# Universal Capture: Image-based Facial Animation and Rendering for *The Matrix* sequels

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ESC Entertainment

# The Challenge

- Our task was to produce photorealistic animated renditions of known actors:
  - Keanu Reeves, Laurence Fishburne, Hugo Weaving
- The synthetic reproductions needed to intercut seamlessly with footage of the real actor

# A Daunting Task

- Photorealistic human faces are the ultimate challenge for computer graphics
- Faces are particularly scrutinized by human observers
  - We grow up and then spend most of our lives looking at faces
  - Incredible variety, richness & subtlety of human facial movement
  - Human viewer's extreme sensitivity to facial nuances
- No examples of believable human face at the time

# Motivation

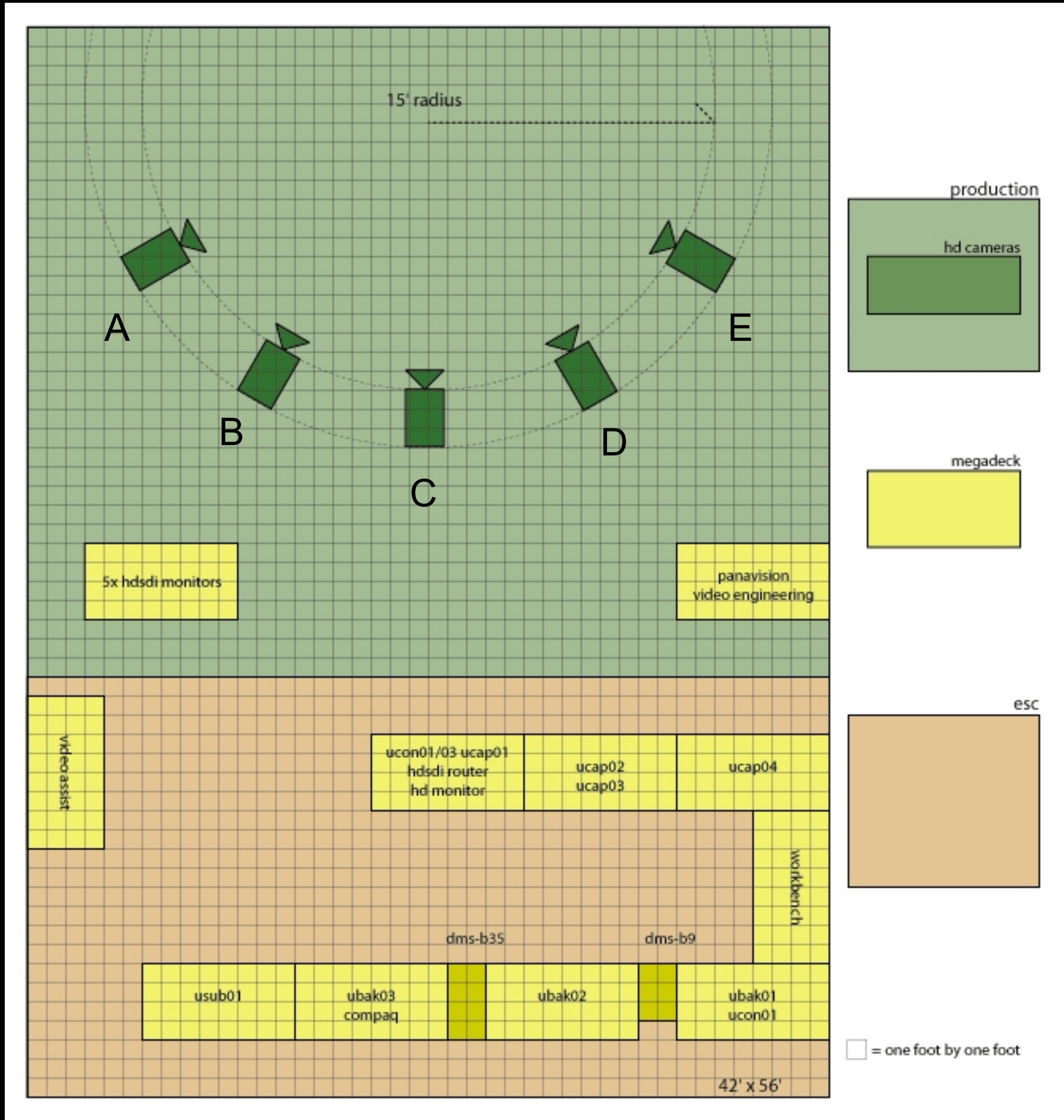
- Traditional facial animation (blendshapes, muscle deformers) would not produce realistic results re-creating a real actor
- Believable facial rendering requires textures that change over time
  - *Color changes* due to blood flow, skin strain
  - Fine wrinkles form and disappear
  - Microscopic self-shadowing effects

# Universal Capture

- Our previous experience with image-based and computer vision approaches (*What Dreams May Come, Matrix I*) suggested a "non-traditional" approach
- Capture a 3-D recording of an actor's performance
- Play it back with different camera and lighting
- Combine two powerful vision techniques: optical flow and photogrammetry

# Hi-Definition Capture

- Five synchronized cameras capture the actor's performance in ambient lighting
- Sony/Panavision HDW-F900 cameras
  - Portrait mode 1080x1920 resolution
  - 60i for maximal temporal information
  - 1/500$^{th}$ sec shutter to minimize motion blur
- Real-time capture/storage
  - Computer workstations with HD capture boards
  - 21 terabyte disk arrays
  - Tape robot for overnight data backup



15' radius
A
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5x hdsdi monitors
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video engineering
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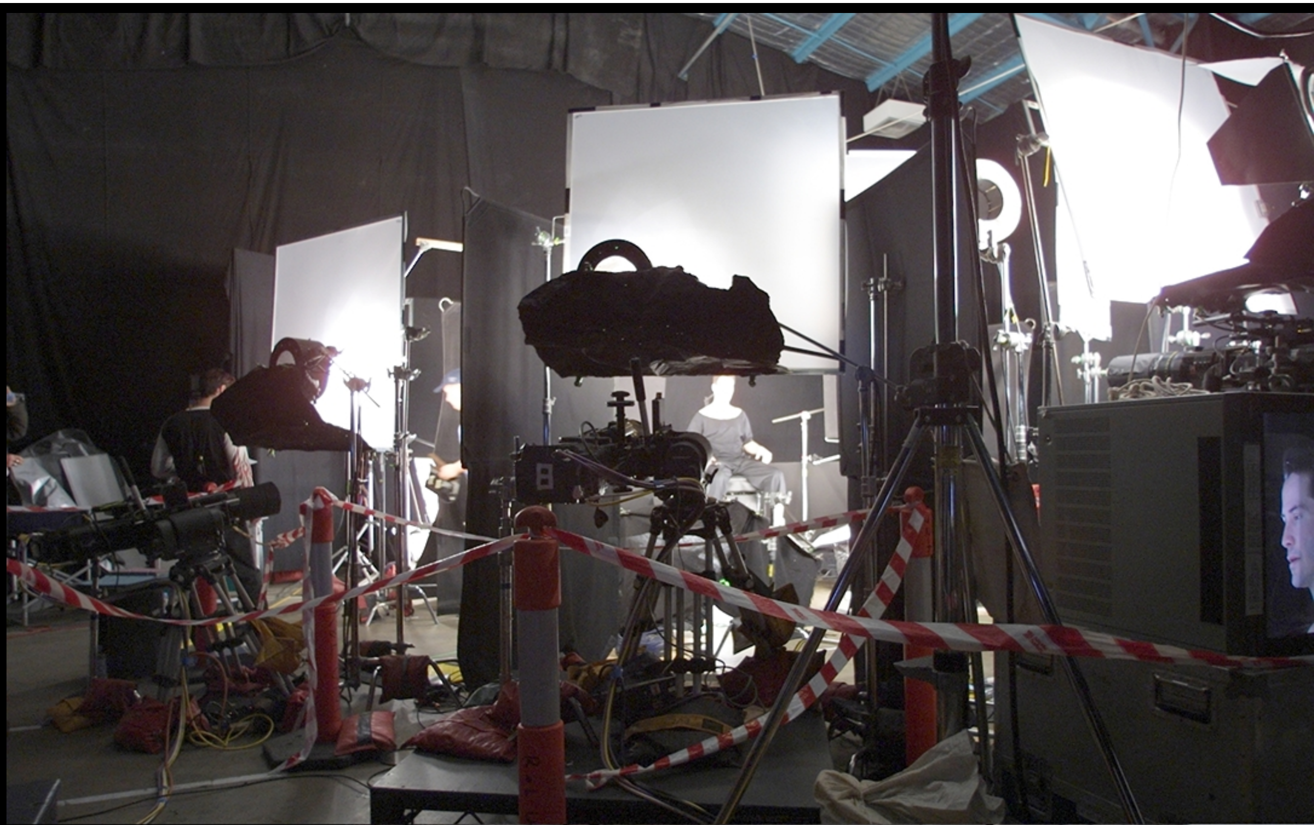
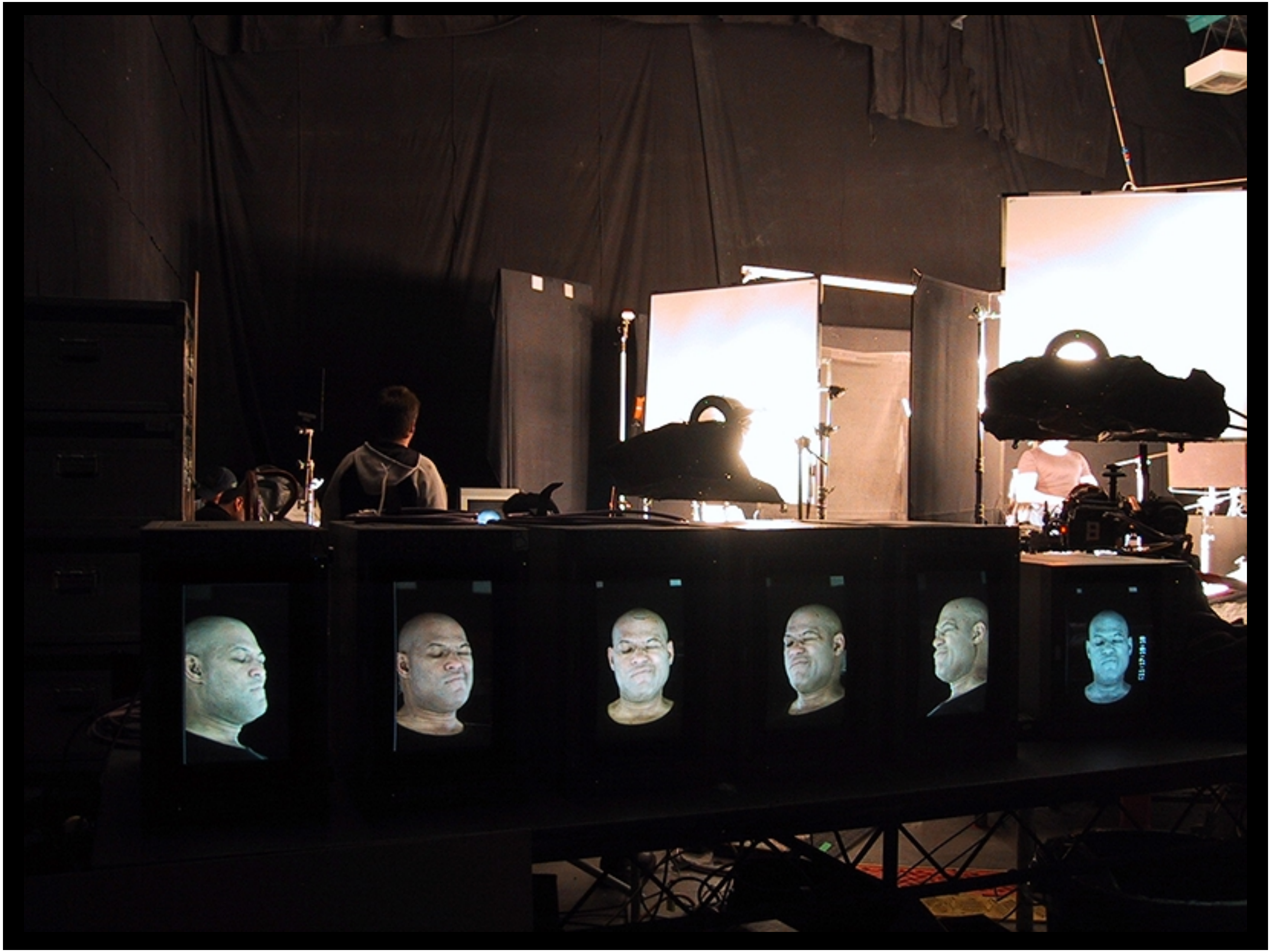
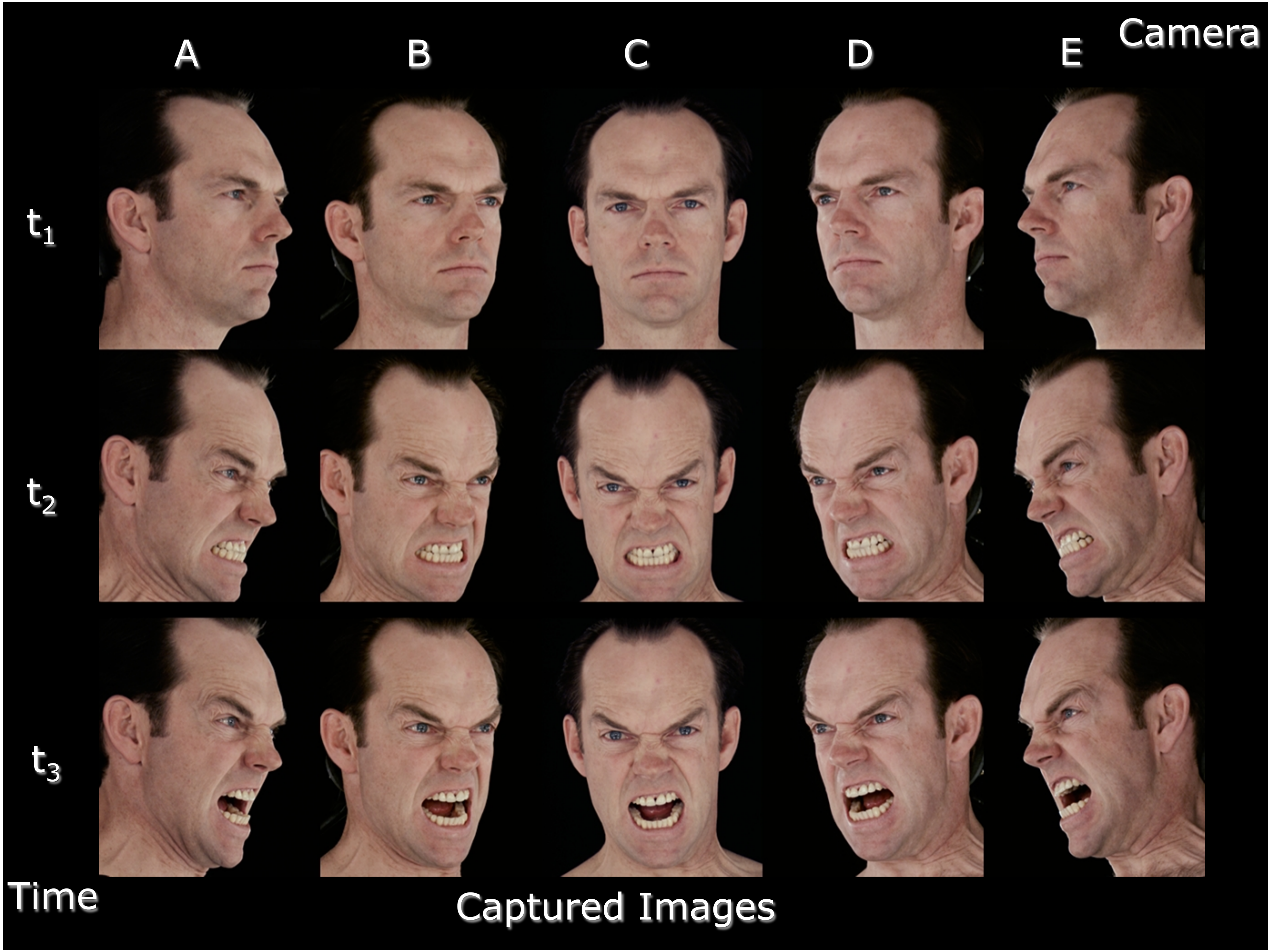
= one foot by one foot


UCAP03
UCAP04






Camera
A
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$t_1$
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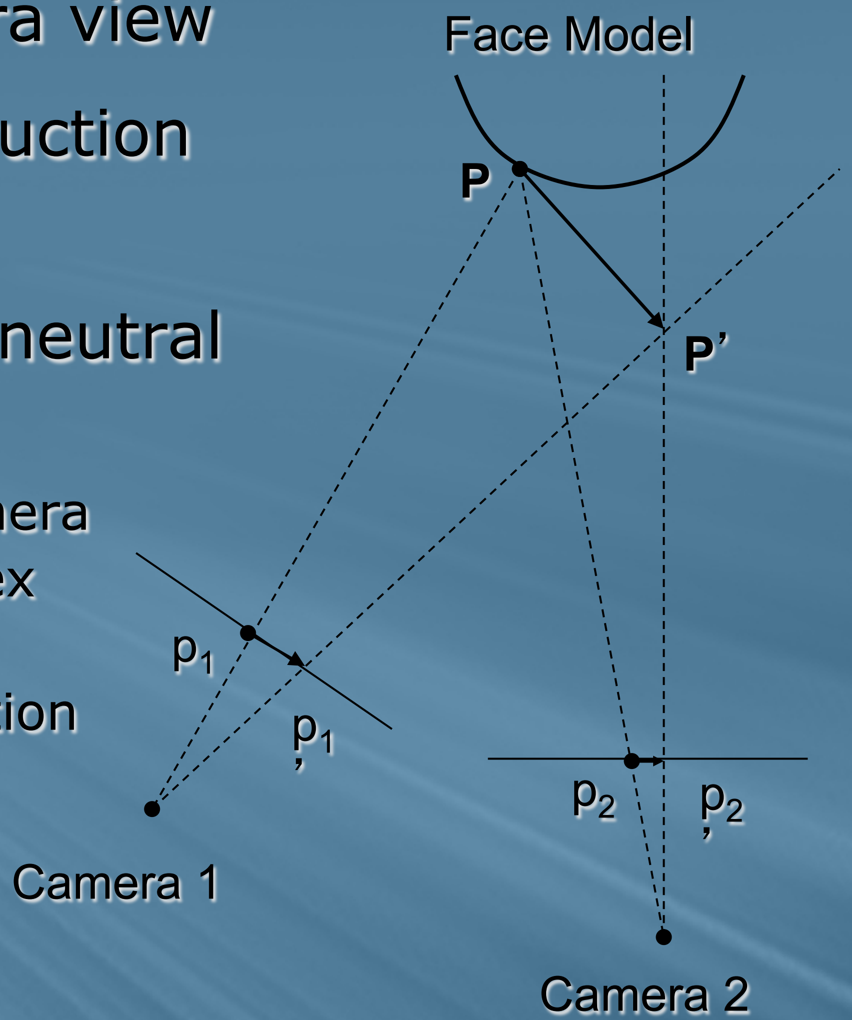
Time
Captured Images

# Optical Flow + Photogrammetry

- Optical flow in each camera view
- Photogrammetric reconstruction of camera locations
- Core algorithm “warps” a neutral face model:
  - Project vertices into each camera
  - Find 2-D motion of each vertex
  - Project back into 3-D
  - Triangulate to obtain 3-D motion



# Optical Flow + Photogrammetry

- Result: *markerless* capture of the complete deforming face geometry

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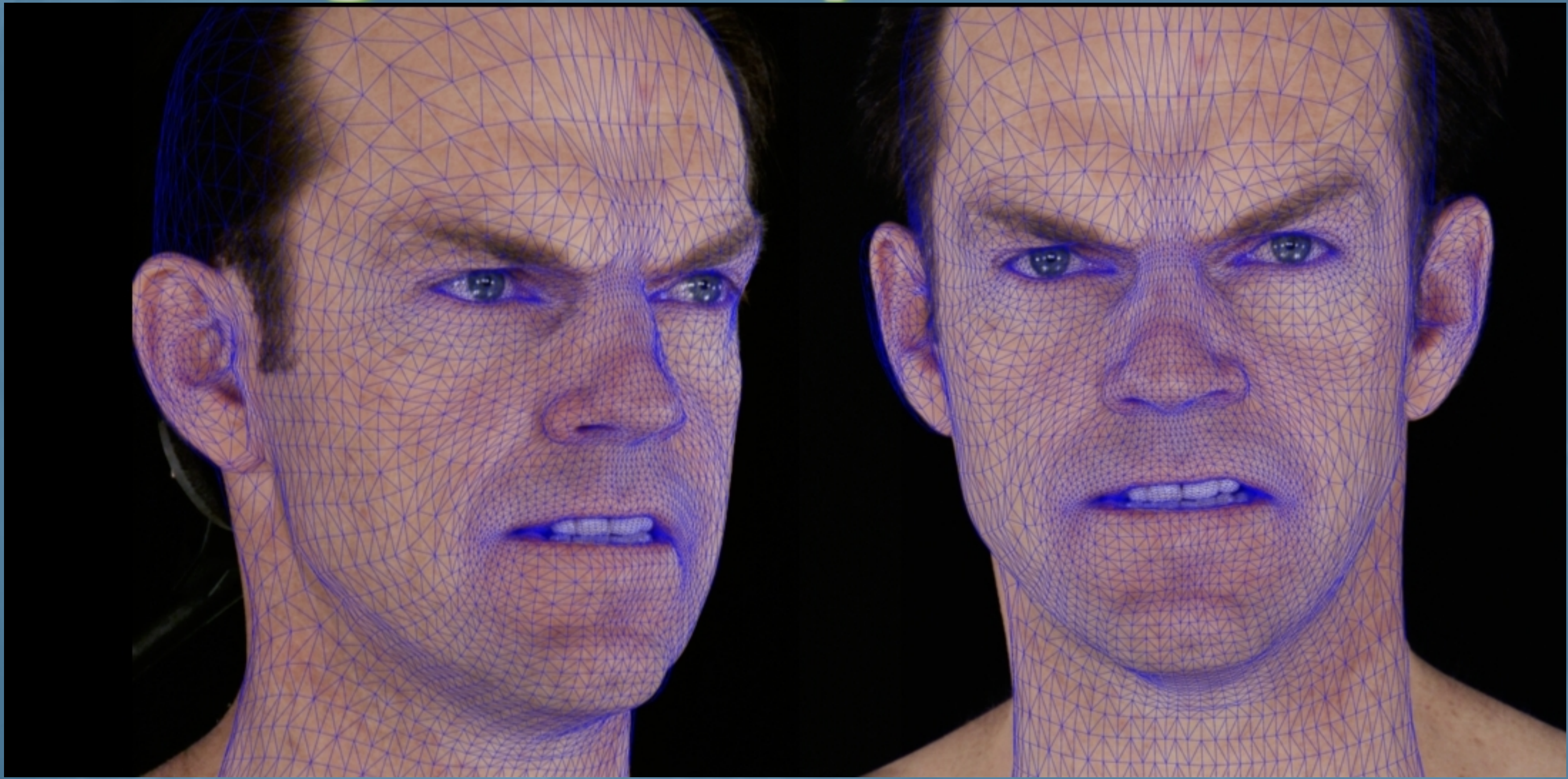

- Result: *markerless* capture of the complete deforming face geometry

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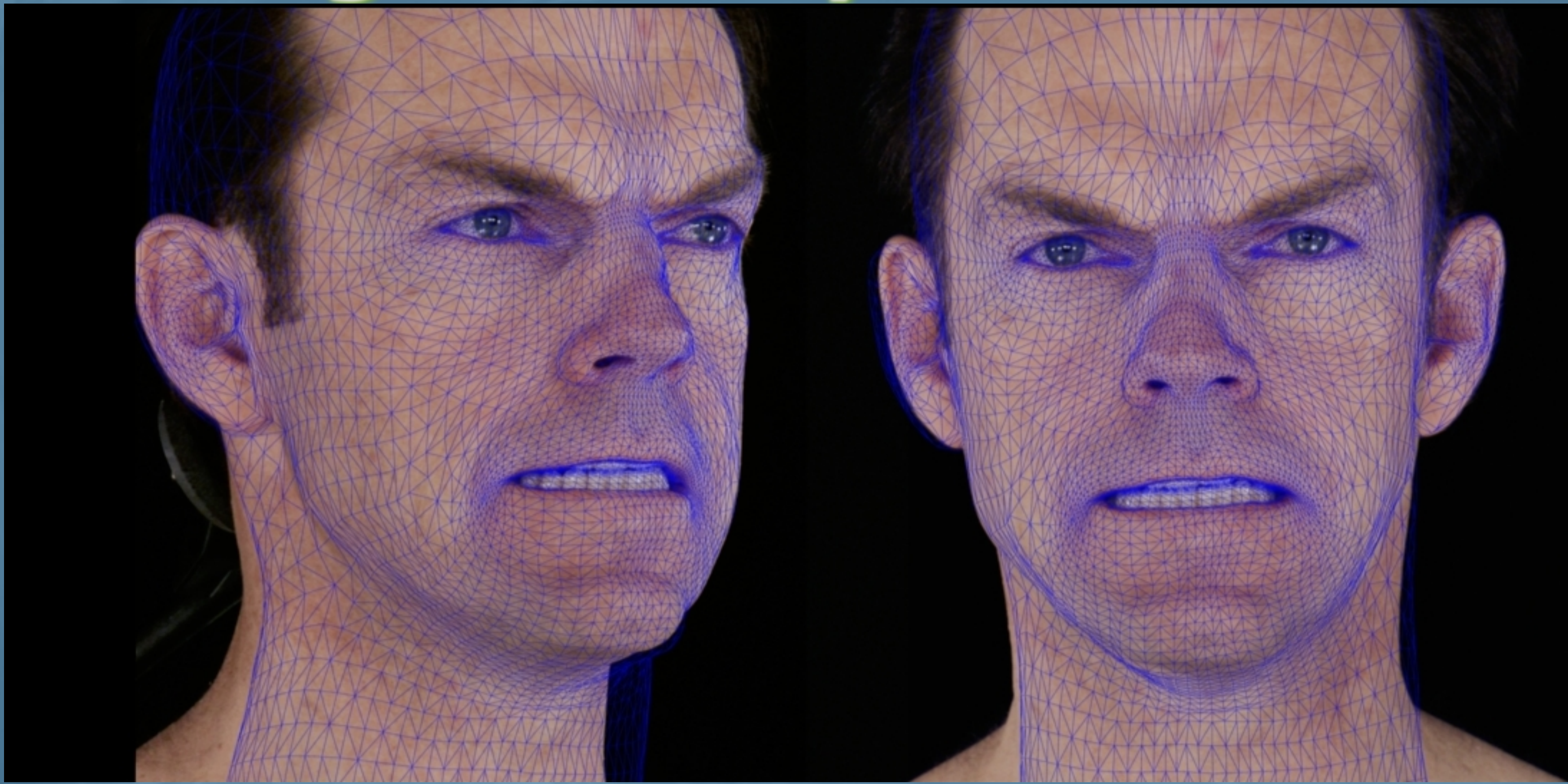
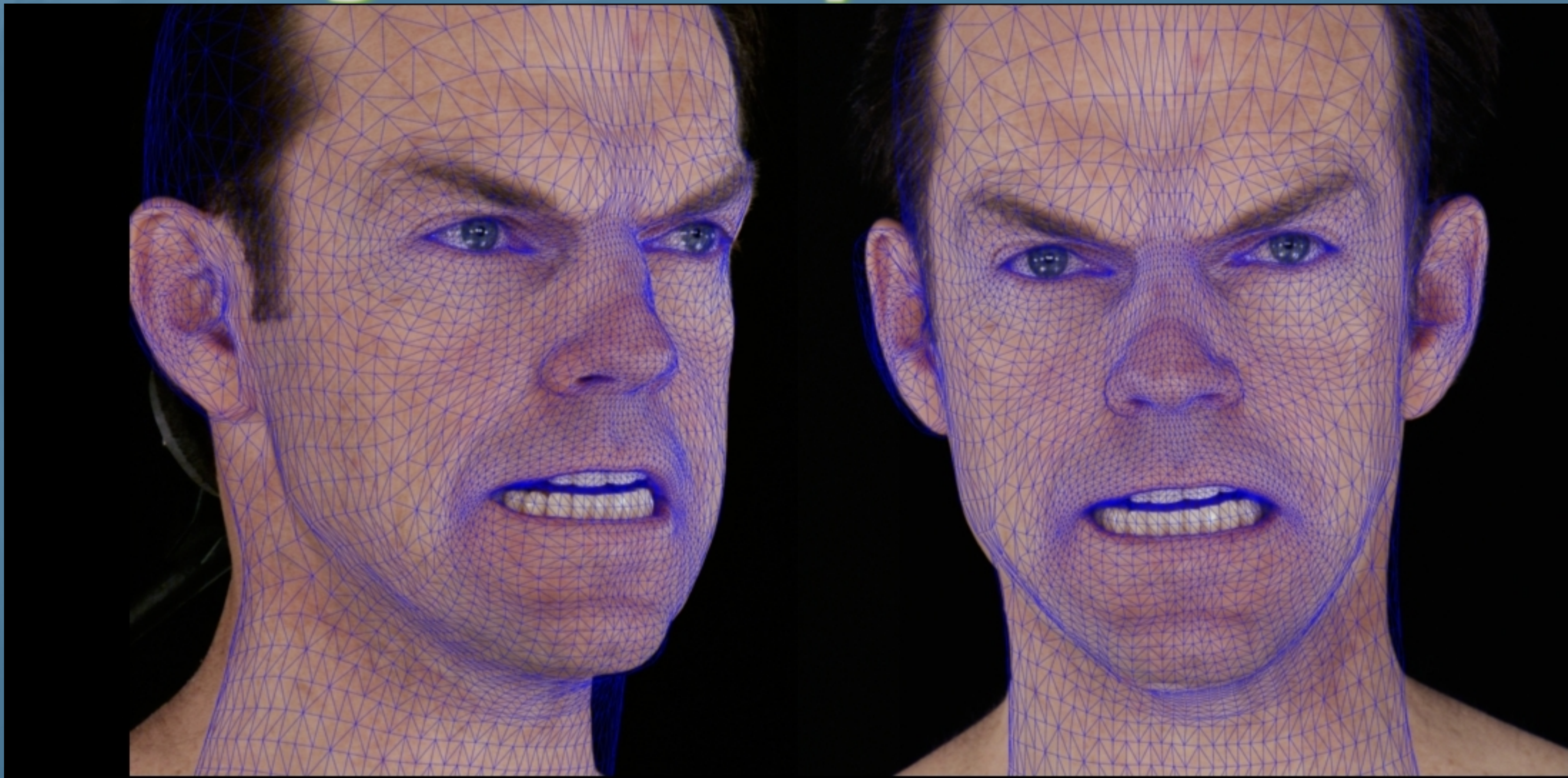


- Result: *markerless* capture of the complete deforming face geometry

# Optical Flow + Photogrammetry



- Result: *markerless* capture of the complete deforming face geometry

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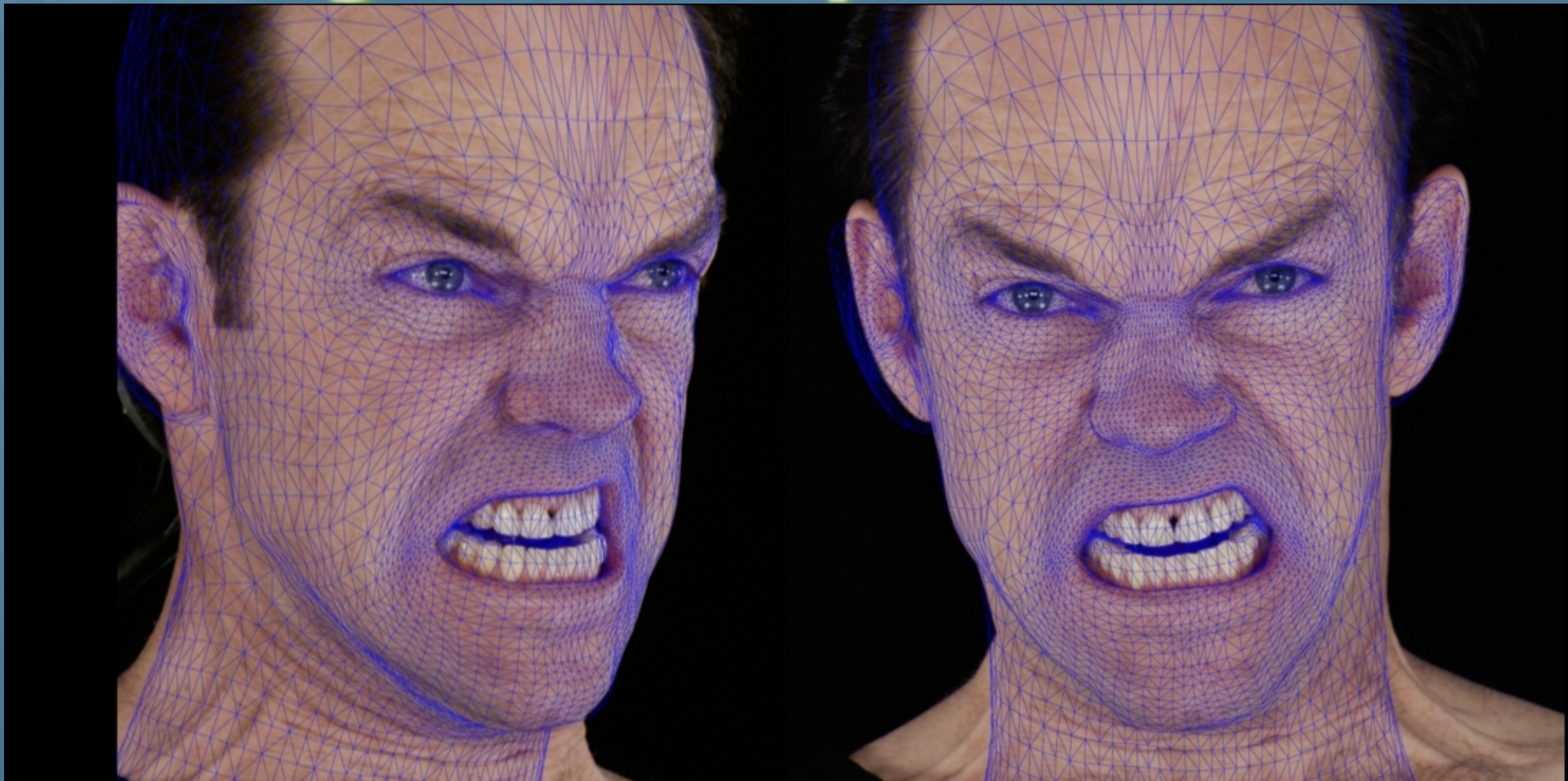


- Result: *markerless* capture of the complete deforming face geometry

# Optical Flow + Photogrammetry

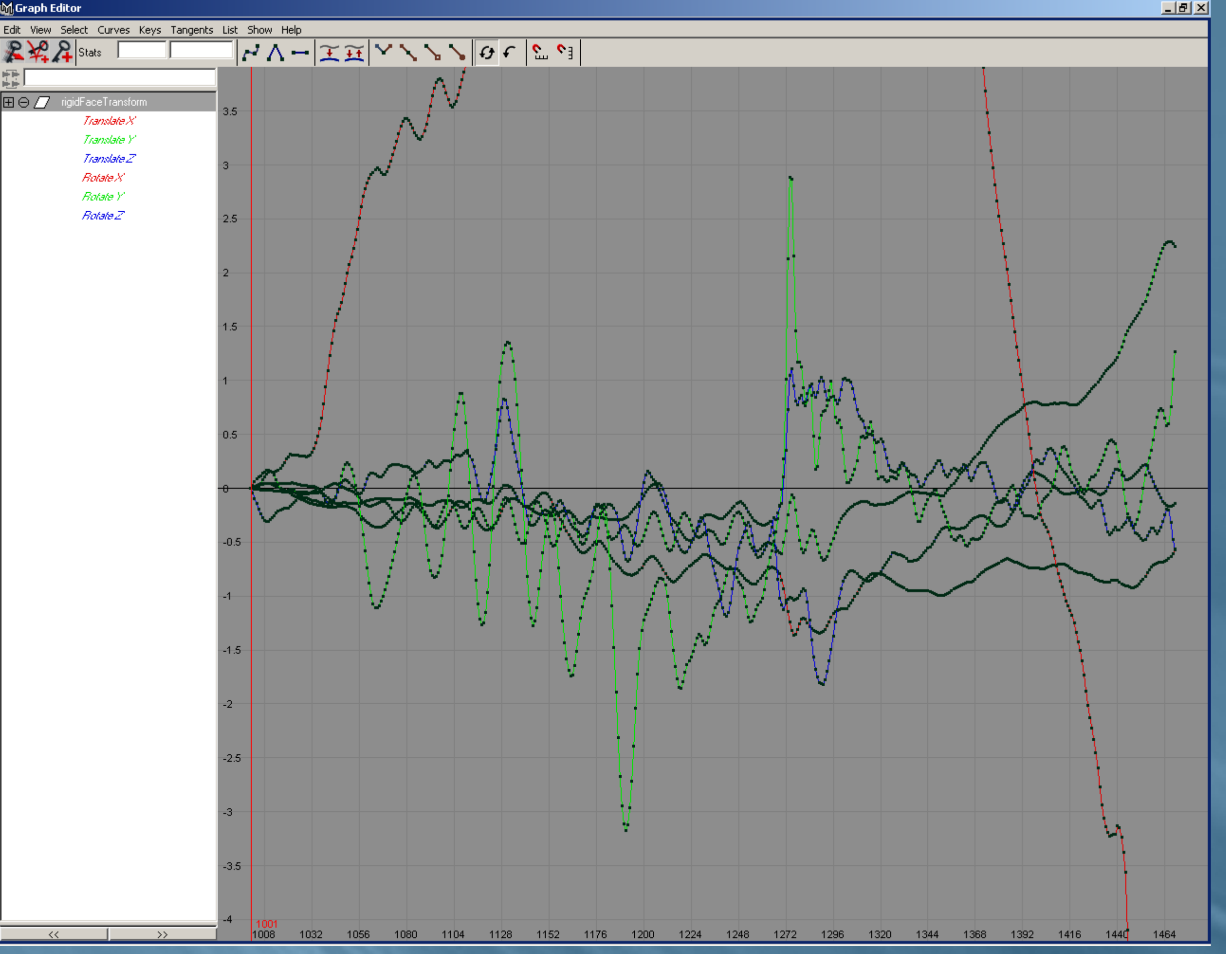
- Result: *markerless* capture of the complete deforming face geometry

# Optical Flow “drift”

- Optical flow errors accumulate over time
- Partially address by reverse optical flow
- After a visible error has accumulated
  - Manually correct using keyshapes
  - Algorithmically interpolate and propagate the correction back through the performance

# Rigid vs. Deformable Motion

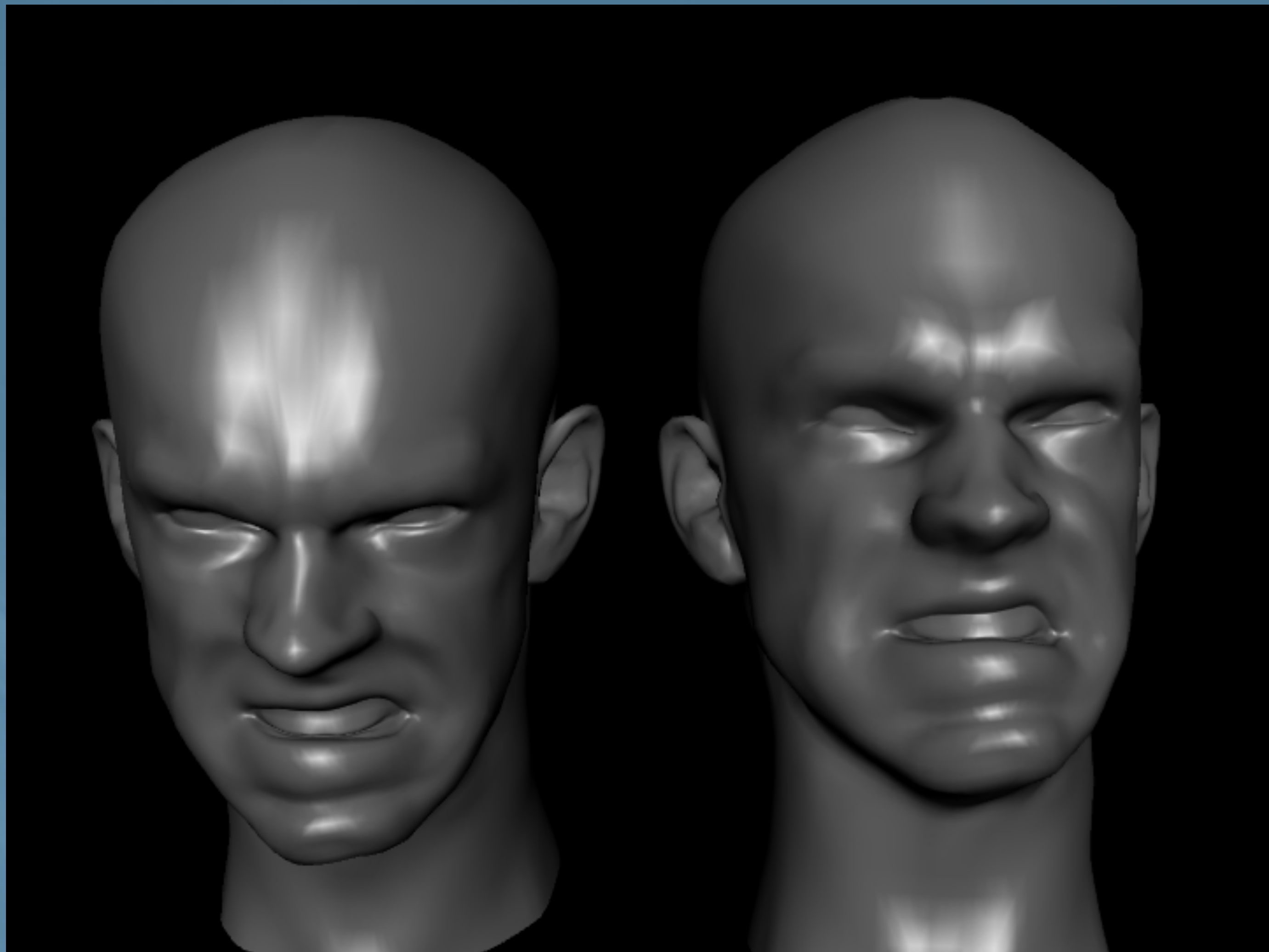
- Underlying rigid (skull) transformation




- Recovered curves estimated using a least squares procedure
- Can apply signal processing to preserve nuance

# Rigid vs. Deformable Motion

- Subtracting the rigidly transformed neutral face from the 3-D reconstruction (left) gives the animated facial deformation (right)



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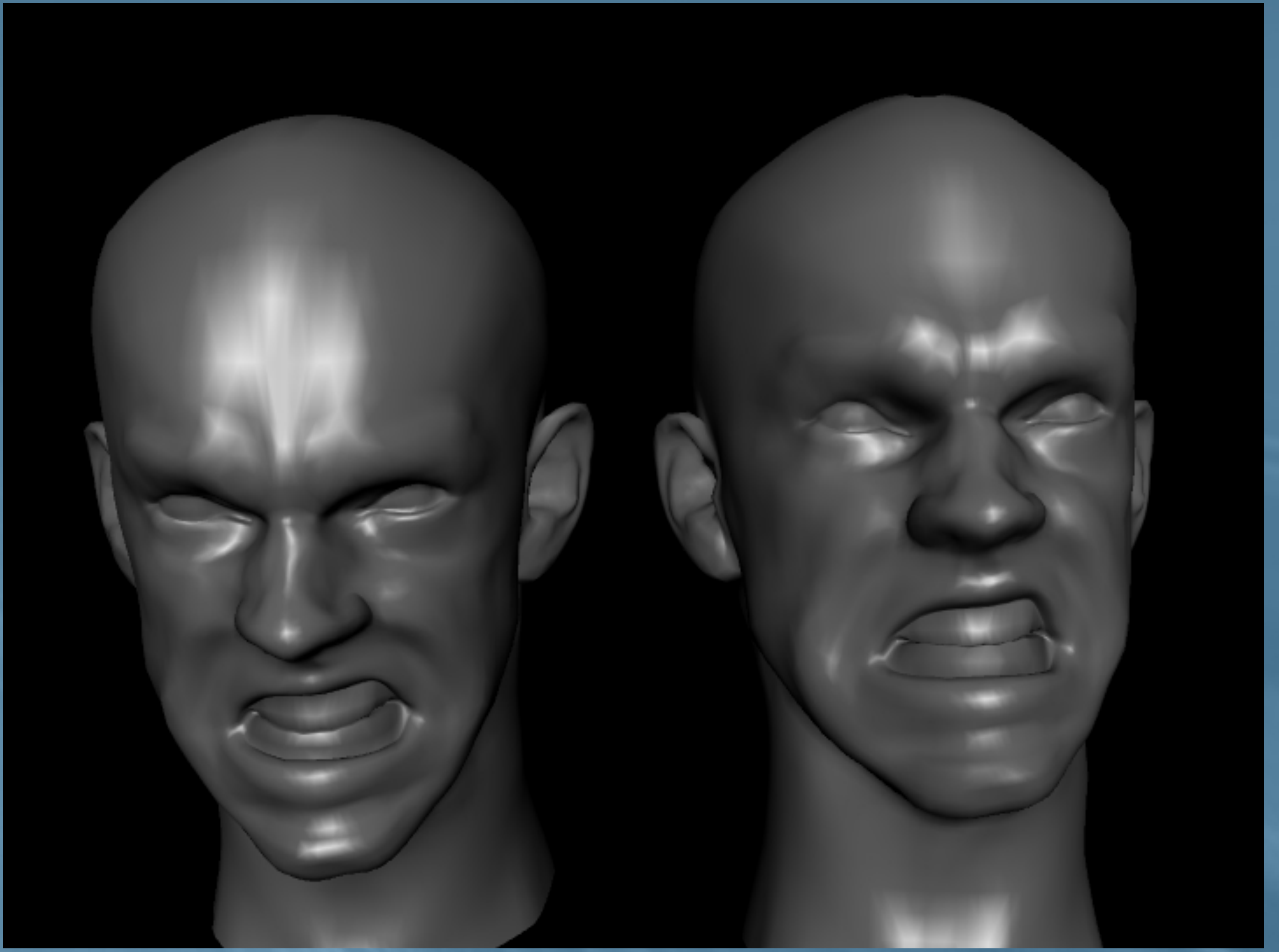

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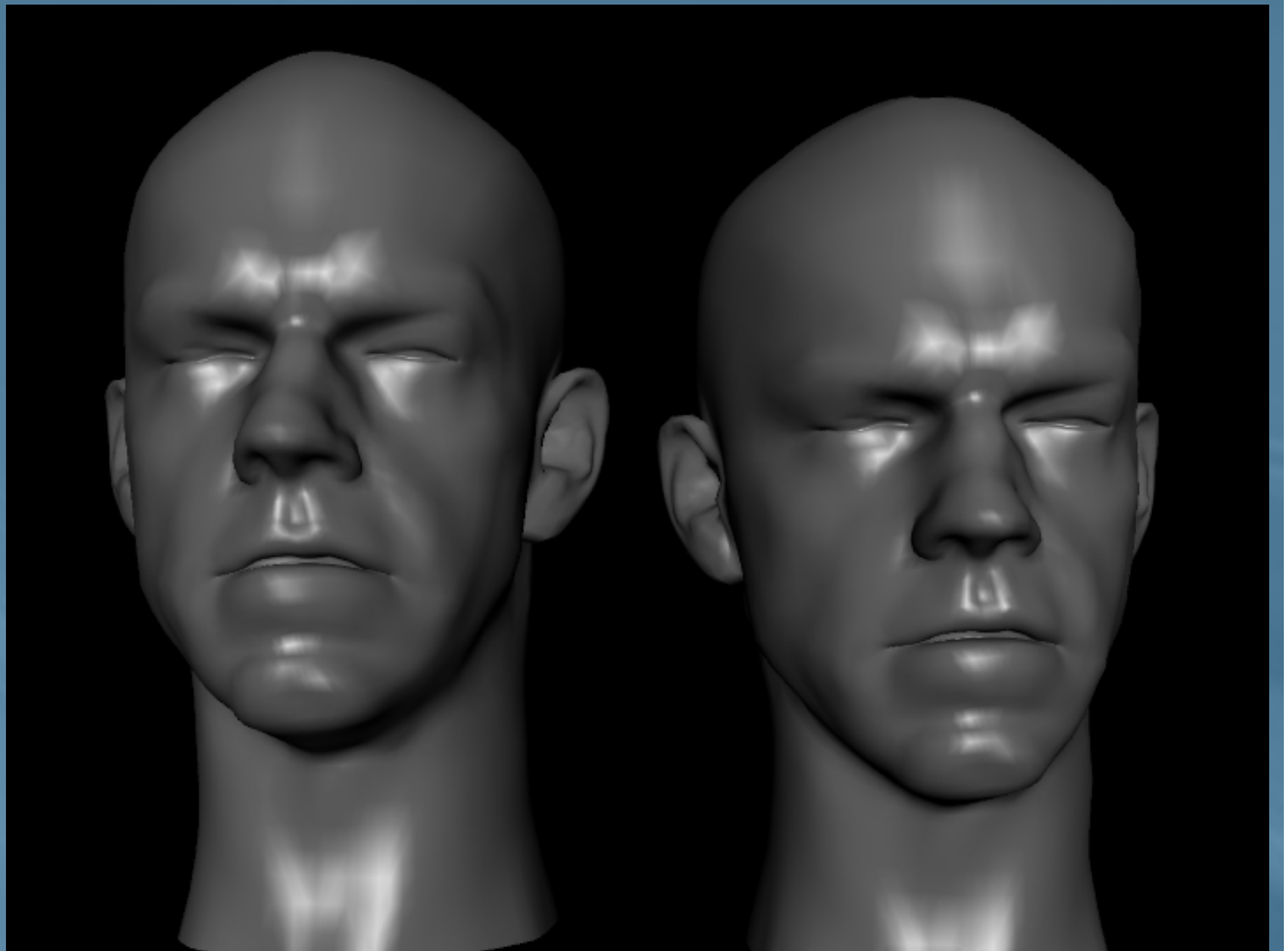
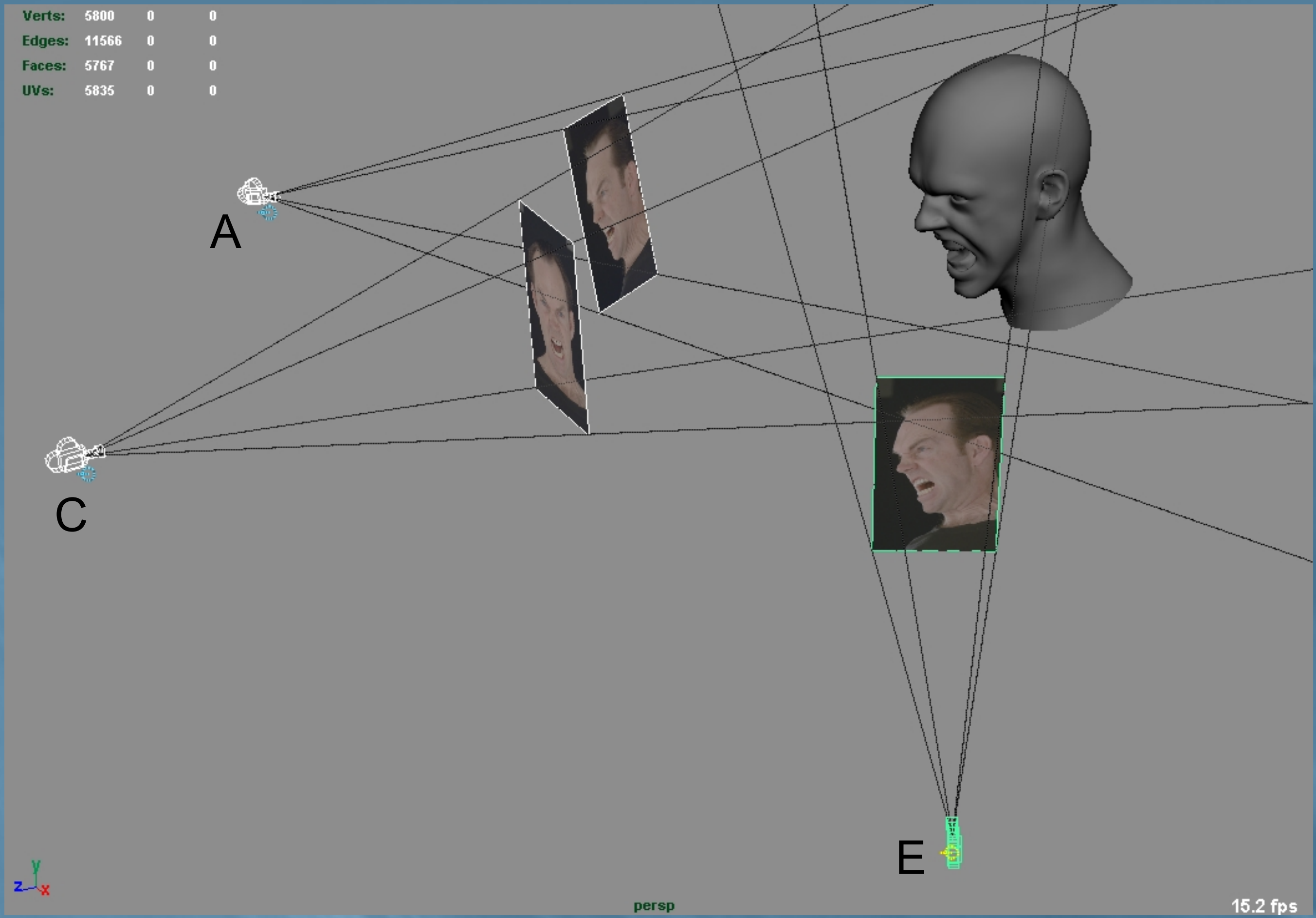


# Animated Texture Map Extraction

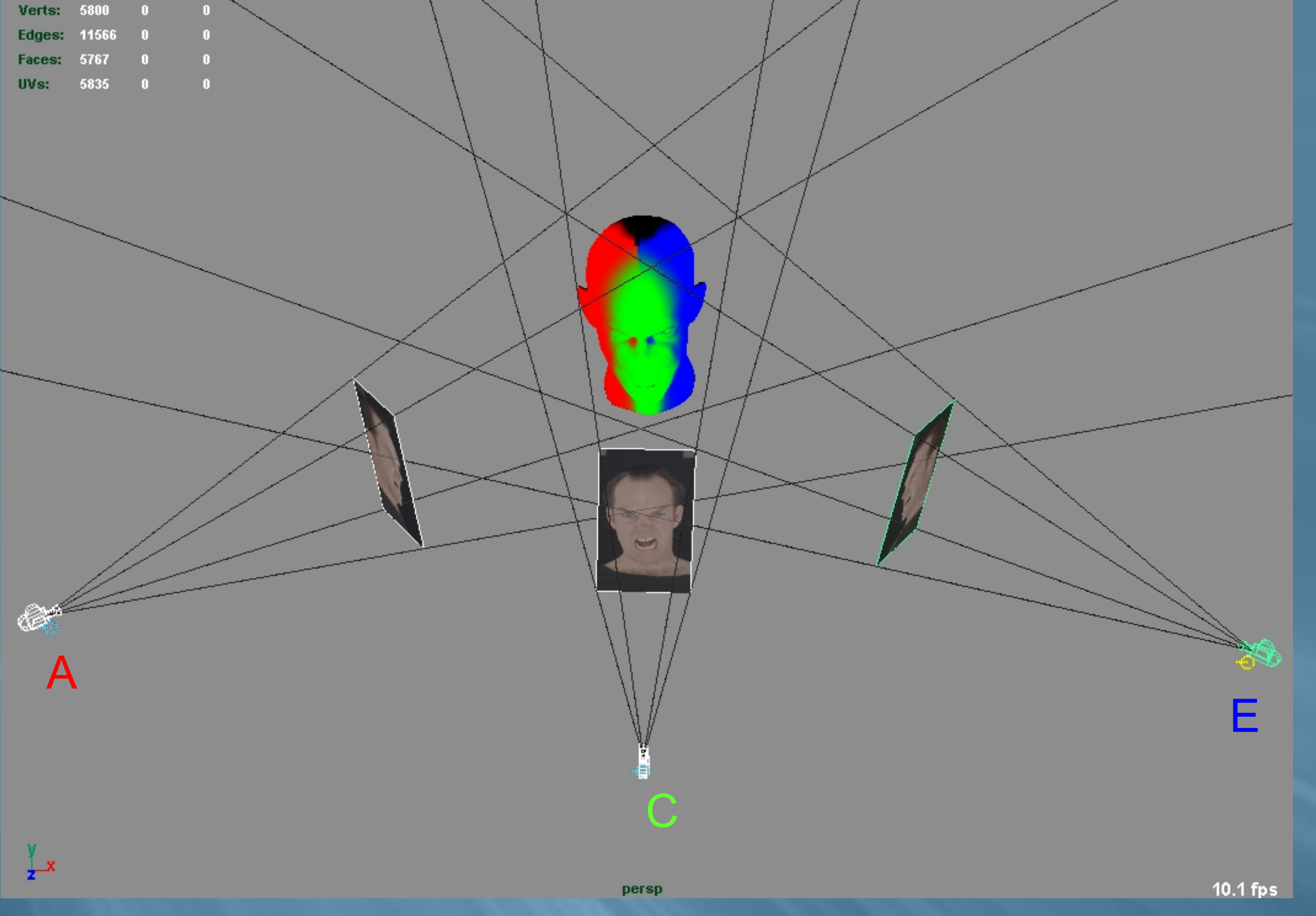
- Image re-projection

- Merge ambient images from multiple camera views over time to produce seamless animated UV color maps



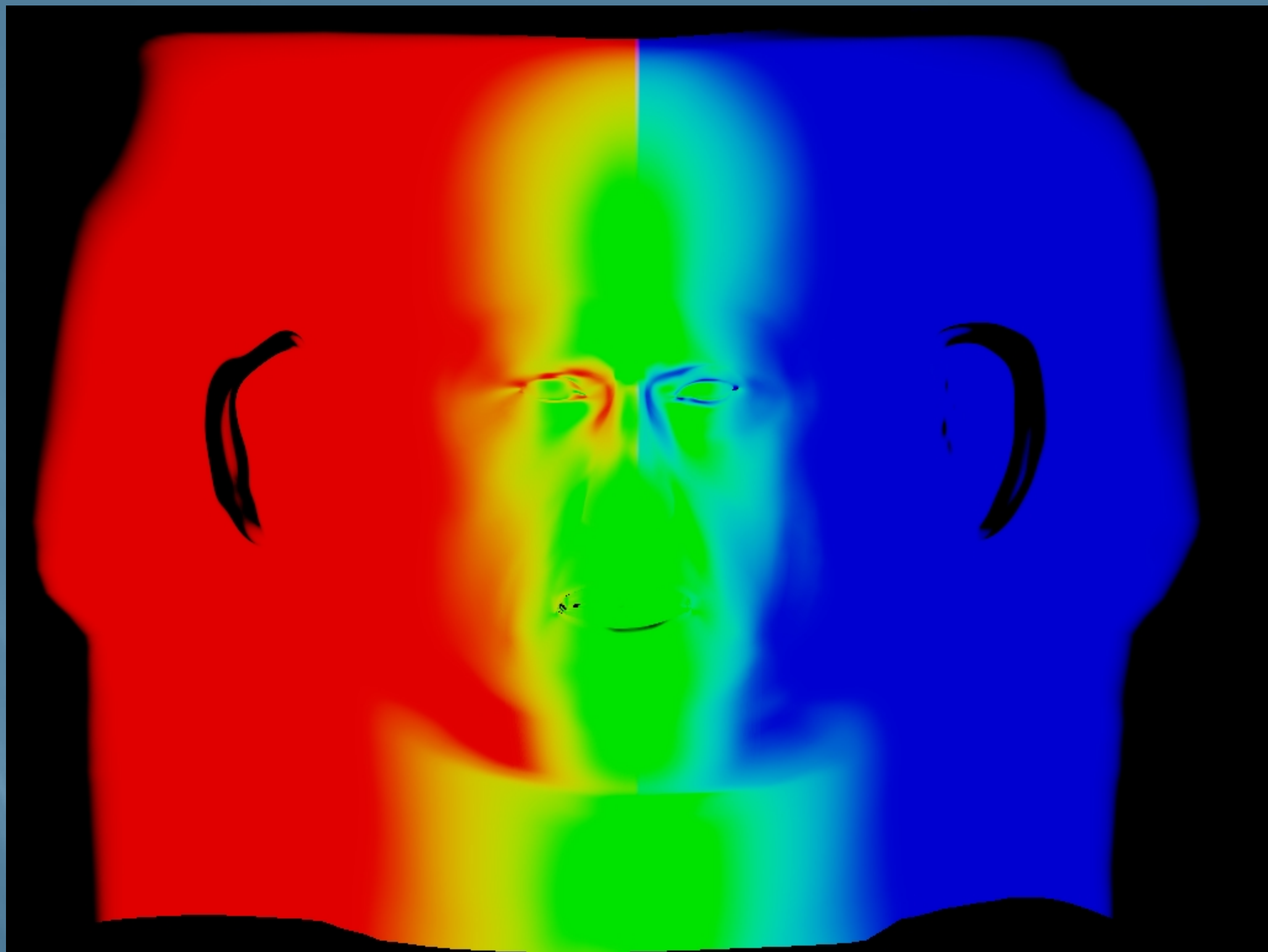
# Animated Texture Map Extraction

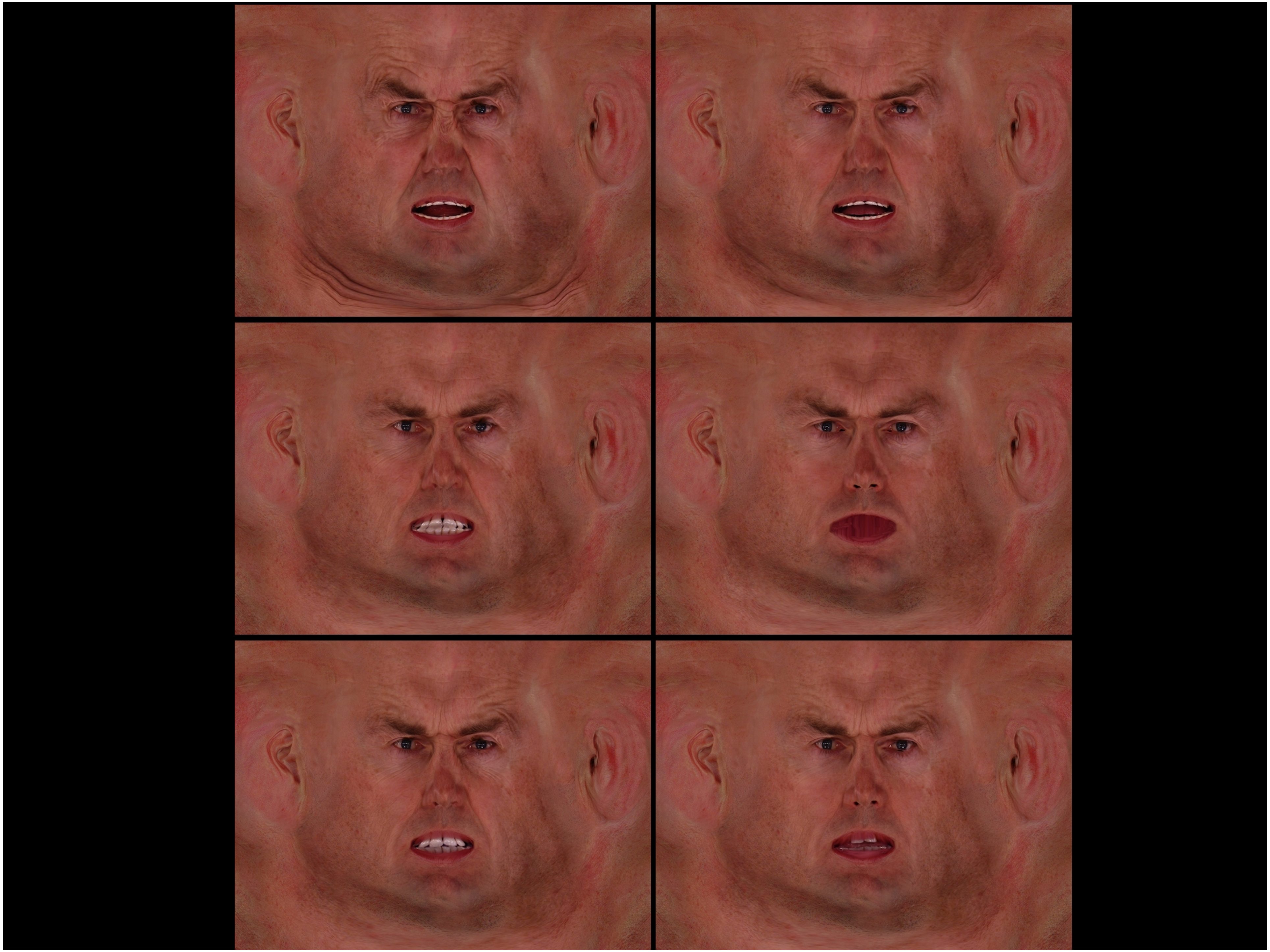
- Image re-projection and blend regions

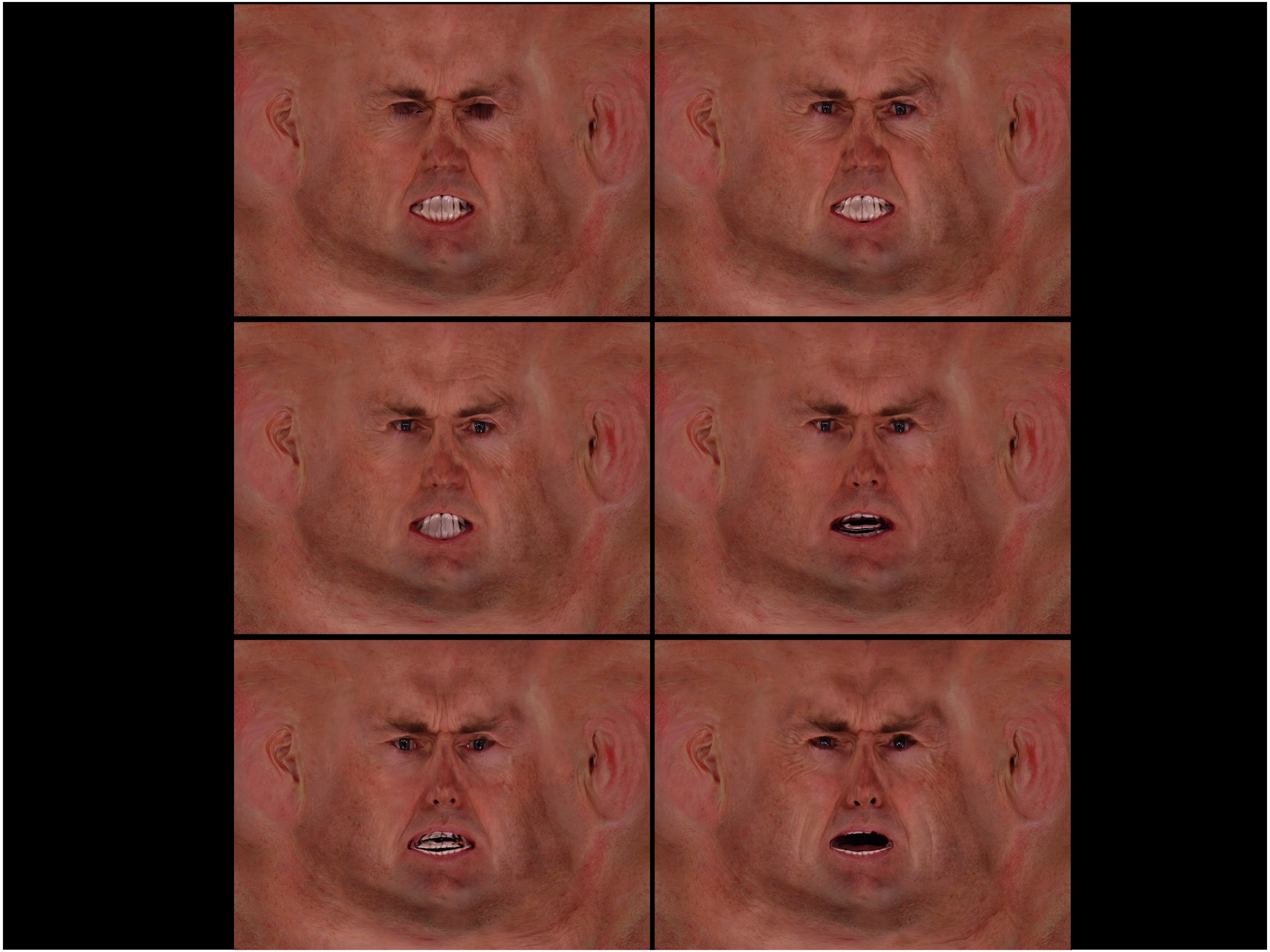


# Animated Texture Map Extraction

- Regions of seamless blend in UV space







# Early Observations – Winter/Spring 2000

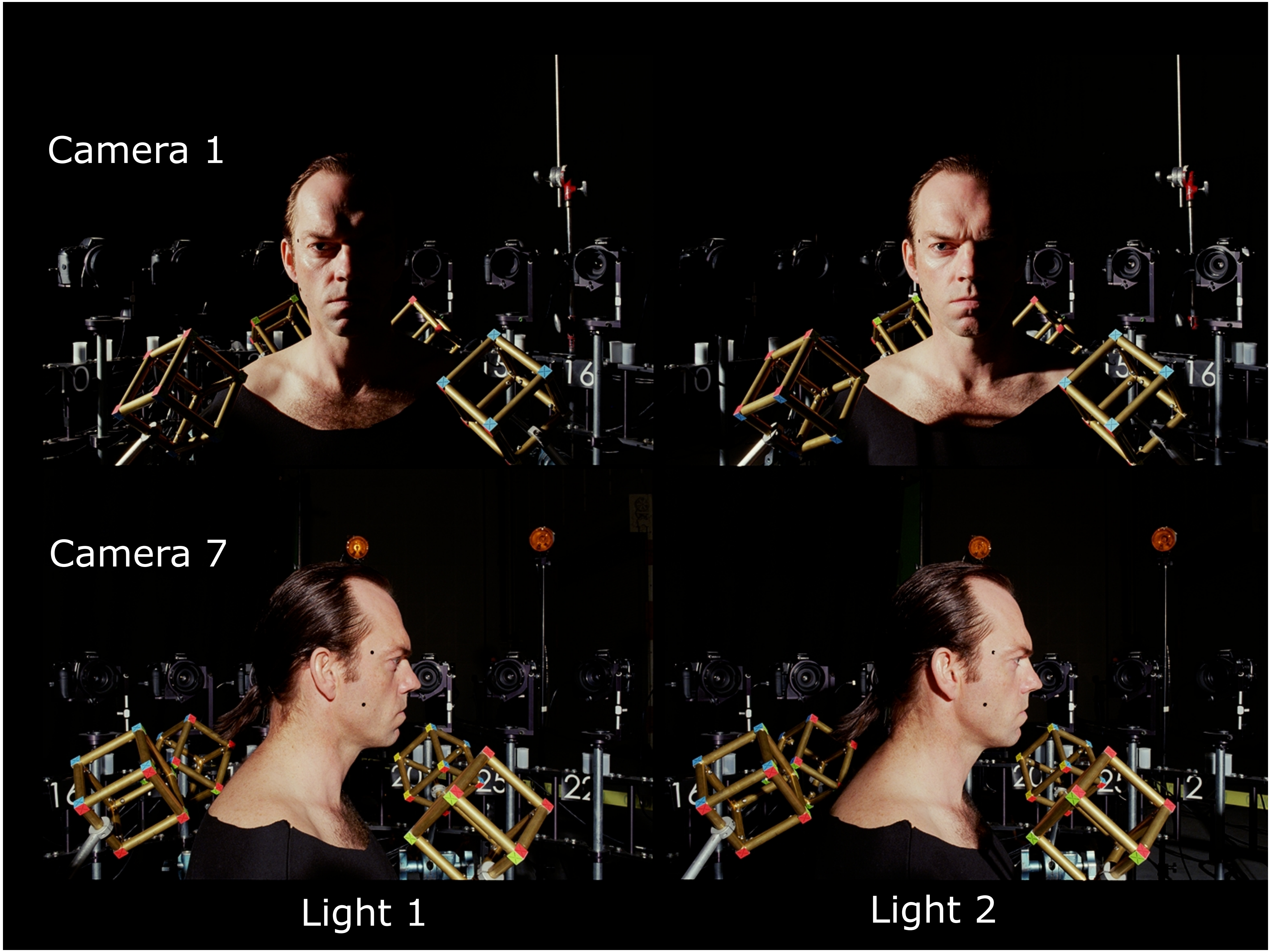
- Surface detail on the face (of human skin)
  - Unique: pores, wrinkles, moles, scars, etc.
  - Highly variable spatially
  - Very small scale ~100 micron features
  - Has extremely complex pattern
    - Hard to paint
    - Even harder to generate procedurally
- Color texture detail also unique and complex
  - We knew we can address that thanks to our photogrammetry and image-based rendering

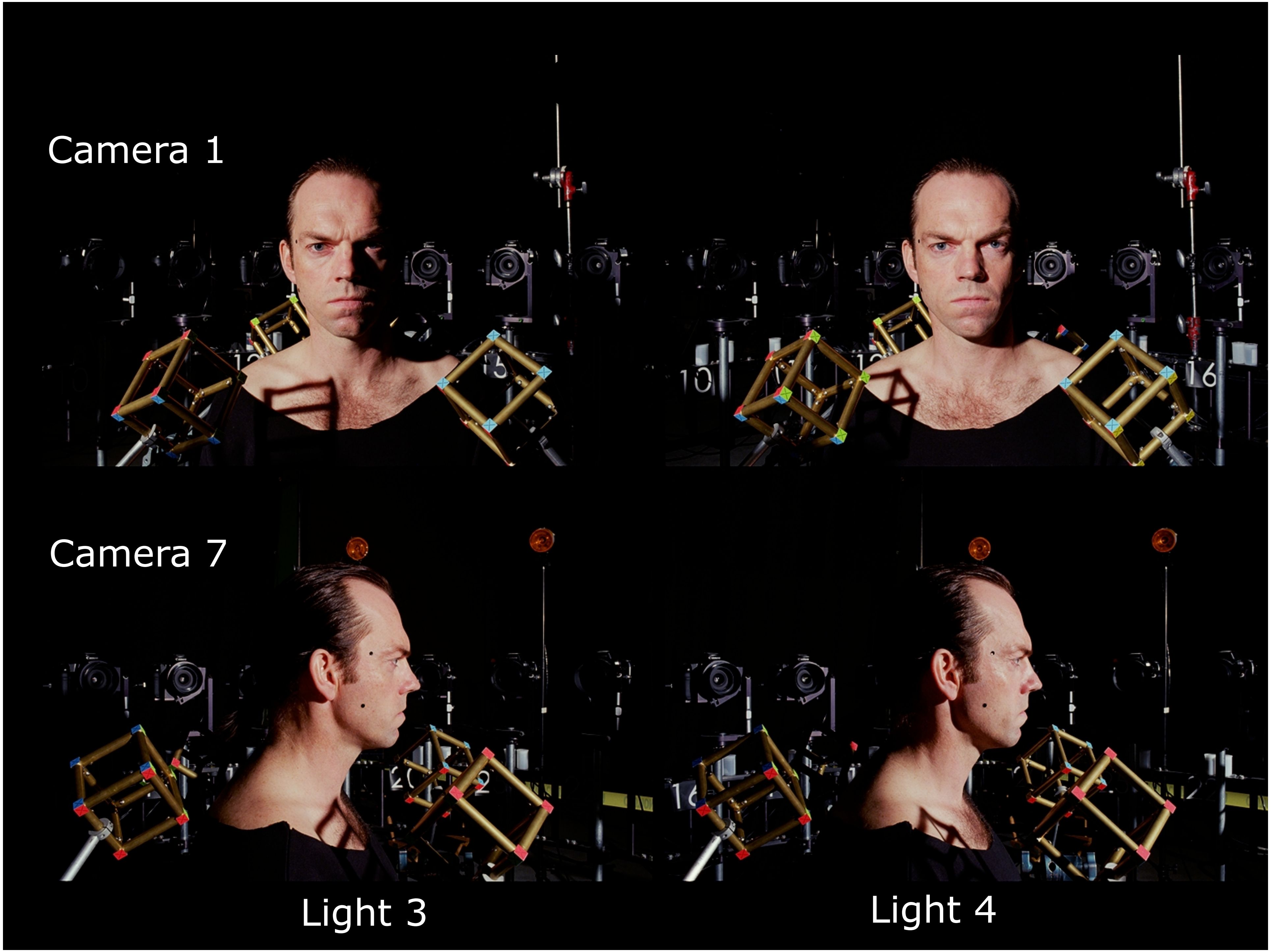
# Early Observations – Winter/Spring 2000

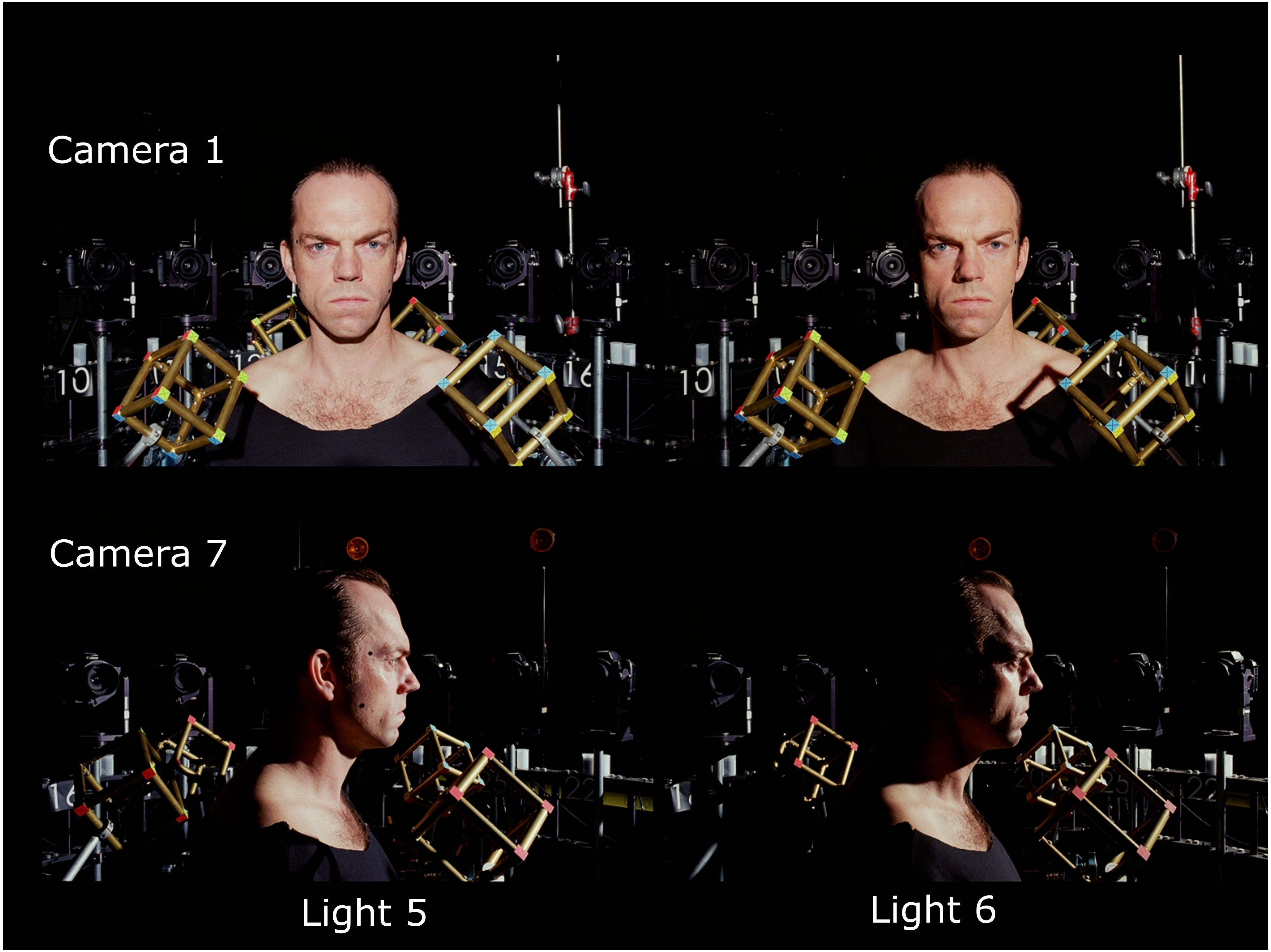
- Reflectance – is BRDF enough or …
- Skin is *translucent*; conventional shaders will not work
- Lighting is just as important
  - Area lights with ray traced shadows
  - Lights from every direction of the environment
  - Does “global illumination” play a role?

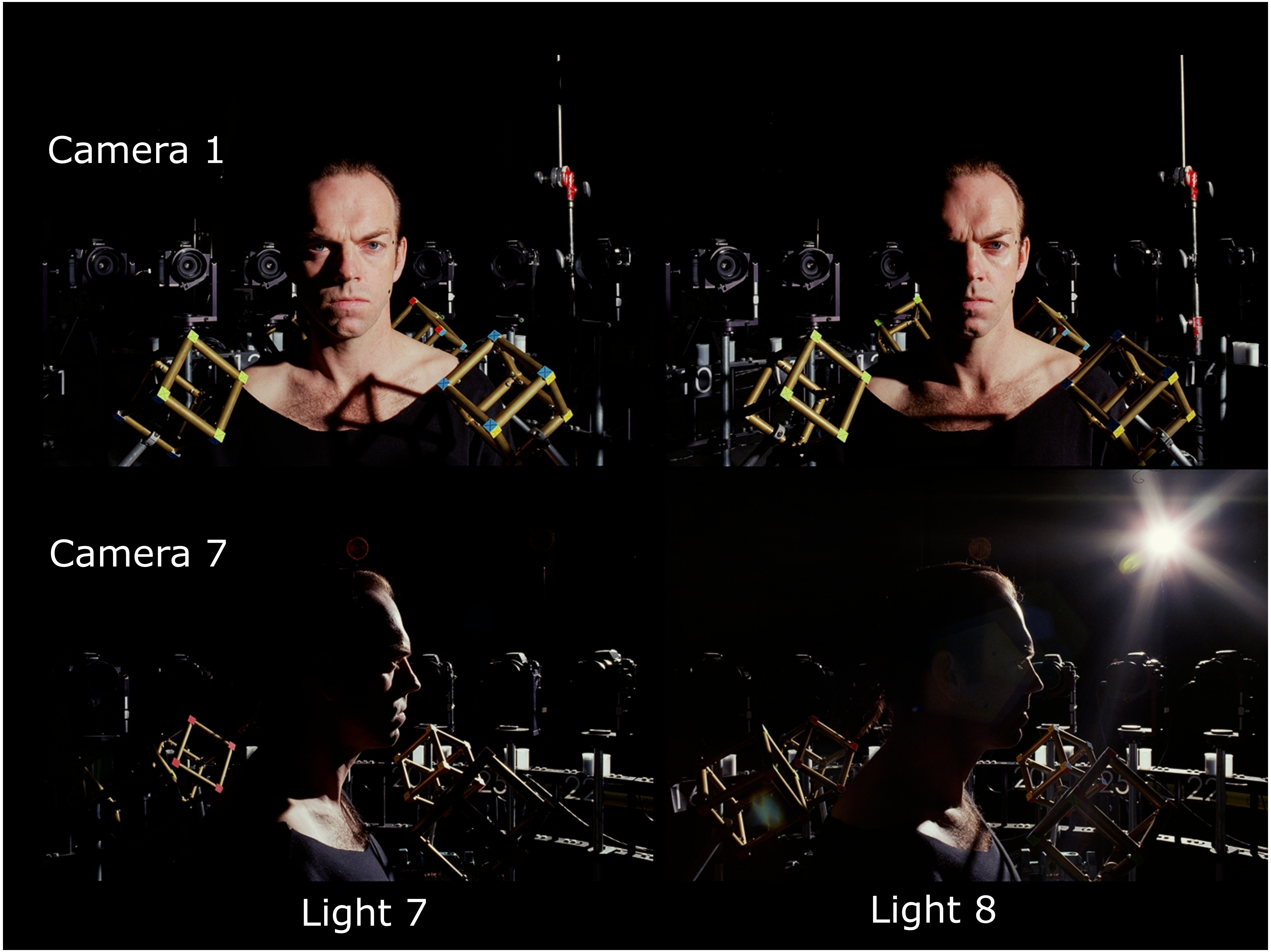
# BRDF Capture

- Marschner et. al. – Image-based BRDF measurement
- Had lots of cameras lying around from the Bullet Time rig and a way to trigger them simultaneously
- Capture actor illuminated from various lighting directions with 30 cameras around the head


Camera 1
Camera 7
Light 1
Light 2

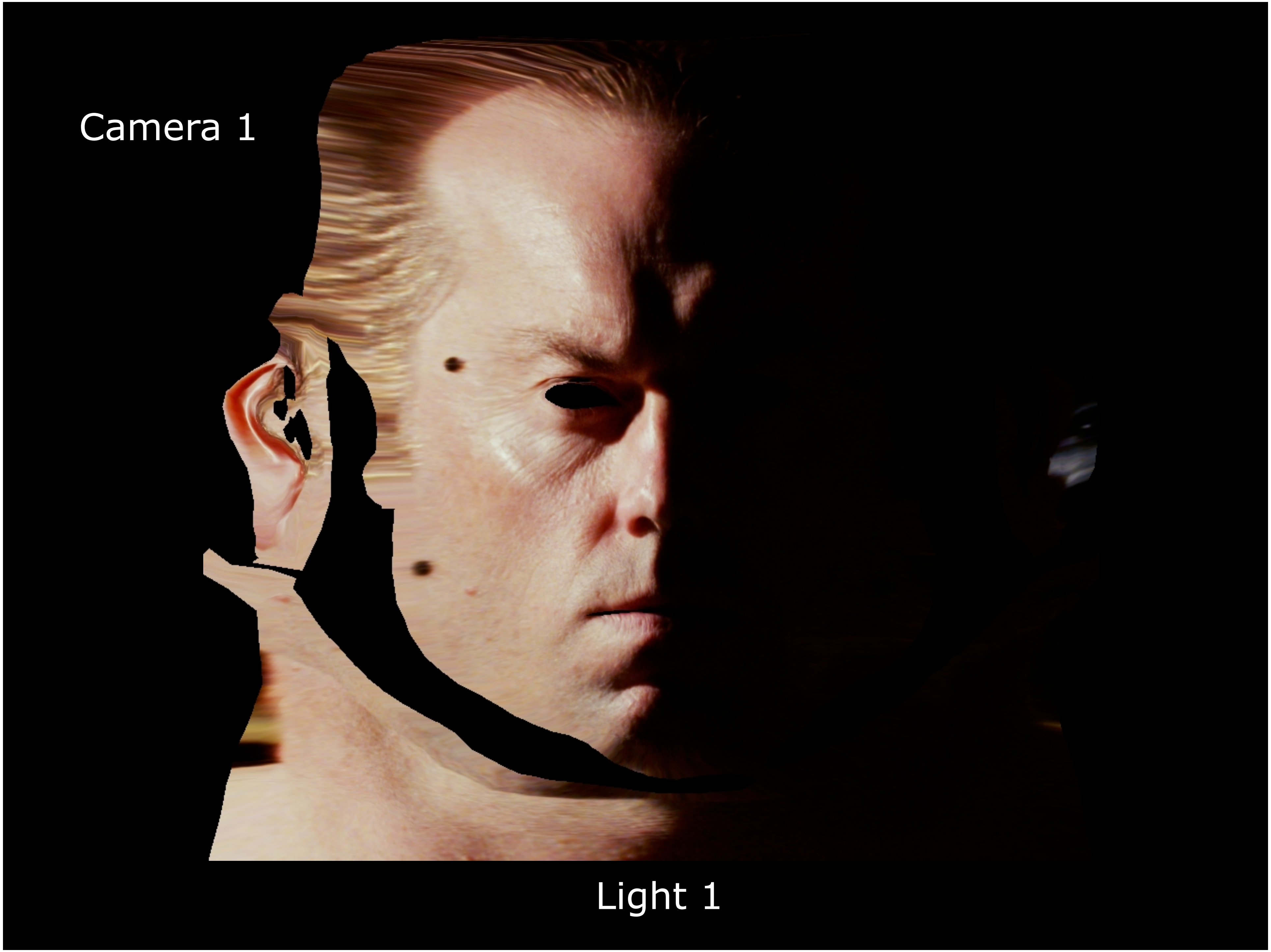

Camera 1
Camera 7
Light 3
Light 4

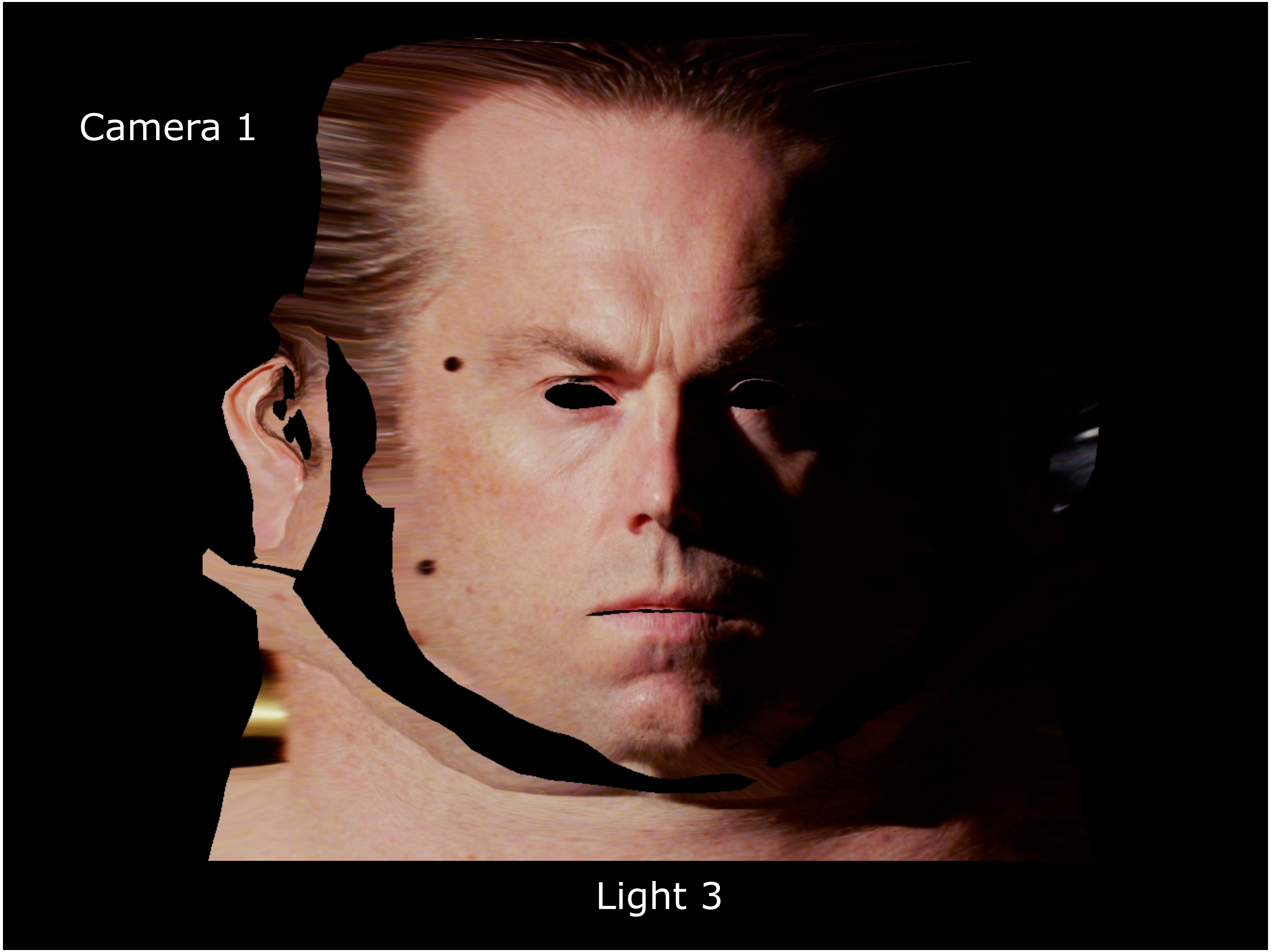

Camera 1
Camera 7
Light 5
Light 6


Camera 1
Camera 7
Light 7
Light 8

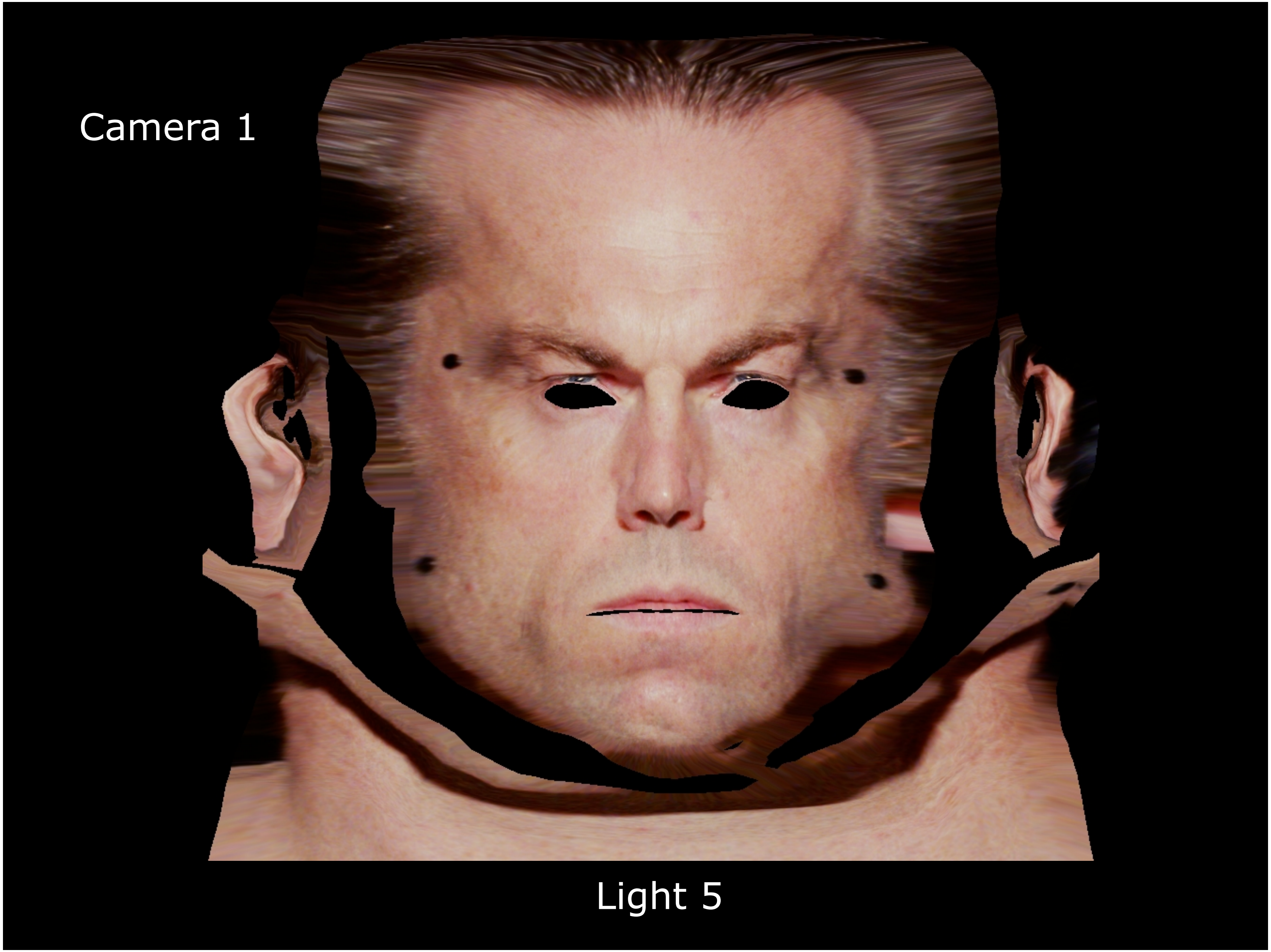
# BRDF Image Alignment

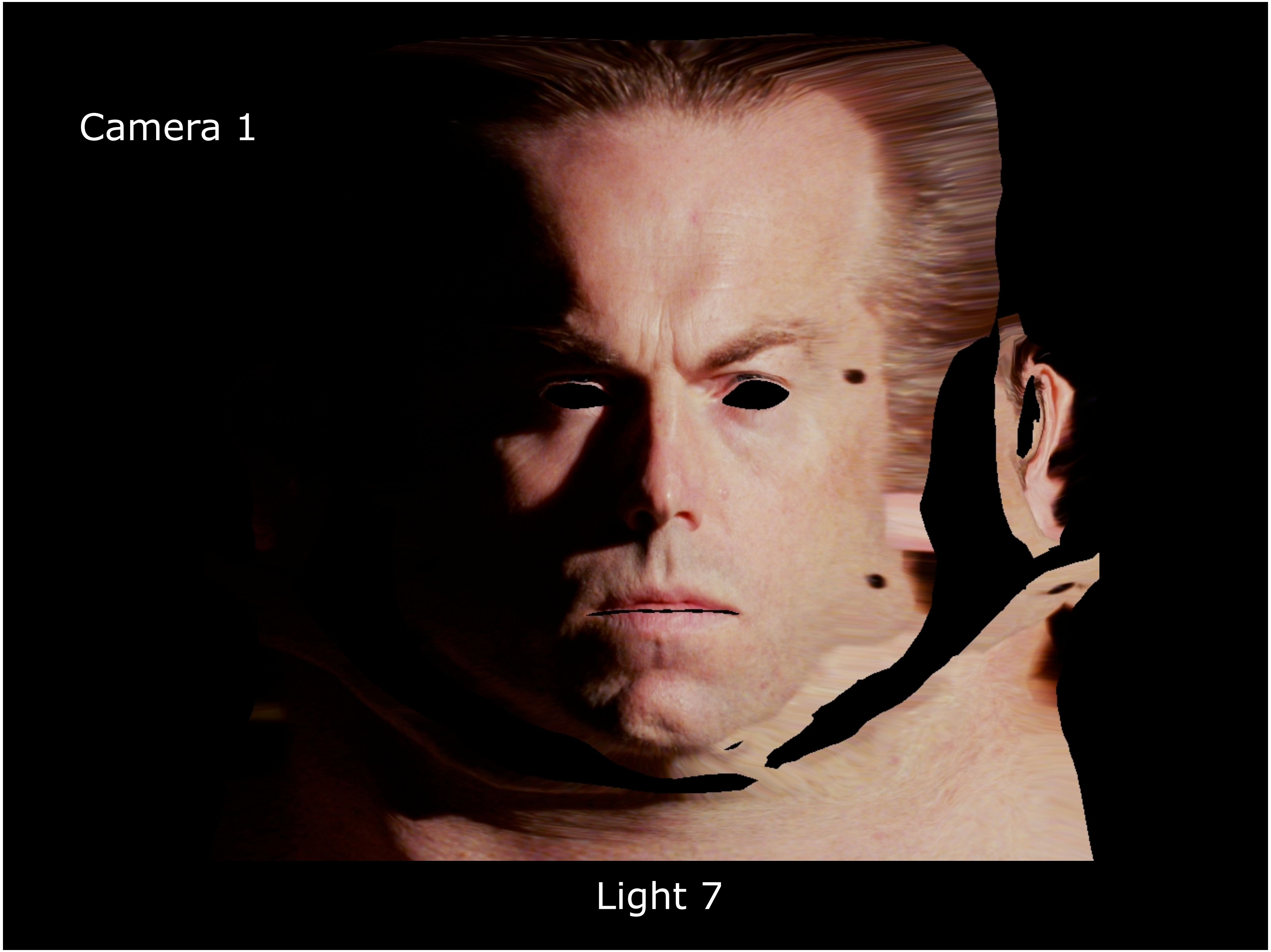
- Photogrammetry used to reconstruct the camera positions
- Color calibrated, image space aligned images from each camera brought into a common UV space by projection onto cyberscan model
- The registered images implicitly contain skin reflectance for various incoming and outgoing light directions


Camera 1
Light 1



Camera 1
Light 3


Camera 1
Light 5


Camera 1
Light 7

Camera 1

Light 9

# Data-Derived Analytical BRDF

- Due to imperfections in our color calibration, image alignment, and cyberscan it was hard to fit a model automatically
- Parameters for an approximate analytical BRDF are derived from this data:
  - Lambert-like diffuse component
  - Phong-like specular with Fresnel effect (acknowledgement: Matthew Landauer)

# Surface Detail

- Applying BRDF to existing model without bump map detail
  - Images were disturbingly fake
  - Tried procedural cellular texture approach – dismal failure
  - Tried extracting bump detail from color map (already had access to UCap color texture maps) – better result but hardly photorealistic
- Convinced that we had to scan the real actor's facial detail somehow

# Raw Facial Geometry

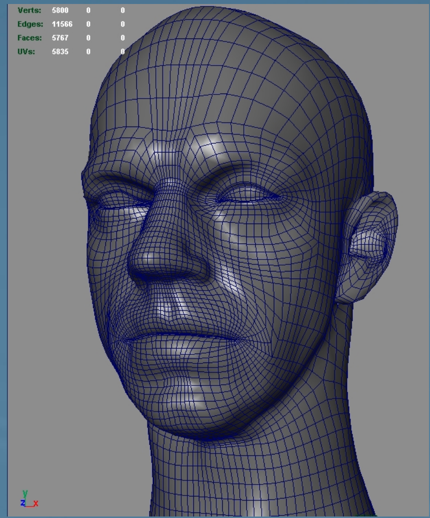
- Plaster casts of the actors
  - Acquired through the movie production
- Aruis3d scanning technology
  - ~$20 million of government funding over 10+ years
  - Service provided by XYZRGB
  - 100-micron scan of actors’ faces
  - Highest resolution model: 10 million triangles
  - Provided multiple resolutions

# Agent Smith Cast/Scan

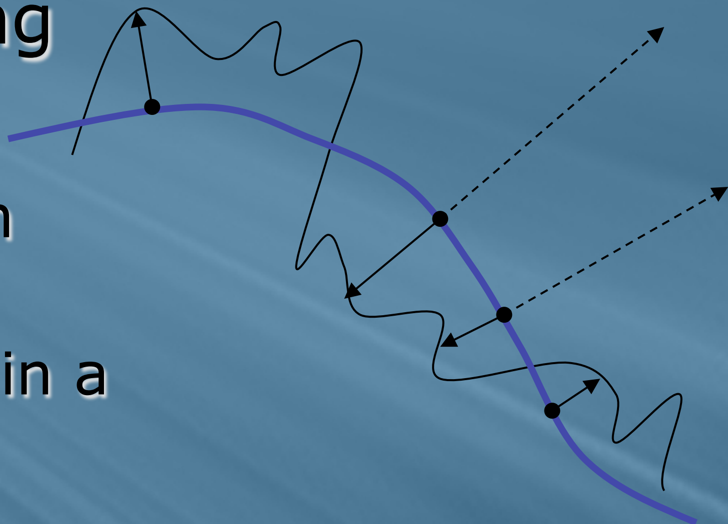
# Morpheus Cast/Scan

# Detail Extraction Approach

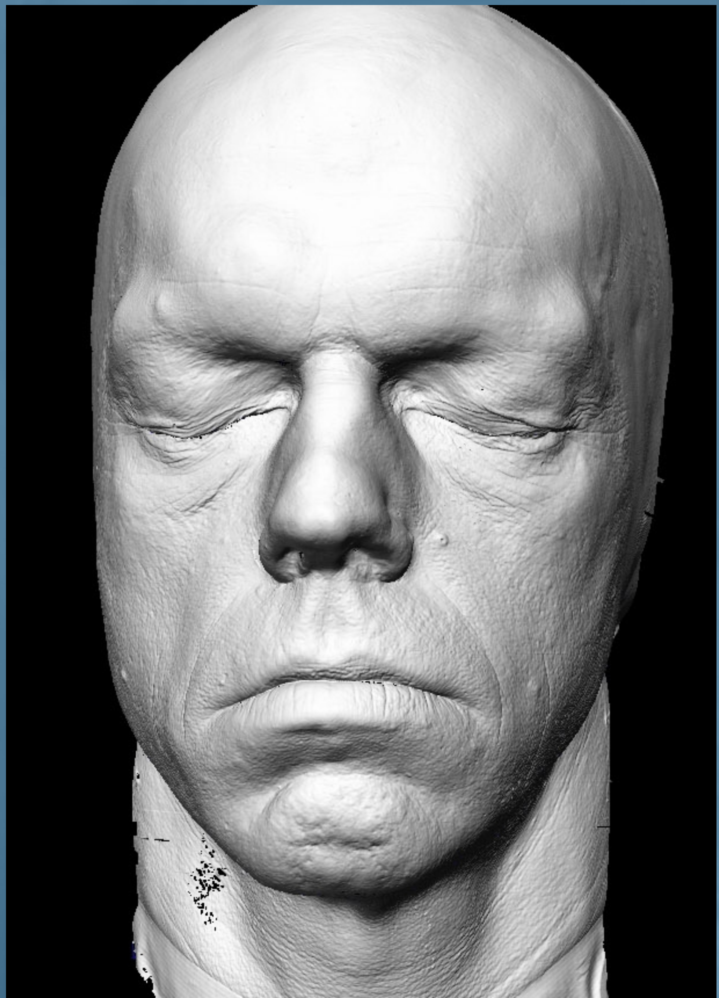
- Base resolution quad mesh (constructed with Paraform)
- Use as subdivision surface



- Residual displacement obtained with mental ray lightmapping and custom shader
  - Ray trace from the subdivision surface to the raw scan
  - Store distance to intersection in a UV map



# Agent Smith Detail Extraction



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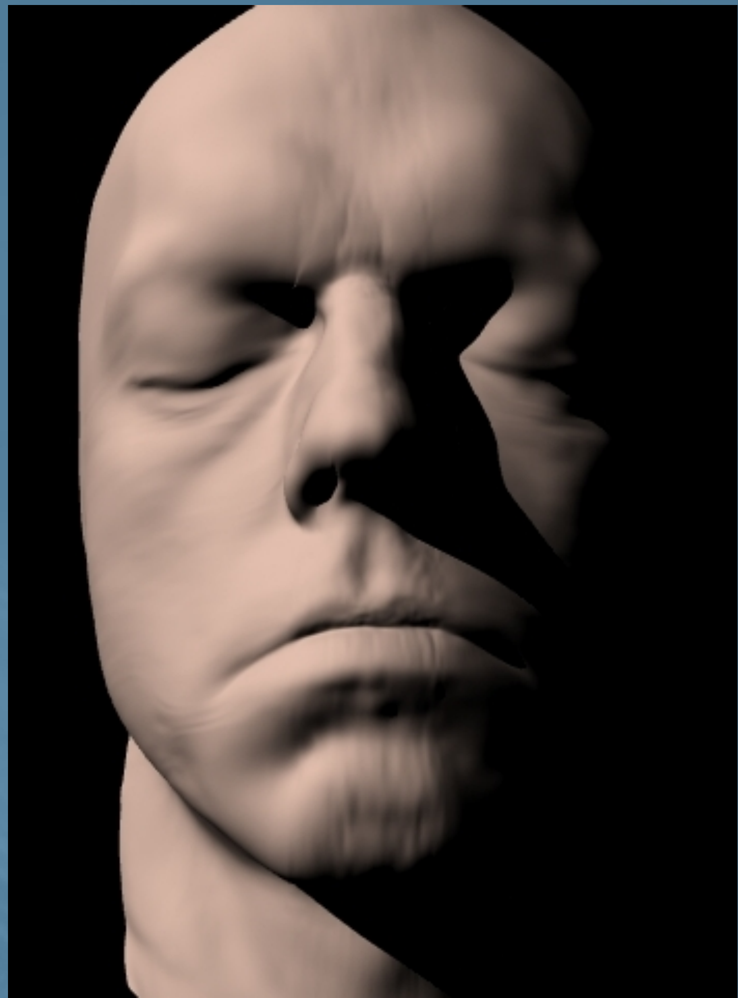

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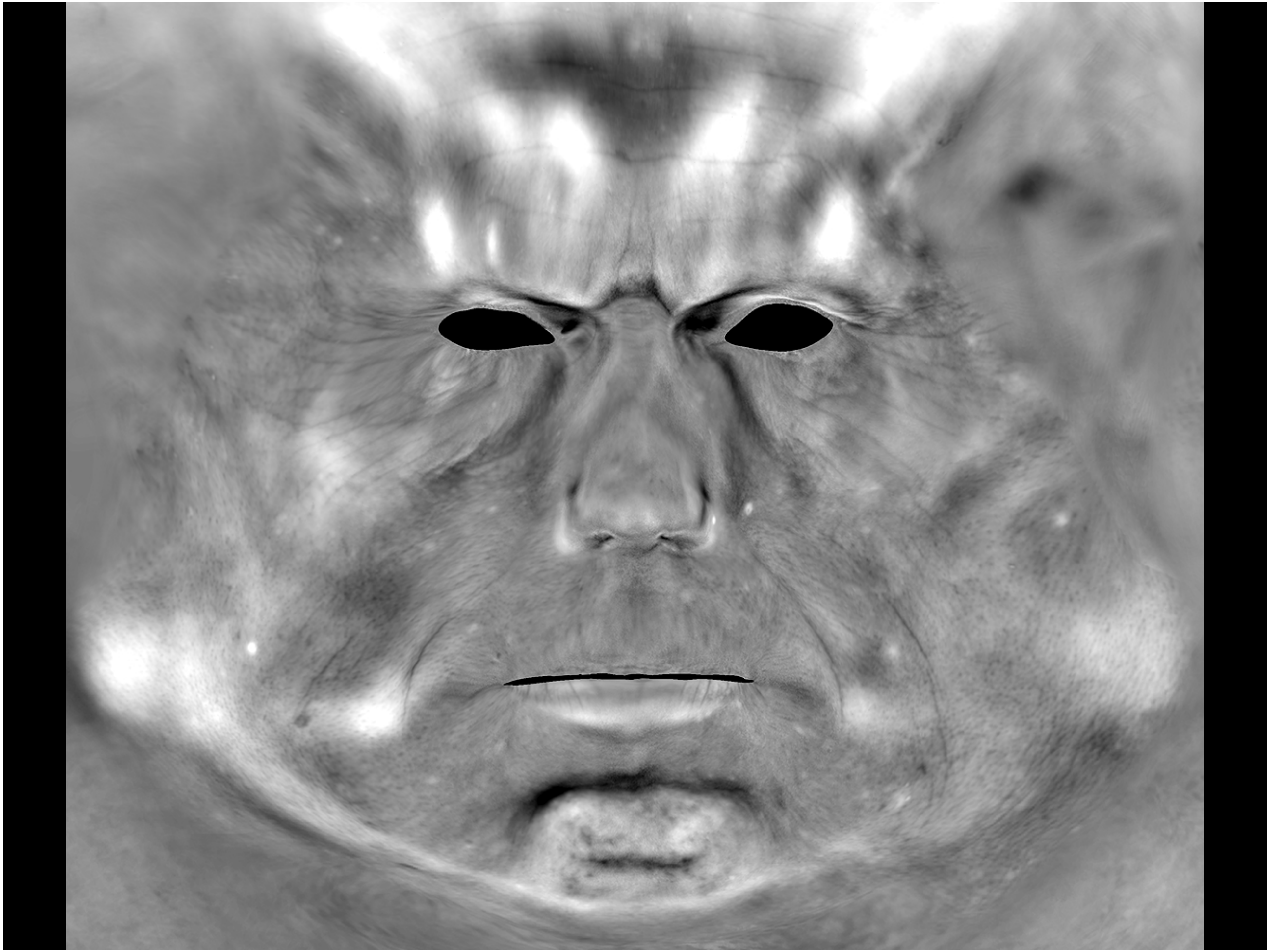
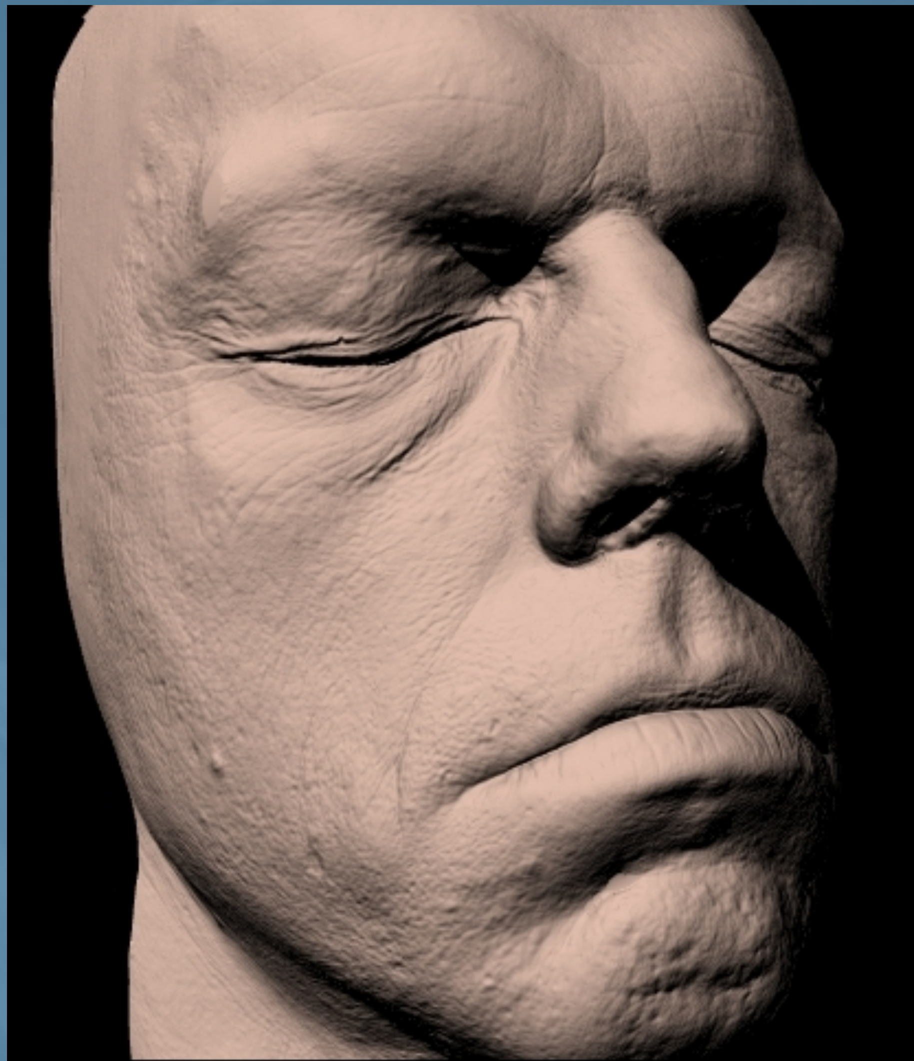


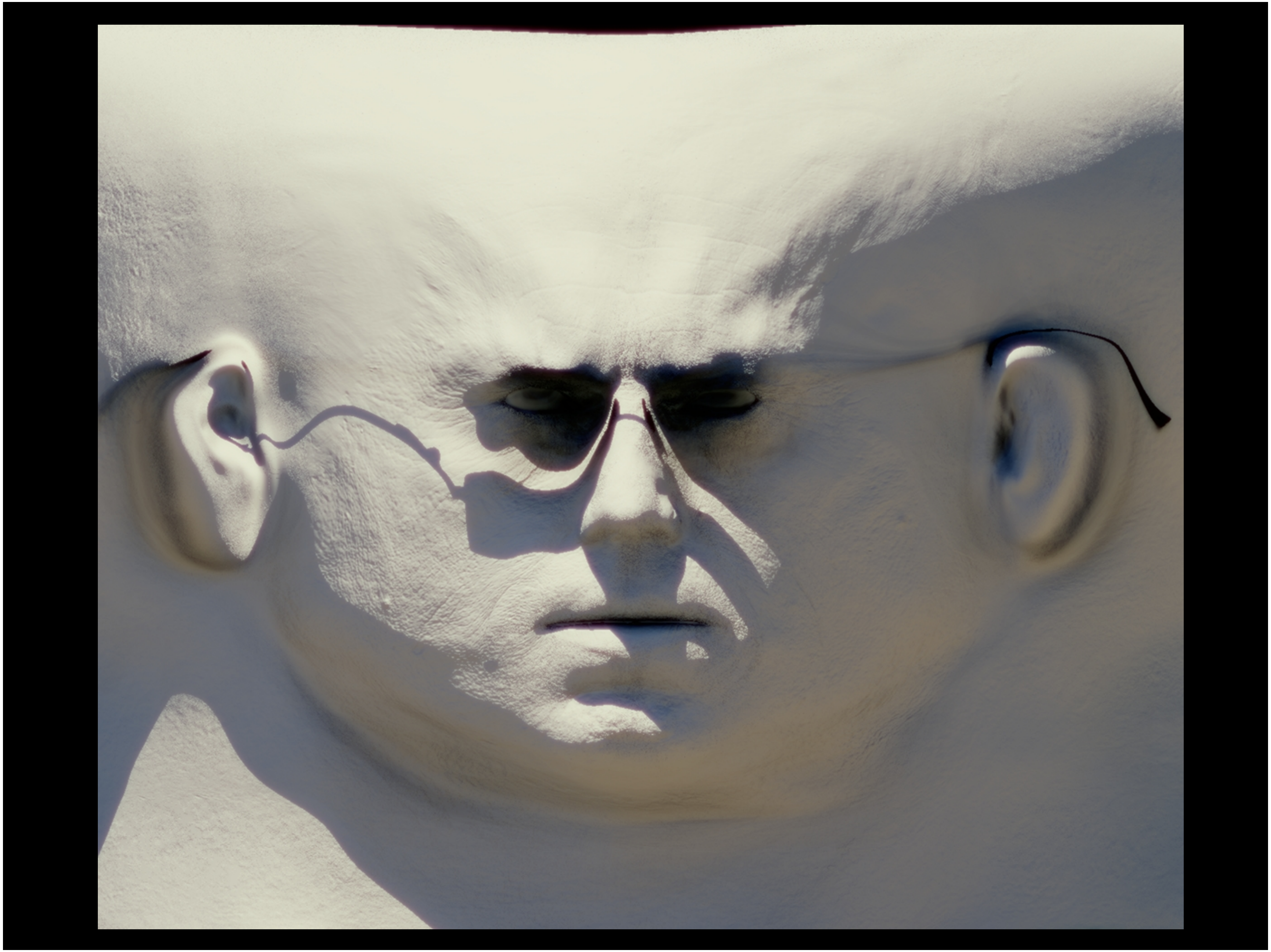
# Agent Smith Bump

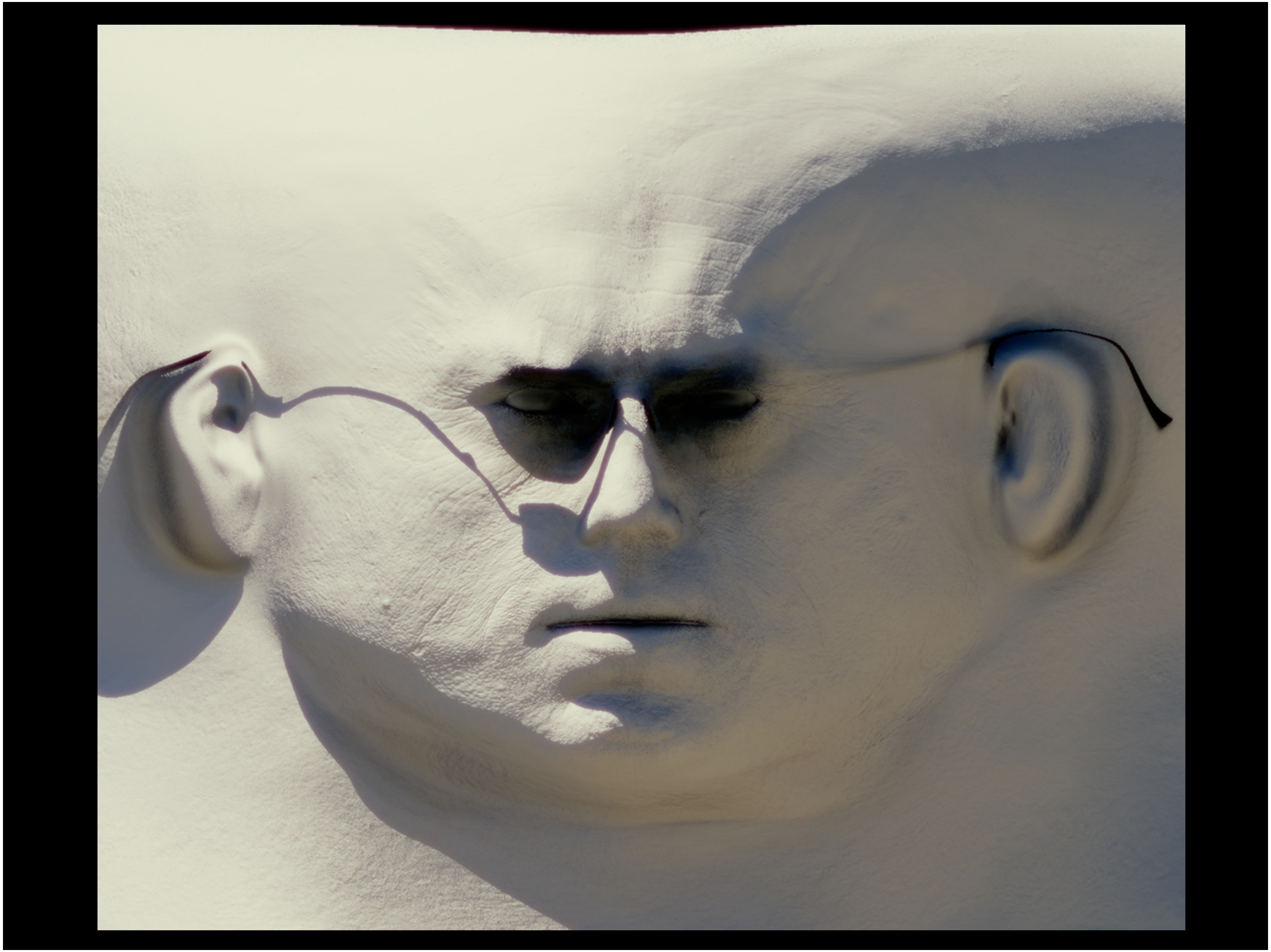


# Neo Cast/Bump

# Subsurface Scattering

- We were very close but the renders looked more like granite than skin – Henrik was right!
  - Existing subsurface models: complex, also not 100% convincing
- Instead, approximately simulate light diffusion in the image map domain
  - Different diffusion length for different colors
  - Heavily translucent areas (ears) handled by ray tracing





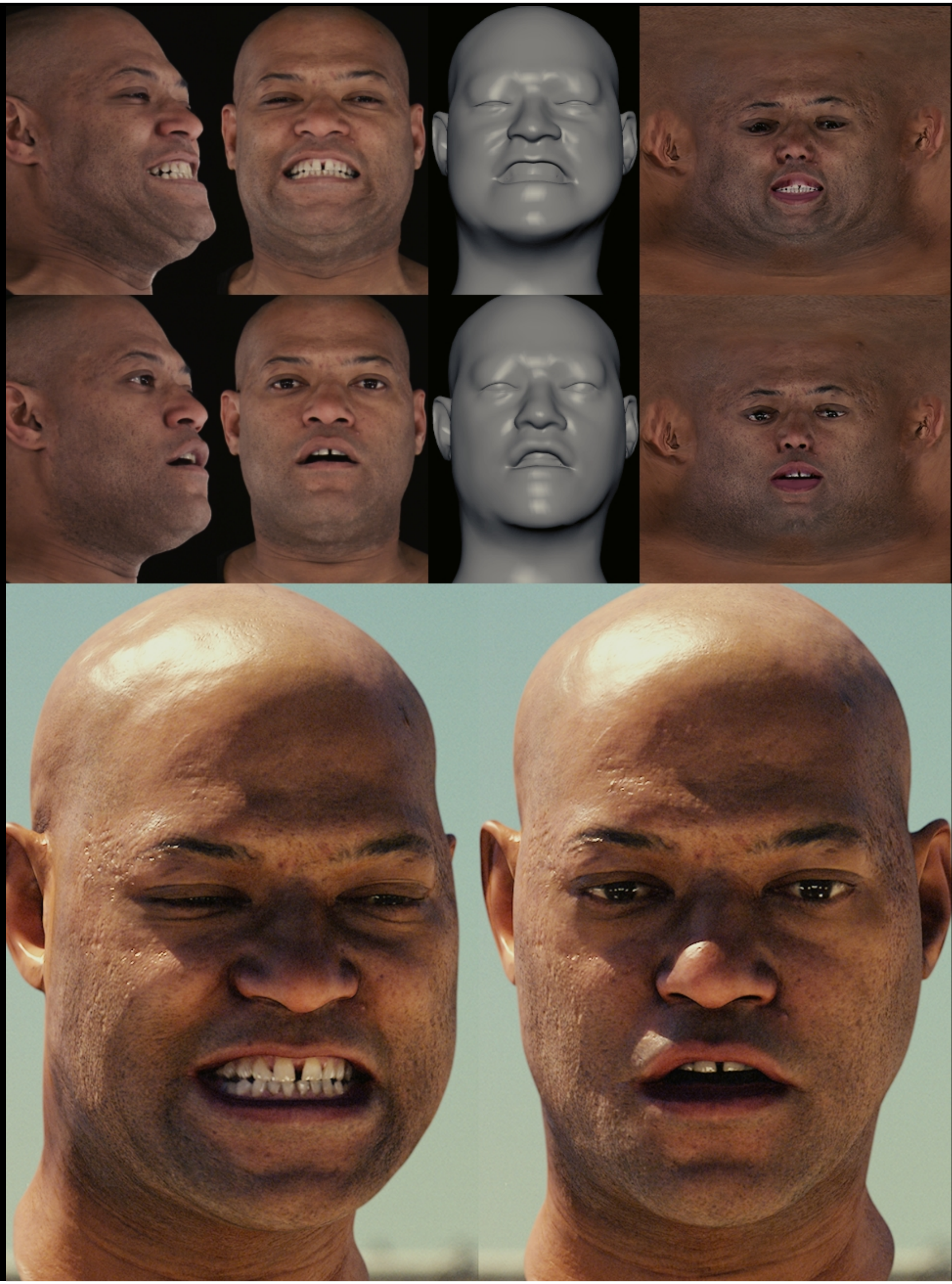
# Rendering

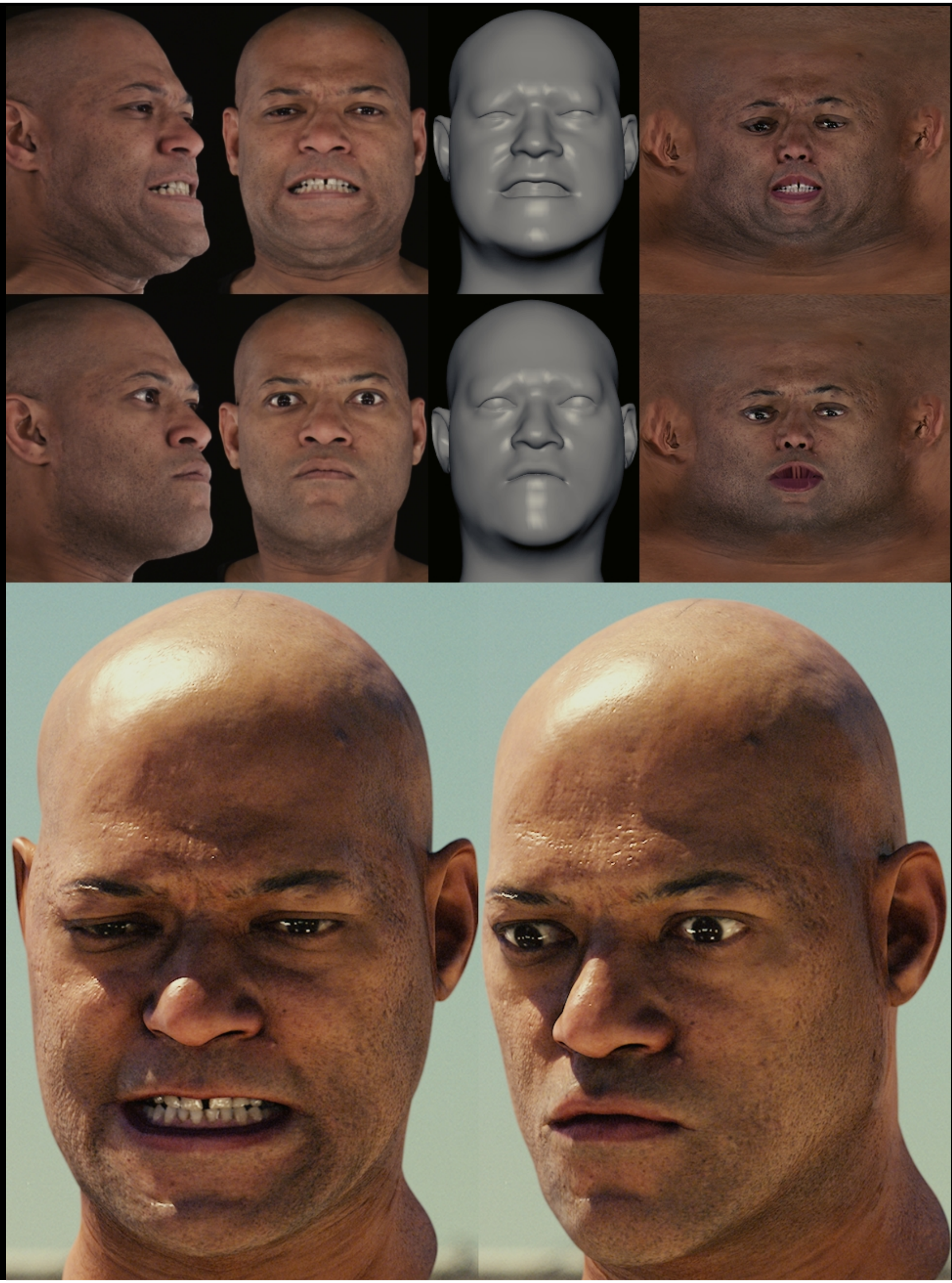
- Lighting Reconstruction Toolkit
  - image-based lighting

  approach gave us the realistic lighting from an environment

- Renderer: mental ray
  - Lightmapping
  - Ray traced shadows
- Reference photo shoot with the actors to verify our results







# Measured Surface Reflectance(BRDF) in Film Production – Realistic Cloth Appearance for *The Matrix Reloaded*

# Motivation

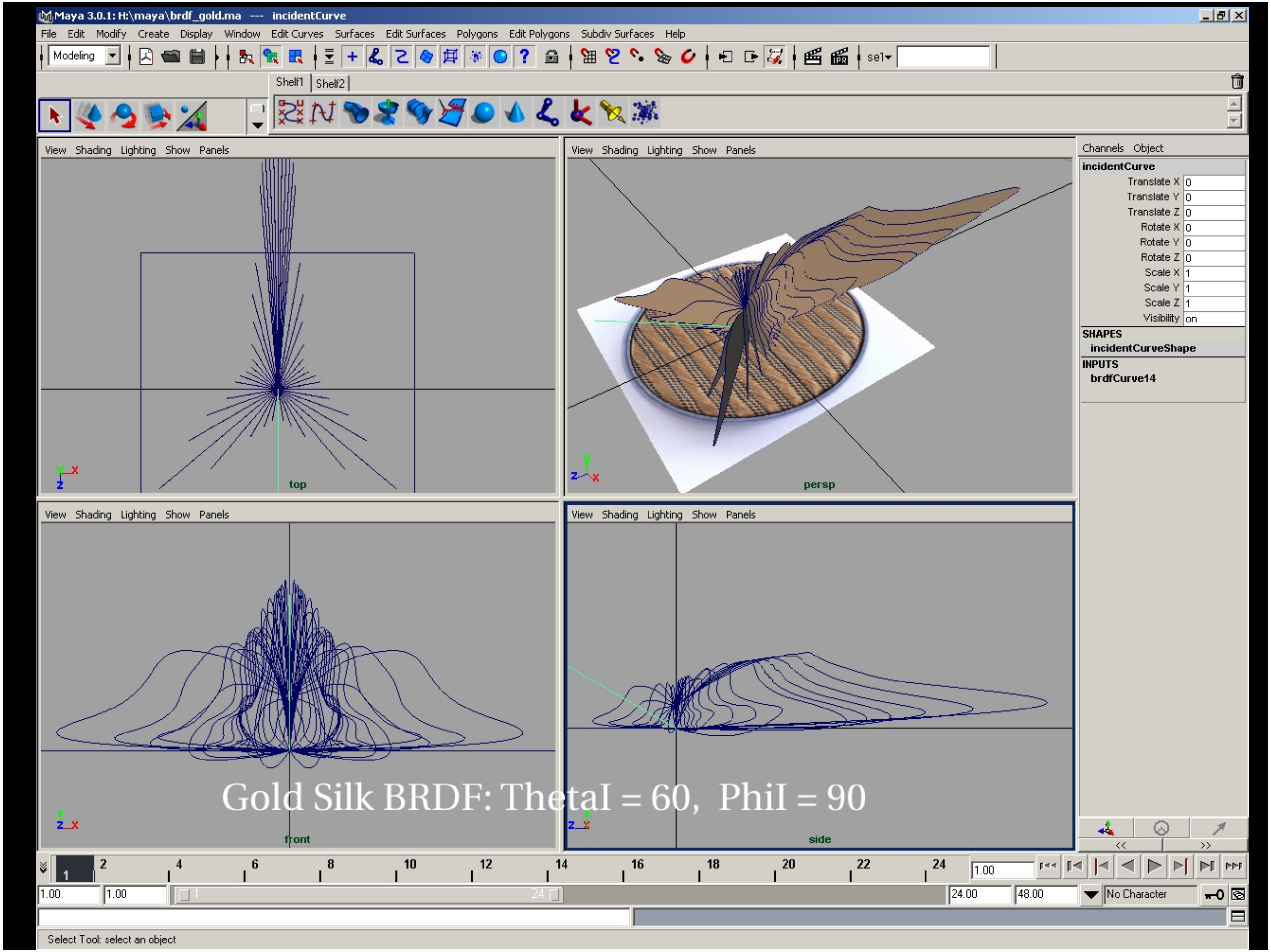
- Plastic look of computer graphics
- Analytical reflectance models – few and limited
- Had to exactly match the actors' costumes – full CG images needed to inter-cut with live action

# Cloth Samples

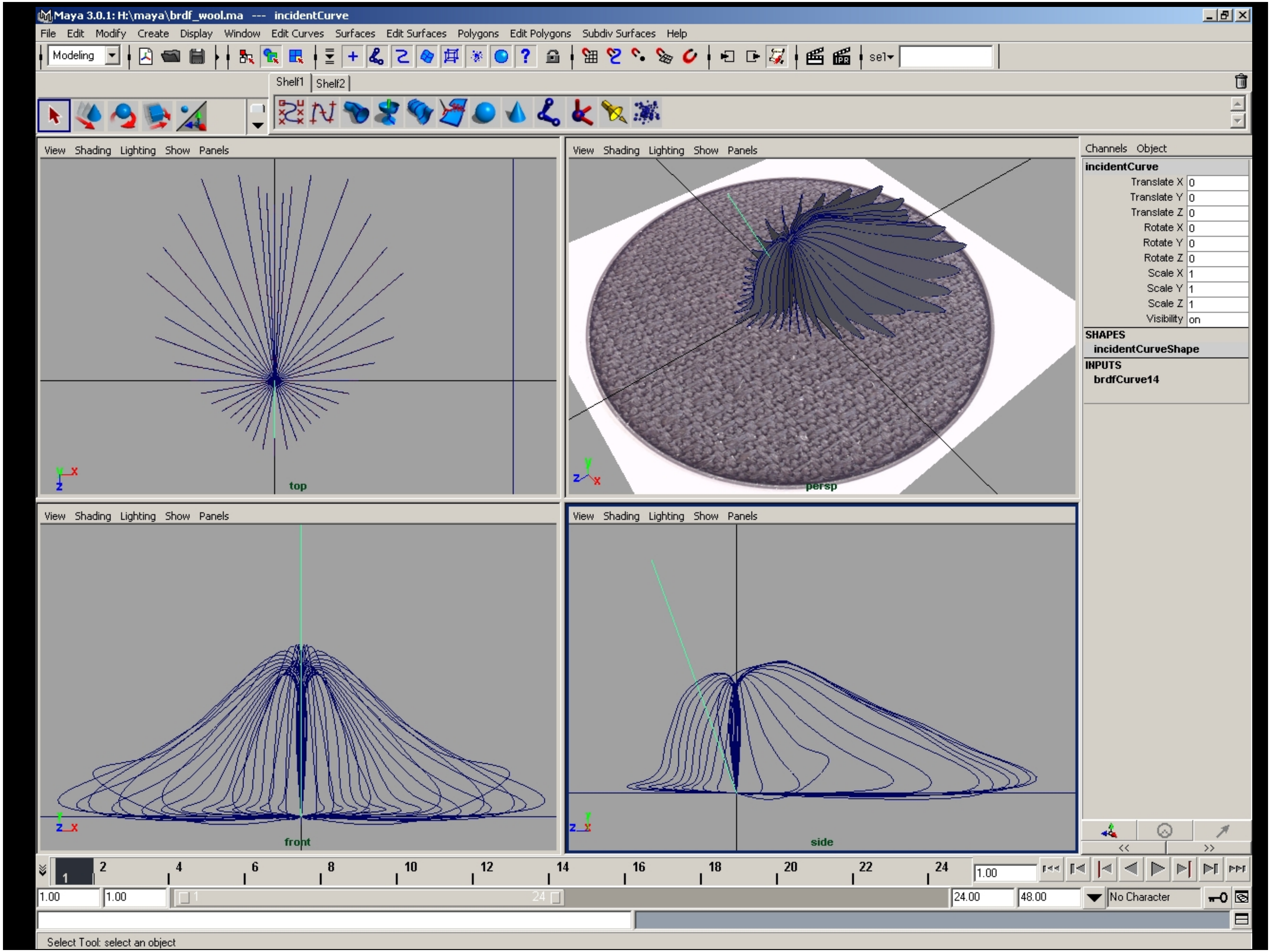

# Measurement Device

- SOC–200 Bidirectional Reflectometer (6’ x 10’ base, 7’ height)
- Price tag $700,000, operating cost $250/hour
- Designed for Lockheed Martin to be used in development of Stealth aircraft (B2, F16, F22)
- Able to get access only because designers’ children loved *The Matrix*


SOC-200
BI-DIRECTIONAL REFLECTOMETER
TMC




Gold Silk BRDF: ThetaI = 60, PhiI = 90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File Edit Modify Create Display Window Edit Curves Surfaces Edit Surfaces Polygons Edit Polygons Subdiv Surfaces Help
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Channels Object
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Translate X 0
Translate Y 0
Translate Z 0
Rotate X 0
Rotate Y 0
Rotate Z 0
Scale X 1
Scale Y 1
Scale Z 1
Visibility on
SHAPES
incidentCurveShape
INPUTS
brdfCurve14
No Character
Select Tool: select an object

# Rendering

- Efficient implementation
- mental ray material shader
  - Argument: a resampled csv file
  - Color/Bump from photos of ambient texture swatches

# Rendering

- Photographic reference shoot with the actors to verify the accuracy of our results

- Real-world Lighting Reconstruction