Color Sampling for Digitized 3D Models: Technologies and Issues

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Talk overview

Decoupling shape and color acquisition/processing

- **Acquiring and mapping apparent color** (using digital photography)
  - Computing the inverse projection (from the image space back to the 3D space)
  - Mapping on 3D geometry
  - Improving image-to-geometry registration

- **More sophisticated color sampling:**
  - Issues for practical usage
  - Flash-based acquisition
  - Using video sequences to recover reflection properties

Prologue & Motivations

COLOR & SPACE IN CULTURAL HERITAGE

- **Digital Cultural Heritage**: the first step is acquiring a **digital model** of the artwork / scene of interest
- Many consolidated technologies available:
  - **Modelling** (Maya, 3DS, …)
  - **Digitization** / **Scanning** (triangulation, TOF, SFM, …)
- *Geometry is not enough: we need technologies for **sampling** and **mapping color data***

What is color? (in CG & physics)

Color is light reflection! So how do we model it?

- **Apparent color**
  - No lighting effects, no moving highlights
  - Lot of illumination-related aliasing (shading, highlights, shadows)
- **Unshaded textures / Albedo**
  - Removal of shading & highlights
- **Spatially varying reflection properties** (e.g. Bidirectional Reflection Distribution Function, **BRDF**)
  - Relightable representation of the real object interaction with light

Image by MPI (Lensch, Goesele)

Why do we need color? (in CH!)

Color is key information leading to **insight!**

- **Basic color**
  - Important to characterize **materials** and **quality/degradation** of materials
  - In many cases, it is **not** calibrated (mandatory in monitoring applications – sampling over time)
  - Should be **high-resolution** & **sharp** (follow photographic quality standards)

- **Reflection properties**
  - Could also be used to characterize **materials** (real gold vs. paint), use for characterizing **degradation** is less common
  - Important for simulating **illumination effects** (museum design, re-illumination of environments)

Color acquisition & mapping

1. **Digitize geometry**
2. **Acquire dense set of photos**
   - Should cover all artifact surface
   - Acquired under diffuse lighting? Using other solutions to have better samples?
3. **Mapping** onto the 3D mesh:
   - Compute **inverse projection** (from images to mesh): **I2G registration!**
   - **Integrate/blend** and **map** on the 3D model:
     - Texture?
     - Color-per-vertex?
     - Just point-based output?

Color data mapping

Issues:

- Color is sampled in a **redundant** manner (useful to reduce aliasing, e.g. shadows, specular effects, defocusing, pigeons, etc.)!
- Color sampling can be 1-2 order of magnitude **denser** than geometry!
- Much easier to **spot inaccuracies** in color mapping (ghosting, blurring, missing/wrong colors) than geometry inaccuracies!

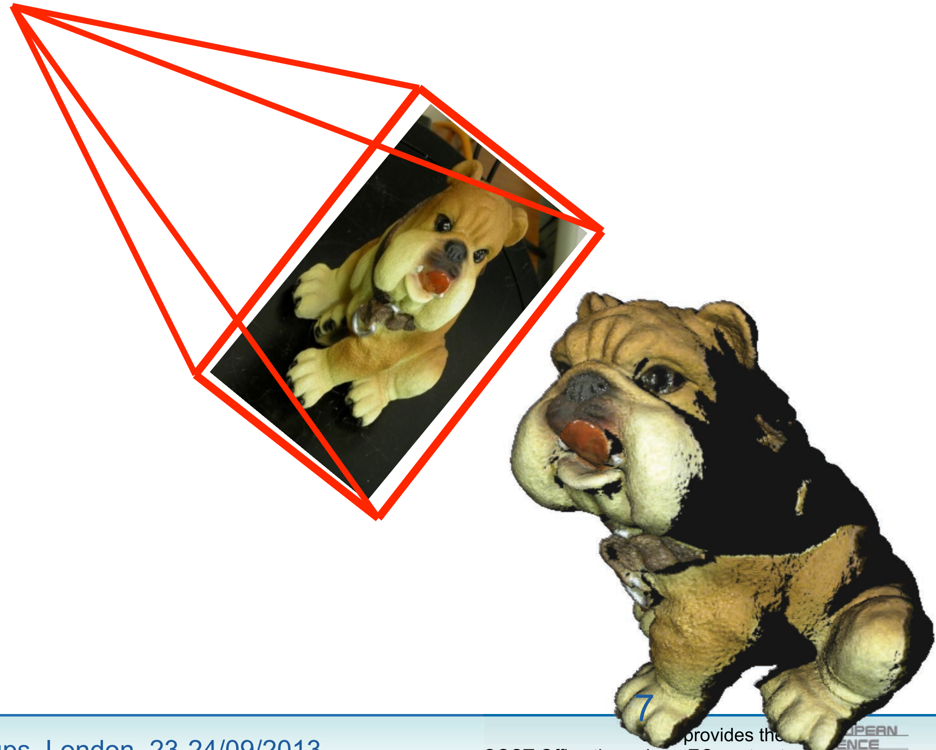
Basic ingredient: **color projection**

COLOR & SPACE IN CULTURAL HERITAGE

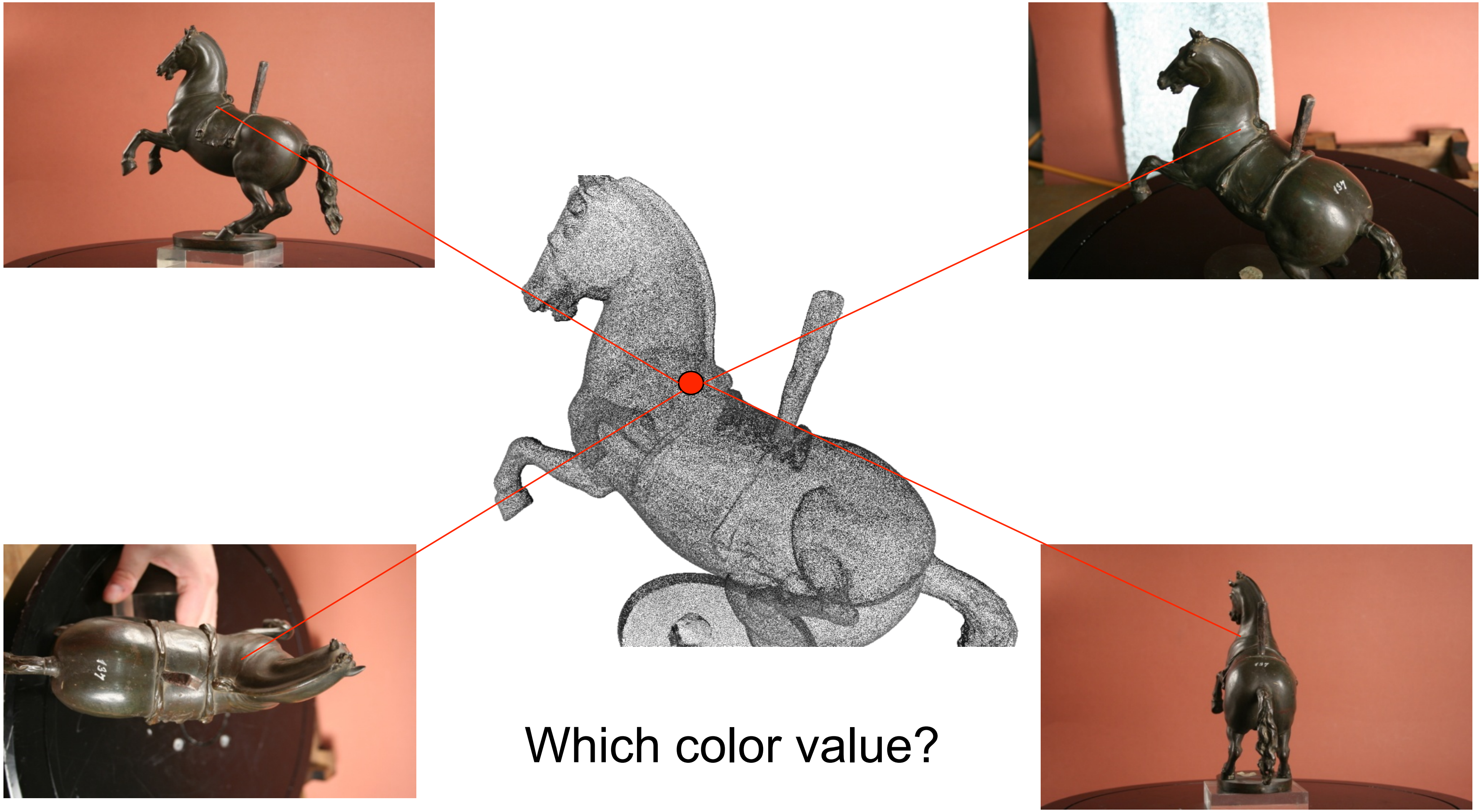
Start from a set of photos covering the surface of the object. In each photo, color information is stored according to optical laws of perspective ...

If camera parameters can be recovered, it is possible to project back the information onto the geometry

Simple and effective...



Mapping the color information



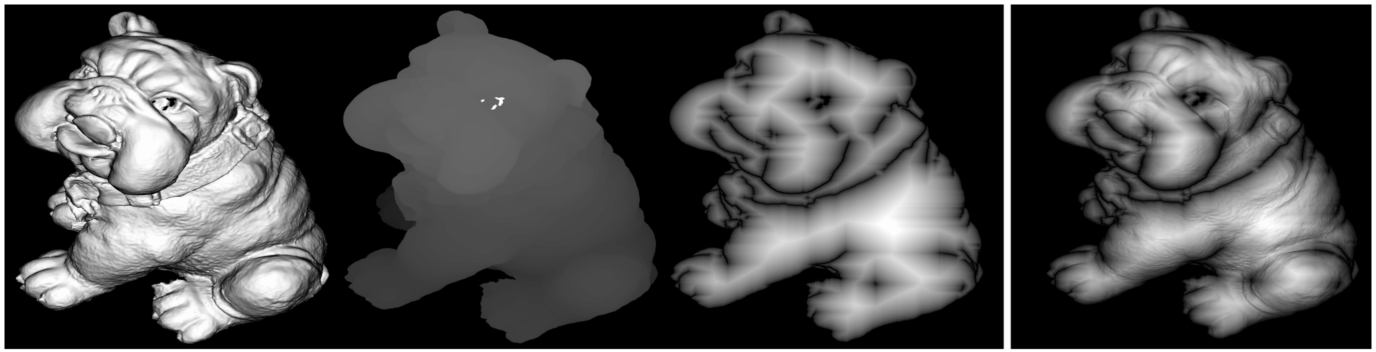
Which color value?

Weighted average

- Many images map to the same object region ==> use a **weighted average to blend** the available color data (out: resampled texture or color-per-vertex)
- Naïve blending usually introduces **blurring**, due to:
  1. Inaccurate alignment
  2. Inappropriate image content (e.g. different resolution density)
- A more sophisticated weighted blending
  – **Weights**: should be **per-pixel**
  – Process input images, and classify the **quality** of each pixel according to several heuristics
  – **Use available shape knowledge!** (For each pixel, compute **depth** and **curvature** from the aligned 3D model) to design weighting kernels

Weighted average [2]

- Compute multiple **masks** for each image to be projected on the mesh:
  - View angle (sampling quality)
  - Depth (sampling resolution)
  - Distance from border (sampling quality)
  - Stencil (remove image portion)
  - Focus (sharpen focus)
  - … others …
- Compose all masks and use resulting value as **per-pixel weighting factor** when blending corresponding pixel with other images' pixels



Angle mask **Depth mask** **Border mask** **Composite**

Accurate color ⇔ Accurate Registration!

- Any weighted integration or inverse illumination approach produces severe aliasing / errors if we have **residual registration error**
  - Insufficiently image-to-geometry accuracy in aligning photos (manual errors, residual of automatic methods…)

- Meshed model are **NOT** the real object – **Geom Approx Error**:
  - Triang.Scanners: +/- 0.1 mm
  - TOF Scanners: +/- 5 mm
  - SFM (images): +/- 1-2 cm

Image resolution vs. 3D models accuracy

Images:

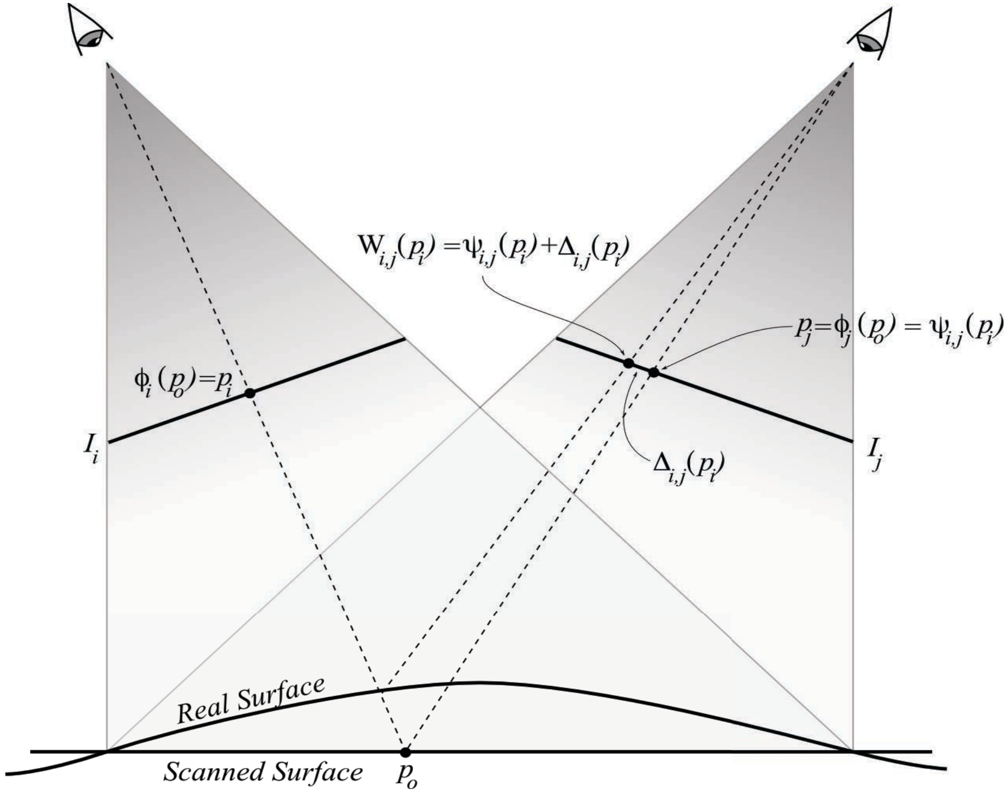
- Consumer: 12Mp
- 4K pix on 50 cm ➔ pixel "size" 0.12 mm

⇕

BUT Digital models accuracy:

- TriangScanners: +/- 0.1 mm
- TOF Scanners: +/- 5 mm
- SFM (images): +/- 1-2 cm

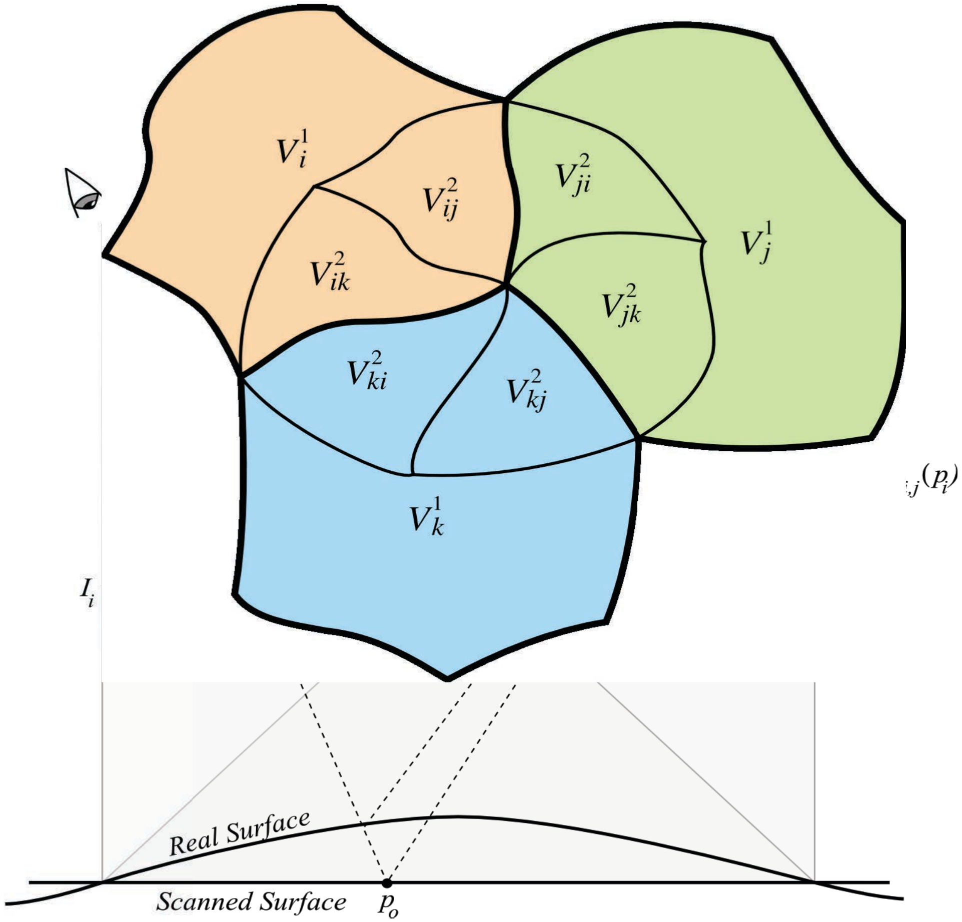
+ improper reconstruction
+ simplification



Blending – Needs accurate alignment!

Flow-based optimization of image registration

- Assume alignment is the best you might produce, but still small errors (up to 1-2 mm)
- Improve the local matching by **slightly locally warping** the input images:
  - Decompose the mesh in **regions**, each region is associated to a single predominant image
  - Run **optical (pixel) flow** over each pair of overlapping images
  - Check how **features** correspond, **compute a local warping** to correct locally the misalignment



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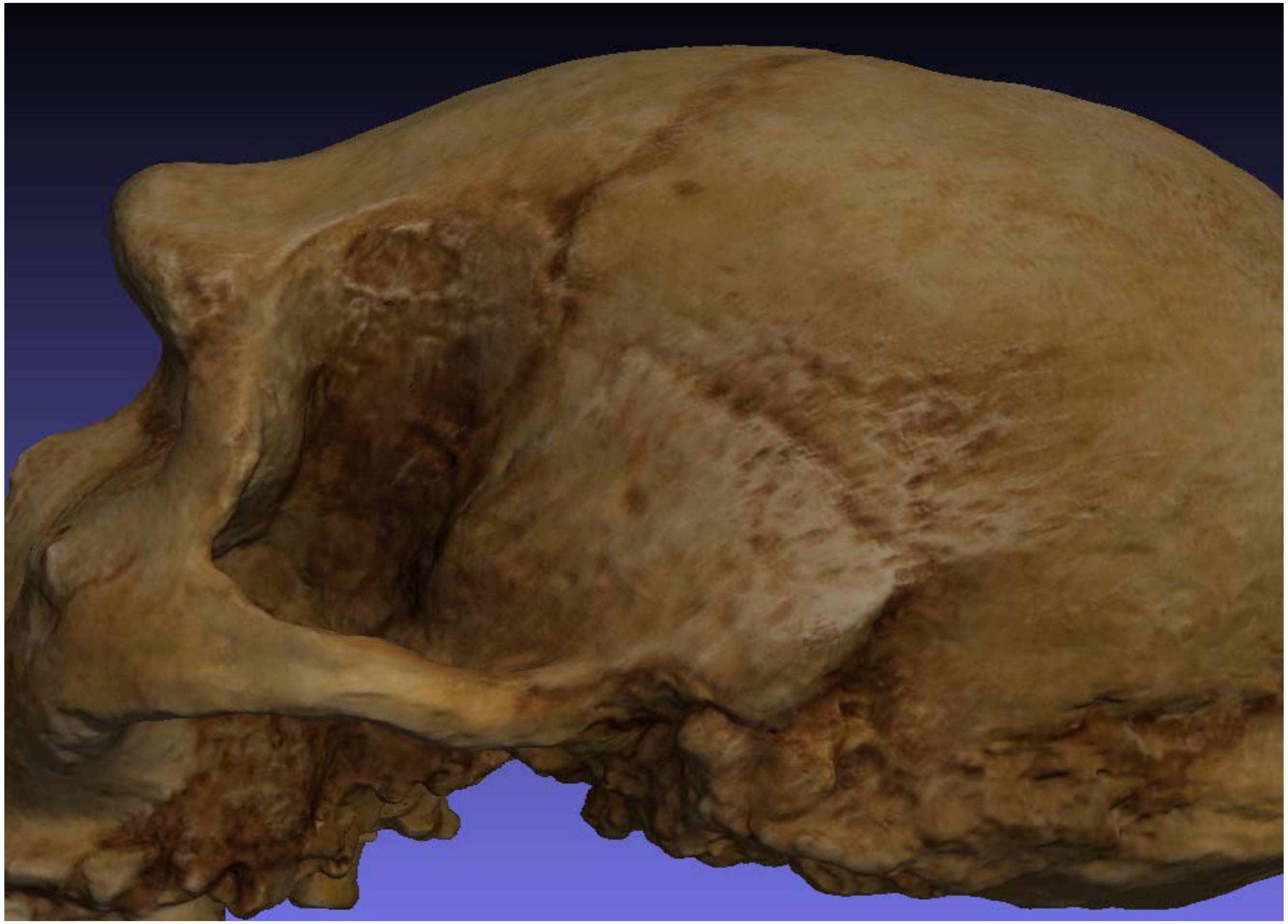
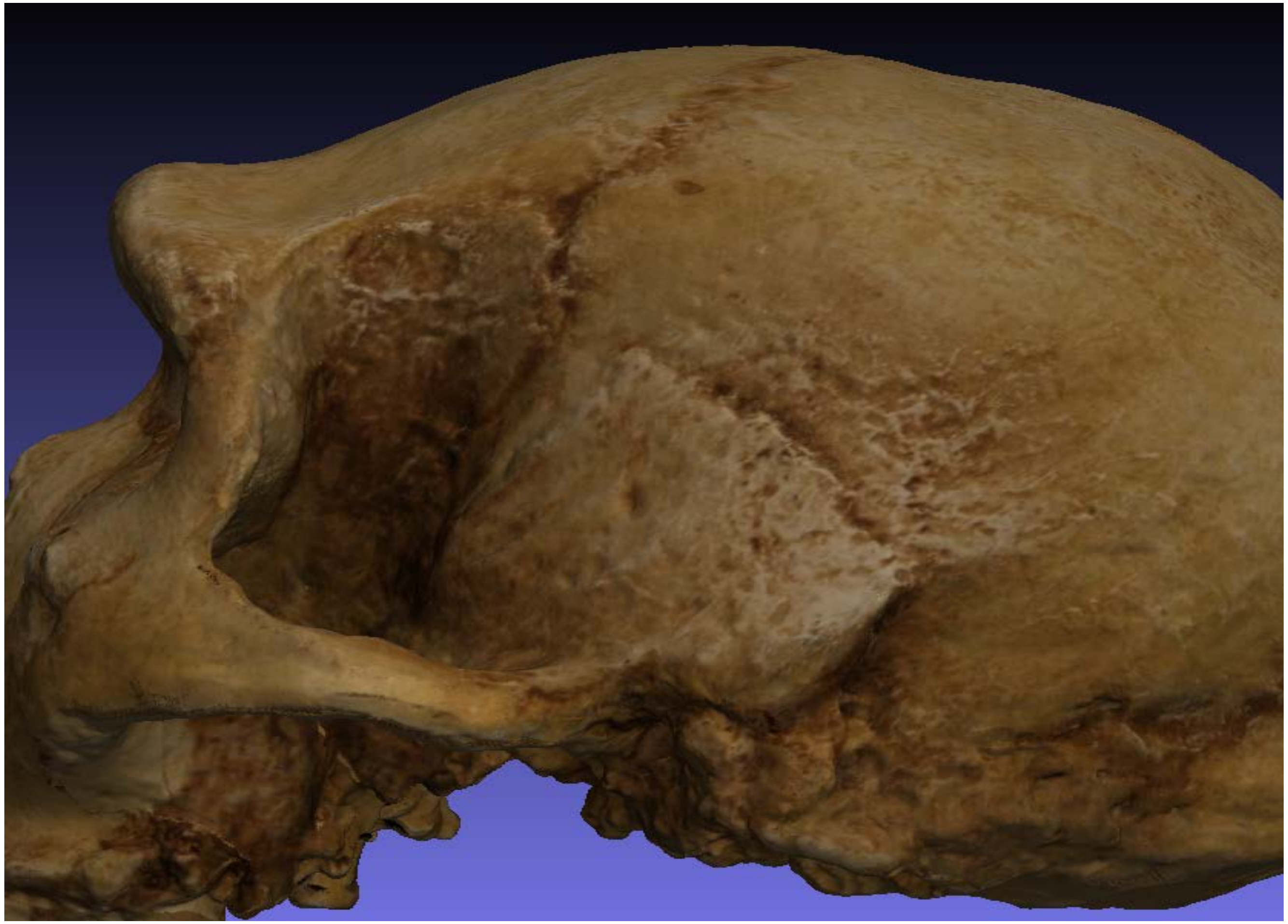
Flow-based optimization of image registration



Flow-based optimization of image registration



Flow-based optimization of image registration

M. Dellepiane, R. Marroquim et al, "Flow-based local optimization for image-to-geometry projection", IEEE TVCG 2011

Bejond apparent color

Advanced surface reflection properties acquisition

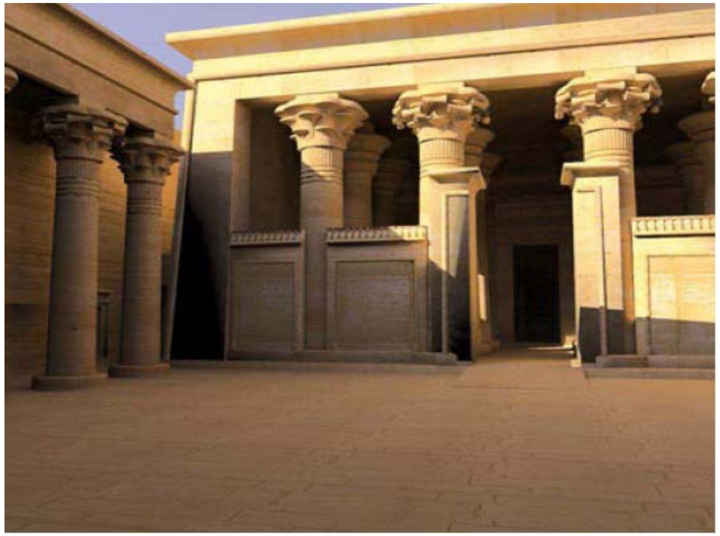
Why reflected RGB colors are not sufficient?

Reflected RGB colors contain **statically fixed shading**

Iteractive graphics – Requires **dynamic changes** of the illumination:

- Light **direction** (with correct highlights)
- **Type** of light source (electric light, burning flame, etc

➔ **Sample reflection properties of surfaces** (e.g. BRDF)

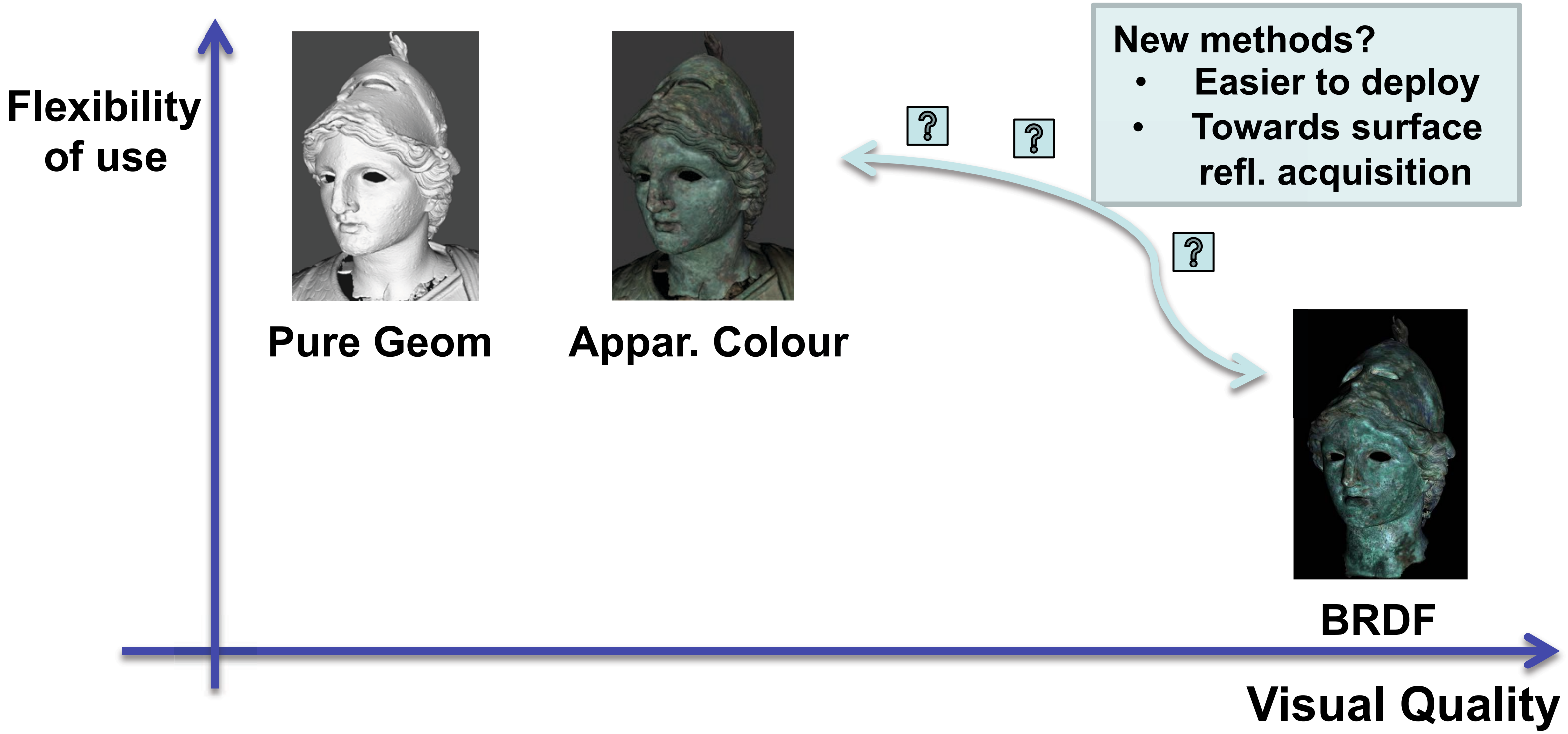


Images by Alan Chalmers

Issues for practical usage of BRDF methods

- **Flexibility**
  - Deliver an acquisition gantry to a museum? Ship by plane?
  - How to cope with different sizes (small or large artifacts)?
- **Time required** (setup + thousands images to process)
- **Controlled lighting conditions?**
  - Often impossible in field conditions (museums, archeological sites)

Design intermediate approaches?



Controlled: flash-based acquisition

Flash-based: use the camera flash as a *known* controlled illuminant

- Simple to displace/use in non-lab conditions
- Very cheap
- Easy to **calibrate** in 3D space (do just once, compute the way flash light covers the 3D view space)
- Might be used to produce a range of results: from de-shaded / albedo (on Lambertian surfaces) to approximations of BRFD

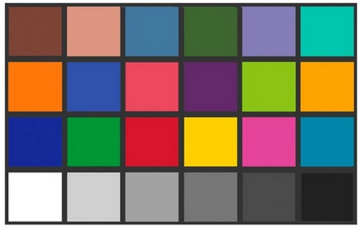
Flash-based lighting space sampling
M. Dellepiane et al. ACM JOCCH 2010

Casio Exilim Z50 Nikon D40x Canon EOS 350D + Nikon Speedlight SB600

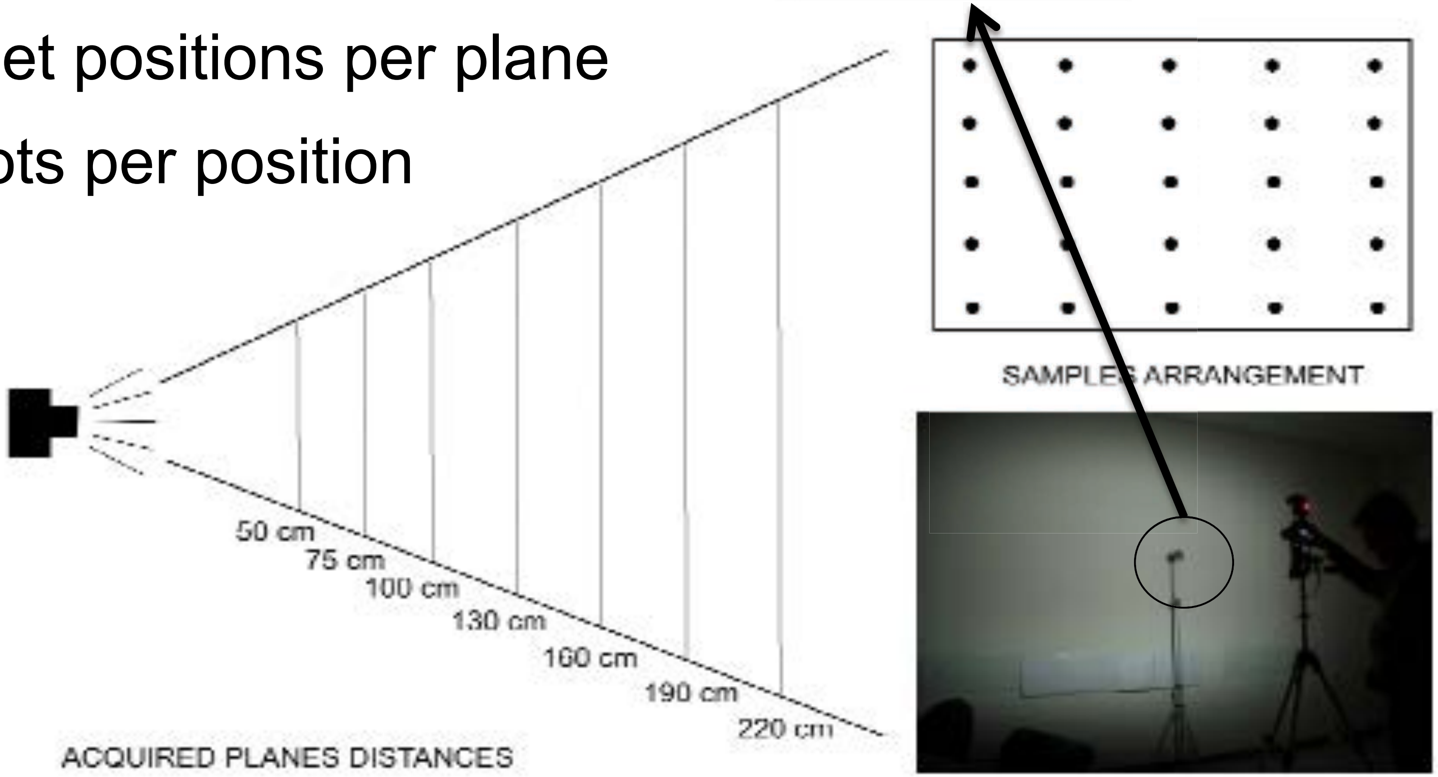
Sampling color correction space:

Space sampling:

- 7 distance planes
- 25 target positions per plane
- 5-7 shots per position



MacBeth calibration target

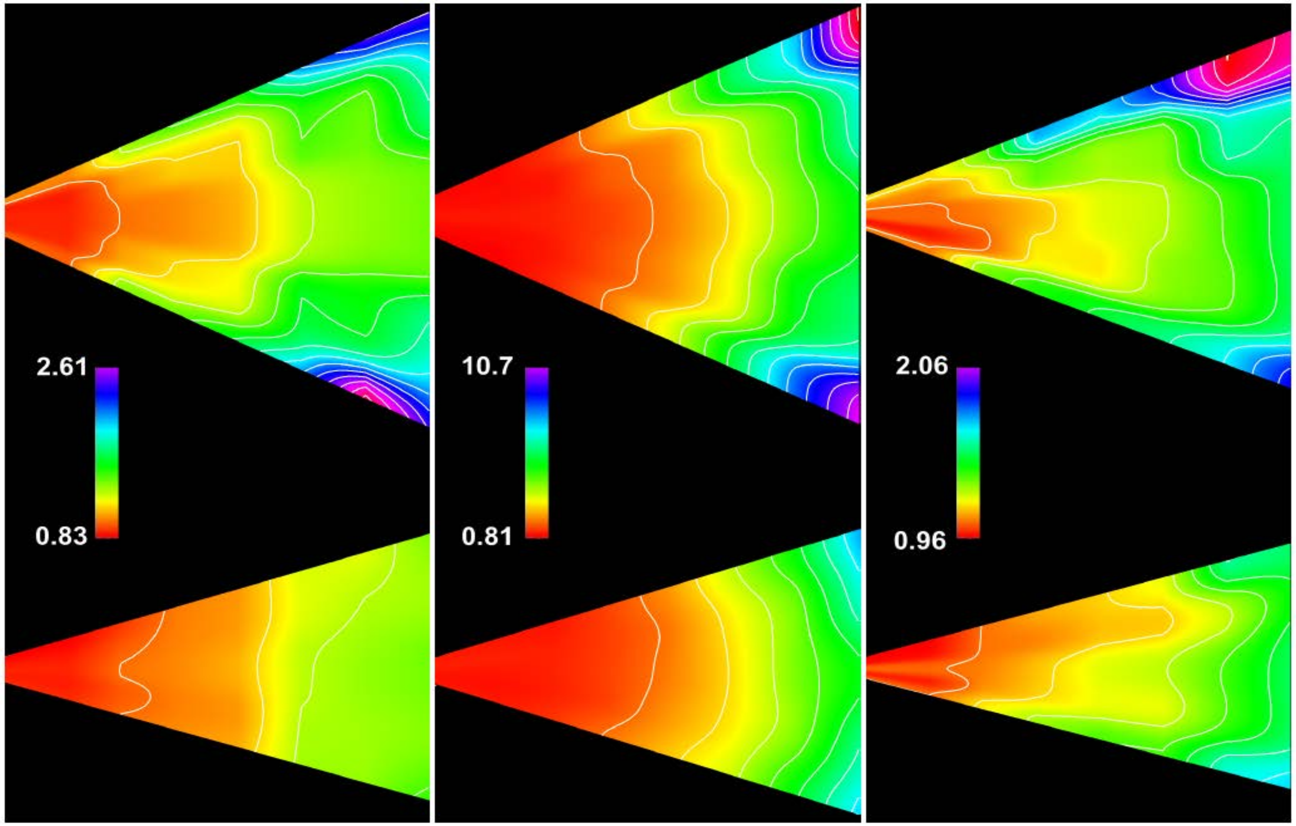


The color correction space: analysis

After interpolation of the calibration samples over the entire camera view volume:

Horizontal section

Vertical section



Effects of color correction

- Calibrate acquired colors (using 3D calibration matrix)

- Remove lighting artefacts (shadows, highlight) once the view specs and flash location have been computed

Recover reflection prop. from video sequences

Acquisition and reconstruction of the surface appearance of a real object

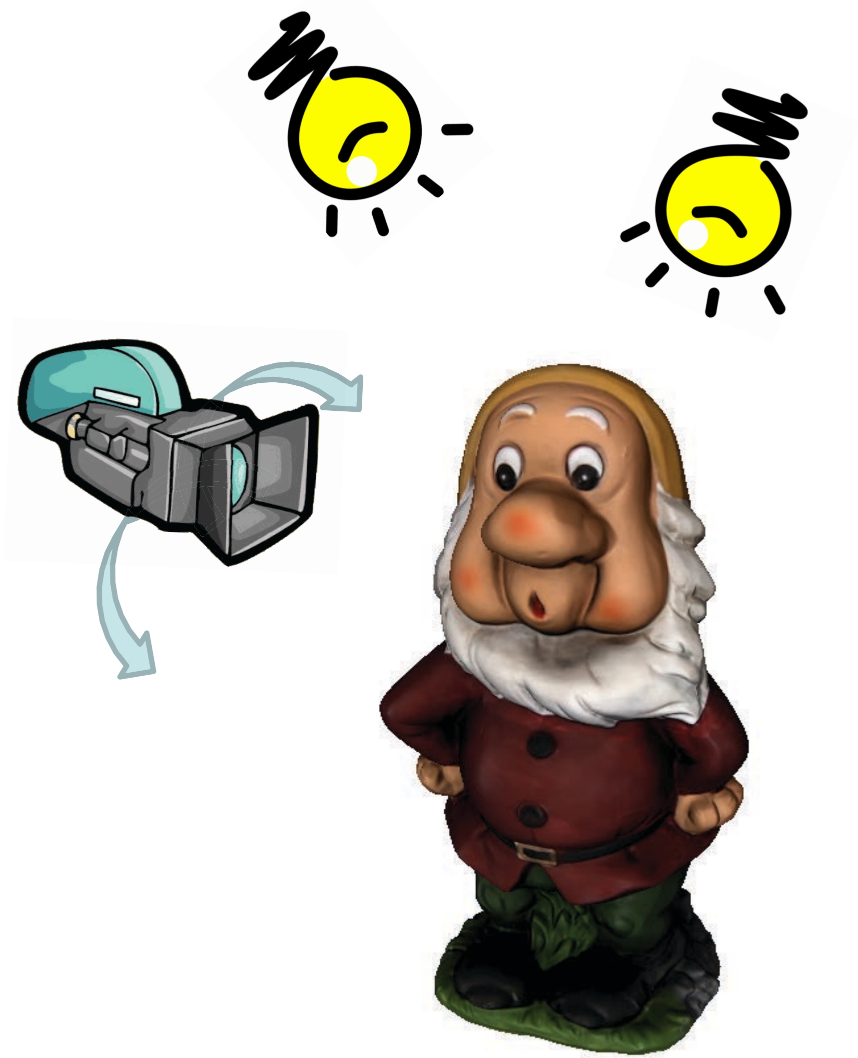
- General and fixed lighting condition
- Process Video Sequences over 3D geometry

Two steps

1.Video-to-Geometry Registration

2.Surface appearance reconstruction

- an approximation of SVBRDF (Spatially Varying Bidirectional Reflectance Distribution Function)



Statistical estimation of SVBRDF

INPUT

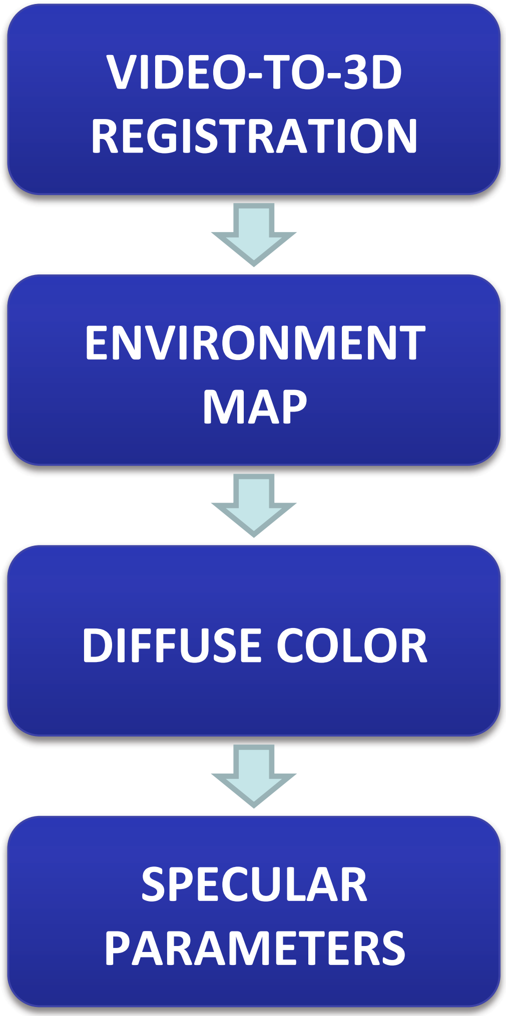
- 3D model with a texture parameterization
- LDR video sequences with fixed and unknown lighting condition

OUTPUT

1. Illumination environment by weighted accumulation (use 3D model as a probe)
2. Diffuse texture map
3. Clustering of the surface in a set of basis material
4. Phong specular parameters for each material

All the computations on GPU

ALGORITHM



Results – Diffuse refl. component

DIFFUSE COLOR

PHOTO

Results – Specular component

Model	205K
Frames	7240 (4:49 min)
Clusters	3
Registr	250 min
SVBRDF	43 min

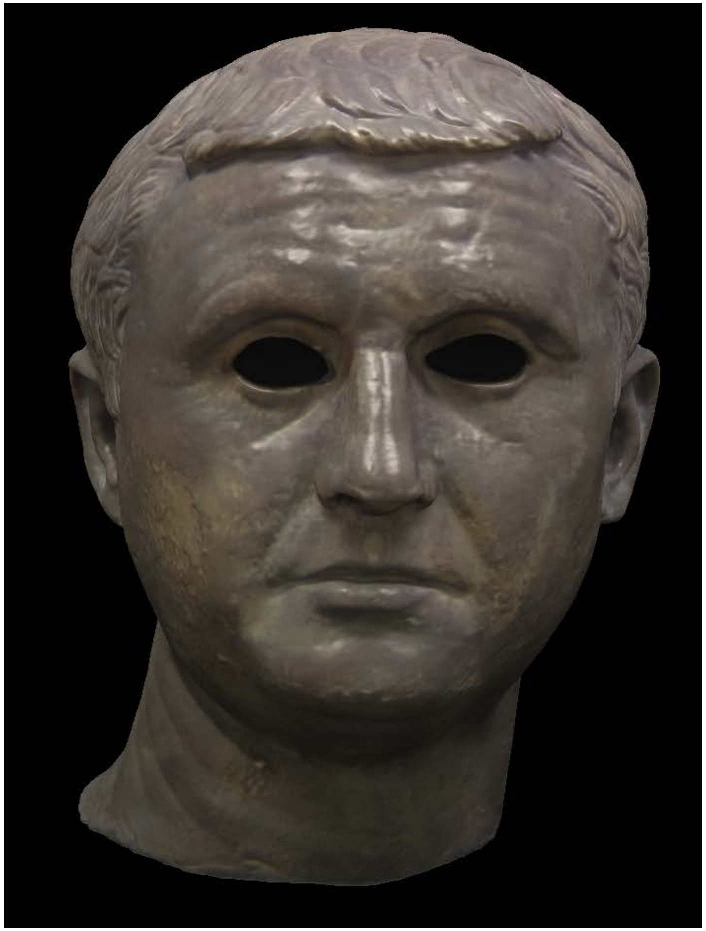
RENDERING

PHOTO

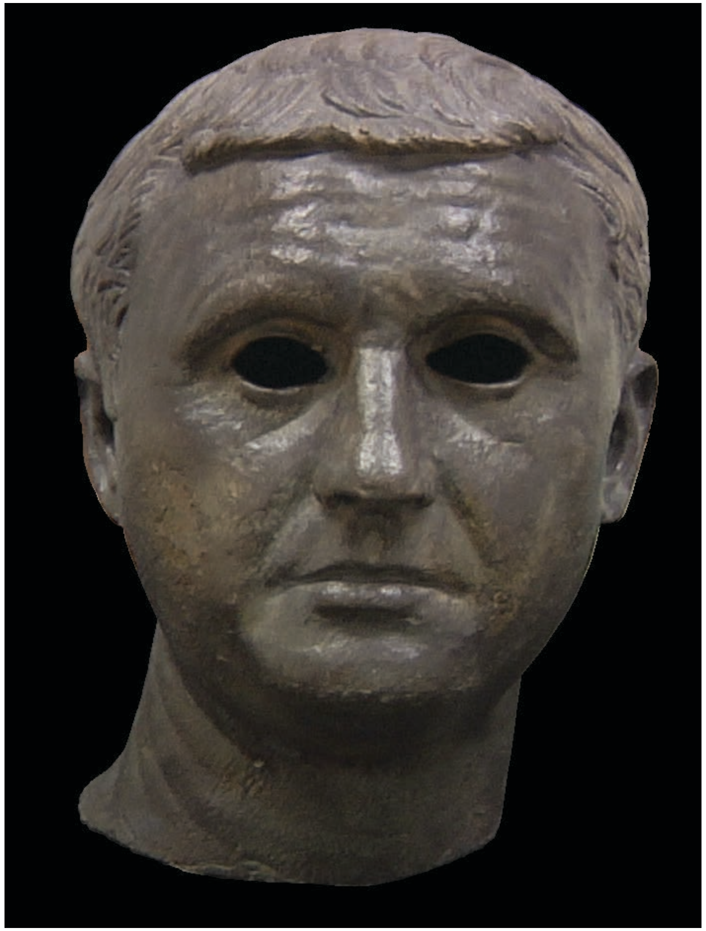
Results

Model	250K
Frames	8386 (5:35 min)
Clusters	1
Registr	265 min
SVBRDF	59 min

RENDERING



PHOTO



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COLOR & SPACE IN CULTURAL HERITAGE

Conclusions

- Several technologies at hand for deploying good quality *"colored"* models to CH applications
- ***The future***: specialized **gantries** (e.g. dome-like) or more flexible **lightweight solutions**? An acquisition lab in each museum? Small museums or archaeology sites?
- Room for **further innovation**:
  - Increase automation and flexibility
  - Improve quality of color/reflection sampling & mapping
  - Develop techniques for **automatic assessment** of the quality of the model (certification of the digital clone)
  - Detect/evaluate **changes** in time-varying datasets?

Questions

Thanks for listening!

- Work presented belongs to several CNR colleagues: M. Dellepiane, M. Callieri, G. Palma, R. Marroquim, M. Corsini, …

- ***Contacts:***

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