

SPECIALISATION THESIS

The creation of an accurate
Mosasaurus hoffmanni visualization

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Date of submission: 21 June 2013

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Abstract

The main goal of the specialization is the creation of an accurate *Mosasaurus hoffmanni* visualization. In order to achieve this, an in-depth analysis of *Mosasaurus hoffmanni* has been performed and multiple problems associated with re-creating the creature digitally have been solved. By securely analyzing the body features a more credible digital visualization can be achieved.

The goal of the thesis is reached by analyzing groups of features separately. First the anatomical support for movement has been studied and clarified as the movement pattern of the creatures reflects directly on its body plan fundamentals. Secondly, muscle deformation and other unique features related to muscles have been reviewed. Studying and re-creating the muscles of the creature has resulted in a deeper understanding of the anatomy and its functionality and enable correct muscle deformation in the digital creature. After musculature, different materials belonging to the external features, such as the eyes, teeth, tongue and skin have been analyzed. This is done in order to achieve a higher degree of realism as the materials should imitate their real-life counterparts accurately. And finally, different production workflow techniques have been studied in order to increase realism and to optimize the efficiency and flexibility of the creation process. During the digital re-creating of each group of features, certain issues were encountered. This thesis deals with these issues and their solutions.

1.0 Introduction

The creature central to this specialization thesis is the *Mosasaurs hoffmanni*. It was a carnivorous marine reptile that lived during the *Maastrichtian age* of the *cretaceous period*, around 70 - 65 million years ago. It got its name from the Latin word *Mosa* which means Meuse and the Greek word *sauros* which means lizard. The Meuse is a natural river from France to the Netherlands where multiple remains have been found. Although found near the Meuse, it didn't actually swim in the Meuse as the Meuse did not exist when *Mosasaurs hoffmanni* lived. In the *Maastrichtian age* the Netherlands was a shallow body of water. The overall length of *Mosasaurs hoffmanni* was approximately more than 14 meter (Schulp 2012). This length makes *Mosasaurs hoffmanni* one of the biggest marine predators of their time. *Mosasaurs hoffmanni* would come to the water surface to breathe as it had lungs. It preyed on fish, turtles, ammoniates and possibly other *Mosasaurs hoffmanni*, making it an excellent deep sea water predator (Schulp 2013). Remains of *Mosasaurs hoffmanni* are found on all continents (Lingham-Soliar 1995). Partial Fossils can be found in the Maastricht Natural History Museum.

Interesting and unique about this project is its scientific value besides the artistic value. The base for creating a credible visualization is found in the field of paleontology as paleontologists have the same goal as many artists: credibility through research. For scientists in the field of paleontology, projects such as these can be used in order to create universal visuals that support their findings. This leads to more support for universities and museums. Another positive aspect that comes through the cooperation of artists and scientists is the educational value, as the people's conception of dinosaurs is based primarily on dinosaur art and not on scientific research. An improvement of their understanding can be achieved through science-based recreations such as this one.

Due to the complexity of the creature and the quantity of indirect reference, multiple experts in the field of paleontology have been consulted in order to create an accurate representation that corresponds with their vision. These experts are Anne Schulp associated with the Maastricht Natural History Museum in the Netherlands, Mike Polcyn associated with the Southern Methodist University in Texas, Johan Lindgren associated with the Lund University in Sweden and Takuya Konishi associated with the Royal Tyrrell Museum in Canada.

Anatomical directional terms have been used throughout this specialization thesis. Anatomical terms facilitate communication as they hold more information than simple normal directional terms and can be combined in order to combine their meaning. The use of an unequivocal naming convention also enables comparability between anatomical sources and experts. The anterior direction is the direction to the front, the posterior direction is the direction to the back, the dorsal direction to the top, the ventral direction to the bottom and the lateral direction to the side. A combination of the terms like anterolateral (anterior and lateral) would indicate towards the front but 45 degrees to the side. Figure 1 displays this naming convention in relation to the body of *Mosasaurs hoffmanni*.

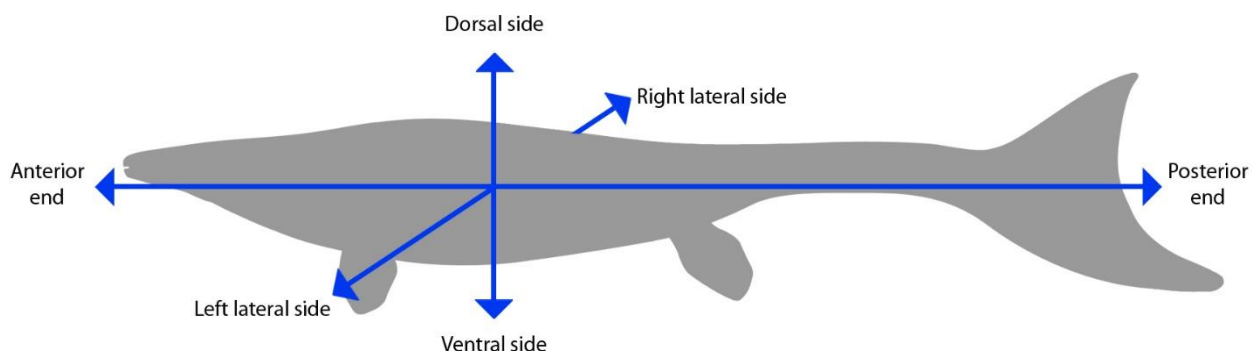


Figure 1 *Mosasaurs hoffmanni* body outline and terms related to direction.

Certain solutions found and explained in this document are software specific as the results are tested in the student version of Autodesk Maya and Pixologic Zbrush.

2.0 Subject analysis

Establishing correct primary functionalities during the digital re-creation of the creature will result in a more interesting and overall realistic visualization. In order to properly re-create primary functionality, the anatomical support needs to be analyzed. Once familiar with the anatomical structure, the materials are discussed. In order to achieve realistic external body features, the material attributes of their real-life counterparts have been studied. Production workflow and lighting fundamentals are important to analyze in order to organize the project and achieve realistic results.

2.1 Movement

When studying the skeleton one should look first at the axial skeleton, consisting out of the skull, spine and rib cage. From body functionality point of view the axial skeleton is important as it encases and protects the brains, spinal cord and vital organs. In the case of *Mosasaurus hoffmanni* the tail part of the spine is also used for movement. The axial skeleton is also important as the entire skeleton architecture depends on it. Once the spine and its functionality is correctly established it will determine the position and orientation of the appendicular skeleton, consisting out of the pectoral girdle, paddles and pelvis.

Figure 2 Figure 2 Isometric lateral view of *Mosasaurus hoffmanni* skeleton showing the vertebrae distribution. displays the skeleton of *Mosasaurus hoffmanni* and the distribution of the vertebrae in the spine. All vertebrae except for the tail vertebrae have ribs attached, similar to lizards and snakes. Research suggests that the skull and the front paddles are a little bit longer than one-tenth of the total length of the body (Lingham-Soliar, et al 1995). This makes the *Mosasaurus hoffmanni* skull small in relation to its body when compared to humans whose skull is one-eighth of the total body length. The hind paddles are a little bit shorter than the front paddles and are approximately to one-tenth of the total length of the body. Both the paddles as well as the pectoral girdle, containing the scapulae and coracoid, are very small compared to the body, relative to other mosasaurs. The tail is considered to be oriented down because in this particular stretch of vertebrae the dorsal centrum edge is longer than the ventral centrum edge (Lindgren 2010). Based on the preceding information it can be concluded that *Mosasaurus hoffmanni* primarily uses its tail and only for left-to-right movement.

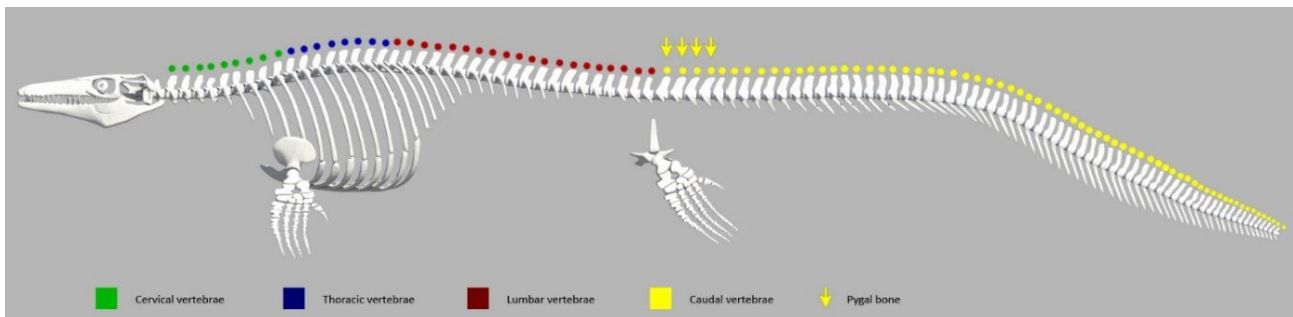


Figure 2 Isometric lateral view of *Mosasaurus hoffmanni* skeleton showing the vertebrae distribution.

Although the *Platecarpus* in Figure 3, has a different amount and arrangement of vertebrae, it is a closely related species of the same era and has similar tail control (Lindgren 2010). The functions of the different parts of the tail in figure 3 can be derived from the size and shape of the vertebrae in each section. The vertebrae in the tail up to the bend have transverse processes, which are bony structures that protrude from each side of the vertebrae. They enable bigger muscle attachment sites for the strong muscles of the tail. The first four vertebrae in the tail base are called the pygals and are the largest vertebrae of the spine. They serve as the main joints of the tail and therefore experience the most pressure. Fossils have been found with pygals grown together in order to withstand the pressure, a condition also found in whales. Besides being a reinforced foundation because of their robustness, they also allow for even larger muscle attachment sites, giving the tail more moving force. By design the creature has less muscle control in the fluke part of the tail, because of the transverse processes disappearing before the bend. However, the fluke part also has top fin which enables increased water displacement. This top fin was revealed in a fossilized ventral outline impression of a recent *Platecarpus* finding (Lindgren 2010). The tail fluke mechanism is similar to that of an oar. The fluke part also have extended haemal spines at the bottom of the fluke part of the tail making the fluke part vertically higher after the bend, also contributing to the amount of water displacement. The combination of a long tail, reinforced foundation for bigger muscle attachment sites and an oar-like fluke mechanism enables the *Platecarpus*, as well as *Mosasaurus hoffmanni*, to be effective at achieving high movement speeds by only using its tail.

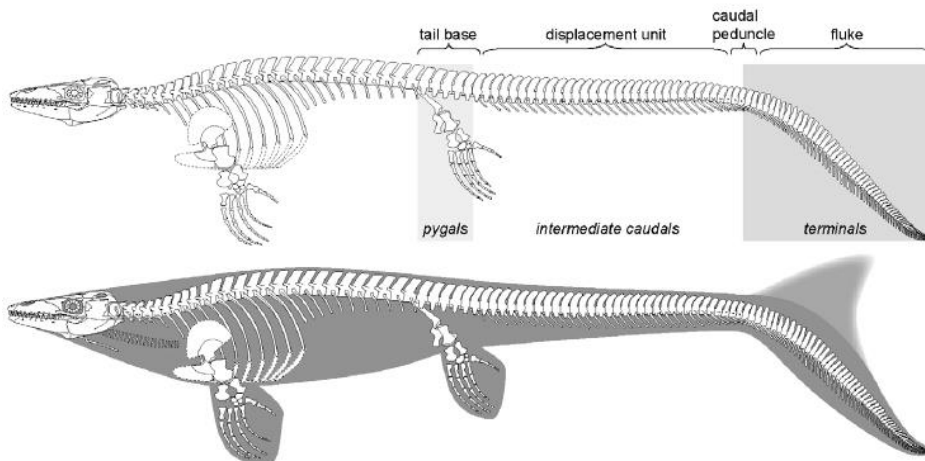


Figure 3 Lateral view of *Platecarpus* skeleton with tail functionality (Lindgren 2010).

From the anatomical structure of the tail it can be concluded that both the *Platecarpus*, as well as the *Mosasaurus hoffmanni*, have a highly optimized tail mechanic. They would presumably utilize a carangiform swim pattern, as opposed to anguilliform and/or sub-carangiform propulsion as was the case with their predecessors (Lindgren 2010). In the carangiform swim pattern the vast majority of movement is concentrated in the very rear of the body and tail as opposed to the anguilliform movement pattern where the entire body contributes to the propulsion. Carangiform swimmers are stiffer and most often faster than the anguilliform and sub-carangiform swimmers. Figure 4 shows the different types of locomotion found in contemporary sea creatures utilizing a left-to-right tail movement. The movement of the *Platecarpus* and *Mosasaurus hoffmanni* can be compared with that of the Markell. Important to note is that from the anguilliform swim pattern to the thunniform swim pattern, the center point of the hips deviates less from the center line with each swim pattern.

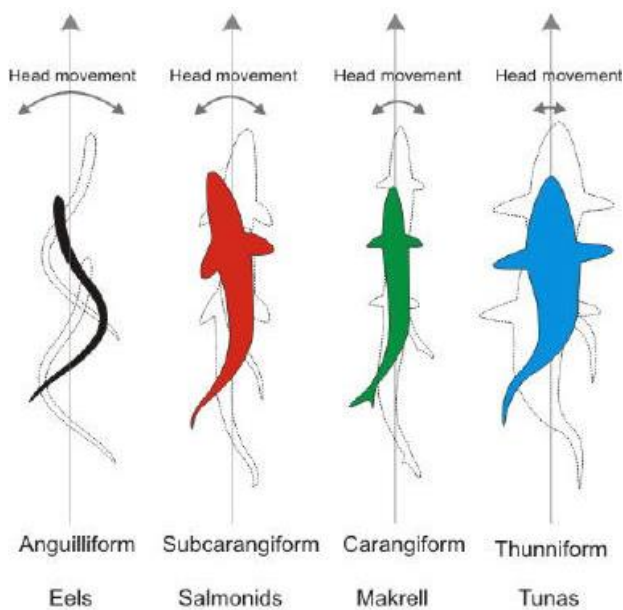


Figure 4 The swim patterns associated with aquatic creatures (psychology 1978).

In order for movement to be re-created digitally it is also important to understand more about the muscle structure and its characteristics. The next section deals with muscles attributes and their organization.

2.2 Muscle structure

Once the primary functionalities of the creature have been established, one should look at authentic muscle features in order to achieve realistic body deformations during movement. The correct placement of actual muscle shapes will also assist in a better understanding of the volume and mass of the body. The muscle shapes will also serve as muscle location and shape indicators when creating the skin. Certain requirements and challenges became apparent when determining an appropriate representation, which is discussed in chapter 3.2.1. Appendix I shows the list of identified muscles including their shape and position. Renders of the created muscle system are added.

Once the muscle system is established the muscles can be given authentic muscle attributes, such as contraction and volume preservation, through the use of a muscle system. The application of muscle systems in humanoid and creature models can be considered a contemporary CG requirement for movie quality projects. All creatures in *The Hobbit*, *Avatar* and *King Kong* are equipped with such systems by *Weta Workshop*, a company in New Zealand. A similar build-in muscle system in *Maya* is *Maya muscles*. Muscles created with *Maya muscles* can be set to influence the shape of the skin of the digital creature, resulting in realistic muscle deformation. However, the *Maya Muscle* system has severe limitations, which will be discussed in chapter 3.2.2.

There are three kinds of muscles. The skeleton muscles (voluntary muscles) are at least on one side connected to the skeleton by tendons and enable skeleton movement. The smooth muscles (involuntary muscles) can be found within the walls of the organs. The cardiac muscles (involuntary muscles) are the heart muscles. Muscles responsible for facial expressions are also skeleton muscles as they are connected to the facial skin to facial bones. The skeleton muscles are the most relevant for a visual artist as many are superficial, meaning that they are visible through the skin. They are also responsible for body locomotion and expressions.

Muscle tension is achieved by the sliding of protein filaments in each cell, which results in a decrease in total length of the muscle. But as the length decreases the total volume of the muscle does not, resulting in the familiar muscle bulge while flexing. This principle applies to all muscles, but the way the muscles are shaped does influence the location of the bulge. There are numerous types of muscle fiber growth patterns throughout the body. Figure 5 displays the different types of muscle fiber growth patterns.

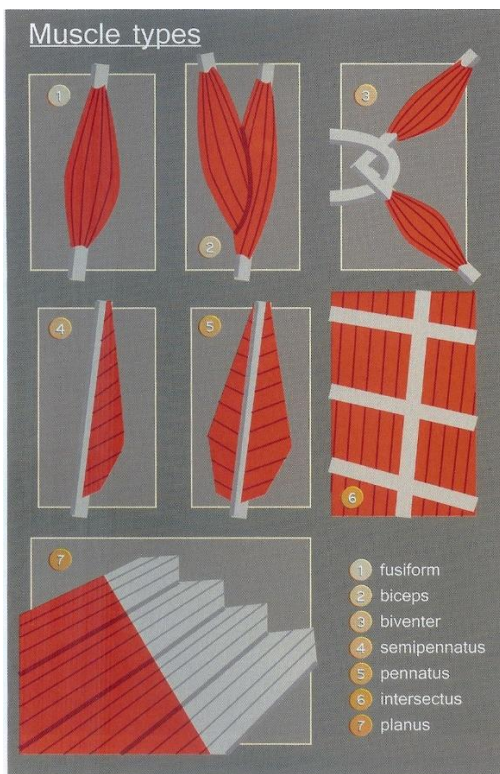


Figure 5 Different types of muscle fiber growth patterns (Paquette 2009).

Most creatures of the same class have the same, or almost the same, set of bones and muscles as the bones and muscles have the same mechanical purpose and are located in the same position in the body plan (Paquette 2009). However, there are clear differences between classes, such as mammals, fish and snakes, due to the bigger differences in mechanical purposes and drastically different living situation where the creature has adapted to. Mosasaurs would have different characteristics from regular dinosaurs, which can be explained through the evolutionary family tree. Although it is easy to mistake the *Mosasaurus hoffmanni* for a dinosaur, it is not. The mosasaurs come from a completely different branch of the reptile family tree. Dinosaurs are more related to crocodiles and birds, while mosasaurs are more related to snakes and lizards (Anne 2008). Because of this lineage, certain features in the bones and muscles of comparable lizards and snakes were already present in the mosasaurs.

One of these features still present in most lizards and snakes would be the pterygoid, which can be described as two extra top jaws in the back of the mouth. They are an important center piece in the mouth that enables the attachment of multiple muscles. Similar to the snake, mosasaurs would also have detached hips, as there is a small space between the ilium and the lateral tips of the transverse processes of the pygals. The hips are being held up by M. supracostalis et intercostalis externus, which has its origin in the thoracic vertebrae and its insertion point on the ilium and pubes of the pelvis. The tail muscle structure does not differ from other reptiles even though the tail has a top fin.

Besides movement, the muscle system and muscle deformation it is also important to represent the materials of external features in a realistic manner in order to create a credible visualization. The next section analyses with real-life attributes of teeth, tongue, eyes. It also validates contemporary reference material.

2.3 Materials

In order to achieve realistic external body features the material attributes of their real-life counterparts should be analyzed. The attributes of materials that should be considered are surface detail, interaction with light and the surface color. In many cases it is not only the upper material of the surface that determines the attributes of a material, but also the materials underneath it. Only after identifying all visible materials and corresponding features, realistic digital counterparts can be created.

2.3.1 Teeth

Multiple teeth have been found from different kinds of mosasaurs which give a precise indication of what the teeth should look like, as displayed in figure 6. The fossilized teeth can be used as surface detail reference as surface detail of the teeth hardly changes by means of fossilization. *Mosasaurus hoffmanni* has a healthy set of teeth with little microwear, meaning they are in a good state with hardly any scratches or dents (Schulp 2012).



Figure 6 Teeth of *Mosasaurus hoffmanni* (Deckers 2012).

The structural elements of the teeth do not differ from creature to creature. All teeth have a semi-transparent enamel layer over them. The normal color of enamel varies from light yellow to gray to blue white. Because enamel is semi-translucent, it shows the dentin material underneath it. Dentin is less mineralized and less brittle, which supports the enamel. The normal color of dentin is yellow. The thickness of the teeth of *Mosasaurus hoffmanni* could be considered as thick as teeth of a crocodile, which will be used as contemporary reference material on the appearance of enamel and underlying dentin, as displayed in figure 7.



Figure 7 Left: yellow dentin in the middle and white translucent enamel as outline (Zocchi 2009). Right: dentin is yellow, but at the root of the teeth the bluish enamel is too thick for the dentin to be visible though the enamel (Winner 2009).

The challenge in creating realistic teeth would be the interaction between the light and the enamel, as the thickness of the enamel is responsible for the degree of visibility of the enamel. The solution to this challenge is discussed in chapter 3.0.

2.3.2 Tongue

In order to establish correct material attributes, the different functions of the tongue parts should be analyzed first. *Mosasaurus hoffmanni* is likely to have a tongue where two parts can be differentiated. It has a flexible front part that would result in two separate tongue tips, where the difference in chemical sampling between the two is used for registration. This is the conclusion after identifying the vomer, which are holes in the palate of mosasaurs, as part of the chemoreception system. The other part of the tongue is the hind tongue, where papillae are responsible for taste registration. The presence of pterygoid teeth suggests the tongue would be used for transporting pray towards the throat, where the pterygoid teeth would hold the prey while the tongue would perform its movement forward, of the back-and-forth-movement, responsible for the transporting the prey to the throat. This suggests the tongue has a considerable width in order to have a grip on the pray. When combining the presence of two separate tongue tips, papillae for taste registration and a wider tongue, it would have a similar shape and function as the tongue of the contemporary Gila monster or earless monitor lizard as displayed in figure 8 (Schulp, Mulder et al. 2005).

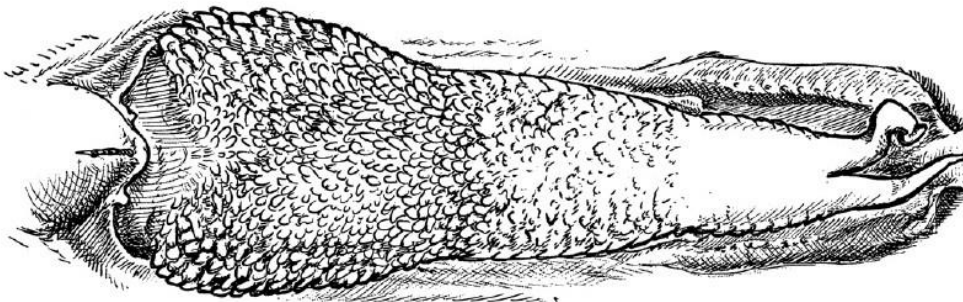


Figure 8 The tongue of the earless monitor lizard (McDowell, 1972).

The color of the tongue of the Gila monster differs from creature to creature as displayed in figure 9. They vary from purple to greyish green to pink. The tongue is richly supplied with nerves and blood vessels which are visible through the surface of the tongue. The tongue would be kept moist in the mouth by saliva mixed with sea water.



Figure 9 Tongue on Gila monster, while in the mouth and during tongue-flicking (McBree 2009) (Jim 2011) (Hendriks 2010).

2.3.3 Eyes

In order to identify the different material attributes of the eye, it is important to first gain an understanding of each part that when combined give the eye its functionality. *Mosasaurus hoffmanni* has a ring of bones inside its eyes called the *sclerotic ring*. Contemporary creatures that still maintain the sclerotic rings are turtles, reptiles and birds. The sclerotic rings consist out of twelve small plates that leave room for an eye opening of 6 cm (Plisnier 1969). The function of sclerotic rings is believed to give support to the eye as the sockets tend to be significantly bigger than the eye itself. The function of supporting the eye becomes increasingly important at greater depths of the sea (Pigdon 1997). The size of the sclerotic rings also gives an indication of the size of the eye. Figure 10 displays the shape of the sclerotic rings and their position in the eye. Sclerotic rings are not visible under normal circumstances when looking at the eyes of birds, reptiles or turtles.

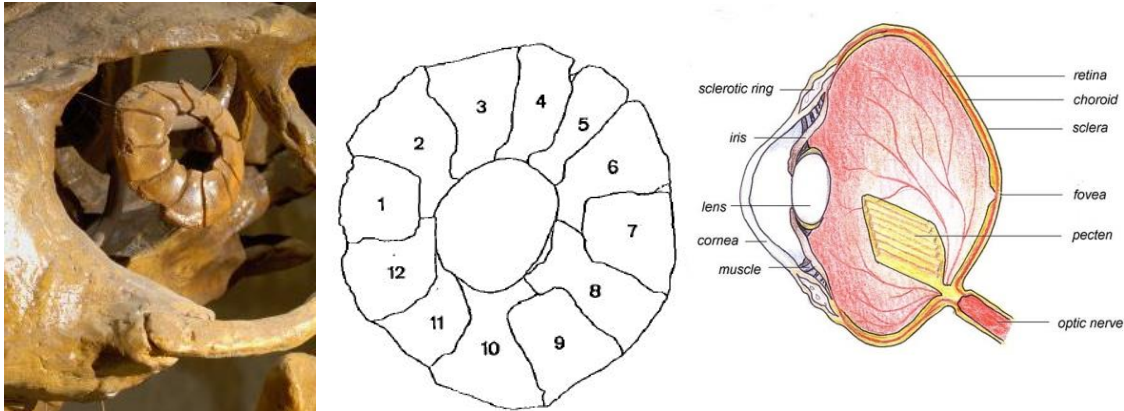


Figure 10 Left: sclerotic rings of *Mosasaurus hoffmanni* (Verlinde 2003). Middle: rings in lateral view (Pilsner-ladame 1969). Right: side view of eye anatomy containing sclerotic rings (Jimfbleak 2008).

The cornea is the outer layer of the eye. It is completely round, but with a bulge in front of the pupil, the dark center of the eye. Although it is transparent, it is highly reflective, giving away its shape. It has small sparse irregularities on the surface as it protects the eye from scratches of fine sea bottom sand particles. Because the eye is transparent it has a certain index of refraction. The index of refraction is a number that describes the amount the medium bends the light, which in short is what refraction means. It is the amount that the cornea distorts the line of sight, resulting in a distorted view of the iris and pupil, which is especially visible from the side. The index of refraction of air equals almost 1.0003 as it hardly distorts our view. The index of refraction of the cornea equals 1.376, bending the line of sight slightly more than the water around it. This will result in noticeable extra distortion when looking through the cornea. The sclera is the white of the eye and it is the surface the cornea blends into. The sclera has visible veins that are placed slightly below till slightly on top of its surface. The iris is the colored circle around the pupil. It serves as diaphragm of the eye, able to regulate the amount of light it lets through. The pupil, or lens, is the transparent squashed ball in the center of the eye. With an index of refraction of 1.406 it bends the view so it is projected on the optic nerve. The pupil looks black as it shows the inside of the eye. Figure 11 displays different eyes of lizards. The eyes can have different colors similar to the human eye.



Figure 11 The color of the eye differs from red to yellow (Sannuti)(King 2009)(Alexander 2001).

2.3.4 Skin

A recent *Platecarpus* fossil finding shows fossilized skin patterns and marks. Because of the affinities of *Mosasaurus hoffmanni* to *Platecarpus*, the skin information of *Platecarpus* can be transferred to *Mosasaurus hoffmanni*. Both the *Platecarpus* as well as the *Mosasaurus hoffmanni* belong to the suborder of *Lepidosauria*, which is Greek for scaled lizards. All scale printings in this chapter are from *Platecarpus* fossils. Because the *Platecarpus* was almost 6 meters long as opposed to the 14 meter long *Mosasaurus hoffmanni*, all measurements have been multiplied by 2 and a half.

Characteristic about scales is that they are overlapping, which is what gives the scales strength. The body scales are around 9 x 8.25mm (width x height), with an exception of the scales just before the bend in the tail where the scales become taller, 26.25 x 11.75mm, as shown in figure 12. The existing information can be used to estimate the scales that remain of unknown size. The paddles have the same kind of scales. However, the scales become progressively larger towards the tip of the paddles. There do not appear to be any specific skin marks such as keels (Lindgren 2010). *Mosasaurus* are considered to have streamlined bodies with no excessive skin surplus, unlike many contemporary lizards, such as the komodo dragon.

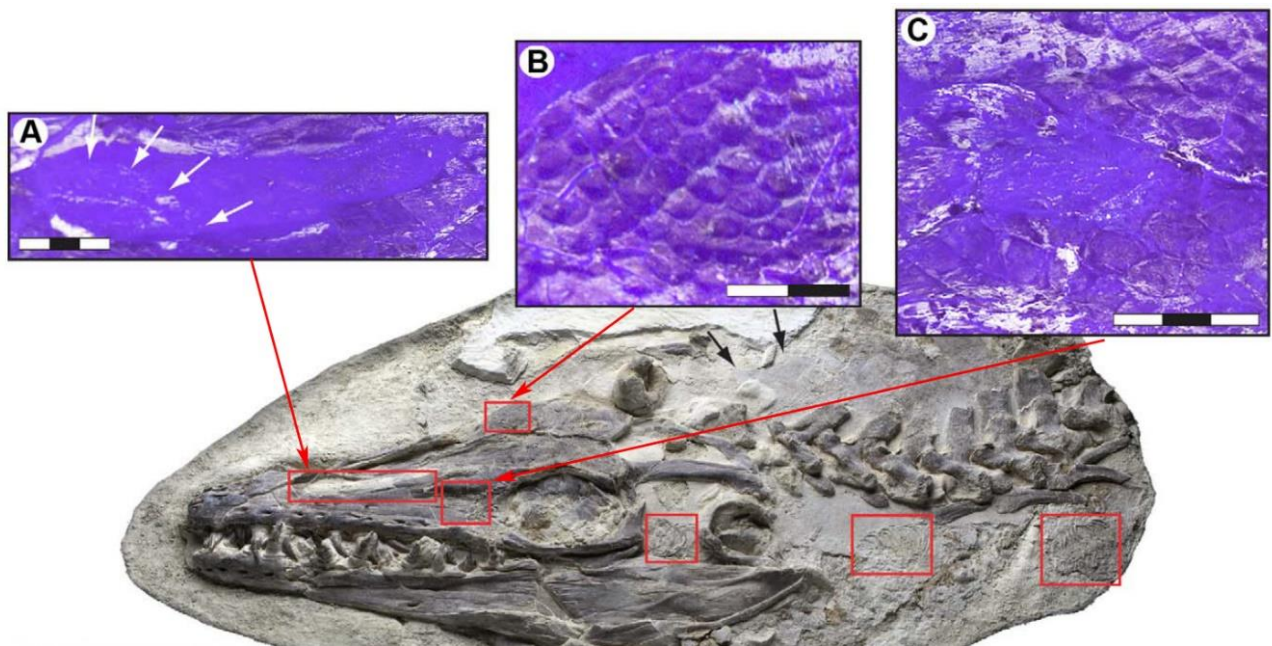


Figure 12 Skull of *Platecarpus* with soft tissue impressions under UV light (Lindgren 2010).

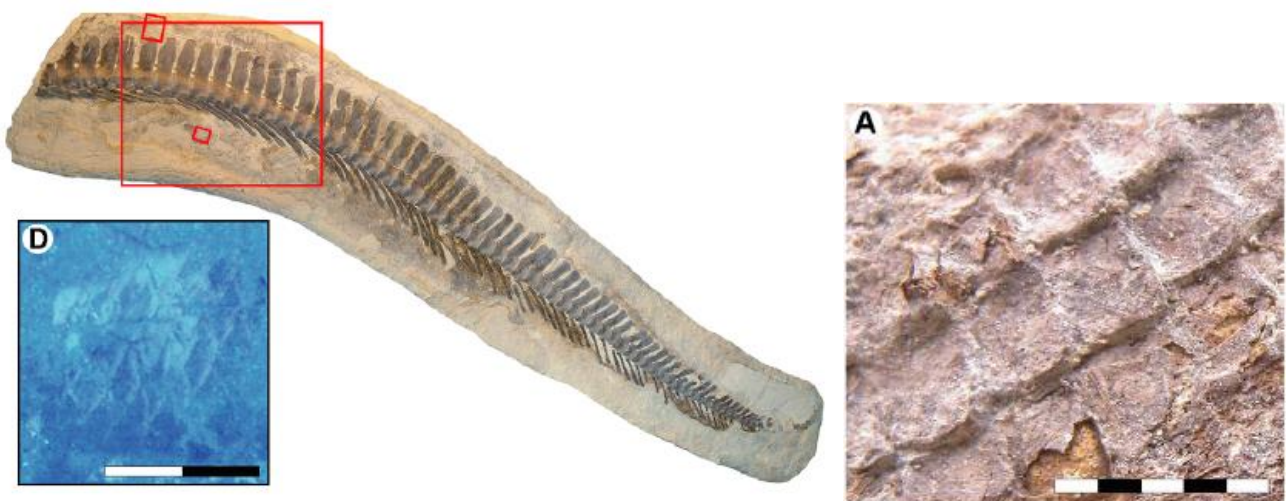


Figure 13 Left: Scale impression of the tall scale at the bend of the tail (modified after Lindgren 2010). Right: A three-dimensional fossil find of the scale in the neck of 11 x 7.5mm. (Lindgren 2010).

The fossil of *Platecarpus* also shows irregular stains and stripes on the premaxilla, third cervical vertebra and along the gum line. This is the result of relative exceptional fossilization circumstances. Because skin and scales are more resistant to biodegradation than the meat, it gets decomposed last. The sediment¹ takes over the shape and color of the skin, which attaches itself to the bone, therefore results in vague printings of the skin. However, this does not happen often and only under special circumstances, which makes this *Platecarpus* fossil in figure 14 extremely rare. Although the color has grown dull during the fossilization, the pattern has remained the same. The scale bar in Figure 14 equals 62.5mm for each partition. This verifies that each stripe would be about 50mm in width.



Figure 14 Color pattern on the third cervical vertebra (Lindgren 2010).

Besides analyzing the creature itself it is also important to understand certain techniques associated with computer graphics. A correct production workflow needs to be established for a flexible project and certain lighting fundamentals are important to understand in order to create realistic lighting. The next section analyzes these matters.

¹ Sediment is naturally occurring material that is broken down by processes of weathering and erosion. Cretaceous sediment is composed of clay, mud, silt (slimy substance at the bottom of a water body), sand, gravel and chalk.

2.4 Project management

Before re-creating the creature digitally, the understanding of certain project management techniques is important in order to incorporate them in the production workflow. Because of the variable nature of the subject it is especially important to establish a flexible workflow. The schedule can be endangered if the project is not set up to be flexible. Besides flexibility the project workflow also needs to take detail into account, which is also discussed in this chapter. In order to have a better understanding about lighting and to acquire realistic renders certain lighting fundamentals have been studied.

2.4.1 Production workflow

A production workflow can be considered efficient if the quality of the project is achieved while maintaining as much flexibility as possible. Flexibility is extra important in this project, because the target is not set in stone up front. Although it is important to figure out as much as possible up front on how the creature should look and move, changes later on may be required. This is because not all information acquired can be considered absolute as most references are incomplete or only partially correct. If the project is not organized to be flexible the schedule could be endangered.

During the re-creation certain issues were solved procedural, in order to benefit flexibility. As described in 3.2.1, the muscles are represented by a procedural material, for which adjustments will be carried out through-out all the muscles, while maintaining the muscle dependent resolution. By setting this material up to be flexible, corrections to the appearance of the muscle can easily be adjusted in a later stadium. The auto swim function in chapter 3.2.2 could be considered a procedural animation, where adjustments can be made by adjusting parameters. This also enables a shorter turn-around time where expert feedback cycles can be almost instant, which benefits the schedule of everybody involved and allows for the creation of a better visualization in the same time.

Another form of flexibility during production is to enable non-destructive changes during development. This could be achieved by using organized layers in *Photoshop*, where feedback could be applied to the corresponding layer without the artist having to start over. *Jellyfish Studios* would apply the same principle in *Zbrush* on *Planet Dinosaur*, a CG dinosaur documentary commissioned by the BBC. After creating the base outline, all details would be sculpted in different layers. *Jellyfish Studios* would also work with paleontologic expert feedback similar to this project and by applying this principle they would be also be able to shorten the turn-around time the expert feedback took (Cooling 2011). Another way to apply flexibility would be through the use of compositing programs such as *Nuke*. With the correct render output from *Maya*, adjustments can be made to the final image.

The goal in mind for an efficient workflow would be that of a desirable end product. All visualizations, both for feature film as well as for scientific purposes, have a high amount of surface and texture detail. Sculpting software such as *Zbrush* are considered to be the CG industry standard for high end feature film products. However, these sculpts is in many occasions not the model that are being rendered for the final product. Instead multiple texture techniques have been developed in order to create the illusion of high detail on simplified models. When done correctly this enables the same amount of detail, in a much faster render time. This is because render algorithms deal much faster with texture information than with model information. This has resulted in the development of bump and normal maps in order to achieve high detail with less render time. Texture information of bump and normal maps will be displayed by fake shadows on models when read correctly by render engines. The uses of displacement maps are beneficial for viewport performance but replace the low poly model with an higher poly model during render time. Displacement maps are grey scale images where each whiter-than-grey-pixel creates a point in the normal direction of a face and each darker-than-grey-pixel creates a point to the other side. These points will be connected during render time, increasing the complexity of geometry.

2.4.2 Lighting fundamentals

Achieving realistic lighting in computer graphics is not as straight forward as it might seem. But it is crucial in achieving realistic renders where light and shadow can benefit the readability of the scene. It also has influence on the color intensity. Artists call this process setting up a linear or physical workflow.

Before going into 3D software applications it is important to know how monitors work, because monitors work differently from the human eye. Normal images have special encoding on them to look correct on the monitor. Correct, in this context, means the way the eye perceives the images. This encoding contains information on brightness, luminance and how colors are displayed. Images that have this encoding are 8-bit images such as JPG, BMP and TGA. On the other hand, 32-bit images will look wrong on the monitor as these do not have this encoding. The same image, but 32-bit instead of 8-bit will look much darker than it is meant to be.

This is the result of the input voltage of the computer screen and the fact that it is not linear to the output light intensity. This relation is displayed in figure 15. The lowest point would be no input voltage and completely black, comparable to the darkest shadow. The highest point would be with full input voltage, comparable to the brightest light. Therefore the encoding has an increasingly stronger modification factor in the middle area. Keep in mind the gamma should be linear (green line in figure 15) in the ideal situation. 8-bit images are encoded to be more bright in this middle area (blue line), while the screen would automatically display it as being normal (green line). Since the 32-bit images are not encoded and would normally be stored as normal input (green line), it would be displayed as being too dark in the middle area (red line). This incorrect display of 32-bit images can be corrected by multiplying the normal input manually with 2.2, similar to the encoding of 8-bit images.

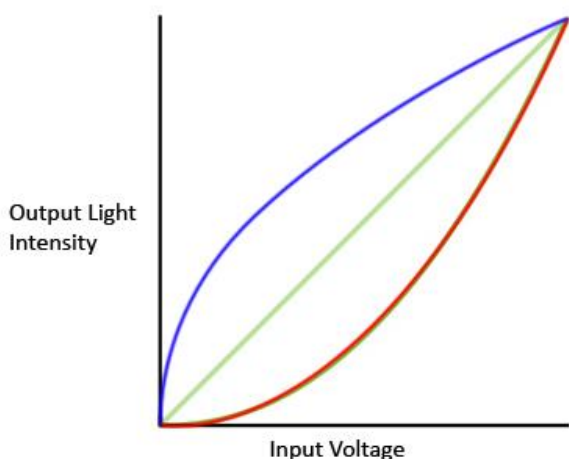


Figure 15 The relation between input voltage and output light intensity of the monitor. The red line is the result of an image with no encoding. The blue line is the multiplication with the red line, which results in the green line.

This concludes the analysis part of the specialization thesis. By utilizing research in this chapter, the accurateness of the digital re-creation will be promoted. The next chapter deals with certain technical issues that became apparent while creating the creature digitally.

3.0 Technical solutions

Acquiring in-depth information on the body anatomy of the *Mosasaurus hoffmanni* would be the first step in achieving the main target for the specialization, being the accurate creation of the *Mosasaurus hoffmanni* visualization. However, during the process of creating the digital model multiple issues occurred and had to be solved. This chapter deals with these issues.

3.1 Movement

Once familiar with the skeleton structure of *Mosasaurus hoffmanni* and its swim pattern, becomes of added value to implement a flexible auto swim function as the creature will swim naturally according to the carangiform swim pattern with the possibility of small situational deviations that fit the pattern. The creation of such a function could drastically decrease animation time for animators that require to animating multiple *Mosasaurus hoffmanni* with versatile deviations to their natural swim pattern.

The first of three important requirements for the auto swim function would be the *overlap and drag* animation principle. When the base of the tail moves left and right the fluke part will move according to that but with a delay as the fluke has a lot less muscle power than the tail base and displacement unit as result of the before mentioned lack of transverse processes on the fluke part. Another important requirement is the fact that the hips almost rotate on one spot as the propellant force operates behind it. The final important requirement is the movement of the upper body and neck. They are required moving opposite to the tail where the head should always be facing forward in order to apply aqua dynamics to its overall shape.

Figure 5 shows the formula and graph that serves as solution to the auto swim function issue. For the tail joints to move from left to right a sinus function on the Y-axis of the joint has been used. This sinus function would move the joint from 1 to minus 1 continuously over time. By multiplying the frame with a number will adjust the frequency of the waves, making the joint rotate faster. By adding or subtracting a number to the frame number times the frequency, the value will delay the wave. This value is important in setting up the *overlap and drag* animation principle required to give the tail a whip-like motion. By offsetting or delaying a certain part of the tail it will start to lag behind in the sinus shape. And because of the cumulative nature of a joint chain, the first delayed joint will not create a sudden noticeable offset compared to the joints in front of it. By multiplying the outcome of the sinus with a value, the sinus waves will be amplified by that number, increasing the degrees the joint will rotate left to right.

$\text{Joint Y rotation} = \sin((\text{frame} * \text{frequency}) + \text{delay}) * \text{amplitude}$

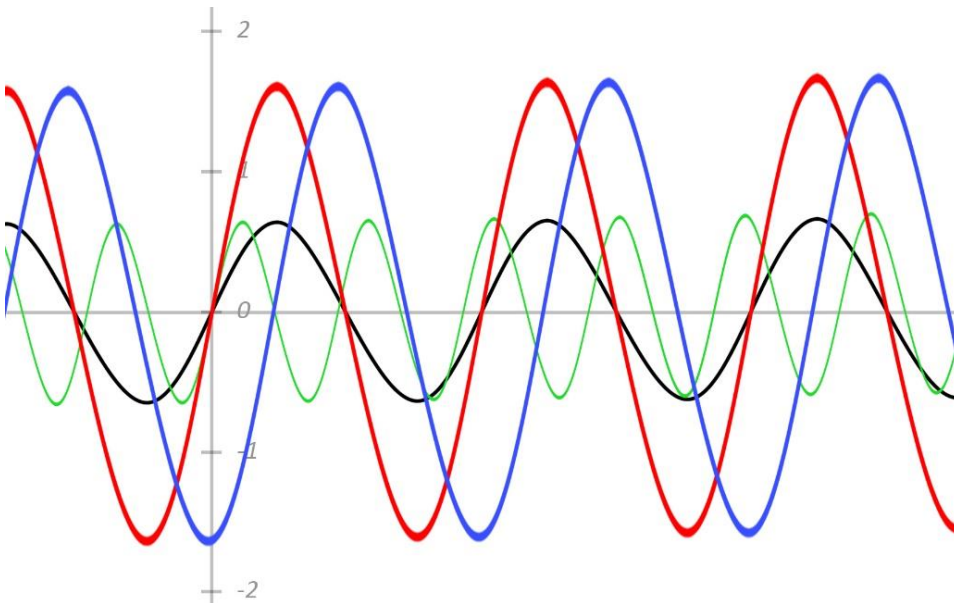


Figure 16 The formula and how the values influence the output of the sinus function.

Using the formula would enable the tail to move correctly from left to right, using the delay function to create the *overlap and drag* animation principle. However, by simply creating a joint chain from the head onwards will not enable the hips to only rotate on one position as it would force the creature to swim anguilliform instead of the carangiform swim pattern that is required. The solution to this problem is inverting the joint chain from the hips towards the head, effectively creating two joint chains that have their orientation opposed by delaying the position in the universal sinus wave for one of the joint chains. By connecting the hips to one of the two chains it would automatically rotate the hips on the same place. Another sinus function can be added for the left-to-right movement value of the hips in order to achieve the slight movement of the hips in the carangiform swim pattern as opposed to the thunniform swim pattern where the hips would only rotate.

Besides the actual swim function, water displacement and currents would add a lot of realism to the animation and can be considered a useful addition to the auto swim function. It uses the same function to operate as the tail. A subtle sinus wave function on multiple axes can be added to the entire model, moving the creature as a whole. The paddles also need to be connected to a sinus wave that has to be delayed from the sinus wave of the entire model. After the current has pushed the entire creature down, the paddles will push down, moving the entire creature up again. This will create the subtle animation in which the creature will constantly use its paddles to stay in one place. By setting up flexible controls the animator can tweak the values in order for the timing to be correct. The water displacement function can also be used while swimming as the paddles are the only instruments for the creature to move itself upwards, no matter how fast the creature swims.

This concludes the solution to the auto swim function issue. Besides correct movement it will also contribute to the final visualization to deform muscles accurately by the use of algorithms. The next section deals with the representation of muscles and the *Maya muscle* system, which is a system that simulates realistic muscle properties through algorithms.

3.2 Muscles structure

After gaining a better understanding of the anatomical features of the *Mosasaurus hoffmanni*, the muscles can be created. This chapter deals with the opportunities and issue that occurred when visualizing the muscle system. A list of identified muscles has been included in appendix I.

3.2.1 Muscles representation

Once familiar with the muscle structure of *Mosasaurus hoffmanni*, the muscles can be created. In order to maintain flexibility in the material of the muscles, a semi procedural muscle material has been designed. It can be considered semi procedural as the muscle fibers should be manually set for different muscles, as each muscle has its own amount of fibers and connective tissue length. This would make the material semi procedural, as some settings are muscle specific, while the creation of the fibers is completely procedural, as only math is used to create them. This method will enable the user control over the likeness between the digital muscles to the actual real-life muscle, without losing the benefits of the procedural texture creation. The advantage of a procedural textures is that they are generated resolution independent, which means that the textures stay crisp and clear even during an extreme close-up. In many situations, designing procedural textures also saves time as opposed to hand-drawing each muscle texture individually. Another benefit for using procedural materials would be the overall project flexibility, just in case if adjustments are desired in a later stadium, as discussed in chapter 2.4.1.

In order to achieve a semi procedural material in *Maya*, only *Maya* nodes can be used to generate texture information. *Maya* nodes are specific mathematical operations, visualized in nodes, which can be connected to material attributes. Another requirement to the semi procedural muscle material would be that, in order to utilize its flexibility, the output of the material has to be visible in the viewport. Some *Maya* render engines, such as *Mental Ray*, do not show the output of complex material networks on their render engine specific material, which render faster than regular *Maya* materials. Also important would be the ease with which the user could make global changes to the muscle material. This enables quick situational adjustments later on.

Figure 17 shows the muscle material network which meets the requirements. The procedural material is a combination of two horizontal ramps consisting of muscle fibers and connective tissue, which are combined in a vertical ramp to indicate where the connective tissue and muscle fibers start and end. The fiber resolution node specifies the amount of fibers and connective tissue strains the muscle has. When set up for each muscle independently the artist has complete control over the look of each muscle. The re-use of the same parameter nodes connected to the bump, reflection and glossiness value allows for easy access in case certain requirements to the material change. The color nodes are used for the muscle fibers and connective tissue are connected in a similar manner. Although this network achieves the flexible procedural requirements it is considered to be complex and therefore will not be visible when applied to a *Mental Ray* material. Regular *Maya* materials do show their complex output in the viewport, but will render slower than material created specifically for a certain render engine. The desired result can be achieved through the use of the shader group, which is a render node that communicates between the material and the render engine. By connecting the output of the procedural material into a regular *Maya* lambert and by treating the lambert as a custom shader it will show the normal lambert, with its viewport preview value, in the viewport while it switches to the mental ray material while rendering for optimal render time.

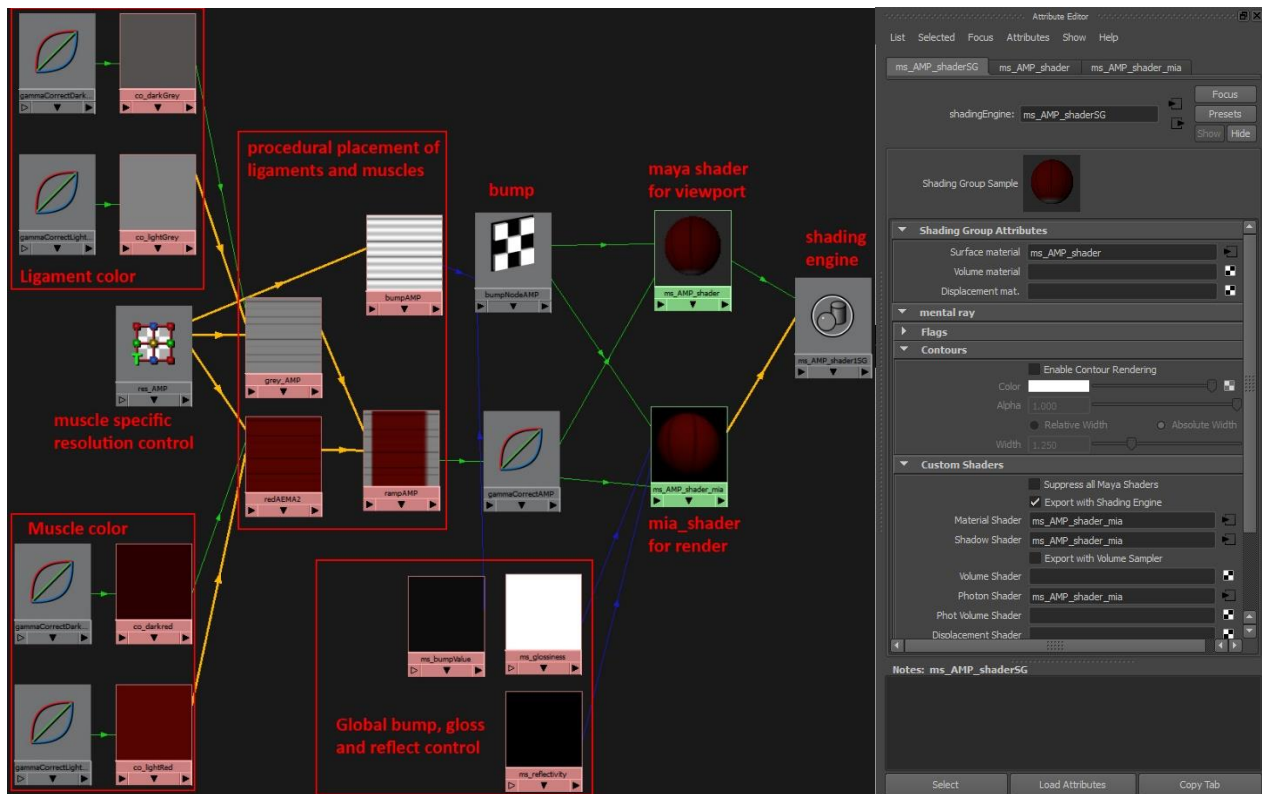


Figure 17 Left: the material network work area of the *M. adductor mandible profundus*. Right: The shader group node in the attribute render showing the lambert as surface material in the viewport and the mental ray material as material, shadow and photon shader at render time.

In order for procedural materials to work the model requires UVs. Therefore *Maya* NURBS surface objects are preferred over regular polygons as they automatically generate UVs based on their patches. This instantly enables efficient UVs that follow the muscle shapes perfectly. *Maya* NURBS are also the better choice for modelling as the shapes are automatically smoothed and they are very flexible when adding or removing surface definition.

3.2.2 *Maya muscle system*

After the muscle system has been established the digital muscles can be given muscle characteristics that can also be found in real-life muscles. This can be done with the use of the *Maya Muscle* system, the build-in muscle algorithm system available for *Maya* since *Maya* 2011. The *Maya Muscle* algorithms can simulate multiple characteristics, such as the contraction and bulging of the muscle, the stiffness of the muscles and the amount of fat that capsules the muscle. Besides those characteristics it also takes the volume preservation of real muscles into account. *Maya Muscle* can also store certain shapes that are connected to certain events, much like *blendshapes*, where a certain shape change occurs while a certain joint is rotated in a specific axis.

There are two ways of creating *Maya Muscles*. One way is to create the shapes through a special *Maya Muscle* user interface and the other way is to create custom muscle geometry after which the algorithms will be applied. The first method automatically connects the muscle to the bones, while for the second one, the user has to set it up manually. After the *Maya Muscle* algorithms has been activated, the muscle shape can still be manipulated by moving the surface points of the NURBS object. But because of how the algorithm works the muscles cannot be scaled with the scale tool. This will result in incorrect deformations when the entire creature is scaled up or down. This can be solved through the use of *expressions*, the build-in *Maya* scripting language. Each *Maya Muscle* has a value for scaling, which directly affects all the scaling attributes in the *Maya Muscle* algorithms. By multiplying this value with the overall creature scale value, the global scale will ensure correct resizing of the *Maya Muscles* relative to the creature.

A severe limitation to the *Maya Muscle* system is that it only works correctly with fusiform linear shaped muscles. The fundamental base shape will always have to be a sphere, in order to deform correctly. *Maya muscle* will create a line between the surface points referring to the UV points on 0,0 and 0,1 in UV space. Because of this, only a NURBS sphere would have a line through the center of the shape, enabling the *Maya Muscle* algorithms to work correctly. When a custom NURBS cylinder, instead of a NURBS sphere, is used, it would create a line and controllers away from the center. This is because the surface points referring to the UV points on 0,0 and 0,1 in UV space are part of the cylinder geometry and the line will always be created linearly. Because the controllers have an offset from the center, the shape will deform incorrectly as no rotation value is passed through to other surface points of the end of the NURBS cylinder. When using the *Maya muscles* user interface way of creating muscles all muscles will automatically be deformed spheres. Another issue associated with *Maya muscles* would be that *Maya muscles* always create a linear path between the first and the last controller regarding the shape of the muscle. This means that if a muscle is not linear by itself it will always deform incorrectly.

From the way *Maya muscles* operate it can be concluded that only simple linear fusiform muscle shapes can be created and attached to the bones. However, the fusiform muscle fiber growth pattern is only a small minority of all muscles in any body. And even those muscles are not completely linear, such as the biceps brachii. Most muscles have shapes that are more complicated. After analyzing the potential it seems *Maya muscles* should only be used for the approximation of muscle deformation of the biggest few, almost linear fusiform muscles, or muscle groups that come across as such. For example, the main volumes of M. gastrocnemius could approximately be considered to be two linear fusiform shapes, even though M. gastrocnemius would be a biceps muscle fiber growth pattern. The same principle can be applied to M. rectus femoris, that in fact has a pennatus muscle fiber growth pattern. However, through the skin it could be approximated by the use of a simple fusiform shape. However, large non-linear and complex shaped muscles such as the m. latissimus dorsi or m. deltoideus would be possible to approximate in a credible manner with only linear fusiform muscle shapes.

This concludes the discussion on the muscle representation and *Maya muscle* functionality. The next step, in order to acquire realism, is simulation of realistic materials. The next section deals with the material attributes required to achieve this.

3.3 Materials

In order to achieve realistic external body features the material attributes of their real-life counterparts have been analyzed in chapter 2.3. Once familiar with actual material attributes such as surface detail, interaction with light and surface color, a foundation for achieving the same attributes for the digital creature has been determined.

Chapter 2.3 describes the enamel and dentin material properties that give teeth their unique appearance and interaction with light. Enamel contains an attribute that is called subsurface scattering. Figure 18 shows a material with two light rays concentrated onto it. The light will scatter upon entering the material but also inside the material the light will change orientation on multiple occasions. This makes the enamel pervious to light passing through even though it is not possible to look through the material.

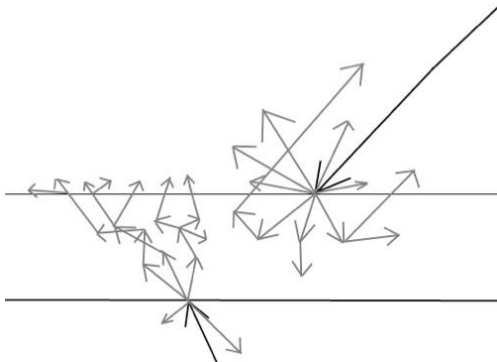


Figure 18 Light rays will be dispersed inside the material with a subsurface scattering attribute.

CG algorithm materials with the subsurface scattering properties can be used in order to achieve the same results. This material attribute gives the material the illusion of light scattering within the object. This will create the illusion of a decrease in density of the material, which results in the light passing through the material without the object being transparent. These features are controlled by two algorithms. One is the front subsurface scattering algorithm, which regulates the amount of light that enters and disperses from the front. The other is the back subsurface scattering which regulates the amount of backlight that comes through the object.

In order to create the teeth digitally only the color and alpha output of the subsurface material have been connected to the mental ray material as that enables the user to use the regular mental ray material attributes such as bump and specular. The front and back subsurface scattering color has been set to subtle yellow which is the normal color of dentin. Figure 19 displays the material network in Maya and the subsurface scattering algorithm attribute editor.

Important to keep in mind is that the values regulating the subsurface scattering algorithm are *Maya* units. This means they are absolute. If the model is scaled up twice its normal size it would effectively halve the amount of subsurface scattering present in the final render. This can also be solved through the use of *expressions*, similar to the issue regarding the scaling of *Maya muscles*. By multiplying the normal values with the overall creature scale value the amount of subsurface scattering can be maintained. Figure 19B shows the algorithm values in purple indicating they are connected to an expression. The expression is also visualized in the material network area in figure 19A.

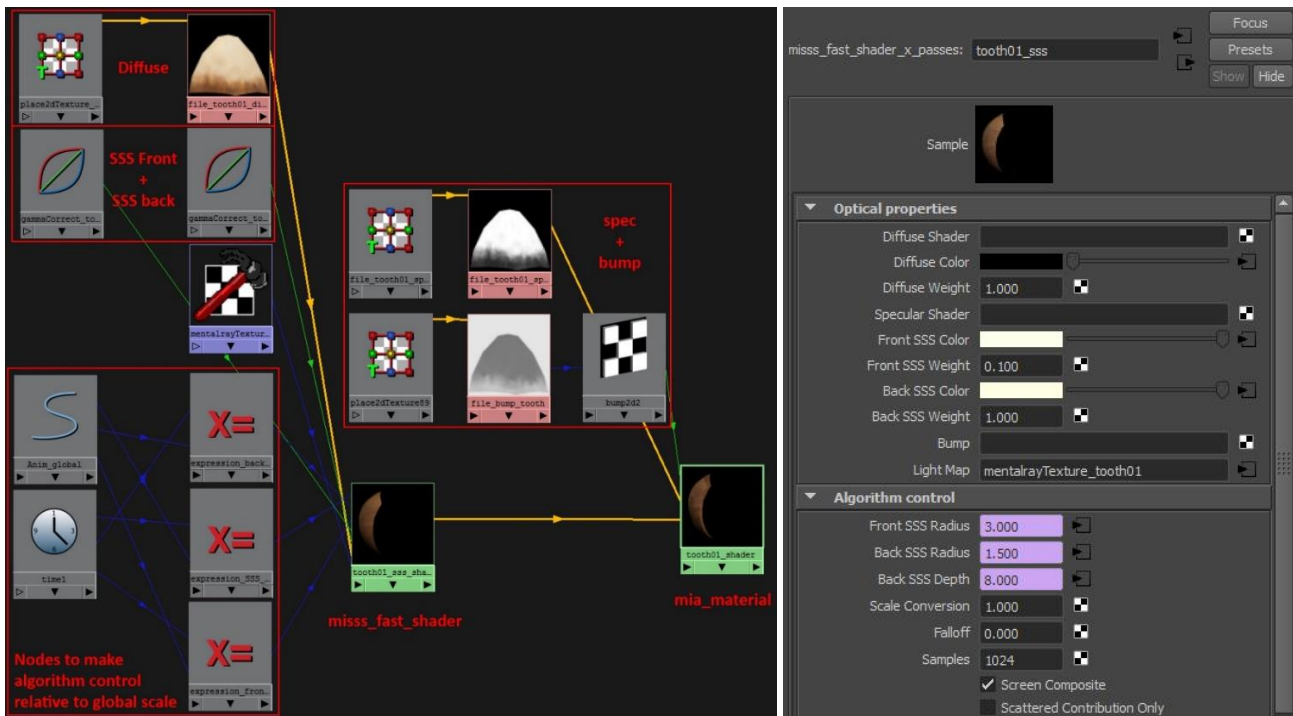


Figure 19 A: The material network area showing the teeth material setup. B: The subsurface scattering material attribute editor.

The setup for the subsurface scattering of the tongue is similar to the setup of the teeth as only the values and textures differ. The tongue has less subsurface scattering as the enamel so it allows less light to pass through. This results in lower algorithm control values. Chapter 2.3.2 describes the tongue as being richly supplied with blood vessels, which will give the front and back subsurface scattering color a subtle red color.

After understanding more about movement and digital muscles, certain project management techniques become important, to manage the project in a flexible way, while achieving the desired results. The next section discusses these issues regarding the production of the creature.

3.4 Project management

Chapter 2.4 analyzed the project management techniques concerning flexibility, detail and lighting in order to achieve an efficient production workflow and realistic renders. This chapter deals with certain issues that arose bringing those methods to use.

3.4.1 Accessibility

An issue that needs to be considered in order to achieve an efficient workflow and desirable end result, is the accessibility of all areas of the creature. It is a common issue amongst digital artists not being able to reach the throat or the space between the gums and the cheeks of digital creatures. This chapter discusses a few methods that have been studied in order to experience less trouble when dealing with hard-to-reach places.

Modelling the creature with its mouth slightly open is a good way in advancing the accessibility of the inside of the mouth. Aside from accessibility it also enables less texture deformation when the mouth completely opens. By opening the mouth half-way it is considered to be a more neutral state between two extremes, jaw clenched or its mouth wide open.

Another way to promote accessibility would be to make the gums as well as the palate bits independently from the mouth. This is almost always the case when visual artists create human jaws and teeth as human cheeks cover all of the transition area between the cheeks and the jaws. This however is less the case with *Mosasaurus hoffmanni* cheeks as it has a wide mouth, similar to lizards. Therefore it is important to be careful with the transition between the jaws and the cheeks. This is also the reason why it is advised to create the palates which are connected to the tooth gum. This way the transition between the gums and the palates would be unnoticeable if handled with care.

In addition to that method it is also possible to use the method of multiregional UV mapping. This method also makes it possible to increase the amount of texture resolution besides promoting accessibility. As the name suggests, multiregional UV mapping requires the use of multiple zero to one UV spaces. All the UVs that are in one UV space will share the same texture. Thus making it possible to have multiple 4096 x 4096 texture maps on one model. The benefit of using these UV spaces is, in relation to accessibility, that it enables the use of polygroups in *Zbrush*. This enables the hiding of different parts of the head for example. That way the user can isolate the area to work with. After hiding all polygroups except one, the color, normal and displacement maps of that polygroup can be generated. Figure 20 shows the UV regions in *Maya* and the resulting polygroups in *Zbrush*.

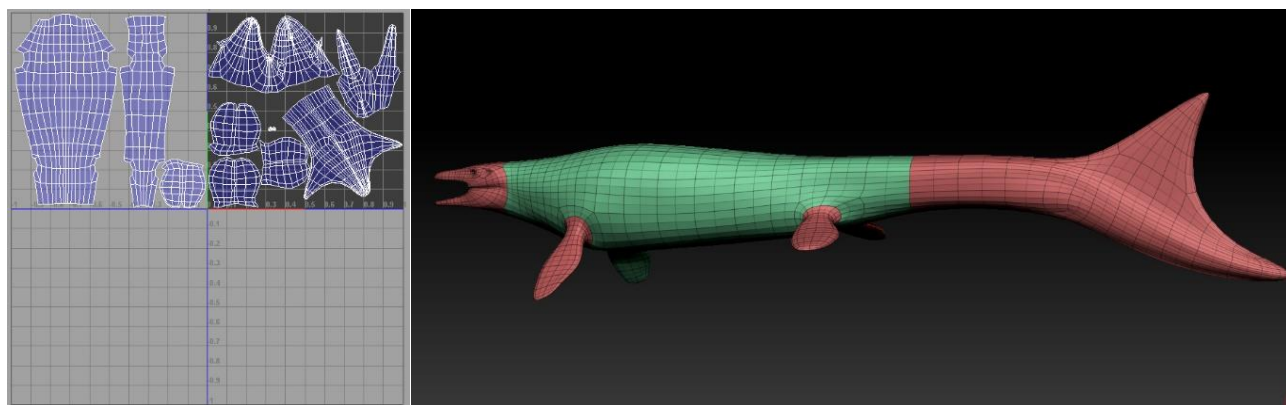


Figure 20 Left: UV editor in Maya with multiple UV regions in use. Right: Zbrush viewport with the different polygroups based on the two regions defined in Maya.

3.4.2 Displacement maps

As explained in chapter 2.4.1, displacement maps are greyscale images which, when applied on geometry, create a polygon point for each pixel of the image and connects these pixels at render time. This creates more complex geometry at render time. This chapter deals with an issue that is the result of the difference in the way *Zbrush* creates displacement maps and *Maya* reads displacement maps.

Zbrush exports displacement maps with 50% grey equals no displacement, 100% white displaces forward into the normal direction and 0% black displaces backwards from the normal direction, displayed in figure 21A. But in *Maya* 0% black equals no displacement and 100% white equals full displacement. This difference between displacement map creation in *Zbrush* and the way *Maya* reads displacement maps will result in incorrect displacement of the model at render time, as displayed in figure 18B.

The solution to this problem requires the use of image alpha offset in combination with an expression. The offset setting allows the user to shift the brightness of the image. By shifting the value of 50% grey 50% down, *Maya* reads the 50% grey as no displacement as *Zbrush* intended it, as displayed in figure 18C. The value that determines the relative amount of displacement is called the gain. So 50% down actually means minus half of the gain. This process can be automated by the use of an expression that automatically updates the alpha offset when the alpha gain is changed. This way it forces 50% grey to always be the value of no displacement, for any value in alpha gain.

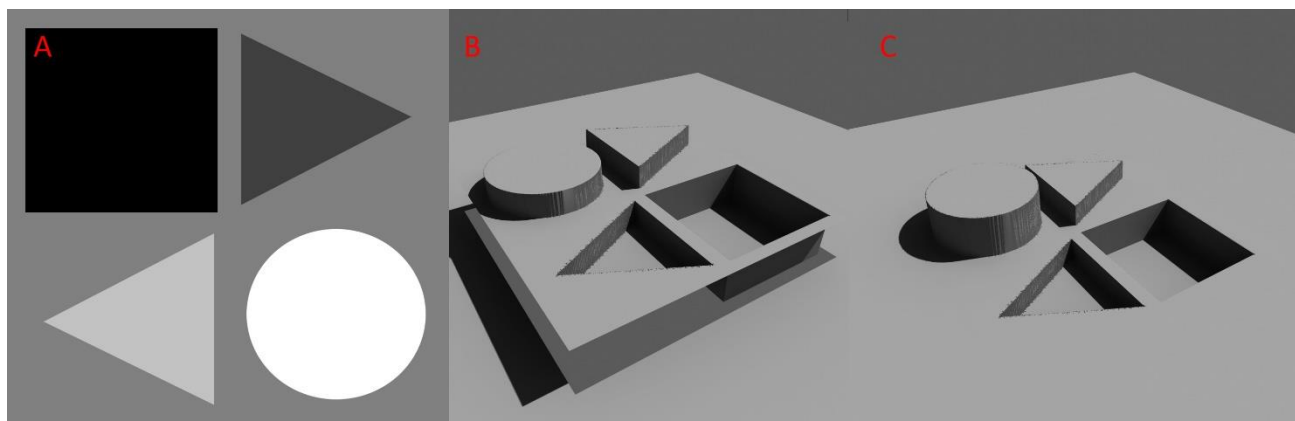


Figure 21 A: The displacement texture. B: The difference in the way *Zbrush* creates the displacement map and the way *Maya* reads it. C: After applying the alpha equals the minus half of the gain solution.

3.4.3 Lighting

Chapter 2.4.2 emphasized on acquiring a linear render output light intensity in order to achieve realistic lighting. For this project *Mental Ray* has been used as render engine. The output of the *Mental Ray* renderer is not linear. So even though the 8-bit textures used in this project are correctly encoded, the output image doesn't have this encoding and would be too dark in the middle vales.

In order to correct the output light intensity so it displays the rendered image correctly, an option to read all inputs as already encoded and the output as linear, has to be turned on in the color management menu. By turning this feature on all textures will be overexposed at render time. This is the result of *Maya's* color profiles. When a texture file gets assigned in *Maya* it will automatically be assigned to the default input profile. So although the inputs in the color management have been set to already encoded, it reads them as being not encoded and encodes them again, resulting in a double correction. This problem can be solved in two ways. In each texture node there is the option to set the input to standard, which means already encoded, in this context. This would remove the second correction and the textures would be displayed correctly at render time again. The overexposure can also be adjusted by connecting the output of the texture into a gamma correct node before connecting it to the input of the material. This gamma correct node works as a multiplier. By settings all channels to 0.454 the render output will also be linear. 0.454 is the result of 1 divided by 2.2 which is needed to undo the second correction. Direct color inputs in *Maya* are also subject to the linear workflow, but can also be corrected by using the gamma correct node as they have no reference to an already encoded file.

Lighting is also crucial in order to display material attributes. Reflective materials such as the teeth and cornea of the eye require light and reflection in order to look credible. For creating reflections, as well as soft natural lighting, HDR images (high dynamic range) are a good solution. And given the fact that the *Mosasaurus hoffmanni* is a sea creature it would make sense to use an underwater HDR image. However, due to the slow shutter speed required to make a 32-bit HDR image in combination with the motion of the water (and all the small particles within it) it is only feasible with high tech cameras and experts operating them. Because of this no free high detail HDR images could be acquired and another solution had to be found.

The solution came in the form of a beach HDR image that has a similar setup as an underwater HDR image. The beach could be considered the sandy ocean bottom and the sky the water. The used HDR file actually had a small line of houses in the distance and a hint of a sun location. Both are not ideal, but have proven not to be noticeable in the final result. Figure 22 shows the used HDR image for the reflections. The free file is downloaded from OpenFootage.net.



Figure 22 Render of the high dynamic range image and a simple scene. The models with different materials showcase the reflections on different surfaces (Openfootage 2013).

After analyzing the subject and dealing with technical issues associated with the digital re-creation of *Mosasaurus hoffmanni*, the main goal of the specialization can be achieved. The next chapter is the conclusion of the specialization thesis, it also interprets the goal of the specialization in a bigger context.

4.0 Conclusion

The specialization deals with the creation of an accurate *Mosasaurus hoffmanni* visualization. The first part of the specialization thesis dealt with collecting as much in-depth information as possible and connecting the dots in order to create an accurate body plan. Gathering reference material is always important when creating realistic digital assets, but especially since no direct reference material exists. Therefore multiple scientific sources and expert feedback have been invaluable in assembling the creature. During the creation of the digital asset certain issues had to be solved, which is discussed in the second part of the specialization theses.

Analysis of the anatomical structure of the creature has aided in justifying the movement of the creature. Without studying literature, which interprets the relation between the shape of the vertebrae and muscles in the tail and the size of the scapulae, it would be impossible to accurately identify the associated swim pattern of the creature. After studying the body anatomy of *Mosasaurus hoffmanni* it also became possible to more accurately determine a likely body outline, which is important for the readability of the creature. Studying scientific literature also specified the lineage of the creature. By identifying lizards and snakes as their lineage the transferability of their external features were validated, providing a variety of reference material.

By analyzing certain production workflows the project would start off with flexibility in mind, while maintaining the required detail. This flexibility becomes especially important when requesting expert feedback, which might endanger the schedule if the project set up with flexibility in mind. And with a firm understanding of the lighting fundamentals the project could start off with a correct linear workflow, enabling the material results to be more realistic.

During the re-creation of the creature many different issues were dealt with, which resulted in a better understanding of the subjects that have been analyzed. After identifying the associated swim pattern of *Mosasaurus hoffmanni*, the mathematical solution in order to achieve the auto swim function had to be figured out. In order to keep the representation of the muscles flexible, as priority production workflow aim, a procedural solution would be suiting. In order to give the muscles of the creature realistic muscle characteristics the *Maya muscle* system has been used to some extent. The *Maya muscle* algorithms are capable representing the muscle characteristics in a good manner. But while working with the muscle system it also became apparent that its functionality only extends to linear fusiform muscles, which represent only a small minority of the muscles present in the body. In order to improve its functionality the system will need to be improved in order to support more complex muscle shapes accurately. During the process of recreating the creature also the use of subsurface scattering materials became clear. They are vital in order to achieve realism in materials such as the teeth and the tongue.

Also part of an efficient production workflow is the accessibility of certain parts of the model. Separating geometry or UVs benefits the accessibility. The generated displacement maps had issues as *Zbrush* exported the maps in a different way as *Maya* reads them. Additionally, a deeper understanding of *Maya's* color management was necessary, in order to actually achieve a linear workflow as each program has its own way of dealing with the issue. Finally, solutions in how to achieve realistic reflections and soft lighting were found in HDR images.

Although this specialization project is mostly focused on *Mosasaurus hoffmanni* or lizards in general, the work method can be applied to any creature that has incomplete or only partially correct reference material. The method can even be applied to imaginative creatures, as referencing features of the creature to actual existing creatures will result in a more credible visualization. Many issues that were being dealt with during this *Mosasaurus hoffmanni* specialization project will probably also be similar, to the issues occurring at the time. The understanding of the different subjects, gained during this project, are a good starting point in solving them.

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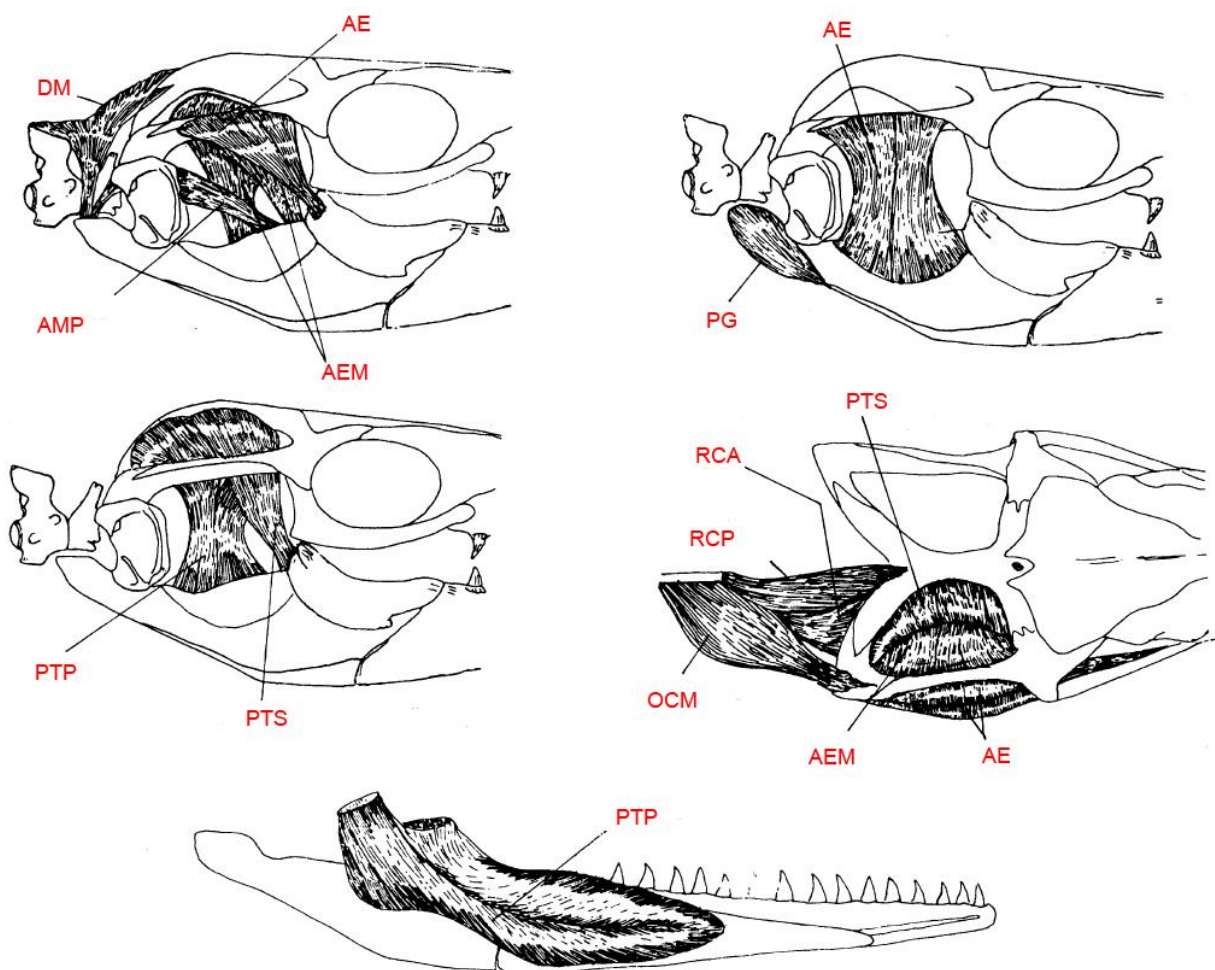
<http://www.betterphoto.com/gallery/dynoGallDetail.asp?photoID=8804172&catID=35284&rowNumber=5>

Appendix I

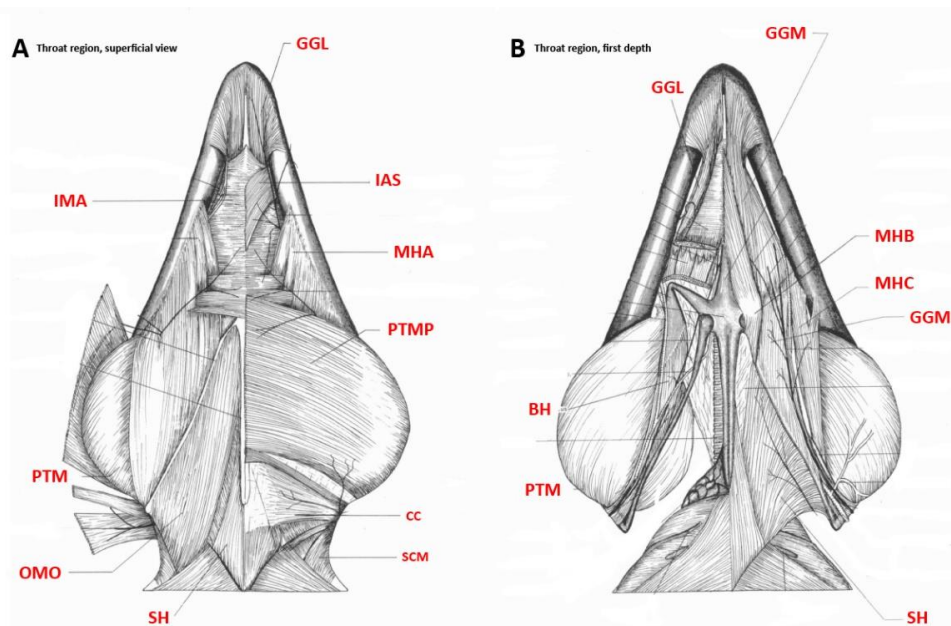
Implemented muscles

Head

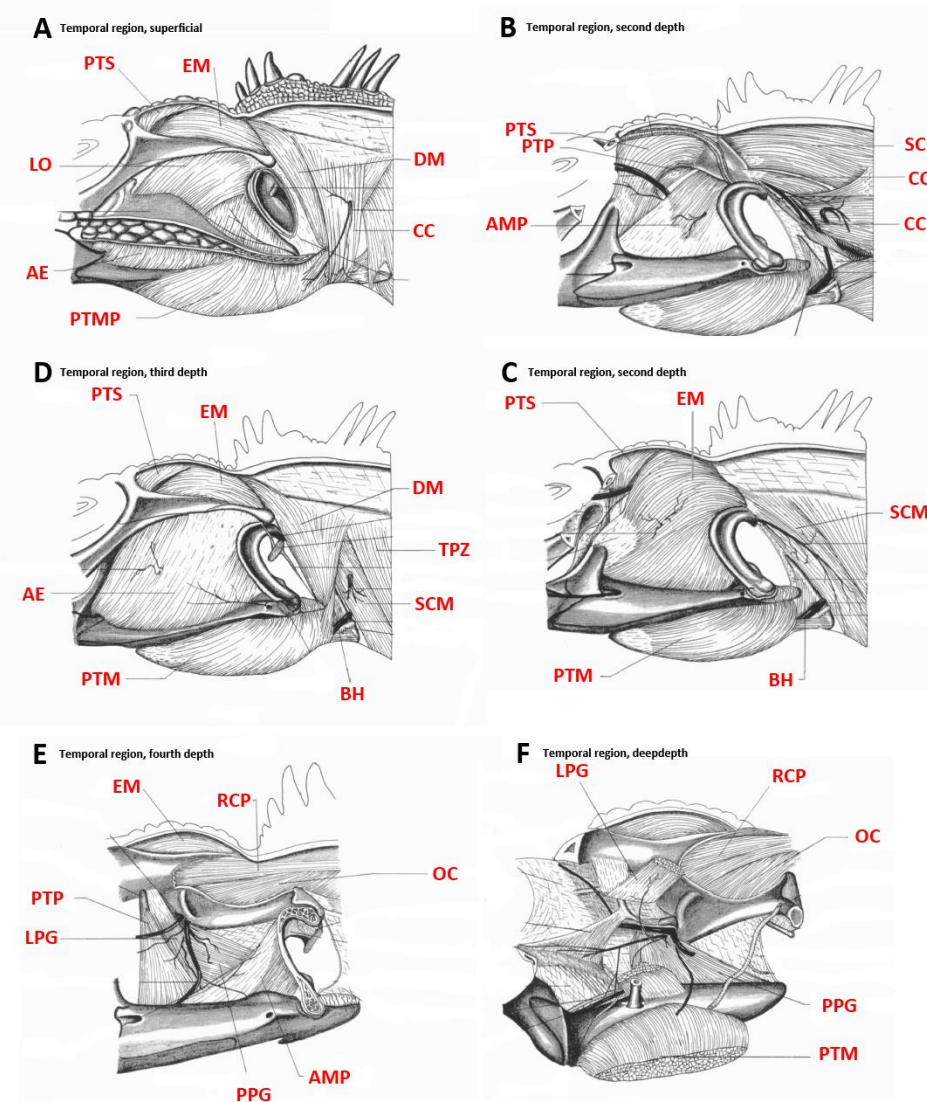
- M. adductor externus (AE) postorbital frontal to surangular
- M. adductor externus medialis (AEM) quamosal to coronoid
- M. adductor mandible profundus (AMP) quadrate to surangular
- M. pseudo temporalis profundus (PTP) parietal to surangular, coronoid and dentary
- M. pseudo temporalis superficialis (PTS) parietal to surangular, coronoid and dentary.
- M. depressor mandibulae (DM) first cervical vertebrae and parietal to surangular
- M. ptyergoideus (PG) rests on surangular
- M. intermandibularis anterior superior (IAS) between dentaries
- M. intermandibularis anterior (IMA) between dentaries
- M. externum medius (EM) postorbital to parietal
- M. mandibular hyoideus A (MHA) hyoideus to dentary
- M. mandibular hyoideus B (MHB) hyoideus
- M. mandibular hyoideus C (MHC) hyoideus to dentary
- M. pterygomandibularis (PTM) hyoideus to the dentary
- M. pterygomandibularis posterior (PTMP) hyoideus to the dentary
- M. genioglossus lateralis (GGL) tip of the dentary to hyoid
- M. genioglossus medialis (GGM) tip of the dentary to hyoid
- M. branchio hyoideus (BH) surangular to hyoid



Left platycarpus skull (modified after Lingham-Soliar 1995). Right: pterygoid muscles in the Iguana (modified after Holliday C 2007).



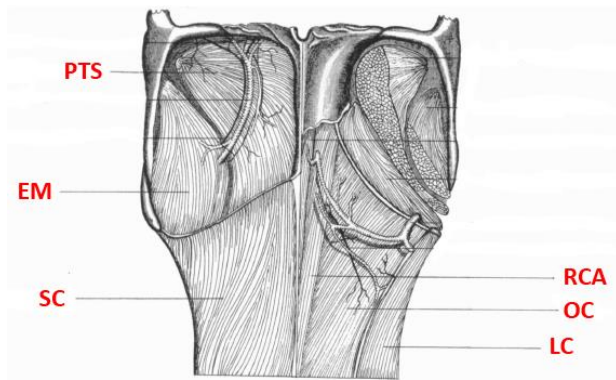
A: superficial view of the throat region of the *Ctenosaurus pectinata* (modified after Oelrich 1956). B: First depth view of throat region (modified after Oelrich 1956).



The dorsal view of the *Ctenosaurus pectinata* from Superficial view (A) to deep depth view (F) (modified after Oelrich 1956).

Neck

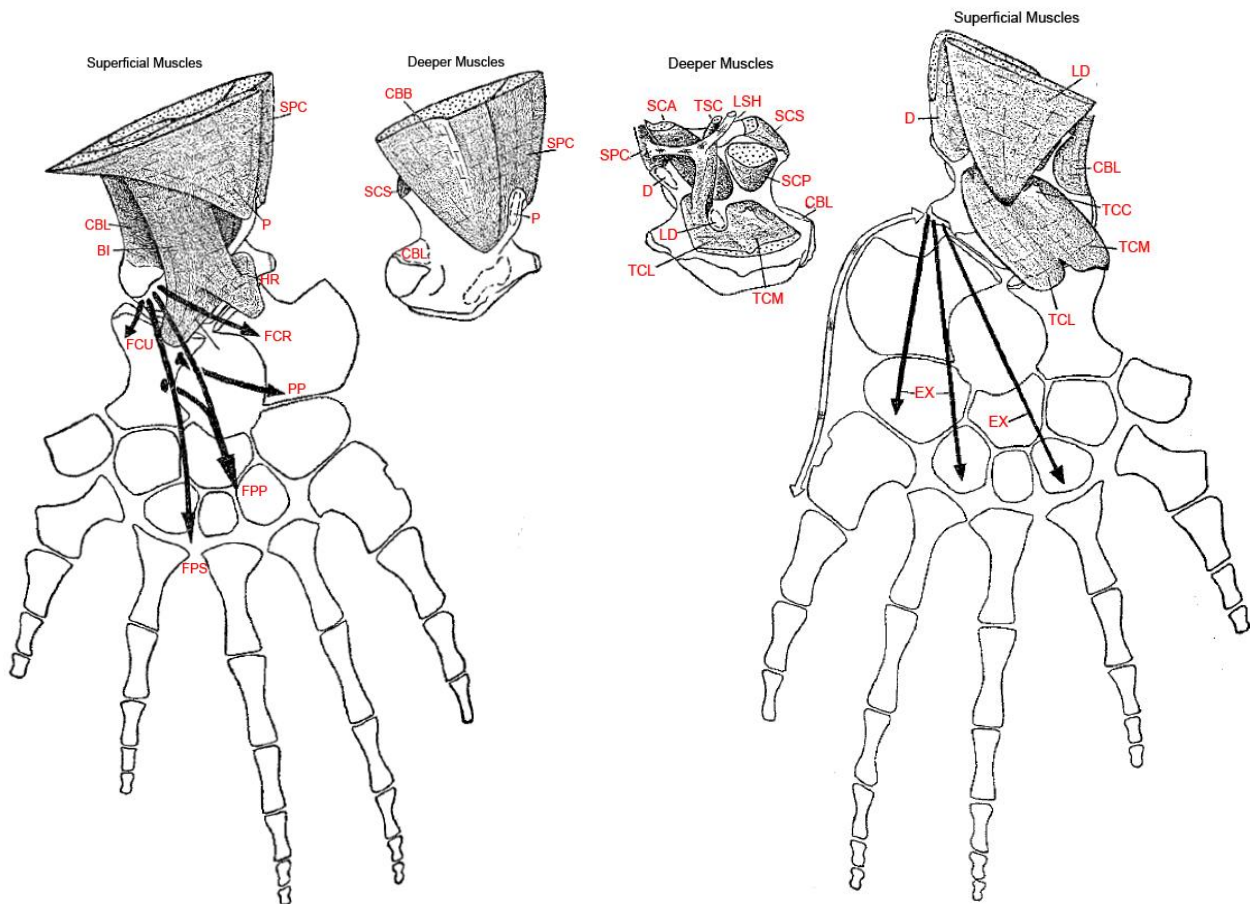
- M. ornohyoideus (OMO) scapula to hyoid.
- M. levator scapulae superficialis superior (LS) scapula to first three cervical vertebrae
- M. rectus capitis posterior (RCP) first cervical vertebrae to parietal
- M. rectus capitis anterior (RCA) first cervical vertebrae to parietal
- M. sternohyoid (SH) coranoid to the lower body of the hyoid bone.
- M. spinalis capitis (SC) transverse processes of the cervical vertebrae to parietal
- M. oblicuus capitis (OC) transverse processes of the cervical vertebrae to parietal
- M. constrictor colli (CC) cervical vertebrae, around neck to other side cervical vertebrae
- M. Trapezius (TPZ) cervical and thoracic vertebrae to scapula
- M. sternocleidomastoid (SCM) sternum to parietal



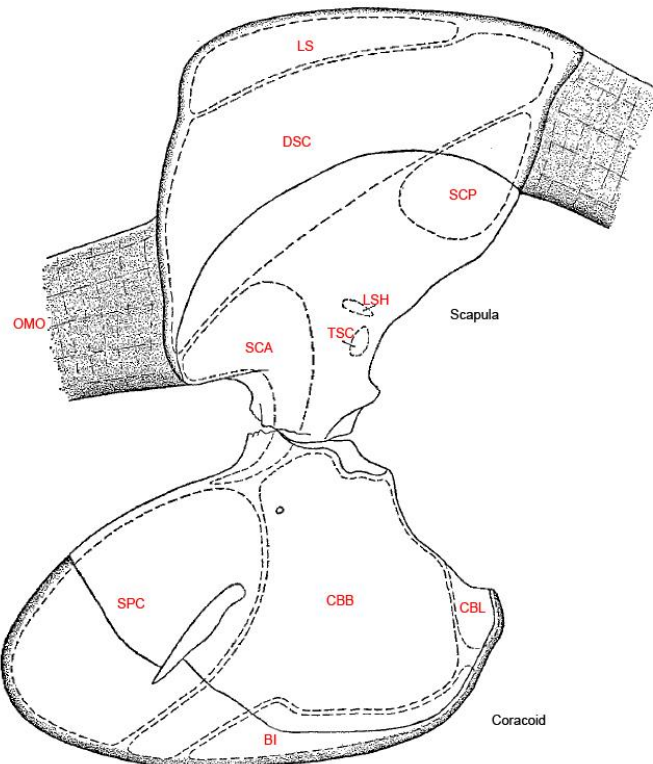
Left side of image is the superficial view of the dorsal neck region of *Ctenosaura pectinata*. The view on the right is the first depth view of the dorsal neck region (modified after Oelrich 1956).

Pectoral Girdle

- M. latissimusDorsi (LD) thoracolumbar fascia to humerus
- M. deltoides scapularis (DSC) scapula to humerus.
- M. scapulo humeralis posterior (SCP) scapula to humerus
- M. triceps caput scapularis (TCM) scapula to humerus
- M. Ligamentum scapula humerali laterli (LSH) scapula to humerus
- M. Pectoralis (P) interclavicle to humerus.
- M. biceps (BI) coracoid to radius and ulna.
- M. supracoracoideus (SPC) coracoid to humerus
- M. coracobrachialis brevis (CBB) coracoid to humerus
- M. scapula humeralis anterior (SCA) scapula to humerus
- M. coracobrachialis longus (CBL) scapula to humerus
- M. triceps caput lateralis (TCL) humerus to ulna
- M. triceps caput medialis (TCM) humerus to ulna
- M. flexor carpi radialis (FCR) humerus to most anterior metacarpal
- M. flexor carpi Ulnaris (FCU) humerus to ulna.
- M. flexor palmaris superficalis (FPS) humerus to most posterior two metacarpals
- M. flexor palmaris profundus (FPP) humerus to capitae
- M. pronator profundus (PPA) ulna to radius



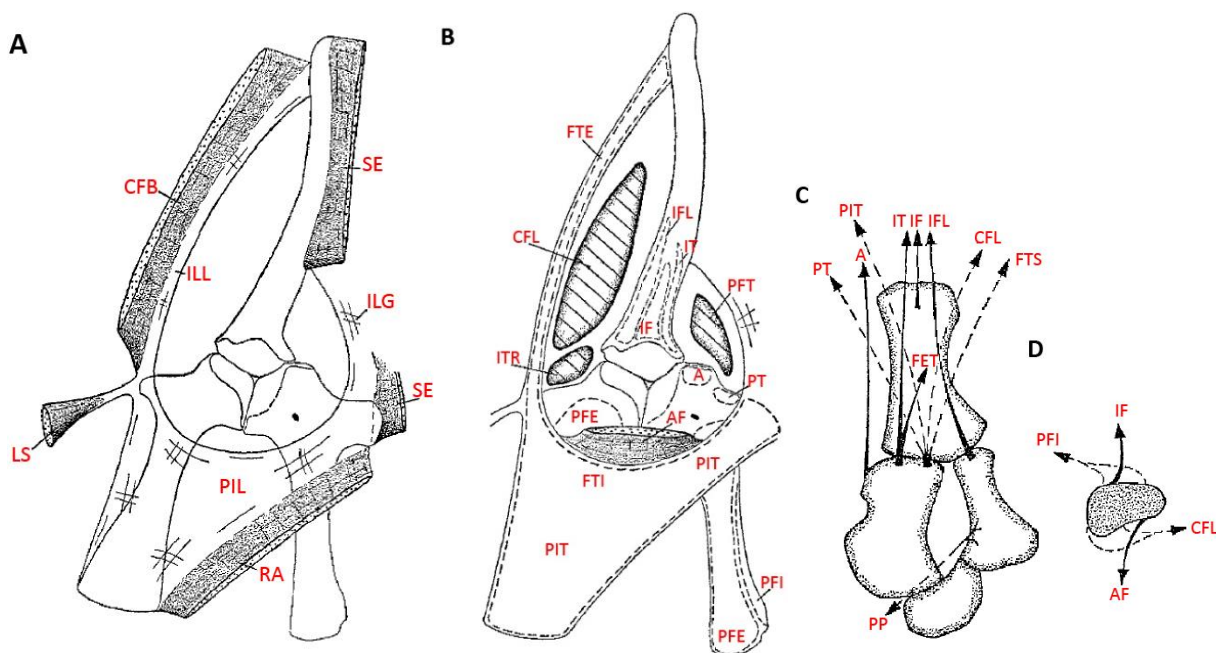
Left: Scapula and coracoid showing muscle attachments sites from ventral view (modified after Russel, 1967). Right: Showing the front paddle with muscles from dorsal view (modified after Russel, 1967)



C: Showing to bottom view of front paddle with muscles (modified after Russel, 1967).

Pelvis

M. supracostalis et intercostalis externus (SE) thoracic ribs to ilium and pubes
M. rectus abdominus (RA) sternum to puboischadic ligemant (PIL)
M. pubotibialis (PT) pubis to tibia
M. ambiens (A) pubis to tibia
M. iliotibialis (IT) ilium to tibia
M. iliofemoralis (IF) ilium to femur
M. iliofibularis (IFL) ilium to fibula
M. puboischiofemoralis externus (PFE) ischia to tibia
M. puboischiofemoralis internus (PFI) ischia to tibia
M. femorotibialis (FET) femur to tibia.
M. adductor femoris (AF) pubis to femur
M. puboischiotibialis (PIT) pubis, ischia and puboischadic ligemant (PIL) to tibia
M. flexor Tibialis internus (FTI) puboischadic ligament (PIL) to tibia
M. pronator profundus (PPB) fibula to tibia



A: Pelvis showing musculature, view from midline (modified after Russel 1967). B: Pelvis showing deeper musculature, view from midline (modified after Russel 1967). C: Hind limb showing appendicular muscles, solid lines are muscles dorsal in position, dotted lines are muscles ventral in position (modified after Russel 1967). D: Cross section of the femur showing the muscles responsible for rotating the hind limb (modified after Russel 1967).

Torso

M. latissimus dorsi (LS) thoracolumbar fascia to fumerus
M. trapzius (TPZ) thoracolumbar fascia to scapula.
M. rectus abdominus (RA) sternum to puboischadic ligament (PIL)
M. great oblique (GO) aponeurosis to ribs

Tail

M. caudofemoralis Brevis(CFB) transverse processes caudal vertebrae to ilioschiadic ligament (IIL)
M. caudofemoralis longus (CFL) transverse processes caudal vertebrae to tibia
M. ischiocaudalis (IS) transverse processes caudal vertebrae to puboischadic ligemant (PIL)

