Image Morphing

Computational Photography

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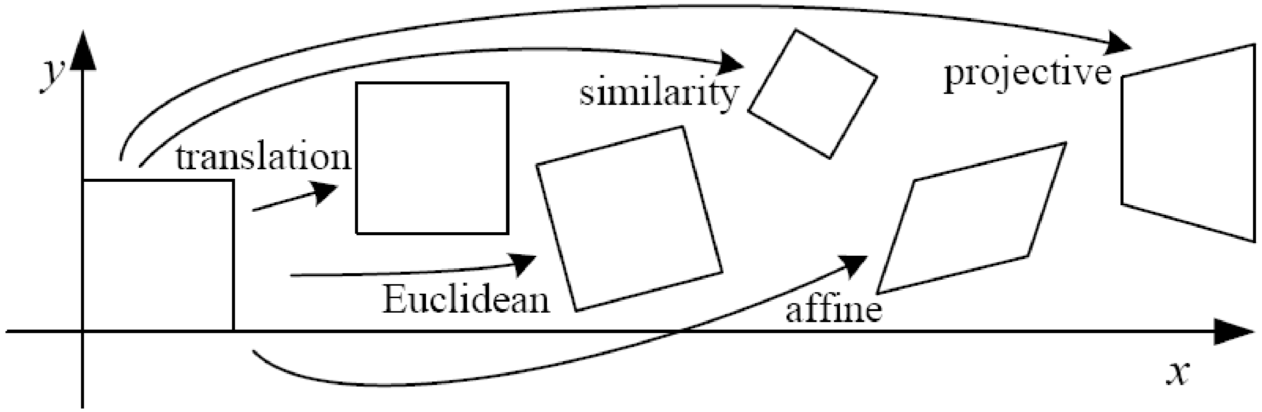
Many slides from Alyosha Efros

2D image transformations



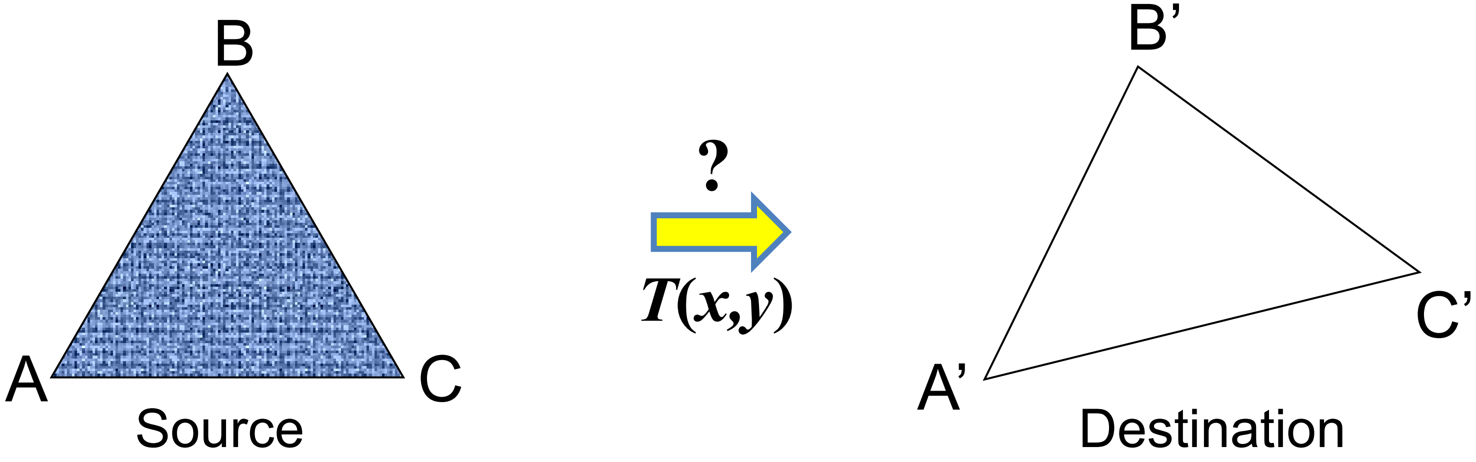
Name	Matrix	# D.O.F.	Preserves:	Icon
translation	$\begin{bmatrix} \boldsymbol{I} \mid \boldsymbol{t} \end{bmatrix}_{2\times3}$	2	orientation $+\cdots$	
rigid (Euclidean)	$\begin{bmatrix} \boldsymbol{R} \mid \boldsymbol{t} \end{bmatrix}_{2\times3}$	3	lengths $+\cdots$	
similarity	$\begin{bmatrix} s\boldsymbol{R} \mid \boldsymbol{t} \end{bmatrix}_{2\times3}$	4	angles $+\cdots$	
affine	$\begin{bmatrix} \boldsymbol{A} \end{bmatrix}_{2\times3}$	6	parallelism $+\cdots$	
projective	$\begin{bmatrix} \tilde{\boldsymbol{H}} \end{bmatrix}_{3\times3}$	8	straight lines	

These transformations are a nested set of groups

- Closed under composition and inverse is a member

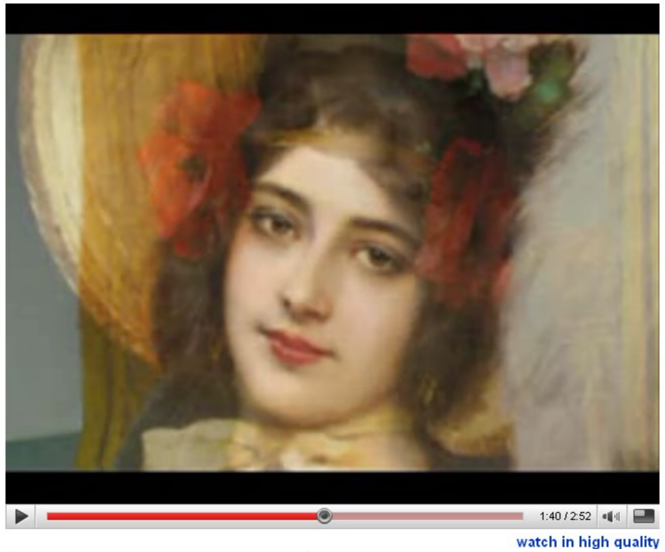
Take-home Question

Suppose we have two triangles: ABC and A’B’C’. What transformation will map A to A’, B to B’, and C to C’? How can we get the parameters?



Today: Morphing

Women in art

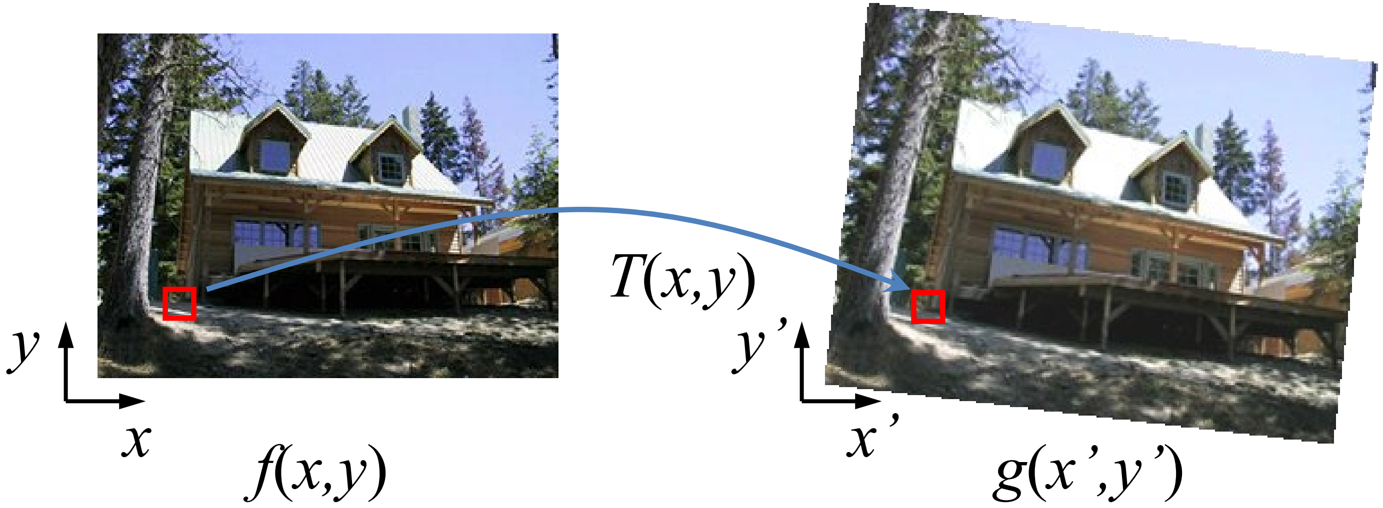


http://youtube.com/watch?v=nUDIoN-_Hxs

Aging

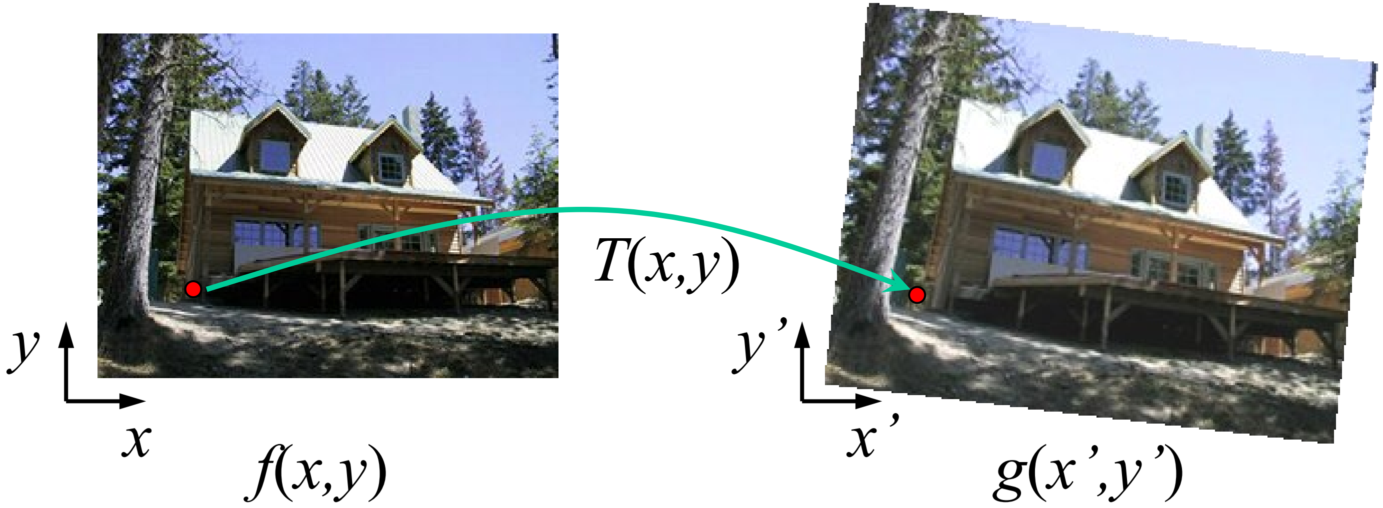
http://www.youtube.com/watch?v=L0GKp-uvjO0

Texturing in transformed coordinates



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 mapping

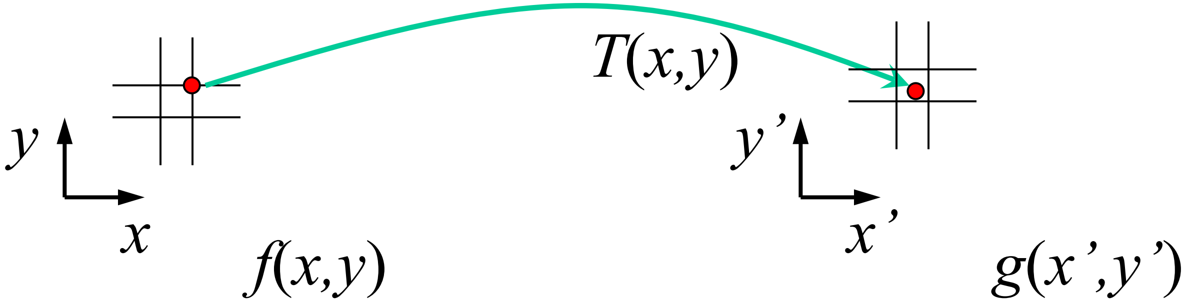


Send each pixel $f(x,y)$ to its corresponding location

$(x',y') = T(x,y)$ in the second image

Forward mapping

What is the problem with this approach?



Send each pixel $f(x,y)$ to its corresponding location

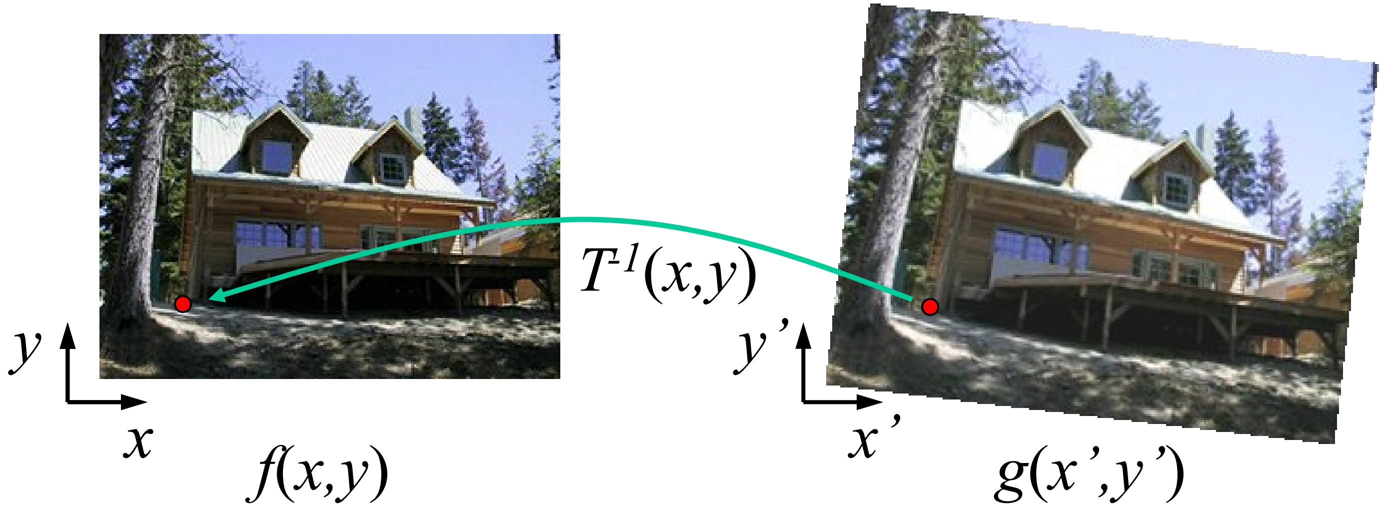
$(x',y') = T(x,y)$ in the second image

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

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

- Known as "splatting"

Inverse mapping

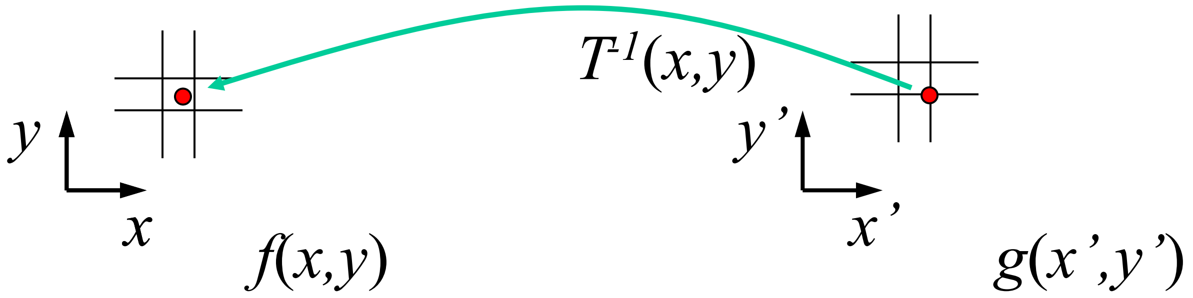


Get each pixel $g(x',y')$ from its corresponding location

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

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

Inverse mapping



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

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

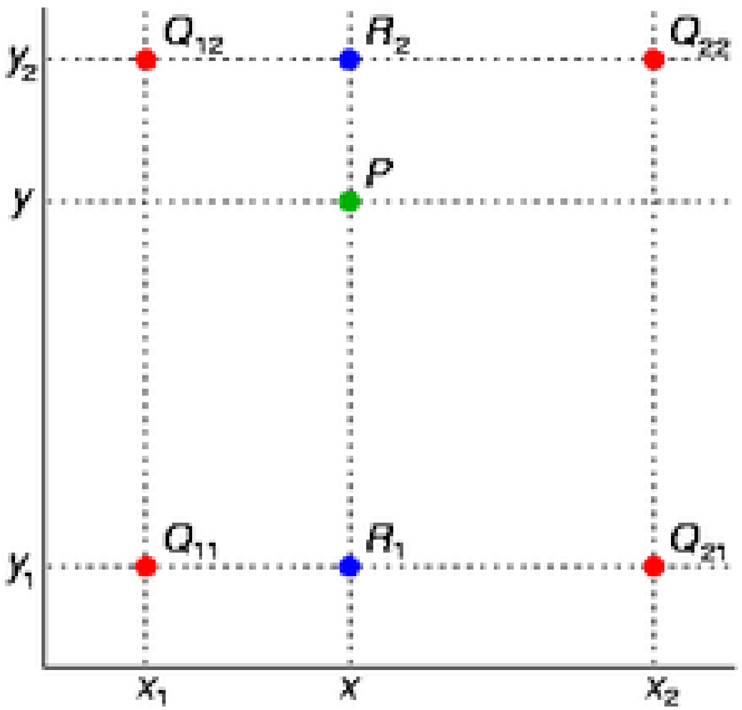
Q: what if pixel comes from "between" two pixels?

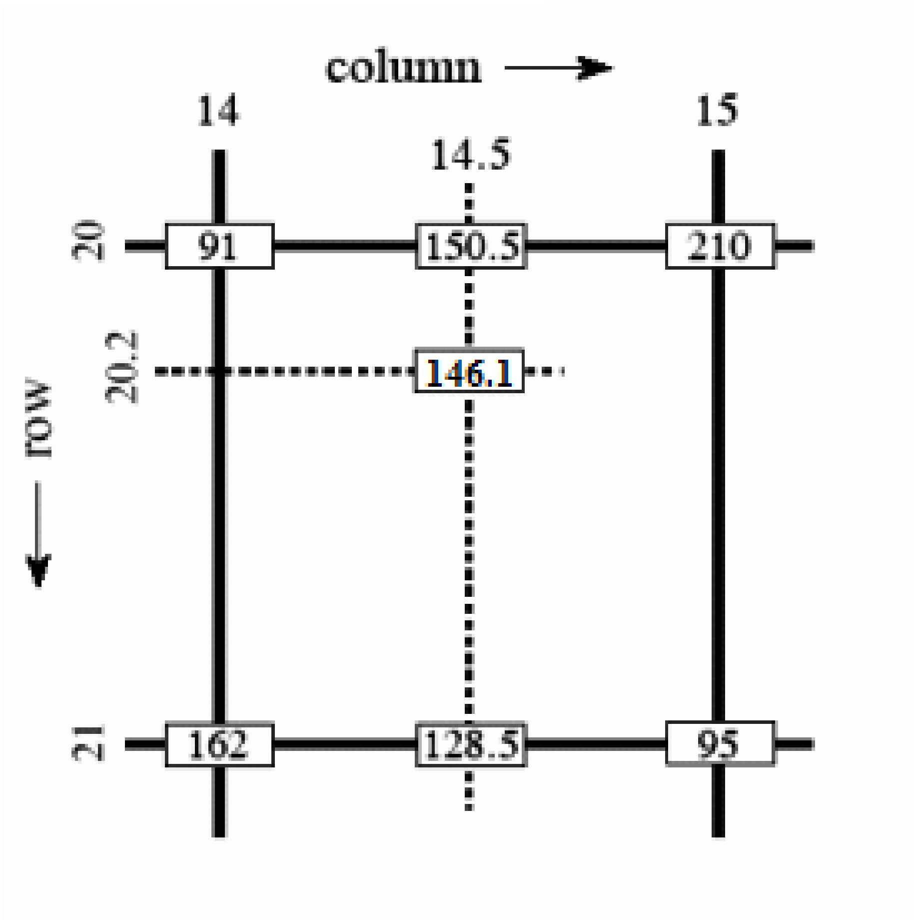
A: *Interpolate* color value from neighbors

- nearest neighbor, bilinear, Gaussian, bicubic
- E.g. `interpolate.interp2` or `ndimage.map_coordinates` in Python `scipy`

Bilinear Interpolation

$$f(x,y) \approx \begin{bmatrix}1-x & x\end{bmatrix} \begin{bmatrix} f(0,0) & f(0,1) \\ f(1,0) & f(1,1) \end{bmatrix} \begin{bmatrix} 1-y \\ y \end{bmatrix}.$$





http://en.wikipedia.org/wiki/Bilinear_interpolation

Forward vs. inverse mapping

Q: which is better?

A: Usually inverse—eliminates holes

- however, it requires an invertible warp function

Morphing = Object Averaging

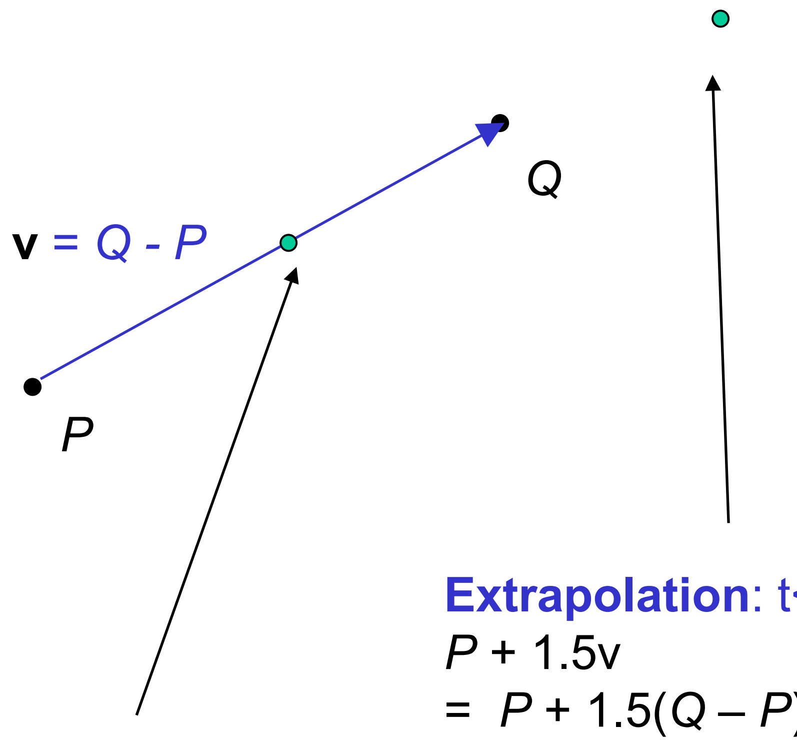
  

The aim is to find "an average" between two objects

- 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

Averaging Points

What's the average of P and Q?



Extrapolation: $t<0$ or $t>1$

$P + 1.5\mathrm{v}$

$= P + 1.5(Q - P)$

$= -0.5P + 1.5\,Q$ $(t=1.5)$

Linear Interpolation

New point: $P + t*(Q-P)$

Or equivalently: $(1-t)P + tQ$

$0<t<1$

$P + 0.5\mathrm{v}$

$= P + 0.5(Q - P)$

$= 0.5P + 0.5\,Q$

P and Q can be anything:

- points on a plane (2D) or in space (3D)
- Colors in RGB (3D)
- Whole images (m-by-n D)… etc.

Idea #1: Cross-Dissolve

Interpolate whole images:

$Image_{halfway} = (1\text{-}t)*Image_1 + t*image_2$

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

But what if the images are not aligned?

Idea #2: Align, then cross-disolve

Align first, then cross-dissolve

- Alignment using global warp – picture still valid

Image credit: Efros

Dog Averaging

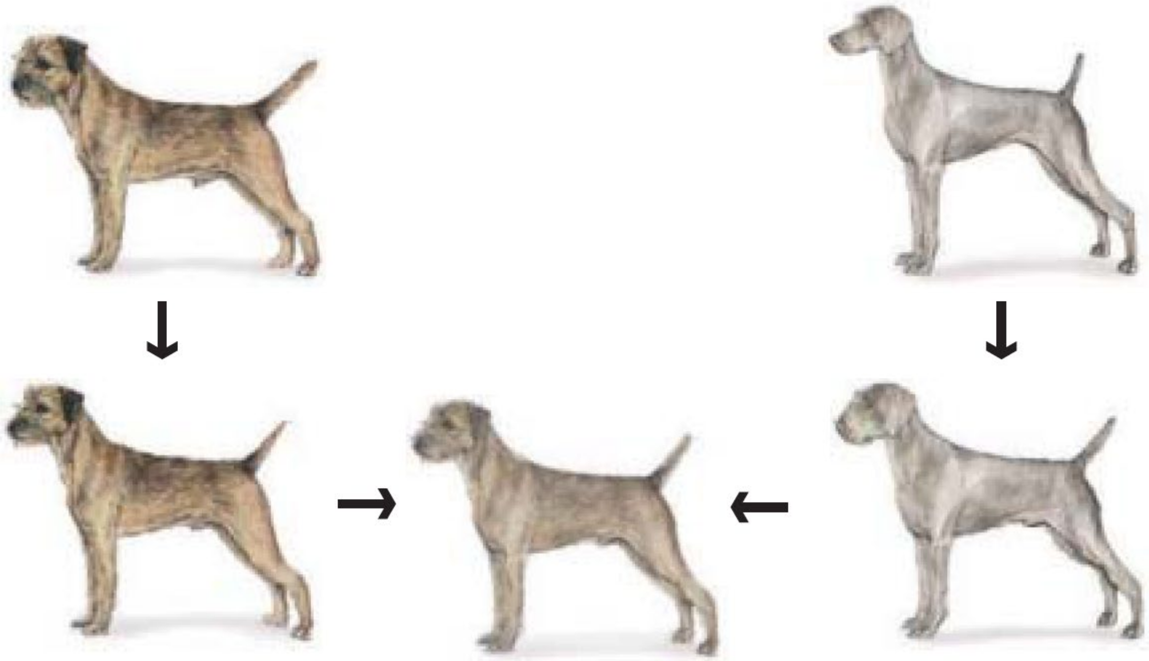
What to do?

- 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 frame t,

1. Find the weighted average shape (the “mean dog”☺)
   - local warping
2. Find the weighted average color
   - Warp each image to weighted average shape and cross-dissolve

Local (non-parametric) Image Warping

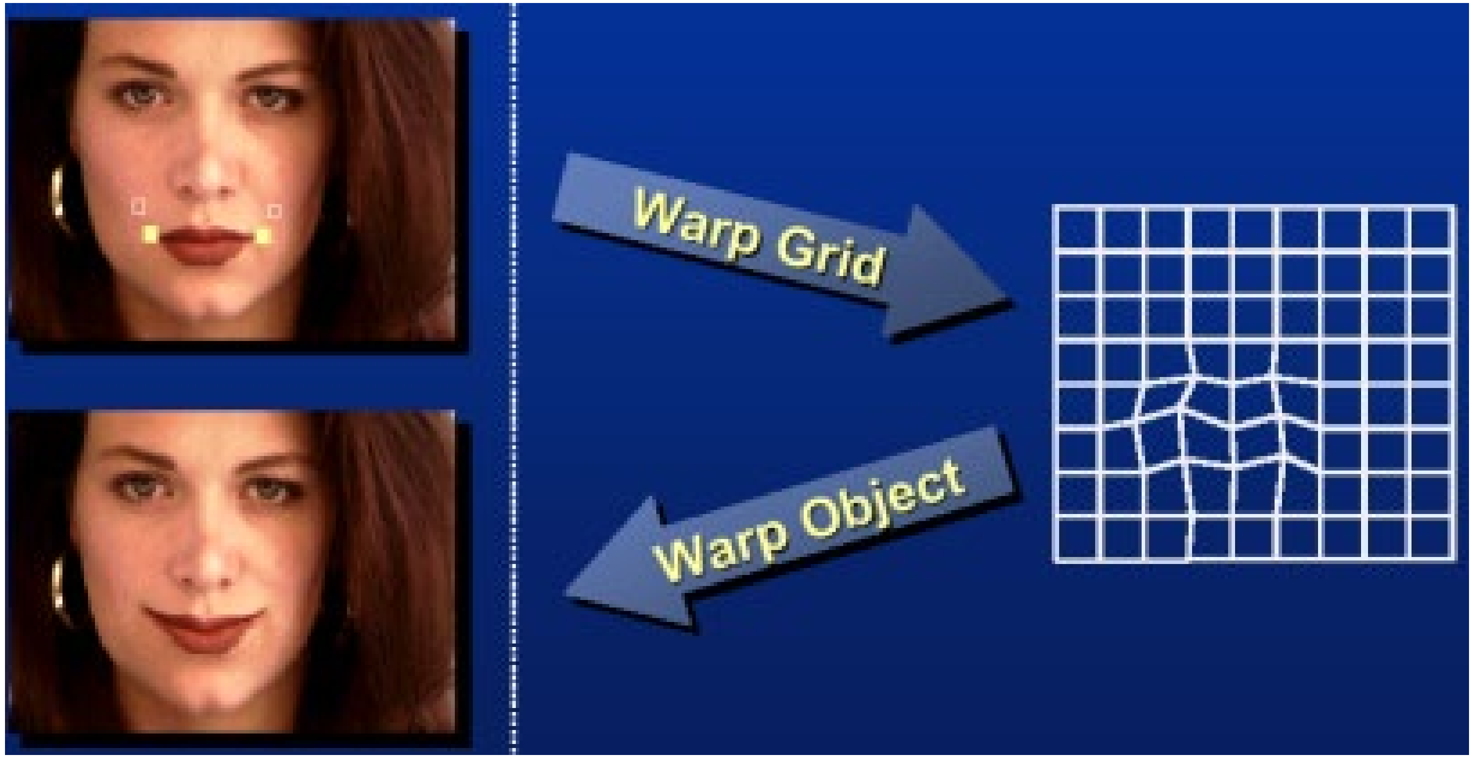
Need to specify a more detailed warp function

- 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)

Image Warping – non-parametric

Move control points to specify a spline warp

Spline produces a smooth vector field

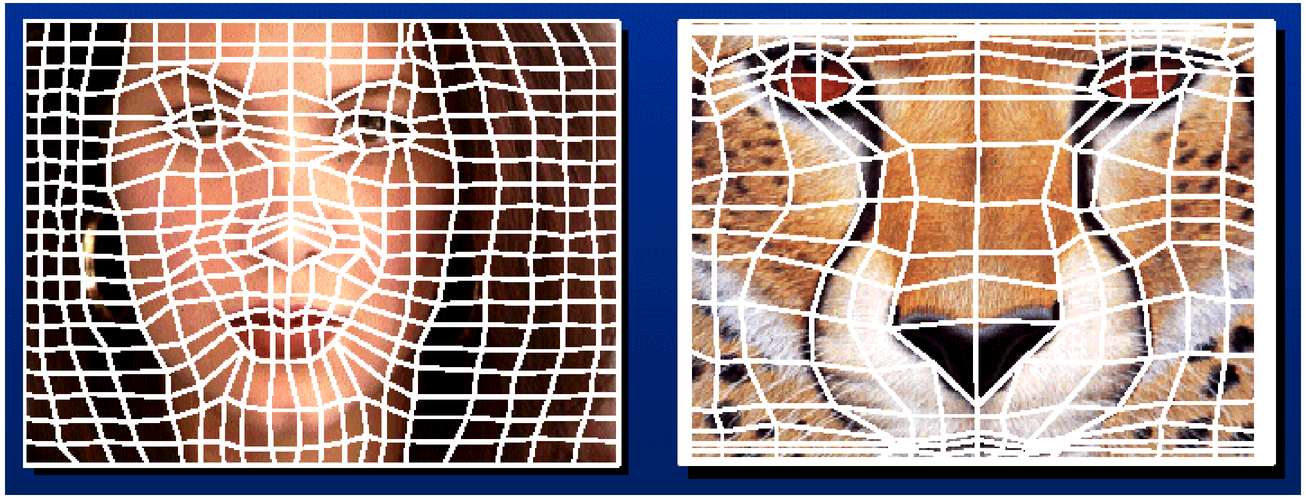


Warp specification - dense

How can we specify the warp?

Specify corresponding *spline control points*

- *interpolate* to a complete warping function



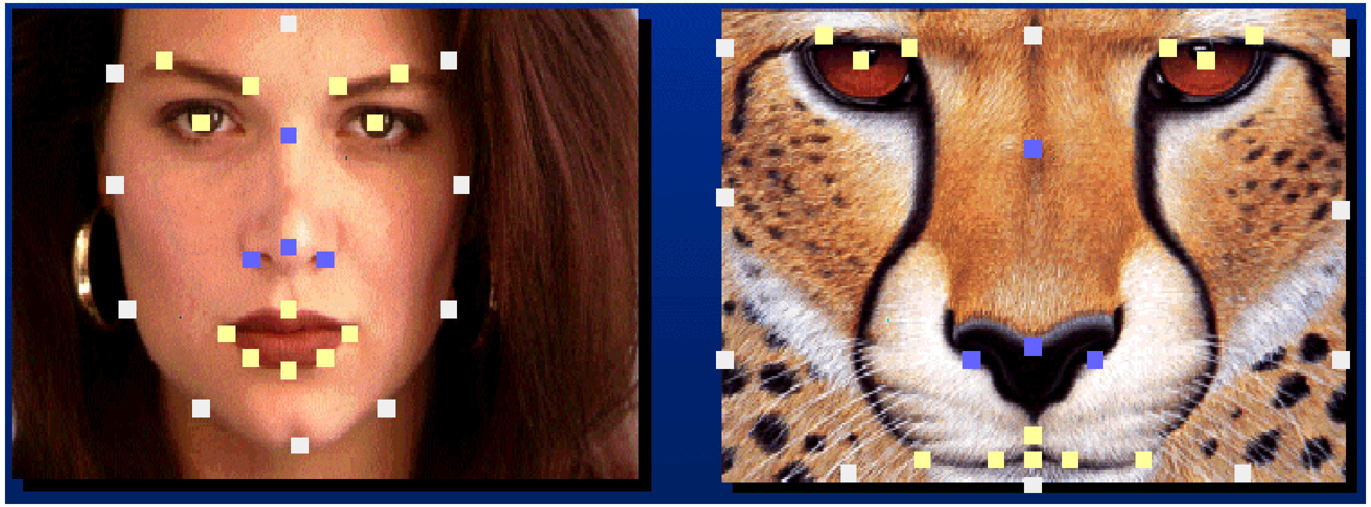
But we want to specify only a few points, not a grid

Warp specification - sparse

How can we specify the warp?

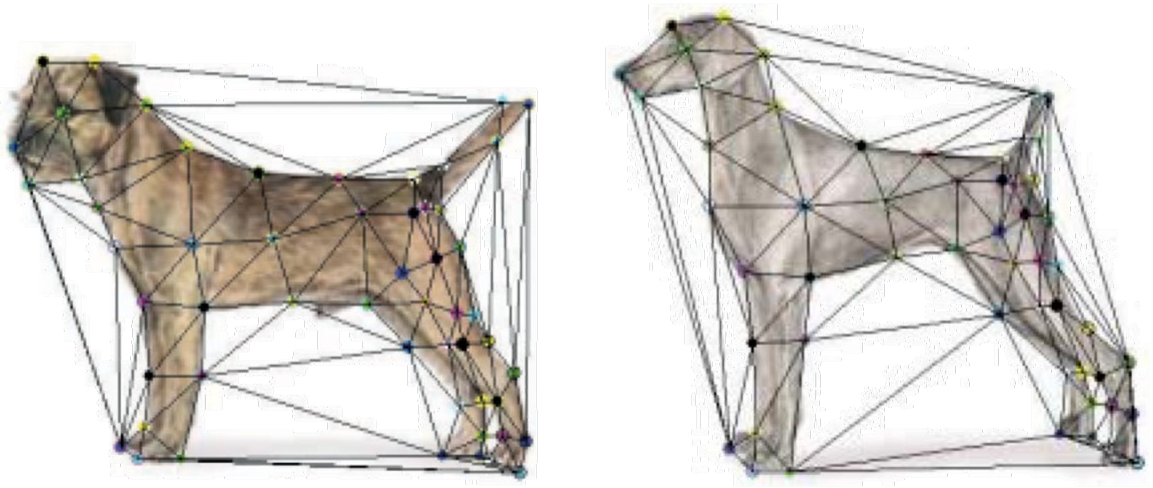
Specify corresponding *points*

- *interpolate* to a complete warping function
- How do we do it?



How do we go from feature points to pixels?

Triangular Mesh

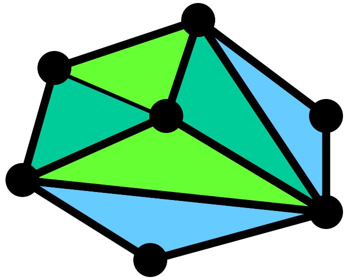
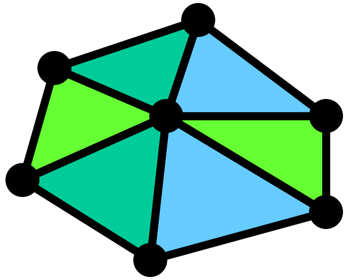
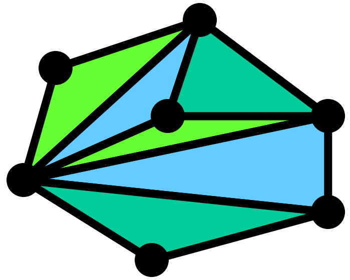


1. Input correspondences at key feature points
2. Define a triangular mesh over the points
   - Same mesh (triangulation) in both images!
   - Now we have triangle-to-triangle correspondences
3. Warp each triangle separately from source to destination
   - Affine warp with three corresponding points (just like take-home question)

Triangulations

A *triangulation* of set of points in the plane is a *partition* of the convex hull to triangles, whose vertices are the points, that do not contain other points.

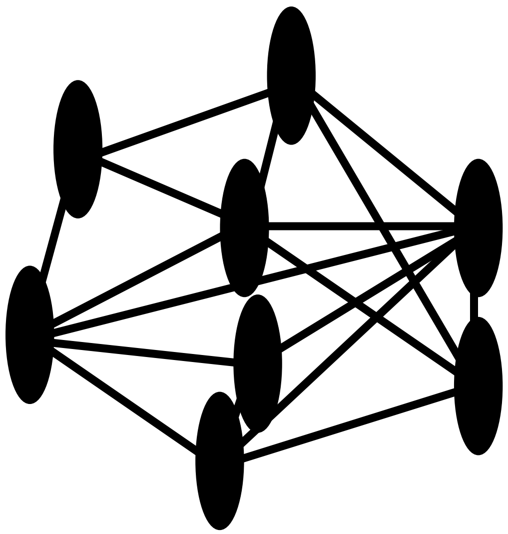
There are an exponential number of triangulations of a point set.

An O(n^3) Triangulation Algorithm

Repeat until impossible:

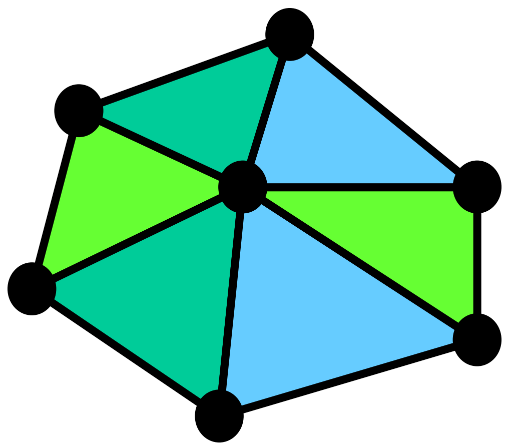
- Select two sites.
- If the edge connecting them does not intersect previous edges, keep it.



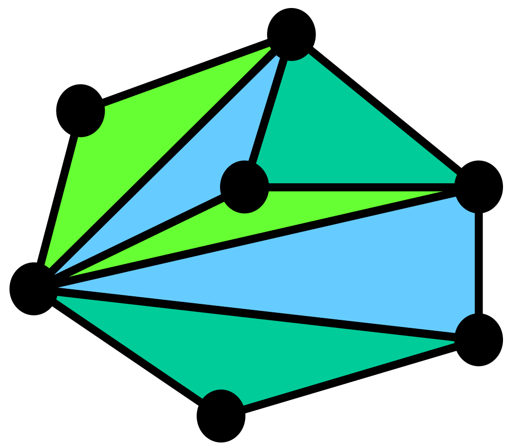
"Quality" Triangulations

Let $\alpha(T_i) = (\alpha_{i1}, \alpha_{i2}, .., \alpha_{i3})$ be the vector of angles in the triangulation T in increasing order:

- A triangulation T_1 is "better" than T_2 if the smallest angle of T_1 is larger than the smallest angle of T_2
- Delaunay triangulation is the "best" (maximizes the smallest angles)



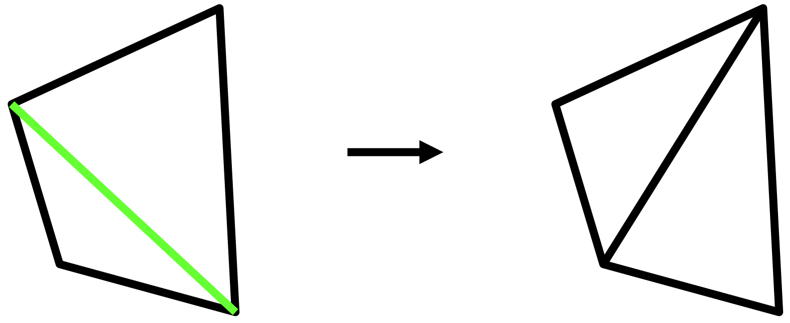
good



bad

Improving a Triangulation

In any convex quadrangle, an *edge flip* is possible.
If this flip *improves* the triangulation locally, it also improves the global triangulation.

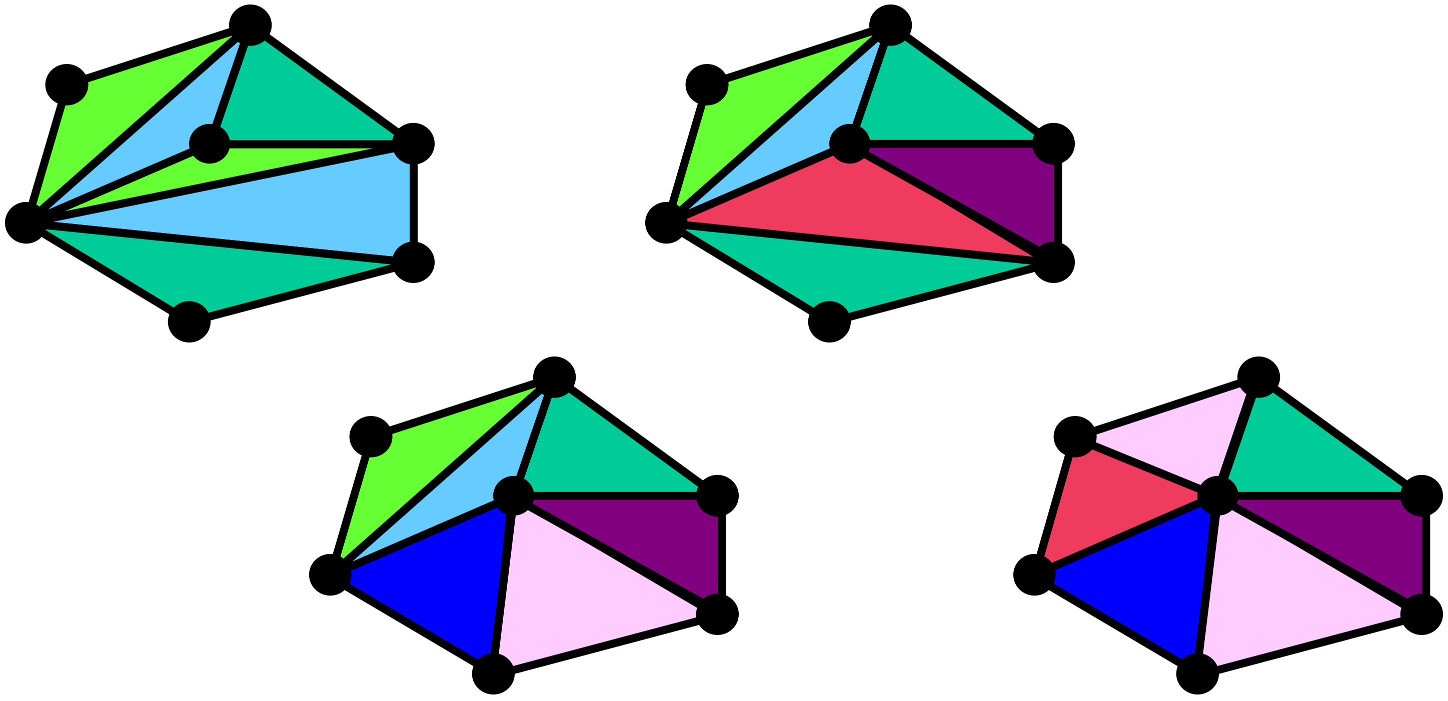


If an edge flip improves the triangulation, the first edge is called “*illegal*”.

Naïve Delaunay Algorithm

Start with an arbitrary triangulation. Flip any illegal edge until no more exist.

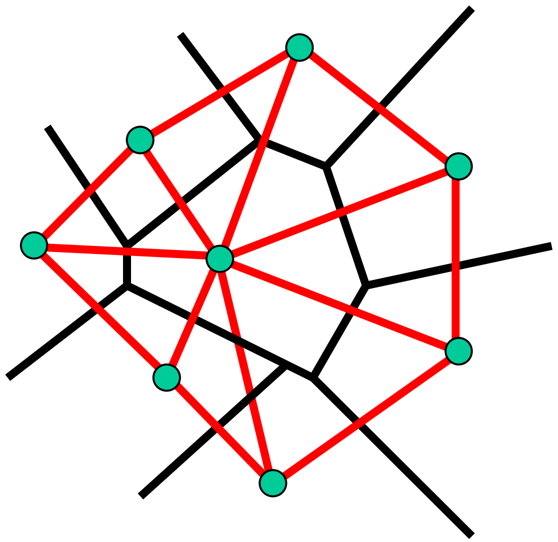
Could take a long time to terminate.



Delaunay Triangulation by Duality

Draw the dual to the Voronoi diagram by connecting each two neighboring sites in the Voronoi diagram.

- The DT may be constructed in O(*n*log*n*) time

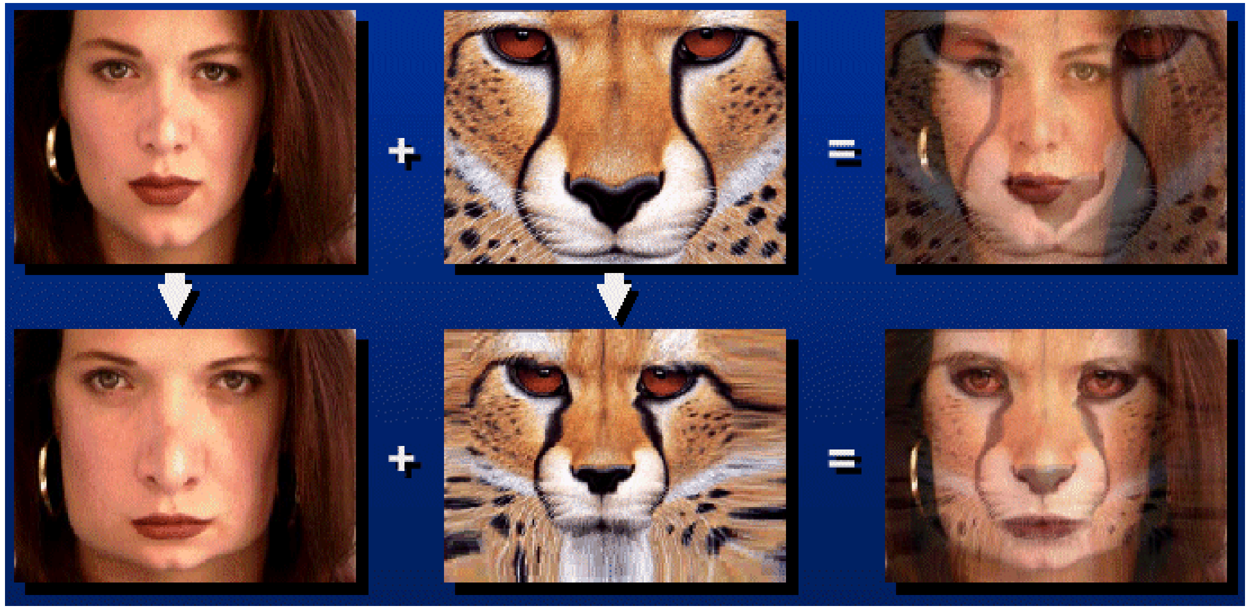


Demos: http://www.cs.cornell.edu/home/chew/Delaunay.html
http://alexbeutel.com/webgl/voronoi.html

Image Morphing

How do we create a morphing sequence?

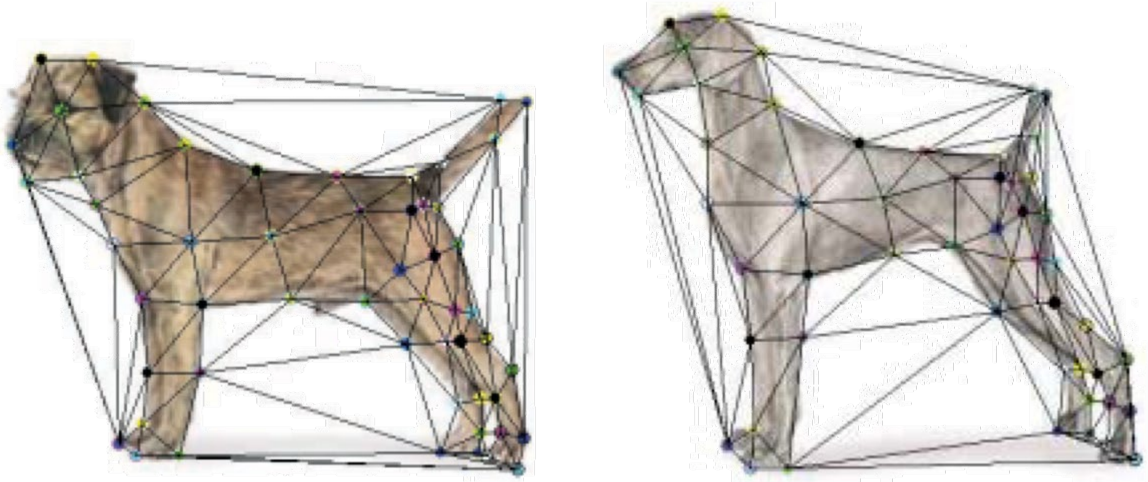
1. Create an intermediate shape (by interpolation)
2. Warp both images towards it
3. Cross-dissolve the colors in the newly warped images



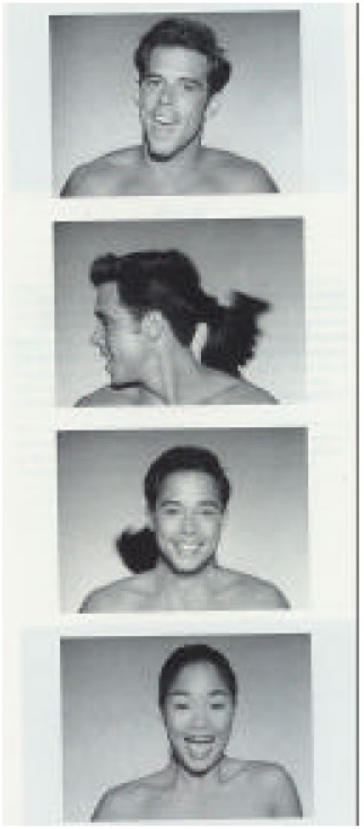
Warp interpolation

How do we create an intermediate shape 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



Dynamic Scene

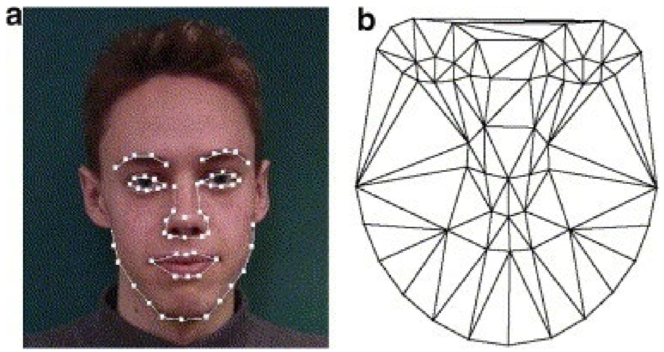


Black or White (MJ):
http://www.youtube.com/watch?v=R4kLKv5gtxc

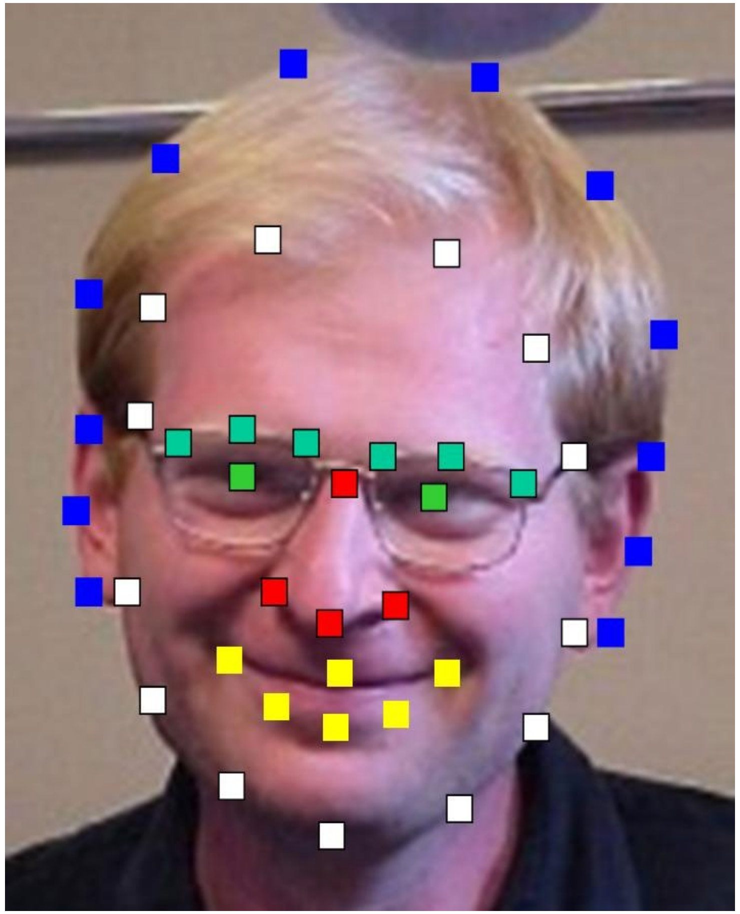
Willow morph: http://www.youtube.com/watch?v=uLUyuWo3pG0

Aligning Faces

- The more key-points, the finer alignment

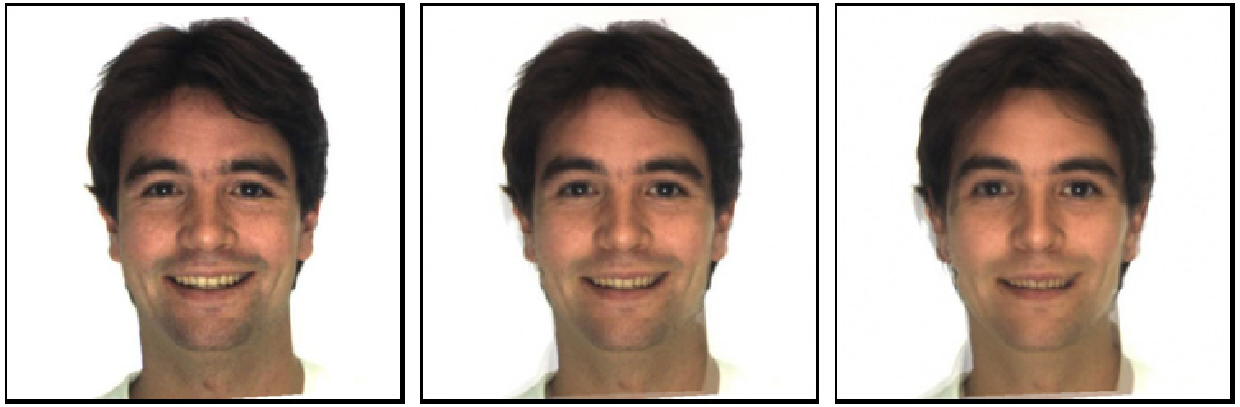


Images from Alyosha Efros



Morphing & matting

Extract foreground first to avoid artifacts in the background



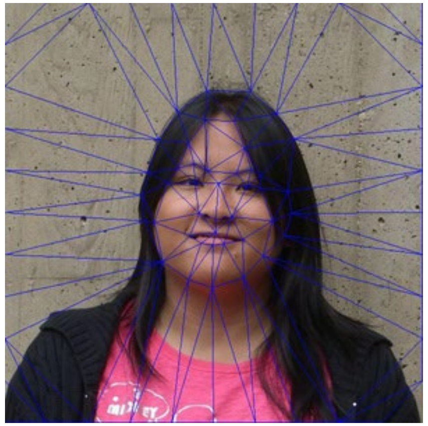
(c) $\alpha = 0.0$ (d) $\alpha = 0.2$ (e) $\alpha = 0.4$

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

Slide by Durand and Freeman

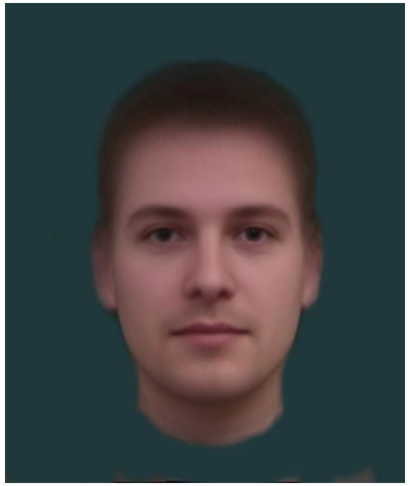
Average of two Faces

1. Input face keypoints
2. Pairwise average keypoint coordinates
3. Triangulate the faces
4. Warp: transform every face triangle
5. Average the pixels

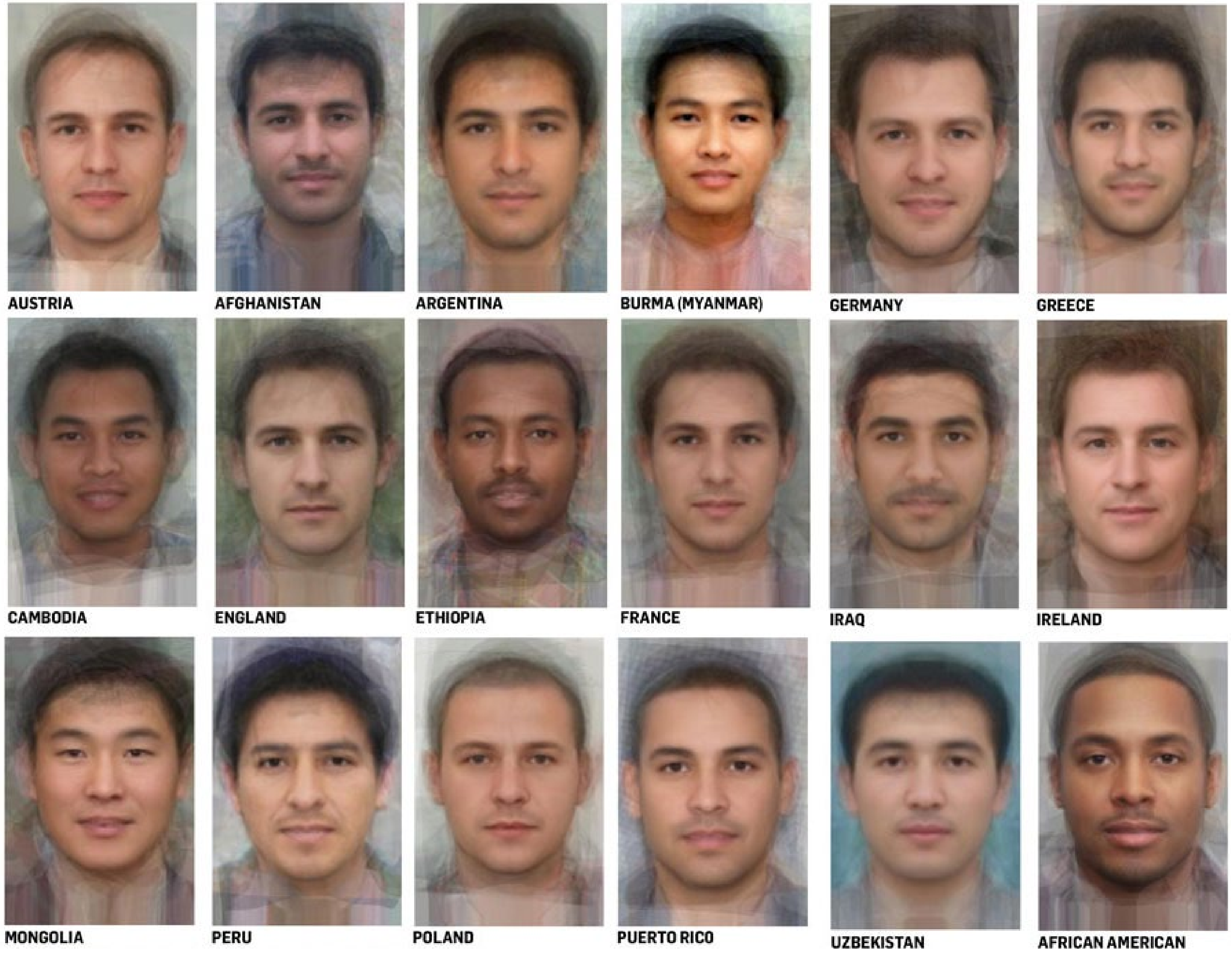

Average of multiple faces

1. Warp to mean shape
2. Average pixels

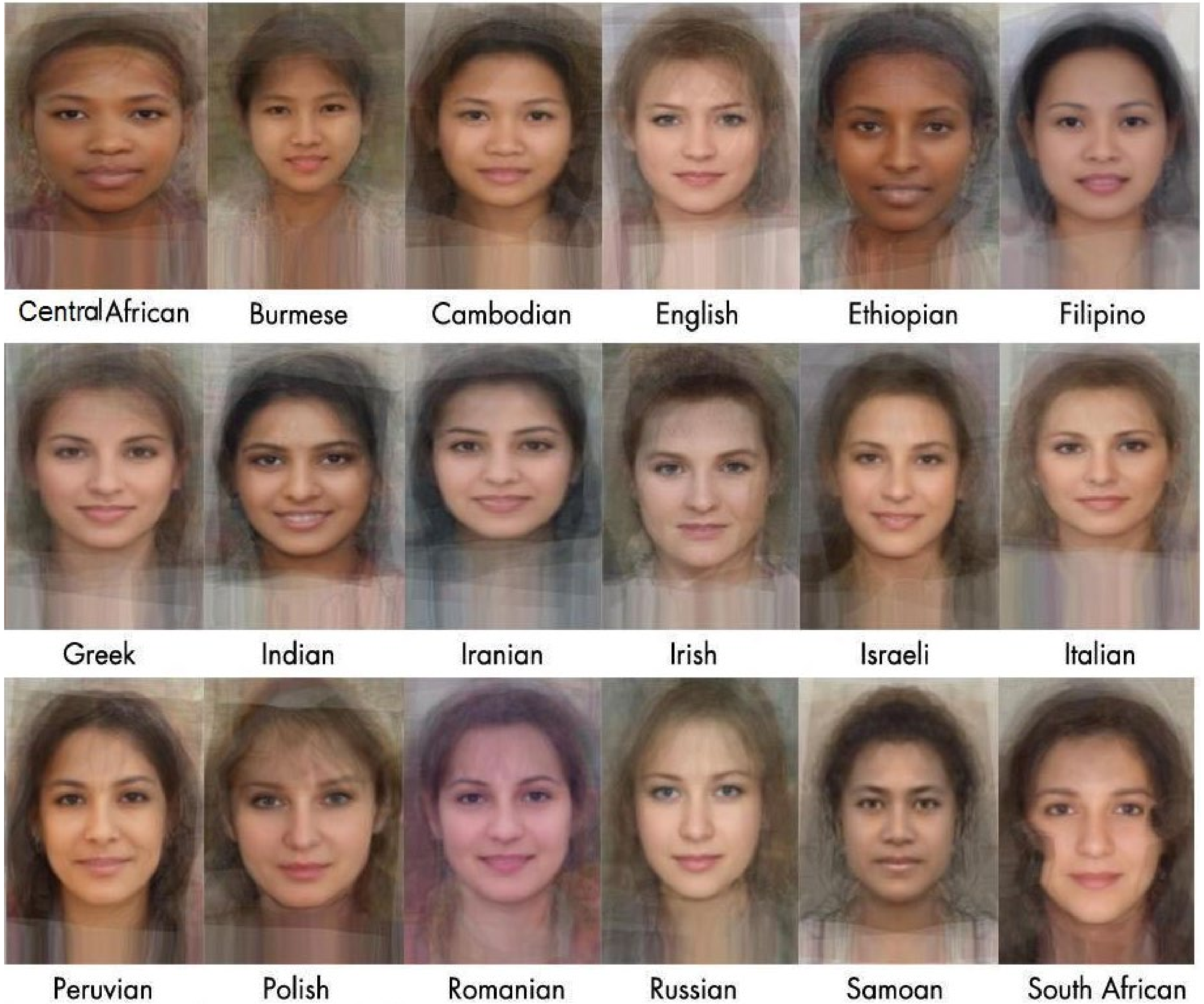


http://graphics.cs.cmu.edu/courses/15-463/2004_fall/www/handins/brh/final/

Average Men of the world



Average Women of the world



Subpopulation means

Other Examples:

- Average Kids
- Happy Males
- Etc.

Average female

Average kid

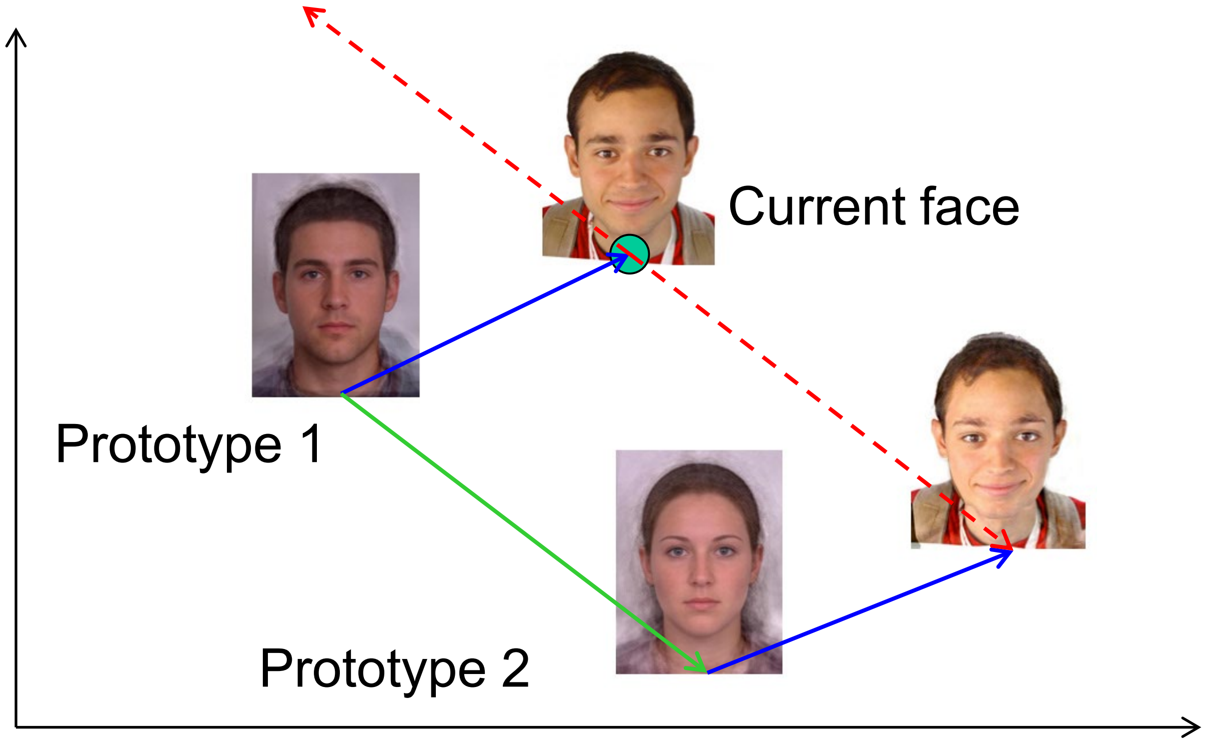
Average happy male

Average male

Manipulating faces

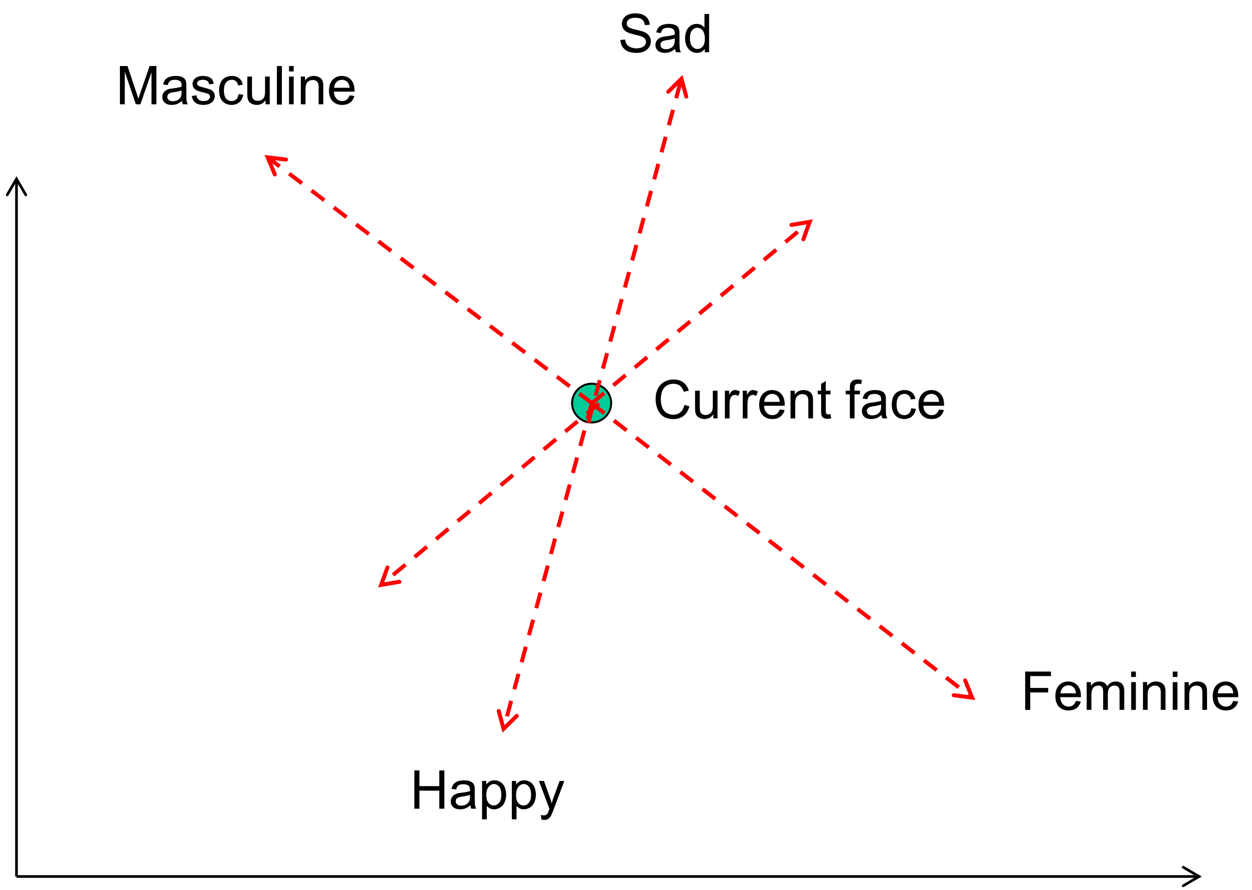
How can we make a face look more female/male, young/old, happy/sad, etc.?

With shape/texture analogies!



Manipulating faces

We can imagine various meaningful directions



Averaging and transformation demos

http://www.faceresearch.org/demos

Summary of morphing

1. Define corresponding points
2. Define triangulation on points
   – Use same triangulation for both images
3. For each t = 0:step:1
   a. Compute the average shape (t-weighted average of points)
   b. For each triangle in the average shape
      - Get the affine projection to the corresponding triangles in each image
      - For each pixel in the triangle, find the corresponding points in each image and set rgb value to t-weighted average (optionally use interpolation)
   c. Save the image as the next frame of the sequence

Next classes

Pinhole camera: start of perspective geometry

Single-view metrology: measure 3D distances from an image