MEASUREMENT FOR 3D PRINTING

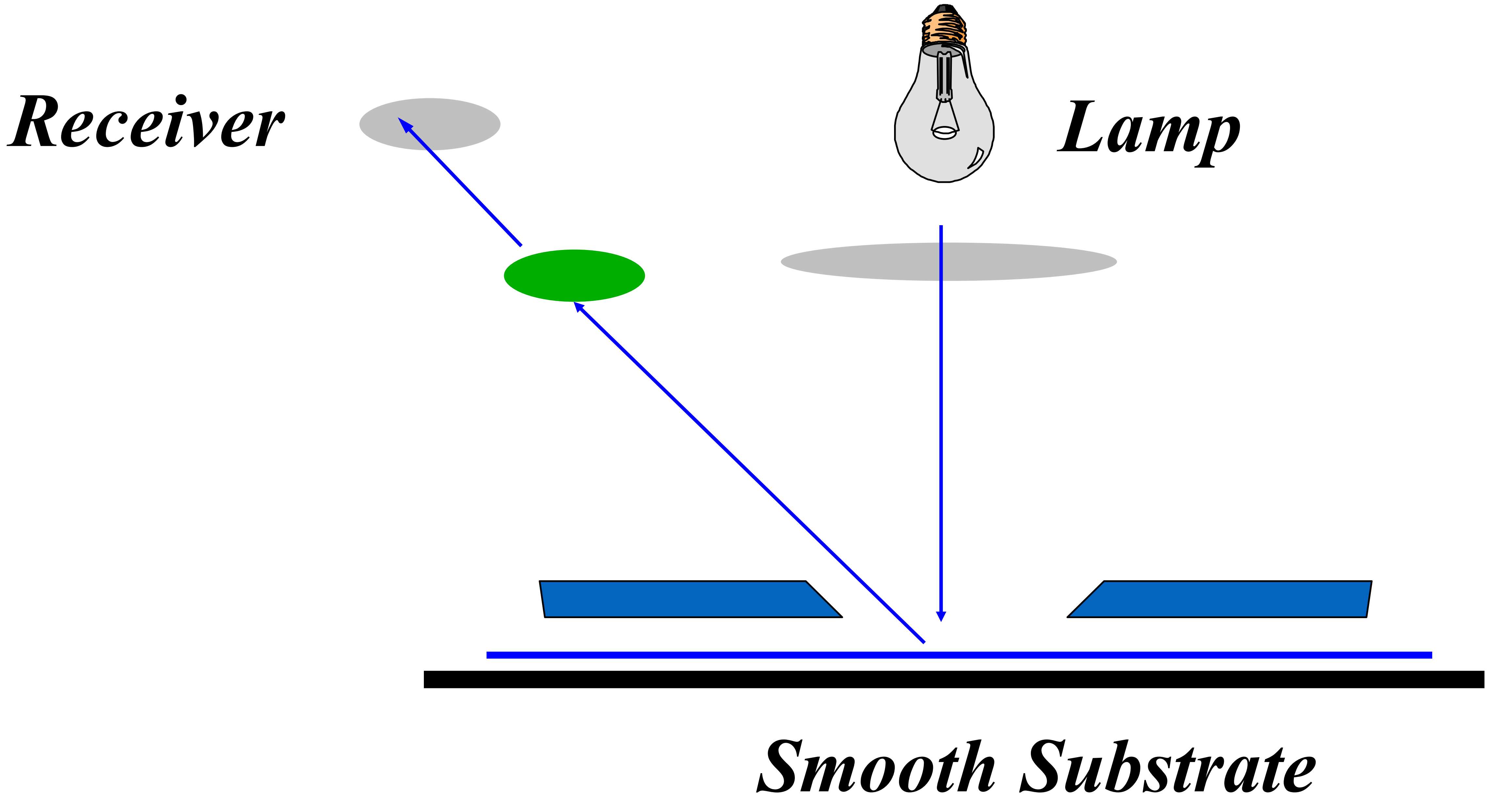
PICKING THE RIGHT TOOL FOR THE TASK

-

RAYMOND CHEYDLEUR

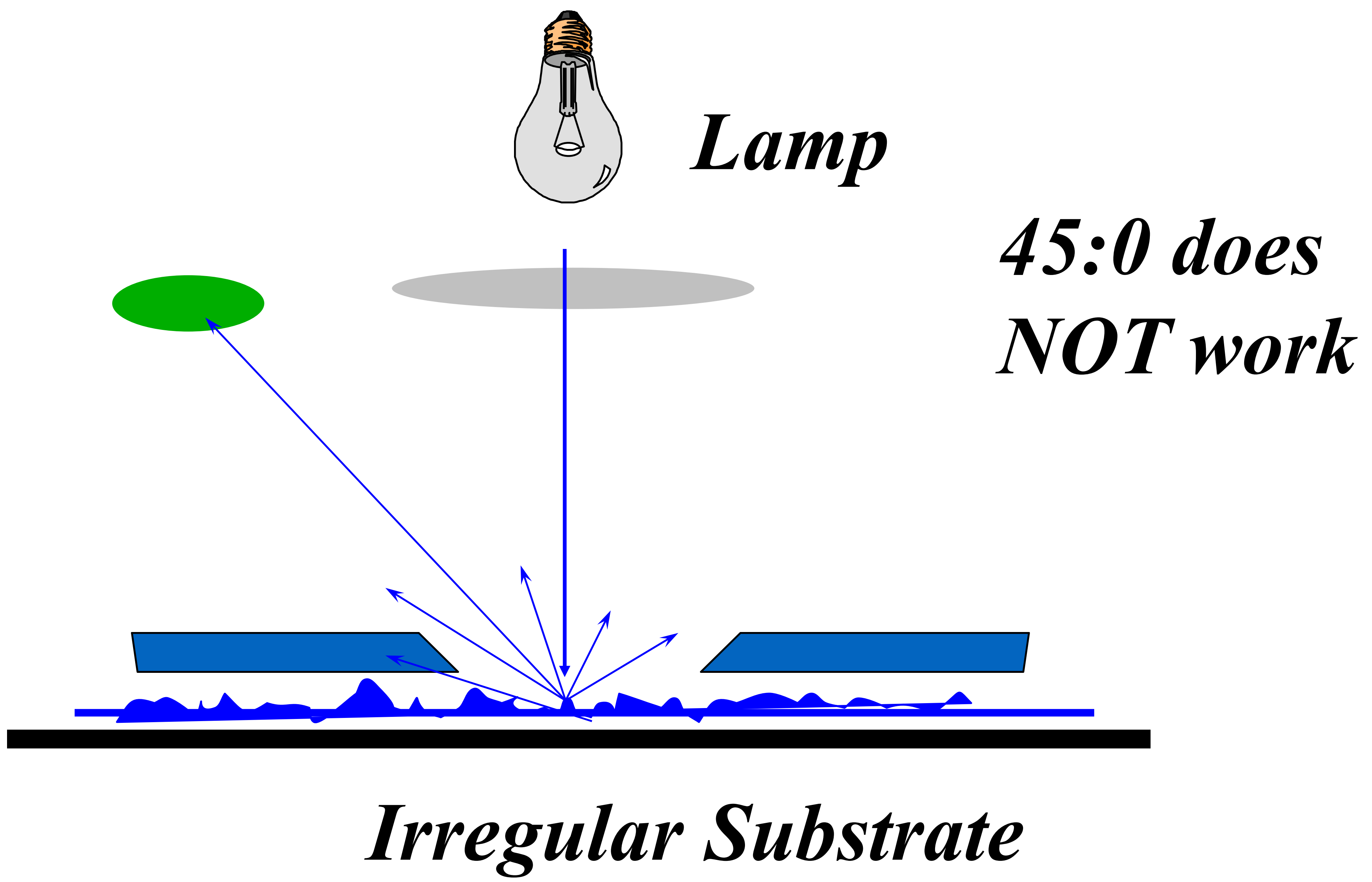
Traditional Graphic Arts Geometry

- Smooth, flat substrates
  - Incident of light shined at 45:0 or 0:45



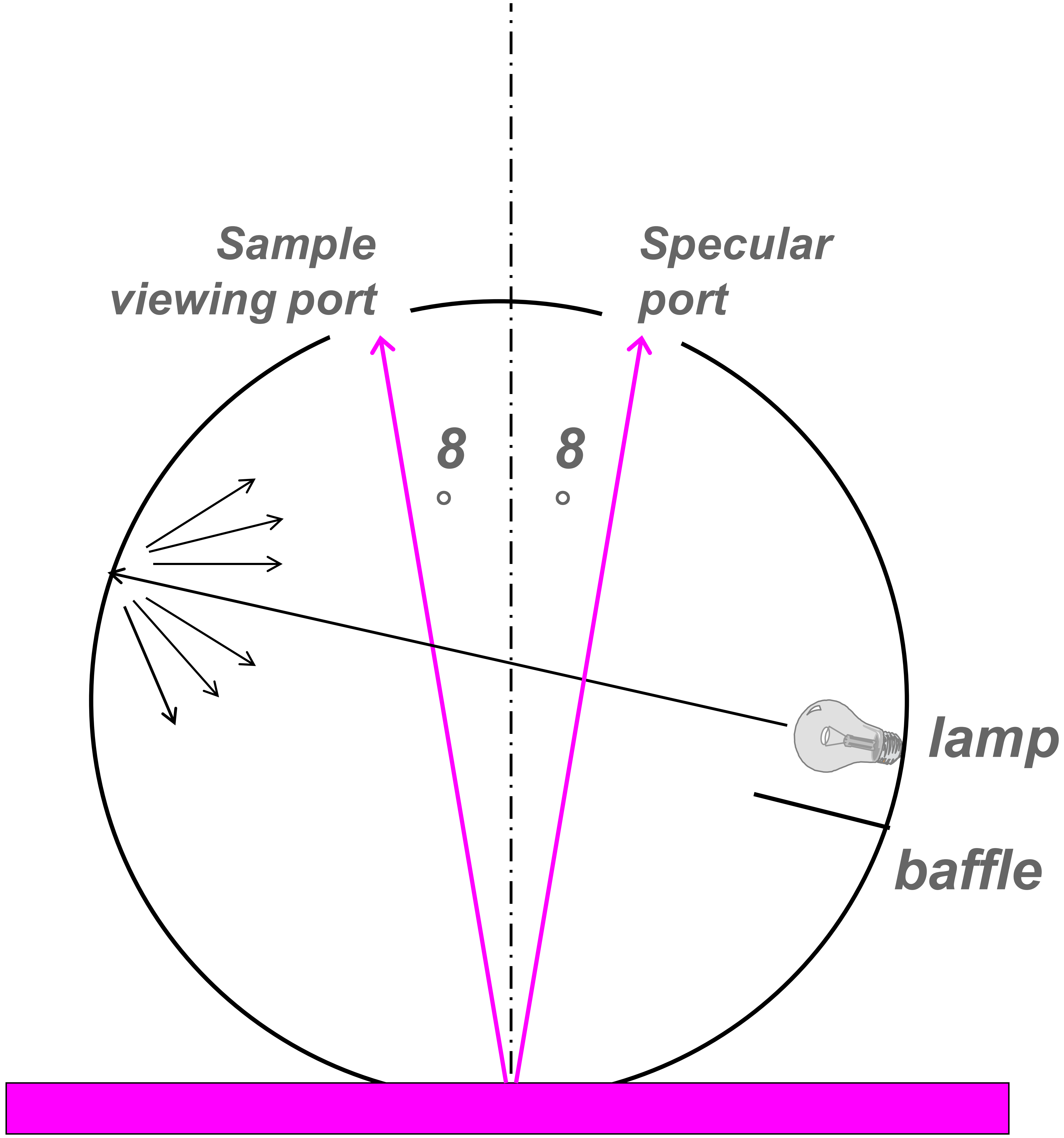
Traditional Graphic Arts Geometry - Challenge

- Heavily textured and uneven
  - Incident of light shined at many angles to compensate for the non uniform reflectance (spherical)
- Sample materials
  - Some Fabric
  - Certain plastics
  - Most metallics

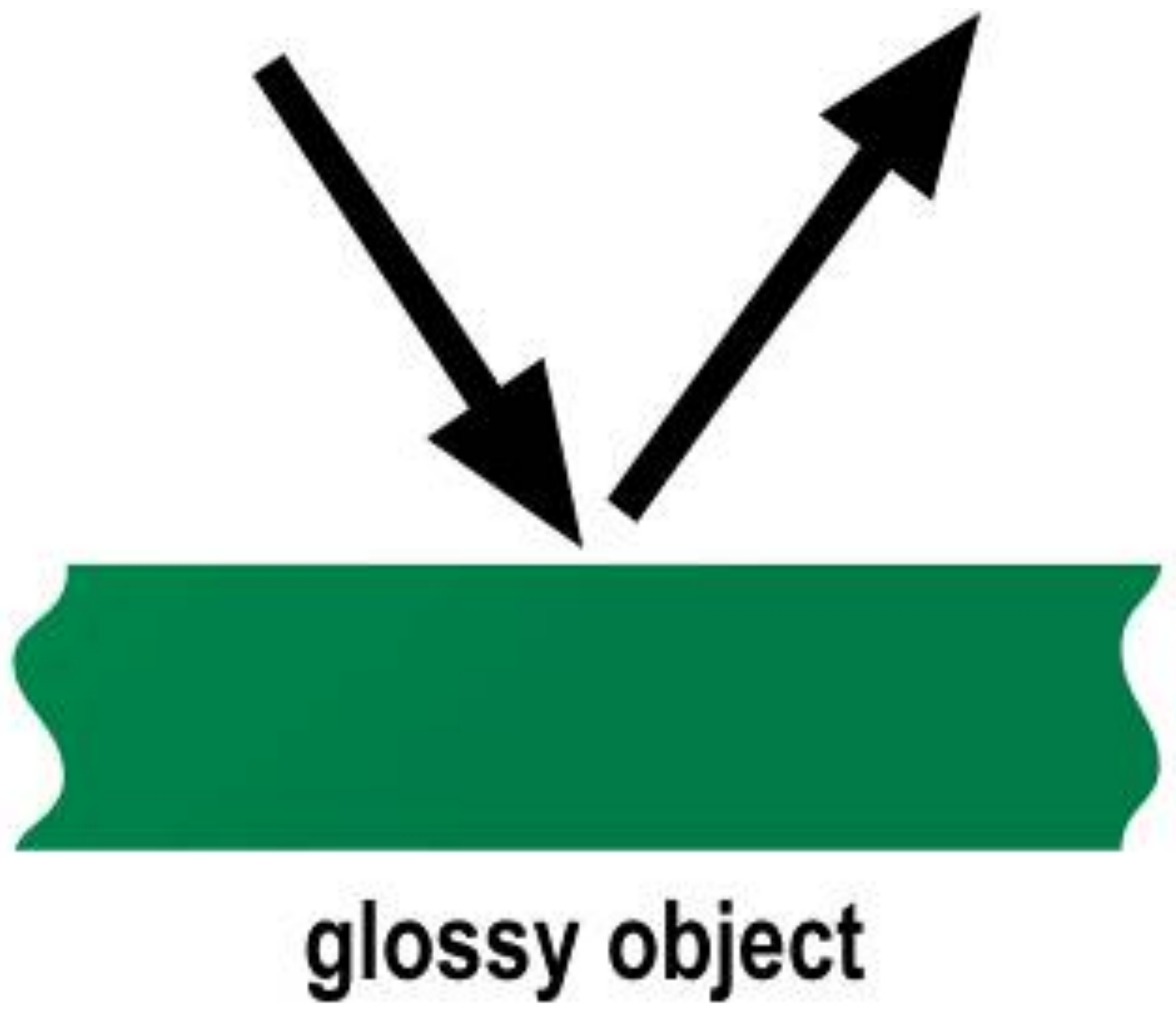


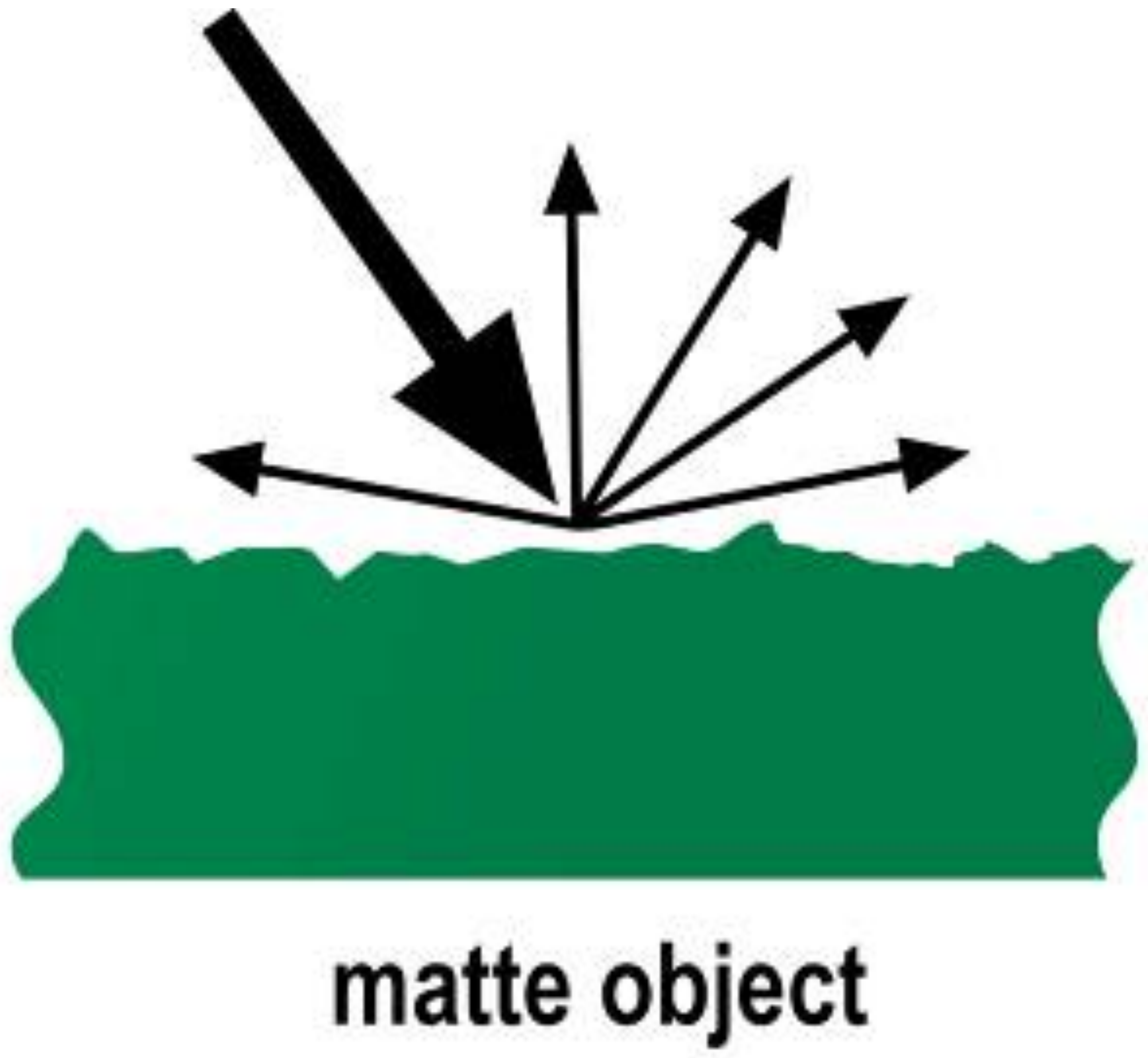
Traditional Industrial Geometry

Sphere (D8)

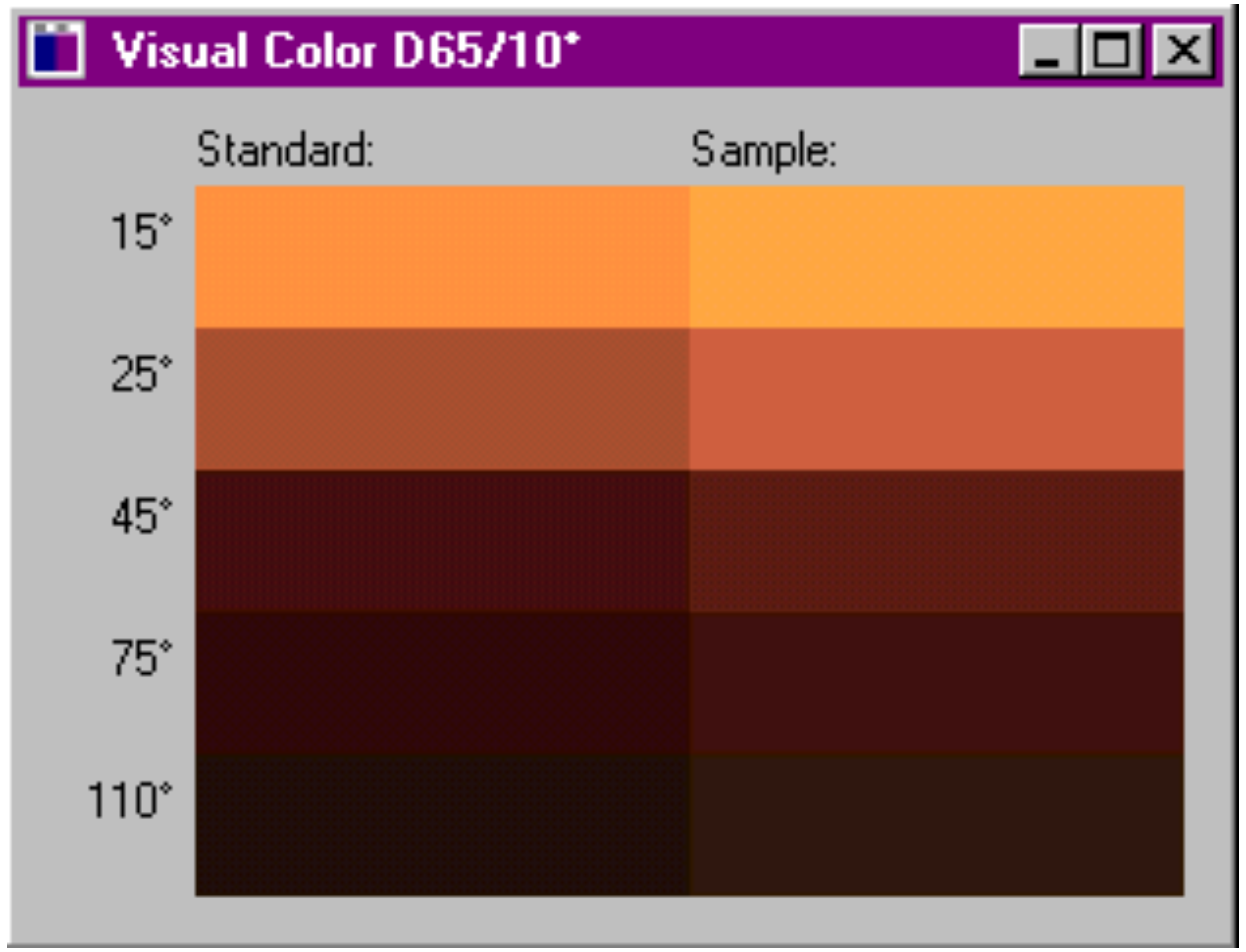


So Glossy, Flat or Matte – Is that all?





Multi-Angle Measurements Why



Change Optical Properties with Illumination and Viewing Angles

- Metallic

  Extend / enhance the gloss or specular appearance

- Mica / Interference additives

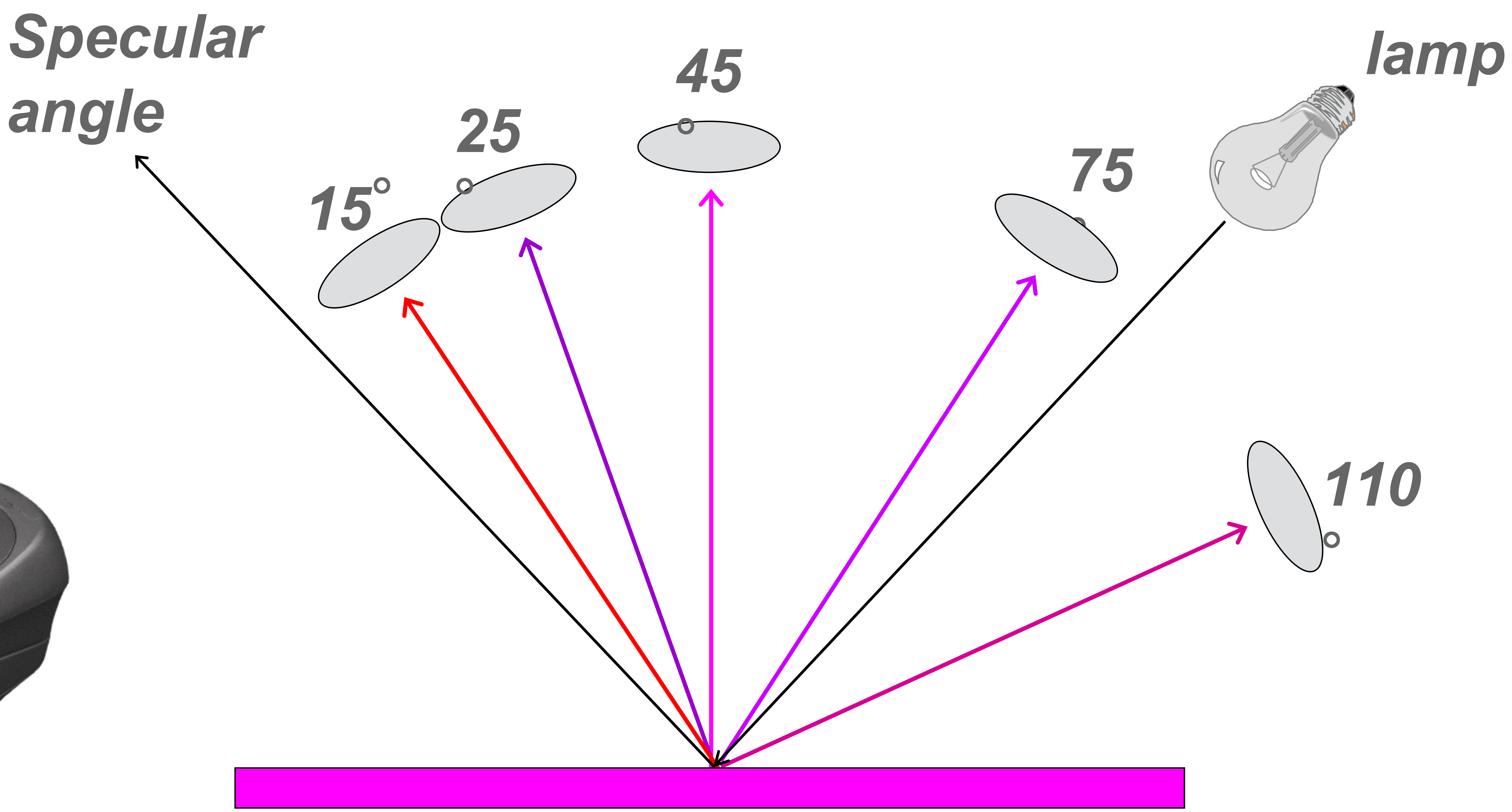
  Change appearance at all viewing angles. Some may introduce strong shifts in both lightness and hue

- Pearlescent

  Make surfaces appear to shimmer – haze effects

Another look at the problem

Multi-angle (15° /25° /45° /75° /110°)

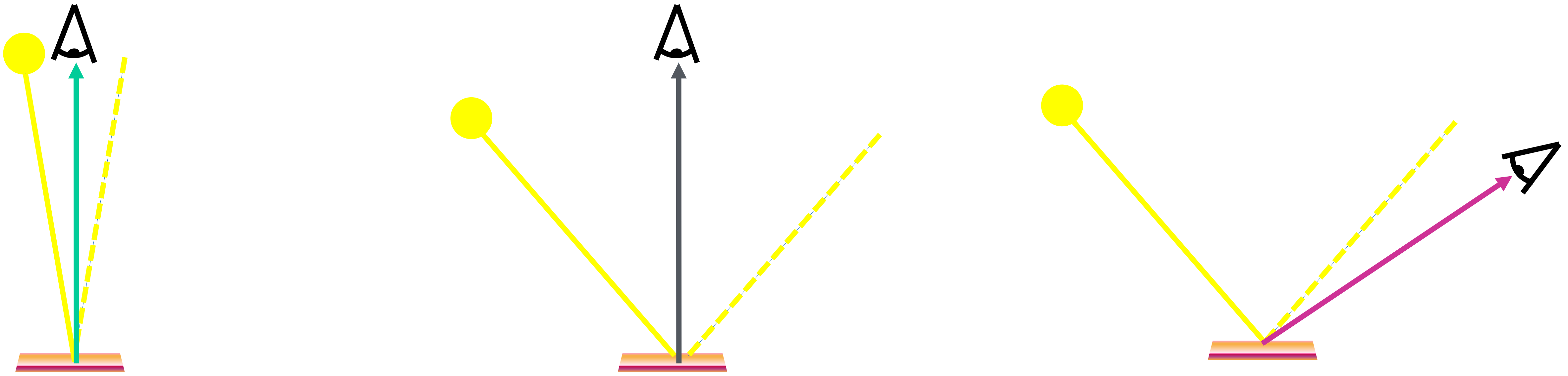


Why Two Illuminations

- 2nd generation effect (interference) pigments show different color NOT ONLY at different observer angles
  BUT ALSO at different illumination angles

The Challenge With Effect Pigments

- Gonioapparent samples change color by changing **illumination and observation angles**



„Face“
steep illumination

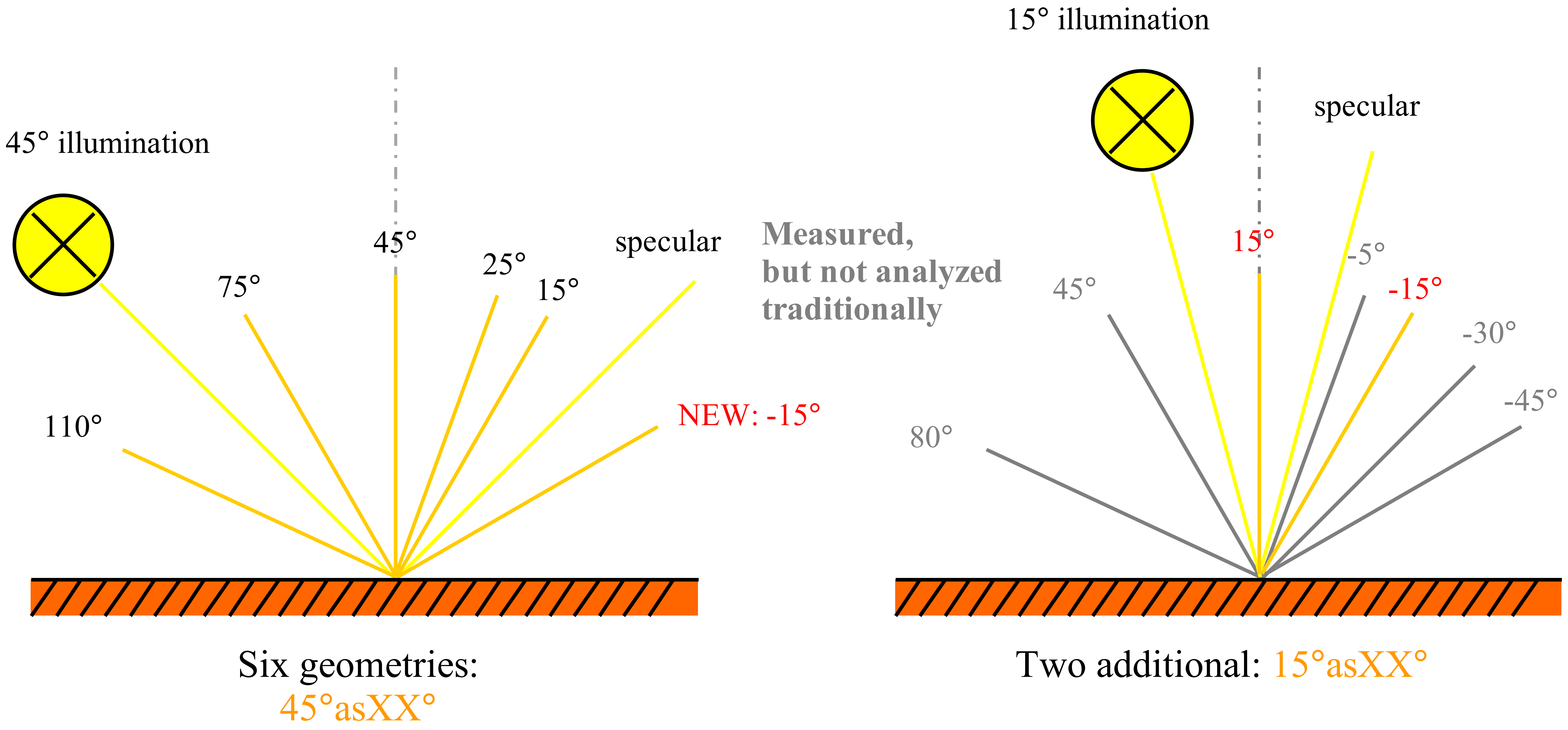
„Face“
45° illumination

„Flash“
behind gloss
45° illumination

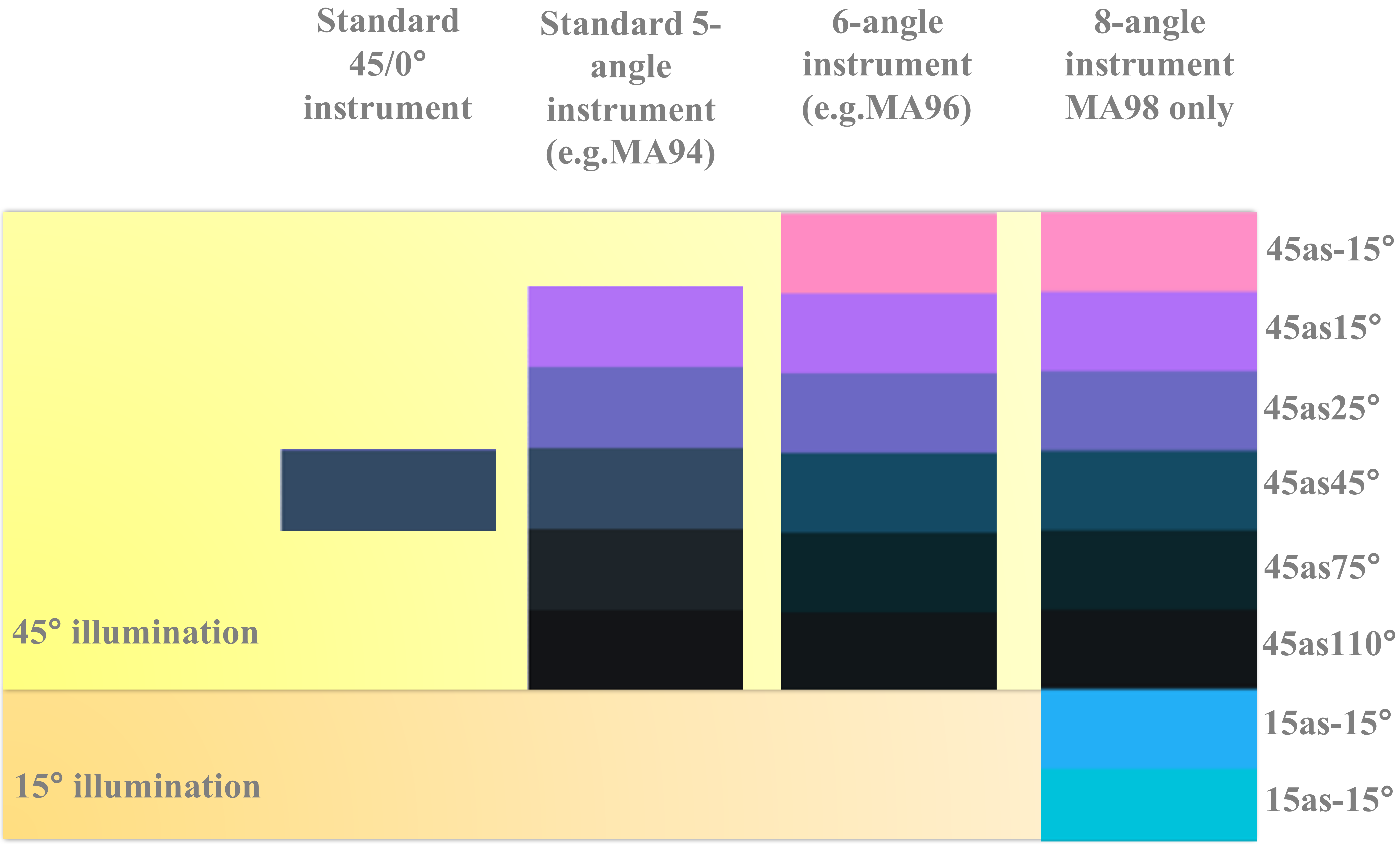
Out of plane geometry

Measurement Geometries

•The MA98 is a portable device equipped with two light sources in order to be compliant to the new standard ASTM E2539 – 08



Results Of A Second Light Source



What Is Material Appearance?

APPEARANCE

≠ JUST COLOR!

≠ JUST A PICTURE!

= THE **VISUAL SENSATION** THROUGH WHICH AN OBJECT IS PERCEIVED TO HAVE ATTRIBUTES AS **SIZE**, **COLOR**, **TEXTURE**, **GLOSS**, **TRANSPARENCY**, **OPACITY**, ETC.!

ALL THESE OBJECTS ARE BLACK BUT THE APPEARANCE VARIES SIGNIFICANTLY

TOTAL APPEARANCE CAPTURE IS THE DIGITIZATION OF MATERIALS WITH TRUE, FULL **APPEARANCE** MEASUREMENT.

APPEARANCE CONSISTS OF:

- **COLOR**
- **TEXTURE (SPATIAL VARIATION IN COLOR)**
- **GLOSS**
- **VARIATION OF HEIGHTS**
- **TRANSLUCENCY OR TRANSPARENCY**

Perceptual Transformations
- Contrast Sensitivity
- Tone-mapping
- Adaption
- Context

Scene
- Direct/indirect lighting
- Lighting color
- Surround
- Object proximity

Material
- Composition
- Physical Properties
- Optical Properties

Viewer
- Distance
- Angle

Geometry
- Size
- Shape
- Surface Texture
- Construction

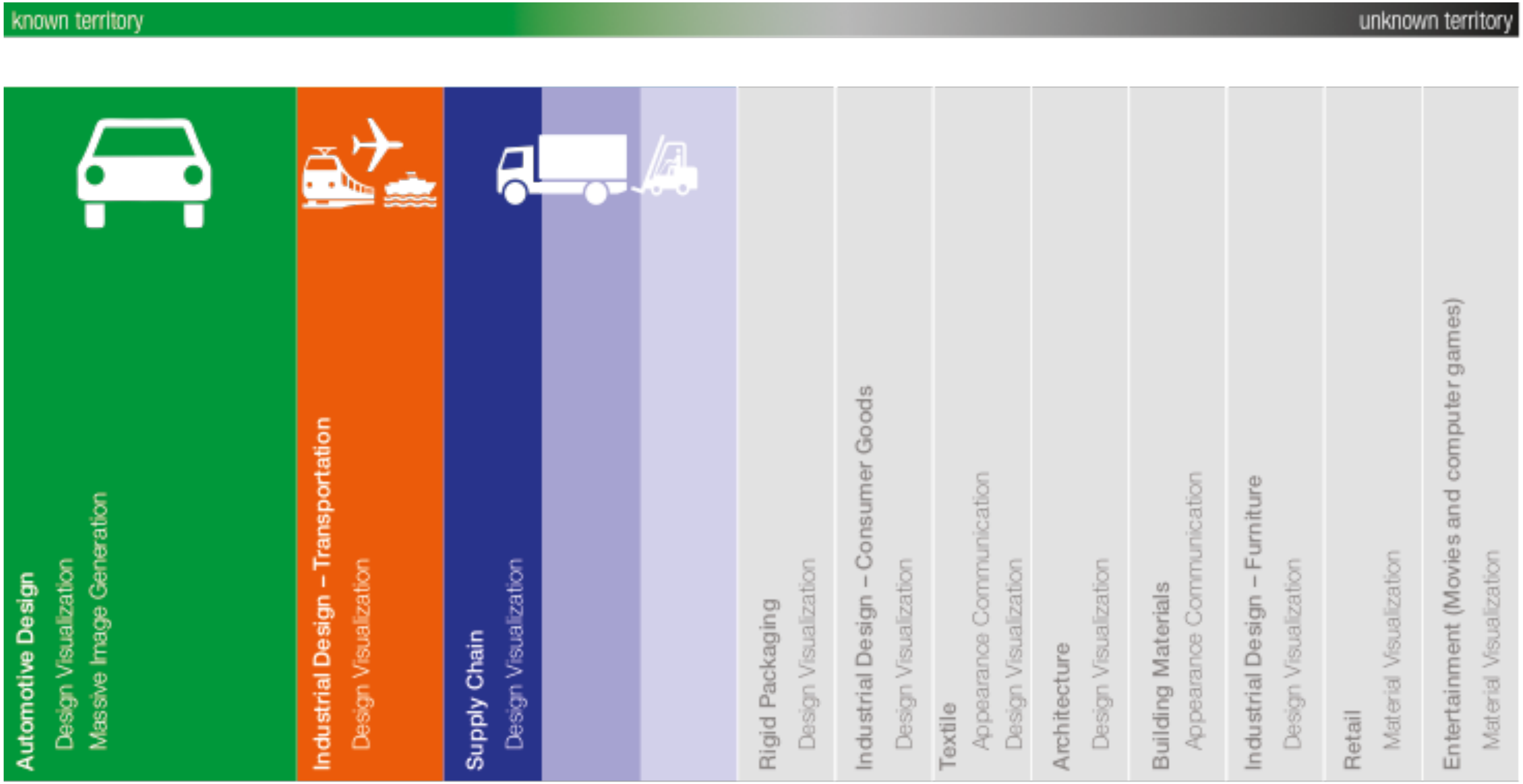
APPEARANCE

AxF

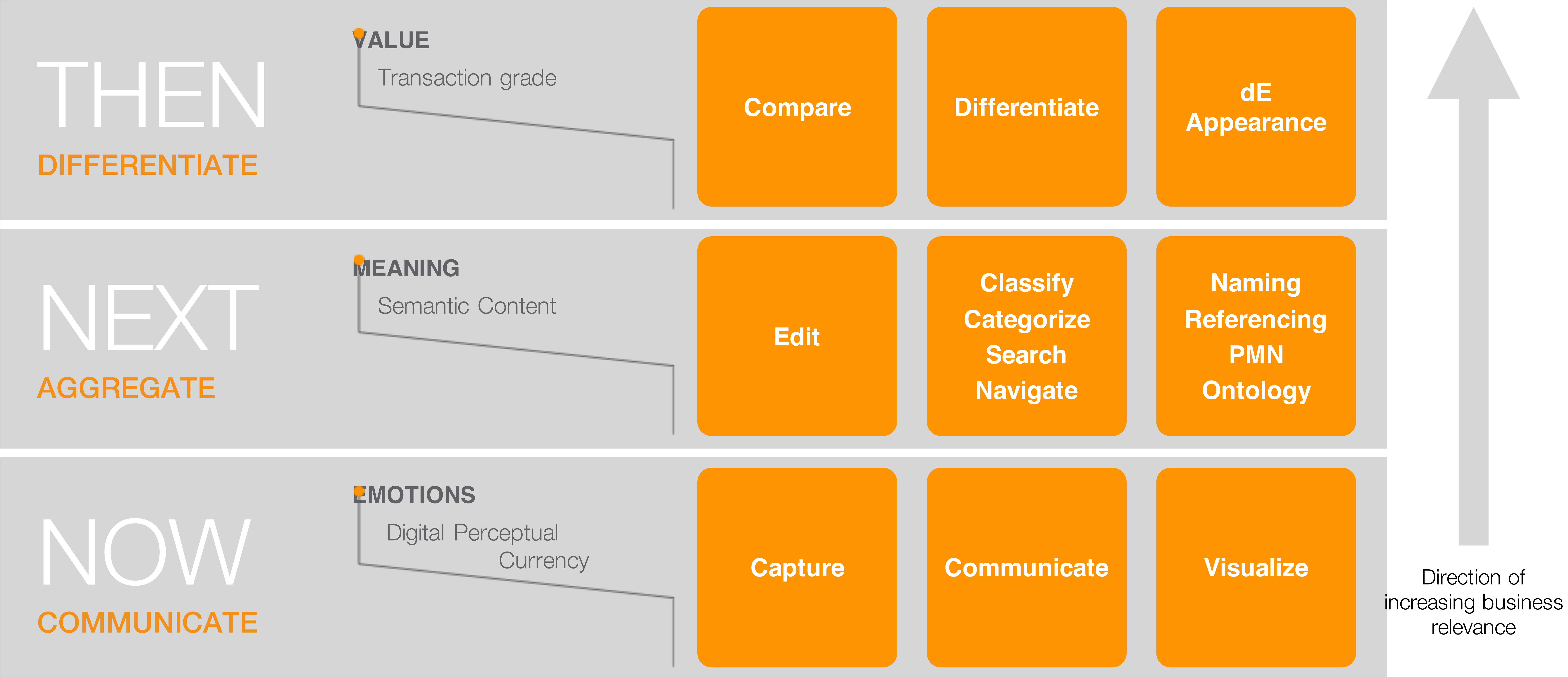
- is the vehicle to describe and transport appearance
- is "neutral", platform- and device-independent
- makes appearance exchangeable and tradable
- functions as a "tamper-proof" material standard
- allows material certification
- connects to real-world materials and SKUs
- drives the PANTONE Material Nomenclature (PMN)

x·rite PANTONE®

Segmentation



The Ecosystem Of Digital Appearance: Functional Articulation



X-RITE TOTAL APPEARANCE CAPTURE ECO SYSTEM

Digital Material **Creation**

X-Rite
Scanning Service
DOME (Switzerland)
TAC7 (USA and Japan)

X-Rite
TAC 7 Scanner

X-Rite
Formulation Software

AxF

Digital Material **Communication**

X-Rite
Material Hub Software (Pantora)

AxF

PANTONE®
Material Catalog iOS (Silk)

AxF

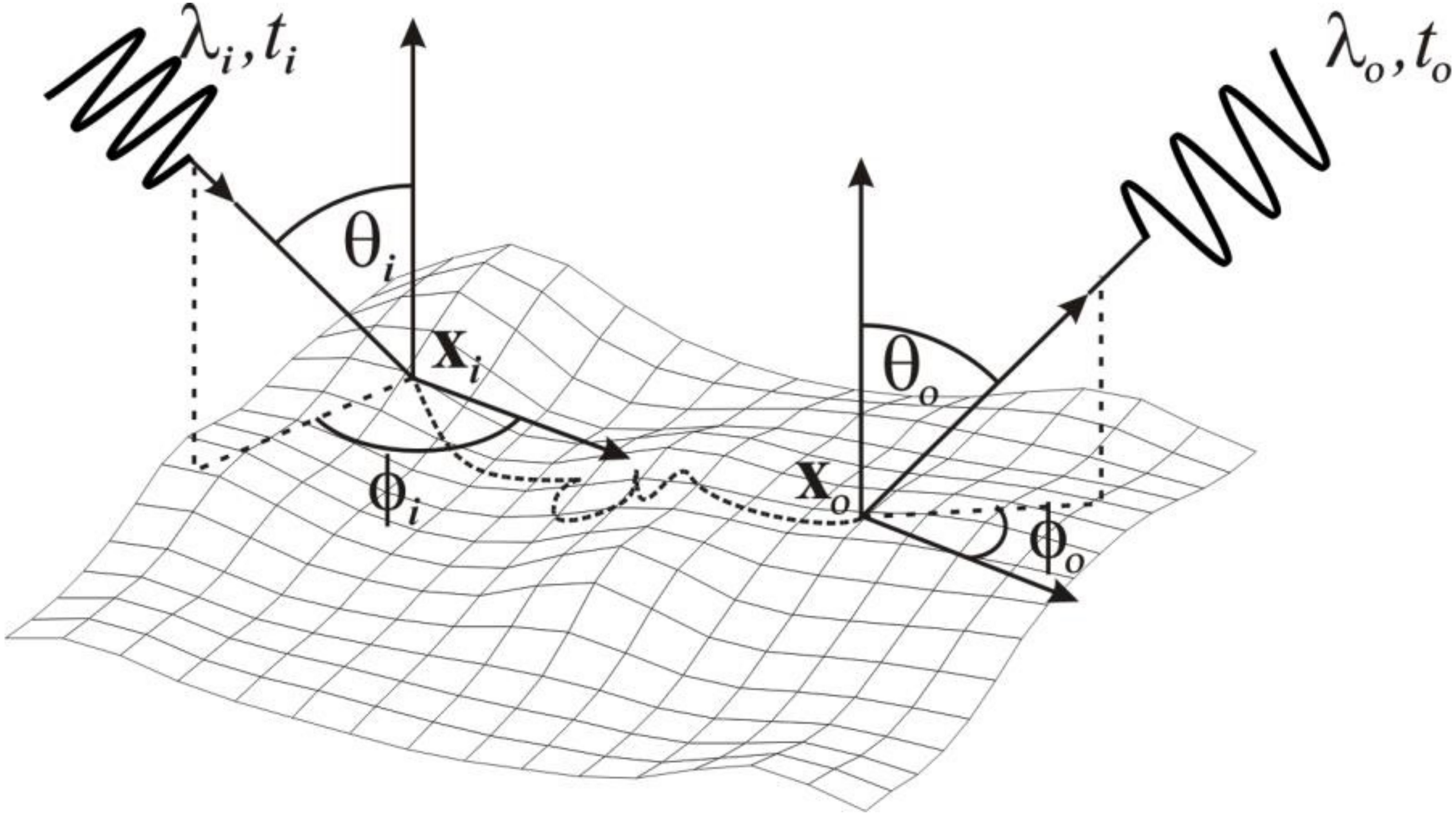
Digital Material **Visualisation**

AUTODESK
VRED™ Professional 2016
VRED™ Professional 2017

NVIDIA
Iray® (available mid 2016)

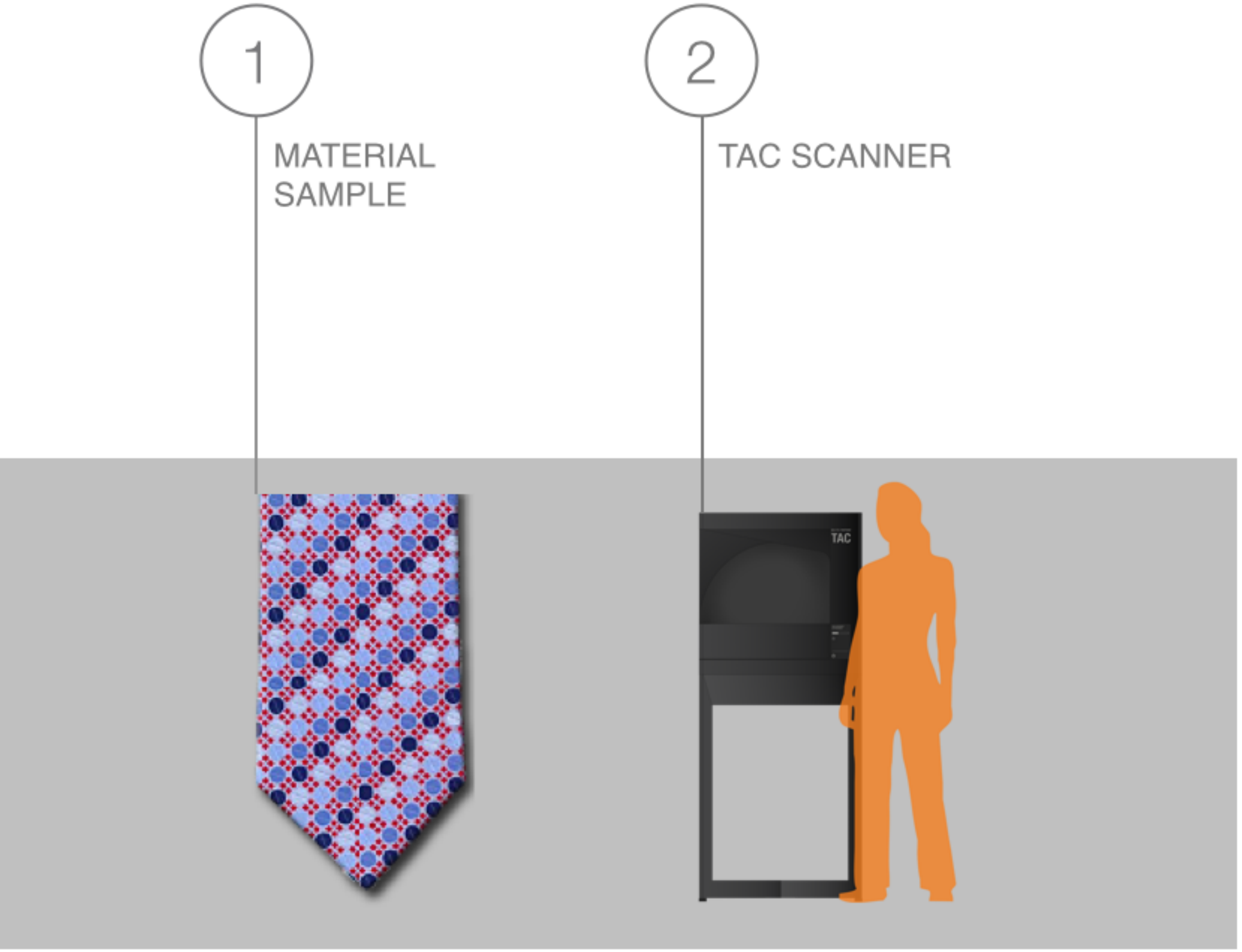
LUMISCAPHE
support announced for mid 2016

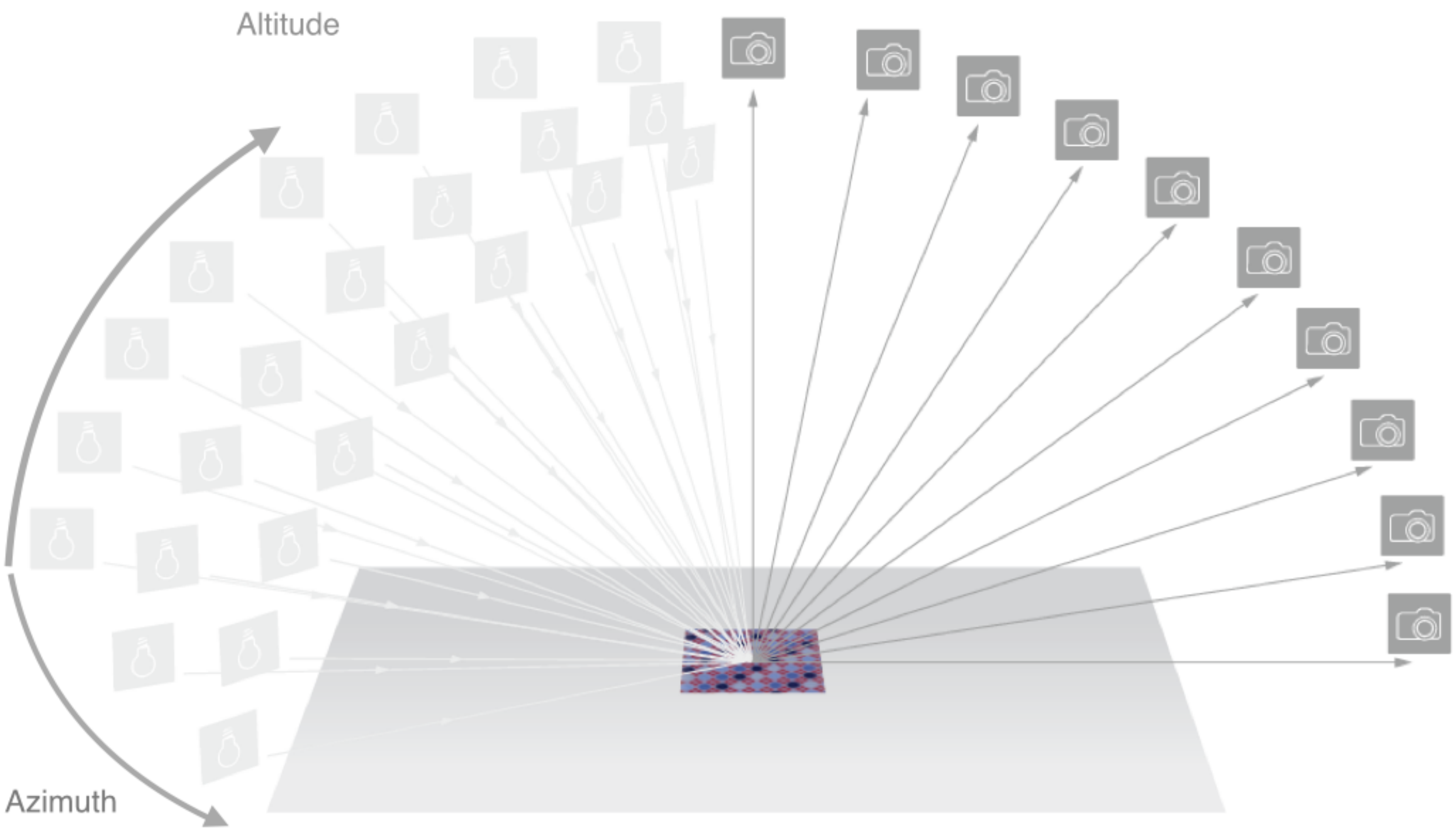
x·rite
PANTONE®



λ_i, t_i
λ_o, t_o
θ_i
θ_o
$\mathbf{x}_i$
$\mathbf{x}_o$
ϕ_i
ϕ_o

INTRODUCTION: **HOW IS A MATERIAL VIRTUALISED?**





INTRODUCTION: **HOW IS A MATERIAL VIRTUALISED?**

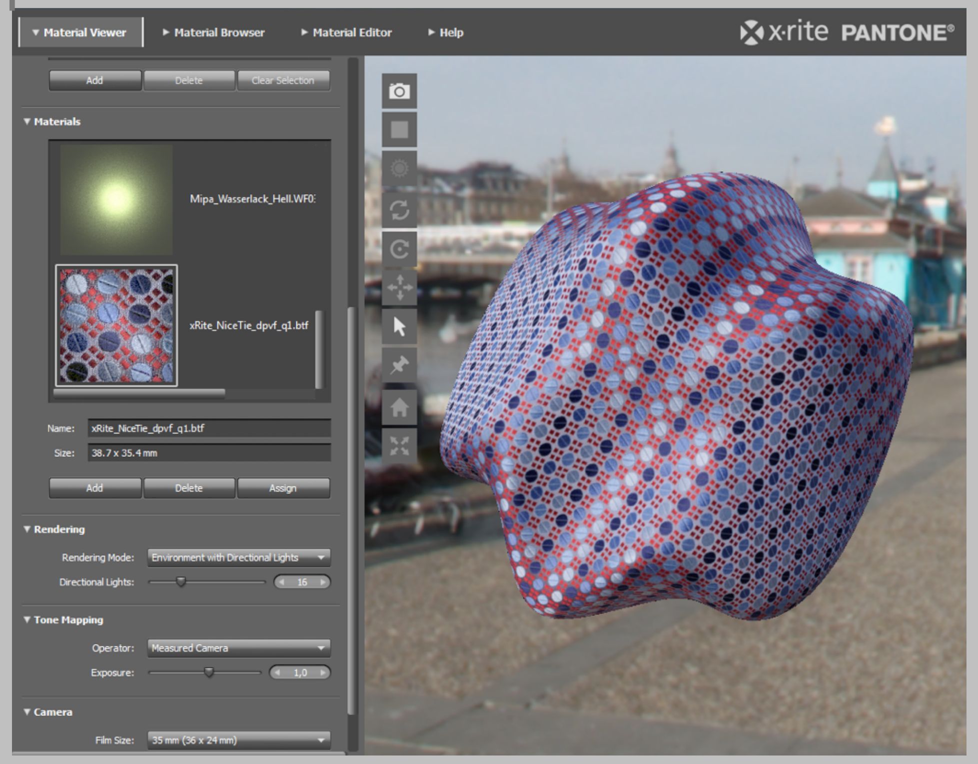
3

POST-PROCESSING GENERATES AN APPEARANCE EXCHANGE FORMAT (AxF) FILE

4

THE PANTORA MATERIAL HUB OFFERS:

- TAC7 DEVICE CONTROL
- POSTPROCESSING
- MATERIAL EDITING
- VENDOR NEUTRAL MATERIAL LIBRARY MANAGEMENT



5

THE VIRTUAL LIGHT BOOTH ENABLES QUALITY ASSESSMENT BETWEEN THE REAL AND THE VIRTUAL MATERIAL

6

RENDERING APPLICATIONS LIKE AUTODESK VRED OR NVIDIA IRAY CAN ALREADY READ THE AXF FORMAT. PANTORA ALSO OFFERS EXPORT TO SOME OTHER MATERIAL FORMATS.

TOTAL APPEARANCE CAPTURE RENDERING PROCESS

1

- Radiometrically calibrated images from TAC7 device

2

- AxF SVBRDF
  - normal-map
  - spatially varying parameters for analytical BRDF model
  - different BRDF models for different types of material samples
  - diffuse albedo is obtained as calibrated trichromatic or multi-spectral
  - height map

3

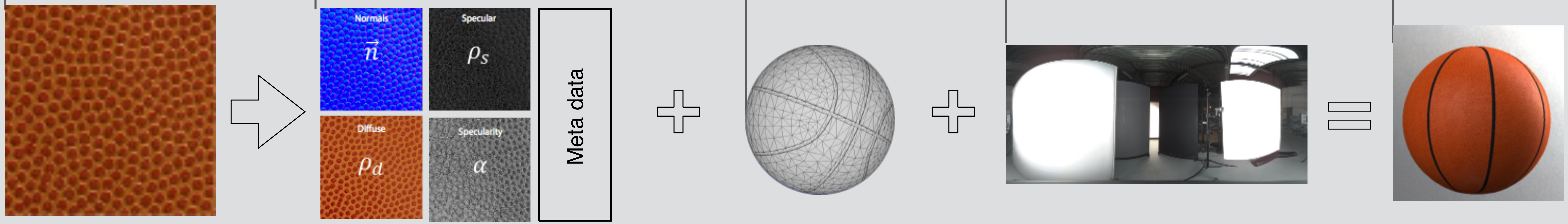
- CAD wireframe model of object

4

- 360º High-dynamic-range image of environment

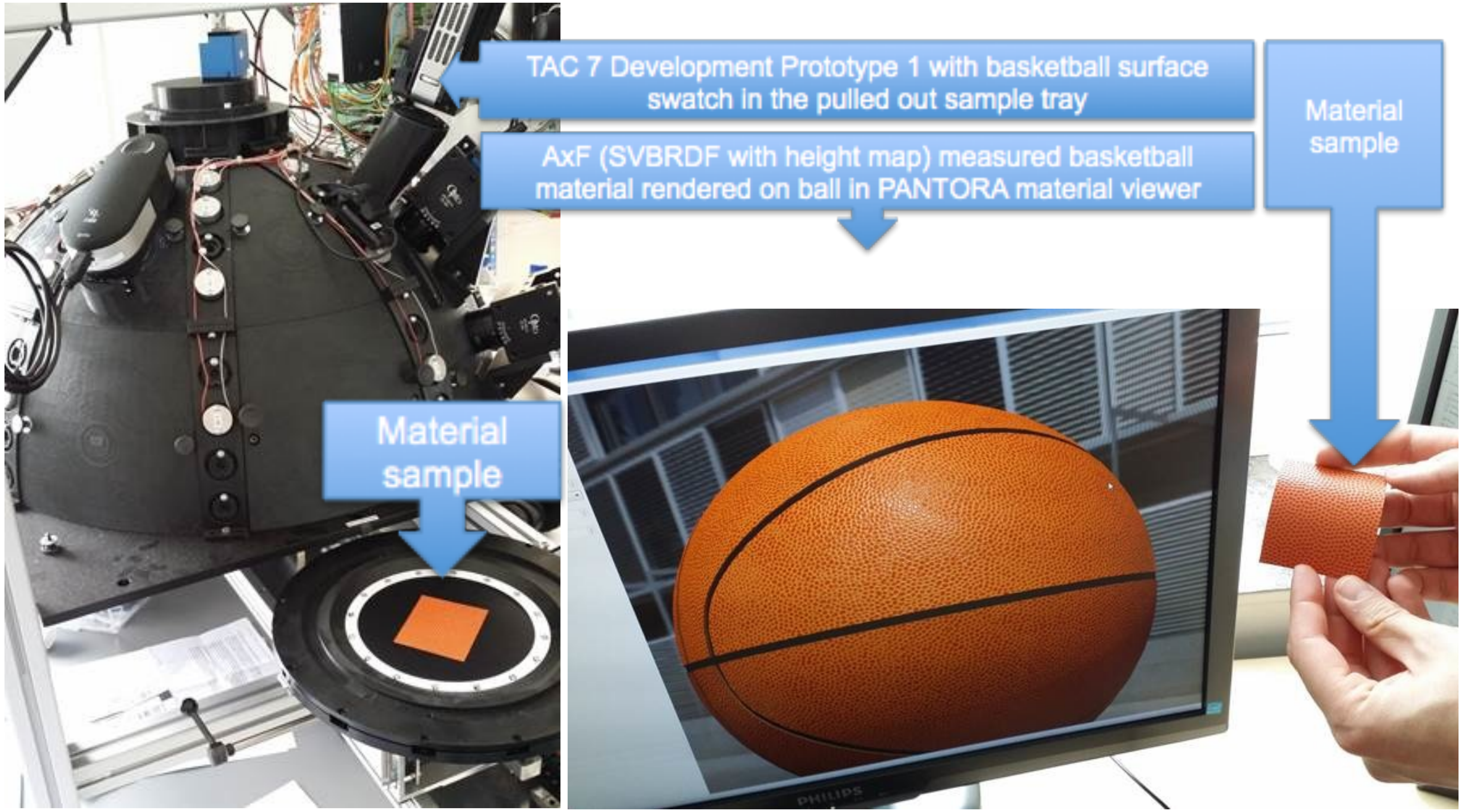
5

- Photorealistic rendering



unbiased rendering pipeline

TOTAL APPEARANCE CAPTURE TAC 7 RESULTS



x·rite
PANTONE®

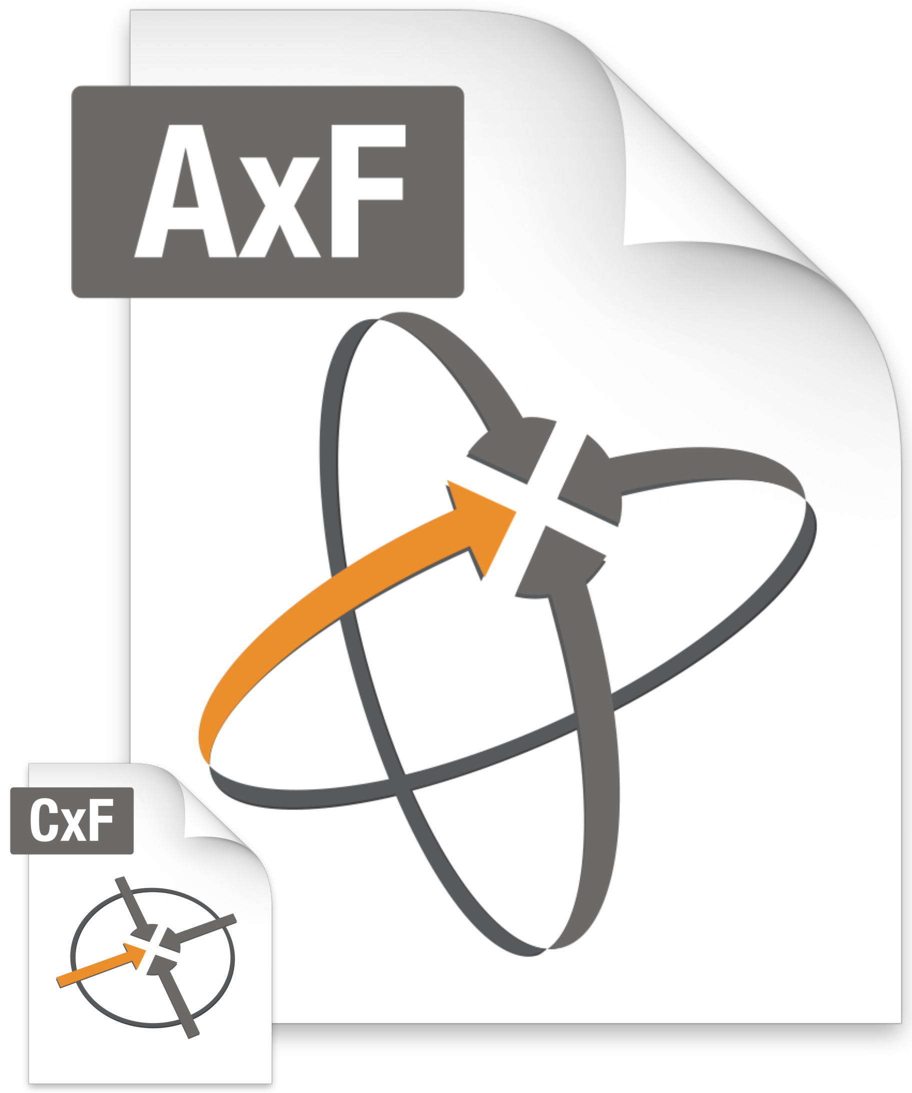
CxF VS. AxF - X-RITE EXCHANGE FORMATS

The data format to communicate color digitally is the

Color eXchange Format (CxF)

CxF was originally developed by X-Rite in the early 2000s as a universal language for transporting **complete color information** from concept to final production across devices, applications and geographies. It was handed over to the International Standards Organisation and has now been published as an ISO standard: **ISO17972 Graphic technology – Colour data exchange format (CxF/X)**

CxF is based on **XML** and can include spectral color values, named colors such as PANTONE®, color spaces and appearance effects (specific lighting conditions, type of substrate, type of ink, density, opacity, transparency of the color, gloss, texture, position and shape of color patches), as well as commercial aspects, mathematical, optical conditions, etc.



- COLOR
  - TEXTURE (SPATIAL VARIATION IN COLOR)
  - GLOSS
  - VARIATION OF HEIGHTS
  - TRANSLUCENCY OR TRANSPARENCY

The data format to communicate appearance digitally is the

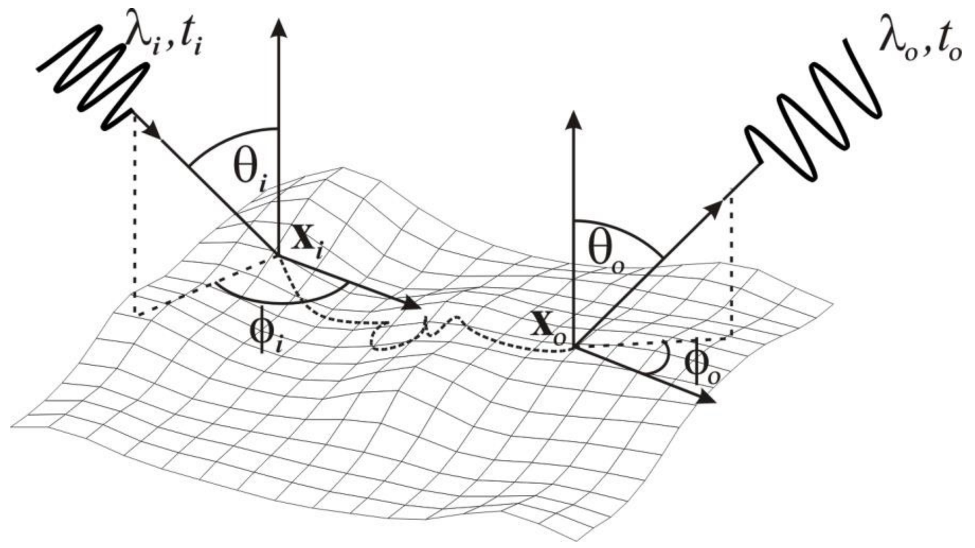
Appearance eXchange Format (AxF)

AxF is a newly developed data container to transport **complete appearance information** of materials across devices, applications and geographies.

In contrast to CxF the information is stored as **binary data** to master the significantly bigger data volume which is needed to describe the total appearance of a material.

AxF is developed as an **complement to the CxF** format and it is able to store CxF based color information inside to save the color information of an material.

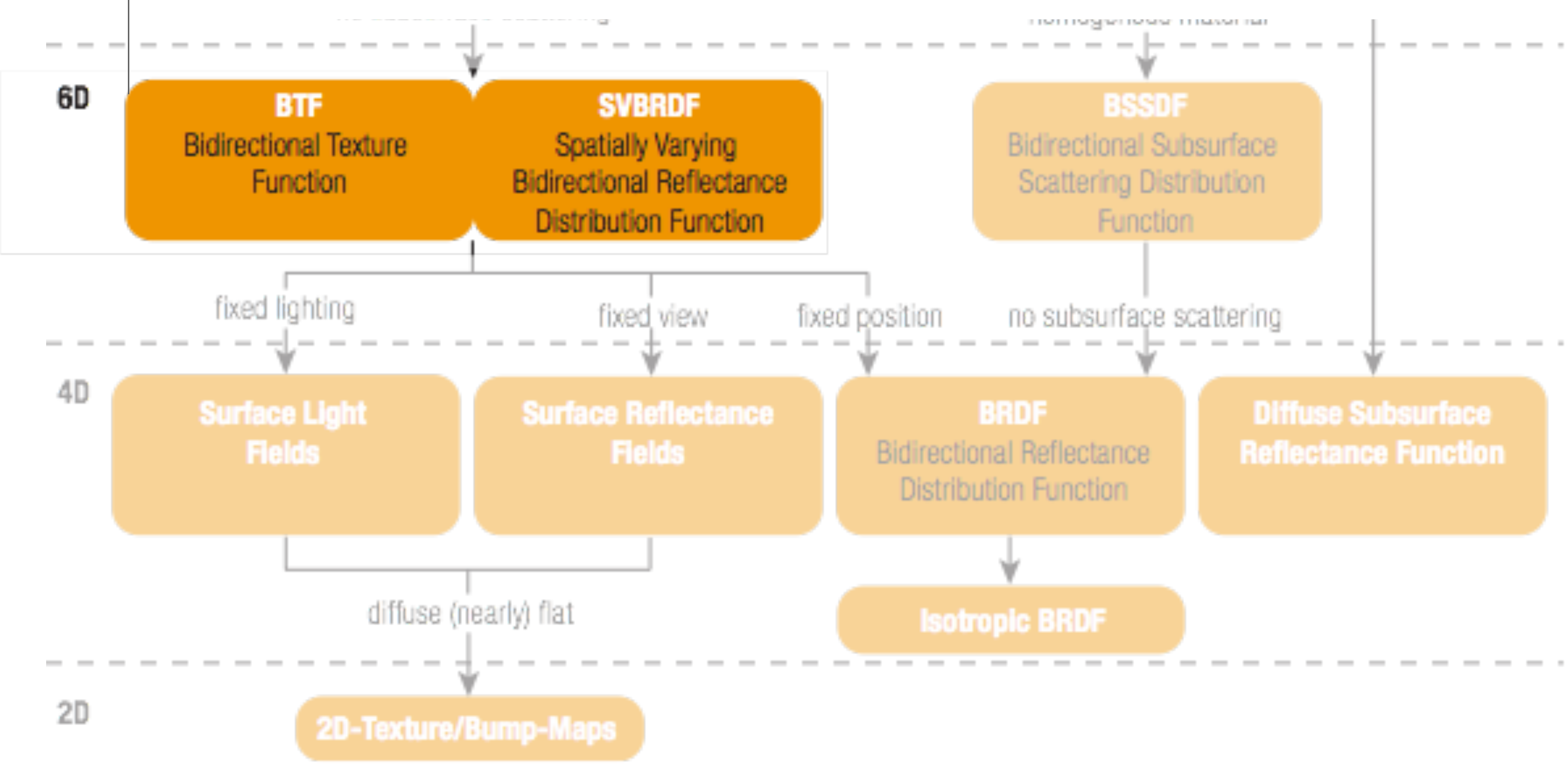
It is our intend that the format gets the same wide adoption across different application and devices like the CxF format today.



MODELLING LIGHT TRANSPORT: HIERARCHY OF B*x*DF FUNCTIONS

- Reflectance functions (**B*x*DF**) are a set of multidimensional mathematical functions which describe the way in which light interacts with the surface of a material.
- **B*x*DF**s are often used in computer graphics for photorealistic rendering of synthetic scenes and in the field of computer vision for object recognition.
- The original idea was to abstract light transport from geometric and physical detail
- The different reflectance functions vary in complexity and are typically limited to specific material types (e.g. transparent or opaque materials).

- THE INDIVIDUAL IMAGES PRODUCED BY THE TOTAL APPEARANCE CAPTURE DEVICE ARE PROCESSED AFTER THE SCANNING PROCESS AND A **BTF** OR **SVBRDF** IS GENERATED AS AN OUTCOME. THESE MATERIAL DESCRIPTIONS ARE STORED AS REPRESENTATIONS IN AN **AxF** FILE.



x·rite PANTONE®

DESCRIBED BY IMAGE RASTER

BITMAP GRAPHICS = BTF

BITMAP to VECTOR CONVERSION = FITTING

MATHEMATICALLY DESCRIBED BY LINES, POINTS, AND POLYGONS

VECTOR GRAPHICS = SVBRDF

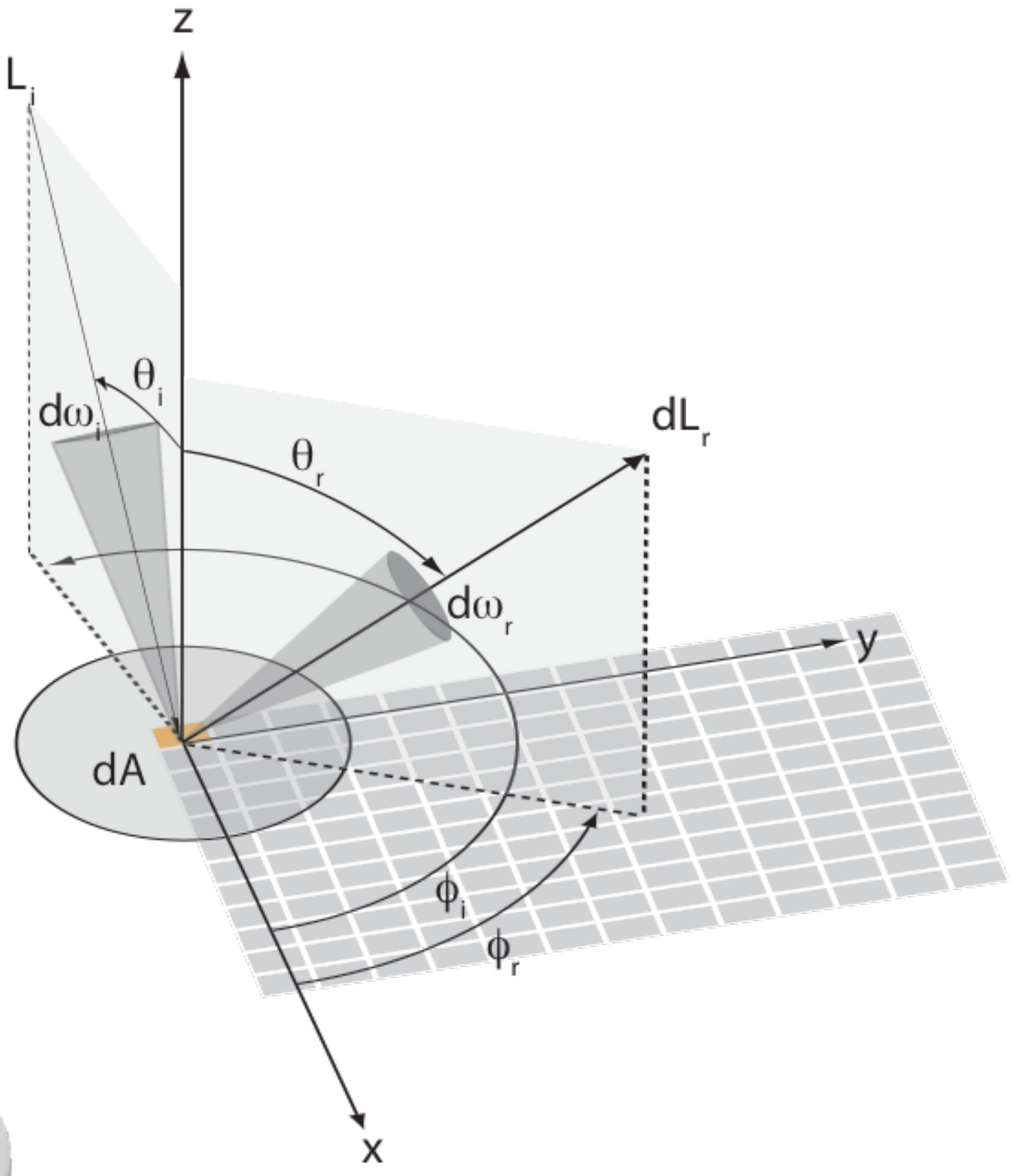
BTF (chunked data)

+ works for most material types regardless complexity
– requires **FULL BTF** acquisition (long measurement time, complex instruments, lots of data)
– AxF: big file size
– limited editing capabilities

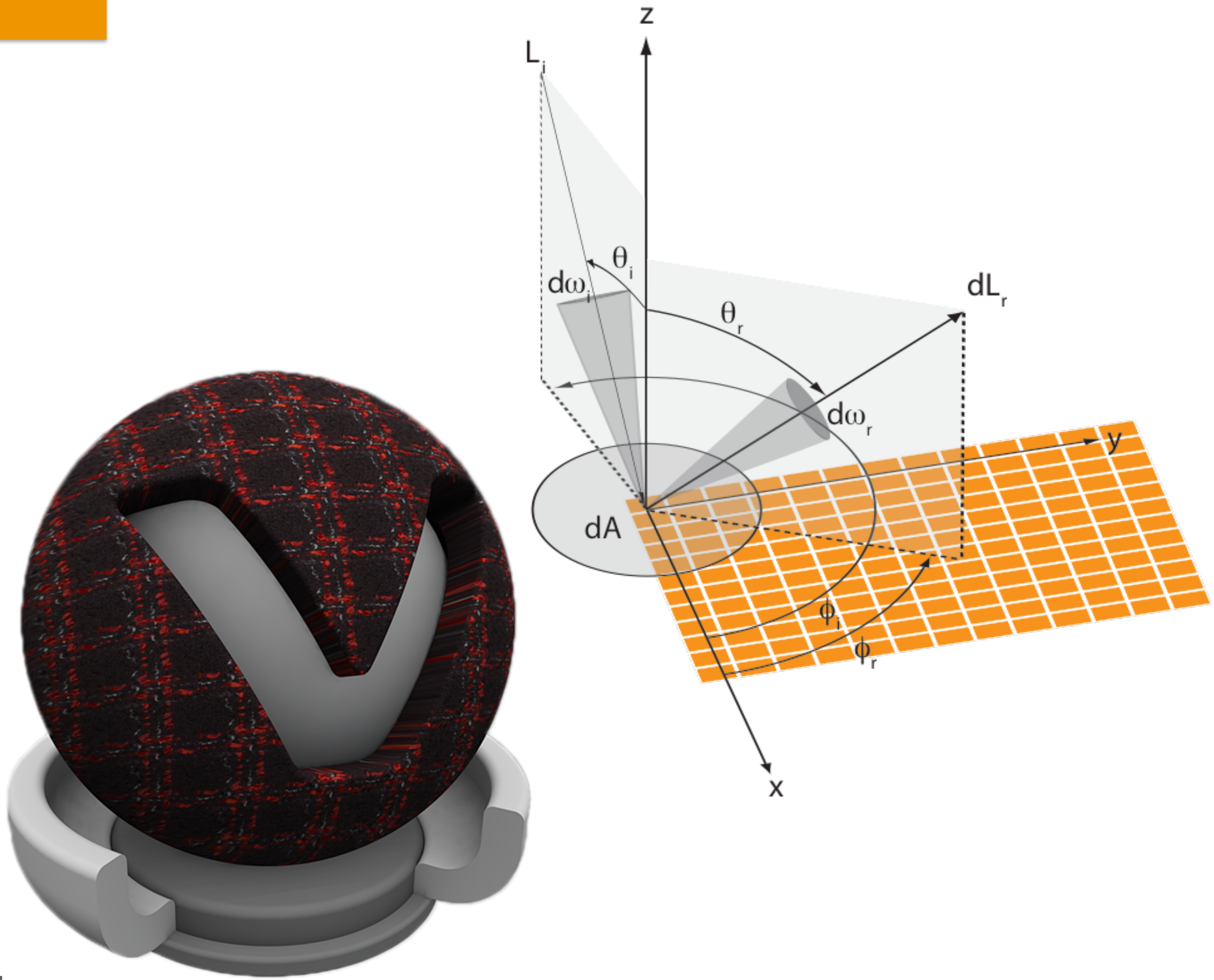
SVBRDF

+ works with **SPARSE BTF** data (shorter measurement time, simpler instruments, less data)
+ AxF: smaller file size and scalable compression
+ good editing capabilities
– results of fitting process dependent on complexity of material

BRDF BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION



- The bidirectional reflectance distribution function (**BRDF**) is a is a 4-dimensional mathematical function that defines how light is reflected at an opaque surface (e.g. metal) scattering distribution from a single point.
- Parametric models for the **BRDF** are widely used in Computer Graphics applications because they require only a few parameters and can be evaluated efficiently.
- Well known examples are e.g. the Blinn-Phong , Ward or Cook-Torrance models which can describe the appearance of materials like plastics or metals.



- If the bidirectional reflectance distribution function (BRDF) considers in addition the planar texture coordinates (x,y) we speak of a spatially varying bidirectional reflectance distribution function (**SVBRDF**).
- The **SVBRDF** is a 6-dimensional mathematical function that defines how light is reflected at an opaque surface. In contrast to the BRDF the **SVBRDF** can also describe textured or inhomogeneous opaque materials.

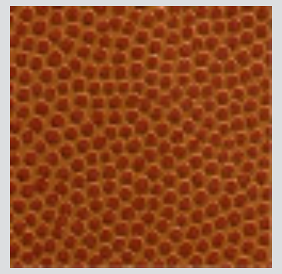
WORKFLOW DIFFERENCES DOME AND TAC7

1 — Data acquisition

2 — Post-processing

3 — Data format / material representations

DOME

- **FULL BTF** (raw data)
  - up to **1.5 TB** data
  - up to **8 hours**

RAW → Paint

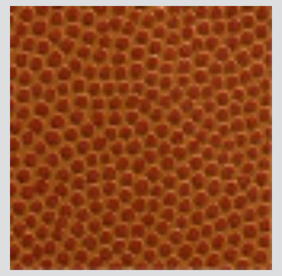
RAW → Generic

- Full BTF **fitted to Carpaint** model (BRDF + BTF)
  - 100 MB data typical
  - up to 30 minutes
- **Full BTF** (compressed)
  - up to 250 MB data
  - up to 10 hours

AxF

- CPA (car paint)
- Chunked Data (BTF)

TAC7

- **SPARSE BTF** (raw data)
  - up to **20 GB** data
  - up to **30 minutes**

RAW → Paint

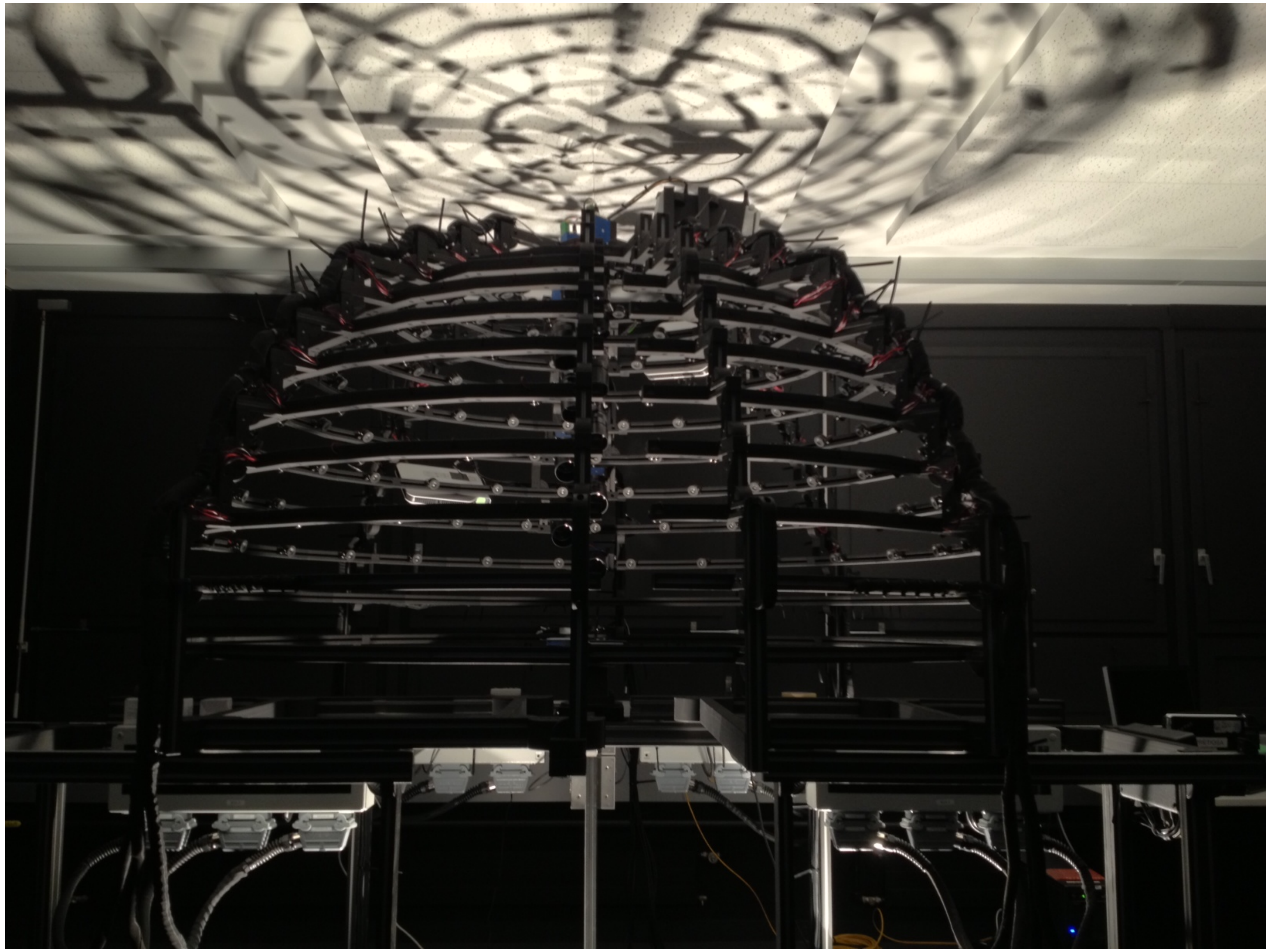
RAW → Generic

- Sparse BTF **fitted to Carpaint** model (BRDF + BTF)
  - 100 MB data typical
  - 15 minutes typical
- Sparse BTF **fitted to SVBRDF**
  - 20 MB data typical
  - 15 minutes typical

AxF

- CPA (car paint)
- SVBRDF normal-map
  - Diffuse albedo map (RGB and spectral)
  - Specular color map (RGB and spectral)
  - Specular roughness map
  - Normal map (which replaces the need for a Bump map as this carries more information)
  - Surface orientation map (to capture anisotropy)
  - Height map (also known as Displacement map)
  - Fresnel map
  - Alpha map

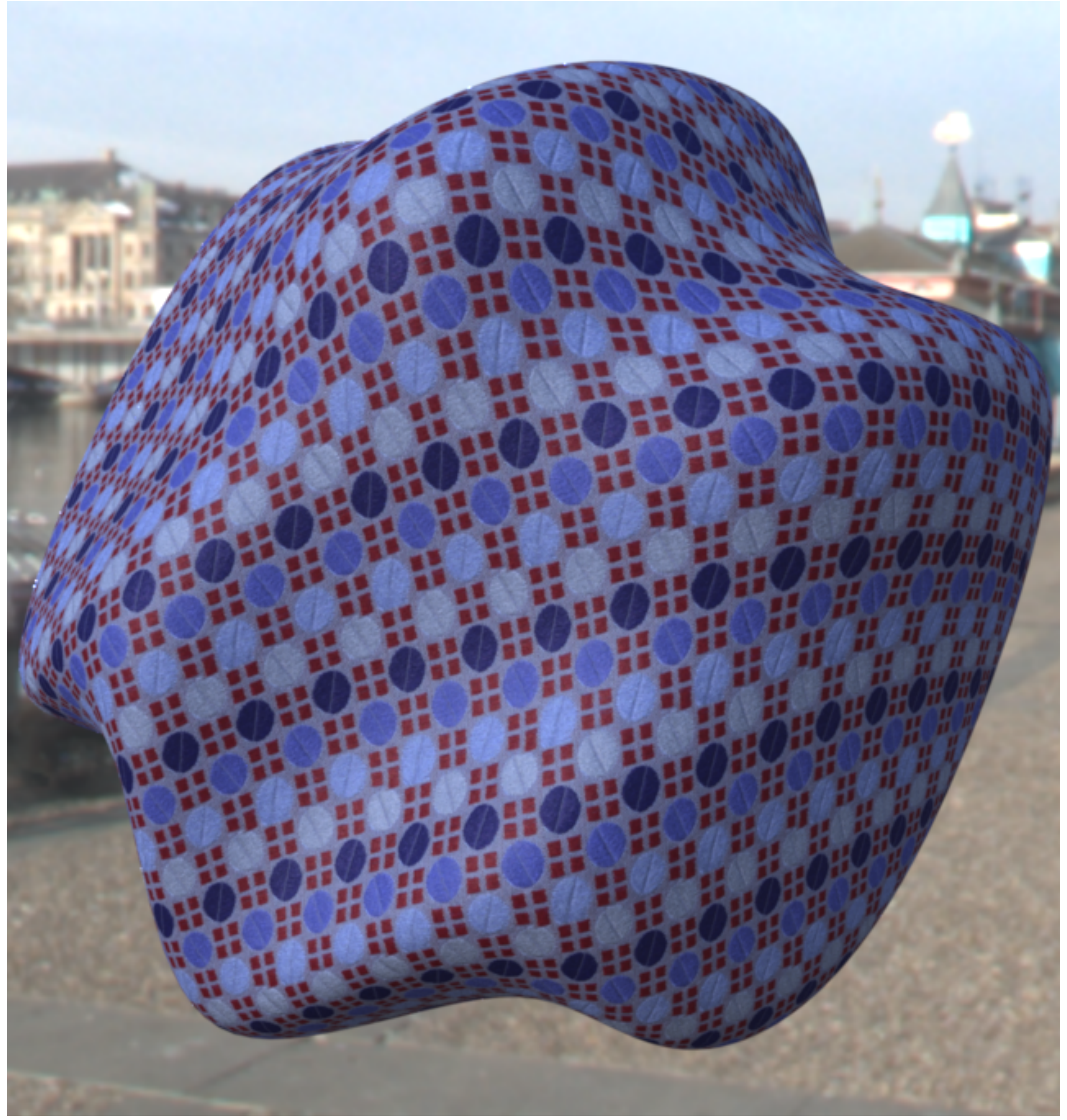
TOTAL APPEARANCE CAPTURE TECHNOLOGY - DOME TAC SCANNER



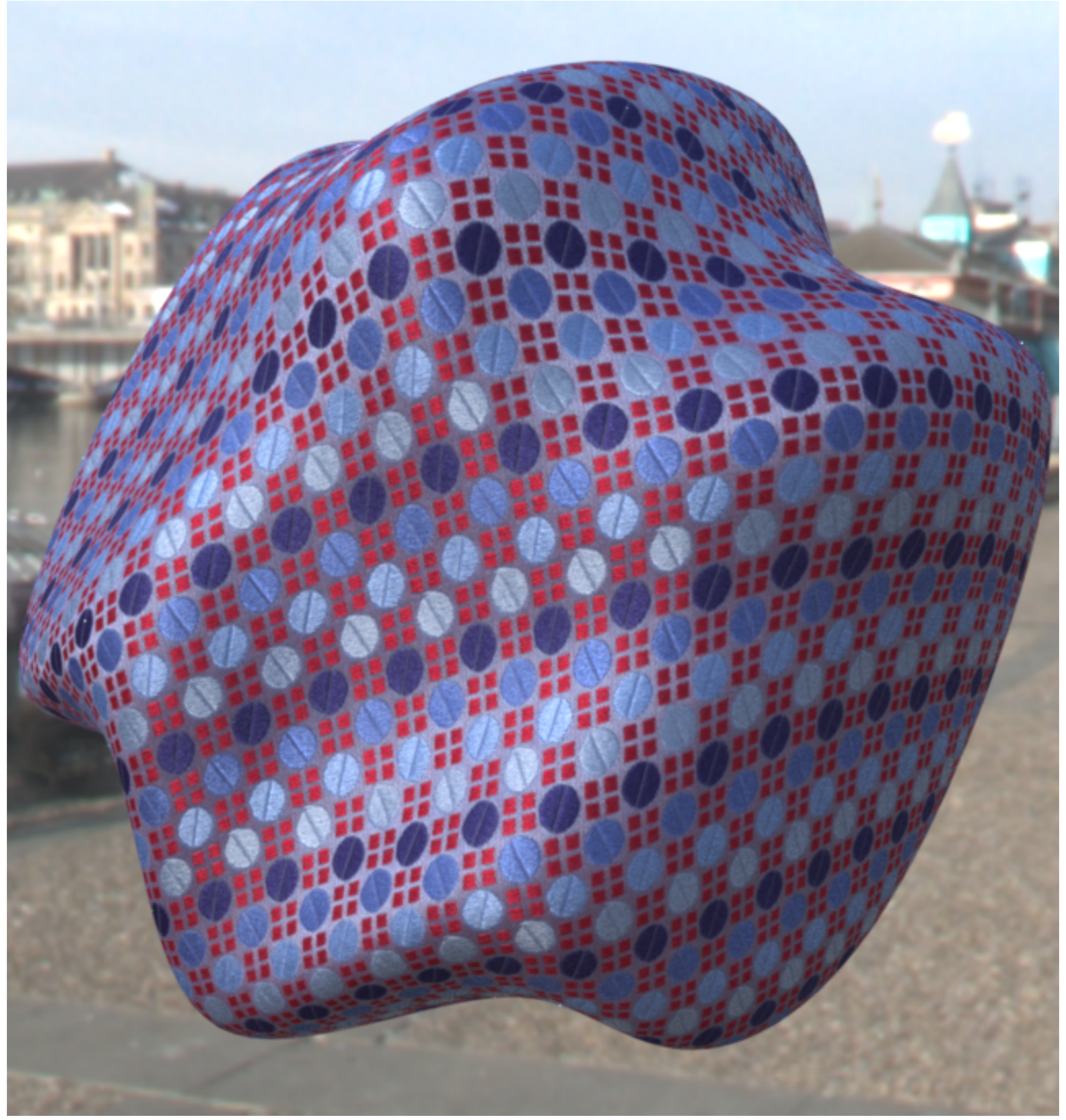
TOTAL APPEARANCE CAPTURE TECHNOLOGY - TAC 7 SCANNER (PROTOTYPE)

- **Diffuse albedo map** (current prototypes are limited to trichromatic color information, will be upgraded to spectral information with AxF 1.3)
- **Specular color map** (current prototypes are limited to trichromatic color information, will be upgraded to spectral information with AxF 1.3)
- **Specular roughness map**
- **Normal map** (which replaces the need for a Bump map as this carries more information)
- **Surface orientation map** (to capture anisotropy)
- **Height map** (also known as Displacement map) (latest feature, currently not used by any rendering application, also our tools like Pantora are not currently make sense out of it)
- **Fresnel map** (AxF 1.1)
- **Index of refraction map** (AxF 1.1)
- **Car paint (CPA)** v1 and v2 (BRDF with 3 lobes and color table + Flake BTF + clear coat)
- **Alpha map** (upcoming feature AxF 1.4)

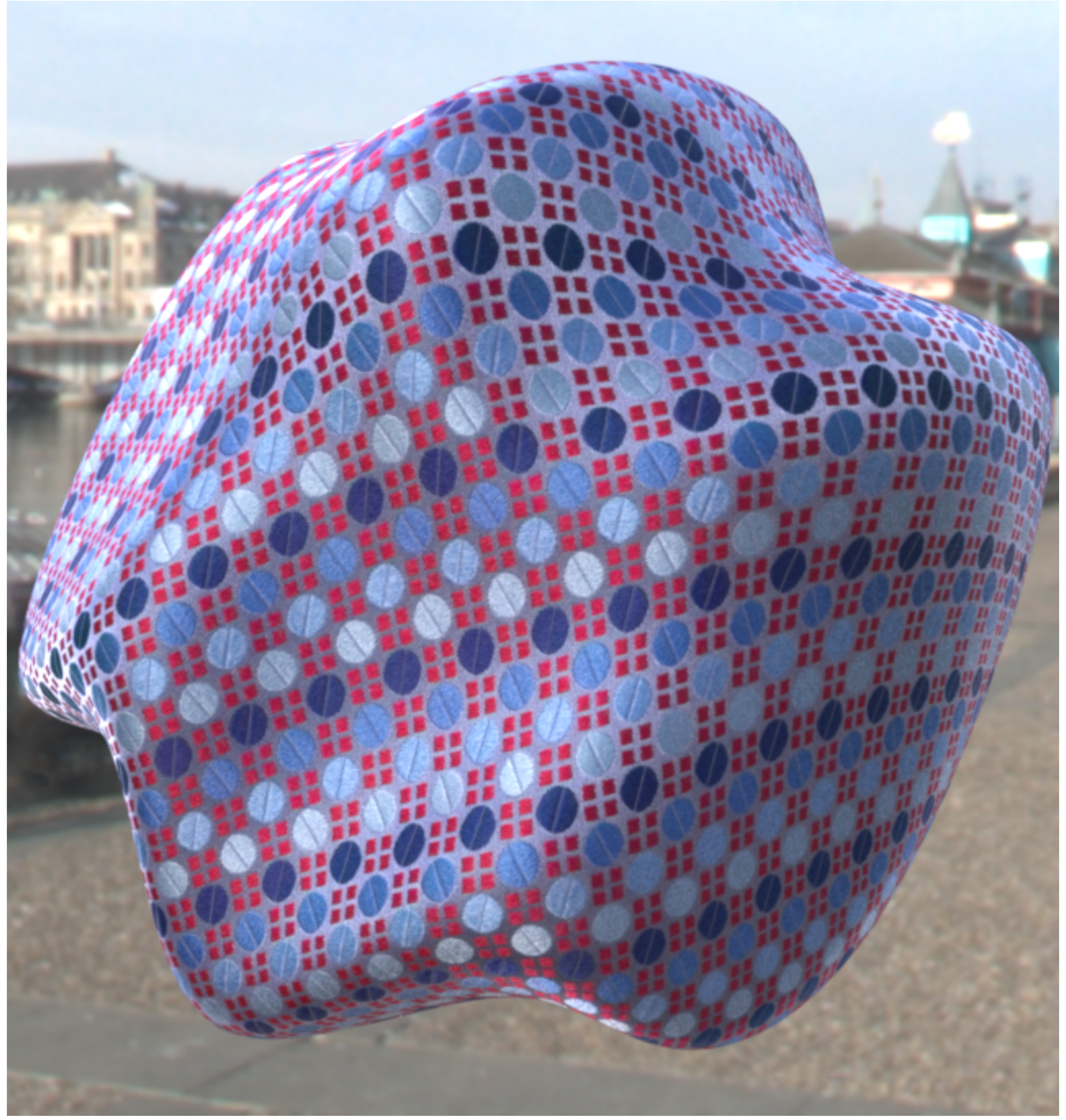
Conventional digital material
Isotropic Ward SVBRDF with spatial variation in diffuse and specular color and normal direction



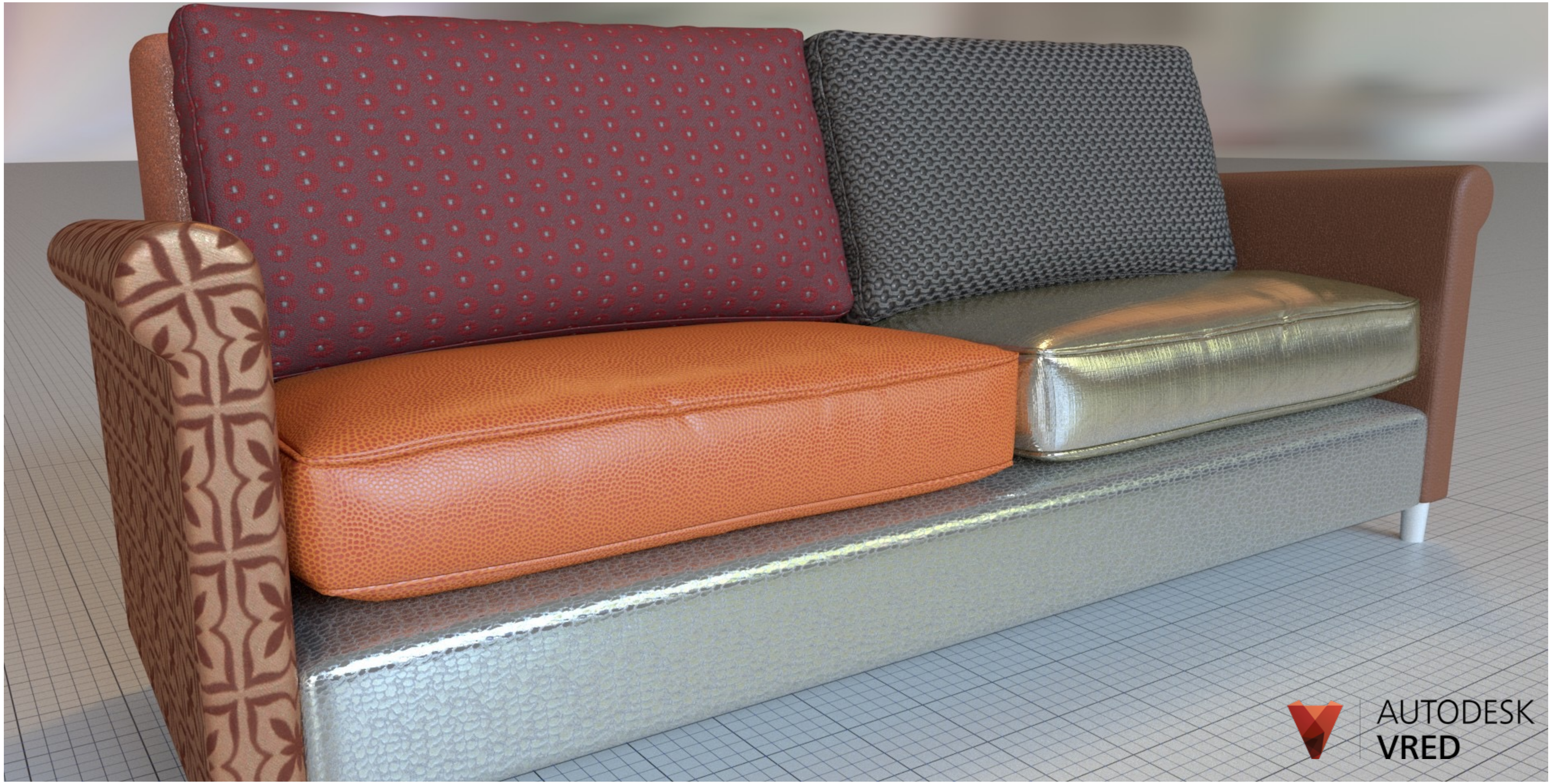
TAC 7 (development prototype)
Anisotropic Ward SVBRDF with spatial variation in all parameters



Dome
Factorized BTF



X-RITE DIGITAL MATERIALS IN AUTODESK VRED



THANK YOU