

# Lecture 23 Active Shape Model (ASM)

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# Outline

- Algorithm 1: Ordinary Procrustes Analysis
- Algorithm 2: Statistical Shape Analysis
- Algorithm 3: Matching model to target

[https://personalpages.manchester.ac.uk/staff/timothy.f.cootes/refs\\_by\\_subject.html](https://personalpages.manchester.ac.uk/staff/timothy.f.cootes/refs_by_subject.html)

## Tim Cootes: Selected Publications by Subject

- Statistical Shape Models
- Active Shape Models
- Active Appearance Models
- Crumpled Level Models
- Geometric and Elastic B-splines
- Face Image Interpolation
- Surface Feature Detection
- Surface Image Compression
- Faces, Morphology and Landmarks

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- T.F. Cootes, C.J. Taylor, A. Mian, Model for Representing Shape Variations, Proc. 9th BMVC, (Ed. J. G. A. Clark), BMVA Press, pp. 110-119, 1997. [\[paper\]](#) [\[abstract\]](#) [\[video\]](#)
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### Active Shape Models

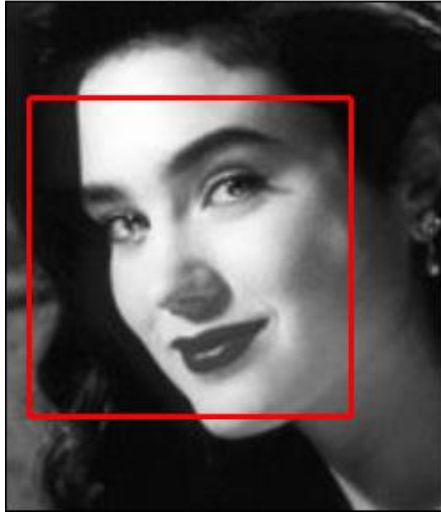
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# Building models

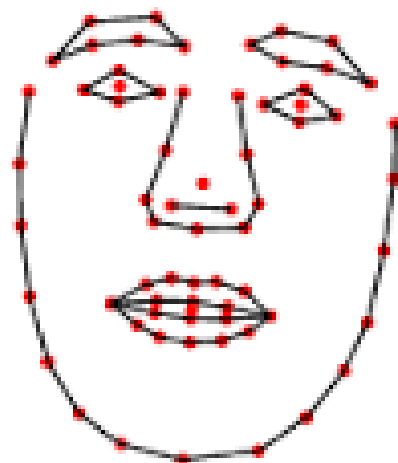
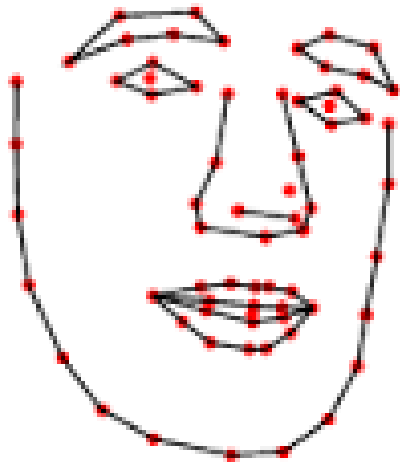
Bounding box



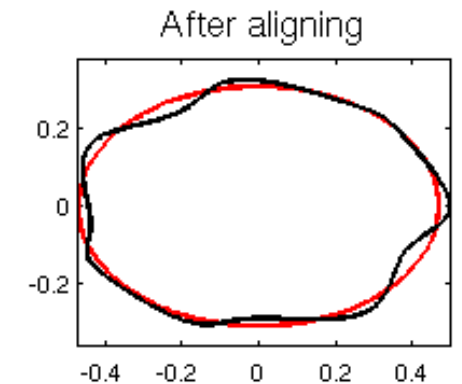
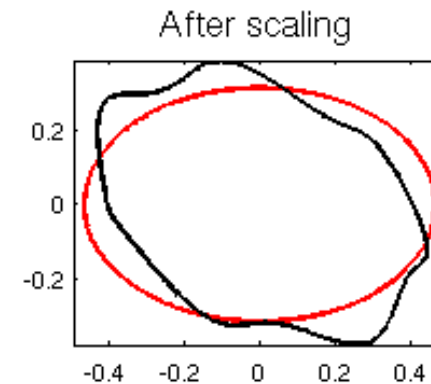
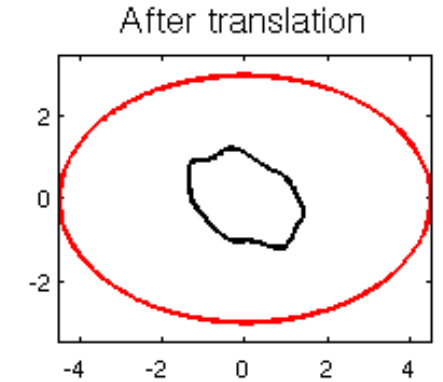
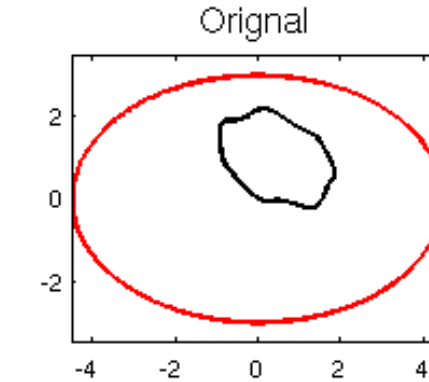
Initial shape



Final shape



# Algo1: Ordinary Procrustes Analysis



# Translation

- Take  $k$  points in two dimensions,

$$((x_1, y_1), (x_2, y_2), \dots, (x_k, y_k))$$

- The mean of these points is  $(\bar{x}, \bar{y})$  where

$$\bar{x} = \frac{x_1 + x_2 + \dots + x_k}{k}, \quad \bar{y} = \frac{y_1 + y_2 + \dots + y_k}{k}$$

- Now translate these points so that their mean is translated to the origin  
 $(x, y) \rightarrow (x - \bar{x}, y - \bar{y})$ , giving the point  $(x_1 - \bar{x}, y_1 - \bar{y}), \dots$

# Uniform scaling

- The scale component can be removed by scaling the object so that the root mean square distance (*RMSD*) from the points to the translated origin is 1,

$$s = \sqrt{\frac{(\bar{x}_1 - x_1)^2 + (\bar{y}_1 - y_1)^2 + \dots}{k}}$$

- The scale becomes 1 when the point coordinates are divided by the object's initial scale

$$((\bar{x}_1 - x_1)/s, (\bar{y}_1 - y_1)/s)$$

- Notice that other methods for defining and removing the scale are sometimes used in the literature.

# Rotation

- A rotation by angle  $\theta$  gives

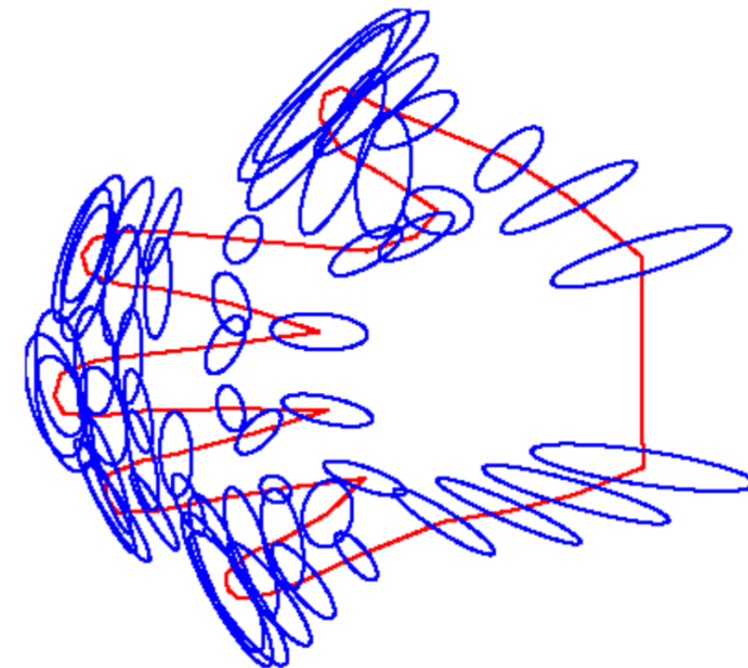
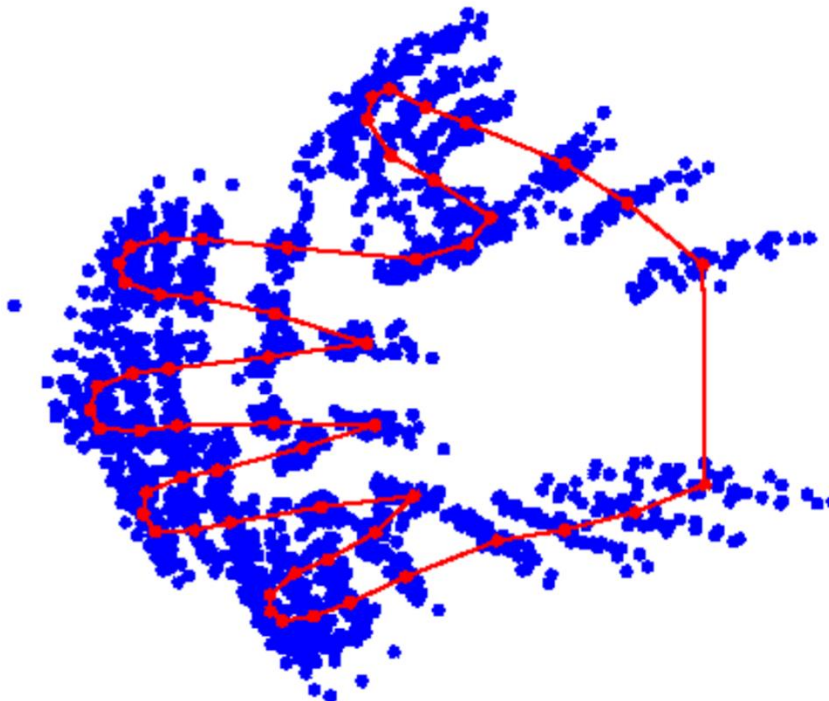
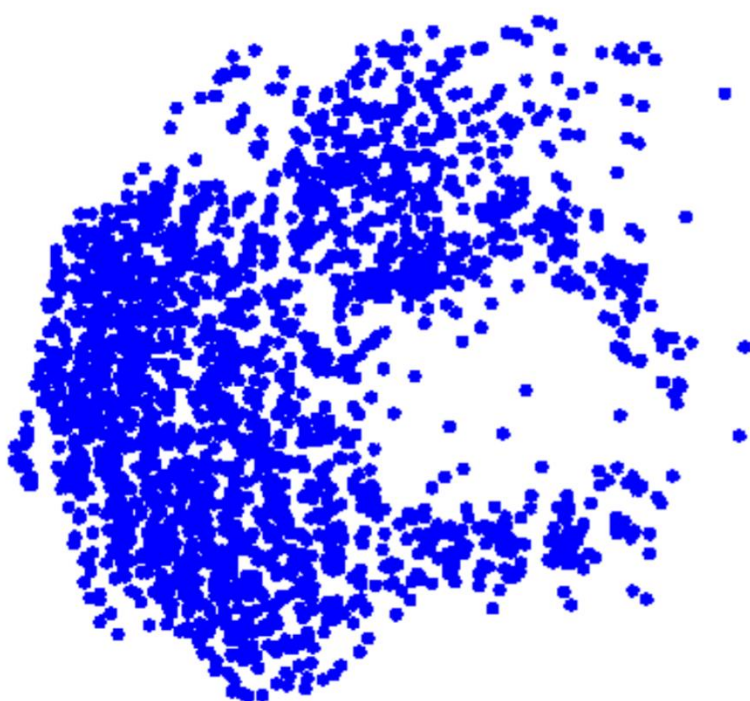
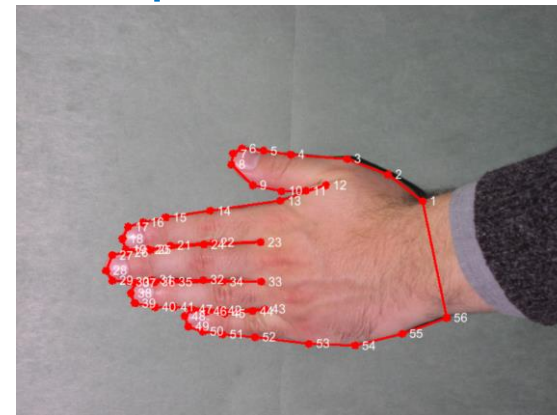
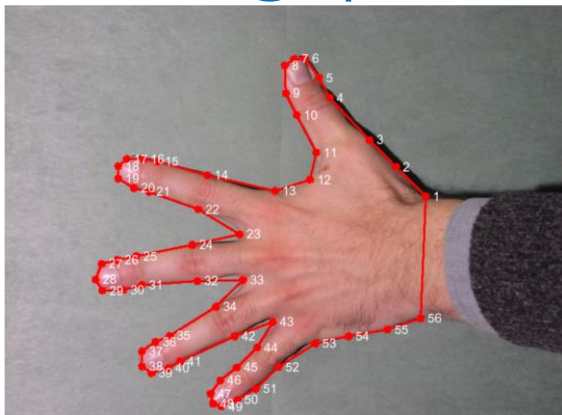
$$(u_1, v_1) = (\cos\theta x_1 - \sin\theta y_1, \sin\theta x_1 + \cos\theta y_1)$$

- Where  $(u, v)$  are the coordinate of a rotated point. Taking the derivative of  $(u_1 - \bar{x}_1)^2 + (v_1 - \bar{y}_1)^2 + \dots$  with respect to  $\theta$  and solving for  $\theta$  when the derivative is zeros gives

$$\theta = \tan^{-1} \left( \frac{\sum_{i=1}^k (x_i \bar{y}_i - y_i \bar{x}_i)}{\sum_{i=1}^k (x_i \bar{x}_i - y_i \bar{y}_i)} \right)$$



# Training points before and after procrustes analysis





# Algo2: Statistical Shape Analysis

- Now we have a set of aligned training shapes. Each is described by a  $2k$ -vector of feature point.
- We want to remove the dimensionality of this set to a number  $n \ll k$ .
- The full hand shape model is then built by computing PCA on all model points collectively, which captures correlations of motion between points.

# Perform PCA

- Compute mean of data
- Compute covariance of data
- Compute eigenvalues and eigenvector
- Each eigenvalue gives variance of data in the direction of the related eigenvector.
- Choose the largest eigenvalues to account for  $p\%$  of the total variance.

# Shape modes

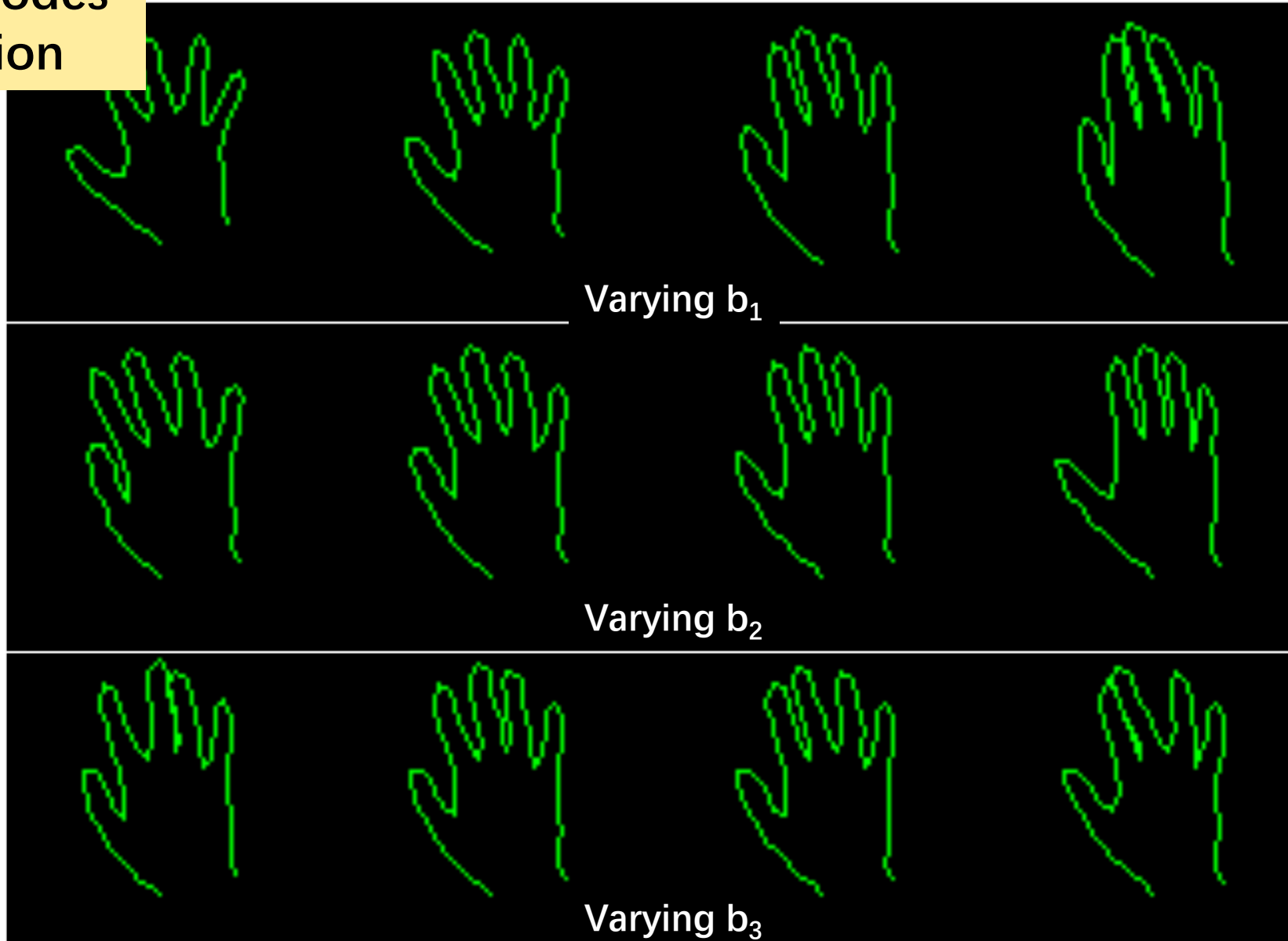
- For shape synthesis, we will use a linear model.

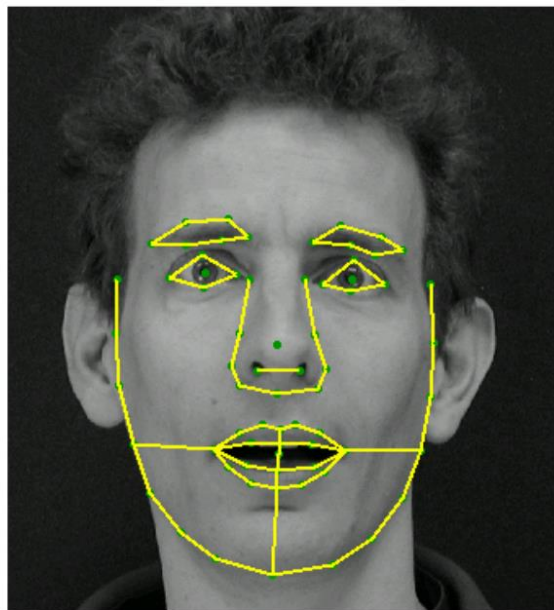
$n \ll 2k$   
95%

$$\begin{array}{c} 2k+1 \\ \downarrow \\ X^k \end{array} = \mu + \underset{\substack{\uparrow \\ 1 \times 1}}{b_1} \underset{\substack{\uparrow \\ 2k+1}}{V_1} + b_2 V_2 + \dots + b_n V_n$$

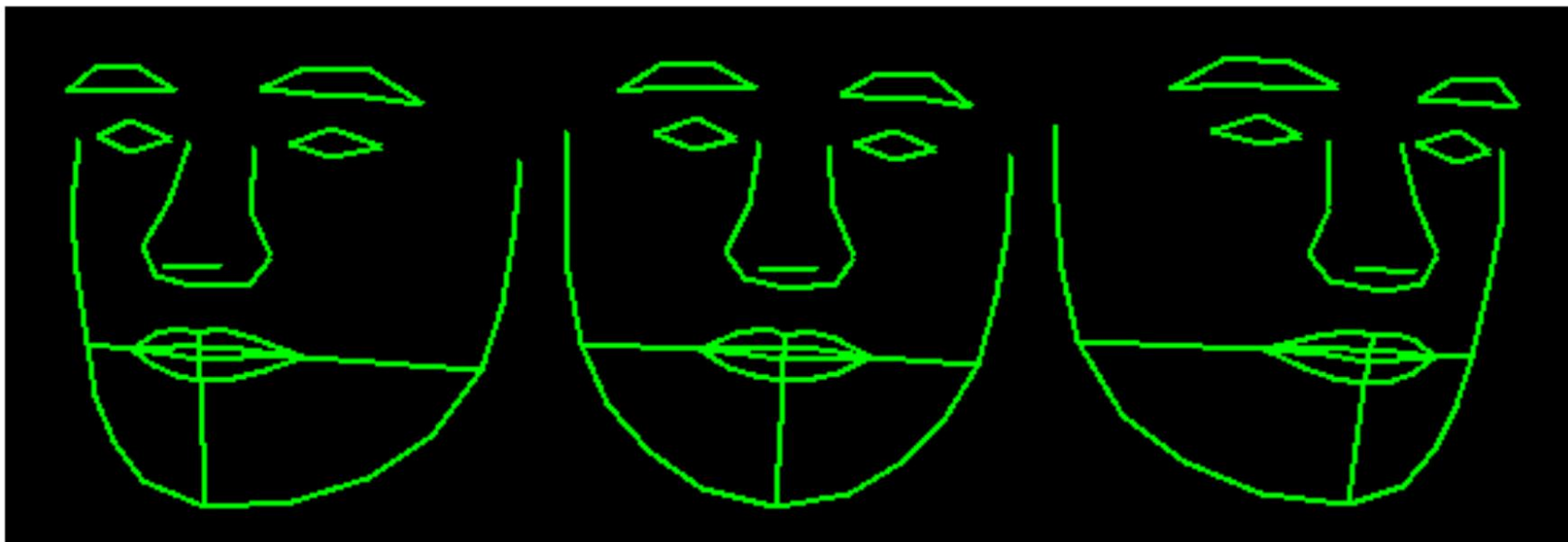
$\mu$                        $\lambda_k, V_k$        $2k \times 1$

## First 3 modes of variation





Sample face  
training image



1st mode of variation

# Fitting the curve to new data

- Assume we have a  $2k$ -vector  $Y$ , we want to fit the model: i.e. best translation, rotation, scaling  $(t, s, \theta)$  and model parameter  $b$ .

$$\min \|Y - M(\mu + Pb)\|^2$$

$$M(x) = s \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} x + t$$

# Algo3: Matching model to target

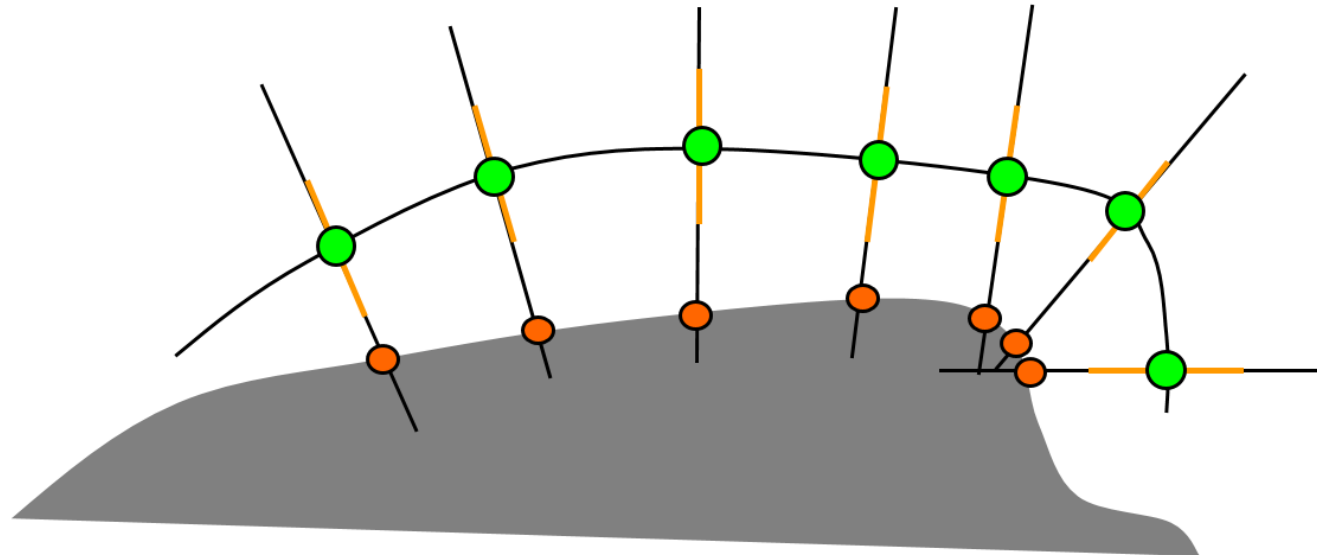
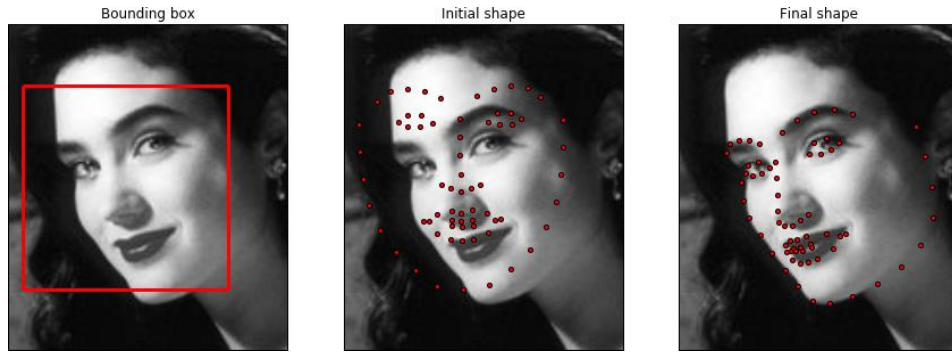
$$\min \|Y - M(\mu + Pb)\|^2$$

- 1. Initialize  $b = 0$ ;
- 2. Generate model points  $x = \mu + Pb$ ;
- 3. Find  $(t, s, \theta)$  to best fit  $Y$  to  $X$  (like in Procrustes analysis)- gives a new  $Y$ ;
- 4. Project  $Y$  into  $X$  space  $y = M^{-1}Y$ ;
- 5. Update model parameter  $b = P^T(y - \mu)$
- 6. Go to step 2, iterate until convergence.



# ASM Search Overview

- How do we know what image point Y should belong to the model?



# Matching model to target

- Initialize  $b = 0, x = \mu + Pb$ ;
- Search around each  $x_i$  for best nearby image point  $y_i$ .
- Algo3: Fit new parameters  $(t, s, \theta, b)$  to  $y_i$ .
- Enforce constraint  $|b_i| < 3\sqrt{\lambda_i}$ , so that shapes are “reasonable”.
- Iterate until convergence.