

# SPECIALISATION THESIS

## A STUDY ABOUT THE CREATION OF ACCURATE ANATOMICAL 3D MODELS

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## ABSTRACT

This thesis will focus on the creation of accurate anatomical 3D models from scanned or digitized data. It will discuss the entire process from cleaning-up the scanned data to the final product. The research will focus on two parts. First: Anatomical research. The final product has to be anatomical correct and extremely detailed. The scanned data has to be compared with anatomical reference and adjusted to create the desired result. Second: Technical research. The final product has to be able to support real-time playback in Maya by a mid-range PC and, at the same time, include a lot of detail.

The final product will be low resolution geometry of bones representing the Skull, Spine and Arm. A normal map will be created from a higher resolution source to add additional detail. This thesis will discuss the entire process; from researching anatomical reference and applying this knowledge, to the 3D models, to the creation, and associated problems, of normal maps.

# 1. INTRODUCTION

Currently the quality of the anatomical models available for purchase ranges from bad to good. But from all of these models only few can be used for extreme close-up illustrations. Anatomy is a field of interest to me and, because of the lack of high quality models; I found it challenging to create the most accurate and detailed anatomical models to this date. The project is collaboration between Andrew Paquette (Sculpting), Nick Peters (Scanning) and me. Completing the entire skeleton would not be feasible in the specialization timeframe. For this reason I will only focus on the Skull, Spine and Arm.

The bones that were used for scanning and digitizing were made available by the NHTV Breda University of Applied Sciences. These bones are molded after reference from an actual skeleton. Recreating this data in 3D would suffice to create an anatomical correct model. Similar to a fingerprint, no two skeletons are exactly alike; there are differences in the number and shape of the bones due to disease, birth defects and genetic disorders. However, there is a composition of bones that will fit the majority of the human population. This is something that has to be taken into account when comparing the digital data with the reference.

## 1.1 SKULL

A standard human skull is made from twenty-two bones. The bones are connected by sutures<sup>1</sup>. Eight bones form the neurocranium<sup>2</sup>. The other fourteen bones form the splanchnocranium<sup>3</sup>. The average adult mouth contains thirty-two teeth (including the wisdom teeth). Sixteen teeth in the mandible and eight in each of the Maxillae.

All the little bumps and cracks on the surface are important to create a realistic looking skull; but foramina<sup>4</sup>, processes<sup>5</sup> and sutures deserve more attention. The smaller bumps and cracks do show where the muscle attachments are etc. but they differ a little from person to person. The foramina and processes are present in every human skull, this makes them key features in creating an anatomically correct skull.

The skull from the supplied skeleton is made from two pieces, and therefore the level of anatomical detail is not at the required level. Therefore the skull used for this project is from a different person than the rest of the skeleton.

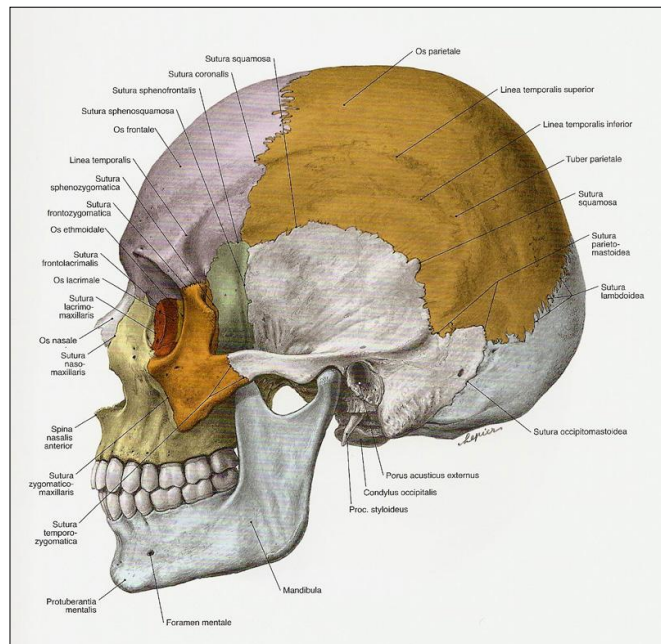


Fig. 01 Skull [1]

<sup>1</sup> A suture is a rigid connection between two cranial bones.  
<sup>2</sup> Part of the skull that houses the brain (Ethmoid, Frontal, Occipital, Parietal, Sphenoid, Temporal).  
<sup>3</sup> Facial Bones (Inferior Nasal Concha, Lacrimal, Mandible, Maxillae, Nasal bones, Palatine, Vomer and Zygomatic).  
<sup>4</sup> A foramen is an opening within a bone to allow for muscles, veins and nerves to pass through.  
<sup>5</sup> A process is an outgrowing of tissue from a larger bone.

## 1.2 SPINE

A standard human spine consists of a total of thirty-three vertebrae (this includes the fused vertebrae of the Sacrum and Coccyx). The vertebral column can be divided into five different sections, namely the Cervical, Thoracic, Lumbar, Sacral and Coccygeal regions.

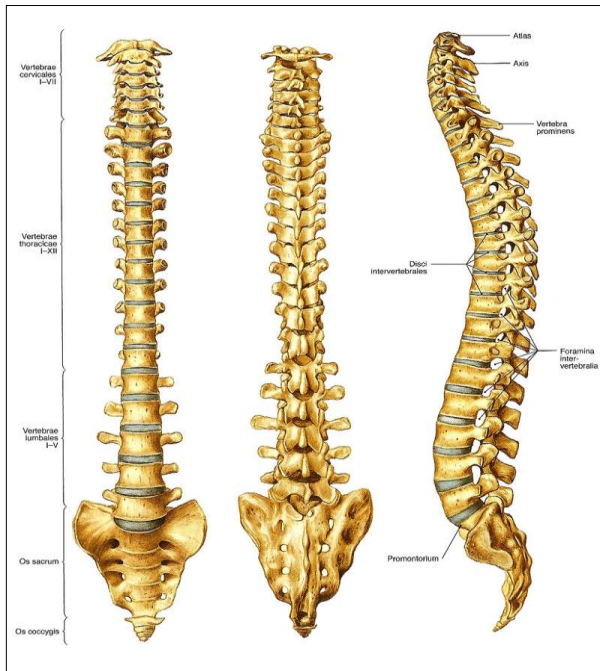


Fig. 02 Spinal Column [1]

The cervical region is made out of seven vertebrae. The first two cervical vertebrae (Atlas and Axis) have a different shape than the other cervical vertebrae, this is what allows the neck and head so much movement.

The twelve vertebrae in the thoracic region are articulated<sup>6</sup> with the ribs. This connection prevents a lot of movement to occur in the ribcage, this is extremely important to protect the vital organs.

The five lumbar vertebrae are bigger than the other vertebrae, because they need to support a lot more weight. The vertebrae are a lot thicker in the front than in the back, this is necessary to create the desired arch.

The sacral region consists of five Sacral vertebrae. At a young age these vertebrae are still disconnected, but when a person reaches adulthood they fuse together into one bone which is called the Sacrum. Variations on the number of vertebrae that fuse can differ from four to six. The fusing of five vertebrae is most common.

Just like the Sacral vertebrae the Coccygeal vertebrae fuse together after twenty to thirty years. In general the Coccygeal region consists of four vertebrae. Again there are variations known with three or even five vertebrae. When the coccygeal vertebrae are fused into one bone it is called the Coccyx.

In exception to the articulation between the Sacrum and the Coccyx, and the Atlas with the Axis, all the vertebrae are connected by intervertebral discs. These discs are made from several layers of fibrocartilage, encapsulated in which is a gel-like substance. This makes the intervertebral discs act as a shock absorber and allows for limited movement of the vertebrae.

## 1.3 ARM

The upper limb is divided into three sections known as the Pectoral Girdle, Arm and Hand. The Scapula and Clavicle are part of the Pectoral Girdle. The Ulna, Radius and Humerus make up the Arm. The hand consists of eight Carpal bones, five Metacarpal, five Proximal Phalanges, four Middle Phalanges, five Distal Phalanges and two sesamoid<sup>7</sup> bones. Excluding the two sesamoid bones, puts the total number of bones in the upper limb to thirty-two bones.

<sup>6</sup> A region where adjacent bones connect with each other.

<sup>7</sup> A bone which is imbedded in a tendon.

In contradiction to the axial skeleton the appendicular skeleton allows for a large range of motion. This is possible because the bones are not fused together. The bones are connected with ligaments and muscles.

The upper limb only directly connects to the axial skeleton with the Clavicle, which is connected to the Sternum. This immediately makes the position where the two connect the rotation pivot for the shoulder.

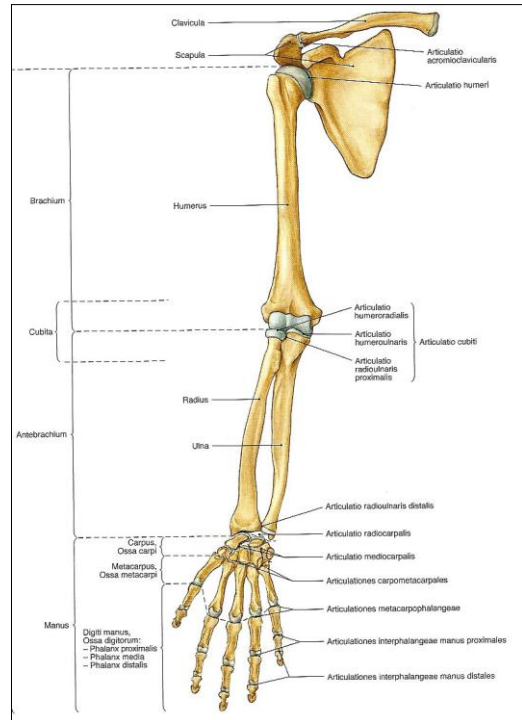


Fig. 03 Upper Limb [1]

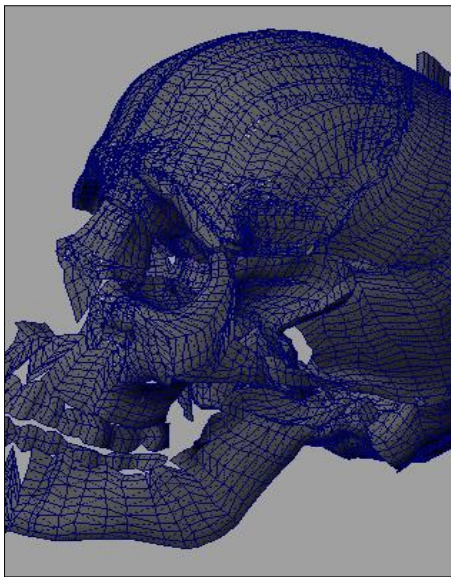
## 2. DIGITIZED/SCANNED DATA

The source material used for this project is either Digitized or Scanned. The source data of the skull is digitized. This means that the resolution is low and the cleaned geometry needs to be brought into a sculpting program to paint and an extra layer of detail on the geometry. The data for the arm and spine is scanned. Scanned data has a lot more points thus a lot more detail than the digitized data, but also this source material has its issues that can be fixed in either a 3D application like Maya or a sculpting application like Zbrush and Mudbox.

Apart from cleaning the data it also needs to be compared with multiple anatomical references and, if necessary, be fixed to ensure the cleaned data is anatomically correct. This means that existing data needs to be split to unveil more bones or data needs to be added to create the inner structure of a bone. Before comparing the data with anatomical references it is important to clean the raw data first. Both scanned and digitized data has its flaws that need to be fixed before manipulating the mesh into an anatomically correct model.

### 2.1 CLEANING (DIGITIZED DATA)

Raw digitized data has a lot of flaws that needs to be fixed before the mesh is ready to be sculpted in a program like ZBrush or Mudbox. The biggest weakness of digitized data is the low resolution. It is possible to add more detail with a digitizer, but this would take a lot more time



*Fig. 04 Raw Digitized Data*

than it would to sculpt the detail in afterwards. The other problem is that the geometry is extremely messy (as can be seen in the image on the right) and overlapping, this means that the higher the resolution is, the more time it takes to manipulate the mesh in something usable. It is also a lot faster to add or split the geometry if the source has a lower polygon count.

It is important to clean the data in a way the new geometry becomes sculpt friendly. This means that the mesh should contain the least amount of triangles possible. Proper planning is important in this stage. Drawing a topology on the object before digitizing will save a lot of trouble during the cleaning process. For sculpting is also important the mesh is closed.

The object will be divided into different patches, because the digitizer has a very limited range of motion. To ensure the patches will be stitched up properly it is necessary to create overlapping patches. By doing this it will be easier to line the patches up to create the final model. Then the excess geometry should be deleted and the patches need to be fused into one object.

#### **Checklist:**

1. Quadrangulate mesh.
2. Fuse patches.
3. Fill holes.

## 2.2 CLEANING (SCANNED DATA)

Scanned data has a lot more resolution than digitized data. With this resolution also come different problems. The scanner is quite small and is only able to scan small sections at a time. The software used for scanning can also be used to fuse all of the patches together. This is an automated process and can't be done by hand. This means that in some cases (cylindrical shapes) the program is unable to fuse the patches. This will leave holes in the geometry. These holes need to be filled by creating new patches of geometry, in Maya, and fusing them with the scanned data. It is important that the resolution of the patches match up as closely as possible with the resolution of the scanned data. Other problems that can occur are overlapping patches or a drop in resolution. Overlapping can be fixed by smoothing the vertices in a sculpting program. A drop in resolution can be fixed by adding more vertices and edges in that area.

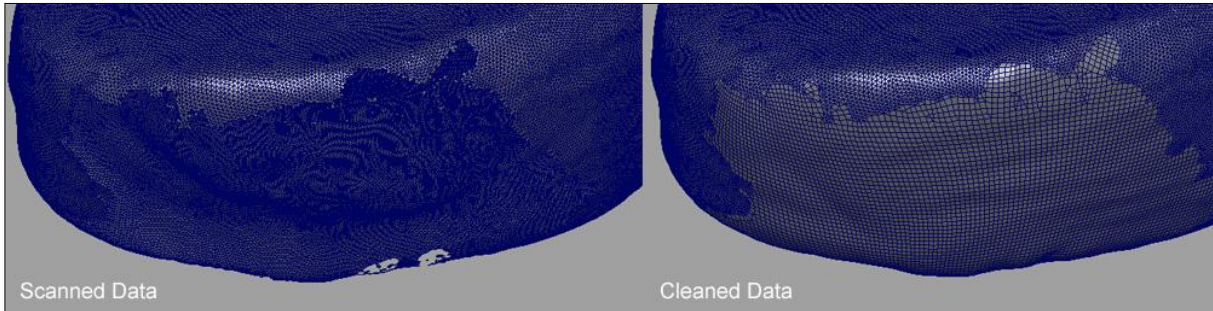


Fig. 05 Hole Example

Because of the high polygon count the mesh doesn't have to be subdivided again, this means that the triangular data doesn't have to be quadrangulated. This is a great relief as editing a multimillion triangle mesh in Maya is very time consuming. This is because Maya is not suitable to handle high resolution meshes. This would also be a very time consuming process.

### Checklist:

1. Fill holes.
2. Add resolution (only where necessary).

## 2.3 COMPARING DATA AGAINST REFERENCE

Not even the real life objects that were used for scanning and digitizing are perfect. This is most evident in the skull. Running through a simple checklist will reveal most of the issues. First of all, it is extremely important to see if the number of bones matches up with actual reference. For example the skull model, the Maxilla is fused with the Inferior Nasal Concha, Lacrimal, Palatine and Nasal bones.

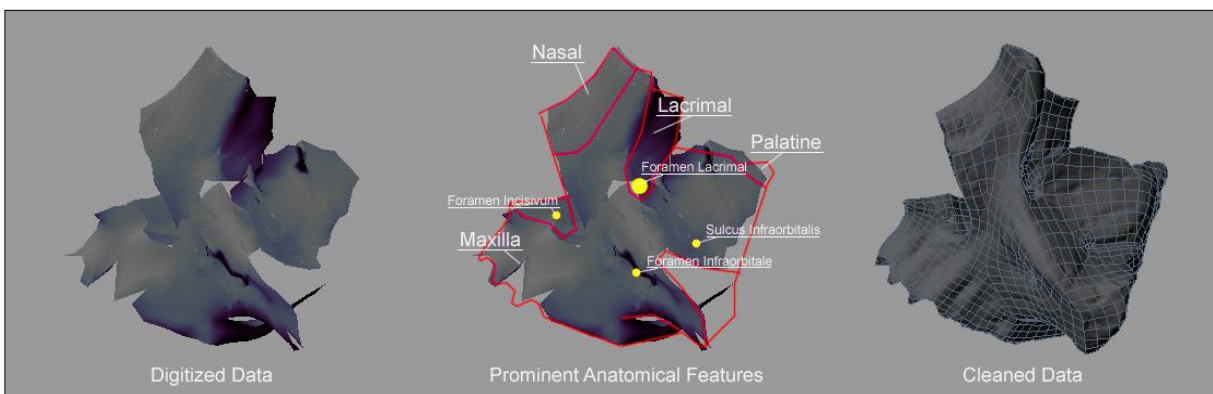


Fig. 06 Process going from Digitized Data to Cleaned Data



When digitizing an object it needs to be divided into different patches (the digitizer has a limited range of motion). Even when the object is securely clamped, placing those different patches to combine them into the full bone needs to be done very carefully. An error is easily made and a lot of different bones need to connect with each other, one small error can create a ripple effect.

Second, the skull used for the digitizing process can be taken apart. Some areas of the bones are thicker than they should be, because they hold attachments pins. The manufacturer of the skull also made some of the bones overlapping instead of creating a suture, all of this was done to maintain the structural integrity of the model. These are issues that have to be taken into account and need to be fixed.

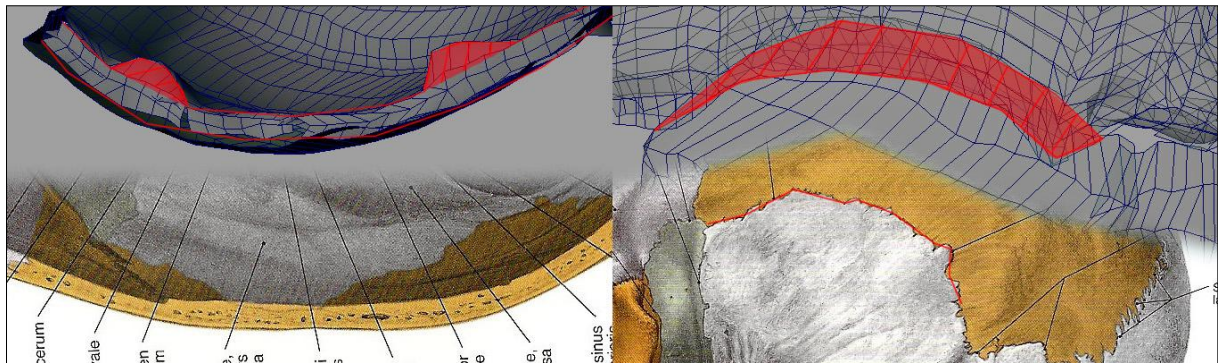


Fig. 07 Excess Geometry [1]

Fig 08. Overlapping Geometry [1]

The skull model is already extremely detailed, but there is still a lot of information missing. The teeth are fused with the mandible, so Dental Alveoli<sup>8</sup> need be added in the Mandible and Maxillae. This also means that the teeth need to be split and the roots and sides need to be modeled. The inner structure of the Maxillae is missing because the digitizer is unable to reach that area. This problem also occurs with foramina of the skull; they are either too small or the canal is too long for the digitizer to reach. It also happens when the geometry needs to be split into different parts to reveal more bones, geometry needs to be added to ensure a closed model.

The scanned data from the spine and arm is less troublesome. None of those bones are articulated, instead they are connected with ligaments and muscles. This makes it a lot easier to position the bones in a correct way, without allowing too much intersection of bones. The shape of the individual bones is also a lot less complex than the ones in the skull (no interior surfaces or complex foramina). This is an advantage as well as a disadvantage at the same time. The

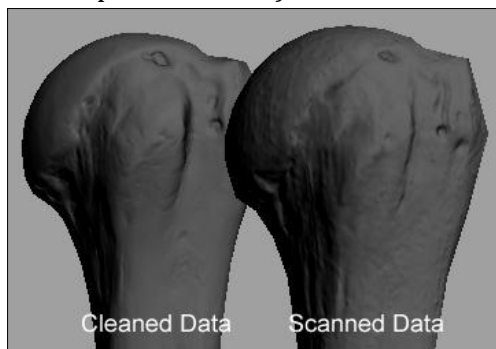


Fig. 09 Scan Artifacts

scanner can only scan a part of the surface at the same time. Some of the bones are elongated and have very regular shapes, this causes problems for the software that is used to fuse the patches together. There are not enough reference points to ensure a correct position. Another thing to watch out for is artifacts left behind by the scanner itself. Looking at the image on the side it is obvious the scanned data is filled with irregular dots and vertical lines.

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<sup>8</sup> Tooth sockets.

**Checklist:**

1. Number of bones. (set of bones).
2. Positioning. (Optional: only necessary for bones with sutures).
3. General shape (individual bone).
4. Adding/Splitting geometry.
5. Adding Foramina and Processes.

### 3. SCULPTING

The sculpting is the most important part of the whole project. After the sculpting of the cleaned geometry one of the project goals will be completed. This is the creation of an accurate anatomical model. The polygon count of these meshes is just too high to be used in Maya or other 3D applications.

During the cleaning of the scanned or digitized data the general information of the bone is already correct. The geometry has been split in the correct number of bones, the shape of the bones is fixed to ensure a clean connection at the sutures and the foramina are added to avoid problems with sculpting since it is extremely difficult to add holes in a sculpted mesh. By going through all this effort in the cleaning stage the sculpting is a pretty straight forward, yet time consuming task.

The sculpting requires an excellent eye for detail. All of the little dents, cracks and bumps have a meaning, but they differ from person to person. Therefore it is not a good idea to use references from different sources. The big issue with reference from images is the fact that there is no depth information. This means that the best reference is the actual bone used for scanning or digitizing. Although there are still areas that require other reference due to the errors in the original model.



Fig. 10 Reference Model

Fig. 11 Scanned Data

Instead of blindly sculpting in the detail based in the reference, it is better to know a little bit more about the detail. Especially with the skull the 3D bones and the real bones will not match up anymore. There is also little information about interior surfaces or articulated surfaces. Additional research needs to be done to fill in the missing information. It is important the additional detail blends well with the detail from the original reference.

Areas to pay attention to are sulci<sup>9</sup>, linea<sup>10</sup>, sutures, muscles/ligament attachments and joints. These areas are all present in the reference models, but knowing where they are and how they look will improve the final look of the model. These areas have a distinctive look. The sutures in the real model are overlapping, so this information can't be used for the final 3D model.



Fig. 12 Sculpting in Progress

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<sup>9</sup> Depression or fissure on the surface of a bone.

<sup>10</sup> A line on the surface of a bone.

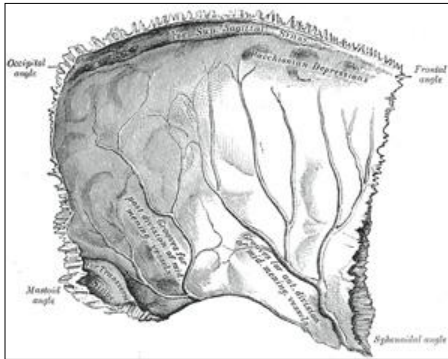


Fig. 13 Parietal Bone [2]



Fig. 14 Side view Parietal + Frontal Bone [2]

An example of a sulcus can be seen in figure 13, it features multiple sulci arteriosi. This image also shows the interior surface of a suture. An example of a linea can be found in figure 14, the inferior and superior temporal line. The surface of the joints in, for example, the arm are very smooth to allow for movement without a lot of friction. The areas where muscles or ligaments attach to the surface of the bone are a little bit more rugged.

The detail on the surface of the bones is very small and the scanned data has a lot of detail present in the model. But due to the artifacts, this detail is wrong. Before sculpting the scanned data, it needs to be smoothed down to eliminate all of the scan artifacts. This means that not only the artifacts will be removed but also the underlying detail. Therefore the sculpting process, is exactly the same for scanned and digitized data. After subdividing the digitized data, both scanned and digitized meshes are smooth and ready for sculpting.

ZBrush is used to sculpt the geometry. The final result is a multi-million triangle mesh, which is detailed enough to be used for extreme close-up illustrations. After this stage the first of the two criteria is completed. Because the second criteria is subjectable to change over the years (as computers become faster every day). This means that the high resolution source should be saved ,so it can be used in the future as a base for new products.

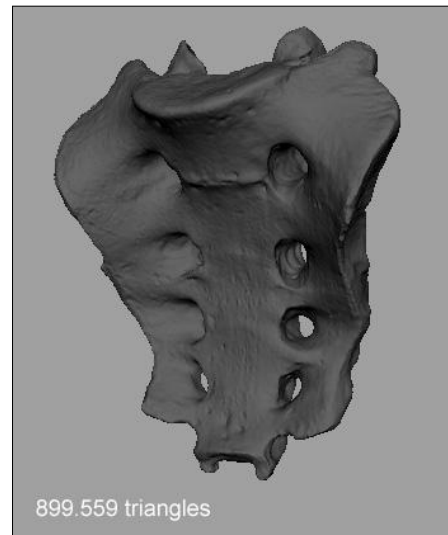


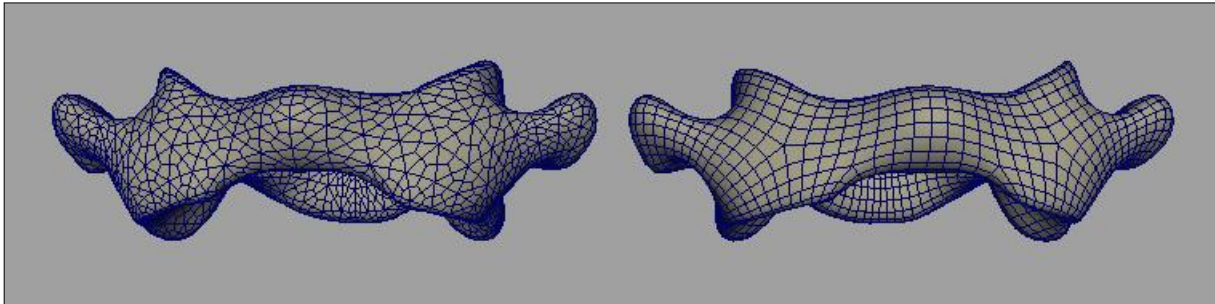
Fig. 15 Sculpted mesh of the Sacrum

**Areas of attention:**

1. Joints.
2. Sulcii.
3. Linea.
4. Sutures
5. Muscle/Ligament attachments.

## 4. BASE GEOMETRY

A low resolution shell needs to be created around the high resolution sculpted mesh. Normal information will be transferred from the high resolution source to the low resolution mesh in the form of a normal map. This is the reason the mesh needs to have proper UVs. Normal mapping has some limitations, this needs to be taken into account while creating the new mesh.



*Fig. 16 Comparison between a smoothed triangular mesh and a quadrangulated mesh.*

The low resolution mesh should be as close to an all quad model as possible. A quadrangulated mesh smooths a lot better than a triangulated one. This is important because two versions of the same bone will be created. One for medium close-up and the other for extreme close-up. The mesh on the left side was a triangular mesh which was smoothed down with a factor of one, as can be seen this creates an ugly edge pattern when comparing it against quadrangulated mesh on the right. The quadrangulated mesh can be projected on the sculpted source mesh with ZBrush. This makes the creation process of different resolutions simple and quick. This also means during the retopologizing process only the medium close-up resolution should be created.

### 4.1 RESOLUTION

Before starting the retopologizing process, the resolution of the new mesh needs to be determined. Maya can handle several million triangles at ones, but it slows down the selection process and the camera movement. This is something that needs to be avoided.

The Maya selection tool slows down after two million visible triangles in the scene, and the camera movement slows down after five million visible triangles are in the scene. It would be easy to create the three sections of the human body described in this document fitting within a polygon budget of two million triangles. But in the long run the project could grow and the final result would be a complete male model featuring bones, muscles, ligaments, organs, nerves, circulatory system etc. Making an estimate on the polygon count of the entire male model is impossible.

Therefore the goal is not to fill the entire polygon budget, but keep the resolution as low as possible without losing detail. A distinction will be made between medium close-up and extreme close-up. This also means that two different meshes will be created for each bone. After testing different resolutions, the following guidelines were created. This guideline is not an absolute rule, detail should be added to maintain the curvature of a bone or to create a normal map friendly mesh.

### Medium close-up:

Larger bones (Spine, Scapula, etc.): square face on every 0.5cm<sup>2</sup>

Smaller bones (Fingers, Toes, etc.): square face on every 0.3cm<sup>2</sup>

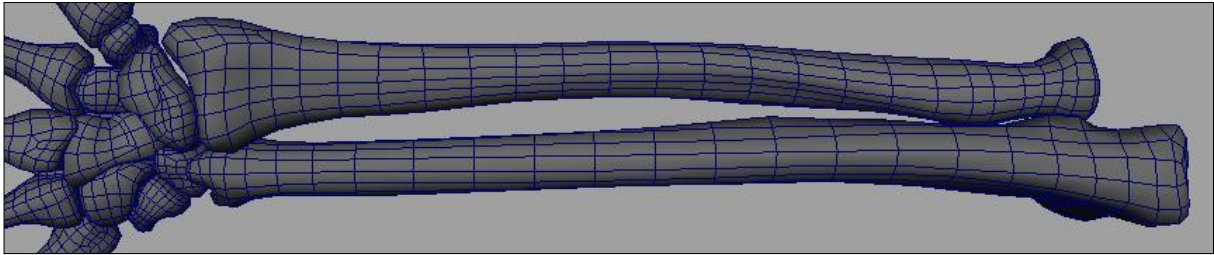


Fig. 17 Medium Close-Up resolution

### Extreme close-up:

Larger bones (Spine, Scapula, etc.): square face on every 0.25cm<sup>2</sup>

Smaller bones (Fingers, Toes, etc.): square face on every 0.15cm<sup>2</sup>

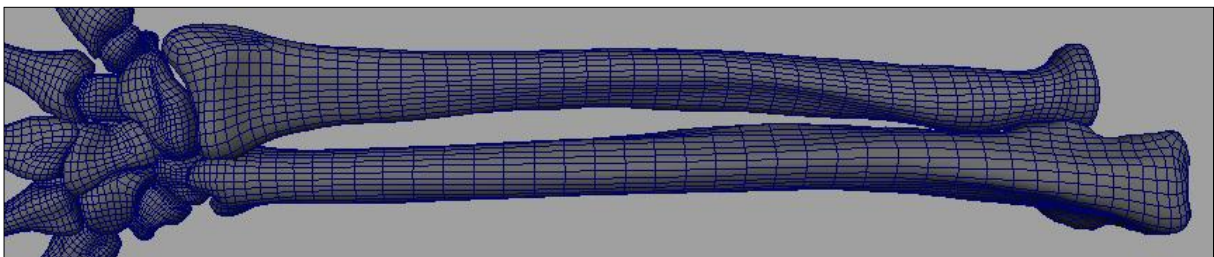


Fig. 18 Extreme Close-Up resolution

### Checklist:

1. Quadrangulated mesh.
2. Resolution.

## 4.2 NORMAL MAPS

Guidelines for the normal map baking process need to be set first. As well as the changes made to the geometry to make the mesh normal map friendly. The biggest issue with normal maps is the fact that it projects rays from the low resolution mesh to the sculpted mesh. If the change in curvature in the low resolution mesh is too high it will not capture all of the detail. This means that the resulting normal map will cause an obvious seam or will just turn out to be black since the information is missing. Beveling these edges will create the additional curvature necessary on the mesh.

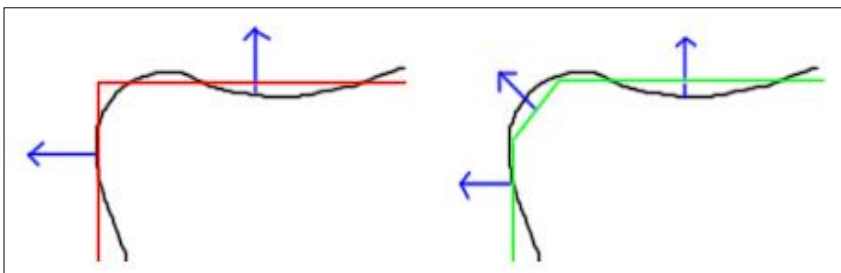


Fig. 19 Curvature Example

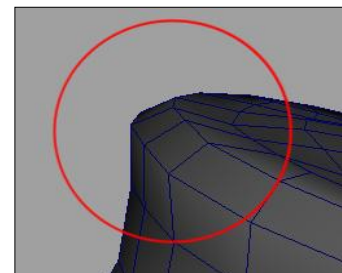
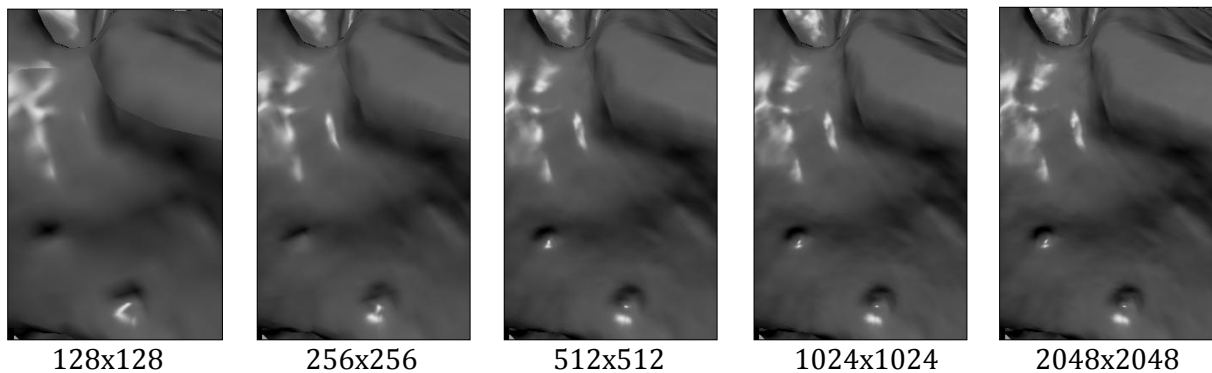


Fig. 20 Bevel Example

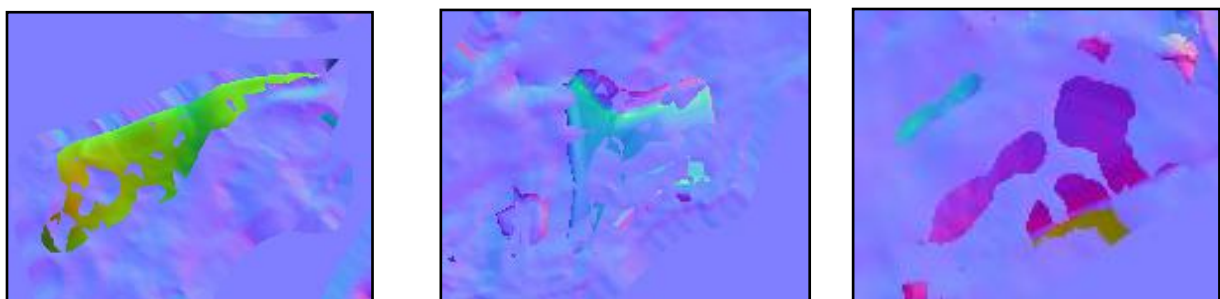
The ideal angle between the faces is 60 degrees or less. A decent result can still be achieved with angles between 60 and 90 degrees, but the outcome will greatly depend on the number of samples created for the normal map. Angles greater than 90 degrees should be avoided at all costs.

Some of the bones have fairly flat surfaces like the side of the temporal or the top and bottom of the vertebrae. It is important that enough resolution is put into these areas. Although it might not seem necessary, additional geometry needs to be added to create enough samples used for normal map baking. There are only an X number of rays casted per face, this means that if the face is too big it will not capture all of the detail on the sculpted source. Making sure the faces have roughly the same size will eliminate this issue and will also create a nice edge pattern throughout the model.

The resolution of the normal map needs to be based on the size of the bone. It is very important it roughly matches up with the rest of the bones. A pixel on each of the bones created should be roughly the same size. In no way should the map resolution limit the amount of detail. But it is important to keep the map size as low as possible.



As seen in the images above, the 128px and 256px clearly don't suffice. The 512px version looks good but when comparing it to the 1024px and 2048px it is still noticeably missing detail. This means that only the 1024px and 2048px are left, when comparing these two the difference is hardly noticeable. The small amount of extra detail doesn't justify the use of four times the map size. This means that every 1024 pixels should roughly cover 12 centimeters of bone surface.



The three images above show how common errors in a normal map look like. If an error like this shows up, the low resolution mesh is not correct and the curvature change is either too high or search range of the rays casted is not big enough.

#### Checklist:

1. Curvature.
2. Average face size.
3. Map resolution (power of 2).
4. Map errors

### 4.3 UVS

The UVs are also a very important part of the low resolution mesh. A balance has to be found between the amount of seams and the amount of distortion. The amount of distortion can be checked with Roadkill, the red and blue areas should be kept to a minimum.

It is also important to use the most of the possible UV space. Some of the bones (especially in the arm) have an elongated shape. Filling the entire UV space would be troublesome without creating extra seams. This is an issue which is easily fixed by scaling the UVs by a factor of two in only one axis. The texture size needs to be changed as well, instead of square the texture should be rectangular.

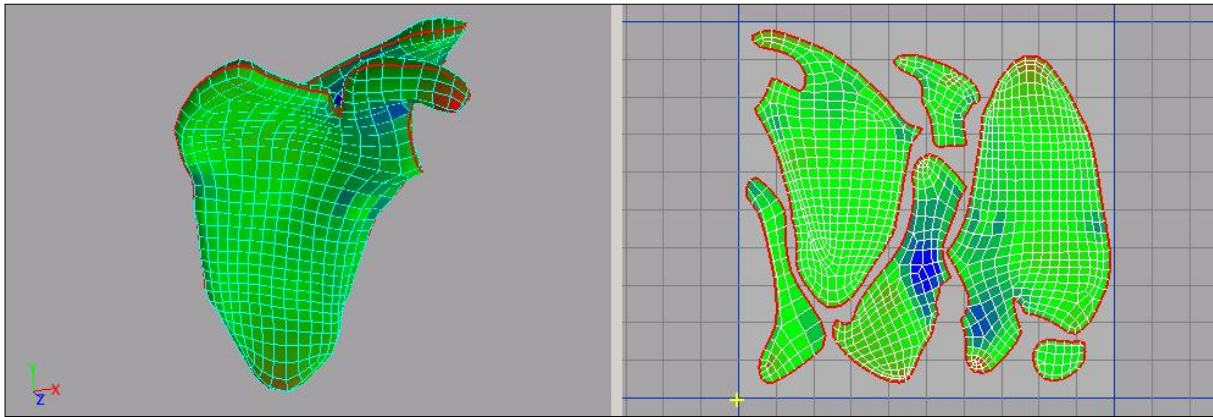


Fig. 21 UV Example

#### Checklist:

1. Fill UV space.
2. Balance seams with distortion.

### 4.4 POSITIONING

The positioning of the cranial and facial bones of the skull is already done; this had to be done earlier to fix the sutures. This leaves the bones that are not connected with each other by sutures but with muscles and ligaments. The NHTV also has assembled models of the skull and arm; this makes the positioning of the skull and arm a lot easier. For the spine it is a little bit more difficult, because there is no three-dimensional reference available. Luckily the shape of the spine is not a very complex and the bones and intervertebral discs articulate with each other.

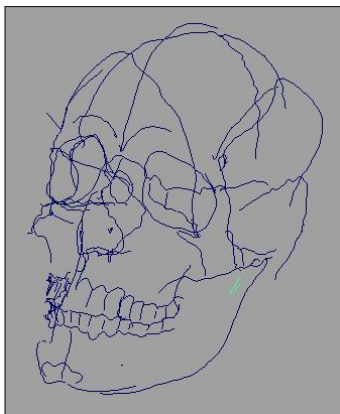


Fig. 22 Curve model

Helping in placing all of the bones in the skull is a curve model of the sutures and prominent features of the skull. This model is created by digitizing the assembled skull.

For the placing of the bones in the arm and spine a little bit of extra information about the connection of these bones is necessary to understand how they are connected. The bones that are articulated and don't allow for much freedom movement have a cartilaginous joint<sup>11</sup>. An intervertebral disc is the cartilaginous joint which connects the vertebrae. The scapula and clavicle are also connected with cartilage.

<sup>11</sup> A joint solely connected with cartilage.



The bones that allow for more movement are connected with a synovial joint<sup>12</sup>. The fluid within the bursa sac lubricates the articulated surfaces of the bone to ensure the movement smooth and doesn't damage the bone. The type of joints in the fingers and rest of the arm are synovial joints. These bones don't directly connect with each other because there is a little bit of fluid in between those bones. This is most evident in the shoulder joint, as can be seen in the image on the side. The area in blue is a bursa sac which ensures the smooth movement of the humerus.

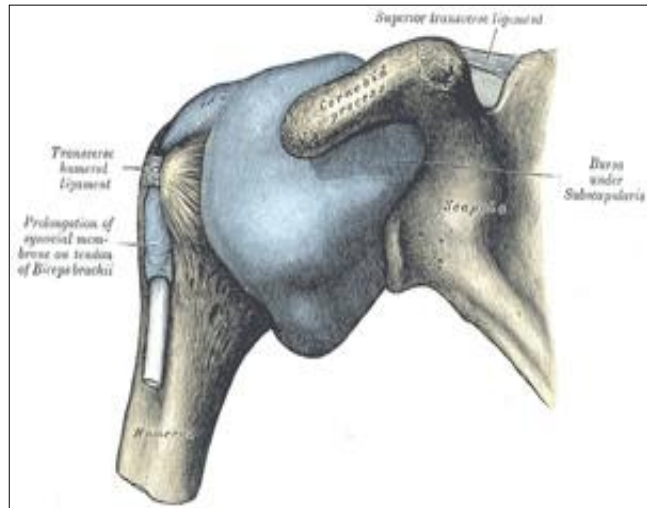


Fig. 23 Shoulder joint [2]

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<sup>12</sup>

A joint with a capsule of fluid around the articulated surface of the bone.

## 5. CONCLUSION

First, it is very important to get familiar with the basic anatomy of the three subjects discussed in the document. The number of bones, their names, the articulations and shape. This information will be used to compare against the digitized/scanned data. The source data needs to be cleaned. The data has holes, overlapping patches, and horrible edge layout. These issues should be fixed first. After the cleaning process the bones with sutures need to be positioned, geometry should be added or split to create the correct shape, number of bones and foramina.

After this stage every bone should be looked at individually. This needs to be done during the sculpting stage. Areas of interest are the joints, sulcii, linea, sutures and the muscle/ligament attachments. Those areas are the most prominent, but every little bump and dent should be added to create the desired result. The actual bones are the best reference to use for sculpting, since it has the actual height information of the bumps and dents present in the model.

The sculpted meshes can then be used to create a low resolution mesh by retopologizing the sculpted source. Two meshes with different resolutions will be created for each bone. One can be used for medium close-up illustrations and the other can be used for extreme close-up illustrations. The resolution is determined by the curvature of the bone and the type of illustration it will be used for (medium or extreme close-up). The UVs need to fill most of the 0-1 UV space and a fine balance between the number of seams and distortion needs to be found for each of the bones. A normal map is then baked from the sculpted source onto the low resolution mesh. This will transfer all of the additional detail to the mesh without adding more polygons.

Finally the bones of the arm and spine are positioned. Looking at real bones for reference will do the trick, but also knowing more about the type connection between the bones will also help in a correct positioning of the bones. There are three types of connections, a cartilaginous joint, a synovial joint and a fibrous joint.

The skull, arm and spine are just the beginning of a huge project. In the future the remaining bones will be created to complete the full human skeleton and after this; organs, muscles, ligaments, nerves and even the circulatory system could be added.



Fig. 24 Skull Render

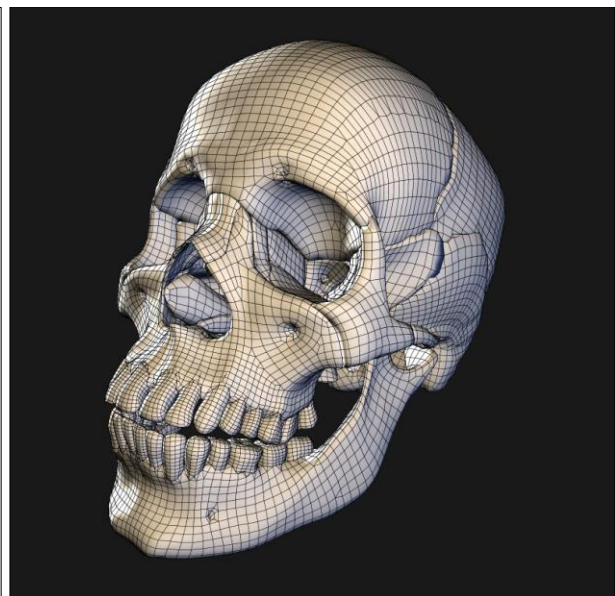


Fig. 25 Skull Wireframe

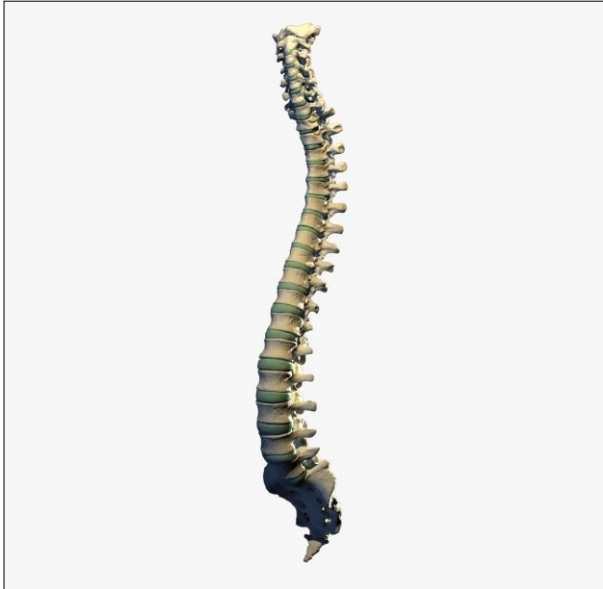


Fig. 26 Spine Render



Fig. 27 Spine Wireframes



Fig. 28 Arm Render



Fig. 29 Arm Wireframes

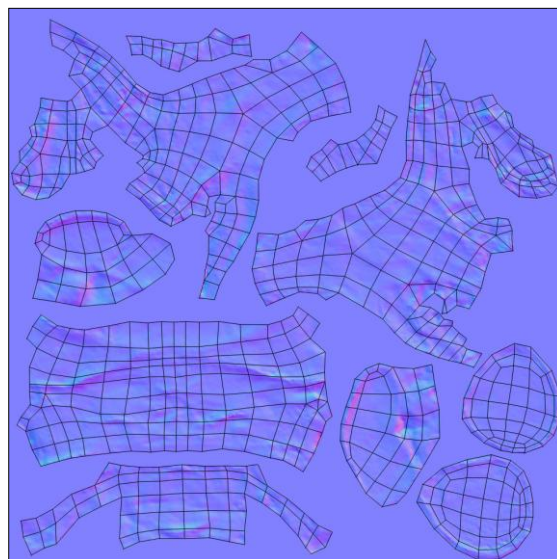


Fig. 30 Normal Map + UV Example

The final product looks impressive but it still needs to be compared to the 3D models already available for purchase. The company that delivers the best anatomical models at the moment is Zygote ([www.3Dscience.com](http://www.3Dscience.com)). I don't have access to the actual models, but based on the images and information found on the site it is possible to make a proper comparison between the created models for this project and the professional models from Zygote.

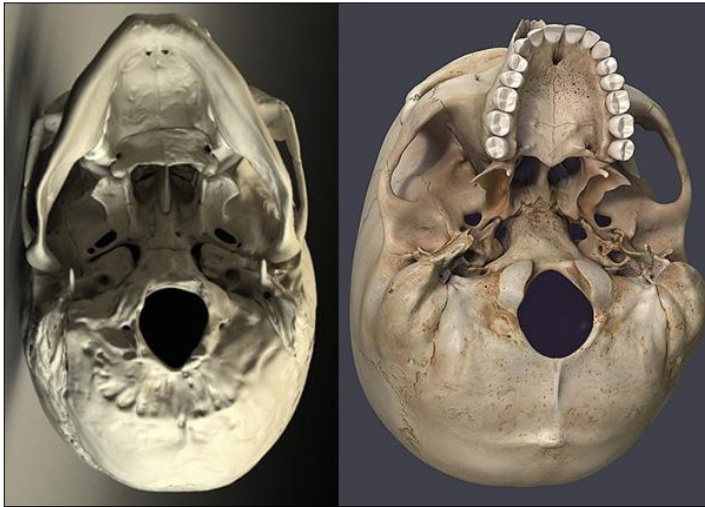


Fig. 31 Skull comparison (Left = Skull, Right = Zygote Skull)

The difference in the skull is most evident in the geometry. The Zygote skull does have all the sutures, but they are only present in the texture map. The skull itself is build from one mesh. The skull created for this project can be taken apart and also has the inner structures of the sutures modeled. The Zygote skull also features a lot less detail in their bump maps. The skull created for this project only loses on one point which is the missing texture map.



Fig. 32 Spine comparison (Left = Spine, Right = Zygote Spine)

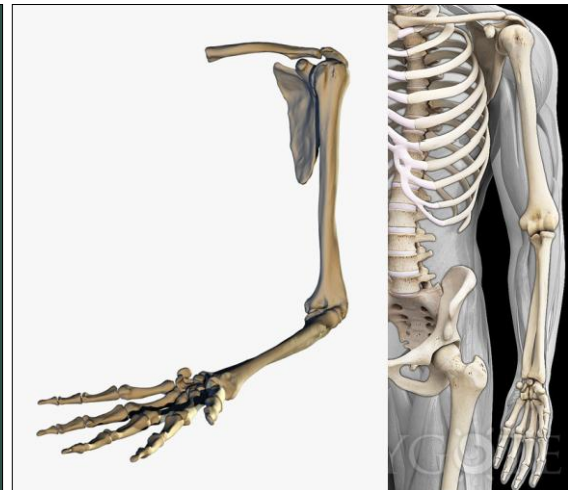


Fig. 33 Arm comparison (Left = Arm, Right = Zygote Arm)

The difference is less evident in the arm and spine model, the number of bones present in both models are the same. Just like the skull, the models created for this project have more detail and the triangle count is lower than the Zygote models. This means that Zygote doesn't use the extra number of triangles to create more detail. Another huge difference between the two products is the number of models created for the each bone. As mentioned in this document, two different resolutions are created for each bone. This boosts the performance for medium close-up illustrations. Zygote only offers one model with its high resolution.

From a distance the models look very similar, but when comparing the two models at an extreme close-up level the difference becomes apparent. Although the models created for this project feature more detail, there is a way of improving the realism even further. A texture map would be the perfect addition to these models.

## 6. SOURCES

- [1] Sobotta – Deel 1 (Hoofd, Hals, bovenste extremiteit)  
*R. Putz and R. Pabst*
  
- [2] Gray's Anatomy  
*Henry Gray, T. Pickering Pick and Robert Howden*