Cognitive Science and AI

Perceptual Constancies, Adaptation, Learning, Generalization

Presentation from: Shimon Edelman, Computing the Mind, 2008 (Chapter 5: Perception)

perceptual constancies, categories, and generalization

- The problem of dimensionality

Perceptual Constancies: The ability of the human brain to perceive objects as unchanging despite variations in sensory input. For example, recognizing an object as the same size whether it's close or far away.

Categories: The process of organizing objects or events into groups based on shared characteristics (e.g., recognizing different types of animals).

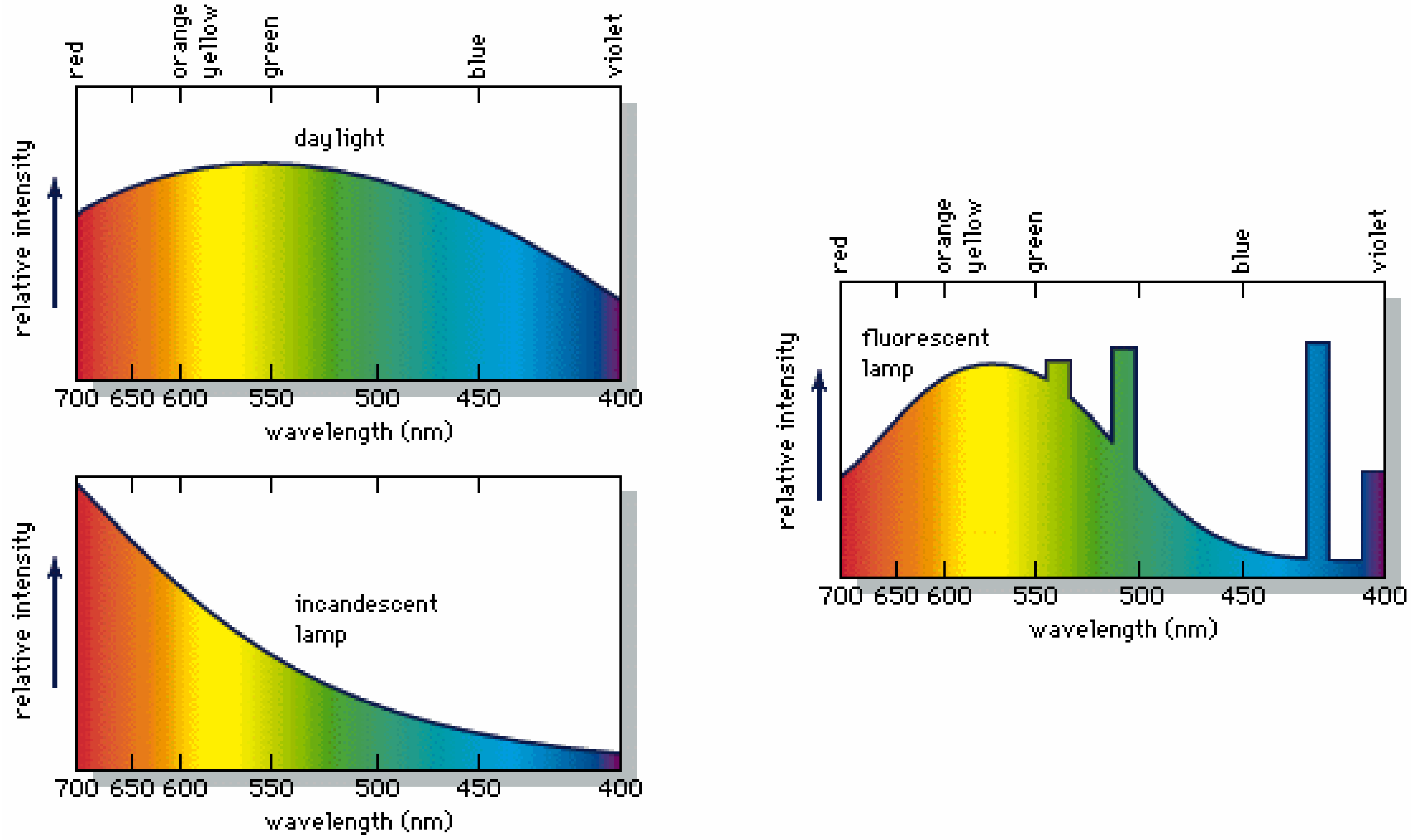
Generalization: Applying learned knowledge or categories to new, unseen instances (e.g., recognizing a dog you've never seen before as a dog).

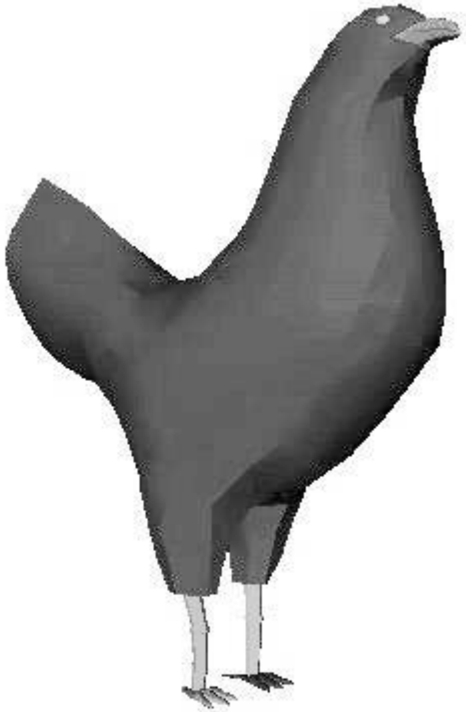
- The problem of indeterminacy

- A common solution:
  - assume the world to be well-behaved,
  - that is, characterized by statistical regularities
  - the technique known as regularization is a mathematical expression of these

Ch 5: Perception: Shimon Edelman, Computing the Mind, 2008

the problem of dimensionality





a multidimensional illumination space

a multidimensional chicken

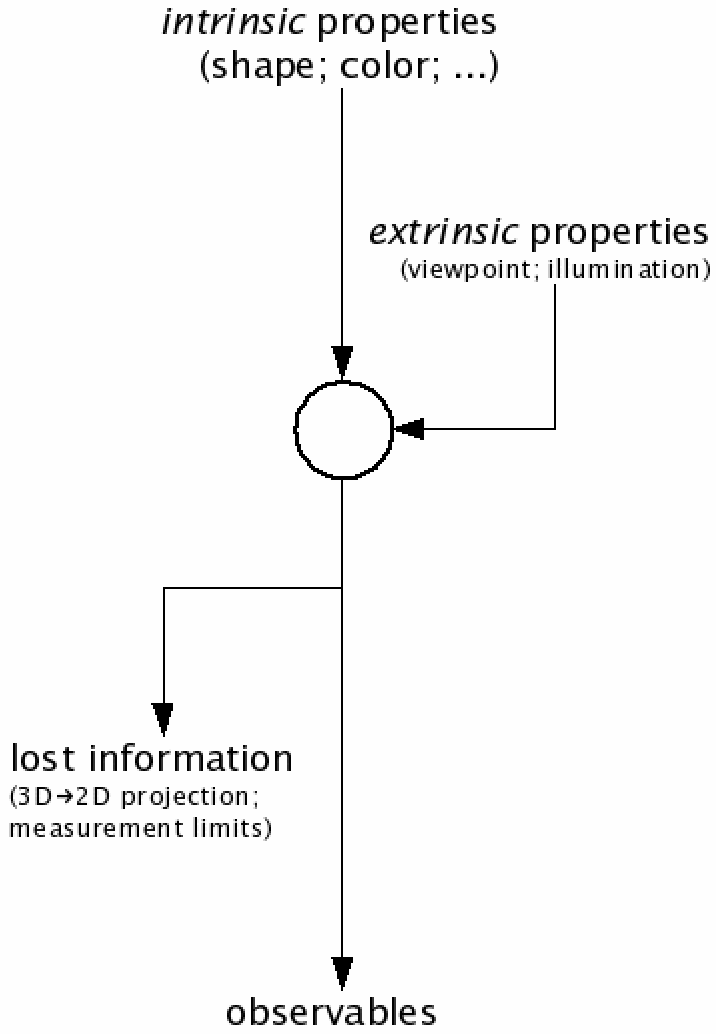
dimensionality reduction

- Solution: assume that the world is statistically well-behaved —
  - a few dimensions suffice to characterize illumination;
  - a few dimensions suffice to distinguish between chickens and ducks, or between horses and donkeys.

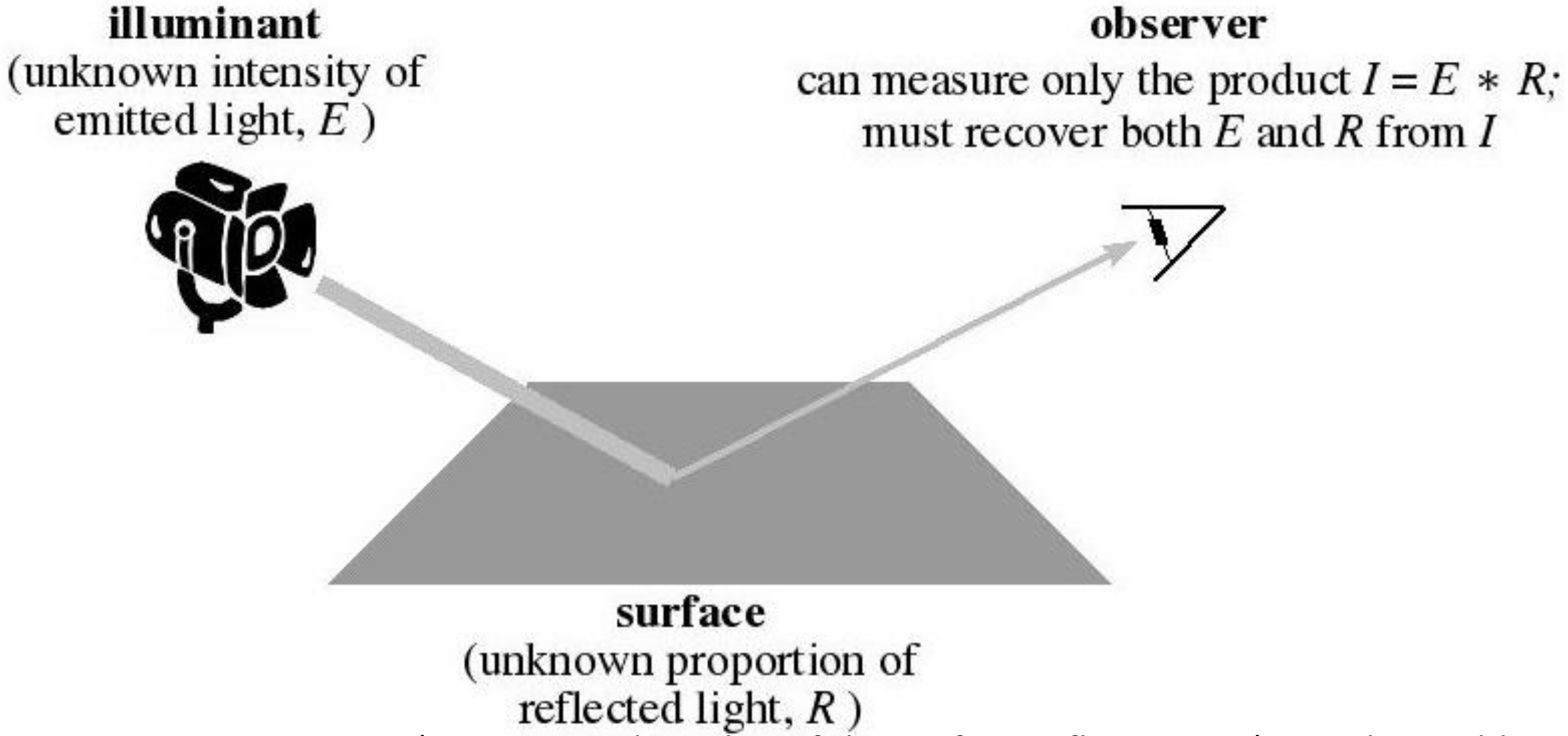
causes of indeterminacy

- All perceptual problems share the same computational structure.
  - What is "intrinsic" and what is "extrinsic" depends on the task.

What is considered “intrinsic” (internal, inherent to the object) versus “extrinsic” (external, dependent on context) depends on the specific task at hand



the problem of indeterminacy



The PROBLEM OF LIGHTNESS (computing the value of the surface reflectance R) = to the problem of prying apart two numbers (R and E) that are only available to a visual system as their product.

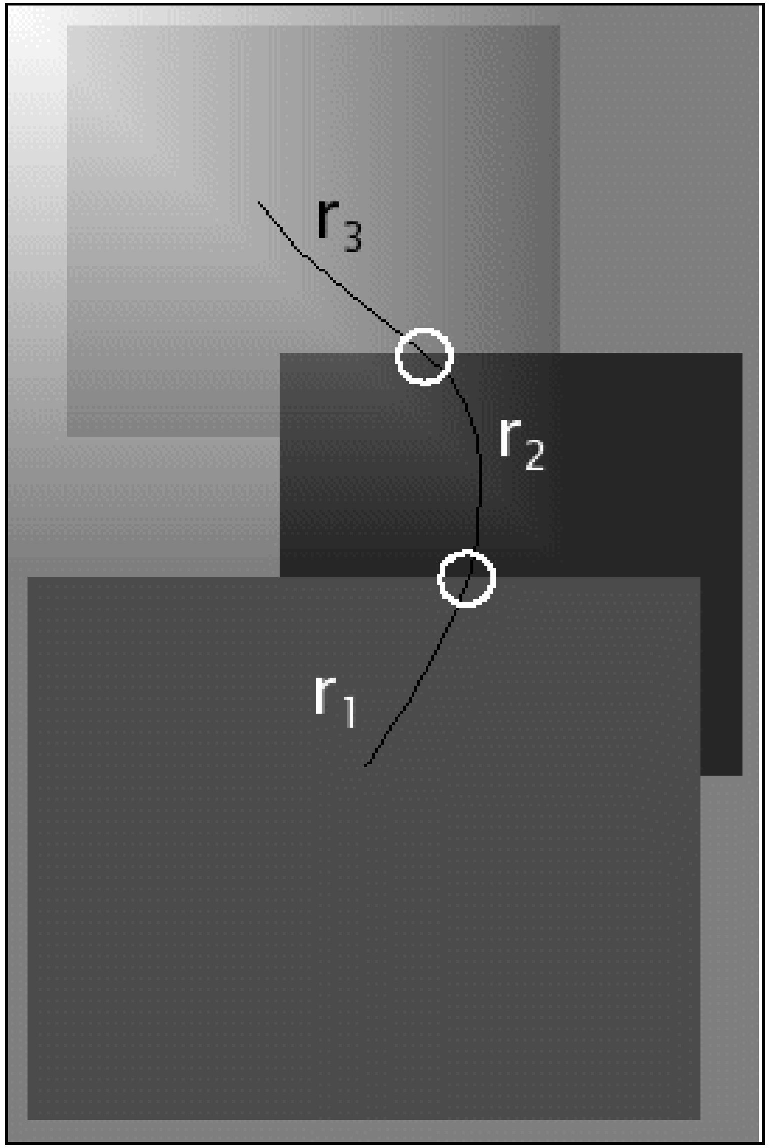
regularization

- Solution: assume that the world is statistically well-behaved —
  - illumination usually varies gradually over the scene;
  - surface lightness (reflectance) is piecewise constant over the scene, with occasional abrupt changes.

n essence, regularization helps to enforce these “well-behaved” assumptions to create models that are simpler, more general, and less prone to overfitting. It ensures that the model doesn’t try to fit every minute detail in the data, instead focusing on the larger, more consistent patterns.

regularization

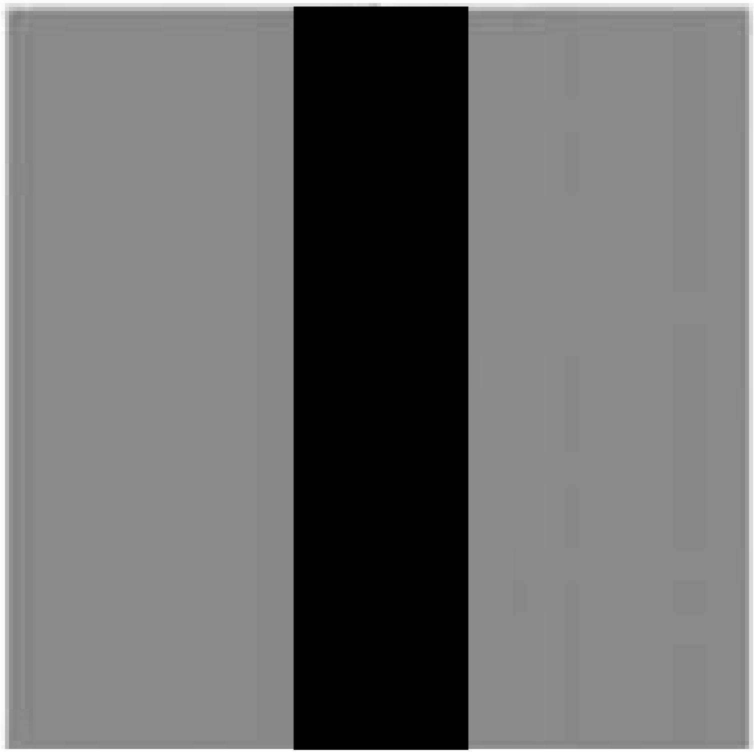
- The following algorithm for recovering lightness:
  - scan the image seeking abrupt jumps in intensity;
  - attribute every such jump to a change in lightness (as opposed to illumination);
  - at the end of this process, calibrate the extreme values ("black" and "white").

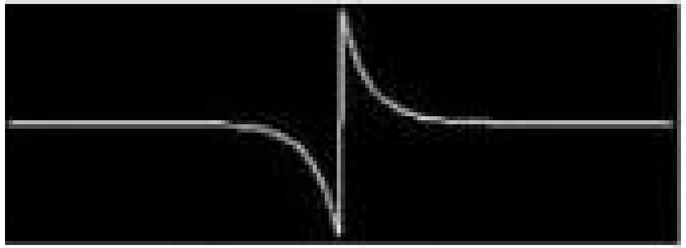


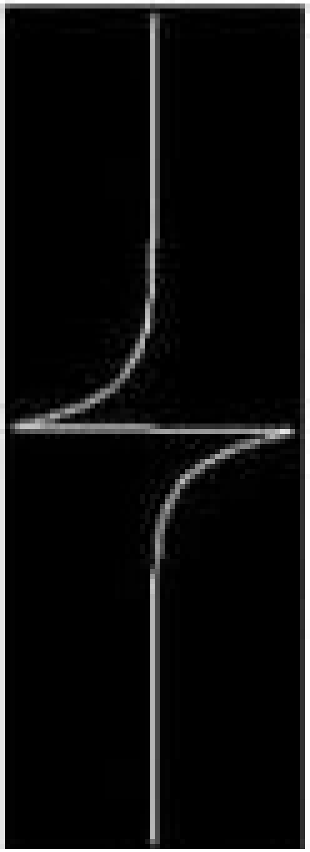
D. H. Brainard and B. A. Wandell (1986). Analysis of the Retinex theory of color vision, JOSA.

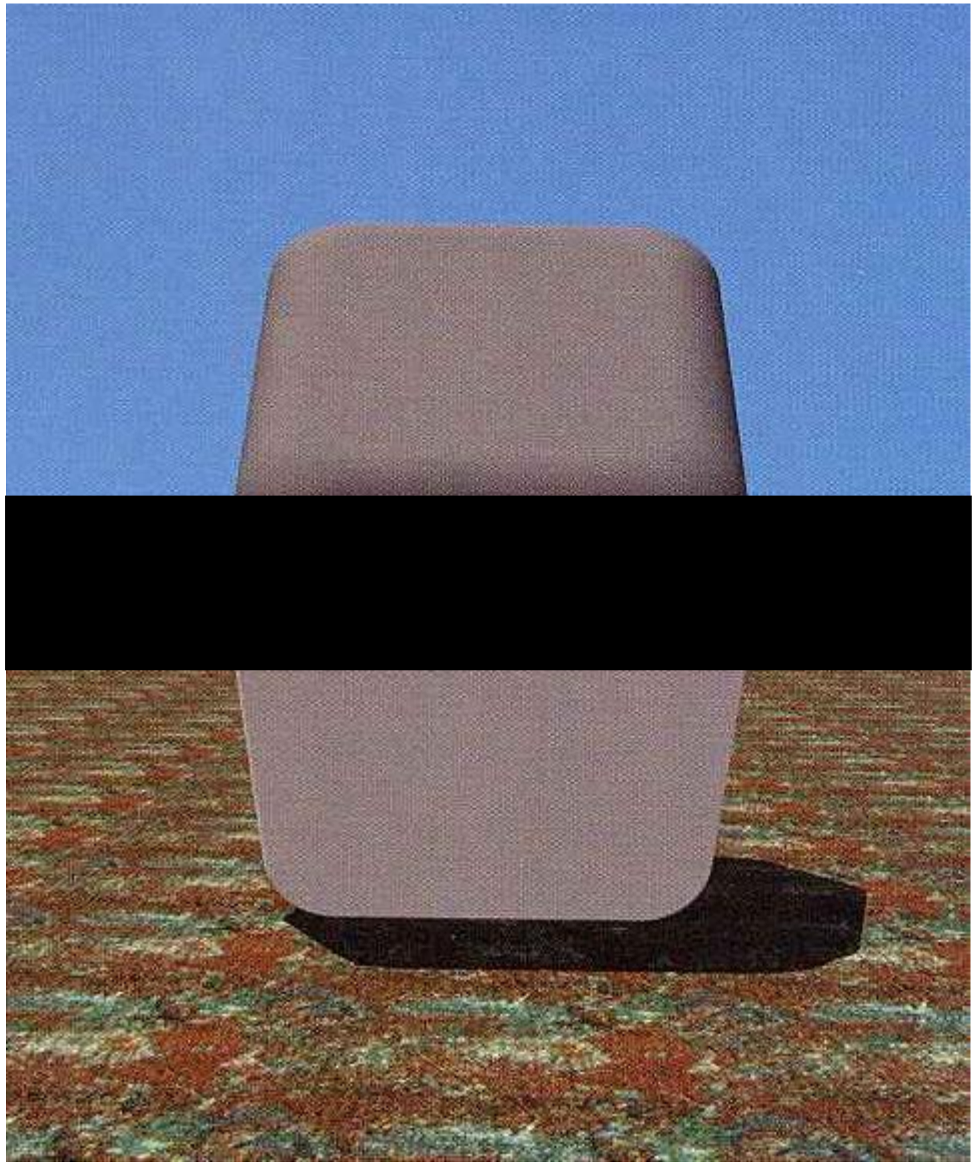
an example of a failure of lightness constancy

- The constancy computation fails when assumptions behind it are violated.





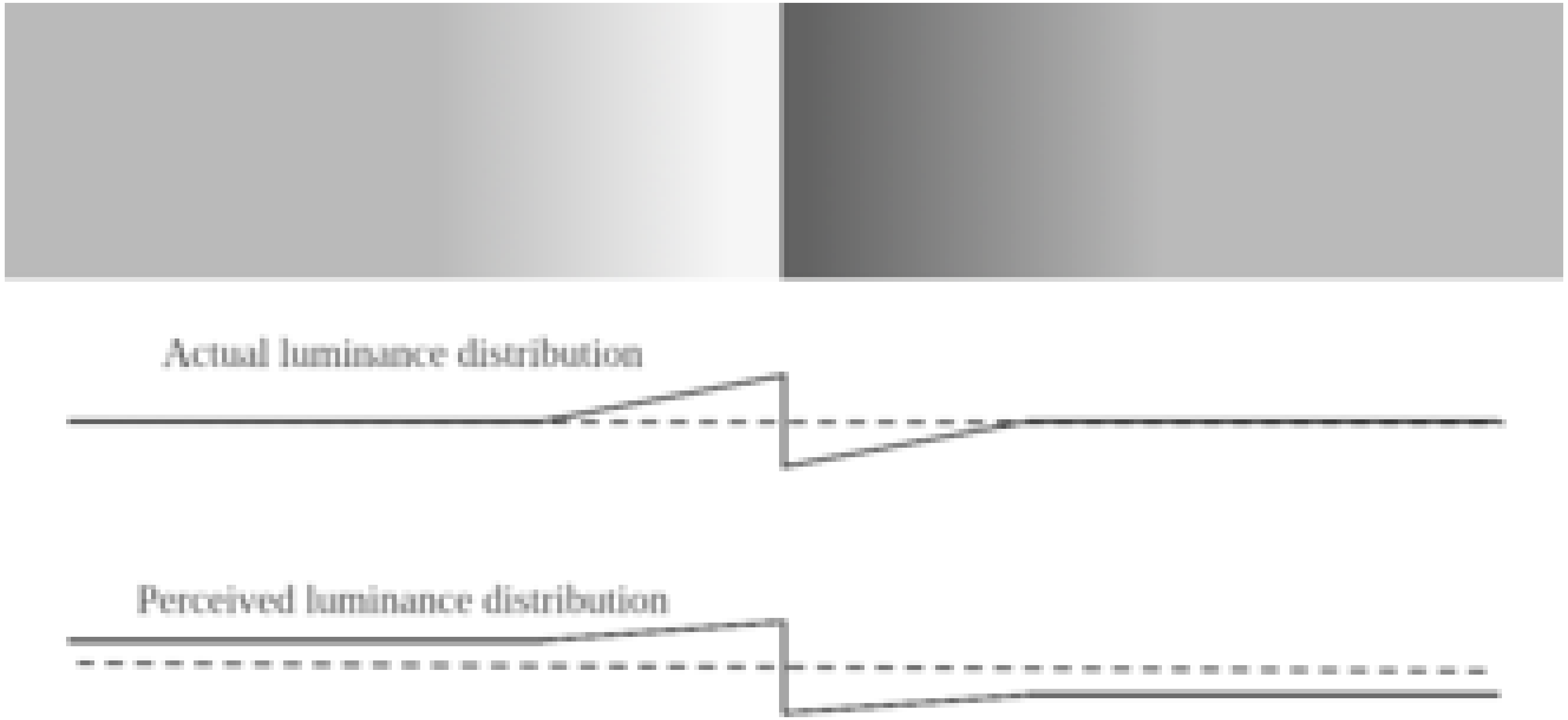




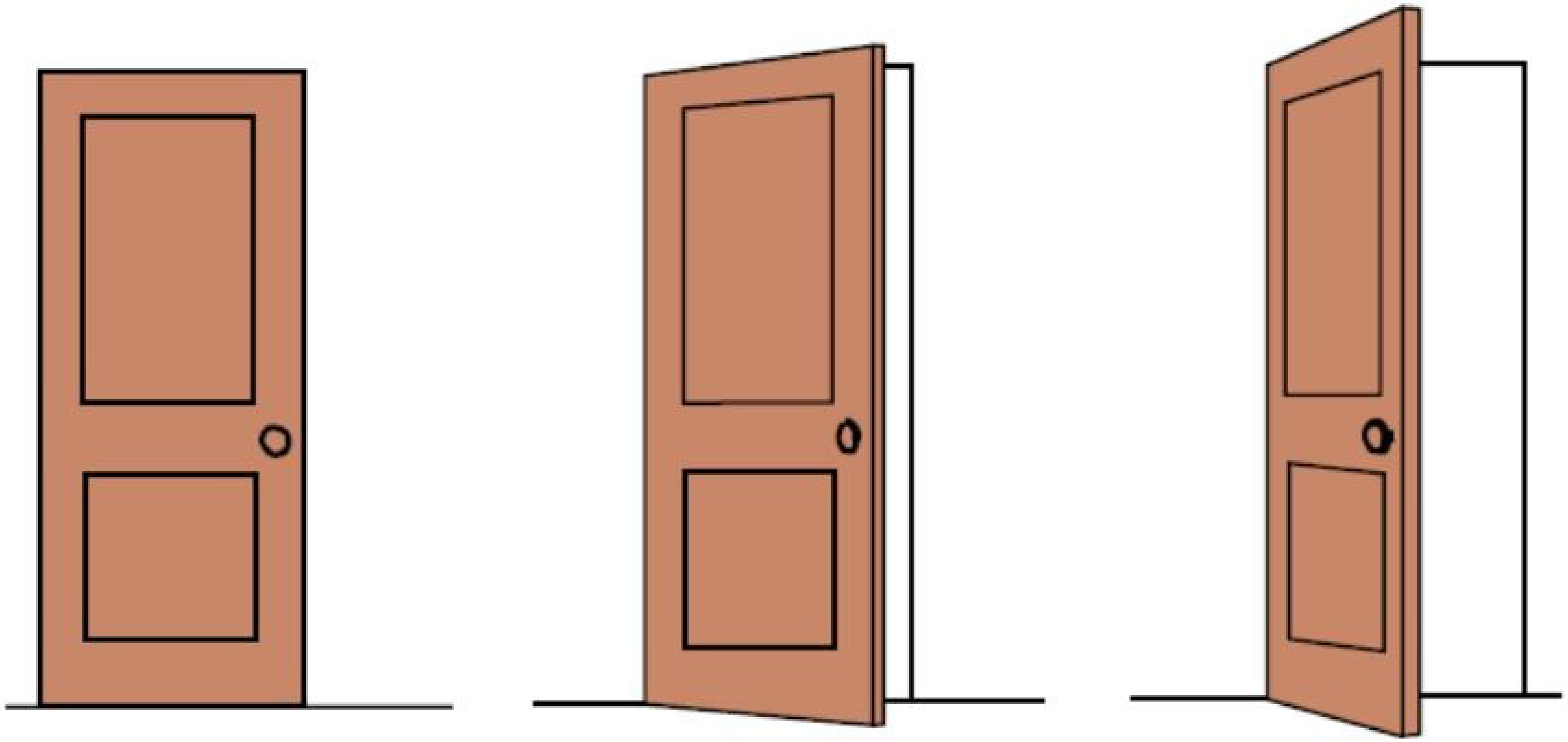
Cornsweet Illusion

The Cornsweet Illusion is a visual illusion where two adjacent areas of different shades appear to have different brightness levels, even though they are physically the same.

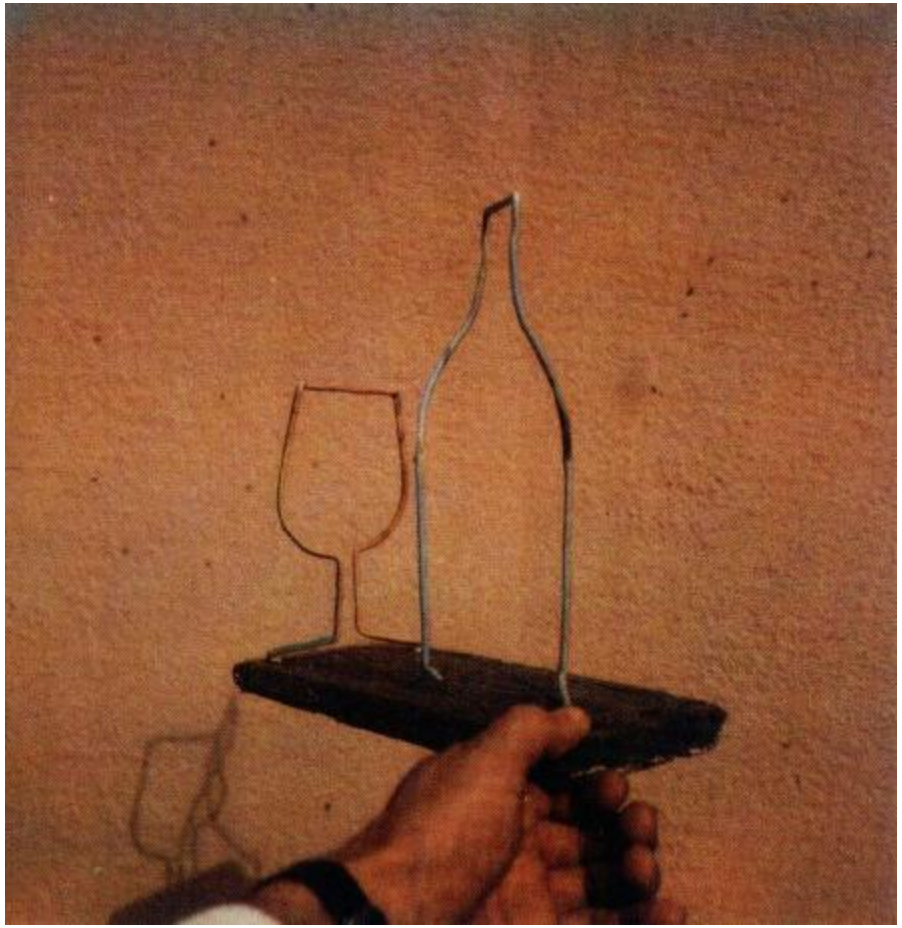
How it works: One side of the boundary is a light gray, and the other is a dark gray. However, due to the way the brain processes edges and contrasts, the light side appears lighter, and the dark side appears darker, making the boundary between them seem like a sharp contrast.



an example of shape constancy



an example of a failure of shape constancy



Markus Raetz: Das grosse Glass (1988) & Gross und Klein (1993)

perceptual learning, categories, and generalization

- Perceptual adaptation (vernier example, earlier)
- Perceptual adaptation (face example, now)
- The emergence of perceptual categories
- Shepard's Universal Law of Generalization

Perceptual Adaptation (Vernier Example): This refers to the ability to adapt to distortions in sensory input. In the Vernier alignment task, people learn to better judge the alignment of two lines as they practice, showing how perception can improve with experience.

Perceptual Adaptation (Face Example): Similar to the Vernier example, this shows how we adapt to perceive faces, even when they are distorted. With exposure, we become better at recognizing faces, even if they are altered (e.g., in different orientations or under unusual lighting).

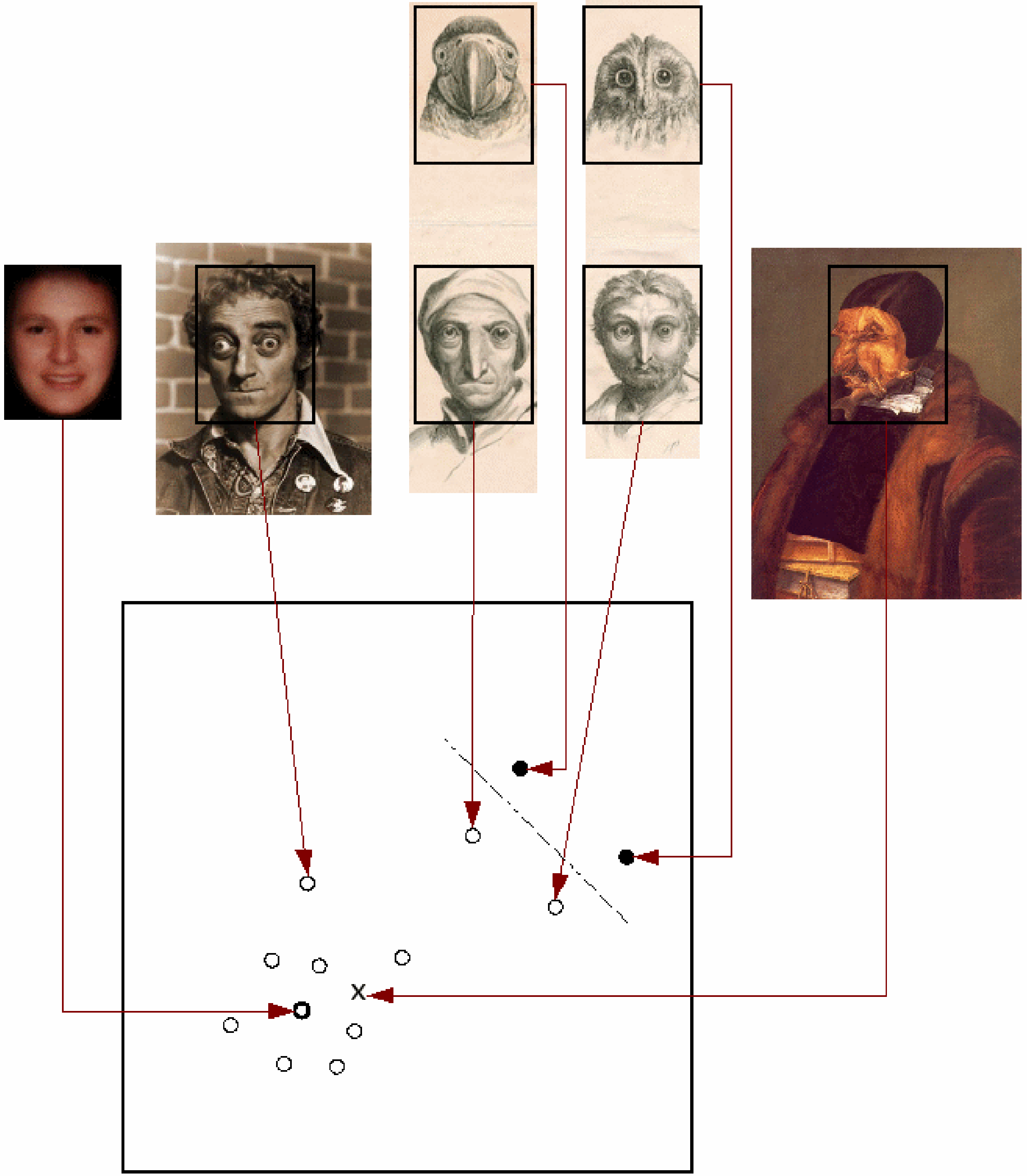
This law suggests that the way we generalize or apply learned information is continuous and gradual. Similar stimuli tend to be grouped together in our minds, and the likelihood of generalizing to a new stimulus depends on how similar it is to the original experience.

The structure of representation spaces

- A schematic diagram of a (high-dimensional) **face space**, illustrating the following concepts:
  - the average face
  - typical faces
  - atypical faces
  - novel faces

Let's Look at:

- Experimental evidence for the representation space being a space
- A powerful tool for studying representation spaces



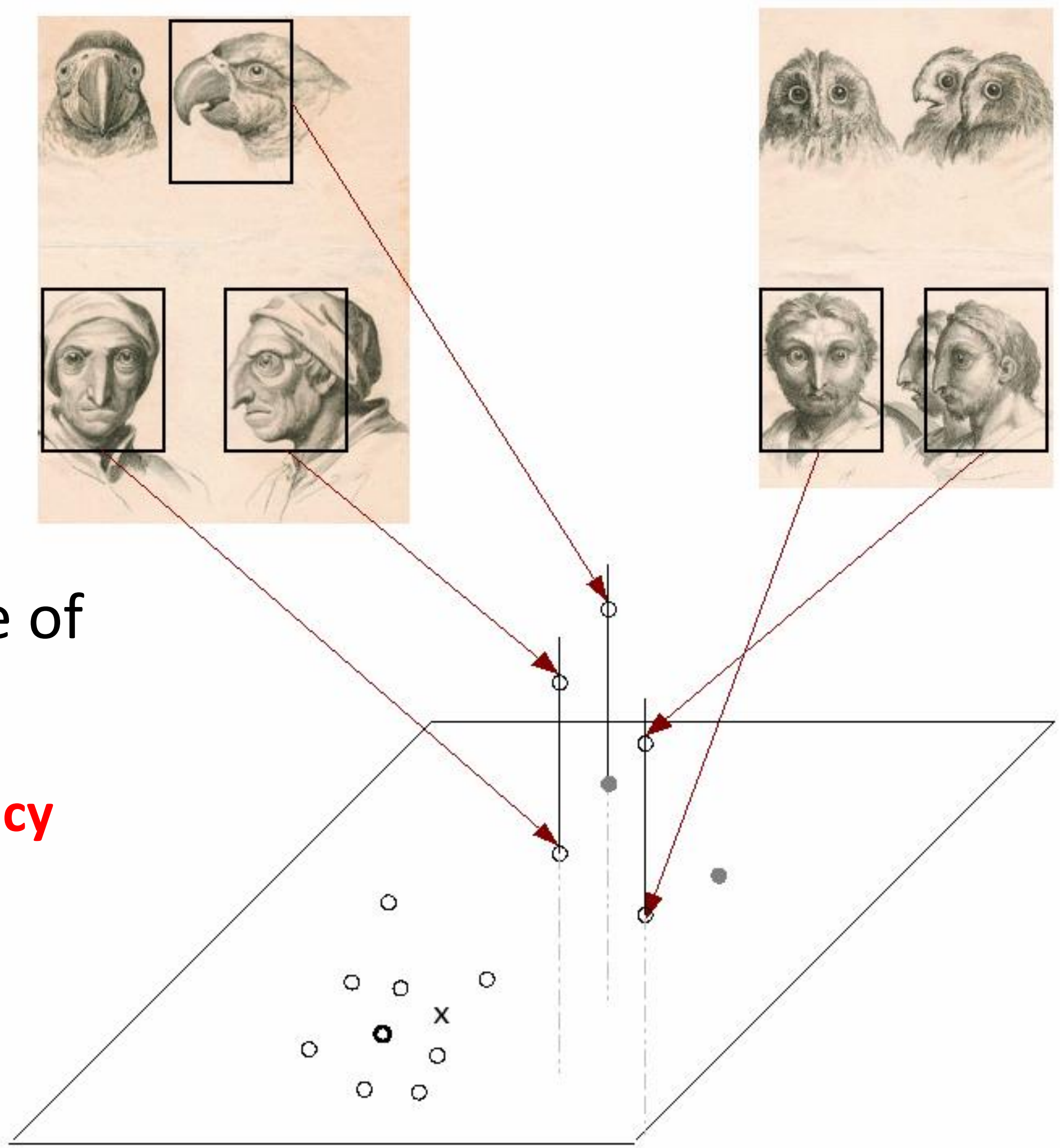
Perceptual Discrimination

FACE SPACE versus VIEW SPACE

In the plane:
the **face [shape] space**.

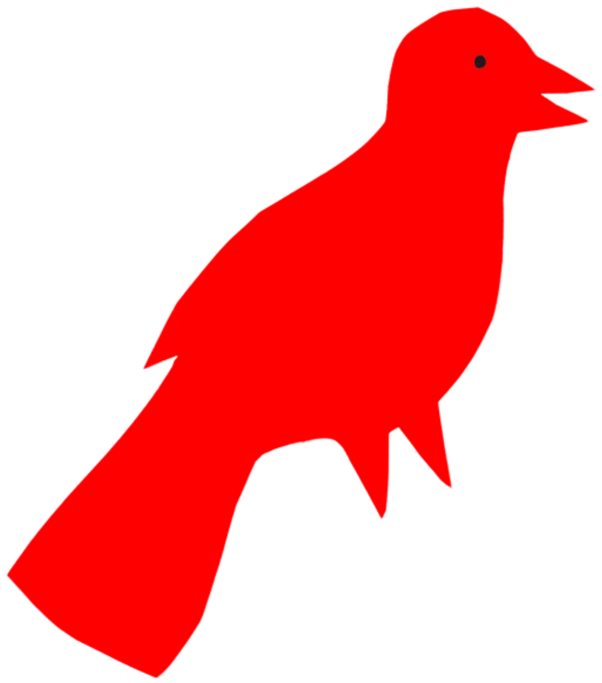
Perpendicular to it:
the **view [orientation] spaces** of some of the faces.

In computational terms, **Perceptual Constancy** corresponds to the ability to distill, out of all the dimensions of measurement performed on a stimulus, the few intrinsic variables of interest – Dimensionality Reduction



perceptual adaptation

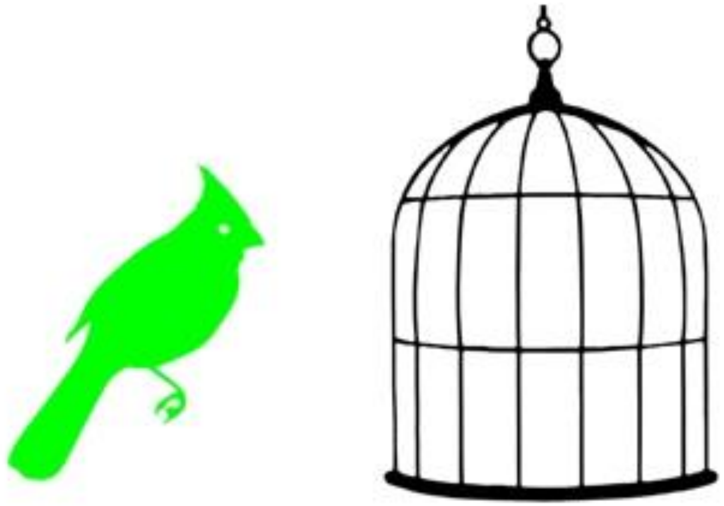
- A quick demo of visual colour adaptation: Stare at the parrot for at least 30 seconds, then look at the center of the cage. What do you see?



perceptual adaptation

- A quick demo of visual colour adaptation: Stare at the parrot for at least 30 seconds, then look at the center of the cage. What do you see?

  This shows how our visual system adapts to constant stimuli.

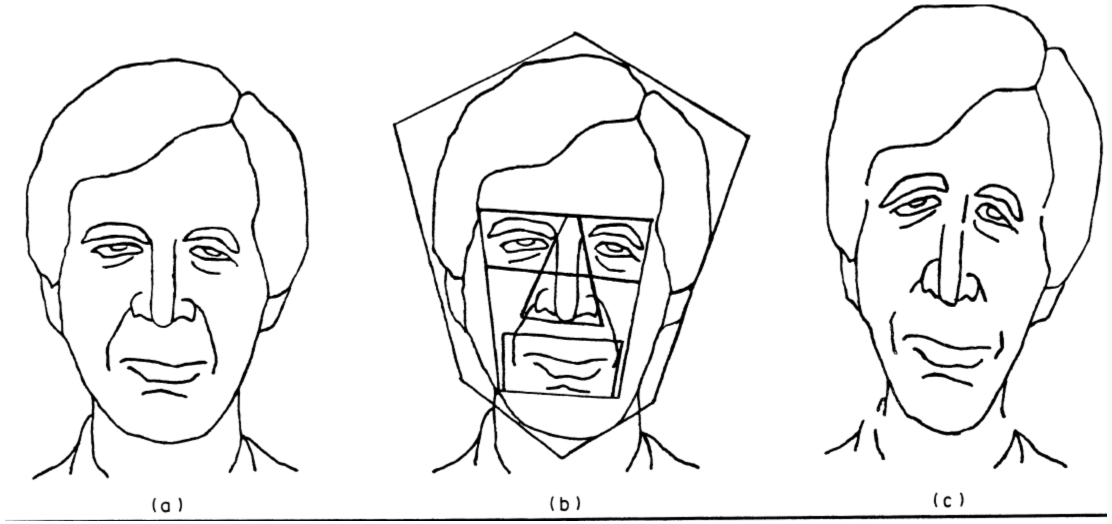


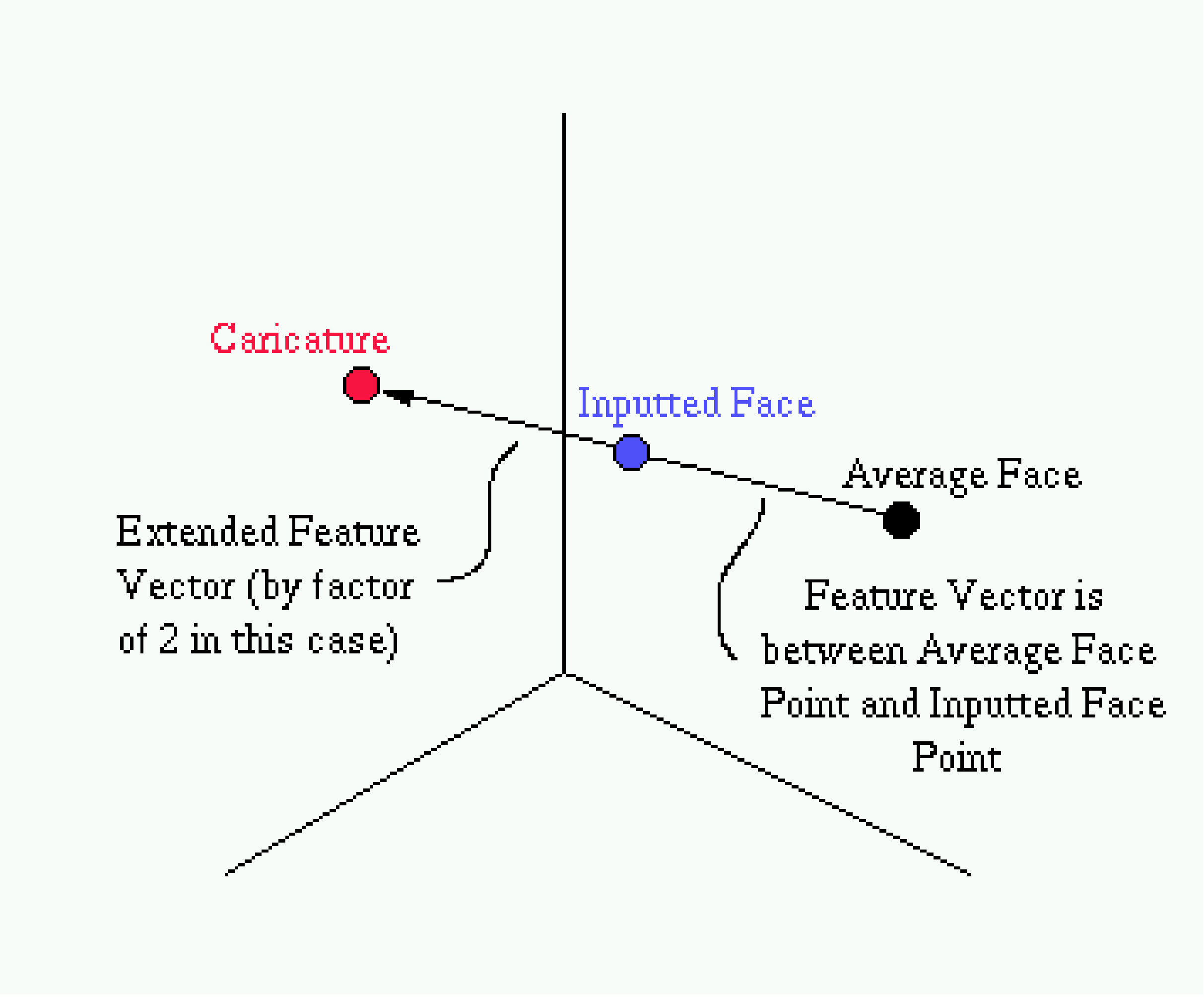
- Adaptation, to which all perceptual modalities are susceptible, reveals an important characteristic of neural coding:
- the brain uses Distributed Representations, so that when some of the units that participate in representing a particular stimulus get fatigued and respond less vigorously, the ones that have not been active "take over" and make the entire representation more like their own preferred features of the stimulus.

Perceptual adaptation reveals a general principle of representation in the brain

caricature as deviation from the mean in the face space

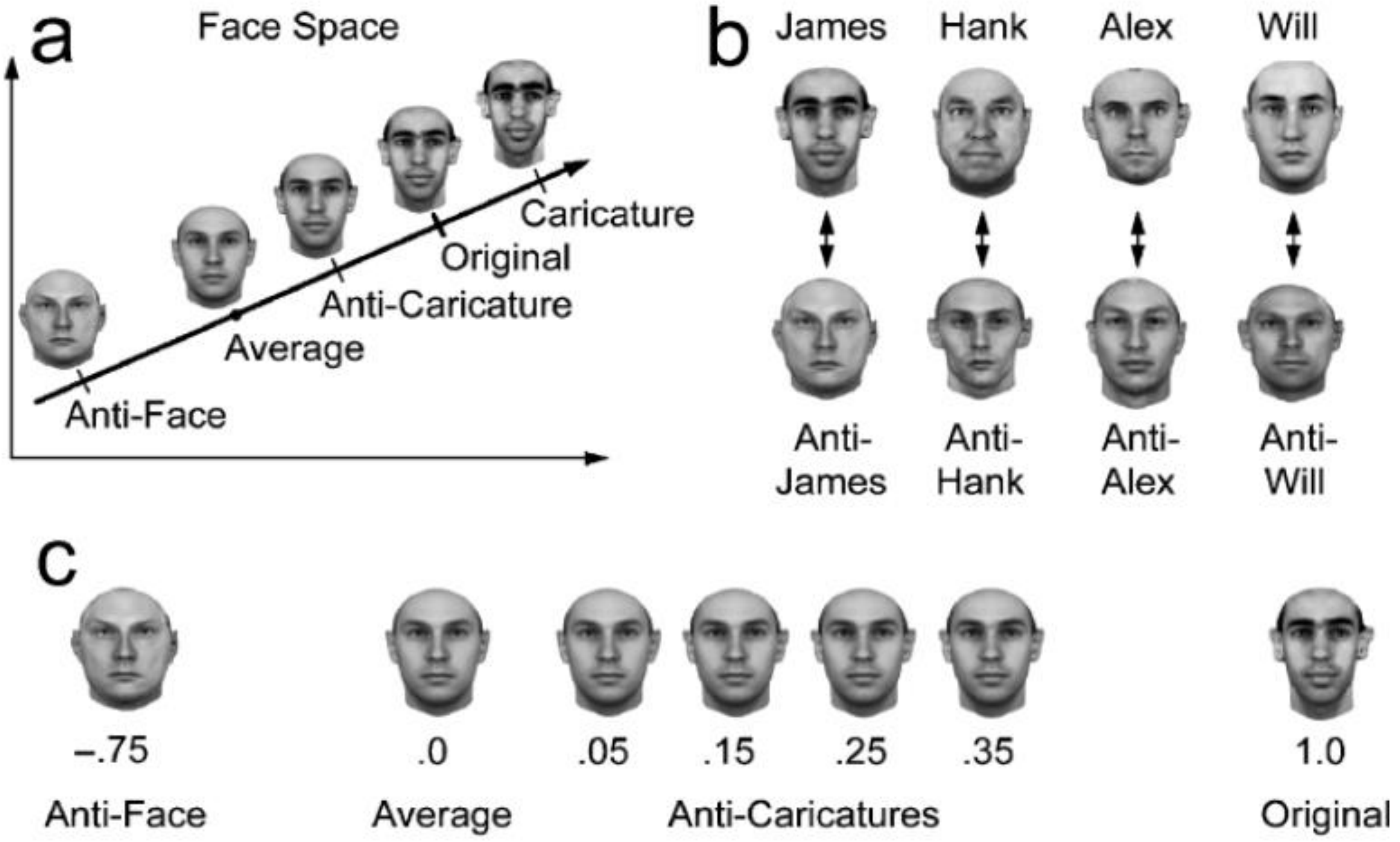
Caricatures and face morphing





Caricature Generator: The Dynamic Exaggeration of Faces by Computer, Susan E. Brennan, *Leonardo* 18:170-178 (1985)

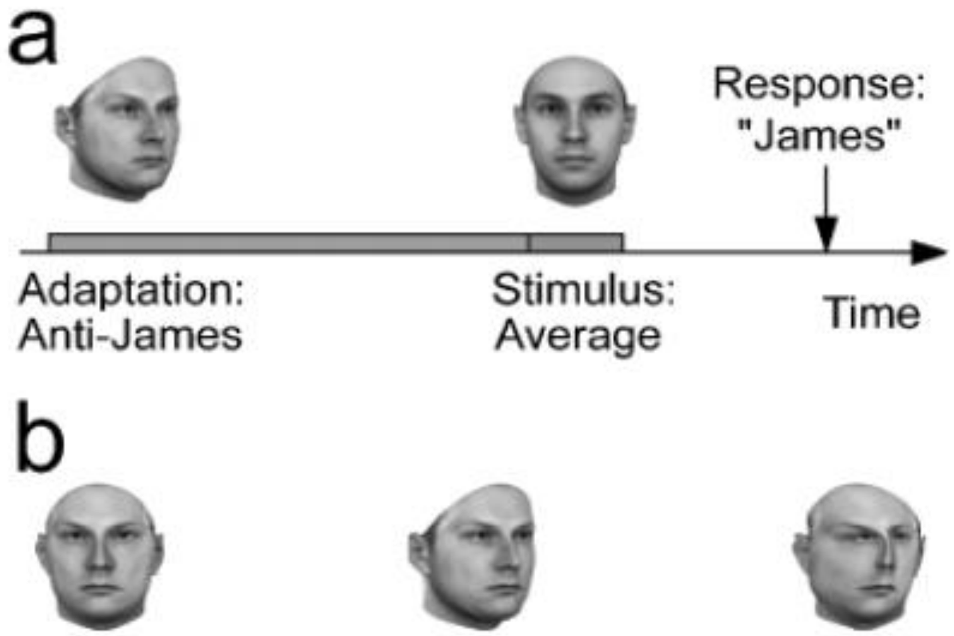
using morphing to study face space in the brain



Jiang, Blanz, and O'Toole (2006)

Experiment: Jiang et al (2006)

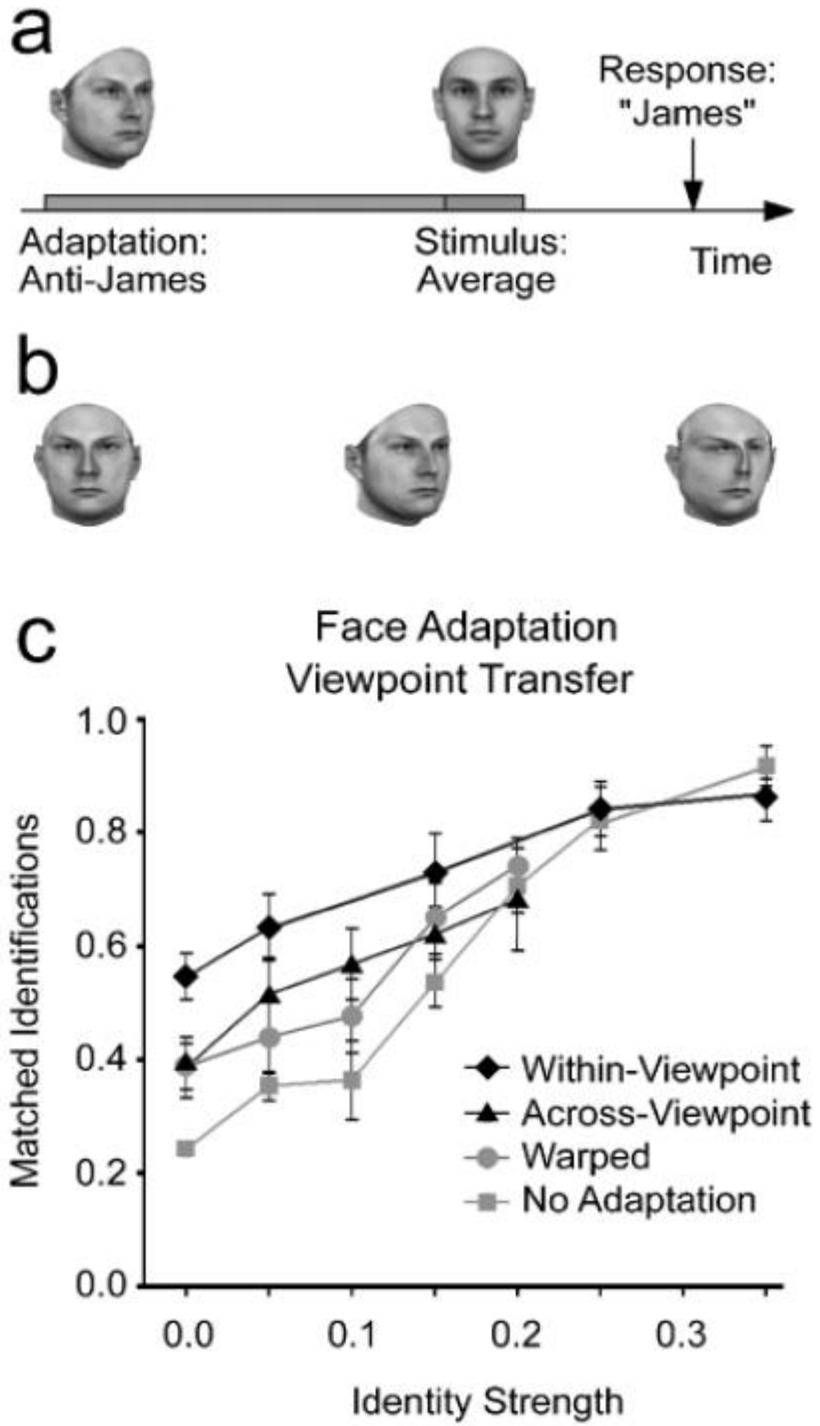
- (a) An example trial: across-viewpoint, neutral condition with 5 sec antiface adaptation, followed by Avg face for 200 ms.
- (b) Left: an antiface adapting stimulus as presented in the within-viewpoint condition; Middle: the corresponding antiface adapting stimulus in the view-changed condition; Right: the corresponding warped antiface.



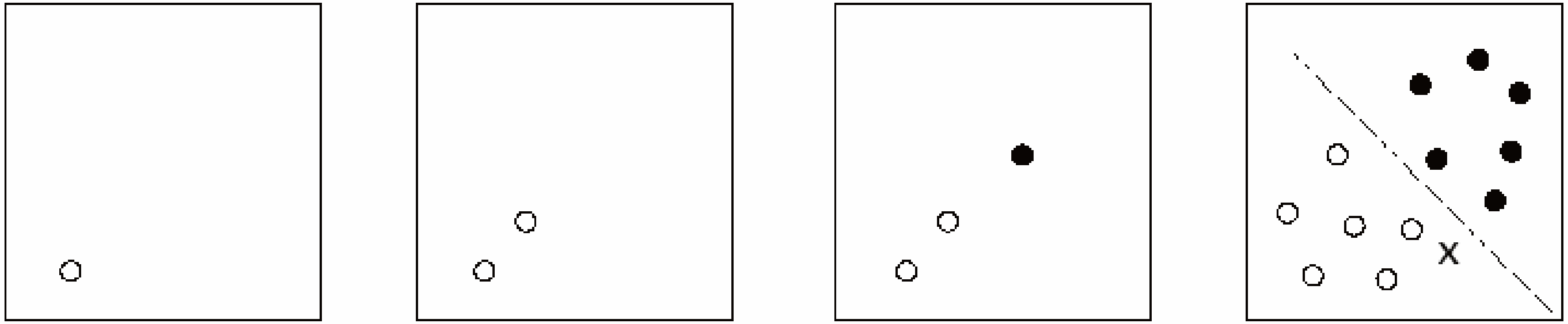
Experiment: Jiang et al (2006)

Findings:

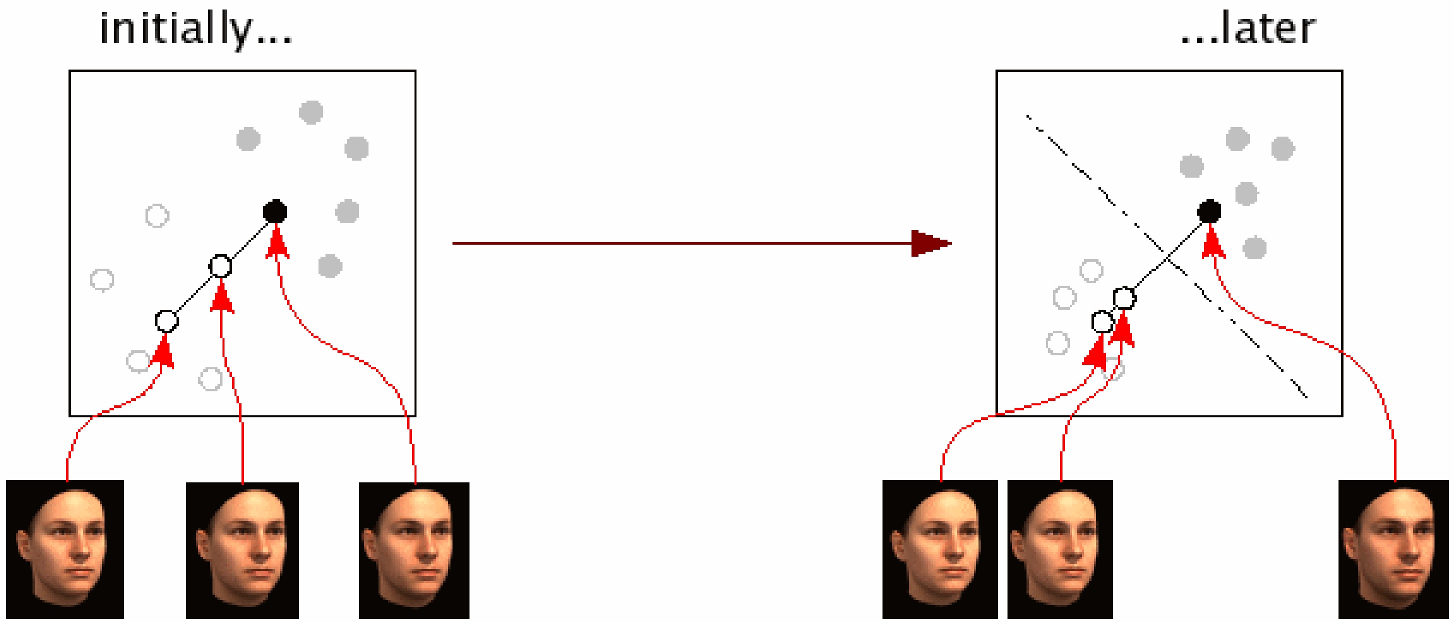
- [within-viewpoint] The average face (identity strength = 0) was identified as the match to the antiface adapting stimulus on .55 of the trials, significantly more often than the .25 expected by chance.
- [across-viewpoint] The average face was identified as the match to the adapting stimulus on .39 of the trials, again significantly more often than expected by chance.
- Bottom line: the face space is not just a fanciful abstraction — subjects maintain representations of the face space and use those in processing face stimuli. [Perceptual Adaptation]



perceptual learning from examples



acquiring the examples and forming a decision boundary in the representation space

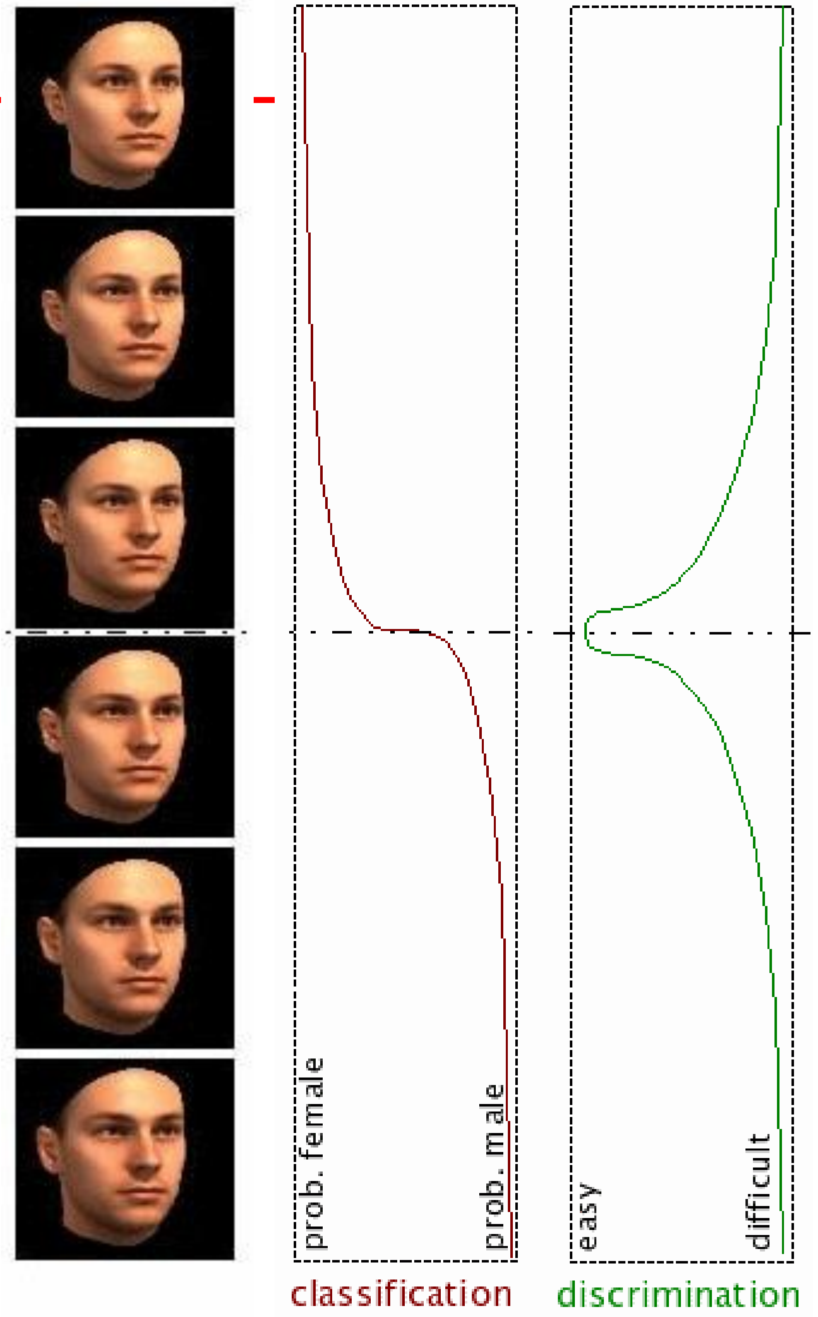


categorical perception through a warping of the representation space

Categorical perception

- A morph sequence of face images, and two revealing signs of categorical perception:
  - (i) sigmoidal response probability in a classification (for a single image, "which category is this?") task.
  - (ii) peaked performance (% correct) in a pairwise discrimination ("are these same or different?") task.

The inflection point of the sigmoid and the peak are both centered on the category boundary.



Bülthoff and Newell (2004)