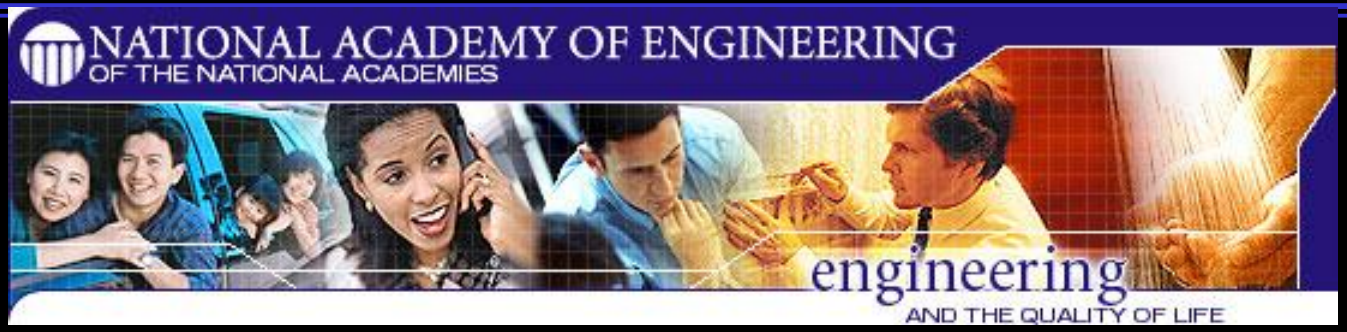


WELCOME TO THE NAE US FRONTIERS OF ENGINEERING SYMPOSIUM 2005

Ongoing Challenges in Face Recognition

Peter Belhumeur

Columbia University
New York City

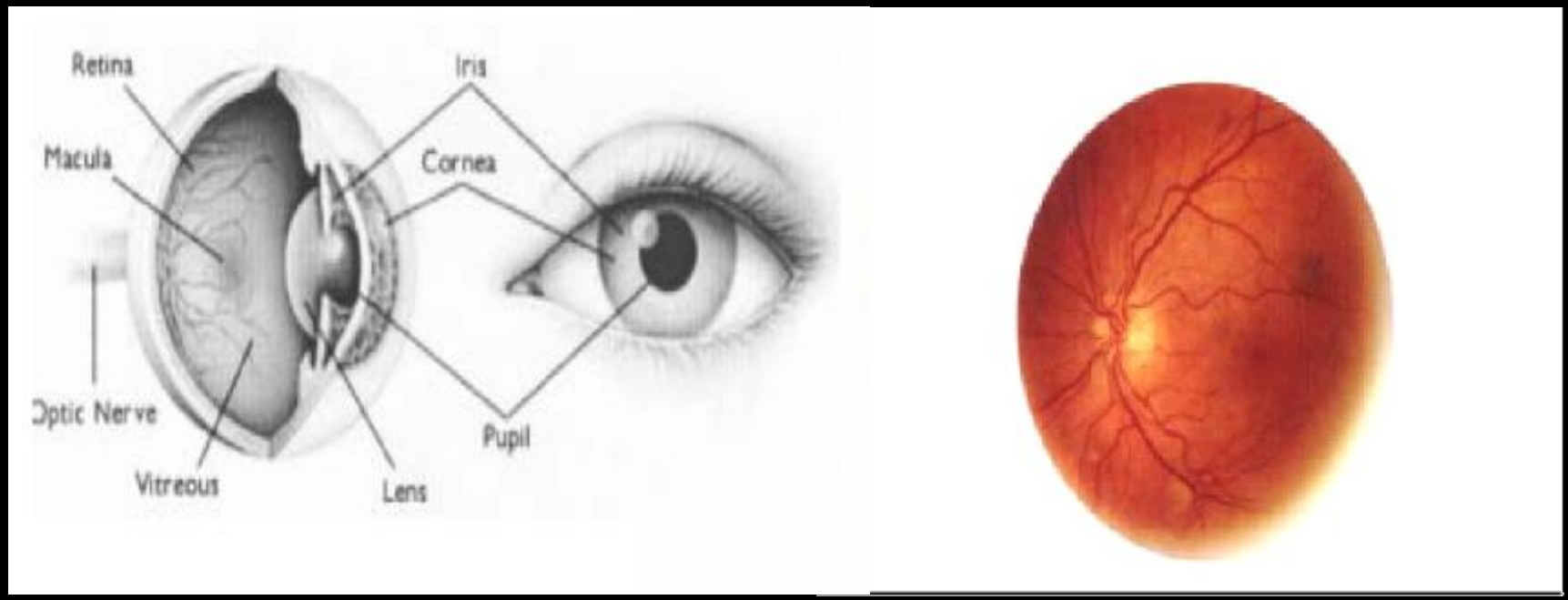
How are people identified?

People are identified by three basic means:

- Something they have (identity document or token)
- Something they know (password, PIN)
- Something they are (human body)

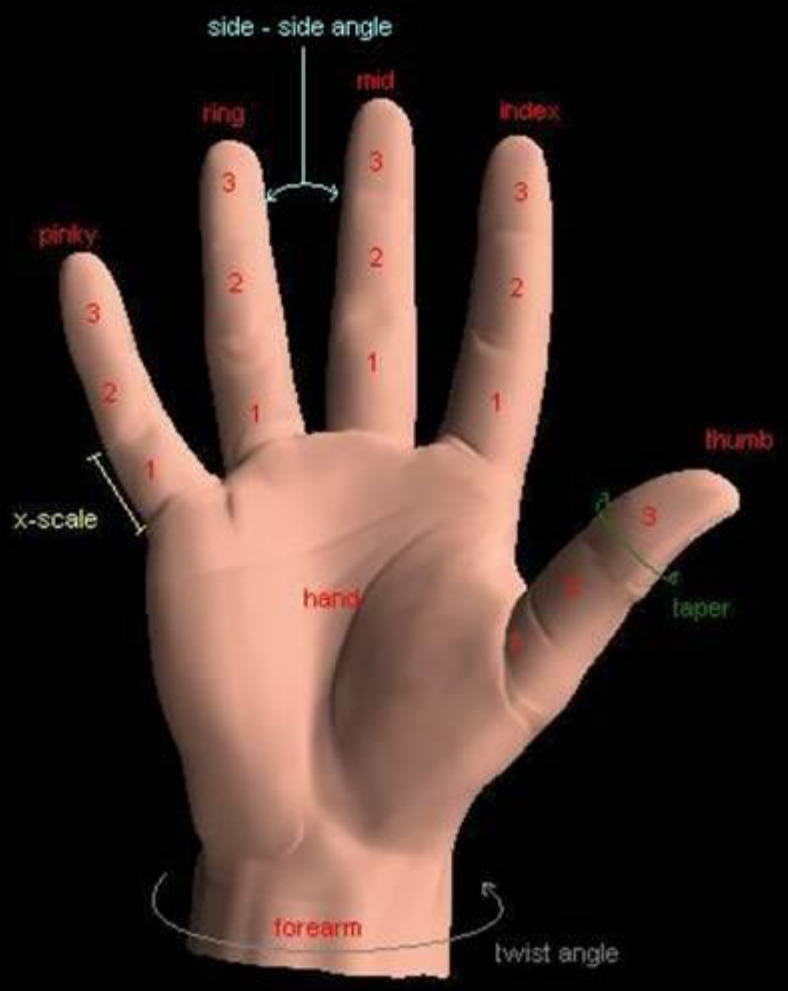
Iris

Retina

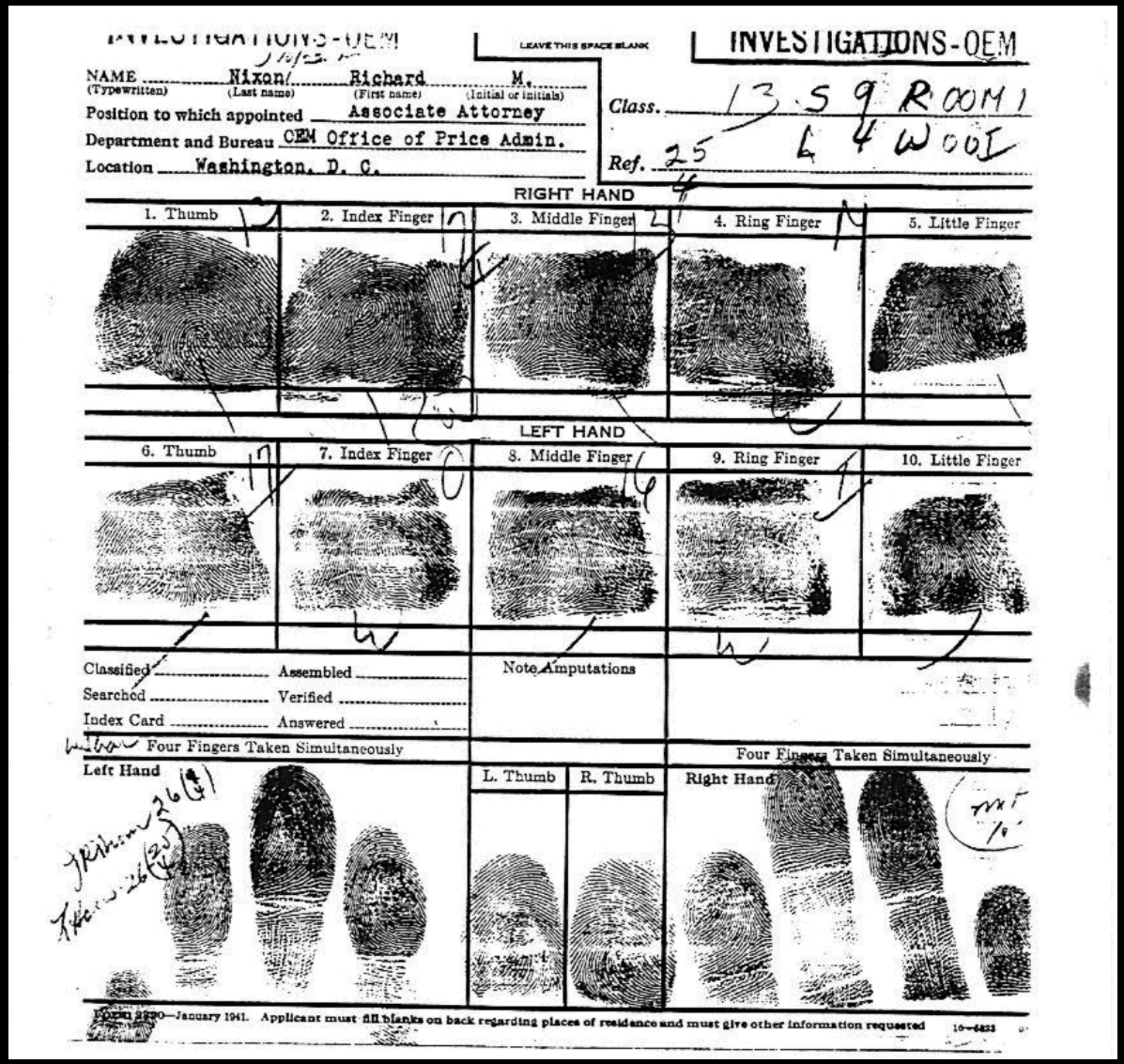


Every eye has its own totally unique pattern of blood vessels.

Hand


side - side angle
mid
ring
index
pinky
thumb
x-scale
hand
taper
forearm
twist angle

Fingerprint



INVESTIGATIONS-OEM

LEAVE THIS SPACE BLANK

INVESTIGATIONS-OEM

NAME (Typewritten) Nixon (Last name) Richard (First name) M. (Initial or initials)

Position to which appointed Associate Attorney

Department and Bureau OEM Office of Price Admin.

Location Washington, D. C.

Class. 13 5 9 ROOM 1 4 W 001

Ref. 25

RIGHT HAND

1. Thumb | 2. Index Finger | 3. Middle Finger | 4. Ring Finger | 5. Little Finger

LEFT HAND

6. Thumb | 7. Index Finger | 8. Middle Finger | 9. Ring Finger | 10. Little Finger

Classified ..... Assembled .....

Searched ..... Verified .....

Index Card ..... Answered .....

Note Amputations

Four Fingers Taken Simultaneously

Left Hand

L. Thumb | R. Thumb

Four Fingers Taken Simultaneously

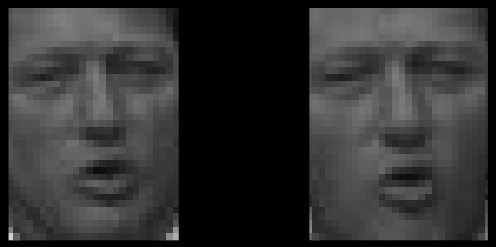
Right Hand

FORM 2370—January 1941. Applicant must fill blanks on back regarding places of residence and must give other information requested 16—6423

Ear

Face

Who are these people?

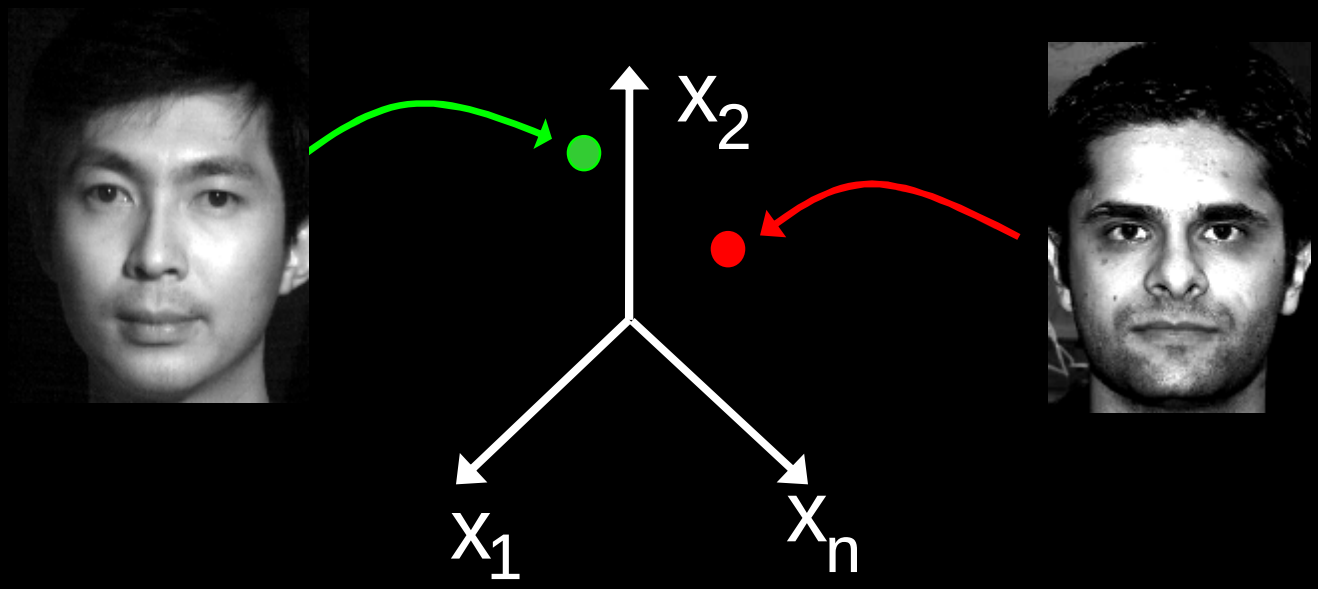


[Sinha and Poggio 1996]

Who are these people?

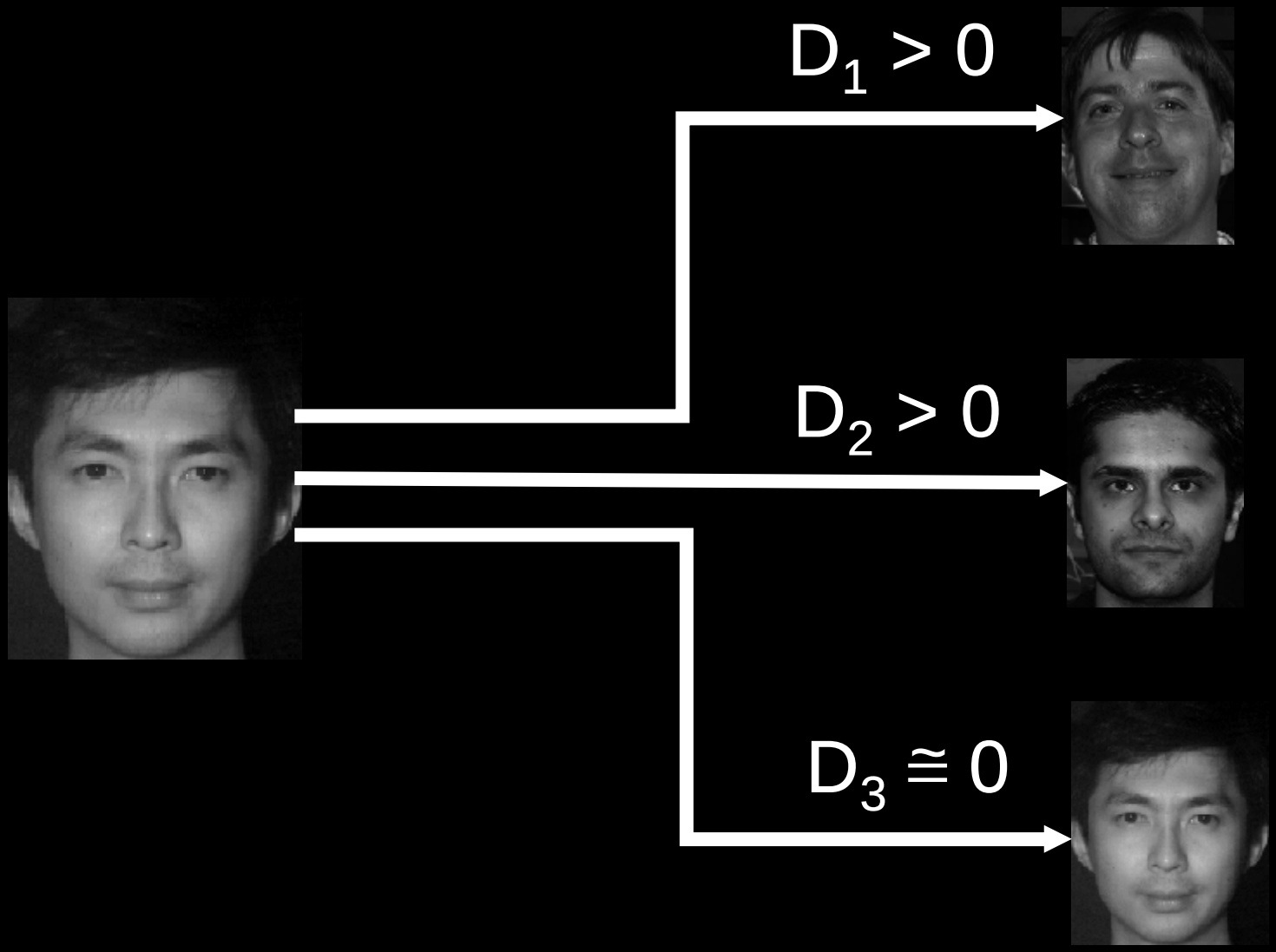
[Sinha and Poggio 2002]

Images as Points in Euclidean Space

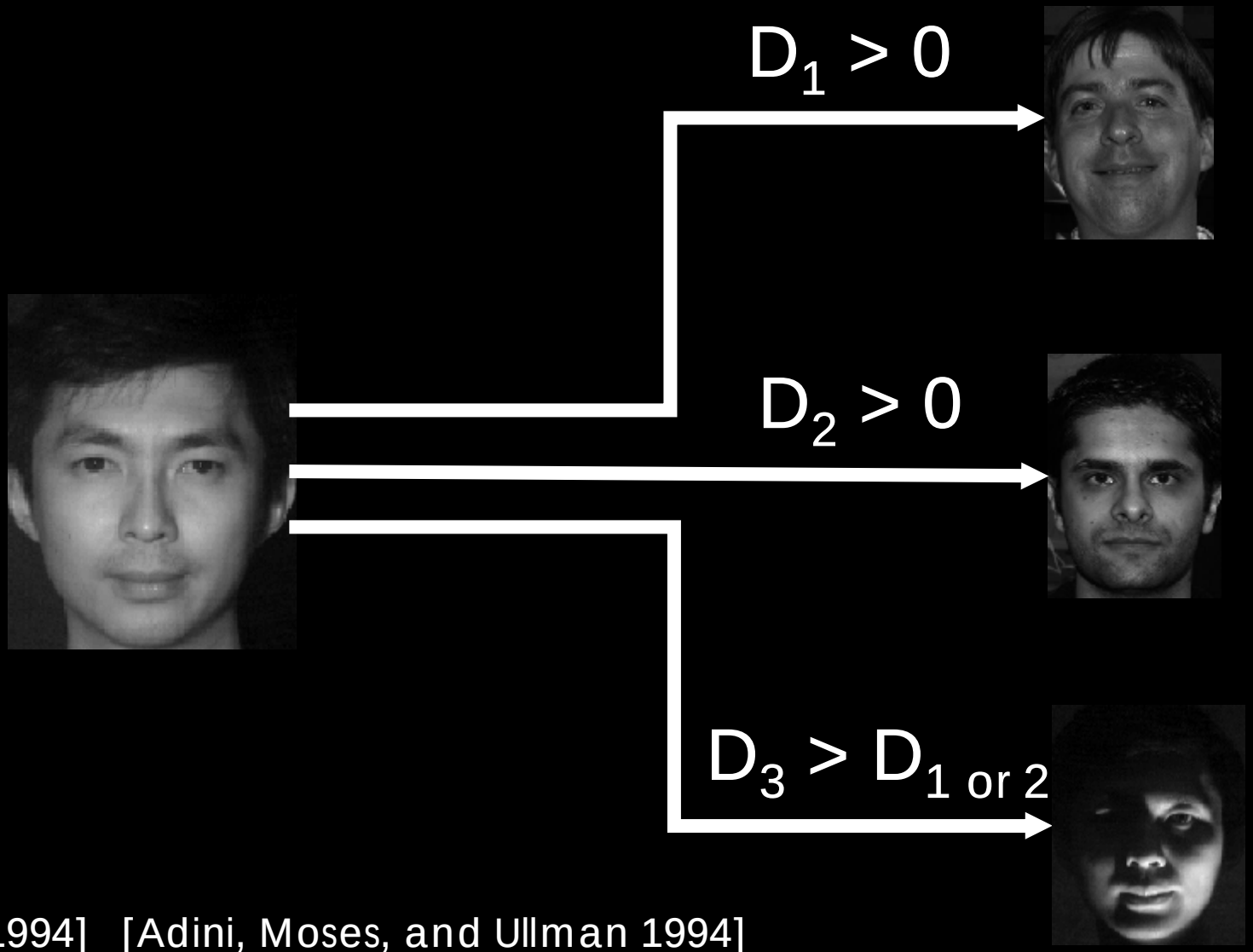


- Let an n-pixel image to be a point in an n-D space, $x \in R^n$.
- Each pixel value is a coordinate of x.

Face Recognition: Euclidean Distances



Face Recognition: Euclidean Distances



[Hallinan 1994] [Adini, Moses, and Ullman 1994]

Same Person

or

Different People

Same Person

or

Different People

Why is Face Recognition Hard?

Challenges: Image Variability

Short Term

Expression

Pose

Illumination

Long Term

- Facial Hair
- Makeup
- Eyewear
- Hairstyle
- Piercings
- Aging

Illumination Invariants?

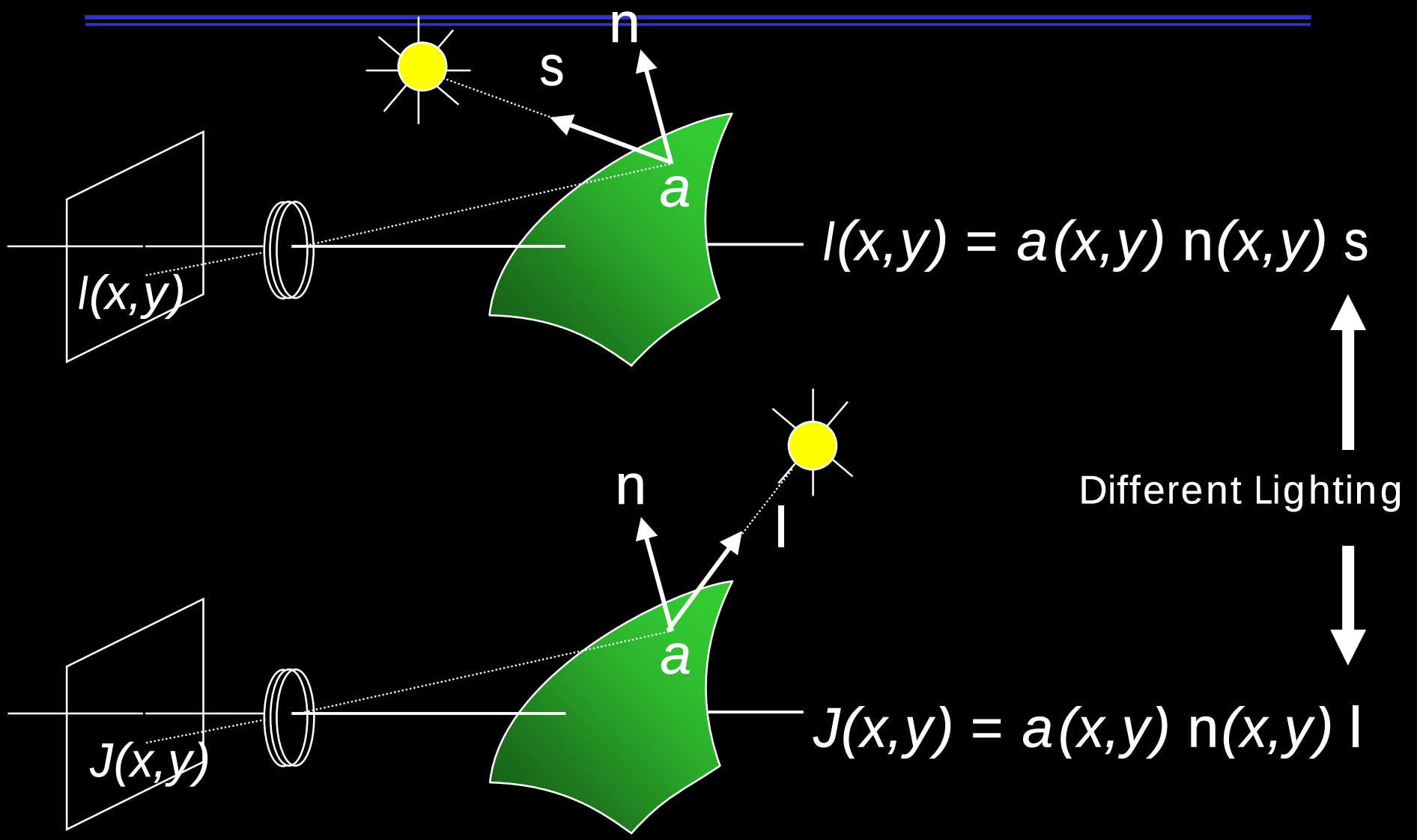
Does there exist a function f *s.t.*

f() = f() = f() = a

and

f() = f() = f() = b ?

Can Any Two Images Arise from a Single Surface?

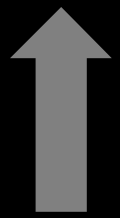


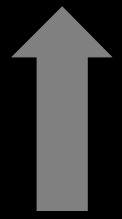
The Surface PDE

$I(x,y) = a(x,y)\, n(x,y)\, s$

$J(x,y) = a(x,y)\, n(x,y)\, l$

$(\, I\, l - J\, s\,)\, n = 0$





Nonlinear PDE

Linear PDE

Non-Existence Theorem for Illumination Invariants

Illumination invariants for 3-D objects do not exist.

This result *does not ignore* attached and cast shadows, as well as surface interreflection.

[Chen, Belhumeur, and Jacobs 2000]

Geometric Invariants?

Does there exist a function f *s.t.*

$f($  $) = f($  $) = f($  $) =$ a

and

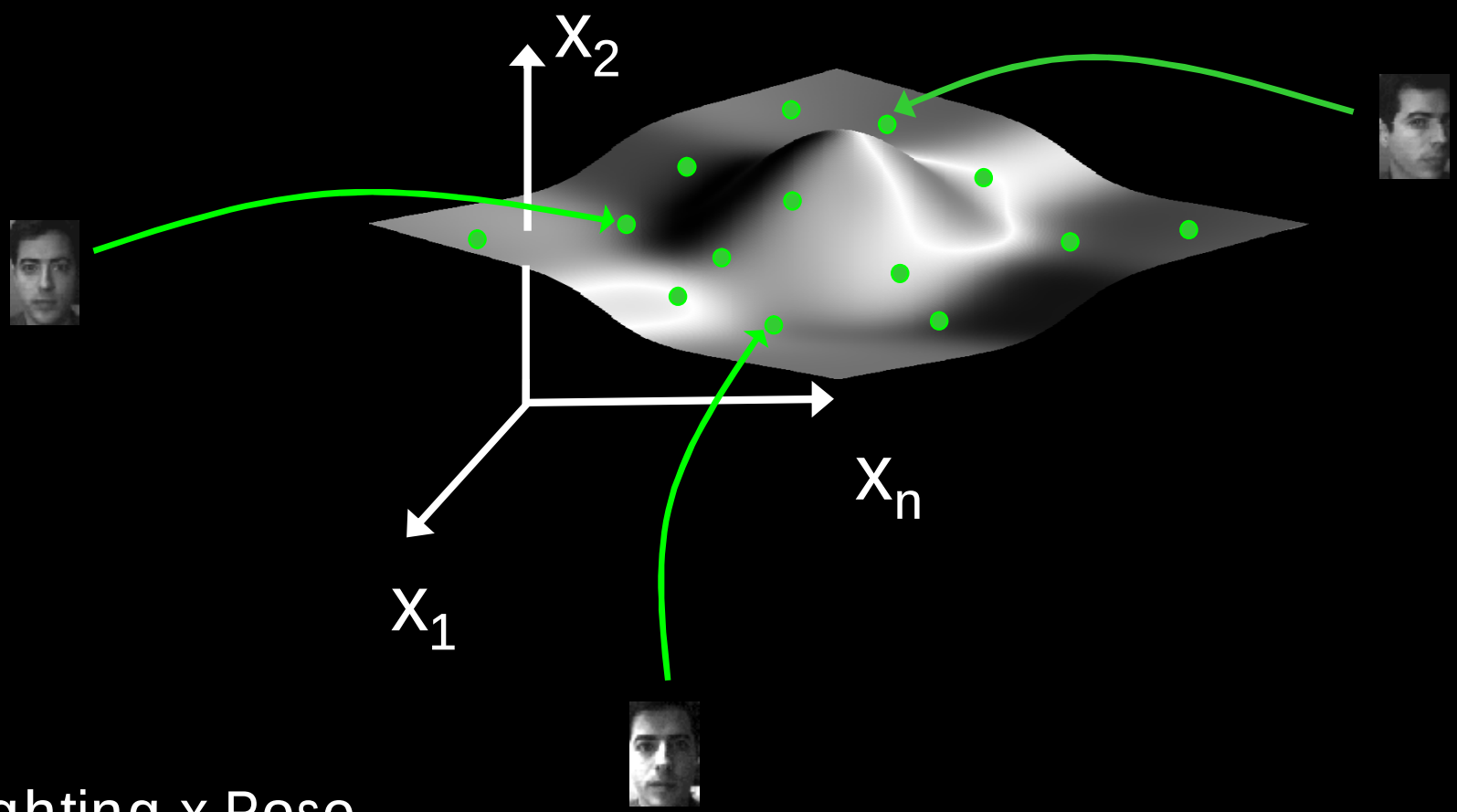
$f($  $) = f($  $) = f($  $) =$ b ?

Non-Existence Theorem for Geometric Invariants

Geometric invariants for rigid transformations of 3-D objects viewed under perspective projective projection do not exist.

[Burns, Weiss, and Riseman 1992]

Image Variability: Appearance Manifolds



Lighting x Pose

[Murase and Nayar 1993]

Modeling Image Variability

Can we model illumination and pose variability in images of a face?

Yes, if we can determine the shape and texture of the face. But how?

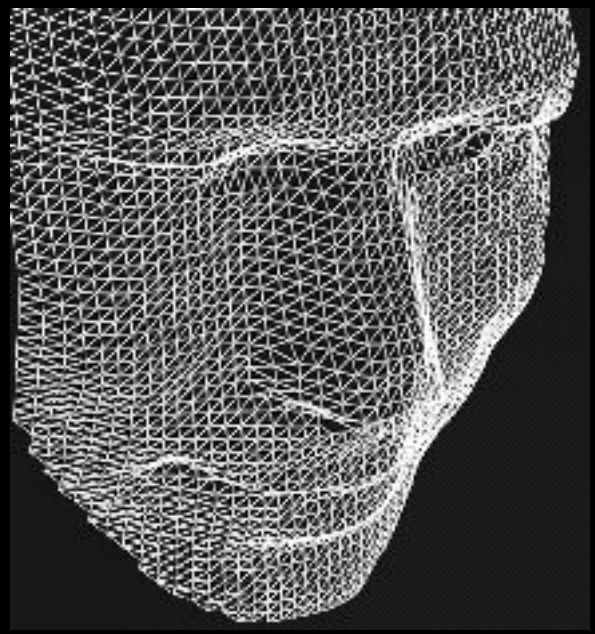
Modeling Image Variability: 3-D Faces

Laser Range Scanners

Stereo Cameras

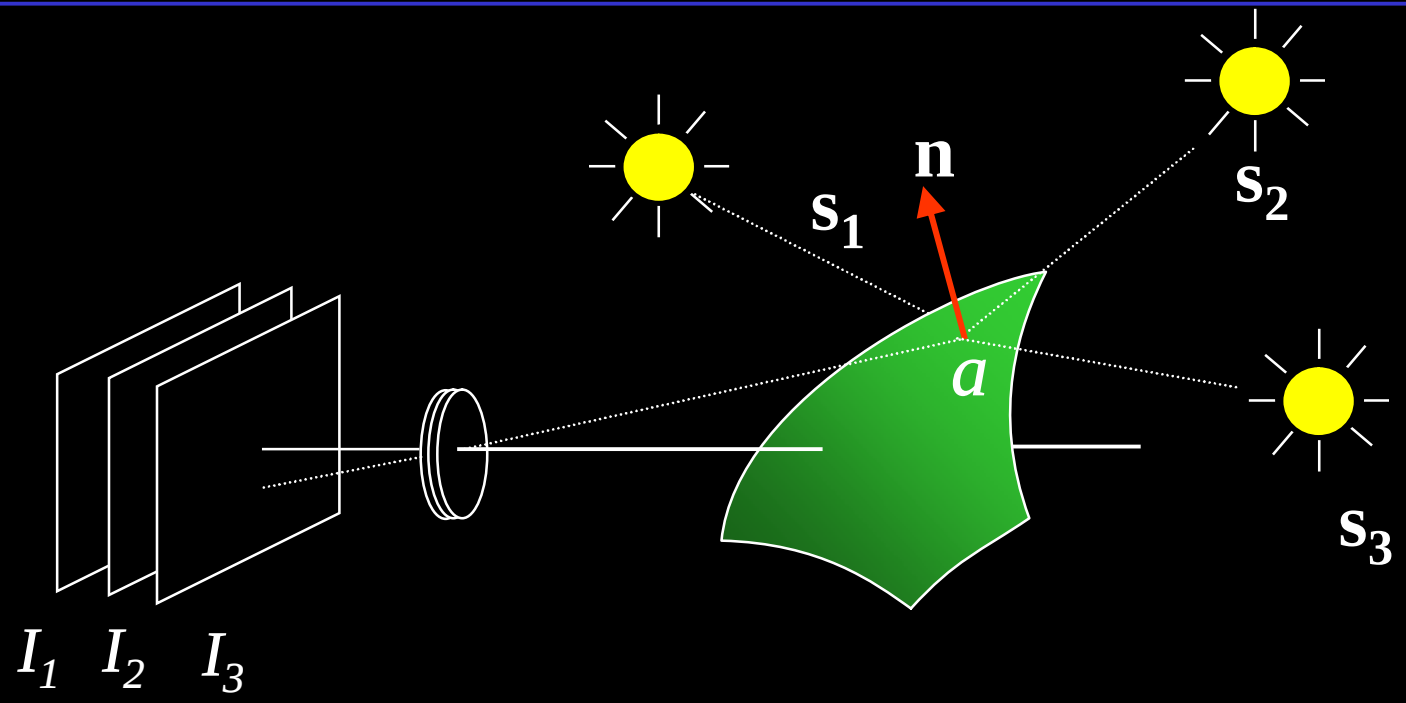
Structured Light

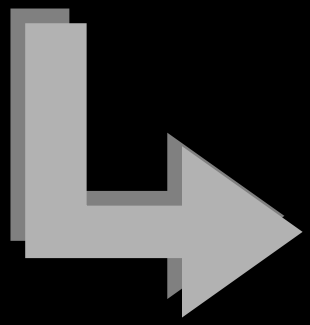
Photometric Stereo

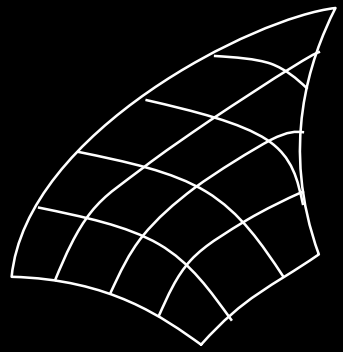


[Atick, Griffin, Redlich 1996] [Georghiades, Belhumeur, Kriegman 1996] [Blanz and Vetter 1999] [Zhao and Chellepa 1999] [Kimmel and Sapiro 2003] [Geometrix 2001] [MERL 2005]

Illumination Variation Reveals Object Shape

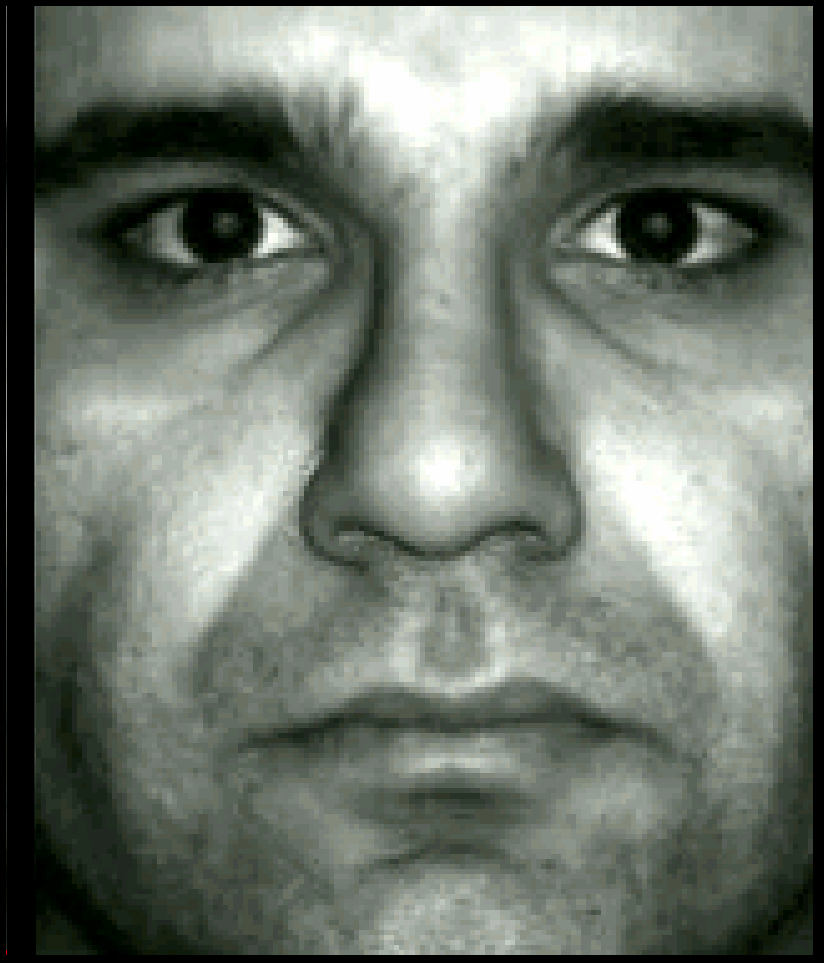






[Woodham 1984]

Illumination Movie

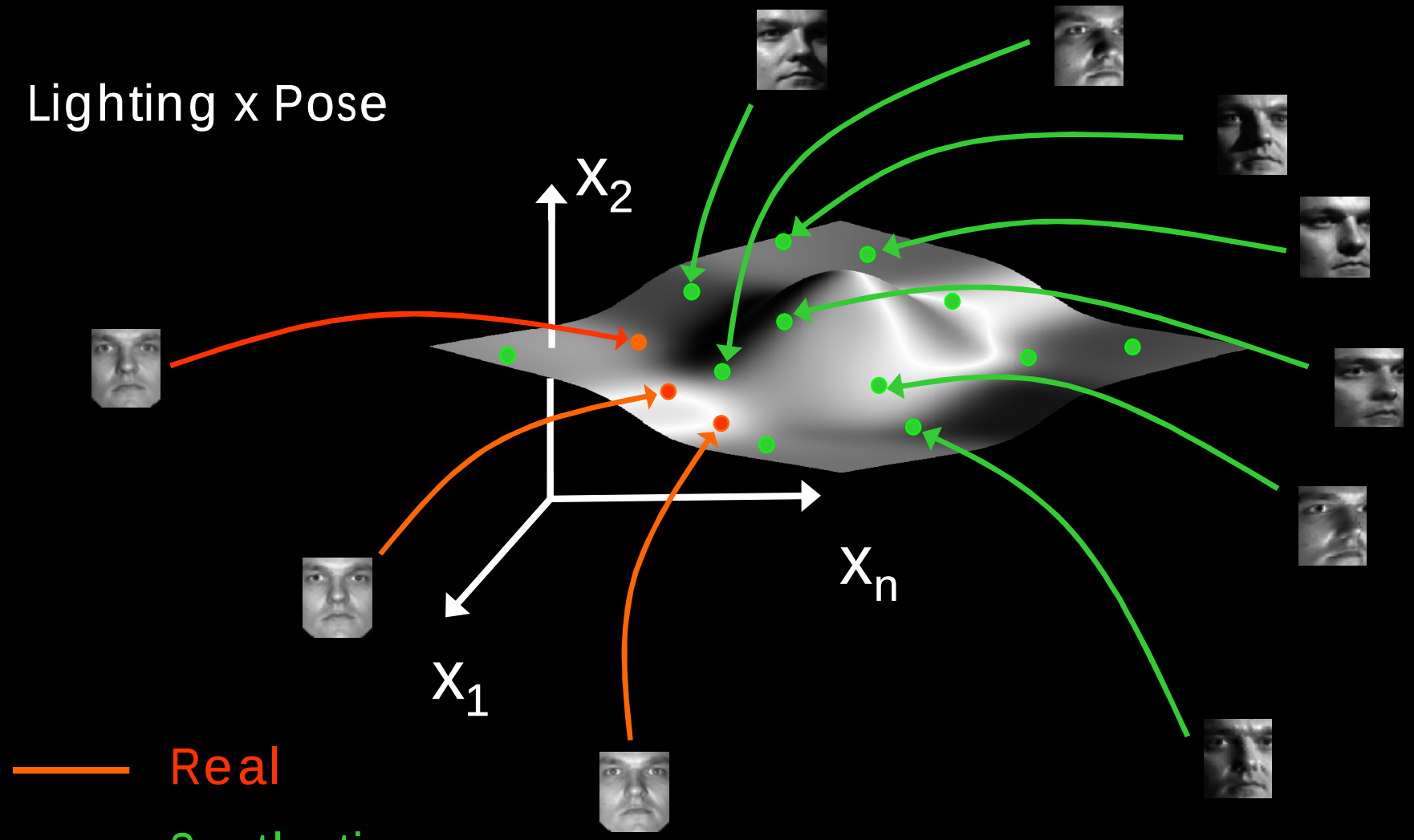


Illumination Movie

Shape Movie

Shape Movie

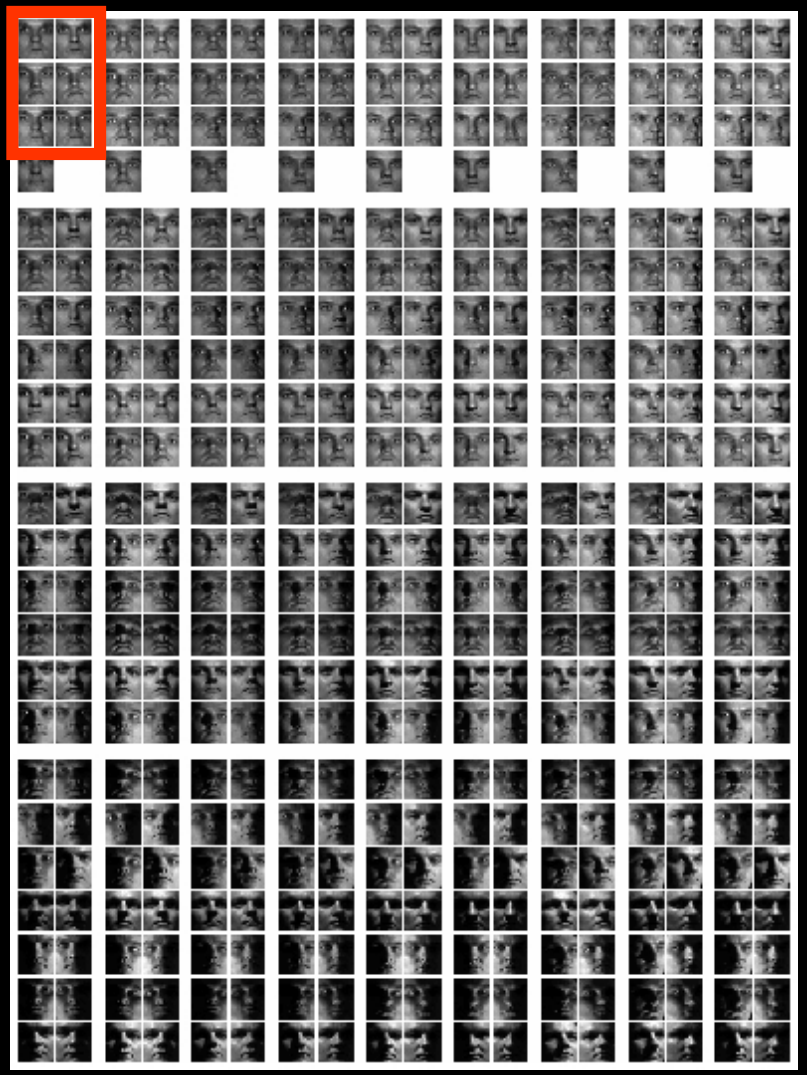
Image Variability: From Few to Many



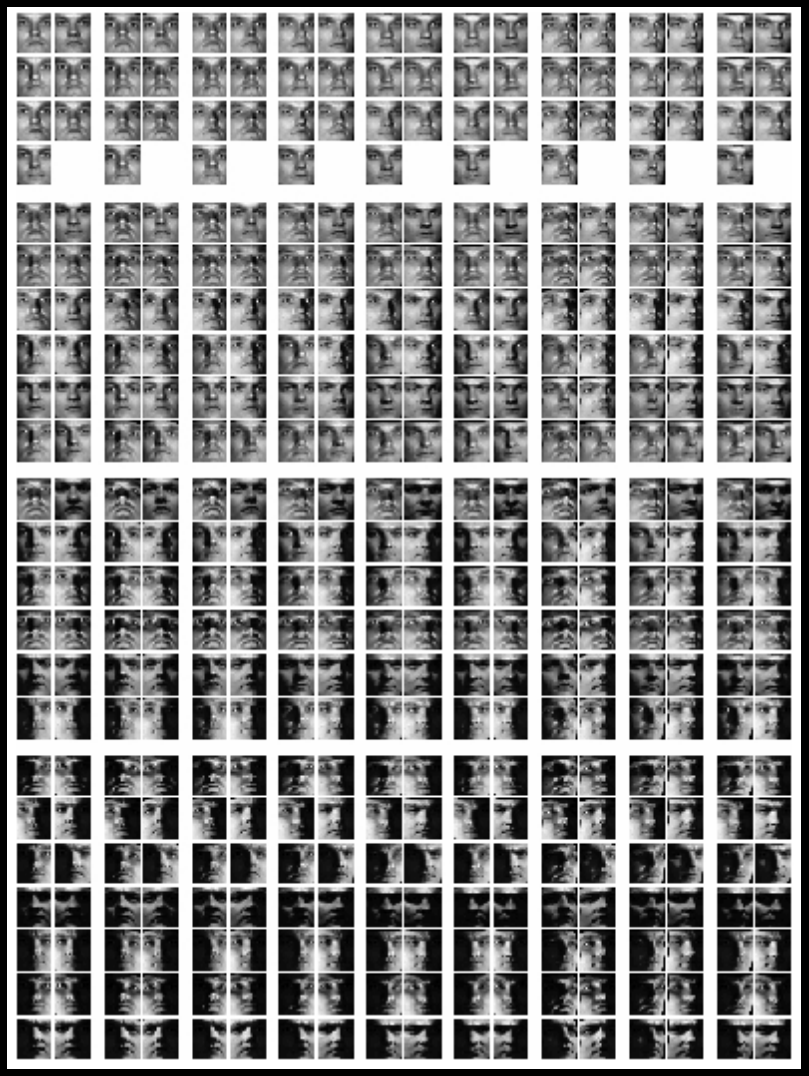
[Georghiades, Belhumeur, and Kriegman 1999]

Illumination Dome

Real vs. Synthetic



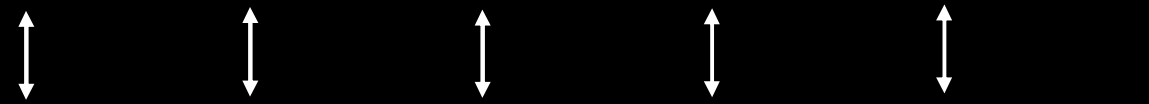
Real



Synthetic

Real vs. Synthetic

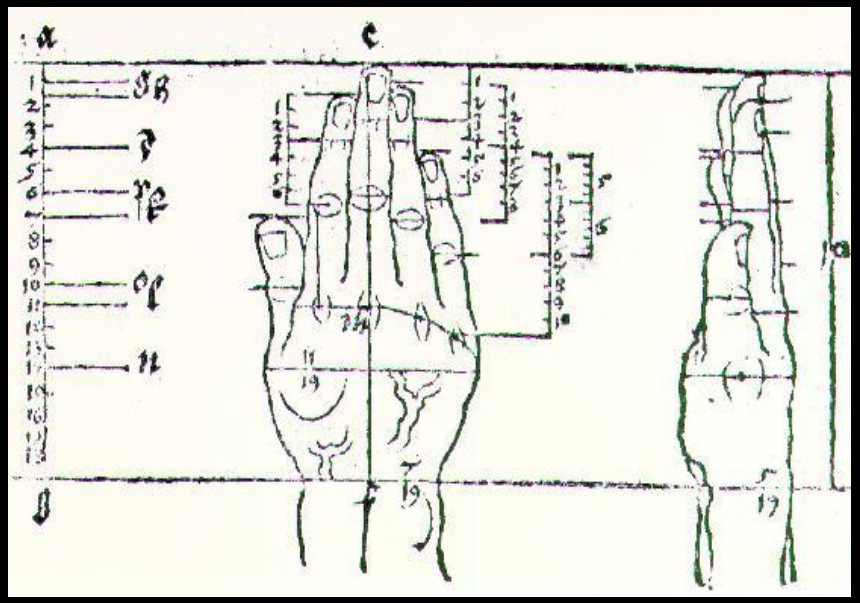
Real

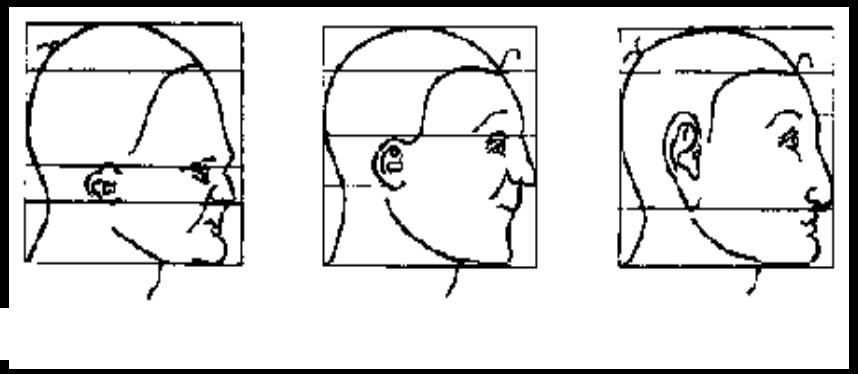


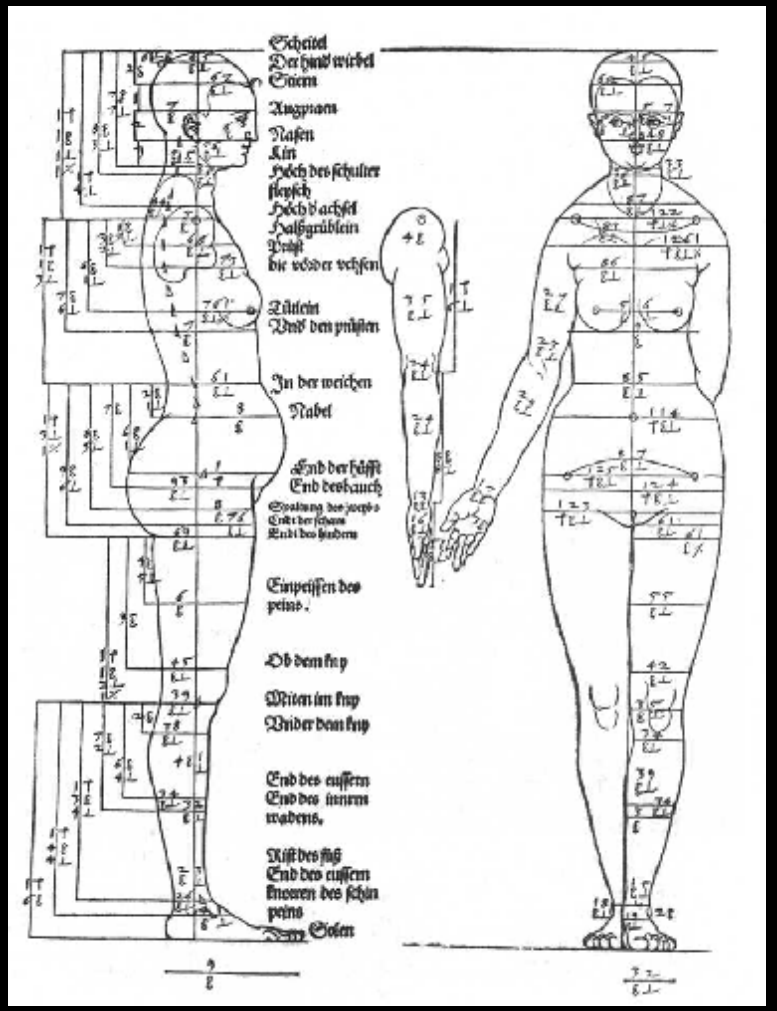
Synthetic

A Step Back in Time

Albrecht Dürer, “Four Books on Human Proportion” (1528)







D’arcy Thompson, “On Growth and Form” (1917)

which fossils are subject (as we have seen, on p. 811) as the result of shearing-stresses in the solid rock.

Fig. 519 is an outline-diagram of a typical Scaroid fish. Let us deform its rectilinear coordinates into a system of (approximately) coaxial circles, as in Fig. 520, and then fitting into the new system,

Fig. 517. *Argyreiodus affinis.*

Fig. 518. *Stethojulis Bandanensis.*

space by space and point by point, our former diagram of *Scarus*, we obtain a very good outline of an allied fish, belonging to a neighbouring family, of the genus *Pomacanthus*. This case is all the more interesting, because upon the body of our *Pomacanthus* there are striking colour bands, which correspond in direction very closely

Fig. 519. *Scarus sp.*

Fig. 520. *Pomacanthus.*

to the lines of our new curvilinear coordinates. In like manner, the still more bizarre outlines of other fishes of the same family of Chaetodonts will be found to correspond to very slight modifications of similar coordinates; in other words, to small variations in the values of the constants of the conic curves.

Figs. 521, 524 I have represented another series of Acanthopterygian fishes, not very distantly related to the foregoing. If we

start this series with the figure of *Polyprion*, in Fig. 521, we see that the outlines of *Pseudopriacanthus* (Fig. 522) and of *Beryx* or *Scorpaena* (Fig. 523) are easily derived by substituting a system

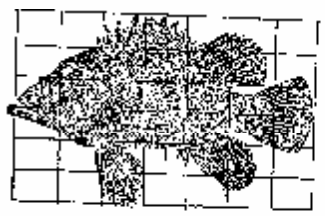


Fig. 521. *Polyprion.*

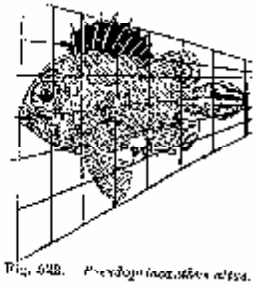


Fig. 522. *Pseudopriacanthus altus.*

of triangular, or radial, coordinates for the rectangular ones in which we had inscribed *Polyprion*. The very curious fish *Antigonia capros*, an oceanic relative of our own boar-fish, conforms closely to the peculiar deformation represented in Fig. 524.

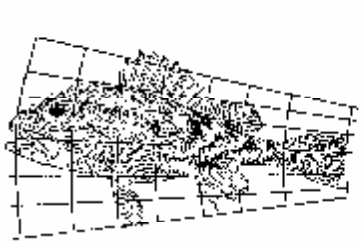


Fig. 523. *Scorpaena sp.*

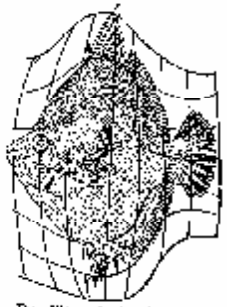
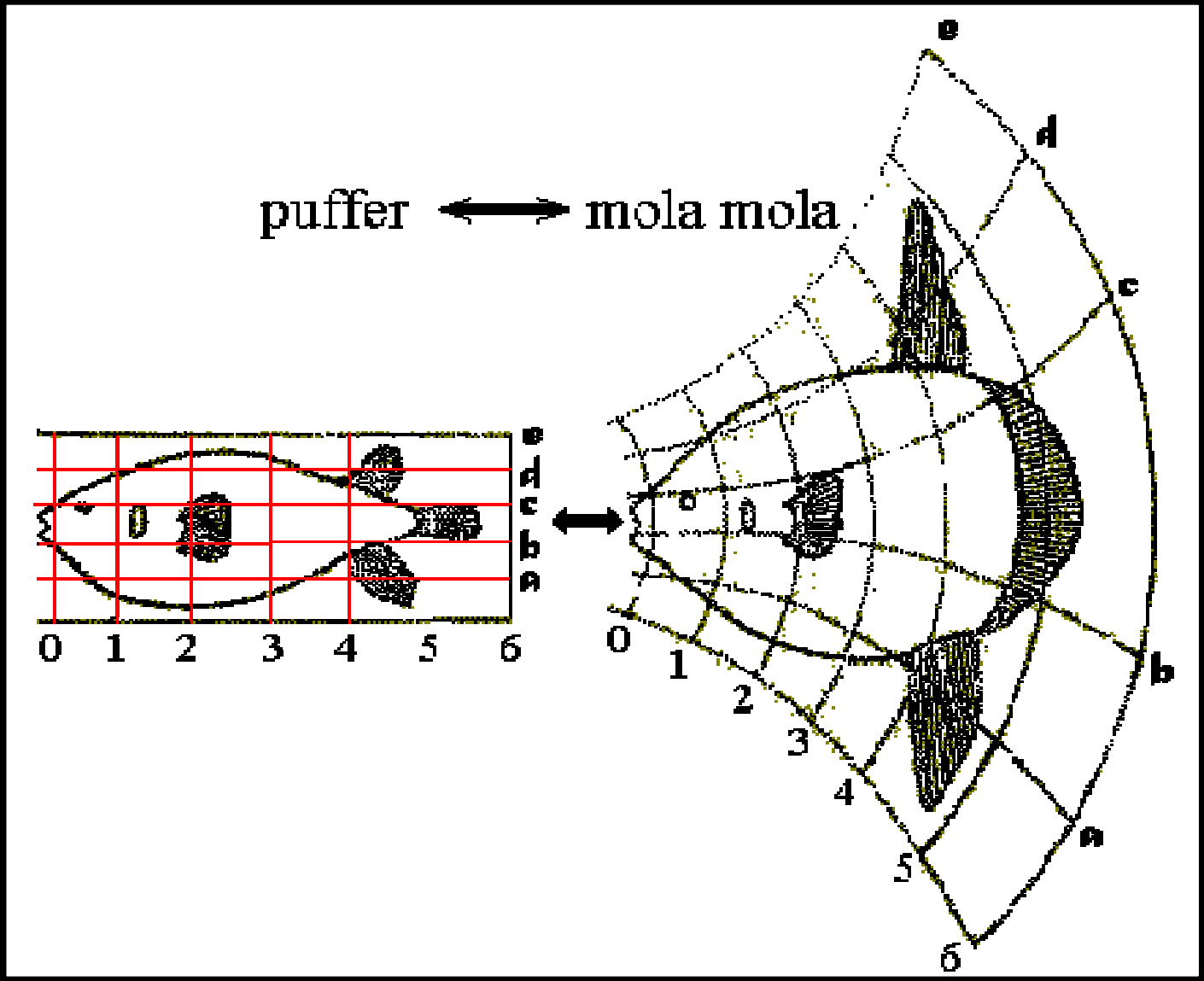


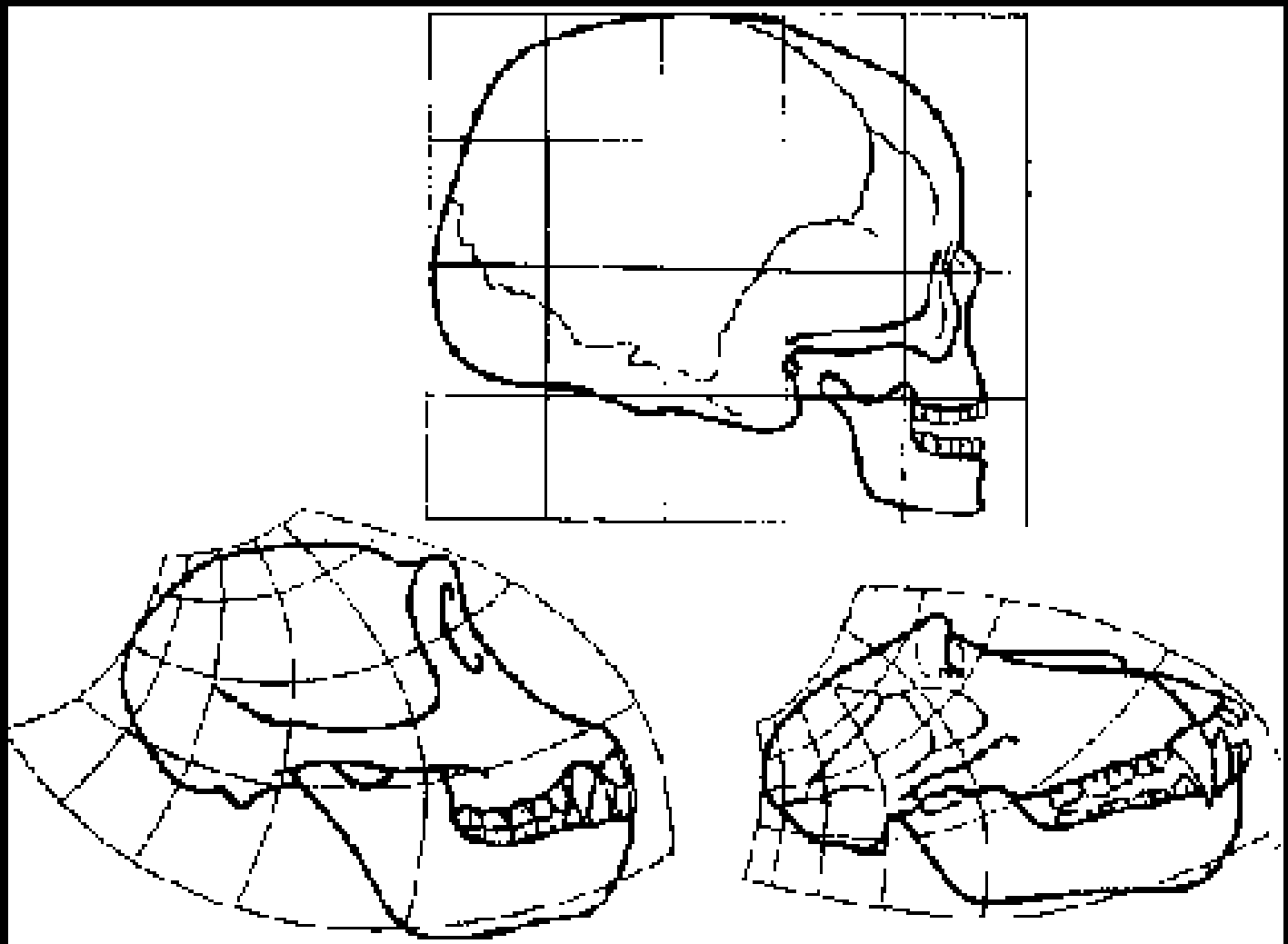
Fig. 524. *Antigonia capros.*

Fig. 525 is a common, typical *Diodon* or porcupine-fish, and in Fig. 526 I have deformed its vertical coordinates into a system of concentric circles, and its horizontal coordinates into a system of curves which, approximately and provisionally, are made to resemble

D’arcy Thompson, “On Growth and Form” (1917)



D’arcy Thompson, “On Growth and Form” (1917)

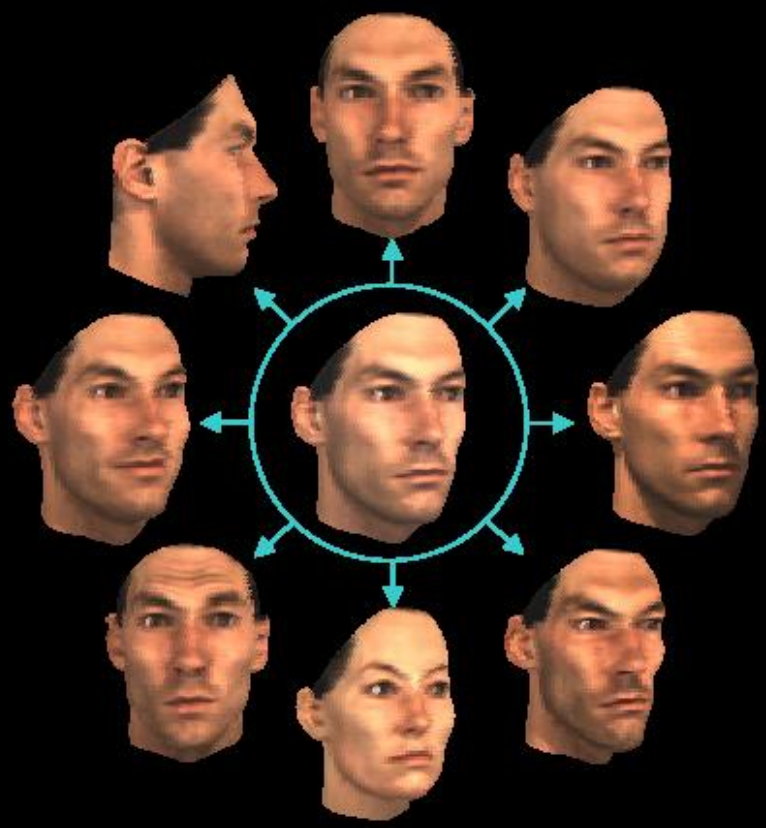


Skulls of a human, a chimpanzee and a baboon
and transformations between them

But what if we could ....?

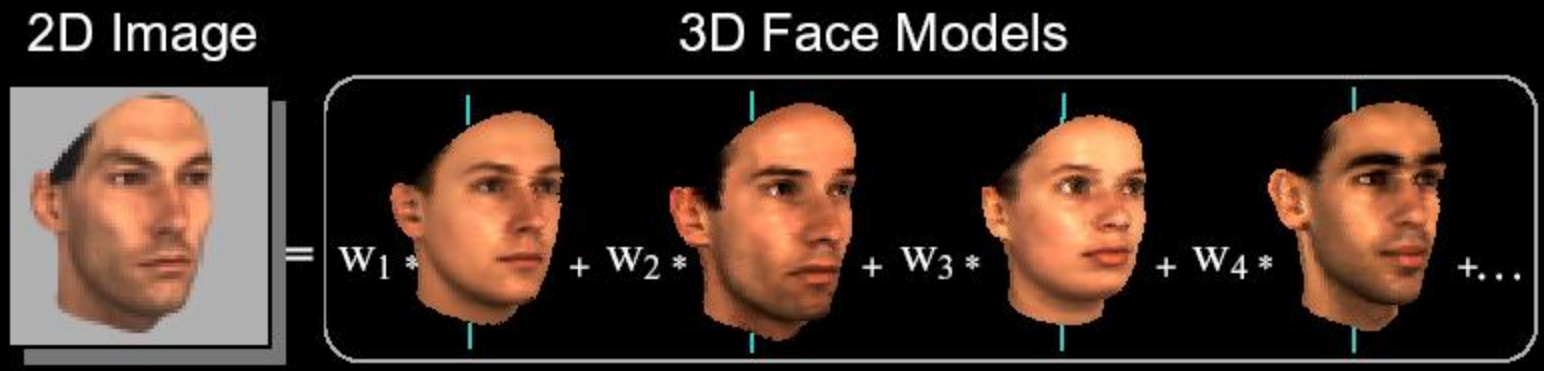
From a single image

- Novel views
- Novel expressions
- Synthesis of siblings
- Change of illumination
- Variations of body weight



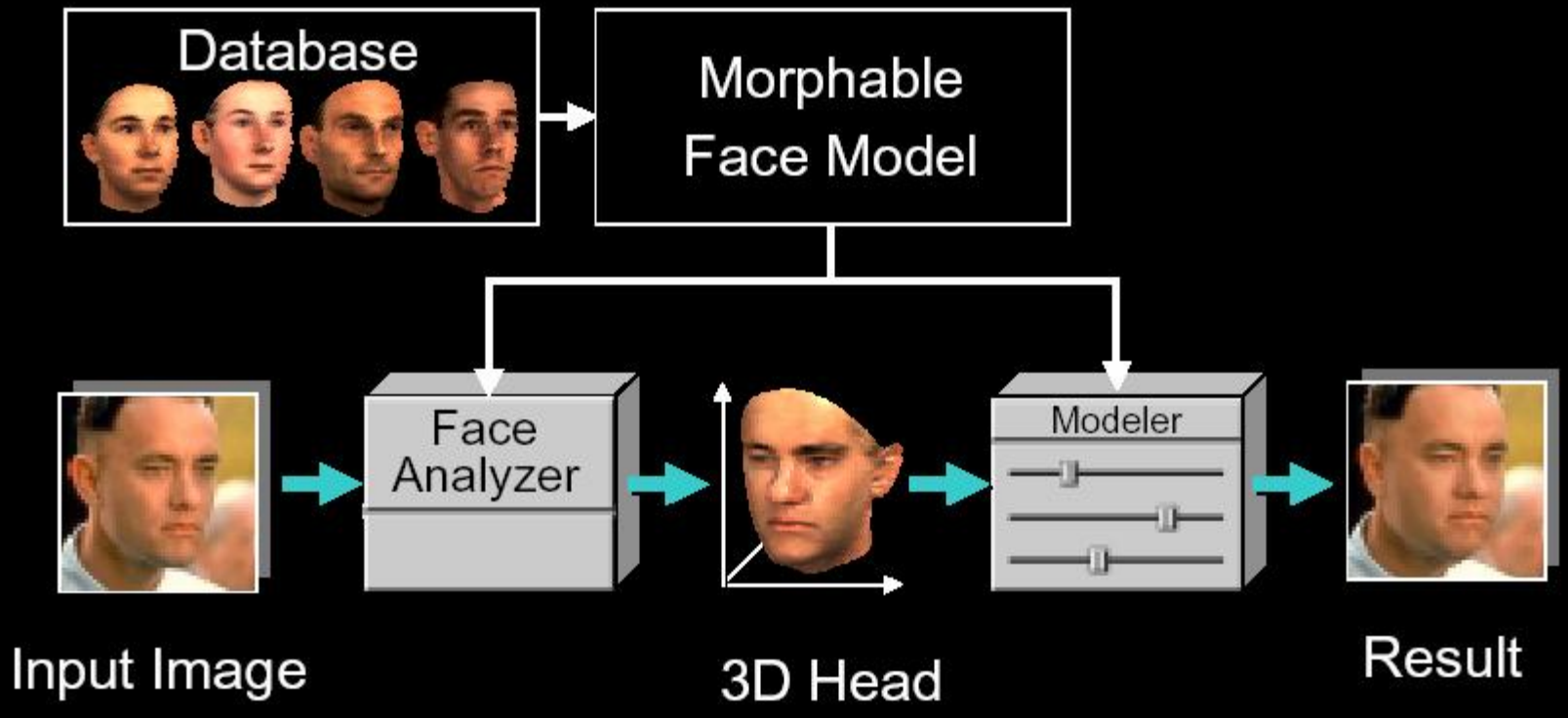
[Blanz and Vetter 1999, 2003]

Building a Morphable Face Model



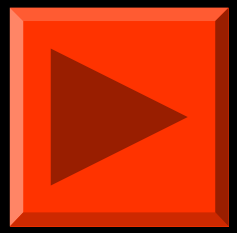
[Blanz and Vetter 1999, 2003]

3-D Morphaple Models: Semi-Automatic



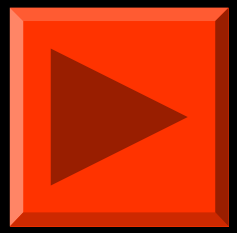
[Blanz and Vetter 1999, 2003]

Building Morphable Face Models



[Blanz and Vetter 1999, 2003]

Fitting Morphable Face Models

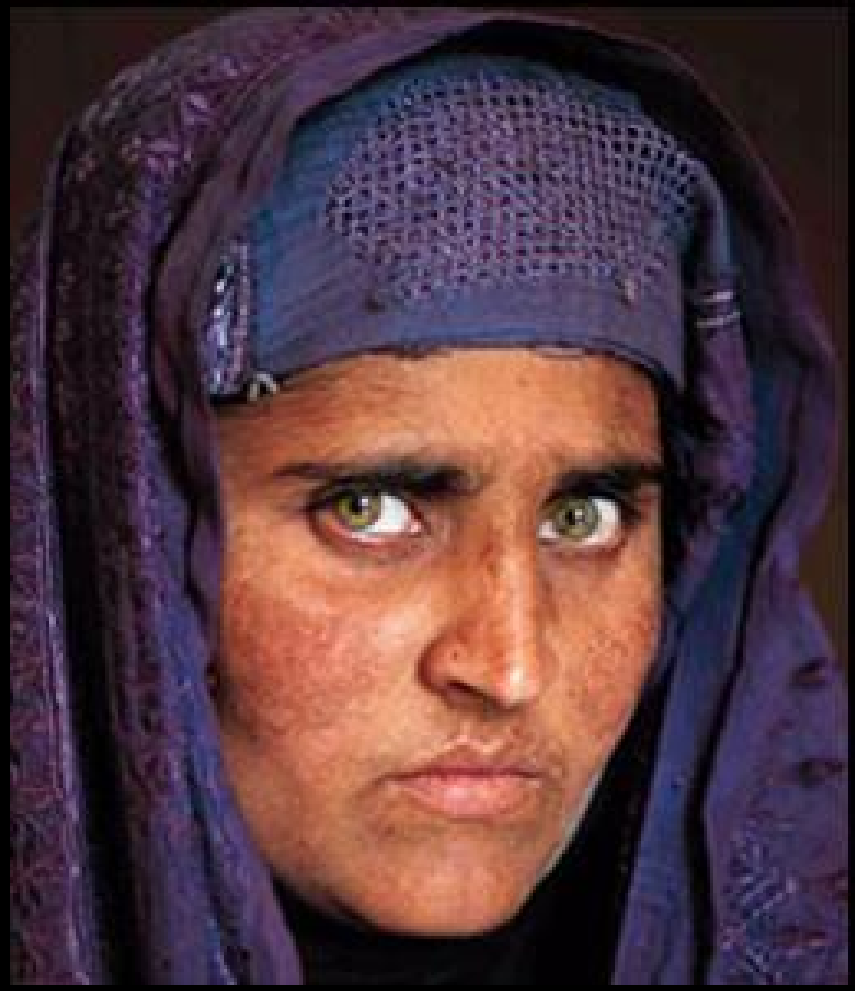


[Blanz and Vetter 1999, 2003]

National Geographic 1984 and 2002

1985

2002



Identity Confirmed by IRIS

=

[Daugman 2002]