Animação e Ambientes Virtuais 2018/2019

Pós-graduação

DI- FCUL

Guião das aulas teóricas
GU-AAV-19- Modelação & Face Cloning

Beatriz Carmo, Ana Paula Cláudio

Outline

Modeling	**Face cloning**
Methods to generate 3D models • 3D Modeling Tools • Procedural modeling3D • Scanners (range data) • Photo-based (image based)	• Generic Human Face Structure • Face cloning using photo-cloning and image analysis • Similar procedure for 3D face scanning with Kinect

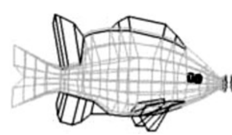
Cloning

To reproduce real objects/beings:

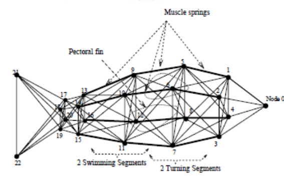
- Modeling – creation of the virtual being/object
- Animation – movement generation
- Interaction with the environment
  - Perception
  - Behaviour

Modeling comprises

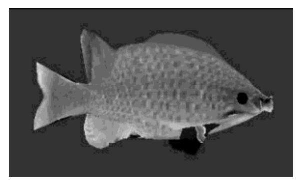
– Generation of a polygonal surface (mesh)
which defines the shape of the virtual being



– Definition of a "skeleton" (usually) (functional structure for animation)
In some cases another layer is placed over the skeleton to model the muscles



– Application of a texture



Types of modeling

- "Artistic" modeling - uses specific software for modeling ("draw from scratch")
- Cloning - recreates real objects/beings

Static Shape Reconstruction

Generates only the (exterior) **shape without a skeleton**

Using

- 3D Modeling Tools
- Procedural modeling (for cities)
- 3D Scanners (range data)
- Photo-Based (or image-based)

3D Modeling Tools

- **Modeling tools** like AutoCAD, 3ds Max, Maya, Blender
- Some of them are usually applied for buildings or objects
- It is more difficult to clone humans with modeling tools
- **MakeHuman** (http://www.makehumancommunity.org/)

"The ultimate goal is to be able to **quickly produce a wide array of realistic virtual humans** with only a few clicks of the mouse and be able to render or export them for use in other projects."

MakeHuman (http://www.makehumancommunity.org/)

- Without clothes, without hair (see some user contributed assets)
- Tools to export models to **Blender**

1170 MORPHINGS FOR EFFECTIVE PARAMETRIC MODELLING

Easy and intuitive parameters, including:

- Age, gender, height, weight
- Body proportions, face shapes
- Eyes, nose, mouth, chin, ears, neck...
- Hands details, feet..
- And more...

Daz 3D (https://www.daz3d.com/ http://www.daz3d.com/technology/)

"Genesis - the first generation of Daz 3D's technology **for creating powerful human 3D figures**

- Create an unlimited range of characters and creatures by **morphing** and **texturing** from a single, adaptable humanoid 3D mesh.
- All Genesis based clothing and accessories fit virtually all Genesis based figures"
- The real power behind Daz 3D is our massive **3D content marketplace**. With over 16 thousand items and more added every day, the Daz 3D marketplace has it all."
- Free software, models can be integrated into **Maya**

Daz 3D (http://www.daz3d.com/technology/)

FarmáciaVirtual

VASelfCare

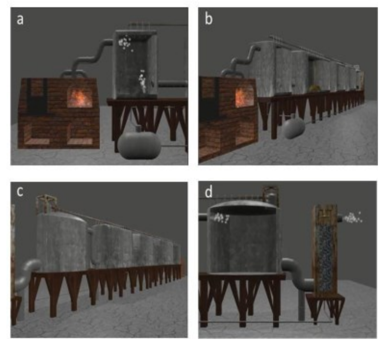
3D Modeling Tools (Blender)

http://www.blender.org

3D Modeling Tools (Blender)

Student project (AAV)

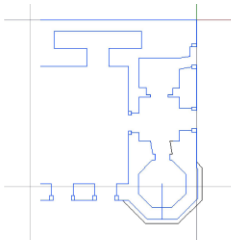
Observatório Astronómico

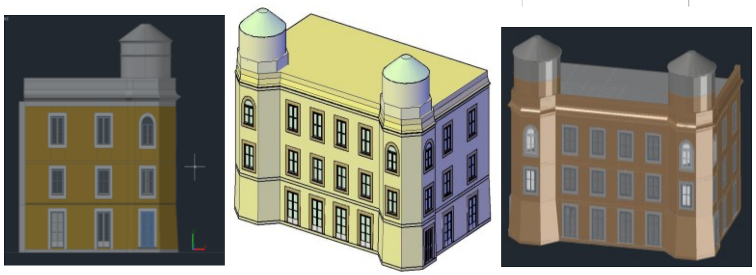


Museu Nacional de História Natural e da Ciência - 19th century coloured panel illustrating a manufacturing facility used to produce sulphuric acid

3D Modeling Tools (AutoCAD)

Student projects (Visualização 13/14)
Edifício das Matemáticas (Escola Politécnica)





3D Modeling Tools

- Although time-consuming, 3D Modeling Tools do not require expensive hardware.
- Can reproduce objects that no longer exist
- The resulting model is **often**
  - low on details,
  - not providing a realistic appearance,
  - but it can be improved applying texture mapping.

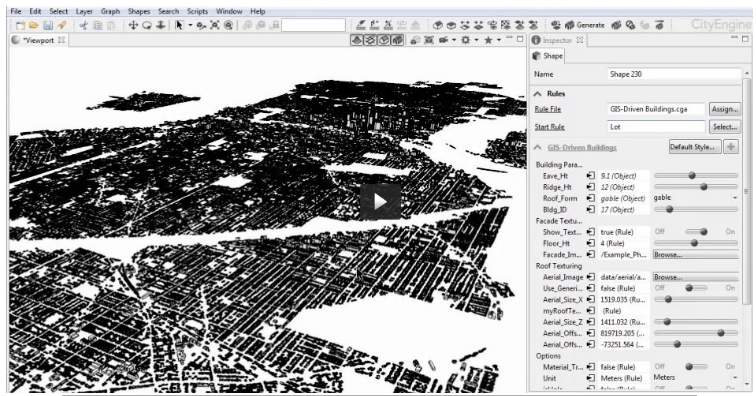
Procedural modeling

Procedural modeling consists on modeling **by rules:**

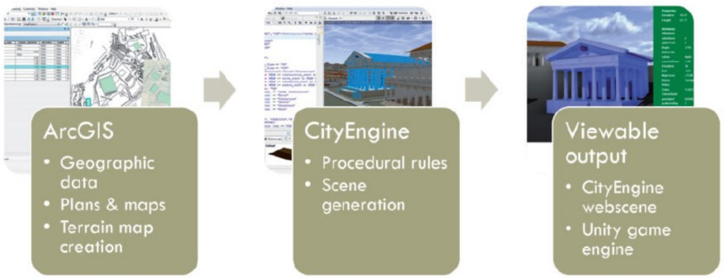
- It is very effective when dealing with a great number of similar objects in 3D (e.g. streets, buildings, trees of a city).
- It is frequently used to produce virtual environments and is very popular for game scenery and 3D city models.
- A **rule** is a short routine, based on the values of a set of attributes, that is applied to each object generating its 3D geometry and appearance.

Procedural modeling - Esri **CityEngine**

http://www.esri.com/software/cityengine

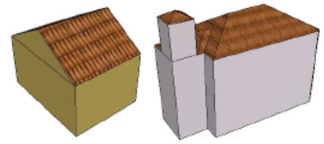


Procedural modeling - Esri CityEngine

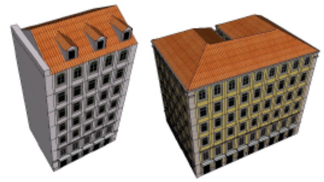


("An Integrated Approach to the procedural Modeling of Ancient Cities and Buildings", Maria Saldana, 2015)

Procedural modeling - Esri CityEngine



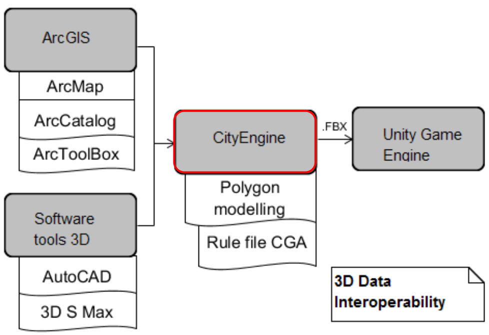
- Number of floors (n_pisos)
- Type of roof (cobertura)
- Texture (revestimento)



- Building height (Min_altura)
- Orientation of the main façade (orientação)
- Building types (edifício)
- Types of main façade (f_principal)
- Types of lateral façade (f_lateral)
- Floors with balconies (v_principa)
- Floors with balconies on the lateral façade (v_lateral)
- Wall cladding (revestimento)
- Lot size – area of the shape of the lot, in m^2

Types of parameters used in model building (Prior to 1755 and current downtown) (Helena Rua, et al., eCAADe,2013)

Procedural modeling - Esri CityEngine Mértola Virtual



[Tese mestrado Alexandre Carvalho, 15/16]

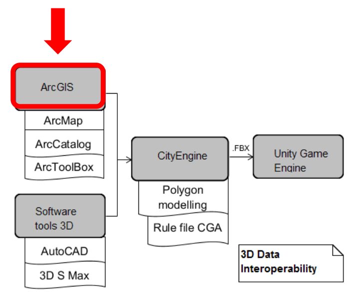
Mértola Virtual –Terrain generation

Terrain Generation:

- **Elevation model** (height map) generated with ArcToolbox based on a raster dataset for digital terrain model (**DTM**) obtained with OpenTopography (opentopo.sdsc.edu/-datasets)

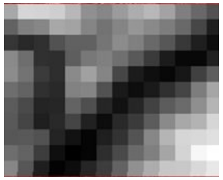
- **Texture** image from Google Earth

DTM
+ Google Earth Image



Mértola Virtual - Streets

The CityEngine feature ***Grow Street***
was used to generate the streets as well as the blocks in between these streets where the buildings were placed.



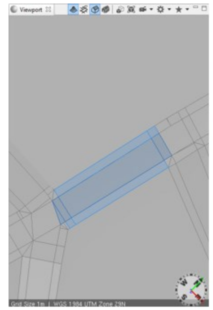
This feature uses the **heightmap file** to automatically adapt the streets to the elevation of the terrain and an **obstacle file** to prevent the appearance of streets on the riverbeds

Mértola Virtual - Streets

Streets depend on several parameters, like:
- Street width
- Sidewalkwidthleft
- Sidewalkwidthright

The texture was extracted from a google earth image

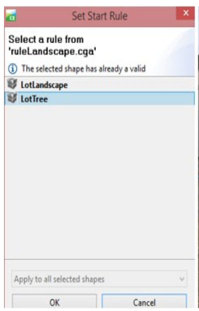
Streets

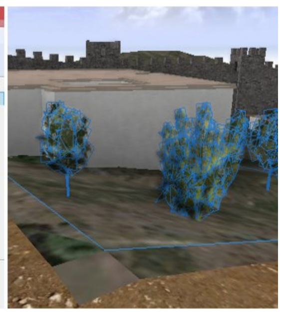


Streets with textures

Mértola Virtual
Procedural modeling - Vegetation

Landscape creation with tree models from a vegetation library provided for City Engine

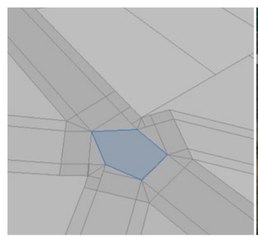


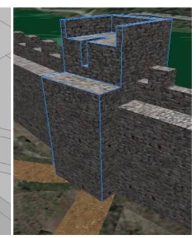


www.arcgis.com/apps/CEWebViewer/viewer.html?3dWebScene=6015f7d48dff4b3084de76bcf22c5bca

Mértola Virtual
Procedural modeling – Defensive walls

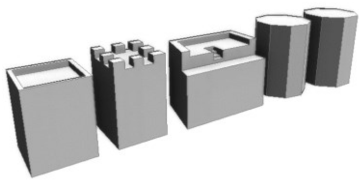
- Grow Street feature was used to draw streets that approximate the contour of the defensive wall
- These streets worked as the basis for lifting the wall





Mértola Virtual
Procedural modeling – Defensive walls

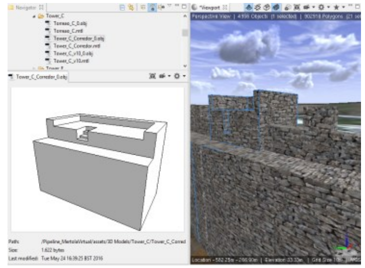
With CityEngine' polygonal modeling, five different models of defensive towers were produced to form the modular basis of the defensive wall



Mértola Virtual
Procedural modeling – Defensive walls

Rule to insert a tower

```
InsertTower -->
   s('2,towerRiverHeight,'1.9)
   r(0,towerAngle,0)
   center(xz)
   i("3D
Models/Tower_C/Tower_C_Corredor_
0.obj")
   t(0,-towerEarthDepth,-1.5)
   TowerSplit(scope.sz)
```



The textures were also applied with procedural modeling

Terrain modeling

Sketchup + Google Earth

Static Shape Reconstruction
Range Data

Range data – topographic data that records the distance from the sensor to points of the surface

- Obtained by 3D digitalization, like laser scan
- Usually, it requires special purpose high-cost hardware

Range data – obtained with 3D scanners

- 3D scanners **acquire** the 3D coordinates of numerous points on an object's surface in a relatively short period of time, obtaining a **"cloud of points"** (Ronchi, 2009).
- To **obtain a 3D model**, these points must be converted into a **mesh of triangles**. This requires three steps:
  - the merging of different clouds taken from different locations to complete the object;
  - the elimination of inaccurate points;
  - and the triangulation operation, which corresponds to find the best way to connect the 3D points to create triangles.
- Finally, to achieve a **photorealistic appearance**, it is necessary to **color** the surfaces of the triangles to mimic the original object. This can be accomplished with **texture mapping**, using textures obtained with <u>digital cameras attached to the scanning device</u>, or from external digital imaging systems.

Range data
Data acquisition

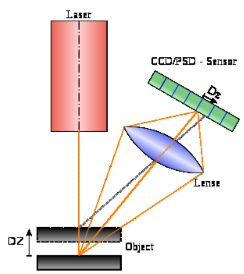
Data acquisition can be performed using three **different approaches,** each one suitable for a specific range:

- laser triangulation (*triangulação*)
- time-of-flight (*tempo de voo do sinal*)
- phase shift (*diferença de fase*)

Range data
Data acquisition

- **Triangulation based sensors** project light in a known direction from a known position and measure the direction of the reflected light through its detected position.

Since measurement accuracy depends on triangle base relative to its height and triangle base is rather short for practical reasons, these systems have a <u>limited range of less than 10 meters</u>.

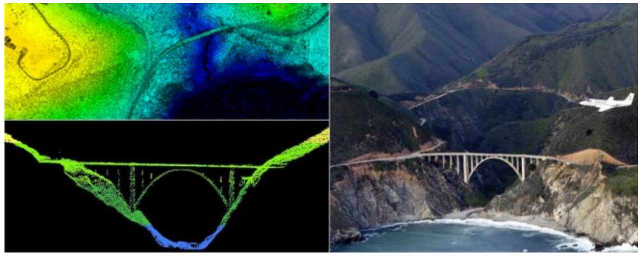


Range data
Data acquisition

- **Time of flight based sensors** measure the delay between emission and detection of the light reflected by the surface

LiDAR
Light Detection and Ranging

These sensors provide <u>accurate measurements at long range</u>, and the range accuracy is relatively constant for the whole volume of measurements; hence they are the preferred choice for large structures



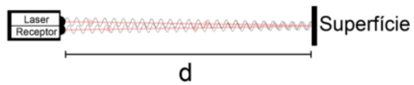
LiDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth

These light pulses—combined with other data recorded by the airborne system— **generate precise, three-dimensional information about the shape of the Earth and its surface characteristics**.
http://oceanservice.noaa.gov/facts/lidar.html

Range data
Data acquisition

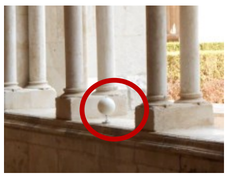
- **Phase shift** (*diferença de fase*)

The distance between the object and the Scanner is determined by the phase difference ($\Delta\emptyset$) measured between the emitted signal and the received signal. It relates the phase difference ($\Delta\emptyset$) the modulated frequency ($f modulada$) and the flight time of the signal (Δt)



Cláudia Silva, 2019

Merging of different point clouds


spherical target

- Each point cloud has a different coordinate system because it is referred to the local coordinate system of the Laser Scanner.
- They need to be combined in a single coordinate system.
- Targets (flat or spherical) are used during the survey, placed strategically, so that they can be seen and corresponded between each two scans, requiring a minimum of 3 common noncollinear targets.

Cláudia Silva, 2019

Input

- Real persons vs plaster models (*modelos de gesso,* ex.aranha)

-Sculptures

- Buildings

BODYSCAN SCANNER

http://www.techmed3d.com/#!scanneur/c249s

BODYSCAN SCANNER

http://www.techmed3d.com/

BodyScan Features

- Uses structured light, or white light, to capture a 3D form in real time.
- Use of reflective positioning targets on the body is not necessary, even though they can be used as reference points.
- Scanner is held 40-50 cm from the body part
- Accuracy up to 1 mm
- Scanning session takes between 30 to 60 seconds.
- Used with acquisition software MSoft
- Used in combination with a reference board for lower extremities, called Optimisation Module, which facilitates the scanning process, the alignment and measurement.

Main O&P applications

Whether it is for **orthotics** or **prosthetics**, with the BodyScan and MSoft, it is possible to scan the whole human body, everything from head to toes, with the highest precision you can imagine.

Range data and face cloning

- Only the visible part of the eyes are modeled
- Eyes make one single surface with the rest of the face
- Large number of points for the static face without **any functional structure for animation**

⬇

Requires post-processing because animating the face requires having eyes independent from the rest of the head

3D scanners -Trimble VX

http://www.trimble.com/3d-laser-scanning/index.aspx

Capture and combine scanning, imaging and surveying deliverables.
Integrate the technologies of advanced optical surveying, metric imaging and 3D scanning

Software:

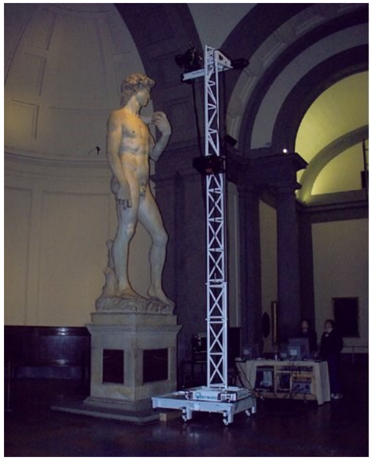
- **Trimble RealWorks**

Trimble 3D scanning software allows you to integrate 3D point and survey data to extract measurements, generate deliverables and utilize inside 3D CAD software.

Static Shape Reconstruction
3D Scanners (David)

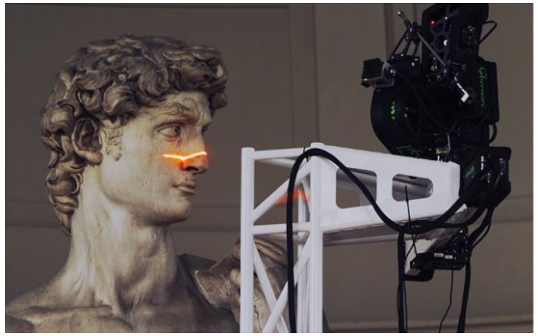
David (Miguel Ângelo)

Galleria dell'Accademia
Florença (Itália)



http://graphics.stanford.edu/projects/mich/more-david/more-david.html

Static Shape Reconstruction
3D Scanners (David)



http://graphics.stanford.edu/projects/mich/more-david/scanner-head-and-david-head-s.jpg

Static Shape Reconstruction
3D Scanners (David)

Statistics about the scan of David (15th Feb- 15th March 1999)

480 individually aimed scans For each scan, the gantry was moved to a new position. In its maximum configuration, our gantry weighs 1800 pounds. It can be rolled, with difficulty, by two strong people.

2 billion polygons Each part of the statue was covered by at least two scans. Difficult sections were covered 5 or more times

7,000 color images Each image is 1520 x 1144 pixels. For each position, one image was taken with our calibrated spotlight and one without. Subtracting the two eliminates ambient lighting.

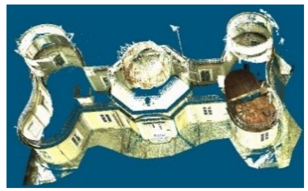
32 gigabytes Data was stored on hard drives.

1,080 man-hours of scanning This doesn't include 1,000 hours of editing, aligning, and combining the scans, and 1,500 or so hours pumping up our software to handle the increasingly large datasets.

22 people, 15 were full-time and 7 were part-time.

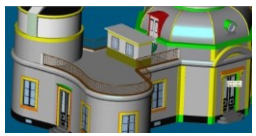
3D Scanners
Astronomical Observatory of the Lisbon Polytechnic School

Complete survey of the observatory building and of one accessible interior room using a photogrammetric laser scanner Leica C10 from University of Extremadura (Spain) (one day, 2012)



Point cloud

Master thesis, DEGGE



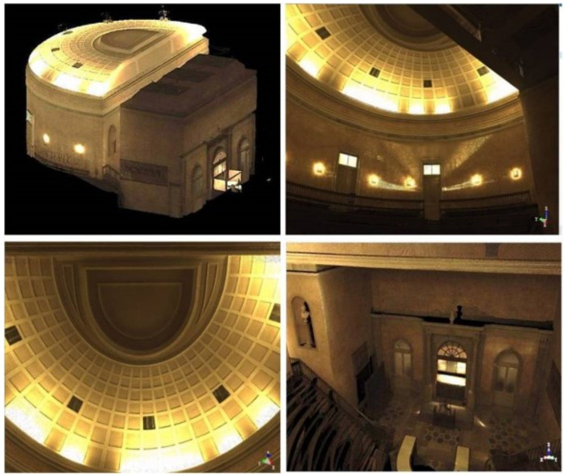
Complete 3D Model

Complete 3D Model with texture

3D Scanners

Point cloud:
Amphitheatre of the Chemistry laboratory

(Museu Nacional de História Natural e da Ciência)



3D Scanners

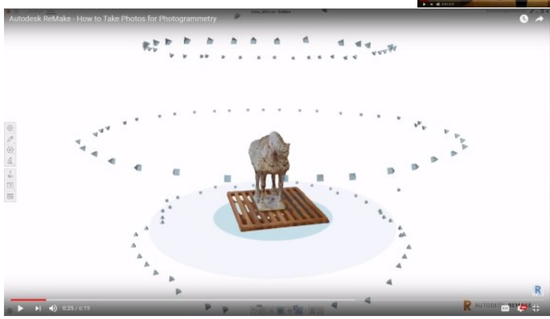
Aula de AAV, Maio de 2017

Equipamento

Nuvem de pontos

Static Shape Reconstruction
Photo-based modeling
Photogrammetry

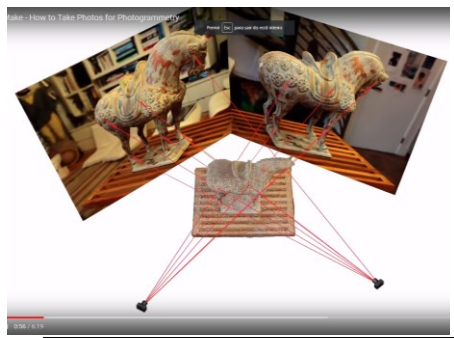
Take multiple photos



Autodesk ReMaKe https://www.youtube.com/watch?v=D7Torjkfec4

Static Shape Reconstruction
Photogrammetry

Calculate 3D position of common points



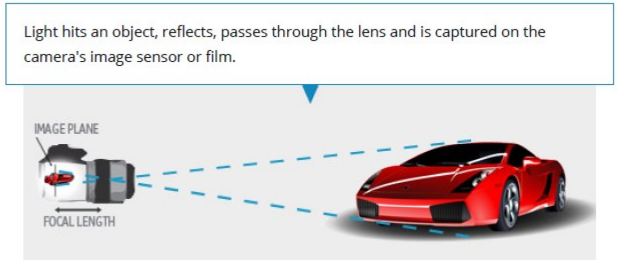
Point cloud

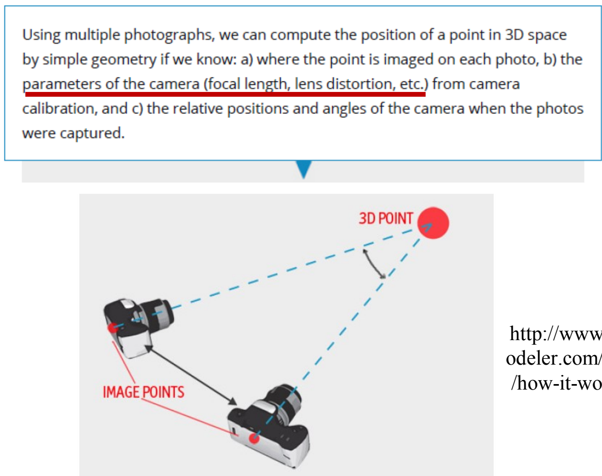
Geometry and texture

Static Shape Reconstruction
Photogrammetry

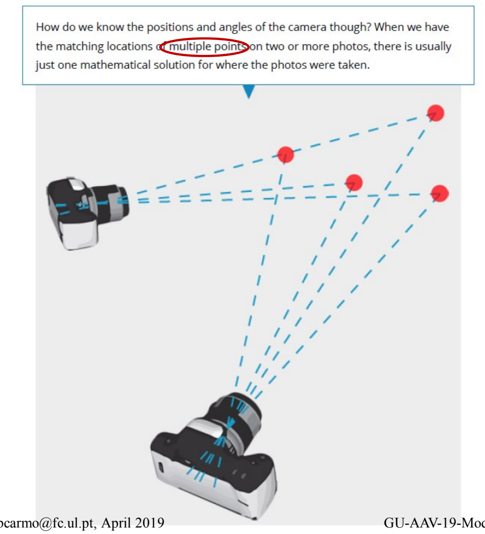
- **Photogrammetry** is a measurement technology in which the three-dimensional coordinates of points on an object are determined by **measurements made in two or more photographic images taken from different <u>positions</u>** (stereoscopy).
- **Common points are identified with marks on each image**. A line of sight (or ray) can be constructed from the camera location to the point on the object. It is the intersection of these rays (**triangulation**) that determines the 3D location of the point.

http://www.photomodeler.com/products/how-it-works.html





http://www.photomodeler.com/products/how-it-works.html

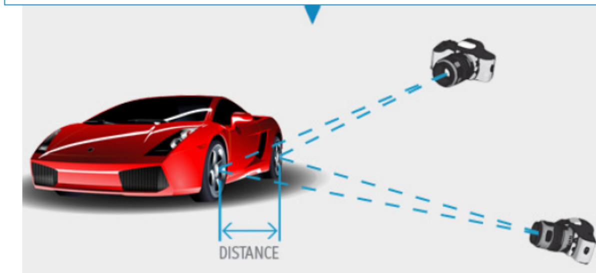


http://www.photomodeler.com/products/how-it-works.html

Finding the correct position and angles of the camera involves first a rough approximation stage, which must then be refined to achieve higher accuracy. This is handled by a key algorithm in photogrammetry called 'Bundle Adjustment' that takes advantage of the massive processing power of modern computers to adjust the solution until the bundle of light rays between all points and camera positions is optimal.

http://www.photomodeler.com/products/how-it-works.html

To get absolute measurement in real units (e.g. "those two points are 6.23cm apart") one last thing is needed - a reference scale. In the picture below the distance could be 10cm, and the object a toy car, or it could be 2.8m and represent a real car. This problem is easily solved by measuring one or more scales (ruler, tape measure, other distance/survey device) and adding that to the photogrammetric project.

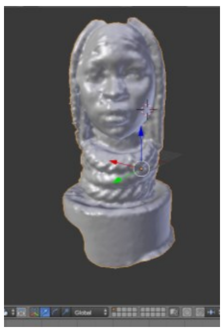


http://www.photomodeler.com/products/how-it-works.html

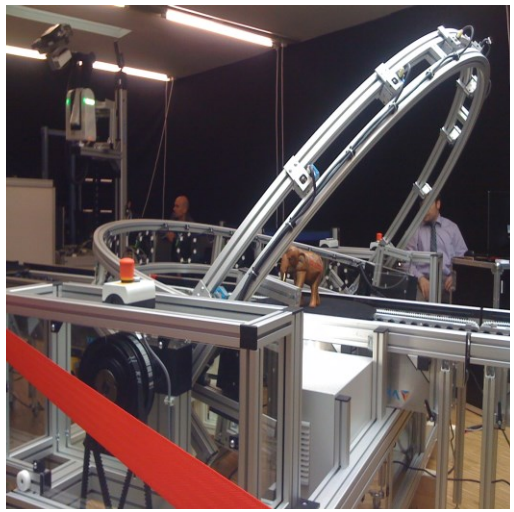
Photogrammetry
Jardim Botânico Tropical

36 photos taken (angular distance +/-10º)

Photogrammetry Software used: Pix4D



3D model in Blender

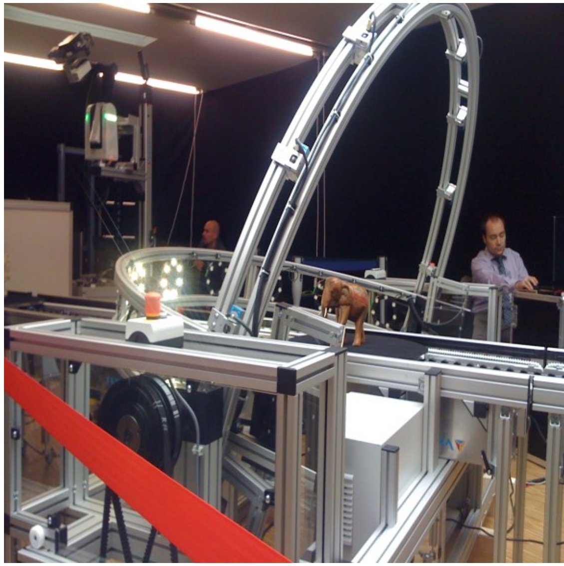


Darmstadt University
of Technology

http://www.tu-darmstadt.de/index.en.jsp

The arcs of the structure support:

- lights
- cameras



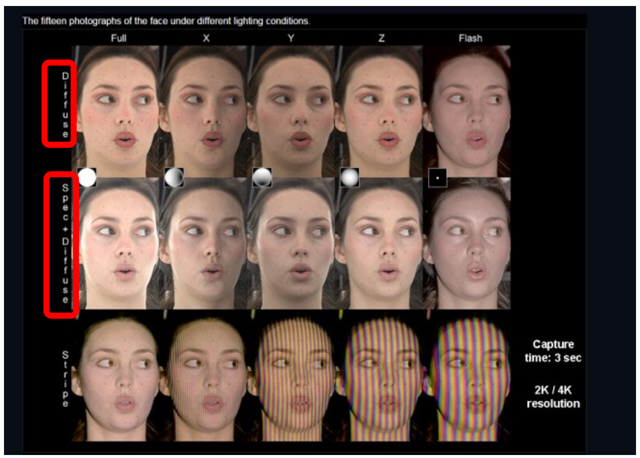
USC ICT’s Light Stage 5 with 156 white LED lights turned on

Polarized spherical-gradient illumination

The photos are taken from a stereo pair of off-the-shelf digital still cameras

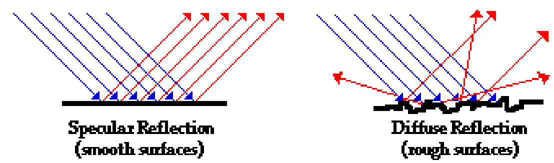
Image Metrics and the University of Southern California’s Institute or Creative Technologies (USC ICT), March 2008

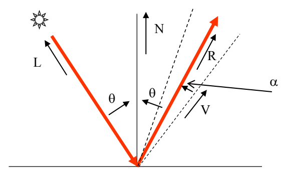
http://gl.ict.usc.edu/Research/DigitalEmily/

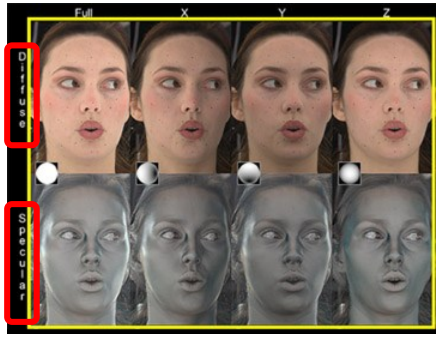


About **fifteen photographs** of the face under **different lighting conditions** to capture the geometry and reflectance of a face

Specular Reflection vs Difuse Reflection







We have subtracted the entire first row from the entire second row to produce a set of **specular-only images** of the face <u>under different illumination conditions</u>.
The images of the face under the gradient illumination conditions will allow us to **compute surface orientations per pixel**.

The last set of images in the scanning process are a set of color fringe patterns which let us robustly **form pixel correspondences between the left and right viewpoints of the face**. From these correspondences and the camera calibration, we can **triangulate a <u>3D triangle mesh</u>** of Emily's face.

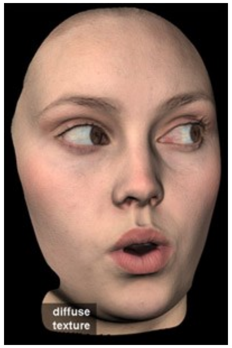
The makeup dots which help us to align the images in the event there is any drift in her position or expression over the fifteen images; they are relatively easy to remove digitally.

33 facial expressions captured based loosely on Paul Ekman's <u>Facial Action Coding System</u> to cover a broad range of human emotions

Two of the scans acquired from the two sides of the face as well as from the front, as seen in the insets. This allowed us to merge together a 3D model of the face covering from ear to ear.

Geometry

Texture



It needs: adding digital **eyes**, rigging the skin around the eyes, adding the **teeth**, and creating a rig that not only replicated the scans faithfully but also did reasonable things for the infinite variety of intermediate positions Emily's face could produce - especially while speaking!

Figure 9. Final renderings from the Digital Emily animation. The face is completely computer rendered, including its eyes, teeth, cheeks, lips, and forehead. Emily's ears, hair, neck, arms, hands, body, and clothing come from the original background video.

"The Image Metrics **team** took the set of our high-resolution face scans and within the course of **a few months** created a fully rigged, animatable face model for Emily"

Scanning the whole body

Face cloning

Reprodução da Face

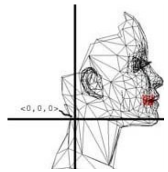
Face cloning means to make a virtual 3D representation which resembles the shape of a given person´s face.

Limitations
- time
- equipment
- how realistic it looks

Issues involved in modeling a Virtual Human face:
- acquisition of human face data
- realistic high-resolution texture
- functional information for animation of the human face

Generic Human Face Structure

Triangular polygonal mesh is one of the most suitable ways to model a generic face



http://www.miralab.unige.ch/

We have to consider that
- the **triangles must be well distributed**,
  so that it shows finer triangles over the highly curved and/or highly articulated regions of the face and large triangles elsewhere

- an **animation structure** (functional information) must be included

Photo-cloning

Generate a virtual clone with photo-cloning based on a **vision system**

The main idea
- **detect feature points** (eyes, nose, lips and so on) on photos

- obtain the **3-D position** of the feature points to modify a **generic head** using a **geometrical deformation**.

To generate a new face
the pre-defined feature points and lines need to be positioned properly.

Photo-cloning

A method to generate a face from <u>two orthogonal pictures</u>

Keypoints:

- Prepare a **generic head**
- Prepare a **generic animation structure**
- Definition of **feature points** and feature lines that show the connection of feature points
- **Shape modification** to convert 2D positions to a 3D model
- Texture mapping

Feature Location

Feature detection – to catch the 2-D or 3-D positioning data of most visible points on a face
eyebrow, eye outlines,
nose, lips,
the boundaries between hair and face,
chin lines

Non-feature points – parts that are not always ease to locate on 2-D photos (forehead and cheeks)

Feature Location

Lee et al. divide feature detection in

segment division

1) global matching to find location of features

detail region recognition

2) detail matching to find each feature shape by a specific method designed for each feature

Feature Location

Global matching

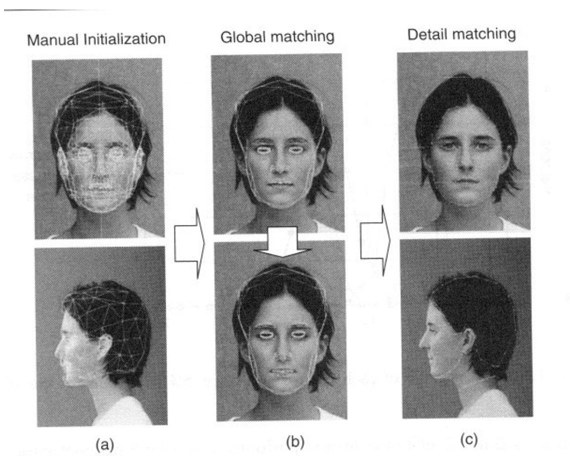
(an initial approach)

A **generic 3-D facial model** is used

An operator has to locate the generic face model on the face image

(this process is done manually to avoid the of methods to recognize the background)

After indicating the facial region, the global matching is fully automatic



Feature Location

Global matching

The generic model is separated into several feature regions: eyes, nose, eyebrows, mouth and jaw regions

To find the feature positions it can be used statistical data for image processing.

From the analysis of 200 people a graph of feature positions has been constructed. (Lee et al.)

Feature Location (7)

Global matching

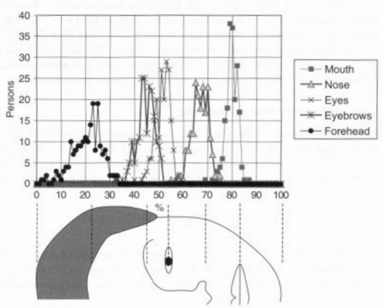


Figure 2.5 Distribution graph of features

Since most humans have almost symmetrical faces, only the vertical distribution is used to calculate the features position

Feature Location

Global matching - position of facial features

The position of each feature is also applied to the side face.

Some problems occur when the front photo and the side photo are not taken at the same time:

- the person can move and the head angle is different

- the direction of the ligth can also change

Detail detection- recognition of size, shape and exact location of features

The analysis of detail shape is done with a kind of multi-orientation edge detection method. (Lee et al.)

The detailed shape extractionpart is separated into

- Forehead
- Jaw
- Eyes
- Nose
- Mouth
- Side view

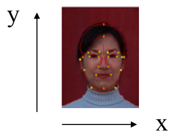
Shape modification

Only one side view is taken, so we consider that the virtual clone has a symmetric face.

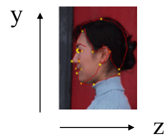
We have to convert **2-D coordinates** to **3-D coordinates**

Some points are visible both on front view and side view and the two photos may not be perfectly orthogonal
So
the y coordinate of a feature point can be different on front view and side view

Shape modification



Front-view



Side-view

Shape modification

1) Two 2-D coordinates in the front view (XY plane) and side view (ZY plane) are combined to be a 3-D point.

2) A global transformation is used to move the 3-D feature points to the space of a generic head.

3) Dirichlet Free Form Deformation (DFFD) are used to find new geometrical coordinates of generic head adapted to the detected feature points (the control points for DFFD are feature points detected from images)

4) Shapes of the eyes and teeth are recovered from the original shape with translation and scaling adapted to a new head.

Texture Mapping (1)

Texture mapping to cover the rough matched shape and also to get a more realistic colorful face.

The goal is to get an image by combining 2 orthogonal pictures in a proper way to get the highest resolution for the most detailed parts.

Actually the side view is flipped and 3 pictures are combined.

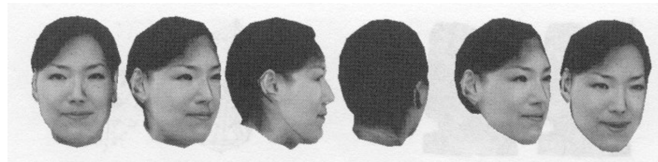
Texture Mapping (2)

Connect 2 pictures with a pre-defined index for feature lines using a geometrical deformation

Texture Mapping (3)

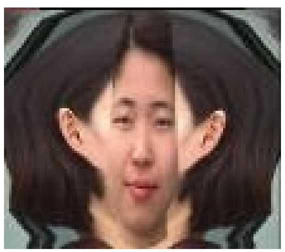
Then remove boundaries between different image sources.

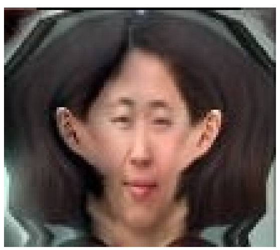
Texture Mapping (4)



Texture Mapping (5)

Another example





In (Lee, Magnenat-Thalmann,98)

3D face scanning with kinetic (similar procedure)

- http://www.youtube.com/watch?v=llNSQ2u2rT4&feature=related

- http://onlinelibrary.wiley.com/doi/10.1002/cav.405/full

"Automatic reconstruction of personalized avatars from 3D face scans", Michael Zollhöfer, Michael Martinek, Günther Greiner, Marc Stamminger, Jochen Süßmuth

Computer Animation and Virtual Worlds, Special Issue: CASA' 2011, Volume 22, Issue 2-3, pages 195–202, April - May 2011

Proceedings of 24th International Conference on Computer Animation and Social Agents (CASA 2011)

Data preparation

- The depth data we receive from the Kinect in a single frame are quite noisy and can contain holes at arbitrary positions.
- To reduce these effects, we **average the depth values of eight successive frames**, which leads to a much smoother result.
- To avoid motion blurring artifacts, it is required that the **user remains motionless for at least eight frames** (0.27 seconds) while capturing the image.

Left: raw data from a single frame.
Middle: temporally smoothed data.
Right: additionally Gauss-filtered data.

Face and Feature Detection

- detect the face along with a number of significant feature points
- we use OpenCV to find the bounding rectangles of the face, the eyes, and the nose in the RGB image

Left: face-, nose- and eye-detection on the RGB image.
Middle: temporary chin features (red) and search domain for the final chin feature (blue area).
Right: final feature points.

Face and Feature Detection (2)

- Since the feature detection runs in real-time, a person sitting in front of the camera gets real-time feedback of the resulting face scan together with the detected feature points.
- This allows the user to optimize his position before he eventually captures the current data.

Overview of the proposed avatar reconstruction:

•The upper image shows our acquisition setup in action.

•The lower row shows the recorded color image and depth scan and the fitted mesh without and with textures.

Face Segmentation

- The recorded depth data still contain unnecessary background data at this point.
- From the feature detection, we already know some points which definitely belong to the face.
- The rest of the points are found with a floodfill-like algorithm using the detected face feature points as seed.

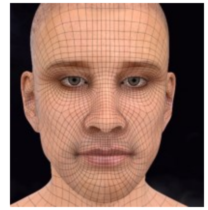
3D face scanning with kinetic

Fitting a Generic Face Model

- The point cloud that was generated in the previous step represents the geometry of the scanned face
- However, except for the few detected feature points, **the geometry does not contain any semantic information** which would be necessary to animate or further process the face.
- To attribute a semantic meaning to the scanned face, a morphable face model is fitted to the scan.

https://www.mydidimo.com/

MyDidimo's proprietary software gives you the power to generate as many Didimos as required to populate your digital environments.



your digital you

CREATE YOUR DIDIMO

Didimo - A digital version of you from a single photo

Didimos can be used to radically enhance many digital experiences including VR, gaming, messaging, digital marketing and social platforms.

Facial clones

Models from Verónica Orvalho
Virtual Tutor project