Universität Bamberg

Einführung Digitale Denkmaltechnologien, Lecture: 3D rendering, capture… and some museology

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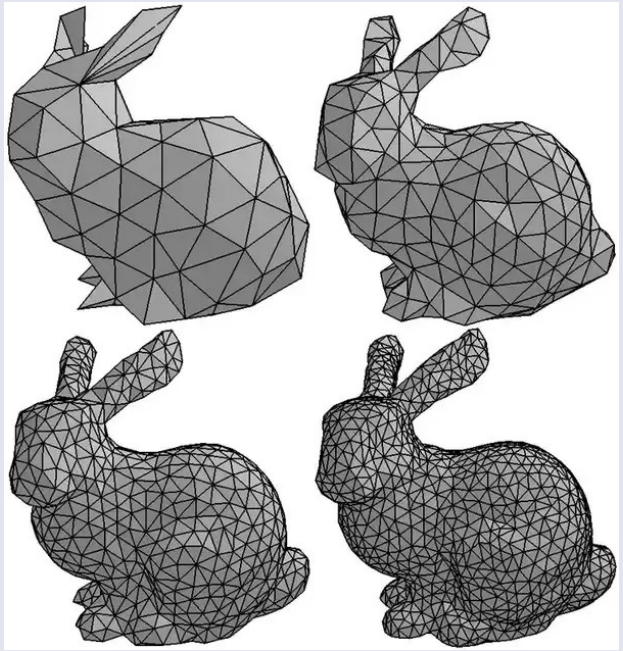
KDWT

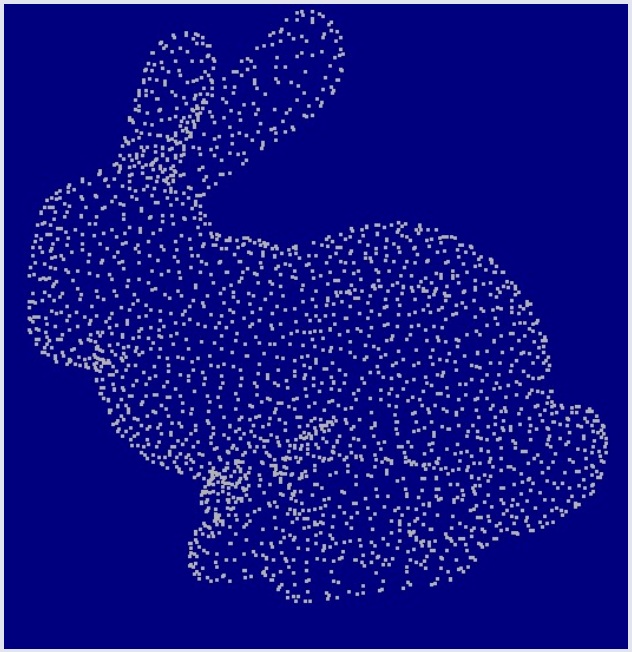
Today…

1. How we render 3D models
2. Why is capturing a good, coloured 3D model so difficult?
3. What do we do with 3D models
4. Why (1.) *maybe* doesn't matter

What is a 3D model?

- A *point cloud*
- Or a *mesh*
- *with:*
  - 3d points/vertices (x,y,z)
  - Colour information (r,g,b)
  - Normal vectors (i,j,k)
- Other 3D types:
  - voxels, nurbs, CAD





Point cloud properties

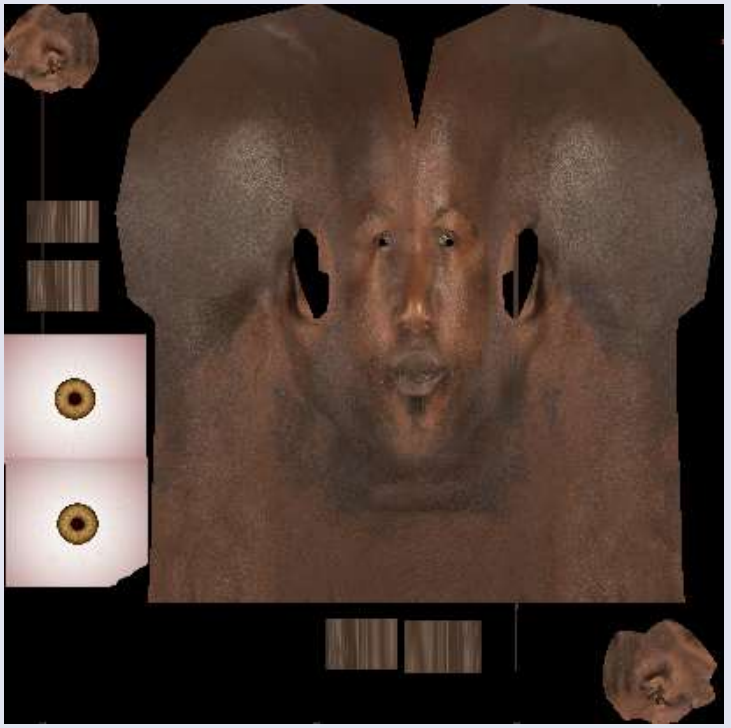
- All scanned or captured models begin as point clouds
- Raw data – each point corresponds to a measured point on the object
- Not always possible to mesh a point cloud
  - Noise, geometry, point density
- Colour comes from multiple laser wavelengths (rare!) or projecting photographs onto point cloud
- Not a 'solid' model – rendering as solid can 'blur' model

Mesh properties

- Made up of coloured or textured polygons (always triangles!)
- Efficient: two triangles can define an arbitrarily large plane
- Default method for rendering 3D models for decades
  - Software methods for processing and rendering meshes very well developed
  - Computer hardware (GPUs) designed to render triangles and jpeg textures quickly and efficiently

Mesh properties 2

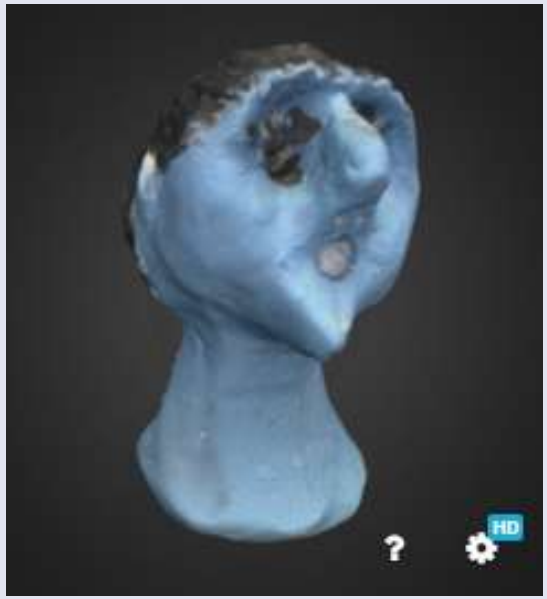
- 'Simple' method for making a mesh from a point cloud:
  - Each point = one triangle vertex
  - 1 million points = approx. 1 million triangles
- Meshes usually 'decimated' for efficiency
- 'Per vertex' colour inherited from point…
- …or textured via *uv* mapping

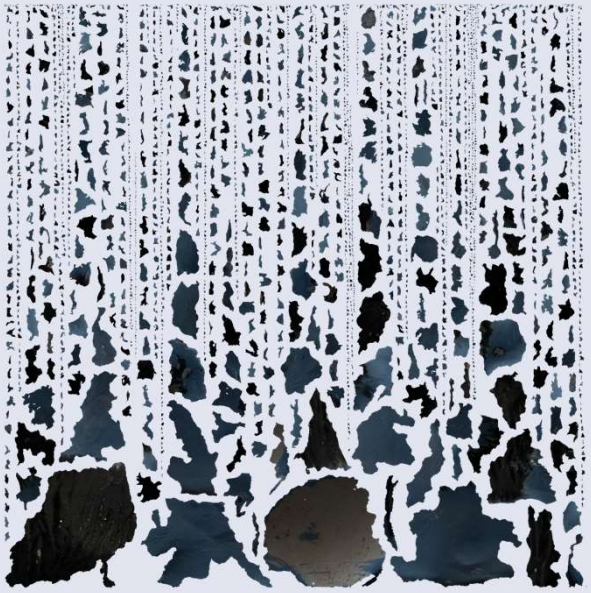


Lewis Kennedy
https://learningtonormalmap.wordpress.com/

Texture mapping

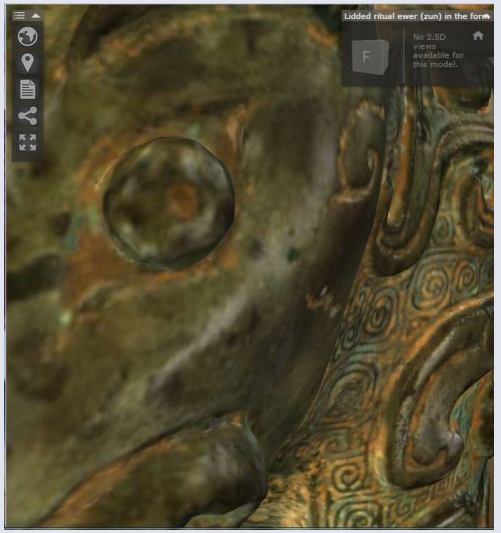
- Mesh generated from point cloud
- Images projected on to mesh from known camera positions
  - Can do this manually (but very difficult)





Issues…

- Meshing invariably involves some amount of averaging or interpolation in both geometry and texture
- Geometry can be improved by 'bump' or 'normal' mapping
- Texture only by more/higher resolution photographs



- Projecting an image works best when the photograph is taken orthogonally (*senkrecht)* to the surface (triangle)

Image: dvdhns https://blender.stackexchange.com/questions/84956/project-a-photo-onto-a-surface

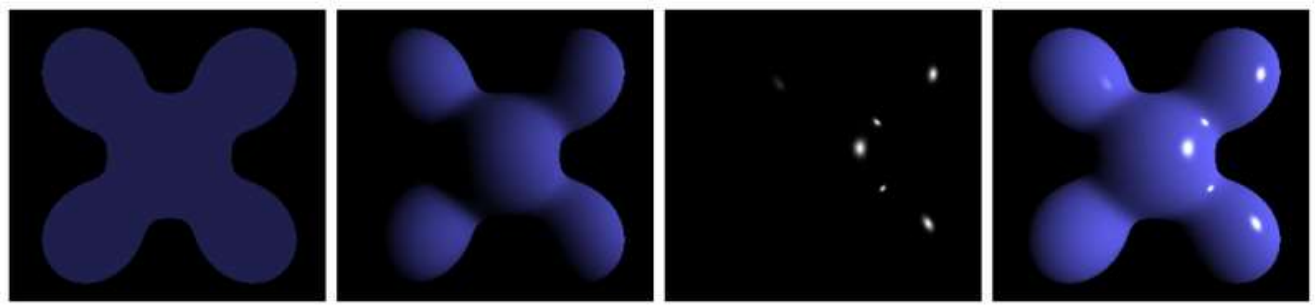
Rendering 3D models

- Modern graphics pipelines (OpenGL, WebGL, DirectX) use *shaders*
  - Written in a 'C-like' language
- The *vertex* shader draws the geometry
  - Transforms the 3D model's vertex coordinates using the camera position to determine where the triangles are in 3D space
- The *fragment* shader determines what colour each pixel should be rendered
  - Usually by looking at each pixel's UV coordinate and picking a colour from the texture map
  - And then (possibly) applying a *lighting model*

Lighting models

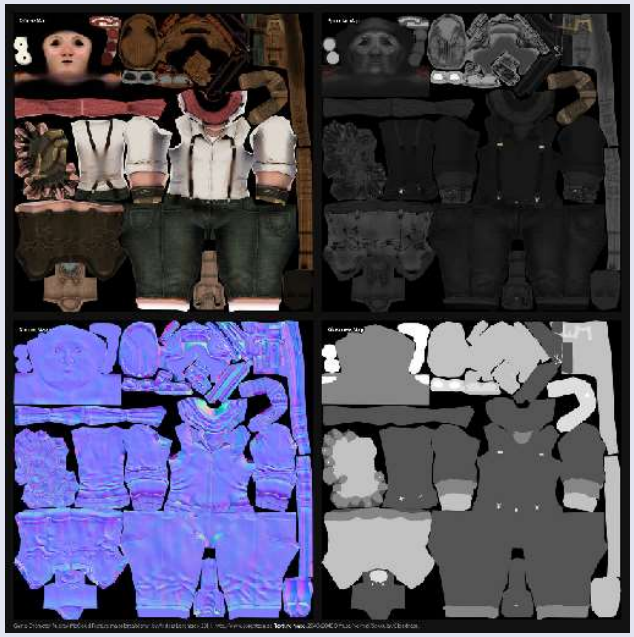
- The colour value taken from the texture is modified depending on the *normal* value at that point and the angle of incoming light.
- Specular highlights can be added according to viewing angle, angle of light and the shininess of the material
- The *Phong model* was developed in 1975 – and is still very popular

http://www.mathematik.uni-marburg.de/~thormae/lectures/graphics1/code/WebGLShaderLightMat/ShaderLightMat.html

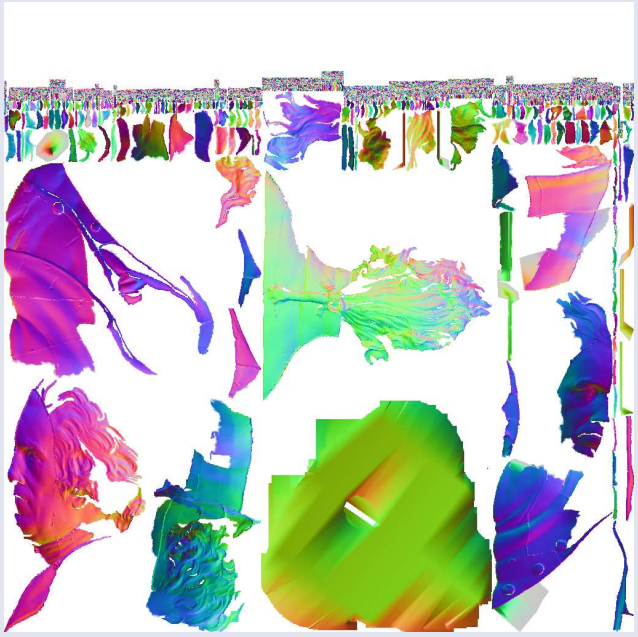


By Brad Smith - Own work, CC BY-SA 3.0,

It can be more complex…



Clockwise from top left: Texture, specular, gloss and normal maps; Anders Lorentzen - Audrey: http://www.lorentzen.se/



Watt bust bump map
Mona Hess / Science Museum

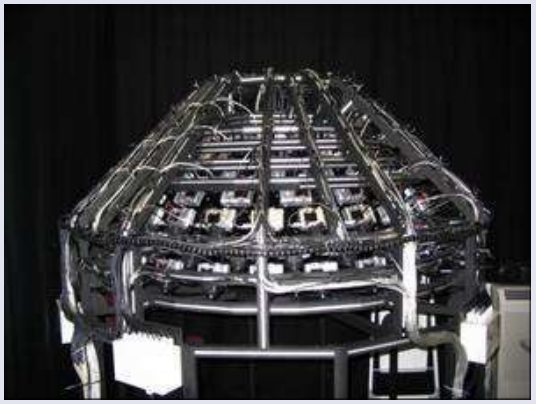
But…

- For anything other than a completely diffuse material, our texture colour *already* depends on the lighting angle of the photograph
- Our texture image *already* includes specular highlights
- What is the 'shininess' of our model?
  - One material?

MERL BRDF Database
https://www.merl.com/brdf/

BRDF & BTF

- *Bidirectional Reflectance Distribution Function*
- *Bidirectional Texture Function*
- Measures colour of point with multiple viewing angles & multiple light source angles
- But… needs *10s of thousands* of images!
- … and a special renderer…



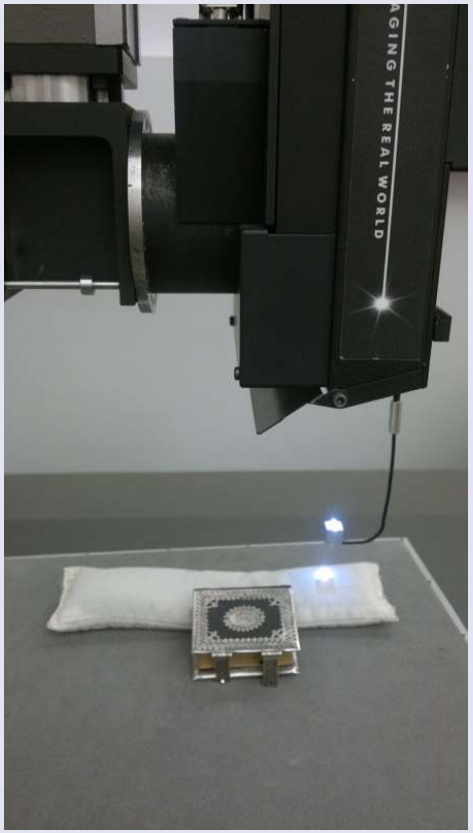
https://cg.cs.uni-bonn.de/en/projects/btfdbb/dome/
https://cg.cs.uni-bonn.de/fileadmin/btf_viewer/shoe.html
https://cg.cs.uni-bonn.de/fileadmin/Downloads/Videos/Multiview%20Dome%203D%20Object%20Acquisition.mpg

Why is capturing 3D data so difficult?

- All(?) 3D capture technologies involve some form of electromagnetic radiation reflected off an object
  - Visible light (sunlight, a camera flash, a projected pattern)
  - A laser (visible or otherwise)
- Why is this an issue?
  - Electromagnetic radiation travels in a straight line
  - How much is reflected depends on the angle of incidence (*Einfallswinkel*)

You can't capture what you can't see…

- Complex geometry causes *occlusions*
- Interiors can be impossible to image
- Cracks can cause problems
- Be aware of triangulation!



Miniature German picture bible, Courtauld Institute
https://courtauld.ac.uk/gallery/what-on/exhibitions-displays/illuminating-objects/german-miniature-picture-bibles

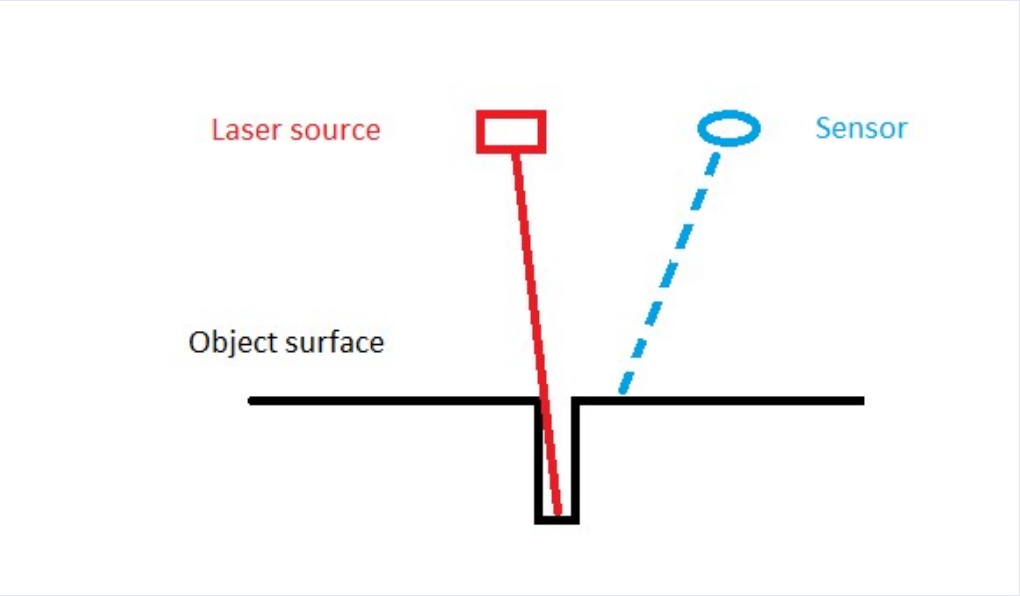
You can't capture what you can't see… 2

- Interiors can be very hard to image
- What is the range of your laser / depth of field of your scanner?
- Can you light them properly?
- Can you photograph interior surfaces orthogonally and from multiple angles?

The Islamic Wallet - a bag made in Mosul, Northern Iraq around 1300 (Courtauld Institute of Art)
https://courtauld.ac.uk/gallery/what-on/exhibitions-displays/archive/court-and-craft-a-masterpiece-from-northern-iraq

You can't capture what you can't see… 3

- Thin openings – such as cracks – offer the same issues as interiors
- Can you light and image them from multiple angles?
- Triangulation: Don't assume that just because you can see your laser spot / projected pattern, you can capture the surface



Other geometry problems…

- Non-rigid objects
  - Can you scan the object in multiple positions?
- Thin surfaces
  - How can you register two surfaces with no common points?
- Practical issues
  - Where is the object? What sort of access do you have?
- Very high frequency geometry
  - Hair, fur etc.

Dish Tin-glazed earthenware, painted with lustre. Probably Manises, Spain, 1500-1525. 47.5 cm diam. Samuel Courtauld Trust: Gambier-Parry Bequest, 1966

But it gets worse… Materials

- We measure amount of radiation reflected for just one combination of angle of incidence and angle of reflection
  - Affects both colour and intensity
- This is ok for *Lambertian* or *perfectly diffuse* materials
  - As used in colour checker charts, Spectrolon
  - Every material 'in the real world' has some element of gloss (*glanz*) or shininess
  - Resulting in specular (*spiegelnd*) highlights

Image: Element 3D

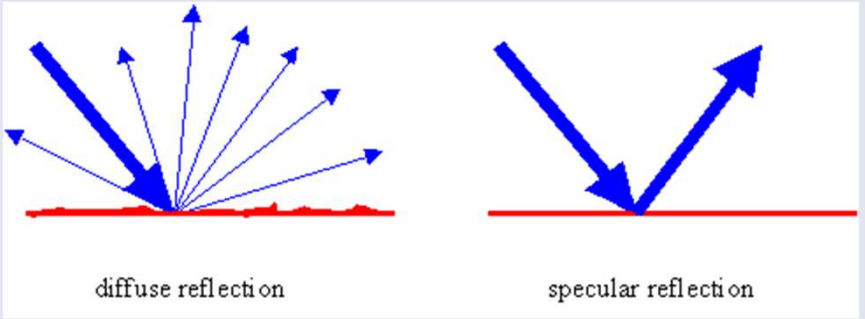


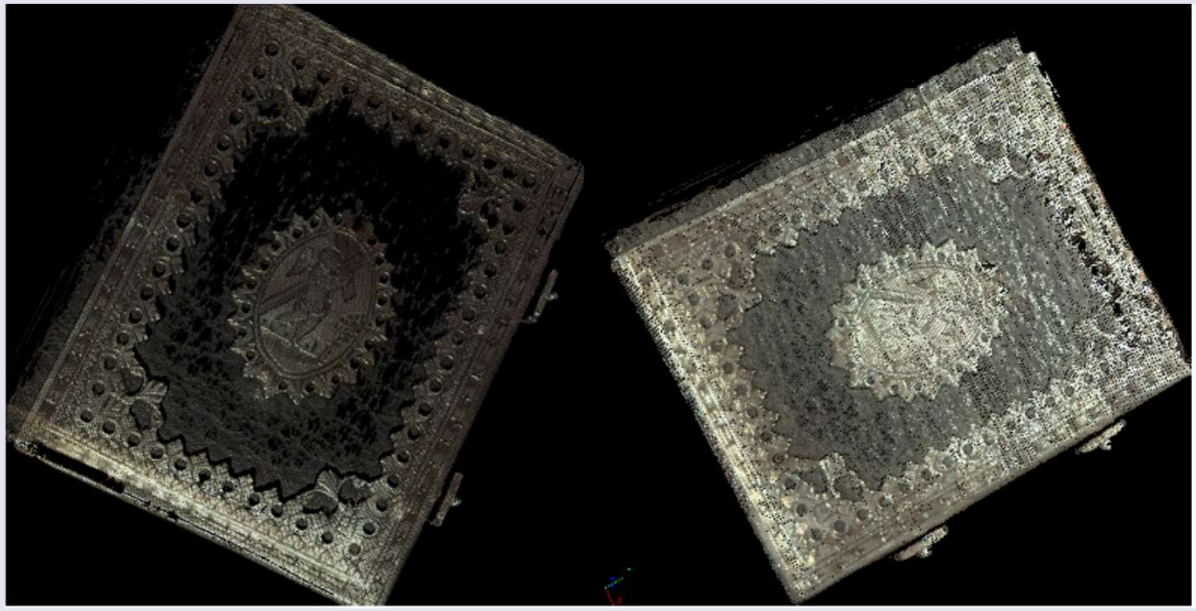
Image: Prof. Seyffie Maleki

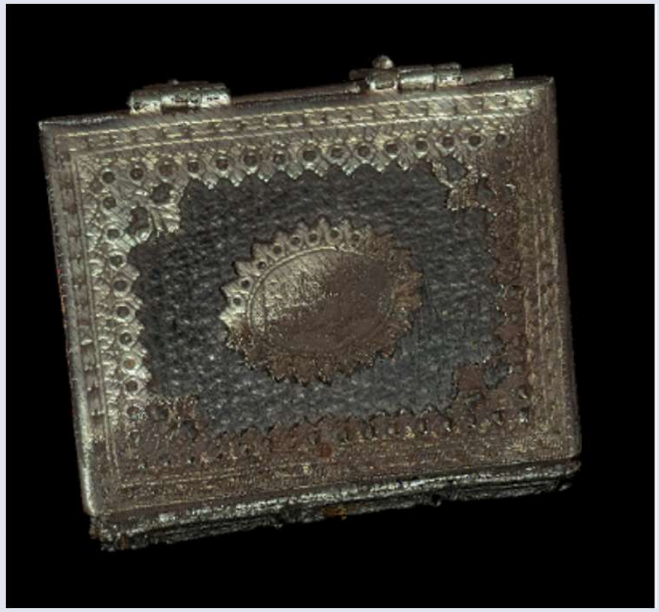
Specular reflections / highlights

- Reflections aren't part of surface, and the colour captured depends on the relation of light source and observer
  - Either we get one image with false colour or many images with different colours
  - Intensity can blind sensor or give false readings
  - Holes need to be filled with 'made-up' data

Spanish lustreware bowl, Courtauld Institute

Two laser scans of the same surface, one at 30°, one at 45°

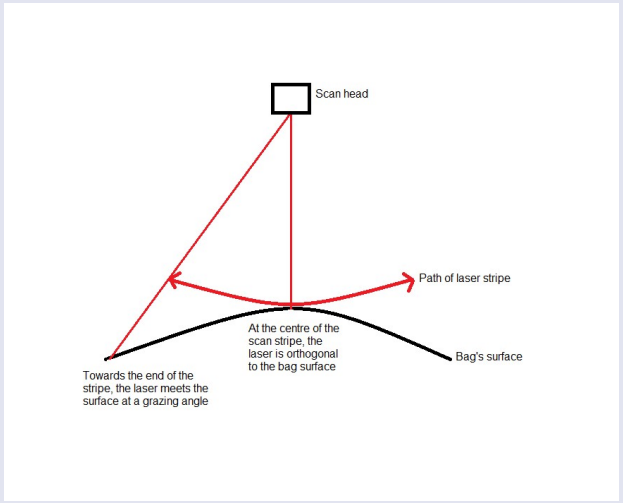




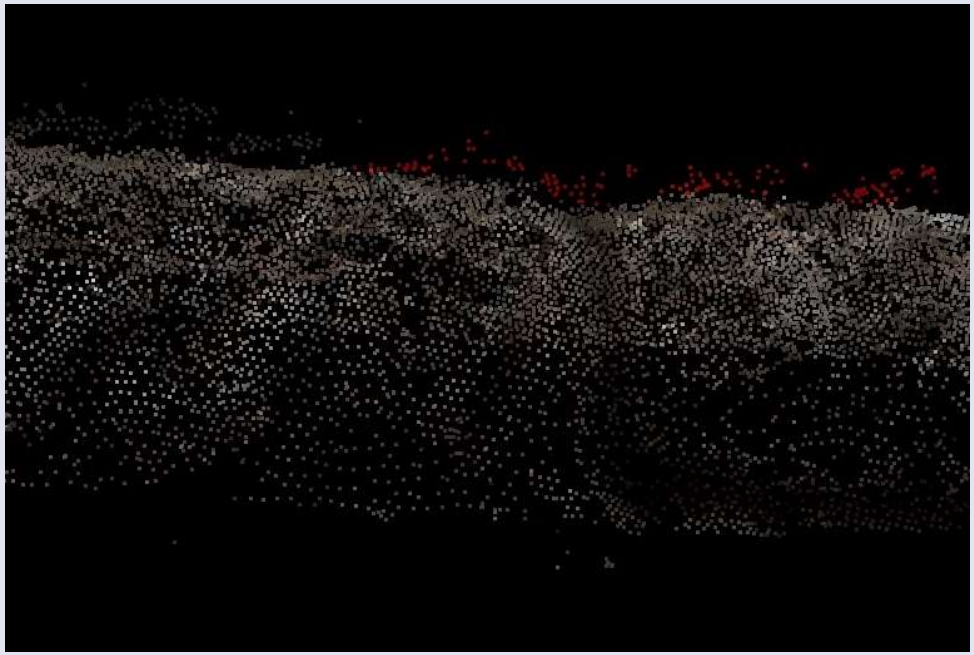
German miniature picture bible, Courtauld Institute

Shiny surface scanned at multiple angles

The Islamic wallet (Courtauld Institute of Art)



Same object, captured with photogrammetry

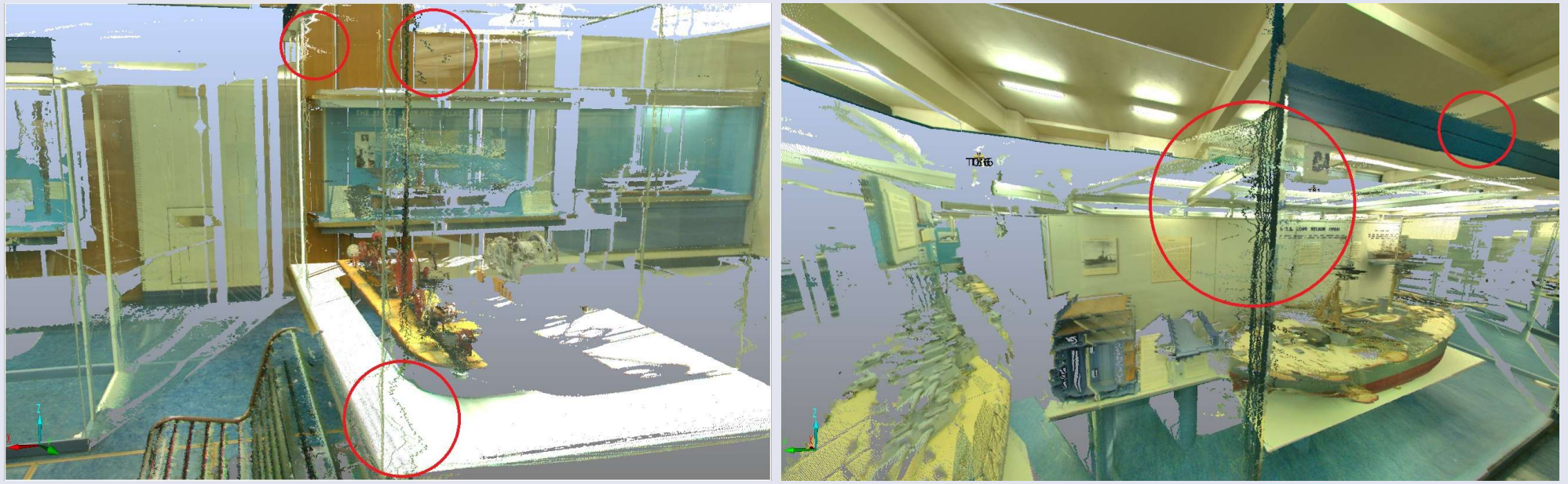


As well as being too bright…

- Dark materials don't reflect *enough* light…

German miniature picture bible, Courtauld Institute

Noise in a terrestrial scan caused by glass



Science Museum Shipping Gallery, Scanlab Projects

If you want to read more…

- MacDonald, L., Hindmarch, J., Robson, S., & Terras, M. (2014). Modelling the appearance of heritage metallic surfaces.
- Investigating the use of 3D digitisation for public facing applications in cultural heritage institutions http://discovery.ucl.ac.uk/1527400/7/Hindmarch_JHindmarch_thesis.pdf.REDACTED.pdf

And there's more…

- Anisotropy
  - Materials appear different from different directions (velvet (*Samt*), brushed aluminium (*gebürstetes Aluminium*))
- Translucency / transparency
  - Some or all the radiation is transmitted rather than reflected (jade, glass)
- Subsurface scattering
  - Some radiation penetrates the surface, bounces around and is emitted from a different point (skin (80%!), marble)
- Iridescence
  - Tiny surface features diffract light, different wavelengths diffract different amounts causing 'rainbow'-like sheen (oil, shells)
- Flourescence
  - Radiation is absorbed and readmitted at a different wavelength

From top left: Subsurface scattering, translucency, iridescence, fluorescence, anisotropy

Images: Jensen et al (2001), http://www.aliexpress.com/, http://www.fossilmall.com/, http://finent.net

So…

- We can't always capture all geometry
  - Holes must(?) be filled in with 'made-up' data
- Our colour is always going to be an approximation
- We can't render light accurately

Part 2: Implications

What do we use 3D models for?

- As a *digital surrogate* for the real object
  - Can 'stand-in' or substitute for real object
  - Interacting with model will provide same results as real object
  - If you ask two people to describe object or answer questions about object, get the same answers from real object and 3D model

"[the digital surrogate's] goal is to reliably represent real world content in a digital form. Their purpose is to enable scientific study and personal enjoyment without the need for direct physical experience of the object or place. Their essential scientific nature distinguishes them from speculative digital representations"

A digital future for cultural heritage, Mudge, 2007

What is a digital surrogate

- Created with repeatable methodology ("essential scientific nature"). Traceable connection between each point of data and corresponding point on object.
- Digital surrogate (as opposed to a visualisation or representation) is:

  "closest fidelity to the actual object that can be achieved digitally"
  Digital artefacts: possibilities and purpose (Arnold 2008)

- What do we mean by closest fidelity?
  - Today, or tomorrow?
  - Geometry, or colour?

The digital surrogate… *for what purpose?*

- Clearly, a 3D model can't stand in for an object for all purposes
  - We can't weigh it
  - We can't take a sample
  - We can't perform multi-spectral analysis on it…
- 'Greatest fidelity' in one aspect may involve compromise in other aspect
  - Different capture methods provide different data

What do we use 3D models for? (2)

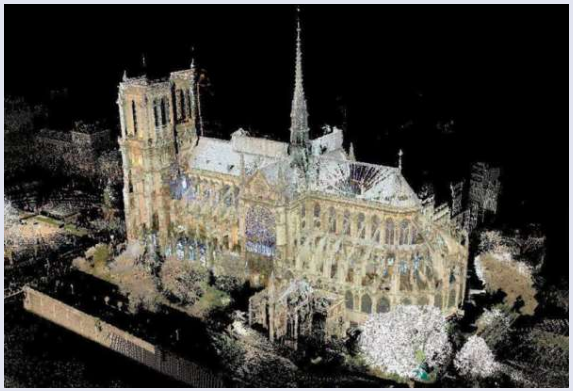
What do we use any cultural heritage object for?

"[A museum is] A non profit, permanent institution in the service of society and its development, open to the public which acquires conserves, researches, communicates and exhibits the tangible and intangible heritage of humanity and its environment for the purposes of education, study and enjoyment."

ICOM definition: http://icom.museum/the-vision/museum-definition/

3D models for professional purposes

- The acquisition, conservation and preservation of Cultural Heritage
  - '4D' imaging, condition monitoring
  - Detailed description and recording when preservation is not possible
- Academic research to increase knowledge and understanding of Cultural Heritage to benefit ourselves and future generations
  - Remote object assessment, increased access, comparison, virtual reunification
- See, for example, 3D colour scans for object assessment (Hess et al, 2008)



3D models for professional purposes (2)

- But…
  - 3D model can only act as a digital surrogate in a limited domain: visual, non contact inspection, in a particular spectrum with restricted resolution
  - For a Cultural Heritage professional with access to the object this will usually be a poor substitute
  - A camera with a telephoto lens or a powerful magnifying glass will often give better results
- (though access, non-contact etc. still relevant)

The digital surrogate… *for the purpose of X*

- Digital surrogacy no longer tied to 'greatest fidelity' or ability to 'reliably represent'
- But ability to substitute for the object for a *specific purpose*
- The ability of the model to be a digital surrogate depends on communication between the Cultural Heritage professional and the digitisation expert.
- The CH professional specifies the properties they need to record, the digitisation expert communicates the limits of the capturing (and rendering) technology

3D models in public facing applications

- Museums duty to display, provide access to Cultural Heritage and disseminate knowledge (beyond academia)
- For education + entertainment, study + enjoyment
- Is this 'edutainment' (engagement?) a secondary role?
  - In a sense, yes: Without preservation & collection, there would be nothing to exhibit
  - Without research, there would be no knowledge to disseminate

Museums' responsibilities to the public

- UNESCO 1978 "Cultural property representing the different cultures forms part of the common heritage of mankind"
- ICOMs code of ethics "museums maintain collections in trust for the benefit of society and its development"
- Museums Association Code of Ethics:
  - Hold collections in trust for the benefit of society
  - Focus on public service
  - Encourage people to explore collections for inspiration, learning and enjoyment
  - Consult and involve communities, users and supporters https://www.museumsassociation.org/asset_arena/7/17/15717/v0_master.pdf

3D models in public facing applications

- Increasing access for people…
- …and for collections
  - V&A 24%, Smithsonian 2%, British Museum 0.5% of collections on display
- Fulfilling one mission (access) entails risk to another (preservation)

  "the growing desire of the public to know and appreciate the wealth of the cultural heritage has led to an increase in all the dangers to which cultural property is exposed as a result of particularly easy access"
  UNESCO: Recommendation for the Protection of Movable Cultural Property
- Can virtual models provide an alternative?

3D models as digital surrogates (in public facing applications)

- Public often view object behind glass; from a certain distance; at a particular angle with particular lighting
  - Digital surrogate might be a *better* experience?
- We don't need to make measurements or have particular accuracy requirements
  - But we do need a holistically authentic model?
  - Is it the complex interaction with light which makes objects interesting?

View of the bag on display in Court and Craft (picture courtesy The Courtauld Gallery)

Digital surrogate… *for what purpose*?

- We are faced with the same issue – what is the particular purpose of a 'public-facing' museum object?
- Beware of technological determinism:

  "the implementation of [dig tech] in museums is assumed will positively impact visitor satisfaction even while there is little verification of whether these technologies really achieve their goal"

  Pallud, J. (2009). The application of a phenomenological framework to assess user experience with museum technologies, ECIS 2009 Proceedings. Paper 395.

Some basic museology…

The changing role of museums through time:

- Legislative: "display not debate", "a container for collections of objects" (visitor is passive, awestruck, *andächtig, ehrfürchtig*)
- Interpretive: Objects are in context, and secondary to a narrative - disseminators of information rather than simply collections.
- Performing: Storytelling, education, entertainment

The museum effect: gazing from object to performance in the contemporary cultural-history museum (Casey 2003)

http://www.valcasey.com/ichim/assets/casey_ichim.pdf

Museum objects: Aura & affectual power

- Benjamin, 1935: 'The Work of Art in the Age of Mechanical Reproduction'
  - Introduced concept of Aura: ineffable (*unaussprechlich*) quality inherent in the object, not captured by any form of mechanical reproduction.

    Benjamin, W. (1935) 'The Work of Art in the Age of Mechanical Reproduction (repr 2001)', in Thomas, J. (ed.) *Reading images*. Basingstoke: Palgrave (Readers in cultural criticism), pp. 62–75.

    Benjamin, W., 1990. Das Kunstwerk im Zeitalter seiner technischen Reproduzierbarkeit (erste deutsche Fassung, 1935) in: Gesammelte Schriften / Bd.1, Abhandlungen / Walter Benjamin, 3. Aufl. ed. Suhrkamp, Frankfurt am Main.

    Online : https://de.wikisource.org/wiki/Das_Kunstwerk_im_Zeitalter_seiner_technischen_Reproduzierbarkeit_(Dritte_Fassung)
- Aura is what makes people engage with museum objects; they have *affectual power* (ability to elicit emotional response)

Where does aura come from?

- In a work of art, aura is inherent in the work itself(?) In a museum object?

- From the context
  - Label text
  - The display
  - The visitor's knowledge
  - The museum itself?

The Tarkhan dress, Petrie Museum
http://www.ucl.ac.uk/news/news-articles/0216/150216-tarkhan-dress

Moon rock exhibits…

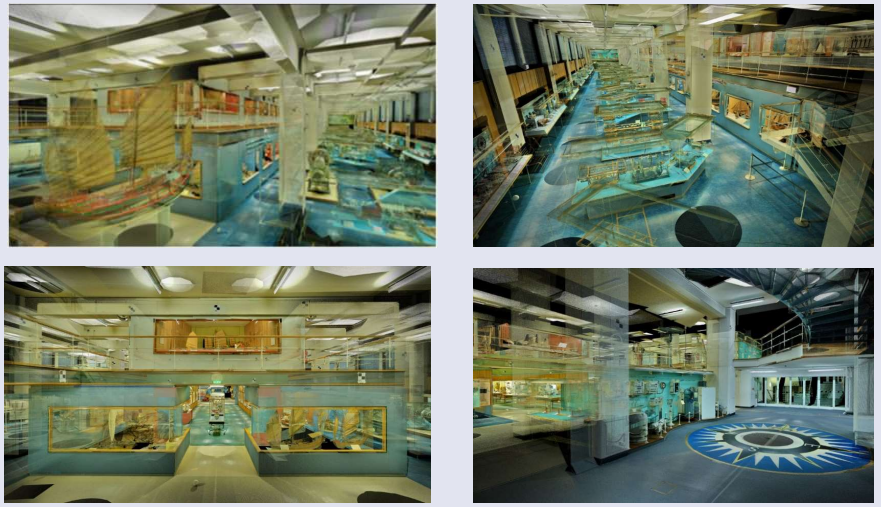
Left: The National Mining Hall of Fame and Museum, Colorado right: Tellus Science Museum, Atlanta. Pictures: NMHFM & Charles Atkieson/examiner.com
Previous slide: Lunar basalt, Natural History Musuem

Can a virtual model have aura?

- If the aura is not inherent solely in the object, can we recreate it with a virtual model?
  - Perhaps by providing the same context
  - Can it inherit the museum's authority?
  - People are impressed by the use of new technology…
- The 'purpose' of the digital surrogate then becomes evoking an affectual response
  - Instead of simply communicating information
  - Then does it need to be photo-realistic?

The Science Museum Shipping Gallery video…

- The Shipping Gallery was scanned before it was decommissioned
  - The video was narrated by the curator
  - It was accompanied by specially commissioned music
  - The 'point cloud aesthetic' was chosen for artistic reasons
- All worked together to create an 'elegiac' (*elegisch*) feel



The Shipping Galleries - A 3D Point Cloud Fly Through
https://www.youtube.com/watch?v=gDTbFhFZl9I

Did it work?

- In unsolicited comments the video was described as 'spooky' or 'ghostly'
- People often used emotive language (positive and negative!)
- Fitted *purpose* which was to commemorate something no longer there

“I actually applauded at the end of that.”

"A very moving experience"

“Great. Now I'm feeling wistfulness over the non-existence of a place I never knew existed.”

Conclusions

- Creating perfect, photo-realistic 3D models is hard!
- This may not be important so long as we pay attention to the specific *purpose* of the 3D model
- Context is important in public facing applications
- Virtual content can possibly have aura – but more research is needed!