Visual Appearance: Reflectance Transformation Imaging (RTI)

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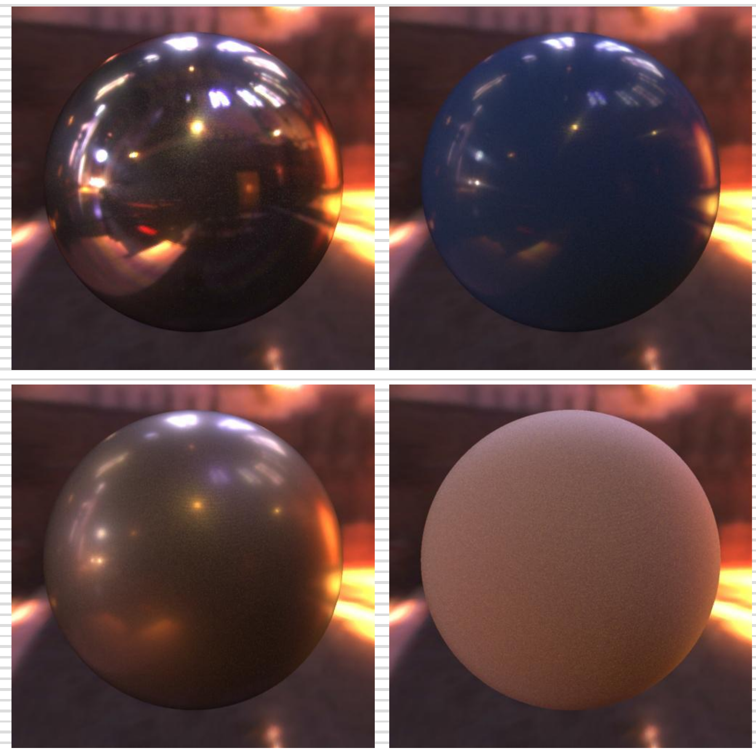
Visual Appearance

Visual Appearance

Color due to the interaction between the lighting environment (intensity, position, …) and the properties of the object surface and material.

LIGHT

MATERIAL



Visual Appearance: why?

Photorealistic rendering – High fidelity reproduction of the real world

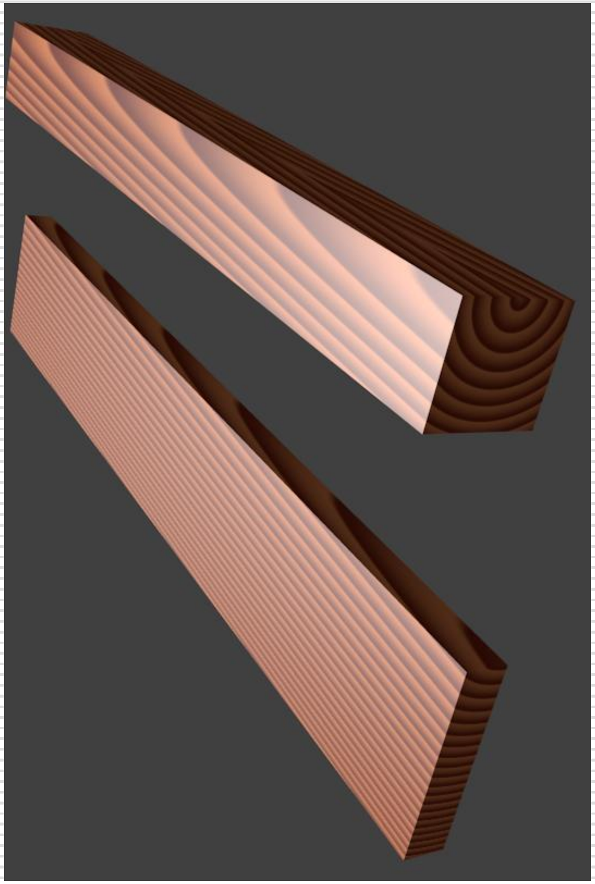
PHOTO **RENDERING**

Visual Appearance: why?

Perception – Better understanding of the details (even with a fake appearance)

Visual Appearance: why?

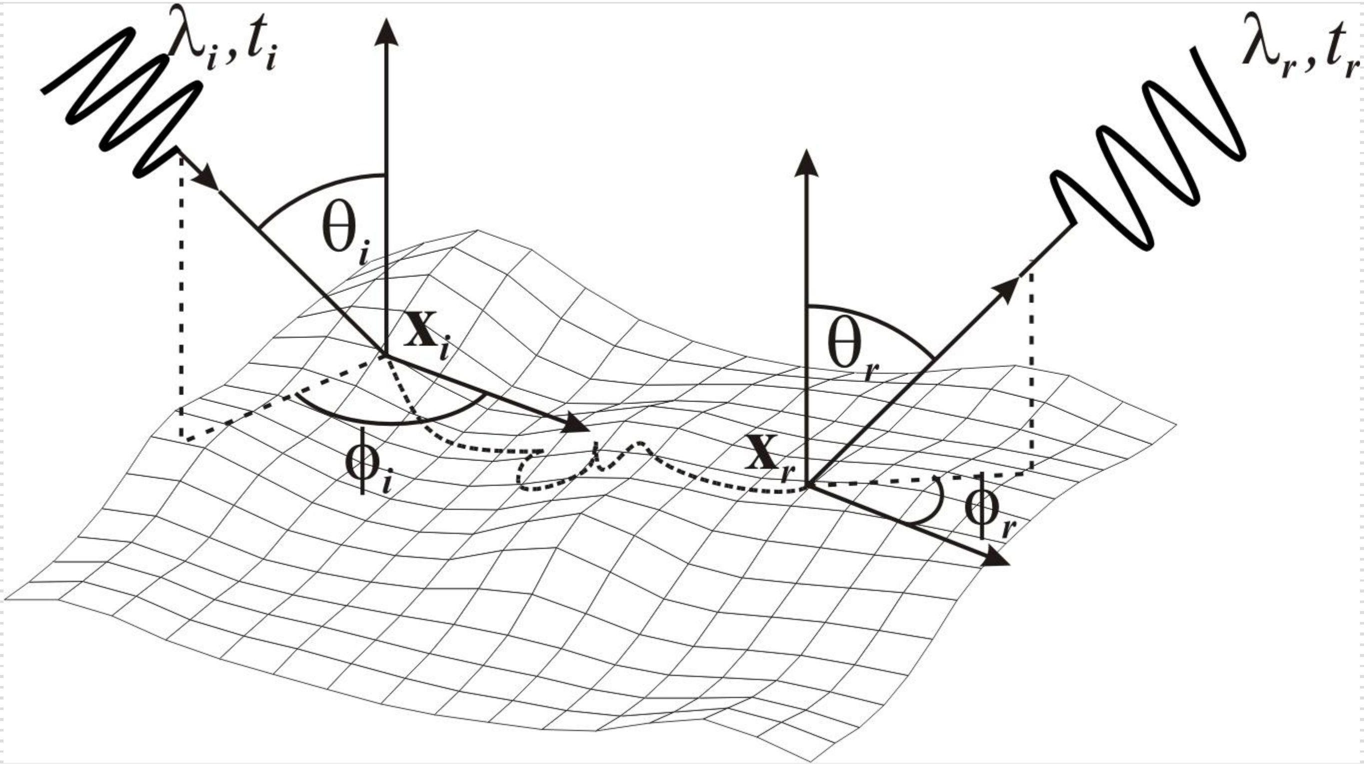
To infer more cognitive data from color details



Visual Appearance: Definition

Reflectance Scattering Function (12D)

(Light and view direction, Incident and outgoing surface point Wavelength, Time)

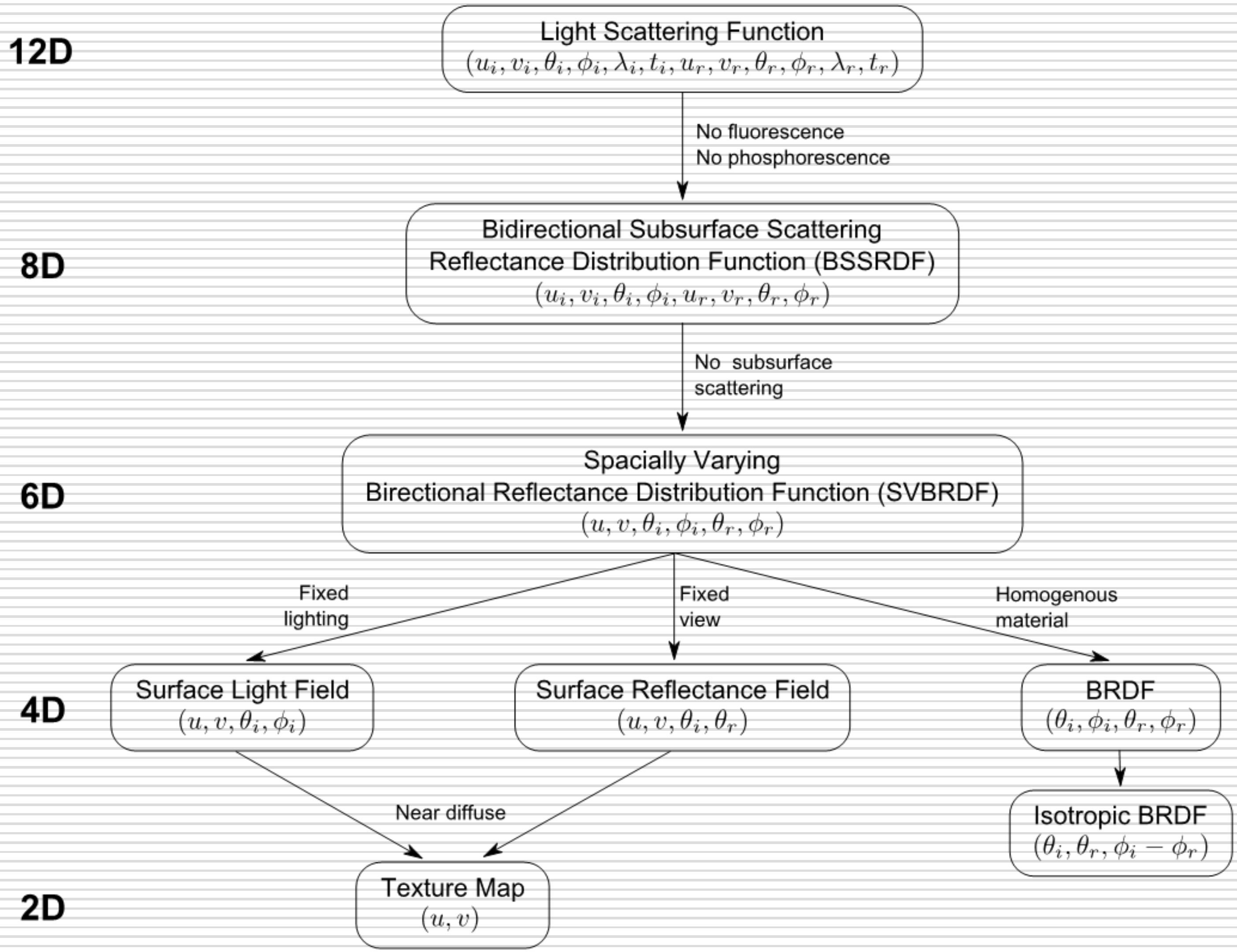


Visual Appearance: Definition

Reflectance Scattering Function (12D)

- No mathematical formulation
- Measurement impractical
- Simplification by constrains on the set of possible reflectance effects
    - Phosphorescence
    - Fluorescence
    - Subsurface scattering
    - Specular scattering
    - Backscattering
    - Diffuse scattering

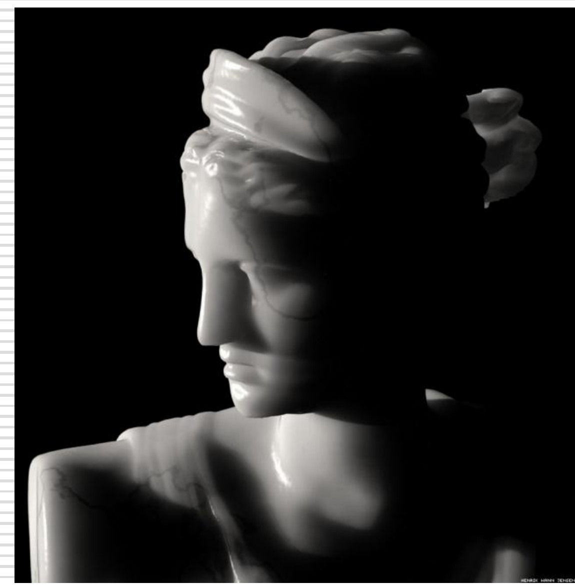
Visual Appearance: Definition



Visual Appearance

BSSRDF (8D)

- No fluorescence (no wavelength change)
- No Phosphorescence (zero time light transport)
- Subsurface scattering (translucent material)



Visual Appearance

SVBRDF (6D)

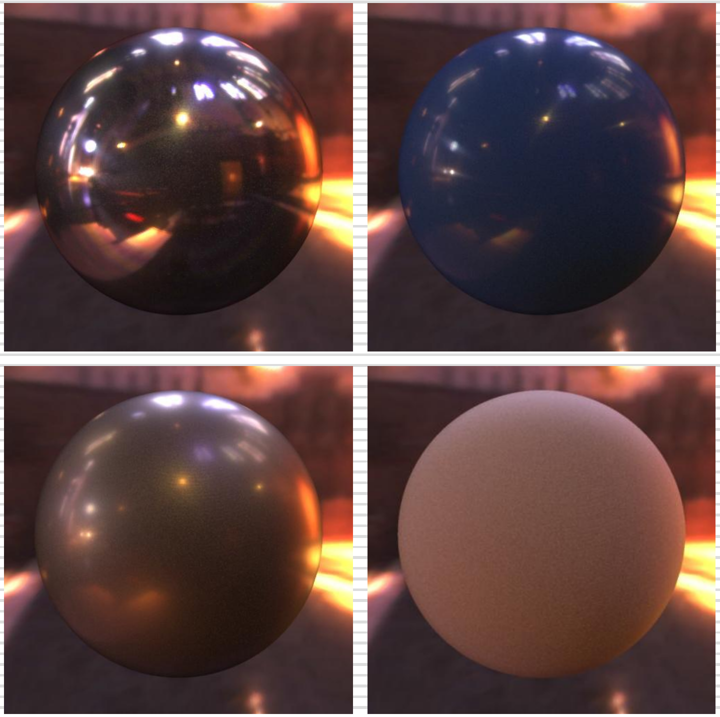
- No Subsurface scattering (translucent material)
- Opaque material (reflection on the same place)
- Spatially varying glossy material



Visual Appearance

BRDF (4D)

- No spatially varying
- Uniform material



Visual Appearance

Light Field (4D)

- Amount of light faring in every direction through every point in space (simplified plenoptic function)
- Fixed lighting condition and variable view direction
- Spatially varying
- Image-based rendering (no geometry)

Surface Reflectance Field (4D)

- Fixed view position and variable light direction
- Spatially varying
- Image-based relighting **(RTI)**
- Implicit geometry

Visual Appearance: how to use?

BSSRDF and BRDF

Model-based rendering

- Explicit geometry
- Modeling or acquisition of the appearance
- Global illumination algorithm
- More precise but computational heavy

Light Field and Reflectance Field

Image based rendering

- Set of photos (“interpolation”)
- No geometry or “implicit” geometry
- Realistic rendering but trade-off between data and precision

Reflectance Transformation Imaging (RTI)

RTI: Overview

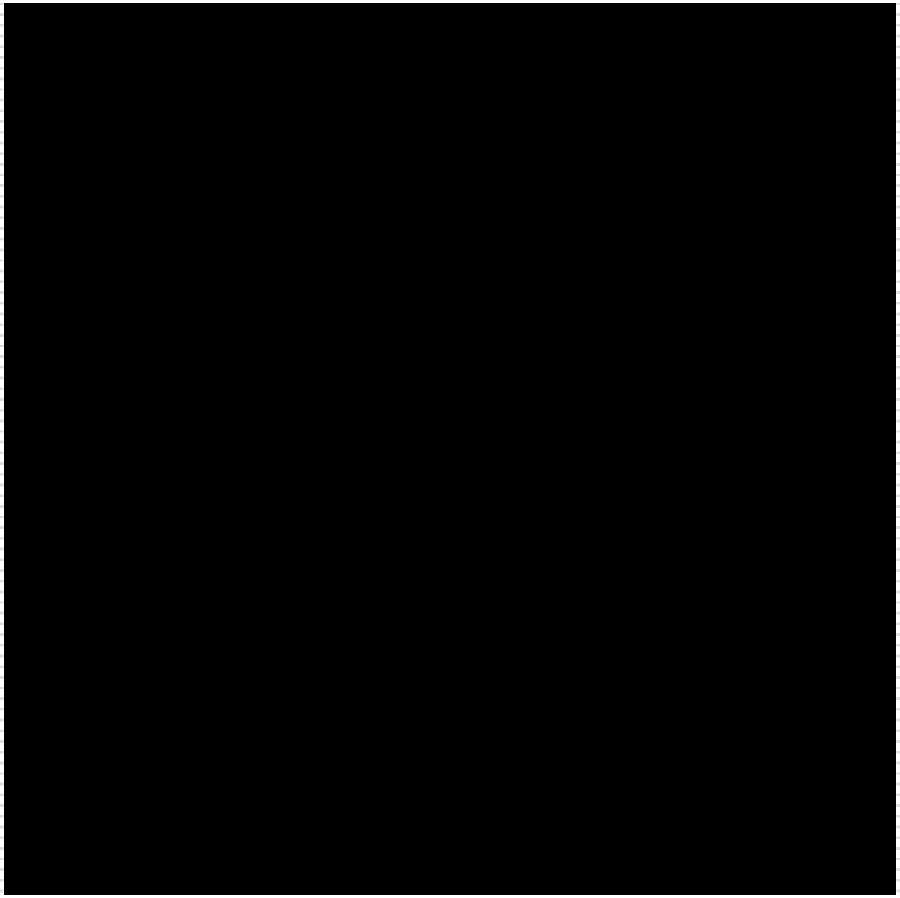
Technique for the estimation of the Reflectance

2001 HP Labs – Polynomial Texture Map

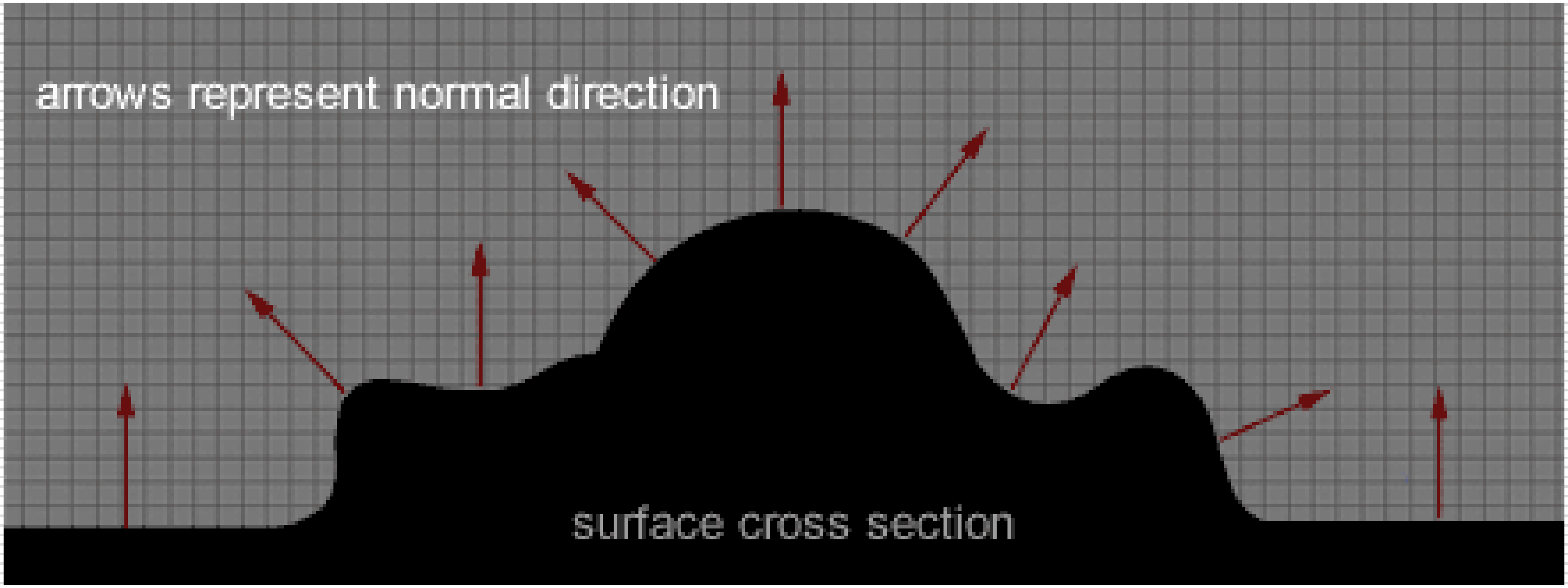
- New type of texture mapping with the possibility to change the light direction in an interactive way
- Presented as a powerful tool to improve the study of ancient writings and inscriptions.

RTI: Overview

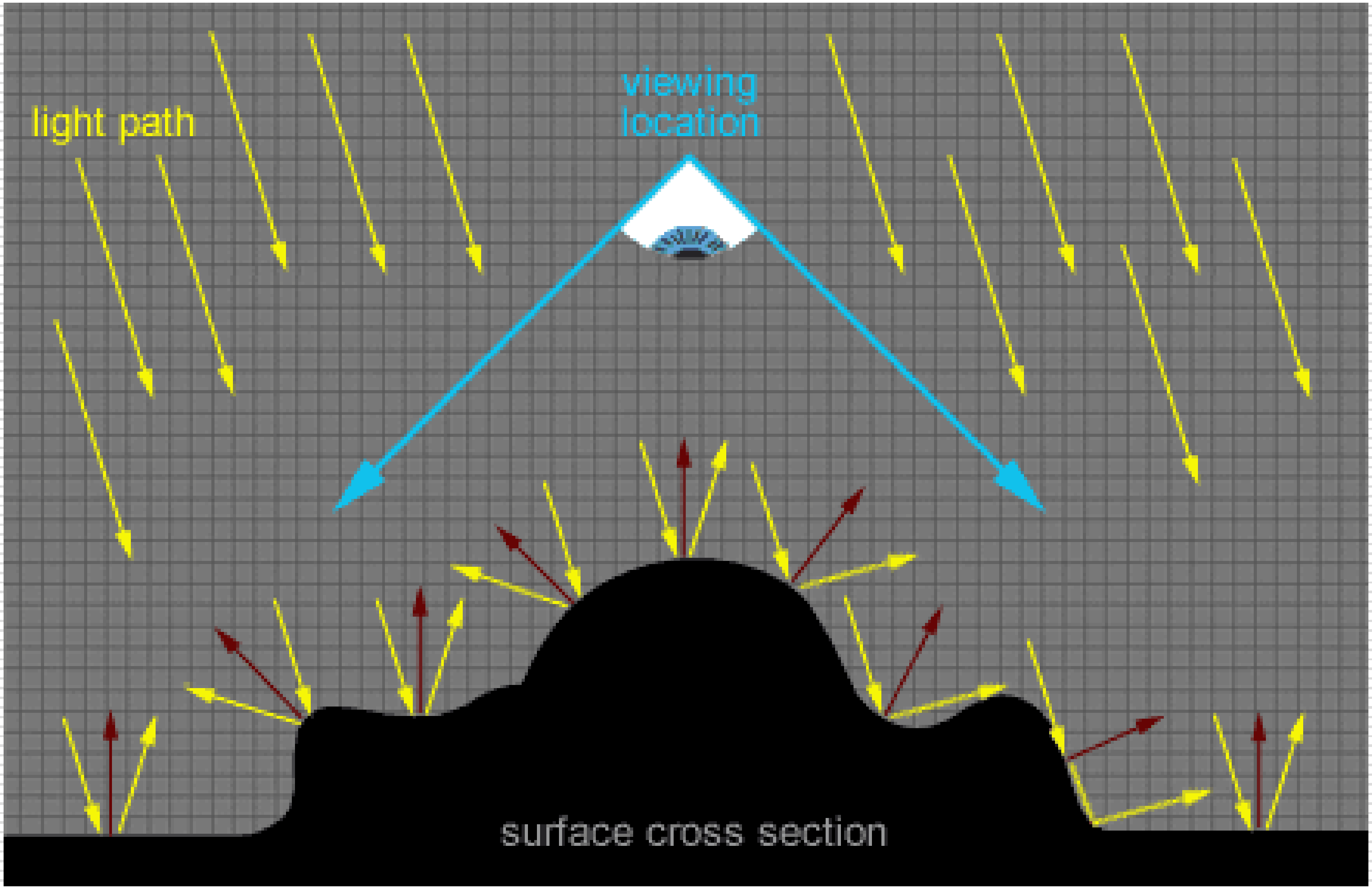
- Multiple digital photos taken from a stationary camera with different know light directions
- 2D image that synthesizes the surface lighting information for each pixel with a mathematical model
- Capture the subject’s surface shape (implicit geometry) and colour
- Enable the interactive re-lighting of the subject from any direction



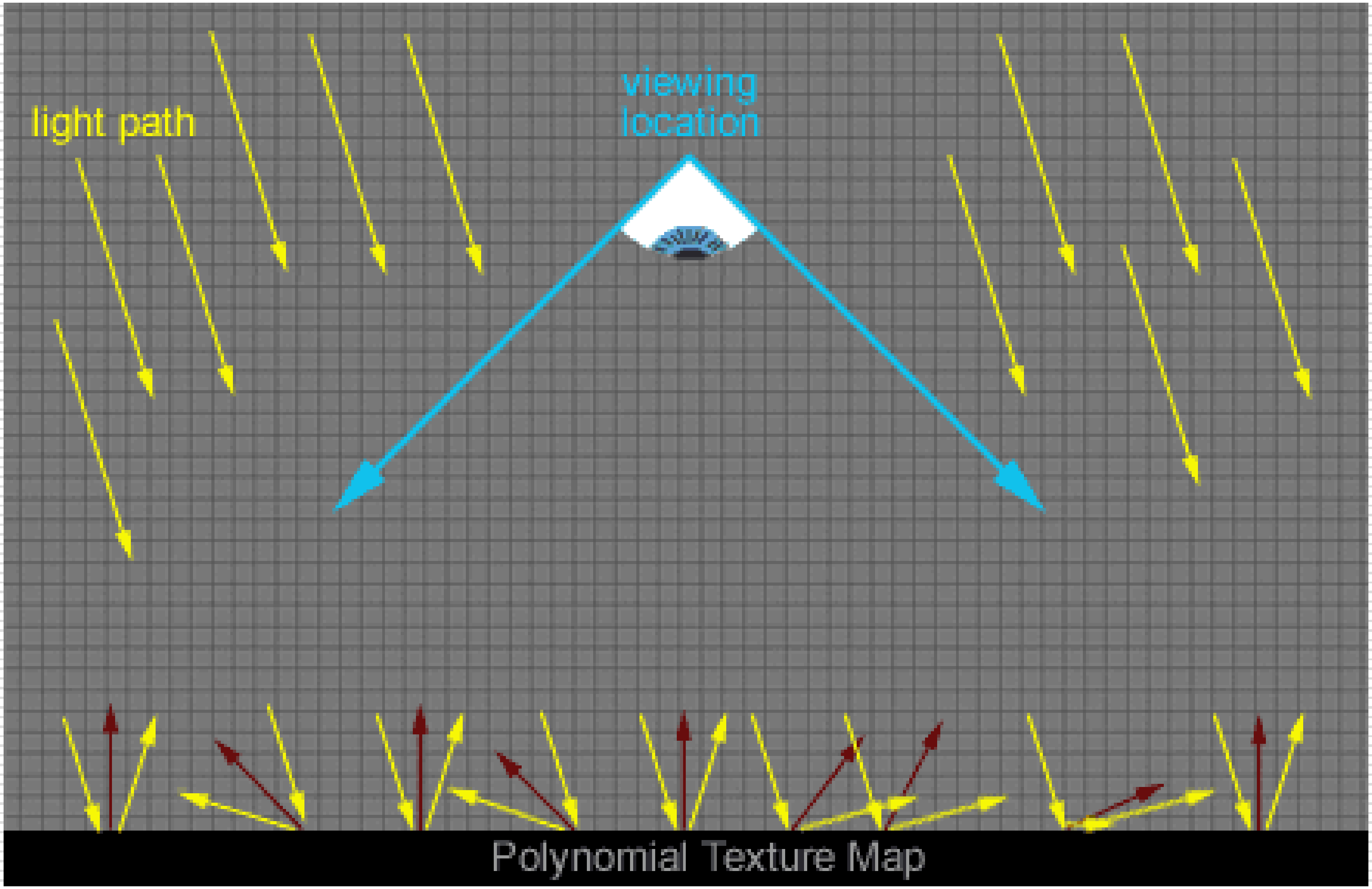
RTI: Overview



RTI: Overview



RTI: Overview



RTI Format

Polynomial Texture Map (PTM)

- Bi-quadratic polynomial to model the variation of the pixel color in function of the light direction
- LRGB PTM (6 coefficients *a0 ... a5* + *RGB* color)

$$\vec{\omega} = (l_u, l_v, \sqrt{l_u^2 + l_v^2})$$

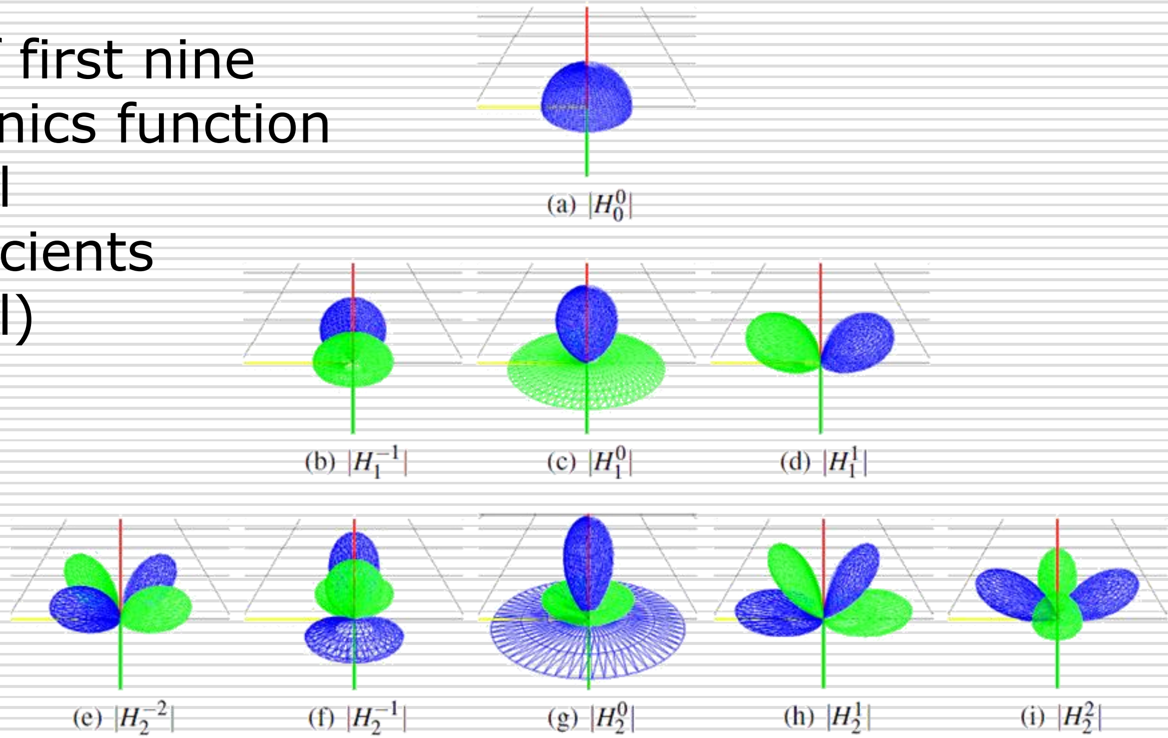
$$\begin{aligned}
L(l_u, l_v, x, y) &= a_0(x,y)l_u^2 + a_1(x,y)l_v^2 + a_2(x,y)l_u l_v \\
&\quad + a_3(x,y)l_u + a_4(x,y)l_v + a_5(x,y) \\
R(l_u, l_v, x, y) &= L(l_u, l_v, x, y)R(x,y) \\
G(l_u, l_v, x, y) &= L(l_u, l_v, x, y)G(x,y) \\
B(l_u, l_v, x, y) &= L(l_u, l_v, x, y)B(x,y)
\end{aligned}$$

- RGB PTM (18 coefficients – *a0...a5* for each color channel)

RTI Format

Hemispherical Harmonics Map (HSH)

- Linear combination of first nine Hemispherical Harmonics function for each color channel of each pixel (9 coefficients for each color channel)



$$\vec{\omega} = (l_x, l_y, l_z)$$

$$\theta_\omega = \arctan(l_y / l_x)$$

$$\phi_\omega = \arccos(l_z)$$

$$C(\theta_\omega, \phi_\omega, x, y) = \sum_{l=0}^{2} \sum_{m=-l}^{l} a_i(x, y) H_l^m(\theta_\omega, \phi_\omega)$$

$$i = l^2 + l + m$$

RTI: PTM vs HSH

PTM

- Lower contrast
- Fail to capture important specular component
- Poor results on reflective material (gold or silver)

HSH

- Higher contrast
- Better representation of the specular component
- More photorealistic results with highly reflective material

RTI: Computation

INPUT

- A set of *(n+1)* photo acquired from a fixed position with a different position of a directional light
- Light direction for each photo

OUTPUT

- Function coefficient for each pixel by solving an overdetermined linear system using Singular Value Decomposition

HSH EXAMPLE

?

N + 1 Photo

$$\begin{bmatrix} H_0(\vec{\omega}_0) & H_1(\vec{\omega}_0) & H_2(\vec{\omega}_0) & H_3(\vec{\omega}_0) & H_4(\vec{\omega}_0) & H_5(\vec{\omega}_0) & H_6(\vec{\omega}_0) & H_7(\vec{\omega}_0) & H_8(\vec{\omega}_0) \\ \vdots & & & & & & & & \vdots \\ \vdots & & & & & & & & \vdots \\ \vdots & & & & & & & & \vdots \\ H_0(\vec{\omega}_n) & H_1(\vec{\omega}_n) & H_2(\vec{\omega}_n) & H_3(\vec{\omega}_n) & H_4(\vec{\omega}_n) & H_5(\vec{\omega}_n) & H_6(\vec{\omega}_n) & H_7(\vec{\omega}_n) & H_8(\vec{\omega}_n) \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ a_5 \\ a_6 \\ a_7 \\ a_8 \end{bmatrix} = \begin{bmatrix} C_0 \\ \vdots \\ \vdots \\ \vdots \\ C_n \end{bmatrix}$$

Color vector

RTI: Acquisition

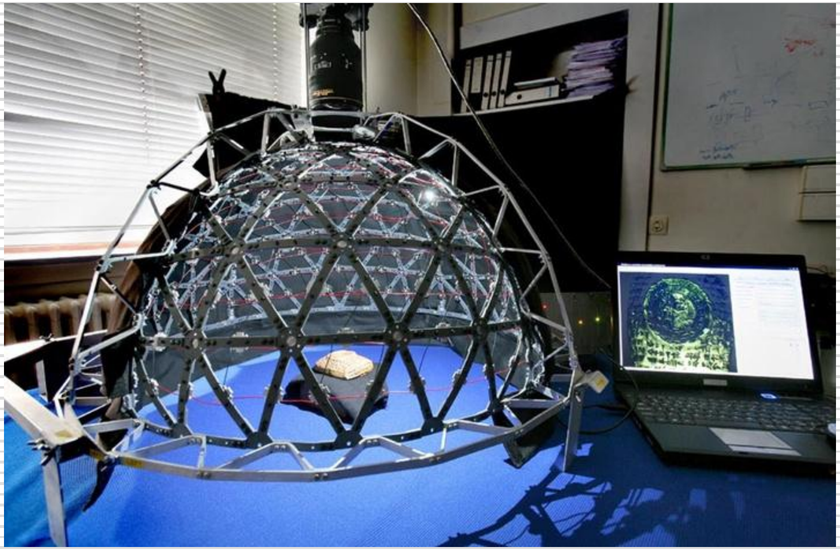
DOME

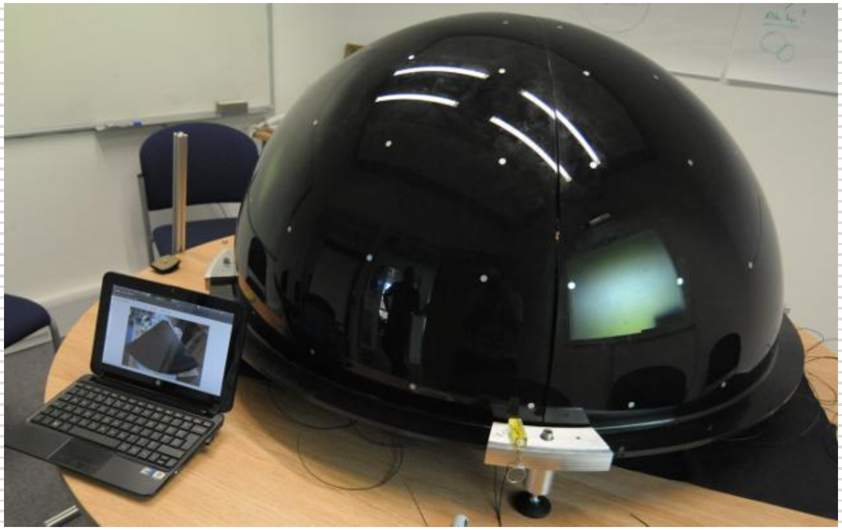
Pro

- Set of light in fixed position
- Automatic and fast acquisition

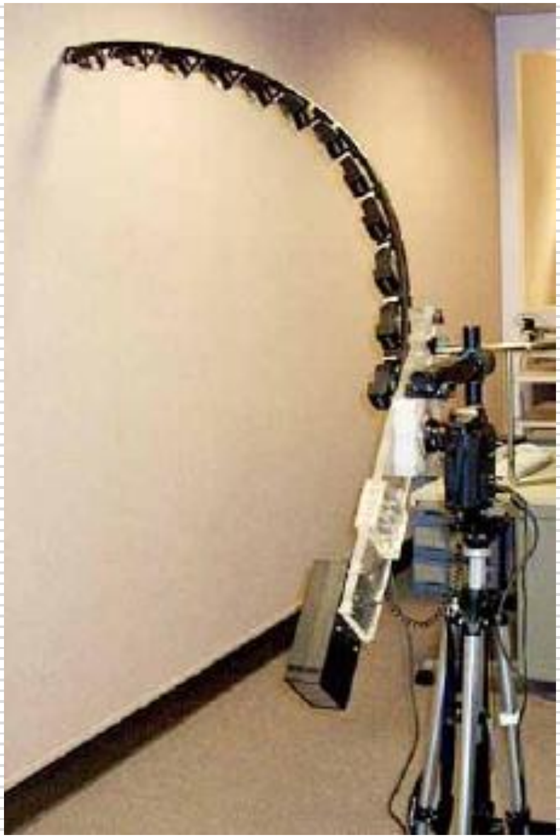
Con

- Limitation on the maximum object size

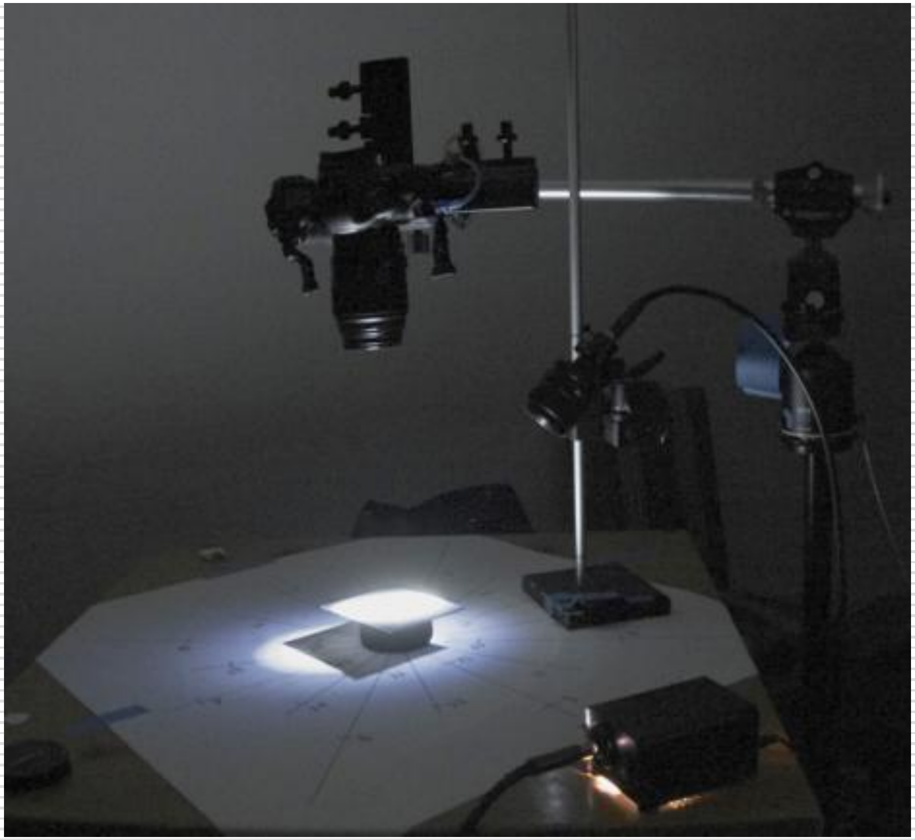




RTI Acquisition



Arm with 12 flash
National Gallery of London



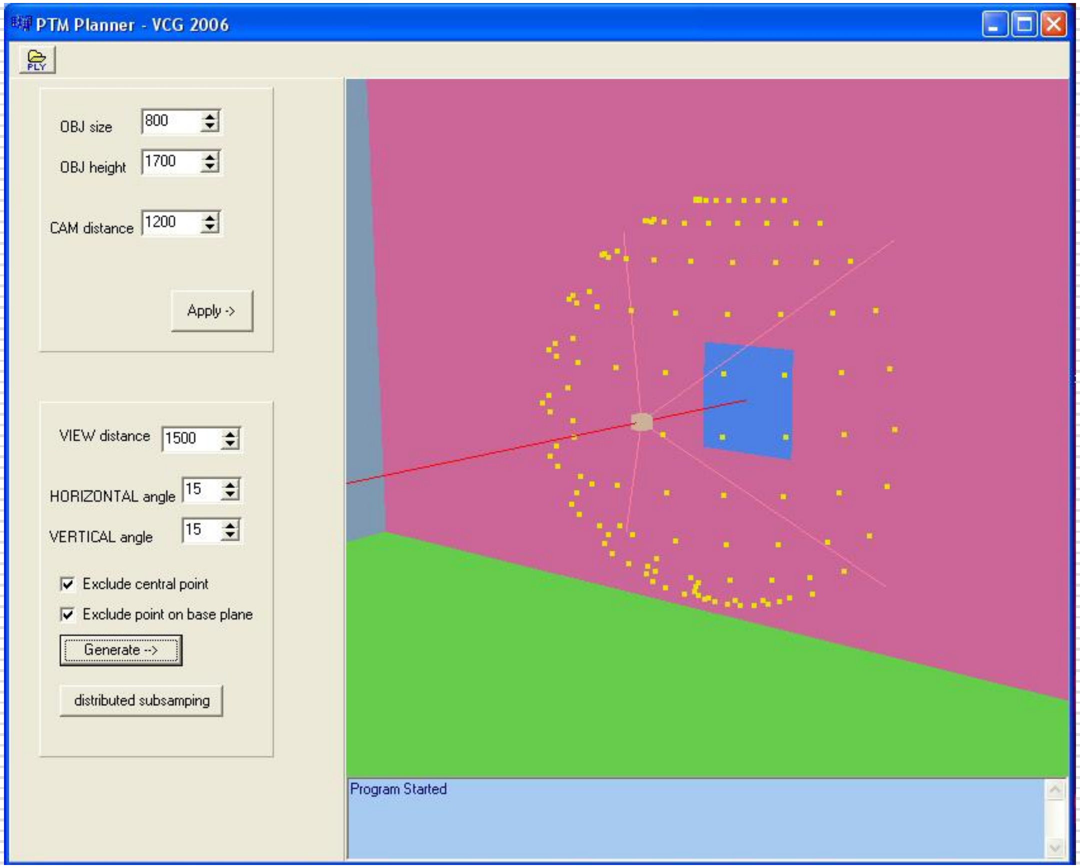
Manual Template Rig
Cultural Heritage Imaging

RTI: Acquisition for large object

PTM PLANNER

Virtual Dome

Producing the position in the space of the light for the acquisition of the RTI starting from some info of the object (size and height from the floor) and the position of the camera



RTI: Acquisition for large object

Plumb line

Halogen floodlight 1000W

8 Mpixel digital camera

Boom stand

Plan with the light direction

tripod

RTI: Acquisition for large object

Reflective sphere

- Free movement of the light in front of the object
- Tool able to find the light direction from the photo in a semi–automatic way using the highlight (LPTracker)
- Sphere diameter in the image must be at least 200 pixels wide to obtain good result

RTI: Processing

1. Correction of small misalignment in the set of photos due to movement of the camera using the tool for the creation of panoramic images
2. Image correction (white balance, crop)
3. Estimation of the light direction (LPTracker)
4. Generation of the final RTI (PTMFitter or RTIBuilder)

RTI: Acquisition and Processing

chi Cultural Heritage Imaging
a nonprofit corporation

Guide, tutorial, video and software for the acquisition and processing of RTI images

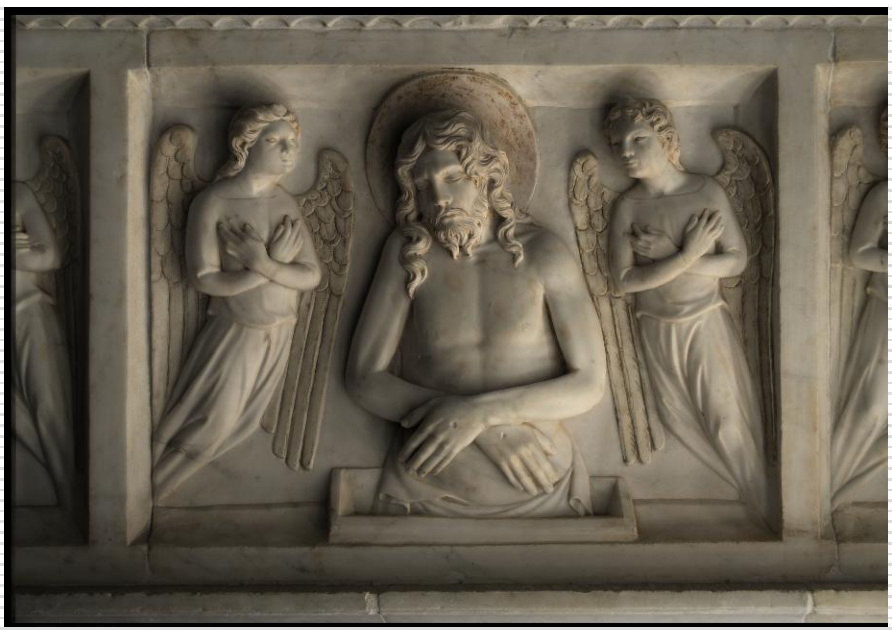
http://culturalheritageimaging.org/What_We_Offer/Downloads/

Live acquisition in the next lesson…

RTI: Results

Tomb of the Archbishop Giovanni Scherlatti, made by Nino Pisano, Museo dell'Opera Primaziale di Pisa, XIV Sec.

Size: 70 x 80 cm, 105 photos,
acquisition with PTMPlanner 3.5h, PTM



RTI: Results

Roman Sarcophagus II Sec. DC, legend of Fedra and Ippolito, Camposanto Monumentale, Pisa

Size: 100 x 70 cm, 66 photos,
acquisition with PTMPlanner about 2 h, PTM

RTI: Results

Silver "Ducato" 1587-1609 Pisa
Museo di San Matteo, Pisa

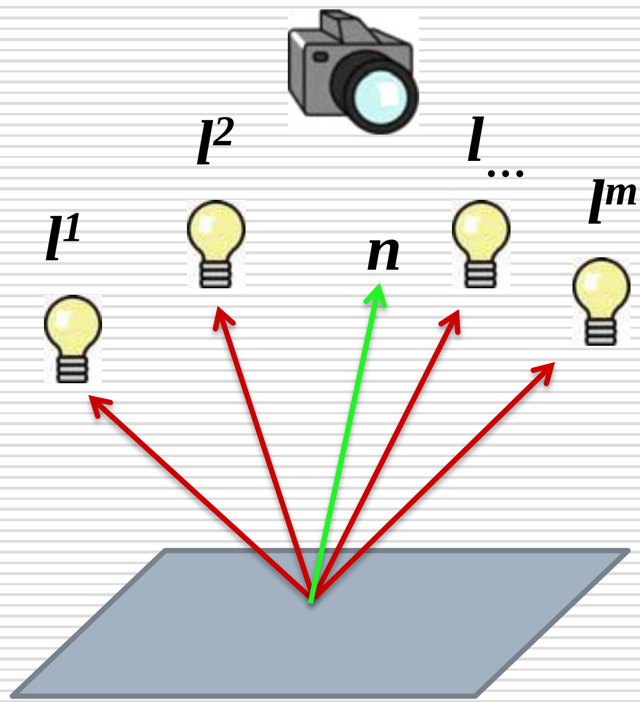
Diameter 41.5 mm, 256 photos,
Dome in about 10 minute, HSH

RTI: Implicit geometry

Computation of the surface normal for each pixel under the assumption of Lambertian reflection

- Photometric stereo

$$\begin{bmatrix} l_x^1 & l_y^1 & l_z^1 \\ l_x^2 & l_y^2 & l_z^2 \\ \vdots & \vdots & \vdots \\ l_x^m & l_y^m & l_z^m \end{bmatrix} \overset{?}{\boxed{\begin{bmatrix} n_x \\ n_y \\ n_z \end{bmatrix}}} = \begin{bmatrix} I^1 \\ I^2 \\ \vdots \\ I^m \end{bmatrix}$$



- Light direction that maximizes the reflectance function

RTI: Implicit geometry

3D Scanning

Vs.

PTM

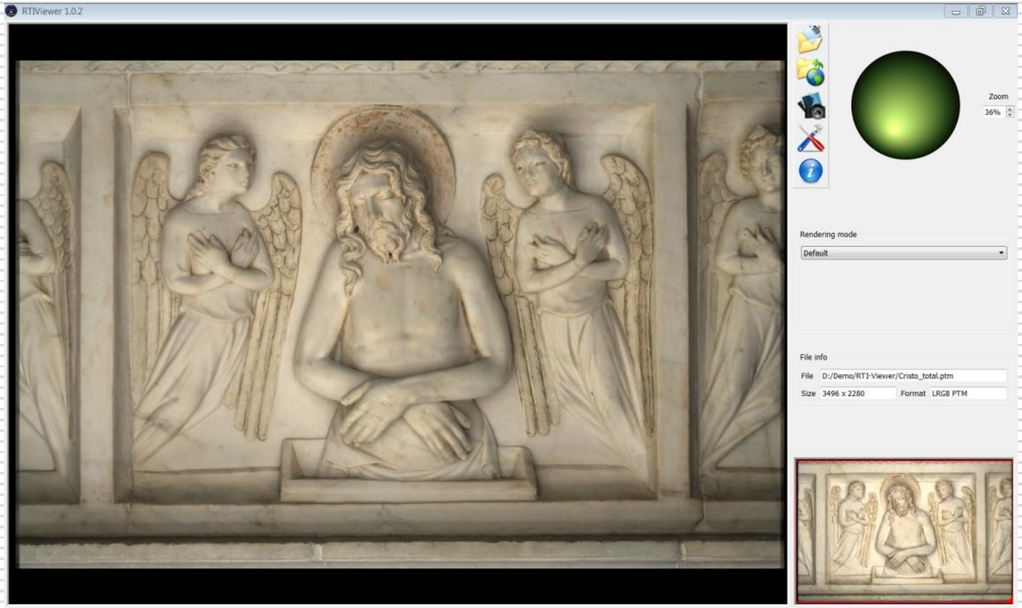
Smoother normal but coherent value

RTI: Visualization

RTIViewer

Developed by Visual Computing Lab, ISTI-CNR.

- PTM and HSH
- Multi-view RTI
- Rendering Modes
- Snapshots



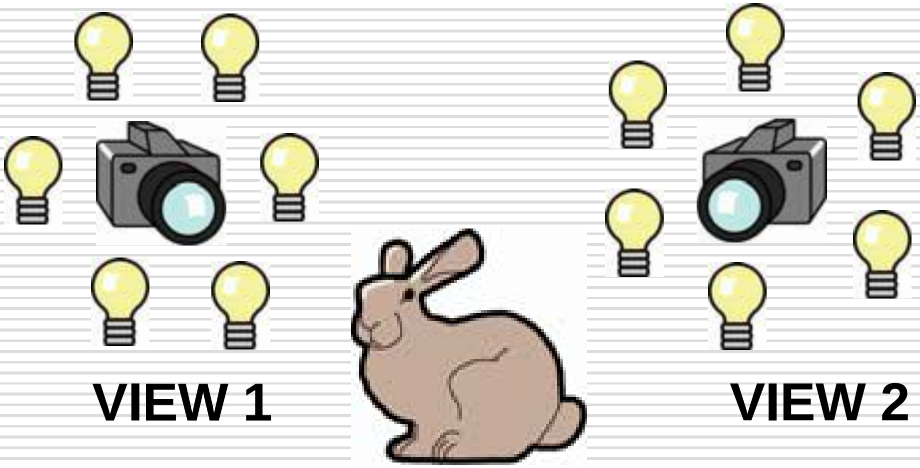
Download Link:

http://www.c-h-i.org/learn/learn_RTIviewer_download.html

RTI: Visualization

RTIViewer - Multi-view RTI (Experimental)

- Interactive change of the view position
- Collection of RTI images taken from different positions
- Flow data to interpolate the viewpoint between two RTI images (optional)



RTI: Rendering modes

Improve the examination of the details and shapes:

- Diffuse Gain (PTM)
- Specular Enhancement (PTM and HSH)
- Unsharp Masking (PTM)
  - Normal UM
  - Luminance UM
  - Coefficient UM
- Multi-Light Detail Enhancement (PTM)
  - Dynamic and static version

RTI: Rendering modes

Diffuse Gain

- Increase the directional sensitivity of the surface to the light changing
- Gain parameter to increase and decrease the effect

Results

- Enhancement inscription

RTI: Rendering modes

DEFAULT RENDERING

DIFFUSE GAIN

RTI: Rendering modes

Specular Enhancement

Add specular effect to the image changing the reflectance properties of the surface:

- Original color (parameter Kd)
- Specularity (parameter Ks)
- Shininess (parameter n)

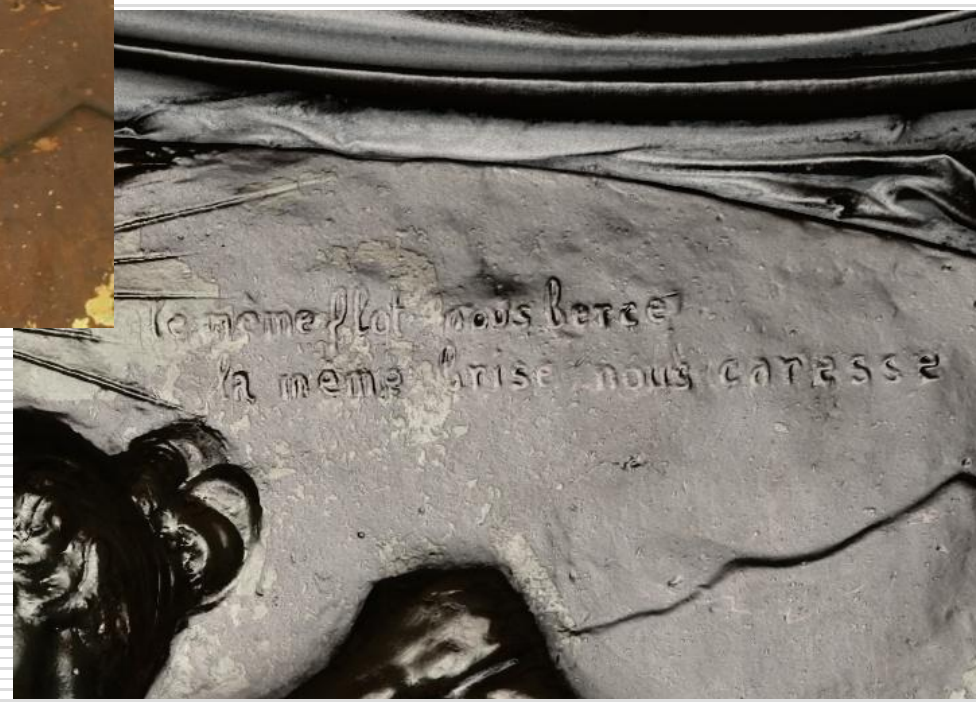
Results

- Enhancement inscription

RTI: Rendering modes

DEFAULT RENDERING

SPECULAR ENHANCMENT



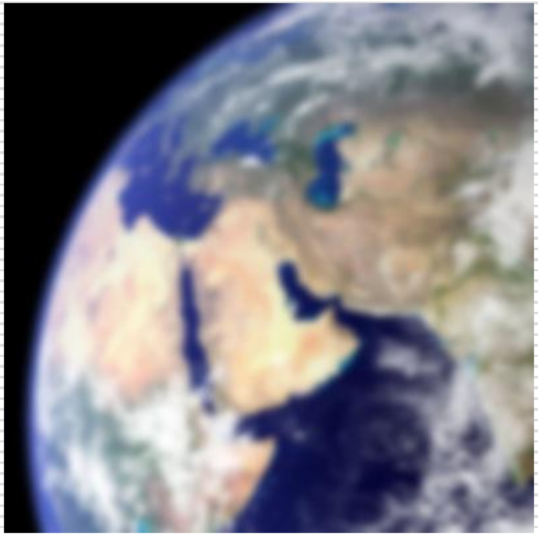
RTI: Rendering modes

Unsharp Masking

Enhance the high frequency details to increase the edge contrast of the image

$$I_E = I + k(I - I_S)$$

ORIGINAL IMAGE I



SMOOTHED IMAGE I_S

ENHANCED IMAGE I_E

RTI: Rendering modes

Unsharp Masking

Gain parameter k to select the amount of enhancement

- Image Unsharp Masking
- Normal Unsharp Masking
- Luminance Unsharp Masking
- Coefficient Unsharp Masking

RTI: Rendering modes

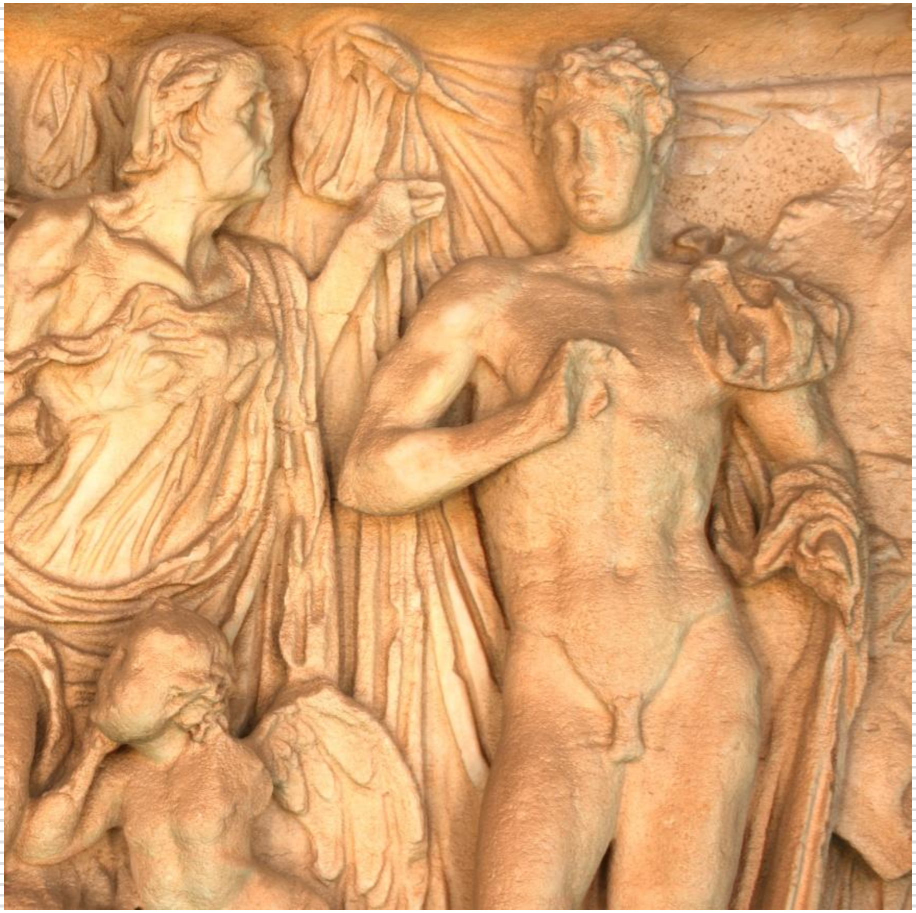
Normal Unsharp Masking

DEFAULT RENDERING

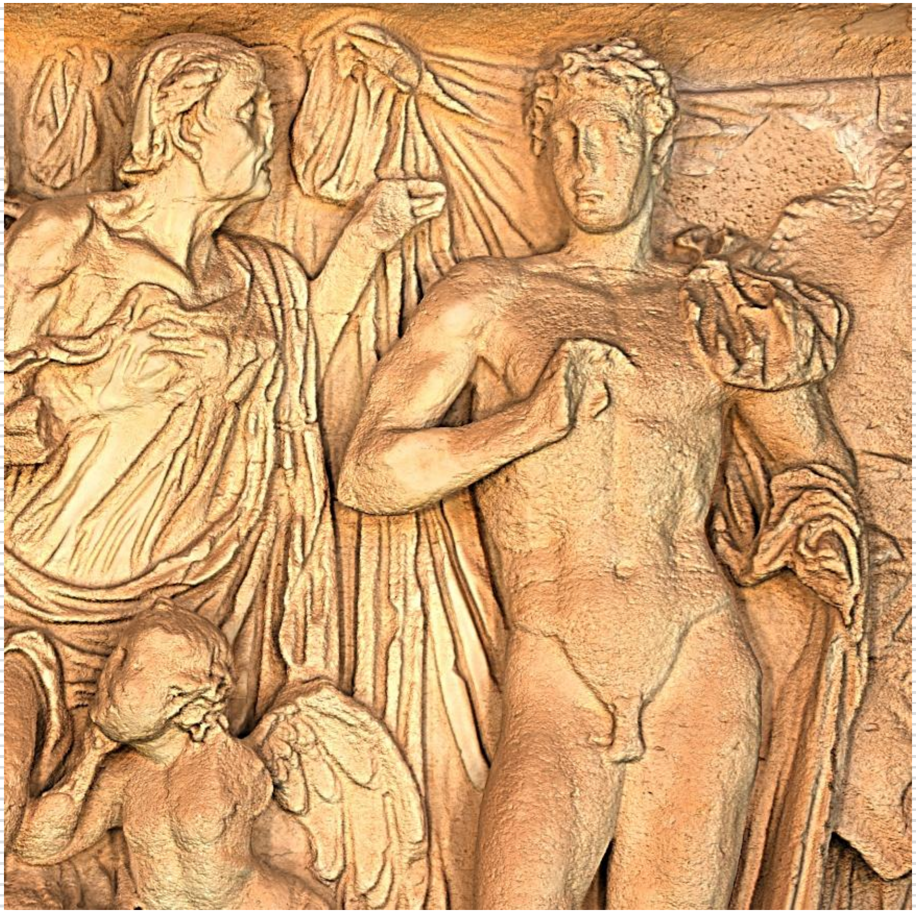
NORMAL UM

RTI: Rendering modes

Luminance Unsharp Masking



DEFAULT RENDERING

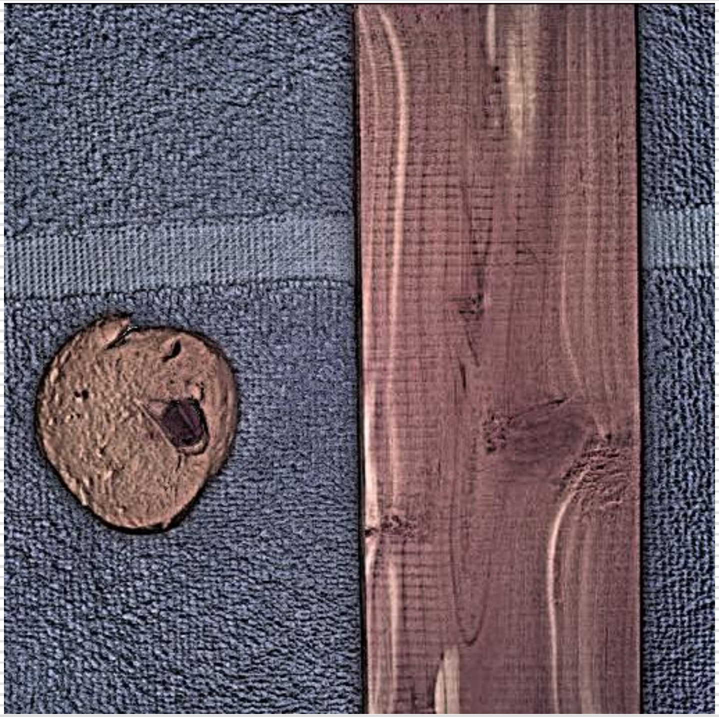


LUMINANCE UM

RTI: Rendering modes

Luminance vs Image Unsharp Masking

- Depth discontinuities are amplified
- Color discontinuities are not exacerbate

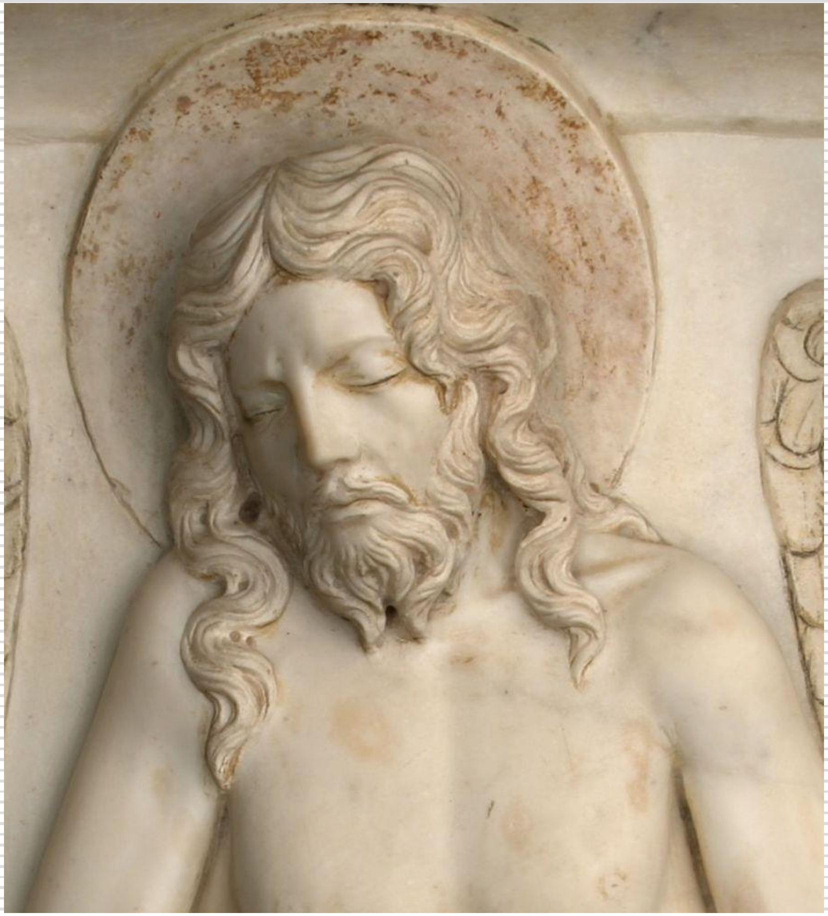


LUMINANCE UM

IMAGE UM

RTI: Rendering modes

Coefficient Unsharp Masking



DEFAULT RENDERING

COEFFICIENT UM

RTI: Rendering modes

Multi-Light Detail Enhancement

- Using different light direction for each area of the RTI image in order to enhance the surface details
- Per-tile light direction maximizing an energy function (local sharpness *S* and brightness *Y* with a parameter "*alpha*" to tune their ratio)

$$\mathcal{E}(T,l) = \alpha\mathcal{S}(T(l)) + (1-\alpha)\mathcal{Y}(T(l))$$

- Final interpolation to compute the per-pixel light direction
- Dynamic Enhancement (local perturbation of the light direction chosen by the user)
- Static Enhancement (static image sampling all possible light directions)

RTI: Rendering modes

Dynamic Multi-Light Enhancement

DEFAULT RENDERING

DYNAMIC MULTI-LIGHT

RTI: Rendering modes

Static Multi-Light Enhancement

DEFAULT RENDERING

STATIC MULTI-LIGHT

RTI on the WEB

Visualization of RTI images in the next generation of web browsers in an interactive way (WebGL + SpiderGL)

WebGL (Safari, Firefox and Chrome)

- Graphics API for Javascript to use the GPU capabilities in the web browser without install external plugins

SpiderGL

- Javascript library to develop 3D web application based on WebGL

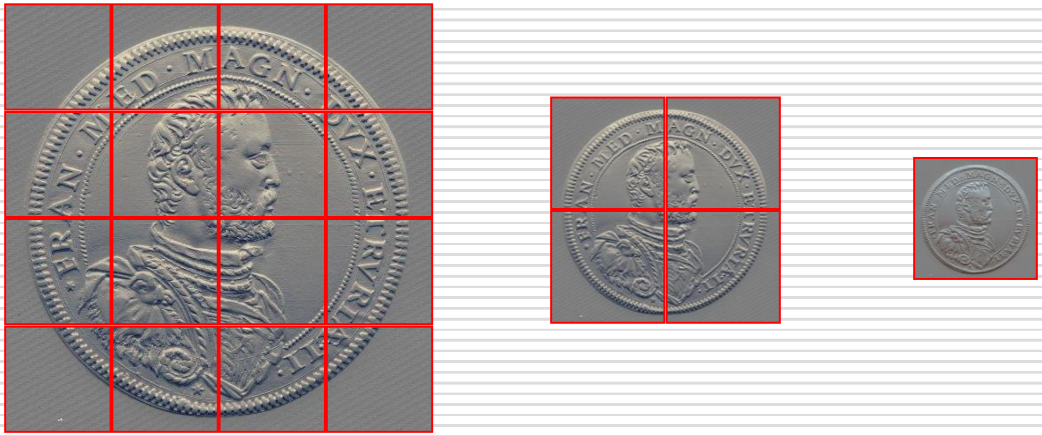
DEMO

http://spidergl.org/example.php?id=9

RTI on the WEB

Issues

- Pre-processing of the RTI image to build a hierarchical layout to store in the web server (multi-resolution and multi-layer quad-tree)



- Algorithm to visit the hierarchy
- Loading the node of hierarchy asynchronously

RTI: Application

Employed in several Cultural Heritage projects

- Palaeontology (high relief fossil, ancient stone tool)
- Surface textures of oil paintings (National Gallery and Tate Gallery of London)
- Numismatic collection
- Antikythera Mechanism




RTI: Pro and Con

PRO

- Compact structure
- Fast and easy acquisition
- Few post-processing
- Realistic rendering result
- Bas-relief or similar
- Implicit geometry or material
- Detail Enhancement

CONTRO

- Fixed point of view
- Approximation
- No object with big depth discontinues
- Max size of the object

RTI: Not only Reflectance

Encoding other attribute

- Depth of focus

- Time varying effect

RTI presentation

The coin collection of the National Museum of San Matteo

The project

Rational

Presenting to the public a collection of coins in an innovative way

Why?

- Coins are very small artworks, presented from a distance(>50 cm), only one side visible
- They don’t tell their story by themselves

Who?

National San Matteo Museum and VCG, Pisa, Italy

The project

Virtual inspection of coins.
How to manage it?

- Rotate the coin under directional illumination, to help our brain to build a cognitive model by inferring data from dynamic reflection and shading
- A representation to simulate in real time the illumination effects in an accurate manner
- ATTENTION!!! Extremely complex to produce images of coins due to the reflection effects of different materials

Idea

Project

Design and implementation of an interactive kiosk to allow the presentation and the virtual inspection of coins:

- Easy to use for the user
  - Ordinary (inexpert) public
- Interactive manipulation
  - Zooming, panning, rotating the coin, changing the light direction
- Telling their story throw multimedia data
  - Organization in several overlapping subset
  - Descriptive data for specific location on the coin

Virtual Inspection: 3D vs 2D

Solutions

- 3D - Geometry + Surface appearance
  - 3D acquisition of coins is still a complex task (sides are very thin, alignment problems)
  - Higher acquisition and processing time
  - More expensive (complex and ad hoc instruments)
  - 3D manipulation is more complex to understand and control for the user
- 2D – Reflectance Transformation Imaging (RTI) techniques
  - Relightable images
  - Higher quality of illumination-dependent effects
  - Higher resolution
  - Cheaper acquisition and processing step
  - Very easy to understand and to control for users

Coin kiosk

Interactive kiosk

- Organization of the coins in categories and present these categories
- Virtual inspection of each coin
  - RTI manipulation (HSH)
  - Presentation of the coin
  - Hotspots on selected areas to tell the story of coin's details
- Multi-touch screen and web site

Implementation details

- HTML + Javascript (presentation of multimedia data)
- WebGL + SpiderGL (RTI visualization)

RTI Acquisition

Subset of the museum's collection(41 coins) selected from the museum curators following value and storytelling criteria

Digitized with MiniDome (KUL):

- 4 shells, easy to assemble
- 260 white LEDs
- Overhead CCD camera (5Mpx)
- Computer controlled for automatic acquisition (10 minutes per coins)
- Raw data

Digitalization time: 1 day

RTI Processing

Processing steps

- Raw data converting (8h, 21320 images)
  - From Bayer Pattern to RGB
- RTI images generation (7h, CHI tools)
  - 2 HSH per coin (front and back)
- Generation of multi-resolution streamable RTI format (5h)
  - Multi-resolution quad-tree
  - Tiling of each level
  - Allow the asynchronous loading of the images
  - Immediate interaction with the image

Coin kiosk – HTML presentation

Kiosk setting (20 d)

- Customizable HTML template
  - Graphics layout (CSS)
  - User interaction (JavaScript)
- XML file to store the content to visualize in the kiosk
  - Categories
    - General multimedia content
    - List of coins
  - Coins
    - General description
    - Position and content of the hot-spots

Coin Kiosk

DEMO