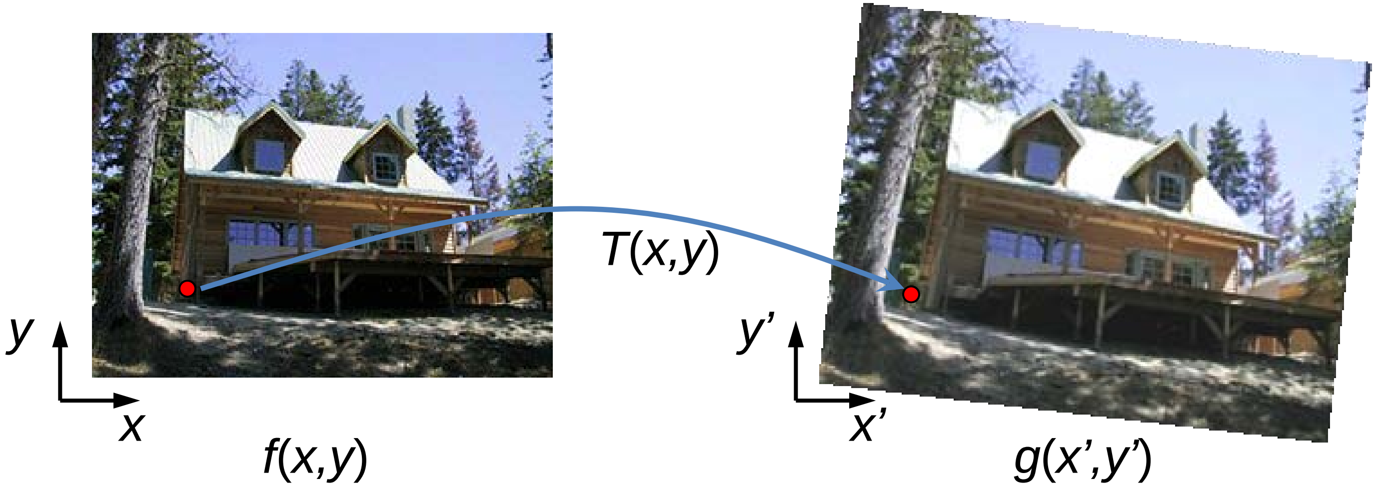
- How many correspondences needed for projective?
- How many DOF?

Image warping



- Given a coordinate transform *(x',y')* = *T*(*x,y*) and a source image *f*(*x,y*), how do we compute a transformed image *g(x',y')* = *f*(*T*(*x,y*))?

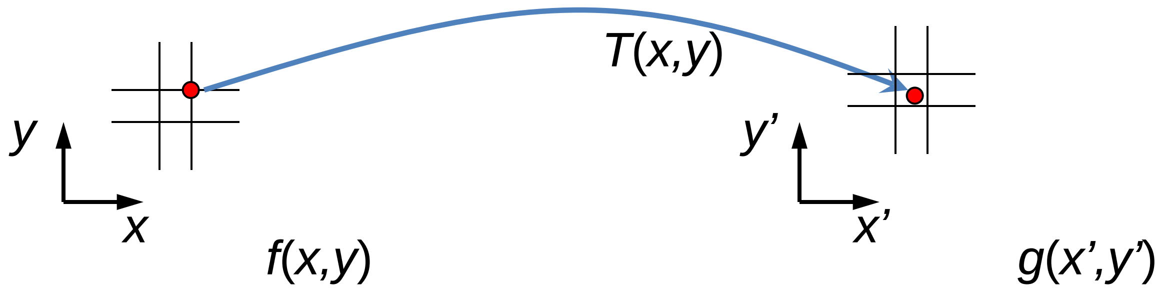
Forward warping



- Send each pixel $f(x,y)$ to its corresponding location $(x',y') = T(x,y)$ in the second image

Q: what if pixel lands "between" two pixels?

Forward warping



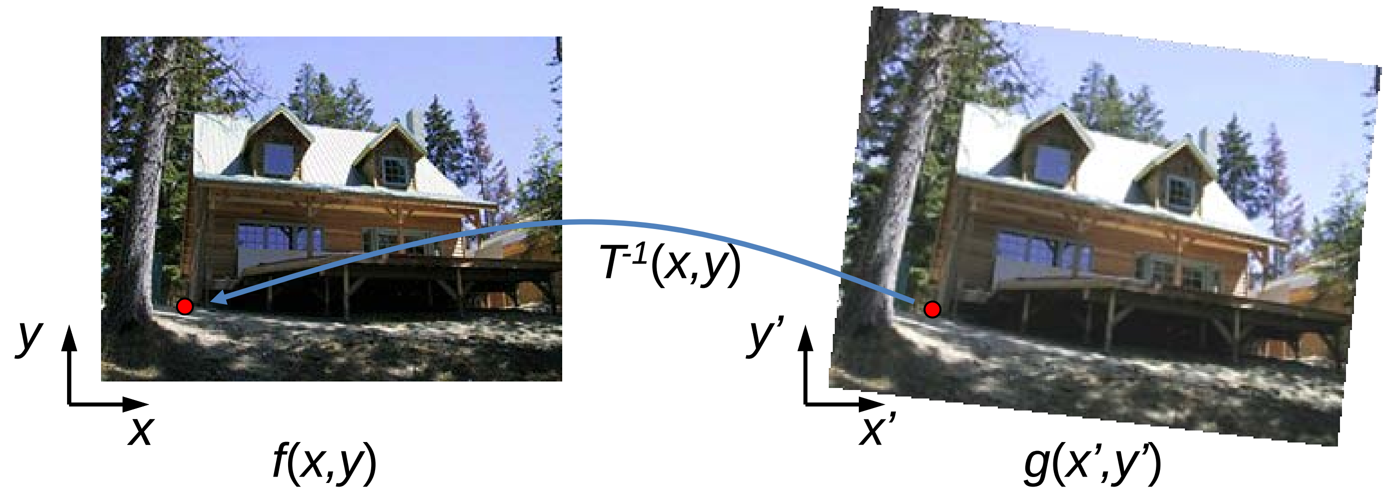
- Send each pixel $f(x,y)$ to its corresponding location $(x',y') = T(x,y)$ in the second image

Q: what if pixel lands "between" two pixels?

A: distribute color among neighboring pixels (x',y')

- Known as "splatting"
- Check out griddata in Matlab

Inverse warping



- Get each pixel $g(x',y')$ from its corresponding location

  $(x,y) = T^{-1}(x',y')$ in the first image

Q: what if pixel comes from "between" two pixels?

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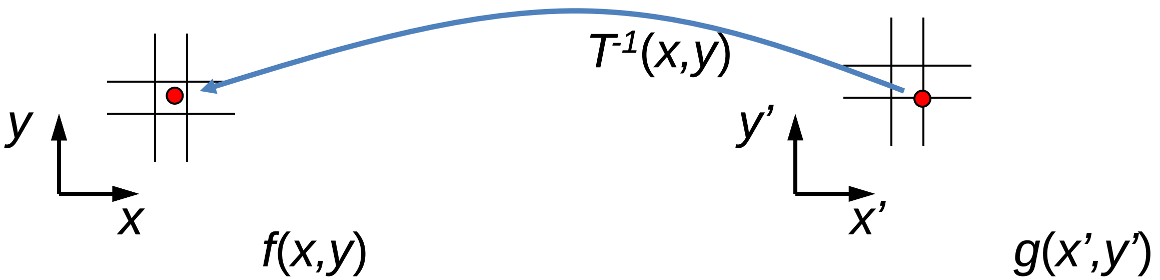
Inverse warping



- Get each pixel $g(x',y')$ from its corresponding location

$$(x,y) = T^{-1}(x',y') \text{ in the first image}$$

Q: what if pixel comes from "between" two pixels?

A: *Interpolate* color value from neighbors

- nearest neighbor, bilinear, Gaussian, bicubic
- Check out interp2 in Matlab

Forward vs. inverse warping

Q: which is better?

A: usually inverse—eliminates holes

- however, it requires an invertible warp function—not always possible...

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Today's schedule

- Last week's recap
- Warping
- Mosaics
- Morphing

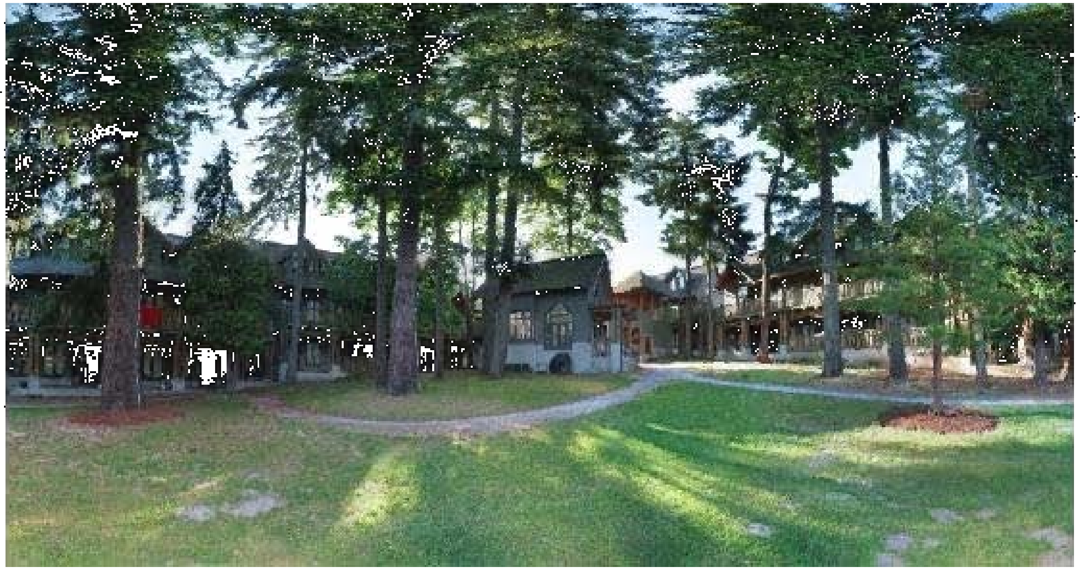
Why Mosaic?

- Are you getting the whole picture?
  - Compact Camera FOV = 50 x 35°

Slide from Brown & Lowe

Why Mosaic?

- Are you getting the whole picture?
  - Compact Camera FOV = 50 x 35°
  - Human FOV = 200 x 135°



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Slide from Brown & Lowe

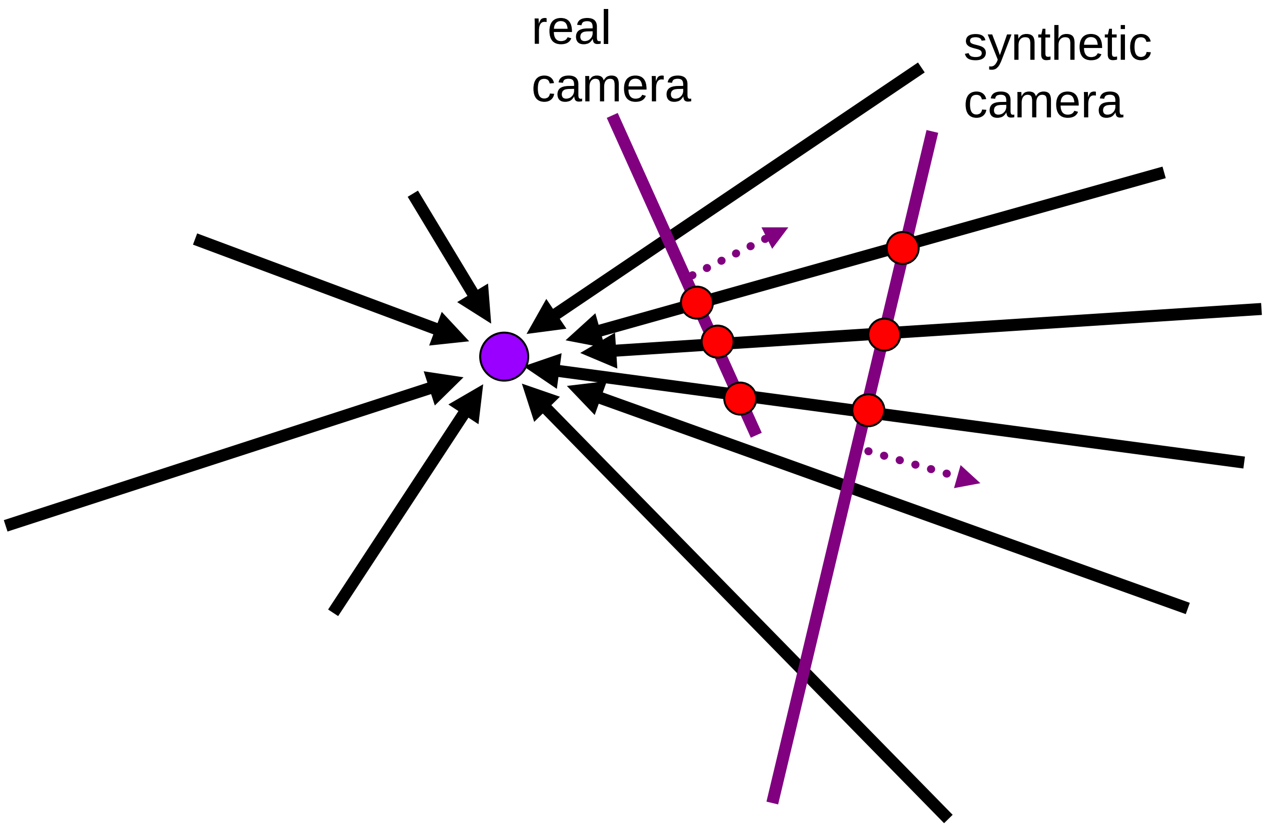
Why Mosaic?

- Are you getting the whole picture?
  – Compact Camera FOV = 50 x 35°
  – Human FOV = 200 x 135°

Mosaics: stitching images together

virtual wide-angle camera

A pencil of rays contains all views



Can generate any synthetic camera view
as long as it has **the same center of projection**!

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How to do it?

- Basic Procedure
  - Take a sequence of images from the same position
    - Rotate the camera about its optical center
  - Compute transformation between second image and first
  - Transform the second image to overlap with the first
  - Blend the two together to create a mosaic
  - If there are more images, repeat

- …but **wait**, why should this work at all?
  - What about the 3D geometry of the scene?
  - Why aren't we using it?

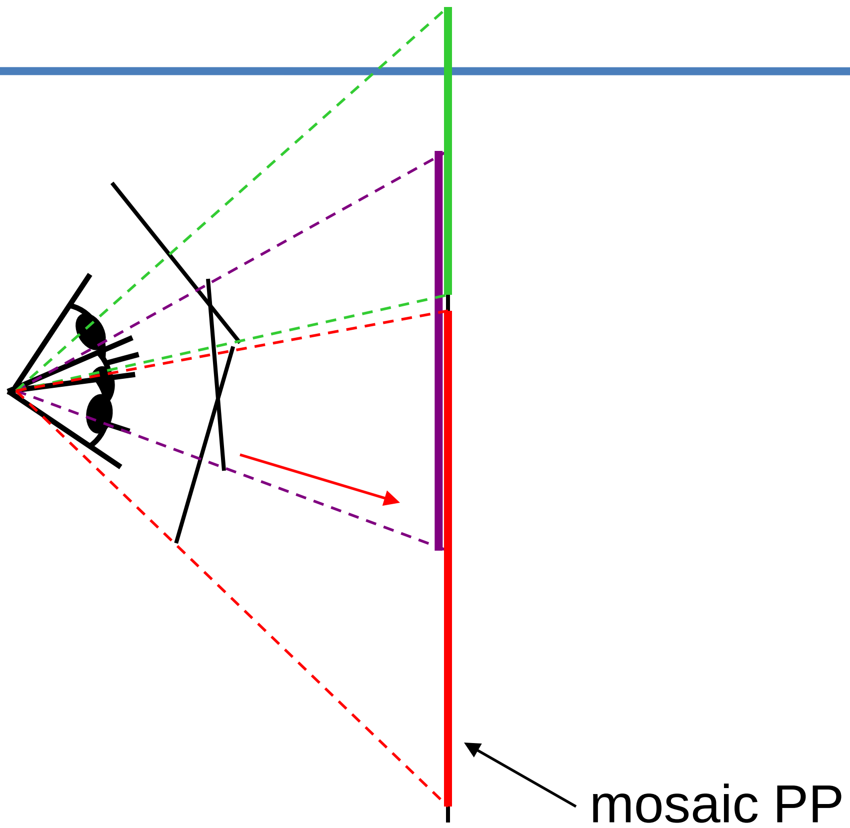
Aligning images

left on top

right on top

Translations are not enough to align the images

Image reprojection

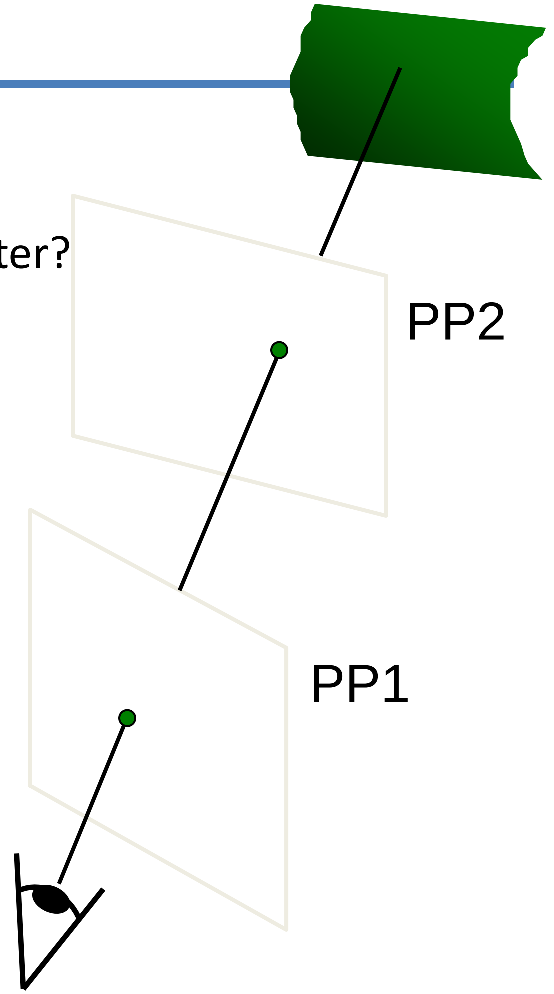


- The mosaic has a natural interpretation in 3D
  - The images are reprojected onto a common plane
  - The mosaic is formed on this plane
  - Mosaic is a *synthetic wide-angle camera*

Image reprojection

- Basic question
  - How to relate two images from the same camera center?
    - how to map a pixel from PP1 to PP2

Answer
- Cast a ray through each pixel in PP1
- Draw the pixel where that ray intersects PP2



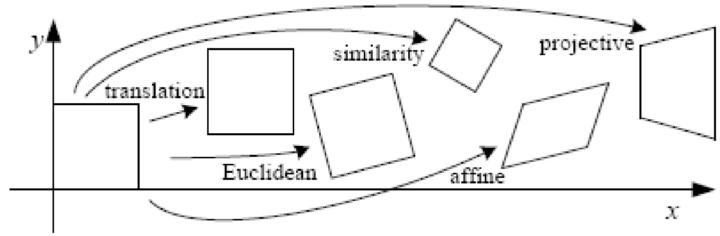
But don't we need to know the geometry of the two planes in respect to the eye?

Observation:
Rather than thinking of this as a 3D reprojection,
think of it as a 2D **image warp** from one image to another

Back to Image Warping

Which t-form is the right one for warping PP1 into PP2?

e.g. translation, Euclidean, affine, projective



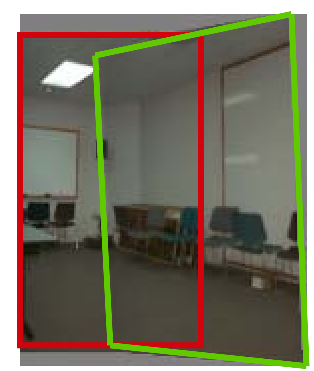
Translation

2 unknowns

Affine

6 unknowns

Perspective



8 unknowns

Homography

- A: Projective – mapping between any two PPs with the same center of projection
  - rectangle should map to arbitrary quadrilateral
  - parallel lines aren't
  - but must preserve straight lines
  - same as: project, rotate, reproject
- called Homography

$$\underset{\mathbf{p'}}{\begin{bmatrix} wx' \\ wy' \\ w \end{bmatrix}} = \underset{\mathbf{H}}{\begin{bmatrix} * & * & * \\ * & * & * \\ * & * & * \end{bmatrix}} \underset{\mathbf{p}}{\begin{bmatrix} x \\ y \\ 1 \end{bmatrix}}$$

To apply a homography **H**

- Compute **p' = Hp** (regular matrix multiply)
- Convert **p'** from homogeneous to image coordinates

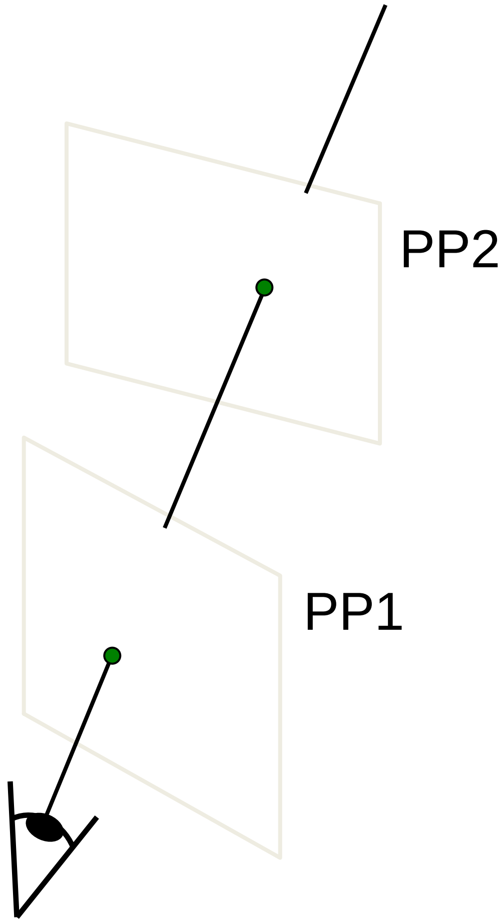


Image warping with homographies

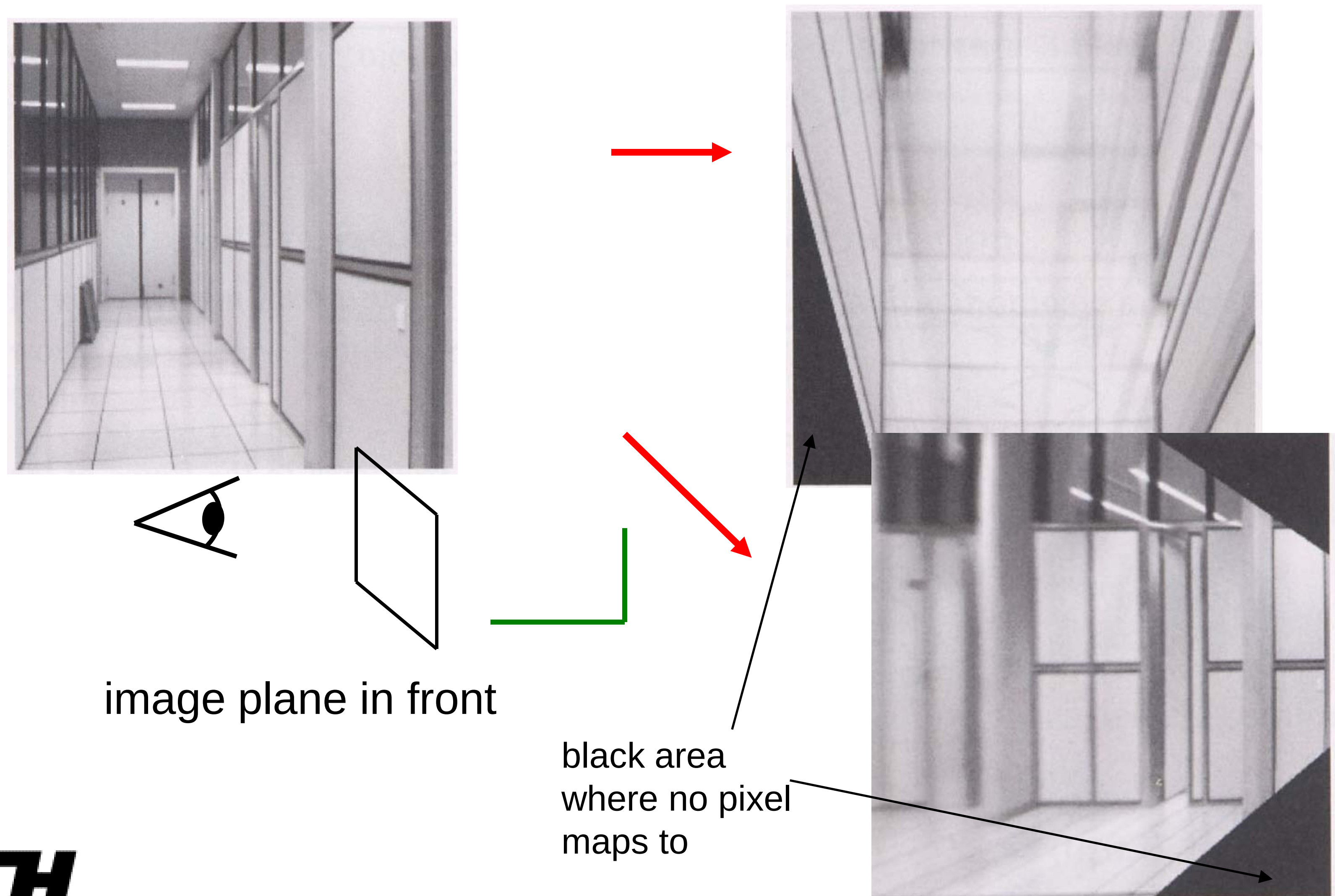
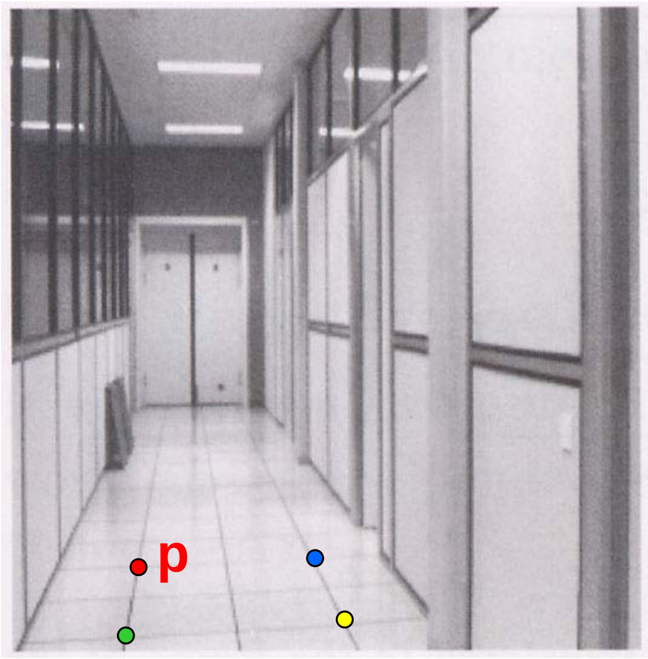
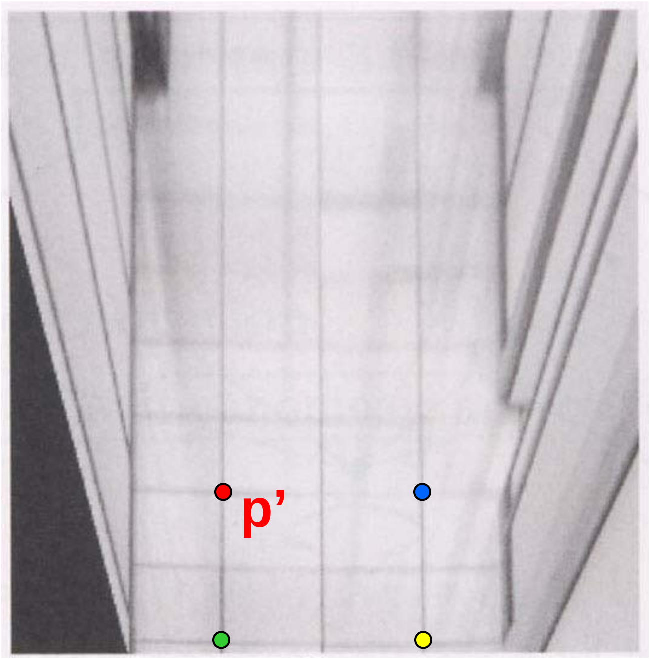


Image rectification





To unwarp (rectify) an image

- Find the homography **H** given a set of **p** and **p’** pairs
- How many correspondences are needed?
- Tricky to write H analytically, but we can <u>solve</u> for it!
- Find such H that “best” transforms points p into p’
- Use least-squares!

Computing a homography

2 equations/point

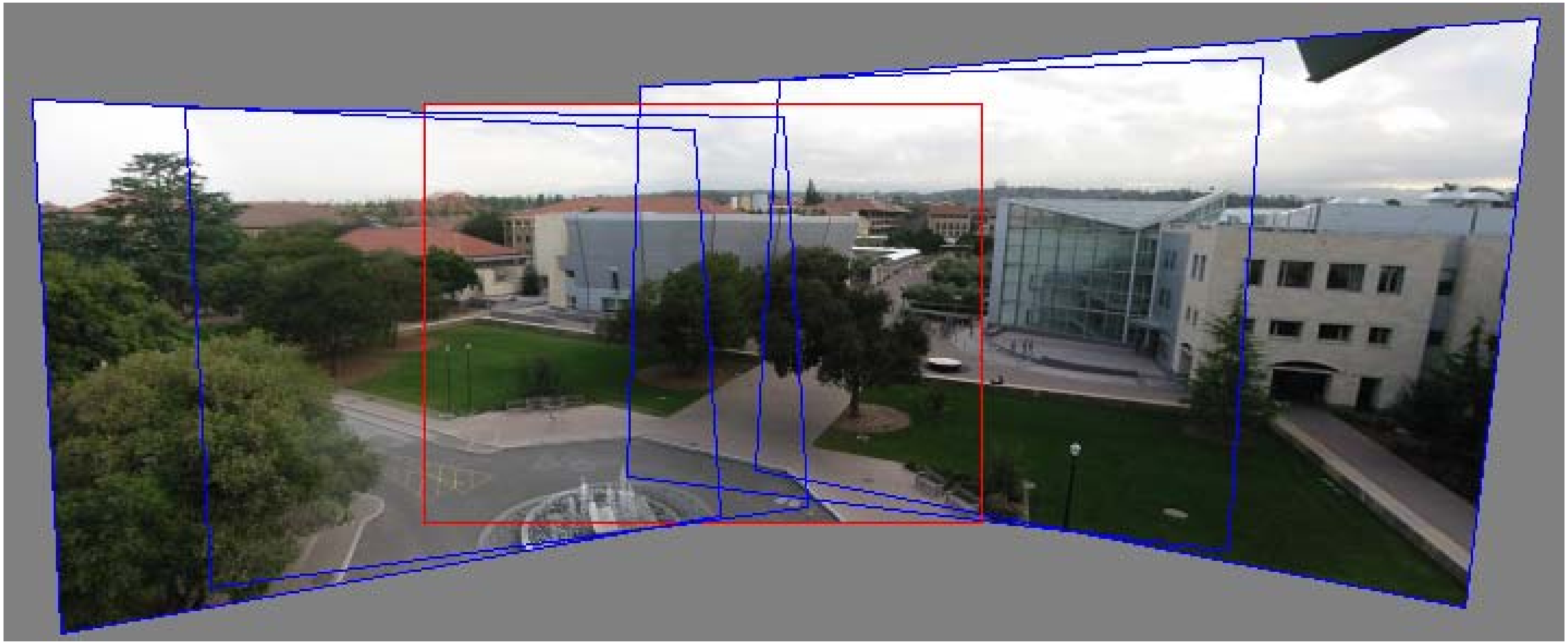
Stack matrix representing equations for 4 or more points

Solve through SVD, least-square solution is given by last right singular vector

(i.e. smallest singular value)

Numerically better if image coordinates scaled to [-1,1]

Panoramas



1. Pick one image (red)
2. Warp the other images towards it (usually, one by one)
3. blend

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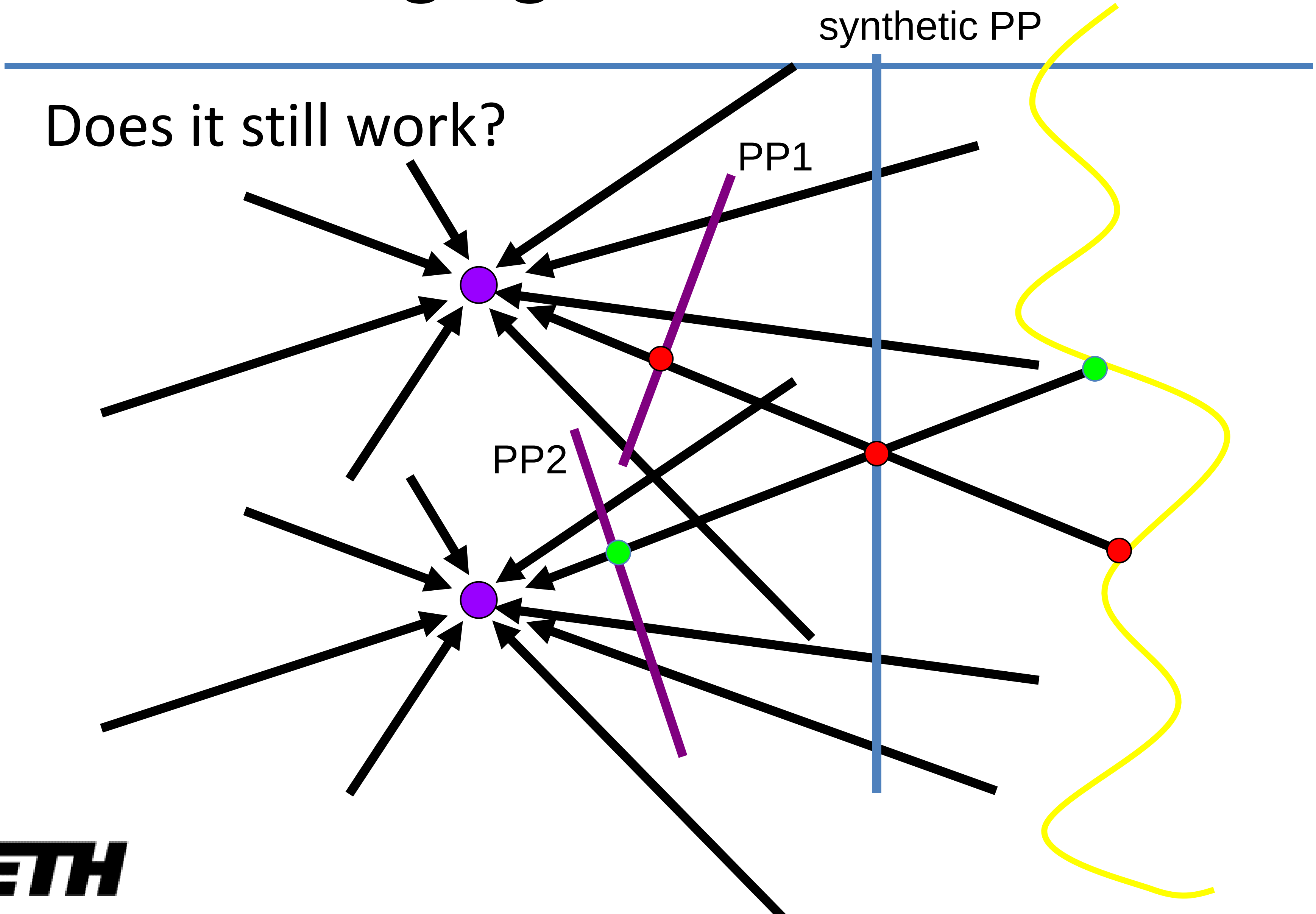
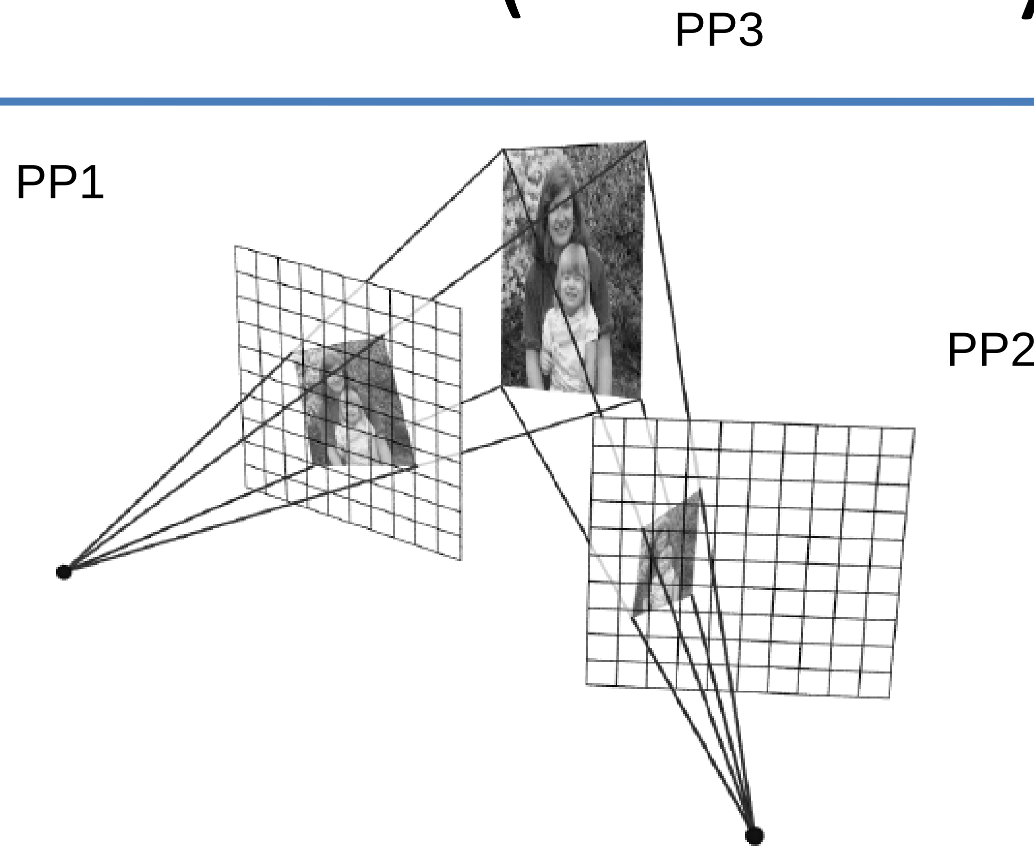
changing camera center

Does it still work?

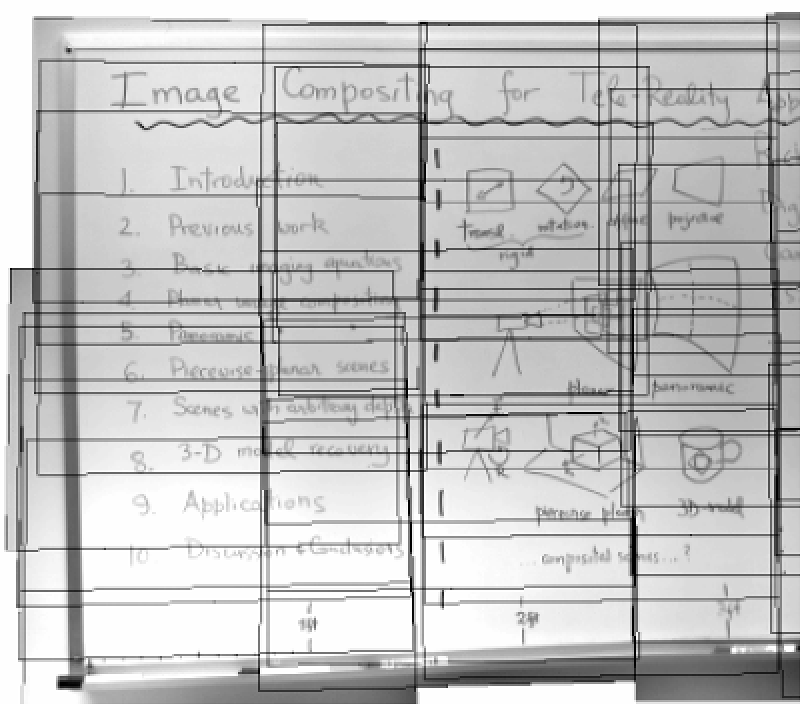


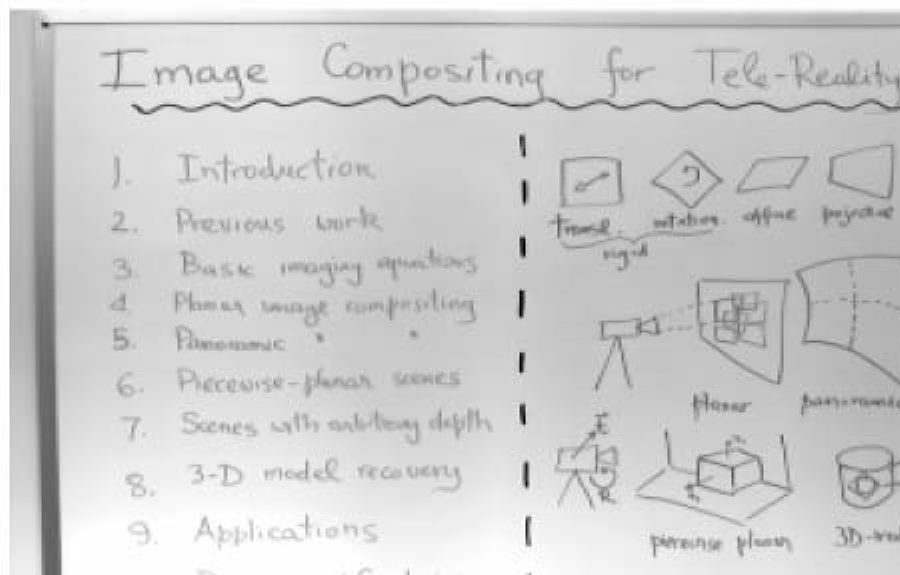
Planar scene (or far away)



- PP3 is a projection plane of both centers of projection, so we are OK!
- This is how big aerial photographs are made

Planar mosaic

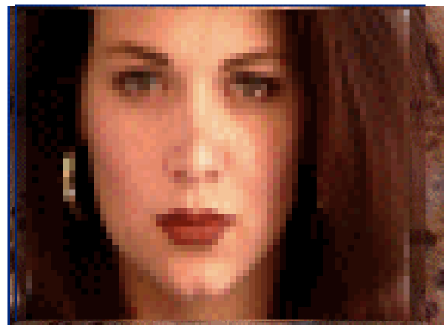




Today’s schedule

- Last week’s recap
- Warping
- Mosaics
- Morphing

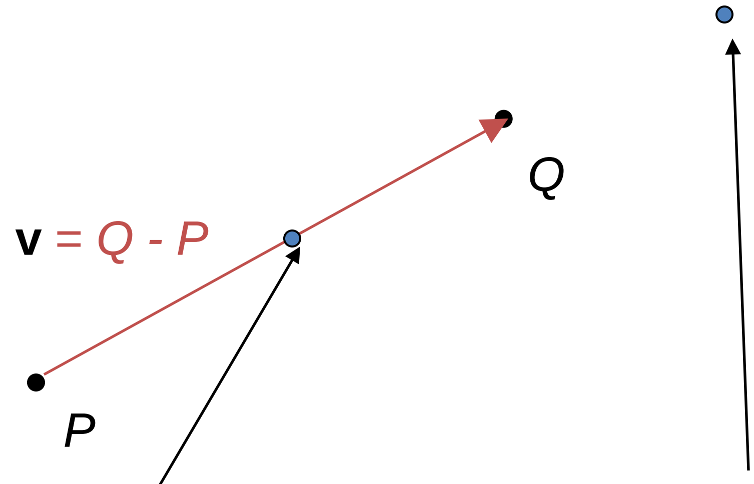
Morphing = Object Averaging


- The aim is to find “an average” between two objects
  - Not an average of two images of objects…
  - …but an image of the average object!
  - How can we make a smooth transition in time?
    - Do a “weighted average” over time t
- How do we know what the average object looks like?
  - We haven’t a clue!
  - But we can often fake something reasonable
    - Usually required user/artist input

Averaging Points

What's the average of P and Q?



$P + 0.5\mathrm{v}$
$= P + 0.5(Q – P)$
$= 0.5P + 0.5\,Q$

$P + 1.5\mathrm{v}$
$= P + 1.5(Q – P)$
$= -0.5P + 1.5\,Q$
(extrapolation)

Linear Interpolation (Affine Combination):
New point *aP* + *bQ*,
defined only when a+*b* = 1
So aP+bQ = aP+(1-a)Q

- P and Q can be anything:
  - points on a plane (2D) or in space (3D)
  - Colors in RGB or HSV (3D)
  - Whole images (m-by-n D)… etc.

Idea #1: Cross-Dissolve

- Interpolate whole images:

  $$\text{Image}_{\text{halfway}} = (1\text{-}t)*\text{Image}_1 + t*\text{image}_2$$

- This is called **cross-dissolve** in film industry

- But what is the images are not aligned?

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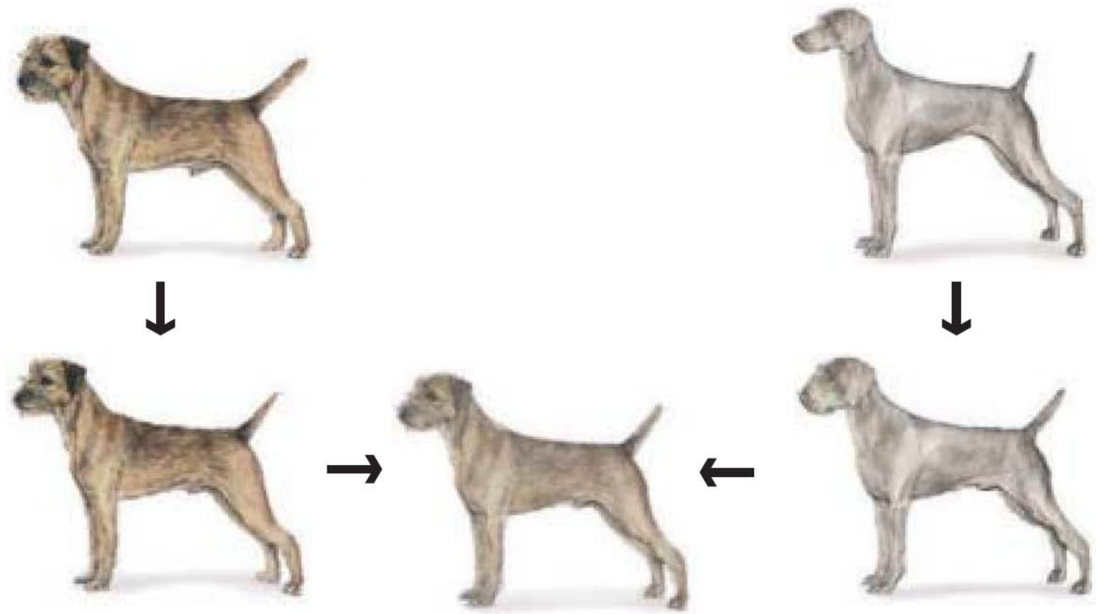
Idea #2: Align, then cross-disolve

- Align first, then cross-dissolve
  - Alignment using global warp – picture still valid

Dog Averaging

- What to do?
  - Cross-dissolve doesn't work
  - Global alignment doesn't work
    - Cannot be done with a global transformation (e.g. affine)
  - Any ideas?
- Feature matching!
  - Nose to nose, tail to tail, etc.
  - This is a local (non-parametric) warp

Idea #3: Local warp, then cross-dissolve



Morphing procedure:

for every t,

1. Find the average shape (the “mean dog”☺)
   – local warping
2. Find the average color
   – Cross-dissolve the warped images

Local (non-parametric) Image Warping

- Need to specify a more detailed warp function
  - Global warps were functions of a few (2,4,8) parameters
  - Non-parametric warps u(x,y) and v(x,y) can be defined independently for every single location x,y!
  - Once we know vector field u,v we can easily warp each pixel (use backward warping with interpolation)

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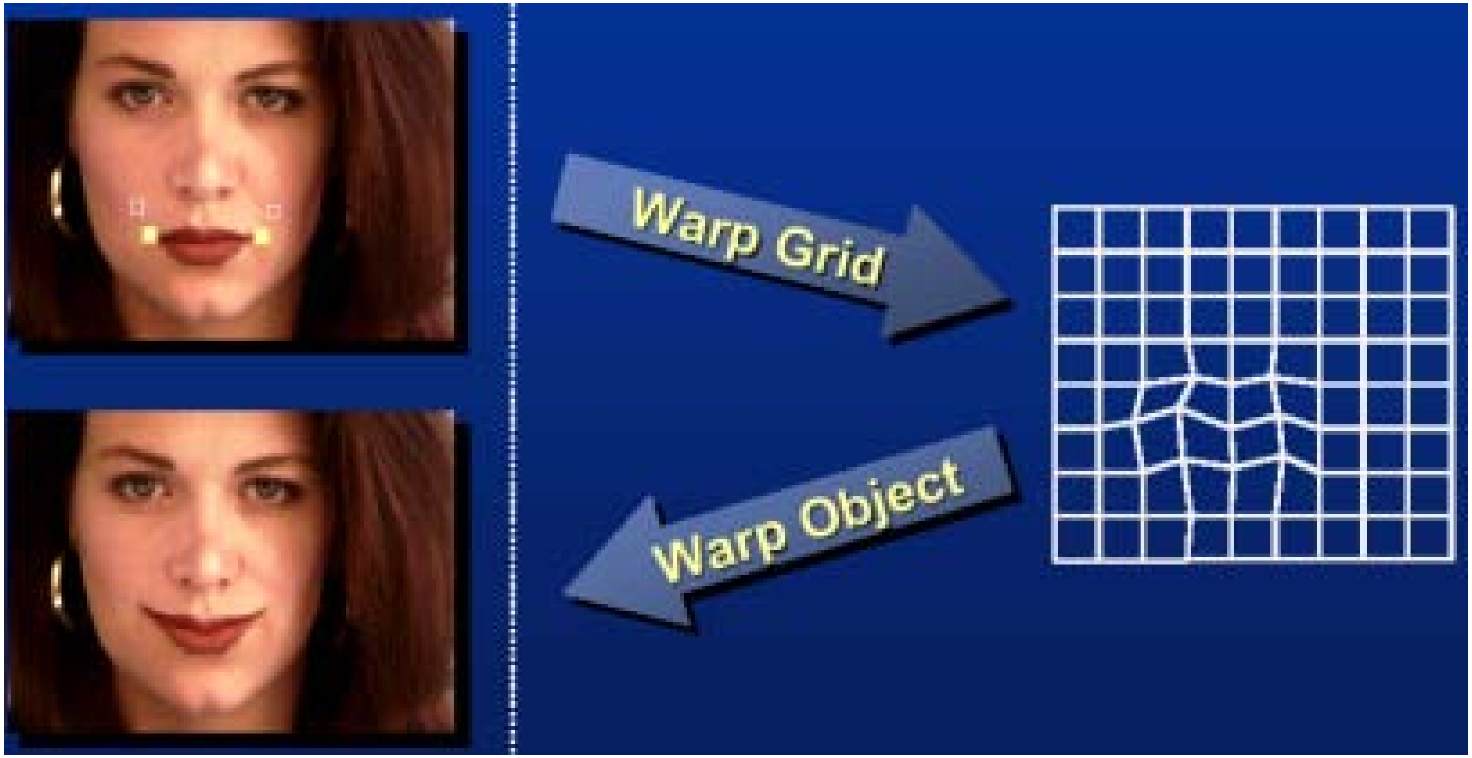
Image Warping – non-parametric

- Move control points to specify a spline warp
- Spline produces a smooth vector field



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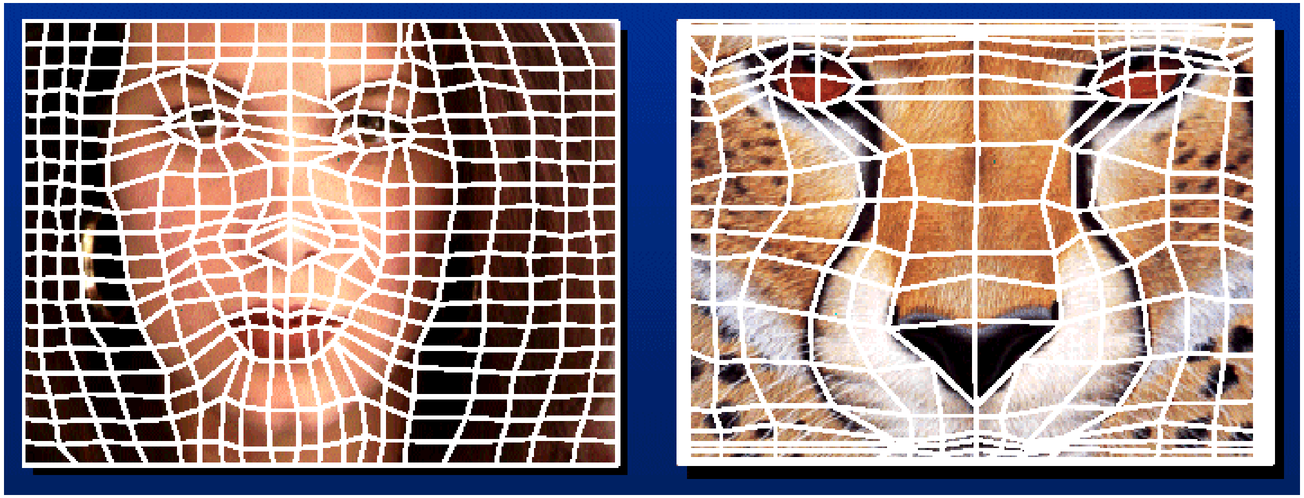
Warp specification - dense

- How can we specify the warp?

  Specify corresponding *spline control points*

  - *interpolate* to a complete warping function



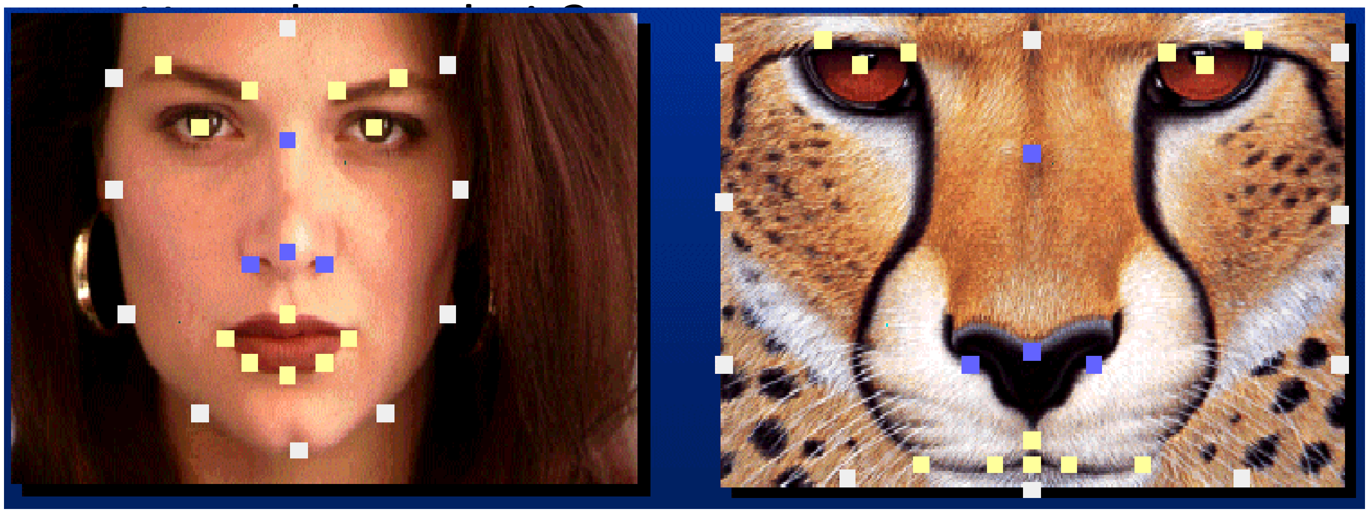
But we want to specify only a few points, not a grid

Warp specification - sparse

- How can we specify the warp?

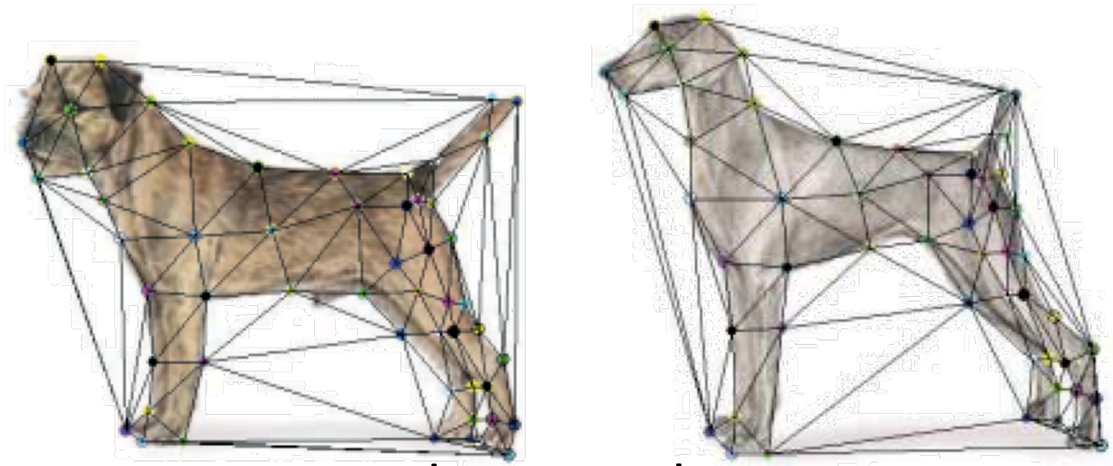
  Specify corresponding *points*

  - *interpolate* to a complete warping function



How do we go from feature points to pixels?

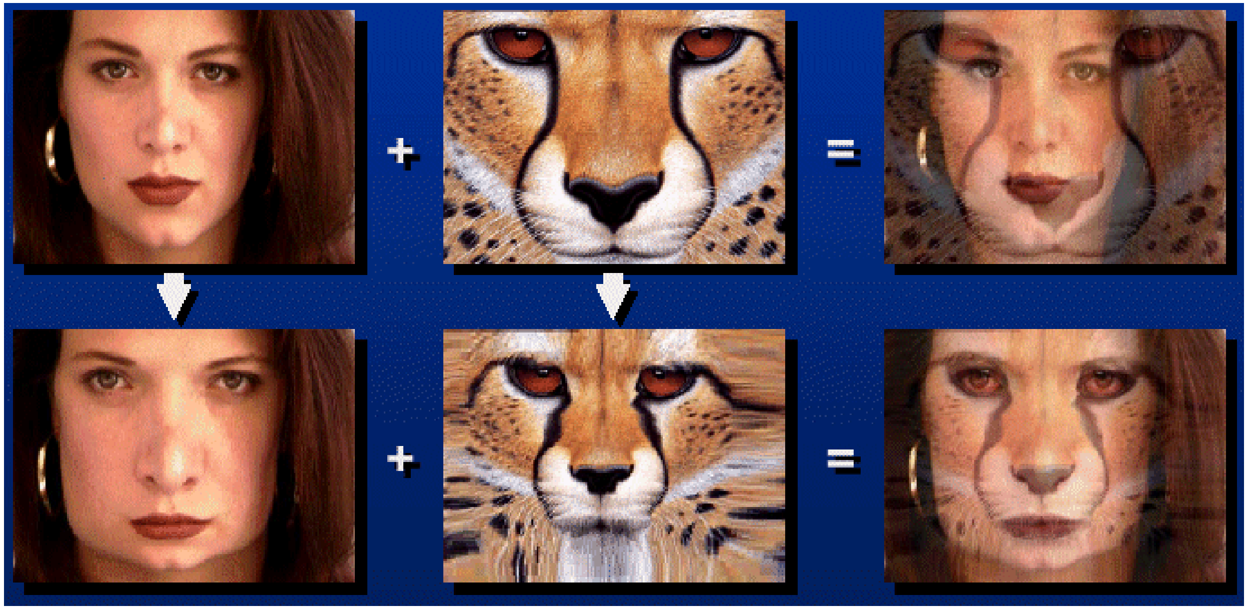
Triangular Mesh



1. Input correspondences at key feature points
2. Define a triangular mesh over the points
   – Same mesh in both images!
   – Now we have triangle-to-triangle correspondences
3. Warp each triangle separately from source to destination
   – How do we warp a triangle?
   – 3 points = affine warp!
   – Just like texture mapping

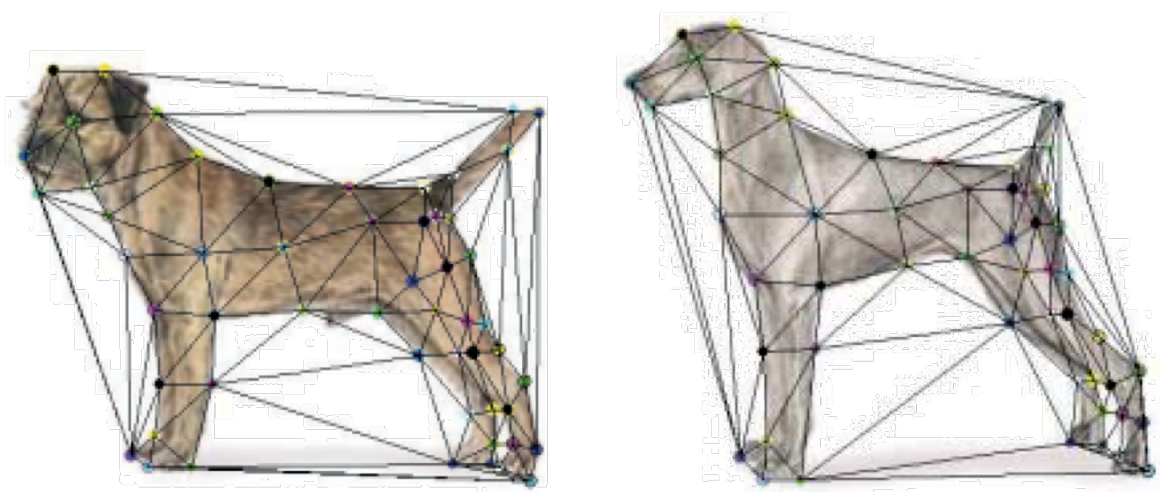
Image Morphing

- We know how to warp one image into the other, but how do we create a morphing sequence?
  1. Create an intermediate shape (by interpolation)
  2. Warp both images towards it
  3. Cross-dissolve the colors in the newly warped images



Warp interpolation

- How do we create an intermediate warp at time t?
  - Assume t = [0,1]
  - Simple linear interpolation of each feature pair
  - (1-t)*p1+t*p0 for corresponding features p0 and p1



Morphing & matting

- Extract foreground first to avoid artifacts in the background

(c) $\alpha = 0.0$ (d) $\alpha = 0.2$ (e) $\alpha = 0.4$

(f) $\alpha = 0.6$ (g) $\alpha = 0.8$ (h) $\alpha = 1.0$

Slide by Durand and Freeman

Women in Art video

- http://youtube.com/watch?v=nUDIoN-_Hxs

Problem with morphing

- So far, we have performed linear interpolation of feature point positions
- But what happens if we try to morph between two views of the same object?

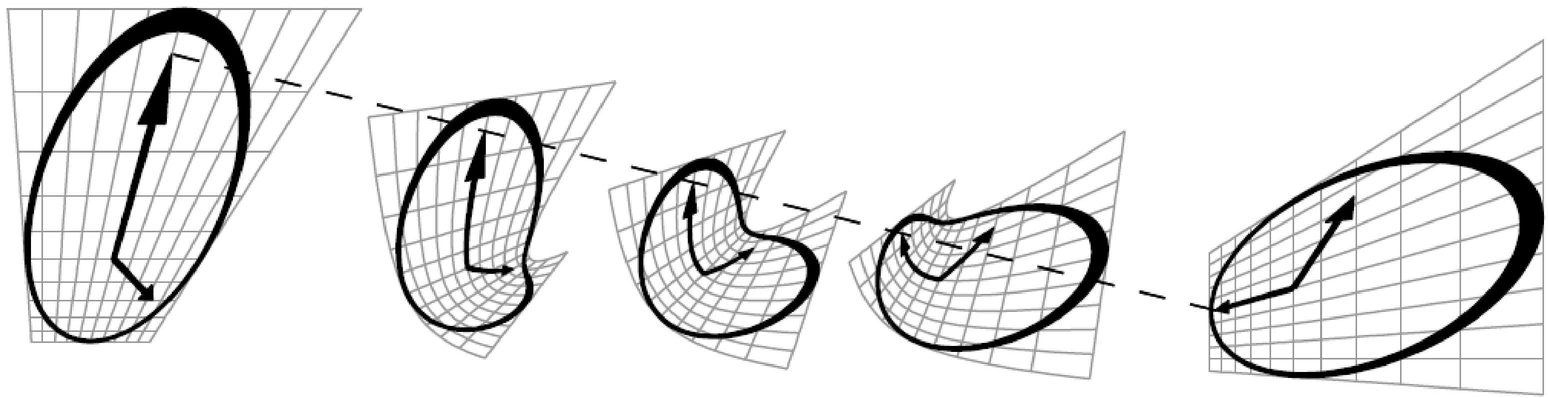


Figure 2: A Shape-Distorting Morph. Linearly interpolating two perspective views of a clock (far left and far right) causes a geometric bending effect in the in-between images. The dashed line shows the linear path of one feature during the course of the transformation. This example is indicative of the types of distortions that can arise with image morphing techniques.

View morphing

- Seitz & Dyer

  http://www.cs.washington.edu/homes/seitz/vmorph/vmorph.htm
- Interpolation consistent with 3D view interpolation

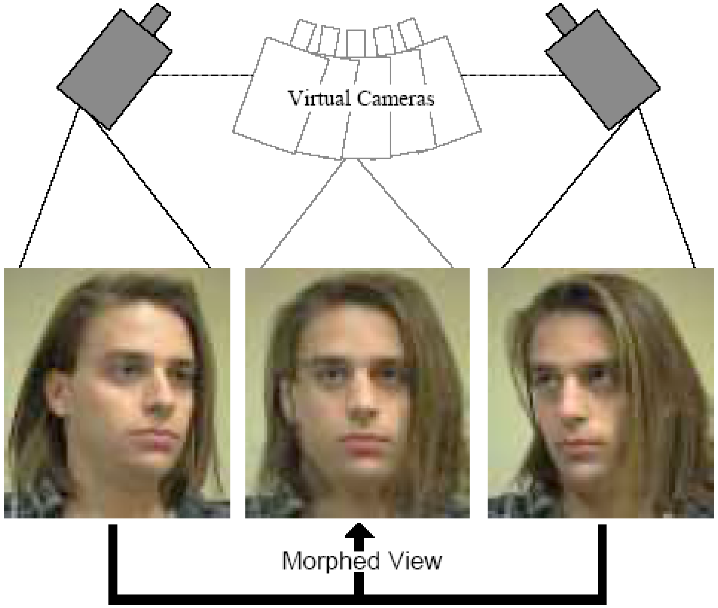


Figure 1: View morphing between two images of an object taken from two different viewpoints produces the illusion of physically moving a virtual camera.

Main trick

- Prewarp with a homography to "pre-align" images
- So that the two views are parallel
  - Because linear interpolation works when views are parallel

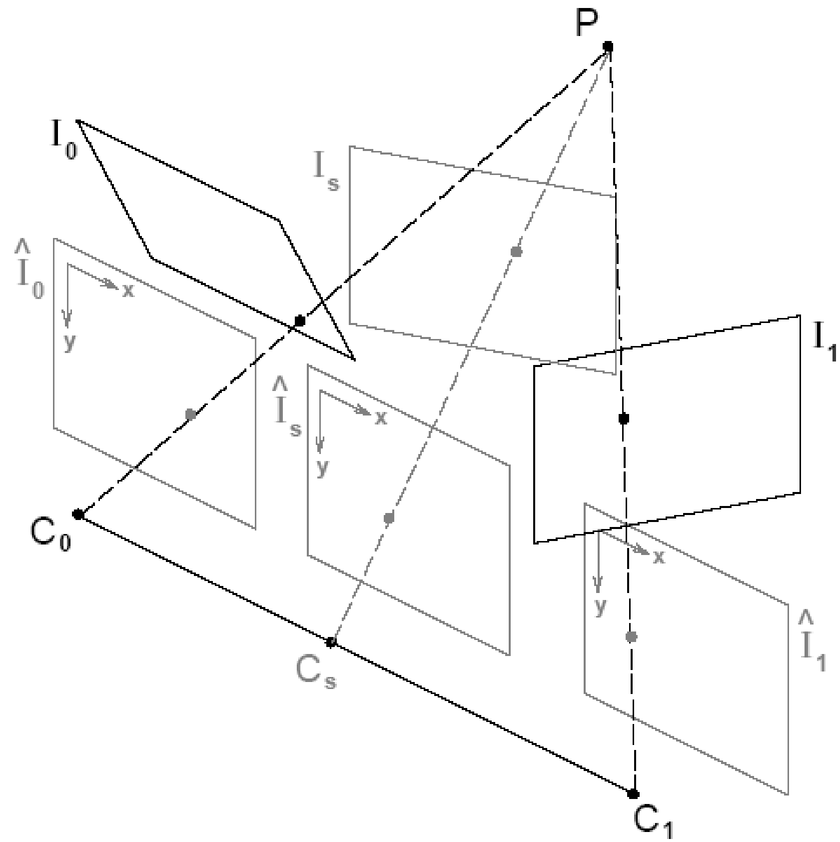


Figure 4: View Morphing in Three Steps. (1) Original images $\mathcal{I}_0$ and $\mathcal{I}_1$ are prewarped to form parallel views $\hat{\mathcal{I}}_0$ and $\hat{\mathcal{I}}_1$. (2) $\hat{\mathcal{I}}_s$ is produced by morphing (interpolating) the prewarped images. (3) $\hat{\mathcal{I}}_s$ is postwarped to form $\mathcal{I}_s$.

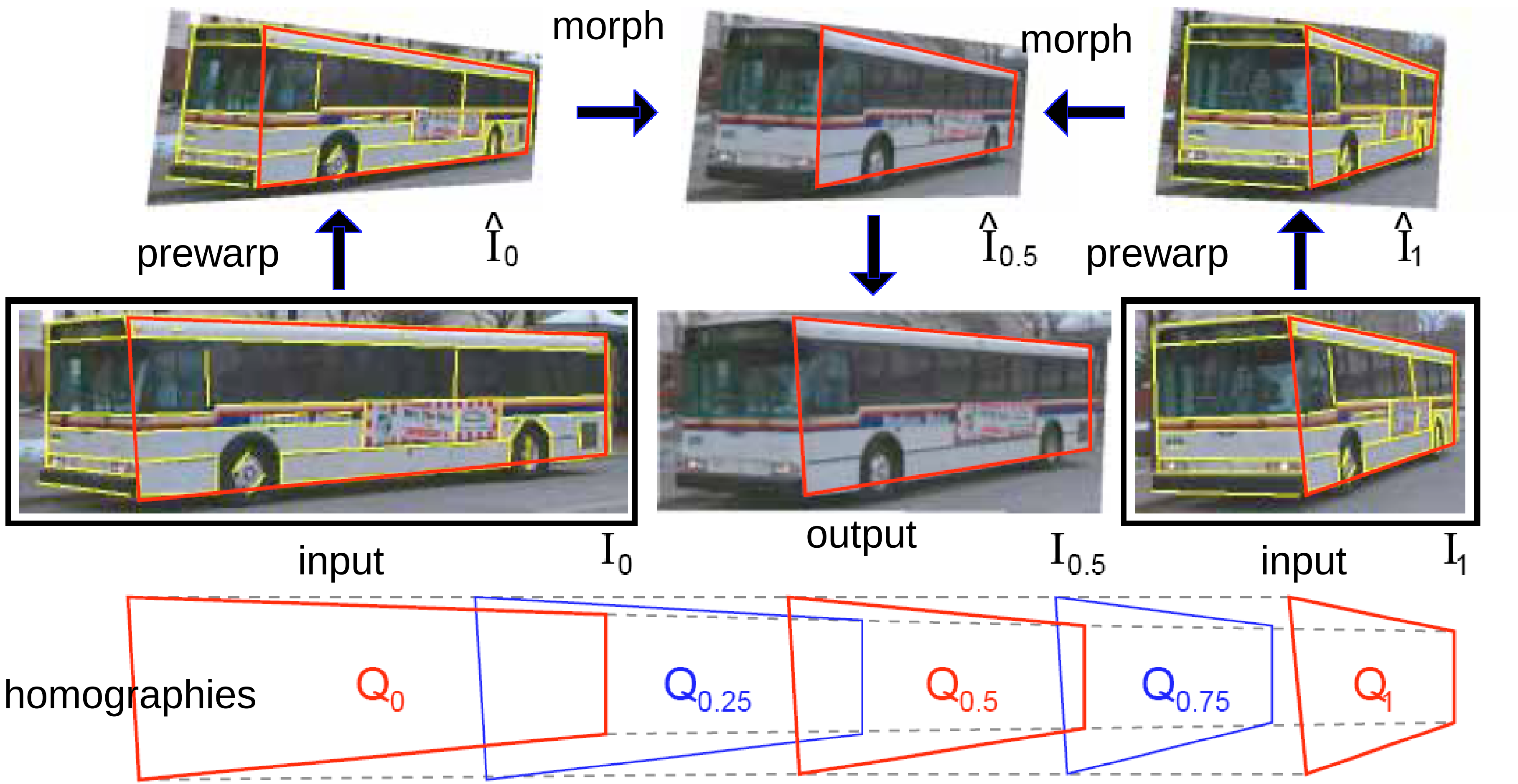


Figure 6: View Morphing Procedure: A set of features (yellow lines) is selected in original images $\mathcal{I}_0$ and $\mathcal{I}_1$. Using these features, the images are automatically prewarped to produce $\hat{\mathcal{I}}_0$ and $\hat{\mathcal{I}}_1$. The prewarped images are morphed to create a sequence of in-between images, the middle of which, $\hat{\mathcal{I}}_{0.5}$, is shown at top-center. $\hat{\mathcal{I}}_{0.5}$ is interactively postwarped by selecting a quadrilateral region (marked red) and specifying its desired configuration, $Q_{0.5}$, in $\mathcal{I}_{0.5}$. The postwarps for other in-between images are determined by interpolating the quadrilaterals (bottom).

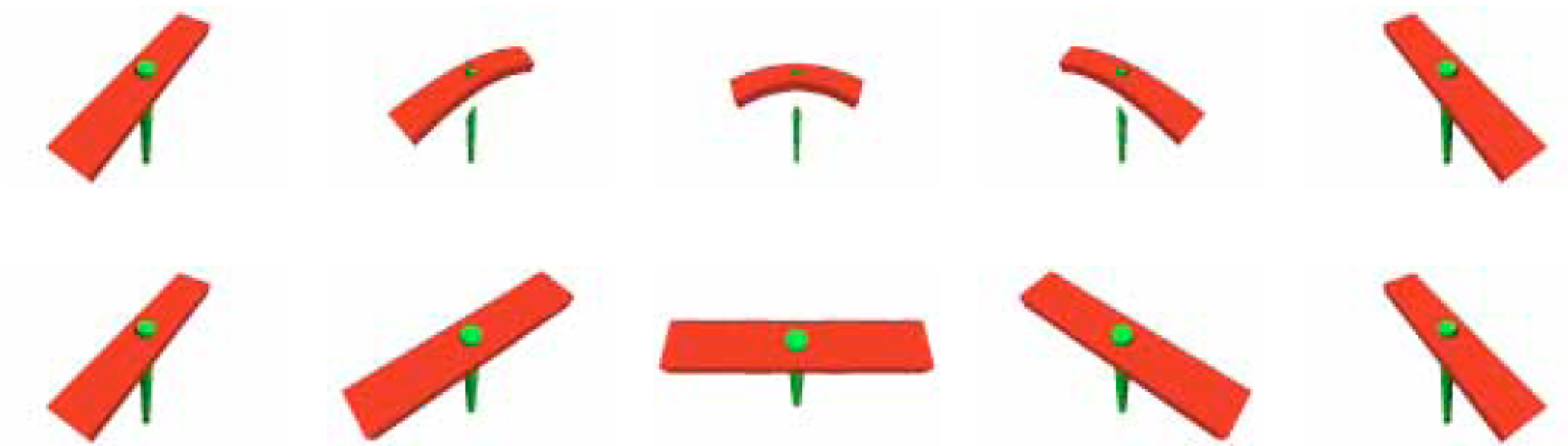


Figure 10: Image Morphing Versus View Morphing. Top: image morph between two views of a helicopter toy causes the in-between images to contract and bend. Bottom: view morph between the same two views results in a physically consistent morph. In this example the image morph also results in an extraneous hole between the blade and the stick. Holes can appear in view morphs as well.

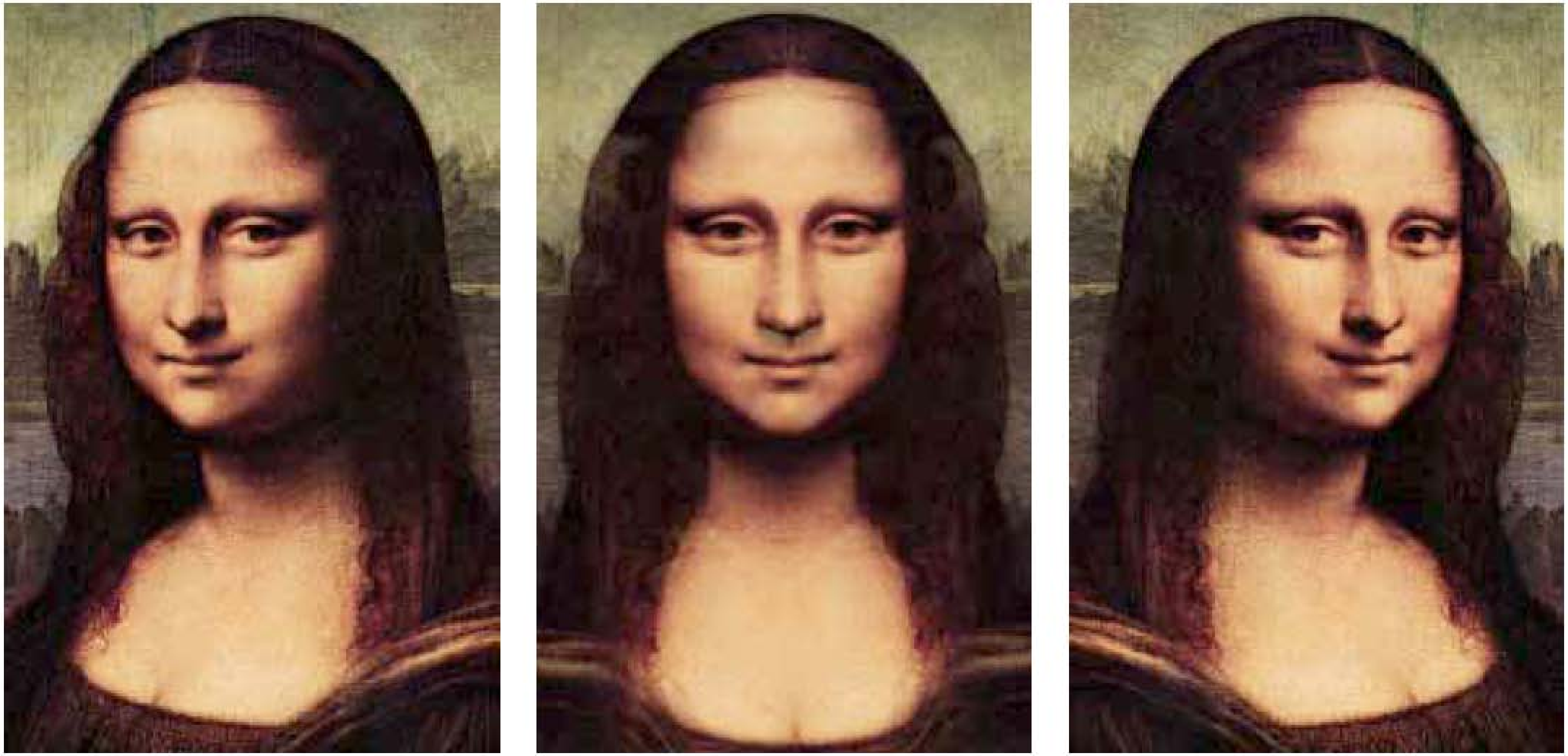


Figure 9: Mona Lisa View Morph. Morphed view (center) is halfway between original image (left) and it's reflection (right).

$\mathcal{I}_0$ $\mathcal{I}_{0.25}$ $\mathcal{I}_{0.5}$ $\mathcal{I}_{0.75}$ $\mathcal{I}_1$

Figure 7: Facial View Morphs. Top: morph between two views of the same person. Bottom: morph between views of two different people. In each case, view morphing captures the change in facial pose between original images $\mathcal{I}_0$ and $\mathcal{I}_1$, conveying a natural 3D rotation.

Next week

- Image pyramids and graph-cuts