Eigenfaces for Recognition

Matthew Turk and Alex Pentland

presented by

Kimo Johnson

Face Recognition

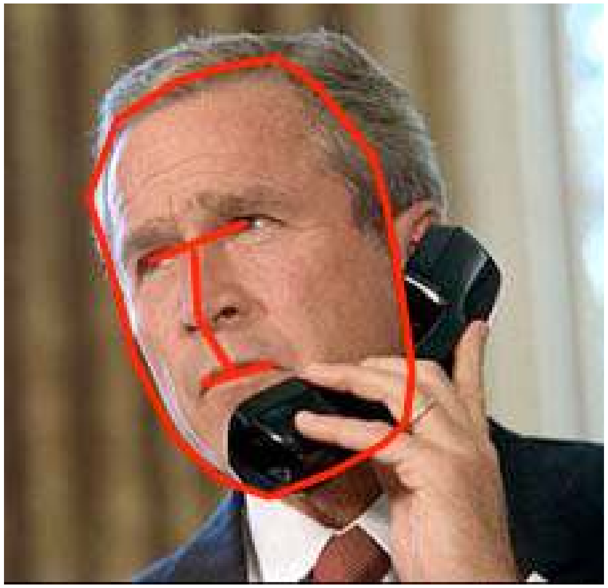
- Faces
  - primary focus of attention
  - determine identity and emotion
- Human ability
  - speed
  - robust to changes

Face Recognition

- Computational models
  - criminal identification
  - security systems
  - human-computer interaction
- Goals
  - fast
  - reasonably simple
  - accurate in constrained environments

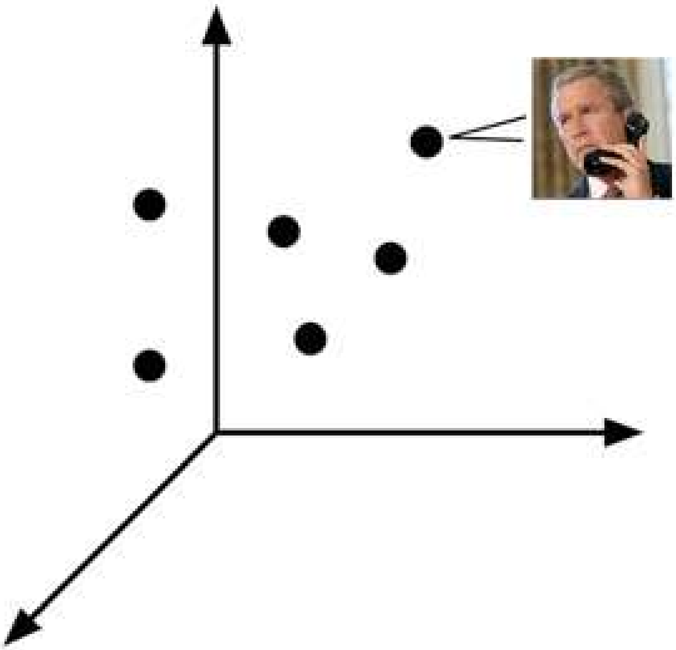
Background

- Individual features
  - eyes, nose, mouth, head outline
  - position and size relationships
- Disadvantages
  - multiple views
  - fragile and complex



Eigenfaces

- The eigenface approach
  - images are points in a vector space
  - use PCA to reduce dimensionality
  - face space
    - Sirovich & Kirby 1987
    - Kirby & Sirovich 1990



  - compare projections onto face space to recognize faces

PCA

- Principal component analysis
  - X is *m* x *n*
    - *m:* dimensionality of image
    - *n*: number of images
  - orthogonal change of variable

$$X = UY$$

  - maximize variance of projected samples
  - eigenvectors of covariance matrix

$$S = XX^T$$

PCA

- Optimization
  - We want eigenvectors of S (*m* x *m*)

$$S\mathbf{u} = \lambda\mathbf{u}$$

  - If *m* is much larger than *n*, form T (*n* x *n*)

$$T = X^T X$$

$$T\mathbf{v} = \lambda\mathbf{v} = (X^T X)\mathbf{v}$$

$$X(X^T X)\mathbf{v} = X\lambda\mathbf{v} = \lambda(X\mathbf{v})$$

$$S(X\mathbf{v}) = \lambda(X\mathbf{v})$$

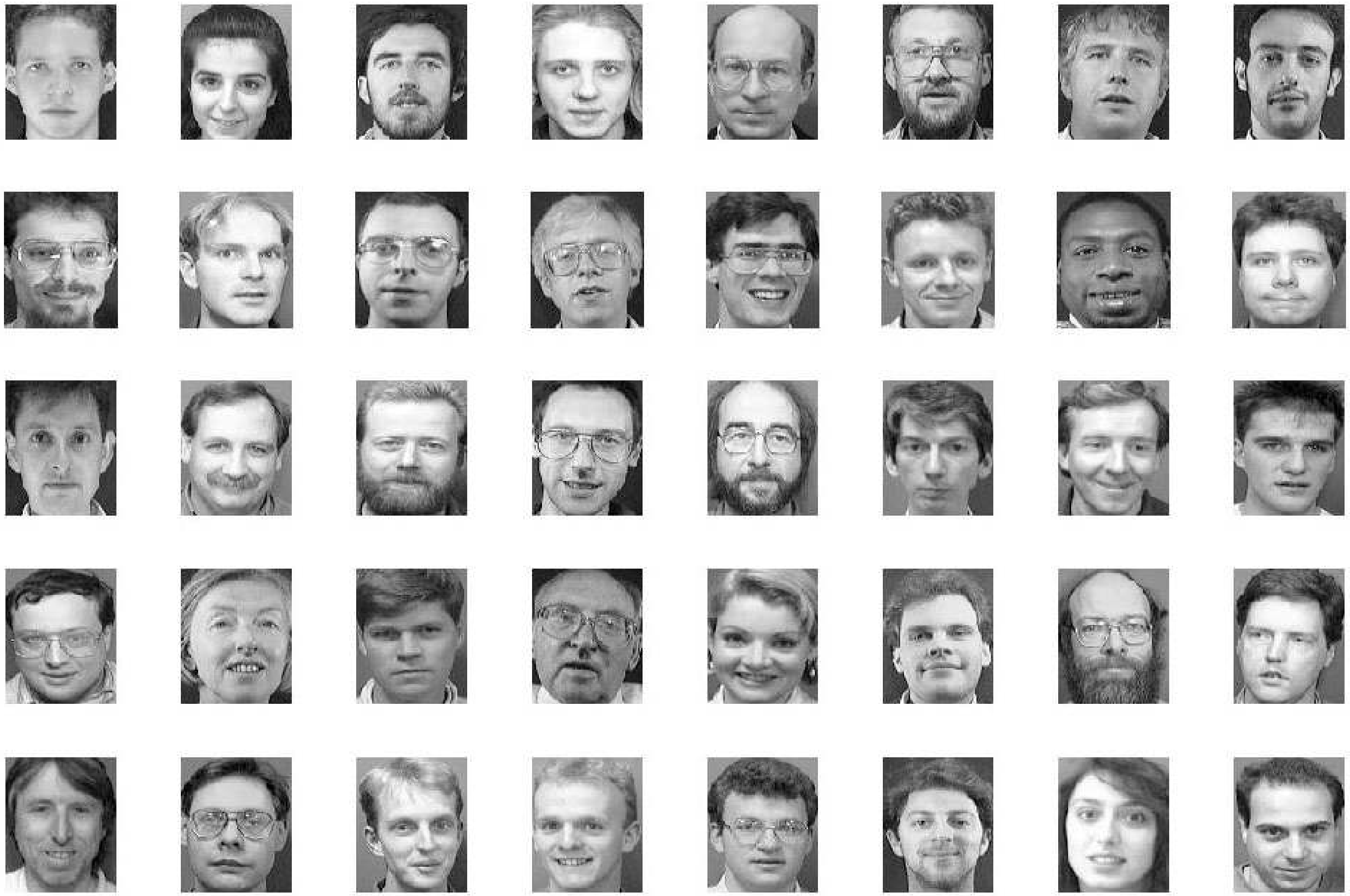
Eigenface Recognition Procedure

- Build face space
  - PCA
  - choose M’ eigenfaces as a basis for face space

- Project image vectors onto face space
  - nearest known face (Euclidean distance) matches
  - thresholds for distance to face class vs. distance to face space
    - in face space, but no match
    - not in face space

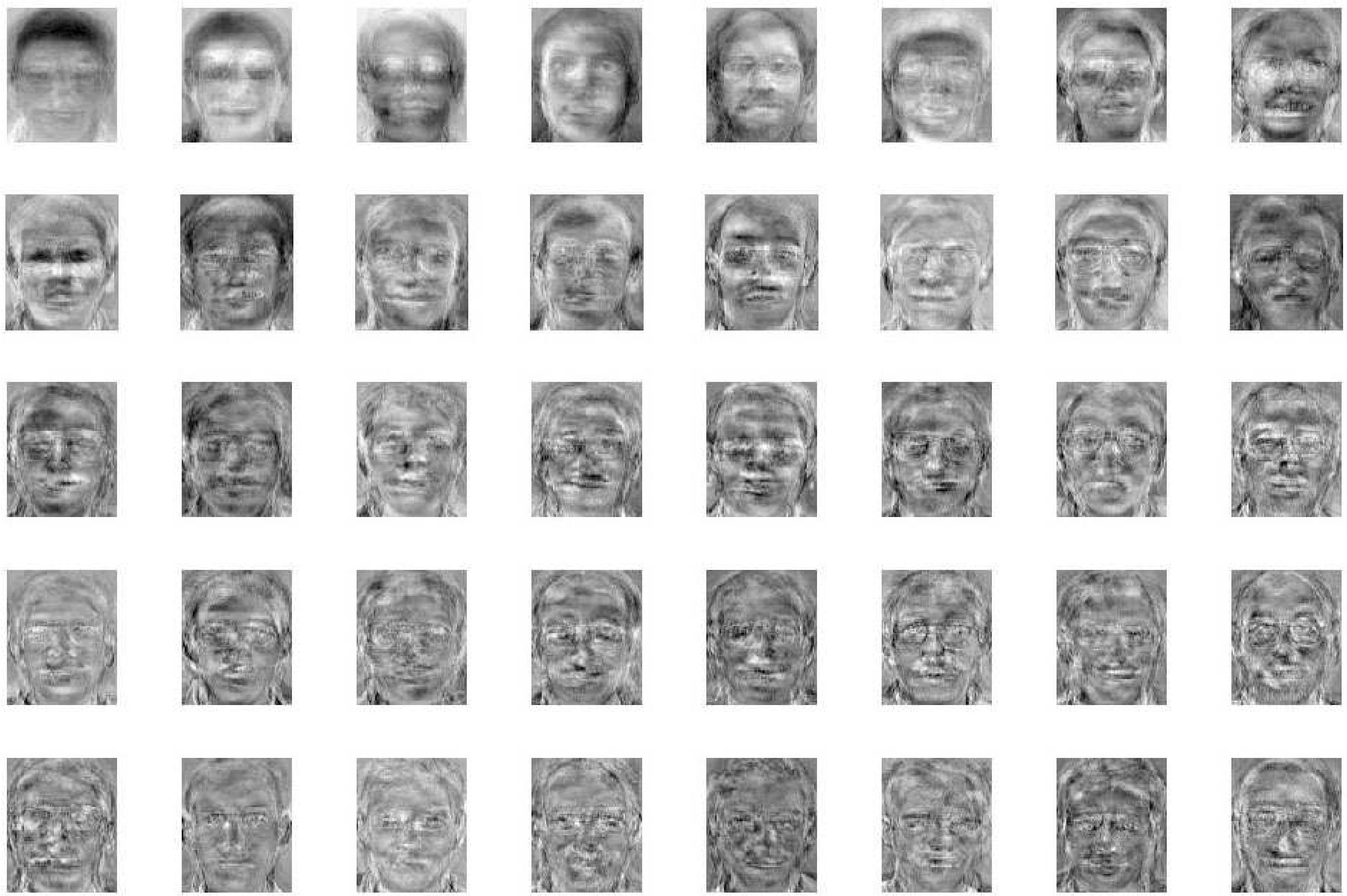
Example: Build Face Space

40 faces, 112 x 92 pixels = 10,304 pixels



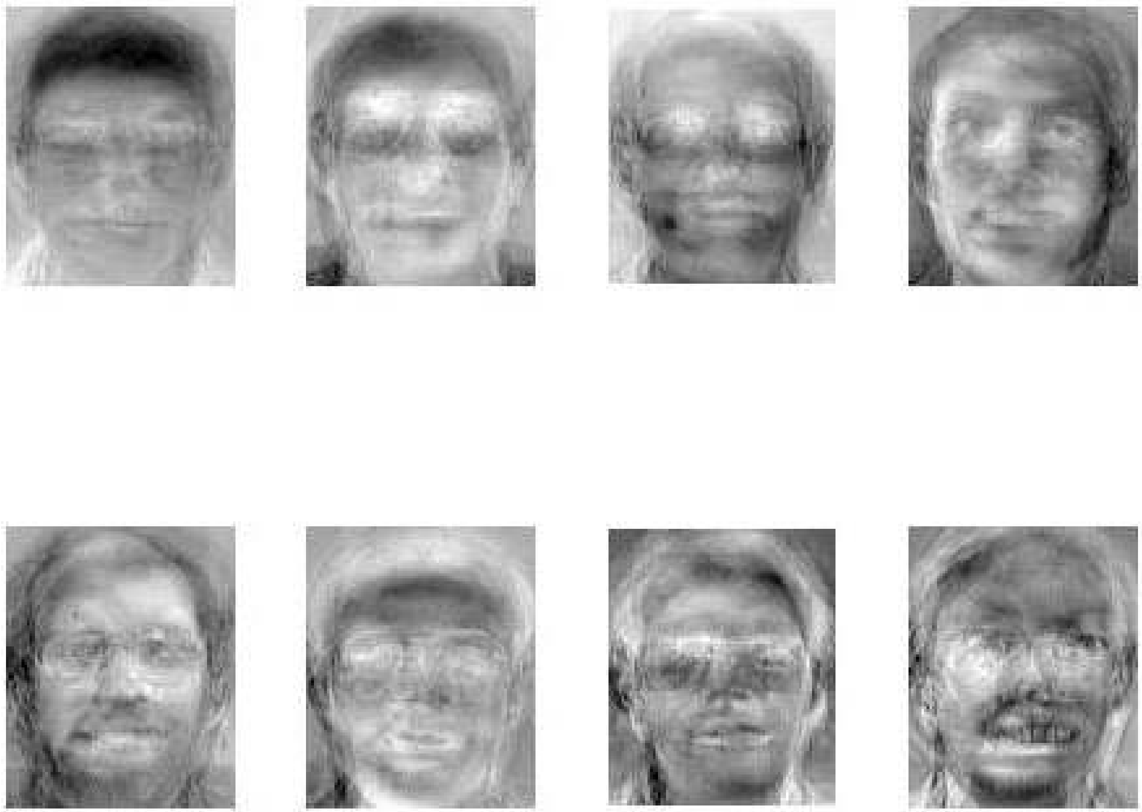
Example: Build Face Space

X is 10,304 x 40, T is 40 x 40



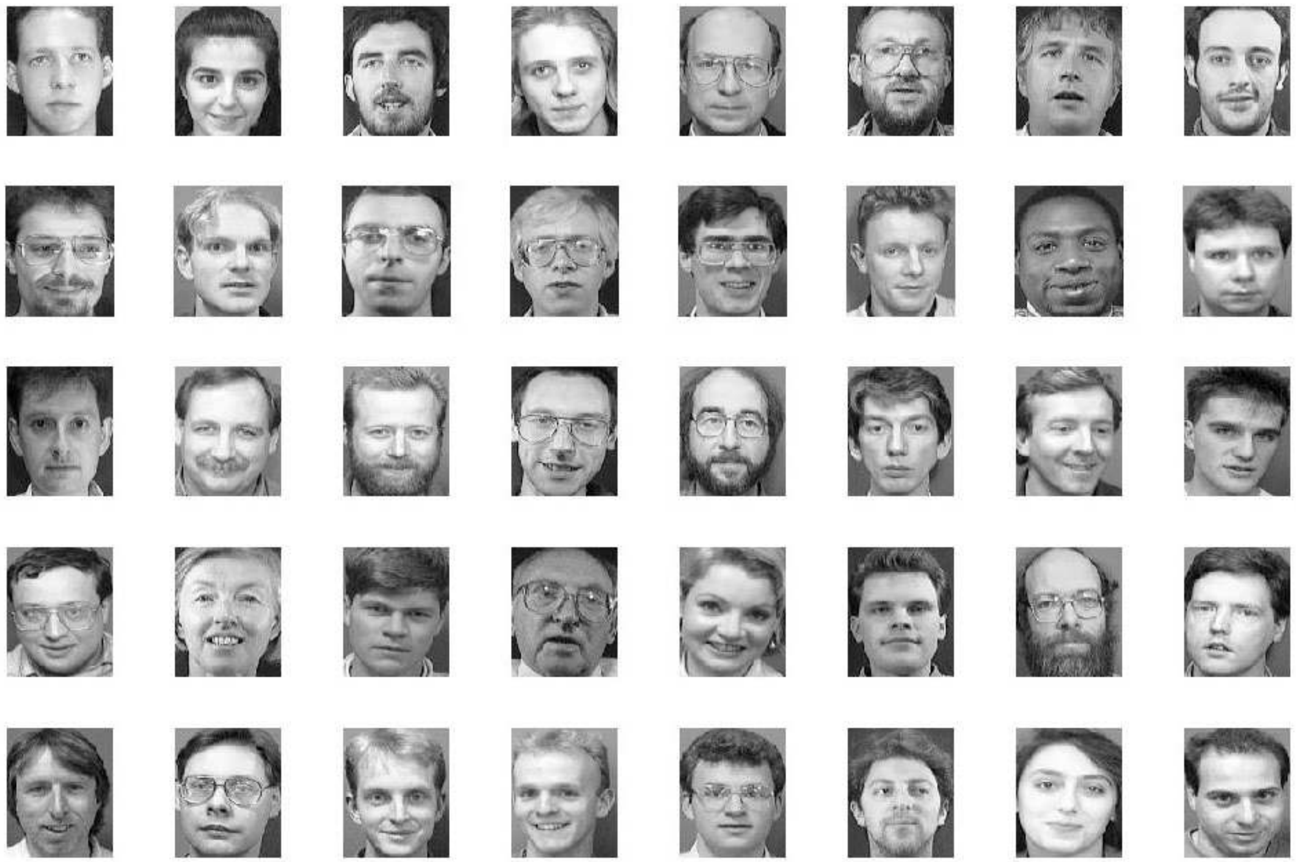
Example: Build Face Space

Face Space = top 8 eigenfaces



Example: Recognize Faces

Same 40 people, different images



Example: Recognize Faces

recognize 34/40 = 85%

Extensions and Other Issues

- Extensions
  - locating and detecting faces in images and video
  - recognizing new faces
- Other issues
  - eliminating the background
  - scale and orientation invariance

Conclusions

- Face recognition system
  - fast
  - reasonably simple
  - accurate in a constrained environment

- Future work
  - robustness to changes
  - learning new faces
  - eigenfaces to determine gender or facial expressions

PCA details

- Maximize variance of projected samples

$$
\begin{aligned}
\mathrm{E}[(\mathbf{u}^T\mathbf{x} - \mathrm{E}[\mathbf{u}^T\mathbf{x}])^2] &= \mathrm{E}[(\mathbf{u}^T(\mathbf{x} - \mathrm{E}[\mathbf{x}]))^2] \\
&= \mathbf{u}^T\,\mathrm{E}[(\mathbf{x} - \mathrm{E}[\mathbf{x}])(\mathbf{x} - \mathrm{E}[\mathbf{x}])^T]\mathbf{u} \\
&= \mathbf{u}^T S\mathbf{u}
\end{aligned}
$$

PCA details

- Solve using Lagrange multipliers

$$L(\mathbf{u}) = \mathbf{u}^T S \mathbf{u} - \lambda \mathbf{u}^T \mathbf{u}$$

$$\frac{\partial L}{\partial \mathbf{u}} = 2S\mathbf{u} - 2\lambda \mathbf{u} = 0$$

$$S\mathbf{u} = \lambda \mathbf{u}$$

- Solution is eigenvector of covariance matrix