Facial Memory is Kernel Density Estimation (Almost)

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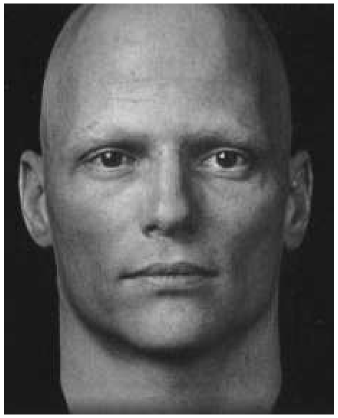
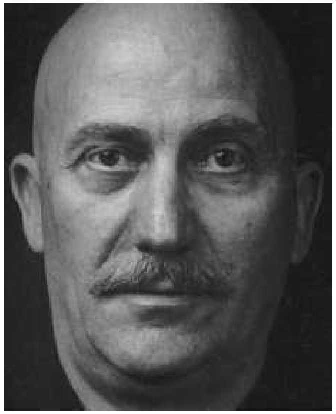
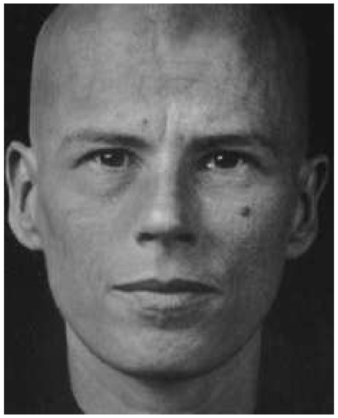
Introduction

- Question: what are the mechanisms and representations underlying memory for faces?
- Here's a broad classification of memory models:
  - Exemplar-based (e.g. the Generalized Context Model)
  - Superpositional (e.g. CHARM)
  - Manifold-based (e.g. autoencoders, PCA)
- We compare a PCA (eigenface) model and a novel exemplar-based model that exploits human similarity judgments for pairs of face stimuli.
- The exemplar model outperforms PCA; the similarity representation outperforms eigenface-based representations.

The Experiment (Busey & Tunnicliff)

- 179 subjects studied 68 images of bald males.

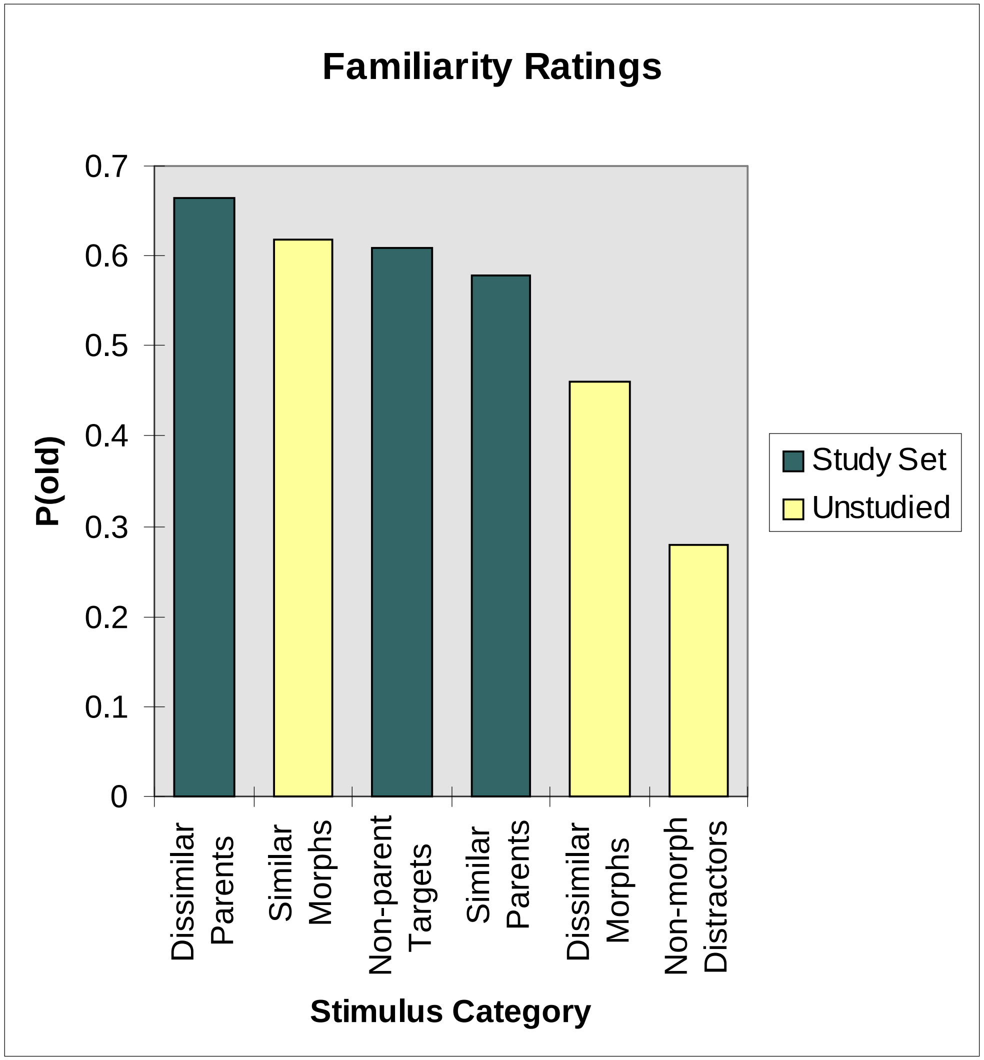
- Then tested (old or new) on the original 68 images, 16 **morphs** between pairs of studied images, and 20 new distractors.
- Morphs between studied faces potentially activate representations of both “parents,” causing recognition errors.

Morph Distractor Stimuli

- Morphs: 8 between similar parents; 8 between dissimilar parents.
- Similar-parent morph:

- Dissimilar-parent morph:

Experiment 3 Results



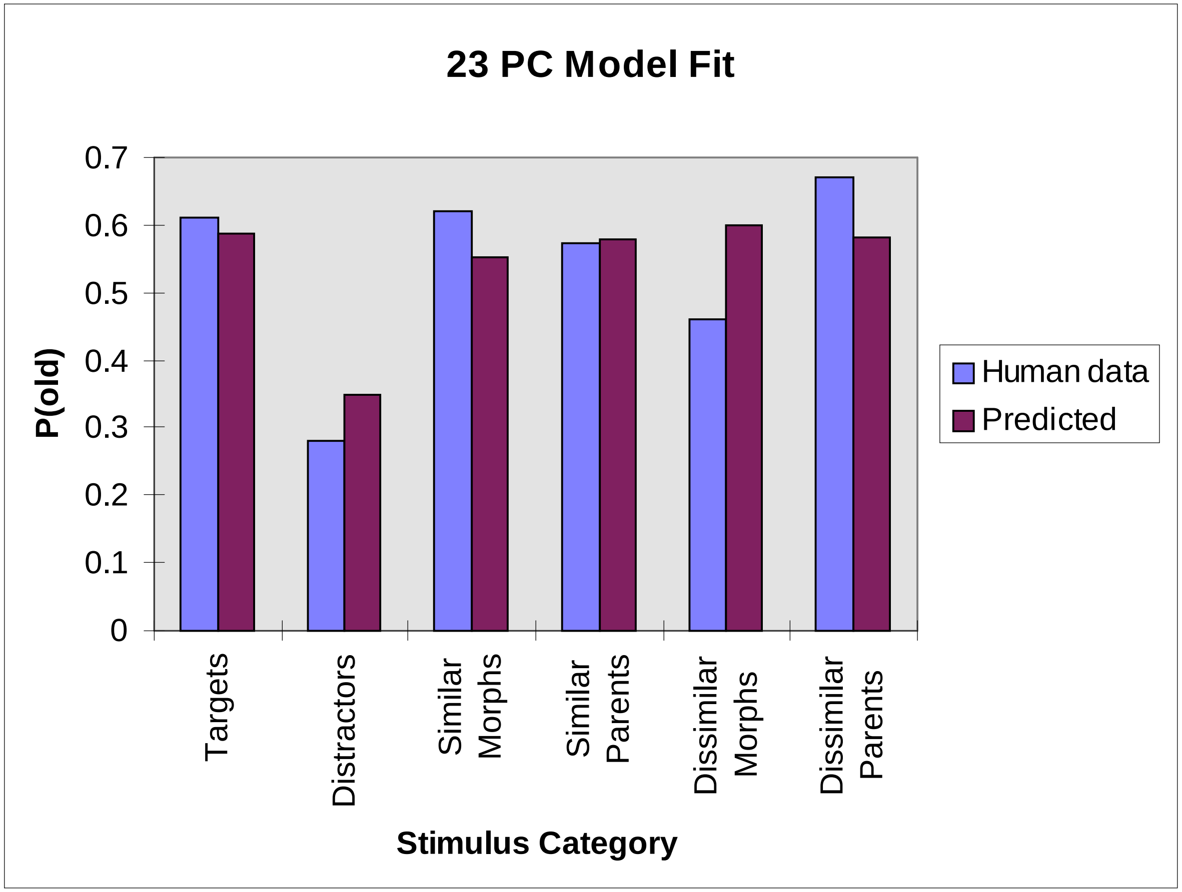
- Least likely to say "old" to non-morph distractors.
- Similar parents and morphs: a *familiarity inversion effect* (only marginally significant).
- No inversion effect for dissimilar-parent morphs.

Models and Representations

- Principal component analysis (PCA):
  - Assumes that subjects construct a (noisy) manifold containing the stimuli they've studied, and new/old judgment is based on distance to the manifold.
  - The manifold is defined by projecting test stimuli onto the study set eigenvectors (eigenfaces).
- Exemplar-based Gaussian mixture model:
  - Assumes that subjects construct a probability density function by storing the studied exemplars explicitly (kernel density estimation).
  - Assumes the new/old judgment is based on the density at a test stimulus' location.
  - Representation is Valentine's "multidimensional face space" (MDS of human similarity judgments).

PCA Results

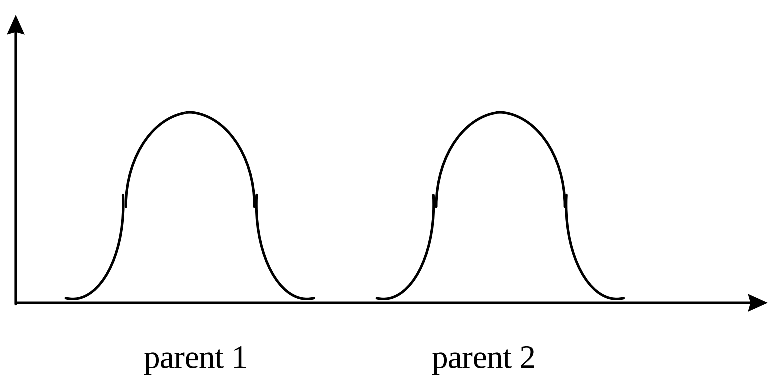
- Reconstruction error model roughly captures the relationships (RMSE: 0.169; r^2: 0.315).
- For some morphs, P(old) is greater than for parents. But the pattern is backwards!



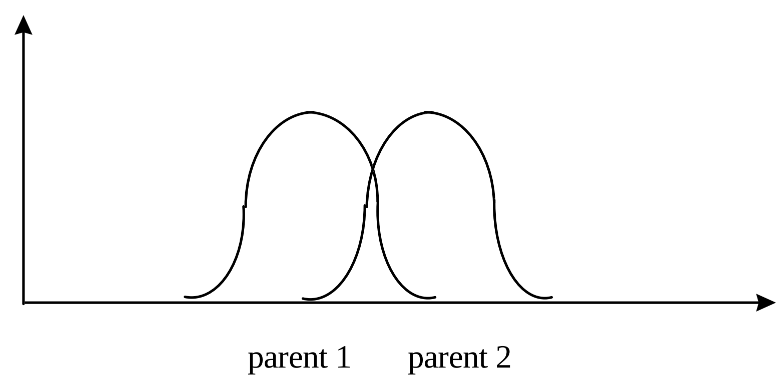
The exemplar model, basic version (essentially Nosofsky's GCM)

- Busey had subjects rate similarity of the face images used in the experiment.
- Multidimensional scaling (MDS) resulted in 6-dimensional representations for each face.
- Treat positions in the 6-dimensional space as exemplars (mean vectors of the Gaussians)
- Example in one dimension:

Dissimilar parents: no overlap



Similar parents: large overlap



But a twist: explicit coding of distinctiveness

- The model as described is a form of Nosofsky’s Generalized Context Model.
- GCM does not fit this data set.
- Idea for improvement: distinctive faces have larger “attractor fields”
  - given 50% morph, humans pick the more distinctive parent as more similar (Tanaka).
- Modulated height and width of each exemplar’s Gaussian by its distinctiveness.
  - Used average 5-neighbor distance in MDS space as a measure of distinctiveness.

The Distinctive Blob Model (DBM)

- Given a test probe **y** and set of studied exemplars **X** (in MDS space)

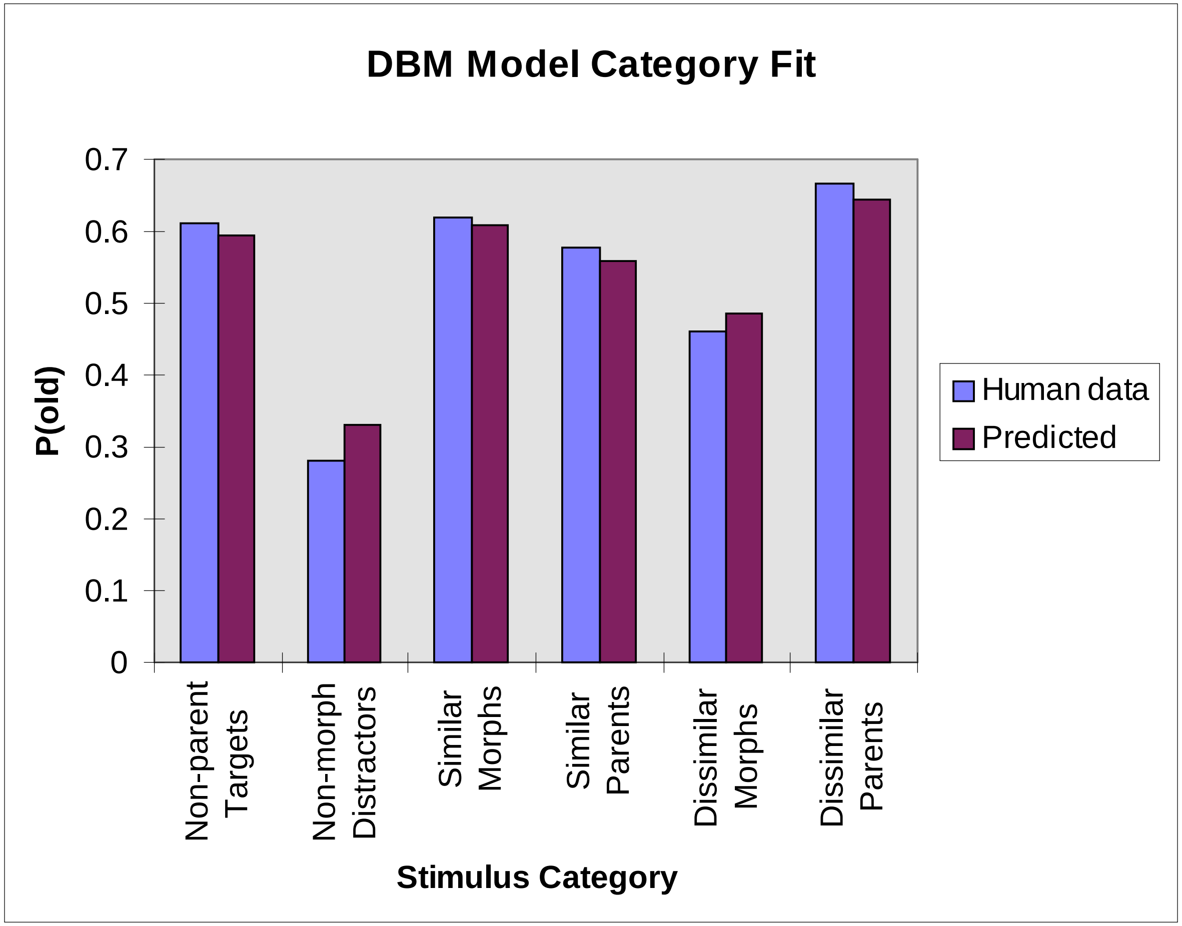
$$pred_{\mathbf{y}} = \sum_{\mathbf{k}\in\mathbf{X}} h(1+c_h d(\mathbf{k}))e^{\frac{(\|\mathbf{y}-\mathbf{k}\|)^2}{2(\sigma(1+c_\sigma d(\mathbf{k})))^2}}$$

Free Parms

- where h is the average height, σ is the average width, $d(\mathbf{k})$ is the z-scored 5-neighbor distance for exemplar **k**, and c_h and c_σ are constants.
- Four free parameters, fit to the human responses.

Exemplar Model Results

- Four-parameter fit: RMSE = 0.1601; r^2 = 0.4150.
- Adding 6 “attentional” weight parameters: RMSE = 0.1528; r^2 = 0.4639.
- Predicted category relationships are correct:



Conclusions

- Explicit exemplar-based memory models seem to fit this data the best.
  - Suggests that human memory in new/old tasks may be a form of noisy density estimation.
- Exemplars in a psychological space seem to outperform simpler image-based exemplars.
  - Suggests that the representations used for recognition are closely related to those used for similarity judgments.
- Current work: how to compute?
  - I.e. how to derive an MDS-like code from a retinal image? Preliminary work: Gabor jet distances correlate with MDS distances (r = 0.547).