Image Analysis

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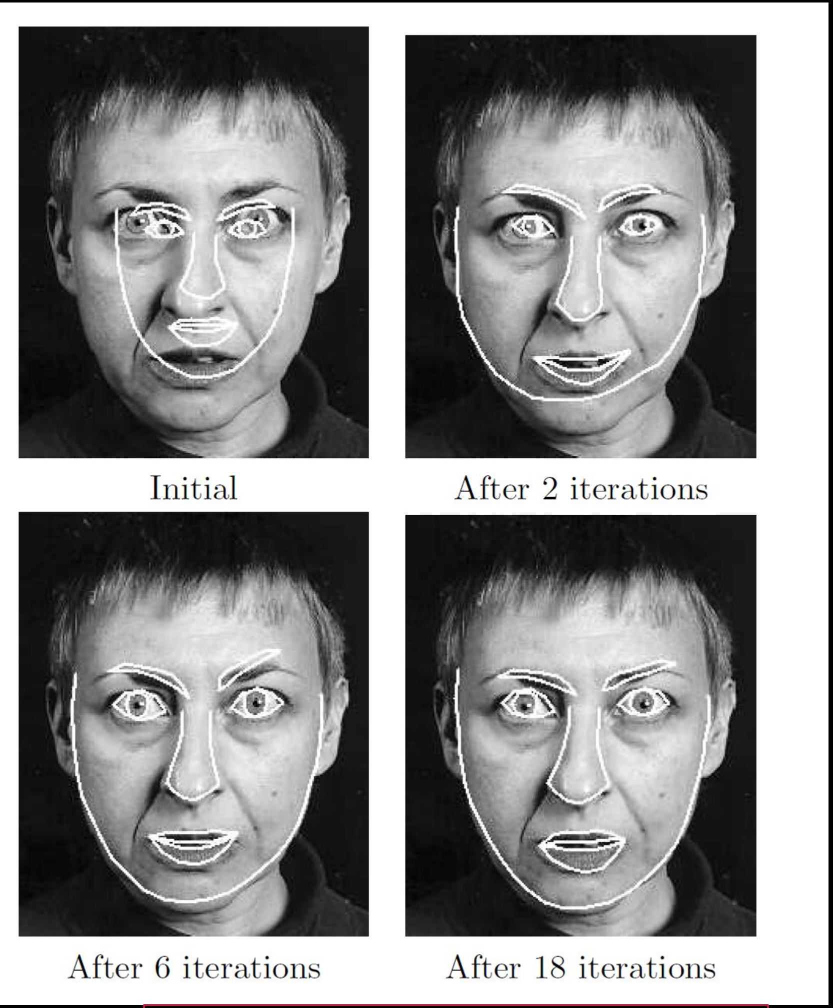
Lecture 12b – Active shape models

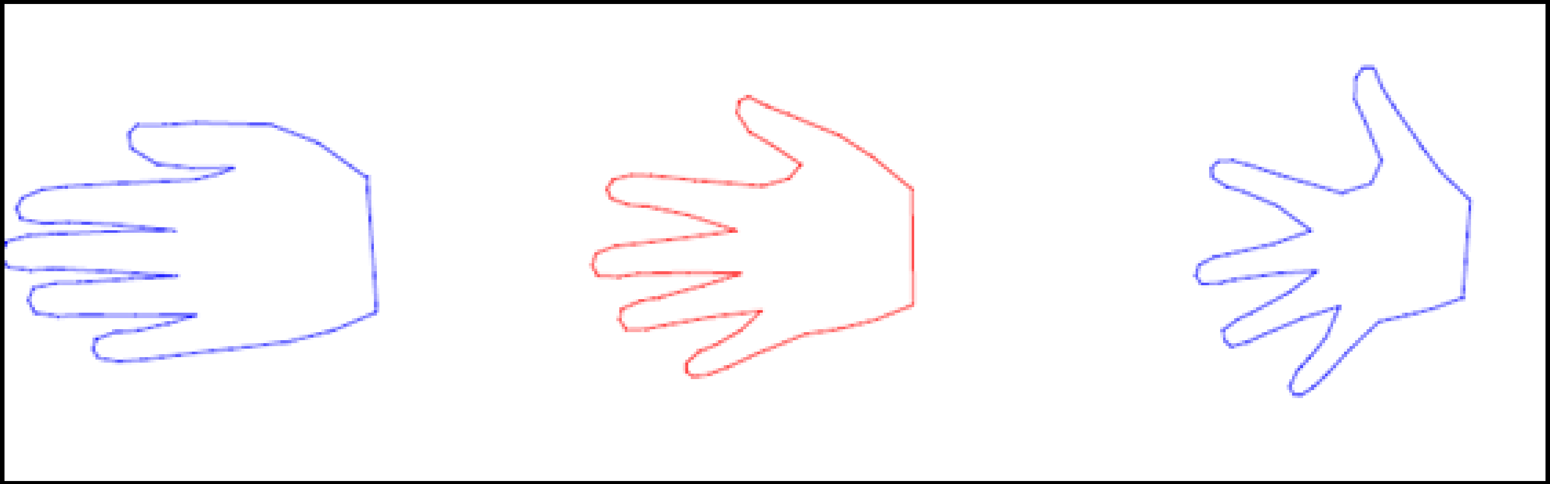


Tim Cootes: Active shape models

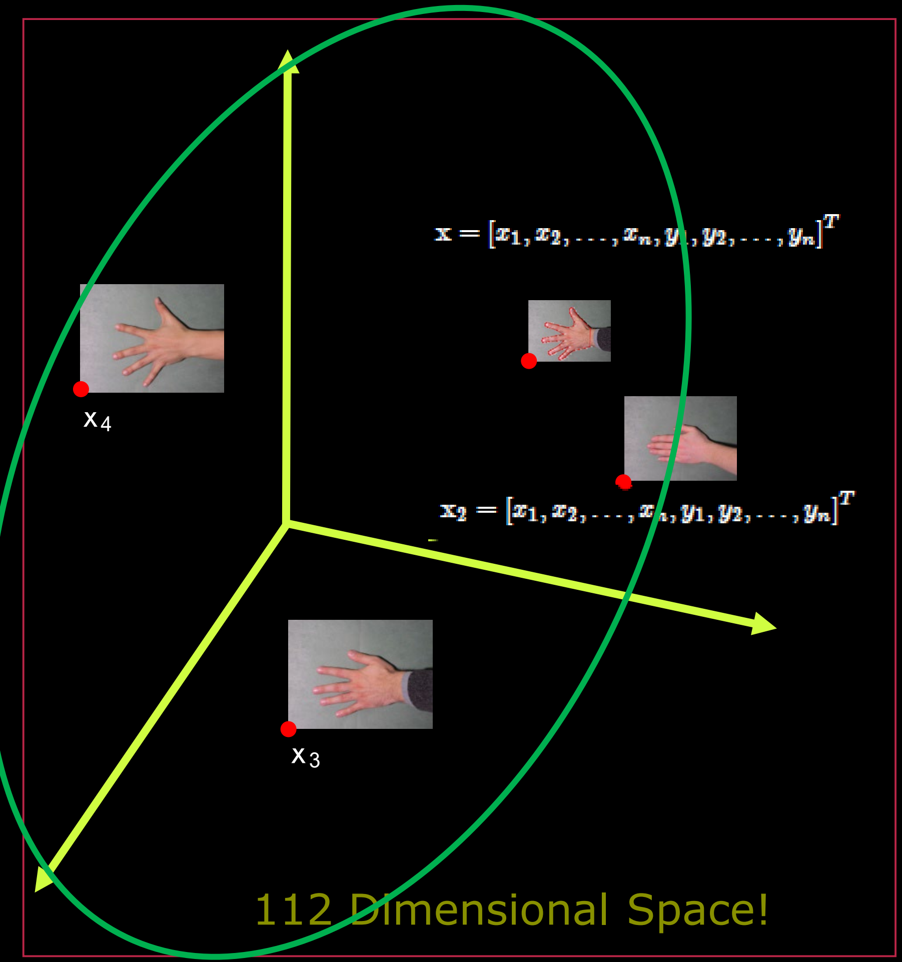
Today's Learning Objectives

- Describe how shapes can be synthesized using the shape space
- Describe the generative model based on a statistical shape model
- Describe the concept of analysis by synthesis
- Describe how the Eigenvectors and Eigenvalues can be used to constrain a shape model
- Describe how a statistical shape model can be fitted using the gradients in an image
- Describe how a statistical shape model can be fitted by modelling local variation
- Explain the problem of strong priors in statistical models

We have a statistical model of shape

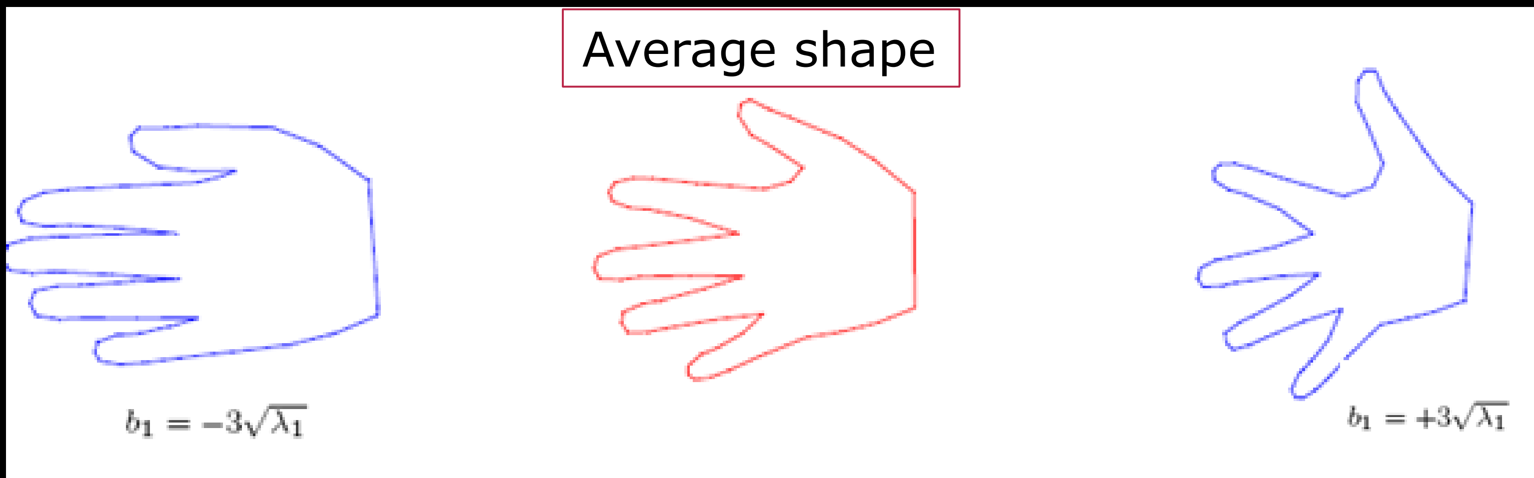


Shape space



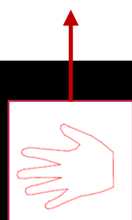
- A mapping of the shape space
- PCA based description of the "hand space"

Synthezising new shapes

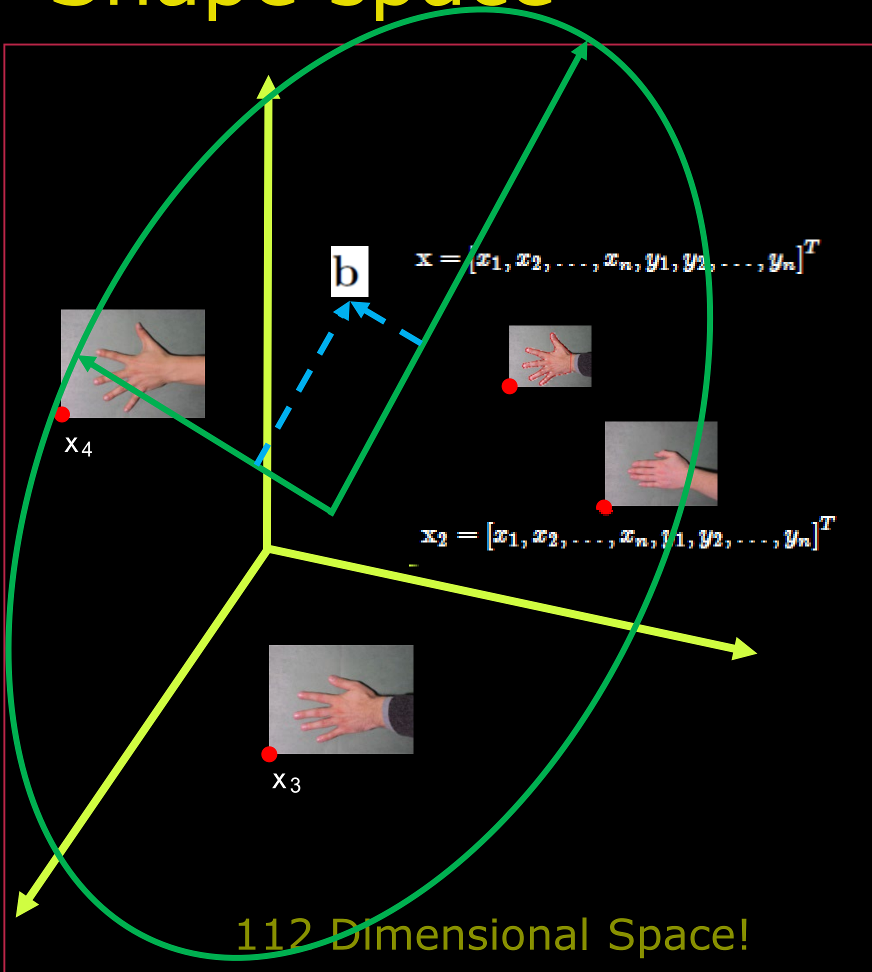


$$\mathbf{x} \approx \bar{\mathbf{x}} + \mathbf{\Phi}\mathbf{b}$$

Φ contains the t eigenvectors



Shape space

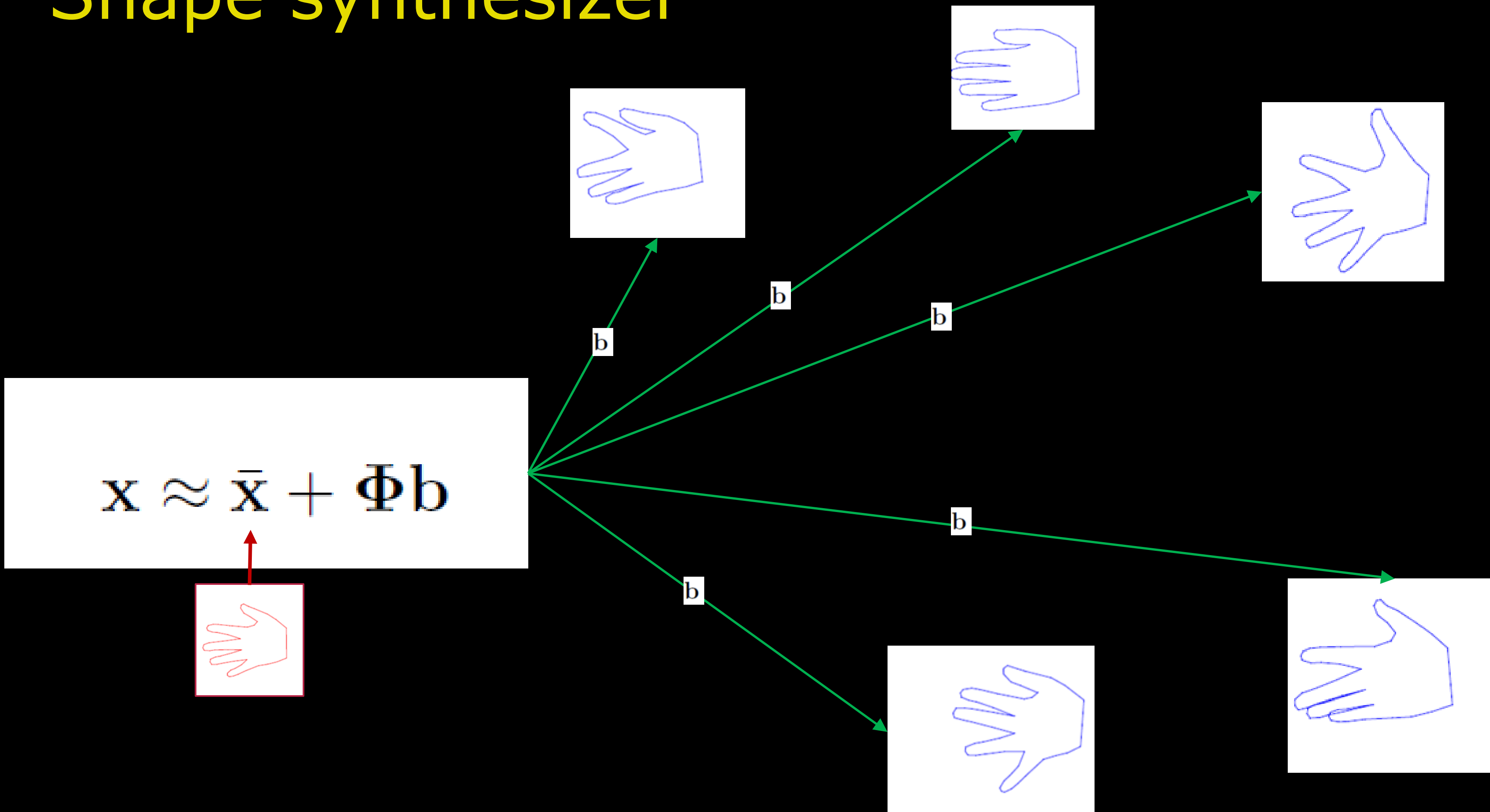


- We can *sample* new shapes by moving around in shape space
- b are the *coordinates* in shape space
- The shape space is defined by the Eigenvectors
- b are the coordinates on the Eigenvectors

$$\mathbf{x} \approx \bar{\mathbf{x}} + \Phi \mathbf{b}$$

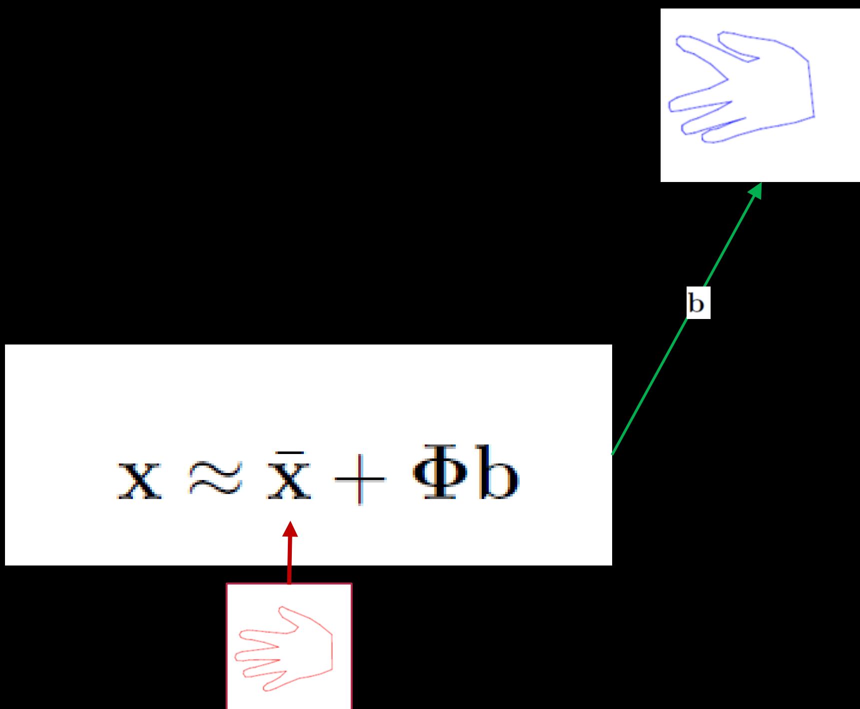
Shape synthesizer

$$\mathbf{x} \approx \bar{\mathbf{x}} + \Phi \mathbf{b}$$



A *generative* model

Shape synthesizer



$$x \approx \bar{x} + \Phi b$$

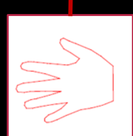
- b needs to be *constrained*
- Should be bounded by the learned shape space
- Using the size of the Eigenvalues

$$-3\sqrt{\lambda_1} < b_1 < 3\sqrt{\lambda_1}$$

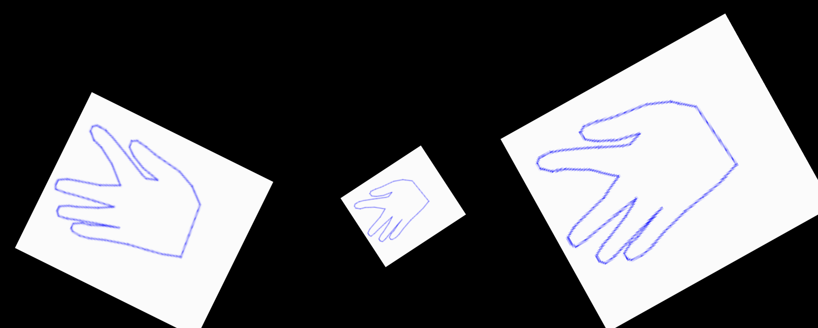
A *generative* model

Shape synthesizer + geometrical transformation

$$\mathbf{x} \approx \bar{\mathbf{x}} + \Phi \mathbf{b}$$



- Adding a geometrical transformation
  - Translation X_t, Y_t
  - Scale s
  - Rotation θ



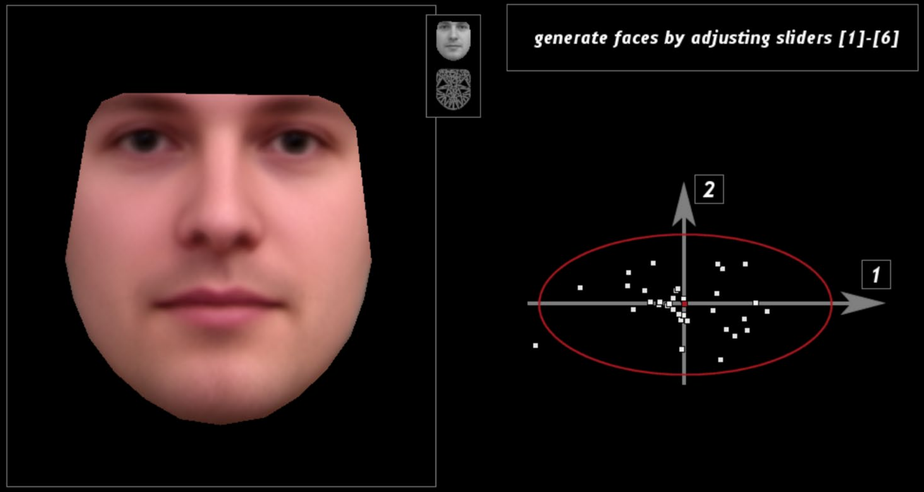
A *generative* model

Pattern recognition

- Classical image analysis
- Hand crafting features
  - Eye detector
  - Nose detector
  - Mouth detector

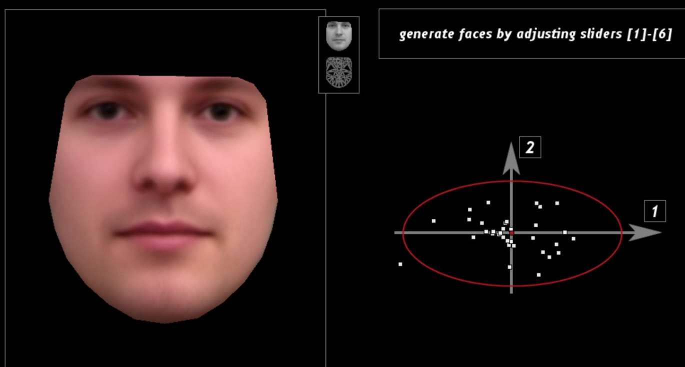
Hybrid approach – Viola Jones. Learning a limited sets of features

Analysis by synthesis



- We have a generative model
  - A face synthesizer
  - A face is represented by a *few* parameters: *b*

Analysis by synthesis



Generative model

Target

- Compare synthetic face with target face
  - Sum of squared differences
- Change parameters of model until difference is minimal
  - Position, rotation, scaling
  - b vector

Similar to image registration with a deformable *moving image*

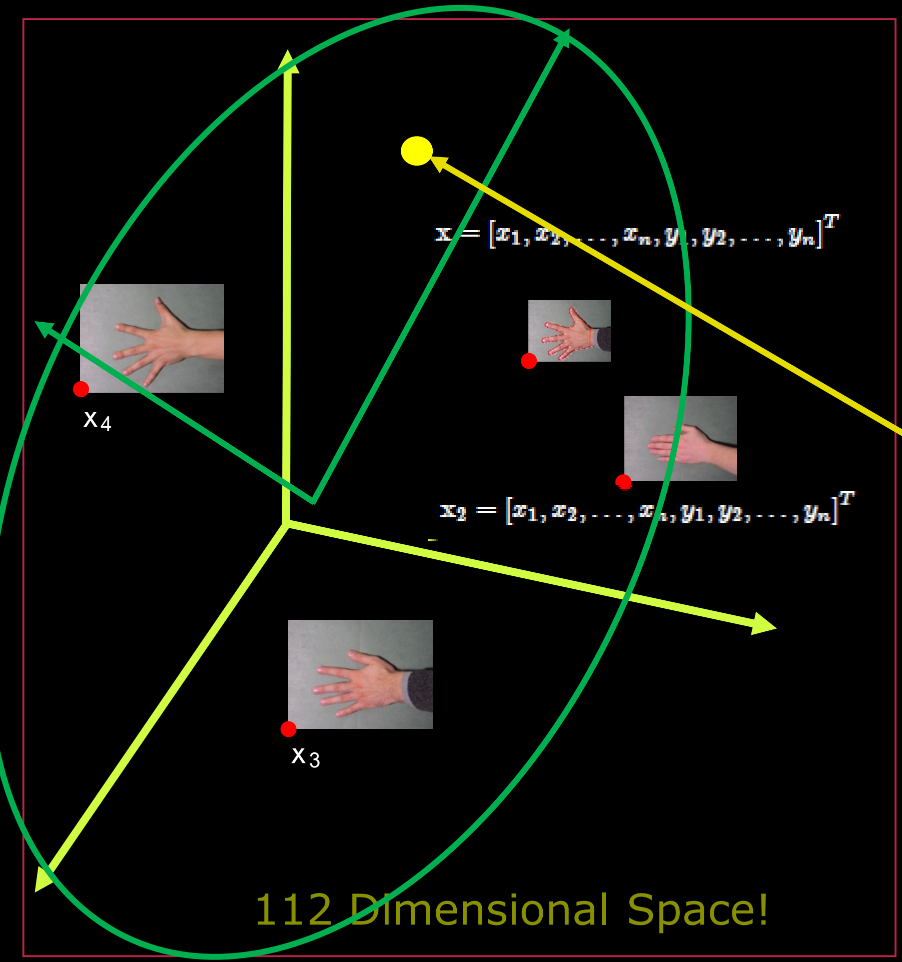
Fitting a shape and appearance model

- Finding the optimal set of parameters: position, rotation, size and b vector of model
- An *optimization* problem
- In general very hard
- Custom solutions exist

Left: Fitted model
Right: Real photo

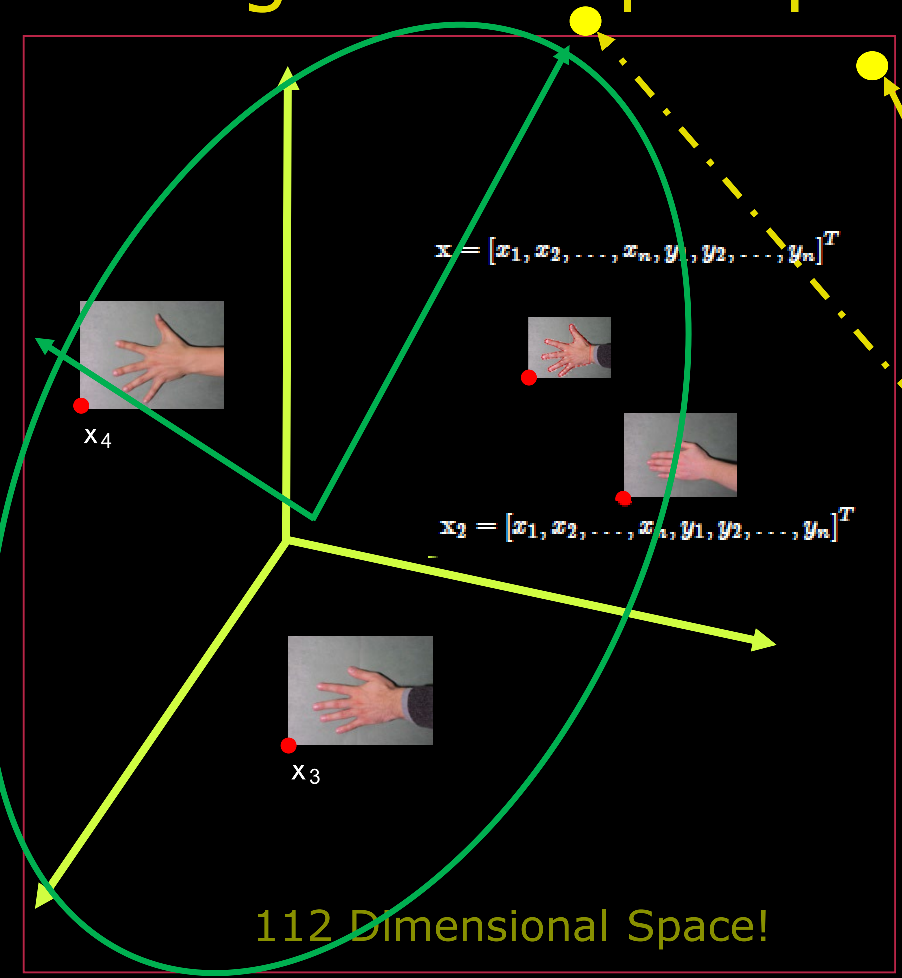
Tim Cootes: Active Appearance models

Using the shape space



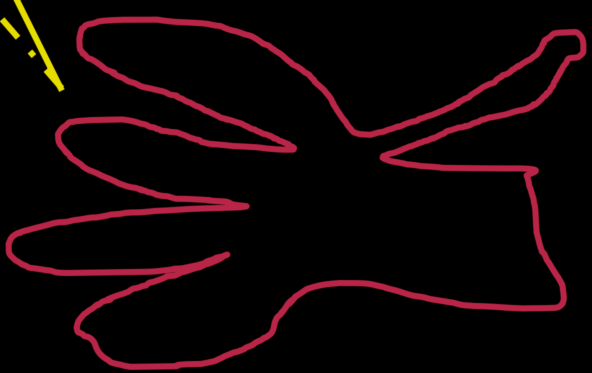
- Given a shape
  - It can be placed in shape space

Using the shape space

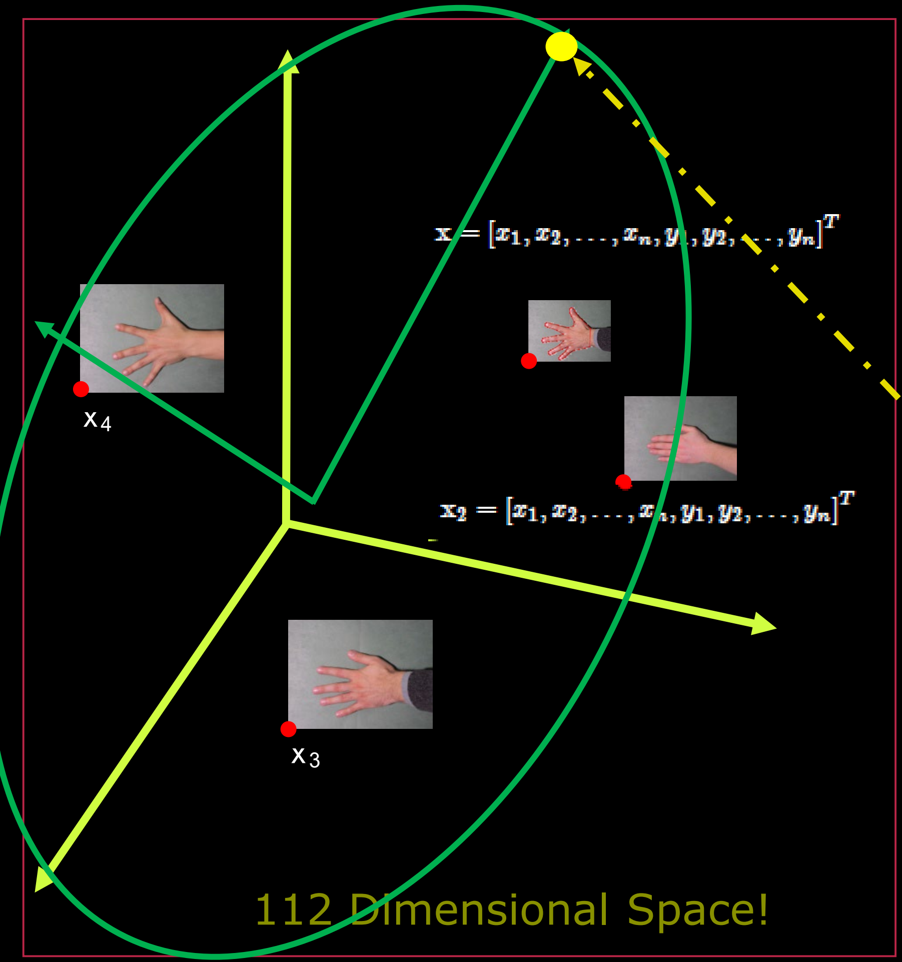


- Given a shape
  - It can be placed in shape space
- It can be projected to the Eigenvectors

Not anatomically plausible



Using the shape space



- Given a shape
  - It can be placed in shape space
- It can be projected to the Eigenvector
- And bounded by the Eigenvalues

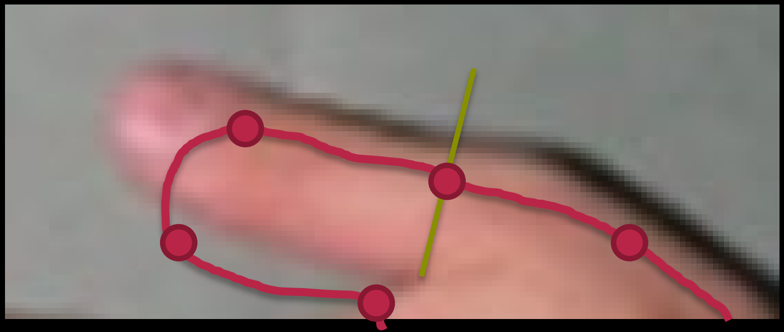
$$-3\sqrt{\lambda_1} < b_1 < 3\sqrt{\lambda_1}$$

Closest anatomically plausible shape

Fitting the active shape model to a new image

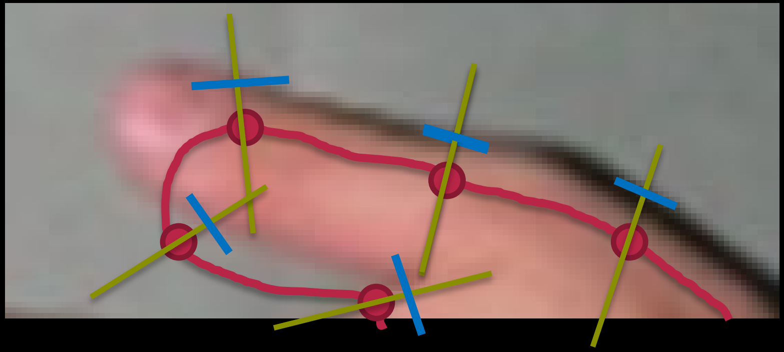
- Place the average shape on top
- Fit model points to actual image

Fitting the active shape model to a new image



- Fit model points to actual image
- For each point:
  - Search along normal direction
  - Find highest grey level gradient

Fitting the active shape model to a new image



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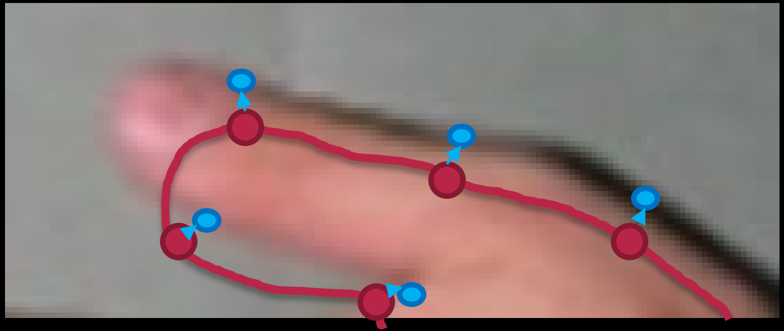
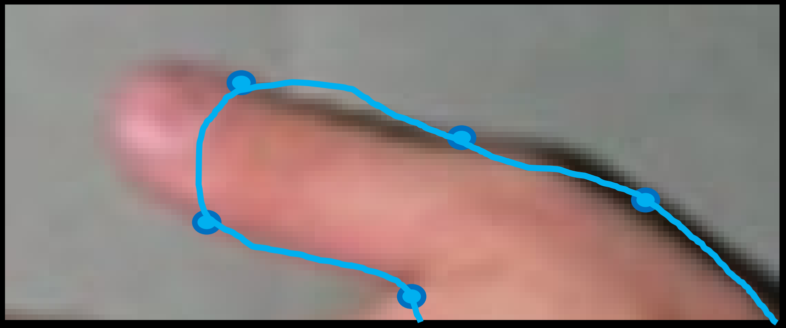
Fitting the active shape model to a new image



- Compute translation, rotation and scaling
  - Landmark based registration
- Move points to create new shape

Fitting the active shape model to a new image



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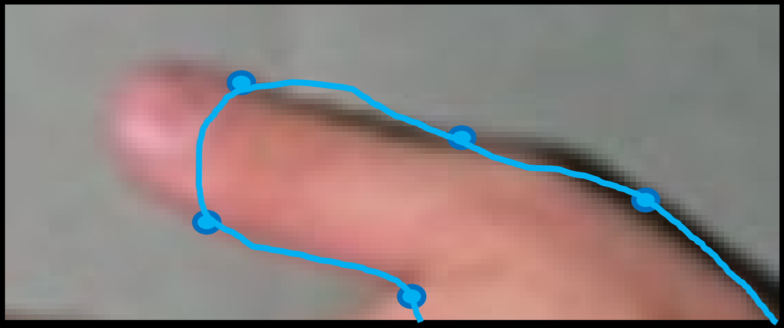
Fitting the active shape model to a new image



- Put new shape in shape space
- Project on Eigenvectors
- Constrain using Eigenvalues
  - Also called *regularization*

Result: Shape that matches image and that is anatomically plausible

$$-3\sqrt{\lambda_1} < b_1 < 3\sqrt{\lambda_1}$$

Modelling local structure

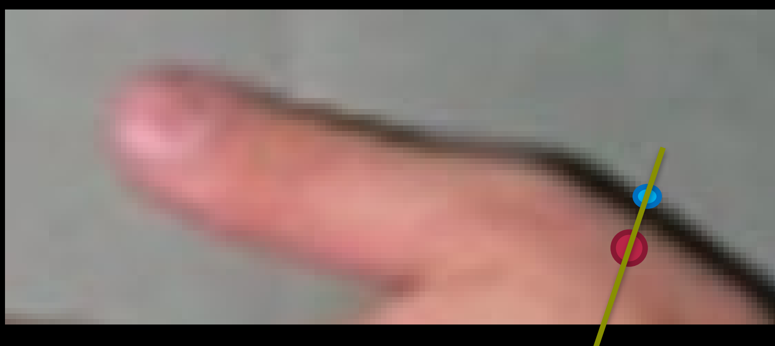
True boundary

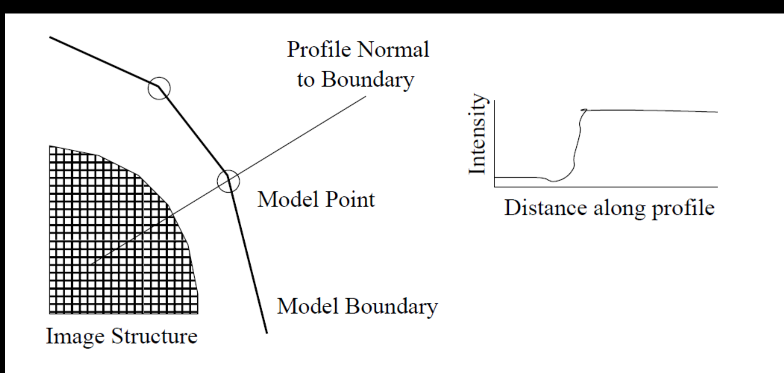
Highest gradient

- The boundary is not always where there is highest gradient

Modelling local structure

- Sample along profile
- Normalise using sum of values



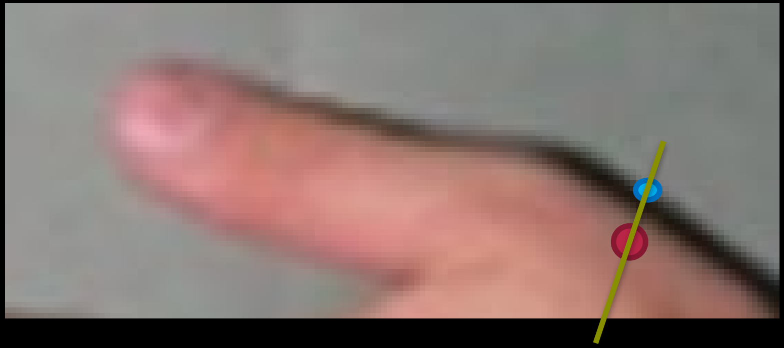


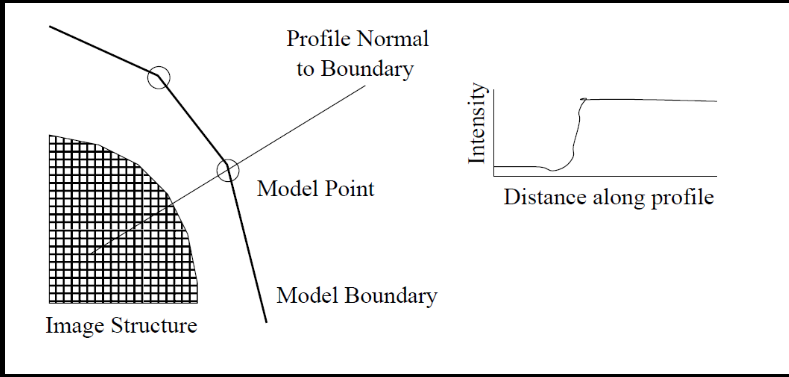
$$\mathbf{g}_i \rightarrow \frac{1}{\sum_j |g_{ij}|}\mathbf{g}_i$$

Modelling local structure

- Approximate distribution of samples
  - Multivariate Gaussian

mean $\bar{\mathbf{g}}$ and covariance $\mathbf{S}_g$

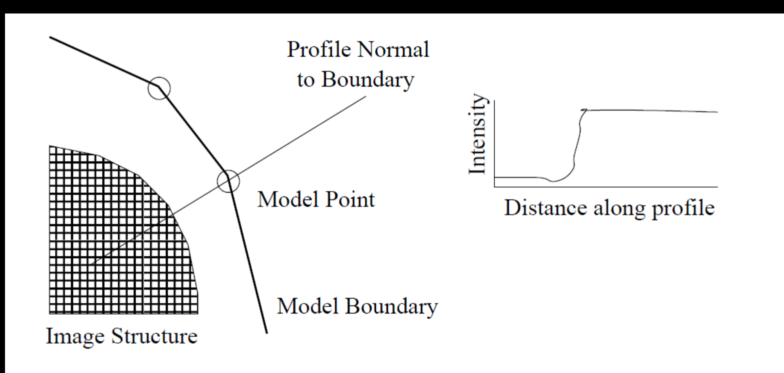




$$\mathbf{g}_i \rightarrow \frac{1}{\sum_j |g_{ij}|}\mathbf{g}_i$$

Modelling local structure

- Instead of using the gradient to search, a quality of fit is used:



The quality of fit of a new sample, $\mathbf{g}_s$, to the model is given by

$$f(\mathbf{g}_s) = (\mathbf{g}_s - \bar{\mathbf{g}})^T \mathbf{S}_g^{-1} (\mathbf{g}_s - \bar{\mathbf{g}})$$

This is the Mahalanobis distance of the sample from the model mean.

$$\mathbf{g}_i \rightarrow \frac{1}{\sum_j |g_{ij}|} \mathbf{g}_i$$

Tim Cootes: Active Appearance models

Modelling local structure

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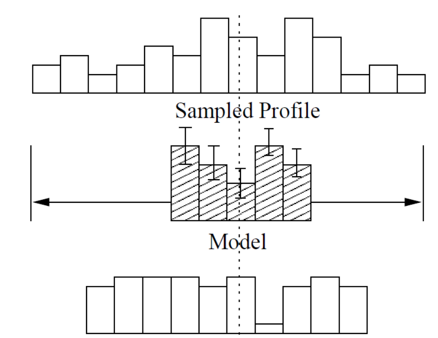

Search along sampled profile to find best fit of grey-level model

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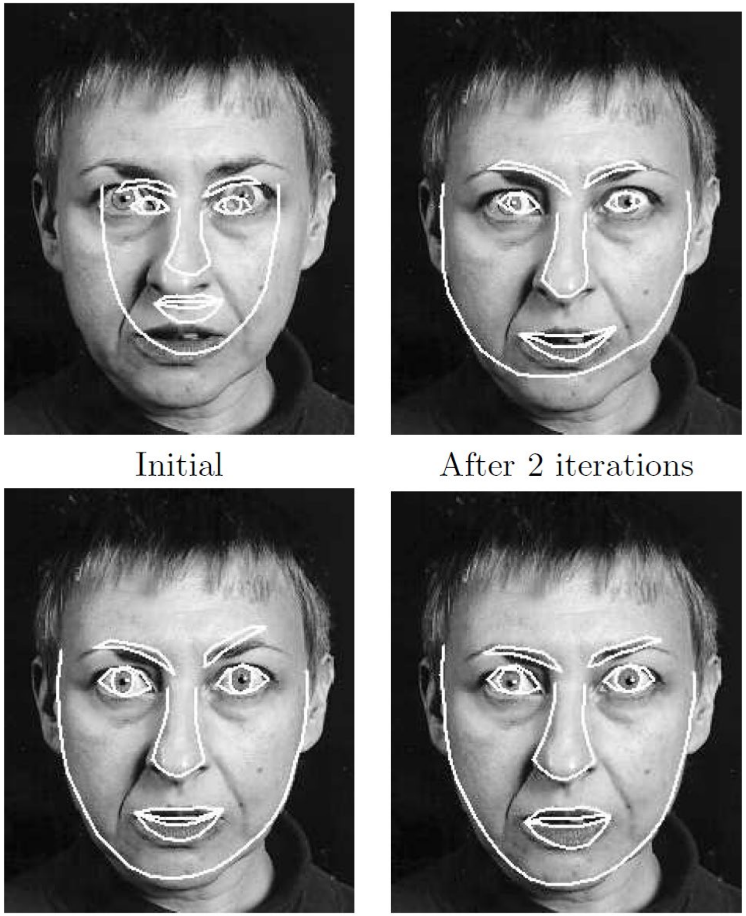
Fitting to a new shape



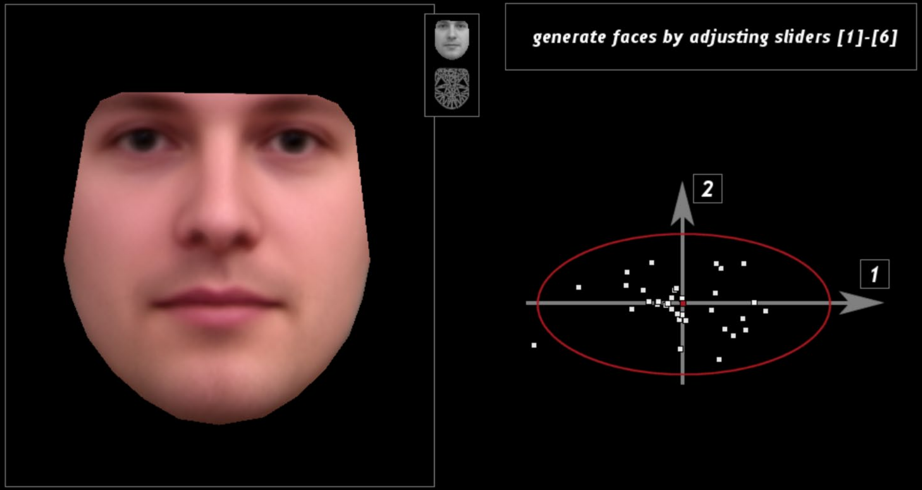
Initial | After 2 iterations

After 6 iterations | After 18 iterations

Initial | After 2 iterations | After 20 Iterations

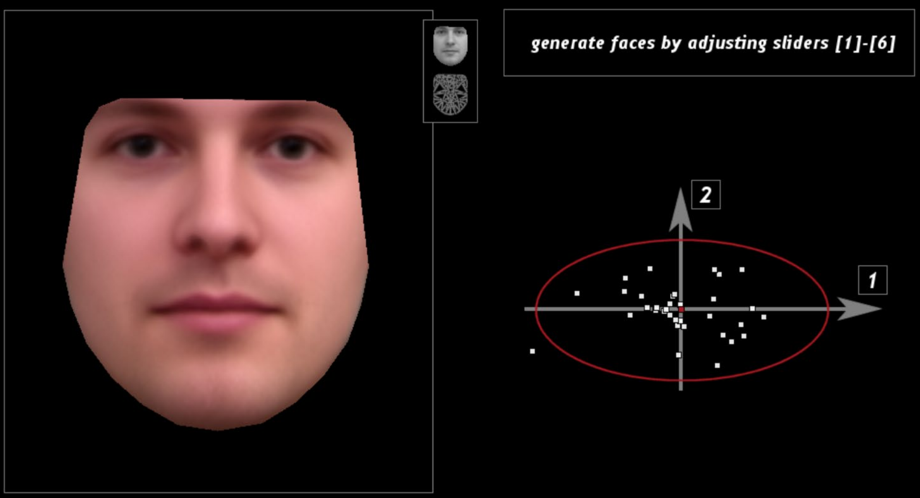
Tim Cootes: Active Appearance models

The problem with strong priors



- A *prior*
  - What was known before
  - A statistical shape model

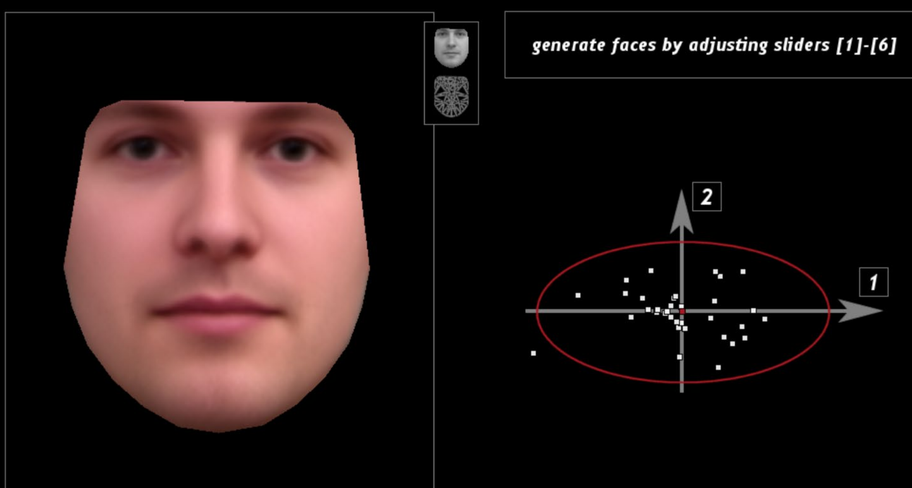
The problem with strong priors



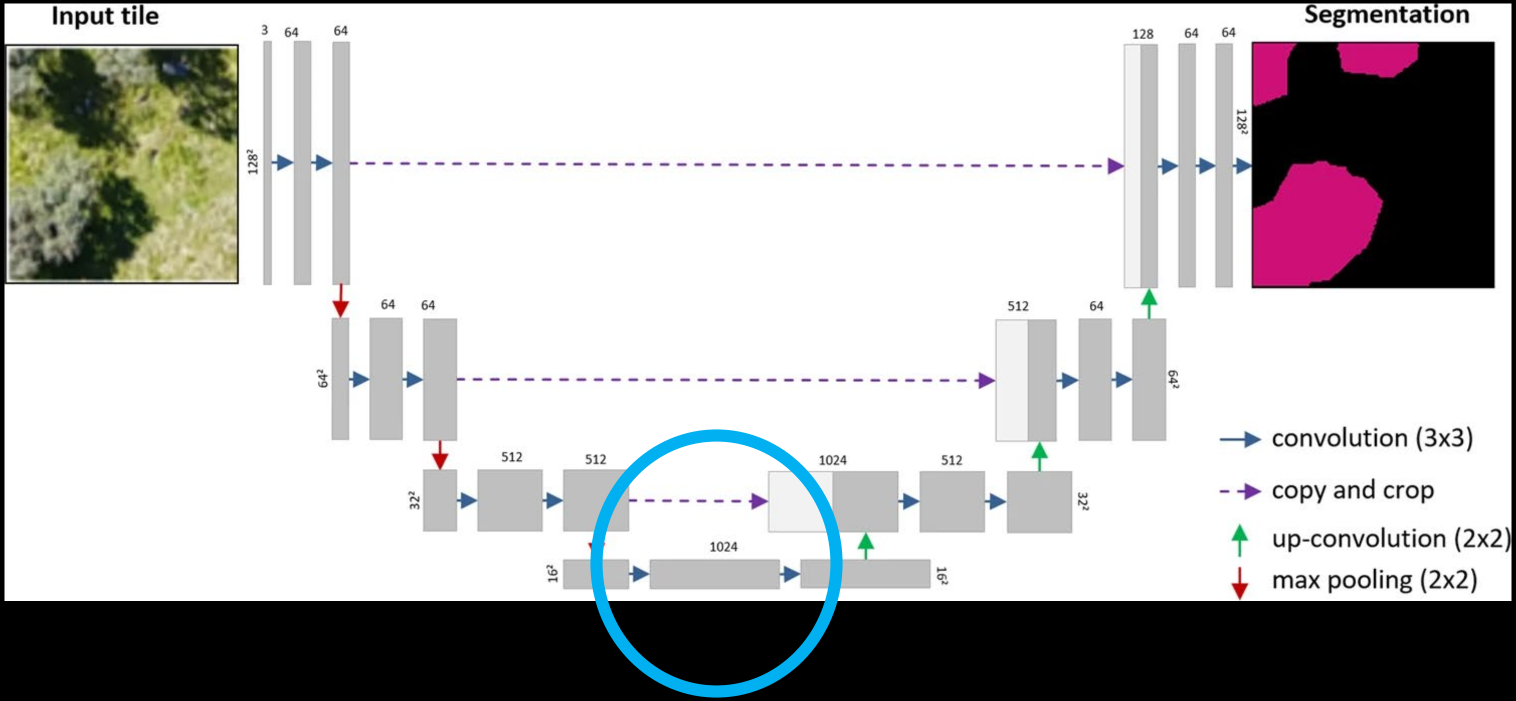
- Model is trained on images of adults
- Will try to force all fits to *look like adults*
- Will not work well with images outside the *prior*

Testing the model

- Important to the model on independent data
- How it *generalizes*
- Is the prior too strong?



PCA space vs. Latent space



Latent space

Kattenborn, T., Eichel, J. & Fassnacht, F.E. Convolutional Neural Networks enable efficient, accurate and fine-grained segmentation of plant species and communities from high-resolution UAV imagery. *Sci Rep* **9,** 17656 (2019).

About the exam

- 4 hours written exam on DTU Campus
- Very important: Be sure you are seated at the right table
- Digital exam – multiple choice. 20-25 questions
- All aids allowed
  - Notes, computer, but not telephone
- NEW! Open net: You can access the internet
- Very important: You are not allowed to communicate with anyone during exam.

The appendix / mellemregninger

- You should upload your code/prompts etc
- As a PDF or a text format
- NOT used for grading
- For plagiarism check and validations

The exam

- What should I do if I find a problem with a question
  - Contact one of the monitors/tilsyn in the room
  - They will contact the exam administration and we will then come to the room
  - A formal procedure is necessary for logging, time extensions, IT support and fairness

- DO NOT contact the teachers or TAs directly using email – use the formal procedure above.

The exam – about cheating and fairness

- By default, we believe you do not cheat and follow the code of conduct.
- The exam should be fair and measure the students ability to fulfil the learning objectives
- BUT having an open net of course introduces a risk of answers being distributed during the exam

- DO NOT SHARE OR RECEIVE ANSWERS:
  - Both the ones sharing an answer and the ones receiving an answer will undergo a juridical procedure and risk being expelled from DTU

The use of AI tools during exam

While it is a complicated topic, you are hereby allowed to use AI tools during the exam. By AI tools, we mean tools like Github Copilot and ChatGPT.

You are obliged to upload your appendix/code/solution/prompts on the "mellemregninger/appendix" part of the exam.

The grade is solely based on the answers of the multiple-choice part of the exam. The appendix is used for plagiarism and validation checks but is not used for grading.

On a personal note, we do believe that AI tools can give some help, but personally we would still validate the results and there is no better validation than being well prepared and have solved all course exercises.

We have informed the study office and all the observers of the exam should be aware of the allowed use of AI tools. In case of any doubts during the exam, let the exam supervisor know and they will contact us.